



Los Angeles Section and
Space Systems Technical Committee

Responsive Space Launch with the Scorpius Family of Low-Cost, Expendable Launch Vehicles

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Premise

Responsive Space (RS) – our industry currently does not have, nor is currently even able to support “responsive space”. In order to achieve Response Space, we cannot rely on Heritage Based Systems (HBS).

If we are to convert our industry with the capability of “RS”, then how does our industry think that we can achieve “RS” when stuck on heritage mentality that relies upon HBS components, processes, procedures and regulations? We cannot just start to produce HBS items and spacecraft with much greater efficiency, or greater performance.

Argument

Old techniques, old regulations, and old designs – Heritage - cannot fundamentally change from a mostly art business (sometimes Responsive in capabilities, non-responsive to cost and schedule) to an assembly line business which is responsive in cost and schedule, and still be hopefully configurable for ‘responsive requirements’. We try to mold ourselves away from the art business, to creating new space missions systems out of the heritage components and spacecraft. This is not optimal, nor is it practical.

This Paper’s Definition of Responsive Space

- 1) The ability of a Principal Investigator, Experimentalist, or a Commercial Venture to acquire the proper system to carry out the desired mission. Responsive in Capability
- 2) That there are existing products, or products that can be quickly developed that are can satisfy the mission. Responsive in Time
- 3) Ability to finance, and acquire the proper system. Responsive in Costs


1.0 First impediment to RS –Perceived Risk

Our industry has been able to convince most of the customers, Principal Investigators (PI's) or various mission program managers, that heritage systems are the least risk. We have stated that new developments are either very risky, or the risk is so high and vague, therefore unmanageable in the cost, schedule, and performance. We seem to insist on, and advertise all the wonderful benefits of Heritage. This concept may be true for a dynamic, high throughput very fast pace industry, where new products are being developed and interjected into the marketplace; but our industry is an art industry, and our time constant for new product implementation is mostly measured in years. Our goal should be to maximize science return and minimize risk, not maximize heritage and minimize perceived risk, and that is point. Heritage systems and components do have their place, and should be used if analyzed for a best fit to the system.


Systems designers and PI's routinely keep track of all the newer technologies in development and in qualifications, they read about them, keep apprised of them, but rarely recommend them for the space missions we are designing – let someone else be first. It takes us years to accept technologies that the commercial markets take months; lithium based rechargeable batteries for instance. We rate all the benefits with small weightings, such as Watt-hour/Kg, operational temperature ranges, prismatic form factors, and trump it with a high weighted rating for actual flight heritage “well, it has not been flown before” – even if the technology would facilitate the mission, and even if the technology has gone through a qualification program.

It will be very difficult for us to get to a dynamic RS industry if it takes us years to implement new technologies.

The two charts below come from a NASA briefing on the Indefinite Delivery Indefinite Quantity (IDIQ) program, and are examples of our industry insisting on ‘selling heritage’. Most all of our industry’s brochures also tout how wonderful the heritage items are, and even celebrate that the item has not been improved for years.



Introduction to Rapid



- Rapid II is the follow-on to the original Rapid Spacecraft Acquisition
- Purpose of Rapid II is to place Previously Developed Spacecraft Busses on Contract for Quick Access by Customers
 - Quick Access allows Payloads to mature prior to SC buy
- **Goal is to minimize Cost and Risk by utilizing Proven Hardware where Applicable**

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The comment on “minimizing cost and risk” should not be taken at face value. Newer technologies (almost always) are less risky once qualified, and costs less once the technological improvements are compounded at the systems level.



Maturity Bar (cont.)



- Some things we couldn't do ...
 - Different criteria for different “classes”
 - Accept anything but Flight HW for maturity evaluation
 - Accept a criteria that was open for interpretation
 - “Provisional Acceptance”

- **Bottom line, Our Customers expect Busses to have flight heritage!**

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The IDIQ program is a good and very useful program in itself, but many customers see this list, and other heritage items as a closed shopping list. We need to add all near term technologies and products to the shopping lists to ensure that the PI has the best choices to both maximize their science return and minimize their risk. If an IDIQ bus's requirements do not fit a science requirement, then the PI's are often encouraged to degrade the science mission to fit within one of the bus's capabilities. This leads to the 2nd impediment.

