Private finance for public space missions

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Executive summary

The Private Finance Initiative allows government departments to transfer responsibility for the provision of public services to private industry. The transfer of risks and potential profits can result in substantial cost savings and service improvements. This report concludes that publicly funded users of space - scientists, meteorologists and space agencies - could benefit greatly from PFI purchases, that the space, finance and insurance industries and Treasury would welcome this approach and that space agencies, including ESA, should consider it as an opportunity to develop a new role.

Context

This report was written on behalf of BNSC to promote discussion of a new approach to space missions. It goes beyond the "Two Step Approach" because it explores the case when government is not the anchor tenant for a service with potential commercial application but is the only possible user of the service.

What is PFI?

In the Private Finance Initiative, a private company undertakes, for a fixed price, to supply a product or more usually a service to a government department. The company accepts technical and operational risks in exchange for being allowed to make a profit if it successfully manages those risks.

By placing the risks with the party best able and motivated to manage them and by introducing market pressures on pricing, it is possible for: the public sector to save money; the users to obtain a better service and the supplier to make a greater profit than would be possible with a conventional procurement.

PFI has been successfully used to supply, for example, IT services to government departments. This report shows that it might be extended to space services.

Model missions

Three model missions were used to illustrate the use of PFI and to explore its challenges:

- a replacement for Cluster
- a meteorological sensing network
- a communications link from Mars.

Cluster is explored in the greatest detail. It is shown that a PFI mission could offer much greater value for money and, because it would be insured, would offer greater certainty to the science users.

The meteorological mission uses a constellation of small satellites for atmospheric sounding. The data would complement those obtained by terrestrial methods but at a much lower cost and without disrupting on-going programmes.

Many missions are planned to Mars over the next few years, all of which would need to transfer large amounts of data to Earth. A data relay service is proposed and costed in outline, showing how a private supplier could support the work of several space agencies, leading to reduced costs and improved reliability.

Implications

PFI only makes sense if the responsible government department imposes output measures of performance by the users. In other words, it must attribute value to the work done by the user rather than regard it as pure expenditure, and then must allow the users freedom to achieve their goal in the most cost-effective way.

One direct consequence is that delaying a mission can no longer be considered cost-free - the value of achieving a goal depends on when it is achieved. A further change is in the attitude to insurance - since the mission is valuable, it is worth insuring and, without insurance, the investor is vulnerable if there is a failure.

Industrial policy can no longer be the primary driver for selecting missions or suppliers. It will still be necessary to accommodate national interests in collaborative missions but the policy changes from subsidising mediocre space companies to purchasing from excellent ones.

Private missions would also set new challenges for the users. Although they are consulted, the missions are chosen at present by the space agencies. Users have to become demanding customers and make rational trade-offs between competing missions and solutions.

New and challenging roles emerge for ESA, recognising that the European space industry is now sufficiently mature to be the prime contractor for missions, not merely the supplier of spacecraft. Successful PFI requires a demanding and professional procurement executive which is able to bridge between users and suppliers. It also requires a technology programme which allows the space industry to build missions from off-the-shelf technology. ESA could evolve to be the procurement executive and the manager of the technology programme.

Conclusions

- Private missions appear to be viable and to offer benefits to users, government and industry.
- Approximate cost models indicate significant potential savings where a direct comparison can be made with a conventional mission and a cost-effective service in other cases.
- PFI for space is in accord with UK government policy
- A new and defensible role for ESA emerges.
- Industry (space, finance and insurance) is apparently keen to extend commercial practices to space missions for publicly funded users.

Recommendation

It is recommended that the conclusions be tested and explored in more detail, by carrying out a feasibility study of one of the model missions explored in this report. The feasibility study should be conducted by a consortium of space, finance and insurance companies, with close liaison with the potential user of the service, and should test the conclusion of this report that there is no barrier to private investment in public space missions.

Contents

1 Introduction

1.1 Objectives

This report has been prepared by Dr Chris Elliott on behalf of the British National Space Centre. It explores the feasibility and consequences of introducing private financial investment to areas of space exploration and exploitation where it has been assumed that space missions must be directly funded by government because the users of those missions are themselves directly funded by government.

1.2 Approach

The approach is to take three model missions, representative of a range of potential users, and to explore the financial, administrative and management issues that arise from private finance.

The model of a space science mission (Cluster II Option II) is explored in greatest detail, with explicit allowance for insurance and launch failures. Similar finance structures are assumed for the other model missions, but the impact of a launch failure is not considered.

One important consequence of private finance is that the contractors take greater responsibility for the successful conduct of the mission. There are few hard, well-documented and public estimates of the impact of this on the cost and timescale of space missions. Many estimates have been prepared within space companies but they are reluctant to make these public because of their possible impact on their existing business. The estimates of costs, benefits and timescales in this report are given with no attribution because of the need to respect commercial confidentiality. Although these estimates have therefore to be considered with care, informal discussions with leading space companies have indicated that they are not unreasonable.

The author is grateful to many friends in the space and finance communities who contributed information and who offered comments on the draft of this report. Special thanks are due to Dr Peter Ryder CB who contributed much of the text for section 5 - the meteorological mission.

1.3 Scope

This report does not explore the sources of finance that might be used to back PFI projects in space. They have been examined in detail in a recent report[1] from Esys, with examples from real projects. Rather it is assumed that finance would be available if the right business plan were put forward, and the report examines what would be needed for such a plan.

It also does not explore the commercial structures that would be needed. The term “supplier” will be used for the combination of space company (or companies) and investors that jointly take responsibility for design, build, launch and commissioning of the mission. It is possible that a large space company might have the financial resources to undertake the mission alone. A smaller company would have to work with a finance company to provide working capital. In either case an insurer would probably be an active member of the team.

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[1] “Finance for satellite ventures”, ESYS-96137-RPT-02, November 15 1996

2 Private finance for public projects - the Private Finance Initiative

2.1 Background

The Private Finance Initiative is a collection of measures introduced by the UK government to allow private investment in areas which have traditionally been seen as the responsibility of government[2]. It should be distinguished from:

- procurement - where government purchases a product or service from the private sector; and

- leasing - where private money is used to purchase a product or service which is then leased back to government.

The essential difference between PFI and either procurement or leasing is the transfer of risk and reward to the private sector. By this means it is believed to be possible to achieve real cost savings because there is an incentive for the private investor to make a rational trade-off between risk and reward and to seek a more efficient or timely solution. Where there is true risk transfer, it is not necessary to treat the investment as part of the Public Sector Borrowing Requirement.

2.2 Types of PFI

Three types of PFI contract have been undertaken:

1. **general public as sole customer** - these are commonly seen in infrastructure projects. The first well-known UK example was the Second Dartford Crossing, where the contractor undertook to build and operate a new bridge and was granted the right to operate the existing tunnel as part of the package. The Skye bridge and Second Severn Crossing are similar schemes. Other public services, such as railways, have become open to PFI investment after privatisation.

2. **government as major but not sole customer** - these can take the form of “anchor tenant” agreements whereby government guarantees to take a significant fraction of the resource but the contractor has to find other customers in order to make a profit. Some of the management contracts (GOCO - government owned, contractor operated) fall into this class, such as Devonport Dockyard.

3. **government as sole customer** - many departments of the UK government have obtained their more recent IT services by PFI. Other examples are the supply of hospitals (or hospital services) and of facilities and equipment for the Ministry of Defence.

2.3 Current practice for space

Telecommunications missions are of the first type and are now financed either by private operators or by quasi-private PTTs. Both the **market risk** (will anyone buy the service?) and the **technical risk** (will the satellite operate correctly?) have been transferred to the private sector. Government has little or no role in the definition or supply of telecommunications satellites other

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[2] " Private opportunity, public benefit”, HM Treasury Nov 1995

than for defence and even here there is a systematic move to seeking the maximum synergy with civil private procurements.

Missions for which government acts as an anchor tenant have already been proposed. In the USA, the SeaStar ocean monitoring satellite is to be funded in this way. It is understood that NASA has undertaken to pay $43M for off-line low resolution data over five years. The contractor is responsible for all design decisions and, if it fails to deliver data, does not get paid. The contractor is free to sell real-time high resolution data commercially. It is argued that $43M is at best the “break-even” price and that the contractor has to make significant commercial data sales to show a profit. A similar model has been advocated in the UK for Earth observation under the name “Two step approach” whereby the first step involves an anchor tenant contract. In these examples, some of the market risk has been transferred to the private sector along with all of the technical risk.

Private finance of space missions for which government or a publicly funded user is the sole customer is believed to be untried. There have been some proposals in the USA for such missions (for example SpaceHab) but it is believed that none has been undertaken. The PFI argument is that the market risk remains with the government but the technical risk has been transferred to the private sector.

This report is concerned entirely with missions of this third type, because:

- there is already a considerable body of analysis and experience of the other two types, and

- the implications for government, industry and users are very different from those that emerge from the other two types.

It is understood that the Ministry of Defence is exploring the possibility of a PFI contract for the supply of the next generation communications satellites. In practice it would contract for a communications service, rather than for spacecraft. It also hopes to purchase the service jointly with allied countries. Many of the practical problems of PFI for a public space mission that are identified in this report might be expected to have been encountered in the course of that exercise.

3 PFI for space where government is sole customer

3.1 Issues

The presumed benefits of PFI were stated above to be that the contractor is free to make a rational trade-off of risk and reward and has an incentive to find a more efficient or timely solution than in a public procurement. How do these translate into the context of governmental space missions?

There are three key issues which can be identified before examining any candidate missions:

- the customer's perception of value for money
- the supplier's approach to the acceptance and management of risk
- both parties' view of timeliness.

The potential impact on costs and benefits of private finance can then be identified.

3.2 Value for money

The critical change of attitude implicit in this report is from an input measure of public space missions - how much will it cost? - to an output measure - what will it achieve? This may seem trivial but it has far-reaching implications, because it allows rational trade-off of performance and cost. Furthermore, because any useful measure of "performance" will include "timeliness", it allows a realistic cost to be put on slippage. The common practice of delaying a mission because the cost has risen is not cost-free if an output measure of success is adopted. Implicit in applying an output measure is that the user becomes a customer, whereas at present the user of public space missions has to behave more as a grateful supplicant.

If the user is the customer, he will be seeking the solution that gives the greatest effect for his budget - the most cost-effective or alternatively greatest "bang for the buck". In order to think in these terms, he must first be able to express the value of the mission in financial terms. He can then take into account the incremental change in value of the mission associated with any proposed change in the performance or timescale.

Cost-effective is not the same as cheap. The user has to value the mission as a function of its quality. This may be a continuous curve (the value of the data is proportional to its spectral resolution) or it may be discontinuous (an accuracy of 1 part in 10^{15} will resolve two competing theories, 1 in 10^{17} will test the accuracy of one of them but 1 in 10^{16} is no better than 1 in 10^{15}). In practice the cost of the mission might be constant up to a certain level of quality and it will rise rapidly beyond that level. The optimum cost-effective design will then lie very near the corner of that cost curve.

This process may be uncomfortable for many users but is necessary to allow rational trade-offs. It is however implicit in the current process where space agencies provide missions to government-funded users. PPARC (and its counterparts in other countries) have a finite budget and they negotiate with national space agencies and ESA to distribute that budget between science missions. The meteorological users work through Eumetsat and ESA in a similar way.

It is not necessary to make the step to measuring benefits directly in terms of cash value but the users do have to use some **quantitative** scale in order to be able to react rationally to a change in mission design proposed by the supplier or to a change in timescale.

3.3 Risk management

The supplier needs to be able to understand and manage (not necessarily eliminate) risk. There are technological and management risks, and insurance has a vital role to play.

What might be different in a private mission? The first problem is the development of new technology. Ideally Phase C/D (or its private mission equivalent) should start with no technological development risks remaining, so that the spacecraft can be built entirely from “shelf technology”. This in turn requires space to follow the practice of other industries that depend on technological innovation, such as the automotive industry, where a technology programme exists in parallel with a product development programme. The technology programme attempts to **anticipate** future product needs and the product programme draws on the **available** technology.

