New Technology in Space – is the U.S. Losing Ground?

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Abstract.

Access to Space for small R&D payloads is one of the key enablers for innovative space technology development. For a vibrant space R&D environment to exist space access needs to be available on a regular basis at a cost commensurate with R&D program budgets and with a minimum of custom interface requirements. The United States has a long heritage of developing new technologies for space applications, enabled by numerous space launches in the early 1960s. Many space experiments are launched as secondary payloads due to their relatively small mass and modest program budgets. NASA and DoD have organized processes to evaluate and select experimental payloads for space access (such as the DOD Space Test Program's SERB). The payload interfaces are usually custom-made for each payload and are scheduled on a case-by-case basis depending on primary payload excess margins and acceptance of secondary payloads. The International space community has taken a dramatically different approach since the early 1990s with the introduction of a regularly scheduled standardized launch interface for secondary payloads – the Ariane Structure for Auxiliary Payloads (ASAP). Nearly 30 free-flyer secondary payloads have been launched from ASAP since its introduction over 10 years ago. In comparison, the US STP program has only launched an average of 1 free-flyer per year since its inception in 1965. Is this disparity in secondary payload launch rates a cause for concern for the US space R&D community? Is the US losing ground to the International space community as a leader in the introduction of new space technologies? Regularly available space access is a key factor in the rapid introduction of new space technologies. If a country such as the US is experiencing a slower rate of experimental payload launches compared to the International community, then the US may be at risk of losing its leadership role in space technology. This paper will explore the background history, supporting data and space access capabilities necessary to evaluate such a concern. The paper will propose potential approaches to improve the US capability for support of space R&D.

1.0 Background

The current US approach to space test involves a tightly coupled loop of risk averse (higher reliability) processes driving higher launch/payload costs which leads to fewer missions. Such an environment discourages space research payloads. Because there are fewer missions, the pressure for success on each mission increases and the risk-averse environment becomes more conservative spiraling the space test process downward or directly opposite to what is needed for a healthy research and development environment. Downward is used here to describe a direction that is away from a high frequency, rapid turnaround space test process environment. This downward spiral was well described by Sellers and Milton.[1]

In order to reverse this downwardly spiraling process, the paradigm of space testing needs to be changed dramatically to encourage more frequent low-cost space experiments. A new paradigm would have to accept risk as part of the R&D space payload launch process. The cost of failure would be mitigated by the lower cost of testing and the smaller size of higher-risk test payloads. The process would achieve dramatic benefits from more frequent iterations of the development cycle, even when failure occurs. Space test programs have almost forgotten that failure should be an integral part of any research program. Secondary payload risk must be balanced against the overall risk allowable by the primary payload. There are approaches available to address secondary payload risk minimization prior to launch vehicle separation.

Jim Wertz presented his overview of this new paradigm in a 2001 paper[2], summarized in the Figure 1 below. The first "Circle" in this graphic depicts where the US space test program is now, taken from Sellers and Milton. The second "Circle" in the graphic depicts where we need to be in the US Space Test Program as suggested by Wertz.