2.0 Second impediment to RS – we believe the first impediment!

Why does our industry and our customers believe that if some component or technology has not yet flown before, that it will not work? I would hope that we all had confidence in ourselves and in our organizations to build better products, year after year. Do we think that the market will not bear the costs or bear the risks, even when we can demonstrate that the risks and costs are less than the heritage systems? Accepting a new technological development does not mean that we do not do our ‘homework’. We still need to qualify the new products, and evaluate the specific use of the product for the mission. It just means that sometimes the benefits in performance and even costs outweigh the issues of the developmental risks.

We should all be striving to improve our products, our systems and our capabilities – we should advertise our “heritage between the ears” and our capabilities to improve our products. As designers, manufacturers and customers, we should insist upon at least 10% performance improvements of even the HBS, mass improvements, cost improvements (either in the profit or price or both). A simple example would be an LN-200 gyro with an option to supply it with only an unregulated voltage input (like most all other components sold), vs. the necessity to supply it with +/-15 and 5 volts. Not hard, but simplifies the system level costs of implementation (dedicated DC/DC converter in another subsystem, EMI on regulated distributed voltages, more wire harness issues, etc).

The problem of over-reliance on heritage causes us to propose an entire new space mission using almost all heritage components. We try to shoehorn in the ‘heritage’ items to new applications without really doing our homework to see if the new

application will really work for us. We have made mistakes on trying to put Guidance and Control systems designed for one rocket system, and installing into a newly designed rocket, performing the first level of analysis and declaring that it is good for launch. “Look at how much time and money was saved”, until the launcher goes unstable, and all the ‘homework’ and design effort saved, gets spent into the failure analysis report, plus all the loss of the rocket and spacecraft. We need to do a better job on investigating the risk of the heritage components, and how we are using the heritage components within the new design. – And we need to trade the risk of the heritage systems vs. the risk of a newly developed system.

The IDIQ charts above states the customer’s desires for heritage - we think that we are smart by not taking any ‘developmental’ risks at the proposal level. Though that is precisely the place where it ought to be taken, and even highlighted and celebrated in a way. The non-heritage should show how, in the development of the new product, that the final system is actually facilitated, and that the new development also makes the system more robust and less expensive at the program level. We certainly need to be smart about this, and the new development needs to have a strong relationship to improving the spacecraft or space mission at the system level. We need to show that we are trying to maximize the science/dollar or mission/dollar returned, versus maximizing the heritage content.

Developing new capabilities and products are totally different from the development of basic research products. Basic research is not manageable in the time and dollar frameworks which we produce our products for RS, so we should not equate the two. The PI’s also do not want to spend resources ‘improving’ items that have diminishing returns for the improvements. It comes down to our ‘managing available resources’ at the project level. We certainly need to educate ourselves, and our customers of what the risks are at the project and development level, and we need to show how to mitigate the risks to attempt to maximize the customer’s return on their investments

2.1 What happens at the new RFP mission proposal level?

The company or organization that performs enough systems engineering to show that the ‘heritage based system’ is plausible, and then builds their proposal around this heritage. If some component is absolutely necessary, and the component does not have heritage, we try to ‘link it’ somehow to heritage; and describe all of the necessary steps to qualify the component. Once the organization wins the proposed ‘heritage’ system (because most of the competition also proposes heritage), the detailed systems engineering, and the science mission analyses are performed. The detailed results often show that the mission will not work as originally proposed.

What happens next? One or several ‘bad’ things happen.

- 1) Most often - one of the science instruments are thrown off the mission, or
- 2) The science is degraded by lack of the supporting systems, or
- 3) The Mission gets stretched out to accommodate developing new components that would take the place of the heritage system, or
- 4) Mission is re-vamped and/or de-scoped, or
- 5) Mission gets cancelled

All the above is certainly bad for the science return, and a lot of money is spent even getting to the risk mitigation / de-scope options. Whereas we should see if any new

developments could actually fix the proposal and the system and the monies being spent in options of de-scoping would be better used for investments in newer products and capabilities that could hopefully get us to a robust RS infrastructure.