The second issue is management. The supplier must have true prime contractor responsibility for the entire mission to be able to make rational trade-offs. At present the so-called prime contractor is in practice responsible only for the spacecraft or even possibly just the bus. Mission responsibility includes integration, launch and operations before hand-over to the users. This has a profound effect on both costs and timescales, since many of the current expensive and time-consuming processes are only needed to satisfy the legitimate concerns of the additional layers of management implicit in a space agency procurement.

The third issue is insurance. The supplier will only get paid if the mission is successful and so will require insurance to protect his revenue stream. The insurance premium will increase the cost of the mission but there is the possibility of a constructive relationship between the insurer and the supplier in which they work together to manage risks, either by spending more to eliminate them or saving cost by insuring them. The other side of insurance is of course that the user will only pay if the mission is successful.

At present, space agencies and the states that fund them act as their own insurers. However no notional premiums are charged to projects and, whilst there may be an understanding that such action will be taken if required in respect of an operational data service, no guarantees are provided to fund replacement or make other forms of restitution in the case of a catastrophe. As a result:

- there is a tendency for risks to be unmanaged, other than by minimising them through design at almost any cost. This may or may not be the optimum solution, and is certainly not a strategy likely to appeal to suppliers investing their own money

- if the mission fails, the users suffer the loss of the mission. Any comparison of the benefits of agency and private missions has to make allowance for the greater statistical benefit of the insured private missions and hence their increased value for money.

Insurance assumptions

It is clear that insurance must be considered for any privately financed mission, even if the supplier chooses to “self-insure” (that is, take the risks himself and therefore build an insurance factor into his costings). It will be assumed that the price of a commercial launch includes the supply of a replacement launch in the event of a failure but does not include any contribution to the customer's other costs. These include replacing the satellite and the loss or delay of the revenue stream.

These issues are explored explicitly in the case of science missions (section 4). The probability of launch failure or other failure to enter service will be assumed to be 10% and the insurance premium will be assumed to be 12% of the cost of the risk insured. So for example, a spacecraft costing 100 MECU will be insured against these losses for a premium of 12 MECU. The premium will of course depend on the extent to which the insurer is able to work with the supplier to manage risks but this figure is approximately correct and ensures that the mission model does not overlook this element of cost.

The mission model considers two cases - where the first launch is successful and where a second spacecraft and launch is needed. The probability that two launches would fail is only 1% on the assumptions made here and this possibility will be ignored for simplicity. There is also a risk that the spacecraft will fail after entering service. Historically this is less common and, although it would be possible to insure against this risk, it too will be omitted from the model mission for simplicity. Neither of these omissions should materially affect the calculations of cost-effectiveness.

3.4 Timeliness

Once the output of a public space mission is measured, it is necessary to consider not only "how much" but also "when" a cost or benefit will occur. This is a normal principle of commercial business and is known as discounting. A benefit in the future is not worth as much as an earlier one and a cost that can be deferred is better than one that must be paid sooner. The same principle applies when the customer is the public sector.

Both costs and benefits are discounted to give a Net Present Value. The discounted cost, C_D, is given by:

$$C_D = C \exp(-r_c t)$$

where C is the actual cost when incurred, r_c is the discount rate for costs and t is the time before the cost is incurred. The NPV of costs is the sum of C_D over all costs of the mission. Similarly each benefit B has a discounted value, B_D, given by:

$$B_D = B \exp(-r_b t)$$

but note that the discount rate for benefits, r_b may be different from the discount rate for costs. The NPV of the benefits can be calculated in the same way as that for the costs and the NPV of the project is the difference between the NPV of the benefits and the NPV of the costs. This represents an objective measure of value for money or cost-effectiveness.

3.5 Costs and benefits - user's perspective

In a conventional space mission, the costs are the contributions to national space agencies and ESA. For a PFI mission, they will be the fees payable to the supplier when the mission is successful.

The users receive funding from government. In the UK the Treasury uses a discount rate of 6% or 8% per year (depending on the type of project) which reflects the rate of interest that government has to pay on its borrowings. This rate is relatively low because government is considered to be a trustworthy borrower which does not renege on its debts. The political and economic consequences of this safety are manifested in the PSBR, which government wishes to minimise because it indicates the liabilities to which government is exposed.

The benefits as perceived by users also have a value that falls with time. Consider for instance an environmental monitoring system. The benefit of the data is reduced the longer that we have to wait for it, if only because corrective action will be more difficult and expensive. Purely scientific data also has a falling value with time. Scientific careers and the international reputation of institutions depend on being first with results. The efficiency of research will be greater if it can be conducted more promptly, if only because the accumulated costs of maintaining the research facilities and paying the staff will be lower. More generally, the rate of scientific progress will be greater if the lead-time between conceiving an experiment and receiving results is reduced. All of these arguments will be used to justify the arbitrary assumption that the value of scientific data is halved if it is necessary to wait an additional five years. This corresponds to a discount rate for benefits of around 15% per year.

This report will assume that the user discounts costs at 8% and benefits of 15% per year.

3.6 Costs and benefits - supplier’s perspective

The costs are the actual costs incurred in building and launching the mission. The benefits are the fees that the supplier receives from the users.

Private investors think in terms of rate of return, from the initial investment to the point at which their involvement ends. This is often called IRR for Internal Rate of Return and corresponds to the discount rate on costs and revenues at which the project just breaks even over its life (that is, its NPV is zero at the start). For this to be meaningful, there must be an “exit” at which the investor’s involvement ends. This may either occur when he sells his investment to another investor (or even to government) or when the project comes to a natural end with zero residual value (for example when the spacecraft reaches the end of its operational life). The IRR that is demanded will depend on the level of risk. The examples in this report are all constructed so that there is no significant uninsured risk.

In practice finance is likely to come from a combination of loan and equity finance. The availability of each is considered in detail by the recent Esys report. For this report, it will be assumed that:

- 70% of the costs of the mission are raised by loan, the balance being equity

- the loan will be at a rate of interest of 10% per year

- the equity investor will require an IRR not less than 20% per year.

3.7 Potential advantages and disadvantages of private finance

Governments currently buy space solutions by giving money to space agencies who then build solutions on behalf of the users. It might appear that there is no difference between that and a PFI version - “it’s all government money” is a common remark - but in practice they could lead to very different mission architectures, with consequences for the cost, performance and lead time.

Without a customer-contractor relationship, the programme managers have no incentive to make a rational trade-off between risk and performance (why take risks when there’s no reward for it?) and the “customers” have no incentive to make a rational trade-off between cost and performance (why not ask for the best if you’re not paying?).

What might be the advantages? One layer of management might be eliminated (the space agency duplicating the role of the prime contractor) and the relationship between the users and supplier can be much closer - it will be clear from some of the mission models that this may be essential. The projects should be completed more quickly, both because there are less management decisions and because the supplier has an incentive. The user (or rather his governmental sponsor) will only pay when and if data is delivered - this both postpones payment and removes the risk of large payments for no return if there is a mission failure.

What might be the disadvantages? The role of the space agencies will change, from being effectively the prime contractor for the mission to being a procurement executive and responsible for technology programmes. The political issue of geographic return will have to be handled on a mission by mission basis. There will be additional costs, both because the investor will need to see a return and to pay insurance premiums. Above all, the role of the users will change, from being essentially passive recipients of missions to being active customers for the service that they require, with consequent power and responsibility.

It is not obvious that the advantages outweigh the disadvantages, either financially or politically. The model missions which follow will be used to explore the balance.

4 Private missions: science customers

4.1 Introduction

The PFI proposition is:

- ***A private investor would design, build, launch and commission (and possibly operate) a space science mission using private funds. Payment would be made when the data is delivered to the science users.***

Space science is the most controversial of the possible applications of PFI to space considered in this report. It also requires the greatest changes to the present management and procurement practices and the political principles that underlie them. Some of the complicating factors are:

- instruments are designed and constructed by scientists rather than the space industry - the rapid advances in space science arise as a result of the close interaction between instrumentation and theory, and the excitement and motivation that this generates

- the spacecraft, launch and operations are funded by the ESA mandatory programme, whereas the instruments and exploitation of the data are funded by national science or space programmes

- space science missions have the dual purpose of enabling science and supporting the space industry.

Perhaps the most important factor is that:

- the culture of the space science community is that of subordinate partners, with only an indirect influence on the choice and conduct of missions, rather than that of demanding customers who are purchasing the solution to a specified problem.

For those reasons space science provides a useful tool to investigate the opportunities and challenges of private finance and it is explored in greater detail than the other model missions in this report.

4.2 Management and procurement

Supplier

Two possible contractual structures are:

- the supplier is responsible for delivering a spacecraft bus on which the scientists' instruments are mounted

- the supplier is responsible for delivering a complete spacecraft, including the instruments.

The first structure requires a smaller change in current practice but is fraught with potential difficulties. In the worst case, if the spacecraft fails to meet its specification, it will be necessary to establish where responsibility for this lies in order to decide whether the supplier should still be paid. In the extreme this might be after an in-orbit failure, but similar difficulties could arise if there are problems with integration of instruments and bus, or even if there is a delay in the construction of either.

It is also hard to see any benefits from such a structure. There are no economies to be made from eliminating technical or contractual interfaces or from trading off functionality between bus and instruments which, it is argued in the financial model below, could lead to significant cost savings.

It is concluded that this structure, although superficially easier to implement, offers none of the potential benefits of PFI. In particular, it does not lend itself to a true transfer of risk and reward to the private sector and thus should be excluded.

The second structure needs radical changes to the current way of working. The supplier will have to be an integrated team of spacecraft builder and instrument scientist. Although this may be harder to achieve, it has many benefits:

- possible cost savings as outlined above and quantified in the financial model below
- opportunity for instrument scientists to take advantage of the better resources and management experience of industry
- opportunity for industry to learn from the innovative techniques and creative excitement of instrument scientists

and, above all,

- freedom for the supplier to make rational trade-offs between risk, cost and performance.

The team may not need to be collocated - this will depend on the number and location of the industrial partners and of the instrument scientists.

Users

The users have to play three roles:

- as a science community, to define the goals for the mission and to assess the scientific value as a function of mission performance
- as members of the supplier's team for building the spacecraft
- as customers for the data to be delivered by the spacecraft.

There is clearly a potential conflict of interest here and it is necessary to devise a management structure to avoid the conflict arising. The first and third roles are probably best tackled as part of the contribution of the space agency.

The second role is essentially the same as that played by the instrument scientists at present, but they would be answerable directly to the supplier as sub-contractors. They would have to be involved in the system study and mission definition stages (as in Phase B now), in the spacecraft construction and in the testing, commissioning and operations. However the closer working relationship should ease the flow of information and hence allow management and technical interfaces to be eliminated or at least greatly simplified.

Space agency

Space agencies (ESA and national agencies) can provide a neutral forum in which users from different space science disciplines and from different countries can cooperate in their first role, which involves two activities:

- agreeing the relative merit of different missions (eg a solar physics mission, an X-ray telescope and a planetary explorer)

- for any one mission, establishing how its merit varies when the performance of the mission (eg duration, angular resolution, measurement accuracy) is varied.

It is likely that space scientists and space agencies will not be comfortable with these challenges. In practice they already accept the former, although they do not express the prioritisation of missions in such explicit terms and are strongly influenced by the interests of the space industry. The second challenge is perhaps less uncomfortable in principle but still requires a fundamental shift of thinking towards recognising that they must behave as responsible customers, trading off performance and cost, rather than simply demanding the best performance that is possible (albeit possible within a fixed budget).

The third role of users can also fit well within a space agency structure. Although the people who analyse the data derived from the instruments may be the same as those who build the instruments, it will be necessary to have a separate mechanism to verify the satisfactory operation of the spacecraft and hence to authorise payment to the contractor. This might consist of a panel chaired by the space agency and including representatives of the supplier and users. The panel would have to arbitrate in cases where, for example, the spacecraft and instruments appear to be performing according to specification but the data is found not to be adequate for the scientific needs.

Space agencies also act as a channel for governmental funds, both those allocated to space and those allocated to science for the instruments. They are thus already a kind of procurement executive and could be responsible for ensuring that:

- the correct missions are selected
- the appropriate mission design is selected
- the best contractor is selected
- public funds are correctly spent.

There remains an important role for space agencies in executing the technology programme which should complement this approach to procuring missions. It was argued above that, in order to manage risk, the supplier would want to use only tried technology in a privately financed mission. An agency technology programme could be a source of tried technology.