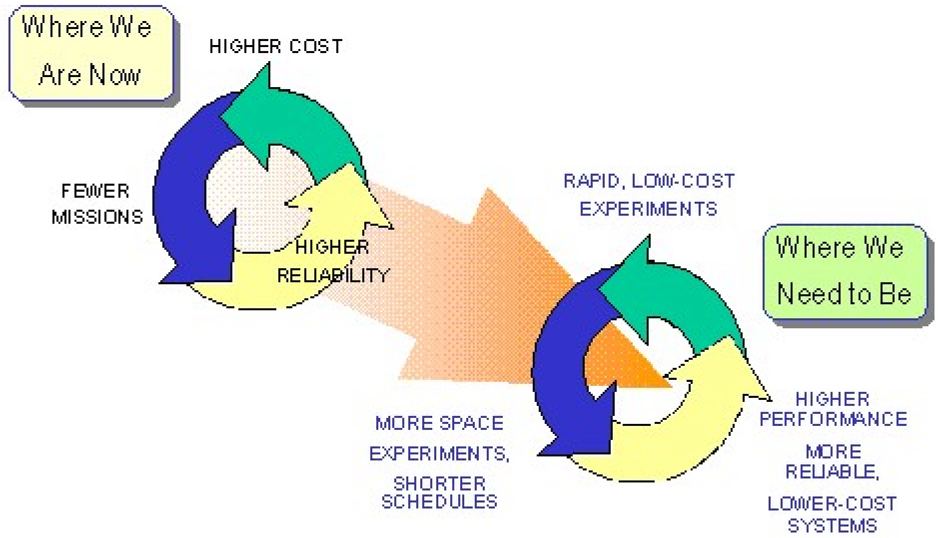

Figure 1 – Changing the Space R&D Process

If the lower circle defines the desired process, then how do we get there? This paper attempts to provide answers through a series of focused questions, such as:

- Are there any specific impediments to Space R&D (why is Space R&D so difficult)?
- Does the rest of the International Space Industry perform space R&D in a similar manner?
- What is the business case for the US Aerospace Industry
- Is this a case of solutions looking for problems?
- Who is interested in Space R&D?
- Where can the Space Market Grow?
- What are the current launch opportunities?
- What's the next step? (and a Sample Process)
- What is the Incentive?
- Summary – or Where do We go from Here?

2.0 Why is Space R&D Difficult?

Compared to ground or even airborne research and development processes, space R&D has a number of unique constraints that make it more difficult to conduct. Included are:

- Costs are high ($10-20K per pound to LEO)
- Frequency of testing is low
- Opportunities for small payloads to achieve desired orbits are few and far between
- Delays between payload development and launch can be measured in years, not months.

The last factor alone would be unacceptable for any ground-based R&D program.

Space R&D is not unlike ground based R&D in the basic approach. Both follow the Scientific Method: 1) Observe a phenomena, 2) Develop a hypothesis on how it occurs, 3) Test the hypothesis, 4) Repeat until test agree with actual phenomena. Experiments are developed based on observations and are often developed before launch opportunities are defined or obtained. R&D payloads are launched as "piggyback" on other missions/launch vehicles, often resulting in a non-optimum orbit. Secondary payloads are ejected from launch vehicle after the primary payload is delivered and have to accept the primary payload orbit.

Embedded experiments that are part of a larger R&D spacecraft seldom achieve orbits that are optimum for R&D mission. R&D payloads seldom have onboard propulsion for orbit adjustments once they are deployed from the primary launch vehicle (to minimize risk). Launch vehicle failures can "wipe out" years of payload development effort, which discourages testing of high-risk concepts in space. Putting this in the context of the scientific method, the Table 1 below provides a comparison of ground and space-based R&D. Space R&D is truly harder than ground-based R&D

Scientific Method	R&D on the Earth	R&D in Space
1. Observe	• Straightforward in situ	• Difficult in situ – often done remotely
2. Develop Hypothesis	• Develop based on Many observations	• Develop based on limited observations
3. Test Hypothesis	• Straightforward and "hands-on"	• Very difficult, costly, and done remotely
4. Iterate 3 & 4 until data matches hypothesis	• Iteration cycle in days to weeks	• Iteration cycle in years

Table 1. Why Space R&D is harder than ground-based R&D

3.0 Comparison of US to International Space R&D

It could be useful to look at how Space R&D is done outside of the US and determine if it is being done better or worse than in the US. The parallel issue is whether we are losing ground to the International Community in our ability to do R&D in Space.

