The importance of Complex Product Systems to the space industry in Australia:

A small satellite case study

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James Bradfield Moody
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Abstract

The great paradox of the space industry in Australia is why, given a strong history of space involvement and a capacity for excellence in space and other complex projects, Australia is unique among developed countries in that it does not have a recognizable space agency and it has little space policy.

To try and understand this paradox, this thesis follows the development of the FedSat satellite project, formed in 1998 to 're-ignite the Australian Space Industry'. It asks the central question, "Can Australia develop an indigenous satellite industry made up of high-value, complex products?", framed against the backdrop of innovation, management and policy issues in a multidisciplinary context.

The techniques used to analyse the FedSat project draw heavily on the Complex Product System (CoPS) framework, which proposes that high-cost, one-off products have unique innovation, management and policy dimensions and as such, require a different approach to analysis. It is found that CoPS are not only an ideal mechanism for analyzing a satellite project, but also a means of placing the space industry within the purview of innovation theory for future comparison with other projects across a range of industry sectors.

Within the space industry, a popular management technique in the 1990s was the 'Faster, Better, Cheaper' Small Satellite Philosophy. This philosophy was applied during the development of the satellite project, once successfully and once unsuccessfully, highlighting the importance of the inherent drivers of the management philosophy. A theory is developed around the Small Satellite Philosophy to give benefits to other reduced resource CoPS, giving an insight into the relationship between complexity, management and risk in these projects.

As a key aspect of answering the research question, the policy issues surrounding the development of the satellite under the Cooperative Research Center (CRC) programme are presented. It is found that, while there may be an inherent capacity within Australia for the development of CoPS, Australia's innovation policy does not recognise their importance and the CRC framework is inherently unsuited to their development.

The key conclusion of the thesis is that, based on the current space policy and innovation mechanisms in Australia, it is currently impossible for Australia to develop a space industry made up of high-value, complex products. However, drawing on the FedSat experience, a new way for Australia to enter the space industry is presented; one that is based on the formation of specific policy to address the development of CoPS. This policy would enable projects such as FedSat to be properly coordinated and funded, if it was found that they are in the national interest and continue to build the nation's capability in the development of complex products.

This thesis aims to contribute to literature on both the application of CoPS to new industries and the development of the space industry in Australia, through the empirical analysis of a high-profile Australian project. Indeed, ideas developed in this study will form a resource for the future development of other indigenous space projects within Australia and CoPS projects internationally.

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Chapter 1

Background and Motivation

1.1 Introduction

Global revenues from the international space industry were worth $US82.8 billion in 2001 (Euroconsult, 2001). A number of developing and developed countries and regions, including the US and Europe, Japan, Canada, Russia, India, China and even Brazil have recognisable space programmes, funded from 0.01% to 0.31% of their Gross Domestic Product (ISAG, 2002). In this context Australia is unique among developed countries in that it does not have a recognisable space agency.

Australia does, however, have a history of space involvement. Australia was the country which received the initial video feed from NASA's first moon landing and an early participation in international space events provided a momentum for domestic interest and research in space. In 1967, Australia launched its first satellite, Weapons Research Establishment Satellite (WRESAT), into orbit from its own territory and was only the fourth nation to do so after the US, USSR and France (Dougherty and James, 1993).

Australia also has a history of involvement in the development of complex projects, from the Snowy Hydro Electric Scheme to the Sydney Olympics. To date, however, there has been little analysis into the development of these projects from an innovation and policy perspective.

In order to undertake this analysis, this thesis is largely based around a case study of one such complex project, the FedSat satellite project, formed in 1998 to *re-ignite the Australian Space Industry* (CRCSS, 1999). It asks the central question, "*Can Australia develop an indigenous satellite industry made up of high-value, complex products*", framed against the backdrop of innovation, management and policy issues concerning the Australian space industry.

Previous literature and reports have detailed, in-depth, the past strengths and weaknesses of the Australian space industry and its potential for development (see for example (ISAG, 2002), (BIE, 1996), (ASICC, 2001)). However, these have mostly concentrated on examples in the context of current government policy and have neglected other issues such as the impact of Australia's national system of innovation on the industry. There have also been no in-depth case studies conducted into large projects within the Australian space industry to draw from, which analyse them from a multi-disciplinary perspective.

1.2 Approach to the Research Question

The research question is expressed in terms of the experiences of the Cooperative Research Centre for Satellite Systems (CRCSS) in developing the FedSat satellite. FedSat is a joint government-private sector initiative and is Australia's first indigenously produced satellite in thirty years (CRCSS, 1999). The 58kg satellite is designed to conduct space-science and engineering experiments orbiting 806km around the earth and was launched in late 2002.

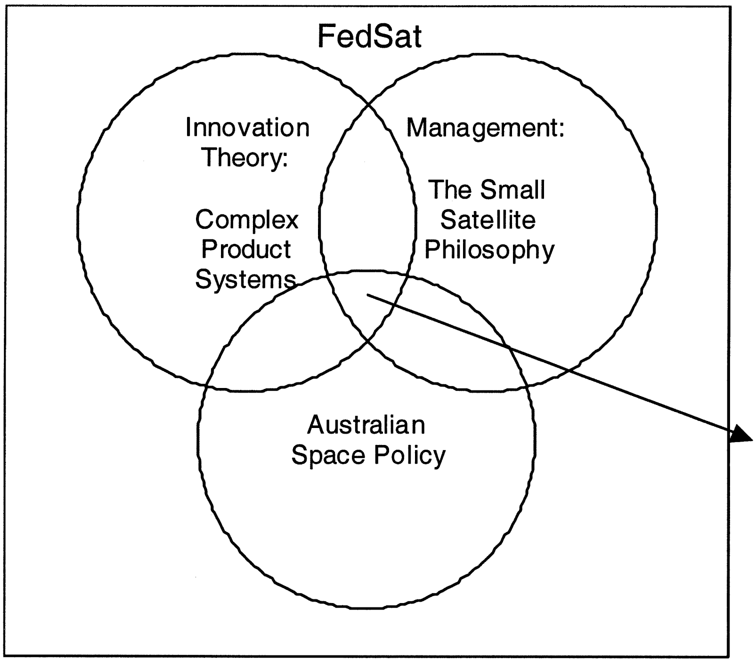
The CRCSS is an example of one of 64 Cooperative Research Centres established by the Australian Government to facilitate partnerships between the public and private sectors. The CRC program aims to "bring together researchers from universities, CSIRO and other government laboratories and private industry or public sector agencies, in long-term collaborative arrangements which support research and development and education activities that achieve real outcomes of national economic and social significance" (DITR, 2002). It formed a major part of the Government's 2000 innovation policy (DISR, 2000a).

The FedSat satellite was chosen as the focus of analysis for a number of reasons. First, it is the only significant Australian space project for more than three decades and gives an insight into the core question of this thesis. The project also involves a large number of current participants in the space industry brought together in a structure which makes up a key component of Australian innovation policy. As the author was given excellent access to the project almost from its inception, there is a wealth of information available and the project also provides a convenient unit of analysis of the industry with measurable success criteria. Finally, experiences of the CRCSS in undertaking the project promise to highlight an array of issues into the development of new complex systems industries in Australia. As such, the CRCSS's experiences in the development of the FedSat satellite can be utilised to generate knowledge on issues such as private-public partnerships, the development of new industries and the management, organisational and political challenges facing the development of the Australian Space Industry.

Another dimension to be considered is the international nature of the FedSat project. The satellite bus was originally outsourced to a company in the United Kingdom, as it was determined that there was currently no indigenous space-qualified capability to manufacture it in Australia. However, one of the core goals of the project was to transfer satellite technology to Australia (CRCSS, 1999), which became critical following the bankruptcy of the English subcontractor in June 2001. As well as being a threat to the project, this event also offered an opportunity for Australia to capitalise more fully on the satellite technology developed. The project also draws on experiences with a number of other international sub-contractors employed in the manufacture of the satellite components and the implications of using international best-practice techniques in the satellite management.

As well as answering the core question of the thesis, this work also aims to create a number of key explanatory hypotheses about the nature of the space industry in Australia. This was considered a worthwhile approach, given the paucity of literature placing the space industry in an innovation policy perspective, and generates a number of potential prerequisites for the development of the industry. However, it does not attempt to develop a sophisticated model for the development of the future industry, rather giving signposts for the direction that it should follow.

Three bodies of literature are used to undertake a multi-disciplinary analysis of the FedSat satellite project in the context of the development of the Australian space industry: Complex Product Systems provide a framework for the analysis of the project from an innovation theory perspective; the Small Satellite Philosophy provides an insight into the management of the programme and the best practice techniques which were aimed to be employed in its development; and the wealth of literature on government space policy provides a framework for analysing the satellite from a policy perspective. The synthesis of these three fields of analysis is shown in Figure 1-1.



Can Australia develop an indigenous satellite industry made up of high-value, complex products?

Figure 1-1: Areas of Investigation

An explanation of each of these fields of analysis and its appropriateness to this thesis is given in the following sections.

1.2.1 Complex Product Systems

In the early stages of the research, consideration was given to the most appropriate conceptual and analytical tools which might be used to investigate the key research question. There are a number of possible innovation and management frameworks that might be used for this analysis, from dynamic capabilities (Teece, 1994) which looks at how competitive advantage is gained and held within a changing environment to absorptive capacity (Zahra and George, 2000) which is a construct to investigate various organisational phenomena within and across firms. However, in review, the CoPS framework was by far the most appropriate, incorporating as it does the key elements of many other theories and being currently considered the most cutting edge conceptual tool to look at these issues.

The framework used to investigate this question draws heavily on the area of innovation theory known as Complex Product Systems (CoPS). CoPS theory proposes that high-cost, one-off products have unique innovation, management and policy dimensions and as such, require a different approach to analysis (Hobday, 1998). Over recent years, there has been a shift towards the production of CoPS, particularly in advanced industrial nations (Heighs, 1997). Only recently, however, has the importance of CoPS been recognised and investigated systematically (Davies, 1997e).

Complex Product Systems are usually supplied in unit or small batch production and are tailored to meet the requirements of particular large users (Hobday, 1998). They undergo continuous innovation and development and often have long service life expectancies. Examples of Complex Product Systems include intelligent buildings, telecommunications exchanges, flight simulators, aeroplanes, weapons systems and manufacturing plants. CoPS theory draws together studies from innovation, industrial sociology, project management, systems engineering, military systems and the history of technology.

Initial investigations by the author indicated that the Space Industry was a good example of a Complex Product System industry, but until now, it has not been placed into this field of research. By treating FedSat as a Complex Product System, the underlying drivers identified in other CoPS case studies can be compared against the project and existing CoPS techniques can be used to determine the required preconditions for the industry's development. One of the first tasks of this thesis is to investigate the suitability of using the CoPS framework for the analysis of the FedSat project.

As part of the research question, the author also attempts to place CoPS into the Australian innovation policy framework. It is shown that, while Australia may not have a strong capacity for process innovation, it may have an aptitude for the innovation and management of Complex Product Systems.

1.2.2 Small Satellite Philosophy

An initial investigation into the development of the FedSat satellite also revealed that the project team was attempting to implement a management style known as the "Small Satellite Philosophy". Often known as "Faster, Better, Cheaper", this management philosophy became prevalent in the United States' National Aeronautics and Space Administration (NASA) in the 1990s and was aimed at reducing costs and schedules for satellite missions by an order of magnitude (NASA, 1999).

The thesis first critiques the existing literature on the small satellite philosophy and tests the hypothesis that FedSat is an example of a small (or micro) satellite, a type of satellite which is becoming more prominent in today's space industry (Dornheim, 2000). By using the existing literature surrounding this management philosophy, FedSat can then be benchmarked against international practice in the development of small satellites.

Complex Product Systems have also been shown to have a large impact on project management (Hobday, 1998). Using the information gathered in this thesis, an investigation into the small satellite philosophy management of the FedSat Complex Product System is undertaken and the structure of key bodies is compared to other CoPS projects in the space industry. This thesis thus speculates on new areas within the CoPS framework essential to the Small Satellite Philosophy, such as relationship building and organisational behaviour.

1.2.3 Australian Space Policy

As the development of the FedSat satellite relies heavily on the Cooperative Research Centre scheme, it is necessary to investigate the impact of the programme on Australian space and innovation policy. There have been a number of studies into the Australian Space Industry over the past ten years (Curtis, 1993; BIE, 1996), the most recent of these being the International Space Advisory Group (ISAG) report to the Department of Industry Tourism and Resources (ISAG, 2002).

One of the central questions asked in this investigation is whether the CRC framework is indeed the best (or indeed an appropriate) mechanism for the development of this industry. In answering this question, it is necessary also to compare the CRCSS against other CRCs, with particular reference to the use of the CRC scheme to develop large projects.

There are also many questions to be answered which are not addressed in previous government reports into the Australian space industry. For example, has the interregnum in space projects in Australia reduced the capacity of the country to re-enter such a complex industry and what are the policy and institutional requirements needed to re-build an industry? A critical analysis of the current state of the industry is undertaken and a number of suggestions on how the Australian Government can influence patterns of technological innovation through different policies to promote technical leadership in the development of Complex Product Systems will outline potential areas for future policy development.

1.3 Significance of this Study

The significance of this research question lies in its ability to uncover the underlying drivers in the development of new complex system industries in Australia. By determining if it has the right conditions for the construction of a new Complex Product Systems industry, an insight into Australia's ability to develop high-technology projects through industry policy can be gained. The key regulatory, technological, industrial and market factors which constitute the innovation environment for CoPS are also addressed at the policy level, and it is hoped that ideas developed in this study will form a resource for the future development of other indigenous projects.

There is the potential that, as with other countries such as the United Kingdom (Heighs, 1997), CoPS make up a significant proportion of the Australian value-added Gross Domestic Product. Australia has a history of successful project management of large complex systems such as the Snowy Mountains Hydroelectric Scheme and the Sydney 2000 Olympics. However, despite these early indicators there is no coordinated policy to nurture or further develop CoPS industries. If CoPS are a significant area of the economy to be further developed, it may help to address a current international perception that Australia is 'slipping' with respect to global competitiveness:

> "There is a perception that Australia is too heavily reliant on its traditional 'old economy' industries and that, for future wealth creation, the Australian economy has too few 'new economy' companies. Australia's own science capability, and the innovation system more generally, are crucial to the creation of these 'new economy' businesses which will be the basis of Australia's wealth creation and job growth."
> Chief Scientist Robin Batterham, (Batterham, 2000).

The work reported in this thesis is also significant from an Australian Space Industry perspective. By focusing on the development of CoPS in the space industry, an additional insight into the nature of the industry can be gained, providing an assessment of the success of current initiatives and the path which future initiatives should take. In this context, a qualitative indication on the output and effectiveness of the FedSat project and the Cooperative Research Centre for Satellite Systems will provide a framework for future space industry development.

The space industry is also investigated using the Complex Product Systems framework. This is the first time that this area has been investigated within this framework and will allow cross-sectoral analysis with these other industries in the future.

Finally, this thesis places the management of space projects into traditional innovation management theory. Space management and space policy are often investigated in an ad-hoc fashion by engineers and managers with little experience in theoretical innovation analysis. This study brings the small satellite philosophy together with CoPS theory and illuminates areas for future investigation in both domains.

1.4 Thesis Outline

Chapter 1 has introduced the thesis and outlines the motivation for studying this topic. It asks the central question of whether Australia can develop an indigenous space industry made up of high-value, complex products and introduces the areas of study important to the answering of this question.

Chapter 2 outlines the research methodology used to investigate this topic. The body of information for this chapter is taken from the case study protocol developed to investigate FedSat and describes the means by which the single case study will allow the investigation of the rich detail, nuance and complexity contained in the project. It also describes the framework for investigating the FedSat project within the CoPS domain, to promote future cross-analyses with other CoPS industries.

Chapters 3 and 4 prepare and investigate the analysis of a satellite project from a CoPS perspective. In Chapter 3, a critical review of CoPS theory and its placement within the traditional body of work on the management of innovation is presented. After an investigation of the history of CoPS theory, the chapter describes the CoPS critical dimensions. A range of tools that can be used to investigate CoPS projects is also outlined and the real significance of CoPS with respect to management and policy is questioned. The chapter concludes that the CoPS theory is a new innovation framework which is effective for the investigation of the space industry in Australia from an innovation perspective.

Chapter 4 then expands upon the CoPS theory and tests the hypothesis that the space industry, and in particular a satellite itself, is an example of a Complex Product System. This chapter begins by giving a history of the space industry and its key characteristics from an international perspective. It then focuses on the satellite industry, detailing the complexity of and providing the technical background to, a typical satellite project. Using the analysis tools presented in the previous chapter and comparing the satellite industry with an already established CoPS industry, the international missile industry, this chapter concludes that satellites are ideally suited to analysis as Complex Product Systems.

Chapter 5 then focuses on a subset of satellites known as small satellites. Firstly, the complexity of a small satellite is investigated, along with other critical dimensions of Complex Product Systems. The investigation shows that even though the size of the satellite is smaller and the budgets are reduced, they have a similar order complexity and, as such, are suited to investigation using a CoPS framework. The chapter then focuses in on the management of small satellite development, presenting a synthesis of the current Small Satellite Philosophy literature with the attempt to identify the international best-practice methods for its implementation. In addition, the claim that the Small Satellite Philosophy can reduce required project resources by an order of magnitude in time and cost is tested.

Chapter 6 focuses on the Australian policy framework surrounding the development of the CoPS space industry in Australia. It presents a history of the Australian space industry from a policy perspective and contends that, despite promising beginnings, the development of the Australian Space Industry has largely been a failure. The chapter then investigates Australia's current space policies and places the FedSat case study at their centre. The chapter also investigates current Australian innovation policy and searches for references to the potential of CoPS within Australian industries. Finally, it makes the suggestion that Australia may have an inherent capacity for the development of CoPS.

Chapter 7 then lays the groundwork for the analysis of the critical case study by detailing the experiences of the FedSat project. A history of the satellite project is given, detailing its intended outcomes, its technical composition and the project organisation. The detailing of key events is used to underscore the challenges facing the project in its different phases and the key drivers behind its successes. This chapter also investigates the likelihood of the FedSat project achieving its intended goals.

The key theoretical interpretations of the FedSat project from an innovation, management and policy perspective in view of the central research question are presented in Chapter 8. The techniques outlined in Chapters 3 and 4 are used to investigate the key innovation drivers to its development and the suitability of the structures, tools and techniques used in the project. The international best-practice techniques of the implementation of the Small Satellite Philosophy detailed in Chapter 5 are compared with the management methodology in the FedSat project and are found to be different in different phases of the project. Finally, the policy implications of the project are investigated and it is found that CRCs are not a suitable framework for the development of a CoPS.

Chapter 9 then synthesises the findings of the previous chapters and the investigation of the project from the three theoretical perspectives; it relates these to one another in an attempt to answer the central question of the thesis. It is found that, based on this analysis, and given the current structure of the industry and policy environment, Australia *cannot* currently develop an indigenous satellite industry made up of high-value, complex products for a number of reasons:

- While there may be an inherent capacity within Australia for the development of CoPS, Australia's innovation policy does not recognise their importance. Specifically, the CRC framework is inherently unsuited to their development.
- The key participants in this industry have the necessary management experience to implement small satellite projects, but the CRCSS's overall success depends on its ability to generate continued and ongoing projects.
- Australian space policy is not positioned to promote the development of small satellites and there are no government mechanisms currently in place to effectively facilitate the industry's development.

Taking the findings of this thesis into account, some recommendations for the Australian Space Industry are then given, including the idea of the industry's segmentation and mechanisms to include CoPS into government policy.

The insights yielded by this theoretical investigation are examined in the final chapter of the thesis. In addition to outlining areas omitted in this analysis, the suitability of the case study analysis is reviewed and the potential implications for other emerging Australian CoPS industries are suggested. The thesis concludes by noting a number of emerging opportunities for future investigation.

Chapter 2

Research Methodology

2.1 Introduction

The previous chapter introduced the research question *"Can Australia develop an indigenous satellite industry made up of high-value, complex products?"* and it was suggested that the FedSat case study is an effective means of yielding information to answer it. In this chapter, this assertion is tested through an investigation of the case study method and the techniques used to perform the theoretical investigation of the FedSat case study are outlined.

There is a large amount of research literature available on the areas of this topic, and the central body of work for this thesis can be sourced from research on Complex Product Systems, the management of satellite projects, space policy, and the theory of innovation. Two critical reviews of the existing literature were created in the development of this thesis, to draw together knowledge of Complex Product Systems and the Small Satellite Philosophy. The results of these reviews are given in Chapters 3 and 5 respectively.

However, the main contribution of this thesis is the in-depth understanding of the FedSat case study and its implications for these different theories. This section outlines the tools and techniques designed to undertake this investigation.

2.2 Alternative Research Designs

There are a number of different methods and paradigms by which the key research questions underlying this study might be examined. These range from empirical and qualitative approaches to quantitative analytical approaches.

With such a rich source of potential information available to the researcher, analytical approaches such as surveys may not be able to capture the complexities of the project, especially with respect to its exploratory nature. In addition, the nature of the research question lends itself to a qualitative, rather than a quantitative investigation for a number of reasons. The aim of this thesis is not so much to prove or disprove a specific hypothesis, but to rather answer a question and to provide useful interpretations of the data obtained. As such, it was decided to use qualitative applied social research methods such as those described in Symon and Cassell (1998) and Huberman and Miles (2002).

There are a number of different qualitative approaches which may be used to provide an empirical analysis of a project, ranging from research diaries and life histories to stories, analytic induction and critical incident technique (Dyer and Wilkins, 1991; Symon, 1998). While many of these different methods might be applicable to analysing a complex system, the case study method is particularly appropriate where the theoretical concepts relevant to the research question are resistant to quantification (Eisenhardt, 1989) and can be treated as within a single experimental unit (Yin, 1984). This method, along with a structured interview process developed around a questionnaire from the CENTRIM/SPRU Project on Complex Product Systems, was chosen as the most appropriate method for analysis in the FedSat case study.

2.3 Investigation by Case Study Method

As a qualitative research method, case studies have been used widely, from policy and political science to organisational and management studies. According to Yin (1984), case studies are mainly used for how and why questions, such as "How does this work" or "Why is this so". This is due to the nature of case studies, which focus on decisions and reasons behind actions.

In Yin, a case study is an empirical inquiry which "investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident." (pg 12). This definition highlights the fact that case studies are used in situations where there are a great number of independent variables, such that the context cannot be removed from the study itself. Experiments, on the other hand, set to remove context by undertaking research in a laboratory or controlled environment. Surveys also aim to limit the number of variables that are being studied, with the aim of making results both statistically significant, easier to analyse, and generalist in nature within the boundary of the study parameters.

Yin describes three types of case studies which can be undertaken. *Exploratory* case studies develop a theory or idea and are usually used for deciding on directions to follow in an investigation. These are different from *descriptive* case studies which describe a situation or circumstance, with the aim of providing examples to support a theory. Finally, *explanatory* case studies develop a causal argument for an event or occurrence, developing a strong argument for reasons behind situations or outcomes. Case studies may consist of either single or multiple cases, depending on resources and requirements.

This method is designed to be all-encompassing; it uses techniques and ideas from a collection of other different methods and synthesises them to yield a whole greater than the sum of its parts. It is hoped that, by using a case study analysis technique, information will be obtained normally outside the scope of surveys, histories or other research techniques, both for explaining processes in the project and exploring new issues arising from the study. Both single and multiple case study approaches are valid for case study analysis, developing information to build or support a theory (Eisenhardt, 1989) (Eisenhardt, 1991).

Using the description provided by Yin and others, it is evident that the case study is a mechanism for capturing the nature of a project which is inherently complex, where interactions between different parts of the project are as important as the components of the project themselves. As this thesis is largely concerned with the theory behind 'Complex' Product Systems, case studies would seem to be an effective mechanism for their investigation.

2.4 The FedSat Case Study

The FedSat case study will be a *single, embedded descriptive* case study, aimed at capturing the detail and complexity behind the CRCSS's experiences in implementing a small satellite project. Expressing the research question in terms of a single case study allows the researcher to go in-depth into all of the subtle nuances and complex interactions experienced during the satellite development, and permits a considered, balanced and critical analysis of the project. In addition, as FedSat is the first Australian satellite to be manufactured in thirty years, there are few meaningful quantitative measures which can be used to compare the satellite against other projects.

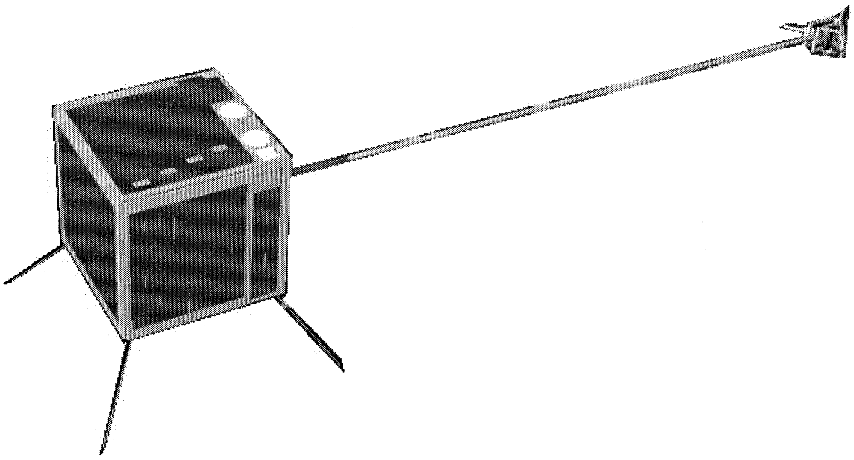


Figure 2-1: The FedSat Satellite, Source: CRCSS

As described in Chapter 1, the analysis is divided into three primary research areas in order to undertake a multi-disciplinary analysis of the FedSat satellite in the context of the development of the Australian space industry; innovation theory, programme management and government space policy. In developing a means of analysing the FedSat project, it is necessary to view it from these three different perspectives.

2.4.1 Questions

Although the case study can be framed in terms of the central question in this thesis, *"Can Australia develop an indigenous satellite industry made up of high-value, complex products?"*, it is necessary to expand upon this question in order to capture an effective picture of the nature of the project. As the principle tools of analysis fall into the categories of innovation, management and policy, a number of secondary questions can be developed as shown in Table 2-1.

Table 2-1: Supplementary Questions

Can Australia develop an indigenous satellite industry made up of high-value, complex products?	
Innovation	• How does FedSat perform in the critical dimensions of CoPS areas? • What was the organisational structure of the project and was it effective? • How was the project phased and how did this phasing affect its implementation?
Management	• What management skills were utilised during the development of the FedSat project and were they sufficient? • How was the small satellite philosophy implemented as part of the FedSat project? • Which management tools and processes were used in the development of the FedSat project and were they used efficiently and effectively? • What were the risks in the FedSat project and how were these addressed?
Policy	• What was the influence of Government policy on FedSat and the space industry in general? • Was the CRC structure effective in implementing the satellite project?
General	• What were the critical success factors of the project and what were the problem areas? • Will the project be a success in providing its desired outcomes?

These secondary questions are used to develop a richer inquiry to frame the analysis of the project in each of the three areas.

2.4.2 Propositions

In order to frame the questions effectively, it was necessary to develop a number of propositions at the beginning of the FedSat case study. These propositions were based on preliminary analysis of the topic and are tested in the following chapters of this thesis.

The propositions that were made and the reason behind their formulation are given in Table 2-2.

Table 2-2: Case Study Propositions

Proposition	**Reason**
That CoPS provide a rich potential for innovation management and policy in Australia.	This is an assertion which is fundamental to the significance of the thesis. It is supported by Australia's apparent success at the development of previous CoPS projects and Australia's large number of project management consulting and systems engineering firms.
That Small Satellites are CoPS and that FedSat is a CoPS product.	As the case study draws from a CoPS framework for analysis, this is a necessary proposition. A preliminary analysis of the FedSat project indicates that it does rate highly in the critical CoPS dimensions outlined by (Hobday, 1998)
That the management of FedSat is intended to employ some elements of the small satellite philosophy	The small satellite philosophy is used for developing the framework for analysing the management of the FedSat satellite project. Initial discussions with the satellite manufacturer point towards the confirmation of this proposition.
That the FedSat project is influenced by (and influences) Australian space policy, and Australian Cooperative Research Centre (and innovation) policy.	The third area of analysis of the FedSat case study is from a policy perspective, and as such it is important to assert that there is a linkage between FedSat and government policy. As FedSat is Australia's first satellite in 30 years, cost $A40million and involves the CRC programme, there is preliminary evidence to support this.

2.4.3 Units of Analysis

The unit of analysis of this study is the FedSat project, focussing on its evolution and describing qualitatively the problems faced by project actors during the different stages of the project. The study follows the development of the satellite from project inception until satellite launch.

The FedSat case study can be broken into two phases; the initial development of the satellite in the United Kingdom, and the subsequent development of the satellite in Australia after the bankruptcy of the UK satellite contractor, as outlined in Figure 2-2.

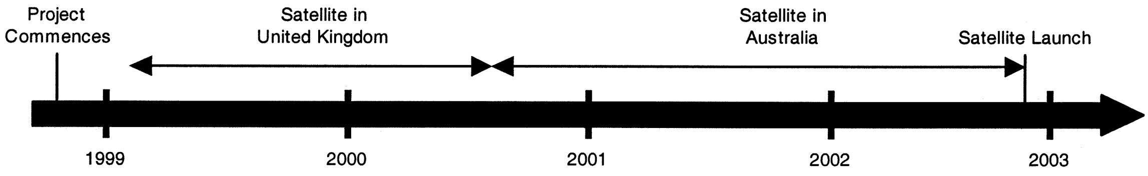


Figure 2-2: Satellite development phases

As the central question of this thesis focuses on the development of an indigenous space industry in Australia, the primary unit of analysis is the development of the satellite in Australia. However, similar information on both development phases was collected, as this provides a convenient means of analysing which aspects of the project are unique to Australia and which are inherent to the project.

The satellite can also be broken into two parts, the satellite bus, including the mechanical structure and the central operating electronics, and the satellite payloads which use the power, communications and computing facilities of the bus. The two parts of the satellite are illustrated in Figure 2-3, with the payloads circled; the remainder of the hardware comprises the satellite bus.

Since many of the payloads were developed overseas and are not essential components to the operation of the satellite, this case study is only concerned with the development of the satellite bus and does not include analyses into the integration of the satellite payloads, except where this had a bearing on the development of the satellite bus. Also not included is an in-depth analysis into the development of the satellite ground station, except where this influenced the development of the spacecraft itself.

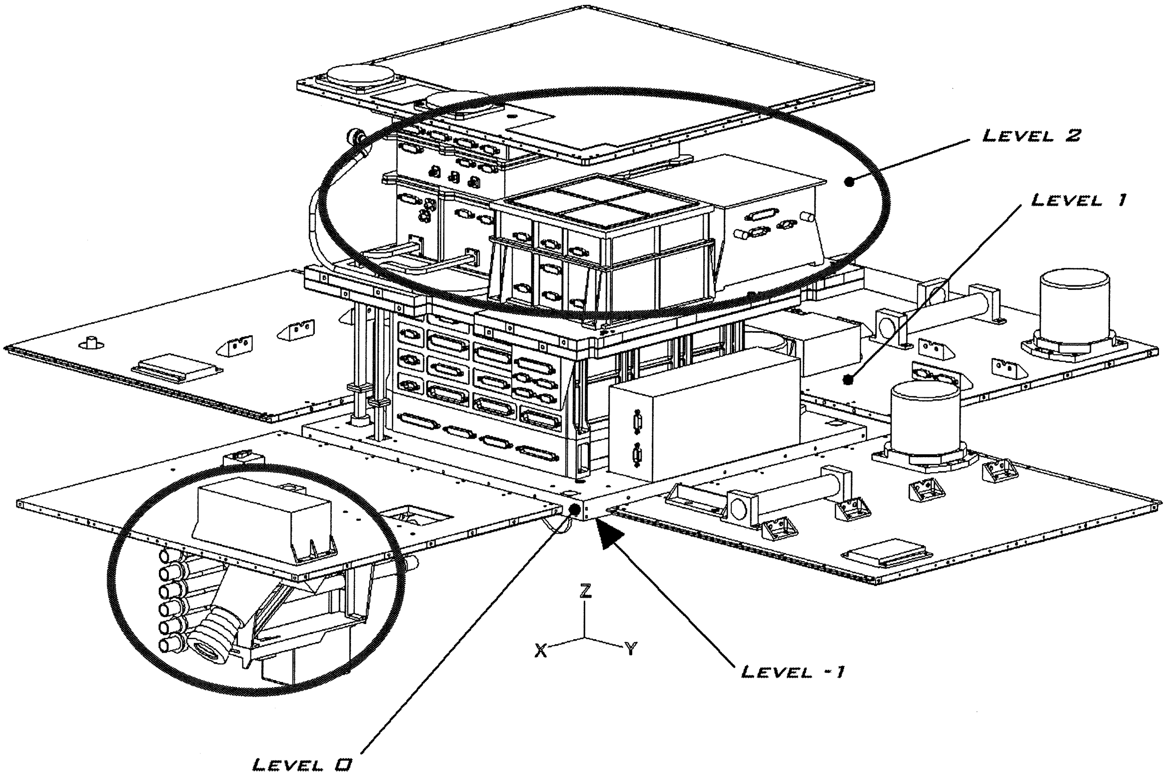


Figure 2-3: The FedSat satellite bus (with payloads highlighted)

2.4.4 Information Sources

As detailed above, one of the strengths of the case study method is that it can draw from a number of information sources and synthesise these to provide a complex picture of the FedSat project. The different information sources used for gathering data on the FedSat case study are outlined below.

Structured Interviews

One of the main sources of information for the case study was through structured interviews. Rather than develop the format of the interviews from scratch, the interview protocol used was based on the Questionnaire from the CENTRIM/SPRU Project on Complex Product Systems (Appendix II), modified to answer the questions posed in the case study. This approach has an additional advantage that by using a common interview template, analysis between this and other CoPS investigations is possible. The interview template is included in the appendix, but the main headings are as follows:

Section 1: Project characteristics
Section 2: Project phasing and feedback loops
Section 3: Innovation management tools
Section 4: Risk and opportunities
Section 5: Learning
Section 6: Managing inter-company technology interfaces and stakeholders
Section 7: Success/failure and performance

The formal interviews were approximately 90 minutes in length and were done at three phases of the satellite development; the first at Space Innovations Limited during the fabrication of the satellite bus, the second after Space Innovations Limited had declared bankruptcy and the satellite was being transferred to Australia, and the third after the satellite had been assembled and was undergoing final integrated system tests. The targets of the interviews were the staff at all levels of management and technical development, from both the CRCSS and SIL. The number and types of interviews are outlined in Table 2-3.

Table 2-3: Structured Interviews

Phase	**Type**	**No. Interviews**
Satellite in production at SIL *November 1999*	SIL – Upper Management	2
	SIL – Middle Management	3
	SIL – Technical Engineering & Support	2
	CRCSS – Middle Management	2
SIL Bankrupt *July 2000*	SIL – Upper Management	2
	SIL – Middle Management	3
	SIL – Technical Engineering & Support	2
	CRCSS – Upper Management	1
	CRCSS – Middle Management	2
Satellite finished construction at CRCSS *May 2002*	CRCSS – Upper Management	4
	CRCSS – Middle Management	3
	CRCSS –Technical Engineering & Support	6
Total		**32**

Notes were taken at all interviews, with the researcher attempting to capture direct quotes as often as possible. The first interview with each of the participants was done without a tape recorder so as not to intimidate the interviewee and to promote open and honest comments. However, from the second interview onwards recordings were made, with reference to the comments made from the first interview if there was a lack of clarity in the initial responses and to verify the information provided. Although all of these interviews were conducted exclusively with members of project team, a number of other interviews were undertaken to look at the shape of the Australian Space Industry, as illustrated in the discussion on "Space Policy Interviews" below.

It should be noted that structured interviews can have some serious handicaps. If the interview is poorly structured with badly designed questions, then the interview can give misleading results (Brusoni, 1998). In addition, there is a tendency for the interview to measure *attitudes* rather than *practices* within the project, and often the interviewees do not have an appreciation of the historical context of the project, underestimating the effect of previous project influences. Also, the nature of the questionnaire was such that it provided a general framework, designed to fit all CoPS sectors; there was a risk that the interview structure may not cover all of the areas of interest, requiring more in-depth investigation into certain areas which became apparent during the interview process. As such, the researcher was required to tailor the interviews to the interviewee in a number of cases, ensuring that these departures from the standard interview were appropriately recorded.

Project Reviews

The FedSat project underwent a large number of internal and external reviews during its implementation, providing a wealth of data towards the case study. The researcher had both the opportunity to sit in on a number of reviews and access to the final reports. The reviews undertaken during the project are outlined in Table 2-4.

At the end of each review, the reviewer was required to submit a report to the CRCSS executive, which outlined the findings of the review and gave some recommendations for the further operation of the CRCSS. These reports gave the researcher an external opinion into the development of the project.

Table 2-4: Project Reviews

Year	Date	Review
1998	30th Nov – 4th Dec	Systems Design Review
1999	5th – 8th Mar	Technical Review Held in the UK at SIL and DERA
2000	14th – 17th Feb	Stage 1 – 2nd Year Review
2000	3rd – 6th Apr	Technical Review Held in the UK at SIL, Surrey and RAL
2000	2nd – 3rd May	Stage 2 – 2nd Year Review
2000	13th – 16th November	Tiger Team Review after bankruptcy of SIL
2001	14th – 15th June	Internal FedSat Review
2001	27th – 29th June	DISR Review of Project
2001	18th July	FedSat Material Review
2002	14th March	Internal Review of FedSat Schedule and Milestones
2002	20th May	AusIndustry Review of FedSat Project
2002	9th Jul	5th Year Review

Internal Project Documentation

A large amount of internal project documentation, including all of the documentation outlining the project tools and systems, was available to the case study. Copies of the project documentation from the bankrupt Space Innovations Limited were also able to be accessed.

Because of the large amount of documentation available, it was necessary to sort documents into a number of categories. These categories are given below.

Email correspondence

The case study was also enhanced through access to internal and external email correspondence during the project. However, as with the internal project documentation, the large volume of emails required the researcher to sort them into a number of categories as for internal documentation. In addition, the emails were sorted temporally, with a more in-depth focus given to communications during critical milestones of the project (such as the bankruptcy of SIL).

First-hand Experience

The researcher was also given first-hand experience of the project throughout its implementation, as one of the systems engineers for the project. As a member of the project team, the researcher was first invited to fully integrate with the systems engineering department at SIL, and then later with the core project team after the satellite had moved to Australia. As such, the researcher gained entry into the internal project structures and operations, giving a tight connection between the research and the project.

While this tight connection should increase the weight of the researcher's conclusions, it was important that all information gathered through first-hand experience was verified by other sources, to ensure that the researcher's judgement was not clouded by a close association with the project. Inevitably, there will be some processes of decision making and actual decisions where the participation of the researcher would affect the outcomes, but an effort was made to keep these minimal.

Space Policy Interviews

With a complex project consisting of a number of linkages, it is important to understand the context in which it is operating. As such, during the investigation into Australian Space Policy and the understanding of the nature of the Australian Space Industry, it was necessary to undertake a number of interviews of people involved in the space industry.

These informal interviews were designed to answer the following questions:

> "What are the different components of the Australian Space Industry?"
> "How does FedSat relate to these different components?"
> "How is the Australian Space Industry Organised?"
> "What should be the relationship between private and public investment in the Australian Space Industry?"
> "What are the key innovation drivers or impediments in the Space Industry in Australia?"

In all, more than twenty people were asked these questions. These answers were then validated against previous investigations into the Australian Space Industry and synthesised in Chapter 6 of this thesis.

2.5 Analysis

The previous sections have described how data for the case study were gathered. However, it is the use of these data which is the key to a successful qualitative analysis of a topic. Without effective tools for incisive and insightful data analysis and interpretation, the amount of data collected can become overwhelming and the meaning of this data can become obfuscated.

This section describes firstly how the data were clustered around a key number of topics for analysis. It then describes some methods which are used to analyse the data collected and highlights one of the major pitfalls of the analysis.

2.5.1 Clustering

Due to the complexity of the project, it was important to sort the information into a number of categories, with particular reference to the four main areas of analysis described in Figure 1-1; Innovation, Management, Policy and General Information. This clustering was applied to the information collected by the structured interviews, the comments made in the project reviews, the internal project documentation and the analysis of email correspondence.

The first method of sorting the data was in a temporal sense, focussing on the different phases of data analysis, or simple pieces of background information about Space Innovations Limited or the CRC for Satellite Systems. The clusters developed in this sense included topics such as Requirements Analysis and Bid and SIL Background.

Within the innovation context, the cluster topics were taken from the questionnaire from the CENTRIM/SPRU Project on Complex Product Systems, as this was the basis of the structured interviews. As the Project Origin and History section was already covered in the general analysis of the project, the subtopics of Organisational Structure, Key Technologies and Interfaces were drawn out into their own topic areas.

The clustering of data in the management sense was undertaken to match the four key competencies required for the Small Satellite Philosophy, developed in Chapter 5. These areas were management capability, technical capability, quality and technology.

Chapter 6 develops some key questions regarding the Australian Space Industry, following an analysis of other space or CoPS industries. These questions included "What are the different components of the Australian Space Industry?" and "How does FedSat relate to these different components?" These are the basis for the cluster topics used in the investigation of the project from a policy perspective.

The cluster topics which were developed are shown in Table 2-5 below. An electronic database was developed to house the information gathered, stored alongside fields of information source and information type. Each piece of information collected was sorted into one or more of these topics.

Table 2-5: Cluster Topics

General	1a – Requirements Analysis and Bid
	1b - Satellite construction in the UK
	1c - Transition Phase
	1d - Satellite Construction in Australia
	1e - Launch & Operations
	2a - CRCSS Background/Project origin & History
	2b - SIL Background/Project origin & History
Innovation	3a – Organisational Structure
	3b - CRCSS/SIL - Intercompany interfaces
	3c - Key Technologies
	3d - Resources Required
	3e - How complex? High vs. Low
	3f - Project Phasing
	3g - Innovation Management Tools
	3h - Risks and Opportunities
	3i – Learning
	3j - Software/Hardware Process
	3k - Managing interfaces
	3l - Success/Failure and Performance
Management	4a - Management Capability
	4b - Technical Capability (systems engineering etc)
	4c – Quality

	4d – Technology
Policy	5a - International Considerations
	5b – Industry components
	5c – Industry organisation
	5d - How does FedSat relate?
	5e – Key drivers and impediments
	5f – Relationship between private and public

2.5.2 Cross Verification

Another tool which can be used to support the data is that of cross validation, both within the same data source and between data sources. As a number of data sources are available for the study, this helps to both remove any specific single-point aberrations and validate general responses. In addition, this is an essential tool to reduce the chance that the results were clouded by the close association of the researcher with the project.

In particular, when validating the data three areas of data confluence were paid special attention:

- Areas of consensus: areas were noted where more than one piece of data within a particular data source agree, or where data were supported across a number of sources. These were taken to have more weight than data which were uncorroborated.
- Differences of opinion: differences of opinion or conflicting data were also taken to be noteworthy, as these have the potential to highlight areas of contention or issues within the project.
- General themes: rather than for specific pieces of data, the frequency of reoccurrence of particular topics in the data was also noted.

2.5.3 Drawbacks

One of the other main difficulties of the case study method is ensuring that the analysis is rigorous and unbiased (Symon, 1998). There are a number of biases which can question the effectiveness of the case study method, for example, “the use of data which support the researcher’s argument, without any proof that contrary evidence has been reviewed” (pg 6).

It is essential that any data collected by this method be analysed in a manner which reviews and debates their authenticity and applicability. Chapter 9 of this analysis gives a review of the data collected and their subsequent analysis using a set of criteria developed by Guba and Lincoln (1989), which can be used to give an indication of the authenticity of an approach taken.

These authenticity criteria are as follows:

1. Resonance (the extent to which the research process reflects the underlying paradigm)
2. Rhetoric (the strength of the presenting argument)
3. Empowerment (the extent to which the findings enable action to be taken)
4. Applicability (the extent to which the findings can be applied to other contexts).

In addition, the analysis of the data will be investigated for rigour along other lines:

1. Breadth (did the analysis capture all of the nuances of the project?)
2. Balance (was the analysis able to present the data from all (or most) angles and structure coherent arguments?)
3. Repeatability (is the analysis able to be repeated?)
4. Verifiability (was the data collected verified by more than once source?).

2.6 Conclusions

This chapter has given an analysis of the case study method and its applicability to the FedSat project. It first outlined the central question of the thesis and divided it into a number of supplementary questions in each of the different areas of investigation. These questions will form the core of the analysis of this thesis in Chapters 8 and 9.

In addition, based on these questions, a number of propositions were made about the nature of this project. These propositions give a strong foundation for undertaking future analysis of the project and are tested in Chapters 3 to 6.

he units of analysis and sources of information for the case study were then outlined. These included both temporal and physical limits to the amount of information collected, and outlined the structured interview process to be followed in particular. There is a wealth of information available on the project, but this needs to be appropriately sorted and verified in order to ensure that it is consistent, in order to get a proper understanding of the project in Chapter 7.

Finally, the tools which were used to analyse the data are outlined. These tools were used as the foundation of the project analysis in Chapters 8 and 9.

Chapter 3

Complex Product Systems

3.1 Introduction

In Chapter 1 it was suggested that components of the space industry in Australia are primarily made up of large, one-off complex systems rather than a continuum of developing and sustainable activities. While this is not tested until the following chapter, it is useful to develop and understand a framework which can be used to analyse these systems.

One potential candidate for analysis is the relatively new field of innovation research developing around the theme of Complex Product Systems (CoPS). These are high-cost, one-off (or small batch) projects, systems, networks and constructs which embody a large number of customised, interacting sub-assemblies and components (Hobday, 1998).

This chapter gives a review of the current innovation theory frameworks which can be used to analyse large, complex systems, and their placement within the traditional body of work on the management of innovation. It focuses on CoPS, with an aim of answering the following questions:

- What are CoPS and how are they measured?
- Are CoPS a new and useful unit of analysis within the innovation framework?
- What are the shortcomings of the CoPS framework?
- Are CoPS a useful framework for the analysis of a satellite project?

Initially, the historical context within which CoPS has developed is investigated, looking at CoPS within the innovation literature. This is followed by an assessment of CoPS themselves, beginning with a comparison between CoPS and mass production and focusing on their characteristics and their critical dimensions. Next, the potential innovation, management and policy impacts of CoPS are investigated, followed by a survey of the tools used for both measuring CoPS and their underlying processes. Finally, a critical assessment of the suitability of using the CoPS framework for analysis is presented.

3.2 Background and Definitions

Within the context of innovation within large, one-off complex systems, it is useful to investigate some of the defining terms which will be used throughout this thesis. This section details the author's understanding of the nature of complexity, project and product processes and the nature of the firm, and gives some explanation of the terms which are used in developing the theory.

3.2.1 The firm

One of the typical units of analysis within the innovation domain is the firm (see, for example Freeman, 1994). As explored in Wang (2000), the standard view of economists is that firms (or 'hierarchies') develop where the sum of the transaction plus production costs make a product cheaper to produce within the hierarchy than it would be if left to invisible market forces. However, Wang (2000) takes another approach, suggesting that firms exist in order to enable the process of transferring technology into products and investigates the processes deep within the firm which enable this transformation.

A taxonomy of business processes within the firm is given by Tunzlemann (1995), which divides the firm into technology processes, production processes, administration (or management) processes and marketing (or product) processes. While this facilitates the understanding of exogenous and endogenous change-agents within a firm (and the impact of their changes), Gann and Salter (1998; 2000) suggest that, for project-based firms, business and project processes also play a key role.

3.2.2 Projects and Products

When looking at the nature of projects and products, we also need to understand the context in which they are produced. A project may be defined as a product which draws together a number of firms, where a firm is an entity that performs a function towards the production of a product (Pavitt, 1997; Tunzlemann, 1997). Firms own knowledge in terms of products and production (or in terms of technologies and processes).

When looking at projects in this context, it is useful to define the difference between firm processes and project processes. This is illustrated in Figure 3-1.

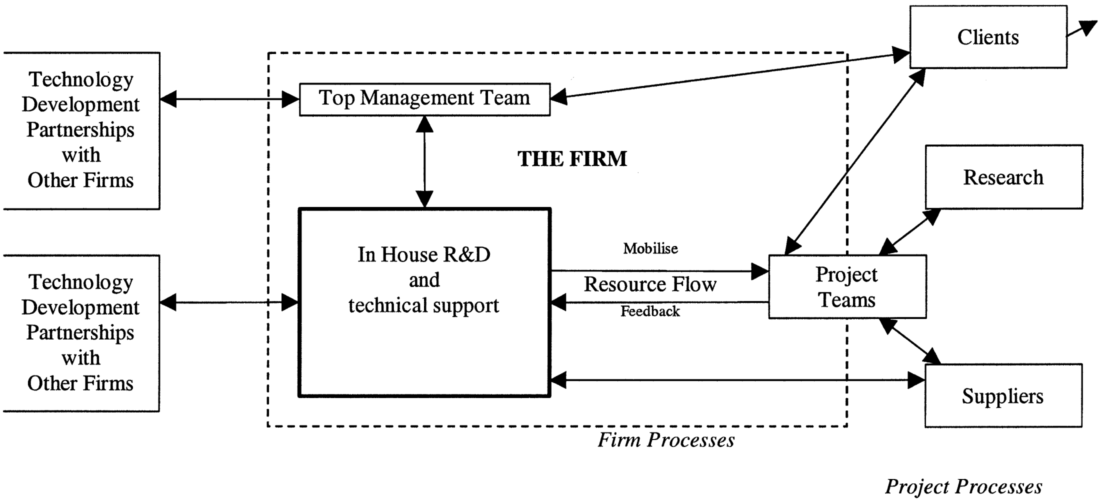


Figure 3-1: Firm vs. Project Processes, Source: (Brusoni, 1998)

It can be seen in the figure above that the project implementation can be divided into two types of processes: project processes and firm business processes. Project processes involve delivering products and services in temporary coalition with other suppliers (Gann and Salter, 1998). In projects with a number of firms involved (either at the partnership or subcontractor levels), the project to produce the product acts as a coordination mechanism across the several participating firms. A firm which works almost exclusively on projects has been defined as the Project-Based-Organisation (PBO). A number of studies into the PBO have been completed with Hobday (2000) suggesting that the PBO may be an ideal form for the management of CoPS.

Business processes within the context of the project are intra-organisational activities which form the ‘glue’ that binds the different parts of a project-based firm (Gann and Salter, 1998). The issue of these processes is not immediately about project performance; instead they focus on the performance and interaction of the different components of the project and the engagement of these components in delivering the project outcomes within the firm.

3.2.3 National Systems

No discussion of innovation is complete without look at its impact on the broader community; the “innovation system”. In this field the focus is mainly on national, regional or sectoral innovation systems, with the innovation system concept introduced first by Lundvall (1985) and then brought to an international audience by Freeman (1987) and Dosi et al (1988). However, the concept didn’t reach full audience until the publishing of two seminal books on National Systems of Innovation in the early 1990s (Lundvall, 1992; Nelson, 1993).

By looking at national systems of innovation and their relevance to economic growth, this analysis of a technological system contributed towards two types of objectives. First through the understanding of how the interaction between firm and knowledge institutions has evolved in specific technological fields, and second through understanding which are the general and which are the specific characteristics of innovation processes in existing innovation theory (Editorial, 2002).

The analysis of an innovation systems is often complex and as such the task is restricted to sectoral or geographically defined boundaries (Freeman, 2002). During an analysis variations in growth of economic regions may be described in reference to the extent to which these variations are a product of the innovation system itself and the institutions that create them (see for example Nelson and Sampat, 2001). Lundvall et al. (2002) takes stock of the current state of theory in this area, and presents a number of future challenges for the concept of national systems of innovation, including the interaction between these systems, economic development, government policy and the learning economy.

3.2.4 Complex Systems

There is some disagreement as to what constitutes a complex system, mainly because of difficulties in defining units of analysis and measurement. For example, a simple definition of complexity is given by (Cowry, 1996) as "anything too complex for one person to understand it alone". However, within the scope of complexity of products, it is commonly agreed (Freeman, 1994), that a complex system takes the form of a hierarchy of levels composed of subsystems or components interacting in a non-simple way that, in turn, have their own components and so forth (Davies, 1997e; Tunzlemann, 1997; Wang, 2000).

Despite a potential for difficulty in measurement, complexity may be measured in a number of ways. These critical dimensions of product complexity include, but are not limited to (Davies, 1997e; Tunzlemann, 1997; Hobday, 1998):

- the number of customised components
- the complexity of the components which make up the product
- the depth and breadth of skills and knowledge required to develop a product
- the degree of new knowledge that is needed to be generated
- the degree of customisation required of both the system and the components and the degree of component interaction
- the quantity of possible design routes
- the elaborateness of the system architecture
- the variety of material and component inputs
- the degree of dependence on sub-components

Many of these critical dimensions form the basis of the measurement of the complexity of Complex Product Systems, which in turn forms the basis for the critical dimensions of CoPS themselves, and are elaborated upon within this context later in the chapter.

In looking deeper into the complexity issue, Tunzlemann (1997) suggests that complexity can have both a breadth and a depth. Complexity in depth refers to pushing a particular subject to its extremes, finding out as much analytical information about it as possible. Complexity in breadth refers to the range of ideas that need to be linked to investigate a particular subject. This is potentially a useful framework within which to analyse the complexity of a system, as illustrated by Wang (2000) who compares this breakdown with other fields of 'complexity theory' within other realms of science. The nature of complexity is placed within the context of the firm, which itself is an organisation facing complexity in breadth and depth, and where each of the functions that it undertakes is subject to complexity in breadth and depth. Strategic decisions for the firm can include shifting complexity around through outsourcing and the like.

There are also a number of dimensions of complexity within the firm or project, each of which has its own breadth and depth; in most cases these can be referenced directly to the firm and project processes given in the previous sections. These dimensions of complexity are catalogued in Figure 3-2.

Complexity in Technology	This dimension is concerned with the complexity of the underlying technology involved in the product and its nature of production. **Breadth:** The diversity of technologies encapsulated **Depth:** analytical sophistication of the technology.	(Wang, 2000)
Complexity in Markets	This dimension is concerned with customer diversity and market dynamics **Breadth:** Variety of market information and range of marketing expertise required **Depth:** Quality and quantity of market information and expertise in a particular market segment	(Wang, 2000)
Complexity in Products	This dimension involves the number of components and the degree of technological novelty required for a product or system **Breadth:** Number of components or sub-assemblies involved **Depth:** Amount of complexity embedded in each component or sub-assembly	(Wang, 2000), (Hughes, 1983), (Hobday, 1998)
Complexity in Production Processes	This dimension is concerned with the way the product materialises, either through labour or capital infrastructure processes and automation **Breadth:** Number of production lines and amount of parallel production **Depth:** Number of individual processes involved in production and scope of individual production steps and automation	(Tunzlemann, 1997; Wang, 2000)
Complexity in Administration	This dimension is concerned with the structure and control mechanisms within an organisation **Breadth:** Number of functions and divisions **Depth:** Number of tiers within the organisation	(Wang, 2000)
Complexity in Projects	This dimension is concerned with the relationships between firms within a project. **Breadth:** Number of firms involved and information sharing **Depth:** Amount of coupling between firms and outsourcing	(Hobday, 1998), (Tunzlemann, 1997)

Figure 3-2: Dimensions of Complexity

Our understanding of the complex nature of innovation (which may itself be becoming more complex) is reflected in the emergence of a number of different conceptual models of increasing sophistication. Simple linear 'technology-push' and 'demand-pull' models have been replaced with more complex, but still sequential, coupling models, and more recently by highly integrated, parallel models which represent close approximations of current best practice (Freeman, 1994).

Finally, it is useful to analyse the complexity of a product by placing it in a product hierarchy, such that an absolute, rather than relative measure of its complexity can be gained. An intrinsic feature of an hierarchical system is that:

> "as the hierarchical chain is climbed products become more complex, few in number, large in scale and systemic in character. In parallel, design and production techniques tend to move from those associated with mass-production through series and batch production to unit production. Towards the top of the hierarchy, production involves the integration of disparate technologies, usually entailing large-scale project management and extensive national and international cooperation between enterprises. Thus, the pyramid is also one of increasing organisational and managerial complexity" (Walker, 1998)

A suitable hierarchy was developed by Hughes (1983) and includes the following four levels of product complexity:

> **Assemblies**: Base unit which performs a single function and not part of a wider system unless connected within a network (e.g. calculator).
>
> **Component**: Part of a larger system (e.g. avionics unit).
>
> **System**: Any system can be grouped into three elements; components, a network structure and a mechanism of control. These are organised to perform a common goal (e.g. aircraft).
>
> **Array**: An array is a system of systems; a collection of distinct but interrelated systems performing independent tasks but working towards a common goal (e.g. airport).

Based on this definition of complexity and its placement within the firm, it is now possible to undertake an investigation of Complex Product Systems in their historical and current innovation perspective.

3.3 The Development of CoPS in the Innovation Literature

Although it is claimed by Hobday (1998) and Davies (1997e) that CoPS is a new field of study in innovation theory, there have been a number of investigations into complex systems over the past thirty years. This section attempts to give an historical perspective of CoPS within some of the existing innovation literature and place some of the more theoretical aspects of CoPS theory. It finishes by asking the question of whether CoPS is indeed a new unit of analysis within the innovation framework.

3.3.1 Complexity in the Historical Context

In the 1950s and 1960s a considerable amount of research was undertaken into complex systems, mainly focussing on the defence sector (Brusoni, 1998). Research conducted by the RAND corporation and the US Department of Defence (Klien, 1962; Marshall, 1962) was aimed at investigating the prediction of time and costs of large-scale projects, as current estimates were often inaccurate and based on optimistic forecasts.

Complexity was then investigated in the context of Large Technical Systems (LTSs), which are defined as coherent structures comprising interacting, interconnected components ranging from relatively simple machines to regional electricity supply networks (Hughes, 1983). An important assumption in the LTS framework was that, because components in a system are interconnected, changes in the activity or design of one component impact upon the activity or design of other components in the system (Davies, 1997e).

However, LTSs were limited in scope, mainly focussing on system characteristics rather than the manufacture of discrete complex products. As such, they were more used as a mechanism for controlling a system of interrelated components and discussed the economic drive to realise cost-saving economies of scale (improvements in the capacity to handle large numbers of products or amounts of information) and economies of scope (using the same plant and equipment to deliver a greater range of services or products).

In contrast to LTSs, Miller (1995) studied the product and the nature of production and as such focussed on the supply of large and complex, customised, engineering-intensive products, in which production is of a one-off kind. In essence, the complex system and its associated analysis were taken together as the unit of analysis. This study paved the way for the development of an area of study known as Complex Product Systems.

3.3.2 CoPS Development

The beginnings of the study of Complex Product Systems began in 1995 and 1996, based on ideas in papers by Brady (1995), Davies (1996) and Hobday (1995). This research suggested that there was a new sector of industry known as Complex Product Systems, which until recently had not received proper attention, as the CoPS sector of industry had typically included it as a special case of normal innovation research with the view that the principles of mass production can be applied to products where only a single output is produced.

The research suggested that Complex Product Systems were large, one-off complex systems usually supplied in unit or small batch production tailored to meet the requirements of particular large users (Davies, 1996). They undergo continuous innovation and development, both during production and after deployment, and often have long service life expectancies. Examples of Complex Product Systems include intelligent buildings, telecommunications exchanges, flight simulators, aeroplanes, weapons systems and manufacturing plants. CoPS theory would draw together studies from innovation, industrial sociology, project management, systems engineering, military systems and the history of technology.

Brady (1995) suggested that much of the research on innovation success and failure in CoPS is based on studies of mass produced consumer products rather than one-off customised or small batch-produced industry-to-industry products. It follows that many of the traditional models of innovation that have been derived from this body of research may not be adequate for considering innovation in CoPS.

From these beginnings, a field of research has emerged, largely centered at the Centre for Research in Innovation Management (CENTRIM)/Science and Technology Policy Research Unit (SPRU)/Economic and Social Research Council (ESRC) Complex Product Systems Research Centre located at the Universities of Sussex and Brighton.

The research trajectory has since come to include studies into management practices, policy implications and more theoretical investigations into the nature of innovation.

As part of this analysis, CoPS researchers make a number of claims:

- That CoPS make up a new analytical category, and as such deserve special attention (Hobday, 1996a; Davies, 1997e)
- That CoPS play a vital role in the modern economy and wider society and underpin the production of modern goods and services (Heighs, 1997; Hobday, Rush et al., 2000)
- That because most conventional innovation wisdom is derived from research into high volume consumer products, new models and concepts are needed to understand the innovation and management processes in CoPS (Hobday, Rush et al., 2000)

The remainder of this section is dedicated to investigating these claims.

3.3.3 CoPS as a new Analytical Category

As stated above, in defining a new research agenda for CoPS, (Hobday, 1996a) suggests that CoPS form a new analytical category of innovation. In order to test this theory, it is useful to ground CoPS within the existing innovation literature, in particular Pavitt's sectoral types of innovating firms, Woodward's spectrum of production processes and the generation of innovation models developed by Rothwell.

It was evident from early R&D statistics in the 1950s that industries fall into a number of distinct categories (Freeman, 1994), based largely on the intensity of R&D. This initial finding was further developed by Pavitt (1984), who suggested three sectoral types of innovating firms:

- Science based
- Scale (or production) intensive
- Supplier dominated (or information intensive).

This taxonomy provided a fruitful framework for analysis and helped describe external relationships or internal technical activities within firms, the acquisition of knowledge within the firm, diversification behaviour and industrial structure (Freeman, 1994). However, there were a number of shortcomings to this taxonomy, especially with respect to service industries, which were typically placed within the 'supplier-dominated' category.

Miller (1995) suggested that complex systems, such as ones that are described by CoPS theory, do not fit into any of these categories. They are neither science based nor scale intensive, nor are they supplier dominated. Pavitt did revise the original taxonomy to include firms in the class of 'specialised suppliers', but this was taken under the production paradigm of mass-market commodity goods. However, one drawback in assessing whether CoPS do or do not fit within Pavitt's categories is the fact that the categories apply to industrial sectors, not products. There is still a lack of clarity as to whether CoPS are an industry unto themselves, fit as a subset of other industrial sectors, or indeed underpin the spectrum of production processes in these sectors. Hobday (2000) suggests the last and this is tested in the following section.

Another means of placing CoPS within the existing innovation literature is by using the classic framework of Woodward (1958), which outlines the typical spectrum of production processes. This spectrum, ranging from project/unit production to continuous processes is illustrated in Figure 3-3, along with some sample products in each category.

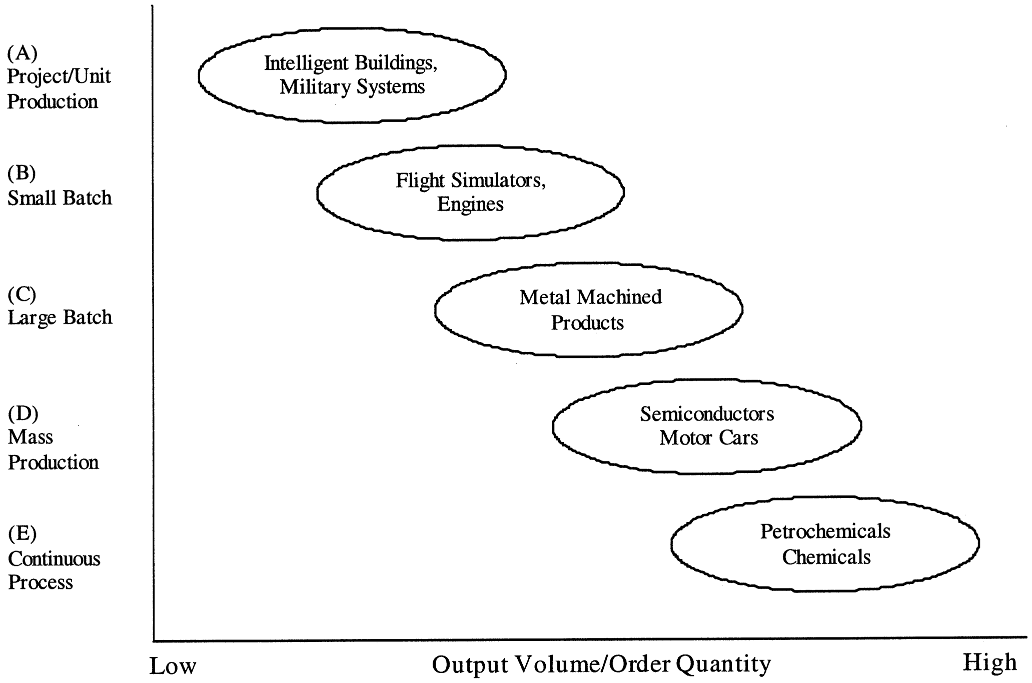


Figure 3-3: Woodward's Spectrum of Production Processes, Source: (Hobday, 1998)

Within this framework, CoPS include the high-technology goods contained in (A) and (B). It would not include low technology goods in these categories (such as roads) or small low cost items (such as tailored software solutions or individual components). However, it is also interesting to note that many of the goods produced in categories (C) to (E) also rely on CoPS for their production, such as computer networks, plants, complex machinery and other upstream goods.

By cataloguing products based on their production processes, the basis for an understanding of the previous research agenda for CoPS can be developed. Hobday argues that most of our understanding of innovation has evolved from studies of categories (C) to (E), with categories (A) and (B) treated as special cases rather than generic categories of research (Hobday, 1996a; Hobday, 1998).

A final means of placing CoPS within the existing innovation literature attempts to locate them within Rothwell's various generations of innovation models (Rothwell, 1992), outlined as adapted by Brady in Table 3-1.

Table 3-1: Rothwell's Generations of Innovation Models, Source: (Brady, 1995)

Generation	**Type of model**	**Characteristics of model**
First generation	Technology-push	Simple linear sequential process. Emphasis on R&D. The market is a receptacle for the fruits of R&D
Second generation	Need-pull	Simple linear sequential process. Emphasis on marketing. The market is the source of ideas for directing R&D. R&D has a reactive role
Third generation	Coupling model	Sequential but with feedback loops. Push or pull or push/pull combinations. R&D and marketing more in balance. Emphasis on integration at the R&D/marketing interface
Fourth generation	Integrated model	Parallel development with integrated development teams. Strong upstream supplier linkages. Close coupling with leading edge customers. Emphasis on integration between R&D and manufacturing/design for makeability. Horizontal collaboration (joint ventures)
Fifth generation	Systems integration and networking model	Fully integrated parallel development and use of expert systems and simulation modelling in R&D. Strong linkages with leading edge customers (customer focus at the forefront of strategy). Strategic integration with primary suppliers including co-development of new products and linked cad systems. Horizontal linkages; joint ventures; collaborative research groupings; collaborative marketing arrangements etc. Emphasis on corporate flexibility and speed of development (time-based strategy). Increased focus on quality and other non-price factors.

Rothwell's fifth generation model, with its emphasis on collaboration with networks of suppliers, close contact with leading edge customers, parallel engineering and use of sophisticated computer tools, is perhaps closer to the process of innovation in CoPS than earlier generation models with their essentially sequential approach (Brady, 1995)

Of course, these are not the only ways of cataloguing CoPS within the existing innovation literature. Other frameworks such as that developed by Shenhar (1993) can also be used to distinguish other features of CoPS, focussing their position within the hierarchy of complexity (arrays, systems, assembly and components) given in the previous section.

A summary of the placement of CoPS within a number of different innovation frameworks is given in Table 3-2.

Table 3-2: Placement of CoPS within the innovation framework

Framework	Scope	Distinguishing features
Pavitt	Industry Sector and R&D Intensity	CoPS do not fit into any of these categories, and may not even be an industry sector
Woodward	Production Process	CoPS fit into the categories (A) and (B), but there has been little research undertaken
Rothwell	Innovation Model	CoPS fit within the fifth generation model of innovation

Using this breakdown, Hobday's initial assertion that CoPS make up a new Analytical category, and as such deserve special attention, can be tested. It is unclear from the literature of what exactly makes up the CoPS industry category, as CoPS not only consist of products which are not covered by existing industry sectors, but also underpin the development of other mass-produced products in the remaining industry sectors. Where CoPS underpin existing industries, the separation of the complex product from the industry is also unclear.

However, Brady (1995) makes the point that the process and dynamics of innovation are likely to differ markedly from those of the 'conventional' Schumpeterian innovation model, which tends to assume mass production industries and relatively simple products. This is confirmed when the existing innovation literature is classified within the context of production processes. As such, while CoPS may or may not make up a new industrial category, it does provide a useful means of aggregating products with similar characteristics for analysis, which is not explicitly covered by existing theory.

3.3.4 CoPS and the Economy

As argued by Pavitt (1997), lack of technological knowledge is rarely the cause of innovation failure in large firms in the 20th Century. In OECD countries the main problems are ones of management and organisation. In addition, large multi-divisional technological firms are responsible for the largest amount of technological innovation;

they employ the most scientists and engineers, maintain a close link with academic research and publish the largest proportion of technical papers.

Davies (1997e) suggests that Complex Product Systems have a big impact on the determinants of technical advance. On the positive side, there is an incentive for more research and development by involving the user throughout the project. This gives a more user push or demand driven focus on the technical advance. In contrast, mass-produced innovation is led by perceptions of market demand. On the negative side, the selection environment can often be highly bureaucratic and politicised, which may lead to low contestability and allow poor performers to dominate the market despite low technical performance.

A study by Heighs (1997) suggested that CoPS may account for as much as GBP68 billion to the United Kingdom economy, or as much as 11% of value added Gross Domestic Product. This figure was obtained through a number of methods, including the analysis of the top 21 CoPS related UK industries. It is also estimated in the same study that CoPS related projects employ between 1.4 million and 4.3 million UK workers.

In addition, Heighs argues that the innovation environment for CoPS in recent years has changed profoundly. Market growth, internationalisation and deregulation of CoPS industries (such as telecommunications, aerospace, electricity and power generation) has increased the demand. Increased investments in technology and embedded systems have also facilitated the production of CoPS, especially in developed countries.

It has also been suggested that industries which include a large number of Complex Product Systems as part of their production capacity are also likely to make up a large proportion of a nation's net earnings. The Aviation industry alone was estimated to be worth around $US150 billion in 1991, more than twice as large as the semiconductor industry (Hobday, 1998). Also, although CoPS are only one category of production process, they often have an impact on the other categories, ranging from small-batch to mass produced to continuous process projects. Many modern services, from banking to transportation to telecommunications depend on CoPS to operate.

Based on this evidence, there is some justification in suggesting that CoPS do play a role in the modern economy and wider society, and underpin the production of modern goods and services (Hobday, Rush et al., 2000).

3.3.5 New concepts and models in CoPS Management

Current research also suggests that management processes may be more important to the success of a firm than its capital resources (Gann and Salter, 1998). It has been suggested that one of the significant aspects of Complex Product Systems is that they have a large impact on the arrangement of the management of the project (Davies, 1997d). Depending on the product, the form of management used has to adapt to the different styles of innovation management.

To illustrate this point Davies (1997c) describes two projects; the first uses a mechanistic approach to the management of the design and production of a GSM base station. It was found that the hierarchical management structure followed that of the product itself, but was relatively stable, reflecting the existing commercial conditions. The second project involved the management of a turnkey GSM Network planning solution. In this case the resultant management structure was organic, which could not be easily broken down into functional roles within a hierarchical structure. This research demonstrated that CoPS can take a number of managerial and structural forms.

Other studies have also suggested that the management of CoPS is different from the conventional management techniques of mass produced systems. Hobday (1998) provides more details on the set of innovation management techniques which can be used in the area of CoPS, while Hansen (1997) undertake a survey of some of the problems involved in the innovation management of Complex Product Systems. In this case they do a survey of three different companies and six CoPS projects in all, finding that the problems involved in the CoPS across the six studies could be separated into three broad groups: Requirements Identification and Analysis, Coordination of Information and Process Issues (including technical uncertainty, staffing pressures, supplier management and inattention to procedures).

One of the main project management challenges in CoPS is the management of components with different lifecycles and development speeds. Previous advances in component designs, the amount of money invested in a project and the need for backwards compatibility all shape the paths of innovation of a project.

Another challenge of CoPS is the intensity of user involvement in the project. Due to the one-off nature of the system there is often a large amount of user interaction focussed on business-business products, which tests the ingenuity of the CoPS producers and requires core competencies in bidding for and executing projects (Hobday, 1998). In addition, uncertainty on the part of the user or changed requirements add to this complexity. Innovation is also shaped both by the lack of control of management over the contracting teams, as well as regulatory involvement from the government or other bodies. The capacity to deal with feedback loops at various stages of project execution is essential to project-based firms (Morris, 1994).

The project as a coordination mechanism also leads to a difference in management techniques. Using the project, which is essentially a temporary organisational form, as a focussing technique causes a shift towards project management and systems integration techniques being paramount for the success of the venture. The project structure is also often shaped by the nature of the Complex Product System and exists to communicate design and architectural knowledge and to combine distinctive resources know-how and skills (Davies, 1997e).

