The Microsat Way in Canada

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Abstract

According to a recent survey, over fourteen microsatellites have been launched per year on average in the last twelve years. These satellites are frequently built, launched and operated by university and amateur teams.

Increasingly, however, small- and microsatellites are being used to fulfill commercial, military, remote sensing, and science missions as well. In the future, the use of microsatellites to achieve high-value missions at lower cost will become mainstream, and will occupy an increasing portion of the spacecraft applications market. The paper supports these conclusions by first examining the potential of microsatellites to reduce entry barriers to new space utilization, and their impact in changing the economics of space applications.

An analysis of what makes traditional space programs expensive is undertaken, with a discussion of the upward cost spiral and how space programs can become trapped by it. Various ideas are put forward to energize a discussion on how things could be done better.

The paper then discusses the economic drivers underlying microsatellites. It discusses why launch cost is a prime mover of spacecraft complexity and how this effect works in reverse for micro- and nano-satellites. It presents the impact of digital electronics in enabling microsatellite missions, and how a microsatellite program can take advantage of the rapid evolution of technology. Finally, it looks at the distribution of risk and return, and presents a proposal for a program blueprint to achieve successful, high-value missions at lower overall cost and lower risk.

Introduction

This paper sets out thoughts on the relevance of microsatellites to Canada's future activities in space. It begins with a discussion of the microsatellite phenomenon, moves to an analysis of space mission cost drivers and concludes by laying out a "microsat way" that could lead to the creation of more advanced and yet less expensive Canadian space missions.

The key motivator in doing things differently is the inevitable advance of silicon based electronics. Where 15 years ago, little practical science or engineering could be done with a small payload that is not the case today. Moore's Law has given us electronics circuits with 1,000 time more processing power per dollar, enabling missions such as MOST to be done in a small form factor at a low overall cost. According the SSTL's compendium of small and microsatellite launches, an average of 14 microsatellites have been launched in each of the past 12 years. (1)

The "microsat way" as promoted in this paper, is to design space missions and an overall corporate program that maximises our ability to offer the most advanced microsatellite equipment offerings at the lowest cost.

The best way to achieve this in the long term is to use multiple, independently launched spacecraft, each using the latest available technology to simplify its design and maximise its utility, and each of which demonstrates the next generation of technology. In this way, practical experienced gained through in-space lessons can be folded back into a (very rapid) design process that allows the maximum benefit to be provided to the end user at least cost.

The Past

The history of microsatellite development has not been written, though one hopes that as the group of people who pioneered this way of building spacecraft gets older, their impulses may lead them to record their experiences and recount to a more general audience what happened and when. It would be unfortunate to lose a piece of the history of technology that serves as an important illustration and worked example of Kuhn's paradigm shift hypothesis.

To say that microsatellites were initially, and to some extent still, built by amateurs is to imply that microsatellites can be built by anyone and don't require an experienced technical team. This is far from the truth. More accurately, microsatellites were initially built by teams including experienced spacecraft builders who were disillusioned with the way of building spacecraft as practised by the NASA and military rule books over the decades.

Rather than follow the methods of the earlier days of exploration, when there was no such thing as an approved parts list, NASA and others wrote weighty and significant books of rules that captured the lessons of the past.

The AMSAT pioneers saw the upward cost spiral that this approach inevitably engendered, and were frustrated by the slowness with which such this standard approach took up new technology.

By successfully building, launching and operating amateur packet radio satellite repeaters and store and forward communications satellites, they demonstrated that more could be done with less.

From this early legacy come the sometimes contradictory characteristics of early microsatellites:

- they are built by amateurs and student teams
- they are built by experts in their spare time
- they are small, so that they can be launched cheaply as secondary payloads
- they are not mass efficient
- they are made with donated spare parts, Radio Shack parts, and equipment made in the basements of hobbyists
- they are in many ways technically sophisticated and have pioneered new approaches to radio communications
- they have poor attitude control
- they sometimes fail to operate to their full design requirements
- they last on the order of 4 - 6 years in low earth orbit, with some living considerably longer

A microsatellite project can be defined as some alchemical combination of small size, low cost, and perhaps also a high technical innovation quotient. The down-side, from the point of view of more traditional approaches to building satellites, is that there is a lot less paperwork and documentation generated, risks are taken (and managed) rather than avoided, and real design authority is passed to those in the best position to exercise it.