If the same constraints for space R&D exist for the US and International space industries, then why would we expect any differences in their respective space R&D performance records. Turning this thought around, if there are differences in their performance records, then the differences in the program approaches for US and International space R&D could be illuminating. Let's take a look at the records of two prominent space test programs, the DoD Space Test Program (STP) and the European Space Agency (ESA) Ariane Auxiliary Structure for Secondary Payloads (ASAP). Table 2 summarizes each of these programs and indicates that ASAP has a nearly 240% better record in launching free-flyer secondary payloads than STP.[3]

Why is Ariane apparently doing a much better job at launching their payloads? Many papers have been written on this subject, but there is general agreement that the regularly scheduled and frequent availability of standardized secondary payload launch interfaces, at a reasonable cost, are the basis for their significantly better R&D payload launch record than US programs. The recent approval by the European Space Agency (ESA) to "finance the infrastructure that will be needed to launch Russian-built Soyuz rockets from Europe's spaceport in South America (French Guiana)" could further enhance ESA's competitive position for launch of primary and secondary payloads. [4]

4.0 Where is the Business Case?

Then what is the problem? The US continues to conduct space R&D, but at a slower rate than the international community. Many business textbooks stress that the organization that can get to market

STP started in 1965

- **Launched 37 Free-Flyer Missions to Date (thru '02)**
- **Rate of 1 per year**
- **Custom Interface**
- **Ad-hoc launch opportunities**
- **Cost subsidized by DoD**
- **Strong success story in DoD spacecraft heritage**
  - Milstar
  - DSCS
  - GPS
  - DMSP
  - DSP

ASAP First Launch in 1990

- **Launched 26 Free-Flyer Missions to Date (thru '00)**
- **Rate of 2.36 per year**
- **Standard Interface**
- **Scheduled launch opportunities**
- **Costs within reach of small research organizations**
- **ASAP has "bootstrapped" several small countries into the space business**
  - South Korea
  - Portugal
  - South Africa

Table 2. Comparison of Launch Records

sooner with more innovative products has a higher chance of market leadership in the long run. Not all of the attempts will result in success, but failure is also a great teacher. This worked for the US in the 60s and 70s. An industry leading organization won't maintain its dominant position without continuous infusion of new products and capabilities. In contrast, a start-up organization that conducts frequent product development activities with an iteration cycle between failure and the revised approach that is sufficiently short can take away market share from the incumbent organization. This is because such an organization that accepts failure as part of the R&D process can outperform a risk-averse or mature organization and introduce better products to the market more frequently.

A typical business cycle for introduction of a new product is shown in figure 2 below. Rapid growth occurs during the initial startup phase if the product has market viability. Once introduced, the product transitions to the "cash-cow" phase of the business cycle and a company gets a return on its R&D investment. If the next generation of product is started up before the "cash cow" phase ends on the previous product, then an organization can establish market position and possibly maintain market dominance.

Should the US be worried about its relative position in the International Aerospace Industry? The recently completed Presidentially appointed Commission on the Future of the US Aerospace Industry had a specific charter of addressing this point in several areas. The bottom line is that we have a significant problem – US leadership is eroding in the International Aerospace Industry. But if we have a problem, they why isn't the US Aerospace Industry aggressively pursuing solutions? More specifically, why don't they increase the rate of space R&D to gain back eroding market share and return us to a position of dominance? The problem may lie in the risk-averse nature of the US Aerospace Industry, which hinders their ability to introduce innovation and new technologies at a rate sufficient to maintain market share. Much of our US Space Industry is content to "ride out" the cash cow phase of the business cycle, oblivious to the approaching business cliff. If the solution, introduction of a more aggressive space R&D program, is so obvious, then why isn't it being implemented?

5.0 Solution Looking for a Problem?

A number of business development training programs and textbooks point out that you can't sell something to a customer unless you are solving their problem(s).