An investigation into CoPS also leads to the project-based organisation, which organises its needs and structures around the needs of projects, often cutting across conventional industrial boundaries. Through its influence on projects, CoPS will influence the character of coordination within and between firms. Management styles must be capable of bidding for and defining large scale engineering systems and often require an organic rather than a mechanistic, hierarchical approach (Burns and Stalker, 1961; Hobday, 1998).

Finally, the use of CoPS highlights the role of Systems Engineering and Systems Integration in many complex systems, including innovative organisational structures and administrative processes. Any analysis of these systems requires some understanding of the social and technical elements that interlock in a myriad of ways in the design and integration process (Prencipe, Davies et al., 2003).

This area of investigation has facilitated the development of new theory known as Integrated Systems and Services (ISS) solutions in complex product systems (Brady, Davies et al., 2001; Davies, 2002; Brady, Davies et al., 2003). It highlights the fact that systems integration activities are essential to manufacture and service provision (Pavitt, 2003) and that modular design is shaping the development of increasingly more complex products. In addition, Dosi et al (2003) has explored the theoretical aspects of the economics of systems integration by placing it within the context of evolutionary economics. Hobday (2001) has looked at this issue at the firm level by looking at the 'business model' for ISS solutions, with the proposition that there is much more money to be made in downstream service and sales than in the sale of the upstream CoPS product.

Brady (1995) sums up many of these issues, while arguing that some of the management challenges faced in CoPS are different from those found in conventional mass-produced systems. These include the following:

Producers of CoPS, usually systems integrators, require distinctive managerial competences capable of defining and executing large-scale (often complex) projects;
Systems integrators, in addition to managing their internal tasks, often have to co-ordinate the innovation activities of large and complex supply networks made up of small firms, major users, large partner companies, regulators, standards bodies and government departments;
Organisational complexity often means that innovation paths must be agreed in advance among the actors, rather than in the marketplace as is the case with commodity goods;
Organisational complexity has risen due to the increased use of software engineering. The latter has transformed many complex systems (through the use of embedded software) and changed the ways in which research, design, production and installation take place;
Much of the knowledge needed to produce CoPS is embedded in people and cannot be formalised to the same degree as mass produced goods such as automobiles and microcomputers;
CoPS tend not to reach the latter stages of incremental process innovations where competitive strategy and the rewards from innovation are centred in conventional innovation models.
In contrast with commodity goods, large CoPS lifecycles typically extend over longer periods of time and decisions to invest may take months or even years;
Users are often heavily engaged in many aspects of the innovation process including research, development, design, installation and the refurbishment of CoPS.

Figure 3-4: CoPS Management Challenges, Taken from (Brady, 1995)

With these different management challenges, especially when compared with conventional innovation wisdom derived from research into high volume consumer products, there is a case for the development of new models and concepts to understand the innovation and management processes in CoPS.

3.4 CoPS Characteristics

The previous section built upon the literature to argue that innovation processes in CoPS differ from those commonly found in the innovation management of mass produced systems. It follows that CoPS may also follow a different pattern of evolution than the one depicted in the product life cycle. As such, process and dynamics of innovation are likely to be different from those of the traditional Schumpeterian innovation model, which tends to assume mass production industries and relatively simple products (Pavitt, 1997).

Brusoni (1998) suggest that there are four characteristics of CoPS that set them apart from mass produced goods. These are: (a) they are high cost systems composed of many interacting and often customised elements; (b) their design, development and production usually involve several firms; (c) they exhibit emerging and unpredictable properties; and (d) the degree of user involvement is usually very high. This section elaborates upon these critical characteristics of CoPS and attempt to define, both qualitatively and quantitatively, the nature of the Complex Product System.

3.4.1 CoPS vs. Mass Production

As a starting point, to summarise this emerging field of management theory, it is useful to define CoPS by looking at the difference between CoPS and mass-produced systems (Heighs, 1997; Hobday, 1998). When compared with CoPS, simpler goods have fewer customised components, fewer suppliers, fewer regulatory constraints and a smaller variety of knowledge and skill inputs. Simpler goods can benefit from a greater degree of learning from prior generations of product and the codification of process knowledge as a result of volume production.

Hobday (1998) gives a good contrast between the two 'ideal' innovation types; a mass production conventional model vs. a CoPS/project scheme. He shows that the conventional model is closely linked to the production of mass produced goods, taking the firm rather than the project as the chief unit of analysis for investigation purposes. Also, it traditionally focussed on a market driven system: "the Research and Development team innovates and the market selects".

In the conventional model of innovation, the entry and exit of firms is defined by the stage of the innovation cycle; initially there are a large number of firms competing for a particular technology; as the technology matures and a common architecture is selected these firms tend to consolidate with a few firms eventually dominating the market.

In contrast to this, Complex Product Systems have contrasting styles of innovation in areas such as product life cycles, processes of manufacture, industrial coordination, corporate strategies and market features. Davies (1997e) outlines some of these differences, reproduced in Table 3-3. As a result of these differences, CoPS do not follow the same product life cycles or innovation paths as those predicted in the conventional model.

Davies (1997e) also questions if Complex Product Systems are merely the same as mass-produced systems with their lifecycles truncated because of lack of demand for a mass-produced product. However, he argues that the differences in design constraints (such as the reduction of the need to account for an eventual high volume production) still make these different from the mass-produced simpler goods.

Finally, it should be noted that there is a continuum of products which sit between CoPS and mass-produced products.

Table 3-3: CoPS vs. Mass Produced Industries, Source: (Hobday, 1998)

	CoPS project organisation	**Commodity products, functional organisation**
Product Characteristics	Complex component interfaces	Simple interfaces
	Multi-functional	Single function
	High unit cost	Low unit cost
	Product cycles last decades	Short product life cycles
	Many skill/knowledge inputs	Fewer skill/knowledge inputs
	(Many) tailored components	Standardised components
	Upstream, capital goods	Downstream consumption goods
	Hierarchical/systemic	Simple architectures
Production characteristics	Project/small batch	High volume/large batch
	Systems integration	Design for manufacture
	Scale intensive, mass production not relevant	Incremental process, cost control central
Innovation processes	User-product driven	Supplier driven
	Highly flexible, craft based	Formalised, codified
	Innovation and diffusion collapsed	Innovation and diffusion separate
	Innovation paths agreed ex-ante among suppliers, users etc.	Innovation path mediated by market selection
	People-embodied knowledge	Machinery embodied knowledge
Competitive strategies and innovation coordination	Focus on product design and development	Focus on economies of scale/cost minimisation
	Organic	Mechanistic
	Systems integration competencies	Volume production competencies
	Management of multi-firm alliances in temporary projects	Focus on single firm (e.g. lean production, TQM, MRP II)
Industrial coordination and evolution	Elaborate networks	Large firm/supply chain structure
	Project based multi-firm alliances	Single firm as mass producer
	Temporary multi-firm alliances for innovation and production	Alliances usually for R & D or asset exchange
	Long-term stability at integrator level	Dominant design signals industry shakeout
Market characteristics	Duopolistic structure	Many buyers and sellers
	Few large transactions	Large numbers of transactions
	Business to business	Business to consumer
	Administered markets	Regular market mechanisms
	Institutionalised/politicised	Traded
	Heavily Regulated/controlled	Minimal regulation
	Negotiated prices	Market prices
	Partially contested	Highly contested

3.4.2 CoPS Defining Terms

In undertaking a review of CoPS literature a number of defining terms for CoPS can be developed, building upon the characteristics defined in Section 3.4 above:

Table 3-4: CoPS Defining Terms

Defining Term	Primary Source
CoPS are high cost with long product cycles	(Brusoni, 1998; Hobday, 1998)
CoPS design, development and production usually involves several firms	(Brusoni, 1998)
CoPS product complexity is high and exhibit emerging and unpredictable properties	(Brusoni, 1998)
CoPS are of a one-off kind to meet requirements of individual business users	(Davies, 1997e)
CoPS require involvement from policy and other regulatory sources	(Davies, 1997b)
CoPS are user driven rather than market driven with a high degree of user involvement	(Hobday, 1998)
CoPS are project based, rather than product based	(Davies, 1997e)
CoPS markets are typically characterised by oligopolies	(Hobday, 1996a)
CoPS require distinct management capabilities	(Hobday, Rush et al., 2000)

Each of these defining areas of CoPS is elaborated upon in the following sections

3.4.2.1 High cost with Long Product Cycles

Complex Product Systems are traditionally involved with high cost products (Hobday, 1998). The complex nature of the system requires projects to have a large number of people involved and require much investment in the form of design and development. In addition to, and as a result of this, CoPS have typically long product lifecycles. These require extra thought in terms of developing systems and structures and add to the complexity of the project, with a focus on robust system-level designs (Rothwell, 1989).

There is, however, no mention of quantitative measures for ‘high-cost’ or ‘long’ product cycles in the literature. However, in investigating the multitude of CoPS case studies provided in the literature it is evident that CoPS projects are typically worth a number of millions of dollars with timeframes that extend over several years.

3.4.2.2 Involvement of Several Firms

Individual components within the CoPS environment are often produced by a number of firms or by a number of departments within the one firm. As a result, communication within and between organisations is vital to the operation of the system.

The links between the project and the output of the project are one unit of analysis for a complex product system (Hobday, 1998). The CoPS project is often a temporary coalition of organisations which usually cuts across the boundaries of single supplier firms.

As mentioned previously, small batch processes are much more capable of codifying knowledge within the production structure, because of the mass-produced nature of the system. In CoPS, process learning between projects and product generations is much more haphazard, as a result of the difficulties of transferring knowledge between projects and the different requirements of each project.

Firm processes and project processes differ primarily in that the former are usually ongoing and repetitive whereas the latter are temporary and unique (Brusoni, 1998). As such, learning in a complex one-off project has the double impediment, in that the project is less likely to be repeatable and the processes involved are more complex.

Production learning and organisation also change within the CoPS environment. This may be due to the disbanding of teams after the project completion and the unrepeatable nature of the project. Isolated improvements at the single firm level only have limited improvements on the entire project. As such, the focus must also be towards optimisation of the entire project network.

3.4.2.3 Product Complexity

Complex Product Systems are engineering intensive, with a high degree of customisation in the final product. They involve more components and interactions and require close attention to interfaces and communication. In addition, Complex Product Systems often have a large number of design paths that can be chosen during the development of the project. Focussing tools are needed to deal with the problem of 'Combinatorial Explosion' (Hobday, 1998), which can result from these large numbers of options.

Decisions in architectures have a big effect on the outcome of the project. Decisions on how components in the system come together to form a coherent whole require both knowledge of the components' core design concepts and their implementation, as well as the way in which the components can be linked together. The number and scope of components in CoPS may also require external communication as part of the architectural decision-making process. Inter-firm collaboration, or technical coordination, is a major part of the management of innovation, regardless of the project.

Another influencing factor in design paths are feedback loops present in the design. These loops require alterations in the overall systems architecture and design of specific components. These loops come about as a result of both insufficient information in certain phases of the project as well as changing requirements during the project's implementation.

CoPS are also subject to a higher degree of customisation in the final product and component parts and involve more components and interactions. This trend has also been fuelled by the introduction of computer technology and embedded systems since the 1970s. CoPS may be assembled using increasingly standardised components produced in high volumes at low costs.

One of the major dimensions of product complexity is the breadth of knowledge and skills required of the project. The need for elaborate systems integration can increase the number of skills required of individuals or specialist firms brought in to complete the work. This also adds another risk to the project as key knowledge is concentrated in the hands of a few key people. Embedded software has also added to the achievable complexity of CoPS, with a strong focus on interface design (Brusoni, 1998).

CoPS mostly falls into the scope of complex components and systems, but not assemblies (too simple) and rarely arrays (too difficult to fit into a single project).

3.4.2.4 One-off products

Complex Product Systems are usually supplied in unit or batch production and are tailored to meet the requirements of particular large users (Davies, 1996). They undergo continuous innovation and development and often have long service life expectancies.

As opposed to mass-produced goods, where much of the innovation goes into improvements in production and obtaining an advantage through economies of scale, CoPS must focus innovation processes towards the product design. This also has issues for product-product and project-project learning, which can be much more easily codified within batch processes.

3.4.2.5 Involvement from policy and other regulatory sources

CoPS industries are heavily influenced by government policies, first addressed by Gann (1997). Governments have used processes such as deregulation and privatisation to stimulate innovation through domestic rivalry and have also been responsible for much of the development of these industries, through the purchasing of equipment and the establishment of standards. As a result of this involvement, CoPS industries may often become highly politicised as alliances are formed between system suppliers, large users, standard-making bodies and regulators.

When a standard is adhered to, any innovation within a CoPS must be backwards compatible with that standard. Once a standard is adopted it is often hard to reverse the direction of innovation as CoPS buyers and providers have sunk large amounts of money into the system. However, this does present a risk or cost if the chosen system turns out to be inferior to currently available or future technologies.

Davies (1997b) argues that there is no role for government policy in the traditional product life cycle. Products are self sustaining and do not require a 'sophisticated industrial environment'. CoPS on the other hand require a large amount of input from government:

- as purchasers they influence market entry

- to supply products from large government owned industries
- to establish technical standards for interfacing purposes
- to provide regulations for competition
- to promote research and development in certain industries through subsidies and tax benefits.

Davies uses the example of the European mobile telecommunications industry as a case where government involvement and promotion of a single standard has shaped the development of the industry.

It may also be seen that certain countries have a strong capability in the production of CoPS. For example, Europe is weak in consumer goods industries but stronger in CoPS industries (Davies, 1997b). Davies even goes so far as to suggest that CoPS may be a new industrial category.

3.4.2.6 Customer-driven

CoPS tend to be business-to-business products; production is triggered in response to user needs rather than through arm's length market transactions, resulting in a demand-driven, rather then supply-driven market (Gann and Salter, 1998). As opposed to many mass-produced systems where the product is produced and then a customer is found, CoPS production normally only begins after an order has been placed. This results in a customer-pull, rather than a supplier-push mode of innovation.

3.4.2.7 Project-based

CoPS firms are usually organised around projects, which act as coordination mechanisms between the end-user, supplier and contracting firms. Project processes are very different from business processes within a firm; project processes are mainly involved with activities outside the traditional boundaries of the firm, whereas business processes are almost always internal.

Because CoPS processes are one-off, the project is focussed on the final product to be released. As such, the focus is on design processes, rather than on production processes and advantages through economies of scale.

In CoPS, the project and the product need to be considered together, as each has a direct impact on the other. In many cases the product shapes the project and the project determines the quality and use of the product (Davies, 1997e). This is different from traditional, batch processes, where the management of the project may not be greatly influenced by each and every product (Heighs, 1997).

3.4.2.8 Markets

In contrast to mass production industries where a small number of suppliers provide to a large number of anonymous consumers, CoPS are usually produced by bilateral oligopolies with a few large and demanding business customers. User requirements are incorporated into the product throughout all phases of the project (Miller, 1995; Davies, 1997e).

Often the degree of market contestability is low, as companies turn to the policies of government or nationally-owed purchasers (such as utilities) for direction in choosing suppliers (Davies, 1997e). For smaller projects, however, non-market mechanisms are evident in areas such as bidding procedures and price negotiations. Both of these models contrast with the traditional model where large number of buyers and sellers compete for prices and purchases.

"Those responsible for an idea have to sell, not a product, but the idea that their firm was able to produce what their customer required" (Davies, 1997e) (Woodward, 1958) . In mass-produced systems this is different; first the product development, then production and then, finally, marketing.

3.4.2.9 Management

Project and Project Based Organisations are natural CoPS based organisational forms (Hobday, 1998). These organisations create and recreate new structures based on the needs of each individual project and major customer.

Project management styles in CoPS can range from mechanistic to organic adapted to the rate of technological and market change; there are a wide range of organisational choices involved in the production of CoPS (Hobday, 2000). Davies (1997d) shows how the management of two projects in the same company in the mobile telecommunications industry can take either form: a mechanistic structure based on authority, control and communication which was adapted to complex but relatively stable technical and commercial conditions; and an organic structure used in a small turnkey project requiring much more dynamic competencies. In the organic project management structure vertical integration among people of different rank is more informal and less important than lateral communication between project members, and overall commitment to the progress of the project is valued more than the loyalty to immediate superiors.

As mentioned previously, CoPS development also requires a strong focus on systems integration (Prencipe, Davies et al., 2003). Systems Integration is an element of systems engineering, which was developed after the Second World War to manage complex defence and aerospace projects (Sapolsky, 2003) as the complexity of weapons and other systems increased in the 1950s and 1960s. As outlined in Johnson (2003) systems engineers coordinate, and in some cases control, the overall technical direction of a project, and systems engineering itself is often subject to the effect of the social environment in which the project is being created.

In summary, emphasis in CoPS is on design, project management, systems engineering and systems integration. This is opposed to batch products, where the emphasis is often on production and economies of scale.

3.5 Examples of CoPS

This section outlines some of the categories of CoPS products, and gives some examples of products that have been investigated in-depth in the literature.

3.5.1 Categories of CoPS

Davies (1997e) and Hobday (1998) outline some of the different categories of products which might fall into the CoPS domain; *infrastructural CoPS*, *stand-alone products* and *constructs*.

Infrastructural CoPS are products such as telecommunications networks, gas, water, and electricity supplies and transportation systems. An infrastructural CoPS is essentially made up of three parts: components, a network structure and a mechanism of control (as detailed in the system category in the Hughes (1983) product hierarchy).

CoPS may also be complex *stand-alone products*, such as a satellite, a flight simulator, trains or aircraft. These may also be considered as a system, made up of a number of interconnected components.

Finally, CoPS may be *constructs* such as intelligent buildings. This category fits in more with the idea of an array, or a system of systems working together to perform a common goal.

3.5.2 Examples of CoPS

Hobday (1996a) gives a large list of potential CoPS while suggesting that they are a new innovation research agenda. Gann (1998) refines this list of Complex Product Systems which include, but are not limited to:

1. Many products in the built environment, such as intelligent buildings, hospitals, R&D laboratories, educational establishments, control stations, offices, retail and distribution complexes, factories and military establishments
2. Utilities and communication infrastructures
3. Power, oil and gas, off-shore and process plants
4. Transport nodes and infrastructure

5. Aircraft, ships and high speed trains.

Davies (1997e) also breaks CoPS into a number of sectors and compares them with mass-produced products in the same sector. His breakdown of products is shown in Figure 3-5.

Industrial Sector	CoPS	Mass Produced Products
Aerospace	Airports, air traffic control, baggage handling systems, commercial jet aircraft	Aircraft tyres, passenger seats, runway lights
Rail and Tramways	Stations, bridges, tunnels, signalling systems, high-speed trains	Train wheels and brake blocks, sleepers
Telecommunications	Mobile phone systems, telephone exchanges, radio base stations for mobile communications, intelligent networks	Telephone handsets, fax machines, pocket pagers, teleprinters
Electronics and Information Technology	Semi-conductor fabrication plants, banking automation systems, business information networks	Personal computers, electronic calculators, office franking machines
Heavy Engineering	Hydro-electric dams, industrial turbines, chemical plants	Earth moving machinery, forklift trucks, hand tools, jigs and dies

Figure 3-5: Examples of CoPS and Mass Produced Goods, Source: (Davies, 1997e)

In the literature CoPS analysis is largely based on the Case Study method (Brady, 1995) and as such, it is useful to investigate the range of products that have been investigated within the CoPS framework. A brief selection of these is given in Table 3-5

Table 3-5: CoPS Case Studies

CoPS Investigated	Main areas explored	References
Flight Simulators	Innovation processes in CoPS, software processes and practices	(Hobday, 1995; Miller, 1995; Hobday, 1996b)
Telecommunications Networks	CoPS Industry Evolution	(Davies, 1996; Davies, 1997b; Davies, 1997c; Davies, 1997a; Davies, 1997d)
Missile Industry	Industry Internationalisation and Government Policy from a historical perspective	(Molas-Gallart, 1997)
Nuclear Power Plants	Entrapment, institutional lock-in and organisational and political commitments	(Walker, 2000)
Aero Industry	Turboprob vs. jet engines, industry evolution, shakeout, breadth & depth	(Bonaccorsi and Paola, 2000; Nightingale, 2000; Prencipe, 2000; Prencipe, 2001)
Capital Works	Railway projects, managing interfaces, offshore manufacturing, technology policy	(Gann, 1997; Barlow, 2000; Geyer and Davies, 2000; Bresnen and Marshall, 2001)
Defence	Procurement, Institutional change	(Molas-Gallart, 2001b; Molas-Gallart, 2001a)

In these investigations, the CoPS project, rather than a single firm, is the main unit in innovation, management and competition analysis. CoPS research is complicated by the fact that the project, which is the CoPS unit of analysis, sometimes does not lend itself to existing standards of classification in existing literature. Companies often publish information in terms of annual reports and accounts, which can mask a range of activities both complex and otherwise (Heighs, 1997).

In reviewing the range of case studies which have been prepared during the investigation of CoPS, it can be seen that the definition of CoPS that is used is extremely broad. For example, they can range from small batch items such as flight simulators, to large arrays such as the telecommunications industry where the complex product is the industry and vice versa. In this context it is hard to find a "pure" CoPS, something which matches all of the CoPS criteria, with a definable timeframe and measurable parameters.

3.5.3 Software and CoPS

Software engineering has become more prevalent in the production of large systems since the early 1980s. With the introduction of embedded software, the control, flexibility and performance of many products have been improved, while systems integration and software engineering have become central to the mechanisms of innovation in many CoPS (Hobday, 1997).

Some key issues for the development of software for CoPS include:

- software project management: especially the requirement to manage distributed development processes that have to bridge between organisational boundaries;
- methods and tools: the appropriateness of formal methods (when and where to apply these), the selection of tools and methods, mandating uniform approaches across distributed teams and the risk of undermining the developers' ownership of the project;
- standards: both technical and quality or process standards;
- re-use: the need for a reuse infrastructure and the potential for productivity increases;
- maintenance: the need for a conceptual shift to seeing the lifecycle as one of continuous development in which systems continuously evolve;
- boundaries around expertise: the need to both protect and maintain core competencies within the organisation whilst making boundaries permeable across CoPS development consortia.

3.6 CoPS Tools

A substantial amount of research has been performed into measuring CoPS using qualitative methods such as critical product dimensions of complex product systems by Hobday (1998), analysis of project phases by Davies (1997e) and quantitative techniques by Brusoni (1998). Comparisons between informal and formal practices and ideal and actual processes give an indication of areas to focus on in CoPS research. This section outlines some of the most popular quantitative and qualitative analysis tools and critically analyses the usefulness of these tools.

3.6.1 Critical Product Dimensions

In a spectrum of products, CoPS can be seen in a number of dimensions (Hobday, 1998). CoPS products may be components, as part of a larger system; they may be the system itself, containing a number of components; or they may be considered an array, or a system of systems.

Hobday (1998) has isolated fifteen critical product dimensions, which he believes can be used to form a complexity profile of a project/product. This complexity profile is shown in Figure 3-6

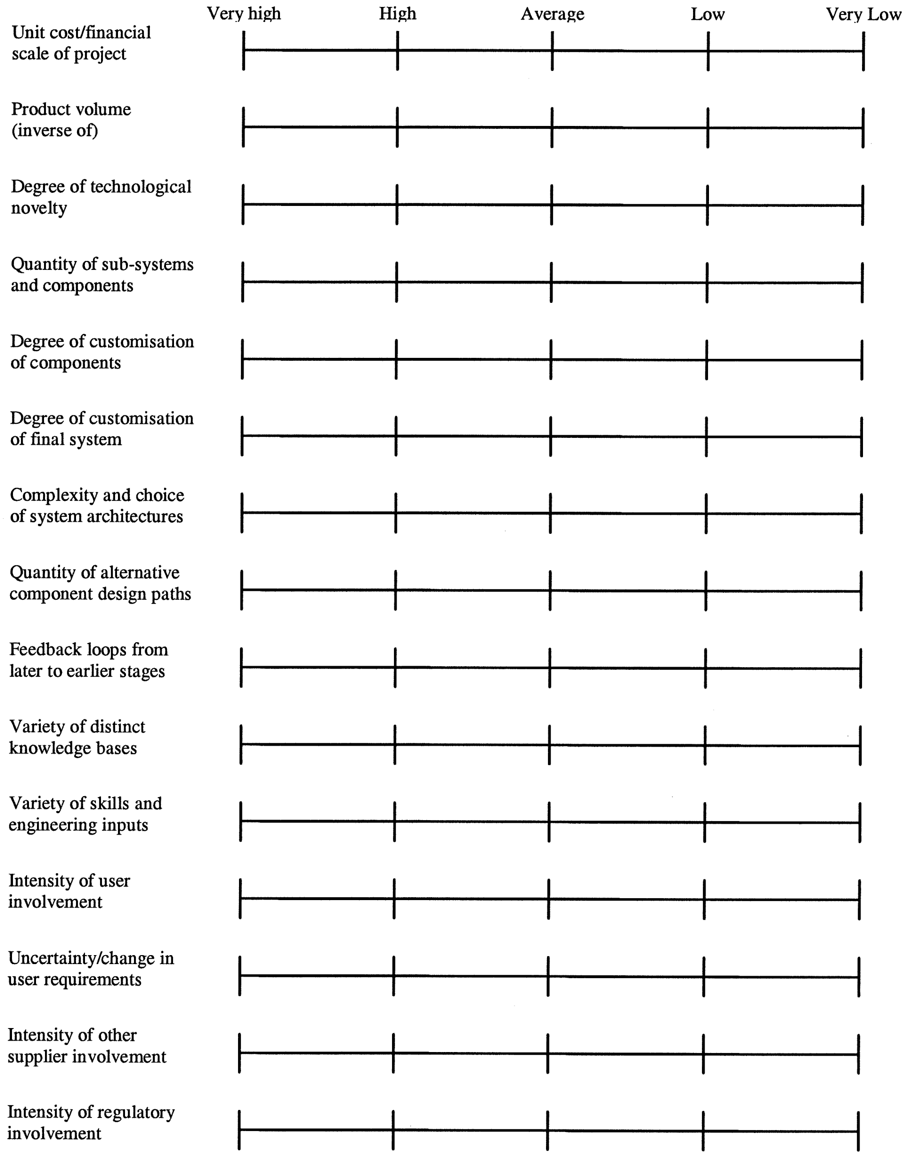


Figure 3-6: Critical Product Dimensions of Complex Product Systems, Source: (Hobday, 1998)

Each item in this list contributes directly to the complexity of the project, as well as to the complexity of managing the production and innovation by adding uncertainty and risk. These critical dimensions provide an insight into the degree and nature of the complexity of the project and effectively make up a complexity profile of the product. It must be noted however, that this scale is to be used to give qualitative indications of complexity only and may not capture all of the complexity of the system and that there is no weighting scheme given for the various complexity units.

Whereas most Complex Product Systems Projects tend to score to the left of the critical dimensions of Figure 3-6, mass-produced systems tend to score low values to the right. These would often have to account for other innovation management challenges not as important for CoPS and in general pose fewer coordination difficulties because of the nature of the product and the reduced number of parties involved in the production.

3.6.2 CoPS Industry Evolution

Davies (1997b; 1997e) presents a framework for analysing phases of innovation in the evolution of a Complex Product System Industry. This evolution model is different from the traditional model of the product lifecycle in that it recognises that CoPS tend to remain in the fluid phase of product innovation (Miller, 1995).

Instead, Davies defines three different categories of product innovation that influence the development of these systems:

> *Architectural Innovation*: Architectural innovation refers to changes in the overall structure of the system and how the system in controlled. It relies on the specification of the architecture of the system and the way in which products are arranged to meet the common system goal.
>
> *Component Innovation*: These are innovations which can be introduced into a single component without having to modify other components or the system architecture.
>
> *Systemic Innovation*: A systemic innovation is a change in the design or functioning of a system that results in a significant redesign or readjustment of other components. Often this is combined with component innovation for analysis purposes.

Davies suggests that the development of a CoPS product may be divided into the architectural phase and the Component/Systemic phase (called the product generation phase), as shown in Figure 3-7.

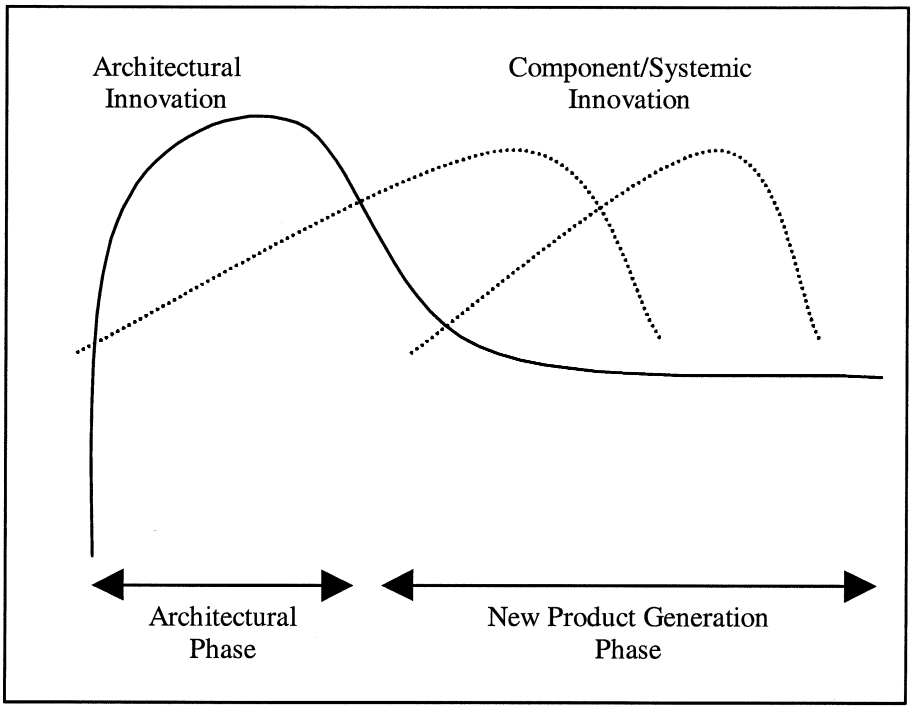


Figure 3-7: CoPS Life Cycle, Source: (Davies, 1997e)

In the architectural phase, there is often a delay between the project inception and the final product. Because of the high costs involved, few equipment manufacturers will take the risk of experimenting with developmental architectures with little or no guarantee of a future market for the product. In CoPS, this process may also involve input from a regulatory framework to choose between competing interests and to produce standards, often with commercial or legal constraints. This period is brought to a close with the agreement upon standards and the selection of core architectural and core component designs.

The new product generation phase commences with the first commercial introduction of the system architecture. During this period of high component and systemic innovation, new product generations are introduced without severely changing the product architecture. One result of this is that, as opposed to mass-produced systems where a new technology can render old technology obsolete, CoPS have a relatively long life expectancy. Products are built in a hierarchical fashion with different product life cycles for each component.

Only after a system has been in operation for some time is it possible to identify weaknesses in the architecture or components. As the performance of a new technology depends not only on its capacity but on the inputs to it, these weaknesses may often be reflected into other parts of the system. As such, components which constrain the full utilisation of a system become the focus of corrective innovation to enable the system to advance as a whole.

As noted previously, there is some ambiguity as to whether this architectural analysis describes a CoPS or a CoPS industry. In his analysis of the evolution of CoPS, Davies uses the case of a Cellular Mobile Telecommunications System as an example to illustrate the three phases of CoPS evolution. However, within this framework it is unclear as to what the actual unit of analysis of the CoPS is, shifting between the description of the entire telecommunications industry to analysing a particular individual telecommunications system. As such, from this analysis it is unclear as to whether the framework for the evolution of a CoPS also applies to the product itself as well as the industry.

3.6.3 CoPS Phases

As well as architectural, component and systemic phases of CoPS systems evolution, the particular phases of development of CoPS projects themselves can be identified and used as a template for the effective analysis of a project. A sample set of CoPS phases is given in Table 3-6.

Table 3-6: Sample CoPS Project Phases

Pre-production bidding
Conceptual (architectural) design
Detailed design
Fabrication
Delivery and Installation
Post-production innovation
Maintenance
Servicing and Decommissioning

Comparing these phases with the phases developed by Davies (1997e), it can be seen that the first two correspond directly to the architectural phase, while the rest are concerned with systemic and component innovations.

3.6.4 CoPS Organisation

Typically, CoPS projects are embedded within dense networks which shape the structure and coordination of innovation. Within these networks and as outlined previously, the project can be taken as the coordination mechanism to allow all of the supplier firms, users, regulators and professional bodies to agree to the detail of CoPS development and production (Hobday, 1998). Hobday gives a template for the analysis of the coordinating bodies within a CoPS project based on a UK air defence system, which is reproduced in Figure 3-8.

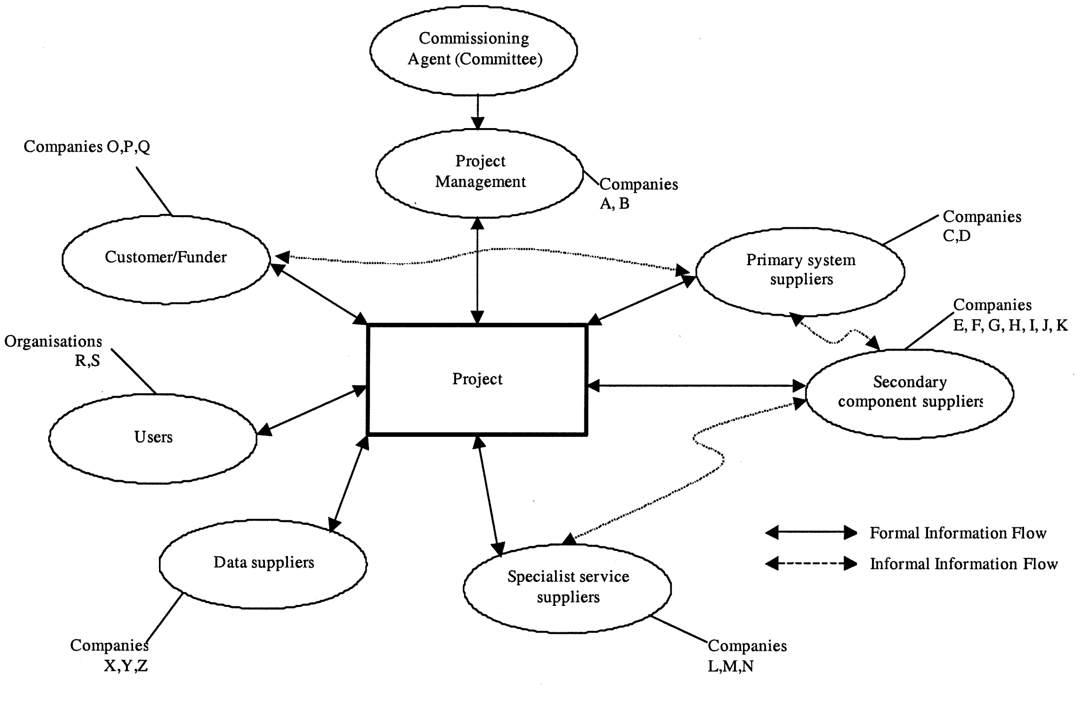


Figure 3-8: Sample Organisation of a CoPS Project, Source: (Hobday, 1998)

In this structure, a commissioning agent made up of a committee would initiate a project which is funded by a customer (e.g. companies O,P,Q). Note that the customer may also be distinct from the eventual users of the system (e.g. companies R,S). The project is typically managed by system integrators (e.g. companies A,B) who govern the project, provide the architectural design and allocate the project tasks. The project in this model is implemented by a range of suppliers, divided into primary systems suppliers (e.g. firms C,D), secondary systems suppliers (e.g. firms E to K), specialist suppliers (e.g. firms L to N) and data supply organisations linked to the user (e.g. firms X to Z).

While this model does not fit all CoPS products, it does provide a starting point for an investigation into the organisation of a CoPS project. In addition, it provides a useful means to investigate the coupling of the project partners and the amount of formal and informal knowledge transfer between them.

3.7 Quantitative Methods

Brusoni (1998) gives an introduction to some of the quantitative methods that can be used for the investigation of Complex Product Systems. Taking the project as the unit of analysis, they give a number of means of investigating these projects in a quantitative manner, focussing on the project processes outlined in Section 3.2.2

The three areas on which the Quantitative methods suggested by Brusoni focus are:

- Inter-industry differences: to what extent does the practice of CoPS perform across industries?
- Inter-project learning: what are the mechanisms used by firms to capture knowledge from project to project? How are these mechanisms implemented and managed in practice?
- Firm Practices and Performance: What is the relationship between firm practices and performance? What is the relationship between project processes and business processes?

Brusoni (1998) also gives some survey approaches that may be used to undertake these analyses.

3.7.1 CoPS Management Tools and Techniques

There has been a considerable amount of research into different management tools and techniques in the area of innovation theory. However, most of these tools were developed for managing mass-produced goods which follow the product life-cycle model (Brady, 1995). While not attempting to be a rigorous survey of everything available, this section outlines some of the different management tools that are suggested for use in the CoPS domain and investigates their applicability.

3.7.1.1 Project Wide Tools and Techniques

A number of tools and techniques have been developed to facilitate the development of an entire project. These include strategic tools such as innovation models as well as diagnostic and auditing tools such as benchmarking to assess management performance.

Learning and technology transfer tools can be used to ensure the smooth transition of information and resources from one project to another. In Complex Product Systems this is particularly important, as it is the main method for capacity building within a company. Models exist which exploit 'economies of repetition' in CoPS projects to improve the efficiency of similar projects (Davies and Brady, 2000).

3.7.1.2 Research & Development Tools and Techniques

High technology industries invest heavily in Research & Development and the development of new technology and products. It is widely recognised that R&D activity creates competitive advantages, allows high technology companies to establish business opportunities, supports existing activities and predicts future trends (Dodgson, 2000).

There have been numerous different tools and models developed to address the management of R&D within the innovation process. Over 250 models have been cited which are designed to assist in the R&D project selection process and a range of literature has evolved to facilitate the introduction of successful R&D campaigns (Brady, 1995).

Firms producing Complex Product Systems have been slow to adopt these tools into their innovation management processes. The more complex decision-event tools have been ignored by industry, although simpler models involving checklists and weighting of alternatives have been used. Especially in the area of CoPS, there is much progress to be made. In particular, until there exists a proper framework for a cost-benefit analysis, companies will take some time to adopt CoPS practices as a standard method of operation.

3.7.1.3 Product Innovation Tools and Techniques

A number of tools exist to assist in the development of the product innovation process. These are used in the process of incorporating the voice of the customer in product design and offer systematic approaches to improving products at a reduced cost.

This type of tool includes areas such as Value Engineering/Value Analysis (VE/VA) and Quality Function Deployment (QFD) both of which attempt to capture user requirements and translate them into a minimum cost for the project (Clausing, 1991). Unfortunately, many of these tools are not sufficiently developed to handle the complexity of the typical Complex Product System.

3.7.1.4 Process Innovation Tools and Techniques

This area of process innovation encompasses the fields of continuous improvement and quality (Brady, 1995; Slack, 1995). Whereas R&D focuses on the development of radical innovations, these tools facilitate the incremental innovations within a firm. This is the philosophy behind many of the Japanese product management techniques that western companies have tried to emulate.

In addition, quality and continuous improvement are becoming increasingly important as firms become more customer-oriented. A number of tools have been developed to ensure that quality is an integral part of process development, including TQM, fishbone diagrams, pareto charts and many more (Dodgson, 2000).

For Complex Product Systems, the product and the project must be analysed together. As a result, process innovation becomes integrated with product innovation, blurring the line between the two. However, tools focussing on quality can still be used on a product to product basis.

3.7.1.5 Project Management Tools and Techniques

Project management is concerned with the planning, scheduling and control of projects. This is the area which is most applicable to the CoPS domain, as many of tools were developed for the defence and missile industry to assist the development of these systems.

The Gantt chart was the first such tool developed for project management purposes. Used extensively for project scheduling, it unfortunately starts to prove ineffective for more complex projects with a large number of interdependencies and is unable to incorporate uncertainties into activity durations. Network planning tools such as PERT (program evaluation and review technique) and CPM (critical path method) were mainly used to take account of both time and cost scheduling, using ideas such as Work Breakdown Structure and Earned Value (Brady, 1995).

Risk management is also an important tool in the development of CoPS. Many projects require effective risk management to anticipate future problems and facilitate contingency planning.

Despite the universal adoption of some of these tools, care has to be taken in their use. Some of the more developed tools should not be regarded as a panacea nor are they applicable to the management of all projects. Many have their main strength in small projects where time is of the essence and may not deal effectively with the complexity of a CoPS project.

It has been noted that, even with these tools in widespread use, projects still continue to be plagued with cost and schedule overruns and technical difficulties, questioning the extent of their success in the effective management of a project.

3.7.1.6 Software Development Tools and Techniques

Software engineering has become more prevalent in the production of large systems over the last twenty years. With the introduction of embedded software, the control, flexibility and performance of many products have been improved, while systems integration and software engineering have become central to the mechanisms of innovation in many CoPS (Hobday, 1996b).

In software project management it is especially important to manage distributed development processes that have to bridge between organisational boundaries. In addition, the appropriateness of formal methods, the selection of tools and methods (seeing through the hype) and software re-use are the key to major productivity increases.

The most often used software development tool is the Capability Maturity Model (CMM), developed by the US Department of Defence (Hobday, 1996b). The idea behind this model is that the quality of the software output relies on the management of the software. The model classifies software design into one of five levels depending on the quality of the organisation's software processes.

3.8 Conclusions

In this chapter, the nature of Complex Product Systems was investigated, looking first at their background and the nature of products and complexity. The characteristics of CoPS were then listed, along with their critical product dimensions, before comparing CoPS with traditional mass produced systems.

Several examples of CoPS in the literature were given and a review of CoPS within the innovation literature was undertaken. Finally, the impact of Complex Product Systems on innovation, economics and management was detailed.

It was found that while CoPS is still an emerging area of innovation theory, much progress has been made. CoPS is a useful framework for analysing complex, one-off technical systems, giving an insight into the nature of their innovation and some of the management and policy areas that arise in their development. However, there are still a number of areas that need to be investigated and questions that need to be answered:

1. The CoPS unit of analysis is unclear. Do CoPS measure industries or products? Or are CoPS just a subset of products within an industry? Is there such a thing as a CoPS industry?
2. The definition of CoPS is extremely broad and often the boundaries between CoPS projects are unclear. Is there such a thing as a "pure" CoPS? Often one

CoPS will build upon another (e.g. the telecommunications industry, the missile industry) – do we have a series of CoPS or one large CoPS?

3. Measurement of CoPS is still ambiguous. While there have been some attempts at providing qualitative and quantitative indicators there is still much work to be done.

The following chapters will use this theory to investigate the satellite industry, with the overall aim of looking at the development of a new CoPS industry in the Australian context.

Chapter 4

CoPS and the Satellite Industry

4.1 Introduction

In the previous chapter a critical review of the nature of a Complex Product System was given. Given that many of the critical dimensions of CoPS involve large, one-off technical systems, a cursory investigation suggests that many of the products developed in the international space industry may indeed fall into this category.

As highlighted in Chapter 3, the unit of CoPS analysis is somewhat unclear as to whether it refers to a particular industry, or the products within the industry itself. This chapter circumvents this problem by both analysing the space industry in general and then investigating satellites, one of the products of the industry.

This chapter begins by following the Schumpeterian doctrine that "history matters" by outlining the development of the international space industry over the last fifty years. In addition, a survey of the current state of a number of space industries is presented, which provides context for the state of the Australian Space Industry investigated in Chapter 5. The Space Industry is then compared with two other CoPS industries, the International Missile Industry and the International Telecommunications Industry.

This chapter then focuses on a particular segment of the space industry, the manufacture of satellites. It details the complexity of, and provides the technical background to, a typical satellite project and details the typical structures within which it operates.

Using a number of CoPS analysis tools, the hypothesis that satellites are ideally suited to analysis as Complex Product Systems is tested.

4.2 The Space Industry in Historical Context

In line with the CoPS analysis of the international telecommunications industry, which uses a number of development generations to outline its growth (Davies, 1997a), one way to describe the development of the international space industry is through the generations of deep-space satellites (NASA, 2001). These generations have been modified to apply to the development of the entire industry in earth orbit, shown in Figure 4-1. This section gives an historical perspective of the space industry by describing each of these phases in turn.

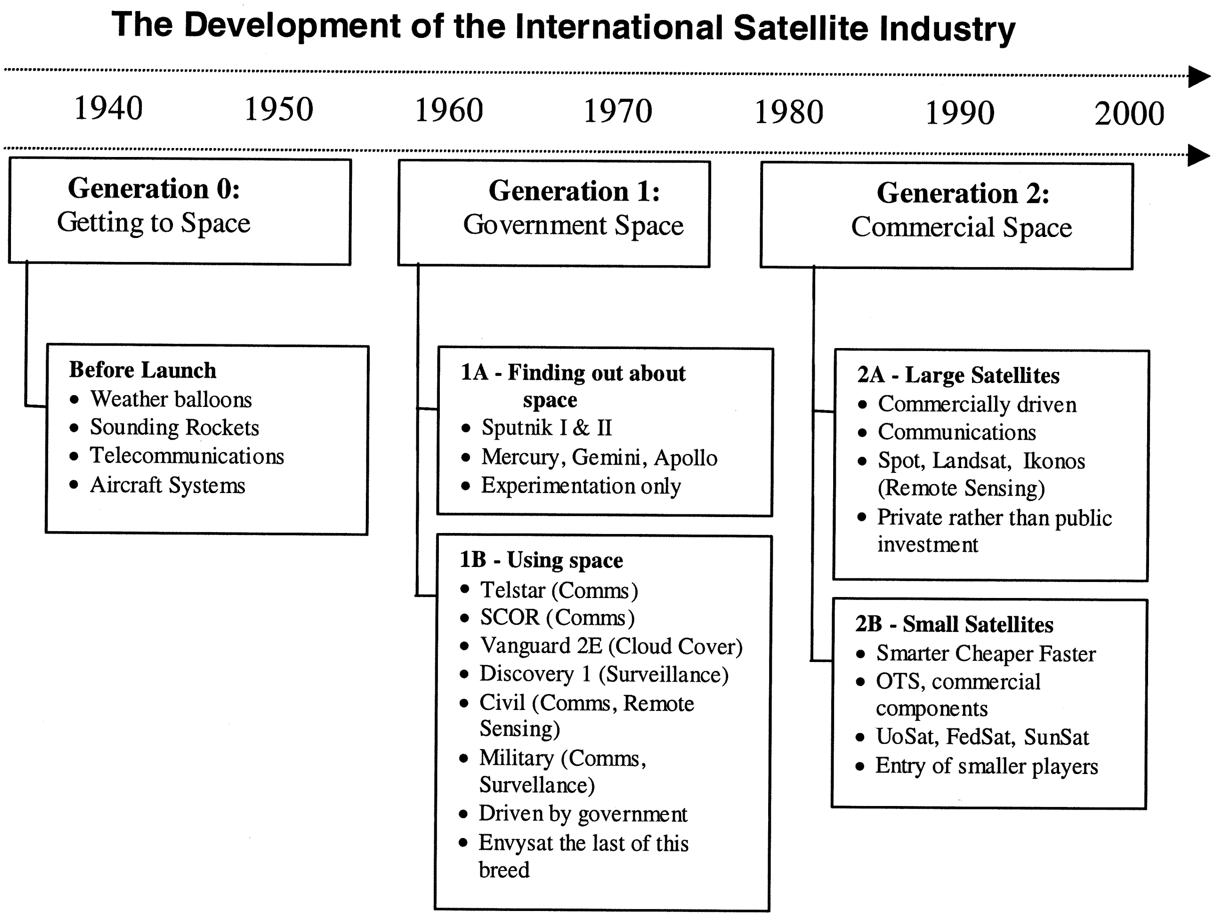


Figure 4-1: The Development of the International Space Industry

4.2.1 Generation 0 - Getting to Space

The space industry dates back to the early days of the missile defence industry. It can be argued that the birth of the international space industry began with the development of the first liquid-propelled rocket by Robert Goddard in 1926.

All of the major international bodies were involved in the missile industry from the beginning of the 1950s. Both America and the Soviet Union were driving development of international ballistic missile capabilities. The European leaders of this industry at the time, France, Great Britain, Sweden, Italy and Germany, had all developed or been part of the development of a wide range of missiles (Molas-Gallart, 1997). Even Australia was involved in the missile industry through the development of the Black Knight and Blue Streak missile programs at Woomera (Twigge, 1993).

The following thirty years from 1926 to 1956 can be considered as the "getting to space" generation of the space industry. It was during this time that all of the technology used to get to space was developed, including the communications, computing and attitude control capabilities that would make satellites possible.

Beginning in the 1940s, devices such as sounding rockets and weather balloons carried scientific instruments into the upper atmosphere. They were essentially prototype satellites and took the first photographs of the earth from space.

4.2.2 Generation 1 - Government Space

On October 4, 1957 the first man-made satellite, "Sputnik 1" was launched by the USSR, closely followed by the launch of the first animal in space, Laika the dog. Following rivalry between the US Navy and the USAF for control of the US space programme, 1958 saw the inauguration of NASA and the development of space in the United States through the launch of the US satellite EXPLORER-1.

This entire phase is defined by large government contributions to both space science and applications. In the 1960s and 1970s United States and Russia dominated the space race with ambitious and costly space missions. During the following twenty years, a number of other nations established national programs directed at developing and applying the benefits of space technologies. For simplicity, the programmes in this generation have been divided into two distinct phases; finding out about space and using space.

1A Finding out about space

From the launch of Sputnik II, designed to determine if life could be sustained in space, there have been a large number of satellites used to investigate the characteristics of space. Much was discovered during this time about both space and the earth's atmosphere, including the Van Allen Belt (Explorer 1) and other phenomena.

1B Using Space

At the same time as more was being discovered about the nature of space, satellites were starting to be used for a number of earth-related applications. Score, launched in December 1958, was the first communications satellite and paved the way for space communications.

Applications of space technology became widespread over the next thirty years, ranging from military communications and surveillance satellites, to civil communications, weather monitoring and remote sensing. The US and USSR also used satellites for Positioning (with the GPS and Glonass constellations).

4.2.3 Generation 2 - Commercial Space

After the development of the government space initiatives, private companies began to develop commercial uses for the satellite industry. Commercial growth has been strong over recent years as the applications of new developments have become apparent, particularly in telecommunications and Global Positioning Systems (GPS). However, commercial markets have been volatile with spectacular collapses in investment (such as the Iridium and other LEO communications systems collapses) along with recovery and double digit growth in other areas. This phase can also be divided into two stages; large satellite and small satellites.

The satellites developed in this generation were markedly different from the previous ones. Where possible, Off-The-Shelf components and subsystems were used, and commercial timelines and budgets had to be adhered to. In addition, as satellite design was being taken over by industries rather than administrations, a plethora of commercial services was developed.

Despite this growth in the commercial nature of the international space industry, governments of many nations have speculated on the diverse economic and national benefits of space technologies, and this is translating into the continued strong presence of government contracts in the space market; however, these contracts are concentrated in applications of national defence and resource management, rather than space research. In addition, escalating costs for space projects and investors' needs for more tangible returns and greater security have led to more collaborative partnerships between government and industry (Johnson, 2003; Sapolsky, 2003).

In 2001, international private expenditure in the space industry exceeded government expenditure, making up $US42 billion of an international $US80 billion market (Euroconsult, 2001). As part of this trend, the International Space Business Council (ISBC) noted that over the last decade "Space has changed form a niche, high-tech market to one that shares common concerns with other industries: mergers and acquisitions, government regulations, changes in the global financial markets, international competition, and the need to attract, retain and service clients" (ISBC, 2002).

2A Large Satellites

These satellites include everything from the first commercial communications satellites to the new breed of remote sensing satellites such as Quickbird, Ikonos and (both government and privately driven) SPOT. However, much of the design philosophy behind these satellites was very similar to that of the original government programs.

Dynamic changes over the last decade are reshaping the global space sector, such that there is more of a commercial focus to its operation, particularly in the communications industry (ISBC, 2002). This shift to commercialisation resulted in commercial and government space expenditure reaching parity in 1999 (Euroconsult, 2001)

2B Small Satellites

Prompted by NASA's push for Faster, Cheaper, Better (which is discussed in detail in the following chapter), the small satellite, and in particular the small satellite philosophy, became a new way at looking at both government and commercial projects. This treated all projects commercially, and re-evaluated many of the underlying assumptions behind risk/cost trade offs and management paradigms (Bearden, 1995). Small satellites, because of their functional and operational characteristics and their comparatively low development and service costs, would allow access to space by more customers and to the space business by more suppliers than with the large systems of the last 20-30 years. As such, this stage marked the entry of smaller countries and companies into the space field. By reducing satellite sizes many of the barriers to space, such as high launch costs and difficult structural analysis, were removed.

The three generations of space activities listed above can also be expressed as a function of the United Nations UNISPACE conferences, which are held on an ad-hoc basis to address a change in the international space industry. In other words, they were convened alongside important structural changes in the nature of international space. There have been three UNISPACE conferences to date (UNOOSA, 2002):

UNISPACE	1966	Address the creation of the space industry and the international treaties required
UNISPACE 82	1982	Address the growth of the space industry and international coordination
UNISPACE III	1999	Address the growth of commercial space and space for sustainable development

In summary, the nature of the space market has changed considerably over the last decade. From an industry that was underpinned by the activities of governments, the space industry is increasingly subject to strategic and commercial decisions made by the private sector. Accordingly, while the industry was dominated for many years by the manufacture of spacecraft, research hardware and the provision of infrastructure to manage those activities of those vehicles, substantial growth is now being seen in the commercial use of satellites for the provision of consumer and business services, particularly in telecommunications.

4.3 The Current International Space Industry

4.3.1 Industry Size

It is somewhat difficult to determine the size of the global space sector for a number of reasons. New space applications and technologies continue to develop, revenue data from all nations is not readily available, and there is no clear delineation of which industries should be included in space industry data (ISAG, 2002). Accordingly, this section presents information from a range of reports on the global space industry which cite a variety of figures that are not necessarily consistent.

The most comprehensive report into the International Space Industry was given by the International Space Business Council in 2002 (ISBC, 2002). According to this report, the a snapshot of the space industry in 2001 was:

- Total worldwide employment was 1,027,785 in 2001;
- Worldwide space revenues in 2001 were $US82.8 billion and are expected to increase to $US97.7 billion in 2002 with an annual growth rate of 12%;
- Worldwide space revenues over the next five years are expected to increase by 60% to total $US763.1 billion;
- Primary growth areas in the space sector are the international direct-to-home television market, which is expected to increase by 102.9%, and the remote sensing market which is expected to increase by 97%;
- In 2001, 81 spacecraft were launched with a total of 20 commercial payloads and 61 government payloads; and
- Government budgets account for around $US35 billion of annual expenditures on space hardware, research and development, and operations. Overall, the government market accounts for slightly less than half (estimated at $US40 billion) of worldwide space activity.

The ISBC report also notes that the space industry has aligned itself around a number of industry segments, including basic infrastructure, satellite services, use of space-based data and assets and support services. The contribution of each of these segments, as well as the products and services which make up these segments is shown in Figure 4-2 and Figure 4-3.

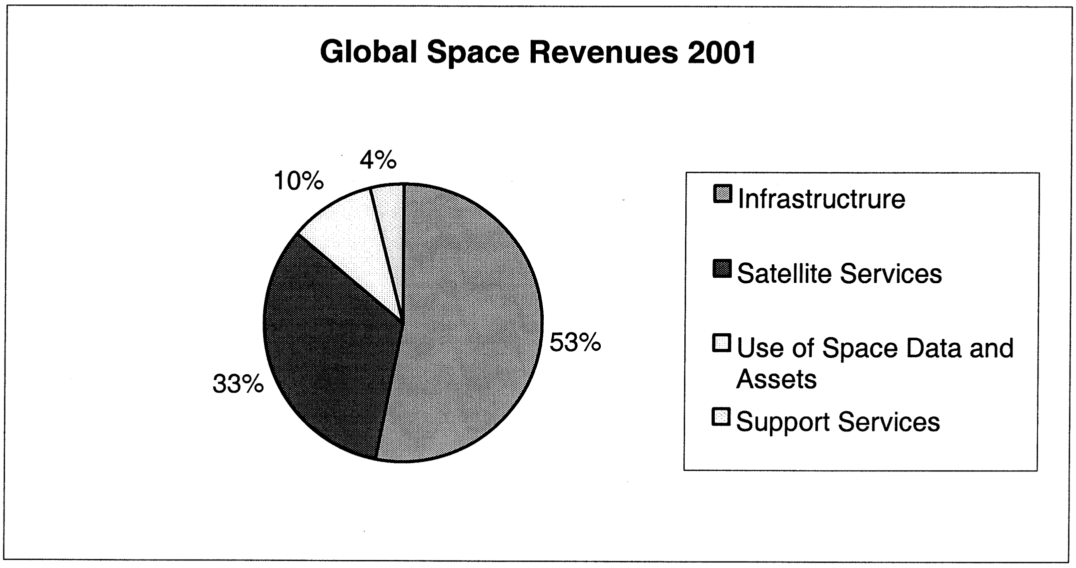


Figure 4-2: Space Industry Revenues 2001, Source: (ISAG, 2002)

	Revenue 2001	Composition	
Infrastructure	$US43,206m	Satellite manufacturing Expendable launch vehicles Reusable launch vehicles Sounding rockets Ground station control centres Ground station equipment Satellite antennas DTH TV antennas GPS receivers VSAT equipment	Software development Spaceport operations Satellite monitoring Facilities development Test operations Space structures / stations Manufacturing and machining Architecture and construction Cryogenic equipment R&D in support of the above
Satellite Services	$US27,451	Cable and video programming distribution Broadband and Internet access Direct broadcast satellite television Direct to consumer radio Distance learning and education	Private business networks Remote communications Streaming media to the desktop Telemedicine Telephone transmission Voice over IP Electronic News
Use of Space Based Assets	$US8,669m	Remote sensing/weather GPS & GIS components	Microgravity Tourism
Support Services	$US3,480m	Legal Licensing Finance	Publishing Insurance Consulting

Figure 4-3: Composition of Space Industry Segments, Source: (ISAG, 2002)

A second source of information about the state of the global space industry is given by the Euroconsult group, based in Paris (Euroconsult, 2001). This study cites world public expenditures for space activities in 2001 at about $US38 billion, with a slight growth of 2% compared to 2000 ($US37 billion), including $US23 billion dedicated to civil applications and $US14.7 billion for military space programs.

In contrast to the American ISBC study, the Euroconsult study believes that governments have been and remain the major clients for the space industry, especially in 2001 with an unusual low commercial launch rate reflecting a depressed market, compared to a sustained institutional market in the United States, Europe and Russia. For example, in 2000, 39 public satellites (18 civil and 21 military), valued at approximately $US7.1 billion, were launched for an estimated launch cost of $US1.14 billion. In comparison, only 15 satellites, amounting an estimated manufacturing value of $US1.7 billion, were launched in 2001 for a launch cost estimated at $US1billion.

The study breaks the space commercial market into three segments; military, commercial and civil, and estimates that this represents $US10.9 billion in 2001, or less than one third of the world government space budgets. A breakdown of commercial expenditure for these segments is given in Figure 4-4.

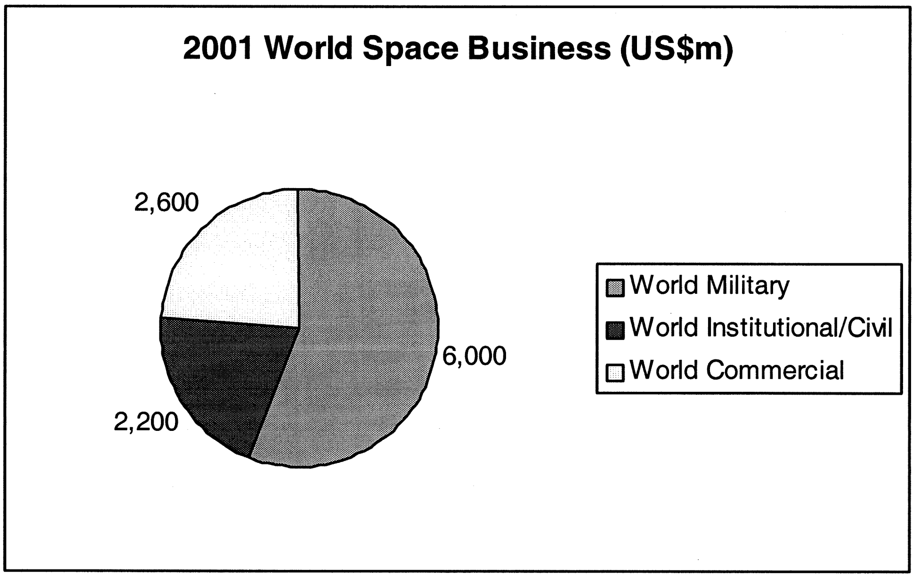


Figure 4-4: 2001 World Space Business, Source: (Euroconsult, 2001)

There are a number of possible reasons for the differences in the findings of these two central sources of information, one written in the US and one in Europe. One major difference is that the Euroconsult study includes the space segment value only (satellite manufacturing and launches) and does not include value-added applications such as broadband internet over satellite communications links and Geographical Information Systems as well as ground station design, manufacture and operation. However, the differences between these two reports indicates that there is still much work to be undertaken in understanding the scope, impact and even definition of the international space industry.

4.3.2 An International Comparison of Space Programmes

The governments of almost all developed nations are involved in one way or another in the development of space applications (sometimes first as the purchasers of products), although through a number of different models. The centralised planning model of the US space programme was implemented through a civilian space agency called the National Aeronautics and Space Administration (NASA). NASA absorbed various aviation researchers and military space laboratories. The formation of NASA helped forge agreement among competing interests, including military branches, universities, the aerospace industry, and politicians. Soviet space activities, on the other hand, were coordinated by special executive commissions. These commissions tried to tie together various space units from military and industrial groups, as well as competing experts and scientists. Finally, as the third-largest participant of the space industry, the European Union tended towards cooperatives and joint ventures between nations.

To give a historical perspective of the differences in expenditure of the different nations on space activities, it is useful to look at the total number of satellites launched. Between 1958 and 1999 almost 4000 objects were launched into space (Euroconsult, 1999). The country spread of these objects is given in Figure 4-5.

Launching State	No. of Objects
Australia	4
Canada	10
China	17
Czech Republic	3
ESA	35
France	99
Germany	9
India	20
Italy	3
Japan	55
Korea, Republic of	1
Mexico	2
Russia (including USSR)	1760
Spain	3
Sweden	4
Ukraine	1
United Kingdom	15
USA	1936
Total	**3977**

Figure 4-5: Number of Objects Launched into Outer Space as of 8/11/99, Source: (UNOOSA, 1999)

A comparison of the expenditure on space in 2000 however, shows the difference between the current expenditure of different nations on space activities. It can be seen that the United States puts almost an order of magnitude more investment into space.

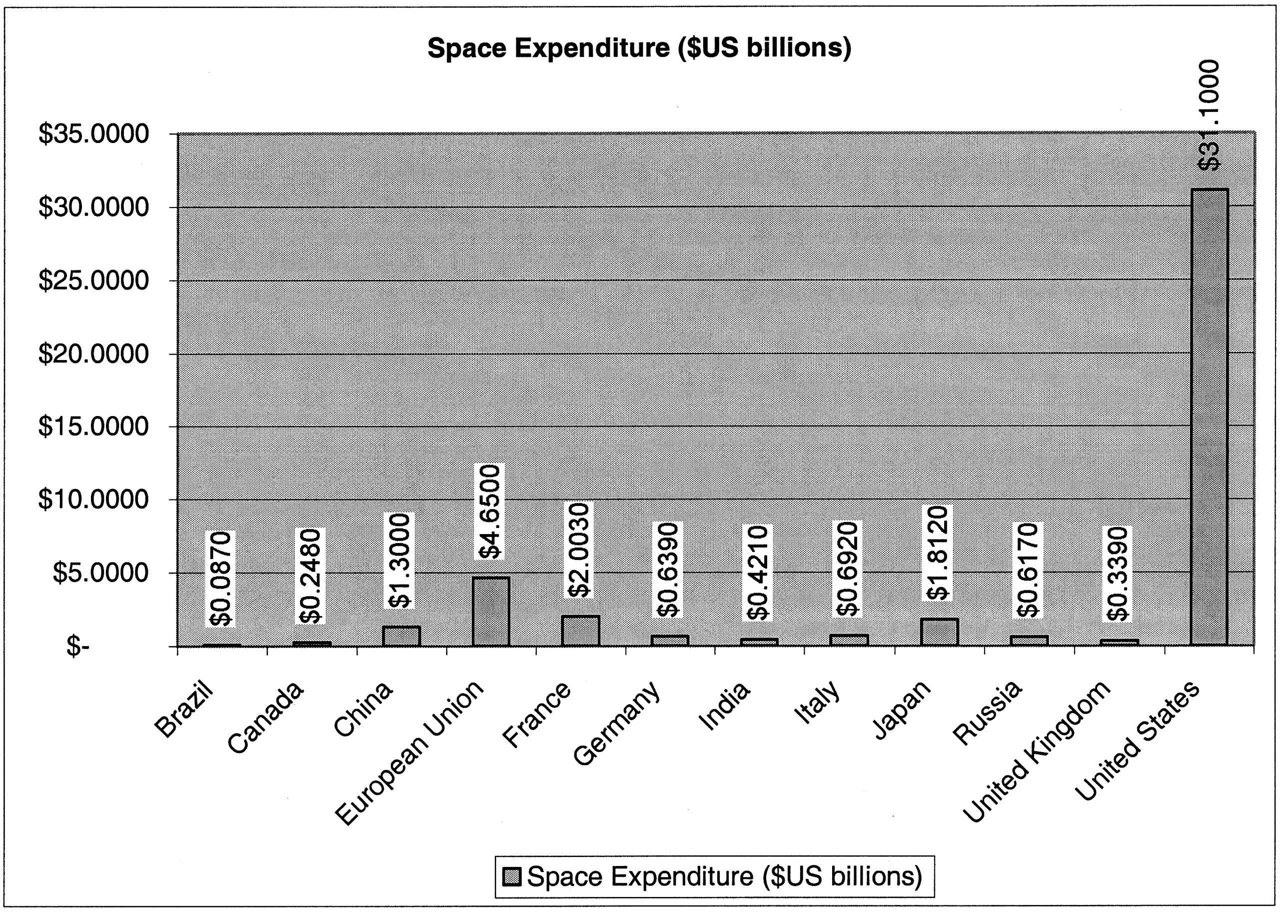


Figure 4-6: Space Expenditure in 2000, Source: (ISBC, 2002)

The US leads in terms of total national space expenditure ($USUS31.1 billion in 2000), and contributes approximately 74.5% of the global budget of the major space faring nations. ESA is the second largest source of space activities, with a total expenditure of $US2.5 billion in 2000. The second largest nation for space expenditure is France, followed by Japan and China respectively. Although one of the most significant space faring nations, Russia only ranks seventh in terms of total national expenditure on space activities.

	Space Expenditure $US billions	GDP $US billions	Space Expenditure % of GDP
United States	31.10	9 962.7	0.31 %
Russia	0.62	246.9	0.25 %
France	2.00	1 294.1	0.16 %
China	1.30	1 101.0	0.12 %
India	0.42	462.9	0.09 %
Italy	0.69	1 074.0	0.06 %
Japan	1.81	4 627.9	0.04 %
Canada	0.25	699.5	0.04 %
Germany	0.64	1 880.4	0.03 %
United Kingdom	0.34	1 421.1	0.02 %
Brazil	0.09	622.4	0.01 %

Figure 4-7: Space Expenditure as a proportion of GDP, Source: (ISAG, 2002)

However, considering national space expenditure as a proportion of GDP (given in Figure 4-7) provides greater insight into space activities as a national priority. Russia, whose total space expenditure is less than that of countries such as Italy and Germany, spends 0.25% of GDP on space activities which is second only to the United States (where space spending is 0.31% of GDP).

France and China are in the top four nations in terms of total space expenditure and also expenditure as a proportion of GDP (0.16% and 0.12% respectively, which is less than half of that of the United States). Italy's position also remains relatively unchanged (fifth in terms of space expenditure and sixth for expenditure as a proportion of GDP). China is also investing more in space after successfully launching a person into space in 2003.

Although eighth in overall space expenditure, India is fifth in its expenditure as a proportion of GDP (0.09%) which perhaps reflects the high priority given to the utilisation of space technologies to address national concerns (ISBC, 2002). Similarly, Canada ranks higher when its expenditure is considered as a proportion of GDP (Canada is tenth for overall expenditure and eighth as a proportion of GDP).

Japan and Germany are third and sixth respectively in terms of national space expenditure, however their positions decline to seventh and ninth respectively when expenditure is considered as a proportion of GDP.

Based on their investment in space and the way in which space fits into their national priorities, nations can be divided into three groups, as shown in Figure 4-8.

Top-tier space centres	USA, China, Russia and ESA	These are characterised by space programs that are drivers of international collaborative ventures. In addition, with the exception of ESA, these nations have a strong military component to the space program and are involved in manned space flight operations. Characterising these top tier nations is the provision of a highly developed system of space infrastructure that includes the capacity for design, manufacture, launch and operation of satellites and space vehicles.
Mid-tier space nations	Japan, France, Italy, India and Canada	Generally, the space programs of second tier nations such as Italy, India and Canada, are more driven by application programs and participation as a collaborative partner in (rather than driver of) multinational projects While not necessarily possessing space infrastructure and launch facilities, nations in this second tier generally place a high priority on the development of a domestic capability and a sustainable space industry in niche market areas. Note that some of these nations are also members of ESA, so effectively play two roles.
Lower-tier space nations	Germany, UK, Brazil and Asia-Pacific Nations	The lower tier nations generally operate smaller scale space programs directed at addressing national needs with selective participation in multinational programs that similarly contribute to defined national benefits.

Figure 4-8: Division of National Space Programmes

4.3.3 Investment in National Space Programmes

A number of common arguments are cited in support of investment in national space industries. In addition to taxes raised from space revenues and the potential export industry which is created, Kingwell (1999) argues that the space industry provides a stimulation for the economy in terms of the amount of innovation which is "spun-off" and cites a number of examples to this effect. It is also argued that the space industry can be good indicator for the state of health of an economy, although this is questionable when Russia is taken into account. A country that can afford to invest money into a high technology industry with no direct connection with the consumer may give the perception of being a high technology player in the international market. Finally, space programs of government continue to perform vital national security missions (Euroconsult, 1999).

There are a number of factors which drive Government investment in space programs, which include, but are not limited to (ISAG, 2002):

- Rising consumer demand for space-based services, particularly those of telecommunications;
- Demands for effective resource management and allocation of increasingly scarce physical resources;
- 'Ownership' of space technology and domestic expertise to protect national interests;
- Capturing elements of the global growth market;
- Encouraging innovation and the integration of space technologies into a range of industries;
- Developing domestic expertise that can utilise space technologies to the applications of solutions to national problems; and
- Promotion of a high tech workforce and provision of employment in these areas.

As a result of these drivers, and in response to the changing nature of the international space industry, national space programs and policies are focussing less on pure research and space exploration, and increasingly are formulating a space policy around the following key objectives (ISAG, 2002):

- Commercialisation of R&D projects that provide or complement existing solutions to national priorities;
- Promotion of an industry-led space sector that establishes collaborative partnerships with government and research bodies; and
- Participation in bilateral and multilateral projects that develop national skills and industries through technology transfer.

4.4 The International Space Industry as a CoPS

In order to ascertain if the international space industry displays the same characteristics as other CoPS industries, it is useful to compare it with two other established cases: that of the International Missile Industry and the International Telecommunications Industry.

4.4.1 The International Missile Industry

Molas-Gallart (1997) outlines the development of the European missile industry in the international context, and its progress over the last fifty years. It takes the missile industry as a subset of the defence industries, citing that this sector is "one of the most important sectors involved in the development and manufacture of Complex Product Systems".

The development of the international missile industry is presented, from its dawn in the 1950s, to the consolidation of the European market in the 1960s and 1970s, and the industry's structural adaptation over the last two decades. The paper also outlines the dominance of French and US prime contractors in the 1990s and the emergence of a large number of medium sized sub-contractors, following with an empirical analysis to examine the ways in which different industries carry their activities across borders. The study uses the missile industry to provide a window to the way in which defence firms (particularly in Europe) are restructuring their activities to take advantage of economies of scale in R&D and production.

In the Molas-Gallart (1997) study it was determined that consolidation of the international missile industry was not as complete as was originally thought; in fact it makes the case that there is little in the recent evolution of this industry to support the notion of a vigorous emergence of a trans-national defence industry. One of the main impediments towards true partnerships was the consideration of national priorities and resistance to transatlantic mergers from some European partners. The pace of integration is very slow, and the traditional forms of cooperation such as joint ventures, joint development programmes and licensed co-production in partnership with national programmes still continue to make up the majority of all cross-border operations.