As a welcome side-effect, microsatellite pioneers opened the door to the use of digital architectures and software on spacecraft long before such technologies were acceptable to mainstream spacecraft programs. By making it possible for a spacecraft to carry out more of its functions through software, they also made it possible for people who were not traditionally spacecraft engineers to contribute successfully to the construction and operation of spacecraft.

Microsatellite projects have demonstrated a much better ability than other space endeavours to stay glued to the technology curve. As a result, the relatively modest mass and power available on a microsatellite now make it possible to achieve science, governmental, and commercial missions previously only possible with larger and much more expensive approaches. Microsatellites are not hobby spacecraft any more.

Crossing Paths with Moore’s Law

The rate of technology evolution is very fast; some say it's exponential. Each new technology adds to the possibilities and scope of previous ones. Gordon Moore’s observation about the doubling of computer power per dollar every 18 months has not only held for the last two decades, but is expected to hold for at least two more decades.

One problem for space equipment developers is that the rate of launching new space projects operates on a different time scale than the one required to track the technology curve. The deployment of new space projects is limited by the high investment required for space activities and by the political processes involved in mobilising that investment. Spacecraft are further burdened by the enormous expense of deployment, upgrades and servicing, leading to a natural reluctance on the part of investors to take risks with technology innovation.

The result is that space projects generally take a long time to fund, develop, and fly.

This mismatch in rates of evolution means that spacecraft companies that do not launch products regularly, perhaps every year, do not have the means by which to maintain technical relevance in their product lines.

This mismatch is not new. It was the case fifteen years ago, when it was already obvious that the satellite industry in general had significantly parted company with the terrestrial technology boom. In fact, the satellite industry is in many ways relatively low-tech.

The high-tech aspect of space programs frequently comes from the brains needed to squeeze a prodigious amount of function into wholly inadequate hardware.

In contrast, microsatellite designers are already done flying their second generation of 386 computers and are now upgrading to ridiculously more powerful StrongARM and DSP computers. The recently launched SNAP-1 microsatellite from SSTL boasts very capable on-board computing hardware, as well as cameras, GPS equipment, cold gas propulsion and attitude control – all in a 6 kg package (2).

In comparison, the Canadian contribution to the Space Station program is powered by Intel 186 and 386 computers. A good choice ten or fifteen years ago, but now looking a bit dated.

Some observers argue that the reason for this technological obsolescence in the space industry is that projects are so large that they take very long to put together. However, this does not take into account the very large and complex projects started and completed in much less time on Earth.

The authors believe that organisational, political, and process factors are the most implicated as causing space projects to overrun and underperform. These factors cause missions to be expensive and infrequent, making it difficult and expensive for their technology to be relevant, and for their builders to keep their product lines glued to the technology curve. This view is not significantly at odds with that held by the upper echelons at NASA who pioneered the Faster, Better, Cheaper approach to space missions

In the next section, we will present the concept of the "death spiral" and how it acts to trap space programs and escalate their costs.

The Death Spiral

High cost is such an endemic part of space programs, that it sometimes seems inevitable. Talking with various colleagues over the years, we frequently said things such as "you can't develop a new unit for less than $5 million to $10 million dollars." A supplier from whom we were recently attempting to source attitude sensor electronics said "the lowest recurring cost for which we can give you a digital interface and signal processing board is $100k."

Initially, if a space program is perceived to have a high cost, there are two distinct consequences. First, in order for enough budget to be assembled to fund the project, various promises have to be made to entice and secure enough stakeholders. Typically, this leads to adding mission objectives and/or payloads to the spacecraft, reducing the number of spacecraft (typically to one) and extending the mission life. It may also lead to various restrictions on how the money may be spent.

In addition, stakeholders must be reassured that they have a high probability of receiving the fruits of the payloads they are sponsoring. Also, because of the perceived high price of the mission, it acquires additional stature within the customer's agenda. This leads to an increase in risk aversion on the part of the missions designers and managers, because failure becomes less acceptable. Instead of taking (calculated) risks, there is an impetus to eliminate risk.

This causes cost growth because conservatism pervades the design process. Designers begin to specify a cascade of margins that radically overspecify the required performance of the various parts and units of the spacecraft. They begin to specify flight-proven parts (i.e. old technology), or parts that have extensive reliability estimates performed to quantify their performance.

As an example, recently, we had the experience of being told that a JAN-S military specification diode was not to be trusted, and that we should specify a JAN-TX part instead. At this point, one moves into the territory of paying as much for a handful of parts as one might for a new car.