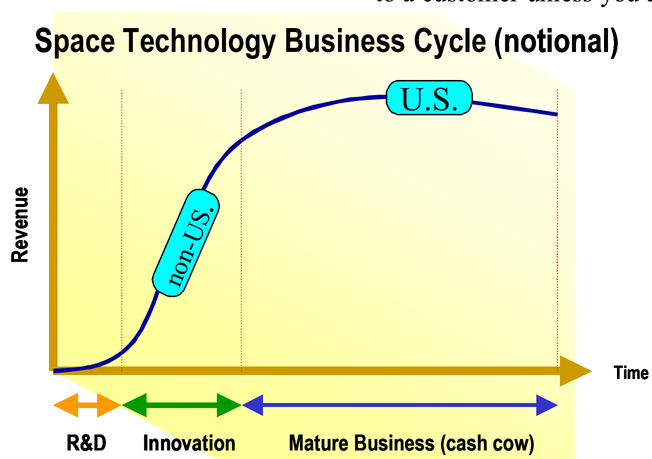

Figure 2. Notional Business Cycle

What differentiates the competent organization from the market leader is their ability to continually inject new and profitable products into this business cycle, at a faster rate than the competition. Not all new products or startup organizations succeed, but those that do form the basis for a new product line and, in some cases, an entire new industry. Risk -averse organizations can be profitable, but they cannot maintain positions as industry leaders. Market growth is "spurred" by innovation and new ideas.

If you haven't identified the customer with a problem that fits your solution, then you don't have any chance of a successful "sale". In many cases, the potential customers are not even aware that they have a problem, so there is an educational process involved in identifying the problem for the customer before a solution (your solution hopefully) can be proposed. This may sound like "motherhood and apple pie", but it is a fundamental fact of business development that is often overlooked. To put this in context, why would a primary launch provider want to add a secondary payload adapter that would not pay for itself and would introduce more risk for the primary (and paying) payload(s). Why would a government research organization want to develop its own secondary payload launch adapter if it had other less costly ways of obtaining one-off launch opportunities for its unique test payloads?

As a frequent participant in the annual AIAA/USU Smallsat conference, I've asked myself the question, "If there is such a vibrant source of new ideas and innovation at the Smallsat conference, why don't we see more of these new ideas in space hardware?" Many of you may have asked similar questions and many have probably come up with the most probable answer: Lack of access to space for small, innovative payloads is a major impediment to Space R&D. It brings most new concepts to a screeching halt or at best relegates them to years on the shelf before a launch is identified.

Let's discuss the innovation cycle described in the beginning of the paper. Rapid low cost space experiments with frequent launches on shorter schedules leads to higher performance, lower cost, more reliable space systems. What's missing from this triad? The answer is the lack of space access (more space experiments launched on shorter schedules). Many designs and multiple business approaches have been developed and implemented to address the lack of space access for small, innovative payloads. One Stop Satellite Solutions (OS cubed) is one of the more recent examples that many of you are familiar with. Their solution to the lack of US small payload launch opportunities was to develop a multiple payload launch adapter on a Russian launch vehicle. Great idea, but many of the US payloads ran into problems with export of technology restrictions imposed by US ITAR (International Trade in Arms Regulations). The ITAR approval process overwhelmed the payload integration and launch process.

If innovation is to grow in the US at a rate that will maintain (or even regain) our leadership in space technology, then I maintain that the launch capability for small, innovative payloads must be resident in the US and readily available (schedule and cost) to small R&D organizations and university research programs. Anything less will not suffice.

So why aren't the US launch primes sufficiently interested to implement a regularly scheduled small payload launch interface? I used the words "sufficiently interested" because there are examples of standardized US launch vehicle secondary payload interfaces. Delta II is one of the most prominent and one of the most prolific for NASA and DoD payloads. The Delta II secondary payload performance is summarized in section 8.0. Why aren't the current EELV launch vehicle companies (Lockheed Martin for Atlas V and Boeing for Delta IV) interested in providing an ASAP-like (ASAP is the ESA Ariane Auxiliary Structure for Secondary Payloads) launch interface? The answer is simple – it does not make a good business case, and in their view it would create potential risk for the primary payload.

The difficulty lies in identifying the organization(s) who have problems that can be solved by implementing a new, standardized, regularly scheduled secondary payload launch interface.