As mentioned in Section 4.2.1 the International Space Industry grew partly out of the International Missile Industry. The ISAG report also investigates the consolidation and internationalisation of the international space industry (ISAG, 2002) and gives a number of factors driving inter-Government and commercial partnerships:

- Leveraging off commercial enterprises to reduce costs and encourage R&D;
- The economies of scale when several countries are contributing resources and technologies and sharing the risk;
- Changes in regional economics and associated pressures for strategic alliances to manage resources and security needs; and
- Technology and skill transfer opportunities through collaboration.

While the Molas-Gallart (1997) paper focuses on the internationalisation (or lack thereof) of the European Missile Industry, it also allows a comparison between this and the international space industry. Some of the aspects that these two industries have in common are:

- Both industries have close linkages to the state;
- The state for a long time has been the sole consumer of space and missile systems. Only recently have private consortia started to participate;
- In the case of both industries the state owns research and production facilities and is responsible for laying up complex regulatory structures;
- Both industries are international in nature, and both have been experiencing globalisation tendencies as a result of cross-border partnerships (and in some cases mergers and acquisitions);
- Both industries are interdisciplinary in nature, with increasing complexity in production;

- Before September 11 2001, both were experiencing a generalised fall in military and space procurement budgets, giving both the conundrum of how to afford increasingly costly equipment with diminishing funds; and
- Many of the same companies are involved in both industries, for example EADS in Europe and Boeing in the US.

In addition, while the focus is on the industry structure itself, it is also apparent that in both cases many of the large projects are one-off and most projects require bidding and close cooperation with the users of the final system. Given these many linkages, there is a strong case to be made that if the international missile industry is an example of a CoPS industry, then so is the international space industry.

4.4.2 The Telecommunications Industry

An industry which has had rich investigation under the CoPS framework is the international telecommunications industry. As such it provides a wealth of information to use when comparing it to the international space industry, which is also standards-based with continual and progressive advances in technology. The range of literature provided by Davies (SPRU) ranges from an investigation of the mobile communications industry from the process of innovation and an innovation management perspective.

As with the space industry, there have been a number of generations in the development of the telecommunications industry such as the mobile communications generations shown below. These generations are mainly defined by the underlying technology and systems architecture, and the development of the system is characterised by improvements in digital switching networks, high-speed signalling systems and handset technologies. It should also be noted that they overlap, and the telecommunications environment is currently between 2G and 3G, depending on location and other factors (for example, Japan has developed a relatively mature system based on 2.5G technologies which uses 2G bandwidths with continuous connection.

First Generation Cellular Systems (1G)	Characterised by analogue transmission using Frequency Division Multiple Access (FDMA)	1982-1994
Second Generation Cellular Systems (2G)	Digital networks with limited bandwidth, employing Time or Code Division Multiple Access (TDMA or CDMA)	1990+
Third Generation Cellular Systems (3G)	Wideband networks using TDMA and CDMA, continuous connection	1998+

Figure 4-9: Cellular Mobile Telecommunications Systems: Source (Davies, 1997e)

The generations of development of the international space industry presented in Section 4.2 are based largely on the product applications rather than the underlying technology, and as such it is difficult to draw a parallel between this and the communications industry. However, the progression in the Space Industry Generation 2 from large satellites to small satellites is a shift in technology and changing market conditions. Davies (1997e) gives a tool to measure these phases of development in the CoPS environment, which was previously presented in Section 3.6.2 of Chapter 3. It describes three phases, the architectural phase followed by the new product generation phase of each generation. In the broader context, this trend can also be seen within the satellite industry through the development of NASA and ESA standards (e.g. (ESA, 1981) to (ESA, 2003)) which determine current architectures of most satellite products.

It is important to note, when comparing CoPS in the telecommunications industry with the space industry, that the telecommunications industry CoPS is the overall network, consisting of Base Stations (BTSs) which provide a connection to user handsets. This complex structure, involving issues such as network analysis, frequency coordination and the development of complex infrastructure is the product against which any comparisons with segments of the space industry should be made.

Davies (1997d) also looks at two projects in the implementation of the cellular phone systems based on the Global System for Mobile Communications (GSM) standard, with particular reference to the development of the communications infrastructure. He shows that the management of projects in the telecommunications industry can be either mechanistic or organic depending on the stability of the technical and commercial conditions. This is similar to the management of projects in the international space industry, where large firms may choose a mechanistic management structure where projects are broken down into specialised and functional tasks organised into sub-projects and vertical integration and coordination is accomplished through a project management team comprising sub-project managers (Wertz, 1998). Conversely, small satellite projects typically employ a much more organic management structure where tasks are continually adjusted and refined as the project develops and there is a commitment from all to the concerns of the project as a whole rather than the completion of individual tasks (Sweeting, 1996).

Parallels may also be drawn between the growth of the telecommunications industry, with a drive to realise cost-saving economies of scale and scope (Davies, 1996) and that of the space industry with it current push towards rationalising large space budgets. In both cases costs are saved through mechanisms such as the use of off-the-shelf components and the growth of embedded systems in the product design. However, it should be noted that much of the innovation in mobile telecommunications systems has been driven by improvements in mechanisms to control the routing of traffic and delivery of services, a problem of lesser importance for space projects.

Finally, there are a number of other parallels which can be drawn between the space industry and the telecommunications industry, including but not limited to:

- Both industries are closely regulated by government and industry standards;
- Both industries are international in nature, and both have been experiencing globalisation tendencies with the consolidation of suppliers and creation of oligopolies; and
- Both industries exhibit complexity in both depth and breadth, with interacting subcomponents.

As can be seen, there are parallels between both the missile industry, the telecommunications industry and the international space industry. While differences between them should not be underplayed, if both these industries and the space industry are CoPS industries, lessons may be transferred between them. Indeed, from the cursory analysis above, it can be seen that the similarities between areas of both the telecommunications and missile industries with areas of the space industry gives an indication that the space industry is indeed a CoPS industry. In the following sections this hypothesis is refined further by investigating one segment of the space industry, that of the development of satellite projects.

4.5 Satellite Projects

In 2001 satellite manufacturing was $US12.4 billion or 29% of the total space industry infrastructure segment (ISBC, 2002). This section gives a brief outline of the characteristics of satellite projects, starting with the applications of satellite programmes, a typical satellite architecture and the different phases of a satellite project. It concludes with a brief review of the current state of satellites within the innovation literature.

4.5.1 Satellite Applications

There are a number of different products that satellites can deliver, ranging from astronomy in space to communications, global positioning and remote sensing as illustrated in Figure 4-10. It should be noted that military applications are also included in this taxonomy as they are often unique in their requirements.

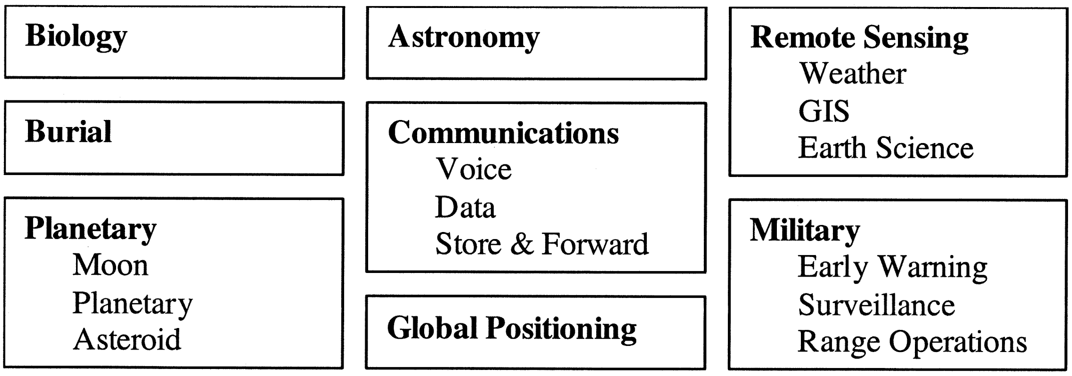


Figure 4-10: Satellite Applications

4.5.2 Satellite Architectures

Within satellite architectures there are a number of specialised definitions which are used repeatedly to describe the components of a satellite programme. In order to understand these, a number of defining terms are given below.

Table 4-1: Satellite Defining Terms

Space Segment	The components of the satellite project which make up the system to be launched into space, including the satellite itself and the test equipment
Ground Segment	The components of the satellite project which remain on the ground to assist with operating the satellite once it is in space, including the satellite communications facilities and the mission control centre
Platform (Bus)	All the components of the satellite which provide basic computing, attitude control, power and communications services
Payload	The experimental devices which are connected to the satellite platform, and provide the systems to implement the satellite's application (such as high bandwidth communications or remote sensing)
Spacecraft (SC)	The satellite itself, made up of the platform and the payloads
Launch Platform	The rocket on which the satellite is launched
Ground Support Equipment (GSE)	The equipment which is used to test the satellite on the ground
Ground Station (GS)	The equipment used to communicate with the satellite from the ground
Attitude	The direction in three dimensions in which the satellite is pointing. The satellite components which control this are called the Attitude Control System (ACS)

The functional hierarchy of a typical satellite architecture is shown in Figure 4-11 (Moody, 2000b). The entire architecture is driven by the operations, or the functions of the satellite and how it is to operate as an entire system. Aside from operational tools such as the programme requirements specification, and operational scenarios and simulators, the project is divided into the space segment and the ground segment. The ground segment includes the satellite ground station and antenna, the communications hardware, the operations control centre software and the mission control centre.

The space segment for a satellite project may be divided into Ground Support Equipment (GSE) and the spacecraft itself. Ground Support Equipment is often built specifically to test either individual spacecraft units or the spacecraft itself, and typically includes communications equipment, power suppliers and devices to simulate inputs into the attitude control system. Often the GSE will use similar (or identical) components to the ground station, such as the Operations Control Centre (OCC) software or transmitters and receivers. In addition, there is a subset of GSE which is used to test or assist with the mechanical components of the spacecraft, such as cranes, test rigs or safety bolts.

The spacecraft can be conceptually thought of as made up of a platform and the payloads which use the services that the platform provides, such as power, attitude control, communications and data processing. In addition, this component of the project also conceptually includes all of the thermal, structural and electrical analyses which are performed to give additional confidence that the spacecraft will survive its launch and subsequent operation in space.

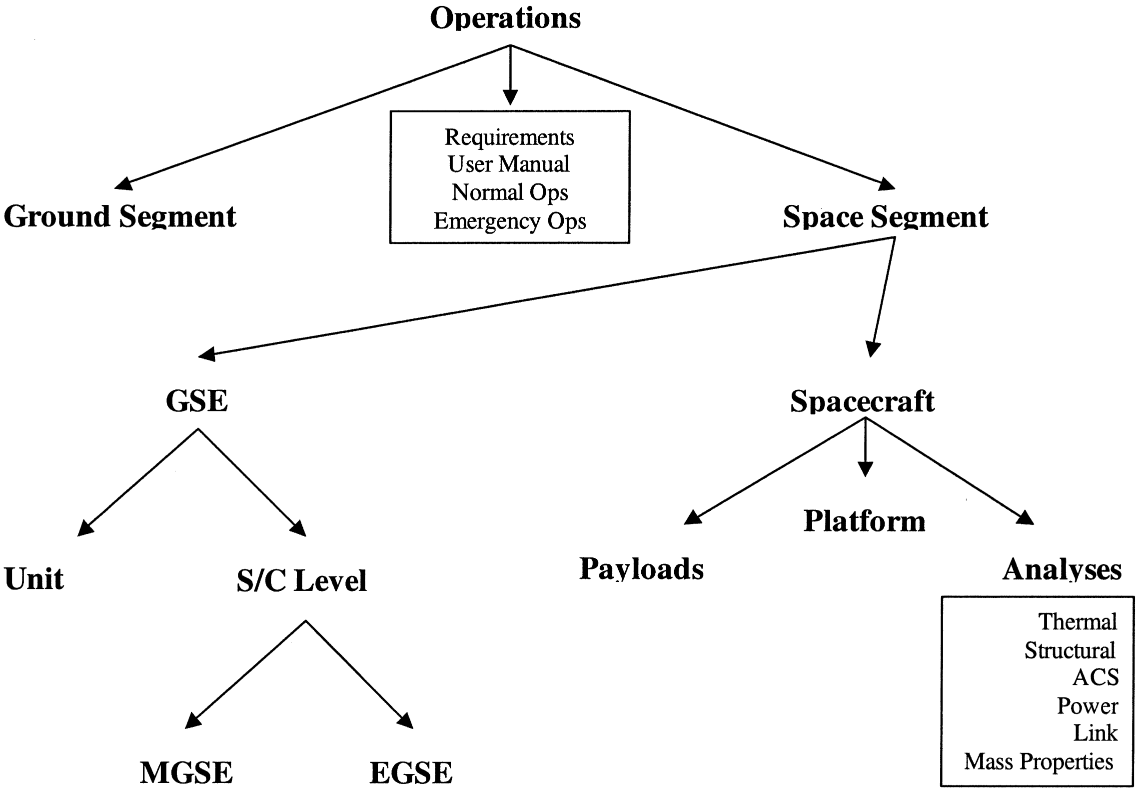


Figure 4-11: Spacecraft Architecture

At the spacecraft level every satellite platform typically consists of the same basic 'building blocks', in that they contain an onboard computer using tailored software, a Communications System, a Power System and an Attitude Control System as illustrated in Figure 4-12. The Attitude Control System takes inputs from sensors such as magnetometers, sun sensors and star cameras; the power system includes solar arrays and batteries as well as all of the power conversion facilities; and the communications system is typically made up of a transmitter and a receiver as well as antennas to communicate with the ground.

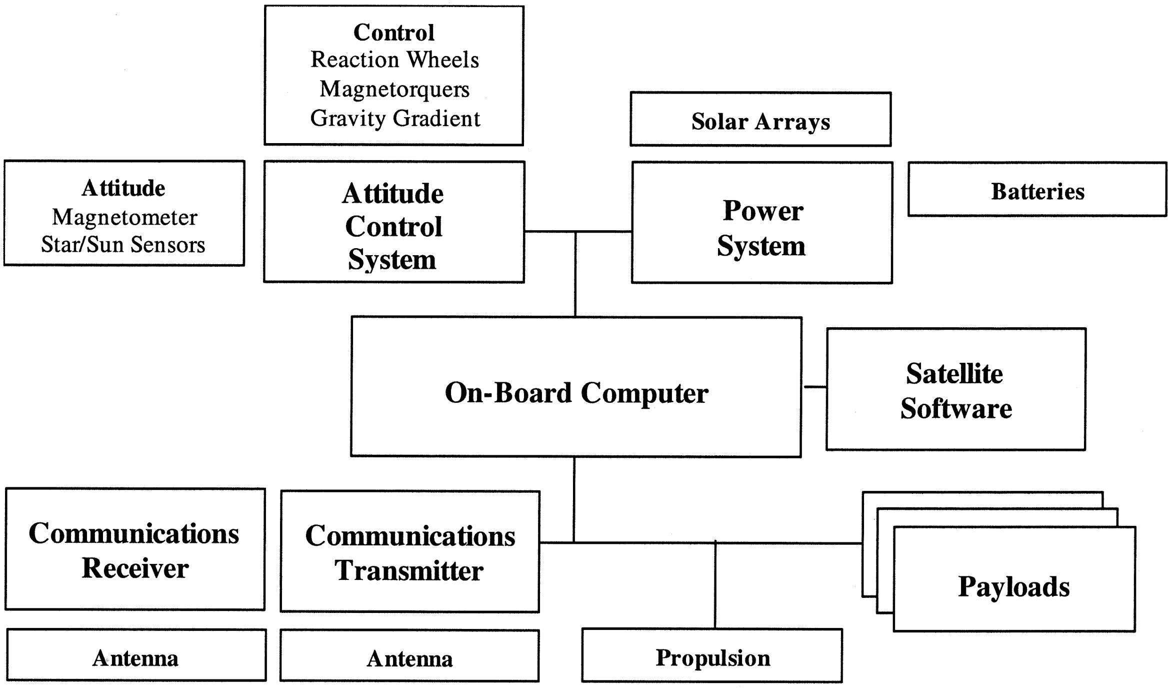


Figure 4-12: Example of Space Segment Architecture

As a result of its complex nature, one of the core capabilities in any satellite project is systems integration. In addition, it is becoming standard practice to outsource analysis and the production of sub-systems. This requires team members with skills that span a wide variety of engineering and software domains. Another core capability is systems verification and testing, because of the difficulties in performing maintenance on satellites once they are in orbit.

4.5.3 Satellite Development Phases

There are a number of phases in the development of a satellite project, shown in Table 4-2. Typically, the initial phases have a few engineers taking part which then ramps up to a large team during the design and manufacture phase. This team then slowly ramps down again until the satellite is launched and being maintained in orbit. Table 4-2 also shows the critical review phases of the satellite development, including the systems design review, the critical design review and the launch readiness review. It should be noted that there may be many other phases involved in the satellite project, depending on the requirements of the project manager or client. For example, NASA takes the approach of a number of phases; Pre-phase A (pre-mission concept), Phase A (requirements), Phase B (preliminary design), Phase C/D (design and implementation) and Phase E (test and operations).

Table 4-2: Sample Satellite Developmental Phases, Source: Adapted from (Wertz, 1998)

Pre-feasibility analysis
Preliminary Design Review
Request for proposal and bid
Requirements capture
Systems Design Review
Architectural design
Detailed design
Critical Design Review
Manufacture and component testing
Assembly, integration and testing (AIT) and launch preparation
Launch Readiness Review
Launch and early operations
Nominal operations and maintenance.

In addition, within these broader phases of a satellite project development, each component undergoes a development cycle as shown in Figure 4-13. During the testing phases, the original requirements and design is verified, and there is also potential for significant feedback within and between phases.

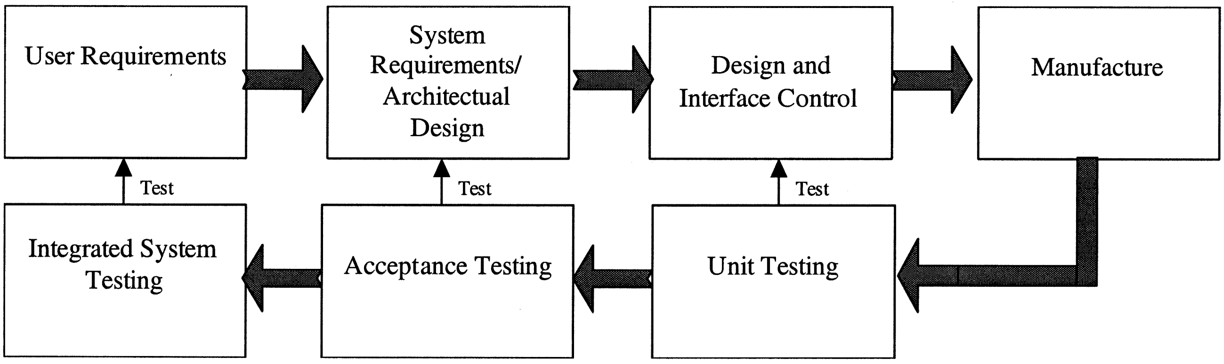


Figure 4-13: Sample Unit Development Cycle

4.5.4 Satellite Management

'Traditional' satellite projects have been implemented by large companies or national agencies and have tended to use the mechanistic form of project management structure.

Projects are broken into an hierarchical form as the standard and attempt to accommodate emerging events by isolating and addressing all known and foreseeable problems within individual sub-projects. The reporting and organisation of the project is codified in manuals such as NASA's series of project milestones (Wertz, 1998) and the structure conceptually allows project deliverables to take place in parallel, coordinated by a project management group.

The typical Work Breakdown Structure (WBS) for a satellite project is given in Figure 4-14. These functions are each organised into departments within an organisation, with the systems engineering and program management groups coordinating the development process.

- PROGRAM
  - SPACE SEGMENT
    - SPACECRAFT
      - Attitude Determination and Control
      - Propulsion
      - Electrical Power
      - Telemetry, Tracking and Command/Data Management
      - Structure
      - Thermal Control
    - PAYLOADS
    - INTEGRATION, ASSEMBLY AND TEST
      - Spacecraft Integration
      - Payload-to-spacecraft Integration
      - Satellite Testing
      - Aerospace Ground Equipment
    - PROGRAM LEVEL
      - Systems Engineering
      - Program Management
      - Data/Reports
      - Special Studies
    - LAUNCH AND ORBITAL OPERATIONS SUPPORT
  - LAUNCH SERVICE
  - GROUND SEGMENT

Figure 4-14: Satellite Work Breakdown Structure, Source: (Bearden, 1995)

4.5.5 Satellite Development in the Innovation Literature

There has been little attempt in the innovation literature to investigate the development of satellite projects[1]. However, there have been many attempts to investigate the management of projects in the space industry (see for example (Bearden, 1995; Callen, 1999; NASA, 1999)) but few have integrated these with a theoretical model of innovation. A search in the journal 'Space Policy' yields only five articles with the word innovation in the abstract, of which only Belleval (2002) studies the space industry from an innovation theory perspective and Austin (1997) looks at the issues of foreign participation in R&D. The other three articles only use innovation to mean technical improvements (Woodell, 2000; Davis and Macauley, 2002; McCurdy, 2002).

An exception to this is the analysis undertaken by Johnson (2003) which investigates the social and technical aspects of systems integration. His analysis of the role of failure in the development of systems engineering demonstrates how systems management reduced the rate of failure of space and missile systems from 40 to 60 per cent in the 1950s, to 5 to 10 percent in the 1970s. He looks at the different methods which were used to improve the success of projects in the space industry, ranging from strong control and documentation, the use of 'tiger teams' to review process and even the 'skunk works' approach which used a relatively small team with much greater initiative and authority that typical of most systems management.

From this investigation it can be seen that there is a gap in the literature regarding the investigation of the lessons that satellite development can yield for innovation theory, and little has been done to apply knowledge of innovation to satellites from the theoretical perspective.

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[1] In a search on the last 10 years of Research Policy magazine, only 22 articles contained the word 'satellite' none of which included it in the abstract nor investigated the satellite industry from an innovation perspective. Only one article in the Technovation Journal Baskaran, A. (2001). "Competence building in complex systems in the developing countries: the case of satel..." Technovation(Feb 2001). looks at using satellites to build complex systems competencies for developing countries.

4.6 CoPS and the Satellite Industry

The previous review of the existing satellite literature suggests that it has not been fitted into the traditional or conventional models of analysis from an innovation perspective. This section tests the hypothesis that CoPS provide a useful tool to perform this analysis and a meaningful framework for satellite investigation.

4.6.1 Satellites within the CoPS Taxonomy

As outlined in Chapter 3, CoPS products may be divided into three different categories of infrastructural CoPS, stand-alone products and constructs. The space segment of a satellite can clearly be identified as a stand-alone product, and remains this way throughout its entire product life. However, if the ground segment (including the ground station and ongoing operations) is included in the satellite project, it begins to display some of the characteristics of an infrastructural CoPS, including individual stand-alone components, a network structure and a mechanism of control.

In order to limit the scope of this investigation of satellites as a CoPS, and in line with the analysis to be completed in this thesis, the remainder of this study focuses on the stand-alone space segment of the CoPS, making particular reference to the ground segment where applicable.

4.6.2 CoPS Defining Terms

In Chapter 3, a survey of the existing CoPS literature gave a number of defining terms. In order to test the hypothesis that CoPS are a meaningful framework of analysis it is useful to investigate a satellite project in the context of these terms.

4.6.2.1 High cost with long product cycles

Ranging from small to large satellites, the cost of a traditional project can range from a few million dollars for small satellites to over one hundred million dollars for large telecommunications satellites. In 2001 39 public (large) satellites (18 civil and 21 military) valued at approximately $US7.1 billion were launched at an average value of $US182 million each (Euroconsult, 2001). In addition, the design life of a satellite typically ranges from 1-3 years for small satellites and more than five years for large ones (Boland, 1999).

One way of looking at the cost/timeframe relationship is by comparing it with different products and services. Wertz (1996) shows the relationship between the space industry and other products on a $/kg basis; space is on the top end of both indices. As such, it can be suggested that, compared to many of the projects in the CoPS domain satellites are also high cost projects with long product cycles.

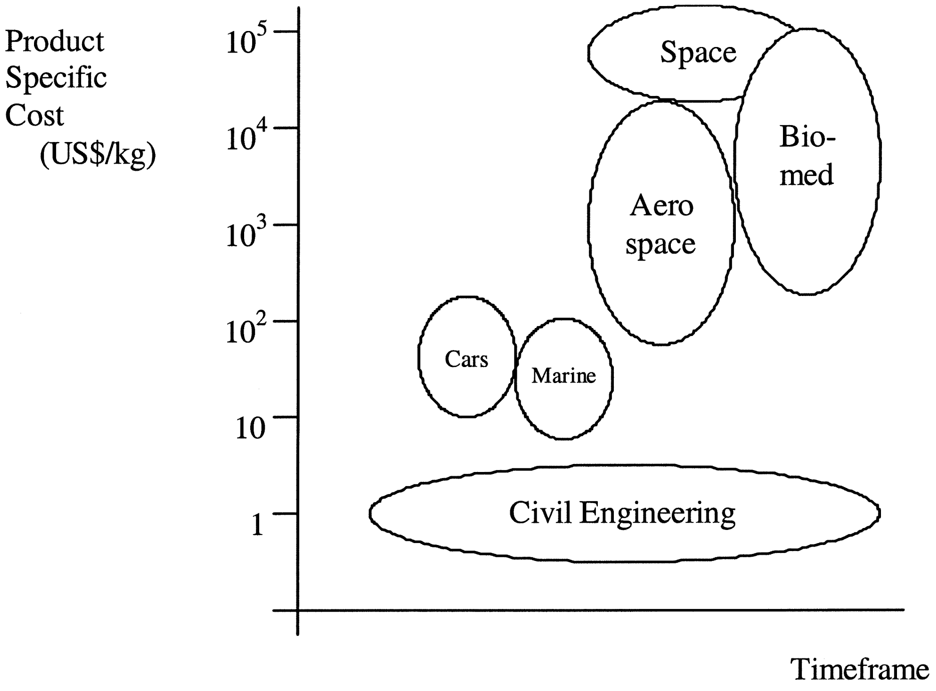

Figure 4-15: Comparing the Cost of Space Systems, Source: (Wertz, 1996)

4.6.2.2 Involvement of several firms

As previously investigated, CoPS design, development and production usually involves several firms. Because of the complexity of the different units required in a satellite project, it is often customary for projects to have interfaces with a potentially large number of subcontractors and suppliers. Although there is little quantitative information available to verify this, the recent growth in niche areas of satellite unit manufacture, such as attitude control systems in Canada, strongly support this conjecture (ISAG, 2002). As an example of the nature of involvement of a large number of subcontractors in a satellite projects is the recent Envisat satellite developed by the European Space Agency whose platform and payload manufacture involved over thirty subcontractors (ESA, 2002).

4.6.2.3 Product Complexity

Satellite projects are engineering-intensive with complex interfaces. A typical satellite project will spend over one third of the available development time in mission and systems design (Wertz, 1998) and will often include technologies as yet untested in space. As such, as with other CoPS, satellite product complexity is estimated to be high and to exhibit emerging and unpredictable properties

4.6.2.4 One-off projects

There have been few cases where the satellites have been made in batches of more than three or four (such as the Iridium satellite constellation which produced more than 66 satellites (Iridium, 2002)), and they are never mass-produced. This results in different approaches to technology transfer and project-to-project learning as might be expected in a CoPS project, unlike those found in large-scale batch processes. Specifically, satellites are unlikely to obtain an advantage through economies of scale, and as such innovation processes are focussed towards the product design.

4.6.2.5 Involvement from policy and other regulatory sources

There is usually a large amount of policy involvement in the development of satellite projects. Governments are still the main purchasers and producers of satellites and satellite technology (ISBC, 2002) and set many of the technical standards for satellite design and manufacture (Wertz, 1998). There are very few commercial launch ventures and even with these, as a result of international space law, permission is required from the launching state to proceed with the launch (UNOOSA, 1999). As such, even with the current trend towards commercialisation, the involvement of government is still paramount.

4.6.2.6 Customer-driven

The satellite industry is a market-pull industry, where projects are tendered and then bid for; as a result of their size, cost and the specific requirements that each satellite programme must adhere to they are rarely manufactured for sale to an unknown user[2]. As such, satellites are user-driven rather than market-driven with a high degree of user involvement

4.6.2.7 Project-based

As all satellites are made as one-off or small batch projects, they are built on a project, rather than product, basis. This occurs even though there is transferability of skills and experience between them; every satellite project commences from scratch, with a mission and operations analysis (Wertz, 1998). The project is the main coordinating mechanism for the manufacture of a satellite where partners come together to deliver a solution.

4.6.2.8 Markets

While there are a large number of companies that provide niche subsystems for satellite projects, there are only a few international suppliers of satellite products, including Boeing, Lockheed Martin, EADS, NEC and national space agencies such as NASA, ESA and NASDA (JAXA). With the advent of the small satellite industry more specialist companies such as the UK company Surrey Satellites Pty Ltd (SSPL) are beginning to emerge. As such, it is a fair to suggest that similar to other CoPS, satellite markets are typically characterised by oligopolies.

4.6.2.9 Management

As mentioned in Section 4.5.5 there has been a large amount of research conducted into the management of satellite projects, but very little has placed this in the traditional management domain. However, as a result of their size and scope, the management of satellite projects does require strong systems integration capabilities (Wertz, 1998) and traditionally employs a hierarchical management structure. However, it is difficult to

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[2] One example contrary to this was the sale by SpaceDev of a satellite to the highest bidder, SpaceDev (2003). News Items 2003 2003. http://www.spacedev.com/newsite/templates/homepage.php?pid=2

find literature which supports the claim that they require distinct management capabilities compared to mass-produced projects in the same industry.

A summary of the findings of the previous sections is given in the table below, as well as a qualitative assessment of whether a satellite can be understood to match this definition in the broader context.

Defining Term	**Satellite Context**	**Complies**
CoPS are high cost with long product cycles.	Satellites are high cost projects with long product cycles.	Yes
CoPS design, development and production usually involves several firms.	Satellite projects have interfaces with a potentially large number of subcontractors and suppliers.	Yes
CoPS product complexity is high and exhibit emerging and unpredictable properties.	Satellite projects are engineering intensive with complex interfaces.	Yes
CoPS are of a one-off kind to meet requirements of individual business users.	Satellites are never mass-produced, and in only a few instances have they been batch-produced. This results in different approaches to technology transfer and project-to-project learning.	Yes
CoPS require involvement from policy and other regulatory sources.	There is usually a large amount of policy involvement in the development of satellite projects. Governments have often been purchasers or producers of satellite technology and, even with the current trend towards commercialisation, the involvement of government is still prominent.	Yes
CoPS are user driven rather than market driven with a high degree of user involvement.	The satellite industry is a market-pull industry, where projects are tendered and then bid for.	Yes
CoPS are project based, rather than product based.	Satellites are built on a project, rather than product, basis.	Yes
CoPS markets are typically characterised by oligopolies.	There are only a few international suppliers of satellite products.	Yes
CoPS require distinct management capabilities.	Satellites require strong systems integration capabilities in a mechanistic structure, but there has been little additional research into this area.	Unknown

Figure 4-16: Satellite CoPS Defining Terms

As can be seen in Figure 4-16, satellites provide a good match for almost all of the defining terms of CoPS developed in section 3. It is interesting that it is easy to ascertain that satellites are good examples of CoPS in all of the critical dimensions except the management one. This highlights the need to further investigate the management of satellite projects.

In addition, based on the analysis of these defining terms, a "typical" satellite project can be placed on the critical product dimensions tool provided by Hobday (1998). Without lengthy analysis, it is difficult to quantify many of these dimensions, such that they have been selected based on observations of the industry based on this analysis. However, the complexity profile developed gives a useful baseline against which other satellite projects can be evaluated, allowing relative measures in each of these dimensions.

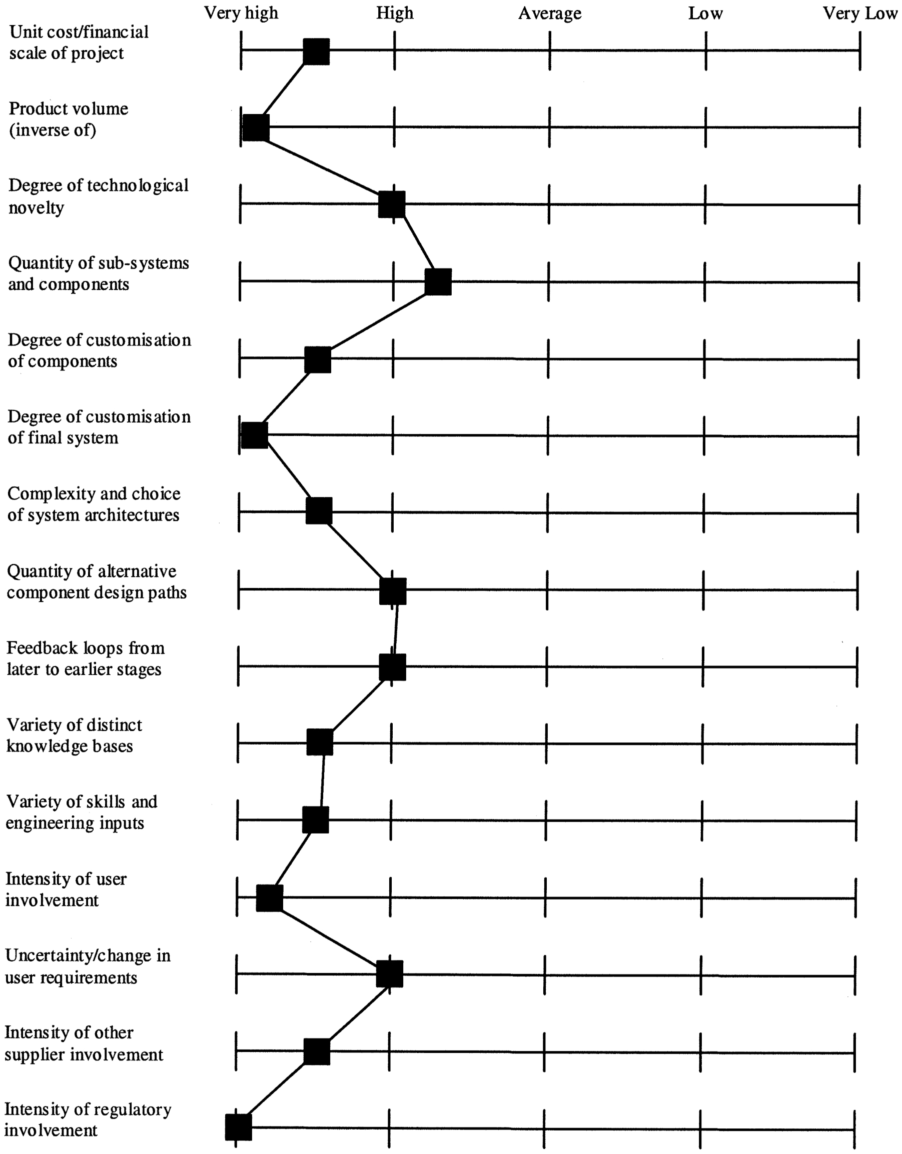


Figure 4-17: Critical Product Dimensions of Complex Product Systems

4.6.3 Satellite Phases

As well as architectural, component and systemic phases of CoPS systems evolution, Chapter 3 identified the particular phases of development of CoPS projects themselves. A sample set of CoPS phases is given in Table 3-6.

Table 4-3: Sample CoPS Project Phases

CoPS Phase	Equivalent Satellite Phase
Pre-production bidding	Request for proposal and bid
	Requirements capture
Conceptual (architectural) design	Architectural design
Detailed design	Detailed design
Fabrication	Manufacture and component testing
	Assembly integration and testing (AIT) and Launch preparation
Delivery and Installation	Launch and Early Operations
Post-production innovation	
Maintenance	Nominal Operations and Maintenance
Servicing and Decommissioning	Deorbit/Decommissioning

These CoPS phases align directly with the phases of the satellite development, with a few additional phases such as requirements capture and launch preparation. This is most likely because of the importance which is placed on these phases as part of a satellite project development due to the difficult nature in altering hardware once it is launched. This also has an impact on the post-production and maintenance phases.

If the phases developed by Davies (1997e) were to be used in the context of the development of a product, it may be suggested that the first three satellite phases correspond directly to the architectural phase, while innovations in the remaining phases are concerned with systemic and component innovations. It should be noted however, that much of the product innovation in situ in a satellite project is cut short by the launch and inaccessibility of the main product, but there may still be project innovations at this stage (for example the Hubble and Voyager spacecraft were both modified once in space, one through hardware and one through software). However, with satellites there is generally limited opportunity for further modification as compared to other CoPS where operating success may owe much to post-implementation alteration and repair.

4.6.4 Satellites as CoPS

Overall, by looking at the placement of satellites within the CoPS hierarchy, the matching of satellite projects to the established CoPS defining terms and by investigating the phasing of a satellite project there is strong evidence to support the claim that CoPS is a useful framework for the analysis of satellite projects (Moody, 2000d).

Indeed, it is conjectured here that satellites may be actually closer to the theoretical definition of CoPS than many of the case studies presented in the previous chapter. In addition, their nature makes them more accessible for analysis. This is due to a number of important factors:

- The degree of satellite complexity is high;
- Satellites are a single, easily defined product with defined boundaries, unlike a telecommunications network or an airport;
- Satellites are never mass-produced and they are designed from the initial mission specification each time;
- As they are launched into space, the end of the satellite development phase is easily quantified; and
- Because of their size and the nature of the industry, satellites always require government involvement.

4.7 Conclusions

In this chapter the international space industry has been placed within its historical perspective and compared with two other CoPS industries, the international missile industry and the mobile telecommunications industry. It was found that a large number of parallels between these industries could be formed, indicating that CoPS may be a suitable framework for analysing the space industry in general. This analysis also provides a useful baseline for comparison with the Australian space industry in Chapter 6.

The underlying attributes of a typical satellite project were then investigated, and the hypothesis that the satellite industry serves as a good forum for the investigation of CoPS was tested. As most satellite projects (if not all of them) fit in the scope of the Complex Product System, it was determined that this framework gives a useful means of investigating them, knowing that the entire industry falls into the area of interest. There is no need to distinguish between CoPS and non CoPS projects in the analysis.

In this chapter a literature search revealed there has been very little analysis into the management of satellite projects from a theoretical perspective. The following chapter looks into the management of a limited subset of satellite projects, small satellites.

Chapter 5

The Management of Small Satellite Projects

5.1 Introduction

As determined in the previous section, Complex Product Systems provide a meaningful framework of analysis for the investigation of satellite projects. This chapter focuses on the management of satellite projects, with particular reference to a subset of these: the management of small satellites.

Initially, the architecture of a small satellite is given, outlining its composition and testing the hypothesis that small satellites still have the order of system complexity of the typical large satellite, such that the Complex Product Systems framework is still a useful mechanism for analysing these projects.

The whole nature of the NASA concept of *Faster, Better, Cheaper* (FBC) is then investigated from a theoretical perspective. Faster, Better, Cheaper does not just aim for cost reduction; it aims for an order of magnitude reduction in costs and timeframes. A central question is asked: 'Within the traditional management literature, is it possible to obtain orders of magnitude reductions in cost and time, while still maintaining the same scientific or commercial benefits?'

A literature review of the Small Satellite Philosophy (SSP), or the established means of managing small satellite projects with the aim of achieving Faster, Better Cheaper, is then presented, including the various methods that project managers have employed to implement these projects. These methods are then placed into a number of logical groups to obtain a better understanding of the true nature of the Small Satellite Philosophy, in particular reference to asking whether the correct preconditions for a substantial change in management styles has been obtained.

Finally, this chapter attempts to draw parallels between the Small Satellite Philosophy and Complex Product Systems, looks at the nature of complexity within small satellite projects, and points towards areas where lessons from the satellite industry may be transferred to other CoPS industries along with areas for future investigation.

5.2 Small Satellites

Traditionally, space missions have required large resources in both finance and manpower and have taken many years to complete. In the late 1980s, a new satellite paradigm, the small satellite, arose and opened up a new class of space applications. Low-profile, low-cost satellites funded by organisations such as the US Defence Force's Advanced Research Projects Agency (ARPA) and university laboratories were being build and placed into orbit (Bearden, 1995). With the advent of lighter, more reliable and more compact electronics, it became feasible to replace large geo-stationary spacecraft with a constellation of smaller and cheaper micro-satellites (Sweeting, 1996).

There are several elements which characterise a small satellite mission; a comparison between typical small satellite projects and large satellite projects is given in Figure 5-1 (Boland, 1999). However, the basic architecture of the small satellite is still the same; this section tests the hypothesis that small satellite projects still exhibit many of the characteristics of larger satellite missions, including mission complexity and innovation requirements.

	Small Satellites	**Large Satellites**
Cost	\$US2 million to \$US100 million	> \$US100 million
Mass	10kg to 500kg	> 500kg
Implementation Duration Concept to Launch	1.5 to 3 years	> 5 years
Number of Participants	10-50 people	> 100 people
Mission Success Criterion Lifetime in Orbit	1-5 years	> 10 years

Figure 5-1: Small Satellite vs. Large Satellite Projects, Source: (Boland, 1999)

5.2.1 Satellite Architecture

Small satellites typically consist of the same basic 'building blocks' as large satellites, in that they contain a Data Handling System, Communications System, Power System, Attitude Control System and payloads as shown in Figure 5-2 (Vesely, 1999). The interfaces between these different components are similarly complex and need to be managed accordingly.

Recent improvements in computer technology have also resulted in the software complexity of small satellites becoming comparable to that of larger ones, especially as small satellites are designed to meet more requirements and perform greater tasks. In addition, as small satellites start to use techniques such as three-axis stabilisation for control, the complexity of the software is at the same level as that of large satellite projects.

As small satellites are often launched alongside large satellites, they are given similarly rigorous testing requirements by the launch authority. It is recognised, however, that the design and manufacture of a small satellite structure is made easier by the reduction in size.

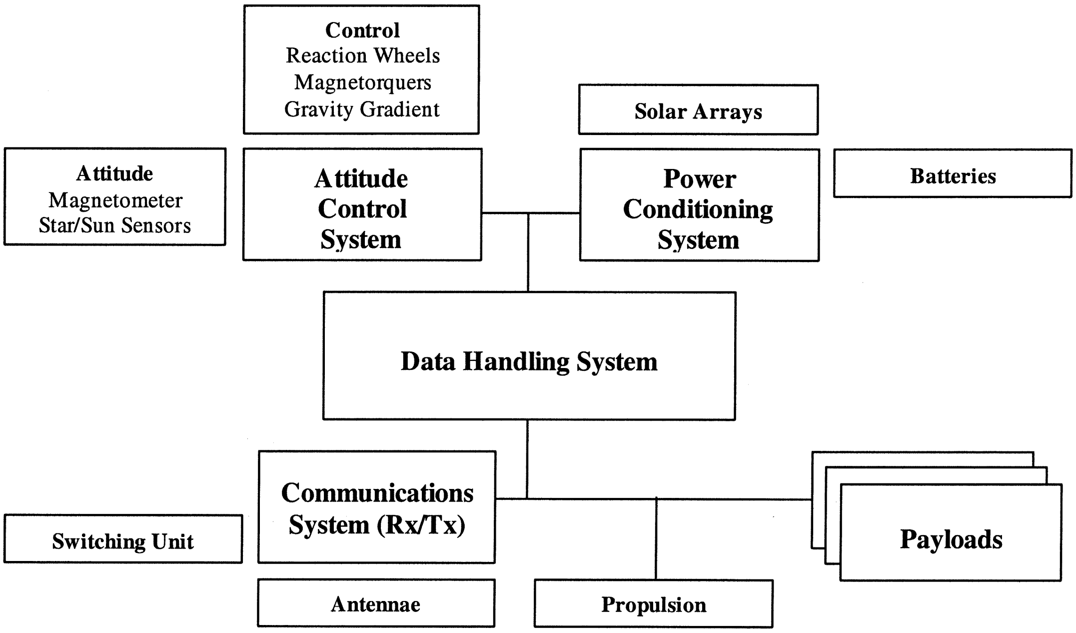


Figure 5-2: Example of small satellite architecture

5.2.2 Small Satellites and CoPS

A small satellite project also exhibits all of the features that normally indicate a Complex Product System, in much the same way that large satellites do. Small Satellite Projects exhibit all of the characteristics of large satellites listed above except, perhaps, for the long product cycles and high costs. Indeed, this also results in different approaches to managing the project and in some cases increases the complexity as a result of the added efficiency that must be obtained from the project resources. Small satellites also exhibit many of the other critical dimensions of CoPS, including one-off or batch production and close user involvement.

In addition, the cost of small satellites, while significantly reduced, still fits into the CoPS 'high-cost' bracket and timeframes still span a number of years. Small satellites adhere to government standards and small satellite projects often consist of government procurement or involvement.

As a result, for the sake of analysis, it is suggested that small satellites can be treated as CoPS alongside large satellites. The impact of the reduction in time-scales and cost on the small satellite project is outlined in the following section.

5.3 Faster, Better, Cheaper?

After becoming the NASA Administrator in 1992, Dan Goldin extolled the virtues of a Faster, Better, Cheaper (FBC) approach to scientific satellite missions (Dornheim, 2000). Aware that the cost of NASA's human spaceflight was unlikely to decrease, and congress was unlikely to give any more money, Goldin focussed on saving costs within NASA's space science programme. He did this by encouraging spacecraft programmes to take more risks within a different management framework, running a large number of small projects rather than a small number of larger ones (Johnson, 2003).

The FBC approach is touted as a mechanism to promote creativity and responsibility on the part of the mission teams, obtaining an *order of magnitude* improvement in schedule and cost while maintaining mission effectiveness. However, as illustrated by recent failures in NASA missions, there is much confusion about the nature of this philosophy, and the means to implement it successfully (Bearden, 1995).

This section first looks at the goals of FBC and then investigates the concept from a theoretical management perspective. It then looks at a number of case studies of FBC projects, including areas in which the philosophy has failed to deliver.

5.3.1 The Goals of FBC

The context for the implementation of FBC satellite missions is summarised in Figure 5-3 (NASA, 1999). As can be seen, there are a number of goals to FBC, but these are still reasonably qualitative. (Mosher, 1999) attempts to describe FBC more quantitatively by developing a number of FBC metrics based on mission parameters such as science return, total mission cost and mission duration. These metrics are summarised in Figure 5-4.

	Faster	**Better**	**Cheaper**
Space Segment	Reduce time from selection to launch	Deliver effective scientific outcomes	Reduce costs by an order of magnitude
Ground Segment	Reduce Mission Operations duration	Simpler operation of ground segment	Capped yearly and total budgets for mission operations phase

Figure 5-3: Small Satellite Goals, Source: (NASA, 1999)

Metric	**Units**	**Measures**
Reduced Development Time	Years	Faster
Reduced Mission Cost	$US	Cheaper
Increased Flight Rate	Fights/yr	Better
Decreased Failure Rate	Percent	Better
Increased Science Return	Instrument-months	Better

Figure 5-4: Faster Better Cheaper Metrics, Source: (Mosher, 1999)

FBC is a methodology that is designed to focus on "competence, empowerment and responsibility" (Watzin, 1998). It espoused an environment to scrutinise all of the elements that contribute to the life cycle cost of a scientific mission to ensure that it delivered the most cost effective implementation of that mission. Mission time was seen as an essential component to reduce cost and as such any non-value added activities were to be "ruthlessly eliminated" (Figueroa and Moos, 1999). More importantly, while quality-based management practices were to be used to continually deliver process improvements, there was an understanding that a degree of mission failure was "acceptable" (Dornheim, 2000).

A list of satellite missions and their systems cited to have been developed by NASA between 1992 and 1999 with the goal of FBC is given in Figure 5-5. In this study, Mosher (1999) reviewed the metrics of a large number of small satellite projects, and grouped them under a number of categories; success, partial failure (where satellite was still operational but the science return was diminished), and failure. Except for interplanetary satellites such as NEAR every satellite cited weighed under 500kg. From this selection it can also be seen that one of the main attributes of *Faster, Better,* *Cheaper* is that it almost invariably requires a focus on *Smaller* quantified in section 5.2.

Mission	Launch Year	Development Schedule (years)	Number of Instruments	Launch Mass (kg)	Mission Cost (FY98$US)	Outcome
SAMPEX	1992	3	4	258	77m	Success
Clementine	1994	1.5	11	424	89m	Partial Failure
Mars Global Surveyor	1996	1.5	6	651	281m	Partial Failure
Mars Pathfinder	1996	3	3	890	273m	Success
NEAR	1996	4	6	818	216m	Partial Failure
HETE	1996	6	6	128	31m	Failure
FAST	1996	4	4	420.5	62m	Success
TOMS-EP	1996	5	1	248	111m	Success
ACE	1997	4	10	785	165m	Success
SeaStar	1997	6	1	309	44m	Success
Lewis	1997	3	3	385	66m	Failure
Lunar Prospector	1998	2.5	6	295	69m	Success
TRACE	1998	2	1	250	49m	Success
SNOE	1998	3	2	132	12m	Success
SWAS	1998	7	3	288	64m	Success
WIRE	1999	2	1	250	50m	Failure
TERRIERS	1999	4	9	272	12m	Failure

Figure 5-5: A selection of NASA FBC Missions, Source: (Mosher, 1999)

Internationally, the management practices employed by NASA's FBC operations in the 1990s became regarded as the Small Satellite Philosophy (SSP) (Fleeter, 1998). Given that this philosophy was central to much of NASA's operations for a decade, and that it had an impact on other small satellite missions internationally, the following sections look at FBC from a theoretical perspective and test the proposition that this mechanism is indeed possible.

5.3.2 A Theoretical Investigation of FBC

An important distinction between FBC and incremental process improvements to a satellite project is that FBC aims to obtain an *order of magnitude* improvement in schedule and cost while maintaining mission effectiveness. This section aims to answer the question: 'Within the traditional management literature is it possible to obtain orders of magnitude reductions in cost and time for satellite projects, while still maintaining the same scientific or commercial benefits'. It begins by looking at some traditional methods to reduce cost and timeframes such as design-to-cost approaches and concurrent engineering and then looks at some radical approaches that may be used.

5.3.2.1 Traditional Methods

Wertz (1996) outlines five different cost approaches that may be used in the management of a satellite project, ranging from minimum cost to maximum performance. In most projects there is a logarithmic relation between cost and performance; at the low cost end a small amount of extra resource will radically improve performance whereas at the higher end of the range a large amount of resource is required for even a modest improvement in performance.

The relationship between cost and performance is given in Figure 5-6. At the lower end there is the low cost option; the minimum that can be achieved and still accomplish a mission outcome. In some cases this may be acceptable, especially if it allows a number of satellites to be built to participate in the mission. The Design-to-cost approach is one taken in many science missions and is used to allow requirements flexibility while maintaining control of the budget. The third approach is the optimum cost-to-performance ratio, and is used in large satellites where resource can be spent on modelling the cost and performance of the final product. The Design-to-requirements option is the traditional approach, still used for many military satellites and the High Cost option aims for the best available performance given the current state of technology.

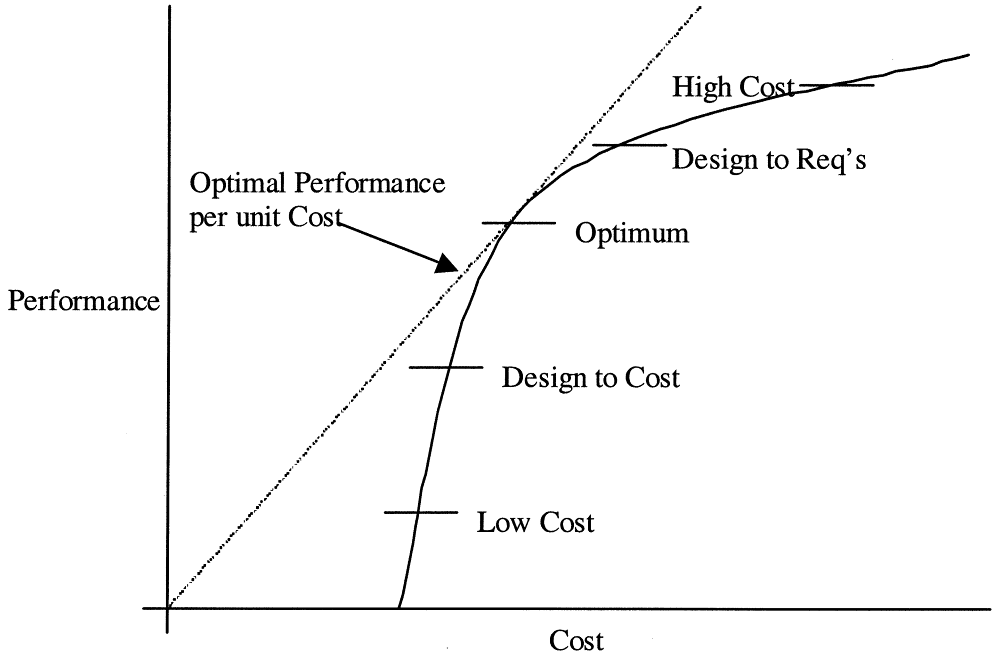


Figure 5-6: Performance vs. Cost Relationship

Of the traditional approaches to achieving a better cost/performance ratio, Design to Cost is the most popular. However there are a few issues; sometimes a reduction in space segment cost can drive up the cost of operations and vice versa. Even using this approach there is still a trade-off between cost and performance, and it is unlikely that there will be order of magnitude improvements.

5.3.2.2 Radical Methods

Other authors (see for example (Figueroa and Moos, 1999), (Watzin, 1998) and (Bearden, 1996)) have investigated the use of more 'radical' methods which can enable large reductions in cost or timeframe. These methods include the changing of the management paradigm, the use of small integrated teams across the entire project, explicit trading on requirements, the balancing of risk and cost and the use of commercial, off-the-shelf (COTS) components. The most dominant of these 'radical' methods is the small satellite philosophy, which also encapsulates all of the other methods outlined above. The SSP forms the key components of the analysis in the following section.

5.3.3 An Empirical Investigation of FBC

As FBC has not been rigorously treated in the innovation management literature, it is also useful to look at its outcomes from an empirical perspective, or whether experiences with previous FBC projects have been able to yield the reductions in schedule and cost that the FBC method aims for.

A recent (Mosher, 1999) study revealed some interesting empirical results regarding the implementation of FBC. It found that, using the metrics of Figure 5-4 and a set of 18 small satellites and 10 large satellites, FBC mission development durations were reduced by 40-50% and decreased in cost by 85%. Whether the missions were better or not was difficult to determine; while the launch rate for FBC missions increased so too did the failure rate. In addition, the amount of science returned also indicated that traditional missions have a greater science return. It concluded that for an individual mission it was not possible to have faster, cheaper and better, but if all three metrics were combined the overall mission cost-effectiveness (the cost/time metric for the same science return) for FBC missions was 74% higher than for traditional missions taken over a number of launches. An analysis of the drivers behind this is given in Section 7.5

A study by the Aerospace Corporation (Bearden, 1996) also found good returns in implementing FBC strategy. Using a model developed for large satellites (Wertz, 1998) the estimated costs for a number of small satellites were determined and plotted against their actual costs, reproduced here as Figure 5-7. It was found that the costs were indeed an order of magnitude less that those predicted by the large satellite model (shown as SMAD in the image).

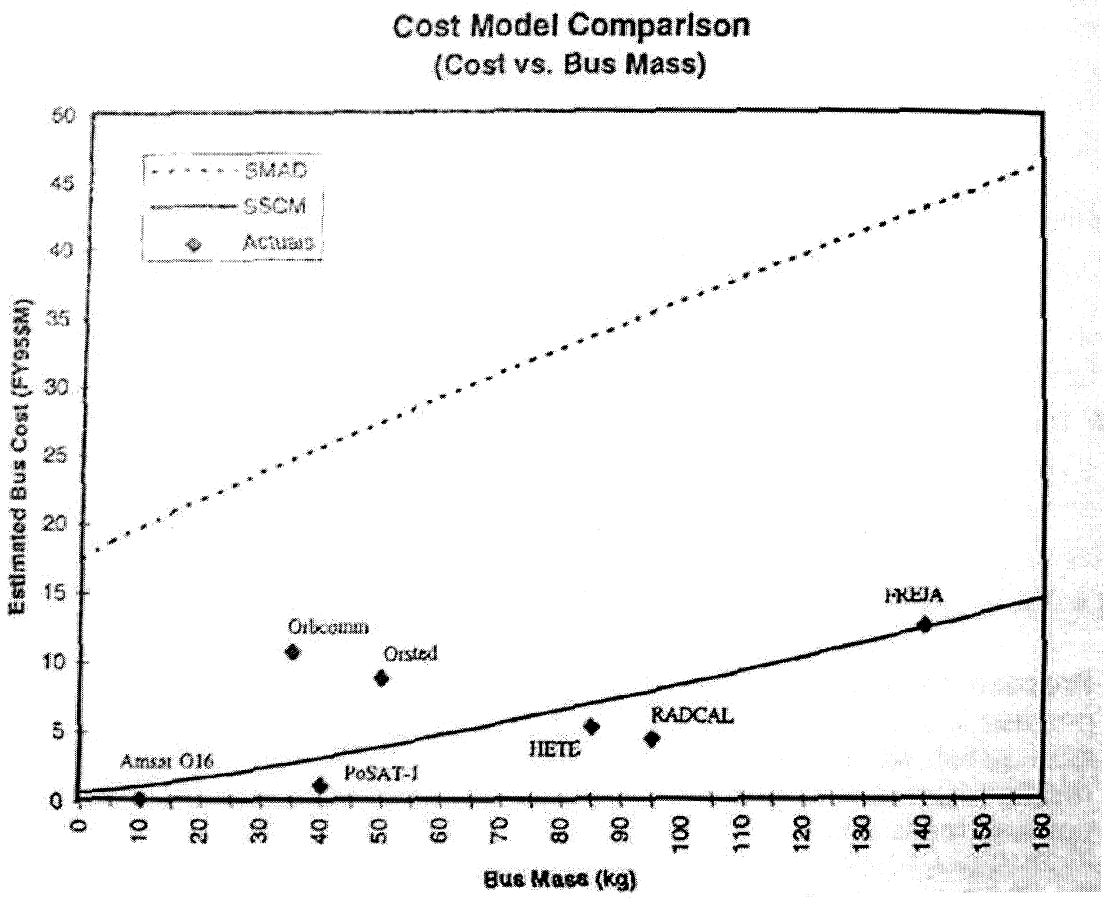


Figure 5-7: Cost Model Comparison between large and small satellites, Source: (Bearden, 1996)

The Aerospace Corporation took this one step further by developing a sophisticated tool for estimating the cost of a small satellite project before its development. It gives two methods of estimating costs, the first by looking at the physical characteristics of the final product (such as structure mass, power requirements and solar array area) (Bearden, 1996) and the second by breaking the satellite into its individual subcomponents and estimating the cost of each of these along with the additional programme cost (Bearden, 1995; Bell, 1995). These parametric models define the mathematical relationships relating the intended satellite outputs (such as mass and power) and the expected cost, using aggregated data from a number of previous small satellite missions.

A similar study by the Canadian Space Agency (Buckingham and Sultan, 1995) looks at the cost estimation model from the point of view of ensuring that expenditure remains under a certain cost cap or the worst-case analysis. It defines small satellites as satellites with a cost ceiling of $US50 million, rather than using the traditional weight metric. It also breaks the programme into a number of core components, such as satellite development, payload development, assembly, integration and test and launch and gives techniques to predict the ceiling cost of each component. Unlike the Aerospace corporation cost model, this model also includes a parameter for management method, but does not quantify the relationship between the parameter and different methods, rather letting the 'user' choose how 'effective' the current method is.

All of these models only apply to estimating the costs of small satellites (or in the case of the CSA report, satellites that cost less than $US50m). If they are used to estimate the costs of large satellite projects they break down, indicating that there is an underlying difference between the manufacture of small satellites and large satellites. Wertz (1996) remarks on this and lists a number of unmodelled cost drivers which may have an effect on this, highlighting system performance, project culture, group size and willingness to accept risk in the project.

5.3.4 Case Studies

In order to understand the nature of FBC a number of short case studies are included below with a range of scenarios from fully successful missions to partial and catastrophic failures. A summary of the missions and their outcomes are given below.

5.3.4.1 Orsted – Success

Orsted, a 60kg Danish Microsatellite was built with the objective of providing accurate measurements of the earth's geomagnetic field (Danmarks Meteorologiske Institut, 2004). The total cost of the programme was $US15million and it was implemented as a cooperative effort among a group of Danish research institutions. The success of the mission was attributed to a number of key implementation guidelines:

- Keep the design simple and use off-the-shelf equipment;
- Understand the underlying physics of the design;

- Use common sense;
- Communicate frequently with other team members;
- Eliminate multiple design margins, such as replacing a series of 10% margins with one 10% margin for the system;
- Define and freeze interfaces at the start of the project;
- Test the hardware design and interfaces wherever possible;
- Use common software for the Ground Support Equipment and the Ground Station;
- Adhere to local company quality assurance standards and procedures as much as possible; and
- Only accept deliverables after integration and test.

5.3.4.2 Freja – Success

The Freja magnetospheric research satellite was launched in October 1992 and weighs 214kg. Its project development timeframe was slightly longer than most small satellite projects at five years and the entire programme cost $US19m (Swedish Space Corporation, 2004). The Swedish Space Corporation that built Freja placed a strong emphasis on the management of the project and believes its success was mostly as a result of the following factors:

- Use of small, integrated teams with distributed but overlapping skills;
- Experienced staff;
- Flat organisational structure with a focus on accountability;
- Frequent review; and
- Simple sponsor interface (funding from one source) to reduce administration.

5.3.4.3 SAMPEX – Success

The Solar Anomalous and Magnetosperic Particle Explorer (SAMPEX) was the first of NASA's SMEX missions, which were designed to study the composition and charge status of particles from supernova explosions, solar flares and nearby interstellar space (NASA, 2004). It was built at a cost of $US72m, weighed 160kg and was launched in July 1992. Once again, management choices were cited as the main driver for accomplishing the mission objectives at a low cost and within schedule, with the main initiatives being:

- Schedule-driven approach;
- Dedicated project organisation and shared support for multiple projects;
- Use of a core team;
- Frequent face-to-face meetings will all participants;
- Distributed architecture with standard interfaces;
- Detailed parts engineering and procurement; and
- Streamlined flight assurance and reduced documentation.

5.3.4.4 Clementine – Partial Failure

Clementine, a 424kg $US89m satellite was launched on January 25, 1994 with the objective of investigating the long-term effects of the space environment on sensors and spacecraft and to make scientific observations of the moon and the near-earth asteroid 1620 Geographos. After completion of the lunar mapping, Clementine's on-board computer malfunctioned causing a misfiring of several thrusters and a complete depletion of the fuel onboard, resulting on the cancellation of the asteroid component of the mission. Partial failure of the Clementine mission is attributed to design failure, although it is unknown whether this is due to the hardware or software (NSSDC, 1996).

5.3.4.5 Lewis - Failure

Lewis was launched on August 23, 1997 at a cost of $US66m and suffered a catastrophic failure, re-entering the atmosphere on September 28. The spacecraft entered a flat spin in orbit resulting in loss of power to the solar arrays and eventual battery power discharge and it never completed its mission of demonstrating new technologies for measuring changes in topography. Investigation into the attitude control system found that insufficient analysis had been done to adapt this pre-existing design to a different spacecraft spin-axis orientation. The failure was attributed to a design error caused by a lack of knowledge about behaviour of the spacecraft in orbit that resulted in rotational perturbations which eventually led to an uncontrolled spin (GSFC, 1998).

5.3.4.6 WIRE – Failure

The 250kg Wide-Field Infrared Explorer (WIRE) satellite was launched on March 4, 1999 and suffered a catastrophic failure as a result of an electrical power surge reaching the explosive devices at start-up (GSFC, 1999). Characteristics which were known about a component in the instrument electronic box were not considered in depth and the failure was attributed to a design error which may have been resolved with further testing and simulation.

5.3.5 Failures in FBC

The FBC initiative spurred new cost reduction ideas such as the use of airbags to land on Mars and cancelled programmes that ran significantly over budget. However, the risk-taking nature of the programme often came at the expense of procedural checks, with some risks paying off while others did not. By 2000 the many failures of the project had shown that too many projects had cut too many corners, with some analysts believing that NASA's cost cutting methods had gone too far, with too many projects cutting too many corners (Johnson, 2003).

A further study by the Aerospace Corporation (Dornheim, 2000) found that when missions reached a certain threshold they became too fast and too cheap and were almost certainly doomed to failure. It found that the failure of FBC spacecraft such as the NASA Lewis and WIRE satellites and the Mars Climate Orbiter may be predictable, when they crossed into an area of high complexity and low development time. The study took into account nine planetary and 12 earth-orbiting FBC missions and developed a means to analyse the mission risk based on its complexity.

It found that "when examined after the fact, loss or impaired performance is often found to be the result of mismanagement or miscommunication. In combination with a series of 'low probability' events, these missteps, which often occur when the program is operating near the budget ceiling or under tremendous schedule pressure, result in failure due to lack of sufficient resources to test, simulate or review work and processes in a thorough manner." (Dornheim, 2000).

This study was also echoed by an official review of FBC by Anthony Spear, the former manager of the Jet Propulsion Laboratory (Spear, 2000). Spear found that the FBC approach wasn't working and needed major changes; a summary of the report is given below:

> In a report released last Monday, a panel of space experts headed by Spear told NASA the FBC approach wasn't working and needed major changes.
>
> "The current mission failure rate is too high and must be reduced," the report stated.
> "Most failures over the past decade can be attributed to poor communication and mistakes in engineering and management," it explained. "Failing due to mistakes is not tolerable."
>
> The original FBC theory was that there would be some failures due to trying more difficult missions and to using more advanced technologies. Such failures were to be expected and tolerated.
>
> But, the report explained, mission failure due to avoidable mistakes "was NOT what was meant when Dan Goldin said, 'It's OK to fail.'"
>
> "We need to slow down some, not rush too quickly into important programs and projects," the report advised. It strongly implied that previous programs had not been planned and implemented with sufficient care, and had been too fixated on cost containment and short-term goals.
>
> If NASA can successfully develop management techniques to achieve its FBC goals, they would be applicable to high technology projects throughout the U.S. economy. Such a process could turn out to be one of the most valuable space spin-offs ever.
> One critical problem which the new report highlights is that there is no authoritative definition of what FBC really is.
>
> "FBC is simply attempting to improve performance by being more efficient and innovative," it concluded. There is also "an intangible element," it added, "a team spirit associated with doing FBC."
>
> This principle was often violated, the report noted, in overzealous cost-cutting campaigns. "Some FBC teams reported that the fun had gone away after having their resources cut too deeply."
>
> "In our zeal to do FBC," it continued, "the challenge bar was raised too high. The cost cap challenges were made too great, along with a mix of unstable funding and escalating requirements."
>
> "It takes a project manager with good judgment and courage to declare under pressure that the project is not doable for the available resources," it stressed. "This requires unprecedented teaming and open, candid communications," the report stated. "No one person has the answer. It takes a lot of debate and evolution of ideas to get there. It takes courage to admit a wrong path and the need to move in another direction."
>
> Source: (Spear, 2000)

These successful and unsuccessful case studies point towards management being a key driver in the implementation of small satellite projects. This is echoed by Wertz (1996) who, in summarising the results of a review of 90 small satellite missions concludes that "mentality and decision-making process with the group seems to be the most important [issue]" (pg11).

5.3.6 Conclusions

Overall, this analysis into the Faster, Better, Cheaper methodology has yielded a number of core characteristics regarding its implementation:

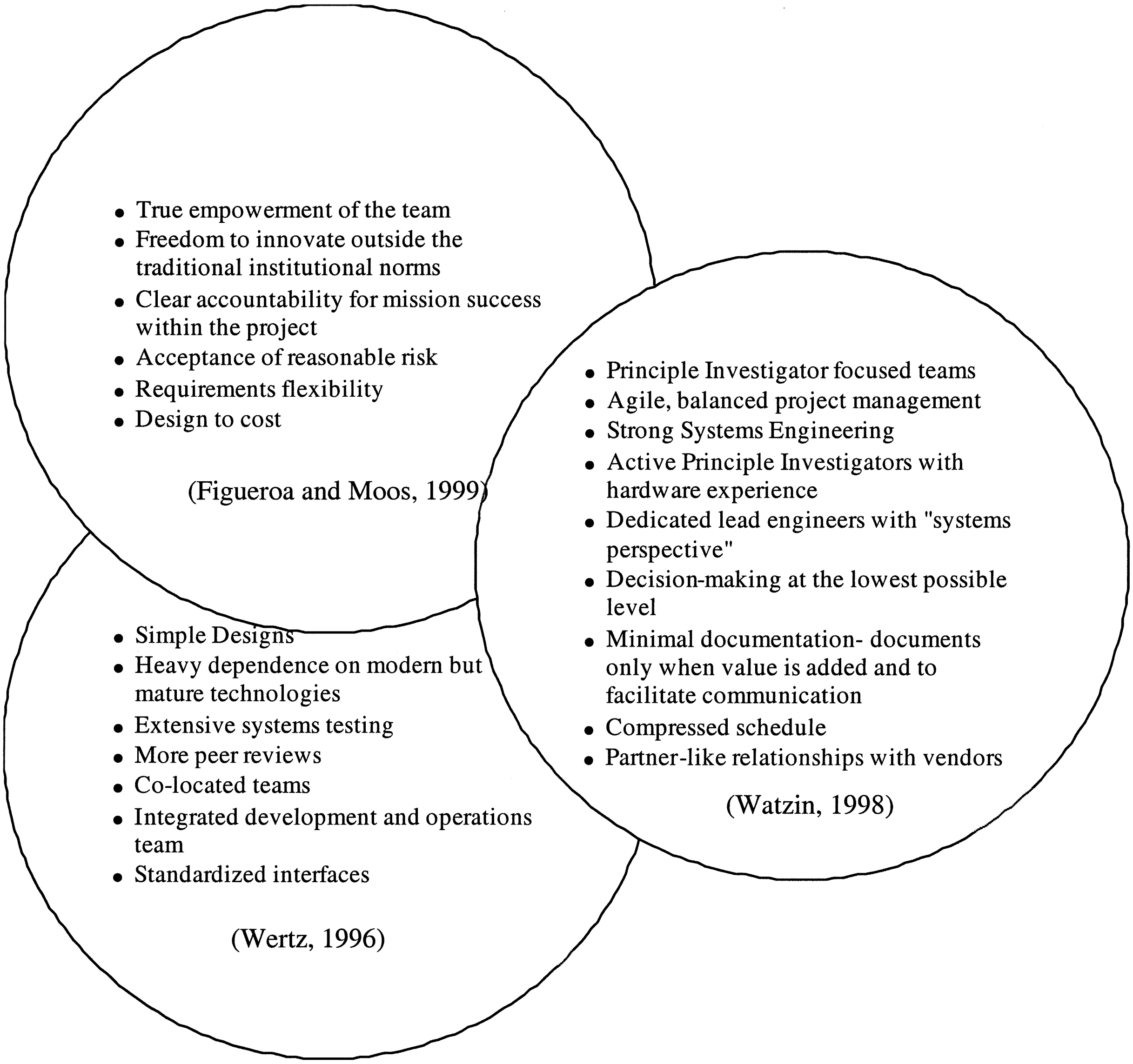
- There is a difference between the cost and development time of small and large satellites.
- Indeed, it is possible, both theoretically and empirically, to radically reduce costs and schedule in a satellite project. When taking only cost and schedule into account there are data to support that this is an 'order of magnitude' improvement for each small satellite mission. However, when looking at factors such as mission success and scientific return (the *Better* component of *Faster, Better, Cheaper*) the support for an order of magnitude improvement is greatly reduced.
- Reductions are primarily enabled through the use of small satellites to reduce complexity, the implementation of a 'new' management philosophy and the acceptance of more risk for each mission.
- However, there is a limit to the amount of reduction that can be obtained and if this limit is exceeded the mission has a high chance of ending in failure, either catastrophic or partial.

The following section looks in-depth into the implementation of the management philosophy behind Faster, Better, Cheaper and tests the hypothesis that it really does implement 'new' management tools and techniques.

5.4 The Small Satellite Philosophy

Small satellites are also differentiated from larger satellites through their management philosophy, which requires effective management of fewer resources and accelerated deadlines. Its goal of the philosophy is to reduce the cost and development time of a satellite project by an order of magnitude through the use of appropriate technologies and alternative management styles. However, this Small Satellite Philosophy requires a number of issues to be resolved; reduced resources require trade-offs between risk and cost, complexity and utility; advanced timelines have an impact on component ordering and project monitoring and innovation to be managed more effectively at a much faster rate.

There have been a number of investigations into this philosophy, each giving a number of methodologies for implementing the small satellite philosophy, most of them concerning the management of the small satellite process. A selection of these methodologies and their sources are given in Figure 5-8. These and other characteristics and techniques of the small satellite philosophy are outlined in the sections below along with some other core characteristics found in other areas of the literature.