Designers also begin to add redundancy to the various subsystems and functions of the spacecraft, radically increasing its complexity and making assembly and testing far more elaborate as a result. Instead of the engineer being able to assure the performance of an electronics board by inspecting and testing it themselves, manufacturing is controlled by heavily documented processes that are checked and cross-checked as they are performed. An entire Product Assurance organisation is frequently called into being to make sure that the avalanche of requirements that are written down are actually being implemented.

The second consequence of starting with the assumption that the program is going to be expensive is that in order to win what is perceived to be a high price program, a consortium of suppliers must be put together.

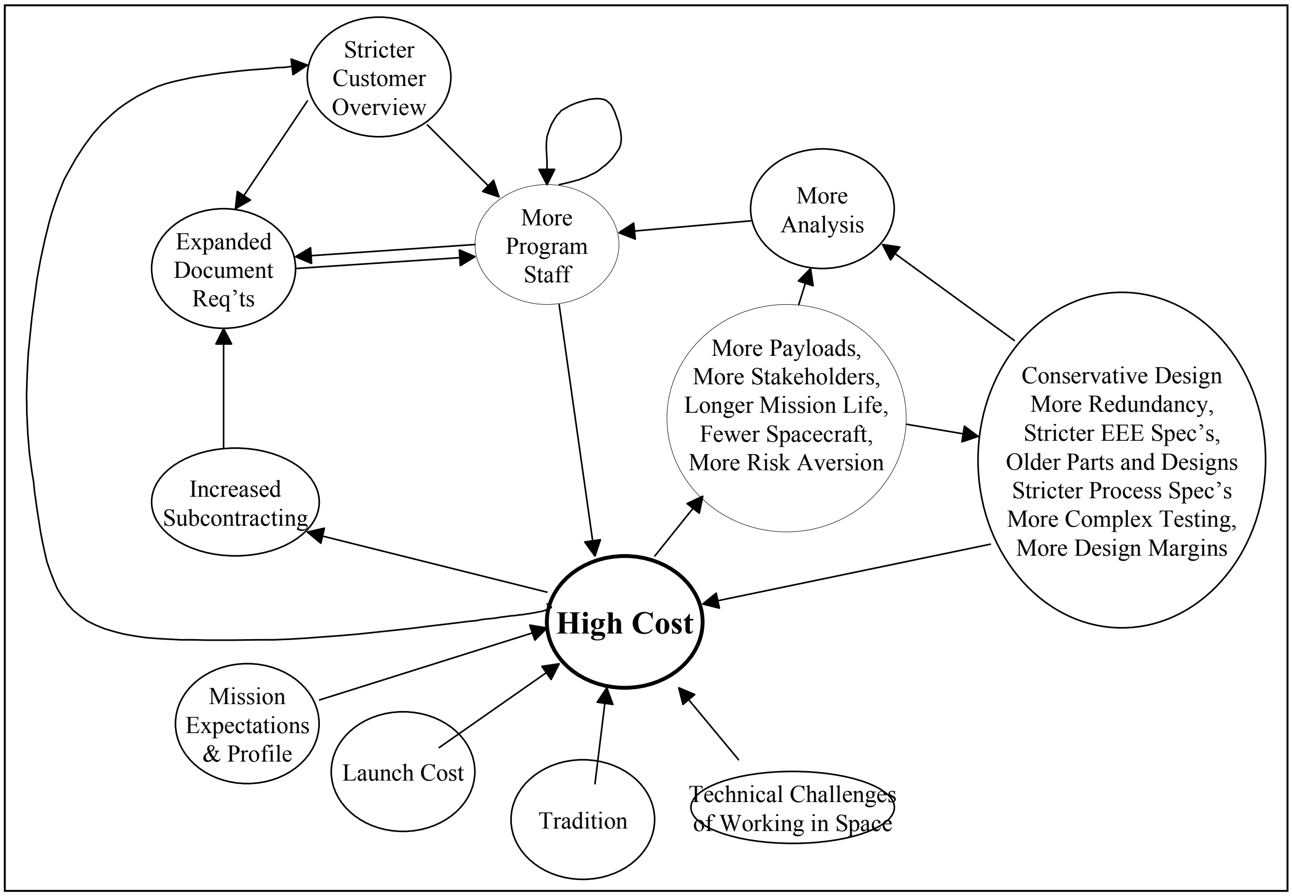

Figure 1: The "Death Spiral" of Space Project Cost Drivers

This guarantees a certain burden of documentation, staff, miscommunication and lack of flexibility that immediately pushes the program cost to a higher category.