3.0 How do we get there (RS) from here (HBS)?

We have two problems that affect our industry's ability for Responsive Space:

- 1) Lack of applications & customers to drive rapid investments
- 2) Lack of modern infrastructure & personnel in the near term- even if the applications presented themselves (see Commission on the Future of the United States Aerospace Industry Report, November 18, 2002).

Although our industry does have many new applications and new technology initiatives from many US Government organizations (USAF, DARPA, NASA, others) and a great government sponsored Small Business Independent Research (SBIR) programs, the integration of the technology improvements into mainstream programs is often measured in years (if at all). There are many examples of faster inclusions, but the industry in general is reluctant to use new products (unlike most all other industries). Some of our technological experiments can sometimes be 'obsolete' by the time we use them on operational systems.

The Space Industry has few space mission applications that make financial sense once one performs realistic Return On Investments (ROI) analysis. Many applications can be made to look good in a static sense, though the years of development, and the years it takes to improve the fielded systems do not lend themselves well for commercial revenue streams.

3.1 Production Infrastructure concerns

We rarely have the monies to 'tool up' for the assembly lines needed to drive costs down, nor to drive up availability by building up an inventory in anticipation of sales. We do not have a 'responsive space' capable industry; we only build one or two units at a time under an executed contract. We also do not have sufficient applications for space utilization in anticipation for emerging markets as we had thought we had with respect to personal communications systems like Iridium, GlobalStar, and expanded military space markets.

Other problems with competing in the space commercial market, is the direct competition with the commercial terrestrial markets. The terrestrial markets' ability to get to market, to infuse new technological advancements, and to finance further improvements make a competing space based equivalent system mostly impractical.

That leaves only business plans that the space market can compete that the terrestrial markets are unable to compete. Broadcasting, remote sensing, space science and exploration, and some communications are the primary moneymakers for our industry.

The impediments, in the economic sense, is - if we tool up for assembly line production without known applications, we cannot sell enough products to retire the infrastructure and sunk costs. If we do not tool up, then we cannot insist that our products will become inexpensive, or timely. The business cases do not close in a

general sense, only closes in some of our niche markets. The recurring '\$5,000' flight computer cannot be developed in this type of market. The environmental testing alone often costs more than \$5,000 in test labor.

Some spacecraft lines and launch vehicle lines can be classified as 'commodities', so the assembly line analogy almost works, though the lack of the number of customers to buy the output of the assembly lines make quantity buying and economic savings by 'production of scale' problematic.

3.2 Comparing our Space Industry Impediments

In the space industry, it is rather unfair to compare satellites and launch vehicles directly with the automobile, computer or aircraft industries. This comparison is unfair because of the following reasons:

- 1) 'Art industry' vs. consumer-production commodity industries; one rarely builds a 2nd or a 3rd spacecraft similar to a previous one. It costs Ford, Dell, Toyota, and Intel millions of dollars to build their next new model.
- 2) Companies rarely build any space-qualified items in anticipation of customers. We build only after we get an order; and ones that did, mostly lost money.
- 3) We do not even buy the design 'off the shelf'. We often insist on changes, and pay for the Non-Recurring Engineering. Rarely do we send out Purchase Orders for components. We send out Specifications, Test Plans, "CDRL's", a list of referenced documents etc, that the vendor has to conform to
- 4) Regulations (safety, NTIA, Environmental Impact, ITAR...) other industries do not have as many stringent, or as many restrictions
- 5) Limited competition, so lack of sheer volume of creativity and product improvements.
- 6) Not many choices of designers, and most customers insist on heritage, so designers do not have as much to 'design'.
- 7) Insistence on heritage by the PI's are limiting and narrowing the differences amongst the bidders.
- 8) Our industries' cautiousness and Risk Aversions, and the leap to the assumption that Heritage Items are less risky than new systems.
- 9) Limited customer/financial base. Not many customers. Some Scientific, some Governmental, some international collaboration, and some commercial. Though most commercial space is tied to the GEO broadcast markets. Average launches worldwide is 1/week, sometimes with multiple spacecraft per launch, and it is a declining market. See table 3.2-1 Order of Magnitude current Production.