Governments

The role of governments is essentially the same but the mechanism by which it works is different. Instead of making payments to the space agency and instrument builders, it allocates funds to the scientists with which they pay the supplier in the form of fees for the data being returned. Governments may apply their own rules for discounting future expenditure to estimate the economic and political impact of these payments.

It is important that governments have a clear view of why they are supporting the mission. The primary purpose of a private mission must be the scientific data that it produces. There is inevitably an additional element of industrial policy which at present is embodied in the juste retour principle. Any sensible supplier is going to try to ensure that at least some of the project is placed in the countries which supply the funds but the pressure to show a profit will mean that this could not be formalised with a precise geographic return coefficient.

The consequence of the private approach to funding, and the consequent changes described above, is that missions will be constructed by the most competitive companies. There will still be an industrial policy implication but the emphasis will have shifted from subsidising mediocre space companies to purchasing from excellent ones.

Procurement procedure

The procurement procedure has to allow competition between potential suppliers and a process of convergence to select the best proposition. It also has to allow the selected supplier to quote a fixed price.

One approach that has worked in other fields is that of the parallel, part-funded project definition studies (PDS), which are approximately equivalent to the current Phase B studies. There is an open (or at least wide) call for proposals to carry out a PDS. Two or three contractors are selected and each is part funded (usually 50%) to work up a mission design. The users, supported by the space agency, iterate the design with each contractor until an optimised version exists, making full use of any proprietary technology or capabilities as well as public domain solutions. Each PDS should result in a viable design for which the contractor is able to quote a fixed price. The selection process reduces to choosing between these solutions.

Of course the process of selection is itself not trivial but there are established methods for doing this (see for example Keeney[3]).

4.3 Model mission

Cluster II Option II has been chosen as a model mission because it assumes most of the improvements in management and procurement practice that are possible within the framework of a conventional space agency procurement. In particular, the specification[4] took account of “technology developments since the original mission was conceived, especially in the field of small satellites” and invited industry to submit proposals in which “simplification of the requirements would have a major impact on cost, without a significant impact on reliability”. Furthermore, the management approach would “follow similar practices that have developed within national small satellite programmes. This is similar to that suggested by ESA at the Small Science Satellite Workshop (ESTEC 6 July 1995)”.

The specification of the mission assumes a completely new spacecraft design and does not depend on inheriting sub-systems or other investments from the original Cluster mission. These cost estimates are therefore representative of a science mission conducted under the simplified space agency procedure and any further savings represent the impact of private finance.

Cost of mission as proposed

The latest estimates of the costs of Option II (excluding expenditure on Phoenix but assumed to include the cost of the Phase B study) are (all in MAU):

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[3] Keeney R L, “Value-focused thinking”, Harvard University Press, 1992, ISBN 0-674-93198-X

[4] Cluster-II/Option-II Invitation for Technical & Cost Proposal, issued 13 September 1996

spacecraft and procurement:	53
spacecraft operations:	28
miscellaneous:	7
JSOC:	2
ESTEC project team:	5
launch:	32

It will be assumed that the cost of spacecraft and procurement is made up of 5 MAU for Phase B and 48 MAU for Phase C/D.

It is also necessary to consider the cost of the instruments although these would be funded by separate, national budgets. The original set of instruments for Cluster cost ~50 MAU. Although replacement instruments could probably be constructed for around half of the cost of the originals, for this case study it is appropriate to consider the original cost since it is being used as a model for a new mission. The total cost of the mission is therefore assumed to be 177 MAU.

The contractual procedure proposed for Option II is essentially the same as other ESA space science missions. ESTEC takes overall mission responsibility, the spacecraft prime contractor is responsible solely for the spacecraft and the scientists are responsible for the instruments.

Private financed mission

A privately financed version of Option II might achieve cost savings because:

- the spacecraft prime contractor will not have to produce detailed PA documentation to allow oversight by the mission “prime contractor” (ie ESTEC). This is a manifestation of the savings to be expected from eliminating one layer of management;

- the instrument scientists will be subject to the management expertise and economies of scale available from the industrial prime contractor;

- management and technical interfaces between the spacecraft and the instruments will be simplified or eliminated because there will be an integrated team. As well as reducing costs and delays, this integrated approach would allow design trade-offs between the spacecraft and the instruments (for example by sharing resources) which are difficult or impossible with the present contractual arrangements.

Informal discussion with specialists in the space industry have suggested that the effect of these might be:

- the cost of building the spacecraft will be reduced by ~ 20% to 38 MAU

- the number of staff needed to develop the instruments and the duration of the development programme will both be ~ 70% of a conventional mission so that the cost of the instruments will be halved to 25 MAU

- the duration of Phase C/D will be reduced by ~ 30%

- the shorter programme and reduced involvement in detail by the ESTEC project team will reduce its costs by ~ 20% to 4 MAU

- the miscellaneous costs will also be reduced by ~ 20% to 5 MAU.

The estimate of Phase C/D cost includes implicitly the profit allowed by an agency programme, which is normally 8%. In the case of the private mission, this must be deducted to give the cost to the supplier, on which the IRR is calculated. The true cost of Phase C/D is therefore (38 + 5 + 25) x 0.92 = 62.5 MAU

In the event of a mission failure, it is reasonable to assume that the cost and duration of the repeated Phase C/D will each be 75% of those of the original Phase C/D. The insurance premium will be 15% of 62.5 x 0.75 = 7 MAU. The launch and commissioning phase will still take 6 months, as before.

Two parallel Phase B studies would be conducted for a private mission. It is assumed that each costs 5 MAU as before and that half of the cost of each study will be paid by the agency and half paid by the company conducting the study. Costs of the company that wins the Phase C/D contract are included in its costs of the mission. The costs of the losing company are written off by that company as marketing expenses.

Other costs (operations and JSOC) will be assumed to remain the same in order to make a fair comparison. In practice, it is likely that a privately financed mission might be able to reduce these by a significant amount.

The fee payable for the data is assumed to be 175 MAU. This is assumed to be paid in 8 equal tranches, with one payment every 3 months throughout the 24 months of operations.

4.4 Financial model

Cost summary

Item	Cost to government		Cost to supplier	
	agency mission	private mission	agency mission	private mission
Phase B	5	5	-	2.5 (each)
Phase C/D[1]	105	-	-	62.5
launch[2]	32	-	-	39.0
operations	30	-	-	30
ESTEC team	5	4	-	-
fee	-	175[3]	-	-

1 includes the spacecraft, instruments and miscellaneous item
2 includes commissioning and insurance premium for private mission
3 this is the total fee payable for data over the operational life of the mission

Timescales

The latest estimate is that the programme will take 54 months and the operational phase will last 24 months. Assumptions were given above of the impact of a private mission of timescales. All times in the table below are in months.

Phase	as proposed	private
Phase B	6	6
Review of Phase B results	6	6
Phase C/D	36	24
Launch and commission	6	6
Total	**54**	**42**

4.5 Cost-effectiveness

The spreadsheet models given in the Annex to this report show how these costs and timescales were used to calculate the costs of the mission to government in each case and the IRR of the private mission to its supplier.

Governmental perspective

	benefit to users	cost to government[4]	cost-effectiveness[5]
Agency mission	1.00[1]	139.1 MAU[2]	1.00[1]
Private mission - 1st launch succeeds	1.29	133.0 MAU[3]	1.34
Private mission - 1st launch fails	0.96	114.7 MAU[3]	1.16
Private mission - weighted average	1.26	131.2 MAU[3]	1.32

1 arbitrarily normalised
2 includes cost of ESTEC contribution
3 includes contributions to Phase B studies and cost of ESTEC contribution
4 assumes a discount rate of 8% in government finance
5 discounted benefit divided by discounted cost

It is apparent that the cost-effectiveness of the private mission is very much greater than that of the agency mission if the first launch is successful. Even if the first launch fails, the cost-effectiveness of the replacement mission is still 16% greater than the original agency mission, and the weighted average cost-effectiveness (assuming a 90% probability of success on first launch) is 32% greater for a private mission than an agency mission.

An alternative view that might be taken by government is that it attributes no value to the greater benefits to the user - neither those arising as a result of the shorter programme nor those arising from the greater security of insurance. This is an extreme view in which the concept of value for money has been sacrificed but might be taken by a hostile finance ministry. Even after allowing for the governmental discount rate, the cost of the private mission is less than that of the agency mission.

Supplier’s perspective

The IRR to the supplier in the baseline case of a successful first launch is 25.7%. The sensitivity of this can be illustrated by calculating various changes to the baseline case:

- Phase C/D overruns by three months and continues to incur costs at the same rate per month as the rest of Phase C/D: IRR = 16.3%

- the first launch fails and it is necessary to rebuild the spacecraft and repeat the launch campaign and commissioning: IRR = 8.0%

It is apparent that the rate of return that can be achieved is sufficient to attract an investor. Even if the programme slips by a few months there is still an attractive rate of return. The rate in the event of a launch failure is the same as that offered by conventional space agency funding but will worry an investor. Although the average value, weighted by the probability of launch failure, is still acceptable (around 24%), it might be desirable to purchase additional insurance to pay out in the event of failure, albeit with a reduction in the rate of return on the baseline (no failure) case.

Users’ perspective

From a purely financial view, the benefit to the user is the greater certainty of a private mission because it is insured. This allows the user to plan the exploitation of the data and to avoid the risk of wasted investment in facilities and staff. No attempt will be made here to estimate the value of this benefit - the Cluster science teams may be able to provide some insight into this.

4.6 Conclusions

It appears that reasonable assumptions as to the cost and timing of the agency and private missions indicate that:

- the funding agency will benefit by greater cost-effectiveness or value for money - even if it does not attribute value to the better service provided by the private mission

- the supplier will benefit by being allowed to make greater profit in the event that it manages the mission efficiently

- the users will benefit because the data is available sooner and is delayed, rather than lost, in the event of a launch failure.

On the other hand:

- the users have to change their way of working by becoming customers rather than beneficiaries and by developing the instruments within the supplier’s team

- the supplier has to accept the same type of risks as would be normal in for example a commercial telecommunications mission

- the space agencies have to define a new role in which they work with the users to specify and oversee the mission but do not have day-to-day authority over its conduct.

5 Private missions: meteorological customers[5]

5.1 Introduction

The PFI proposition is:

> ***EUMETSAT would place a contract, on behalf of the national meteorological services in Europe, for an operational data stream of a defined volume and quality. A private investor would determine how to provide such a data stream.***

Private meteorological missions are made more complicated by the policy of free and open international exchange of meteorological data, which makes it impossible to create an effective market for the resulting data. This is why an organisation such as EUMETSAT is necessary, to act as procurement agency and consolidator of funds for its members or subscribers, who contribute out of a sense of sharing the burden fairly rather than their competitive need for the information. At present, EUMETSAT programmes are funded on a GNP basis, and this or some equivalent arrangement would be necessary to pay for the data streams on delivery. It would be entirely feasible, in principle at least, for EUMETSAT to act in this way for the global community of meteorological services, not just those in Europe. Indeed, this is the logical outcome of the concept of free exchange and equity in burden sharing.

The model mission is atmospheric sounding by radio occultation. This is a powerful method for sounding planetary atmospheres from space with high accuracy and vertical resolution. It has been used successfully to measure vertical profiles of temperature for the atmospheres of Venus, Mars and the outer planets. It has been shown[6] that it is possible to make radio occultation measurements for the Earth's atmosphere with an accuracy and vertical resolution of value to operational meteorology and climate and ionospheric monitoring and research using Global Navigation Satellite Systems (GNSS) transmitters - GPS and GLONASS - and receivers on LEO platforms.

The features of the application which make it attractive are:

- an end-to-end ground based data processing system exists (a) to quantify the incremental value of the data, through their impact on the accuracy of forecasts as a function of lead-time; (b) to realise that value on an operational basis
- it freely exploits both the ground and space based components of the existing and well supported GNSS
- it can be implemented progressively
- it complements and partially replaces existing operational sounding techniques, based on radiosonde and satellite based radiance measurements

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[5] The idea for and much of the text of this section was provided by Dr Peter Ryder CB, formerly Director of Operations, UK Meteorological Office. I am very grateful for his help and advice.