For example, in order to subcontract a unit or subsystem, a contract must be put in place with a statement of work and technical specifications. In practice, this means an initial Design carried out by engineers who do not then carry on with the detailed implementation, premature freezing of the specifications, and a lack of flexibility in changing requirements or eliminating units entirely.

When a program is perceived to have a high cost, then the customer is naturally anxious to have an expanded overview of the design. While this is valuable and provides a better view into the evolution of the design, it also creates another set of opportunities for miscommunication and disagreement. The technical staff from the customer are naturally frustrated if their engineering judgement is overridden by the contractor's technical staff, leading to additional requests for justification of the design and additional analyses to be performed.

Finally, a large staff has a tendency to enlarge itself through sheer organisational dynamics. As more people appear, their individual utilisation tends to decrease as they rub against each other's technical and organisational boundaries. Some things get done more than once, while an increasing number of people is required to make sure that everything is done at least once. More time gets used in meetings, and more people are hired to streamline operations and to solve problems as they come up.

These various consequences of a program initially perceived as highly priced have the effect of igniting a cost expansion bonfire so significant, that a round of cost cutting is required during the very early stages of the program. This cost cutting frequently has the effect of reducing any margin for error in the cost estimates, and makes the program more fragile to cost overruns.

The objectives of all high value-added endeavours is to stay on the high side of the perceived value vs. cost curve (Figure 2). This is true for government sponsored as well as private ventures.

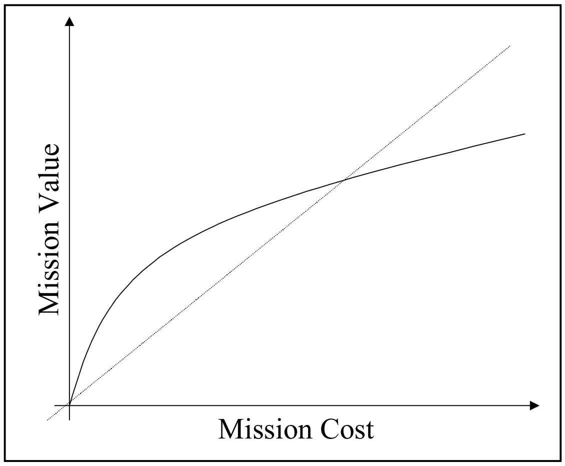

Figure 2: The Problem of Diminishing Returns

The "death spiral" pushes the program along a curve in which additional cost adds a diminishing return of value. This devaluates the project as a whole and damages space projects as not contributing value commensurate with other ventures competing for the same resources. Not only do space projects not run on "internet time", they also don't contribute "internet value added".

Getting On the Spiral

Given that there are many people in both the user and supplier community that understand these cost driving effects, how is it that the cost spiral is allowed to ignite? We are able to trace several proximate causes of ignition for this Spiral. The most important of these are as follows:

- Launch cost
- Mission profile
- Traditions governing design and build
- The space environment

Launch Cost

Even supposing that someone were to build reliable spacecraft for a price of $500/kg (in the neighbourhood of the cost of high-performance communications and computing gear today). The lowest possible price for launching this satellite today is $10,000/kg (US) from the Russian DNEPR launch vehicle.

For Government customers, the cost of a launch vehicle for a large satellite is enough to make any space project that requires such a launch vehicle to be considered expensive. Immediately, the concept of launching two or three spacecraft as part of one program is, if not ruled out of the question, then at least significantly jeopardised

For commercial customers, gain is frequently more easy to quantify than for research missions. The problem for those who are looking to make commercial success using satellites, becomes one of finding space applications that add enough value to warrant the investment.

Finding commercial space applications that are compatible with returning even the price of launching the spacecraft, much less designing and building it, is difficult.

Mission Profile

The price that government and scientific programs pay due to the high ante in the spacecraft game is enormous. In proportion to the amounts that taxpayers are willing to pay the launch cost is high enough to put any large or even mid-sized space project squarely in the political limelight. Entering the limelight is another proximate cause of death spiral ignition.