Finished Product	#/week world-wide manufactured	Comments
Computers	2,800,000 per week	Stable market / market share & new capabilities
Automobiles	~900,000 per week	Reasonably Stable, Market share changes
Aircraft	150 per week	~400 per week 1978
Launch Vehicles	1 to 2 per week	~Stable at the 1/week
Spacecraft	1 to 3 per week	~Stable at the 1/week; searching for new viable applications

Table 3.2-1 Order of Magnitude of current Production.

Where there are dozens of re-useable planes being produced everyday (commercial, military and private), our industry is producing and launching space vehicles less than 2 per week, and the rates have been declining, see Table 3.2-2 Spacecraft Market averages.

Year	# of Spacecraft	Average / week	Notes
1996	133	2.6	
1997	186	3.6	Iridium's/Globalstar's
1998	183	3.5	Iridium's/Globalstar's
1999	140	2.7	
2000	133	2.1	
2001	87	1.7	

Table 3.2-2 Spacecraft Market averages.

Since our Space Industry is so different in production and application, we should only use the comparisons to other industries' development costs to show, in a contextual sense, how they compare to what we do, and not on how we should do it.

If this industry were at all like those industries, we would not need to have this conference. We really do not have the customers similar to those industries that would drive that kind of competition, assembly lines and the very wide range of capability and configurable products with commodity type prices.

Bottom line is, we need more reasons that are economically viable to go to space & we should foster any new ideas with modern development and future technology, and not on rely on 'heritage'.

3.3 Making the Space 'Art' Business Responsive, without production lines

The space industry is primarily an art industry, with no truly 'off the shelf' hardware or systems ready to be configured for your application. We have 'off the shelf designs' that may or may not be configurable, but we rarely build up an inventory of any of the products on anticipation of orders. So, when buying a Heritage based component, the delivery is dependent on NRE design changes, parts purchasing and delivery lag times, board build up and test time, component build up and test time, and final

performance calibration and delivery acceptance. This generally takes the better part of a year, as long as the NRE is not of great complexity.

In order for our industry to compress the time of delivery (being responsive in time), compress the time to implement technological performance (responsive in capability), and compress the total system costs (responsive to PI's budget), we must use as many non-proprietary systems and commercial standards as possible.

As Space professionals, we should spend our focus on the requirements, the environments, and the uniqueness of the mission. We should also attempt at every subsystem to strive for the lowest power consumption components and operations methods as possible, for in most cases, power consumption drives the mass of the spacecraft.

Guidelines to Responsive Space

- 1) Stay away from Closed Proprietary Systems (further limits competition)
- 2) Use Commercial Specifications wherever practical
- 3) Use Commercial Interface Control Documents
- 4) Use Lowest Power Consumption devices and methods.
- 5) Focus on robust single string systems for severely cost constrained missions
- 6) Manage your risks, invest in new technologies that minimize the power and number of components at the system level
- 7) Make sure that there are sufficient people with "Heritage between the ears" performing much of the new mission's analysis and new technology development.