[6] E. R. Kursinki et al, 'Initial results of radio occultation observations of Earth's Atmosphere using the Global Positioning System', Science, 271, 1107 (1996)

- although there is a clear and well organised primary user of the raw data, there are potential secondary users interested in its use to infer the characteristics of the ionised upper atmosphere, and hence so called 'space weather'

- the measurements have intrinsic long term stability, with no significant calibration requirements, making them very attractive for long term climate monitoring purposes

- it can use microsatellites or secondary payloads on other LEO satellites

- it is simple and hence relatively inexpensive, enabling all participants to gain experience of and confidence in a new method of procurement without placing essential operational capability or considerable investment at risk.

5.2 Management and procurement

The arguments advanced here are all illustrated by reference to the model mission but similar arguments would apply to any meteorological mission.

Supplier

There is a substantial transfer of technical risk and freedom to manage it to the supplier. Provided that data of the defined quality are delivered there is market risk only at the margin, i.e. in the secondary market for such data. Once a contract is in place, the planning environment for the supplier is much more stable than at present.

The receivers used to generate the data could be either secondary payloads on other spacecraft or could fly on dedicated small satellites. Dedicated missions offer simplicity in risk management but require dedicated spacecraft and launches; the use of platforms of opportunity hold out a chance of cost, and risk, sharing. These are precisely the sort of trade-offs which should be made by industry, and not customers or procurement agencies.

It will be assumed here that the trade-off concludes that secondary payloads are undesirable because the supplier is no longer in control (thus introducing new and unmanageable risks), it is unlikely that they would be cheaper (the primary user will charge a full commercial price for the secondary payload) and they are unlikely to meet the needs of an operational service. Secondary payloads might be viable if there is an economy of scale but that is a concept increasingly questioned since, if anything, space missions appear to suffer from diseconomy of scale. The financial case for this mission is based on dedicated satellites.

Data users

Users have to define the way value varies with the detailed specification of the data. This is essential guidance for the supplier, through the equivalent of phase A/B, where technical compromises are established and development risks quantified. By the start of phase C/D the contractual obligation of the supplier in terms of quality (in all respects) and volume of data must be settled and payment terms agreed. This is not to deny the inclusion in the contract of performance bonuses or penalties related to end user value.

Because the users are contracted to pay for a defined period for data of the specified quality, there is a powerful incentive for them to be confident that such data will add the expected value to their services, that their customers will be willing to pay for such added value and that this data service is the optimum way of realising such value.

Agency roles

In this scenario, there is no particular role for ESA, other than as one (important) source of expertise or operational capability available under contract to the supplier. However, as with the other model missions considered in this study, it is only possible for the supplier to quote fixed prices for tasks if the technological risks are eliminated or at least well understood. Furthermore, private missions cannot afford long development programmes so must be designed around technology that is already “on the shelf”. ESA could have a vital role in conducting a technology programme that efficiently anticipates mission requirements and ensures a smooth handover to operational missions.

A dedicated constellation of small satellites is fundamentally different from the approach to the introduction of radio occultation advocated by ESAC. It stated[7] that “ESA should liaise with other agencies to get as many instruments as possible included as flights of opportunity and only then assess the need for a dedicated programme of small satellite launches’. Although this might be appropriate if there is doubt about the value of the technique or if experiments are needed to determine the optimum instrument design, flights of opportunity are rarely appropriate for an operational service which has to serve operational users. Furthermore, it might be argued that the need for a dedicated programme should be assessed by meteorologists, not ESA.

European meteorological services and their governments have set up EUMETSAT to consolidate and manage their interests in space. Therefore it would be logical to use that organisation for the purpose of contracting with a supplier to deliver the defined data stream. Although it would be possible in principle for the supplier to take on the consolidation of funding and to dispense with EUMETSAT in this role, that may be a step too far for many small national meteorological services.

This suggests three possible implications for the future of EUMETSAT:

- This model is apparently a diminution of EUMETSAT's current role in the procurement and operation of meteorological space and ground segments, on behalf of its members, where much of the technical risk of a project is managed by a combination of EUMETSAT's and members' technical staff. In practice such risks are borne - often implicitly and without a premium - by those funding the project, whether in the meteorological services or their national authorities. Private supply would make the risks and costs of insurance explicit.

- There could be a fundamental change in the status of EUMETSAT which is currently an agency set up and governed by an inter-governmental Convention. If it were privatised, as is Eurotunnel for example, it could raise equity and loan capital and take on the role of supplier. This would make sense if, like Eurotunnel, its primary mission was to provide operational services - data in the case of EUMETSAT.

- EUMETSAT could act as the procurement agent for the global community of meteorological services, not just those in Europe.

National funding agencies

The role of funding agencies is transformed from that of a supplier of capital to that of the source of a revenue stream on behalf of government acting as customer. Governments need to act in this way where markets fail (as caused by free exchange, for example) or where public good services (such as severe weather warnings) are being purchased.

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[7] Earth Sciences Advisory Committee, ESA/ESAC (96)7, page 7

Procurement procedure

The procurement must be competitive in order to tease out best value for money and innovation but it must be accepted that funding by several nations will inevitably add non-utilitarian goals. The efficient and equitable way of dealing with these is to have them openly declared and agreed by the funding nations as requirements to be met by the supplier. Bids would then be evaluated in an agreed scoring model which takes weighted account of both these requirements and those relating to the volume and quality (widely and carefully defined) of the delivered data. This will ensure that funding nations are aware of the true costs of protecting their industries.

There is merit in keeping the competition active to the end of at least Phase B or its equivalent, which enables informed trade-off between requirements, performance and cost in the design phase and real competition for the contract to build and operate the system.

5.3 Model mission

Description of measurements

When GNSS signals pass through the atmosphere they are refracted through an angle which is a function of the refractivity gradients along the path. These in turn depend upon the gradients of density (and hence temperature), water vapour and electron density of the atmosphere. The effects are greatest when the signals pass through the atmosphere at grazing incidence, and such geometry enables height profiles to be inferred. At radio frequencies it is not possible to measure the refracted angle directly. However, the refraction introduces an additional Doppler shift into the retrieved signal which can be measured very accurately as a phase shift. Use of dual transmission frequencies allows isolation and removal of ionospheric effects from temperature and humidity measurements, but also allows electron densities to be inferred.

Unlike satellite based radiance measurements the technique has inherently high vertical resolution (a few 100m) and is insensitive to cloud. It has lower horizontal sensitivity however, and as with other satellite based techniques, it lacks sensitivity close to the ground, where balloon borne radiosondes are at their best. The occultation technique works particularly well at the jet stream level of the atmosphere, where much of the development of weather systems is initiated.

The data stream would comprise the time of receipt or phase of GNSS signals received at a constellation of LEO satellites.

Measurement system

The receivers are relatively simple, small and undemanding of power and data transmission bandwidth. The ESA specification[8] for the receiver is:

-	12 parallel dual-frequency channels	
-	mass	less than 3 kg
-	volume	less than 3 litres
-	power consumption	less than 15 W
-	data rate	less than 10 kb/s
-	nominal dimensions	300 mm x 180 mm x 60 mm

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[8] C. J. Readings and M. L. Reynolds, 'The Nine Candidate Earth Explorer Missions - Atmospheric Profiling Mission', ESA SP-1196 (7), April 1996

They are ideal candidates for small satellite missions or installation in 'piggy back' mode on platforms of opportunity. ESA has considered whether to construct an Earth Explorer mission based on these ideas but concluded not to go to phase A because the potential of the technique has been demonstrated in early results from experiments launched in April 1995 on the US satellite Microlab 1 (apparently with a budget of $100k). A receiver with the required characteristics has been designed and prototyped for ESA and it is planned to fly a derivative on the Danish Ørsted (in 1997), German CHAMP (in 1999) and METOP satellites.

Spacecraft and constellation

The ESA study concluded that 12 receivers in 800 km orbits, having an inclination of about 75° to 80°, could provide soundings with an horizontal resolution of about 400 km every 6 hours. As well as the receiver, possibly in a redundant configuration, the requirement is an antenna (+/- 45°, no mechanical movement required) mounted fore and aft for observing rise and set occultations. A further (small) zenith pointing antenna is required to determine the orbit precisely. The receiver operates at 2 frequencies in the L-band and measurements of phase are required at a rate of 10 Hz. Receiver operation is autonomous.

These requirements could easily be met by a constellation of microsatellites (<50 kg, gravity gradient stabilisation, fixed solar panels, no propellants). 12 micro-satellites could be distributed over two orthogonal orbital planes, requiring 2 launchers lifting a total payload of less than 300 kg. This is within the capability of the PegasusXL, Taurus and LLV-2 launchers.

If the satellites work in a store-and-forward mode, 35 Mbytes of data would need to be held on board for downward transmission once per orbit. It might be possible to use the constellation also as data relay satellites, as described in COMRING[9]. Each satellite transmits data in real time to the next satellite around the ring until it can be received at a single ground station. The data latency might be reduced from up to 90 minutes using store-and-forward to a few seconds which might greatly enhance its value to operational forecasts.

The loss of a single micro satellite has only a minor impact on observational capacity, offering graceful system degradation.

Ground segment

One high latitude autonomous ground station could receive data on every pass. A pass will last about 10 minutes, so an S-band downlink of up to 1 Mb/s will easily dump the contents of the on-board memory each orbit. Alternatively the COMRING concept might allow the ground station to be located more conveniently. Fiducial data is also required in near real time from the existing network of ground-based sites which monitor GNSS.

The contract could be for the supply of raw data, which EUMETSAT would convert into and distribute as level 1.5 products, or for the supply of these products. Leaving aside the question of competence, the latter is simpler and unambiguous, and therefore preferable from a risk management viewpoint.

Dissemination could be via the Global Telecommunication System of WMO, by broadcast over communications satellites or possibly (given the relatively small data volume) by the World Wide Web. Numerical modelling centres would assimilate the data in real time, alongside other meteorological data, in the cyclical process of generating weather forecasts. Analogous arrangements would be made to deliver data for climate and ionospheric monitoring and research.

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[9] For further information, contact Kayser-Threde, Munich, Germany

5.4 Financial model

The following cost assumptions will be used to explore the viability of a business plan:

- cost of receivers: the receivers will be built as a batch - the total cost for 12 receivers will be $2M

- microsatellites: the microsatellites will be procured as a batch at a cost of $0.5M each, making a total cost of $6M

- insurance for launch failure will add 15% to each of these costs, making $2.3M and $6.9M respectively

- two launches will be needed at $15M each - no insurance is needed because the launch supplier will offer a free relaunch in the case of a failure

- the high latitude ground station will cost $5M to build and deploy and $0.5M per year to operate

- the facility to process the data to Level 1.5 and disseminate it to users will cost $2M to build and $1M per year to operate

- commissioning costs run at the same rate as operations - ie $1.5M per year and hence $0.75M in total

- the Phase B study will be conducted by EUMETSAT - the suppliers will carry out their study as an unfunded part of the bidding process at a cost of $0.5M

The timescales will be assumed to be:

- Phase B study and bids: 6 months

- specification, build and launch of the microsatellites and establishment of the ground infrastructure: 18 months

- commissioning and demonstration: 6 months

- operational life: 5 years.

These assumptions are used in the spreadsheet in the Annex to this report to calculate the rate of return to the investor. The financial model approximates the effects of discounting by treating each 3-month period separately. It also assumes that the expenditure on building the receivers, microsatellites and ground infrastructure is distributed uniformly over Phase C/D but that the cost of launch is incurred at the end of that Phase. As with the other model missions, it is assumed that the finance derives in part from equity and in part from a loan.

If the fee charged to Eumetsat is $20M per year and the project is entirely funded with equity, the rate of return to the equity investor is 31% per annum.

The assumptions that were used to derive this model are fairly robust. Although the cost of the receivers and microsatellites are only estimates, the costs are dominated by launch and an expensive option has been assumed. Other launch vehicles, such as Start, might significantly reduce the cost of launch and easily counterbalance any underestimate in the other costs.

Alternatively, if for some reason the costs of the mission were to rise by $10M, the IRR for the developer is still 21%

5.5 Cost-effectiveness

A receiver capable of observing both setting and rising occultations could deliver, under ideal conditions, about 1100 useful soundings per day for each receiver, globally distributed, with an average spacing of about 700 km. The proposed constellation will therefore deliver around 13,000 soundings per day at a cost of $20M per year.