Being in the limelight means that no technical failure can be tolerated that could lead to embarrassment of the project stakeholders. When a project moves into the limelight, its cost drivers migrate from managing the risk of failure to proving that everything was done to prevent failure. The cost of the latter is far higher than the cost of the former. If, in addition, the project is so expensive that all of its hopes are pinned on one spacecraft, the conditions are set for extreme conservatism and risk aversion as that project is carried out. Every attempt is made to eliminate risk, rather than to manage risk.

When failure is not an option, success can be expensive.

Traditions Governing the Design and Building of Spacecraft

It is probably a universal human desire to want to duplicate successes. The problem with space flight is that there are still unknowns. We frequently know what leads to failure, but frequently don't know what led to success. We are in the old quandary that probably only 20% of what we do to build, analyse and qualify new space equipment designs is all that is required to succeed. Our problem is that we don't know which 20%.

The Space Environment

Another cost ignition source is the technical difficulty of operating in space. Spacecraft exist and operate in nature's high-energy vacuum physics laboratory, where many strange and non-intuitive things can happen. Finding out what they are is expensive and uncertain, and this leads to a great deal of superstition and conservatism on the part of spacecraft designers. As discussed above, it also leads to a body of tradition that makes innovation difficult.

There is a hard core of truth to the challenges posed by making equipment for operation in space. However, it is also true that the environmental challenge of space is also frequently overstated. It was generally popular in some quarters in the early 1980s to say how difficult it would be to make solid state devices survive structural loads due to launch and the wide temperature swings possible on spacecraft. This was the case until the automotive industry started to put significant amounts of silicon processing in their cars, and insisting that it operate -40C to +70C reliably. Today, components designed for industrial and automotive use easily cope with the thermal and structural requirements of spacecraft.

Spacecraft still must cope with ionising radiation, charging effects and vacuum, however. If one had the luxury of doing experiments and being able to learn from one spacecraft and properly incorporate those lessons in the next and in a short period of time, then this environmental challenge is easily enough addressed. The problem comes when, as happens in Canada and in many countries, engineers and scientists can only design one spacecraft every five years or more, and that spacecraft has to succeed or else ruin the program in which they are engaged.

No matter how enlightened the approach, however, designing instruments and equipment to operate in space costs more than designing them to operate on Earth.

Getting Off the Spiral – Worked Examples

Many of the activities undertaken as part of a standard development scheme are done not as much to increase mission reliability, though they may have that effect to some extent. They are done more to provide the illusion of control for those funding and those managing the work.

Here is a thought experiment as an example. Suppose one has a choice of two approaches to building an electronics board. The first approach we'll call Design A and the second Design B.

Design A uses 500 older, MIL-STD components qualified (or proven on multiple flights) for space applications whose reliability figures were well established and which are built in low volumes on controlled production lines. The components are a mix of through-hole and Surface Mount Technology. Processing is done in hard-wired logic (for example, with fused FPGAs) and is not easily reconfigurable. The board uses 4 Watts of power, masses 2.0 kg, and has a calculated reliability of 0.995 for the mission. The board costs $1,500k to design and qualify and $50k per board to build in small quantities.

Design B uses 50 components, the centrepiece of which is a reprogrammable Digital Signal Processor. All of the components use Surface Mount Technology. The components are designed for industrial and automotive applications and are built in large volumes. Most of the functions are implemented in software. The board uses 0.8 Watts of power and masses 0.5 kg, However, for this board there are no reliability numbers associated with the parts. This board costs $80k to design, and $5k to build in small quantities.

Design A appears to offer completely contained and quantified risk. Sure, it's more expensive but at least you know what you are getting. Actually, a spacecraft full of Design A choices is fully trapped by the death spiral and a great deal more expensive than a spacecraft design full of Design B choices. Looking just at the immediate bottom line, however, the total cost of a 3 board “program” for Design A costs $1,650k as compared to a cost for Design B of $95k. Design A is therefore 17 times more expensive than Design B.

Detailing the various mechanisms that make it possible for Design B to be so radically cheaper than Design A would fill a large volume. One example may suffice to illustrate the issues, however. In a time not longer than 15 minutes, an engineer can obtain the price, check availability, fill in the paperwork and order an electronic component for a microsat. That component will then arrive the next day by courier.

Contrast this with the EEE parts procurement process for a Design A program. The prices of these components are not generally advertised. It may take several telephone calls or even a face to face meeting and several days of delay in order to obtain a quote for a MIL-STD part. The amount of engineering time per part can easily stretch by a factor of 10 or 20, given that many other specialists get involved to review and sign off the request for purchase.