- True empowerment of the team
- Freedom to innovate outside the traditional institutional norms
- Clear accountability for mission success within the project
- Acceptance of reasonable risk
- Requirements flexibility
- Design to cost

(Figueroa and Moos, 1999)

- Principle Investigator focused teams
- Agile, balanced project management
- Strong Systems Engineering
- Active Principle Investigators with hardware experience
- Dedicated lead engineers with "systems perspective"
- Decision-making at the lowest possible level
- Minimal documentation- documents only when value is added and to facilitate communication
- Compressed schedule
- Partner-like relationships with vendors

(Watzin, 1998)

- Simple Designs
- Heavy dependence on modern but mature technologies
- Extensive systems testing
- More peer reviews
- Co-located teams
- Integrated development and operations team
- Standardized interfaces

(Wertz, 1996)

Figure 5-8: A Selection of SSP methodologies

5.4.1 Separation of Project Management and Technical Management

Effective project management in a small satellite project begins with respect for, and trust in, the development team (Watzin, 1998). With a strong, competent technical team the project management can remove itself from the technical decisions and focus on motivation, administration and communication. This will give the technical team the freedom to innovate within the constraints of budget and timelines. However, this separation requires the project manager to ensure clear accountability within the project structure.

5.4.2 Strong Systems Engineering

The systems engineering group needs to be recognised as a coordinating mechanism for the entire project (Wertz, 1996). The lead engineers for each sub-system need to understand the entire mission, so as not to get caught up in optimising particular components while removing resources from other parts of the project.

5.4.3 Quality Assurance

Under the FBC small satellite philosophy, quality-based management practices are key to the implementation of the project. To obtain a low cost solution using the philosophy, mission development time should be minimised, requiring the ruthless removal of activities or practices that do not add value. Bureaucratic processes must be eliminated and replaced with the flexibility to change quickly and often. Quality Assurance must transcend from 'police and audit' to 'guidance and education'. Repetitive tasks that do not add value should also be removed, such as complicated purchase orders or equipment negotiated under the umbrella of the original contract with the team (Wertz, 1996).

5.4.4 Small Integrated Teams

In the development of small satellites, experience has shown that smaller project teams with closer and informal communication channels are necessary, with open communication between science, engineering and management (Figueroa and Moos, 1999). Teams need to be co-located and should be insulated by management from the day-to-day operation of the business. Close contact between all members of the team is encouraged with trust and respect being key factors of their operation.

5.4.5 Empowerment

Another key aspect of any small satellite project is the empowerment of all of the engineers in the project. Schedules and budgets need to be mutually developed, and decisions should be made at the lowest possible level, resulting in distributed decision-making (Watzin, 1998).

5.4.6 Experienced Managers

The importance of maintaining the original cost commitment requires that experienced development managers and personnel in key disciplines are selected early, remaining through the duration of the mission. Simple tools must be established and accepted by all from the beginning to provide insight of potential problems well before the contingency threshold is reached. With the aid of these tools the performance of the teams must be reviewed frequently and thoroughly down to manpower levels (NASA, 1999).

5.4.7 Frequent Review

One of the outcomes of the small satellite philosophy is a much closer scrutiny of the project, in order to deliver a more cost-effective implementation of a mission (Watzin, 1998). Managerial procedures and technical decisions must be continually revisited to ensure their effectiveness for each situation. These reviews need to be managed to be quick, with a focus on adding value. The use of experienced engineers (even ones external to the project) is key to ensuring that the review process is effective.

5.4.8 Accelerated development

In a small satellite project with a fixed deadline, time is one of the main drivers (NASA, 1999). Even when cost is a driver an accelerated schedule is the key to success; the wise use of overtime to reduce costs is invariably cheaper than the cost of an on-call "marching army". With this focus on reducing timelines, the team needs to make decisions quickly while remaining flexible to change. Incorrect decisions can be corrected if they are caught early enough; late decisions will either stifle the progress of the project or, if incorrect, threaten the success of the mission. More than just a plan to be tracked, the schedule must be continually updated and dynamically managed to ensure the team is performing at its greatest efficiency.

5.4.9 Minimal documentation

Documents should be used only when value is added and to facilitate communication. Excessive paper or requirements must be reduced, eliminated or limited to areas where value may be added, such as safety. However requirements, systems specifications, interfaces and user manuals are key to the project (Mosher, 1999).

5.4.10 Requirements Flexibility

With capped costs and reduced timelines, the team must be given the flexibility to trade requirements as long as the mission goals are still met (Watzin, 1998). Traditional requirements capture, which aims to encapsulate all of the mission requirements, should be replaced with only the bare bones requirements, allowing the implementers more chance to rescope the implementation where necessary.

5.4.11 Partner-like relationship with vendors

With reduced timelines and costs, vendors need to be treated as partners (Callen, 1999). They should be enrolled in the project team and in some cases involved in decisions affecting the project. The management tools and systems of the vendor should be integrated into the project where effective to ensure good communication.

5.4.12 Exchanging Risk for Cost

One of the main differentiators between the large and small satellite philosophies is the acceptance of a certain amount or risk. Risk can be traded for cost, and the team cannot "push the envelope" if the institution they work within is overly concerned with failure (Watzin, 1998). The project teams should define the guidelines for taking risk at the beginning of the project and use simple tools to assess the risk of certain components or architectures (Wertz, 1996).

5.4.13 Removal of Redundancy - Keep it Simple Stupid

It has also been suggested that large saving can be made to a project with the removal of redundancy in systems. It has been found that a non-redundant design has advantages in simplicity of design and testing, while being only marginally less likely to complete the mission. Rigorous testing of a single design which minimizes the parts count and is built with proven parts and technology can result in a very small probability of failure (Watzin, 1998).

5.4.14 Qualifying by Design or Similarity

Satellite qualification may take up a large proportion of the overall budget. With the right experience, sub-systems in a small satellite project may be qualified by either design or similarity, although there is no substitution for the qualification of the entire spacecraft (Day, 1997). In addition, this technique may include the increased use of Commercial Off-The-Shelf (COTS) components.

5.4.15 Use of modern technologies

Small satellites require high performance, integrated technologies in order to reduce complexity and meet mission criteria. For example, one satellite company in the United Kingdom uses high performance commercial Intel chips with error correction to obtain the performance they require (Sweeting, 1996). However, it should be noted that these technologies should also be reasonably mature so as not to discover problems late into the development process (Watzin, 1998).

5.4.16 Use of software

By encapsulating much of the system's complexity in the spacecraft software, the remainder of the system can be simplified (Wertz, 1996). In addition, software can be updated at a later date, or even during the mission itself. With more intelligence on the spacecraft, the ground station can be simplified, reducing the personnel requirements and scope for human error.

5.4.17 Standardized Interfaces

In a small satellite project the interfaces should be defined early in the development process and adhered to rigidly. This allows development to proceed in parallel, with the use of industry standards assisting in the purchase of COTS components (Boland, 1999).

Figure 5-9 summarises these and other Small Satellite Philosophy characteristics. The following sections take the large number of characteristics shown and attempt to group them into meaningful categories.

Separation of Project Management and Technical Management	Strong Systems Engineering
Freedom to innovate	Dedicated lead engineers with systems perspective
Clear Accountability	Personnel selected early and remain throughout
Separation of technical from managerial problems	Accelerated development
Agile, balanced project management	Quick decision making
Co-location	Technical Experience
Trust and Honesty	Requirements Flexibility
Small Integrated Teams	Partner-like relationship with vendors
Commitment to the project	Teamwork
Empowerment	Decision-making at the lowest possible level
Experienced Managers	Motivation
Compressed Schedules	Exchanging Risk for Cost
Minimal documentation	Removal of Redundancy
Streamline contractual processes	Qualifying by Design or Similarity
Focus on continuous improvement	Use of modern technologies
Frequent Review	Use of software
Reviews should be quick and add value	Standardized Interfaces
Use of small satellites	Use of embedded systems

Figure 5-9: SSP Characteristics

Davies (1997d) describes an organic management structure being established in small scale or highly innovative production processes. This structure has several distinct features (Burns and Stalker, 1961):

- Tasks are continually adjusted and redefined as the project develops. Knowledge and experience of working in project teams becomes more important than the specialised skills required by tightly-defined individual tasks.
- There is a commitment to the concerns of the project as a whole rather than the completion of individual tasks.
- Vertical integration among people of different rank is less important than the lateral communication that takes place among project members irrespective of their position in the hierarchy.
- Information and advice rather than formalised rules are more appropriate forms of communication

- Overall commitment to the progress of the project is valued more highly than loyalty and obedience to immediate superiors.

It can be seen that these distinctive features are all present as a subset of the techniques which have been cited as important to the implementation of the small satellite philosophy. As such, it may be suggested that one of the differences between the SSP and the traditional mechanistic approach to satellite management as described in Chapter 3 is that it employs a flexible organic management approach.

5.5 Classifying the Small Satellite Philosophy

Section 5.3 indicated that if the Small Satellite Philosophy were to succeed in obtaining order of magnitude reductions in timelines and cost while maintaining mission quality, it had to involve a fundamental change in operations. The previous section investigated this claim, and ascertained that this was a change from an organic to a mechanistic project management approach within the space industry, coupled with an advance in satellite technologies.

However, it is still important to ascertain whether a satellite project is indeed implementing the small satellite philosophy or something different. This section attempts to classify the characteristics of the SSP found in the previous section in order to develop a tool for use in future chapters of this thesis. It also aims to investigate the philosophy in greater depth to ensure that there is not something more fundamental being undertaken during the implementation of the SSP.

5.5.1 Functional Lines

The first means of categorising the different techniques involved in the small satellite philosophy is by grouping them along functional lines. Each of the ideas presented above is summarized in Figure 5-10, separated into four different sections: management, technical, quality and technology.

MANAGEMENT	TECHNICAL
Separation of Project Management and Technical Management	Strong Systems Engineering
Freedom to innovate	Dedicated lead engineers with systems perspective
Clear Accountability	Personnel selected early and remain throughout
Teamwork	Separation of technical from managerial problems
Commitment to the Project	Accelerated development
Agile, balanced project management	Quick decision making
Co-location	Technical Experience
Trust and Honesty	Requirements Flexibility
Small Integrated Teams	Partner-like relationship with vendors
Empowerment	Decision-making at the lowest possible level
Experienced Managers	
Compressed Schedules	**TECHNOLOGY**
Minimal documentation	Exchanging Risk for Cost
Motivation	Removal of Redundancy
	Qualifying by Design or Similarity
QUALITY	Use of modern technologies
Streamline contractual processes	Use of software
Focus on continuous improvement	Use of embedded systems
Frequent Review	Standardized Interfaces
Reviews should be quick and add value	Small satellites

Figure 5-10: Characteristics of the Small Satellite Philosophy

This breakdown of the small satellite philosophy isolates two areas of importance from the technical and managerial skills needed to implement the project; that of a focus on new but mature technologies and a focus on the implementation of quality practices for continuous improvement.

5.5.2 Drivers and Outcomes

The analysis of the small satellite philosophy has so far pointed towards the need for an organic project structure and a focus on technology and quality. In attempting to determine if the SSP involves a 'different' management model, this section attempts to group the small satellite philosophy in another way, by focussing on one set of essential management techniques which give rise to all of the others.

The different characteristics of the small satellite philosophy described in the following section may be separated into two groups; drivers of the small satellite philosophy and outcomes which arise from, or are made more effective by, these drivers. For example, it is the experience of the technical team (driver) that allows them to effectively trade the appropriate risk for cost, or use appropriate modern technologies (outcome) and trust and honesty (driver) which is essential to the efficiency of small teams (outcome). In the same way empowerment of the team (driver) can lead to quick decision-making (outcome) and strong, partner-like relationships with vendors (outcome).

There are some cases where drivers may also be outcomes of something else. For example, empowerment of the team may also be a result of trust in the experience of the engineer. In other cases some causes are enablers for effects, such as strong systems engineering allowing requirements flexibility to be accomplished.

In Figure 5-11 the characteristics of the small satellite philosophy have been separated into drivers and outcomes. Note that this may not capture all of the relationships between the different areas, such as when an outcome is driven by two drivers, but only includes the main areas.

DRIVER	OUTCOME
Experienced Management	Separation of Project Management and Technical Management Clear Accountability Separation of technical from managerial problems
Freedom to innovate	Agile, balanced project management Accelerated development Compressed Schedules
Trust and Honesty	Small Integrated Teams Teamwork Good communication Co-location
Strong Systems Engineering	Dedicated lead engineers with systems perspective Personnel selected early and remain throughout Requirements Flexibility
Empowerment & Motivation	Quick decision making Partner-like relationship with vendors Commitment to the project Decision-making at the lowest possible level
Focus on Continuous Improvement	Streamline contractual processes Frequent Review Reviews should be quick and add value
5.5.3 Technical Experience	Exchanging Risk for Cost Removal of Redundancy Qualifying by Design or Similarity Use of modern technologies Use of software Use of embedded systems Standardized Interfaces Minimal documentation

Figure 5-11: Drivers and Outcomes

By organizing the characteristics of the small satellite philosophy in this way, effective projects are seen to be driven by a focus on experience and competence, empowerment with responsibility and freedom to innovate outside the norms; these are also the main drivers identified by (Watzin 1998). Strong systems engineering combined with technical review and experience also enable many of the other aspects of the small satellite philosophy to be implemented successfully.

By looking at the philosophy in this way, an insight into the potential nature of the SSP is revealed. It is suggested that a successful implementation of the Small Satellite Philosophy is due to a combination of an appropriate management structure with a focus on only a small number of very important drivers, which work together to give very powerful techniques. It also follows that SSP project failures may have been due to implementation of outcomes of the SSP without addressing the drivers of the philosophy.

It should also be noted that an analysis of a company that implements the small satellite philosophy may only reveal the effects of the implementation of this philosophy. Effects such as use of modern technologies, partnerships with vendors and small integrated teams may be easily spotted; empowerment, experience and motivation may be something only recognized internally by the company.

5.5.4 A new management methodology?

By investigating the small satellite philosophy literature, there is evidence that it is a new management methodology for the space industry, and as such has the potential to deliver Faster, Better, Cheaper satellite projects. The analysis in this section has brought a number of key implementation guidelines for the small satellite philosophy to light, which are guidelines towards its successful implementation:

- An organic management structure
- A focus on a number of core drivers in the process such as trust, empowerment, systems engineering and experience within the team
- The knowledge of and use of new but mature technologies which also allow the production of small satellites, coupled with developed interface standards
- A focus on continuous improvement through frequent review

These guidelines are used later in this thesis to assess the implementation of the small satellite philosophy during the satellite case study.

5.6 The Small Satellite Philosophy and CoPS

In the 1990s, through the implementation of FBC and the Small Satellite Philosophy, the satellite industry underwent a change which resulted in reductions in cost and schedule while retaining or improving performance outcomes across a mission. This section asks the question of whether this is also possible in other CoPS industries and which lessons may be applicable with respect to the wider innovation literature.

One of the main areas where the small satellite philosophy may offer an insight into the management of Complex Product Systems is in understanding the Relationship between Complexity, Resources and Risk in these projects of reduced scope. In analysing the impact of these changes on the overall mission, we can look at the metrics for 'Faster, Better and Cheaper' outlined above:

Metric	**Units**	**Measures**
Development Time	Years	Faster
Mission Cost	$US	Cheaper
Flight Rate	Fights/yr	Better
Failure Rate	Percent	Better
Increased Science Return	Instrument-months	Better

In a review of the literature, it is apparent that one of the core drivers of the Small Satellite Philosophy was the enabling of better returns through the implementation of smaller satellites. There were three key areas where this reduced scope of the project led to changes; a reduction in complexity, and different management style, and the acceptance of higher risk in each mission with the understanding that there was a potential to undertake more missions and spread the risk over a larger programme.

The reduction in complexity, measured by a reduction in the size of the satellite, the number of interfaces between units, the use of standard products and the removal of redundancy had an impact on a reduction in the overall resources required to complete development. It is difficult to determine the impact of this to the overall risk to the project, as the removal of redundancy in the mission may have offset the gains in risk through the reduction in the number of interfaces. However, one impact of the reduction in size and complexity of the missions is a decreased science return per mission.

Implementing the Small Satellite Philosophy, a ‘new’ approach to the management of these projects focussing on experience, motivation, flexibility and leadership, has also been cited as resulting in accelerated schedules and reduced costs of missions. These reductions are made in the context of staff with experience who can make ‘intelligent’ choices, leaving the overall risk of the mission unchanged. Resource reductions are further enhanced through reduced management overheads and the number of staff required to implement the project.

Finally, in the Small Satellite Philosophy there is the acceptance of a higher risk per mission. This has the impact of reducing resources further through removal of tests or replacement of equipment, but is done with the understanding that an increased flight rate may both mitigate the increased risk to the overall programme and improve the programme’s science return.

Looking at these three dimensions with respect to the different Faster, Better, Cheaper metrics above, the following relationships can be summarised in Table 5-1.

Table 5-1: SSP Relationships per mission

Metric	**Units**	**Reduced Complexity**	**SSP Management**	**Increased Risk/Mission**	**Summary**
Development Time	Years	↓	↓	↓	↓↓↓
Mission Cost	$US	↓	↓	↓	↓↓↓
Flight Rate	Fights/yr	-	-	-	-
Failure Rate	Percent	-	-	↑	↑
Increased Science Return	Instrument -months	↓	-	-	↓

It is important not to draw too many conclusions from this analysis, as some of these factors may have varying impacts on the overall reductions in cost, mission and risk of the project. However, it is fair to say that by aiming for the reductions cited in the

Faster, Better, Cheaper literature, there are three drivers for reductions in time and cost, offset by drivers for increased risk and a reduction in science return. This is consistent with the findings of Bearden (1996) in showing that there is an order of magnitude reduction in cost when compared to large satellite missions.

When taking more than one mission into account, it can be seen that this reduction in science return and mission success may be offset by an increased number of missions. Increased mission numbers increase development time and cost, but decrease overall programme risk while providing improvements in science return. An example of the interactions between the different metrics with an increase in mission numbers is given below.

Table 5-2: SSP Relationships over a number of missions

Metric	**Units**	**Satellite Impacts**	**Increased Flight Rate**	**Mission Impacts**
Development Time	Years	↓↓↓	↑	↓↓
Mission Cost	$US	↓↓↓	↑	↓↓
Flight Rate	Fights/yr	-	↑	↑
Failure Rate	Percent	↑	↓	-
Increased Science Return	Instrument -months	↓	↑	-

This finding also supports the results of Mosher (1999) which concluded that for an individual mission it was not possible to have faster, cheaper and better, but if all three metrics were combined, the overall mission cost-effectiveness (the cost/time metric for the same science return) for FBC missions was higher than for traditional missions. It also illustrates how when scientific return (the Better component of Faster, Better, Cheaper) is included into the understanding of mission effectiveness the support for an order of magnitude improvement is greatly reduced.

Understanding the relationship between the complexity, risk and management of small satellite projects may give rise to greater understanding of these relationships in CoPS. The key question in determining how these reductions may occur is to know how far to take the lessons learnt from the Small Satellite Philosophy and applying them to other complex product system projects. In particular, the Small Satellite Philosophy was based on the decrease in scope of a particular project through the reduction of the size of the satellite. This reduction in scope would reduce the complexity of the project and the team size and prompted the implementation of different management models. Are there similar reductions that can be taken with other industries? It may be that finding the critical dimension of scope reduction (such as the use of smaller Unmanned Aerial Vehicles in the aviation industry or Base Stations accepting fewer connections in a cell configuration) could be the key to unlocking reductions in cost and schedule.

5.7 Conclusions

In this chapter the management of small satellites was investigated. It was shown that even though small satellites may have the same order complexity as larger missions, through a number of core changes a reduction in time and cost can be obtained.

One of the claims of the Faster, Better, Cheaper approach is that it enables an 'order of magnitude' improvement over the implementation of a small satellite mission; when each mission was taken individually there was strong evidence to support this claim in terms of time and cost. However, when looking at all of the small satellite missions over the previous ten years and including factors such as mission success and scientific return the support for a simultaneous order of magnitude improvement in Faster, Better *and* Cheaper is greatly reduced.

Although the improvements attributed to FBC may not be as great as originally intended, there was a common agreement that they were largely as a result of changes in the management of satellite projects. An investigation into the management philosophy, which arose from initiatives such as FBC and the Small Satellite Philosophy, revealed a rich list of approaches which may be used to improve the implementation of a space mission. It was recognised that the FBC Small Satellite Philosophy is a mechanism to promote creativity and responsibility on the part of the mission teams, obtaining improvements in schedule and cost while maintaining the mission effectiveness.

Finally, a detailed classification of the SSP implementation techniques yielded some key guidelines for the implementation of small satellite projects.

A final investigation looked at the small satellite philosophy from the CoPS perspective and asked which lessons from FBC may be transferred into the CoPS domain. It was found that through the reduction of a critical dimension, such as the size of the satellite, qualitative indicators pointed towards multiple gains in cost and schedule, through areas such as reduction in complexity, trading risk for cost and changing the management paradigm.

The following chapter changes the scope of this investigation from the international satellite industry to that of the Australian space industry and concentrates on an important factor in the implementation of a space project: government policy.

Chapter 6

The Australian Space Industry

6.1 Introduction

As the central question of this thesis "*Can Australia develop an indigenous satellite industry made up of high-value, complex products*" is focussed on Australia, it is important to understand the policy framework surrounding the previous development of the space industry in Australia.

This chapter first investigates current innovation policy, looking at how it shapes Australia's competitiveness. As the development of the FedSat satellite relies heavily on the Cooperative Research Centre scheme, it then focuses on the implications of Australian space and innovation policy on this programme. A search for potential CoPS within Australian industries is then undertaken and asks whether Australia has the capacity for the development of Complex Product Systems.

The chapter then undertakes a critical analysis of the current state of Australia's space policies. It presents a history of the Australian space industry from a policy perspective and contends that, despite promising beginnings, the development of the Australian Space Industry has largely been a failure.

Finally, this chapter aims to ask the question of whether Australia's interregnum in space projects has reduced the capacity of the country to re-enter such a complex industry as space research. It also suggests some of the policy and institutional requirements needed to re-build such an industry.

6.2 Innovation in the Australian Context

A country's innovation policy is often difficult to quantify (e.g. (Johnson, 2001)). There is a large number of roles of a government underpinning the national system of innovation and driving competitiveness, from direct policies which formulate, implement and monitor national S&T activities to areas of financing and regulation to strengthen institutions, infrastructure and linkages (IDRC, 2002).

While an analysis of Australia's national system of innovation is out of the scope of this work, there are important areas of it which have a direct impact on its content. This section aims to firstly give an overview of Australia's current innovation policy and then investigate it in the context of Complex Product Systems. As it is found that one of the main policy tools for the development of CoPS is the Cooperative Research Centre programme, this section attempts to highlight the major components of this scheme.

The development of policy may be characterised by a change of national structure in the margins. In the Australian context two types of policies, both implicit explicit are outlined.

6.2.1 Explicit Policies

A number of government programmes over the past five years have aimed at developing programmes within government to promote innovation. This included the "Investing for Growth" statement in 1997 which increased support for business innovation though providing $A1.26 billion over the four years from 1998-99, with additional funding for R&D grants, venture capital and technology diffusion. In addition the "Knowledge and Innovation" statement in 1999 announced a new policy and funding framework for higher education research and research training. These initiatives resulted in the Australian Government committing $A4.5 billion to innovation in 2000-01.

In August 2000, the Australian Chief Scientist released a paper "A Chance for Change", which outlined some of the future potential directions for innovation in Australia. The paper suggested that innovation was a core driver for the future prosperity of the nation, and that without additional strategically driven investment Australia's Science, Engineering and Technology capability would lack the critical mass needed for the future. It highlighted three areas, culture, ideas and commercialisation, which required a focus for investment (Batterham, 2000).

This resulted in the "Backing Australia's Ability" innovation package, which provided an additional Government investment of $A2.9 billion into innovation over five years (DISR, 2000a). The initiatives funded make up the explicit components of Australia's innovation policy and are listed in the table below.

Table 6-1: Backing Australia's Ability Programmes, Source: (DISR, 2000a)

Backing Research	**Backing Commercialisation**	**Backing Skills**
National Competitive Research Grants	Cooperative Research Centres	2000 Additional Targeted University Places
Project Specific Research Infrastructure	Commercialising Emerging Technologies (COMET) Program	Fostering Scientific, Mathematical and Technological Skills and Innovation
Systemic Research and Research Training Infrastructure in Universities	Innovation Access Program	Online Curriculum Content for Australian Schools
ICT World Class Centre of Excellence	Extension of the Information Technology Online Program	Attracting Information & Communications Technology (ICT) Workers
Biotechnology Centre of Excellence	Competitive Pre-Seed Fund for Universities and Public Sector Research Agencies	National Innovation Awareness Strategy
Major National Research Facilities	Biotechnology Innovation Fund	Smart Moves: Raising Awareness of Innovation
175% R&D Tax Concession 'Premium' for Additional R&D	New industries Development Program	
R&D Tax Offset (Rebate) for Small Companies	Intellectual Property Regime	
New Treatment of R&D Plant		
R&D Start Program		

The Backing Australia's Ability agenda is strongly focussed on research, and while it does have some mechanisms for developing markets (such as the Biotechnology Innovation Fund) it has a strong emphasis on R&D.

6.2.2 Implicit Policies

There are a number of implicit policies in Australia underpinning the National System of Innovation. In order to quantify and begin to understand the impact of these policies, a model based on national competitive advantage developed by Michael Porter in his book Competitive Advantage of Nations (Porter, 1990) may be used. Porter discusses the importance of national characteristics for the competitive advantage of individual companies and suggests that national advantage comes from the interaction of four key functions:

- **Factor conditions:** The nation's position in factors of production, such as skilled labor, natural resources or infrastructure, necessary to compete in a given industry;
- **Demand conditions:** The nature of home demand for the industry's product or service;
- **Related and supporting industries:** The presence or absence in the nation of supplier industries and related industries that are internationally competitive; and
- **Firm strategy, structure, and rivalry:** The conditions in the nation governing how companies are created, organized, and managed, and the nature of domestic rivalry.

The different functions guide innovative activity, by influencing the way in which companies deploy their resources and skills. National competitive advantage arises from the dynamic interplay of these four factors, represented by Porter as a diamond as shown in Figure 6-1 below.

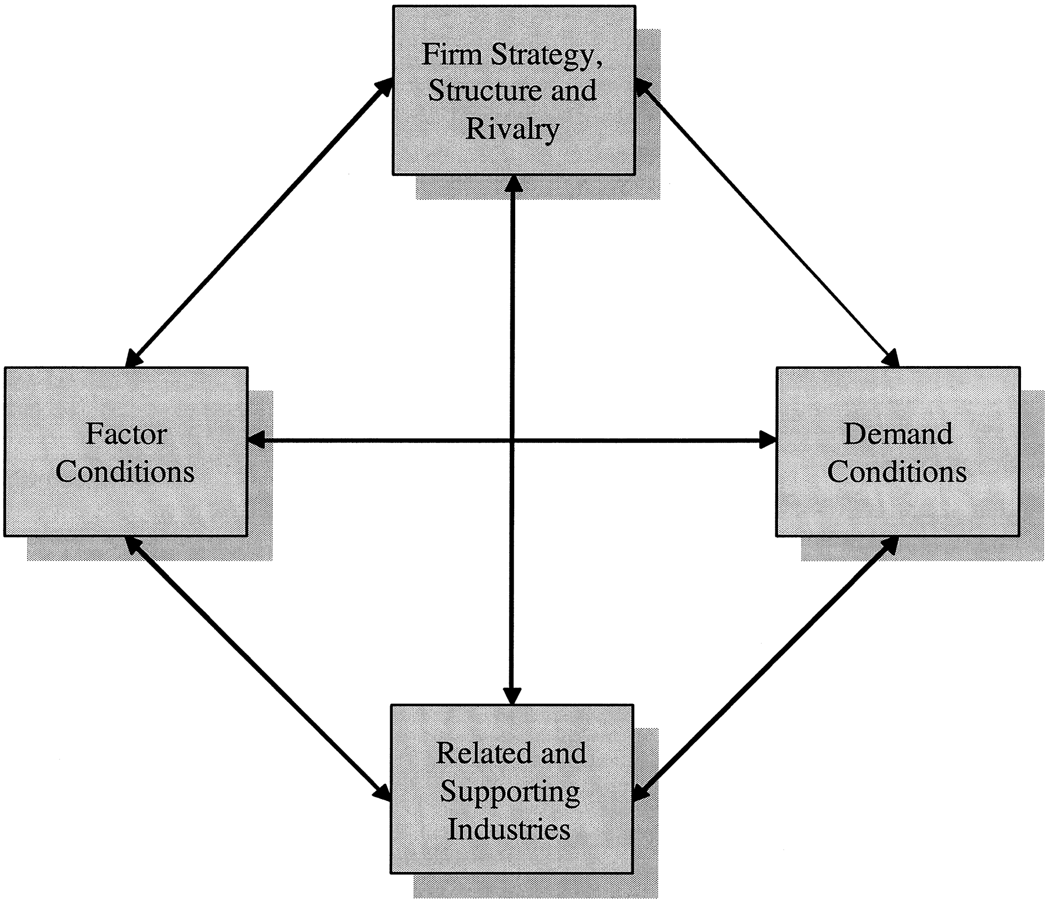


Figure 6-1: Competitive Advantage, Source: (Porter, 1990)

Porter's work suggests that the government's role in national competitive advantage is in influencing the four determinants. Factor conditions are affected through subsidies, policies toward the capital markets, policies toward education, and the like. The government's role in shaping local demand conditions includes establishing local product standards or regulations that mandate or influence buyer needs. A government is also often a major buyer of many products in a nation, among them defence goods, telecommunications equipment, aircraft for the national airline, and so on. Government can shape the circumstances of related and supporting industries through control of advertising media, regulation of supporting services. Government policy can influence firm strategy, structure, and rivalry through capital markets regulations, tax policy, and antitrust laws.

Within the Australian context, implicit policies affecting factor conditions include the amount of human capital, including the quantity, skills, and cost of personnel and management capabilities, as well as the educational system which has a history of focussing on breadth of skills. Within Australia, knowledge resources such as the Commonwealth Scientific and Industrial Research Organisation underpin the nation's stock of scientific, technical, and market knowledge bearing on goods and services. It is also a source of emerging and enabling technologies for commercialisation.

Market factors are influenced by government through purchasing policies, standards and support for market research. The Action Agenda programme is one example of a programme which aims to build interactions actors industry and between industry and government.

6.2.3 CoPS in the Australian Context

To date there has been no analysis of CoPS within the Australian context. Heighs (1997) has investigated the value to the United Kingdom economy of CoPS using the seven-digit Standard Industry Code, and identified 21 industries in which CoPS were produced. Using figures for each industry which estimate the proportion of CoPS production in that industry, Heighs found that CoPS make up as much as 10% of value-added GDP to the UK economy.

For example, A mapping of Australia's capabilities has been undertaken recently by the federal government (DEST, 2003a). This study maps business innovation, commercialisation, research and development, manufacturing capabilities and . In addition, it looked at some of the core capabilities in Australian innovation. However, in this study there was no mention of the role of large complex products in Australia except for a mention of complex systems in the context of within biological systems, financial markets, information networks and meteorology. In addition, infrastructure projects are also not mentioned, other than projects building research infrastructure.

Given that there is a potential for CoPS to likewise make up a large proportion of Australian industry, this section first investigates whether Australia does have an innovate capacity for CoPS. It then undertakes an empirical investigation of different CoPS industries in Australia and investigates previous research into Australian's capacity for Systems Integration. Finally, it investigates the policy mechanisms within the current Australian innovation policy which may be used to establish or develop CoPS industries.

6.2.4 Innovative Capacity

There are a number of innovative capacities which are apparent at the firm level; moving from product innovation of small or large batch units to mass production (Woodward, 1958; Dodgson, 2000). Broadly speaking, these capacities can be divided into capabilities for product innovation and capabilities for process innovation.

The broad mapping of Australia's capabilities study (DEST, 2003a) showed that there were both strengths and weaknesses in the Australian system, with rising expenditure in research and development, but with some barriers to commercialisation. It found that Australian competitiveness was underpinned through scientific and technological innovation, and was often a "fast follower", exploiting both its strong scientific base and a number of niches which compliment natural or geographical endowments or where a core base of scientific knowledge has been built up over time. It also found that there is an increasing focus on the delivery on services rather than products.

It is difficult to determine Australia's comparative performance in product innovation, which requires substantial in-house R&D and is traditionally characterised by the consumer electronics, IT and pharmaceutical industries. At the first glance, Australia's ability to innovate better than other countries in products is not apparent; Australia's R&D in commercial industries is lower than its US or Canadian counterparts (DEST, 2003b), and with few large firms and fewer demanding companies as customers, there is little case to be made for a strong capability in product innovation. In 2001, Australia ranked 18th in the OECD in terms of business expenditure on R&D as a percentage of GDP and 14th in terms of size of R&D expenditure. In addition, a strong capacity for product innovation implies the need for niche areas of specialisation (e.g. Finland).

While Australia does have a number of manufacturing industries, it is not apparent that process innovation is a core Australian innovative capacity, especially compared to other neighbouring economies. Skills and training of Australian firms in the areas of production (lean or otherwise) do not match those of manufacturing organisations in

Asian economies such as Korea and Japan. According to an ABS Innovation in Manufacturing survey (1997), of the estimated 55,000 manufacturing businesses in Australia, 26% had undertaken one or more technological "innovation" activities from 1994 to 1997. The comparable figure between 1991 and 1994 was 32%. However, most expenditure on R&D in Australia is skewed towards these larger manufacturers (Australian Industry Group, 2002), which accounted for 69% of recorded national R&D expenditure.

However, it may be that Australia has an inherent capacity for the production of Complex Product Systems. Australia has a large number of internationally recognised systems engineering and project management firms and has a broad educational base. For example, Australian 15-year old students are among the highest performers in reading, and mathematical and scientific literacy in international surveys (DEST, 2003a). Other indicators, such as the predominance of systems engineering companies in Australia (such as the largest employer of engineers, BAeSystems (BAE Systems, 2003). A capacity in CoPS doesn't lock a country into any trajectories, and as such the country is not disposed towards "picking winners". Australia is generalist rather than specific, looking at the extent of systems integration in a majority of firms. In addition, Australia has been successful in addressing areas of challenge using cross-sectoral skills, with internationally successful projects such as the Sydney 2000 Olympic games being recognised as best-practice.

Brady (1995) suggests that some of the management challenges faced by CoPS industries are those associated with systems integration. He suggests that "producers of CoPS, usually systems integrators, require distinctive managerial competences capable of defining and executing large-scale (often complex) projects" and that "systems integrators, in addition to managing their internal tasks, often have to co-ordinate the innovation activities of large and complex supply networks made up of small firms, major users, large partner companies, regulators, standards bodies and government departments"

If, as is suggested in Chapter 3, CoPS form a new class of innovative capacities, there may be many attractions from a national policy perspective, especially if it were to fit into the Australian National System of Innovation. This would raise a number of important questions, such as what kind of research and education system is required for the development of CoPS and what level of industry specialisation is necessary.

There has been little research undertaken into how specific CoPS fit into Australia's labour markets, financial markets and intellectual property protection. Groups such as Invest Australia have undertaken research into 'mega' projects (monitoring large projects) and the Australian Industry Group monitors large projects, as does the Industrial Supplies Office. However, as CoPS have not been treated as an analytical category in the Australian context, it is difficult to obtain aggregate information on CoPS from these groups, akin to the information available on the United Kingdom economy.

6.2.5 CoPS mechanisms in Australian Innovation Policy

If Australia were to have a core capability in the development of CoPS, does it also follow that there are a number of explicit programmes within Australia's Innovation Policy which can be used to develop these industries. Of all of the programmes listed in Table 6-1, only two are associated with projects which are worth more than $A2M; the Major National Research Facility Programme and the Cooperative Research Centre programme.

6.2.5.1 Major National Research Facilities

The Major National Research Facilities (MNRF) program supports major research facilities to conduct leading edge research in science, engineering and technology. It is an investment in research infrastructure of national and international significance and is characteristically used for projects in the $A50m price range. MNRFs are expensive, large equipment items or highly specialised laboratories used to conduct leading edge research in science, engineering and technology (DEST, 2002). The MNRF program has supported facilities such as the Australia Telescope National Facility, the Australian Genome Research Facility, and the Australian National Seismic Imaging Resource, with all money currently committed until 2006-2007.

An example of a CoPS project which is being supported by the Major National Research Facility programme is the Square Kilometer Array (SKA). This project aims to achieve a telescope with one square kilometre of collecting area, comprising initial designs of 30 stations with the collecting area equivalent to a 200m diameter telescope, and 150 stations each with the collecting area of a 90m telescope (SKA, 2003).

6.2.5.2 Cooperative Research Centre Programme

Cooperative Research Centres, generally known as CRCs, bring together researchers from universities, CSIRO and other government laboratories, and private industry or public sector agencies, in long-term collaborative arrangements which support research and development and education activities that achieve real outcomes of national economic and social significance. At January 2003, there are 64 established CRCs currently in operation (DITR, 2002).

It can be seen that there are few explicit mechanisms within Australia's Innovation Policy to cater for the development of large, complex systems. In addition, it is unclear as to whether these programmes are being used to develop CoPS industries, or indeed whether they are suited to this industry's development. The following section investigates the policy framework behind the mechanism behind the FedSat project; the Cooperative Research Centres.

6.2.6 Cooperative Research Centres

The CRC Programme's overall objective is to strengthen long term collaboration between research organisations, and between these organisations and the users of research, in order to obtain greater benefits from Australia's investment in R&D. Importantly, it also seeks to contribute to postgraduate education in a user-oriented collaborative environment, and to the training of users to raise awareness and transfer knowledge. A CRC is a bridging mechanism linking public sector research and higher education organisations and the users of new knowledge, from the private and public sector (Mercer, 1998).

The objectives of the CRC programme are (CRC Association, 2002):

1. to contribute to national objectives, including economic and social development, and the establishment of internationally competitive industry sectors, through supporting long term, high quality scientific and technological research;
2. to stimulate a broader education and training experience, particularly in graduate programs, through initiatives such as the active involvement of researchers from outside the higher education system, and to enhance the employment prospects of students through initiatives such as involvement in major cooperative, user oriented research programs;
3. to capture the benefits of research, and to strengthen the links between research and its commercial and other applications, by the active involvement of the users of research in the work and management of the Centres; and
4. to promote cooperation in research, and through it a more efficient use of resources in the national research effort by building centres of research concentration and strengthening research networks.

Most CRCs operate at more than one site. They are located in all capital cities and about 40 locations all around Australia. The program "emphasises the importance of developing collaborative arrangements between researchers and between researchers and research users in the private and public sector in order to maximise the capture of the benefits of publicly funded research through an enhanced process of commercialisation or utilisation by the users of that research." (DITR, 2002)

Each CRC is established through a Centre Agreement, which is a contract among core participants, and a Commonwealth Agreement, which is a contract between the participants and the Commonwealth. These arrangements establish collaborative links between researchers and industry and other research users in order to create a multi-disciplinary, multi-institutional research environment focussed on addressing industry and user needs. These collaborative links are designed to increase efficiency and cost effectiveness of research and research training and make better use of research resources through sharing of major facilities and equipment.

Selection rounds for CRCs are held approximately every two years. CRCs are selected on the basis of competitive merit, and the programme has received support from both sides of the political spectrum. The Backing Australia's Ability programme committed to expanding the Cooperative Research Centres Program with an additional $A227 million over five years, and changing the focus to encourage greater access of all the programmes to small and medium enterprises.

Most CRCs are unincorporated joint ventures. Only 14 have incorporated (none of which have CSIRO as a partner in the corporation), although several others have created companies responsible for the management of intellectual property created by the CRC.

Commercialisation is designed to be a core outcome of centres established within the CRC framework, and many centres have a Business Development Manager. Income streams for CRCs include royalty funds for technologies and contract income, and the CRC for Photonics has been successful in spinning off a number of profitable ventures.

In 1997 a review of the CRC programme was carried out by Mr Don Mercer and Professor John Stocker (Mercer, 1998). The Mercer-Stocker report drew a number of conclusions about the effectiveness of the CRC programme, focussing on the role that the CRCs played in the Australian system of innovation. It recommended that funding for the programme continue and that the governance of the programme be strengthened. A further review of the CRC programme was completed in 2003 by Howard Partners Pty Ltd (2003) which found, once again, that the CRC programme was a distinct and world-renowned feature of Australia's science and innovation system and recommended that it should be continued, albeit with more focus on industry and other end-user needs through "attention to the adoption and application of research results" (pg 7). It was also recommended that the programme should be repositioned to be an 'investment vehicle' where research is seen as a means to a commercial end.

6.2.7 Conclusions

This section has given an overview of Australia's current innovation policy in the context of Complex Product Systems and has found that there is a potential for Australia to have a core competency in this area. However, it was also found that there were few tools for the development of CoPS in Australian innovation policy, but highlighted one potential tool - the Cooperative Research Centre programme and its major components.

As demonstrated in Chapter 4, the Space Industry is a good example of a Complex Product System Industry. The following section investigates the history of the Australian space industry, before investigating the current state of the space industry from an economic and policy perspective.

6.3 Australian Space Policy in the Historical Context

Australia was involved in the space industry almost since its inception; it was a launch site, a key site for the reception of satellite data and was the fourth country in the world to launch a satellite from its own territory (Dougherty and James, 1993). This section looks at the history of Australian space as compared to the international space industry, using the concept of space generations developed in Chapter 4. For each generation a timeline of Australian events is given alongside those of their international counterparts, to add context to the development of the Australian Space Industry.

6.3.1 Generation 0 – Getting to Space

The use of V-2 rockets in World War II demonstrated that missiles could be effective weapons capable of striking at a great distance. Recognising the strategic value of these weapons, the major powers, including the United Kingdom, began to establish rocket programmes as the war in Europe came to an end. However, in a small country such as Britain, with limited physical space, it was difficult to test rockets. Australia's immense size, political loyalty to Britain and economic stability became an unexpected asset and in October 1945 Australia was approached by the British government to set up an experimental guided weapons testing range across the centre of the country.

The development of a weapons testing facility offered Australia new opportunities and a chance to engage many of the skilled works and industrial plants which had been developed during the war. The proposal also offered a chance for Australia to have access to advanced weaponry in the event of another war and so agreed to the project on the condition that Australia was an equal partner. From this agreement the Anglo-Australian project was born, a partnership which lasted officially until 1990.

In 1947 the Long-Range Weapons Research Establishment (LWRE) was formed at Woomera, about 480km north-west of Adelaide. The LWRE was to build a range starting at Woomera and to manage the two 'protected areas' downrange. At the height of activity at the rocket range the Woomera township contained a population of around 6200 people.

Australian Events		**International Events**
	1926	Robert Goddard launches first liquid-propelled rocket
	1933-45	Wernher von Braun develops new rocket program in Germany
Britain & Australia agree to develop a rocket testing range	1945	End of World War 2 Wernher von Braun & his team of rocket experts surrender to American forces
Overseas Telecommunications Commission Created Anglo-Australian Joint Project Inaugurated	1946	US and USSR begin rocket tests with modified V2s
Long Range Weapons Establishment created	1947	

Figure 6-2: Australian vs. International Space Industry – Generation 0, Source: (Dougherty and James, 1993)

6.3.2 Generation 1 – Government Space

Interest in space by the community and government was highlighted with Australia selected to receive the initial video feed from NASA's first moon landing. This early participation in international space events provided a momentum for domestic interest and research in space, and Australia joined the European Launcher Development Organisation (ELDO), a predecessor of ESA, and was one of the first countries to have a student group design, assemble and launch an amateur satellite. In 1967, Australia also launched its first satellite, Weapons Research Establishment Satellite (WRESAT), into orbit from its own territory and was only the fourth nation to do so after the US, USSR and France (CRCSS, 1999).

Australia launched two other indigenous satellites from Woomera; AUSTRALIS-OSCAR-5 and PROSPERO before ELDO pulled out of Woomera in 1971, preferring the more equatorial (and French-owned) French Guiana. Following the departure of ELDO, the Woomera range was progressively wound down, and with it enthusiasm for space in government policy. Australia declined to join the newly formed European Space Agency in 1975, the only non-European country invited to join as a full partner.

Australian Events		**International Events**
Sounding rocket launches & hypersonic research begin at Woomera	1957	International Geophysical Year commences First satellite, SPUTNIK-1, launched
	1958	US launches first satellite, EXPLORER-1 NASA inaugurated
Australia Assumes Chair of UNCOPUOS technical & Scientific sub-committee	1959	First USSR space probes to the Moon
	1961	Yuri Gagarin (USSR) first person in space Alan Shepard First American in space
ELDO established	1962	TELSTAR-1, first commercial communications satellite
First ELDO launch	1964	INTELSAT established
First Australian Satellite, WRESAT, launched	1967	UNISPACE
Australia receives first pictures from APOLLO-11	1969	Neil Armstrong & Edwin Aldrin, in APOLLO-11, first men to walk on the moon
AUSTRALIS-OSCAR-5 satellite launched Last ELDO Europa launch	1970	Japan & China launch their first satellites VENERA-7 probe makes first landing on Venus
ELDO withdraws from Australia PROSPERO satellite launched from Woomera	1971	First Space Station, SALYUT-1, is launched by USSR
	1973	USA launches SKYLAB Space Station
Australia declines ESA membership	1974	
Australia sounding rocket program ends	1975	The European Space Agency is formed
UK sounding rocket program ends at Woomera	1979	SKYLAB returns to Earth scattering debris over the Indian Ocean & Western Australia
Anglo-Australian Joint Project officially ends	1980	India Launches first satellite

Figure 6-3: Australian vs. International Space Industry – Generation 1, Source: (Dougherty and James, 1993)

6.3.3 Generation 2 – Commercial Space

The continued participation of Australia in space research and projects through the 1980s was supported by the advisory function of the Australian Space Board and the National Space Program (NSP) (DITAC, 1990), which was funded for a total of $A30.2 million over 1985-1992. In 1987 the Australian Space Office (ASO) was established (DITAC, 1992). From 1990, a program of the Australian Space Board saw the establishment of three Space Industry Development Centres (SIDC) to encourage industry to divert R&D funds from more traditional areas of technology to space-related activities through collaborative ventures with university-based space research centres. The SIDC Program received $A1.6 million of the $A6 million national space program budget annually (ISAG, 2002).

A review of the NSP (known as the Curtis report) (Curtis, 1993) led to the establishment of the Australian Space Council (ASC) in 1993. The ASC was a statutory body and replaced the previous non-statutory advisory body of the Australian Space Board. A sub-committee of the ASC advised on matters relating to remote sensing . In 1996 an Interdepartmental Committee reviewed the economic basis of national space capability and reported favourably on the outcomes of the NSP. Funding for the NSP totalled $A17 million for 1992-1995. However, in 1996, the incoming liberal government abolished the Australian Space Office, following a report by the Bureau of Industry Economics (1996), which argued that the returns on a dedicated space program could not be adequately quantified.

The FedSat Satellite, which was launched in 2002, aimed to create new space products, and government policy groups such as the International Space Advisory Group (2002) aimed to determine the right policy framework for its development.

Australian Events		**International Events**
AUSSAT established	1981	COLUMBIA, first USA Space Shuttle, launched
Australia accepts NASA invitation to fly national payload specialist	1982	US NAVSTAR-GPS navigation system commences UNISPACE 82
COSSA formed Australian born astronaut, Dr Paul Desmond Scully-Power, flies aboard Space Shuttle CHALLANGER	1984	USA President Reagan proposes Space Station FREEDOM
Madigan report on Australian Space Policy AUSSAT-1 & 2 launched	1985	
Australian Space Board & National Space Program established Cape York Spaceport proposed	1986	US Space Shuttle, CHALLENGER, destroyed with loss of seven crew MIR Space Station launched
Australian Space Office established	1987	
First Ausroc amateur rocket launch	1988	US Space Shuttle flights recommence after CHALLENGER disaster Cosmonauts spend full year in space Israel launches first satellite
Cole report on Australian space science	1989	VOYAGER-2, first space probe to Neptune NASA's GALILEO space craft is launched, destination Jupiter & its moons
Expert panel & BIE Australian space policy reviews	1992	International Space Year
Australian Space Council formed	1993	HUBBLE SPACE TELESCOPE repaired while still in orbit
	1997	NASA lands PATHFINDER on Mars (4/7/97)
Astronaut, Andy Thomas spends 141 days in space, 130 aboard the Russian *Mir* Space Station	1998	Assembly begun on INTERNATIONAL SPACE STATION
FedSat construction commences	1999	UNISPACE III
	2000	First permanent crew arrives at INTERNATIONAL SPACE STATION
International Space Advisory Group Formed	2001	
FedSat Due for Launch	2002	World Space Congress in Houston
First year of Operations for FedSat	2003	China launches a manned mission to space

Figure 6-4: Australian vs. International Space Industry – Generation 2, Source: (Dougherty and James, 1993)

Overall, except for a resurgence in the 1980s, the interest in the Australian Space Industry from a policy perspective has progressively waned after its initially promising beginnings. However, despite the reduction of interest in space from the Australian Government, there are still components of the Space Industry in Australia; the following two sections look first at why Australia might be a suitable location for a space industry and then at the current state of the Australian Space Industry itself.

6.4 The Current Australian Space Industry

Although Australia is recognised and represented at the space arena and domestic expertise exists in space, there is no national space program. In the absence of Australian Bureau of Statistics data on the Australian space industry, a number of groups have conducted surveys (such as the International Space Advisory Group and the Australian Space Industry Chamber of Commerce) of companies and organisations known to be engaged in the space industry. In addition, PriceWaterhouseCoopers was commissioned to write a report of the space industry by the Department of Industry, Tourism and Resources in 2000. This section aims to integrate the data presented by these and other reports on the space industry in Australia and the relative proportions of the industry segments, using the competitiveness of Porter's model outlined above.

6.4.1 Factor Conditions

It has often been cited (Dougherty and James, 1993; ISAG, 2002) (CRCSS, 1999) that Australia has a number of attributes favourable to a space industry, including an excellent global location for launching spacecraft, a vast open unpopulated area, a stable political environment, English as the official language and stable atmospheric conditions. Australia is also situated very close to the Asian market, the fastest growing space market, and has a wealth of human resources around science and technology (ISAG, 2002).

Australia also has internationally recognised expertise in certain space technologies (CRCSS, 1999), a historical involvement in space and the design and manufacture in Australia of several sophisticated payloads and instruments to international space projects.

6.4.2 Demand Conditions

Although there is no formal coordination mechanism for space activities in Australia, a number of Commonwealth agencies are significant users of space data and technologies, or advisers on issues relating to space applications. There is also a number of State Government agencies and numerous statutory authorities active in the space industry. Some of these users of space technology are given in Table 6-2 below.

Table 6-2: Commonwealth Agencies using Space Applications, Source: Amended from (ISAG, 2002)

Agency	Involvement
Environment Australia	Purchases remotely sensed data for the provision of advice on environmental management
Department of Communications, Information Technology and the Arts	Advises on national and international satellite communications and information technology matters.
Department of Agriculture, Fisheries and Forestry Australia	Purchases remotely sensed data for the provision of sectoral advice
Department of Immigration and Multicultural Affairs, Australian Customs Service	Uses space information to monitor Australia's borders
Department of Transport and Regional Services	Manages the Australian Global navigation Satellite Systems Committee and liaises with international agencies regrading Australia's participation in the project
Department of Foreign Affairs and Trade	Represents Australia at international forums and provides assistance on developing international agreements on matters relating to space
Attorney-General's Department	Provides advice on legal aspects of space policy and assistance in the development of agreements and contracts relating to space
Department of Education, Science and training	Advises on national and international space science matters and participates in space research through the CSIRO
Department of Industry, Tourism and Resources	Advises on national and international space industry matters, and international treaties on space matters. The Space Safety and Licensing Office implements the regulatory regime for civil space activities in Australia under the Space Activities Act 1998
Ionospheric Prediction Service Australia	Provides information on the radio propagation and space environment
GeoScience Australia	Purchases and distributes remote sensing information and assists with the management of space infrastructure
Bureau of Meteorology	Collects data, researches and provides information and advice on all aspects of Australia's weather, meteorology, hydrology and oceanography
Department of Defence	Develops and purchases space technologies and data to support a range of capabilities, including surveillance, reconnaissance, information collection, communications, navigation, mapping and meteorology.

Despite a range of Commonwealth involvement, the lack of a nationally coordinated program or a formulated direction and set of objectives for the sector means that it is difficult to align the interest of different agencies. At times this may result in duplication of resources or the failure to maximise the benefits of certain space opportunities, in areas such as government procurement, investment and collaboration opportunities (ISAG, 2002). For example, space launch service providers in Australia need to engage with a range of government departments and statutory authorities in order to obtain the necessary support and approvals, creating duplicated work across and within sectors. The dispersal of responsibilities for space matters also makes it difficult for Australian interests to be represented internationally and for a cohesive approach to space interests to be developed.

6.4.3 Related and Supporting Industries

In order to understand it more fully, the space industry can be deconstructed into its constituent parts, focussing on the industries and their relationship with each other (Moody and Schingler, 2001). It argues that there is no one industry which may be called the 'space industry', rather that the businesses within it make up an entire business sector.

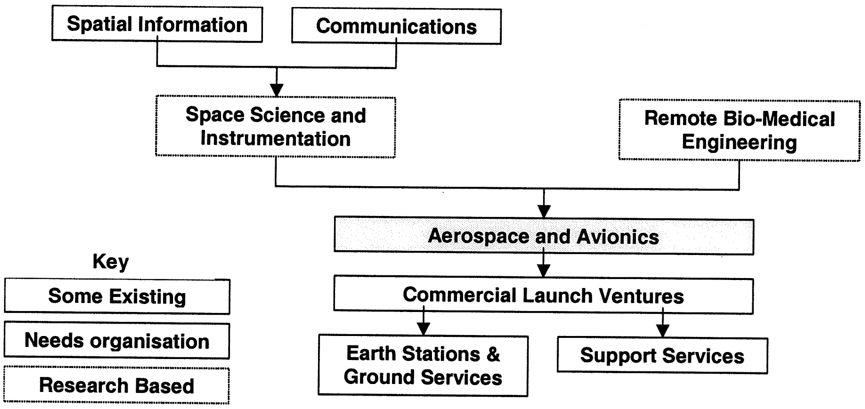


Figure 6-5: The Australian Space Sector, Source: (Moody and Schingler, 2001)

Spatial Information Industry	The Spatial Industry uses information from space (and other sources) and "adds value" to this information to provide services to a number of industries. It includes the areas of remote sensing, GIS, geo-spatial data processing and land information. It is united under the newly formed Australian Spatial Industry Business Association and employs people in information technology, surveying and land management industries.
Communications Industry	This Industry is well established and uses space-based applications for communications. There are a number of businesses in this industry, with applications to remote access and information and communications technologies (ICT).
Space Science and Instrumentation	This industry provides high quality space-based instruments to meet a specific need. It includes instruments to undertake basic scientific research, as well as provide a service to other industries. The Cooperative Research Centre for Satellite Systems is working primarily in this industry and, as with all other Cooperative Research Centres, is a good step toward bringing various players together and consolidating an industry. In addition, Australia already is involved in the construction of instruments for use on board astronomical and other science missions, including a receiver for RadioAstron, the telescope for the Danish MONS spacecraft and a high-precision clock built by UWA.
Aerospace and Avionics Industry	The Aerospace and Avionics Industry includes all of the engineering work undertaken in developing satellites, UAVs and other space-based technologies. There are many companies working in this arena with indigenous and international backgrounds and links with defence. This industry primarily employs electrical, mechanical and software engineers.
Commercial Launch Industry	The Australian Launch Industry would provide the service of launching payloads into space or high-altitudes. There are already a number of commercial launch proposals in Australia, and programs such as Hyshot, which uses high-altitude sounding rockets to undertake their hypersonic engine research (which could eventually be utilized as a middle stage engine for launching). Some launch ventures are considering forming a group for consolidation and lobbying to government. Investment in the launch industry in this area will bring money to rural Australia.
Earth Stations	Australia has built off the legacy of earth stations with top research continuously underway. This potential industry usually associates itself with the Communications industry, but once the entire space industry is envisioned, the earth stations industry can see their potential in entirety. Services

	include Ground Support, Telemetry Tracking & Control, Launch Support, and Earth Stations.
Support Services	The support services industry includes all of the services that are needed for an indigenous space industry. This includes legal, licensing and regulatory (such a launch license through the SPU as per the *Space Activities Act 1998* or communications regulations in the ACA or ITU), insurance, environmental impact studies, and framework for aiding and attracting foreign investment and industries.

6.4.4 Firm strategy, structure, and rivalry

Firm strategy and structure is influenced by the conditions in the nation governing how companies are created, organized, and managed. The Space Activities Act of 1998 and amended in 2001 and 2002 built upon Australia's international responsibilities for the licensing and administration of space launches. The Act specified the conditions under which the relevant Australian minister could grant space licences for launch facilities within Australia and the conditions under which the licensee could operate.

In addition, the act set out the requirements for the granting of a launch permit to authorise the launch of a particular space object or a series of space objects (in this case any object travelling more than 100km into the air). The act also required Australian companies or organisations launching a spacecraft overseas to obtain an overseas launch certificate. Finally, the act specified requirements for insurance and safety, outlining liabilities and administrative requirements for launching parties.

A number of reports have also cited a measure of domestic rivalry within the space industry in Australia. For example, the ASICC report (ASICC, 2001) outlined the competitive nature of some of the industry's participants and its effect on its development.

6.4.5 Size of the Industry

Although several reports have been commissioned by both private and public agencies over the past five years, there has been little attempt made to quantify the scope of space activity in Australia, its revenues or the market demand and supply. The most complete survey was undertaken by the International Space Advisory Group (2002) of companies and organisations known to be engaged in the space industry, with data supplemented by a PricewaterhouseCoopers report of the space industry commissioned in 2000[3]. While these data only included conservative estimates, the relative proportions of the industry segments operating in Australia are considered to be reasonably accurate.

- Total employment is estimated at 1500, compared to over 1 billion worldwide
- Revenues in 2001 are estimated at $A285million. Individual company estimates of growth in space activities range from 0-10% over the next decade. Current worldwide growth across the industry is 12% and some segments experience growth in excess of 20%.
- Infrastructure segment in Australia was estimated at $A80m in 2000
- Satellite services segment was estimated at $A200m
- Use of Space data and assets was estimated at $A50m
- Support services was estimated at $A10m
- Primary growth areas are projected to be in VSAT satellite communications. Pay TV has performed poorly to date, compared with worldwide markets where the direct-to-home television market and the remote sensing market are the primary growth areas.
- The value of space-related R&D is estimated at $A26m, with nearly half of this undertaken by incorporated companies. Research organisations account for nearly a third of R&D, with little R&D undertaken by Government agencies (PWC adjusted estimates)

The comparison of segments globally and in Australia reveals two different structures. Whereas in the global market the infrastructure segment dominates, in Australia the primary segment is in satellite services. Globally, satellite services is the fastest growing industry and at face value, an Australian industry which leads in satellite communications may seem a positive indicator. However, a closer scrutiny of the data

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[3] Defence was unable to quantify its space activities and hence no data in the report includes Defence expenditure.

and structure of the Australian space industry suggests that, rather than satellite services being proportionally more developed in Australia than in other global markets, the skewed proportions are more indicative of an underdeveloped infrastructure segment. Should a launch proposal become operational, the infrastructure revenue figure would increase dramatically.

A comparison of the two different make-ups of the industry is given below in Figure 6-6, comparing the size of the International Space Industry given in Chapter 4 with that of the Australian Space Industry.

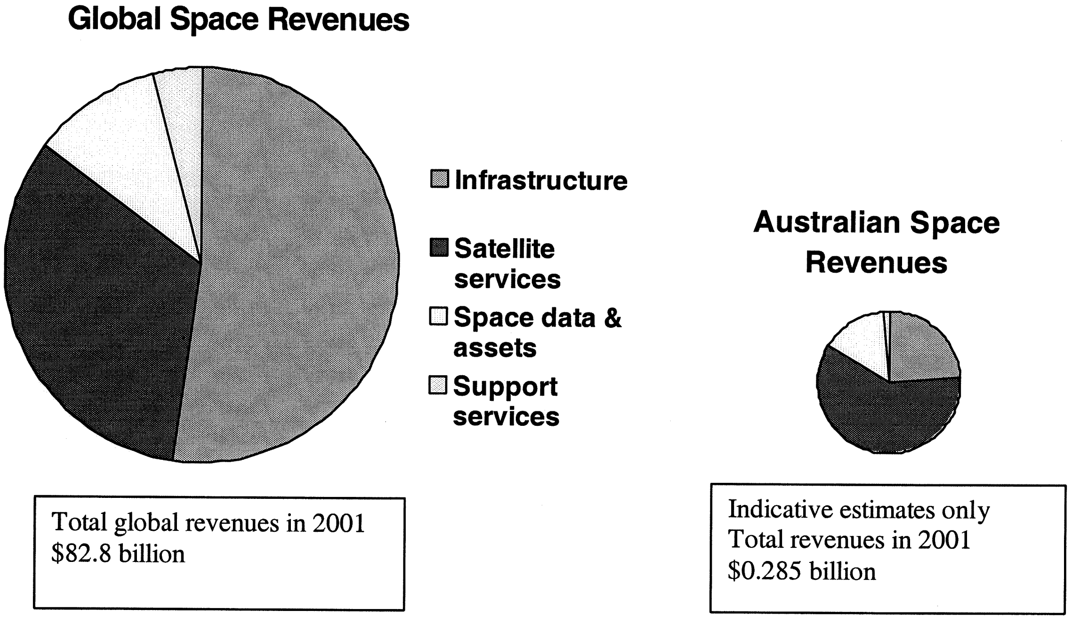

Figure 6-6: Australian Space Revenues, Source: (ISAG, 2002)

Research could find very little trend data on the development of the space industry, except for that of the Remote Sensing industry (taken as a component of the new Spatial Information industry) and as such it is difficult to collate estimates of future growth. The study by the International Space Advisory Group (2002) discovered that "Discussions with individual companies and organisations have revealed a variety of growth projections, ranging from a number of companies that anticipate exiting the industry if Government investment measures are not taken, to companies who have accessed niche supply markets and see solid annual growth of the company at around 10%. The diversity of responses is regarded as indicative of the fragmented and niche nature of the industry which has only restricted access to global markets (as a result of the predominance of national programs favouring indigenous industries)."

An individual assessment of each of the different areas that make up the Australian Space Industry is given in the following sections.

6.4.5.1 Infrastructure

The Infrastructure segment of the space industry is made up of primarily of ground stations and antennas, satellite manufacture and launch services.

According to the ISBC report on the state of the international space industry (ISBC, 2002), space infrastructure is currently the largest industry segment and generated $US43,206 million in 2001. Annual growth is around 4% and the proportion of industry revenues generated are expected to decline from 52% in 2000 to 39% by 2007. Annual growth for 2002 is estimated at 8.4%, but this is predominantly in the area of ground hardware and ground operations caused by the increasing integration of application technologies into the global telecommunications network. The satellite launch segment is projected to remain relatively static overall during the next five years, with marginal increases in satellite manufacturing driven largely by increases in US Defence program budgets.

In the Australian industry there are proposals to develop launch facilities in Australia, designed to capitalise upon Australia's geographical advantage in order to secure a competitive share of the market. These proposals include the Asia-Pacific Space Centre in Christmas Island (APSC, 2002), and the Kistler Aerospace Corporation (Kistler Aerospace, 2002) proposal to be based in Woomera in South Australia. However, up to the publishing of this study no progress had been made in any of these initiatives.

The PricewaterhouseCoopers study of the space industry suggests that, should Australian launch proponents capture 10 to 20 % of the market, the industry could make positive contributions of $A1.1 billion to $A2.6 billion to the Australian balance of payments (ISAG, 2002). The APSC project would be expected to create 300 to 400 jobs during construction and up to 250 jobs for Australians during operation.

The other component of the infrastructure industry is that of satellite manufacture. Although Australia does not have commercial satellite manufacturing capability, there has been some involvement in the design and construction of research microsatellites. A number of experimental projects, such as Bluesat, Jaesat and FedSat (CRCSS, 2003), are under-way in this area.

Australia also has a developing industry in the area of Scramjets, which have possible commercial applications in satellite launching and in hypersonic aviation. HyShot is a research project which has received commonwealth funding into the scramjet engine designed and manufactured by the University of Queensland. NASA and the US military have also shown considerable interest in the HyShot experiment. A launch in October 2001 encountered problems with an arguably successful launch in 2002 (Centre for Hypersonics, 2003)[4].

Australia has a long history of involvement in deep space tracking, illustrated by the first Moon-walk in which two of its facilities (the NASA-funded Deep Space Network station near Canberra, and the CSIRO-funded dish at Parkes), were both used. Current Australian involvement in Deep-Space Tracking activities includes four components :

- Australia hosts the Canberra Deep Space Communications Complex at Tidbinbilla. This facility is funded by NASA (at a total cost of $A10m-$A20m p.a.), and this contract is administered by CSIRO, with the facility itself currently being managed by Raytheon (NASA, 2003; Raytheon, 2003).
- Australia hosts two tracking facilities in Western Australia funded by the European Space Agency in cooperation with Telstra.

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[4] Initially, the success of the Hyshot programme in 2002 was debatable, as the rocket launched successfully, but the successful outcome of the scramjet experiment (which took place within only the last few seconds of the flight, lasting almost 10 minutes) was unclear until some time later. Space.com (2002). Results Just In: HyShot Scramjet Test a Success http://www.space.com/missionlaunches/hyshot_020816.html

- The CSIRO-owned Parkes radiotelescope is used under contract to ESA and NASA to track Deep Space Missions such as Giotto and Galileo, typically earning CSIRO about $A1.5m p.a., including the construction by CSIRO of receivers for the missions (ATNF, 2003).
- The next-generation Deep Space Network is likely to include novel antenna technology developed for the Square Kilometre Array (SKA) by CSIRO and its international partners. CSIRO are currently discussing with NASA the possible construction of such an array in Australia, at a likely cost of a few hundred million dollars (SKA, 2003).

There are also niche-space tracking capabilities in Australian industry. A publicly-listed company, Electro Optic Systems (EOS), have 80% of the international market in the design and manufacture of beam directors and laser tracking. EOS is currently working to build up a space debris tracking capability (EOS, 2003).

6.4.5.2 Satellite Services

Satellite services are primarily made up of the communications industry, from the direct broadcast of information to two-way communications and associated value-added data and entertainment products. Revenues from the satellite services segment in Australia were estimated at $A200m in 2001 (ISAG, 2002).

The satellite communications industry is seen by the government as a commercially mature segment of the space industry in Australia. Primarily this is due to global consortia, which have seen the establishment of satellite networks that provide services to Australia. Optus is Australia's leader in satellite-based communication services and delivers the majority of television and radio satellite services across the country.

Optus (SingTel) owns and operates four communications satellites which provide voice, data and video series to the broadcast industry as well as to corporate and Government customers in Australia. These satellites deliver next-generation telephony, high bandwidth data communications and direct-to-home TV and Internet services across Australia and into Asia (Optus, 2003). The latest satellite also provides dedicated capacity to the Department of Defence for high bandwidth long-range communications. Optus also provides a range of tracking, telemetry and control services to other satellite operators

The Institute for Telecommunications Research (ITR) in South Australia has also developed niche expertise in the development of signal processing techniques and transmission protocols for the transmission of satellite based internet services. Through R&D in this field, the ITR is aiming to improve the throughput and reliability of satellite based internet services (Institute for Telecommunications Research, 2001).

Opportunities for Australia in this industry segment are primarily in the provision of supporting componentry, such as the manufacture and installation of antennae, modem technologies etc, to meet the primary growth in the delivery of services (ISAG, 2002).

6.4.5.3 Space Data and Assets

The Space Data and Assets segment of the industry is primarily built upon the Remote Sensing and Global Positioning components of the market. Areas covered include minerals exploration, agricultural resource management, environmental management, urban planning and planning for transport networks. The highest growth area is GPS equipment and services, which is anticipated to sustain this growth over the next few years as GPS technologies are progressively integrated into other industries. This segment also includes the use of space assets for microgravity research and space tourism.

Australia formed the Spatial Information Industry as part of its Action Agenda programme launched in 2001 (ASIBA, 2002). It was built upon research that showed that Australia has strong capability in the provision of geospatial data, imagery and imaging software for user applications. The industry supports Australian national priorities with space-based solutions in the fields of salinity, surveillance, mineral exploration, agriculture and land planning. There are a number of companies in this segment operating in the domestic marketplace and servicing public and private sector needs. Geoscience Australia also provides fundamental geographic information critical to the support of a range of activities such as defence, education, emergency services, transport, tourism and communications.

In October 2000, the Department of Industry, Science and Resources (DISR) released a report on the remote sensing industry prepared by PricewaterhouseCoopers. The remote sensing industry as defined in that report has some overlap with the surveying services industry, particularly in the areas of aerial photography and photogrammetry, but picks up a number of value adders who see themselves as mainly providing services to agriculture or mining. It also covered some activities of the major GIS and image processing software providers. The report estimated the size of the remote sensing industry in Australia at $A45 million revenue in 1999-2000, 60% of which was generated in the private sector (DISR, 2000b).

Australia also has capabilities in a number of areas of biomedical research. There are some collaborative projects in place between Australian scientists and researchers, NASA and the American National Health and Medical Research Council (NH&MRC).

6.4.5.4 Support Services

There are a large number of support services for the space industry, including financial, legal, insurance and associated consulting industries supporting the industry. Global space support services generated $AUS3,480 million or 4% of total space revenues in 2001. Annual growth in 2002 is estimated at 11%, although this is from a low base.

Without a strong domestic infrastructure space industry in Australia, there is a minimal support services segment, with revenues for the support services segment in Australia estimated at $A5m in 2001. The process of establishing a regulatory regime for the launch activities has created some activity in legal and consulting services. However, in the absence of a sustainable launch sector, there is unlikely to be more than sporadic use of these support services.

Australia had a strong space insurance industry in the 1980's and 1990's, and there remains the potential for this to be redeveloped should global demand emerge. However, the static state of the launch industry globally and the impact of terrorism fears on insurance generally and also on the relatively unchartered area of attacks on space assets, make it unlikely that an Australian company would choose to re-enter the space insurance marketplace at this time. Australia's current legal expertise in space law is highly regarded internationally, and this extends to both public and private sector legal support services (ISAG, 2002).

6.4.6 Space Industry Overview

Overall, an overview of the Australian Space Industry shows that it is a fragmented network of niche activities. Few companies are solely engaged in space activities, and many lack the critical mass or clustering capability to enter the global network of space suppliers and contractors.

It is expected that the industry will diversify to encompass more commercial enterprises. The satellite services sector is expected to continue to experience growth, with strong commercial growth in satellite use for Internet and data transmission technologies. The launch vehicle market is projected to continue to display growth in the short-term, although this is due to a shifting market rather than an expansion in demand. Significant changes are projected in both the LEO and GEO markets, and this will impact on the market demand for particular launch vehicles and facilities. The increase in several national Defence budgets for surveillance and anti-terrorism measures is fuelling some growth in this segment, with flow-on effects in the infrastructure segment. While the market continues to attract some new investment in launch facilities, the commercial market has contracted and longer-term projections indicate an overall decrease in the total number of launches.

Other aspects of the infrastructure market, such as ground stations and hardware and the manufacture and design of payloads indicate a steady growth pattern, although there is likely to be some impact of the flattened launch market. Other segments of the space industry, such as Earth observation, are not yet commercially mature despite vast domains of applications. Government contracts continue to dominate the remote sensing market and, with increased international collaboration enabling more high cost and sophisticated projects to be undertaken, this situation is set to continue. Increasingly, government space programs are also being driven to projects with definable commercial benefits or spin-off technologies with the potential to address national problems.

6.5 Australian Space from a Policy Perspective

Since the abolishment of the Australia Space Office in 1996, Australia has not seen a coordinated national space program. However, the applications of space are such that a number of Commonwealth agencies continue to engage in space-related activities, either through their reliance on space technologies to deliver national services or through the policy responsibility for areas which are impacted by developing space technologies.

While Australia continues to engage internationally in space, albeit sporadically, unlike other nations there is no policy framework or mechanism to direct this engagement towards national priorities. Given Australia's position as a significant user of space technologies, and as a developed nation with substantial expertise across science, engineering and biomedical fields, Australia is unusual in not driving even a modestly coordinated agency approach to space engagement.

As discussed in Section 6.4.2, the lack of coordination across these agencies results may result in some duplication and at times lost opportunities for industry participation. However, even though there is no coordinated space programme in Australia, there are still a number of policy mechanisms in place to capture, build and take advantage of a number of components of the industry.

The Space Activities Act in 1998 provided for the regulation of commercial space launch and other space activities, consistent with Australia's international obligations with the United Nations Committee for the Peaceful Uses of Outer Space (Commonwealth of Australia, 1998). In particular, the legislation establishes a framework for licensing space activities conducted either from Australia or by Australian nationals outside Australia, apportions liability for any damage caused by Australian space activities, and sets out the process to be followed in the event of an accident.