As usual in these cases it is difficult to estimate the incremental or replacement benefits of this type of information: the appropriate numerical model experiments have yet to be carried out. The main benefit will come from improved meteorological services, the current value of which has been estimated[10] to be between $600M and $1500M per annum to the UK economy alone. The profiling mission has only to make a small improvement in forecast accuracy to justify global expenditure of $20M.

There should also be some cost savings. The entire existing global network of some 700 radiosonde stations produces some 1400 soundings per day, concentrated on the continents. Consumables for this network cost around $64M per year (based on $125 per radiosonde) and labour, capital and other costs have to be added. A figure of $75M per year does not seem unreasonable. The profiling mission would not replace the radiosonde network but allow it to be reduced, particularly where there was no local requirement for high resolution data in the lower atmosphere at remote (expensive) island and equivalent sites. Radiance measurements from satellites are also used operationally to infer temperature and humidity profiles. Again, this is a complementary rather than replacement technique but if deployed operationally should allow some reduction in the investment in instruments such as IASI.

5.6 Conclusions

The concept of private investment in meteorological missions is not new and neither is the conclusion that such an investment might be cost-effective. The analysis presented here has added to the discussion in two areas: by examining the future role of EUMETSAT and other agencies and by indicating how an inexpensive mission could be used as an incremental change to test the process.

EUMETSAT is well placed to take a leading role by coordinating the finances of its members and by acting as the procurement authority. It has the technical and administrative capability for this and its status as an international agency governed by treaty allows it to maintain the free exchange of data vital to the world-wide meteorological community. Although it is possible to conceive of an evolution of EUMETSAT into a private body, there is little need for this and some countries might no longer see it as sufficiently neutral. A more likely evolution is that it acts as a procurement authority for nations other than its signatory members, since it may be uniquely positioned to procure competitively and hence take advantage of the savings that private missions might offer.

The distortions introduced by protectionist procurement cannot be ignored but EUMETSAT is in a position to make these explicit by means of a publicly recognised scoring scheme for

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[10] S Teske and P Robinson, “The benefit of the UK Met Office to the national economy”, Conference on the economic benefits of meteorological and hydrological services, WMO/TD 630, pp 21 - 24

procurements. In practice, experienced companies working in large international projects are aware of the need to recognise national interests and can frequently do so in ways that are less damaging than formal juste retour principles.

The model mission is attractive because it is incremental. It adds a new and potentially valuable capability to meteorological data gathering without displacing any of the existing facilities. It appears to offer excellent value for money and, because of the private investment, does not require EUMETSAT or its funding nations to pay until the service is operational. The system is particularly appropriate for private finance because it is dependent on microsatellites and thus there are many companies, in Europe and elsewhere, able to carry out the project. It also degrades gracefully in the event of failure of one of the satellites.

It is also possible to extend the capability using the COMRING principle, which should offer data with a latency of seconds rather than up to 90 minutes that would result from using store-and-forward communications.

The analysis also points again to the vital role of ESA in conducting a technology programme for future missions, although there is no need for ESA to act in the role of procurement executive here because that role is effectively filled by EUMETSAT.

6 Private missions: space agency customers

6.1 Introduction

The PFI proposition is:

- ***A private investor would supply a mission-critical element of the infrastructure needed to support space agency missions. The supplier would have full design authority and would be paid for the service when used***.

The concept of private commercial suppliers of mission-critical services to space agencies is not new. In the late 1980s the UK finance community expressed interest in providing the Data Relay Satellite that would be needed to support the original Columbus concept for Europe's space station. The idea was that a private company would build and operate the data relay system and would charge ESA and national agencies for the service provided. This idea was extended to allow the operator to sell excess capacity to other users but died when DRS became Artemis and Columbus merged with the US initiative.

In the USA, TDRSS is ostensibly privately operated although this may be more of the nature of a lease than a true private finance model. Similarly, the contract for the operations of the Space Transportation System appears to be more like a procurement than a private supply contract, although it might be closer to PFI if there were a significant transfer of risk and authority to the supplier.

This section examines the possibility that several space agencies might contract with a private supplier for a crucial element of the infrastructure to support their missions. The example chosen is a data relay service for Mars probes, consisting of one or more spacecraft orbiting Mars to provide two way store-and-forward communications between landers and the Earth. This was studied by the Communication Standard Subgroup (COST) of the International Mars Exploration Working Group (IMEWG) and the model developed in section 6.3 is based on its report[11] and on the Phase A study of InterMarsNet[12]. Although many of the missions which the COST report considered are now committed to conventional, autonomous communications infrastructure, a Mars communication service (MCS) will still serve as an effective model to illustrate the benefits and disbenefits of this approach and to highlight changes that might be needed.

As with the other models considered in this report, it is reasonable to assume that there will be no private customers for the service within the foreseeable future. It is therefore another example of the third kind of PFI project, where all of the users are funded by government.

6.2 Management and procurement

The arguments given here are illustrated by the problems of a data relay service but similar problems might be expected to arise in any mission in which space agencies rely on a private supplier for a mission-critical element of infrastructure. The main issues are:

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[11] "Recommendations for the Mars Communication Infrastructures", IMEWG-COST Subgroup (Chairman Dr Simonetta Di Pippo), May 1996

[12] "InterMarsNet Report on the Phase A study", ESA Publication D/SCI(96)2, April 1996

- the need for commitment - the agencies will be reluctant to commit to an external service until they are sure that it will be available and the supplier will be reluctant to commit to implementing the service until it has sufficient customers

- the agencies will only get the full benefit of the external service once they depend totally on it and eliminate back-ups or alternatives from their missions

- specifications have to be agreed between the service provider and all of the users

- it is desirable to maintain competition between suppliers but the market is unlikely to be able to sustain more than one service

- the supplier may have to make a substantial investment in specifying and promoting the service before it is guaranteed customers.

The simplest procedure would be for the contributing agencies to issue an Invitation to Tender to supply the service. Competitive Phase B studies could be conducted, each leading to a fixed price quotation, and the best value for money selected. It is unlikely that this alone would result in the full potential benefits of PFI being achieved. The space agencies would rightly be unwilling to relax their control and intervention since, if the venture were to fail, they would still be left with the need to implement an alternative infrastructure. The supplier would therefore not be free to take his own decisions on trade-offs, for example between reliability and cost, and would need to document PA to satisfy the agencies, not just himself and his insurers.

It is argued that this problem will exist with any incremental change in the current practice. A radically different approach is needed, for example where the service is established and demonstrated before any agency has to commit the design of a mission to using it. The sequence that will be explored here is:

- a private supplier specifies the service that he will offer (in practice this would clearly be done in consultation with a group like COST)

- potential space agency users commit to purchase the service subject to satisfactory demonstration

- the supplier builds and deploys an operational system, together with appropriate hot and/or warm spares

- the space agency users enter into a contractual commitment to use the service and design future spacecraft on the assumption that the service will be available

- the agencies' spacecraft are built and deployed and the agencies pay for the service.

Interface standards might be simplified by the service provider selling to the users communications modules which they would incorporate in their landers. These could use an established interface (both electrical connection and software protocols) as seen by the user's on-board computer but would take care of all of the up-link and down-link protocols, encoding and error correction, and addressing and multiplexing. This would also offer a commercial opportunity to the supplier and would, because of the economy of scale of mass production, reduce costs to the users.

The issue of competition cannot be ignored since the supplier would have an effective monopoly. Even though the communications spacecraft might have a limited life and the contract for the service might be of limited duration, the supplier will be in a strong position as the “sitting tenant” which will make it difficult for another supplier to enter the market. The model mission outlined here, for example, shows that it takes around 5 years to establish a new service, which would give an unbeatable advantage to the sitting tenant.

One approach that has been employed with other de facto monopolies is to grant a finite franchise. At the end of the franchise, the ownership of the hardware reverts to the space agencies who may then conduct a competition for the right to take over the hardware and operate the service. It is still likely that the sitting tenant is in the best position to win such a competition but the threat should be enough to ensure a competitive price and quality of service. It would be reasonable for the agencies to make a lump sum payment to the supplier early in the programme or to pay a substantially higher fee for the service in exchange for this way of working.

6.3 Model mission

This model is based on the COST statement of requirements and the spacecraft design of InterMarsNet. It is the least well-developed of the model missions used in this report and therefore requires a greater number of assumptions and has the greatest uncertainties.

The MCS spacecraft is in a near-circular sun-synchronous orbit near the Martian terminator and is spin-stabilised with the spin axis pointing to Earth. A high gain antenna is aligned with the spin axis. Low gain UHF antennas communicate with the user terminals which are assumed to be located anywhere on the surface of Mars. A two way store and forward service is provided with each lander being accessed at least once every 13 hours and typically once every six hours. The data transfer capacity is over 100 Mbday^{-1}.

Spacecraft

The orbiter element of InterMarsNet was designed to provide a service of this type and provides a good model. It would have had a dry mass of ~ 550 kg (including 30 kg of science instruments and a 15% margin) and ~ 650 kg of fuel. Such a spacecraft is relatively simple because:

- the subsystems are those used in any store-and-forward communications satellite
- the thermal environment is simple because the satellite will not suffer eclipse
- no mechanisms are needed because the spacecraft remains nearly aligned with the Sun.

For this model it will be assumed that

- the launch mass of the MCS spacecraft will be no more than 750 kg (based on the InterMarsNet design but without the science instrument, allowing a simpler and lighter structure and a corresponding reduction in the mass of fuel)
- most of the sub-systems will use pre-existing designs
- several MCS spacecraft will need to be built

- the MCS spacecraft are simpler and therefore cheaper to build than geostationary communications satellites, and hence:

    - the first MCS spacecraft will cost $50M and will take 24 months to build

    - each further MCS spacecraft will cost $25M and be built in 12 months.

      Insurance costs (or acceptance of the risk of self-insurance) are assumed to be included in these figures). Note also that they exclude any profit, since this will be calculated for the service as a whole.

- the total life of each spacecraft will be 9 months cruise and commissioning in Mars orbit, up to 18 months non-operational life use as a hot standby and 18 months operational use

- the maximum life in Mars orbit is 36 months, so any standby time beyond 18 months will be taken off the operational period.

Launch

No detailed mission analysis has been attempted for this report. It is likely that a kick motor could be used to boost the spacecraft into cruise to Mars, so the launch vehicle would have to be capable of injecting the MCS spacecraft and its kick motor into a high Earth orbit, near the equatorial plane. The price quoted for two Cyclone launch vehicles and two Star 48 PKMs for Cluster 2 Option II was 32.6 MAU. It is not possible to use this price directly because there is no launch facility near the equator for Cyclone and, even if there were, it is not certain that it would have the necessary capacity. However, it provides a useful baseline for the likely cost of a commercial launch.

A price of $20M for each launch will be used in the model for MCS. This may be optimistic but reflects the discount that might be expected for a series of launches as envisaged for MCS.