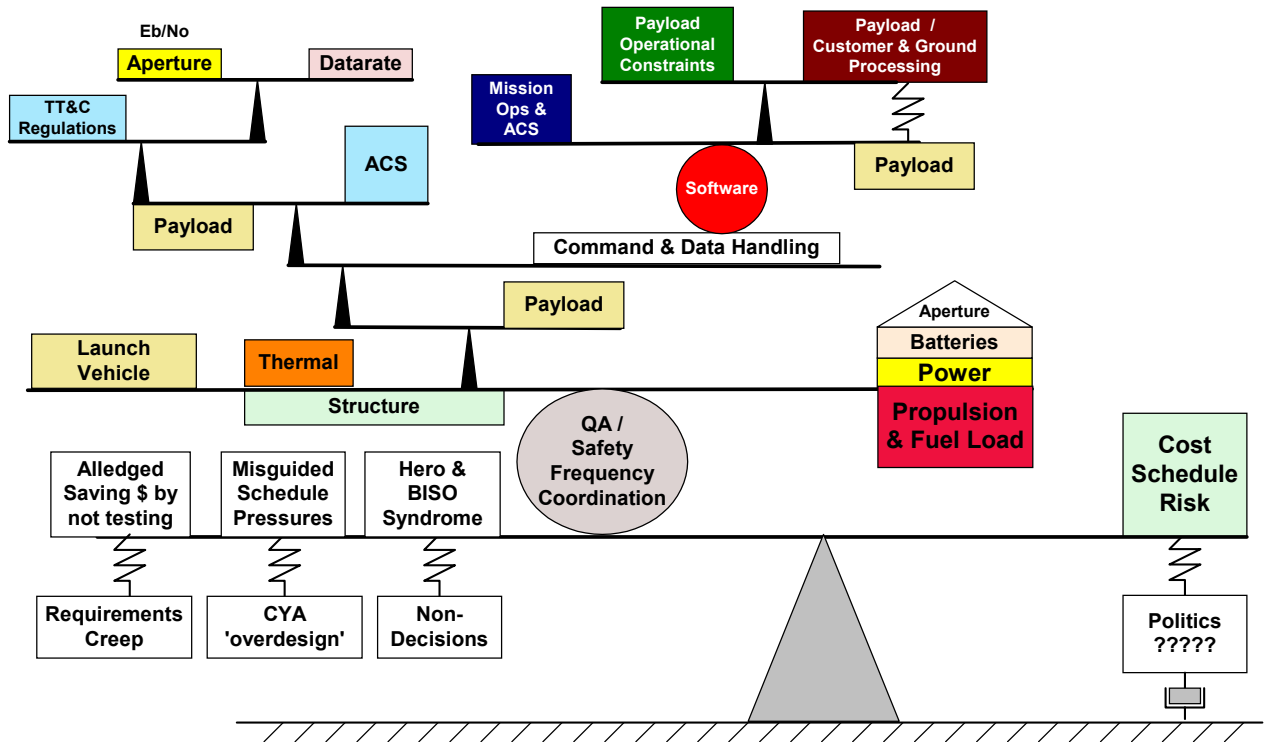


Figure 3.3-1 ‘Non Classical’ Systems Diagram

Figure 3.3-1 depicts most of the classical subsystems space mission’s interplay. This is a conceptual chart and relationships amongst the items can be moved for specific missions. The goal of this chart is to show the interplay and complexity, and the need to simplify the system as much as possible. Simplifying saves time and money while also increasing robustness. System’s designers cannot just be “mass/power/volume” accountants, they need to be integral into balancing and simplifying the system. The first attempt at achieving RS is to start with an analysis of the system, and to attempt to minimize risk. HBS could be a part of the equation, though if relying only on HBS, would severely limits any possibility of simplifying and achieving RS. We should remember that the PI’s primary concern is to obtain their data from their instruments onto their workstations. Everything else about the space mission and spacecraft to the PI’s are either academic, expensive, or just a “necessary evil”.

From the start of any program, one should try to minimize power consumption, which is the driving force behind the dry mass of the system, and the dry mass drives the fuel load for a fixed Delta-V mission; which all in turn, drives the size of the launch vehicle. Some investments in new technologies alone can more than pay for themselves if they enable a smaller launch vehicle.

We should ensure that all of the ‘circles’ above are settled - regulatory and safety items approved, and that software tasks are defined in a way that they can get completed. Finally, be cognizant of the organizational and personal dynamics of the mission and delete all non-essential Requirements Creep as soon as possible.

3.4 Examples of new technologies that are facilitating missions:

It is not that our industry has not been making progress in many subsystems, we have - we have just been slow implementing the improvements. There are many current pushes of technology for further integration of function, and we should use them on our next round of mission proposals.