If qualified components are not available, and a COTS solution is acceptable to that program, the timing and work stretch out further. The engineer must now fill in a Non-Standard Parts Application Request, and convince at least one and possibly several other people that he has selected an appropriate design. Depending on the organisation, various inspection and screening processes will then be discussed with that vendor at length, possibly creating the need for customised handling and paperwork to be done by the part vendor in order to meet the upscreening requirements of the Design A program.

Anecdotally it has been said that doing your own upscreening is just as expensive, if not more so, than just specifying a MIL-STD part in the first place.

A recent paper (3) backs up these cost differences over whole programs.

Table 1: Spacecraft Cost Comparisons

Spacecraft	Cost Reduction Ratio
Orbcomm prototypes (communications)	24
RADCAL (radar testing)	7
AMSAT OSCAR-13 (communications)	102 (assuming free labour) ~24 (correcting for labour)
Freja (magnetospheric research)	11
Clementine (BMDO test and lunar science)	3

The paper calculates the cost of doing several programs with costing models based on standard construction approaches, and then compares these projections against actual costs achieved when various versions of microsatellite-style cost-reduction were actually used. The different projects were carried out by different groups. As Table 1 shows, the results are nothing short of remarkable.

Designers of spacecraft have for many years been pressured to reduce costs without adding significant risk. The standard techniques that meet these somewhat contradictory requirements and that have provided some degree of cost reduction success are as follows:

1. Streamline Procurement and Project Oversight
2. Simplify Mission
3. Reduce Redundancy
4. Integrate Development Team
5. Improve Design and Manufacturing Systems
6. Selectively Reduce EEE Parts Req'ts

These steps are all evolutionary and can lower costs by a significant factor. However, they do not allow costs to be reduced by a factor of 24, as has apparently been achieved by some programs. In order to achieve such a dramatic cost reduction, a fundamentally different design paradigm – the microsat way -- has to be implemented.

Mitigating the Risk

Designers who baseline the more expensive option do so arguing that going the cheaper way introduces risk, and this is quite true. The key is in managing and overcoming the risks, rather than in avoiding them.

The additional risk in Design B comes in two flavours. First is risk that the technical performance and durability of the electronics will not match the need. The definitive way that this risk can be abated by flying test payloads in space. This means that if the program allows building and flying only one spacecraft, no significant risk abatement is possible.

The second risk is in the absence of quantification of the failure rate of the electronics. However, for the low failure rates associated with the vast majority of digital components, the failure rate numbers are always small, and offers only an illusion of control. Most projects only build a few spacecraft. There is no law of large numbers to fall back on.

The need to quantify reliability numbers comes from the large-system realisation of the Apollo days that "if each part were only 99.9% reliable, the rocket would fail many times before it reached orbit". This argument may be true for Apollo, but very few people are building Apollo-sized systems these days. Those of us who are not do not need to be prisoners of the reliability estimation procedure and its associated parts requirements.

In fact, one quantification of the causes and rates of failure for small spacecraft shows the following trend:

Table 2: Causes of Spacecraft Failure

		Secondary Payloads	Primary Payloads
1	Launch Vehicle	25.0%	10.0%
2	Design	18.6%	22.3%
3	Environment	16.0%	19.2%
4	Unknown Cause	14.2%	17.0%
5	Parts (random)	12.2%	14.7%
6	Operations	3.5%	4.2%
7	Quality (random)	5.8%	6.9%
8	Other (random)	4.7%	5.7%

(Note: a launch failure rate was assumed at 25% percent for secondary payloads and 10% for primary payloads. According to unpublished research by Rick Fleeter of AeroAstro, the success rate for launching secondary payloads is actually lower. The rest of the information comes from reference 4)

Of these causes, the first is largely out of the control of the microsatellite designer. Beyond choosing a launch vehicle with a good track record, little can be done by the builder to ensure that the satellite will be launched successfully into the right orbit.

The next two causes emerge from the inattention of designers and insufficient testing and on-orbit experience. Here, the death spiral reveals its malign power. By making the spacecraft more complex, the attention of designers to each element of the design is diluted and opportunities for miscommunication multiplied. It has been argued by AMSAT members with long experience in building spacecraft, that redundancy can introduce more opportunities for bad design and failures than they eliminate.

Failures due to inadequate design or misunderstanding of the environmental loads on the spacecraft can be overcome through a multi-spacecraft program. Lessons are learned and spacecraft designs improved as the program proceeds.