Operations

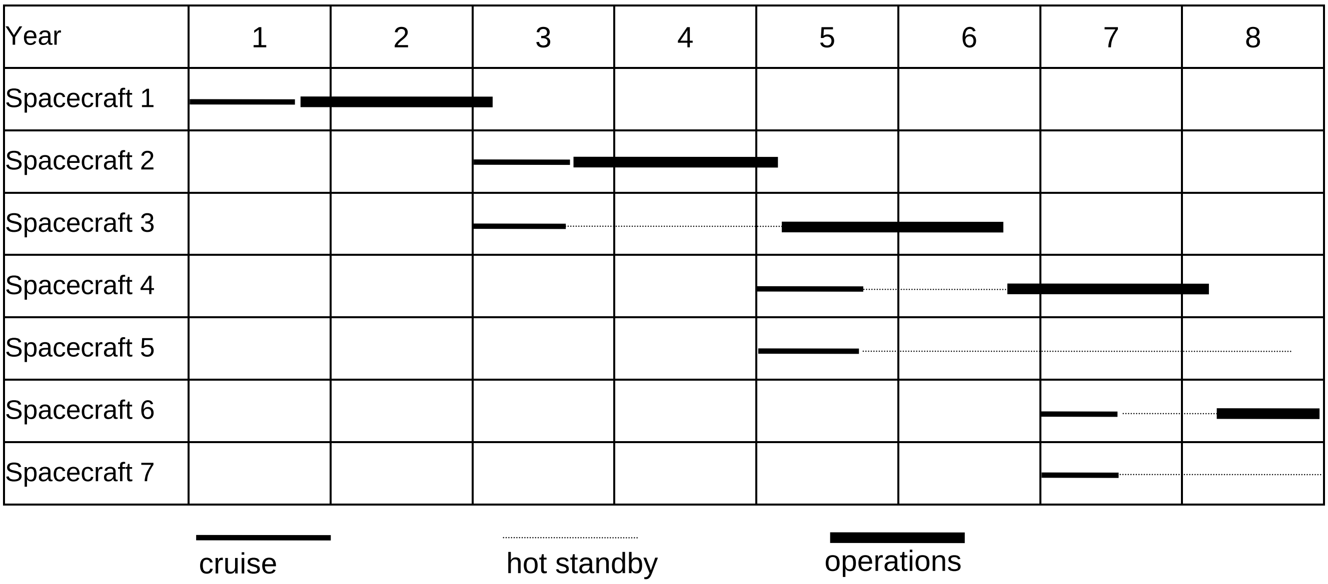
The commercial supplier is responsible for command and control of the spacecraft and for transfer of up-link commands to the landers. Data relayed by the spacecraft will be received directly by the user space agencies using DSN and the other conventional facilities. The supplier will maintain low bandwidth monitoring of the data stream. The total cost to the supplier of operations in the model is $2M per year.

This approach avoids unnecessary duplication of DSN. If however the agencies do not wish to use DSN for this task, or if they would incur considerable cost because DSN is needed for other tasks, the supplier could also establish a network of ground reception stations and deliver the data directly to the agencies. If this were to be chosen, both the costs and the benefits to the agencies would be increased.

Programme

Adequate reliability of service should be achieved by planning for a permanent standby spacecraft in Mars orbit. Opportunities for minimum energy transfers to Mars occur approximately once every two years (for simplicity this has been taken to be exactly two years).

The first 8 years of a possible programme is shown in the following diagram. The programme continues by repeating two launches every two years.



Key points about this programme are:

- the service will be demonstrated one year after the first launch
- a full service, with hot standby, is available within 3 years of the first launch, other than a period of 6 months during year 5 when there is no standby
- on some occasions there are two standby spacecraft available because of the requirement to launch only when minimum energy transfers are available.

This programme will be used to illustrate the economics of the service. However, it is likely that a more efficient programme could be devised by changing the exact times of launch at the cost of greater ΔV or longer cruise time. This would probably allow the gap in year 5 to be covered and would eliminate the periods when there are two standbys. It seems reasonable to assume that the latter savings would balance the greater cost of these sub-optimal launches.

6.4 Financial model

The financial model is based on the following:

- three space agencies (NASA, ISAS, ESA?) each make a grant of $25M to the supplier after the first spacecraft has been demonstrated in Mars orbit - this approximately covers the cost of that demonstration. Any landers deployed over the next year by those agencies would be provided with a free service.
- 5 missions will be committed to use the service, the first starting 3 years after the successful demonstration, two more starting 4 years after the successful demonstration and the other two starting 5 years after the successful demonstration
- each pre-committed mission will, on average, deploy 3 landers which will have a life of three years and will pay a fee of $3M per lander per year for the service

- 1 additional similar mission will sign up for the service every year, starting 5 years after the successful demonstration and will pay a fee of $8M per lander per year

- the service will lose its monopoly and any spacecraft still in operation will revert to the three space agencies 10 years after the successful demonstration

- the service provider will sell at cost communications modules for inclusion in the landers so these will make no contribution to profits.

These assumptions are built into the spreadsheet in the Annex to this report. As before, it is assumed that part of the cost is met from a loan and the balance from equity investments. They lead to an IRR for the investor of 21%.

That rate of return assumes that the service will continue without interruption. The supplier has continued to replace the ageing spacecraft and, at the end of the 10 year contract, hands over to the agencies two newly deployed spacecraft with at least 2 years operational life. The supplier could satisfy his contract without building and launching those two spacecraft and, as a consequence, could save an expenditure of $90M. In practise this would lead to an undesirable loss of continuity which can be avoided by the agencies holding the competition to continue the service at least 2 years before the end of the contract.

6.5 Cost-effectiveness

Does the proposed service represent a cost-effective alternative to autonomous landers with direct communications or to orbital communication satellites dedicated to a single mission (as in InterMarsNet)?

Consider as a model Mars Pathfinder. This represents one of the newer style of planetary missions, using many of the “small satellite” principles of engineering and management. Assume that the mission could be extended to achieve an operational life of 3 years. The total cost of the mission, including launch and operations, is around $300M. It has both a stationary lander and a rover. Eliminating the need to provide a communications link to Earth would save mass and hence allow more instruments to be carried, or possibly even allow a second rover to be accommodated within the mass budget. Alternatively, the cost might be reduced by eliminating the cost of the communications hardware and operations might be easier because there are more frequent opportunities to send commands and receive data.

If the communications hardware represents 20% of the mass landed on Mars, excluding the bus, air bags and other structure, MCS might allow an increase in the useful payload of 25% which, if the mission as planned can justify a cost of $300M, represents an increase in value of $75M.

Alternatively, the cost of the mission might be reduced by perhaps $30M. The charge for using MCS used in the financial model above was $3M per year per lander assuming a 3 year mission, giving a total cost of $18M to support the rover and stationery lander.

Is this cost-effective? The argument against it is that the target price can only be achieved if there are many other missions using the service. The arguments for it are that:

- MCS would offer a well-tried and reliable service with a hot standby

- the landers would be simpler and make use of a standard commercial sub-system for communications, allowing shorter development time and closer alignment with the management philosophy advocated for Mars Pathfinder and other missions.

6.6 Conclusions

The Mars Communication Service represents a radical change in the way in which space agencies might work. It requires them to rely on a mission-critical service which is designed, built and operated by a private supplier.

The simple financial model developed here leads to the conclusion that the system is possibly viable provided that there is a large number of Mars missions using it, for example if there were a systematic campaign to instrument the surface of Mars to understand its climate and geology.

The greatest benefit of such a service might arise not from its direct impact on cost but from lowering the technological and organisational threshold for planetary exploration. Many of the nations which at present could not sustain a Mars lander mission, and many organisations within those that can, might find that the availability of reliable infrastructure makes a significant difference to the barrier to participation.

Even if the conclusion is that a Mars Communication Service would only be of marginal value given the likely level of demand, the model mission shows a way of working in which the space agencies could collectively act as customers for a mission-critical element of their activities.

7 Institutional implications

7.1 Introduction

The primary purpose of this report was not to identify candidate missions for private finance but to use model missions to identify possible benefits of private finance and the difficulties which might be encountered if private finance were to be introduced to public space missions.

The three model missions all indicate that there might be significant benefits in terms of cost and quality of service. An indirect but possibly greater benefit from the point of view of the space industry and the users of space services would be that the expenditure would be more robust against criticism. Some departments of government view space budgets as a subsidy to industry - an increasingly unpopular concept. Purchasing space services from competitive suppliers would remove that objection.

It is apparent that the present institutional structure could not manage private supply of public space missions. This section brings together the issues that have arisen from the analysis of model missions and offers some tentative solutions.

7.2 Industry

The least difficult area is the space industry. Successful space companies would welcome the chance to extend the range of their commercial activities, since private finance missions would allow greater profits and more efficient operations. Similar support has been indicated by the finance and insurance sectors that would have to take part. Both are keen to expand their range of operations and there are new companies entering the market who are hungry to do business.

There is a danger that private missions would squeeze out smaller companies, because the large companies have the financial strength to make long term investments and commitments. This may be balanced by the enthusiastic involvement of financiers who will be seeking the kind of entrepreneurial firms which are sufficiently flexible and responsive to take advantage of new commercial opportunities.

A consequence of privately financed missions will be greater polarisation of the market, whereby the good companies will do well and the poor ones will suffer.

7.3 ESA

An implicit assumption of this report is that the countries of Europe will wish to continue to undertake public space missions collaboratively. Furthermore, it is reasonable to assume that it is much easier for ESA to evolve into the sort of organisation that Europe needs than for it to be replaced by a new organisation. Given that, the model missions explored here highlight two critical potential roles for ESA:

- as a procurement executive
- managing a technology programme.

The term “procurement executive” may be misunderstood. The Ministry of Defence Procurement Executive in the UK has demonstrated the breadth and challenge of the role. In particular, the business of setting demanding specifications, conducting fair and open competitive procurements and ensuring that the contractors satisfy their contracts is a highly demanding technical task which, in MoD's case, is attracting some of the brightest young engineers away from industry and into PE. The core of the technical task is the reality that it is not possible to specify exactly what is to be procured. New technology can emerge in the course of a development programme or the requirements of the user can change after the contract is let. Managing the programme under these circumstances requires a fine balance to avoid either of two disasters:

- persisting with a specification which will not be useful when the system is delivered
- "moving the goal posts" so that the programme spirals out of cost and time budgets.

It is suggested that ESA is the only organisation in Europe which has the expertise and credibility to achieve this for technologically challenging missions that are funded by many nations and for which the users are in many nations.

Each of the model missions was based on the assumption that there was no uncertainty in the technology. It was argued that the investor will take the technical risks that the supplier builds the spacecraft correctly but will not also take the technological risks that the technology will not be available. This was summed up in a recent conference presentation from a space insurer[13] who stated that "Insurers will not pay for R&D" and that "Insurers will insure proven technology..". The ideal situation is where the technology needed for a mission is all available and proven at the start. This allows a short and reliable development programme and minimises the likelihood of the procurement problems described above.

Managing a technology programme requires anticipation of future needs and ensuring that these, and not individual company interests, determine the technology programme. There is always a danger that a pure technology programme can become detached from reality.

As with the procurement role, it is suggested that ESA is the only organisation in Europe which has the potential capability to manage a suitable technology programme, although of course much (if not all) of the actual development would be conducted in the space industry.

ESA grew up in a time when the European space capability was immature and it was necessary to help and guide industry. It is clear from the commercial success in both spacecraft and launch that the industry is now mature and capable. This allows ESA to move to a new and, in many ways, more challenging role of exploiting that capability on behalf of Europe.

7.4 National space agencies

National space agencies have a crucial role as champions of a more commercial approach to government-funded missions. They occupy the middle ground between governments, users, ESA and industry, and their active support will be needed to bring about change. The recent collaboration between BNSC and DARA in proposing Cluster II Option II shows that space agencies can promote radical alternatives to orthodox missions.

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[13] M A Quinn, "Satellite constellations and risk management", presentation by Willis Carroon Inspace, AIC Space and Satellite Finance Conference, London, January 1997

The national agencies are needed to:

- identify national political interests and funding priorities
- help users to become responsible and demanding customers
- encourage ESA to recognise and grasp a new role as a procurement executive, responding to the needs of the users
- promote public space missions as good candidates for private investment to the space, finance and insurance industries.

It is unrealistic to pretend that there are not industrial policy objectives in missions for government-funded users which can distort the procurement process. However, a process based on openness, and competitive commercial procurement of services rather than spacecraft, will make explicit the costs of those objectives. It was suggested in section 4.2 (science customers) that there should be a shift in the objectives of industrial policy from subsidising mediocre space companies to purchasing from excellent ones. The recent changes in ESA procedures[14], promoted by 13 of the Member States, indicate a willingness to make such a shift.

7.5 Scientists and other public sector users

The private finance model puts considerable demands on the users. At present they behave as “grateful supplicants”, without the authority to determine what should happen and hence without the mechanisms to behave responsibly. The private approach requires the users to make trade-offs between price and quality, rather than simply to demand the best. In system engineering terms, they need to define a “Figure of merit” for their missions, which allows the value of competing solutions to be compared.

It is implicit that publicly funded users will have to present their case for funds in terms of output measures of success rather than input measures. The present position allows programmes to be delayed at no cost because no value is attributed to the service. Output measures have to be agreed with the funding parts of government, considered in section 7.6.