6.0 Where can the Space market grow?

There are many technology applications and orbital regions yet to be explored and applied. One example is in the highly elliptical orbit belt that is currently underutilized. Novel elliptical orbits have been designed by individuals such as John Draim that provide the continuous coverage of GEO with only a few MEO satellites.[5] A major problem is that the satellites will have to regularly survive passage through the Van Allen belt. Why not develop a more thorough knowledge of the radiation environment by "seeding" the belt with numerous small instruments that can conduct measurements and/or test components until failure. This could provide the stimulus to open up a whole new segment of commercial-service satellites for services such as Broadband data. Launching "clouds" of small satellites to instrument the Van Allen Belt would require a secondary payload launcher interface. This could be the "first user" application to pave the way for regular secondary launch opportunities.

NASA Goddard's Living With a Star Program advocates research such as this and was very receptive to initial discussions on the use of radiation-measuring smallsats de-orbited from a GTO launch capability. Their program, summarized below, could be the basis for development of a standardized interface. The only thing lacking is funding. Figure 3 below summarizes the NASA GSFC Living With a Star Program.[6]

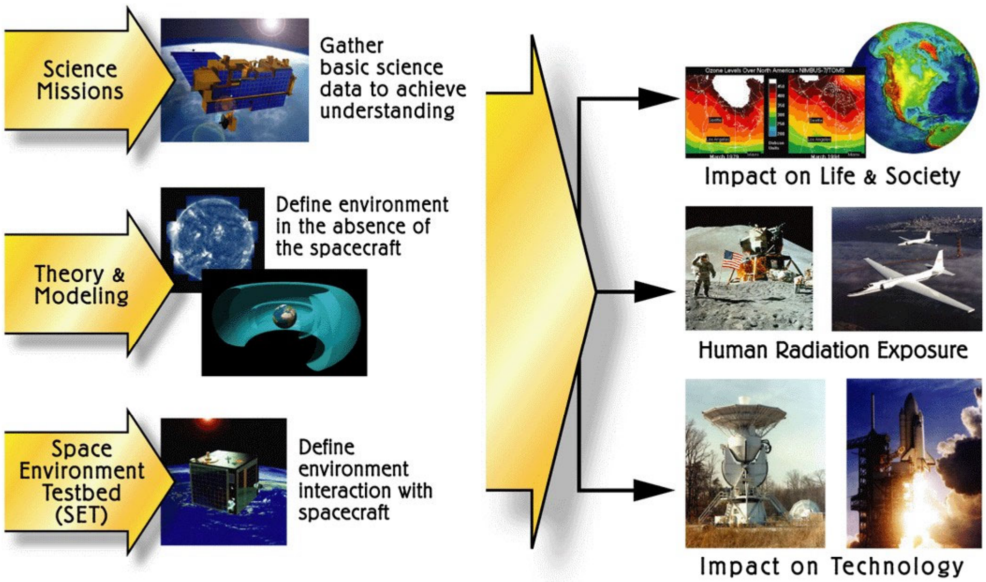

Figure 3. **The NASA/GSFC Living With a Star Program**

7.0 Who are the Interested Parties?

The primary launch providers (Boeing, Lockheed Martin) will be the principal interface for the payloads, either directly or through a payload interface/broker organization. This would lead most to believe that the primary launch providers are the organizations most interested in providing secondary launch capabilities. The opposite is true. Launch providers do not see a business case for small, secondary payloads and are seldom willing to accept the risk introduced by adding secondary payloads onto a primary launch. So if the launch providers aren't the interested parties, then who is? Herein lies the problem. Many proponents of standardized secondary payload adapters feel that the launch providers should "step up to the plate" and build these interfaces. They have not looked beyond the obvious relationship of payload to launch provider to realize that they are addressing the wrong audience. The real organizations that need to be addressed are the ones that are concerned with the erosion of US Space technological leadership, the reduction in a trained US space workforce, and the shrinking role of the US in the international space marketplace. These organizations provide the best opportunities for advocacy. Advocacy without funding is a hollow victory. The best "targets" are those organizations that have a vested interest and have funding "clout". These are the "Big Gorilla" organizations. More discussion is provided on how to deal with the "Big Gorillas" in a later section.