The mitigation for avoidable failures is therefore the same as the mitigation for the use of previously unknown or unqualified parts: fly multiple spacecraft.

By flying spacecraft more frequently, there is more accumulated experience both in terms of knowing how well various designs work as well as building a well-experienced cadre of technical and programmatic staff.

The factors that make Design B the cheaper alternative in our example have a lot to do with the fact that the electronics is much simpler, and thus easier to design robustly. A second important factor is that many functions are undertaken in software, which is easier to change and adapt both on the ground and in orbit. In the production process, the fact that Design B uses radically fewer components means that parts procurement, manufacturing, and testing are far simpler, cheaper, easier, and that makes the end product more robust.

Next comes the set of failure causes that capture the essence of why space is still a frontier. Every now and then, spacecraft fail without providing a conclusive indication of why.

Finally, spacecraft failure due to the failure of parts is fifth in line, accounting for roughly 12% of failures. It may seem strange, then, that such a small source of failures is accorded such a large element of the typical development and build cost.

The implication of this risk has frequently been that such new parts are simply not considered or chosen. The "microsat way" is to develop a process and program by which such parts can be considered and qualified for use on a regular basis. Beyond that, parts can be used even if they are fundamentally of lower reliability, assuming that the system design allows for this.

Rather than considering new technology as a threat, feeding new technology into spacecraft design should be the highest priority among spacecraft builders and the spacecraft customer and user community.

The key in getting an operational system that costs less at the same time as it delivers more and, and this is the critical point, with higher system reliability and robustness is to use a series of spacecraft. The details are worked out in the next section.

Getting More For Less

In order to get more for less, we have to move more generally from what we have called the "death spiral" to its positive analogue: a "virtuous spiral" shown in Figure XXX.

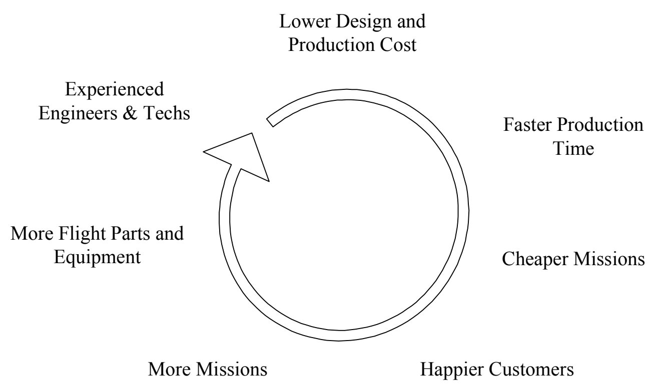

Figure 3: The Virtuous Spiral

The general idea is that faster and cheaper missions mean more results more quickly, thus priming the pump for more missions. Indeed, as more missions are flown, a larger number of formerly COTS components are qualified, thus bringing down the cost and increasing the reliability of further missions.

Now, it remains to be seen whether the spacecraft market is indeed price elastic. That is, with cheaper missions, will there be a larger overall volume? One argument that can be made is that if the market is not elastic, then lowering the price of missions simply deflates the value of the market and moves margins from the spacecraft producers to the customers.

This would simply aggravate an already poor situation. A recent study by Booz Allen & Hamilton (5) revealed that return on sales in the space sector in the United States has fallen by over 20% since the early 1980's.

(from around 8.5% to just over 6.5%). In addition, that study concluded that "decreasing cycle times for design and production of satellites has resulted in an excess capacity of approximately 50%".

If the cost of spacecraft acquisition were to drop significantly, then market volume and margins might well take a further beating.

These observations provide one explanation why existing spacecraft companies might find it difficult to radically lower their costs using fundamentally different approaches to spacecraft design, and why these innovations are being pioneered by companies such as SSTL and SpaceDev, who have no role in the traditional spacecraft supplier infrastructure.

The authors believe that the market is indeed elastic. Cheaper missions mean that science budgets that previously were not large enough to afford spacecraft would now be drawn into the market. Without new science and exploration missions, it is not clear where a significant enlargement of the spacecraft applications market will come from. The world needs only so many traditional-style communications and remote sensing satellites.

Radically cheaper spacecraft mean that new business cases that might have previously looked dubious or risky may be more viable and therefore also be drawn into the market. Only with successful new business models can the commercial market enlarge.