The operation of the Act was supplemented by a comprehensive set of regulations and was amended in 2001 and again in 2002 to include a number of provisions, such as specific space cooperation agreements and the establishment of a bilateral agreement with Russia for the provision of launch vehicles.

This section outlines these and other policy initiatives within Australia which are linked with the development of an indigenous space industry.

6.5.1 Launch sites

The infrastructure segment of the market represents an opportunity for Australia to participate internationally through design and construction of hardware and the supply of services. As the infrastructure segment of the market is also typically characterised by large-scale projects, there are opportunities for Australia to access global supply chains and become niche providers in areas where we have existing expertise.

In May 2001, Russia and Australia signed a bilateral agreement to transfer Russian launch expertise and technology to Australia, made possible by the amendment to the Space Activities Act of 1998. This was largely based on the fact that two space launch initiatives, the Asia Pacific Space Centre (APSC) and Spacelift Pty Ltd, envisaged the use of Russian launch technology as part of their business. The government also conducted a range of visits to Russia in 2002 and 2003 to strengthen this agreement.

APSC is an Australian company founded in 1997 to establish a satellite launch facility at Christmas Island. It proposes to use the Russian Aurora rocket to target geostationary launches and twelve launches per annum are planned. APSC also proposes to establish a Space Research Centre as part of the Christmas Island spaceport. The Centre will offer post-graduate teaching and research in collaboration with other Australian and international research institutions (APSC, 2002).

As a result of the national security issues surrounding satellite and launch vehicle technology, access to launches in countries such as Russia and China has been impeded by satellite export restrictions. This has added costs to the utilisation of these otherwise cheaper launch services. Australia's strong relationship with the US means that security concerns are limited and export restrictions and compliance costs are reduced.

If successful in finding investors, the federal Government will providing $A100 million in support to the APSC project under the Strategic Investment Incentives program. This financial support is primarily for the upgrade of common-use infrastructure on Christmas Island, with some funding to support costs associated with spaceport infrastructure, such as ground station facilities for telemetry and tracking. However, despite this support, the project is currently in a state of uncertainty, seeking funding from other backers.

6.5.2 SLASO

As outlined above, the Space Activities Act of 1998 (amended in 2001 and 2002) aims to outline Australia's international responsibilities for the licensing and administration of space launches, both domestically and abroad. The Department of Industry, Tourism and Resources (DITR) was given the responsibility for developing policies and preparing the Regulations behind the Space Activities Act. Within this department the Space Licensing and Safety Office (SLASO) was formed (DITR, 2003), with responsibility for developing the technical details and implementation of the new regulatory regime. SLASO also has responsibility for licensing space launches and other space activities according to the procedures prescribed in the Act and the Regulations.

SLASO also tracks past and future launches of Australian payloads; at the time of publishing this work, the next licensed launch of a payload is by JAXA in the second quarter of 2007.

6.5.3 FedSat

Within the satellite manufacture sector, the FedSat project has been seen as one of the major initiatives in recent years (CRCSS, 1999).

In 1996, the then Minister for Science and Technology, the Hon. Peter McGauran considered a draft proposal for a new national space agency. The proposal was rather weak and did not appear to be well directed (ASICC, 2001), so consequently it became necessary to draft a fresh approach. Given that funding was scarce, it appeared that salvation lay with an initiative linked to the Centenary of Federation in 2001 as a vision for the future. It was also necessary to build on national research experience and industry capabilities with a suitable but small demonstration project; i.e. Federation Satellite 1 (FedSat). In the 20 August 1996 Budget Statement, the Minister announced the start of the FedSat program and changed the prevailing administrative arrangements for space.

News followed later of Commonwealth support for building FedSat through a new Cooperative Research Centre for Satellite Systems (CRCSS). On 10 July 1997, Mr McGauran announced an initial program grant of $A20 million. A necessary part of the CRCSS context was industry participation and contribution of $A36 million over a seven year timeframe. Australia had committed itself to a space applications project that would demonstrate national capabilities, to both its own people and markets around the world. Other changes to space programs also occurred, as discussed below.

The CSIRO Office of Space Science and Applications (COSSA) undertook development of the program and establishment of the CRCSS in Canberra. With the official start of CRCSS operations on 1 January 1998, the core of COSSA staff transferred to the CRCSS. The CRCSS has research and development, education and training, engineering and project management functions. The CRCSS was also to have a broader role than FedSat, covering the long-term strategic operational and commercial role for satellites.

At the launch of the Cooperative Research Centre for Satellite Systems, the Minister said "The space mission, to be known as FEDSAT, will conduct scientific experiments and develop practical applications such as communications and earth observation. I have asked CSIRO to play a leading role in this effort and to develop a research plan that will include universities and industry ...we will gain this in a focused, step-by-step fashion, drawing on expertise already in CSIRO and our universities, and involving those companies willing to share some of the costs. This new program will develop our experience in managing real space projects, and will reduce the risk involved in the more demanding and complex space projects we may want to pursue later." (APH Hansard)

Shadow Minister for Industry Martyn Evans also showed that this was a bipartisan initiative. "The government has made a number of changes to space policy in recent years. For example, they have abolished much of the limited effort which occurred previously and consolidated it in a practical effort through CSIRO to launch FedSat in about the year 2000. There is the residual national space policy unit within the department, but funding is now even tighter than it has ever been, and it has never been generous. The reality is that Australia's effort in space is very much a constrained one, but one which I think we should endeavour to improve in future years on a bipartisan basis." (APH Hansard).

Despite these high hopes, the FedSat project has not featured prominently in parliamentary debates since its inception, with an investigation of the parliamentary Hansard showing few mentions of the satellite, even with its launch in 2002. The programme was mainly administered through the AusIndustry CRC programme (CRC Association, 2002).

However, within the CRCSS and in the Australian Space Community in general, the FedSat project was seen as a vital step in developing an indigenous space industry. These and other aspects of the FedSat project are analysed in-depth in the remainder of the thesis.

6.5.4 Conclusions

As with an analysis of the Australian Space Industry from an economic perspective, Australian space policy seems to be fragmented and without a 'whole of government' approach.

There is some agreement that Australia's development of a cohesive plan for the space industry must similarly be determined by national objectives, and a program of projects developed to meet these objectives. It is noted that the 'significance' of different space nations is not necessarily reliant on the total space budget of a nation. A strategic space industry is one that is carefully structured to meet identified national objectives and takes account of the trend towards commercial applications and international collaboration. While Government support and funding is key to the development of capacity and to participation in some international projects, the careful structuring and selection of these projects will assist in ensuring that a space program delivers concrete national benefits to Australia.

6.6 Re-entering the Industry

Given that Australia's space industry is largely fragmented and an interregnum of activity has potentially reduced Australia's abilities to develop a viable industry, it is important to assess whether it is in the nation's best interests to attempt to re-enter the industry.

The previous sections showed that there is an absence of firm data on Australian space industry turnover and capability, which makes economic modelling of the spin-off benefits of the industry difficult. In addition, there is no sign that government patronage of the sector to match the other national space program investments will be forthcoming.

In this section the benefits of an indigenous Australian Space Industry are investigated, along with some of the impediments to its growth. These are then assessed and, given the current state of the space industry from a economic and policy perspective the opportunities for the industry are assessed.

6.6.1 Benefits of an Australian Space Industry

Benefits of an indigenous space industry, although in many cases difficult to quantify, could be estimated to be similar to those of any high-tech industry. These benefits could include increased R&D, technology transfer across sectors leading to productivity gains, employment attraction and retention for skilled personnel, high levels of innovation, greater industry and research alliances, and the economic wealth gained from an export-orientated industry sector.

However, these benefits are, broadly speaking, generic to many high-tech sectors and do not argue for a unique strategy to address development in the space industry. Indeed, Government has a range of industry assistance programs, which aim to facilitate innovation and R&D to promote the commercialisation and uptake of new technologies across sectors. These programs are available to the space industry, as they are available to many other sectors. Some Australian space companies do access these programs, although it must be admitted that the characteristically high entry costs, long lead times and predominance of international collaboration in the space industry does limit the usefulness of some of these programs.

While the public or private returns on an Australian investment in space may be difficult to quantify, a number of intangible benefits have been put forward which argue for Government intervention and fostering of a domestic space industry. These arguments relate to the unique solutions which space is able to provide for national priorities and, as the nation becomes increasingly reliant on space technologies for weather forecasting, crop and land management, search and rescue, and surveillance, the need to secure continued access to the data and technologies which inform national decision-making and drive productivity gains across sectors.

The ISAG report (2002) focussed heavily on the benefits for an indigenous space industry may include, and found that they included:

- Security of continued access to data and space technologies upon which national services are increasingly reliant;
- Tailored solutions to Australian national priorities;
- Maximising benefits from existing Government expenditure by using procurement to leverage industry growth;
- Access to spin-off commercial applications which benefit across sectors; and
- Ability to pro-actively seek participation in international collaborative projects in areas in which we have niche capability.

The benefits of developing an indigenous space capability, like other Government initiatives promoting innovation, relate to access to and uptake of technologies, strengthening Australia's position globally, ensuring our skills, services and goods are marketable and internationally competitive, and securing economic growth and wealth. Indigenous space capability also has the specific long-term benefits of fostering self-reliance in the space technologies, which enable vital national services.

6.6.2 Impediments to Growth

The domestic space industry currently faces a number of impediments to growth. Some of these are generic to an emerging industry and relate to the need for industry-research alliances and networking to attain a critical mass, which facilitates access to larger contracts and supply opportunities. However, the global space industry is also distinct in that Government contracts account for nearly half of worldwide activity.

The strong role of government as a key player in the sector suggests that government intervention is required to establish the domestic framework, investment facilities and national and international connections, which would enable the industry to achieve a sustainable level of activity and enter supply chains in global and domestic markets.

A report commissioned by the Australian Space Industry Chamber of Commerce (2001) highlighted a number of potential impediments to the development of the space industry. These were further augmented by the International Space Advisory Group report of the following year (ISAG, 2002). A summary of these findings is given in the table below:

Fragmentation across the sector	• Lack of coordination across industry segments and across industry, research and Government agencies • Lack of co-ordinating body to provide a point of contact for international approaches and to negotiate engagement protocols. In many instances Government is needed to be part of international collaborative projects in order for industry to access supply opportunities • Lack of policy framework to determine national objectives and needs • Dispersed industries and research organisations often lacking the critical mass to compete internationally for contracts • Domestic industry is insufficient to sustain a viable space industry, but impediments inhibit access to global markets.
Restricted access to market opportunities and investment	• Lack of consumer awareness of space applications and potential productivity or decision making gains • Government is a high user of space technologies and remotely sensed data, but this procurement is not utilised to foster private sector growth • Existing investment facilities do not meet the specificities of space • Space is often only part of a company's business so there is fluctuating capability and activity in the domestic marketplace • No promotion of Australia's competitive advantages internationally
Impediments as a result of the nature of the industry	• Many organisations within the industry, spreading resources and commitments thin • Personalities dominate business • Lack of communication and cooperation in the industry • High entry and costs, and long lead times

6.6.3 Industry Opportunities

As outlined in the previous section, the building blocks for Australian participation in the global space market include the geographic advantages given to commercial launch operations from Christmas Island and Woomera and strong foundations in optical and radio astronomy with industrial spin-offs into the design and manufacture of ground antennae, spacecraft instrumentation and associated technologies. In addition, a diverse portfolio of specialist capabilities in the technologies of remote sensing, signal processing, space systems, space instrumentation, debris tracking, geodesy, and certain propulsion technologies and a developed infrastructure for telemetry and tracking are also key elements towards the future development of a space industry.

6.7 Conclusions

This chapter began with an investigation of Australia's Innovation Policy from the perspective of Complex Product Systems and the CRC programme. It was found that there was a potential for Australia to become a supplier of CoPS products, but that, apart from the CRC programme, there were very few government mechanisms in place to promote this sector of the industry. As the FedSat satellite relies heavily on the Cooperative Research Centre scheme, an in-depth investigation of the impact of Australian space and innovation policy on the programme was also given. It argues that Australia may have an inherent capacity for the development of CoPS, in which case a project such as the FedSat project, with a niche oriented, small scale (to CoPS) project should be successful in taking on the world market.

The chapter also outlined the development of the Australian Space Industry and summarised a number of investigations into its development. It was found that, despite promising beginnings, Australia's industry is largely fragmented and uncoordinated. However, there are a number of current initiatives which are being undertaken in various areas to develop the industry.

The final section of this chapter asked whether Australia indeed has the capacity to re-enter the space industry, and whether there are benefits for Australia to do so. It was found that while Australia does have the core components of a space industry, it lacks the critical mass to make it viable. However, given the potential benefits of the industry an argument can be made for government assistance.

There still remain many questions to be answered, which are not addressed in previous government reports into the Australian space industry. One of the central questions asked in this investigation is whether the CRC framework is indeed the best (or indeed appropriate) mechanism for the development of this industry. In future chapters the CRCSS is compared against other CRCs, with particular reference to using the CRC scheme to develop large projects.

Chapter 7

Small Satellite Case Study

7.1 Introduction

This chapter lays the groundwork for the analysis of the critical case study by detailing the experiences of the FedSat project. It is based largely on structured interviews from the participants of the project validated by other project information.

A history of the satellite project is given, detailing its intended outcomes, its technical composition and the project organisation. The detailing of key events is used to underscore the challenges facing the project in its different phases and the key drivers behind its successes. This chronological study of the project is based around two key periods; the satellite construction in the UK and the satellite construction in Australia.

This chapter then undertakes an analysis of the project along a number of functional lines, ranging from the overall project organisation to the risks involved and aspects of learning inherent in the project. Finally, this chapter also investigates the critical success factors seen as key to the FedSat project achieving its intended goals and the eventual outcomes of the project.

In all interview responses, the interviewer's names have been removed, reflecting the confidential nature of the interview process. In the outline of the FedSat project and associated analysis, each interviewer has been given a reference number, displayed within curly parentheses { }.

7.2 Project History

Although it was a number of years in the planning, the FedSat project commenced officially on the 1st of January 1998 with the formation of the Cooperative Research Centre for Satellite Systems and culminated in the launch of FedSat on the 14th December 2002.

In order to undertake a chronological analysis of the project, the events before, during and after the project can be grouped into a number of phases shown below (Moody, 2000c).

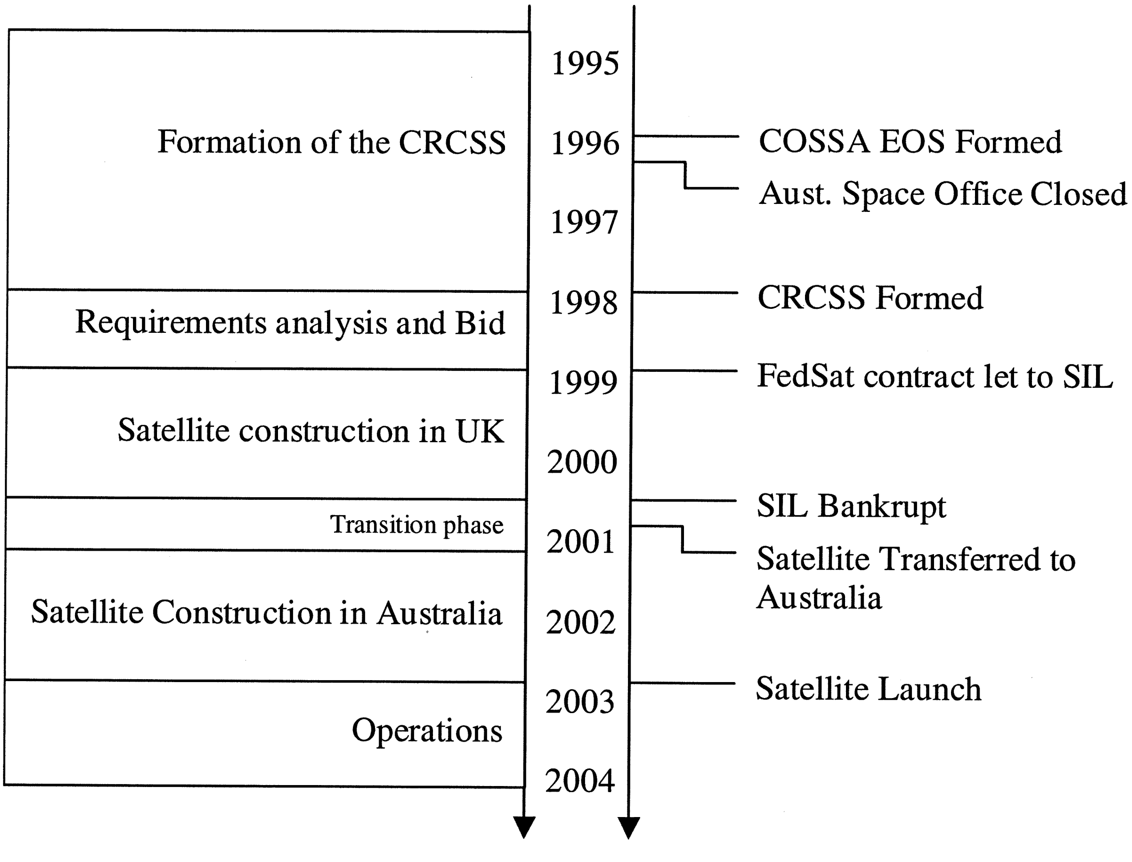

Figure 7-1: The Development of the FedSat Project

Each of these different phases had different goals and underlying challenges, and while some were planned, many like the satellite construction in Australia, were not part of the original project design. This section describes the different phases of the satellite project and outlines its development from a chronological perspective.

7.2.1 The Formation of the CRCSS

The inception of the CRCSS dates back to staff members of the CSIRO Office for Space Science and Applications (COSSA), which was created in 1984 to coordinate all of the CSIRO's Space Efforts. Its first director, Dr Ken McKracken, founded the division with the goal of increasing Australia's role in satellite projects, while undertaking research in space applications (COSSA SpIN, 1999). Over the following decade COSSA became involved in a number of space hardware projects, including RADIOASTRON (a Russian-led orbiting radio telescope, currently awaiting launch), ATSR (Along-Track Scanning Radiometer) and the APS (Atmospheric Pressure Sensor).

Dr McCracken, "wanted to turn Australia into a space provider, not just a user of data, but having a piece of the action upstairs. And that's what we were doing with the Along-Track Scanning Radiometer". In the minds of the office's staff, COSSA provided the role of a national space organisation, akin to international partners, albeit much smaller. "The best thing of all was Australia had a space organisation again, albeit small, but it was there, it was doing things, it was not just shuffling paper." {Dr McKracken}

Ken McCracken left COSSA suddenly in 1989 and was replaced by Dr Graham Harris whose background was in space applications for freshwater ecology. Harris lobbied successfully for the CSIRO's continued involvement in space. According to Harris, "I think what I succeeded in doing was straightening out the budget and actually giving it, at the time, a pretty good corporate mandate. There was recognition that it could do good things and that we knew what we were there for, we knew what we could do and what we couldn't do." (COSSA SpIN, 1999)

It was during this time that the Australian Space Office (ASO) was formed by the federal government. There was a poor relationship between the ASO and COSSA due to disagreements on priorities and focus. According to Harris, "the problems with the Space Office, continual problems, niggling, nagging problems with the bureaucracy versus the scientists ... were fairly rife, but it was clear to me ... that Australia was never going to develop a major space program. ...". According to a future CRCSS member, this tension between the ASO and COSSA was a case of "power and territory" {#6}.

Dr Harris resigned from COSSA in 1993 and was replaced by Dr Brian Embleton, who had recently finished his tenure as CSIRO Chief of Exploration and Mining. Dr Embleton succeeded in building alliances with the different groups with an interest in space activities in the CSIRO. "Since Brian's arrival," said Chris Graham, one of the CRCSS engineers, "we've spent more time concentrating on the space aspects, which has culminated in the CRC."

Dr Embleton divided COSSA into two main sections; one which would focus on earth observation science and one which would focus on space projects. In 1996, the section of COSSA which focused on earth observation was turned into the CSIRO Earth Observation Centre (EOC), as a direct result of the recommendations of a report by Dr Jim Simpson, Director of the Digital Image Analysis Laboratory of the US Scripps Institution of Oceanography. (Jupp, 1996)

The remainder of COSSA was focussed on space hardware and continued after the Australian Space Office was closed in 1996. Dr Embleton used this to COSSA's advantage: "With the closure of the Space Office, opportunities were then presented to CSIRO, through COSSA, to put a proposal together to establish a space program." "As part of my vision for COSSA, I wanted to recapture some of the original vision that Ken had when he started COSSA. And that was that COSSA would be a catalyst for developing a space industry in Australia."

In 1996-1997, the idea behind the CRC for Satellite Systems was formed. Support for the venture in government circles was obtained mainly through champions such as Tony Staley (Previous Chair of the Liberal Party of Australia and CRCSS Chair) and Peter McGaruan (Minister for Science). With the aid of key researchers from universities and SME participants from industry, the CRCSS was created on the 1st of January 1998, with all of the remaining COSSA staff transferring to the centre.

The CRCSS was designed to be a commissioning agent. A senior committee of civil servants, academics and businessmen initiated the project, which was funded primarily by the Australian Government under the Cooperative Research Centres (CRC) scheme. Using the CRC scheme was seen as a novel way of developing the satellite, as it provided an existing framework for funding and coordination and did not require any changes to government policy or regulations (Kingwell, 1999).

The partners of the CRC for Satellite Systems spanned Australia, coming from the CSIRO, universities and private companies, as shown in Figure 7-2.

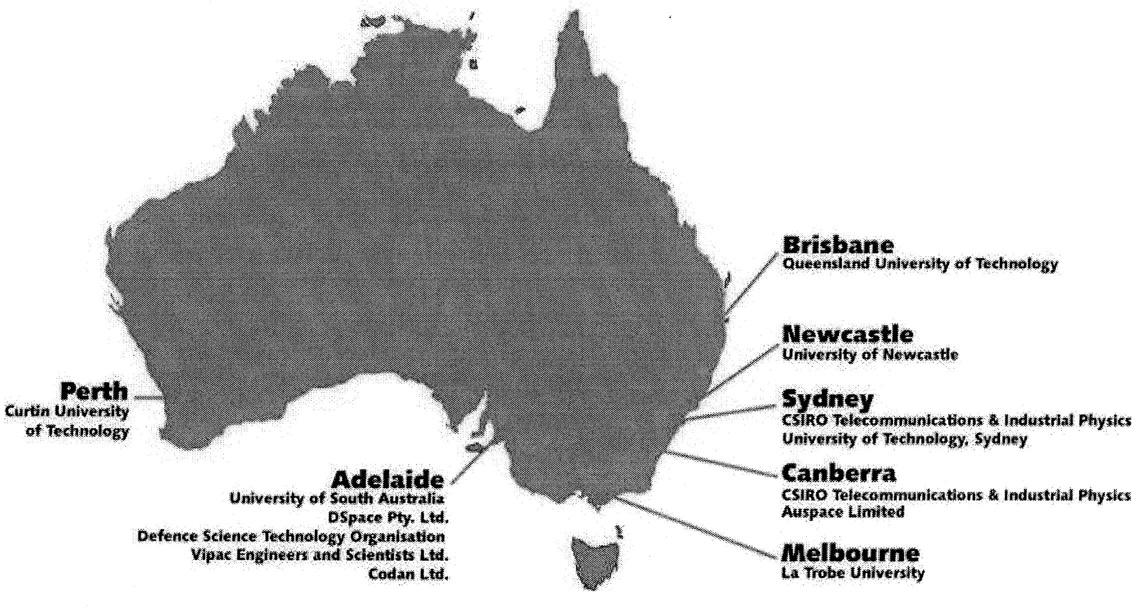

Figure 7-2: CRCSS Partners, Source (CRCSS, 2002)

It was noted by a number of participants of the CRC that it was formed as a joint venture of the different partners and not as an incorporated entity in its own right. As remarked by a staff member of one of the company participants, "[The CRC] was formed at a time when [the CSIRO] would not incorporate. Some of the impacts of this became more evident further into the project." {#2}

The organisational structure of the CRCSS was one of a Governing Board, made up of high level representatives of project partners and a Centre Executive made up of heads of the different centre programmes (also drawn from project partners). The programmes were designed to reflect the core areas of business for the CRC, with research having a number of sub-divisions (CRCSS, 1999). The structure of the CRC is given in Figure 7-3.

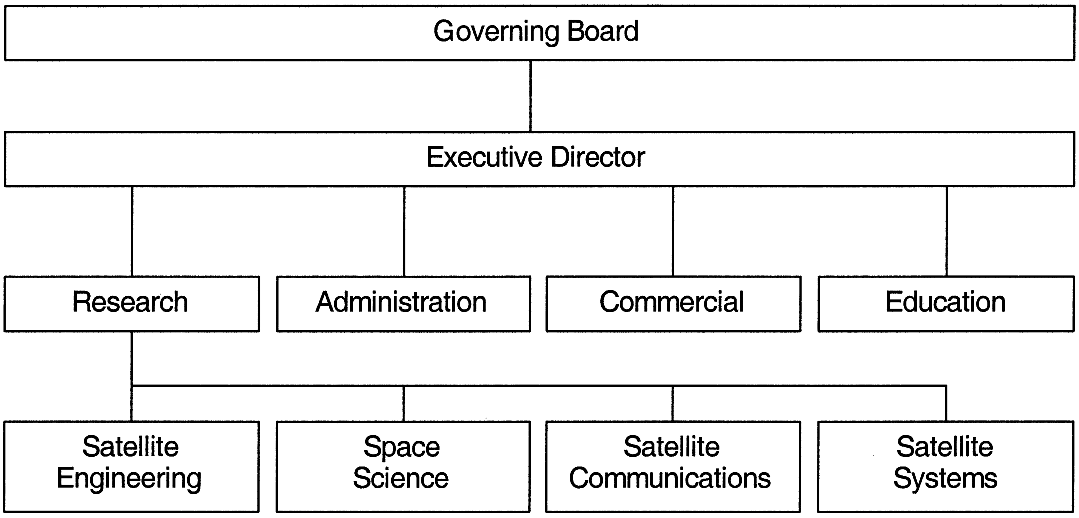

Figure 7-3: CRCSS Organisation Structure, Source (CRCSS, 1999)

7.2.2 The FedSat Satellite

Although there were a number of programmes within the CRC structure, the central mission of the Cooperative Research Centre for Satellite Systems was to build and launch Australia's "first satellite for more than 30 years" (CRCSS, 1999). FedSat was to be a low-cost micro-satellite, designed to conduct communications, space science and engineering experiments and was intended to be launched to celebrate Australia's Centenary of Federation in 2001.

Project Goals

According to the Executive Director of the CRCSS, "The main goal of the CRC was to build a small satellite and demonstrate our abilities to do it." {Embleton}. However, there were other influences on the CRC programme. "We were advised to use the CRC programme as the vehicle to fund the space project. To qualify for CRC funding you have to meet the guidelines - requiring a comprehensive R&D, education and training and commercial programme. These are the performance criteria for the CRC."

In the first CRC Annual Report, a number of goals of the FedSat mission were listed (CRCSS, 1999):

1. To build and operate a satellite;
2. To establish an inherent technological experience which can be used to nurture innovative ideas;
3. To create links between research institutions and industry;
4. To improve and promote industrial knowledge and practices; and
5. To foster recognition of Australian abilities in current and complex technology.

However, despite these clear goals, there was some disagreement as to what was most important to the CRC and to FedSat.

A large group, particularly those from university partners, focussed on the research outcomes of the project; "From my perspective the customer was always the universities and the PhD students doing the research." {#3} This view was also shared by those involved in the CRC programme management. "Few CRCs focus on a device and so there was a challenge on us to explain the role of FedSat as a research tool, as a flexible space laboratory which serviced three research programmes. The feeling was that the CRC programme was intended to be research oriented and so the money should be spent on the traditional areas of research, that being staff and equipment. Some felt that too much money was being spent on engineering." {#2}

To many of the engineering team, the goal of the project was simply "to make the best satellite that we could" {#4}. This group held to this vision throughout the development of the project. "I don't think that the research goals looked that valuable. It was about building technical goals" {#5}. Even one of the members of upper management remarked that, "When we started down this track, the payloads were of second importance to me. I was not interested whether the payloads perform or not – I was not interested in whether they were delivered on time or not. All I wanted was the satellite." {#1} A successful flying satellite was seen as the key deliverable for the mission for this group.

Yet another group saw the satellite mainly as a project to make up for Australia's lack of a space policy or agency. According to the CRCSS chair, Tony Staley, FedSat represented " ... us getting our feet wet, taking on something we can bite on and digest and do, and hopefully get into the business in a relatively modest way, but get into the business. It threatens almost to be too late, but it is ***not*** too late, because there is not the slightest doubt that we're in for a new wave of satellite [benefits]. The great aim is to get Australia into the business". (COSSA SpIN, 1998)

Finally other groups, especially from the industry partners, saw commercial goals from the project. In particular, they were interested in the commercialisation of technologies from the satellite project. "Vipac's interest was in the commercialisation of platform technology. Vipac wanted to get in and become a platform supplier much like Hawker DeHaviland did a decade before, using Surrey satellites. Their main aim was to get into space to build platforms. They weren't interested in the payload side, they weren't interested in the building side and, in fact, that is where some initial conflict between Vipac and Auspace occurred, because Auspace had the capability to do the work that Vipac wanted to do." {#1} Vipac believed that the main areas of commercial interest were mission operations, systems engineering, and aimed at building a business in platform provision. A summary of these different goals is given in the table below. These are sourced from both CRCSS literature and interviews with key CRCSS participants.

Table 7-1: CRCSS FedSat Goals

Technical	To build and operate a satellite	(CRCSS, 1999)
Research	To undertake space research To create links between research institutions and industry	{#4} (CRCSS, 1999)
Commercial	To commercialise research and create opportunities in the space industry	{#6}
Industry-wide	To kick start a space industry To establish an inherent technological experience which can be used to nurture innovative ideas To improve and promote industrial knowledge and practices To foster recognition of Australian abilities in current and complex technology	(CRCSS, 1999) (CRCSS, 1999) (CRCSS, 1999) (CRCSS, 1999)

When reviewing the project, a large number of participants remarked that the lack of clarity of the goals was to have flow-on ramifications, especially when the project started to run out of money and difficult choices had to be made. This is discussed later in this case study.

Project Value

One of the core aspects of the programme was that FedSat was to capitalise on the emerging global trends of using small satellites for science applications. The CRCSS's advantage compared with previous efforts to develop Australian space hardware was to be this move towards smaller satellites, which brings the size of projects into a more appropriate and achievable level.

Dr Brian Embleton, the Director of the CRCSS, when asked in a press interview about the significance of FedSat, said, "Why a small satellite program for Australia? To begin with, it's affordable and it's manageable. With technological advances, we don't have to compromise on the kinds of services we can provide from small satellites; their capabilities are enhanced; the risk is reduced, the expense reduced; and you can get there quicker. There are opportunities for cooperation, operating small satellites in cluster mode. So to provide a range of services there is an attractive proposition, through cooperative ventures, working with agencies and partners in the region. (COSSA SpIN, 1998)

However, there were critics of the programme. Dr Bruce Middleton, the previous head of the Australian Space Office believed "FedSat looks like the same thing, where major investment returns little to Australian industry." He claimed the Australian Government's commitment to FedSat is not equivalent to the commitment other Asian countries have made to their programs. He claims, "On the face of it, Australia will not get much more, for an expenditure of $A55 million over seven years, than the Malaysians will get with their TiungSAT for $A22 million over perhaps three years." He claimed FedSat, " ... will lead nowhere unless the Government is really prepared to make a substantial commitment." (COSSA SpIN, 2001)

Other members of the space community were dubious of the benefits of the Cooperative Research Centre. Even one of the partners of the CRC itself was not convinced; "The only reason why [name withheld] became a member of the CRC was that we couldn't afford not to be associated with it. We were dubious of the benefits for [name withheld] and Australia." {#1}

Free Launch

Early in the development of the satellite programme the Japanese National Space Development Agency (NASDA[5]) donated a free "piggyback" launch on a Japanese HII-A rocket. This provision of a free launch was nominally given in return for scientific collaboration on the NewMag, GPS and UHF payloads (CRCSS, 1999).

However, this put a considerable amount of schedule pressure on the programme, as the initial launch of the HII-A was originally scheduled for November 1999, less than two years after the centre's formation. Problems with the HII-A rocket ultimately delayed this launch date, but this was not known until well into the implementation phase of the project. In hindsight, some of the project participants believed that the free launch dictated the future course of the project. "It was always about schedule push – we would have done things very differently if we had known how much time we really had". {#6}

Due to this tight schedule and, to some, a perceived lack of experience in Australia, this validated the decision made by the executive that a subcontractor would be found to build the satellite.

Ground Stations

Another decision that was made during this phase of the project, and which was later identified to have resulted in a major impact on the project implementation, was the management and development of the Ground Station.

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[5] NASDA changed its name to JAXA (the Japanese Aerospace eXploration Agency) in late 2003. To maintain consistency, the name NASDA is used throughout this thesis)

Even members of the upper management had doubts about this decision: "For the FedSat project they put in the budget of a spacecraft and a launch and it was too much, so ITR stood up and said that they would take on the ground station. Much to the chagrin of myself and other people, they split the project into two entities - the ground segment and the space segment. We didn't want to split up – but the project manager at the time always thought that they were split." {#2}

Splitting the ground station from the satellite was seen as a convenient solution for the executive, as it helped to simplify their management of the process and also saved some money for the centre. As stated by an engineer on the project "The executive's focus was never the ground station. The satellite had the highest profile. It was later that the profile of the ground station started to increase as problems arose." {#6}

In hindsight, there was general agreement that this caused problems later in the mission. "I don't believe that this was a good decision. Things didn't go right because there wasn't unified control of the whole system. Once we decided that the Operations Control Centre and the test software would be the same, this muddied the waters between the two - there was self interest on both sides. Part of the FedSat programme was to get elements of the ground station delivered and so ultimate control of where money was spent and directions of work was developed by the individual groups." {#2}

7.2.3 Requirements Analysis and Bid

It was decided that a prime contractor with previous satellite experience would be found to build the satellite platform. "When we started the CRC, we had 18 months to build the satellite. So we decided that the only prudent way of achieving [the project] was to get someone else to build the platform. We decided to put all of our R&D funding into the smart end of the satellite, the payloads" {Embleton}.

The two major CRC industry partners were initially brought together with the CSIRO to undertake the requirements analysis for the satellite. At first, the 'generalised' requirements for the payloads were also developed. Initially, six payloads were slated to be included on the satellite:

- The Communications Experiment, developed by the Institute for Telecommunications Research at the University of South Australia, the University of Technology Sydney and CSIRO Telecommunications & Industrial Physics. It includes UHF and Ka-band equipment to study the transmission characteristics of Ka-band, store and forward at UHF and new coding methods.
- The NewMag Experiment, developed by the University of Newcastle. It comprises a three axis magnetometer mounted on the end of a 2.5 m boom to study dynamics of the Earth's magnetic field.
- The Global Positioning System (GPS) payload, developed by the Queensland University of Technology. It will test GPS positioning of the satellite, precise orbit determination, timing and meteorology.
- The High Performance Computing Experiment (HPCE), also developed by the Queensland University of Technology. It will study reconfigurable gate arrays in the space environment.
- High efficiency solar cells, developed by the University of New South Wales.
- A Compact Disk, developed by CSIRO. It acts as a 'Time Capsule', in that it has on it messages from the Australian public solicited by an outreach program and record of telephone calls.

For completeness it should be noted that a further payload was added to the satellite requirements in early 1999. A Star Camera, developed by the University of Stellenbosch in South Africa, was added at the suggestion of the University of Newcastle, with the hope that this device would add to the attitude determination accuracy of the satellite platform and to the performance of the NewMag experiment.

Due to a perceived lack of funds, there was some attempt made during this phase of the project to de-scope the mission. However, as each of the university participants had contributions linked to their payloads, only the solar array payloads were removed from the original specifications.

As a result of launch specifications from NASDA, FedSat would conduct these communications, space science and engineering experiments orbiting 800km around the

Earth at an inclination of 98.6 degrees. Due to the requirement for stability in the NewMag and Communications experiments, the specifications included a 3-axis stabilised bus. The mass of the satellite was required to be less than 50kg and the structure was to fit within a $50cm^3$ box in order to interface with the NASDA H-IIA launcher.

In February 1998 a Request For Proposal was sent out and bids for the FedSat bus were accepted from four small-satellite providers; NEC in Japan, Surrey Satellite Technologies Ltd (SSTL) and Space Innovations Limited (SIL) in the United Kingdom and a Korean consortium lead by the Korean Advanced Institute for Science and Technology (KAIST).

Drawing up the specifications for the tender required conflicts for resources to be resolved. It was at this time that the differences in goals between disparate groups began to surface. "There was a flaw in the tender process. The scientists were interviewed and asked what do you want, the engineering group came up with a set of specs and then went to the tender process. Everything should have been brought in line - science, business & finances and engineering capability as different pegs. Each peg would be moved towards the centre. If the scientists had known how much it would have cost in terms of opportunity cost and how much would have been ripped out of their programmes, they would have compromised on their specs and, to me, that would have been a more appropriate way to go." {#7}

Assessing the Tenders

The tender review process started with a technical review of the responses with the prices of the different satellite solutions were quarantined. One engineer described the process as, "We went through a big tender review exercise with a lot of people and we tried to do it the best way we could - it dissolved a little bit into more qualification rather than quantification but we tried to quantify it with aggregate scores with weightings for various issues." {#1}

Others were more critical of the process. "We didn't have a good structure for assessing the tenders. It was not clear or considered in the tender process. You should consider on what basis you will make a judgement. In my mind the judgement was too heavily based on what was felt to be the best engineering solution rather than what was the best fit with the range of objectives of the CRC, which was the research objectives, the budget, the timeline, our level of experience, which was extremely low for us." {#7}

Of the four tender responses, three were non-compliant. The names of the tendering companies have been suppressed in the following discussion.

Tender 1, Company 1 (C1)

C1 presented a tender which had a very small payload bay, such that it could only carry one payload, and so did not meet the requirements of all of the CRCSS partners with their various payloads. In addition, the solution, being stabilised with a gravity gradient boom, was not compatible with the HII-A launch vehicle due to a large boom which protruded from the bottom of the spacecraft. Finally, C1 indicated clearly that, for technology transfer such as satellite designs and documentation, a premium price would be charged.

- "C1 came up with a design that would carry a part of one payload - we wanted four" {#6}
- "C1 was not compatible with the launch vehicle and no documentation" {#1}

Tender 2, C2

The C2 tender response had only a small amount of orbit average power available to the payloads and there was no payload Interface Control Document. It was also clear that it would only accommodate at most two of the payloads for the satellite.

- "The C2 design was based on Powerpoint slides coming from a number of people so that there was no thread to it. We saw that approach as technically sad." {#2}
- "C2 came up with a design that could accommodate one or two payloads, but the design was out of the ark - it did not excite anyone in the centre." {#6}
- "From one point of view the C2 bid was so bad technically that we couldn't have flown a light bulb, so that wiped that out in terms of what we were trying to do." {#1}

Tender 3, C3

The C3 solution was able to accommodate all of the payloads, but more than doubled the weight budget for the satellite. This would have meant that it couldn't be launched by the HII-A rocket.

- "C3 came up with a design that was complex and way over budget" {#7}
- "C3 offered the best overall but it was 110 kg so it couldn't fit on the launch." {#2}

Tender 4, Space Innovations Ltd

The Space Innovations Limited (SIL) response met all of the budget requirements, and was able to accommodate all four payloads required by the CRC. In addition, SIL committed to including a great deal of in-kind to the project, and was open to including technology transfer as part of the project package.

- "SIL was the only one that came up with a design that went anywhere near meeting our scientific requirements - on budget, meeting requirements - we should have smelt a rat then." {#6}

SIL's bid had a number of core aspects that made it attractive to the CRCSS. At a price of \$A4million, it was within the CRCSS's price range and was also the only proposal that would accommodate the payloads for all of the partners in the CRCSS. Moreover, SIL were prepared to contribute an addition \$A1.5million of in-kind support into the CRCSS. In addition, SIL was prepared to make technology transfer a core component of the project, something that other providers such as C1 charged additional money for.

Internal Politics

It wasn't completely apparent that SIL was the winner however. There were some elements that were pushing for the selection of C2, even though it presented a non-compliant solution.

"This is when the next bit of politics came in, the CRC was all about politics, it was all about competing interests; [a project partner] had an association with C2 through some of the other programmes they were involved in and there was a strong political push to get the C2 bid accepted on the technical team. Immense pressure was felt; it was going to be clear to us, the people doing it, that the C2 bid was going to be very cheap. We were in fact trying to highlight the deficiencies of the C2 solution compared to SIL. There was extreme political pressure to justify and rejustify why we couldn't use the C2 bid rather than SIL." {#1}

However, in the end, SIL was selected as the prime candidate to win the bid. According to one engineer "It was clear, we had three non-compliant tenders; one excellent from C3 but non-compliant, one arrogant from C1, one abysmal from C2 and one excellent from SIL. In the end, surprisingly, the SIL bid was the lowest price and so it was a fait accompli." {#9}

Taking the Risk

A British firm, Dunn & Bradstreet (D&B), was commissioned to undertake due diligence on SIL before the contract was awarded. The D&B report gave SIL a very poor credit rating and highlighted a risk that the company was very fragile in terms of cash flow. An internal CRC review was conducted to assess the risk associated with contracting SIL to provide the bus. It identified two major risks, schedule and finance and highlighted the perceived degree of severity of the risks. A selection of these comments are given below:

- The worst case risk is that financial difficulties at SIL will cause it to cease operation, that there will be no final delivery and that staged payments will be lost.
- Based on the D&B report these risks are significant and action must be taken to mitigate against these risks (Dunn & Bradstreet, 1998).

Suggested actions to mitigate against the schedule risk included breaking the work into small work packages, ensuring transparency of SIL's operation and frequent (weekly and monthly) reports. Actions to mitigate against the financial risk included those suggested for the schedule risk and included rigorous but 'sensible' acceptance tests for payment against tangible milestones. It also suggested placing senior CRCSS personnel at SIL.

In SIL's favour, there were some positive reports about SIL from the UK, including the British National Space Centre (BNSC). According to the centre director, "I wanted to know what company it was, what kind of people they were and so I spoke to various organisations in the UK that had dealt with them and in the United States... I got good vibes." {Embleton}

In addition, SIL's cash flow situation was expected to be alleviated somewhat by a deal that they had made with SpaceDev, a company based in the United States which had apparently purchased the company around the same time as the tender process. SpaceDev was to have provided financial backing to SIL if required.

The technical risk was perceived to be mitigated somewhat by the quality of the SIL tender. "On the face of it, the SIL bid made it seem as if it was a qualified bus; [they said] that they had already built a bus for Pakistan and that all of the major sub-systems had been qualified either on ESA programmes or other programmes. On the face of it, it seemed like they had a credible technical solution and the only issue for us was going to be a trade off in terms of payloads. {#1}

So, based on a combination of the fact that the SIL tender was the only compliant tender and the perception that the CRCSS would accept and try to manage the risks, the CRCSS opted to secure the services of Space Innovations Limited.

- "SIL was a risk that we took. We knew their cash flow was bad and we knew they never built a satellite. However, we knew they had capability, we knew they had some good management in the satellite area, but this was removed soon after. However, it basically came down to the fact that SIL was the only company that designed a satellite to meet our requirements and this was a big factor in our decision." {#6}

- "SIL was the only one to match. The only problem was that there was a risk with the company. Also the CRCSS knew that they had never flown a satellite before. They did have a space qualified design, but had flown some equipment." {#7}
- "There was a conscious decision to take the risk. We knew there was a risk with SIL's viability, but at the time the risk seemed smaller than it turned out to be. At the time they had backing from SpaceDev." {#9}
- "SIL had good documentation and they met the uni's criteria and they met all of the requirements for the different payloads and the price was a reasonable price. The biggest risk was the financial situation. The thing we missed was we should have spent more time getting to know them." {#1}

The decision to proceed with SIL was one of the first explicit areas where the CRCSS decided to trade risk for project cost. While the company was seen not to be as experienced as some of the other bidders, the CRCSS was unwilling to either de-scope the project or seek additional funds.

After selection, SIL, as the prime contractor, was invited to become an associate member of the CRCSS in an attempt to draw the two organisations closer together. "One of the steps we took in the CRC was to appoint SIL as a supporting participant to the centre in recognition of the contribution they would make to the centre. SIL estimated that they put in a million dollars of additional effort… properly costed" {#7}. Another reason for doing this was, "Rather than seeing themselves as a contractor and providing a piece of equipment under a fixed price, I want them to regard themselves as a partner in the CRC, working collaboratively… I made this point pretty strongly." {#6}

7.2.4 Satellite Development in the UK

The satellite being developed was based on what was presented by SIL as a 'standard MicroSIL' satellite design. The main sub-systems of the satellite are shown in Figure 7-4. As can be seen, the satellite is controlled by the Data Handling System (DHS), which provides the interfaces between all of the other main subsystems; S-band

Communications, Power Conditioning System (PCS) and Payloads. This is a fairly traditional structure for a satellite system, and was detailed in Chapter 5.

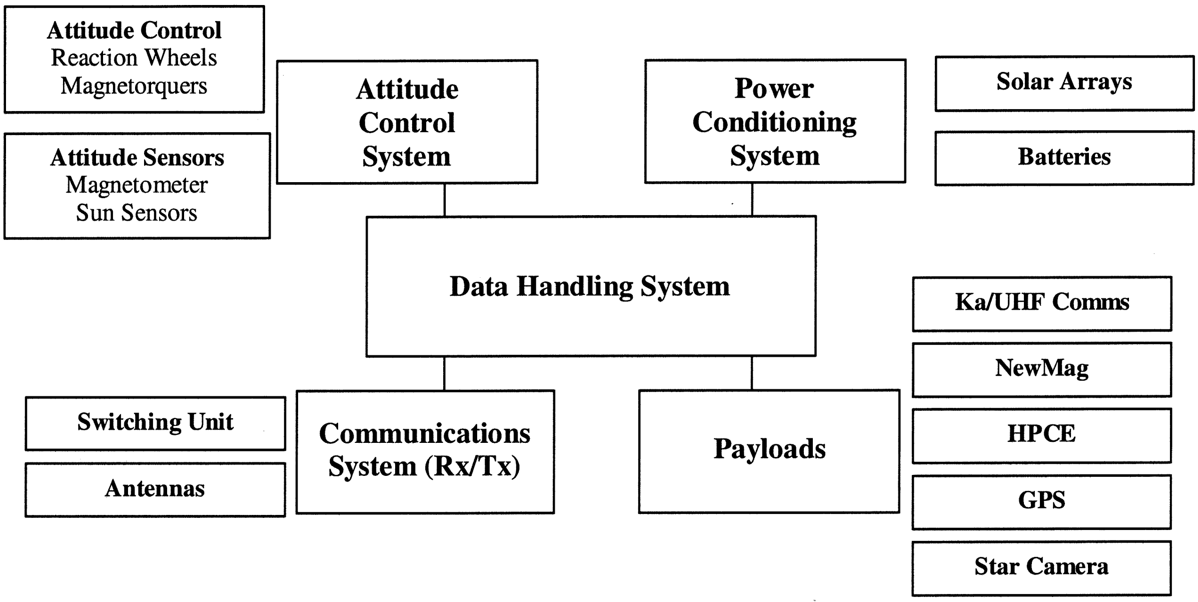


Figure 7-4: FedSat Architecture

The physical structure of the satellite was quite compact. The Data Handling System and Power Conditioning System platform sub-elements were placed at the centre of the primary structure. This was done to "simplify the design considerably and minimise the mass while efficiently utilising the available volume" (SIL, 2000). This structure required careful and rigorous design however; if any member of the load-carrying path should change, the complete design would require verification once more. Each of the payloads sits upon the payload shelf above the main satellite sub-systems.

The physical design of the satellite is shown in Figure 7-5.

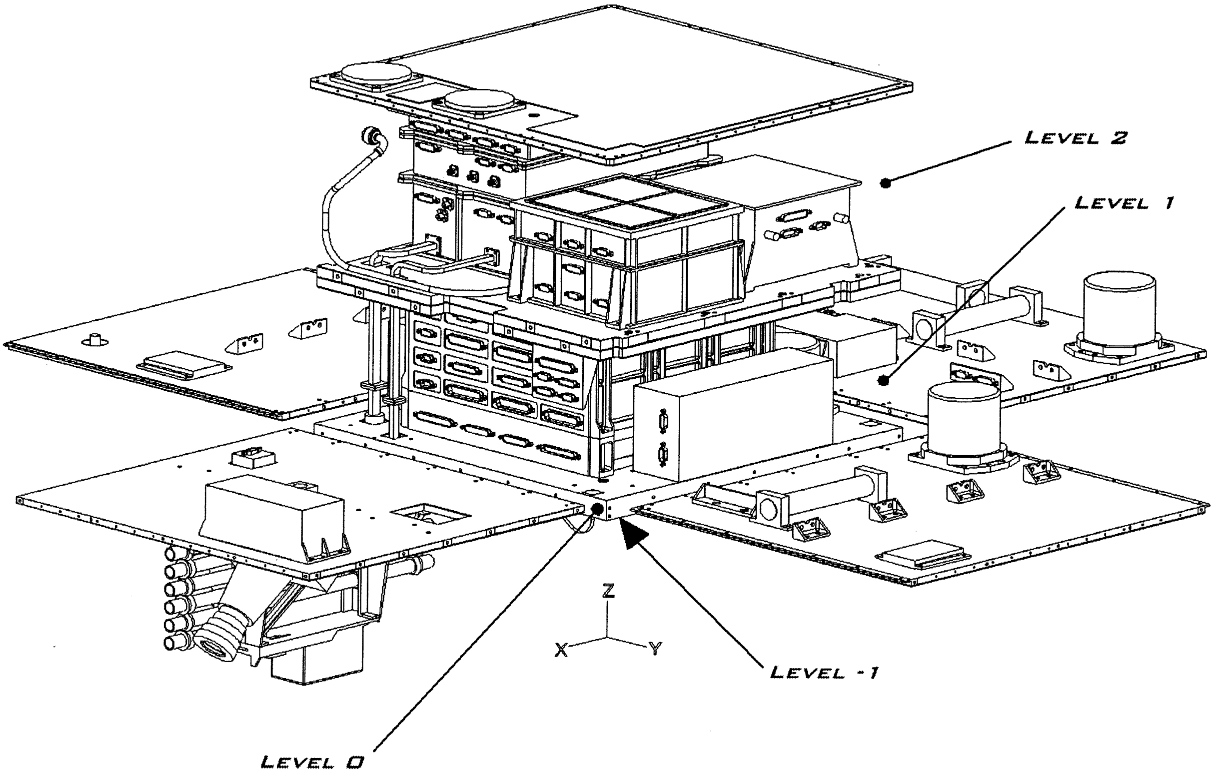


Figure 7-5: The FedSat satellite bus

FedSat Platform Technical Specifications

- Physical dimensions of approximately 500mm3 and a 2.5m deployable boom. The total mass is 58kg.
- All on-board processes are controlled via the Data Handling System (DHS)
- 3-axis stabilized Attitude Control System (ACS) incorporating:
    - 3 digital sun sensors and magnetometer to determine orientation
    - 3 reaction wheels and 3 magnetorquers to provide orientation torques.
- Power Conditioning System (PCS) providing a regulated +28V bus that generates an orbit average power of >35W in the summer season. The energy sources are:
    - Body mounted GaAs solar cells on 4 sides of the spacecraft
    - A NiCd battery split into 2 packs
- S-Band communications providing:
    - Uplink: up to 4 kbps
    - Downlink: up to 1 Mbps

Starting off well

As was agreed during the tender process (and reinforced by the recommendations of the Dunn and Bradstreet report) two CRCSS personnel were placed at SIL "to facilitate technology transfer to subsequent projects" and to assist in the development of the satellite bus. Not only would these engineers add to the resources available within the project, but they were also tasked to return to Australia after the satellite's completion as a "walking user manual"{#3}.

One CRCSS engineer was placed into the SIL systems engineering team while the other was placed into the SIL software team. The engineers were quickly accepted into the two teams.

The SIL employees were seen to be technically proficient, but the engineers and management were seen to be somewhat inexperienced in the production of small satellites. In the words of one of the CRCSS engineers, "SIL was quite a good little company. They did quite well, they were a good group of guys but they had absolutely no management at all. They were living day to day in terms of cash flow so that their management style was horrendous. They had really good technical people but no overall technical management, no experienced people guiding them and telling then where the pitfalls were and what to watch out for and that was their undoing. They had a lot of keen young engineers that got things out before they should have, so had to do a lot of retesting and a lot of rework which was not good for their cash position or their image either." {#3}

In order to monitor the project from the point of view of the CRCSS, contract management was divided into two areas, financial and technical. Technical control was given to the CRCSS Systems Engineering Group made up of Mike Petkovic and Mirek Vesely, while financial (and overall) control was given to the overall Project Manager, Chris Graham.

The Start of Problems

Towards the end of 1999, tensions between SIL and the CRCSS began. SIL started to slip on deliverables and CRCSS staff started to become concerned. "We were still very happy with SIL for six months or a year or so, but then they started negotiating their future... Their cash flow was low." {#6}

In addition, the money promised to SIL from SpaceDev never arrived. "In the end, SpaceDev did not deliver the dollars and SIL found themselves overcommitted. Our project schedule kept blowing out as SIL was looking for joint ventures or partners." {#2} The financial controller of SIL was also concerned. "The promised investment from SpaceDev never came - the only reason why the company was sold in the first place was to raise the additional capital. One of the reasons why we went with SpaceDev is because of the funding issues. Bastards." {#13}

Another issue was the removal of one of SIL's key technical people from the project due to internal SIL politics. This was a concern for the CRCSS, as it left no one on the project who had previously built a satellite. "I lost confidence in SIL's ability to deliver when Kim Ward was replaced as the Managing Director, as he was driving the company from a technical point of view and as soon as he was taken out of the loop then I think the underlying expertise on which SIL had built its future had just been removed. Young people, as good as they were, had never actually built a satellite. He was the only one that had, so the writing was on the wall from then on." {#6}

SIL were still keeping the CRCSS informed of their financial situation however. One member of the CRCSS executive said "SIL kept us informed of the viability of the company. They kept the contractual managers informed on what was happening but we weren't sure that the information was always correct. We didn't know the veracity of their claims – gave us feelings of hope." {#6} "We did get fairly constant updates. We were fairly comfortable, then unsure, then comfortable, then unsure." {#9}

The Critical Design Review

It was at the first critical design review (CDR) that it became apparent that the SIL delivery schedule was beginning to slip. However, the CRCSS decided to pay SIL for the milestone attached to a successful review. "Everything that they said sounded ok, it was only after the contract was let that we started to see that things weren't quite right.

Even the so-called CDR which wasn't a CDR which was referred to as the platform review - we fought against it being called a CDR as there was no way it was a CDR." {#8} Another member of the review team agreed "At that point it still seemed ok but it was getting clear that they had great limitations in their mechanical design but we weren't that concerned as mechanicals were relatively easy to correct; that's where Mirek came in - Vipac wanted the mechanicals and they had the experience so that wasn't seen to be too big an issue. The software was going to be an issue but we had [the two CRCSS engineers] there. Then again what was the alternative?" {#1}

There were also internal frustrations from the CRCSS staff placed at SIL. "There were a lot of people flying over back and forward and staying in hotels and having a great old time and making sure that everything was going well because we were telling them that it wasn't and they didn't see anything in their trips that persuaded them not to give them money." {#3}

In late 1999, interviews with SIL staff began to highlight problems. The financial controller said "[I] know that the company is undercapitalised. There are insufficient funds to progress." {#13} Delays were compounding the situation and the company was looking at restructuring. "James [the marketing manager] is looking at finding other partners – we need money!" {#16}

In addition, fundamental disagreements arose over the approach to the satellite project. From the beginning of the project, both parties, the CRCSS and SIL communicated their desire to build FedSat using the 'Small Satellite Philosophy'.

However, one of the core areas of disagreement between the CRCSS and SIL was what exactly the Small Satellite Philosophy was. The CRCSS believed that SIL was taking too many risks, and SIL management believed that the CRCSS was trying to micromanage them using 'big satellite' techniques. In the words of one of the SIL executive "A small amount of big satellite philosophy screws up small satellites" and they used this argument to "do things our way" {#14}. The CRCSS believed, conversely, that SIL did not have enough experience to make informed choices about the satellite implementation by themselves.

There were other issues between the SIL management and the CRCSS management, especially as the CRCSS management started to demand more control over the project. One of the CRCSS engineers believes “SIL did not give the CRC for Satellite Systems enough credit for our own engineers understanding of the technologies involved in building small satellites. They had never built a small satellite, nor had we, but they being a satellite company believed that they knew what was required and were not prepared to listen to our arguments.” {#2} “If they hadn't overextended themselves and had been more conducive to advice from us in the areas that we understood, they probably would have got there.” {#1}

SIL saw it in a different light. “They are trying to micromanage us. Just because we take a different approach to them doesn’t mean that we are wrong.” {#14} SIL accused the CRCSS of not trusting them and the CRCSS accused SIL of ignoring or hiding technical problems. To the CRCSS, this was not micro-management, but risk management {#2}.

The partnership first envisioned for the two organisations started to become looser. Personal issues between SIL staff and CRCSS staff, often started over technical issues, began to surface. “We probably didn’t have the right structure in place to manage SIL. We left it up to the project manager to manage them … Everyone knew best of course”. {#2}

There was also the issue that the CRCSS was receiving information from two sources, their staff placed at SIL and SIL itself. “The CRC as a whole had not the best relationship because obviously the engineers would tell us the truth. We would then report back to our bosses which was either Brian or Chris and they would ask [name withheld] and he would say something different and blatantly lie. That dishonesty at the interface on SIL's part gave their organisation a very bad look.” {#3}

“At the CRC we had a lot of experience in terms of knowing the process and a lot of questions were shrugged off as 'that’s the way small satellites were done' - that catchphrase was used a lot, knowing that the CRC partners had only worked on large projects before and it started to wear thin. I don't know what caused the (SIL) systems management to lie but it strained the relationship between the organisations." {#2}

All the while, the project schedule slipped and the SIL budget became tighter, which became a problem for the CRCSS. "The CRC kept paying money even though milestones weren't being met. It is a matter of weighing-up the risks. There was a period where if we had stopped paying money overall then the project would have gone down overnight. The Systems Engineering at our end started getting hazy." {#8}

"For some time it was considered that without that money we would go nowhere and if they went into liquidation overnight then we would lose the whole lot." {#6}

7.2.5 Transition to Australia

In April 2000 it became apparent that SIL's financial problems were becoming severe. SIL staff hadn't been paid for a month and CRCSS management was becoming concerned. "We knew that they were going to go under and of the potential receivership certainly for about two months in advance." {#6} The uncertainty continued for a number of months; for example in April 2000 SIL stated that they had a backer, but by late June this fell over.

An executive meeting was held to assess the situation and it was decided to send a CRCSS technical manager to the UK to be on the ground in the case that the company went into receivership. However, there was still hope that SIL would be able to find a company to rescue it. "For a lengthy period we were in denial, firstly that the company was in trouble, secondly that the trouble was as bad as it was and thirdly that even when it went broke that the thing could still be mostly built in England." {#2}

A number of precautions were taken, such as labelling the CRCSS equipment which had already been purchased as part of a milestone payment and the rental of a secure lockup in a neighbouring warehouse.

Bankruptcy

SIL declared itself bankrupt and ceased trading as a company early in July 2000, without completing the FedSat platform. Many of the platform components and parts were in the final stages of preparation prior to platform assembly.

While SIL's bankruptcy was not totally unexpected, there were a number of 'how could this have happened?' questions, both from the SIL staff and the staff at the CRCSS. With the benefit of hindsight however, it was commonly agreed that the two main causes contributing to the demise of the company were poor cash flow and a lack of systems engineering and technical management causing a slip in the schedule. The fact that SIL had promised such a large in-kind contribution to the project was also a factor in the company's cash-flow problems.

The CRCSS was given one day's notice on the eve of the bankruptcy. The following day, after gaining permission from SIL management, the staff placed in the UK removed all of the equipment identified as belonging to the CRCSS and took it to the lockup.

The following weekend was the opportunity for the CRCSS to work out what to do, based on plans developed previously. According to one of the Executive, "We had lots of plans and contingencies – simplistically, it was to recover everything." {#9} How this occurred however, was more complex than at first thought.

Recovering the Equipment

Before the company went into receivership, an agreement was already in place that the CRCSS would have access to equipment and documentation to continue the satellite project. However, after the company was put into administration the receivers initiated a bidding process for the purchase of test equipment, the formal design and satellite components. The CRCSS placed a bid, and also began discussions with another company Surrey Satellites Pty Ltd (ironically one of the unsuccessful tenderers) to contribute money towards a Surrey Satellites bid for the company in return for certain assets such as the Electrical Ground Support Equipment and access to key staff.

Some of the technical team thought that it could have been done better however. "It was very frustrating for the technical team because there were plans afoot to salvage as much of the designs, databases and hardware as possible. This could have been done by a seizure early on. It got into 'let's wait for the administrator and let's do this all above board and what that degenerated into was a waiting game where we had very little access to the hardware.' {#1}

"Everything in the CRC is formulated on timescales. We put in a claim for what we could put in the budgeting process for what we could do." {#6} "I suggested afterwards that we put in an ambit claim to buy them. We should have upped our ambit claim. With what we paid SSTL we should have upped the ambit claim." {#2}

Eventually, Surrey Satellites Pty Ltd, one of the original tenderers for the satellite project, was successful in purchasing the business assets of SIL. Although this meant that the design of the satellite was owned by Surrey, the CRCSS was able to licence the knowledge of the satellite to complete the units and to get all of the other components.

Shipping to Australia

There were different approaches to risk during this transition of the satellite back to Australia. One half of the CRCSS executive wanted to ship the equipment home immediately, assess it and work out how to move forward. The other half wanted the equipment to be finished as well as it could be by the now unemployed SIL "experts". "There were different philosophies on how you do the work. One was risk averse, the other was suck it and see." {#2}

One of the core areas of discussion arose from the fact that the two commercial SME partners of the CRCSS, who were supplying most of the technical staff for the project, each believed in a different approach to bringing the satellite back.

The engineers in the UK were keen to have the units completed there where possible. "Unfortunately we couldn't get any funding and people in Australia were calling to get it back. Auspace thought they had the expertise and could finish things off. We were trying to get things done but in the end we were unable to get the people we required and all was shipped back in an incomplete state to Australia. It was frozen with no access to any of the gear - Auspace wanted to assess it and not have the UK team over or getting the gear into a position where the work could start. They were holding out to finish it off themselves. They wanted funding to go directly to Auspace to finish the satellite." {#3}

It was decided fairly quickly that some of the work would be undertaken in England. The CRCSS engineers arranged for clean room facilities at Rutherford Appleton Laboratories and were able to undertake cataloguing of the equipment and finished some engineering work on particular units using now-unemployed SIL staff.

An engineer who wanted to ship the units directly to Australia believed that there were two problems with this approach:

> "(1) we had some hardware and there was some working going on in the UK to complete this hardware. I was one of the key people saying that we should not be completing this work in the UK - we should bring everything back here to understand it and see where the holes are bring over the two or three or four people across, hire them for six months. We are in a dire situation here - if we are going to make this work we have to act quickly decisively and lets do this.
> (2) They had already committed three quarters of the funds - they had a million dollars left plus additional Australian funds to complete the satellite. Rather than bid aggressively to get the whole lot of what SIL used to be and then dumping the rubbish, they went into some stupid agreement with Surrey where they thought by only bidding \$A50,000 they were making a real bargain. What transpired was that SSTL put in a bid of a quarter of a million dollars - once Surrey had the technology we had wasted 5 months and we had to try and extract things from them." {#1}

In the end a hybrid approach was decided upon, with some of the SIL staff reemployed to finish what they could in the following months before shipping the half-completed units back to Australia. "I think that we had the right level of risk, we had [company] who manages around risk and minimises that at the charge of an arm and a leg. Neither did I want to just pack it up and ship it back" {#6}

There were also a large number of external sub-contracts in the United Kingdom which had to be finished, and CRC staff located in the UK facilitated these. According to the project manager at the time "contracts were picked up and contracts taken over. Essentially the whole design was brought back to Australia. Everything was taken over by the engineering management team." {#9}

"In the long term we didn't do too badly after the transition. I think with the knowledge we had at the time it was a good strategy to reemploy some of the guys - they had the knowledge. We tried to get everything to a built functioning stage before it came back." {#2}

Back in Australia

Two months later the team and most of the equipment and satellite components were back in Australia. It was decided that the satellite would be finished in the Auspace offices in Mitchell, Canberra. However, there was very little infrastructure in place. "When we got back from the UK the offices were not set up, the cleanroom wasn't ready - we had to physically do it ourselves. I think it had to do with the culture of the project; no one really wanted to do anything." {#3} This lack of progress was attributed to a "lot of political manoeuvring" on the part of the partners after the demise of SIL. {#2}

Another engineer agreed. "The room wasn't set up - that was terrible - we weren't treated all that badly on the project but we weren't necessarily made to feel as an important part of the team." "We came back and nothing was set up - because the people controlling the facility didn't have the will or the finances to get it into a good state. They didn't have anything so if you wanted the facility you had to spend the money - you had to filter through all of the garbage." {#2}

This caused a delay to the recommencement of the project; even the project manager believed that things could have been started more quickly. "It took a number of months - few compared to some of the things that may have happened. We never had the resources."

There were also some issues about the state of the equipment that arrived. We found that there were still many things to be resolved with the satellite, from poor workmanship to systems engineering. "It was going to be a big task". {#3}

Looking Ahead

After the SIL collapse and the units were returned to Australia, a new phase of the project was to begin. The CRC had contracts with some of the major suppliers, they had most of the satellite units and they had four engineers with in-depth experience in the satellite bus. The challenge was now to assemble a team to complete the satellite, while ensuring that there was enough money available to finish the project.

"In hindsight it was a great problem to have because it really challenged our people to find solutions and they did it. It turned a fixed price project into a research programme - we can be grateful to NASDA for the delay of the launch ... I had all the confidence necessary in the people doing the work". {#6}

Some however were still bitter about the SIL issue. "Looking back now I am even more convinced that the wrong decisions were made. This was the crucial mistake of the CRC - they didn't act quickly, they didn't act decisively, they had already paid three quarters of the funds without receiving anything and they were into arse covering." {#1} This opinion was endemic of the turmoil and uncertainty following SIL's collapse, and certain levels of conflict within the CRC itself.

The project management decided that the best course forward was to build an independent, tight team with a common goal and approach to building the satellite, and then to isolate them from any politics. International experts were to be brought in to help achieve this 'common path' towards project completion.

7.2.6 Satellite Development in Australia

With the return to of the satellite to the laboratories in Auspace, the project was due to recommence. However, it didn't start immediately. "It took a very long time before it dawned on people that we had to adopt a completely different approach, which was that we had to build the satellite itself." According to some of the project leaders this delay was due to the need to balance demands of different project stakeholders.

As with the shipment of equipment back to Australia, a difference in implementation styles arose within the CRC. Some of the engineers wanted to start work on the equipment immediately, while others wanted to do a formal review of every unit, starting with physical reviews of the board. "In the end we opted for the slower but safer approach of looking at everything for three months. This was the least risky thing to do but it cost us time. I think the unit preparation took us longer than necessary." {#3}

The Auspace clean room also made the implementation of the work reasonably difficult, since although there were currently no other projects being undertaken, it was being maintained at a very clean level. "Auspace's cleanroom started out in class 100 instead of class 100,000. This was over the top and just cost so much time and so much annoyance and equipment - it was a really bad way to start off the project when we just wanted to get in there and do the work." {#3} Auspace engineers disagreed however. "We had to do this the right way; the clean room was part of this." {#1} It was when international experts were brought in to review the progress of the satellite project that these restrictions were relaxed; in effect the international reviewers were used as independent arbitrators to resolve disagreements.

Working at Auspace

Working at Auspace also caused some friction within the project members. Where convenient, Auspace staff were employed to undertake technical work as they were collocated. "It was hard, as we had to rely on the expertise from companies like Auspace to do the work – painting, soldering, conformal coating etc - as that was the way we were doing the project at the time. It would have been better going to a high quality soldering house in Australia - getting other people to do the work. Relying on Auspace seemed to be a bad thing because they had other interests and projects going and they had their own agenda."

The 'own agenda' issue was raised a number of other times throughout the development of the project. "They seemed to want to take control of the project engineering in terms of budget and work and control but not take on any of the responsibility and we were based at Auspace and so it made it very hard and once the decision was made not to make them the prime contractor for the satellite bus, it made relationships frosty and the way they acted hindered the project in a lot of ways." {#3} However, when interviewing staff from Auspace there was no mention of this agenda.

Building the Team

To compliment the four engineers with knowledge of the satellite a team was formed in Australia. As well as sourcing staff from CRC partners, the project also brought in a number of young students from partner universities. The project quickly grew from four technical engineering staff to eight.

Chris Graham, the project manager during the time of operations at SIL, retired from the CSIRO after the return of FedSat to Australia and was replaced by Mirek Vesely, the platform manager from Vipac. As Mirek was based in Adelaide, it was decided to bring in a systems manager from Auspace to manage the day to day technical development of the project. This person was not accepted very well by the team and three months later was not reemployed after the 2000/2001 Christmas break.

Managing the Process

There were a number of challenges identified during the management of the satellite production phase of the project in Australia. These included the distributed nature of the team, the separation of the management of the ground station from the satellite, issues of cash flow and budget and technical difficulties.

The project was managed with a very flat structure; most of the team were across many of the issues involved. Other people in the project had different ideas about how the project should be managed. "We never managed, even internally once the collapse came, the project as a commercial company would have managed a project." These people believed that the project should have been managed in a more hierarchical, fixed-price manner: "It should have been a fixed price project - we set in place the project control mechanisms, the project management mechanisms and responsibilities (delegation of authority etc) and we implement a tracking structure and a risk management philosophy." {#1} However, this approach was discounted by the CRC project manager, who believed that the constraints on the project such as available funds, cash flow, location, and politics necessitated a more flexible approach.

While much of the team was located in Canberra, elements of the project were distributed across locations in Australia. Indeed, the management of the project was undertaken remotely from Adelaide, with the project manager spending one or two days a week in Canberra. Also, the different payloads for the satellite were located in Brisbane, Adelaide, Newcastle and Sydney, which created challenges in communication.

Even though the project was being managed by the CRCSS, cash flow and lack of resources were still identified as a major issue. The first step in finishing the project was for the project manager to develop a budget to completion. This initial budget was $A3.2M short of the remaining funds in the CRCSS. {#2}

In order to resolve the budget issues, the CRCSS applied to the government body AusIndustry, who managed the CRC process, for an additional $A2M supplemented by $A1.2M transferred from the research projects within the CRCSS. This was eventually successful, although it meant that a lot of the money for ongoing research was taken away from the payload groups.

However, while more funds were being sought, there was pressure on the team and the managers to 'make do' with what they were given. "The payments quarterly couldn't keep up with the expenditure so I had to tone down what we did. Cash flow became a real issue when we started to run short of cash and we didn't have the $A2M. Even when we were promised it for the next 10 months it never came to fruition so we were getting squeezed more and more slowly." {#2}

Finally, there were many technical issues to overcome. Two of these issues are illustrated in the boxes below. It can be seen that different approaches were taken to solve the technical issues presented; one through solving the problem using existing resources, the other by outsourcing the work to an external contractor.

Case Study – Power Budget

After the satellite was shipped to Australia a number of modelling tools were developed to investigate the operation of the satellite in orbit. It became apparent to the project team that the satellite's power budget (the amount of power available to the satellite) would only be capable of operating the satellite alone, with no provision for the operation of the payloads.

In order to address the power needs of the satellite a number of systems had to be redesigned, including the Attitude Control System (see below) and the satellite batteries. In addition, the operation of the satellite in orbit had to be changed, with scheduling of the payloads to match the available power.

This problem was largely solved with resources within the team using existing units, apart from the Attitude Control System.

Case Study – Attitude Control System

It was found early after the return of the satellite to Australia that the SIL ACS electronics had a number of deficiencies. The electronics were power hungry and placed a large burden on the DHS for calculations and were subject to noise from other electronics components.

Given the size and skill set of the project team and the importance of the ACS electronics to the success of the satellite mission (a full or partial failure of this system would cause problems with both communications and power) an external contractor, Dynacon, was chosen to redesign the board and provide embedded software to manage the attitude control system.

The design used was for another satellite, ChipSat, and tests on ChipSat uncovered a number of faults with the ACS system. "Having [Dynacon] in there saved us a lot of time and effort - they found a lot of problems in vacuum testing. ChipSat also found problems – which meant we had to pull apart the satellite, this was complex in the SIL design, a few times before launch." {#1}

Reviewing Progress

During the development of the project in Australia, there were a large number of formal project reviews. These reviews were chaired mostly by members external to the project team, bringing in team members as required. The different project reviews are shown below:

2000	13th – 16th November	Tiger Team Review after bankruptcy of SIL
2001	14th – 15th June	Internal FedSat Review
2001	27th – 29th June	DISR Review of Project
2001	18th July	FedSat Material Review
2002	14th March	Internal Review of FedSat Schedule and Milestones
2002	20th May	AusIndustry Review of FedSat Project
2002	9th Jul	Internal FedSat Review

The reviews were designed to give the project team guidance, building off the experience of the external reviewers. These reviews would focus both on the engineering aspects of the project, as well as the project management approach being taken.