The position is complicated in the case of space science, where the same organisations and people have the expertise in instrumentation and are the customers for the data that they will produce. The scientists will have to recognise these separate roles and set up procedures to accommodate them. In particular, it is suggested that they will have to carry out instrument development as part of the supplier’s team whilst remaining customers for the eventual service.

EUMETSAT might provide a model for the way in which publicly funded users could organise their affairs. It has a clear role as the procurement executive for meteorological missions and, if the arguments as to ESA’s future role are accepted, would need to liaise with ESA to ensure that meteorological interests were represented in the technology programme. There is no reason why EUMETSAT could not offer its services as a procurement executive to non-member countries.

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[14] see for example “ESA adopts new, flexible guidelines for contractors”, Space News, March 10-16 1997, p 1

7.6 Government

Government is the source of funds for publicly funded users. In the UK this is the responsibility of Treasury, although finance for space missions is also controlled by DTI and OST. Treasury has for several years actively pursued a policy of private finance, and consequently less intervention in the management of funds by departments, and the effects are now being seen in many areas of public expenditure, including transport, health and administration. The limitation on the extent of private finance is that advance commitments should not so predetermine the future behaviour of a department that it is unable to respond to new political requirements - a process known as “silting up”.

Coupled with this has been the use of output measures of performance, leaving to the departmental management the decisions as to how to achieve the output. This is close to recognising that government expenditure may be treated as investment, not just spending, and hence the results appear as assets on a “balance sheet”, not merely debits in the annual budget. This is formalised in the process of resource accounting.

The way in which publicly funded users obtain space services is an anomaly, and is seen as such by some in government. There is little enthusiasm for expenditure to support or even establish a new industry or to subsidise the development of new technology. It is however accepted politically that science as an intellectual discipline is worth investment and may lead to industrial capability, either via products and technologies or more probably by generating skilled people for industry. The case for public investment in meteorology is more direct, since the benefits can be expressed in economic terms but the market does not exist for a purely private sector activity.

It would appear that Treasury would strongly support public users of space obtaining services by PFI, and it would be easier for users to rationalise their funding if they could be seen to be purchasing products or services on behalf of citizens, rather than spending taxpayers’ money to subsidise industry.

The term “output measures” reflects the objective that Treasury would set the users. It may be translated directly into the kinds of goal or Figure of Merit that are necessary to attribute realistic value to reliability, insurance and timeliness. It means that the science that is derived from a space mission is seen as being worth a certain sum of money, rather than deciding how much money can be afforded for science.

8 Conclusions

8.1 Feasibility of private missions

This report has explored the concept of private finance being used to fund space missions which are designed to serve publicly funded users such as scientists, meteorologists and space agencies. A model mission in each case has been used to explore the financial and institutional consequences in practice. Some general observations are:

- the cost models are probably robust (at least in the science and meteorological cases where good cost data was available). There are significant savings to be made by allowing contractors the freedom to take rational purchasing and design decisions and by making them truly responsible as prime contractors for PA and quality. This was illustrated for example by studies commissioned by ESA[15] and many internal studies carried out by space companies.

- it is possible to devise procurement mechanisms which give an appropriate distribution of responsibilities between the customer and supplier for private missions. It is however clear that these require significant changes in the existing institutional structures, or at least in the roles played by those institutions.

- rational decisions depend on attributing realistic value to the service provided to government-funded users of space missions. This is essential if reliability, insurance and timeliness are to be correctly valued. In effect, it is necessary to stop treating publicly funded users of space as “second-class” and to give them the quality of service that would be afforded to a commercial user. The other side of this is that publicy funded users have to behave as responsible customers.

The purpose of the report was to explore the institutional changes that might be needed to allow private finance to be exploited. These indicate a new and, it is suggested, more stable and defensible, role for ESA. They also point towards an evolutionary strategy for EUMETSAT and towards a new attitude to be taken by scientists. The users have to undergo a considerable change in culture in order to be able to agree rational output measures of success and use those measures to guide difficult choices between competing options.

Although the three model missions are based on many estimates and assumptions, the overall conclusion is that privately funded space missions appear to be feasible for publicly funded customers and that they would be more cost-effective than the current procedure in which space agencies act as prime contractors. Informal discussions with users, Industry (space, finance and insurance), space agency and Treasury representatives have all indicated support for this approach.

8.2 Possible way ahead

This report has argued that there is an opportunity to develop new ways of procuring space capability which will lead to reduced costs, better services and more competitive industry. It brings a positive and crucial role for ESA and is consistent with the growing support for transferring responsibility for supplying public services to the private sector. US companies have

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[15] “Scrutiny of potential cost drivers in scientific projects” - three parallel ESA studies reported in 1996, led by Satellites International, CRI and Smith System Engineering

already proposed private missions in at least one of the cases studied here (meteorological missions) and, if they were to start offering much lower prices, might threaten European suppliers.

The analysis and models used here have been based on many assumptions and approximations. It is argued that the cost assumptions are the most robust of these and that the institutional assumptions need to be explored in greater detail. Firm commitments are needed from those who have already expressed general support and interest. Some questions that need to be considered are:

- are the users willing to act as responsible customers? if so, what institutional mechanisms can they devise? can they agree on output measures of success which allow rational trade-offs between cost, performance and timescales?

- are national space agencies willing to make their industrial policy objectives explicit and to show their impact on costs?

- can ESA grasp a new role as a procurement executive and the manager of a European technology programme?

- will the finance community invest in these missions? at what charge, with what pre-conditions?

- what risks will the insurance industry bear? at what premium?

- what will the effect of private supply be on mission timescales?

- is government willing to recognise the value of reliability, insurance and timeliness to the users that they support? if so, what are they worth?

It is recommended that one of the model missions used in this report is made the subject of a feasibility study in which each of the points listed above should be explored with the space, finance and insurance industries, users, national space agencies, ESA and Treasury.

Annex Cost and benefit models

A.1 Introduction

Each of the missions has been modelled using a spreadsheet to calculate discounted costs. Discounted benefits may be found by a trivial calculation so no spreadsheet is needed.

The cost model for Cluster includes specific consideration of the effect of a launch failure and the cost of two parallel Phase B studies, and a parallel calculation is made of the likely cost of an equivalent conventional mission run by ESA. The financial models of all three missions include realistic assumptions for the way in which funds are raised and repaid and include an allowance for insurance premium where the accuracy of the estimates justifies this.

The spreadsheets are reproduced at the end of this Annex.

A.2 Assumptions and approximations

Calculation of costs

The main assumptions are:

- the cost of each Phase is incurred uniformly throughout the Phase, other than launch which occurs at the start of the relevant Phase

- the costs to the funding agency of a private mission are incurred only when fees are charged for the delivery of data or other service

- the private mission receives 70% of its funding from loan and 30% from equity and money is drawn down in that ratio from each source as needed

- the loan is repaid in full before any dividends are paid to the equity investor

- the insurance premium is paid at the time of launch

- no allowance is made in the private costings for the possibility that the tax treatment of the project may change after the price is agreed.

Key approximations are:

- time is considered in three month or annual increments

- interest on the loan is calculated on the balance in the previous increment and added to the loan, together with any loan drawn down in the present increment and any fees earned

- the IRR is calculated by treating equity in a similar way to the loan but using an effective interest rate which sets the balance of the equity to zero at the end of the mission.

For Cluster only, additional assumptions and calculations are needed to model the agency mission and the case of a private mission in which the first launch fails:

- for an agency mission, all of the cost of Phase B is paid by the agency

- the costs to the funding agency of an agency mission are incurred when they occur

- management costs (and contributions to Phase B) incurred by the funding agency in either the agency or private missions are assumed to be incurred at the start of the project

- separate spreadsheets are used to calculate the cost to Government for either type of mission and the IRR for the supplier in a private mission. A second version of the private mission spreadsheet is used to repeat the calculation in the event of launch failure followed by an insurance claim.

- in the event of a mission failure, Phase C/D is effectively extended by the time taken to rebuild the spacecraft and repeat the launch campaign. A lump sum payment is made by the insurance company at the start of the rebuild. No explicit payment is made for the cost of a second launch as this is assumed to be provided by the launch contractor.

Calculation of benefits

This only applies to the Cluster model mission where it is possible to compare private and agency versions of the same mission.

The benefits of any mission to support publicly funded users are indirect and cannot easily be expressed in money terms. However, this is not necessary for comparisons of cost-effectiveness. If it is assumed that the benefit of the mission would be 1.00 if the data stream were to commence immediately, it is possible to calculate the relative effectiveness of the mission when subject to delay and risk of failure. This defines a quantitative scale as introduced in section 3.2.

The delay will be taken from the start of Phase B, since this is effectively the time at which the mission is initiated. The discount rate of 15% per year given in section 3.5 will be used.

The risk if failure was assumed in section 3.3 to be 10%. This risk is not insured in an agency mission so the benefit is effectively reduced by this factor.

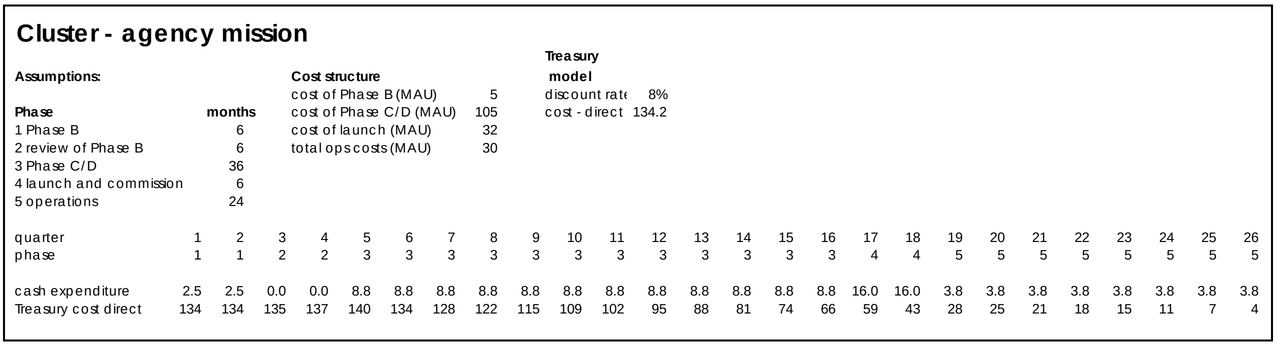
The agency mission requires 54 months from start of Phase B to start of data service. The benefit of the agency mission, B, is therefore given by:

$$B = 1.00 \exp(-0.15 \times 54/12) \times 0.90 = 0.458$$

The benefits of a private mission would be calculated in a similar way. If the first launch is successful, the mission is operational after 42 months and the benefit is 0.592. If the first launch fails and a second launch is needed, the mission is operational after 66 months and the benefit is 0.438. The average or expectation value of the benefit of a private mission is the weighted average of these (weighted by the probability of a successful launch) which gives a benefit of 0.577.

These benefits are normalised so that the agency mission has a benefit to users of 1.00 for the table of costs and benefits in section 4.5.