A final, though perhaps the most critical, element in this virtuous spiral is that faster and more frequent missions lead to more excitement in the industry. This will draw in more young, talented people both on the technology and also on the science and business side.

The Booz Allen, & Hamilton study points to a "greying" space workforce and the perception that space is a "smokestack industry" as key challenges for the industry. It finds that "in 1990 aerospace was the third most desirable career field for science and engineering graduates. By 1999, it had dropped to No. 7."

The fact is that working on missions which take 15 years from initial idea to flight is a highly resistible proposition for young people used to the pace of "Internet time". In the next two decades, whole new fields will be created in the areas such as functional genomics, wired and wireless communications, and nanoscale technologies. Compared to that, otherwise worthy large and long-term space projects like the Next Generation Space Telescope may well appear to exist in stasis.

The Future

Perhaps the most important objective for a spacecraft component maker or integrator is to ride the technology tiger. In the electronics arena, offering technology that is more than one or at most two years old will mean being squeezed out of the business.

Here are some observations and ideas that we believe will shape and describe the future of the space industry:

1. Product innovation must be continuous, upgrades must happen every year or two years at most. One reason for this is that electronic parts become obsolete very quickly. Unless one has pre-purchased parts or is some other way guaranteed their availability (driving up cost), electronic parts will simply not be available for extended periods of time. A second reason is that there are vast increases in cost performance from one generation to the next. A design that takes advantage of newer parts will perform better, use fewer parts, and cost less.

2. The logical consequence of this observation is that any supplier of space electronics must have a continuous pipeline of hardware products undergoing space qualification testing. There is a role here for the Canadian Space Agency to serve as a road to space, offering regular and frequent technology flight opportunities. Project cycle times must be reduced and the number of projects increased, if new technology is to effectively be injected into the spacecraft procurement cycle.

3. While this pipeline will generate a source of flight proven designs, it will not eliminate risk. Mission designers of missions based on the highest performance to cost ratios must accept a certain degree of risk in their missions, rather than attempt to design all risk out. However, using a series of cheaper satellites can provide an overall mission reliability as high as required, even if each satellite is significantly less reliable. The key is to design not only the spacecraft procurement but also the business case overall to take advantage of this approach. Without an adjustment of the business case, there will always be significant pressure to revert to an expensive and high-rel approach to building spacecraft.

4. Volumes will always be low, so development cost must also be low. The days when we thought we could reduce the cost of spacecraft units and subsystems simply by increasing volumes are over. Constellations of dozens of satellites are the exception, not the rule. Development cost is best

reduced by having a cadre of technical staff continuously employed and with access to frequent opportunities to test designs. Building only one spacecraft every five to ten years maximises development cost, because those who designed the initial spacecraft will be the "stick in the mud" technical superiors who will hold back the next generation from using the most advanced technology.

5. Barriers to entry are dropping, and the number of suppliers of units and subsystems for both micro and larger satellite applications is set to surge as the microsatellite industry develops and its methods begin to infiltrate more traditional spacecraft builders. Dynacon is among those companies working to drop entry barriers for new spacecraft organisations, by demystifying and providing support in attitude control and other arcane subsystems for which no analogue exists in ground based equipment.

6. In the past, spacecraft operators have improved their cost performance by demanding longer spacecraft life. For many commercial communications applications, longer-lived spacecraft are highly desirable, because the stabilising effect of entrenched standards and a large, installed user base means that technology upgrades are not necessarily a driving requirement.

   This is not the answer for everyone, however. In particular, it is not compatible with the explosion of technology represented by Moore's Law. In many cases, a larger number of spacecraft, each with a shorter life is a better answer. And even in the case of the traditional applications, operators may come to prefer upgrading their spacecraft every three or four years rather than every fifteen years, assuming their total costs and risks were the same. Newer technology spacecraft would allow them to try new product offerings and tap new revenue streams.

   For science and remote sensing missions, and for new services in which standards are not yet solidified, technology can be a significant discriminator and frequent upgrades to spacecraft functionality is almost mandatory.

7. Although it is not a panacea, the use of multiple smaller, cheaper, better spacecraft to implement space mission objectives is not only likely to be the best solution for the customer of the mission, but it is by far the best alternative for the space industry. In order to mitigate the risk of failure on launch, the spacecraft should be launched on separate launch vehicles. This total strategy will ultimately have the effect of significantly adding to the value added contribution of space missions, thereby expanding the market base and increasing opportunities and services for everyone.

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