8.0 What are the potential Launch Opportunities

The Secondary Payload launch process in the US is essentially ad-hoc – there are no standardized launch interfaces available on a regularly scheduled basis. Table 4 below summarizes launch vehicles and launch methods/agents available in the US for placing secondary payloads into orbit.

Launch Vehicles	Methods / Agents
– Piggyback on EELVs • Delta, Atlas, Titan – Dedicated Small Launcher • Pegasus, Taurus, Athena – Shuttle • Getaway Specials (GASCAN) • Payload bay attach points/launchers • Cross-deck payload attachments (Spartan)	– USAF/DOD Space Test Program (STP) • SERB (Space Experiments Review Board) process to prioritize and select payloads – University launches – NASA • Small Explorer, Shuttle

Table 4. Launch Vehicles and Methods

Delta II qualifies as the most prolific small, secondary payload launcher – and comes the closest in the US inventory to ESA's Ariane IV in providing a standardized secondary payload launch interface. Table 5 below summarizes the Delta II performance record for small, secondary payload launches. The only problem is that the Delta II production line is closing out and few opportunities remain for its use as a secondary payload launch vehicle. NASA has the orders for the bulk of the remaining Delta II Launches.

- Many US launches have excess capacity
- There is no incentive for the US Launch industry to introduce secondary payload capabilities
- Payload Managers would rather not complicate their primary missions by adding secondary payloads

To break this downwardly spiraling trend in US Space R&D it will take a Government "Big Gorilla" to step up to the plate. What or Who Is this "Big Gorilla" organization? It should have many of the following characteristics:

SECONDARY PAYLOAD	LAUNCH DATE	LAUNCH SITE	PRIMARY PAYLOAD
LOSAT-X	July 3, 1991	CCAFS	Navstar II-11
DUVE	July 24, 1992	CCAFS	Geotail
SEDS-1	March 29, 1993	CCAFS	GPS-1
PMG	June 26, 1993	CCAFS	GPS-3
SEDS-2	March 9, 1994	CCAFS	GPS-6
SURFSAT	November 4, 1995	VAFB	Radarsat
SEDSAT	October 24, 1998	CCAFS	Deep Space 1
Ørsted, SUNSAT	February 23, 1999	VAFB	P91-1 ARGOS
Munin	November 21, 2000	VAFB	EO-1/SAC-C

Table 5. Delta II Launch Record for Secondary Payloads[7]

9.0 Where Do We Go From Here?

Summarizing the current state of the US Space Industry and more specifically, the US Space R&D Industry, one can come to the following conclusions:

- The pace of US space R&D is falling behind that of the International Space Community
- Ariane ASAP is outperforming STP
- Several Concepts exist for new, standardized interfaces for secondary payloads
- an organization chartered to do high-risk, high payoff space R&D
- willing to change the space R&D paradigm by implementing new payload interfaces for secondary payloads
- possessing the funding authority to implement the needed changes
- having a charter or objectives that can support small R&D payload launches

Once the capability of a regularly scheduled, standardized interface and reasonable cost secondary payload launch capability is made available on a regular basis, the US Space R&D community will respond with multiple payloads for space testing.

The approach is clear: identify the "Big Gorilla" first user and develop a multiple small satellite launch concept that becomes the solution to a problem (current or unstated). Then convince the "Big Gorilla" to fund the program as a solution to their problem. Sounds simple, but then why hasn't it been accomplished by now? The answer may lie in the inability of innovative organizations to articulate their concepts so that the "Big Gorillas" will support their programs. As a hypothetical approach, let's walk through a process with a potential customer.