They were greeted with differing views of their success. "The project reviews did help the project; they helped us get our documentation together. However, they were in not enough technical depth and review staff with not enough experience to get into the detail." {#2}

Some, mostly the technical engineers, thought that they were a waste of time however. "There were countless review meetings with experts flown in to try and give us some guidance and tell us what was going wrong. I don't think that anything technical came out of these reviews in terms of us doing anything wrong. Everyone had their own opinions." {#3}

There were others that were even less diplomatic. "Our energy was always being diverted to responding to ridiculous reviews or arse-covering costings." {#1}

The reviews themselves also became political. Firstly, they were used both to demonstrate progress of the team "The reviews that we had with the external reviewers were a good political exercise to demonstrate to the board that we were doing something."{#4}. However, some team members also used them to obtain support for their view of how the project should be managed. "The reviews confirmed some of the ways that we wanted to proceed. You had Auspace on one side (a $A10m job in 6 years vs. $A1m job in 6 months). I was trying to be the middleman. I sympathised with both sides and the reviews helped me to do this." {#2}

However, when asked whether the reviews made the project any more efficient, the responses can be summed up by one of the technical staff. "We always tried to come up with something positive. The guys all tried to come up with something positive whether it was a plan, schedule, work packages or technical decisions. When the pressure was off - nothing." {#1}

Doing the work

The work in Australia can be divided into a number of distinct phases; unit preparation, electronics and mechanical integration, satellite integration and satellite testing. A fifth phase, rework, was also identified as a phase of the satellite completion.

Phase I – Unit Testing.

During this phase, the units were prepared in isolation and then integrated into the different satellite subsystems. This was a learning phase, as much of the tacit knowledge about the units still remained in SIL staff overseas. According to one engineer "it wasn't ideal but it went ahead. Each subsystem was completed to a stage where we felt it was ready for integration." {#3}

A large amount of systems reengineering took place in parallel to meet the required specifications for the project. A number of issues which hadn't been recognised at SIL, such as a lack of on-board spacecraft power, poor harness design, the Attitude Control System and DHS errors, were identified.

Phase II – Electrical and Mechanical Integration

After most of the subsystems had been integrated, the next phase in the development of the project was the electrical integration, known as 'Flatsat'. This involved testing the different units together as a system on the bench.

"[This phase] started too early because we were trying to meet a tight deadline and the units hadn't gone through exhaustive unit testing. We didn't have the money to do exhaustive testing, to buy the MGSE and the ACS sensors and actuators and test beds for the DHS etc but we went to an integrated system as quickly as possible to find bugs which would have been found in exhaustive unit testing." {#1}

During this phase the mechanical integration of the satellite was performed in parallel. This included the manufacture of the satellite harness, the individual piece parts and the overall mechanical build.

Phase III – Satellite Integration

Once the electrical and mechanical systems had been tested, the satellite was integrated. This brought together the entire system, and a series of tests similar to those undertaken in Flatsat was performed. It was in this phase that many of the changes to the satellite were tested to ensure that they interfaced with the remainder of the satellite system. A selection of these changes included the rewriting of the majority of the flight code, the new attitude control system and modified power system and batteries. In addition, a new electrical harness (replacing the one which made by SIL which was found to have too many deficiencies in the design and build) was integrated into the system.

Phase IV – Satellite Testing

During this phase the satellite was put through a series of comprehensive tests, attempting to reflect conditions in space as best as possible. This phase was the time to test the operations of the satellite, but it became apparent that there was more work to be done in this area. "The launch and early ops were underdone - there wasn't enough people and they had no experience." {#3}

Originally it was intended to complete both vibration testing and thermal vacuum testing, but due to time restraints the thermal testing was removed from the satellite programme. "We cut off thermal testing ... [replacing this with] unit testing of identified problem units to get rid of the risk." {#7} "We still spent money on the thermal vac chamber. We didn't have enough time or money to do it but the executive and board wanted to be perceived to be doing the right thing so even though thermal vac testing couldn't be accomplished because of the schedule they wanted to give Auspace money and do it in parallel in case there was a slip." {#3}

It was during this phase that the relationship between managers and the engineers became tense. “The engineers worked relentlessly when really they have been put in that position by management putting a lot of money in certain areas - engineers made up for it by putting in a lot of free hours. In a lot of respects it became an "in spite of" project.” {#3}

Phase V - Rework

During the testing phase, a large amount of rework for the satellite was identified, in a number of areas including the Attitude Control System and the flight software.

However, the most serious problem was found with the DHS. Towards launch the satellite was having a problem where it would reset at random intervals. It was thought that this was due to a hardware design fault, but was later found to be due to a problem with the system using a non-verified ADA compiler which was used to save money. “In the end we found it was a hardware fault with the ERC so we had to remove the RTEMS operating system and implement a Round-Robin scheduling algorithm which meant late nights. I did that in my spare time while the software guy was rewriting functionality which wasn't that small a task and had to be done. The other version would reset instantly. We then had to tidy up that code and do the full regime of testing. That happened not very long before launch.” {#3} Because of these software problems, software engineers were included in the team right up to the launch date.

7.2.7 Launch and Operations

After the final phase the satellite was shipped to Japan along with three technical engineers. “During the preparation for launch, transport and setup in Japan we would install pyros, flight parts etc. We actually found that we had missed one of the requirements; no isolation between the satellite and the adaptor ring. I don't know how that was missed but we managed to adapt a grounding method using aluminium. We worked pretty hard and were starting to get a little bit tired and sloppy.” {#4}

The engineers there believed that they were understaffed. "Management didn't see the value in having more people 'surely three people is enough' – the engineers had to work themselves to the bone and then lots of people turned up just to watch the launch." {#3}

"There were a lot of people there at launch - what were the priorities for the project? We only had two guys for round the clock battery charging. They haven't valued the engineering effort." {#5} However, the project management believed that the amount of engineers working on the launch preparation was sufficient; there were limited funds for staff after the launch of the satellite, and a lack of experienced personnel who could do the job.

On the 14th of December 2002, the satellite was launched on the Japanese HII-A rocket and successfully deployed into orbit.

Operating the Satellite

During the operations phase of the satellite project the focus was entirely on the ground station, hosted by the Institution for Telecommunications Research (ITR) in South Australia. However, it was now that tensions arising from the split between the ground station and the satellite project, which had been performed at the start, reached their peak.

"[ITR] weren't really ready for that initial phase. They hadn't put enough effort in - the engineering team did most of the fault finding on the ground station components because they didn't have the funding as far as they were concerned. They didn't take ownership or anything constructive which was the fault of the original people in dividing up the project. They didn't have control - it was running over time - the way it was set up was a bad thing." {#6} These complaints were fairly constant throughout this phase of the work. "So much money - the way that ITR organised themselves they have a lot of things going on - developing things for other organisations. They have spent so much money - where has the money gone? … they needed a lot of help from the satellite engineering team." {#2}

However, despite these difficulties, the satellite was successfully operated for over a year. At the time of the publishing of this thesis the satellite is still fully operational.

7.3 Functional Analysis

Given the context of a chronological investigation of the satellite, the project was then analysed in a number of key areas, including the project organisation, the project phasing and feedback loop, risks and the overall success and failure of the project. This section looks at each of these different areas in turn, and also applies the CoPS tools outlined in Chapter 3 to the project.

7.3.1 Overall Project Organisation

The FedSat programme was initially organised with the satellite project itself as the primary form of coordination. The project existed to communicate design and knowledge and to combine the resources and know-how from a number of sources and suppliers. The relationship between the different companies in the FedSat project are shown in Figure 3-8 using an outline for CoPS projects developed by Hobday (1998).

The overall responsibility for the CRCSS centre activities and performance was vested in the Governing Board, which signed off on strategic planning, budget determination and senior appointments (CRCSS, 1999). The coordination of the day-to-day activities of the centre was achieved through an Executive, comprising the Executive Director and Program Leaders made up of all of the core CRC partners.

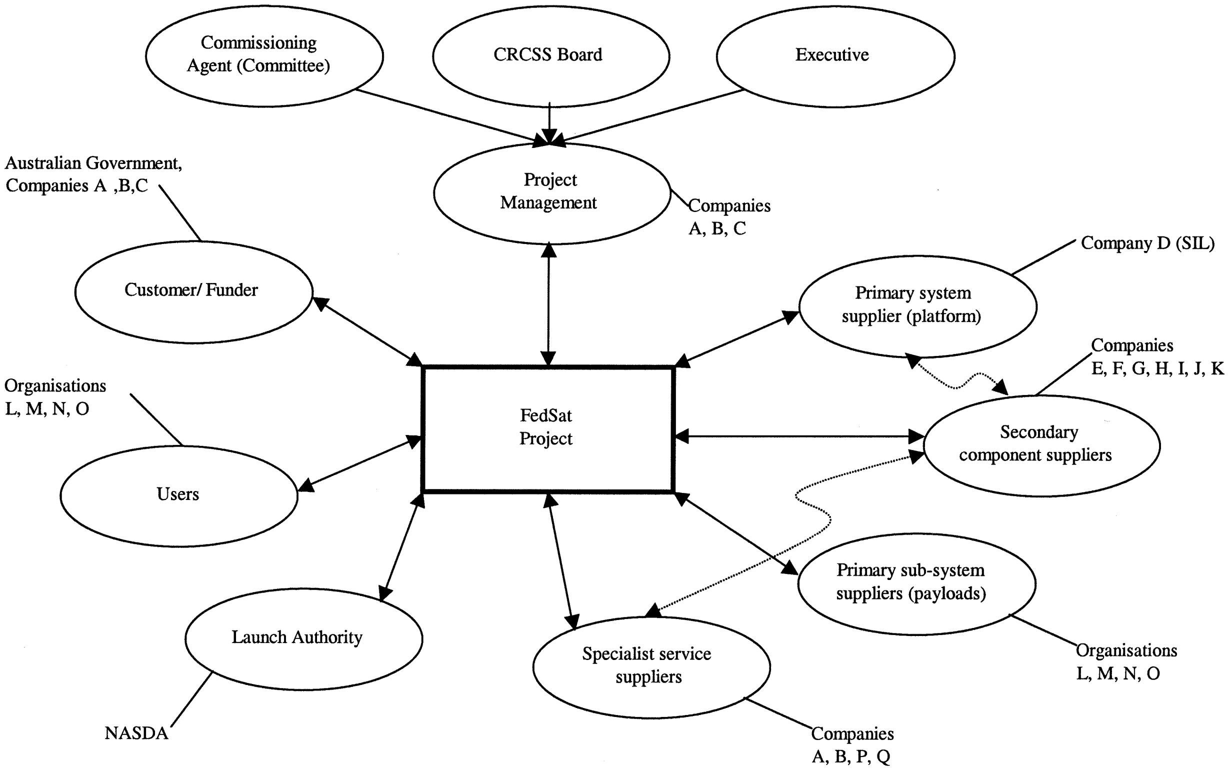


Figure 7-6: Organisation of the FedSat Project

The direct project management of the FedSat project was undertaken by representatives from three of the core partners (Companies/Organisation A to C). These representatives filled the positions of Mission Manager, Platform Manager and Payload Manager. Their main job was coordinating the other stakeholders in the project, including the primary system supplier (Company D (SIL), who was also an associate member of the CRCSS) and the sub-system suppliers (Organisations L to O who were building the payloads). The project management team also liaised with the launch provider NASDA. The executive and board were made up of representatives of the full CRC partners.

There were a large number of sub-contractors for the mission (companies E to K), coming from countries including South Africa, Canada, the United Kingdom and the United States. In addition, there were a number of specialist service suppliers (Companies A, B, P and Q) who were contracted to provide software development, manufacture, testing and analysis services to the project.

The primary users of the project were researchers from Organisations L to O, who would use FedSat as an orbiting research laboratory. One organisation in particular was also developing the Ground Station for the satellite, and was to manage the day to day operations after launch.

The CRCSS was formed out of its partners as part of an Unincorporated Joint Venture. This document outlined the goals of the CRC and how the partners were to work together and with outside contractors; for example any agreement between the CRCSS and an external body had to be signed by all core partners.

The FedSat project fit very tightly into the organisational structures of both the CRCSS and the prime contractor. For both organisations, the success of FedSat was significantly linked to their own success. In the words of one of the stakeholders "it was make or break time".

There were a number of different structures which formed during the implementation of the FedSat project. These ranged from the matrix-style management structure of Space Innovations Limited, to the Organic management structure of the FedSat Project Team. Each of these is investigated below.

7.3.1.1 Space Innovations Limited – Matrix Structure

Space Innovations Limited operated using a matrix management structure. There were a range of departments, some of which would focus on skills, such as mechanical engineering or PCB design, and some of which would concentrate on particular applications, such as the Attitude (Onboard) Control System. Staff members and information would be shared between these different departments in implementing a particular project.

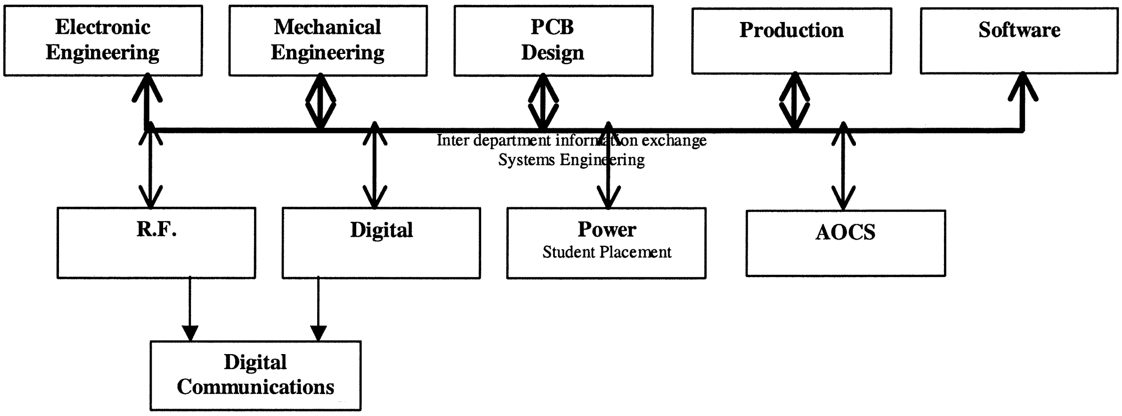


Figure 7-7: SIL Structure, Source: (SIL, 2000)

Each project was managed by a project manager, usually from the systems engineering team.

On the whole, the staff at SIL believed that this was an appropriate and effective mechanism to implement the project. Staff would gain additional skills by moving between departments, and resources could be shifted to match demand. However, it did cause some areas where individual domains were formed. For example, the RF team within the company refused to share resources with others, and was effectively a 'company within a company'. "The only reason why we let Javad work this way was that his stuff was so good". {#12}

There was also the issue of trust and honesty within the SIL organisation. Many staff reported on breakdowns in communication, particularly with members of the executive and project managers. The tea room would become a place for complaints about the management staff, who were apparently unaware of this.

7.3.1.2 CRCSS Executive – Arms Length Management

While SIL was the prime contractor, the satellite project was managed at arms-length from Australia. In this case the organisation of the project was through a core Systems Engineering Management Group (SEMG) comprising three people. "It was quite simple when we were at SIL. There was a lot of people managing the project (a lot of people who had their say) it was very top-heavy but it was a safe management role because they were just waiting for delivery of the satellite from SIL." {#3} These people would also look after a number of other functions of the CRCSS, such as the coordination of the payload groups and interfacing with the launch provider.

However, after SIL went into bankruptcy, this structure was used to manage the remainder of the project within the CRCSS, with the SEMG remaining in place. This was identified by a number of the project executives as being an area where not enough attention was spent. "The organisation didn't seem to change when satellite came back. The budget for the satellite plus extra money was given to the engineering team to manage." {#9} Essentially this team had to work with a limited timeframe, lack of resources and a high amount of perceived risk.

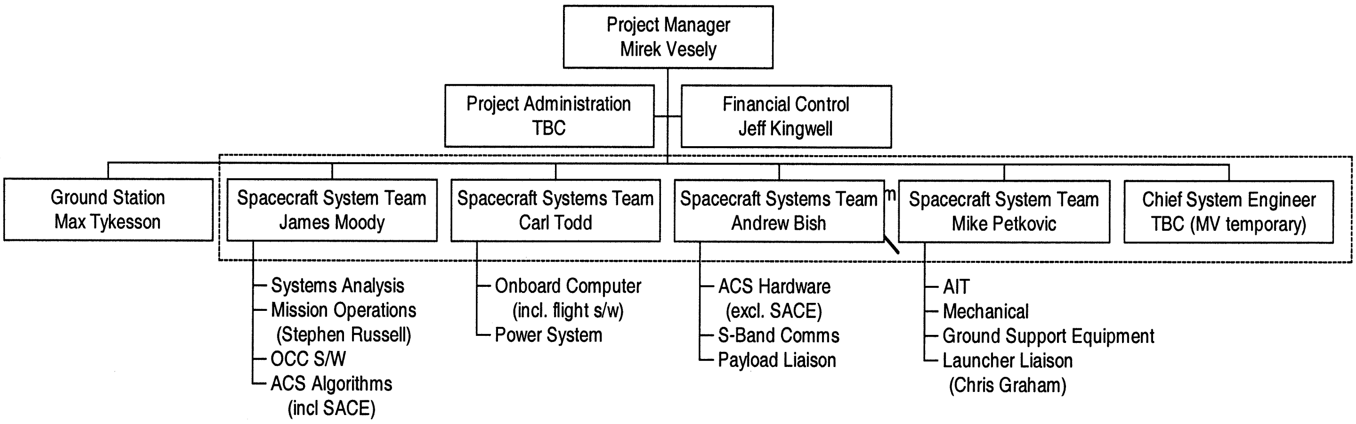
However, not everyone agreed with this method of operation. "There was a committee which was a board and an executive and Brian and then there was the engineering group and the science advisory group and an education group and an administration group. I used to think that autocratic organisations was bad but now I think they are good as you might do the wrong thing but at least you would do something." {#1} "The project was run by a committee - I never really knew exactly how it all worked. It seemed to be an overly complicated and convoluted system. I don't think that the complexity of the management was justified given the complexity of the project." {#8}

In particular, the different goals of each partner organisation were made apparent within this CRCSS management structure. "When you get university, business and government together they are all vying for what they see is valuable (whether it be profile or getting work out of the CRC) it all starts to cloud the objectives and what the best way to go about something is." {#4} "It was an ineffectual democratic structure. Democratic are good when you have cooperative group with similar goals but we had different goals" {#2}

7.3.1.3 FedSat Project Team – Organic Structure

However, in July 2000 an Overall Project manager was appointed to the project, rather than having the project run by the SEMG, with the aim of creating more definition of an authority role with the project.

This project manager implemented a flat management style, with key team members given equal status within the team. Often one team member would be given particular responsibility for specific project items. However, all budgetary control for the project remained with the project manager, who also acted as the chief systems engineer. The eventual structure of the FedSat project team is shown below.



FedSat Project Structure: Source (Vesely, 1999)

In the absence of any formal structure the project developed its own distinct organisational and management style. In particular the project team recruited people from outside the traditional areas of expertise, such as students and university postgraduates. The project adopted a super-organic structure; apart from the project manager there was very little definition of roles. In the opinion of many of the project members, this made things more difficult, rather than more flexible.

The final Assembly, Integration and Testing team was drawn from the spacecraft systems team, as they were seen to have the required design knowledge of the satellite and mission. The fundamental management strategy for this was to have the spacecraft systems team take responsibility for bringing subsystems to a state of readiness for integration into a functionally representative spacecraft system, and then on to launch.

The project manager intended the project to be organised organically: "I wanted an organic structure. The biggest issue with the team is that we had a lot of strong personalities with very contrasting views. Getting that to move along in a way with different organisations and no control. While Carl was still in Auspace you had the Auspace view and Carl's view ... One of the tasks was to identify people's strengths and to utilise them. At the end of the day it was about strengths, trust, commitment and ownership." {Vesely}

In addition, the systems manager believed in flexibility for the team: "We had too few people and I didn't want to introduce rigid working regimes or responsibility regimes so all had to help each other as required. It has been a lot about the human challenge in many respects." {Vesely}

Over the course of 2001, the group was expanded to include a number of engineers, mostly sourced from the project partners. With the Project Manager located in a different state, the executive decided to appoint a Technical Manager in 2001.

The technical manager didn't feel entirely empowered in this role. "Sometimes I felt like a technical manager, but the engineering team had such a small group that it was more of a lead role rather than a full management role due to the small number of people. Never had a budget or a say where the money is spent. I had to go to someone else for every decision so you are not making those management decisions ... I was more of a liaison officer or an advisor or a lead technical engineer. The times when I was a technical manager was when things went bad and people would start retiring to the shadows." {Todd}

The structure of the FedSat team became more organised, the closer the satellite came to launch. By the time of launch, each engineer was given a particular role within the team, and matching authority to make decisions in this role. This shifting structure was seen as a way to enforce more rigour in the satellite project, as during this phase more work had to be documented and procedures had to be followed. This process also aimed to match team member's strengths with particular tasks.

7.3.1.4 Ground Station – Hierarchical Structure

A contrast with the organic management structure of the FedSat project team was the strongly hierarchical management structure of the Ground Station team. This team was located in South Australia within the University of South Australia.

The ground station was managed by an overall project manager, with staff reporting through different channels and sub-managers. Within this structure, each role was clearly defined, with little work being undertaken outside these different roles.

The management of this phase of the project was seen to be top-heavy. Indeed, there were four managers in the chain of command for four staff members. "We've got Steve who is the operations specialist, Terry with the ground station and me with the satellite and Hidayat with the stack builder, but this is less people that will be managing us. It's not good because all these people cost more to run than the workers themselves. If you have four people working on the project and it takes more than one person to manage it then you have something wrong." {#4}

The differences in style between the management of the different parts of the project became apparent when these two teams interacted. The differences in style caused tensions between the groups. "[The ITR culture] was a terrible culture for getting anything done. It seems to be very risk averse – no one wants to take responsibility – someone's left they don't want to pick up the running - tell you over and over again that they had nothing to do with it. They email people who are not involved in the project and try to get their input." {#3}

7.3.2 Project phasing and feedback loops

While the project phases developed alongside the project and consisted of a number of feedback loops, they followed the broad structure of a typical satellite project as outlined in Chapter 4. This section looks at these phases from within the context of

CoPS and identifies feedback loops in the project and the overall flexibility of the project planning.

The development of the FedSat project was reasonably typical of most CoPS projects, in that it followed a traditional development path of bid, design, analysis, fabrication, test and delivery. These phases were agreed upon during the bid and requirements analysis phase and were built upon an experience of the operation of previous projects.

Much of the architectural innovation was undertaken by SIL during the bid phase of the project, with the project focussing on component innovation once the contract had been let. However, when the satellite returned to Australia the systems engineering group reviewed the satellite system, making changes to the Attitude Control System, the Power Conditioning System, the satellite software and the wiring harness to name a few. In essence, while there were a number of component innovation phases throughout the project, there was one main systemic innovation phase. These phases are shown in the figure below.

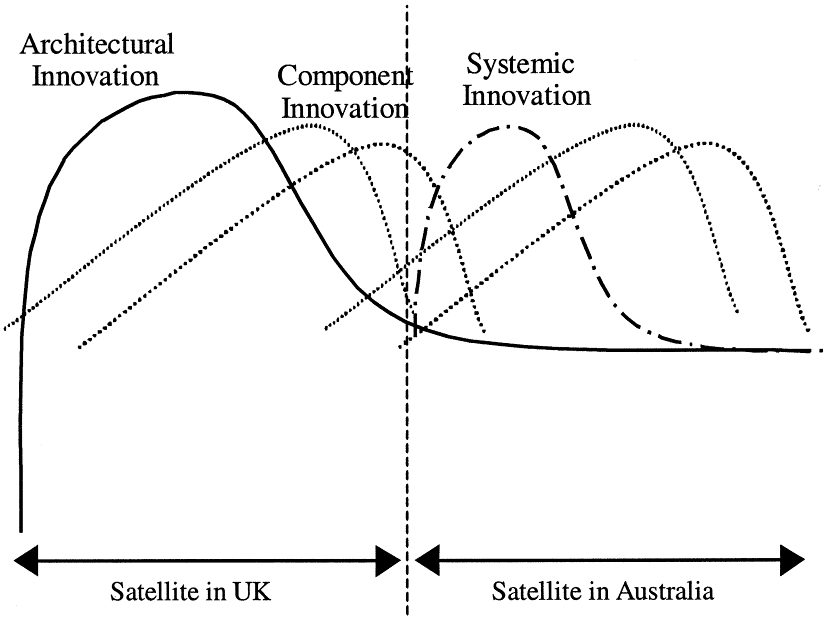


Figure 7-8: FedSat Life Cycle

There was a reasonable amount of continuity between the requirements analysis phases and the remainder of the project, with the systems engineers responsible for the bid carrying on as the project management team for the project. However, there did seem to be some confusion between what *could* occur (as specified in the SIL bid), and what *would* occur (as specified in the CRCSS requirements).

There was very little formal feedback between different stages of the project; only towards the end of the implementation phase were changes to the system documented. This was not seen as a problem to many of the participants in the team, as it was seen as part of the process of removing a certain amount of documentation from the process.

In addition, due to reduced timelines and the need to smooth resource usage, some project phases had to be executed out of sequence. For example, the manufacture of flight model equipment commenced before the testing of the satellite structure model and the development of the thermal model had been finished. The CRCSS believed that this was because SIL underestimated the complexity of the mechanical tasks and its impact on the electronic units, and necessitated redesign of some of the structural components after the satellite arrived in Australia. It was seen by some that the phases in the project were necessarily very flexible to accommodate the short schedule and reduced cost of the mission.

A planned launch date of November 2000 was a big driver on the initial satellite development. It necessitated an accelerated schedule, which in turn took time away from systems engineering and caused financial stress on SIL. Indeed, in the minds of some of the CRCSS executive, it changed the course of the entire project; "If we had known in 1998 that we would be launching at the end of 2001 even, let alone the end of 2002, we would have chosen a very different path. I believe that we would have chosen to design and build our own satellite totally from the ground up, without having to have designs imposed on us, designs that are less than optimal for what we want to do."{#6}

7.3.3 Management tools

In the implementation of the FedSat project a range of innovation management tools was used, similar to the management of other high-technology projects. Throughout the life of the project, traditional project management and scheduling tools were used to monitor progress. The evolution of these tools, from project conception and tender to design, implementation and finally Assembly Integration and Testing (AIT) are described below.

Initially, a mixture of professional and in-house tools was used to develop both the request for proposal and the main proposal from the subcontractor. These tools used a mixture of information from previous projects and in-house research. In addition, in-house accounting packages and engineering estimation tools provided information on costing for the project tender.

In the design phase, different techniques were used to manage the execution of the project. Once again, the traditional scheduling and accounting tools were used to maintain control of costs and schedules. In addition, as opposed to general procedures and systems, specific stand-alone management tools were designed to achieve particular tasks.

Finally, in the Assembly, Integration and Testing (AIT) phases, software tools were used to transfer learning from the design team to the testing team. Much of the design knowledge was stored in these tools developed in-house to speed the operation of AIT.

Tools were also used to maintain company wide technology and experience, essential for project-to-project learning. The prime-contractor developed a large number of in-house systems engineering and design tools for use in the development of satellite projects, such as SILBud (for budgeting) and SILPMP (for power management). These tools retained much of the engineering knowledge stored within the company and also resulted in large efficiency improvements in later satellite development phases.

It was also noted that the nature of this small satellite project meant that larger commercially available tools could not be bought due to their prohibitive cost. As a result, many management tools needed to be developed in-house, or existing tools were used in innovative ways. In addition, there were very few software management tools used in the development of the project software, other than a version control system.

Many of the project team remarked that additional tools may have resulted in more effective management of the project. This was limited by the difficulty in finding the correct tools, as many were aimed at mass production industries and not at the speciality satellite market. It was also noted by some that certain tools were not being used effectively by management to maintain firm control of the project.

Within the project, however, it was seen that resources were spread too thinly and across too many areas to use some of the tools already developed. As there were many unknowns to be discovered during the project tools would require constant update, and the value of these updates was not known. Many of the tools used were only used once at the beginning of the project.

7.3.3.1 Modelling Tools

It was believed by the CRCSS management that certain tools could be used to make the project more cost and time effective. It was asserted that project costs and schedules could be reduced if much of the design and testing phases were performed using engineering prototyping and modelling tools. This was effectively a risk management strategy chosen by SIL, with the key to success being the intelligent choice of areas to focus upon.

As such, a number of in-house modelling tools were developed. These include tools to model the power budget of the satellite and the attitude control system, as well as the Finite Element Model of the satellite structure and the thermal model of the satellite in space. As the project evolved and more was understood about the operation of the satellite, these tools were developed in parallel. These tools became sophisticated enough to become simulators used to drive system tests for particular satellite units.

7.3.3.2 Technical Interface Tools

As there were many units and sub-systems to test, a number of technical interface tools were developed in-house to assist with the automation of this testing and the simulation of a ‘realistic’ space environment. For example, tools were developed to drive inputs for the Attitude Control System which would simulate the magnetic fields and sun intensity on the sensors. These tools were eventually integrated into one unit known as the Electrical Ground Support Equipment (EGSE).

In many cases these technical interfacing tools, with their simulation of the space environment, were integrated with the modelling tools, which provided a dynamic model of the spacecraft, to provide a dynamic systems environment for Integrated Systems Testing. These combined tools were also used to highlight deficiencies in the hardware and software, with a main focus on testing the satellite system as a whole, both pre- and post-launch. The complexity of this dynamic model grew with the development of the satellite, and was most developed in areas of higher perceived risk.

In addition, the technical interface tools was eventually adapted as a major component of the satellite Operations Control Centre software, used to communicate with the satellite in space. This was seen as a useful move, as it would be the same equipment used in space as on the ground, with the same tests being carried out.

7.3.3.3 Process Innovation Tools

The main process innovation tools used during the project were ones of quality management. Within SIL, a sophisticated tool was developed in-house to manage document version control and sign-off procedures. These procedures were transferred to the CRCSS with the satellite, but the tools were not used after the insolvency of SIL.

Additional tools may have been useful to form a closer integration between the contractor and suppliers through the integration of information systems and joint problem solving. However, other than progress report spreadsheets, none of these tools were used. Throughout the project, there was a tradeoff between the available resources and the value added through the use of these tools.

7.3.3.4 Project Management Tools

The overall project was managed using Microsoft Project. This project planning tool was also used by the prime contractor to manage the arrangements with suppliers and other outside company stakeholders to monitor the production of externally manufactured goods.

As discussed below, there were a large number of risks inherent in the FedSat project, due to its developmental nature. However, there were no tools used for risk management to help with the identification of these risks and effective mitigation and contingency planning.

7.3.3.5 Software Development

Finally, a number of software management tools were used in the development of the FedSat flight code. However, these were mostly debugging and coding mechanisms and there was no analysis of the project from a software perspective. In addition, version control tools were used throughout the development of the FedSat flight code.

7.3.4 Risks and opportunities

Many of the risks outlined during the FedSat project are similar to other CoPS projects. Hansen (1997) details the identified 'hotspots' in six projects and groups them into three areas: Requirements Identification and Analysis, Co-ordination of Information and Process Issues. Many of the risks identified during the project were process issues, with the communication risk spanning both requirements analysis and coordination of information.

During the case study a number of risk areas were identified, particularly during the development of the satellite in the United Kingdom. These risks, and their impact on the project are outlined below. It should be noted that there was very little formal risk management undertaken during the project. One of the directors of SIL lamented this after the company's demise; "In FedSat the risk management should have been done formally." {#12}

7.3.4.1 Requirements

FedSat began with an ambitious set of requirements to meet. The cooperative nature of the CRC meant that there were a large number of partners that had to be catered for during the requirements analysis of the satellite. In particular, it was decided to include four out of five potential payloads on the satellite, seen in hindsight as an ambitious move for such a small satellite.

These requirements also required that the satellite have other constraints placed upon it, such as the need for 3-axis stabilisation and large power budgets. Indeed, at the time of construction FedSat was one of only a few microsatellites to incorporate three axis stabilisation (Moody and Ward, 1999).

These requirements made the project an ambitious one from the start, and resulted in a risk, not only of the satellite failing to meet these requirements, but of the increased complexity and new technologies causing unexpected side effects. This may have been reflected by the fact that three out of the four tender responses from potential prime contractors were non-compliant as described in the previous section.

7.3.4.2 Changing needs

From the original requirements definition in the project bid to the final specifications, the project underwent a large number of changes. This caused a risk in project shift and was acknowledged early on by both the project manager at SIL and the head of the CRCSS management group as a potential risk area.

These changes ranged from the addition of payloads (such as the Star Camera from the University of Stellenbosch) to the abandonment of externally purchased Operations Control Centre software for replacement by an in-house system.

In addition, after every review of the budget, the assumptions behind the implementation of the project would change. "There were a lot of reviews on work packages and how much money - you had to have less. We can do it for less but all the assumptions are that everything we got back is supposed to be working as it was supposed to. Then you move forward and they forget the assumptions." {#3}

7.3.4.3 Project Structure

There was the risk that the project structures used would not be suited to the successful implementation of the project. Although an organic structure has some advantages in flexibility, it was seen that care had to be taken to ensure that there are structures in place to ensure accountability and stability. There was also a lot of pressure placed on the Project and Mission manager, who had high levels of project responsibility.

It was suggested by one member of the executive that a stronger project structure and enforceable lines of authority might have strengthened the FedSat management structure. {#9} However, this structure was also seen to be very successful in ensuring that there was input from a range of stakeholders, with particular focus of including a strong research component to the FedSat mission. In addition, as the project manager was located off-site, there was the potential that this could cause this management to become disconnected from the technical aspects of the project.

Finally, the cooperative and distributed nature of the CRCSS, and its strong composition of government and university partners, also meant that there was both a tendency for the project to be effected by politics, and a risk averse attitude resulting in an inability to make quick decisions. "There was certainly a lot of arse covering, especially from the company's point of view" {#1}

7.3.4.4 Technology Risks

There were a number of technological risks in the FedSat project, as its state-of-the-art and experimental nature necessitated that it includes a number of 'firsts'. For example, in addition to it being the first satellite built by the CRCSS, it was also one of the first 3-axis stabilised micro-satellites. It was the first integrated satellite platform developed by the now defunct prime contractor and it was the first official external customer to be launched on the new Japanese H-2A rocket.

Technological risk management may have addressed all of these contingencies. However, there was little focus on this area of project risk to help with the identification of these risks and facilitate effective mitigation and contingency planning.

7.3.4.5 Schedule Risks Due To Work Pressures

Due to the 'first of its kind' nature of the project, there was also a great deal of pressure faced by the employees to deliver to schedule and budget. The project was also designed to run with reduced resources which could have impacts on the timely purchases of components and sub-systems. Combining the first-time nature of the project with the small satellite philosophy was seen to be a challenge to the management of the project.

A strong commitment to the project schedule was seen as a way to address some of these schedule risks. As commented on by one respondent, the FedSat management team must ensure that they "work to the schedule, rather than schedule to the work" {#14}. However, although a schedule delay would impact on the cost of the project, in hindsight it would not have affected the overall success of the project due launch delays.

7.3.5 Learning

One of the main success criteria of the FedSat project was the amount of knowledge that is brought to Australia. As a research organisation, the CRCSS had a number of performance measures relating directly to academic investigation, including the number of cooperative arrangements instituted, the number of publications generated, education and training, and applications of this research.

It was believed by members of the CRCSS executive that the CRCSS accomplished many of their objectives in this area, particularly during the development of the payloads themselves and the transfer of the satellite to Australia. In addition, as FedSat remains in orbit the amount of this research continues to increase.

As discussed in Molas-Gallart (1997), technology does not only consist of the deep understanding of the technical context of the application, but requires the tacit knowledge contained in the structure and management of the organisation. As such, internal organisational capabilities have an effect on the firms' ability to engage in the external acquisition of technology.

With this in mind, one of the main components of the FedSat Project was Technology Transfer. It was argued that an effective means of accomplishing this was the positioning of two of the customer's engineers as part of the team building the satellite platform. These engineers not only added manpower to the project, but would take some of the tacit knowledge back to the client.

7.3.6 Managing inter-company technology interfaces and stakeholders

7.3.6.1 Communication

Effective communication within the project was seen by many as a core issue for the CRCSS. Due to the diversity of the payloads, the different components were built or acquired by four separate universities distributed around Australia. This required effective interface management between each of the different partners and a strong flow of information between the different stakeholders. In addition, the international nature of the project necessitated accurate and continuous communication with subcontractors.

There was a risk that the distributed nature of the project may have resulted in some communication difficulties. This could cause misunderstandings over requirements or incompatibilities in sub-systems. It was suggested by a number of interviewees that the collocation of members of the project team would have been effective in managing some of this risk.

Some suggested that closely uniting the information resources (such as document control systems) of the CRCSS and the prime contractor might have helped to ensure that the information being used was current and accurate, and would have assisted in the recovery of the satellite after the demise of SIL. It would also have cut down on the amount of work performed by the platform and payload managers in facilitating communication exchange and given more ownership of the project to sub-contractors.

7.3.6.2 Supplier Management

Due to the reduced budget and schedule, the management of the project attempted to accepted higher risks in return for reductions in necessary project resources (Moody, 2001), particularly when the satellite was in the United Kingdom. While both the CRCSS and SIL agreed that the reduced timelines of the project required documentation to be streamlined and the acceptance of some risk, there was some debate on both management philosophy and the amount and nature of component testing.

It was agreed, however, that customer feedback was essential in the development of the FedSat platform, and regular weekly meetings were held to update the CRCSS on the project progress. There was also the issue of trust between the CRCSS and the prime contractor, as the CRCSS management team believed that the prime contractor was withholding information or being deliberately misleading.

In addition, sub-contract management was also seen as a risk area, as many of the components and sub-systems to be externally manufactured were on the critical path of the project. It was suggested by some that both the prime contractor and the CRCSS itself should involve suppliers more closely in the project design and the component specifications to mitigate this risk.

7.4 The Small Satellite Philosophy

Both the CRCSS and SIL aspired to implement the satellite project using the Small Satellite Philosophy (e.g. as outlined by respondents {#1}{#6}{#12} and {#13}). This section looks at some of the ways in which each of the organisations implemented the project according to their perceived methods of implementing this philosophy, and the definition of that philosophy from the point of view of SIL and the CRCSS.

7.4.1 Space Innovations Limited

The SIL management developed a number of papers on the Small Satellite Philosophy as they saw it and were keen to promote their approach. This philosophy focussed on reusability, reduced documentation, outsourcing and balancing risks - a summary of the SIL view of the SSP is given below.

7.4.1.1 Reusability and Semi-Standardised Designs

Although a Small Satellite is a one-off, complex system, a large amount of reusability was seen as a core way of improving efficiency from one project to another. SIL would achieve this reusability by ensuring spacecraft components were designed to be 'semi-standardised'.

According to SIL, satellite providers had previously used an 'off-the-shelf' philosophy for the design of components (Tobin, 1997) which embraces standardised interfaces with fixed protocols for communication. Although this may reduce design times, it was argued that this reduces the flexibility of a spacecraft to adapt to different components or sub-systems.

SIL would take another approach by employing a semi-standardised design philosophy for the design of its components. This philosophy was based on the recognition that, with a good systems design, most of the cost and development effort of a complex system is in its functionality and not its local electrical and mechanical interfaces (Ward, 1996). This meant that in the early design phases of a mission such as FedSat the interfaces were loosely defined, allowing a design to evolve which is optimised for that particular mission. Once defined, however, the interfaces would have to be rigidly adhered to for the remainder of the development phase.

7.4.1.2 Technology Transfer and Reduced Documentation

SIL saw another key issue within the small satellite environment as the retention of corporate knowledge, or technology transfer between projects. Traditional large satellite projects accomplish project to project knowledge transfer using documentation and standardisation techniques (European Space Agency, 1981). SIL would accomplish this transfer by ensuring that key technical and managerial knowledge is documented, but other technology transfer is maintained by intentionally distributing tasks around an entire workgroup.

7.4.1.3 Risk Mitigation

SIL believed that balancing risk and cost was one of the most important roles of a manager in a small satellite project. Unlike large expensive space missions, it was accepted that some risk is inherent in the project and the mission duration success criterion is deliberately shorter than for large missions.

SIL managed risk using the ‘weakest link in the chain’ philosophy. This philosophy assumed that there was no point in making one component risk free while others have high probabilities of failure. As such, it aimed to create a system where the risk is evenly balanced between different sub-systems and within sub-systems.

7.4.1.4 Scheduling

In the same way that the overall project risk is reduced using the 'weakest link in the chain' philosophy, the implementation times of different project components was also designed to be equal, as shown in Figure 7-9. Using this philosophy bottlenecks in the process were ideally identified in the early phases of the project conception and were outsourced to different working groups within the company or externally.

Even though this approach places all tasks on the critical path of the project, it was seen to have an advantage from a management viewpoint, as project delays would be identified immediately and acted upon. In addition, by lengthening tasks to follow the critical path some resources can be freed in the early phases to allow work on other projects to occur.

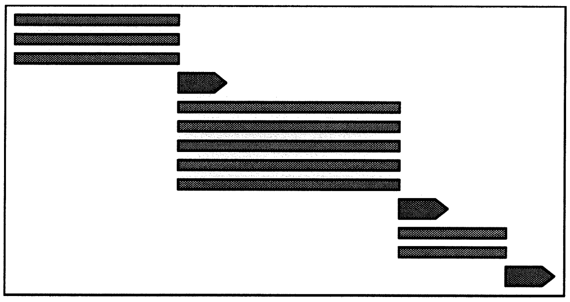


Figure 7-9 Ideal SIL Project Gantt Chart: Source (Moody and Ward, 1999)

7.4.1.5 Development Phases

SIL saw one of the goals of the small satellite philosophy being the reduction of development phase durations while maintaining acceptable risk. Each project phase would be analysed to ensure the amount of work was produced efficiently with respect to time and resources. Where efficiency can be increased phases would either be split, merged or overlapped.

An example of these manipulations of development phases was found in the implementation of the FedSat software. Following the large satellite philosophy, it is recommended that the waterfall model given by the European Space Agency (1981) be used to implement the software. As shown in Figure 7-10, this model involves a number of discrete phases, with a document produced at the end of each phase.

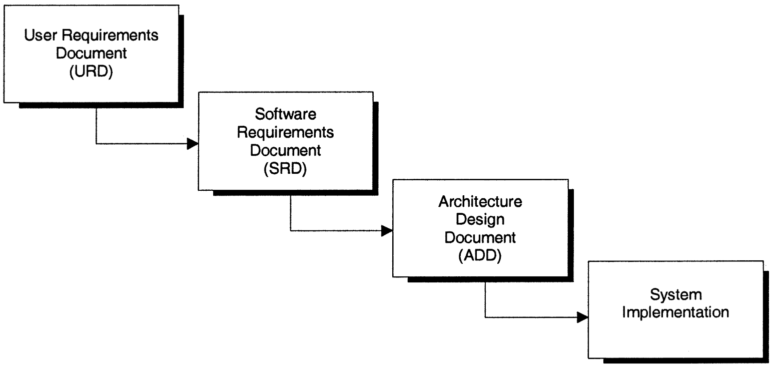


Figure 7-10: Large Satellite Software Engineering Waterfall Model, Source: (European Space Agency, 1981)

In the FedSat project the User Requirements Documentation (URD) phase was broken into a number of phases, with preliminary URDs being issued at the end of the first phase. This allowed the URDs to be reviewed by external parties during the completion of other phases.

It was also claimed by SIL that much of the information contained in the following SRD and ADD phases was complementary. As such, these two phases were merged into one phase, the Software Specification Document (SSD) phase to save time in documentation creation and review.

The third change was to incorporate part of the Implementation phase into the SSD phase during component specification. Components were specified using header files in the code, which were later copied into the SSD document. As such, all of the design information was contained within the header code, speeding up the implementation phase and reducing the number of implementation errors.

SIL believed that their development model was more akin to 'rapids' than to a 'waterfall' and is illustrated in Figure 7-11. Whilst 'rapids' is a good in description of the increased speed of the process, it did have the potential for increased 'turbulence'.

This method was perceived to be quicker, but increased the risk of errors being introduced into the system.

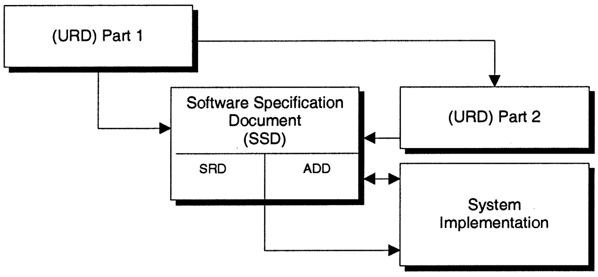


Figure 7-11: Small Satellite Software Engineering Rapids Model, Source: (Moody and Ward, 1999)

7.4.1.6 Software Tools and Procedures

Space Innovations Limited had developed a large number of in-house systems engineering and design tools for use in the development of satellite projects. It was found that a relatively small amount of time expended in developing a flexible and useful tool resulted in large efficiency improvements in later satellite development phases (Ward, 1996).

7.4.1.7 Internal Communication and Systems Engineering

SIL believed that due to the smaller nature of the satellite one engineer, or a group of engineers, should be actively involved in the whole project. For this reason great importance was placed on Systems Engineers at SIL who were given the role of both overseeing and managing the project development.

Project team sizes were kept deliberately small, to remove the need for interdepartmental interfaces. SIL believed that size increases above thirty people in the project add exponentially to both cost and complexity of the mission (Boland, 1999).

Without care however, smaller teams could cause problems due to key staff being overburdened. SIL believed that the resolution to this was by assigning staff to a range of different tasks, not necessarily in their previous area of expertise, in order to train them 'on the job'. This would allow flexibility in planning and would ensure that information is not dependent on any one staff member.

SIL also believed that although documentation should be accurate, it should be kept to a minimum to make the most effective use of resources. The value added by each document produced for the FedSat platform was determined from the outset during the contractual phase of the project.

7.4.2 CRCSS FedSat Team

The CRCSS also used a number of techniques in their implementation of management systems, with the overall methodology evolving throughout the implementation of the satellite project in Australia by the FedSat team. The key elements of the CRCSS management philosophy are given below; it was noted that while the CRCSS believed in implementing the small satellite philosophy, unlike SIL they didn't believe that this was the driving factor behind their choice of management styles for the project.

7.4.2.1 Small Dedicated, Independent Teams

The teams working on the FedSat satellite were small, with a number of engineers selected early in the project and remaining with the satellite from implementation to launch. Due to the small nature of the team, changing tasks were allocated to different people, with a lead engineer in the team responsible for each of the different satellite sub-systems.

As the project manager was not located with the remainder of the team in Canberra he would fly there from Adelaide for two to three days a week. This necessitated that the team was independent, with the ability to make day-to-day decisions. While the choice of an external manager for a small team was questioned by many of the engineering team, the CRCSS believed that this person was both the most capable person for the job, would be able to liaise with the ground station in Adelaide and would balance internal politics.

7.4.2.2 Creating a Nurturing Environment

Due to the size of the engineering team, the creation of a nurturing environment was seen as a core area of importance to the project manager. In particular the project manager and team members were committed to the concerns of the project as a whole, rather than to the completion of individual duties.

In FedSat the successful delivery of the platform was seen as a result of a good team spirit and highly qualified individuals. Generally, team members of the CRCSS were motivated to see the project to completion and there was a recognition of many of the project risks and willingness on the part of both the managers and engineers to address these. In the words of one of the engineers "We knew the risk and we did it anyway". {#4}

Also, the project manager endeavoured to place trust and honesty within the team. "I was not just a manager most of the time, I was a facilitator" {Vesely}

7.4.2.3 Reduced Documentation

Within the development of the project, information and advice were the norm, rather than formalised rules. Documentation was also seen as a means of capturing design choices for future reference, and the reviews were used as an opportunity to update this documentation.

However, due to the demise of SIL, there were a number of document and hardware shortfalls with half-completed units. These shortfalls were mainly overcome by ensuring that there was a closely knit team with a wide range of experiences, and a focus on strong systems engineering (Vesely, 2003). Further to this it was important to pick the right areas to focus on, which relied on the experience of the team members to quickly ascertain the core issues for a particular problem.

7.4.2.4 Flexibility and Freedom to Innovate

The transfer of the satellite to Australia after the insolvency of the prime contractor gave the team an opportunity to 'rethink' the requirements for the satellite. A number of in-house modelling tools were developed to model the power and attitude control systems, and changes were made to the satellite requirements to reduce risk to the overall project through a reduction in complexity (such as in the case of the Attitude Control System) and to more fully realise the overall satellite requirements (such as the Power Conditioning System).

The project team also had to remain flexible in their strategic direction, as there were periods where it was uncertain as to how much money would be available to finish the satellite. New information was being discovered about the satellite almost on a daily basis, requiring the team to react to difficulties or opportunities as they arose.

Ideas from project team members were welcomed, and all members were invited to take part in important decisions. The aim of this process was to both train all of the team members in different areas of the satellite development, and to ensure that any innovative ideas could be incorporated into the satellite implementation. Keeping the team abreast of the whole system was also seen as a good way to promote ownership of the project.

7.4.2.5 Experience

The CRCSS had two members of the team with experience in developing and managing previous satellites, as well as other 'experts' within the project partners for particular sub-components. "[We had] a good group of people working together - the CRC technical people knew what had to be done - they could work though a problem - left egos behind no matter what management were doing we had our clear goals and the best interest of the project at heart." {#3}

However, it was noted by the some of the CRCSS executive that limited Australian space infrastructure was also very challenging, with a large amount of technology having to be developed in-house. The team was fortunate that a number of international CRCSS associates were on-call to confirm strategies and offer their high-level experience. Also, the outsourcing of the Attitude Control System to Dynacon in Canada was seen as an essential component of the project success.

7.4.2.6 Accelerated Development

The Launch schedule primarily dictated the project end point. This meant that launch date considerations were a significant driver to the technical decision making processes and necessitated technical decisions to be made quickly within the project team. While very welcome, the slipping of the launch also placed pressure on the total budget and project cash flow.

However, the project was not always in a state of accelerated development. For example, after the satellite arrived in Australia many team members expressed their displeasure in "how long it was taking for us to get our act together" {#3}. Despite this perceived delay, schedule pressure was always felt by the engineering team.

7.4.2.7 Frequent Review

Finally, the project underwent a large number of reviews as outlined in Section 7.2 above. While some engineers believed that these reviews were "a waste of time and money" {#1}, the management of the CRCSS believed that they were important to "ensure that the project was on track" {#6}. The reviews were also used as a means of keeping project stakeholders (such as the government) comfortable with the project's development, set high-level development agendas and to benefit from external experience in the development of satellite projects.

7.5 Success/failure and performance

As mentioned in Section 7.2 above, there were a number of different goals within the CRCSS as part of the FedSat project. This section outlines some of these goals, and attempts to develop a number of success criteria for them. It also looks at the differing perceptions of the likely success of the project from the project team members and management.

7.5.1 Technical Success Criteria

The main technical goal of the satellite project was "To build and operate a satellite". From this goal, a number of technical success criteria for the satellite were established by the CRCSS executive after the satellite returned to Australia (Vesely, 2003). These are outlined below.

i.	The transfer of space technology into Australia
ii.	Develop necessary space infrastructure to perform all system integration and testing in Australia.
iii.	Qualified and working ground station and spacecraft “Fit for Launch”.
iv.	Successful launch of the spacecraft and first communication.
v.	Achieving nominal in-orbit operation of the spacecraft platform.
vi.	Basic “low level” communication with the payloads
vii.	One month of operations of the spacecraft platform
viii.	Successfully perform an experiment campaign with each payload
ix.	Three months operation of the spacecraft
x.	Six months operation of the spacecraft
xi.	First anniversary of launch with continued spacecraft communication
xii.	Achieve design life of three years

7.5.2 Research Success Criteria

There were a number of research goals for the FedSat satellite. Some of these were technical goals related to the success of the payload operation in space (Vesely, 2003).

xiii.	To commission the payloads in space
xiv.	To successfully operate payloads in space
xv.	To received payload data for analysis

In addition, according to the CRCSS Annual Report (2002), the main research goals of the CRCSS are:

xvi. External money attracted for research
xvii. To publish in a number of publications
xviii. Invited keynote addresses
xix. Conference presentations
xx. Recognition of research awards
xxi. Patents, licences and royalty agreements
xxii. Number of citations of CRCSS related research
xxiii. Cooperative involvement between partners

Even the FedSat satellite was included in these research goals. "You know, in hindsight (SIL) was a great decision because it had really challenged our people to find solutions and workarounds and it turned what was a fixed price contract into a research programme. It's had tremendous benefits". {#6}

7.5.3 Commercial

Another goal of the CRCSS was "to commercialise research and create opportunities in the space industry". Indeed a commercialisation programme within the CRCSS was started, and a commercial manager put in place to commercialise the CRC technology. Some of these commercial goals can be found in the CRCSS annual report development milestones (CRCSS, 2002).

xxiv. Formation of a private company using the IP of the CRCSS
xxv. Development of products based on CRCSS technology
xxvi. Income from contracts, royalties, licences and consultancies
xxvii. Recruitment speed and first employers of graduating students
xxviii. Benefits to end users and changes in industry practice based on CRCSS's research programme

7.5.4 Industry-wide

Determining the success criteria for the development of the Australian space industry is more difficult, as although this was one of the stated goals of many of the CRCSS executive, these were never directly stated as outcomes in the CRCSS documentation, other than the overall goals of the establishment an inherent technological experience which can be used to nurture innovative ideas, the promotion of industrial knowledge and practices and the fostering of recognition of Australian abilities in current and complex technology.

However, some of these success criteria can be developed based on the interviews with CRCSS staff. The first goal was to form an Australian concentration in Space Activity in lieu of a Space Agency "When the space office collapsed COSSA was the only thing that the government had" {#7}

FedSat was also not just a project being developed by Australia and the UK. It also had a large number of internationally developed components. "FedSat is not just an Australian project; it is an international project led and managed by Australia. This is good for an Australian future in space". {#6}

In addition, as one of the goals of the project was to build Australian capability, it was seen as important to provide opportunities for Australians in order to promote the industry. "We want to attract the best young engineers and scientists that Australia has to offer. And attract them at a time when many of them will be going overseas" {#6}.

xxix. Public awareness outputs
xxx. Opportunities for Australian scientists and engineers in the space industry
xxxi. The promotion of international cooperation around Australian Space Technology
xxxii.The formation an Australian concentration in space activities
xxxiii. The formation of a de facto Australian Space Agency
xxxiv. Ongoing projects

7.5.5 Factors for Success

Before the launch of the satellite, the main factors for success were seen as a few people who knew what we were doing who would put in the hard yards. In addition, the need for "sufficient cash to get there in the end" was seen as the key driver for success, as was the creation of an environment in which the team would thrive and were encouraged to put in extra work. The best way to do this was seen as recognising to the individual's personal strengths; people management was seen as key to a successful mission.

The most influential factor in the successful (or otherwise) development of the satellite project was the demise of the prime subcontractor. Of all the tender responses, only Space Innovations Limited complied, but they were identified as a higher risk option; rather than descope the mission it was decided to continue with this provider, marking one of the first trade-offs between risk and cost in the project. However, the fact that SIL was the only compliant tenderer may have raised warning signals that the mission was too ambitious.

In hindsight, a number of engineers and managers within the programme suggested that a different path may have been taken, were it not for the schedule constraints imposed on the mission from the beginning by the free NASDA launch. Suggestions such as the CRCSS being the main systems integrator to configure the spacecraft and purchase the various subsystems from SIL or others were made at a number of occasions. The approach of only purchasing the subsystems would have placed less strain on SIL and the CRCSS would have ultimately undertaken the work that they knew about and did in the end anyway.

The CRCSS did make conscious decisions about identified risk areas, be they technical, commercial, programmatic or political. However, a factor for a successful mission was best summed up by a key stakeholder: "We needed a bit of luck along the way". {#9}

7.6 Conclusions

This section has looked at the satellite project from both a chronological perspective as well as a functional perspective. It has outlined some of the different challenges facing the project and the ways in which they were overcome, as well as looking at the functional aspects of the project's implementation, including an overview of the organisational and structural issues surrounding the project, the project phasing and major areas of risk.

In addition, this chapter has outlined the perceived implementation of the small satellite philosophy from the perspective of both SIL and the CRCSS. It has looked at the core approaches taken and outlined ways in with the management of the project attempted to ensure a successful project outcome. These implementations of the SSP will be analysed in the following section, using the tools developed in Chapter 5.

Finally, this chapter has outlined some of the key success factors for the FedSat project. While the satellite was successfully launched and is still in operation, it was seen that the overall success of the project in areas such as commercial outcomes and industry-wide renewal will depend on factors external to the mission. The overall success of the project is analysed in Chapter 9.

While an attempt has been made to give an unbiased outline of the project, there are a number of questions raised by this chapter. Does the application of the Small Satellite Philosophy have a tangible impact on the reduction of budget and schedule? What lessons learnt from the FedSat project apply to other satellites, or indeed other Complex Product Systems? What is the best way to manage the learning, risks and phasing of this and similar projects? Can the project be classified as a success? These and other questions will be the topic of the following chapter.

Chapter 8

Project Analysis

8.1 Introduction

The previous chapter outlined the development of the FedSat project and some of the key milestones in its development. In this chapter the key theoretical interpretations of the FedSat project from an innovation, management and policy perspective are presented.

First, the techniques outlined in Chapters 3 and 4 are used to investigate the key drivers behind the development of the satellite and the suitability of the structures, tools and techniques used in the project. The FedSat project is placed within the CoPS framework and, even though it has been demonstrated that a small satellite can be considered as a Complex Product System for analysis, the project is assessed against the CoPS defining terms. Some of the structural issues of the project are analysed, and the lessons learnt from FedSat are applied to the CoPS framework.

One of the core management capabilities which was cited to have been used during the development of FedSat was the Small Satellite Philosophy. The core management capabilities of the project are outlined, and the project's management is tested against the core SSP competencies discussed in the previous chapters. In particular, the international best practice techniques of the implementation of the Small Satellite Philosophy detailed in Chapter 5 are compared with the management methodology drivers, and some of the lessons learnt from the FedSat mission with respect to management, complexity and risk are detailed.

Finally, the project's role within the Australian Space Policy perspective is investigated, and the suitability of the CRC framework for the development of a Complex Product System is assessed. In addition, the role of the Australian government in this and other CoPS projects is investigated, and future projects are speculated upon.

This chapter is based largely around answering a number of key questions about the project. These key questions are outlined in the table below.

Table 8-1: Key Analysis Questions

Innovation	
CoPS and FedSat	Was FedSat an example of a CoPS?
Structural Issues	What was the structure of the project and did it work?
	Were there structural issues preventing the project from being successful?
Lessons Learnt	What lessons were learnt from FedSat and how can these be applied to other projects?
	What lessons from FedSat can be applied to CoPS theory?
	What lessons from CoPS theory may have been applied to the satellite project?
Management	
SSP in the FedSat Project	What management techniques were being used?
	Was the SSP being applied in the FedSat project?
SSP and CoPS	Is the SSP a new paradigm in the space industry and CoPS?
	How do we apply benefits of the SSP to other CoPS industries?
The Management of Space CoPS	Why was the project over cost and schedule and could this have been avoided?
	Does Australia have the management/leadership capacity to create a satellite industry?
Policy	
The CRC Programme	How does it compare against other CRCs?
	Was the CRCSS an appropriate policy mechanism for the development of a satellite?
The Role of Government	Did the structure of the space industry in Australia play a role in the development of the satellite project?
	What is the role of government in the space industry and CoPS in general?
Future Projects	Will there be other satellite projects?
	Has the interregnum in space projects in Australia reduced the capacity of the country to re-enter such a complex industry as space research?

8.2 FedSat from an Innovation Perspective

In this section the FedSat project is analysed from an innovation perspective, using the CoPS framework of analysis developed in Chapters 3 and 4. First, a formal investigation of the FedSat satellite as a CoPS is undertaken, and FedSat is placed within the same CoPS defining terms as were used for the small satellite projects in order to understand the different dimension of complexity and organisation within the project.

A number of CoPS tools are then used to analyse the project, particularly with respect to the organisation of the CRCSS, building upon the analysis undertaken in Chapter 7 along the different functional lines of investigation. A number of structural issues which may have prevented the project from being successful are outlined, allowing them to be are addressed again when looking at the policy implications of the FedSat project.

The core lessons learnt during the FedSat project from an innovation management perspective are then investigated and their application to CoPS theory are examined. In particular, the application of CoPS tools outlined in Chapter 3 are speculated upon, and recommendations are made as to some of the areas in which the project may have been implemented differently.

The implications of the space industry to CoPS theory and vice versa, outlined partly in Chapter 4, are then examined in light of the analysis of the lessons learnt from the FedSat project. A number of synergies between the investigation of the space industry and CoPS theory are outlined in the context of the project, and the idea that FedSat may indeed be a "pure" CoPS is introduced, suggesting an area for future analysis.

8.2.1 CoPS and FedSat

Much of the analysis of Chapter 7 assumed that FedSat was a Complex Product System, as was asserted during the analysis of small satellites in Chapter 5. In this section this assertion is tested, to ensure that CoPS are still a viable means of analysing the FedSat project. In addition, by looking at the CoPS defining terms, this enables a number of core aspects of the satellite project to be investigated, including issues of project complexity and organisation.

8.2.1.1 High cost with long product cycles

Although the figures vary, depending on the source of the information and the inclusion of in-kind contributions to the project, a breakdown of the costs of the FedSat mission has been estimated at $A35million dollars (CRCSS, 2002). It should be noted that this cost includes the manufacture and integration of the project payloads; when these are removed the cost of the satellite is of the order of $A10 million Australian dollars. The total time taken to develop the FedSat satellite product was a little under four years, which places it well within the range of other CoPS projects investigated in Chapter 3.

8.2.1.2 Involvement of several firms

As previously investigated, CoPS design, development and production usually involves several firms. The nature of the CRCSS dictated that there were a large number of partner firms involved, ranging from universities to private organisations to the CSIRO, placed into a coalition of organisations through the CRC Joint Venture. In addition, there were a range of subcontractors involved in the project. The organisation of the project investigated in Chapter 7 found that the satellite was the primary means of coordination, with the organisation easily mapped on using the structure devised by Hobday (1998).

8.2.1.3 Product Complexity

Most engineers involved in the project described much of the technology used as "low tech". However, most agreed that the project itself was "very complex", mainly due to the large number of interacting units, and the strong coupling between these units. According to one engineer "[FedSat] was a complex project. No one thing in the satellite is complex but bringing the whole system together and all of the many interacting parts make it quite a complex product, a complex system. For example, if you want to change the pointing of the satellite you have thermal, power and processing ramifications. When you design it you have to design thermal properties, mechanical properties, everything has a bearing on each other and everything feeds into another." {#3}

There were a number of key architectural design choices that had an impact on the final complexity of the satellite project. One of these was to develop a 3-axis stabilised bus, driven by the Attitude Control System. Attitude determination and control of the satellite in all three axes required sun sensors, magnetorquers, reaction wheels and a magnetometer in addition to complex real-time control algorithms, and it was later questioned as to whether this additional complexity was justified. Another choice that influenced the complexity of the system was the inclusion of five payloads into the overall mission. Each payload had a different interface to be accommodated by both the satellite power supply and the Data Handling System.

Respondents also highlighted the distributed nature of the project and the number of interfaces between organisations as increasing the complexity of the project. It was agreed that the large number of partners required a complex approach to the management of the system, and many different and often competing agendas needed to be managed. There were also a number of areas, such as mechanical or thermal analysis, where the prime contractor had little or no direct previous experience. The nature of the project meant that there was a breadth of skills required to undertake the work, from electrical and mechanical engineering to finance and administration, to frequency coordination with the Australian Telecommunications Authority.

Finally, there were a significant number of feedback loops in the project, especially after the return of the satellite to Australia. This was partly due to the loss of much of the tacit knowledge of the SIL staff, requiring a degree of "experimentation" by the satellite engineers. In addition, a few systems issues caused rework to be undertaken right up to the shipment to the launch facility.

When comparing FedSat with other larger satellite projects, there was a common understanding that, while in the same order of magnitude, there was a reduction in complexity of the satellite bus. FedSat did not have many redundant systems, and while it had many of the same subsystems of a larger satellite, many of these were reduced in operational scope.

8.2.1.4 One-off projects

From the perspective of the CRCSS, FedSat was a one-off project. There was no money for another satellite in the budget of the CRCSS, and if there were to be any FedSat II it would be a different project with different goals and technological challenges. Even after the launch of the satellite this was still the case. When one executive member was asked about the future of the CRC after the launch of the satellite he responded "We don't have any plans except to get some more money." {#9}

Interestingly, when asked about the one-off nature of the satellite, SIL saw the satellite as the first in a series of satellite projects. Staff would talk about "semi-standardised designs" where much of the functionality would remain the same while the interfaces changed. In addition, SIL sold the concept of the FedSat bus as "a Standard MicroSIL™ bus" (SIL, 2000).

8.2.1.5 Involvement from policy and other regulatory sources

In the case of FedSat, the Australian government, as primary source of funding for the CRCSS, was the main purchaser and producer of the satellite. In addition, FedSat was recognised to make up a significant part of Australian space policy of the time; the nature of the satellite project itself, being the first satellite built in Australia for 30 years, made it a politicised project. There was considerable political pressure placed on the CRC to make the satellite a success; as one executive member said "If it works we might get some publicity… if it doesn't we'll make national news". {#9}

There was also some regulatory involvement in the satellite project. Not only did the CRCSS have to obtain radio frequency licences for the Australian Communications Authority, but it also had to obtain a launch license from the newly-formed Space Licensing And Safety Office (SLASO) within the Australian Department of Industry, Tourism and Resources.

However, there was little policy developed specifically around the FedSat project. Instead, the CRC framework was used to fund and develop the satellite. This is further investigated later in this chapter.

8.2.1.6 Customer Driven

From the perspective of first SIL and then the CRCSS Project Team, the requirements of the FedSat Satellite were customer driven. However, there was some confusion as to who the customer was; the payload groups, the executive or the Australian Government. One of the engineers summarised this best: "From my perspective the customer was always the universities and the PhD students doing the research. The perceived customer to the project was the executive and the board from the way that the project was driven and [the] perceived success was for the govt for extra funding or the public so that they could see a success in space for Australia."{#3}

However, whoever the customer, it was very clear that there was a high degree of involvement in the project from each of the payload groups, the executive (made up of different industry and university partners) and to a lesser extent the Australian Government through the CRC programme.

8.2.1.7 Project based

As a one-off, the FedSat satellite was built on a project, as much as product, basis. The project was the main coordinating mechanism for all of the CRCSS initiatives and formed a means of communication for the entire CRC. A review of the CRC Executive Minutes during the course of the project gives a good example of this. Over three quarters of the documentation is discussion pertaining to the satellite, even though this is only one of seven (supposedly equally-weighted) agenda items.

8.2.1.8 Markets

When tendering for a prime contractor to build the FedSat satellite the CRCSS received four responses, with only one response meeting the tender requirements. While it is not possible to determine whether this means that the small satellite industry is characterised by an oligopoly, it does point towards a market with only a small number of participants, and one in which the degree of market contestability is low.

As with many CoPS, the satellite bidding process focussed on architectural designs and capability. During the tendering process SIL sold the concept of the satellite that they were to build, rather than the satellite itself.

8.2.1.9 Management

The management and organisation of the FedSat satellite project is discussed in depth later in this chapter. However, the investigation in Chapter 7 of the management philosophy used during the project shows an organic management structure with a great deal of informal communication between team members during the time that the satellite was in Australia.

All of the participants of the project agreed that one of the key skills needed for the project was systems engineering and systems integration. As one of the directors of SIL said at the start of the project "The Systems group is vital - the more money spent early the better". {#12} At both SIL and during the development of the project at the CRCSS in Australia, the project manager also fulfilled the role of lead systems engineer. The systems integration team were involved in most of the decision making processes of the satellite project, and made up the Assembly, Integration and Testing team that prepared and delivered the satellite to launch.

Was FedSat an example of a CoPS?

A summary of the findings of the previous sections is given in Figure 8-1 below, as well as a qualitative assessment of whether FedSat complies with the CoPS definition.

Defining Term	FedSat Context	Complies
CoPS are high cost with long product cycles	Satellite was a $A40m, 4 year project.	Yes
CoPS design, development and production usually involves several firms	The CRC structure involves a large number of firms.	Yes
CoPS product complexity is high and exhibit emerging and unpredictable properties	While much of the satellite was based on low technology, the complexity due to the large number of interfaces was seen to be high.	Partly
CoPS are of a one-off kind to meet requirements of individual business users	FedSat is a one-off	Yes
CoPS require involvement from policy and other regulatory sources	The Australian Government is the primary purchaser and producer.	Yes
CoPS are user driven rather than market driven with a high degree of user involvement	The customer had a large amount of involvement in the satellite development.	Yes
CoPS are project based, rather than product based	FedSat was built on a project basis.	Yes
CoPS markets are typically characterised by oligopolies	There were few companies who tendered for the construction of the satellite, and only one which met all requirements.	Yes
CoPS require distinct management capabilities	FedSat required a strong systems integration capability, and was managed in a primarily organic structure.	Yes

Figure 8-1: FedSat CoPS Defining Terms

As can be seen in Figure 4-16, satellites provide a reasonable match for all of the defining terms of CoPS developed in Chapter 3, justifying the assumption that FedSat is a CoPS and the use of CoPS tools to analyse the project. In addition, based on the analysis of these defining terms, the FedSat satellite project was placed on the critical product dimensions tool provided by Hobday (1998), using a qualitative scale determined in the same means as the analysis developed in Chapter 4. In this analysis the placement of a 'typical' satellite project has been included in grey, giving a means of comparing the FedSat satellite to these projects. As can be seen, while the FedSat project is generally to the right of a typical project, as one would expect as a result of its smaller nature, it remains towards the very-high end of the Critical CoPS Product Dimensions.

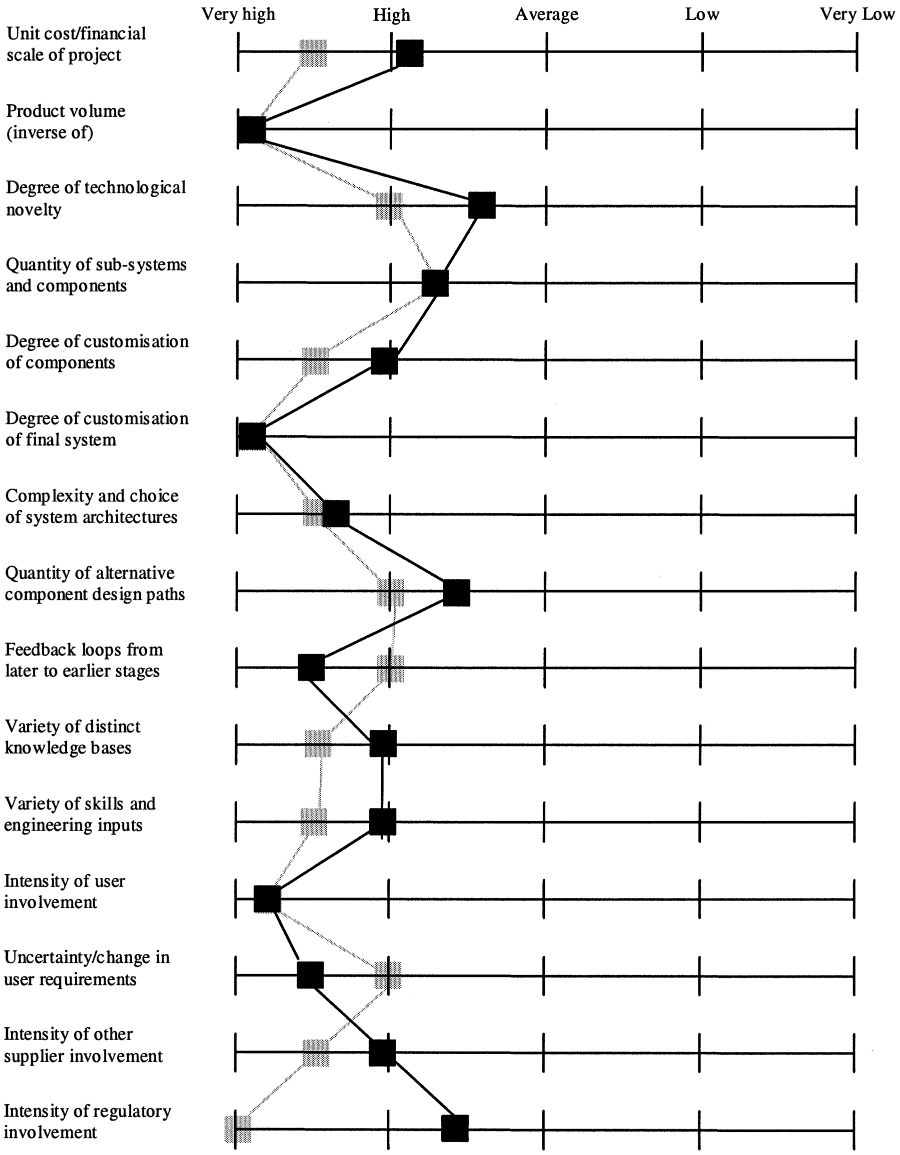


Figure 8-2: Application of CoPS Critical Product Dimensions to the FedSat Project

The areas in which FedSat is predominantly to the left of the critical dimensions when compared to a 'typical' satellite project include a measure of uncertainty and change in user requirements, feedback loops and intensity of user involvement. This is partly attributed to the demise of SIL and the subsequent adoption of the project by the CRCSS.