Higher FPGA gate count allows the industry to use a single 3U cPCI board, that 5 years ago took two or three 6U VME boards. Lithium batteries are just finally flying in limited applications, MEMS technologies for IMU's and accelerometers. Faster processors, higher data rate transmitters, higher efficiency solar arrays and more. Other task of which some progress has been made is to achieve the "Spacecraft on a Chip" (SOC), is to try and combine functions into a single device. Our industry has made 'software radios', Integrated Avionics, combined payload and spacecraft avionics and software, as well as made much progress in higher I_{sp} fuels and thrusters.

To further speed up the technological improvements, we should add timelines and categories to the NASA's Technology Readiness Level to start retiring some of the older technologies. A suggestion is in Figure 3.4-1 below.

Technology Readiness Level - Extended

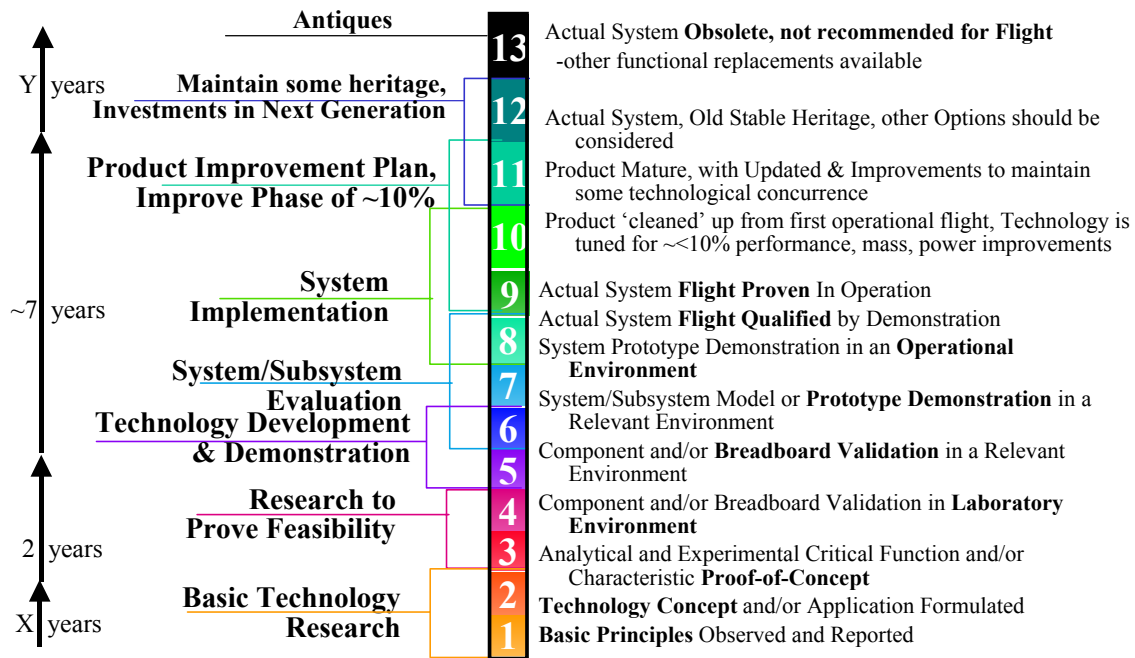


Figure 3.4-1 Extended TRL diagram.

Conclusions

Using new technology gets you closer to Responsive Space. Smart investments in new technology, properly applied, can reduce your risk, simplify your system, and can reduce your costs and schedule.

Try and maximize the science or mission return by calculating parameters such as Science/\$; Science/Kg, Science/watt, Science/bit received. Try to refer everything about the space mission back to the primary objectives.

Though heritage based systems, processes and components may work for your mission, your budget, and your timeline, newer technologies may still be a better robust option, as well as possibly leave more money for your science.

Bottom line is – we cannot improve just using heritage. Only new concepts, new products, and new processes will enable us in making progress toward Responsive Space.