10.0 A Sample Process

Big Gorilla: DARPA – a "venture capital" organization for defense R&D

Problem to be solved: DARPA seeks innovative technologies for tactical space applications. Most projects are mission oriented, but some component development activities exist that have needs for space experiments to measure environments and qualify component performance in space. Space access is a common thread for all DARPA space R&D programs

Current Solution: DARPA uses the DOD Space Test Program for space testing needs and also pursues ad-hoc opportunities for space launch. DARPA does not currently perceive a lack of launch opportunities for their planned payloads (i.e. where is the problem?). Also, they are not at the stage of exploring new concepts that would utilize smallsats on a regular basis where they would need to plan for regularly scheduled small payload launch opportunities.

What should be done: Educate DARPA on potential new missions for smallsats, and once they agree on the need, develop a smallsat program that requires a multiple payload launch adapter. Do not expect DARPA to develop a secondary payload adapter in the absence of a "DARPA-hard" technology challenge.

11.0 What is the Incentive

Why should the US Space R&D community and the larger US Space industry be concerned about the lack of opportunities for space R&D? To answer the question, it must be posed in terms of the economic impact on the US, the relative performance of the US Space industry in the international community, and the effect on the trained US aerospace workforce. If I told you that an industry exists that provides return on investments lower than government bonds and is shrinking in market share (from a once dominant position in the International market place), then what would your prediction be for the future of this industry? Continued growth and a return to dominance? Most, if not all of you would predict exactly the opposite. The US Aerospace industry is currently in the situation described above.

To put some factual "teeth" into this generalized example recent statistics on the state of the US Aerospace Industry were generated. The Presidential Commission on the Future of the US Aerospace Industry completed their 12-month assessment last fall and issued their findings in November 2002 [insert reference]. The panel was made up of 12 very senior experts in areas across a broad range of factors involved in the US Aerospace Industry. Included were former Congressmen, an astronaut, a former Secretary of Defense and senior financial analysts. Heidi Woods, the panel member leading the "financial" analysis area presented some sobering statistics on the financial state of the US Aerospace industry. Figure 4 below summarizes relative market performance of several industries over a common period. Near the bottom of the stack is the US Aerospace/Defense Industry, with a MINUS 2.0 percent return over a 5-year period.[8] Is there a problem here? In addition to the poor financial returns, the labor pool of new engineers and scientists is eroding (some would say disappearing) in the US Aerospace Industry. Development of a more vibrant Space R&D environment may be a key factor in recruiting more talent into this diminishing workforce. The Aerospace Commission addressed both factors of the dwindling labor pool and low profit margins. Specific recommendations were proposed in their final report, including increases in the incentives (profits) for large Aerospace Companies to support R&D activities.