8.2.2 Structural Issues

Within the context of the Complex Product System framework, the project organisation and the different linkages between project partners give an insight into the management of the project and the drivers behind its successful completion. This section aims to ask questions about the organisation of the project in particular:

- What was the structure of the project and did it work?
- Were there structural issues preventing the project from being successful?

What was the structure of the project and did it work?

As outlined in the functional analysis of the project in Chapter 7, the project was organised in a flat, organic structure upon its return to Australia, to the extent that very few roles were formally defined. This organic structure continued throughout the project development, with only the project manager (and later the technical manager) given formal roles and responsibilities, and the other engineering staff being assigned to different areas across the project. The accelerated nature of the project and the small size of the team meant that a number of jobs overlapped within it. For example, the project manager for the platform was also the head of the ACS group, as well as the systems group.

The systems group as a coordinating body was seen as very important in the FedSat project. Members of the systems group collected the information for the initial bid, as well as promoting the bid to other areas within the company. Also, the systems group became the main point of contact for much of the information produced by the other groups, and was used to coordinate this information. The systems group was party to many of the decisions taken during the satellite development as they had an overall perspective of the project. In addition, the platform project manager had a background in systems operations and relied on the systems group to help co-ordinate the development of the project.

This organic structure evolved into a more hierarchical structure towards the end of the project. This was partly due to a reduction in project numbers, with each member assuming a clearer role in the project, but was primarily driven by the necessity to ensure that all of the appropriate checks and balances were being followed. This hierarchical structure provided the security and familiarity of a stable infrastructure, specialisation of functions and division of responsibilities during the critical phase of the satellite delivery.

In trying to determine whether this structure 'worked', it can be looked at from a theoretical perspective. The blend of organic and hierarchical structures provided discipline when needed, but with the ethos of flexibility to accommodate new problems and adapt to changing external pressures. This transition from an organic to a highly organised structure allowed flexibility during the early stages of the project (when the number of feedback loops was high and there was a lack of understanding of the satellite) to a more formalised and disciplined group. However, management encountered some issues with this structure in terms of delegation and resource management, as some stakeholders believed that people were undertaking tasks inappropriate to their skills and experience (either above or below). With a small focussed team this was seen as a necessity.

The distributed CRC structure was a different matter, with many goals and stakeholders. This was enforced by the legal status of the CRCSS; it was formed as an unincorporated joint venture between the different partner organisations with shares allocated on the inputs promised by the partners. In addition, the CRC programme was designed primarily with research in mind, not for the development of a single product.

The CRCSS was a flat structure with the CEO and an executive made up of representatives of the major partners. The board comprised senior executives of the partners and independent industry representatives and the executive, who would meet on a weekly basis, was coordinating mechanism. Partners for the most part acted independently of each other and autonomously; for example, each would hire their own staff. The public nature of the CRCSS also required strong accounting and disclosure practices, but had the advantage of having guaranteed funds for the project.

The CRC structure 'worked' in the sense that there was a range of experience to draw upon from the project partners in building the satellite, and there was also leverage from the government involvement to create international partnerships and in-kind contributions from other national organisations such as the British National Space Centre (who contributed to the solar arrays), the Canadian Space Agency (who subsidised the acquisition of the Attitude Control System) and the National Space Agency of Japan NASDA (who provided a free launch). In addition, it can be said that the structure of the CRCSS worked in the sense that the centre was able to successfully build and launch the satellite within it. Also, there was the potential to have project partners to draw upon if additional funds were needed, and it was possible to disseminate the results of the project and the lessons learnt widely among these partners.

However, the structure of the CRCSS didn't work in a number of areas. For example, it was not successful in having the FedSat project completed to budget and on time. The delay caused in the development and launch of the satellite resulted in a delay in starting the serious research projects and a significant reduction in funding of the research. Also, there were few commercial outcomes from the project, seen by partners as a result of not having a commercial focus from the beginning of the project. Finally, the CRC was constrained by the requirement to focus on research when the major project in the CRC was a development project. In the words of one of the executive "it had to have what looked like a serious research function because it was a C"R"C but we had to build our own research facility. We expected this facility to be 10 percent, but in the end it took up 30 to 40 percent. There was less money for research." {#9}

In looking at the success of the project, and which parts of it to attribute to the structure of the CRCSS, it is important to look at it also from the overall management and policy perspectives. The following section outlines some of these particular issues raised by the project participants. Section 8.2 then details the impacts of this organic/hierarchical management structure on the implementation of the project, and an analysis of the suitability of the CRC structure for the development of large systems is outlined in Section 8.3 of this chapter. Finally, a full analysis of the success of the CRCSS and FedSat project taking a number of different factors into account is given in Chapter 9.

Were there structural issues preventing the project from being successful?

Most of the structural issues perceived to be preventing the project from being successful were attributed to the structure of the CRCSS, rather than the structure of the project team. Indeed, these structural issues surrounding the organisation of the CRCSS resulted in difficulties for the management team of the FedSat satellite. This section outlines some of these issues which emerged from an analysis of the structure and interviews with the project participants.

8.2.2.1 Different Goals

A common complaint about the organisation of the project was the differences in goals between the different project partners. The different goals of the centre were outlined in Chapter 7, where it was found that the many organisations of the CRCSS saw the core goals differently, ranging from technical, research, commercial and industry-wide objectives. As highlighted in interviews with the CRCSS executive director, "I would imagine that there would be a problem no matter what just because of the different types of goals from the different organisations. You've built an organisation on three different opposing groups of people and then you have located them in different places and they don't know each other and work together." {#6}

Within the engineering team this sentiment was reflected. "I would have thought that having one goal would have made it easier but it didn't because actually the people making the satellite were actually a very small part of the CRC. There were many people more … the goals are diverse and the main goals aren't even to make a satellite." {#4} "People would ask 'Why is the engineering programme spending so much money?' 'Why can't they get it done a lot quicker?' Maybe having a small group on one task screwed the CRC - maybe with everyone doing bits of the satellite everyone would have had a desire to see the satellite fly." {#1}

This diversity of goals was compounded by the disperse nature of the project. Members were distributed around Australia and would only see the main satellite project infrequently. "There is little incentive for people to be unified about the goal. Most people were involved in the flying and going overseas but that doesn't engender any real commitment." {#4} These different and not always congruent goals of the partner organisations also created some difficulties during the project in determining the application of resources. This is discussed as part of the cooperative nature of the CRCSS below.

8.2.2.2 Separation of Satellite and Ground Station

An early decision made by the CRCSS executive was to separate the management of the satellite from the management of the ground station. At first this was seen as a means of abstracting and outsourcing some of the complexity of the satellite project to a project partner. However, this was seen in hindsight to have created a problem in the eventual project delivery.

The main issue that this created was the successful integration of the satellite with the ground station. Each was being built in a different state of Australia, and communication and requirements definition were difficult due to the complex nature of the project. As it was seen as a vital component of satellite development, the satellite project team eventually developed their own Ground Station Operational Control Centre (OCC) software, taking a project philosophy that the Assembly Integration & Test (AIT) software should be essentially the same as the Ground Station (GS) software. This was seen to help the transition from test to operations, but involved writing off the software previously purchased by the GS team.

Another issue was the difference in management approaches between the two groups. While the FedSat project team believed in a highly flexible management style, the ITR team believed in a hierarchical model with "strict adherence to the waterfall management model of software development without going backwards". These tensions surfaced as personal differences between the managers of each programme, and communication became strained. "I told him to stop wasting everyone's time. He wrote back asking for a public apology. I wrote back telling him that all mail from his account was automatically directed to the trash box. If I ever have to work with him it will be interesting" {#2}.

8.2.2.3 *Risk Management*

Different partners in the project had different approaches to risk. For example, when the satellite arrived in Australia from the UK, one commercial partner wanted to stop and undertake an analysis of all of the spacecraft units while the other wanted to commence working on the hardware immediately.

The nature of the CRCSS made it a risk averse organisation. Being part of a 'public good' national programme with the potential for strong media involvement, there was a perception that there was no room for failure in the project. The perceived inability to take risks was seen to manifest itself in the CRCSS being slow to react to issues of importance and unwilling to take risky decisions. For example, the CRCSS did not wish to withhold payments to SIL for failing to meet milestones as it was afraid that it may cause SIL to go bankrupt. This was further compounded by the fact that most of the research based around the CRCSS depended on FedSat meant that there was a single point failure in terms of the research facility; if FedSat failed much of the research would fail with it. This was unlike many CRCs which have a number of different, independent and loosely coupled research programmes.

8.2.2.4 *Incorporation*

The CRCSS was formed at a time when the CSIRO would not be part of incorporated Cooperative Research Centres, and as such the centre was formed around an unincorporated joint venture 'centre agreement'. Project partners would contribute based on their agreed contributions and the project was organised based on quarterly payments from the government. This meant that not only was cooperation needed for every major decision within the CRCSS (discussed below), but that the allocation of funds was made to match that of the money which was put in by different partners.

The investment in the various components of the project (mainly the payloads) was not related directly to the cost or expected outcomes of the payloads. This is because the funds were divided based on the contributions of the partners and not on the complexity or importance of the payloads themselves. This led to inefficiencies in spending money, such as in the case of South Australia, which was contributing in kind to the project for the ground station, but was using much of the corresponding government money to build their payload. {#9}

It was also seen that the unincorporated nature of the project meant that there was some “milking the project” {#1}. In the words of another team member “People would take things from it, it was seen as a cash cow. We were not building something together.” {#4}. The executive would try to make the project something that partners would jointly build, but some had fears that members were “just using it to help their cash flow” {#9}. This may have resulted in there being fewer commercial outcomes from the project as it was not seen as a corporate entity in its own right.

8.2.2.5 Cooperative Nature

Many centre participants cited a great deal of internal politics between members. The distributed nature of the CRCSS required that it had strong leadership to perform, which was provided primarily by the Executive Director of the centre, a figurehead and mediator. However, some partners did not always follow this lead, and would often bring issues to the board level where they could garner support for their point of view. An example of this was during the bid process, where ITR in South Australia pushed heavily for a different bid to be accepted by the executive.

In the words of one of the executive “I don’t think the model we have for the CRC is the best model. We should say what it is that we want to do, get the partners to bid and then write out a contract. A project such as this wants a fixed price contract, delivery schedule and performance milestones - not regular quarterly payments.” {#6}

In addition, many of the decisions made were done on a consensus basis. For example, the nature of the management structure meant that none of the payloads would be removed, “no matter what”. When the tender responses provided by more reputable companies couldn't handle all of the payloads it was decided to go with a less reputable manufacturer.

8.2.2.6 Authority

Finally, the cooperative nature of the CRCSS also resulted in an issue of authority within the project. Members of the upper executive cited a lack of authority over different project staff as a problem in implementing the project.

"You don't have the management authority over individuals within the partnership. You can only make things happen if you can fire them or withhold payment to them. The CRC programme is based on cooperation with a capital C so you must not resort to threats of withholding funding. This is seen as a big no-no". "You really need management authority – you really need to be able to act in the best interest of all, even if it means shifting resources around, moving people around and insisting that person X works in location Y for a period of time. At the moment we are at the behest of the goodwill of the partners to agree to all of this" {#6}

The satellite engineering team also believed that they did not have sufficient authority over the payloads or the Ground Station to ensure that the satellite bus, the payloads, the Ground Station and the mission itself were well coordinated. In addition, it was impossible to shift resources between different groups, resulting in insufficient money being spent on the ground station and the mission planning. "There was no overall control from the engineering team – the project was farmed out to relatively autonomous groups. This was particularly associated with the support, for example the ground station. Payloads were by their nature autonomous." {#6}

Many of these structural issues, ranging from the unincorporated nature of the centre, its multiple goals and the cooperative approach to decision making, were as a result of using the CRC structure to fund the project. The applicability of the CRC programme to develop Complex Product Systems such as FedSat is discussed further in Section 8.3.

8.2.3 Lessons Learnt

There were a number of lessons learnt during the FedSat project, with some of these applicable to other satellite projects and other CoPS projects in general. This section attempts to outline some of the core lessons learnt, and place them in a context which can be applied to other similar projects (Moody and Vesely, 2000).

In particular, a number of core questions are asked in this section:

- What lessons were learnt from FedSat and how can these be applied to other projects?
- What lessons from FedSat can be applied to CoPS theory?
- What lessons from CoPS theory may have been applied to the satellite project?

What lessons were learnt from FedSat and how can these be applied to other projects?

As this was the first such satellite project in Australia for thirty years, the members of the CRCSS were understandably learning lessons throughout the project's implementation. These lessons range from the development of technical capability in Australia to the applicability of the approach used, and can be applied to other projects, both within Australia and internationally.

8.2.3.1 Technical

A number of technical lessons were learnt during the FedSat project, as one of the core missions of the CRCSS was to improve and promote industrial knowledge and practices in the Space Industry. These technical skills include many types of engineering (systems, electrical and mechanical), software development, skills in operations and production and manufacturing capabilities.

In hindsight, most of these lessons were learnt as a result of the rework that occurred after the return of the Satellite to Australia. It is arguable that, had SIL been successful in delivering the project, many of the technical skills acquired in Australia would not have been developed. A summary of the main activities undertaken by the Australian FedSat team is given below.

Table 8-2: Australian Project Team Initiated Technical Changes, Source: (Vesely, 2003)

Spacecraft:

1. Re-wrote majority of Flight code.
2. Designed and implemented thermal finishes based on in-house analysis.
3. Corrected build quality deficiencies and implemented minor modifications to the PCS unit and DHS (ERC –32) unit PCB's.
4. Re-worked and calibrated the Digital Sun Sensors (DSS) and Magnetorquers (MTQ)
5. Minor re-worked of the Deployable Boom.
6. Replaced SACE card with ACS node.
7. Replaced the platform Magnetometer (MFM).
8. Designed and verified a spacecraft isolation system to reduced excessive electronic equipment environments - included a revised spacecraft FE analysis.
9. Replaced the complete electrical harness to remove deficiencies in the design & build.
10. Replaced FM battery cells and modified the battery packaging.
11. Negotiated and implemented a fixed UHF antenna solution with NASDA.

Ground Support Equipment:

1. Designed and manufactured a new set of Mechanical Ground Support Equipment (MGSE).
2. Replaced battery conditioning EGSE.
3. Carried out extensive repairs and modifications to the RF EGSE (latter implemented on the GS rack) and Spacecraft EGSE.
4. Designed & purchased/manufactured assorted test aids to support additional development activities.
5. Modified the Spacecraft container to accept the revised spacecraft configuration with isolation system.

8.2.3.2 Authority

An important lesson learnt during the management of the project is that there has to be an overall system controller in order to coordinate the entire project. Many decisions needed to be made during the FedSat project, which required tough calls to be made by the project manager. This manager must have the authority to shift resources from one place to another, and direct participants to undertake actions for the good of the project as a whole, even if it might be detrimental to the short-term goals of their own organisation.

The management of FedSat was criticised on a number of occasions for not having developed this authority structure. In particular there was a perceived hiatus of authority after the project returned to Australia, with a change in project managers and a lack of clarity on the best way forward. Many people were given responsibility for particular pieces of project hardware, but not the authority to mobilise the resources or make the decisions needed to complete the work on this hardware.

In addition, there needs to be tight control of budgets within the project management and across the different project participants. A lack of control or transparency of operation in the FedSat project caused confusion and ill-will between project partners. "I am sure that [name withheld] ripped us off but you can never prove it." {#9}

8.2.3.3 Whole System Approach

A space mission is comprised primarily of two parts; the space segment and the ground segment. In FedSat it was felt that too much emphasis was given to the Space Segment, and not enough to the Ground Segment, resulting in both mismatches between the two systems and tensions between the different groups. It was found during the project's implementation that there need to be similar management approaches taken for each of the different teams within the project, such that they communicate and share similar approaches to implementation. The organic management style of the FedSat engineering team clashed heavily with the hierarchical structure of the Ground Station team.

This decision to not integrate the whole system under one manager was seen as a major failing of the project. "As far as the satellite is concerned we have managed it well, but I think that we have really failed as far as the ground station is concerned, as far as integrating that". {#6}

8.2.3.4 Key Staff

From the beginning of the project the three roles that were seen as key to the project were the systems engineer, a mission operations specialist and the quality assurance manager. These people were to be involved in the specification of the satellite, and the definition of the interfaces between the different satellite components. In order to get the most efficient use of resources, these people should then continue with the project until after the satellite launch.

Within the FedSat project, the systems engineering group was seen as the key group, and was involved in almost all of the decision making processes. Many of the pitfalls identified during the project, such as the amount of available power or interface issues, were as a direct result of intervention from the systems team. The project manager was also ideally a member, if not the leader, of this systems team.

8.2.3.5 Experience

Another lesson learnt from both SIL and the CRCSS was the need for people with experience to be part of the project. In a complex system such as FedSat with a large number of interfaces, interacting components, a harsh space environment and unknown risk areas, experience was seen as the key way of overcoming pitfalls in the project. Some also saw a strong partnership between experience and enthusiasm for hard work. The correct mixture of experience with enthusiastic junior engineers would not only increase the chances of a successful mission, but would transfer skills for use in future projects.

8.2.3.6 Aligned Goals

There was some discordance within the CRC arising from different groups having different goals for the project. Within the FedSat project resources needed to be shifted between projects, which caused problems when partners disagreed on priorities for funding. A strong emphasis on developing the goals of the project, and then engaging project members to commit to these goals would reduce tension in these areas and limit politics within the organisation.

This may also be a lesson for future government initiatives in the space industry. Funded satellite projects may be best given under two separation funding arrangements; one for the national facility (the satellite) and one for the research (payloads). The national facility would then specify the satellite interface and the payloads would have to conform to this. This would also give more authority to the satellite engineers who are responsible for the successful operation of the mission.

In addition, the key drivers for the customers should be integrated into the goals of the organisation. For example, the government wanted something 'exciting' which could give a successful outcome and the company partners aimed for commercial success. These goals should be integrated not only into the goals of the organisation, but into the satellite design from the initial phases of the project.

8.2.3.7 Team Structure

The development of FedSat saw a large number of system (and component) changes and feedback loops between project stages. This required the project management to remain flexible enough to cope with these changes, but rigid enough to retain control of the system and ensure quality assurance of the final product.

To cope with this requirement for flexibility the project began (from the Australian perspective) with a very organic management structure, becoming more defined closer to the launch date. Procedures were developed on an as-required basis, but then adhered to rigidly. In addition, the project management had to remain open to advice from both within the team and externally, with frequent review to measure progress. At the very end it was the dedication of a small team that saw the project through from inception to completion. Getting these people is essential to the project's success.

8.2.3.8 Requirements Analysis

The original requirements for the satellite were based around the payloads supplied by the partners of the CRCSS. This meant that very specific requirements were given to the satellite contractors, of which the only one that could meet them was a risky (and untested) option. The lesson learnt from this was to be reasonable with the project requirements, even if this means defining the project up front and then finding partners who will contribute resources. The nature of the CRCSS being part of the competitive programme meant that the organisation of the CRC and the goals were set up before the centre knew what the extent of investment in the final project was going to be.

The CRCSS had no single customer, rather providing an "open-ended wish-list" {#7} as the initial requirements document, without any real idea of how much that would cost. Having made the wish list and having secured the support of the partners with their payloads, there was no mechanism for denying them their desired outcomes or place on the satellite.

8.2.3.9 Supplier Management

The CRCSS learnt a great deal about supplier management, with the unexpected experience of having to deal with the project prime contractor going bankrupt. These lessons include the need for close integration of the organisation with the prime contractor's management, and the need for tight contract management to ensure that problems are identified as early as possible. The CRC's relaxing of requirements on SIL (for example by paying the Critical Design Review milestone before it was complete) was seen by some as timid, but by others as a way of managing risk. These choices should be made as explicit as possible within a satellite project.

In addition, there are a number of lessons which have been learnt about international cooperation in the space industry. The CRCSS has a number of templates for setting up other co-operations, agreements relating to Intellectual Property and other legal documentation that could be applied to future projects.

8.2.3.10 Ongoing projects

The importance of ongoing projects was also seen as a lesson to be learnt from the FedSat project. After the end of the project, many of the engineers either left the country or moved into academia, although some remained with the project partners not working on space projects {#2}. For large projects such as a second satellite mission there is a need to have a plan to either keep the team together or deploy them to productively use what they have learnt, in order to not lose the training that they have received, to keep their skills relevant and to give them opportunities to remain in Australia.

In the words of one engineer "If we got a contract tomorrow to build the satellite we would find that a lot of the data is not well kept" {#1}. There should have been a central controlled repository for IP and mechanisms for retaining skills and knowledge about the project.

8.2.3.11 Risk Management

The final area where the FedSat project has lessons for other projects is in the management of risk. Although the risk management undertaken throughout the project varied between different phases and organisations, it was identified by many of the project team that many of the decisions that were made were based largely on risk factors. A better understanding of these risks would have assisted with the allocation of resources in the project and the speed of the decision making process. This is closely aligned with the need for an awareness of quality from the beginning of the project, taken all of the way through to the project's completion.

What lessons from FedSat can be applied to CoPS theory?

Many of the lessons learnt from the FedSat project can be applied to CoPS theory. In particular, the ways in which FedSat performs in new areas within the CoPS framework such as relationship building and organisational behaviour can be compared with other projects.

As an important part of the nature of the satellite project was the use of the Small Satellite Philosophy management paradigm, there are a number of lessons to be learnt about the reduction of resources in CoPS projects. These are outlined in the following Section 8.2.

Bringing the space industry into the CoPS domain has some benefits for CoPS theory in terms of the understanding of phasing and feedback loops. It can provide additional areas for investigation, as well as insights into best practice systems engineering and systems integration techniques, building upon work already undertaken by Prencipe, Davies and Hobday (2003) and others as outlined in Chapter 3. In particular, the space industry has developed a large number of tools to assist with interface design and critical systems software management (see for example Caltech, 2001). Space agencies such as NASA and ESA have also undertaken detailed investigations into the development phases of particular space projects (Wertz, 1998), and have some of the world's best practice in developing systems for reuse and longevity, through the management of adaptability and redundancy.

FedSat is also high on almost all of the critical dimensions of CoPS, but moreover it is a CoPS with very clear boundaries. In this project the unit of analysis was fairly easy to determine for a number of reasons:

- FedSat had a definable beginning and end;
- FedSat was a discrete, self-contained product (the satellite);
- FedSat exhibited a clear shift between the implementation and support phases of the project (i.e. before and after launch); and
- The project implementation team was small enough to analyse in depth.

In Chapter 3 it was noted that the definitions of CoPS that used are extremely broad ranging from small batch items such as flight simulators to large arrays such as the telecommunications industry. In this context FedSat may be a 'pure' CoPS, something which matches all of the CoPS criteria, but has an easily definable timeframe, fixed success criteria and measurable parameters. The FedSat project may indeed be seen as a good template for the analysis of CoPS, with clear boundaries. Moreover, the space industry in general may be an effective means of testing theories within the CoPS domain.

There are a number of institutional issues that may be applied from the FedSat project into the broader CoPS domain. For example, it was found that there were a number of limiting structural factors in the cooperative nature of the CRCSS, ranging from the various goals of different stakeholders to mismatches in authority and the risk management approach taken. Also the approaches taken in a the satellite project, such as using the operation of the spacecraft to define requirements and the use of Off-The-Shelf components are areas where CoPS theory may benefit from lessons leant while building satellites.

However, it is important to know when to apply the lessons from the space industry to other CoPS. For example, while there are a large number of formal methods and tools as well as technical quality and standards used in the space industry, they may or may not be applicable to other industries. In addition, and as is investigated in more detail in

Section 8.2, the reduction of resources in CoPS using a methodology akin to the small satellite philosophy is a result of reducing a critical dimension of the project while maintaining a similar architecture and outcomes.

What lessons from CoPS theory may have been applied to the satellite project?

CoPS theory gives the space industry a mechanism for analysis. In particular it provides a mechanism for the comparison of satellite projects with best practice CoPS in other industries. Using examples from other CoPS projects, the best means for collaborating and using joint ventures within the space industry can be analysed. The use of CoPS theory to illuminate interactions between firms also allows for the more effective management of complexity within a large project.

Some of the lessons that may have been applied to the CRCSS and the FedSat project are outlined below. These include issues of the structure of the CRCSS, the tools that were used during the project and the understanding of the unique role that CoPS might have played in the development of the project. It should be noted that even though the FedSat project was being studied using the CoPS framework, CoPS did not have any bearing on the implementation of the project.

8.2.3.12 Structure

CoPS theory could assist the FedSat project and future projects in understanding the processes involved in the development of a Complex Product System and which structures are more appropriate to its successful implementation. The organisational complexity of the project gives guidance on the innovation paths taken during the project and the ways in which research, design, production and installation take place.

For example, and as illustrated in Chapter 3, producers of CoPS, usually systems integrators, require distinctive managerial competences capable of defining and executing large-scale projects. These systems integrators, in addition to managing their internal tasks, often have to coordinate the innovation activities of large and complex supply networks made up of small firms, major users, large partner companies, regulators, standards bodies and government departments (Pavitt, 2002; Prencipe, Davies et al., 2003).

CoPS theory provides guidance on the different management models which can be used during a space project, for example when to have fixed and when to have fluid management. Hobday (1998) gives a good summary of which techniques to use, and pointers towards best practice in requirements identification and analysis, coordination of information and process issues.

CoPS also stresses that the project is the coordination mechanism. This could have been applied at Space Innovations Limited to understand the management of different lifecycles and different speeds within the project, as well as the importance of a single project team working closely together to finish the project.

8.2.3.13 Tools

There are a large number of tools developed and being used in CoPS projects; many of these tools may have been useful in the development of the FedSat project (Moody, 2000e).

Although there is already a focus on learning within the CRCSS, there are no tools to facilitate this. Procedures to ensure that the intellectual property generated from the FedSat project is retained could be put into place to ensure that it is available for the next project. In addition, tools to assist with the technology transfer mechanisms from the prime contractor to the CRCSS could ensure that the money spent on technology is used in the most effective fashion.

Diagnostic or benchmarking tools might be used to compare the efficiency and success of the project. However, as with many Complex Product Systems this is difficult as the number of independent variables makes finding comparable products difficult. Another important component of the project could be the ex-post evaluation, using tools to facilitate this. More attention might also have been given to product selection tools in the developing phases of the FedSat project. Many of the decisions that have been made have been done so in an ad-hoc fashion using tacit experience of employees. In addition, there were a large number of risks inherent in the FedSat project, due to its developmental nature. Effective risk management tools (Hauge, 1995; Mosher, 1999) may have helped with the identification of these risks and effective mitigation and contingency planning.

Product analysis tools such as QFD could be very useful in the FedSat project to effectively capture requirements at an early phase of the project development. This is particularly important in the specification of payload requirements, which have undergone a number of changes over the development of the project. Cost management tools (Bearden, 1995; Bell, 1995) could also facilitate the management of the satellite by ensuring that financial resources were available when required.

As with any project, a focus on quality will offer benefits to both the customer and the supplier. In the FedSat project Lean Production techniques could have been useful to form a closer integration between the contractor and suppliers through the integration of information systems and joint problem solving.

Finally, software management tools could be very useful in the development of the FedSat flight code. Due to the nature of the project and the requirement for risk-averse code, it could be good to analyse the project using the CMM model to determine the current level of project management. This model could point to areas in need of improvement as well as areas of excellence.

8.2.3.14 Architectural design

CoPS theory also gives a more complete understanding of the different phases of a particular project, and how best to focus on architectural design. This is important when understanding that CoPS tend not to reach the latter stages of incremental process innovations where competitive strategy and the rewards from innovation are centred in conventional innovation models.

In a project as complex as FedSat it is necessary to work out what is essential and what is 'nice to have'. Understanding the different design choices during the architectural design phase may offer considerable efficiency improvements in later phases of the project. CoPS also highlights the need to involve the user all of the way through the development process, similar to the now understood requirements in the space industry to involve the operations team from the beginning of the project. CoPS theory may provide pointers and experiences on how best to do this.

8.2.3.15 CoPS as an analytical category

Finally, the awareness that CoPS are a different analytical category may have assisted in the specification of the FedSat project. In other words different mechanisms are needed for the development of CoPS projects when compared with more traditional programmes. Knowing this, the CRCSS may have looked more closely at the structures used and compared them with other similar projects used in the CoPS domain, as well as the suitability of its own structure to undertake the FedSat project.

It is also important to acknowledge that much of the knowledge needed to produce CoPS is embedded in people and cannot be formalised to the same degree as mass produced goods such as automobiles and microcomputers. In CoPS this focus on the training and retention of staff should is integral to transferring skills and knowledge across projects, something that the CRCSS aspired to, but had differing views on how to implement.

CoPS may also have given the CRCSS a stronger case for government involvement. CoPS theory shows that the space industry can be different to other industries. It stresses the traditional understanding that the space industry has high barriers to entry and requires supportive and direct government involvement in order to succeed. As a CoPS, space can be integrated into a particular role in the national economy, which may be a strong area for growth in developed countries. This issue is discussed in more detail further in Section 8.3 of this chapter when asking the question of whether the CRC model was the most appropriate model for the construction of a satellite.

8.3 Management of the FedSat Project

As noted in Chapter 7, the implementation of the FedSat Project can be divided into two phases, the development of the satellite in the United Kingdom and the development of the satellite in Australia. During its time in the UK, the satellite was over budget and behind schedule, eventually resulting in the insolvency of the company Space Innovations Ltd, while in Australia the project was eventually delivered to the launch provider on time and under budget (taking the additional money requested from the government after the demise of SIL into account). Was there a difference in management style in each of these phases that may have influenced the differing successes of the project?

This section aims to look at the management of the FedSat project during each of these phases. First, the different management techniques used to manage the FedSat project at both SIL and the CRCSS are summarised, based on the analysis undertaken during the project investigation in Chapter 7. The implementation of the Faster, Better, Cheaper management philosophy, which was cited to have been a driving force during the development of the project, is tested using the functional capabilities outlined in Chapter 5. The differences in approaches between the SIL and CRCSS implementation are investigated and the effectiveness of each model is ascertained.

By comparing the implementation of the satellite in Australia and the United Kingdom a fuller understanding of the Small Satellite Philosophy can be obtained, and the implications that the SSP paradigm may have for CoPS industries are explored. In particular, the question of what happens when you reduce resources within a CoPS project, first asked in Chapter 5, is investigated in the light of the information gained through the analysis of the FedSat case study.

8.3.1 The Small Satellite Philosophy in the FedSat Project

The effective implementation Faster, Better, Cheaper management philosophy was found to have been a goal of both the CRCSS and SIL during the development of the FedSat satellite. However, the two organisations implemented the philosophy in different ways. Chapter 7 outlined some of the core management methodologies used by different organisations during the project development. This section summarises these and asks whether they were indeed following the FBC paradigm during the project's implementation. In particular, two core questions are answered in this section:

- What management techniques were being used?
- Was FBC being applied in the FedSat project?

What management techniques were being used?

The previous chapter describes some of the management techniques used during the development of the satellite project both at SIL and the CRCSS. It found that along with different organisational structures the organisations had different approaches to management. This section summarises these approaches in order to prepare for their analysis within the Small Satellite Philosophy framework developed in Chapter 5.

8.3.1.1 The Case of SIL

At SIL the managers described their approach towards the Small Satellite Philosophy in three main categories: reusability, resource management and communication.

Reusability included the ideas of semi-standardised designs and standardized interfaces when appropriate. It also included technology transfer both within and outside the organisation, with judicious use of reduced documentation. They had also developed a large number of in-house software tools and techniques to assist with design and development. SIL saw a need for innovation in the company and gave people the freedom to do this (Moody, 2000e).

Resource management included ideas of risk mitigation. SIL believed in balancing the risks in the project, and trading risk for cost to stay within budget. They also tried to outsource where appropriate to sub-contractors, and the project management believed in making quick decisions. The project management team also believed in accelerating the development of the project by compressing development phases and setting ambitious targets for the staff. Many staff, however, were not committed to this schedule and would only work after hours if paid overtime.

Communication included the use of small teams to implement the satellite project, although almost everyone in the company was on the team. They placed importance on systems engineering, by combining the roles of head systems engineer with project manager. Finally, the communication aspects of the project also included the reduction of documentation only to a level at which it was necessary.

8.3.1.2 The Case of the FedSat Project Team

Once the satellite had returned to Australia, the Australian team assumed management of the project. The approach taken by this team may be grouped into four different areas; accelerated development, a small integrated team, experience and empowerment.

The project was almost always under pressure from the launch provider. This caused the management of the project to take an accelerated path for development. However, the team members were committed to the project's success and would often work long hours to see the project meet its launch deadline.

The small integrated team that formed the core of the project was also seen as a key mechanism for decision making within the project. The team members would be involved in project reviews and choices to use particular technologies, and were multi-skilled across many areas of the satellite development. This allowed the amount of documentation in the project to be reduced with little impact on the communication within the project.

The project also attempted to combine experienced people with enthusiastic junior staff, and systems engineering was seen as the most important area for project's success. In addition, the executive organised frequent reviews with external experts to either endorse the direction that the management and engineering teams were taking or to suggest areas for improvement.

Finally, the management attempted to empower the members of the project team, and to give them the freedom to innovate within the project environment. Flexibility was also promoted, as was trust, and honesty was built up between members of the project team.

Was the SSP being applied in the FedSat project?

In the analysis of the Small Satellite Philosophy given in Chapter 5, it was found that there were a number of key components of the small satellite philosophy:

- An organic management structure
- A focus on a number of core drivers in the process such as trust, empowerment, systems engineering and experience within the team
- The knowledge of and use of new but mature technologies which also allow the production of small satellites, coupled with developed interface standards
- A focus on continuous improvement through frequent review

Almost all of the elements of both the SIL and CRCSS Small Satellite Philosophies described above echo those of other small satellite projects. Why then was SIL running so far behind schedule and over cost, while the CRCSS managed to deliver the satellite to budget and on time? By looking at the separation of causes and effects and comparing the two organisations we can gain another picture however; SIL was implementing the effects of the philosophy but not the causes, while the CRCSS was implementing the causes.

8.3.1.3 The Case of SIL

Although SIL had a strong focus on reducing documentation they did not have the experience to know what the impacts of their decisions would be. Many of the critical design choices and inputs were required to be investigated again due to lack of knowledge about the system.

One of the main approaches followed by the SIL management team was that of consciously swapping risk for cost within the project. However, the lack of experience within the company meant that they were not necessarily taking appropriate risks, and there were a number of cases in which they were required to repair the damage to flight hardware at a greater cost than the original implementation would have required.

The company also outsourced some of their work, but didn't empower the sub-contractors to become involved in the project or understand the need for particular requirements. This resulted in specification and manufacture problems which cost more money later in order to rectify manufacturing defects or mismatched interfaces. In addition, they neglected to take up the offer of the CRCSS to undertake work in areas in which it had experience, which would have resulted in an 'automatic' partner-like relationship with the sub-contractors.

The timescale of the project was compressed and there was neither a good review process nor a philosophy of continuous improvement in certain areas of the company. Motivation in the company was very low. In addition, despite the company being small, the employees remained in small groups, each not trusting the other to the detriment of intra-office communication.

Finally, although placing the head systems engineer as project manager recognized the importance of systems engineering it actually had the opposite effect, placing an inexperienced manager in charge of the project and forcing the systems engineering to be neglected.

In other words, SIL did indeed implement some aspects of the Small Satellite Philosophy. However, it was proactive in areas which were the outcomes of the small satellite philosophy, but neglected the core drivers developed in Chapter 5. This is outlined in the table below, which highlights the area of the small satellite philosophy that was implemented, and the corresponding area neglected. In almost all cases the outcomes of the small satellite philosophy were implemented, and the drivers were ignored. In Table 8-3 the drivers are highlighted in bold.

Table 8-3: Implementation of the SSP at SIL

AREAS IMPLEMENTED	AREAS NEGLECTED
Standard Interfaces	
Reduced Documentation	**Technical Experience**
Swapping Cost and Risk	**Technical Experience**
Outsourcing	**Empowerment**
Making Quick Decisions	
ISO 9001	**Focus on continuous improvement**
Accelerated Development/Compressed Schedules	**Motivation**
Small Teams	**Trust and Honesty**
Systems Engineer is Project Manager	**Experienced Management** **Focus on Systems Engineering**
Freedom to Innovate	

8.3.1.4 The Case of the FedSat Project Team

The FedSat project team took a different approach to that of SIL, with a small, integrated team as opposed to the SIL matrix management structure. The management of the project aimed to draw in experience when required, promoted trust and honesty within the team and the systems engineering team was headed by a manager with experience in the space industry.

There were a few cores areas of the Small Satellite Philosophy which were neglected, however. For example, while the project undertook frequent internal and external reviews, there were few quality management systems in place. This was partly addressed towards the end of the project when the team would follow more rigorous procedures in the lead up to the launch of the satellite. However, on the whole this team was only missing a few of the core drivers developed in Chapter 5, those of technical experience which allows reduced documentation, and a project-wide focus on continuous improvement.

The areas of the Small Satellite Philosophy implemented by the CRCSS FedSat team are outlined in the Table below. Once again the core drivers of the Small Satellite philosophy are highlighted in bold.

Table 8-4: Implementation of the SSP at the CRCSS

AREAS IMPLEMENTED	AREAS NEGLECTED
Freedom to innovate	
Teamwork	
Commitment to the Project	
Trust and Honesty	
Small Integrated Teams	
Experienced Managers	
Strong Systems Engineering	
Personnel selected early and remain throughout	
Accelerated development	
Requirements Flexibility	
Minimal documentation	**Technical Experience**
Frequent Review	**Focus on Continuous Improvement**
Empowerment	

8.3.1.5 Comparing SIL and the CRCSS

While it is not clear cut, comparing the SIL and CRCSS small satellite philosophy implementations using the drivers outlined in Chapter 5 it is apparent that the CRCSS was closer to implementing the philosophy than SIL was. One of the executive members of the CRCSS summarised the differences in approach between the two organisations. "In our [CRCSS management] team we believed in leadership. SIL managed." {#9}

While SIL was unable to deliver the satellite, the FedSat project team successfully delivered to the launch facility on time and budget. However, it should be noted that without the additional time provided by a delay of the launch platform and the additional funds provided the federal government, there would have been insufficient time or money for the implementation of the project in Australia. It is very likely that the remaining funds and timeframe remaining after the collapse of SIL would have been an impossible task for the Australian team no matter which management style was used.

There were also some other differences in approach between the SIL and FedSat teams. As already noted, the FedSat team was totally project-based, with FedSat being the primary unit for satellite production. SIL on the other hand, used a matrix-based management structure with business carried out both across projects and functional lines. This difference in management parallels a study by Hobday (2000), were a Project Based Organisation (PBO) was compared with the management in a more functional organisation. Many of the same issues arose in the functional organisation as arose at SIL, such as a lack of direct control from the project manager, mismatched goals and poor customer relations. In the PBO, as with the FedSat team, high levels of communication and trust were formed, sub-contractors were empowered and the team was flexible and responsive to requirements changes and risk.

SIL was unable to establish a proactive approach to risk management, and due to a perceived confusion over specifications in the early phases of the project, was unable to control client needs and expectations. This caused the relationship with the CRCSS to become defensive, deteriorating into a lack of trust between the two organisations. Once again, these are characteristics exhibited by a matrix based organisation during the implementation of a CoPS project (Hobday, 2000). A comparison of the SIL and FedSat team experiences lends weight to the conjecture that the PBO is a more appropriate form of management for a CoPS project.

When looking at the project from the overall CRCSS perspective however, the project was still over cost and budget when compared to original estimates. It is impossible to say whether this was due only to the demise of SIL, or whether the collapse of the prime contractor concealed other problems with elements of the project such as the development of the payloads or the ground station. However, the fact that three out of four tender responses for the satellite bus were non-compliant is an indication that the project may have been overly ambitious given the original budget and timeframes.

Using this analysis framework, there are also a number of pointers into areas where the CRCSS may want to concentrate for future mission development. These include the areas of technical expertise and a focus on continuous improvement, with the first being addressed somewhat though the team members having gained experience through the development of FedSat.

8.3.2 Small Satellite Philosophy and CoPS

It was seen in the previous section that there were indeed differences between the implementation of the small satellite philosophy at SIL and the CRCSS. This section looks at the relationship between the SSP management paradigm and CoPS theory. It asks whether the Small Satellite Philosophy is a new management paradigm for Complex Product Systems and then looks at some of the lessons that can be applied from the FedSat case study in reducing the resources to other CoPS projects.

Is the SSP a new paradigm in the space industry and CoPS?

Traditionally, space missions have required large resources in both finance and manpower and have taken many years to complete. However, as shown in Chapter 5, taking the current improvements in technology into account, the small satellite philosophy has the potential to influence the management of the entire satellite industry. It found that the FBC Small Satellite Philosophy is a mechanism to promote creativity and responsibility on the part of the mission teams, obtaining in some cases an order of magnitude improvement in schedule and cost while maintaining nominal mission effectiveness.

It was also contended in Chapter 5 that implementing the drivers of the project and embracing the outcomes will help to ensure that the benefits of the SSP are capitalized upon. When analysing the implementation of the FedSat satellite it was found that while SIL implemented mainly outcomes, and subsequently was unable to deliver the satellite, the CRCSS FedSat team was more successful in implementing the causes. The lessons learnt from the demise of SIL are particularly important for projects such as

FedSat; in the next phase of FedSat's development care needs to be taken to ensure that the mistakes of SIL are not repeated.

However, it is difficult to ascertain whether this is a new paradigm within the CoPS framework, as there are few case studies to compare it to. As detailed in Chapter 3, many of the related case studies were in industries such as the international missile industry, the aero industry and the communications industry. It is unclear from these case studies whether an attempt was made to reduce the resources of these projects compared with the 'traditional' method of implementation. However, using the Small Satellite Philosophy as an example gives a basis for comparison of what happens in CoPS projects when attempts are made to reduce the timeframe and resources of the overall project.

It was found in Chapter 5 that the SSP was indeed a new paradigm in the space industry; based on this finding and the assumption that the previous method of implementing space projects is more typical of the implementation of CoPS, it may indeed be a new paradigm. However, this would have to be compared with other industries where resources are being reduced, such as the mining industry (with small exploration teams) or the aviation industry (with a move to "skunk works" to implement complex projects).

The key question in determining how this reduction occurred is to know how far to take the lessons learnt from this case study and apply them to other complex product system projects. With the FedSat project, the Small Satellite Philosophy was implemented based on the reduction in scope of a particular project based on the size of the satellite, while maintaining the basic components of the satellite architecture. This allowed a reduction in complexity and a single team to be involved with all major aspects of the satellite implementation. Finding the critical dimension of scope reduction in Complex Product Systems may be a significant factor in deciding whether to employ these techniques or not, discussed further in the following section.

A second area where the SSP made improvements in the space industry was by distributing the risk of a mission across a number of smaller cheaper objects. In other words, a particular programme would consist of a increased number of smaller missions that would return fewer scientific benefits, such as was the example of the missions to Mars in 2000. In effect, the increased risk of each mission was able to be spread over the entire programme, reducing the overall programme risk. This spreading of increased risk may be replicated in other CoPS industries such as distributed power networks or communications systems, providing that individual 'mission' failures are acceptable (i.e. that the systems are not mission or life critical).

Finally, and as outlined in the previous section, the core SSP drivers point to a focus on leadership capabilities as opposed to traditional management methods. This important shift in focus may be the difference between the successful implementation of projects in this domain, and may apply to other CoPS projects. Relationship building in the FedSat satellite (such as a focus of developing trust and honesty between the project engineers) is potentially an area for investigation in other CoPS projects wishing to reduce the cost of the overall project. The organisational behaviour aspects of the project, and the way that the project was structured, with a small integrated team willing to see the satellite launched at any cost, also points to areas for future investigation within the CoPS framework.

How do we apply benefits of SSP to other CoPS industries?

The previous section looked at whether the Small Satellite Philosophy was indeed a new paradigm in the implementation of Complex Product Systems. While it is unclear whether it is a new paradigm, or just one example of best practice in implementing a complex project with reduced scope, there are, nonetheless, lessons from FedSat which can be applied to other CoPS industries and projects. Using the critical drivers developed in Chapter 5, and the FedSat case study as an example, it is possible to determine a number of areas where the Small Satellite Philosophy may be applied to CoPS projects.

First, the central area of investigation of the small satellite philosophy, the relationship between complexity, resources and risk are investigated in context of the FedSat project, with particular focus on how the understandings gained through this process can be applied elsewhere. Following this, some specific areas of application taken from the SSP core drivers and lessons from the FedSat project are examined.

8.3.2.1 Relationship between Complexity, Resources and Risk

As developed in Section 5.5, one of the core drivers of the Small Satellite Philosophy was the enabling of better returns through the implementation of smaller, riskier and potentially less complex projects. This section looks at the relationship between different metrics of development time, mission cost, risk and science return, and attempted to draw some broad conclusions about the interaction between these when the 'Faster, Better, Cheaper' paradigm was applied. Earlier in this analysis it was seen that the FedSat project embraced all three areas of Faster, Better, Cheaper; reduced scope and complexity, the small satellite philosophy management style and a preparedness to accept increased risk.

The FedSat project, weighing 58kg, had reduced complexity compared to other satellite missions. Compared to larger missions, FedSat had fewer interfaces, although some of this was due to the removal of redundant units and the use of Off The Shelf (OTS) units. This reduction reduced some of the risks inherent in a complex system, but this was offset through the use of commercial-grade components and a lack of redundancy of subsystems such as the Transmitter and Receiver. In addition, while FedSat contained five payloads, these were power limited due to the amount of power that was able to be delivered by the solar arrays. Many of these payloads could only be operated for a few hours a week which decreased the science return compared to larger satellites with more power availability.

Table 8-5: FBC effects due to reductions in complexity

Reduced Complexity			
Metric	**Units**	**Techniques Used**	**Outcome**
Development Time	Years	Fewer interfaces (evident in wiring harness) OTS units (e.g. reaction wheels, magnetorquers)	↓
Mission Cost	$US	Less redundancy (no redundant components except for ACS and some DHS boards)	↓
Flight Rate	Fights/yr	-	-
Failure Rate	Percent	-	-
Increased Science Return	Instrument -months	Less power available to payloads (only 20W available max)	↓

As illustrated in the previous section, the CRCSS FedSat team also used a management style which is akin to that of the small satellite philosophy. The smaller, integrated team aimed to draw upon appropriate experience, motivation, flexibility and leadership. This approach reduced management overheads and the overall number of staff required, while leaving the risk to the project unchanged. The staff also aimed to make intelligent decisions to reallocate resources; an example of this was the elimination of the Thermal Vacuum tests in order to spend more money and time on integrated systems testing.

Table 8-6: FBC effects due to SSP management

SSP Management			
Metric	**Units**	**Techniques Used**	**Outcome**
Development Time	Years	Accelerated schedule, experience, motivation, flexibility and leadership	↓
Mission Cost	$US	Reduced management overheads and documentation	↓
Flight Rate	Fights/yr	-	-
Failure Rate	Percent	-	-
Increased Science Return	Instrument -months	-	-

Finally, the project further reduced the resources available and accepted a higher risk of overall mission failure. FedSat used commercial components where possible, eliminated time consuming procedures and relaxed the cleanliness requirements on the satellite. This trade off between risk and cost was not always explicit; some of the decisions made, such as a reduced focus on some quality procedures, were as a result of the inexperience of the project team.

Table 8-7: FBC effects due to increased risk/mission

Increased Risk/Mission			
Metric	**Units**	**Techniques Used**	**Outcome**
Development Time	Years	Eliminated some procedures (e.g. thermal vacuum testing) Relaxed some procedures (e.g. comprehensive ACS testing)	↓
Mission Cost	$US	Commercial components (e.g. ACS system) Relaxed cleanliness costs	↓
Flight Rate	Fights/yr	-	-
Failure Rate	Percent	Risk of failure increased as a result of actions above	↑
Increased Science Return	Instrument -months	-	-

All three of these allowed a reduction of resources, with some increased risk or reduced science return. It should be noted that this is what was predicted in the analysis of the small satellite philosophy, reproduced below.

Table 8-8: SSP Relationships per mission

Metric	**Units**	**Reduced Complexity**	**SSP Management**	**Increased Risk/Mission**	**Summary**
Development Time	Years	↓	↓	↓	↓↓↓
Mission Cost	$US	↓	↓	↓	↓↓↓
Flight Rate	Fights/yr	-	-	-	-
Failure Rate	Percent	-	-	↑	↑
Increased Science Return	Instrument -months	↓	-	-	↓

This matches the conclusions found in the overall implementation of the satellite project. Using the cost model developed for large satellites (Wertz, 1998) as detailed in Chapter 5, the FedSat satellite bus should have cost in the order of $A50 million. The satellite was successfully launched for one fifth of this price in under four years. However, there was a strong perception that the risk of the mission was high, and a knowledge that available power limited the science return from the satellite.

It is important to stress the importance of the reduction in a critical dimension (such as the size) of the satellite to this analysis. This may be a key area for analysis within CoPS projects. For example, in the telecommunications industry could a reduction in the overall number of base stations (BTSs), but an increase in the range and the number of users connected to BTS, accompanied with a new management model give an order magnitude reduction in time and cost of implementation? Or are smaller missiles more cost-effective in the long run? Finding the critical dimension for reduction in a CoPS which allows a new management philosophy, reduced complexity and a tradeoff between risk and cost while maintaining a similar architecture and outcomes may offer large gains in other industries.

8.3.3 Specific lessons

In addition, there are some specific lessons that can be learnt from the FedSat project which are as a result of implementing the Small Satellite Philosophy. These lessons may be applicable to other CoPS projects where resources are being reduced. The CoPS (FedSat) being implemented in this case was within the framework of a joint public and private sector Cooperative Research Centre initiative, although many of these lessons would be equally applicable in an entirely private sector setting.

8.3.3.1 No Contingency

Even through the FedSat project was completed on time and budget, originally there was no contingency money for when things went wrong. This became apparent after the bankruptcy of SIL, which resulted in the need for more funds and tight budgets for the remainder of the project. This lack of funds also had implications for other parts of the programme as the centre used funds for both commercialisation and research in order to find enough resources for the whole system. In a project where resources are being reduced and 'intelligent shortcuts' are being taken there need to be resources available in the event of extra-budget contingencies (although this does not have to be made apparent to the entire team).

The lessons from the Small Satellite Philosophy also indicate that when resources are reduced there may be more risk for the overall mission, and there needs to be a framework to take advantage of this. Reduced resource CoPS programmes should ideally contain a series of projects where one can either cross-subsidise or replace another when something goes wrong.

8.3.3.2 Limiting effects

As outlined in Chapter 5, while projects implemented using the Faster, Better, Cheaper paradigm can offer improvements in resource reduction this can only work to a limit. Reduced times and schedules may be used to drive for innovation in the process and motivate staff, but if these staff do not have the required experience or are forced to make too many reductions, the risk of failure becomes too high.

The reduced resources may have another impact on the project. Within the CRCSS the reduction of resources gave little scope for a degradation of the mission. In other words the satellite would either have worked or have resulted in a catastrophic failure - there was little in between. The removal of redundancy had the impact of reducing the complexity and cost of the mission, and even if the overall risk of the project success was not affected, the project success became a more binary result. This technique would not have been applicable for CoPS which were mission- or life-critical.

Finally, there were times during the FedSat project in which the team was pushed to the limit, working a large number of hours overtime in order to complete the mission. For FedSat this was did not affect the delivery of the mission in the end, although arguably it did create some tension within the team. "We had staff burnout – a lowering of morale – no one left though which was interesting." {#7} This is a common occurrence in small satellite missions and most likely other projects with reduced resources (Rick Fleeter's: The Logic of Microspace: Technology and Management of Minimum-Cost

Space Missions (2000) gives a detailed and entertaining account of the tensions arising in small satellite missions)

8.3.3.3 Multiple Benefits

It was also seen in the FedSat project that there are areas in the reduction of resources where gains in one area are accompanied by gains in others. For example, a reduction in scope allows a reduction in complexity and enables a different management style, to give an order of magnitude reduction in cost and timeframe. This was a way of thinking and an approach to the management of the project more than anything else.

8.3.3.4 Small Teams

Finally, one of the key areas believed to have resulted in the success of the FedSat was the use of a single small committed team with overlapping and complementary skills. This team was made up of a proportionately large number of systems engineers, with each member of the team having knowledge across the breadth of project. The members also had to display depth in particular areas of specialisation. This reduction in team size also had the impact of reducing the number of overheads required to manage the project. In CoPS with reduced resources the key may be to reduce the scope of the mission to the point where most of the team can be across the entire project.

In the FedSat case study the different implementation phases of the project were blurred, with phases added as required, such as the rework phase of the satellite just before launch. This flexibility of implementation phases – which can only be done with a small team that can be across everything – may be the key to a successful reduction of resources. Reducing the scope to the point where the team can be across all aspects of the project may give better results.

It was important with this small team to have the right management systems and structures in place. The characteristics of the Small Satellite Philosophy, focussing on areas such as experience and trust, may be applied to other projects of a similar nature.

8.3.4 The Management of Space CoPS

Why was the project over cost and schedule and could this have been avoided?

There were a number of reasons why the overall project was over cost and schedule, with most of the project participants citing the collapse of the prime contractor as being the main reason for these increases. This single event overshadows many of the other factors that may have contributed to the overall delivery of the satellite project.

As SIL was chosen as the successful bidder with the full knowledge of the CRCSS about their financial situation, some of the responsibility needs to be given to the CRCSS for this decision. As already detailed, SIL was selected because it was the only bidder to integrate all of the satellite payloads into their tender response. Should this have been taken as an indicator that the requirements for the satellite were very ambitious for the amount of money and time available? With the funds available to the CRCSS through the CRC programme, and the nature of the centre's operation not allowing it to remove payloads, the executive had little choice but to proceed with SIL.

It is also difficult to determine whether this is typical of Space CoPS or of the space industry in Australia. Chapter 5 detailed a large number of small satellite missions. Most of these delivered to cost and schedule, with the success of the mission being the varying factor between projects. Being the first satellite to be developed in Australia for thirty years, there are no other satellite projects to compare it to in the modern Australian context.

Does Australia have the management/leadership capacity to create a satellite industry?

Using the FedSat case study as an example, a combination of systems engineering skills and leadership capability was seen as one of the key drivers for the successful implementation of the project. As outlined in Chapter 6, Australia may have a strong capability in the area of systems engineering. Do the people with this systems engineering capability also have the management capability for the delivery of a satellite project?

Many of the participants in the Australian space industry are Small to Medium Enterprises (SMEs), or SME subsidiaries of larger international firms. This was reflected in the composition of the CRCSS which had only SME company participants. The advantage of these organisations is that they are flexible and prepared to take risks in pursuing a goal, two of the drivers of the Small Satellite Philosophy.

It should be noted that the CRC programme was not originally intended for SMEs (Mercer, 1998). Large corporations have financial backing which was seen to be a core part of the CRC programme. However, the CRCSS believed that having SMEs as partners was an advantage. "SME's ... are flexible, innovative, highly manoeuvrable in the market place and are prepared to take risks. Even if they can't afford them". "One advantage is that you can talk to them on equal terms. If I had a Telstra or a BAeS [British Aerospace Systems] I would feel that their culture would overlay the rest of the CRC so much." {#6}

The FedSat project was successful in finding people with the required management capability within its SME partners. The management of the satellite project team while in Australia was sourced directly from the SME participants, with experience both in the space industry and working with and building small teams. The motivation, flexibility and leadership brought to the group may be partly attributed to the experiences of these staff working with small teams within their respective companies.

Based on a mixture of experience in the industry and the ability for SMEs to implement the small satellite philosophy there is an indication that the key participants in this Australian space industry have the necessary management experience to implement small satellite projects. Indeed, the inclusion of SMEs within the CRC programme may indeed be a low risk mechanism for encouraging the deepening of CoPS capabilities in the Australian context.

8.4 Policy Implications

This study has focused primarily on the satellite manufacture component of the space infrastructure industry (currently the largest industry segment) within the Australian context. In this section a number of policy implications of the FedSat project are investigated. One of the central questions asked in this investigation is whether the CRC framework is indeed the best (or appropriate) mechanism for the development of this industry (Moody, 2000a). In answering this question it is necessary also to compare the CRCSS against other CRCs, with particular reference to using the CRC scheme to develop large projects.

There are also many questions to be answered which are not addressed in previous government reports into the Australian space industry. For example, has the interregnum in space research in Australia reduced the capacity of the country to re-enter such a complex industry as space research and what are the policy and institutional requirements needed to re-build an industry?

Finally, an investigation into how the Australian Government may influence patterns of technological innovation through different policies to promote technical leadership in the development of Complex Product Systems will outline potential areas for future policy development.

8.4.1 The CRC Programme

How does the CRCSS compare against other CRCs?

The CRCSS met all of the criteria for funding within the CRC programme, making it similar in structure and process, if not outcomes, to many other Cooperative Research Centres. This included the need for a number of programmes within the CRC such as an R&D programme, education and outreach and a commercialisation programme. The CRCSS was also formed as an unincorporated joint venture with partners across Australia, similar to many other CRCs formed at the same time (Mercer, 1998)

However, the main difference between the CRCSS and many other CRCs in that it was based around a single large product. Other CRCs are designed around the development of basic or applied research to the point where it can be commercialised. If the prospects for this product are promising, the CRC would set up a small company, licence the technology and work with them. The CRCSS was different in that it required a final product (the satellite) from the outset, which consumed much of the centre budget.

In addition, the traditional CRC model is to have a number of parallel research projects. If one fails the others are relatively unaffected. In the CRCSS, as all of the research was centred around a single piece of hardware; there was little room for other parts of the CRC to 'take up the slack' in the event of a failure of FedSat.

The CRCSS has, to date, been unsuccessful in developing any commercial outcomes. This may be for a number of reasons, including the high cost of the satellite project or the risky nature of the satellite industry. In the words of one of the CRCSS centre participants, "the CRC programme is not about that seven years. It is about what comes out of it that you can commercialise and make money out of it. Why would you put all this money into effort with such a high risk of getting nothing at the end." {#1} This is not different from many of the other CRCs which have been unsuccessful in developing commercial products from their research and development.

Finally, the CRCSS commercial partners were all Small to Medium Enterprises. This is different to CRCs with large organisations as partners, which have the financial might to take advantage of any new business opportunities that the research may deliver. In the case of the CRCSS, even if it did develop products it didn't have the financial resources to commercialise them. In addition there was no commercial focus from the beginning of the project. One of the industry partners strongly believed that the project requirements were largely driven by the universities, not industry, and that the companies had no impact on the research. This caused the CRCSS to be academically driven rather than commercially driven.

Was the CRCSS an appropriate policy mechanism for the development of a satellite?

At the time of its inception, the CRC programme was the only funding mechanism which could be used to implement the project. In the words of the director of the centre, "We were advised to use the CRC programme as the vehicle to fund the space project."

It was shown in this thesis that space is a classic CoPS, and as is the case for many CoPS, the satellite was completed over budget and not to schedule (Hansen and Rush, 1997). What role did the structure of the CRCSS play in this, and how might this shape the understanding of the implementation of CoPS?

Section 8.1 detailed some of the structural issues limiting the successful implementation of the FedSat project. These included the unincorporated nature of the partnership and the range of goals identified by the centre participants. This section demonstrates that many of these limitations are as a result of the structure of the CRC programme itself, and looks at the applicability of the CRC structure to develop CoPS such as satellite projects.

In the FedSat project the satellite had to be matched to the CRC framework, rather than the other way around. "To qualify for CRC funding you have to meet CRC guidelines. Their rules require a comprehensive R&D programme, a substantial education and training programme, a commercial programme and other performance criteria tailored to measure performance in each of these areas" {#1}. Much of the research undertaken by the CRC was not possible until after the satellite launch, four years after the centre's inception.

The mix of participants in the CRCSS resulted in a range of different goals for the project. As stated by one of the engineers "You've got a mixture of academia, government and industry. Industry are there to make a profit and they understand the commercial world. Academia knows how to best make use of their meagre funds in terms of research. Government have limitless resources due to their infrastructure.

They are quasi industry and academia. These three different groups are coming together with different outlooks". {#4}

The unincorporated nature of the CRC also caused some problems for the management of the project. It was difficult for the management of the CRCSS to enforce decisions on the partner organisations, who were responsible for the day to day management of their own staff. The range of participants who made up the board and executive of the centre also resulted in politics between the different centre partners. The distributed nature of the cooperative also required increased communication between the partners.

The success of the CRCSS was also based largely around the success of FedSat. If the satellite were to fail, the majority of the research outcomes for the centre would be lost. This 'single-point' failure accompanied with a perception that CRCs are not designed to fail catastrophically, meant that there were differences in approach between the different project partners, some opting for a more risk averse approach than others.

One of the goals of the CRC programme is to commercialise the research arising out of the work of the centre. In order to commercialise a single product with large costs, partners need to be able and willing to invest significant resources, something not present in the CRCSS. However, it may be that the centre can commercialise less complex spin-off technologies (such as sub-systems) or add-on technologies (such as the payloads). However, as many of the original requirements were not developed with a commercial focus, this commercialisation has not yet been successful.

In summary, some of the issues facing the development of the satellite project within the CRC structure were:

- Being unincorporated, the CRC structure worked on a partnership model rather than an authority model;
- Members of the CRC saw the programme as an opportunity for sourcing funds, rather than a business which needed building;
- The CRCSS was based around a single product, with little room for shifting funds or obtaining additional resources in the event of difficulties;

- The CRC had a research focus, not a product delivery or commercial focus; and
- CRC partners range from industry to government to academia, with many different goals.

In looking at whether the CRC model is appropriate to the development of Complex Product Systems, the critical CoPS dimensions can be used. The applicability of the CRC structure to cope with these different dimensions is outlined in Table 8-9.

Table 8-9: Applicability of the CRC structure to CoPS

Dimension	**Applicability**	
High cost product	No	The product takes up most of the budget of the CRC. If it fails the remainder of the research is lost
Long product cycles	No	The life of a CRCs is 7 years, but they ideally have research starting from the beginning. If it takes too long to build the product you won't get the research
High complexity	Maybe	The CRC is distributed around partners and can source both breadth and depth of skills and experiences.
Emerging & unpredictable properties	No	The CRC structure is risk averse and unincorporated joint ventures have difficulties with authority mechanisms
One-off kind	No	Commercialisation of the final research and product is the aim, with an ongoing life for the centre after the end of the programme. A single product gives risk of failure for the centre, and also the potential for the centre to "finish" after the product is completed.
Involvement from policy and regulation	Yes	Government is a partner in the CRC model
User driven	No	The user of the project is the centre with multiple goals. There is no single customer.
Project rather than product	No	CRCs are designed to have a number of research programmes.
Oligopoly markets	Maybe	The CRCs may attract SMEs or large organisations wanting to come into the market
Distinct management capabilities	Yes	This depends on the capabilities of individual partners

In Chapter 6 it was seen that of many of the explicit industry-driven policies in Australia, only the CRC programme (and the limited and sporadic MNRF programme) was large enough in size to cater for Complex Product Systems. From above it can be seen that the CRC framework is unsuitable to the management of many of these critical dimensions of CoPS. As such, while there may be an inherent capacity within Australia for the development of CoPS, Australia's innovation policy does not recognise their importance. Specifically, the CRC framework is inherently unsuited to their development.

8.4.2 The Role of Government

Did the structure of the space industry in Australia play a role in the development of the satellite project?

If the CRC programme is not inherently appropriate to the development of satellite projects, what are the structural preconditions for the industry's development? This section shows that Australian space policy is not positioned to facilitate the development of small satellites and there are no government mechanisms currently in place to effectively facilitate the industry's development.

Within the space industry in Australia there is a great deal of competition. With little space policy and competing visions there are many expectations and conflicting ideas from different parties. The satellite was also high profile compared to other small satellite projects. This created schedule pressure to launch during the centenary of federation in 2001, and a risk averse attitude towards the satellite development. However, Australia does have a great deal of existing research in the space industry, as well as a wealth of experience in implementing satellite projects.

Using the FedSat project as an example, and the interactions of the project partners as a guide, a number of structural issues that need to be addressed for the space industry in Australia.

- **Clarity in purpose**: Companies within the industry need to understand their role, and where they fit into it in order to work with one another. In the FedSat project it was perceived that the companies were competing for the same amount of work available, creating politics and a loss of good will (whether this perception was correct or not).
- **Building a market**: Australia needs to tap into the existing market for space products. This includes the need to address issues of national concern, area not necessarily covered in the ambit of the FedSat project.
- **Domestic Suppliers**: Understanding the range and scope of domestic suppliers is important in order for the industry to collaborate, rather than compete. Projects should be used to build domestic capability where possible.

What is the role of government in the Australian space industry and CoPS in general?

Chapter 6 looked at some of the developments in the Australian space industry from a policy perspective. In the policy domain, investment in the space industry has always been justified with respect to the creation of spin-off technologies (NASA, 2002) as well as direct benefits from the products themselves. This may be an additional area for investigation in other CoPS projects.

The consolidating nature of the international space industry outlined in Chapter 4 may also provide an insight into the nature of international CoPS industries. For example, the consolidation of the space industry in Europe may prove an example for the future directions of the international telecommunications industry; the trends being experienced in national space agencies may also be occurring in national telecommunications providers:

- Commercialisation of R&D projects that provide or complement existing solutions to national priorities;
- Promotion of an industry-led sector that establishes collaborative partnerships with Government and research bodies; and

- Participation in bilateral and multilateral projects that develop national skills and industries through technology transfer.

There is currently little space policy in Australia. "In a policy sense the government didn't know what was going to come out of it. This is more credit to the [then Minister for Science] McGauran's of this world, because they were willing to listen to arguments about how Australia could get into this business. They were convinced by us that microsatellite technologies, subsystems and niche areas in the space technology business are ways to make inroads into the global market and get itself involved internationally as a global player, without annunciating a policy. They accepted the arguments at the time." {#6}

The CRCSS has been successful in launching a satellite. "Now that we have achieved a lot of that I would like to see it turned into policy. Now is certainly the time for a policy statement and policy statements of course bring commitments of funding and that's where the government has to take the courage and make that step." {#4}

Has the interregnum in space projects in Australia reduced the capacity of the country to re-enter such a complex industry as space?

FedSat was the first indigenous satellite to be developed in Australia in thirty years. Is the success of this project sufficient for Australia to re-enter the space industry, or are there deeper issues to be faced?

In Chapter 6, the different areas of the Space Industry were outlined. These included infrastructure, satellite services, space data and assets and support services. Satellites fit into both the space data and satellite services sides of the industry. This industry is mainly made up of Small to Medium Enterprises; the partners of the CRCSS are one indication of this. "The fact that only SMEs would be involved tells you about the state of the Space Industry in Australia. Large organisations weren't keen to be part of it because they couldn't see a business opportunity, whereas SMEs are far more risk taking and adventurous. That's why they are there and not large companies." {#1}

Without an additional project, the gains made in awareness and the skills developed during the implementation of the FedSat project will be lost "We didn't ignite the space industry, we just kept it from dying" {#4}

8.5 Conclusions

This section has answered a number of key questions about the FedSat project, and analysed it from a number of perspectives.

It has looked at the suitability of CoPS theory to the satellite, and used the frameworks developed in Chapters 3 and 4 to analyse some of the key aspects of the structure and examine the lessons learnt. It was found that FedSat was indeed a good example of a Complex Product System, and that a number of lessons could be learnt and applied to other CoPS.

The implementation of the Small Satellite Philosophy during the two main phases of the project was then investigated. It was found that, while in the UK the outcomes of the philosophy were implemented without an awareness of the drivers and in Australia the drivers were mostly implemented. The propositions found in the FBC literature were then tested using FedSat as an example.

Finally, the effect of the Australian policy regime was investigated in the context of the FedSat project. It was found that the CRC programme was not a suitable structure for the development of complex, one-off projects, and that there were a number of structural issues that needed to be addressed in order for Australia to re-enter the international space industry.

Chapter 9 synthesises the findings in these three domains of innovation, management and policy. It looks at the overall success of the CRCSS, particularly with respect to the goal of creating a space industry. It then identifies some key areas of investigation for further analysis and makes some recommendations for the essential components of any future space endeavours.

Chapter 9

Conclusions

9.1 Introduction

In Chapter 9 the findings of the previous chapter and the investigation of the project from the three theoretical perspectives of innovation, management and policy are related to one another in an attempt to answer the central question of the thesis. It is found that, based on this analysis and given the current structure of the industry and policy environment, Australia *cannot* currently develop an indigenous satellite industry made up of high-value, complex products for various reasons. These are repeated here for emphasis:

- While there may be an inherent capacity within Australia for the development of CoPS, Australia's innovation policy does not recognise their importance. Specifically, the CRC framework is unsuited to their development;
- The key participants in this industry have the necessary management experience to implement small satellite projects, but the CRCSS's overall success depends on its ability to generate continued and ongoing projects; and
- Australian space policy is not positioned to promote the development of small satellites and there are no government mechanisms currently in place to effectively facilitate the industry's development.

The FedSat case study has shown that Australia has the right mix of capability and expertise to do so in a technical sense, but that the business motivations and underlying reasons for having such an industry are not currently present. The foregoing chapters highlighted flaws in the approaches taken to create a small satellite based industry in

Australia, but given sufficient structure and policy change there would appear to be no reason that a sustainable industry cannot be assembled.

This chapter first looks at the success of the FedSat project, using the metrics developed in Chapter 8. Given this success and a synthesis of the findings in the previous chapter, some recommendations for the Australian Space Industry are then made, including the idea of the industry's segmentation and mechanisms to include space into ongoing government policy.

Finally, based on the FedSat experience, a new way for Australia to enter the Space Industry is presented; one that is based on the formation of specific policy to address the development of Complex Product Systems. This policy would enable projects such as FedSat to be properly coordinated and funded, if it was found that they are in the national interest and if they continue to build the nation's capability in the development of these products. These different mechanisms and future areas for research are outlined.

9.2 Project Success

Was FedSat a success?

In Chapter 7, a number of critical success factors were developed for the satellite. These included success factors in the dimensions of technology, research, commercialisation and benefits to the entire industry. In determining the success of the FedSat mission, each of these critical success factors can be analysed, starting with the technical success factors in Table 9-1.

Table 9-1: FedSat Technical Success

	Technical Success Factors	*Success*
i.	The transfer of space technology into Australia	*Achieved, with much internally generated*
ii.	Develop necessary space infrastructure to perform all system integration and testing in Australia.	*Achieved in terms of project specific needs*
iii.	Qualified and working ground station and spacecraft "Fit for Launch".	*Achieved*
iv.	Successful launch of the spacecraft and first communication.	*Achieved*
v.	Achieving nominal in-orbit operation of the spacecraft platform.	*Achieved*
vi.	Basic "low level" communication with the payloads.	*Achieved*
vii.	One month of operation of the spacecraft platform.	*Achieved*
viii.	Successfully perform an experiment campaign with each payload.	*Achieved*
ix.	Three months operation of the spacecraft.	*Achieved*
x.	Six months operation of the spacecraft.	*Achieved*
xi.	First anniversary of launch with continued spacecraft communication.	*Achieved*
xii.	Achieve design life of three years.	*In progress*

From a technical standpoint, the project was a success. The primary task of the CRCSS was to have a laboratory in space, which it has successfully done for over a year. All of the main systems on the spacecraft were successfully operated, as was each of the payloads. These payloads were also successful in delivering research outcomes to the CRCSS academic partners. However, there are limitations due to cost overruns of the technical budget, which mean that there are two years less research to be undertaken, and despite funding to overcome this aspect, little money was left in the budget for commercialisation of the technology developed during the CRCSS's operation.

The success of each of the different groups in meeting the research dimension of the success criteria are given below.

Table 9-2: FedSat Research Success

Research Success Factors	***Success***
xxxv. External money attracted for research	*Over $A500,000 attracted*
xxxvi. Publication of papers	*Over 300 publications in 3 years*
xxxvii. Invited keynote addresses	*Over 30 keynotes*
xxxviii. Conference presentations	*Over 250 presentations*
xxxix. Recognition of research awards	*10 awards in 3 years*
xl. Patents, licences and royalty agreements	*None*
xli. Number of citations of CRCSS related research	*Unknown*
xlii. Cooperative involvement between partners	*All projects had more than one participant*

In hindsight, as a whole the technical team believed that the technical and research outcomes could have been achieved if the CRCSS had built the satellite by themselves. It is hard to say what impact the reduced research budget will have on the overall project, as there is no benchmark to compare this with. This may have had a bearing on the commercial success of the project as well.