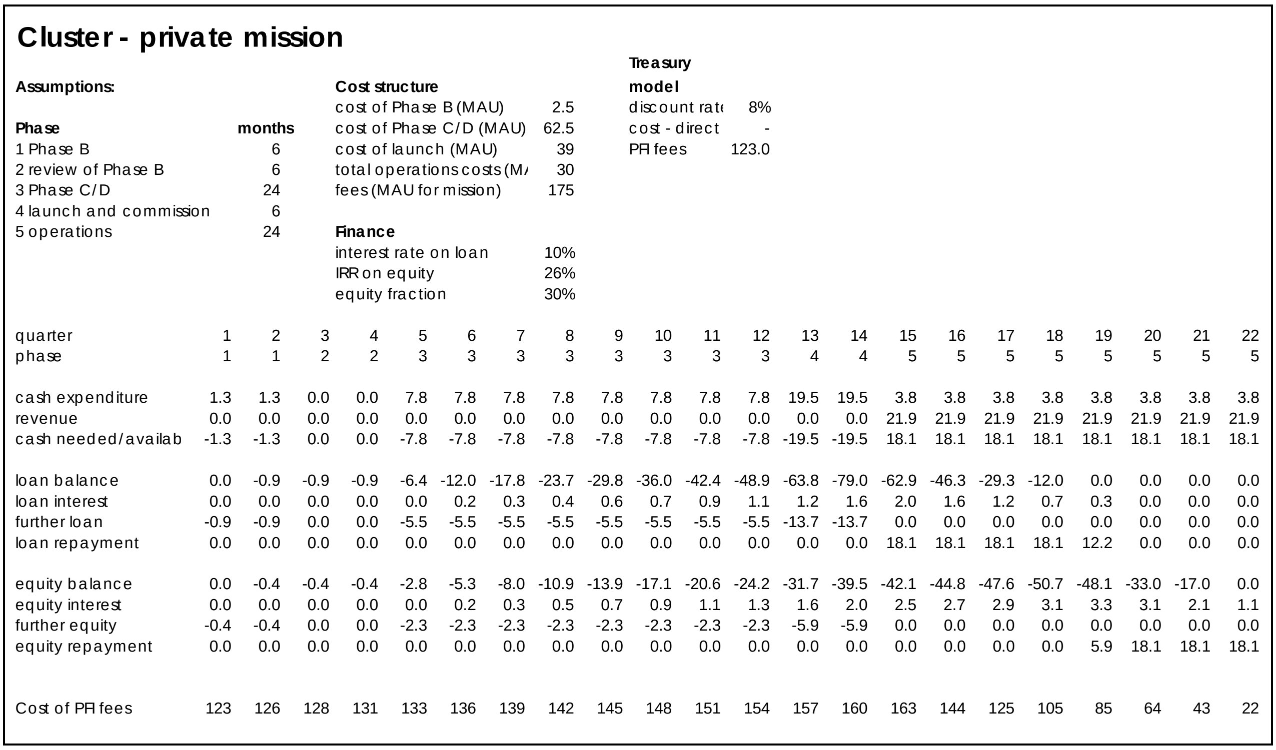
A.3 Spreadsheets



Cluster - agency mission

Assumptions:		Cost structure		Treasury model	
		cost of Phase B (MAU)	5	discount rat	8%
Phase	**months**	cost of Phase C/D (MAU)	105	cost - direct	134.2
1 Phase B	6	cost of launch (MAU)	32		
2 review of Phase B	6	total ops costs (MAU)	30		
3 Phase C/D	36				
4 launch and commission	6				
5 operations	24				

quarter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
phase	1	1	2	2	3	3	3	3	3	3	3	3	3	3	3	3	4	4	5	5	5	5	5	5	5	5
cash expenditure	2.5	2.5	0.0	0.0	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	16.0	16.0	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
Treasury cost direct	134	134	135	137	140	134	128	122	115	109	102	95	88	81	74	66	59	43	28	25	21	18	15	11	7	4



Cluster - private mission

Assumptions:		Cost structure		Treasury model	
		cost of Phase B (MAU)	2.5	discount rat	8%
Phase	**months**	cost of Phase C/D (MAU)	62.5	cost - direct	-
1 Phase B	6	cost of launch (MAU)	39	PFI fees	123.0
2 review of Phase B	6	total operations costs (M	30		
3 Phase C/D	24	fees (MAU for mission)	175		
4 launch and commission	6				
5 operations	24	**Finance**			
		interest rate on loan	10%		
		IRR on equity	26%		
		equity fraction	30%		

quarter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
phase	1	1	2	2	3	3	3	3	3	3	3	3	4	4	5	5	5	5	5	5	5	5
cash expenditure	1.3	1.3	0.0	0.0	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	19.5	19.5	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
revenue	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9
cash needed/availab	-1.3	-1.3	0.0	0.0	-7.8	-7.8	-7.8	-7.8	-7.8	-7.8	-7.8	-7.8	-19.5	-19.5	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
loan balance	0.0	-0.9	-0.9	-0.9	-6.4	-12.0	-17.8	-23.7	-29.8	-36.0	-42.4	-48.9	-63.8	-79.0	-62.9	-46.3	-29.3	-12.0	0.0	0.0	0.0	0.0
loan interest	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.4	0.6	0.7	0.9	1.1	1.2	1.6	2.0	1.6	1.2	0.7	0.3	0.0	0.0	0.0
further loan	-0.9	-0.9	0.0	0.0	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5	-13.7	-13.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
loan repayment	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.1	18.1	18.1	18.1	12.2	0.0	0.0	0.0
equity balance	0.0	-0.4	-0.4	-0.4	-2.8	-5.3	-8.0	-10.9	-13.9	-17.1	-20.6	-24.2	-31.7	-39.5	-42.1	-44.8	-47.6	-50.7	-48.1	-33.0	-17.0	0.0
equity interest	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.5	0.7	0.9	1.1	1.3	1.6	2.0	2.5	2.7	2.9	3.1	3.3	3.1	2.1	1.1
further equity	-0.4	-0.4	0.0	0.0	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-5.9	-5.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
equity repayment	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.9	18.1	18.1	18.1
Cost of PFI fees	123	126	128	131	133	136	139	142	145	148	151	154	157	160	163	144	125	105	85	64	43	22

Cluster - launch failure

				Treasury model	
Assumptions:		**Cost structure**			
		total cost of Phase B (M	2.5	discount ra	8%
Phase	**months**	cost of Phase C/D (MA	62.5	PFI fees	105
1 Phase B	6	cost of launch (MAU)	39		
2 review of Phase B	6	total ops cost (MAU)	30		
3 Phase C/D	24	fees (MAU for mission)	175	**Launch failure**	
4 launch and commission	6			delay mths	18
5 operations	24	**Costs of finance**			
		interest rate on loan	10%		
		IRR on equity	8.0%		
		equity fraction	30%		

quarter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
phase	1	1	2	2	3	3	3	3	3	3	3	3	4	4	0	0	0	0	0	0	0	0	5	5	5	5	5	5	5	5
cash expenditure	1.3	1.3	0.0	0.0	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	19.5	19.5	-39.1	7.8	7.8	7.8	7.8	7.8	0.0	0.0	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
revenue	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.9	21.9	21.9	21.9	21.9	21.9	21.9	21.9
cash needed/available	-1.3	-1.3	0.0	0.0	-7.8	-7.8	-7.8	-7.8	-7.8	-7.8	-7.8	-7.8	-19.5	-19.5	39.1	-7.8	-7.8	-7.8	-7.8	-7.8	0.0	0.0	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
loan balance	0.0	-0.9	-0.9	-0.9	-6.4	-12.0	-17.8	-23.7	-29.8	-36.0	-42.4	-48.9	-63.8	-79.0	-41.9	-48.4	-55.1	-62.0	-69.0	-76.2	-78.1	-80.0	-63.9	-47.4	-30.4	-13.1	0.0	0.0	0.0	0.0
loan interest	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.4	0.6	0.7	0.9	1.1	1.2	1.6	2.0	1.0	1.2	1.4	1.5	1.7	1.9	2.0	2.0	1.6	1.2	0.8	0.3	0.0	0.0	0.0
further loan	-0.9	-0.9	0.0	0.0	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5	-5.5	-13.7	-13.7	0.0	-5.5	-5.5	-5.5	-5.5	-5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
loan repayment	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	39.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.1	18.1	18.1	18.1	13.4	0.0	0.0	0.0
equity balance	0.0	-0.4	-0.4	-0.4	-2.7	-5.1	-7.6	-10.1	-12.6	-15.2	-17.9	-20.6	-26.8	-33.2	-33.9	-36.9	-40.0	-43.1	-46.3	-49.6	-50.6	-51.6	-52.6	-53.7	-54.8	-55.9	-52.3	-35.2	-17.8	0.0
equity interest	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.7	0.7	0.7	0.8	0.9	0.9	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.0	0.7	0.4
further equity	-0.4	-0.4	0.0	0.0	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-2.3	-5.9	-5.9	0.0	-2.3	-2.3	-2.3	-2.3	-2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
equity repayment	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.7	18.1	18.1	18.1
Cost of PFI fees	105	107	109	111	113	116	118	121	123	126	128	131	133	136	139	142	145	148	151	154	157	160	163	144	125	105	85	64	43	22

Atmospheric sounder

Cost of receivers ($M	2.3		months		
Cost of microsats ($M	6.9	Phase	6	**Finance**	
Cost of infrastructure	7	Ph C/D	18	interest rate on loan	10%
Cost of ops ($M per	1.5	Comm	6	IRR on equity	31%
Cost of launches ($M	30	Ops	60	equity fraction	30%
Cost of phase B	0.5				
Fees ($M per year)	20				

Quarter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Phase	B	B	C/D	C/D	C/D	C/D	C/D	C/D	Comm	Comm	ops	ops	ops	ops	ops	ops	ops	ops	ops	ops	ops	ops	ops	ops	ops	ops	ops	ops	ops	ops
Expenditure	0.25	0.25	2.7	2.7	2.7	2.7	2.7	32.7	0.375	0.375	0.375	0.375	0.375	0.375	0.375	0.375	0.375	0.375	0.375	0.375	0.375	0.375	0.375	0.375	0.375	0.375	0.375	0.375	0.375	0.375
Income	0	0	0	0	0	0	0	0	0	0	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
net income	-0.25	-0.25	-2.7	-2.7	-2.7	-2.7	-2.7	-32.7	-0.38	-0.38	4.625	4.625	4.625	4.625	4.625	4.625	4.625	4.625	4.625	4.625	4.625	4.625	4.625	4.625	4.625	4.625	4.625	4.625	4.625	4.625
loan balance	0.0	-0.2	-2.1	-4.0	-6.0	-8.0	-10.1	-33.3	-34.4	-35.5	-31.8	-27.9	-24.0	-20.0	-15.8	-11.6	-7.3	-2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
loan interest	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.8	0.9	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
further loan	-0.2	-0.2	-1.9	-1.9	-1.9	-1.9	-1.9	-22.9	-0.3	-0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
loan repaymer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
equity balance	0.0	-0.1	-0.9	-1.8	-2.7	-3.7	-4.8	-15.0	-16.3	-17.7	-19.1	-20.6	-22.2	-24.0	-25.9	-27.9	-30.1	-32.4	-33.3	-31.2	-29.1	-26.7	-24.2	-21.5	-18.5	-15.4	-12.0	-8.3	-4.3	0.0
equity interest	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.4	1.2	1.3	1.4	1.5	1.6	1.7	1.9	2.0	2.2	2.4	2.5	2.6	2.5	2.3	2.1	1.9	1.7	1.5	1.2	0.9	0.6	0.3
further equity	-0.1	-0.1	-0.8	-0.8	-0.8	-0.8	-0.8	-9.8	-0.1	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
equity repaym	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6

Mars Communication Service

Assumptions:	Cost of first spacecraft ($M)	50	**Finance**	
	Cost of subs. spacecraft ($M)	25	interest rate on loa	10%
	Cost of ops ($M per year)	2	IRR on equity	21%
	Cost of launch ($M)	20	equity fraction	30%
	Grant by each agency ($M)	25		
	Fee - orig ($M per year)	9		
	Fee - later ($M per year)	24		

Year	1	2	3	4	5	6	7	8	9	10	11	12	13
Expenditure	25	45	2	92	2	92	2	92	2	92	2	92	2
Income			75			9	27	69	90	72	72	72	72
net income	-25	-45	73	-92	-2	-83	25	-23	88	-20	70	-20	70
loan balance	0.0	-33.3	0.0	-64.4	-72.2	-130.5	-111.3	-127.4	-41.0	-55.0	0.0	-14.0	0.0
loan interest	0.0	1.8	3.2	0.0	6.4	0.1	5.8	0.0	1.6	0.0	1.4	0.0	1.4
further loan	-17.5	-31.5	0.0	-64.4	-1.4	-58.1	0.0	-16.1	0.0	-14.0	0.0	-14.0	0.0
loan repayment	0.0	0.0	36.4	0.0	0.0	0.0	25.0	0.0	88.0	0.0	56.4	0.0	15.4
equity balance	0.0	-15.1	18.7	-8.9	-15.2	-40.2	-45.4	-52.3	-53.7	-59.7	-47.4	-53.4	0.0
equity interest	0.0	1.6	2.8	0.0	5.7	0.1	5.2	0.0	1.4	0.0	1.2	0.0	1.2
further equity	-7.5	-13.5	0.0	-27.6	-0.6	-24.9	0.0	-6.9	0.0	-6.0	0.0	-6.0	0.0
equity repaymen	0.0	0.0	36.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.6	0.0	54.6