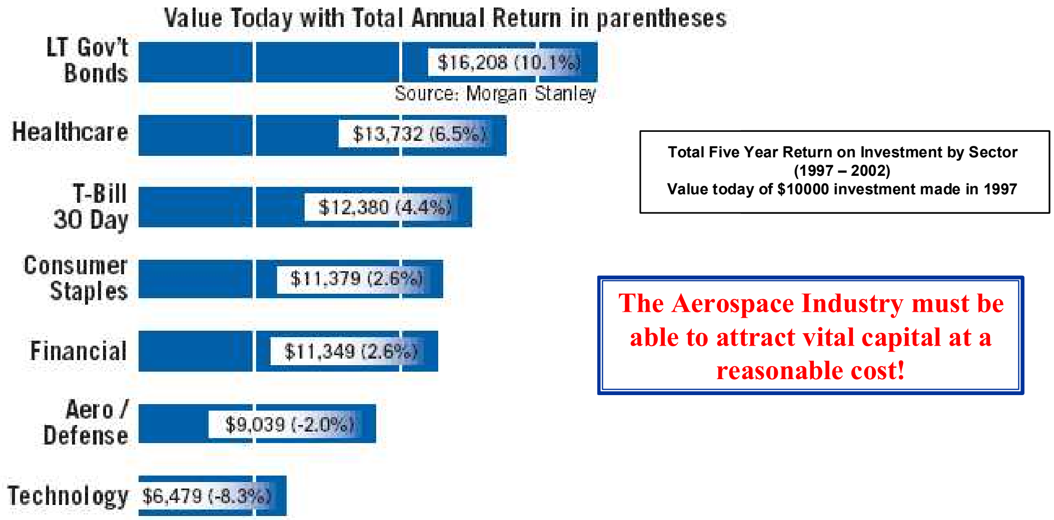

Figure 4. Aerospace Commission Comparison of Industry Profit Margins

Daniel Baker, Director of the Laboratory for Atmospheric and Space Physics at the University of Colorado, Boulder, recently stated: "The continuing vitality of the U.S. space research program is strongly dependent on having cost-effective, reliable and readily available access to space. The lack of availability of a wide range of sub-orbital and orbital flight capabilities severely hinders the ability of the solar and space physics research community to carry out leading-edge science programs, validate new instruments and train new scientists."[9] He went on to state: "Small spacecraft missions can be extremely productive scientifically and can also provide a fertile training ground for students of science and engineering."…"To push back the frontiers of science, to train the next generation of scientists and engineers, and to help enable small, focused space missions we need access to space that is commensurate in cost with the payloads we are capable of building. The United States should use every method at our disposal to make this access to space a reality."

Where do the small R&D payloads "fit" into the overall Aerospace Industry? I maintain that they are the foundation of future space capabilities. Without them, there will be no new space technologies and the current space capabilities will be overtaken by newer and more effective approaches. Daniel Baker's comments above echo this sentiment for the space R&D community. To put this in the context of a business life cycle, if new ideas and innovations are not constantly being "incubated", then there is a cliff at the end of the business "cash cow" cycle that marks the demise of an industry. Competitors who have a better solution, as shown in figure 2 will almost always overtake a mature industry.

If we maintain a business as usual approach to Space R&D, then that is exactly where the US space industry is headed. Maybe this is just a natural evolution of technology cycles, like the Steam Age or Consumer Electronics. I for one certainly hope not when it comes to the US Space Industry.

11.0 Summary: Where Do We Go From Here?

The key points in this paper are:

We have a declining Space Industry in the US that does not conduct a sufficient level of space R&D to remain competitive in the International Space Marketplace. A major impediment to space R&D in the US is the lack of regularly available, scheduled space access opportunities for R&D (secondary) payloads. In order to correct the problem we need to:

1. Identify the "Big Gorillas" with funding and/or clout
2. You can't sell something to someone unless you are solving their problem(s)
3. Problem identification can be used to focus on selected organizations – with funding
4. Once the funded organizations are identified with the problems requiring smallsat solutions, they must be approached in the proper manner (proposal, briefing, white paper)
5. If a match is formed between the organization's problem and the proposed smallsat solution, then the organization can serve as the "first provider" for a standardized space access interface

6. Before the first provider has completed a successful mission with the standardized secondary payload interface, additional users and funding organizations need to be lined up to capitalize on the new space access capability

Where are the primary launch providers in this process? For the "first provider" application, they would be paid for all of the non-recurring engineering and procedures development to add the payload interface to a primary launch mission. Beyond the first paid mission there must be a business case established to keep the primary launch providers interested in and motivated to provide a regularly scheduled secondary payload launch interface (profit driven, government offsets, first user funding for non-recurring)

What are the missions that justify the first user? Two have been discussed in this paper as examples:

- Space radiation environment measurements – "seed" the Van-Allen belts with measurement instruments from a GTO launch – use novel de-orbit techniques to tailor the instrument orbits

- Large arrays in space – use constellations of small satellites to test our new concepts – evaluate the network/comm./position measurement issues before implementing in larger platforms

Many more mission examples exist among the smallsat community. Let's get the process rolling! I'm more than willing to serve as an interface to organizations I support (such as DARPA). Other organizational interfaces are needed. Time's a wasting….

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The Author

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