Table 9-3: FedSat Commercial Success

Commercial Success Factors	***Success***
xliii. Formation of a private company using the IP of the CRCSS	*Achieved*
xliv. Development of products based on CRCSS technology	*Not achieved*
xlv. Income from contracts, royalties, licences and consultancies	*$A95,000 over three years*
xlvi. Recruitment speed and first employment of graduating students	*Mostly overseas*
xlvii. Benefits to end users and changes in industry practice based on CRCSS's research programme	*Unknown*

The commercial goals for the satellite were largely not met. There were no commercial products developed nor was there much additional revenue generated by the company that was formed, Satellite Systems Pty Ltd. It was seen by some that what the CRC lacked in the commercial arena was the imperative that a champion has for success and the lack of commercial outcomes was perceived to be as a result of running a joint venture with non-commercial people. The business partners on the satellite were able to capitalise on some of the skills created during the satellite project, but these people were working largely on non-space-related projects.

This failure to reach commercial expectations was not unexpected. Within the CRCSS the commercial activities arising from the centre had the potential to be competitors with the commercial partners and the university participants wishing to commercialise the technology developed. For example, there was an attempt to form a ground station company but it was found that the market for this was already taken; industry partner ITR had already developed a commercial opportunity in this area.

It should also be noted that the CRCSS does not own much of the IP in the satellite itself; this is owned by SSTL, the company which purchased the insolvent SIL. As such, any commercialisation of the platform would require redevelopment of many of the sub-systems and/or commercial agreements with SSTL.

Table 9-4: FedSat Industry Success

Industry-wide Success Factors	***Success***
xlviii. Public awareness outputs	*Achieved, with some media awareness particularly at launch*
xlix. Opportunities for Australian scientists and engineers in the space industry	*Achieved, but not ongoing other than in research*
l. The promotion of international cooperation around Australian Space Technology	*Achieved, but not ongoing*
li. The formation an Australian concentration in space activities	*Achieved, but no ongoing projects*
lii. The formation of a de facto Australian Space Agency	*Not achieved*
liii. Ongoing projects	*Not achieved*

The CRCSS successfully built a laboratory in space and, in doing so arguably increased Australian capability to be part of the space industry. However, based on the success criteria above, it is apparent that unless the CRCSS is successful in finding additional funds for another project, it would not meet its objective of promoting a sustainable Australian Space Industry. In essence, the CRCSS was not kick-starting a new and vibrant space industry - it was keeping the old one alive.

FedSat was seen as an opportunity that needed to be capitalised upon and it was thought that this was the key to the overall success of the CRCSS. Even if the CRCSS was seen to have taken the first bold step in kick-starting the space industry in Australia, it needed to ensure that it continued to address this issue proactively. It was thought that the centre should continue to commercialise the technology associated with FedSat and that a great deal of attention and resources should be given immediately to an investigation into the development of the next large indigenous space project.

In general the CRCSS was a success in the sense that it was able to launch a satellite into space, meeting the needs of a government after a visible space project. However, it was not a success in four areas:

- The project research programme was greatly reduced as a result of overruns in budget;
- There are no future projects to build upon the expertise generated;
- Many of the technical team have been lost to other industries; and
- It is not yet apparent that the CRCSS "kick-started" a space industry.

This inability to commercialise the outcomes from the space project and to develop an industry may have been due to the overruns in budget, causing less money to be spent on the commercial programme. It was shown in Chapter 8 that many of the drivers for the decisions made by the CRCSS leading up to these overruns are linked to the structure of the CRC programme itself, which was found to be less than ideal for the creation of a Complex Product Systems such as a satellite project.

It was noted in Chapter 2 that the analysis of the FedSat project was only concerned with the manufacture of the satellite bus, including the mechanical structure and the central operating electronics. The satellite payloads and the satellite ground station were not analysed in great depth during the study. However, looking at the different success criteria above which are still to be determined it can be seen that the remaining success criteria are heavily dependant upon the operation of both the payloads and the Ground Station. Indeed, the overall long-term commercial success of the centre may ultimately depend on either the commercial benefits of the ground station or the payloads. Given the linkages between the different payload providers and international partners such as Johns Hopkins University and NASA in the United States, NASDA in Japan and Stellenbosch University in South Africa, the satellite might also lay an early foundation for future initiatives with an international focus.

However, although that there are still some potential benefits to be realised as a result of the satellite industry, it is clear that the CRCSS sustained space interest, but not dramatic enough to create enough interest to catalyse investment. Would this have been possible given the current policy mechanisms? Is there a need for a long-term view based on specific policies, which might be able to further mobilise capital investment? These questions are addressed in the following section.

9.3 Rebuilding an Industry

What are the policy and institutional requirements needed to re-build an industry?

The space industry has often argued that it is 'special' and, as such, should be treated differently from other industries in terms of government support and intervention. A number of arguments, such as high barriers to entry and public good "spin-off" benefits are cited as the reason for governments to become involved. This section looks at some of the policy and institutional requirements for the formation of a space industry in Australia, based on the lessons learnt from the CRCSS. It is found that new policy settings and adjustments in administrative structures are essential if Australia is to seek advantage from national and international engagement in space.

9.3.1 Market

In building FedSat, the CRCSS was focussing on an area of the space industry which was in the middle of the industry value-chain, as outlined in Chapter 6, used for industries such as space science and instrumentation. There was little indigenous market for this technology, which meant that the infrastructure created for the project and the skills learnt during its implementation did not have immediate application in other projects.

In order to create sustained involvement in the industry, projects need to focus on the market end of space, for which there are both emerging indigenous and international applications. In order to make these decisions, there is a need for more market information about the industry, in order for the participants to find niches and effectively collaborate with one another.

To attract international clients and investment, Australia needs to prove itself in the space industry. This can also be done at the infrastructure end of the market, with support services and ground stations ensuring that Australia remains as a key participant in programmes.

9.3.2 Human Resources

The FedSat project was successful in attracting good people into the industry and giving them skills in this area. However, these people are now either overseas or working on non-space related projects. In order to maintain a level of expertise within Australia, there is a need to capture the current skills resulting from FedSat which would result from a collection of projects and a sustained long-term view.

9.3.3 Capital

There was little capital available from within the SME partners of the project, and the CRCSS did not obtain any external (non-government) funds. In order to create a viable space industry, there needs to be a healthy risk investment regime in the country, or participation with large players who are able to fund future developments, either in partnership with or outside the ambit of the government. In order to mobilise this capital, there needs to be solid government support for the industry or, at the least, defined policy to reduce barriers such as long lead times for return on investment, high risks and high entry costs. Access to capital would have direct benefits to the growth of the Australian space industry, and would also provide domestic capability to service both public and private sector needs in Australia.

9.3.4 Government Support

Many of the limitations outlined above point to the need for government support in order to create and sustain a successful space industry in Australia. Even if not for space directly, government policy needs to be such that there are tailored, strong policies for CoPS, either through providing business as a customer, defining frameworks for their operation or providing mechanisms for nurturing their development. This may be seen also as a requirement for the government to build upon successes in this industry. For example, within the satellite industry there may have been an approach taken of “if you are successful, we will find money for another satellite to keep the team together and if you aren’t then we will leave the industry”. Currently, there has been no decision made either way.

Space opportunities are also not linked to current government priorities. In order to stimulate investment, there is a need to recognise the proper role of public funding in catalysing a space industry through coordinating government procurement to promote domestic industry. In addition, as many benefits of space technology are distributed across areas of industry involvement there is an essential need for a whole-of-government approach during the development of this industry. Given that the market globally is characterised by Government intervention and that, with the exception of the satellite communications segment, the public sector is a primary purchaser and user of space technologies, the coordination of space procurement as a means of investment is essential to achieving a sustainable domestic space industry.

There is also a current lack of focus and priorities in space-related R&D (with the exception of astronomy) and a lack of strategy for the development of a commercial space industry outside of the launch sector. This makes it difficult to engage opportunities in international global corporate and public projects.

9.3.5 Industry Structure

Despite the need for government support, any initiative in the space industry needs to have a commercial focus in order to be sustainable. As learnt from the example of the CRCSS, unless this commercial approach is instilled into the project from the beginning, guiding the use of technology and selection of partners, the project may have few commercial outcomes. In addition, without a clear commercial goal, there may be the tendency for project partners to see the endeavour as a chance to source money, rather than as a participant in growing a particular commercial company.

The whole industry needs to be engaged, not just a small segment. This could be done with a segmented structure and clear industry vision and goals. Within the CRCSS the goals were reasonably distributed across the partners, which was seen to cause issues within the organisation, such as internal politics and inefficient application of resources. This attempt to get a clear industry vision and goals has been undertaken a number of times by the Australian Space Industry Chamber of Commerce and the International Space Advisory Group, to name two. This vision has not yet been accepted by the industry.

In summary, some of the policy and institutional requirements for the formation of the space industry are given below. It can be seen that many of these areas require cooperation between the public and private sectors, but with support from the government in the form of sound policy development.

Market	A healthy Australian reputation and experience in the space industry
	A home-grown market or need for space services
	Ability to be an aggressive marketer and have good market research
Human Resources	Key personnel with experience
	Ability to import knowledge and key personnel not matter what cost
Capital	A healthy risk investment regime
Government Support	A legislative framework to enable activities, to define the rules and to allow the mobilisation of investment
	A mechanism for ongoing funding, aligned with goals and with reasonable targets
	Long term government support to get it going, or existing infrastructure in place to promote industry development
	A formalised role of the government vs. the private sector
Industry Structure	Segmented industry roles to reduce competition
	A clear 'industry vision' and goals
	Engagement of the whole industry

In addition, there is also widespread recognition of the role of public-private research partnerships in Australia. For example, Howard (2003) believes that "the emergence of public-private research partnerships reflects a fundamental change in the way in which knowledge is generated and applied as well as changes in approaches to the management of industrial research and development" (pg19). As illustrated by the CRCSS example, a sound space industry most likely has components of both public and private investment working in partnership.

Is it possible in the current climate to create a space industry?

As outlined in Chapter 6, there are a number of strengths of the space industry in Australia (ISAG, 2002):

- Strong foundations in optical and radio astronomy with industrial spin-offs in the design and manufacture of ground antennae, spacecraft instrumentation and associated technologies;
- A diverse portfolio of specialist capabilities in the technologies of remote sensing, GPS, signal processing, microsatellite design, space systems, space instrumentation, debris tracking, geodesy and certain propulsion technologies;
- A developed ground station infrastructure for telemetry and tracking and established international collaborations in these areas;
- A wide expertise in biomedical research of relevance to enduring health in space and with applications on Earth for medical research and remote health service delivery; and
- A rich and continuing history of being host to and participating in the testing, tracking and ground receiving facilities of foreign space agencies and approaches to further this involvement through the MUSES-C and X-38 CRV projects.

However, based on the experiences of the CRCSS and the FedSat satellite and given the current structure of the industry and policy environment, Australia *cannot* currently develop an indigenous satellite industry made up of high-value, complex products for a number of reasons. This section outlines some of these reasons based on the lessons learnt during this study.

As the FedSat project illustrated, once the satellite was built and the surrounding infrastructure (including the ground station and test equipment) was created, there was no available market for future projects, either within Australia or internationally. In other words, there was a gulf between market and infrastructure.

In addition, it is unclear whether the current industry structures are conducive to the formation of a space industry. For example, while there is some networking and industry clustering, the industry is more competitive that collaborative. This was evident in the dispersed nature of the CRCSS both before and after the FedSat project and the fact that the centre partners were also competitors for the scarce work available.

Finally, and as outlined in Chapter 8, the CRC framework is unsuited to the development of CoPS, even through it is the only policy mechanism (other than the Major National Research Facilities) within Australia's formal innovation policy which is of sufficient scope for their development.

In summary, the FedSat case study has shown that Australia has the right mix of capability and expertise to do so in a technical sense, but that the business motivations and underlying reasons for having such an industry are not currently present. The foregoing chapters highlighted flaws in the approaches taken to create a small satellite based industry in Australia, but given sufficient structure and policy change there would appear to be no reason that a sustainable industry cannot be assembled.

9.3.6 Management Skills and Future Projects

Once the satellite returned to Australia, it was found that the team was able to complete the project on (the revised) time and budget. Based on this experience and the analysis of similar SMEs within the space industry in Australia and their skill base, Chapter 8 of this thesis found that the key participants in this industry have the necessary management experience to implement small satellite projects.

While this is not a limiting factor in the development of the Space Industry, unless the CRC or other organisations are capable of generating continued and ongoing projects these skills will be either lost overseas or applied in other areas.

9.3.7 Government Policy

Finally, and most importantly, Australian space policy is not positioned to facilitate the development of small satellites. There are no government mechanisms currently in place to effectively facilitate the industry's development, as outlined in the previous section. Given Australia's lack of space policy, long-term projects and uncoordinated domestic markets for satellite technology, it is not possible in the current climate to create an indigenous space industry.

In addition, without government involvement it is difficult for Australian companies to enter international markets. The CRCSS used its government connections to source a number of in-kind contributions from other nations, such as a launch from the Japanese Space Agency NASDA and funding from the British National and Canadian Space Agencies. Unless there are mechanisms to formalise these arrangements it will be difficult for any other companies, especially ones outside the CRC structure, to undertake these international collaborations.

9.3.8 Future Projects

What is the future of the Australian Space Industry and what path should future initiatives take?

Although it may not be possible in the current political climate, a vibrant Australian space industry may be achievable without excessive expenditure. It can be argued that this may be achieved by strategically focussing procurement and investment into projects of national benefit, rather than of national prestige or capital-intensive research. However, this industry would require a space policy that recognises the need for investment by both the private and public sectors. This section looks at directions that future initiatives should take in order for this industry to be created, building on the policy analysis of the industry in Chapter 8.

9.3.8.1 Investment

Australian industry will be unable to use its domestic skills or compete internationally without investment in the Australian space industry and the facilities to develop the applications of space technologies. As the CRCSS experience showed, Australia is currently reliant on the purchase of overseas technologies and in the absence of commercialisable, Australian-owned IP, the industry will be increasingly restricted to 'build to print' activities.

Any space industry needs to be market driven, but government should recognise that it is a consumer of space products across its many areas of operation. As such, investment in the space industry could be undertaken through the government leveraging opportunities based on current purchases. In order to do this, policies and structures should be formed which will determine national priorities among projects and facilitate their funding and linkage into international and regional programmes. With increasing public sector usage of remote sensing and GPS, these areas may provide the solutions to identified national priorities.

9.3.8.2 Industry Segmentation

One of the challenges facing the Australian space industry is defining exactly what the space industry is. Organisations harnessing space related opportunities come from a diverse and often apparently unrelated range of industries. Indeed, as the applications from space related technology and space derived information continue to benefit terrestrial industries, the borders of the space industry will continue to become even less apparent.

As a nation seeking access to a greater market share from a relatively small base, Australia's ability to compete in this market will hinge on alliances with major market participants, at both industry and government levels. Due to the international and competitive nature of the space industry, it is essential that Australia builds its capabilities with a clear sense of national priorities, industry vision and future steps.

However, while it is important to understand the industry, there is also the need for a unified voice that can come to government. The CRCSS fulfilled this role partly and had a number of members on policy development groups such as the International Space Advisory Group. This policy advice mechanism, using strong industry participation, should be formalised, rather than the current ad-hoc structure.

9.3.8.3 Industry Coordination

As mentioned above, it is essential to have a coordinated industry in order to promote its development. This coordinated approach would link together existing niche strengths and to develop those links to foster an internationally credible and significant space industry. In order to facilitates this, the government's role may be to set a policy framework which both provides an environment conducive to growth and enables the development of capabilities to meet public and private sector market needs, both nationally and internationally.

As outlined in Chapter 6, the space industry can be deconstructed into its constituent parts, focussing on the industries and their relationships with each other (Moody and Schingler, 2001). This idea of breaking the industry into constituent parts gives a good mechanism for analysis which allows approaches to be tested.

In particular, a properly understood and coordinated space industry would have the following benefits (built upon from some of the recommendations made based on the CRCSS experience):

- **Clarity in purpose**: Companies can understand their role and where they fit into the sector.
- **Building a market**: By uniting various industries within the space industry, their services can be marketed together to create a unique product. An example is to combine the industries of services, earth stations, final assembly and integration and launch. The potential client can get many services in a package, such as regulatory filing with ACA to ITU, insurance through an Australian company, legal, final assembly and integration of their satellite, launch and TT&C.
- **Domestic Suppliers**: By dividing the sector into different industries, it becomes clear which goods are being procured overseas. Breaking the industry up allows us to focus on vertically integrating the domestic suppliers.
- **Promoting Partnerships**: Promoting cross-industry partnerships and communication will allow industries to utilise each other's strengths and ideas.

By promoting this multidisciplinary communication, these linkages may drive new developments in products or in service.

- **Fluid Structure**: Without having a set structure, each industry doesn't necessarily rely on another. This fluid structure promotes innovation and formation of new industries or (Cooperative) Research Centers, and has the ability to shift direction with changes in time and to foresee areas of potential big business.
- **Business Focus**: The model given has a very strong business focus, building on current strengths and keeping Intellectual Property within Australia.

9.3.8.4 International Coordination

As outlined in the previous section, there is need for a body within the Australian Space industry to coordinate partnerships within the space industry, as internationally it is not a free market. Australian researchers and companies already have opportunities for engagement in international space programs (ISAG, 2002), although the lack of a Commonwealth policy framework may limit the scale of such engagements. If taken, these opportunities may yield benefits to the Australian partners concerned and build upon existing experiences of projects such as FedSat.

Finally, an understanding of how space fits into Australia's national priorities is key to obtaining support for the industry. Currently, benefits from space are diverse and uncoordinated, with little clarity as to how they fit into the overall strategy of government. In order to stimulate new projects and ideally mobilise the private sector, these benefits need to be identified, and targets set for their implementation.

What lessons learnt can be applied to future Space projects?

There are a number of lessons which can be learnt from the FedSat case study, which could apply to future space projects, both within Australia and internationally. The main lesson was one of management using the Small Satellite Philosophy. In particular, it is important to implement the drivers of this philosophy, and embrace the outcomes, as detailed in Chapter 5 of this thesis. This philosophy, along with the strong definable and time-constrained overall project goal (such as launching the satellite) can then become a uniting driver across the entire mission.

There were also a number of specific lessons which were learnt, which can be used to shape future programme development, and are outlined in Chapter 8. These included the need to match authority to responsibility, ensure that there was transparency within the programme and to implement a whole systems approach to the project with be similar management approaches taken for each of the different teams within the project.

It was also found that it was important for key staff to be trained and retained throughout the project, and that the systems engineering team would play an important role in ensuring the success of the project. The need to draw upon experienced engineering and management within the project was emphasized, as was the transfer of these skills to enthusiastic junior engineers.

Finally, it was found that it was important to structure the project correctly, and in the case of the FedSat project it was found that an organic management structure, moving to a more mechanistic or hierarchical one, was most appropriate for the development of the small satellite project. Future projects should also closely integrate the primary suppliers into the project, both in terms of organizational structure and risk management. It was also important that the goals of all of the different stakeholders were aligned, such that when difficult decisions had to be made on project resources or issues of risk, and that these goals were fully integrated into the satellite mission from the beginning. This would translate into more effective requirements analysis, which would need to be based on reasonable needs of the project, not the contributions of particular partners.

9.3.9 The Role of CoPS

Many of the recommendations presented above have been made in other reports on the future of the space industry in Australia. To illustrate this, some of the recommendations from the ISAG report are given in the box below. It can be seen that the experiences of the CRCSS in developing the space industry is merely reinforcing suggestions from previous reports.

The Government space sector development strategy should seek to:

- bring focus, priorities and critical mass to those space technologies where Australia has excellent but disparate capabilities;
- encourage an enduring market base for Australian participation in the domestic and global space industry;
- enhance national interests through whole-of-government coordination and appropriate public investments in space technologies, particularly in the remote sensing sector;
- leverage Australian space technologies and enterprise off engagement in the programs and projects of international space agencies and corporations; and
- in so doing, gain maximum advantage from Australia's favoured position as a site for launch, testing, tracking and ground receiving operations.

A coordination strategy is needed to:

- Set policy objectives and framework to ensure self-reliance (where appropriate) and continued secure access to technologies to meet national priorities and services;
- Align the synergies of research, industry and Government;
- Obtain greater value from Australian Government procurement by leveraging industry development;
- Direct the development of technologies to address Australia's national priorities and to provide commercial applications which meet domestic and global market needs; and
- Assess the benefits of collaborative projects against Australian priorities and negotiate entry to projects through inter-Governmental agreements

An investment strategy is needed to:

- Enable research and industry development to be directed to areas of national priorities where the national benefits and Government returns on investment are maximised;
- Develop the industry and research expertise that will enable Australia, as a nation, to 'market' itself into relevant international projects and negotiate skill exchange;
- Secure access to new technology and develop niche expertise to supply domestic and global markets;
- Promote R&D, innovation and commercialisation of technologies across the sector; and
- Align industry and research expertise and foster collaborative partnerships.

A collaboration strategy is needed to:

- Enable Australia to leverage off international projects for a modest, shared risk investment;
- Advance regional national security and environmental monitoring through participation in regional space initiatives and forums;
- Maximise the use of existing space facilities and infrastructure to market Australia's capability and comparative advantages;
- Reverse the net flow of space specialists overseas and increase Australia's technological capacity through exchange programs; and
- Promote self-reliance in appropriate areas of space activities.

Source: (ISAG, 2002)

However, this thesis has shown that the space industry is not necessarily different to other industries, but through a theoretical investigation and the analysis of this theory in a tangible project it is apparent that areas of this industry are made up of a number of Complex Product Systems.

CoPS do not currently have determining claims on just one industry. In other words, another way in which to enter the space industry is to divide the space industry into areas that are CoPS industries and areas that are not. For areas of the space industry that are not CoPS (such as the spatial information industry) it is possible to use existing policy mechanisms (e.g. the action agenda for the spatial information industry). Other CoPS areas have the potential to be treated alongside other Complex Product Systems in the development of policy. In other words, the development of policy to address CoPS may both give the space industry a unit for inclusion in government, and may even stimulate further interest in space as a means to develop CoPS. This idea is explored further in Section 9.5.

9.4 CoPS and Australia

While there may be an inherent capacity within Australia for the development of CoPS, Australia's innovation policy does not recognise their importance. Specifically, and as shown in this work, the CRC framework is unsuited to their development. However, in looking at the role of CoPS in Australia, it is important to determine whether CoPS are indeed a meaningful analytical and empirical option for innovation policy.

As the global space industry grows, it might be expected that there would be opportunities for Australia to take part in this growth. However, in a fledgling industry with higher risk and higher costs, there is a need for companies to work together in order to address this global need. In order to address the development of CoPS in Australia, there must be mechanisms to promote industry coordination.

Within the Australian context, CoPS may be a viable policy option for further development; currently there is no mention of CoPS within policies such as Backing Australia's Ability. This option may give industries such as the satellite industry opportunities for new to develop new mechanisms for appropriate support. This section looks at the role of CoPS within the Australian context and proposes some potential areas for future analysis.

What are the underlying drivers in the development of CoPS in Australia and what conditions are necessary for the construction of these new industries?

As already discussed, Complex Product Systems usually contain a number of participant organisations. One of the key aspects of industry policy is the creation of mechanisms that can be used to develop these structures.

The FedSat case study has uncovered a number of underlying drivers in the development of new complex system industries in Australia. In creating the right conditions for the construction of a new Complex Product Systems industry, further Australian capacity in the development of high-technology projects through industry policy may be gained.

The Australian (or other) Government(s) may wish to influence patterns of technological innovation through policies to promote technical leadership in the development of Complex Product Systems. The following table outlines some suggestions for the key regulatory, technological, industrial and market factors that might be engaged to constitute the innovation environment for CoPS at the policy level.

Table 9-5: CoPS Policy Suggestions

Dimension	Policy Suggestions
High cost	Any policy would have to mobilise large investments in public and private capital. This may use similar approaches to those of the Canadian Government which invests in large projects where a similar (larger) project in other countries is on the horizon, in order to both build Canadian capacity and give Canadian firms an edge in bidding for these projects.
Long product cycles	Policies would need to have support from both sides of government, as project durations would likely span the election cycle.
High complexity	A number of partners would need to be involved, with the potential for the formation of a project based organisation to coordinate the product. These partners should ideally be located in close proximity to one another.
Emerging & unpredictable properties	The entity created should be incorporated, should have authority structures in place, but should remain capable of reacting to unpredicted events. There should be contingency in the budget to address risk areas and industry should be a core participant.
One-off kind	While any policy should accept the one-off nature of the project, mechanisms should be put in place to capture skills and learning.
Involvement from policy and regulation	The government should acknowledge that it has a vital role in the development of these projects. It must see them through to completion and be prepared to commit further resources subject to the project's success.
User driven	The goals of the project should be carefully developed, should have a commercial focus and should be completed before potential partners are invited to participate.
Project rather than product	The focus of the policy should be both on the mechanisms for organising projects as well as the products created, and any spin-off benefits.
Oligopoly markets	There should already be indigenous capability in supporting or rival markets.
Distinct management capabilities	Depending on the capabilities required, projects should attract managers with experience in large projects.

9.4.1 CoPS: A New Way of Entering the Space Industry in Australia

By having a unit of analysis such as Complex Product Systems, there is another approach that might be taken in the development of the space industry in Australia. This approach would centre on the idea that space is not treated differently to other industries with large, high-cost one-off products, but that this entire class of CoPS industries are treated together. In other words, the development of policy to address CoPS may give the space industry a unit for inclusion in government policy while directly drawing on Australian skills in areas such as systems integration.

Chapter 8 outlined the idea of a 'pure' CoPS which matches all of the CoPS criteria, but has an easily definable timeframe, fixed success criteria and measurable parameters. If the space industry is indeed a prime example of a Complex Product System, then this may stimulate further interest in space as a means to develop and strengthen an indigenous capability in CoPS.

The role of Complex Product Systems may be an immediate area of policy development to be investigated in Australia. This may also have other advantages for the development of other industries in a similar state of development as the space industry. However, more research is needed in order to create a supportive environment for the development of CoPS. This includes research into the role of CoPS in Australia's economy and some of the spin-off benefits. The following section looks at this issue in detail.

9.4.2 CoPS and Australia

This thesis has already hypothesised that that there is the potential for CoPS to play a strong role within the Australian economy, and that Australia may indeed have a strong capacity for the development of these products. The example of the CRCSS supports this hypothesis, but in order for these claims to be verified, future investigations may centre around a number of different areas:

- What proportion of the Australian economy is made up of CoPS?
- Does Australia have internationally competitive skills in the production of CoPS?
- Are there other industries similar to the Satellite Industry that are finding it hard to develop as they do not have the right frameworks or support mechanisms in place?

If CoPS do indeed play a significant role within Australian industry, there would then be cause to investigate the most effective ways of stimulating and nurturing these industries. Similar investigations into projects such as FedSat may yield areas for future policy development in this area.

9.4.3 CoPS and spin-offs

The space industry is often justified in terms of the spin-off benefits to other industries, ranging from materials science to communications technologies. A fertile area for investigation is the role that CoPS play in the creation of these spin-offs and how they might be promoted in justifying investment into the development of CoPS industries. This is particularly important in determining the best way to fit large one-off projects into the national system of innovation. The technique of dividing a complex industry into it constituent parts and determining which are CoPS and which are not may also assist in this analysis.

9.4.4 The Creation of CoPS Industries

As outlined during the analysis of CoPS in Chapter 3 of this thesis, it was unclear as to whether the CoPS unit of analysis was an industry or a subset of products within an industry. During this analysis it was found that both the satellite industry and the FedSat satellite itself were capable of being analysed using the CoPS critical product dimensions, giving weight to the idea that it is possible to have both CoPS products and CoPS industries.

This thesis has been largely concerned with the formation of a CoPS industry, the satellite industry, and the development of a CoPS within it. It has looked at some of the institutional and policy mechanisms that might be used to create this industry and used the FedSat satellite to illustrate the effectiveness of one Australian example.

However, this is just the first pass at an analysis into the effective creation of CoPS industries, both within Australia and internationally. Future investigations may compare CoPS projects and the structures and policy mechanisms which promote their implementation, particularly in the initial stages of the industry development.

9.4.5 CoPS and reduced resources in other industries

Chapter 5 of this thesis introduced the notion of the Small Satellite Philosophy and investigated the relationship between the reduction of a particular critical dimension, such as the size of a satellite, with other factors that this enables, such as a reduction in complexity or the ability to adopt a different management paradigm. Chapters 7 and 8 then looked at its implementation in the context of the FedSat project, giving empirical support to the theory outlined in Chapter 5. It was found that, when implemented properly, there were multiple benefits to be gained in the production of Complex Product Systems, which, when measured across a number of projects (or missions), gave overall reductions in timeframes and cost.

In determining whether other industries have experienced similar multiple benefits through the reduction of scope of a particular product, it would be useful to undertake investigations of existing case studies in the CoPS domain. An understanding of these techniques and the use of management approaches similar to those of the Small Satellite Philosophy may give further insights into areas for future investigation, and provide a competitive edge for firms or countries that are successful in nurturing these approaches. In this area it is particularly important to determine the critical dimension for reduction, such as small UAVs in the aviation industry or fewer base stations in the telecommunications industry, as outlined in previous chapters. An investigation into the critical dimension for a particular CoPS would be recommended for comparison with the small satellite industry.

9.5 Generalisation

In Chapter 1, it was noted that Australia is unique among developed nations in that it does not have a recognisable space agency and little space policy. This thesis has outlined just one of the attempts that was made to created such an industry, the FedSat satellite project. It asked the central question, "*Can Australia develop an indigenous satellite industry made up of high-value, complex products*", framed against the backdrop of innovation, management and policy issues concerning the Australian space industry.

During this work, the different nuances of the project were investigated, using the techniques from three main bodies of work: Complex Product Systems, the Small Satellite Philosophy and Australian Innovation Policy. Each was found to give a meaningful insight into the development of the project, which could be built upon using the result of the case study research. The key conclusion of the thesis was that, based on the current space policy and innovation mechanisms in Australia, it is currently impossible for Australia to develop a space industry made up of high-value, complex products.

CoPS were found to be a meaningful unit of analysis for the FedSat project. In addition, using CoPS tools allows a comparison of this CoPS product with other similar analyses, highlighting some of the structural, coordination and management issues that might be faced during such a project. As there were two different phases of the project, the implementation of the Small Satellite Philosophy while in the UK and Australia could be compared, highlighting some of the core drivers of this approach. In addition, the lessons learnt during the FedSat case study not only confirmed previous recommendations for Australia's entry into the space industry, but also suggested a new approach that might be able to be taken; one that is based on the formation of specific policy to address the development of CoPS.

The applicability of the results of this work to other areas should be approached with caution however. The FedSat project is only a single case study and all results should be examined before they are generalised to other industries or nations. It is unclear whether the findings of this thesis are space industry specific but, based on the number of linkages between the space industry and other CoPS industries, it is believed that they are not. A number of suggestions have been made on ways to extend this research to other industries, to see if similar results may be applied elsewhere.

In addition, this case study, while international in nature, was based largely in Australia and was subject to Australian policy and institutional issues. The findings made may not be the same in another location, especially as Australia is in the process of developing the space industry itself. However, this work may point to areas of interest for the development of other CoPS industries around the world.

Finally, the limits of the case study data should be recognised. While every attempt was made to ensure balance of the arguments presented, there is always the danger, however unlikely, that biased results were obtained. However, through a broad analysis of the wealth of available data and the use of different data sources to verify the information gathered, it is believed that this case study can not only confidently illuminate issues within the scope of the work presented, but the approach may be able to be repeated in this or other domains.

The methodology approached in this case study was useful in the sense that it brought together a range of data sources about the project, using a number of core questions to focus the analysis. Also, by being a member of the project team, access to information was granted that would have been otherwise difficult or impossible to obtain. Also, due to the emergent nature of the project (for example, the bankruptcy of the prime contractor), having a close relationship with the project enabled flexibility in analysis. In a future analysis of a satellite project in Australia, it would be interesting however, to have a more analytical rather than empirical analysis of the project; applying the lessons from this or other CoPS projects and investigating the impacts.

Overall, this thesis has aimed to contribute to literature on both the application of CoPS to new industries and the development of the space industry in Australia, through the in-depth analysis of a high profile Australian project. Indeed, it is hoped that ideas developed in this study will form a resource for the future development of other indigenous space projects within Australia and CoPS projects internationally.

Appendix I – Glossary

ACS	Attitude Control System
AIT	Assembly, Integration and Testing
APS	Atmospheric Pressure Sensor
ARPA	Advanced Research Projects Agency (US Defence Force)
ASB	Australian Space Board
ASC	Australian Space Council
ASIBA	Australian Spatial Information Business Association
ASICC	Australian Space Industry Chamber of Commerce
ASO	Australian Space Office
ASPC	Asia Pacific Space Centre
ATSR	Along-Track Scanning Radiometer
BNSC	British National Space Centre
BTS	Base station
CDMA	Code Division Multiple Access
CDR	Critical Design Review
CENTRIM	Centre for Research in Innovation Management
CMM	Capability Maturity Model
CNES	Chambre Nationale des Experts Specialises
COMET	Commercialising Emerging Technologies Programme
CoPS	Complex Product Systems
COSSA	CSIRO Office of Space Science and Applications
COTS	Commercial Off-The-Shelf
CPM	Critical Path Method
CRC	Cooperative Research Centre
CRCSS	Cooperative Research Centre for Satellite Systems
CSIRO	Commonwealth Science, Industry and Research Organisation
D&B	Dunn & Bradstreet

DHS	Data Handling System
DISR	Department of Industry, Science and Resources
DITR	Department of Industry, Tourism and Resources
DSS	Digital Sun Sensors
EGSE	Electrical Ground Support Equipment
ELDO	European Launcher Development Organisation
EOC	CSIRO Earth Observation Centre
EOS	Electro Optic Systems
ESA	European Space Agency
ESRC	Economic and Social Research Council
FBC	Faster, Better, Cheaper
FDMA	Frequency Division Multiple Access
FedSat	Federation Satellite
GDP	Gross Domestic Product
GEO	Geostationary Earth Orbit
GPS	Global Positioning System
GS	Ground Station
GSE	Ground Support Equipment
GSM	Global System for Mobile Communications
HPCE	High Performance Computing Experiment
ICT	Information & Communications Technology
ISAG	International Space Advisory Group of Australia
ISBC	International Space Business Council
ISS	Integrated System and Service
ITR	Institute for Telecommunications Research (South Australia)
KAIST	Korean Advanced Institute for Science and Technology
LEO	Low Earth Orbit
LTS	Large Technical System
LWRE	Long-Range Weapons Research Establishment
MEO	Middle Earth Orbit
MFM	Magnetic Flux Magnetometer
MGSE	Mechanical Ground Support Equipment

MNRF	Major National Research Facilities
MTQ	Magnetorquers
NASA	National Aeronautics and Space Administration (United States)
NASDA	National Space Development Agency (Japan)
NewMag	University of Newcastle Magnetometer
NH&MRC	National Health and Medical Research Council
NSP	National Space Program (Australia)
OCC	Operations Control Centre
OTS	Off-The-Shelf
PBO	Project-Based Organisation
PCS	Power Conditioning System
PERT	Program Evaluation and Review Technique
QFD	Quality Function Deployment
R&D	Research and Development
RFGSE	Radio Frequency Ground Support Equipment
RW	Reaction Wheels
SAMPEX	Solar Anomalous and Magnetosperic Particle Explorer
SC	Spacecraft
SEMG	Systems Engineering Management Group
SIDC	Space Industry Development Centre
SIL	Space Innovations LTD.
SKA	Square Kilometre Array
SLASO	Space Licensing and Safety Office
SMAD	Spacecraft Manufacture and Design
SME	Small to Medium Enterprise
SPRU	Science and Technology Policy Research Unit
SSD	Software Specification Document
SSP	Small Satellite Philosophy
SSPL	Surrey Satellites Pty Ltd
TDMA	Time Division Multiple Access
TQM	Total Quality Management
VE/VA	Value Engineering/Value Analysis

WBS	Work Breakdown Structure
WIRE	Wide-Field Infrared Explorer
WRESAT	Weapons Research Establishment Satellite

Appendix II – Project Chronology

The following sequence of events represents the FedSat development schedule from March 1999 to December 2002, and the intended schedule from then to completion in February 2003:

Formation of the CRCSS	January 1988	
Contract let to SIL	Mar 1999	
System Progress Review	Jul 1999	
System Progress Review	Sep 1999	
Ground Station Delivery Review	Dec 1999	
System Progress Review	Mar 2000	
CRCSS representation on-site at SIL	April 2000	to Sep 2000
SIL announces bankruptcy	Jul 2000	
FedSat Recovery Planning	Jul 2000	to Aug 2000
Contracts let in UK	Aug 2000	
System development analysis in Australia	Aug 2000	to Dec 2000
Completion of mechanical assembly in UK	Sep 2000	to Feb 2002
System analysis/re-build in Australia	Sep 2000	to May 2002
S/C initial assembly, integration and test	Apr 2000	to May 2002
S/C system testing	May 2002	to Jun 2002
S/C thermal-vacuum testing	Jun 2002	to Jul 2002
S/C vibration testing	Jul 2002	to Aug 2002
Final Integration and Test	Aug 2002	to Sep 2002
Ship to Tanegashima	Sep 2002	
Pre-launch support	Sep 2002	to Oct 2002
Launch	14th Dec 2002	
Post-launch activities and commissioning	Dec 2002	to Feb 2003
Operation	Feb 2003	onwards
1st Year Anniversary	14th Dec 2003	

Appendix III – Interview Template

CoPS Questionnaire

Based on a Questionnaire from the CENTRIM/SPRU Project on Complex Product Systems

ESRC Technology Management Initiative GR/K31756 and GR/K21726

INTRODUCTION

Objective of the project questionnaire

Is to analyse and compare projects in order to:

- Identify best practice technology management
- Identify key success factors in CoPS projects
- Develop new CoPS tools with firms (both specific and generic)

Key Generic Questions

- What are the key problem areas and critical path activities for managing technology in CoPS?
- How best can technology be managed in CoPS?
- What new tools are needed to improve innovation and efficiency in CoPS project (specific and generic)? Is there a new management philosophy being used?

Other background questions that might arise

- Does best practice technology management differ between CoPS and other products? And between project and non-project based activities?
- Does best practice technology management differ from one CoPS project and another? If so why?

The Structure of the questionnaire is as follows

- Section 1: Project characteristics
- Section 2: Project phasing and feedback loops
- Section 3: Innovation management tools
- Section 4: Risk and opportunities
- Section 5: Learning
- Section 6: Managing inter-company technology interfaces and stakeholders
- Section 7: Success/failure and performance

SECTION 1: PROJECT CHARACTERISTICS

This section gathers basic factual data on the project:

1. Please describe the origin and history of the project?
2. How does the project fit in to the organisation?
3. What is the basic organisational structure of the project?
4. What is the value of the project? - meaning?
5. Who are the main stakeholders involved (in and outside of the company, e.g. regulators, users, suppliers)?
6. Please describe the customer and its needs?
7. What are the key technologies involved (hardware and software)?
8. Which other resources are required to complete the project?
9. How complex would you say the project is (as indicated by scale, number of actors, uncertainty). Measurements
10. How many lines of software code are there?
11. Do you consider this as a 'high' or 'low' technology project? – definitions
12. Was there any government input into the project?

SECTION 2: PROJECT PHASING AND FEEDBACK LOOPS

Our research identifies three project phases: (a) bid (b) implementation and (c) post-implementation phases. Although useful, this may be an ideal type, rather than what happens in the real world. We expect to gain the company's view on how the phases operate and key milestones, from start to end, in an open ended way - rather than to squash them in to our three phase model. The following questions allow the firm to explain the main phases as they see them.

In some cases the project is complete and the interviewee can give an historical account. In others the project is not complete and the interviewee is invited to give his or her view on likely phases or typical phases for such a project.

1. Please describe the phasing of the project from start to finish - key milestones etc?
2. How much effort goes into each phase, in terms of person days?
3. Are there any feedback loops from one phase to another? If so please describe these?
4. How was technology managed [see definitions/categories] during the various project phases? [R&D, design, detailed specification, prototype dev, product engineering, process engineering]
5. At what stage (if any) are the design details frozen and why? What does the design freeze signify for you? How important is this event?
6. How important are particular stages to the successful completion of the project? Are some more important than others? If so, why?
7. How flexible were the stages? Once planned can they be altered? If so how?
8. Who decided the phases of the project? Which groups/people were involved?

Other questions may also have a historical phasing dimension according to the issue in question.

SECTION 3: INNOVATION MANAGEMENT TOOLS

1. In contrast with general procedures and system, are specific, stand-alone management tools designed to achieve tasks?
2. Which are the main categories of tools used on the project, if any? (e.g. positioning, diagnostic/benchmarking, improvement, ex-post evaluation)? Which specific tools were used on the project?
3. How do the project management tools fit into other general company management systems and procedures?
4. Were any informal tools used (i.e. Ones developed by individuals to get the job done)? If so, which ones and why?
5. How important were these tools (both formal and informal) to the completion of the project?
6. Did you use any specific tools for managing technology (acquiring it, developing it, adapting it, implementing it)? Ditto for software, risk and learning?
7. How were the tools used during the different phases of the project? Were there any phases in which tools were used more than in other phases? If so why? Were there any phases in which no tools were used?
8. What were the main benefits and costs/disadvantages of the tools used? Did benefits outweigh costs? If so by how much?
9. Were all the formal tools used fully and willingly? If not, why not?
10. Were any specific tools used for managing the arrangements with suppliers and other outside company stakeholders? If so why? If not why not? If so how well did they work - what was their perceived impact in the project's performance?
11. Do you search for new tools/methods? How are they evaluated?
12. Do you think the tools used could be improved? If so how?
13. Are there areas where tools are not currently used where they might be useful?
14. Were there any philosophies driving your decision-making process? How did these shape the implementation of the project?

SECTION 4: RISK AND OPPORTUNITIES

1. What were the major categories of risk associated with the project? (prompts: poor bid estimate, cost overrun, poor support, deliver, weak engineering staff, technological problems, implementation difficulties, post delivery servicing and reliability, failing to meet customer needs. Deadlines, other)?
2. How did the project team attempt to identify and manage any risks? (by category)
3. Were any specific tools used to manage risk? Is do which? If so how useful were they?
4. Did any unexpected risks appear? If so which and why?
5. How successfully do you think the risks were managed? (by type)
6. What effort, if any, was put into opportunity management? What kinds of opportunities emerged in the project? (e.g. to win customer confidence, to gain new business, to train up new people, to use smart methods to reduce costs etc.)
7. Do you think risk management could have been done better? If so how? If not why not?
8. How do you relate risk to cost?

SECTION 5: LEARNING

1. What are the main sources of possible learning on (and prior to) the project (possible sources: from finished projects, from ones going on concurrently, from outside organisations;
2. In your experience how difficult is it to capture and transfer learning to produce changes in work behaviour
3. To what extent did the project learn/benefit from previous ones?
4. What were the benefits of learning to the projects? [learning is supported to underpin innovative and new behaviour, problem solving activities and creative new approaches to problems]
5. How did learning occur during the phases of the project?
6. How does learning differ across different categories of technology, from the point of view of (a) project management and (b) day-to-day project engineering?
7. How does learning in software differ from hardware? If at all?
8. Is any attempt made to manage learning? If not why not? If so how?
9. Is any attempt made to measure learning? If not how can it be managed?
10. Are there any mechanisms for ensuring the learning from the project is transferred to other projects ongoing? And/or new project in the future?
11. What is the role of people in learning? Same for networks (formal and informal)? Ditto for tools (formal and informal)?
12. Did you learn from other organisations in the project? If so what and how?
13. Were there any constraints on learning? (e.g. not enough time, no reward for it; no facilities for learning workshops etc.; not the sort of thing that can be formalised or managed…)
14. Do you think learning from the project could have been improved? If not why not? If so how?

SECTION 6: MANAGING INTER-COMPANY TECHNOLOGY INTERFACES AND STAKEHOLDERS

1. Who were the main outside stakeholder in the project? (by category) What were their function? How many were there? How important were outside organisations and individuals to the projects successful completion?
2. Does the management of the CoPS with respect to outside stakeholders differ, if at all, from in-house stakeholders (e.g. other departments)? If so how and why? What, if any, specific practical difference are there (a) from the project management perspective and (b) from the day-to-day engineering perspective? If any?
3. How are organisational interfaces managed in different phases of the project? (e.g. bid, implementation, post-implementation phases)
4. Focusing on technology management, how are these interfaces managed? Do they pose any different problems, compared with other areas of inter-organisational management? (prompts: different companies may have different aims, tools, procedures, shared values, styles, etc)
5. Could the management of outside stakeholder have been performed better? If so how? If not why not? Ditto for technology management.

SECTION 7: SUCCESS/FAILURE AND PERFORMANCE

1. How do/did you judge the success of a project? What are the categories of success? What constitutes a 'success' from your point of view? What constitutes a failure?
2. Do you know if your views of project management success differ from others (a) inside the company (b) outside (especially the customer)? If yes, how do your views differ and why?
3. Was technology management important to the success of the project? If not, why not? If yes why and how?
4. Was performance monitored during the projects phases? If so how (by phase) If not why not? Were there any specific methods for measuring productivity, especially for software tasks?
5. Were tools important to the success of the project? If not why not? If yes why and how?
6. How successful was the project (a) compared with objectives (b) compared with other similar projects? (c) compared with your personal expectation? (if a differs from c please explain)
7. What do you think were the key reasons for the projects performance (success, failure or whatever)?
8. Could the project have been more successful? If not why not? If so why and how?

Appendix IV – Space Innovations Limited

Source: Internal SIL documentation

Company profile

Since its formation in 1983, SIL has been developing advanced, cost-effective and innovative systems for the exacting world of space technology. The company, originally known as Satellites International Ltd was re-formed as Space Innovations Limited following a management buyout in 1996. Under this new identity, with a revised mission and new management team, SIL is enjoying consistent growth and expansion.

Our products combine versatility and innovation at low-cost, coupled with the assurances of quality and reliability evidenced by our exemplary test record and ISO9001 accreditation. From the first digital modem, (which we developed for ESA's ground station network in 1986), and our first space flight instrumentation, (which has been flying successfully on ESA's Meteosat spacecraft since 1988), our expertise and reputation as a quality manufacturer has grown. This has been through successfully completed projects for agencies and company's world-wide such as ESA, CNES, CRCSS, CONAE, OSC, DRA, ALCATEL, CRI, DASA and MMS.

At present, our product range covers virtually all requirements of the small satellite builder, from complete spacecraft though to their on-board sub-systems, control hardware and software, support equipment and complete ground stations. We have developed close links with internationally renowned space groups at a number of UK universities, research establishments and agencies. These include the Mullard Space Science Laboratory of University College London, the Universities of Leicester, Birmingham and Southampton, Rutherford Appleton Laboratory, the BNSC and DERA.

Projects underway at present include the SILVER spacecraft, (a derivative of SIL's MiniSIL spacecraft, which SIL are developing and marketing in partnership with

Verhaert Design and Development N.V), the 'Humble' Space Telescope project, FEDSAT MiniSIL, as well as numerous contracts to supply spacecraft subsystems.

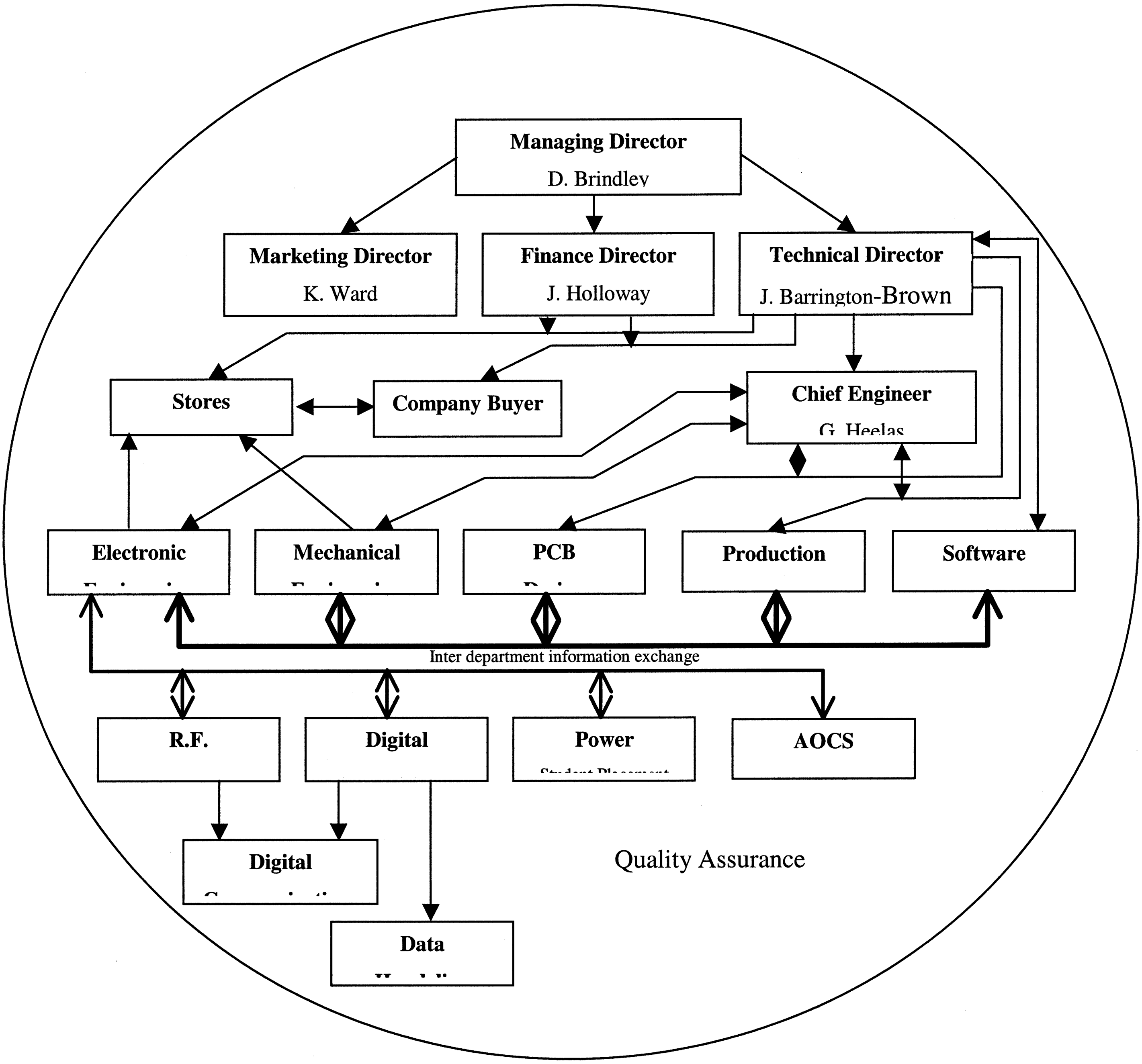
Facilities

Comprehensive facilities at SIL support the development of advanced technology systems and products for the aerospace industry. Design offices, development laboratories, clean assembly and test areas, optical laboratory and production area are all located at our Newbury site. Software is designed and managed using a range of code compilers and code management facilities including object-oriented methodology.

Networked facilities include workstations and Pentium PCs supported by printers, plotters and scanners, e-mail and access to the Internet. Electronic and mechanical CAD systems include Cadstar, VHDL, Matlab, Viewlogic, Solidworks and AutoCAD. The network also has external links to ESA's EMITS and we maintain SIL's web site at http://www.sil.com/.

Structure

The company has many interdependent departments co-ordinated from a relatively flat management structure. This consists of a Managing director overseeing the marketing, finance and technical departments. The majority of the workforce, carry out their duties under the co-ordination of the technical director. This results in an overall company structure as follows:

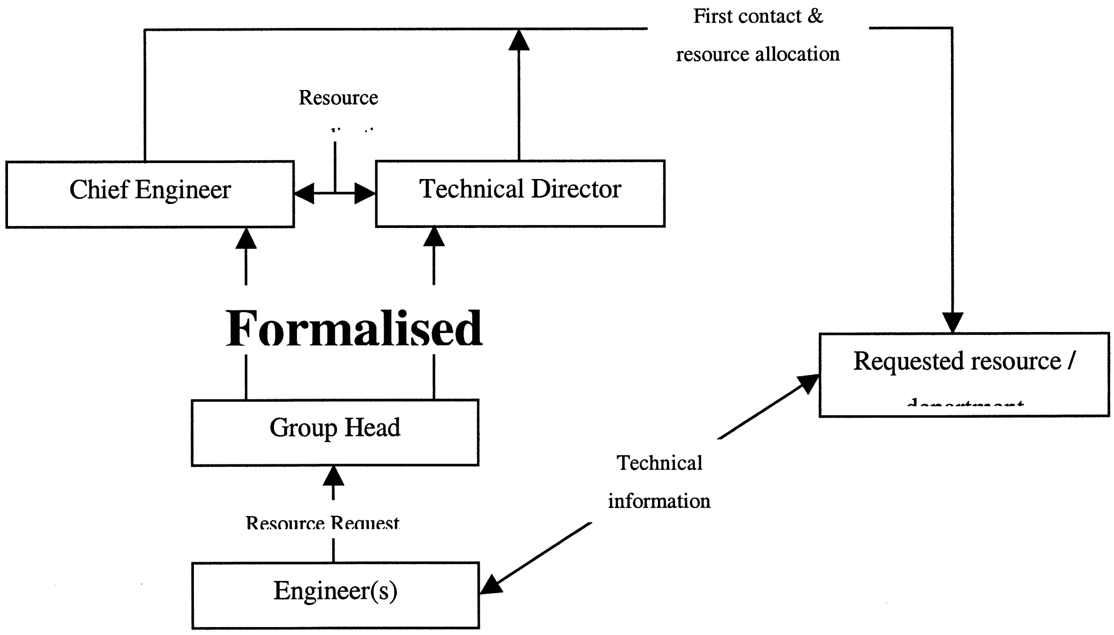

Managing Director
D. Brindley
Marketing Director
K. Ward
Finance Director
J. Holloway
Technical Director
J. Barrington-Brown
Stores
Company Buyer
Chief Engineer
G. Heelas
Electronic
Mechanical
PCB
Production
Software
Inter department information exchange
R.F.
Digital
Power
AOCS
Digital
Data
Quality Assurance

It can be seen from the above diagram that there is a complex array of information that requires movement around the company. The management philosophy required to operate the company efficiently needs to be readily identifiable and flexible.

The philosophy enabling efficient, overall, co-ordination within the company is largely based on the 'single point of contact' principle. This principle enables employees to identify a static, defined management profile through which contact with other departments can be made.

A flexible approach to the single point of contact system enables the management to co-ordinate & allocate company resources efficiently. The management only initiating first contact between departments achieves this. All of the required technical information is then passed directly between departments, thus bypassing management (who have little interest in the raw technical information). Contact with management is only reinstated on discovering that insufficient resources have been allocated or the allocated resources have now become available for reallocation.

The management profile to enable the application of such a system is as follows:



Information exchange between departments is facilitated via a controlled document system. Communications between departments will generally consist of reference to the relevant controlled document. Should there be any ambiguity in the referenced documentation then direct communication with the relevant engineer is used to ensure that both quality and efficiency are not compromised.

Example Hardware: PCS Overview

The Power Conditioning System for the spacecraft is intended to supply all of the electrical power requirements of the spacecraft. The PCS must provide a stable, regulated power source under many different spacecraft operation conditions. In addition to providing a regulated power bus, the PCS is also required to protect the power bus from payload fault conditions. The basic features that ensure the PCS fulfils its mission requirements are:

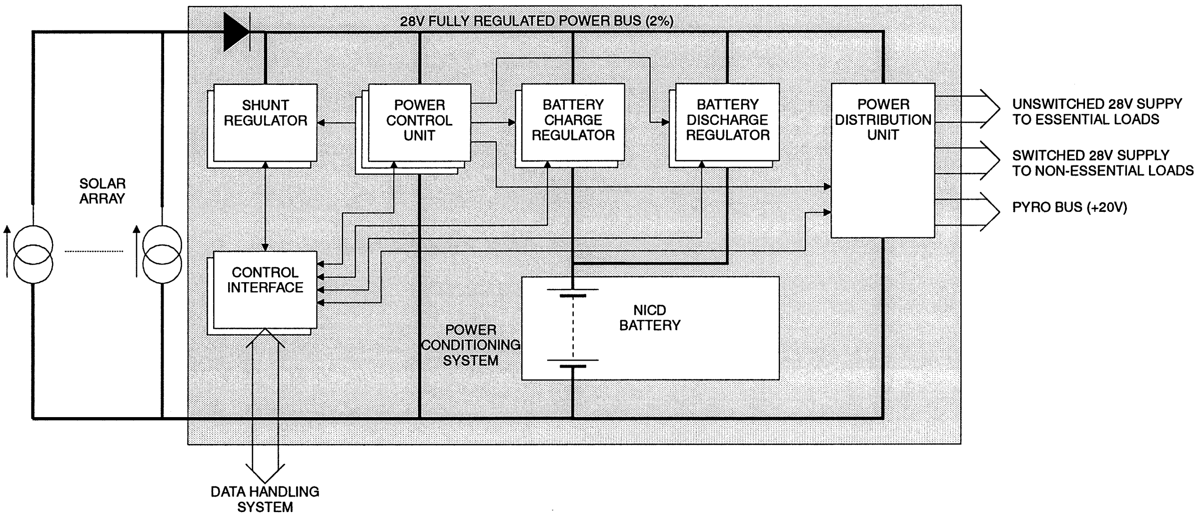
Battery management including charge control based on temperature and voltage, protection against excessive battery discharge and battery monitoring (provided via telemetry to the spacecraft Data Handling System (DHS)).

Switched output stages to provide power to the spacecraft payloads. Switched outputs have active current limiting and auto-shutdown in the event of a prolonged overcurrent condition. The switched outputs are controlled via telecommand from the DHS, they also provide supply current and status (on/off) telemetry to the DHS.

Non-switched outputs are required for the essential spacecraft subsystems (usually the DHS and S-band receiver). These outputs are also current limited to protect the power bus, but they do not completely switch off the subsystem they instead exhibit a ‘foldback’ characteristic. This is a method which progressively reduces the current to zero for a load who’s impedance progressively reduces to zero (i.e. during a fault condition such as DHS latch-up). The aim of such a characteristic is to effectively switch off the subsystem, which should then reset, removing the fault condition. The output stage will then return to its nominal operating condition.

Excess power from the solar array needs to be dealt with. This is achieved by employing shunt resistors, which are switched across the main power bus when excessive power is detected in the system.
There are also various interfaces provided that ensure the PCS operates correctly.

To achieve the above features the PCS has a 3-Domain control system that enables it to operate in either Battery discharge, Battery charge &/or shunt domains. A central, bus error voltage controls this 3-domain functionality of the PCS. This error voltage ensures that the PCS obtains its power from the correct source (i.e. Battery or Solar array) and that the correct domain of operation is selected dependent upon the available power. The various features of the PCS are integrated as follows:



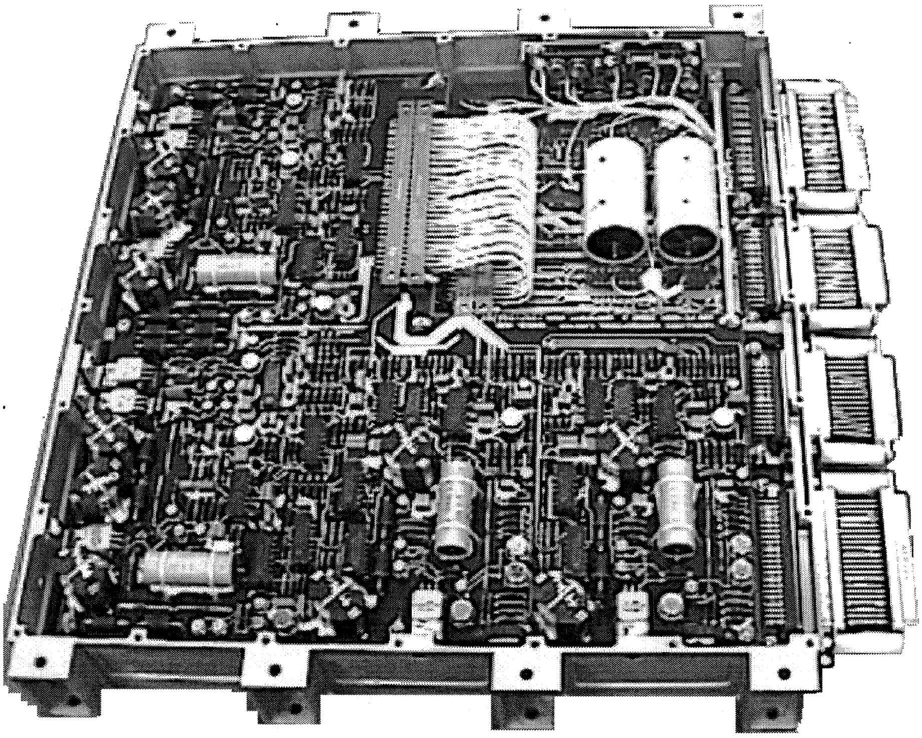
Due to the nature of the environment that the PCS is expected to operate it is also necessary to provide a reasonable level of system redundancy. The redundancy scheme operated in the case of the FEDSAT PCS is as follows:

- Dual redundant battery charge regulators.
- Dual redundant battery discharge regulators.
- Triple redundant, Majority vote, central error signal generator.

- Dual redundant shunt resistors (each resistor is actually a pair of resistors in parallel effecting further redundancy).
- Dual redundant battery monitors.
- Some essential telemetry is also dual redundant.

All of the redundancy operates as 'hot' redundancy. That is, both units operate at the same time unless one of the units fails, the remaining functional unit will then automatically take over the contribution of the failed unit, thus ensuring power bus continuity.

The only system that has not been provided with redundancy is the power distribution system. This system has been designed with such a low failure rate, (within the scope of expected mission life) that it was neither cost effective or necessary to incorporate PDU redundancy.



Appendix V – CRC for Satellite Systems

Taken from the CRCSS Website (http://www.crcss.csiro.au)

Background

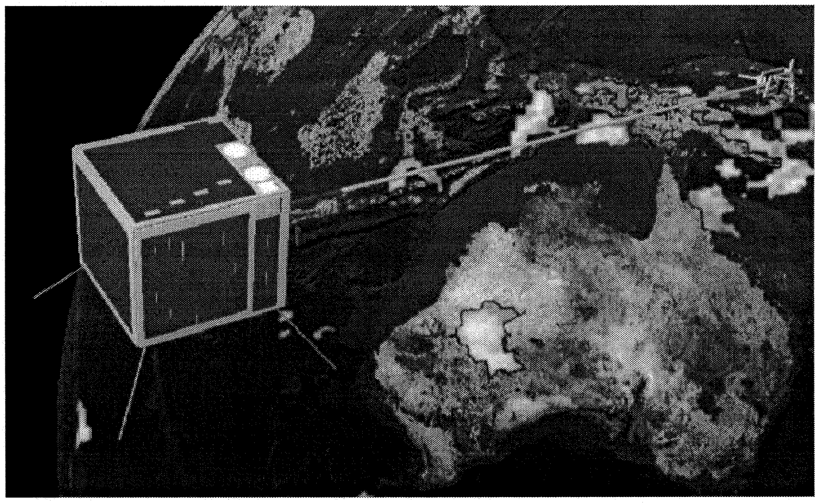
The Cooperative Research Centre for Satellite Systems is a joint venture of four Australian companies, six Universities and two government agencies. It was established 1 January 1998 under the Commonwealth' Cooperative Research Centres Program (http://www.crc.gov.au).

The Centre carries our research and development, education, training, operations and commercial activities relating to space technologies, particularly in the field of low-cost satellite missions. Its first major project was the scientific and engineering satellite. FedSat, launched on 14 December 2002.

FedSat

Achievements and Results

FedSat was launched from the Tanegashima Space Centre, Japan, early on 14 December 2002, on the fourth flight of Japan's HII-A rocket.



The same flight also placed the Earth-observing satellite ADEOS-II, the whale ecology microsatellite WEOS and the engineering research microsatellite Microlabsat into similar high-inclination or polar orbits at an altitude of about 800 km.

Satellite engineers must design the satellite for certain purposes. Depending on the mission purpose, satellites may require special orbits. For instance, remote sensing satellites need to see as much of the Earth's surface as possible and with a quick revisit time, therefore they need polar sun-synchronous orbits (about 800 km). Conversely, telecommunications satellites need to appear fixed in the sky so ground antennas can point at them, and that requires a very high geostationary orbit (about 36,000 km).

Specialist satellites may also need very elliptical orbits taking them far into space and back again. So usually the purpose of the satellite defines the orbit required, since different orbits have a different set of problems and advantages.

Decisions about the orbit type form part of the design process, including such basic things as size and weight. High orbit satellites need more transmission power for their signals to usefully reach Earth, so they must be bigger to accommodate the extra power generation capacity; they also need more radiation shielding since high orbits are a much less benign environment than Low Earth Orbit. Consequently, high orbit satellites are often large and heavy, requiring a dedicated launch from a large rocket, which is extremely expensive.

The strict budget requirements of microsatellite missions usually make obtaining a dedicated launch impractical. Therefore microsatellites are often designed for piggyback launch, where several small satellites may be launched together with one large one, sharing costs. However, this often means microsatellite designers work to a given orbit which may not always be ideal for the purpose.

But this introduces another problem for designers. The launch environment is very demanding on equipment, it involves very destructive vibrational and acceleration forces, so satellites must be designed to cope with those stresses. They must also be shown to cope with them, to satisfy the launch agency that the small satellite will survive launch without threat to the large satellite or to the launch vehicle. So launches, either piggyback or dedicated, require a strict testing regime to certify the satellites' safety.

The testing is also to certify that satellites are reliable before launch, since it's usually not possible to fix them afterwards (however, see High Performance Computing Experiment about reconfigurable computing modules).

Each piece is tested separately, and together after each addition to ensure there are no conflicts. Piece by piece, and then as a whole, the test-satellite is turned on and off, to simulate use. Any problems that arise may require redesign.

The mission budget determines the extent of testing. For large complex satellites, a complete duplicate of the flight hardware may be built just for testing. But this was not possible in FedSat's case, for budget and time reasons.

Before being transported to Japan for launch, FedSat underwent a rigorous series of tests including:

- structural model vibration testing
- payload thermal vacuum testing
- system assembly, integration & testing
- flight model vibration testing

Vibration testing basically involves shaking the equipment on a special shaker, a more precise and larger version of the paint-tin shaker in hardware stores, in each of the three planes in simulation of the launch environment. If the equipment breaks, or sustains microfractures, it must be redesigned and re-tested. If it survives the vibration testing, it is certified for launch.

Satellites usually work in extremes of temperatures, from cryogenic to extremely hot, plus certain components may generate heat. But in space there is no air, so air-convection as a form of heat dissipation is not an option. If satellites can't dissipate the heat, they may burn out. So satellites need special means for dissipating heat, and must be tested to show they survive the temperature extremes in a vacuum.

Some complex satellites have an array of active control systems, but FedSat is small enough to only need passive systems. The thermal vacuum test involves subjecting the satellite to a simulated vacuum in addition to the likely extremes of temperature. If it passes, it's certified for launch.

Payload Experiments

GPS Receiver

The GPS, Global Positioning System, is an American network of satellites which transmit radio signals containing time and orbit-position codes. GPS receivers decode the signals, and by comparing signals of up to 4 satellites with known positions, they can derive their own locations by triangulation. The system serves many scientific and civilian applications.

FedSat's dual-frequency GPS receiver was supplied under a collaborative agreement between NASA and CSIRO.

On-board satellite GPS receivers allow accurate measurement of the satellite's position. This information will support the CRCSS study into methods of precisely determining satellite orbits. This includes metre-level accuracy for satellite operations control; centimetre-level accuracy for mission-data processing; and position determination using multiple antennas.

The Precise Orbit Determination study includes a section on GPS multipath errors. On the ground, reflections of the GPS signal from the landscape give conflicting information to the GPS receiver, causing errors in position-calculation. Investigating the multipath errors on FedSat's simple shape will help establish principles for studying the more complex reflections on the ground. This will help eliminate multipath as a source of GPS position errors.

The FedSat GPS receiver also supports space-science studies of the ionosphere, an electrically-charged layer of the atmosphere. GPS satellites are much higher than FedSat's orbit, so FedSat can detect GPS signals that have travelled through the ionosphere. Interpretation of the GPS signals can illustrate the dynamics of that region. By taking GPS slices of the ionosphere, it's possible to build up a 3D moving picture of the ionosphere. The CRCSS is the only organisation studying the little-known southern region of the ionosphere in this way.

Finally, the GPS receiver will provide timing data for other FedSat payloads.

NewMag

The NewMag magnetometer is a very sensitive and rapid-sampling device for measuring the strength of the Earth's magnetic field. Earth is like a big bar magnet, with magnetic field lines emerging from the poles and far out into space. FedSat's polar orbit crosses all these lines, so NewMag can effectively gain a window into the whole magnetosphere region. NewMag can also measure vibrations simultaneously with ground- based magnetometers, so investigating the dynamics of the magnetosphere (changes in it shape due to variations in the Sun), and study magnetospheric wave-propagation.

Earlier research has shown this is a complex region, with variations in the solar wind having a huge effect on the magnetosphere and space weather. This can also affect ground infrastructure. The CRCSS study will help provide early warning systems against solar- magnetic events and space weather events, which damage satellites.

NewMag is mounted away from the main satellite on a 2.5 m extendable boom, similar to the one used on South Africa's UNSAT satellite. The boom was manufactured by Stellenbosch University, and its purpose is to avoid magnetic interference from the satellite itself.

The CRCSS and University of California, Los Angeles USA, built NewMag to the CRCSS design.

High performance computing experiment

The FedSat high performance computing payload is the world's first use of reconfigurable computing technology in space. Reconfigurable computers permit change of their physical circuits via software control; new physical circuits can be installed into a reconfigurable computer module by remote command. For spacecraft, this technology means that satellites can be rewired without having to retrieve them.

The FedSat payload established the principles of working with these devices in space, including their susceptibility to radiation. This study is of great interest to the international community, and the CRCSS hopes to build in our experience with FedSat in order to be able to build better, more reliable satellite equipment in the future.

NASA and Johns Hopkins University, USA, collaborated with the CRCSS on the research involved in the payload.

Reconfigurable computing could open up new realms of spacecraft adaptability, including re-use of old spacecraft.

Ka-band transponder

The FedSat Ka-band transponder is designed to handle the new experimental high-frequency and high-capacity Ka part of the radio spectrum. The transponder processes signals to and from the ground in the frequency band. The transponder incorporates novel CRCSS-designed Gallium Arsenide monolithic microwave circuits. FedSat is the first microsatellite capable of operating in the Ka band. This ability is due to the superior efficiency of the on-board equipment and the ground station, in Sydney.

The FedSat Ka-band transponder communicates with the CRCSS-designed Ka-band ground station. Together they will lead to new Australian-developed remote area communications applications. The CRCSS will use FedSat and its ground station to study a range of Ka-related issues.

The Ka-band system has been built entirely by the CRCSS.

Baseband processor

The baseband processor provides on-board computer processing of the Ka- and UHF-band payloads. It was designed and built by the CRCSS, to operate as a low power single modem with flexible operation. It will also provide the channel for satellite operations commands.

Students will use the FedSat baseband processor to study and develop a variety of telecommunications protocols, including ground-satellite links and inter-satellite links.

UHF communications payload

The Ultra High Frequency band payload incorporates a new type of packet data service for Low Earth Orbiting satellites to obtain environmental data and for store-and-forward messaging services.

For example, ocean buoys may transmit their data using this means to orbiting satellites, which are retransmitted back to the lab for analysis.

This payload will facilitate high speed transmission via a special multiple access scheme and error-control techniques.

The payload was fully designed and built by the CRCSS. Clones of the CRCSS system will be flown on South Korean and Singaporean satellites over the next few years.

CD ROM

FedSat carries a compact disc mounted on the side, containing the audio messages members of the Australian public recorded to go into space from March to August 2000. The disc also contains a copy of the song From Little Things, Big Things Grow, by Paul Kelly, with kind permission of the writers (Kev Carmody/Paul Kelly) and publishers (Larrikin Music, Mushroom Records).

The CD will orbit Earth as long as FedSat does, about a century, so the recorded messages are a time capsule about life in Australia in 2000.

The FedSat compact disc is made of nickel and is a mastering disk similar to those used to manufacture the normal commercial CDs. The CD is titled "Leap of Faith" and represents the CRCSS' aspirations for a more active space presence by Australians in the future. It is Australia's first long-term cultural artefact in space.

Appendix VI – References

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