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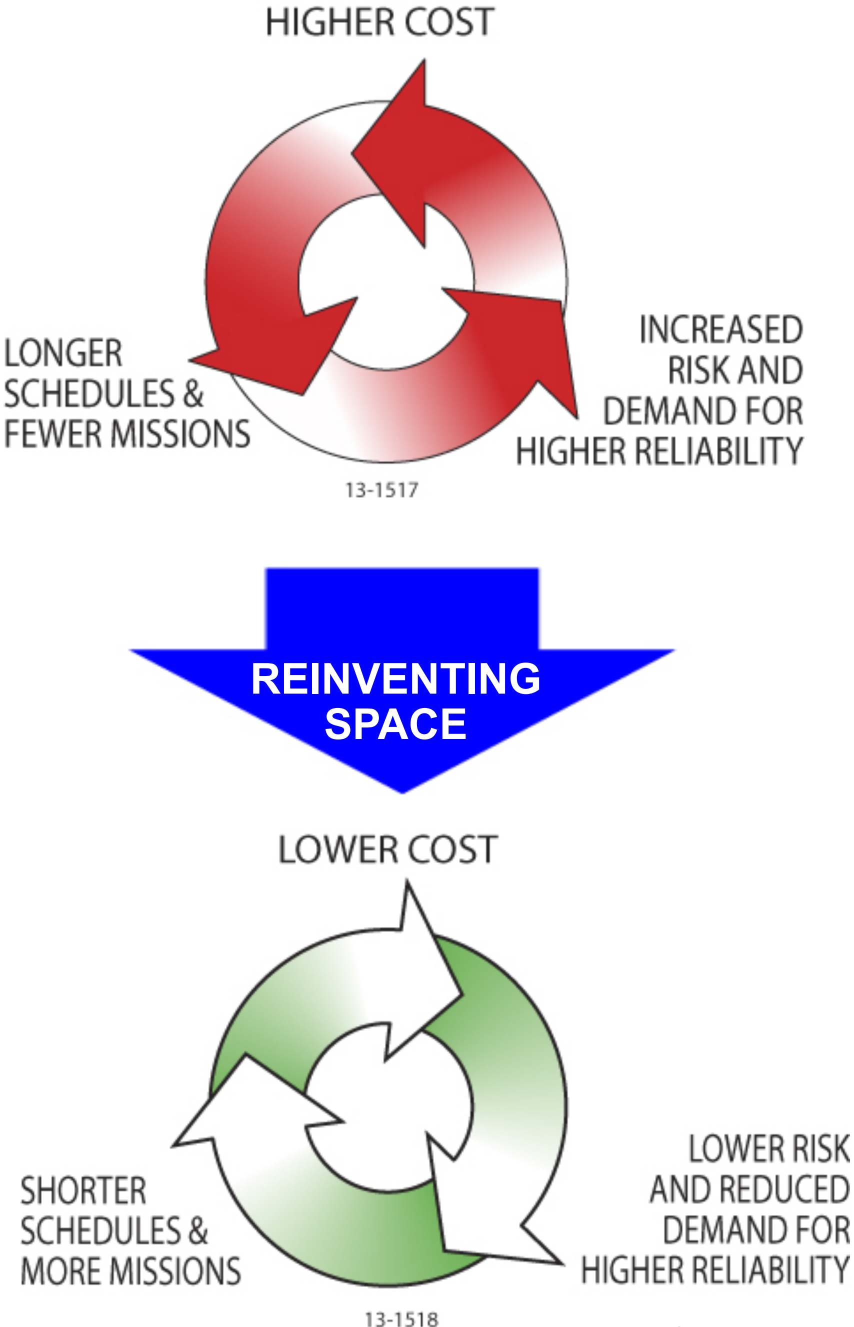
Space 2018

The Need for Reinventing Space



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Topics

- Summary
- What is Reinventing Space?
- Why do we need it? What's the Problem?
- Reinventing SMAD
- FireSat reinvented
- Can it be done?
- How do we get started?
- For more information

Summary

- A while back a billionaire was considering rebuilding the Titanic – start from scratch and build it again for $500M
- For $500M you could rebuild the Titanic or buy a spacecraft that would fit nicely on a small conference table
- This illustrates the ***Need for Reinventing Space***:

Traditional Space Programs often provide exceptional results, but

- **They cost too much by one to two orders of magnitude**
- **They take too long by a factor of 5 to 10 and, therefore, don't keep up with rapidly evolving technology**
- **They are high risk – both at launch and due to vulnerability to enemy attack or debris collisions**
- **Because they are not responsive, they have to cover all the world, all the time, with whatever sensors we will ever need**

Other than these small problems,
traditional space programs work pretty well.

What is Reinventing Space?

What is Reinventing Space?

- In my view, ***Reinventing Space*** means combining the current dramatic advances in microelectronics, software, and material science with the goal-oriented, much more driven spirit of the Apollo, Explorer, or Corona missions to create smaller, much lower-cost, more responsive, and more robust missions
- In short,

***Reinventing Space* is using modern technology**
and old-fashioned determination
to do much more, much faster, with less $$$
and, ultimately, at much lower risk

- Achieving all this means creating what I call ***Mission Diversity***—a mix of large, typically expensive systems and smaller, quicker to build and launch, more flexible, easier to incorporate newer technology, and **much lower cost, more responsive systems**—the PT boats of space, in the words of Doug Loverro

If we fail to do this, I believe that we will lose our dominant position in space and will fail to meet our obligations to the scientist, the military, and the American public.

Is This "Faster, Better, Cheaper" Reincarnated?

- In some ways, Yes, but with two major differences:
- **The problem today is substantially more acute**
  - Space systems are in demand today more than they ever have been
  - In recent years, major DoD and NASA space programs have overrun by billions of dollars—and it's getting worse, rather than better
  - To be relevant today, systems must be responsive in hours or days, not months, or, more commonly, years or decades
- **The technology is available to make it happen**
  - Microelectronics are dramatically increasing the capability of smaller, low-cost spacecraft
  - New, far more capable sensors are becoming available
  - Computer technology and software are allowing major advances in on-board processing and, therefore, small satellite capabilities
  - Advanced materials technology is creating a new realm of lighter, stronger spacecraft and launch vehicles, enabling new mission concepts
  - Advanced productivity tools are available

The now famous retort
"Faster, Better, Cheaper, Pick any Two"
is Bull.

Why Should We Reinvent Space?

What's the Problem?

What's the Problem

- In the last 10 years, the United States launched about 20 space missions per year
  - **The combined US space budget (NASA, DoD, the Intelligence Community, and a few others) is on the order of $60 billion/year**

Over the last 10 years, space systems launched by the United States have cost an <u>average</u> of $3 billion per launch (including infrastructure costs)

No one knows the average time, but it's certainly approaching a decade, and likely longer

- <u>That' s too much and too long and fixing it is going to require that we truly work hard to fundamentally change the way we do business in space</u>
- In my view, many of today's space programs behave like a herd of brontosauruses nibbling on the water lilies at the edge of the La Brea tar pits in LA -- simply ignoring the problem around them

We don't want to come out of this looking like the ground sloth or the Columbian Mammoth in the Page Museum at the tar pits — they're extinct today.

Why Do Space Programs Cost So Much More Than Rebuilding the Titanic?

- Maybe our programs cost so much in order to achieve 100% mission assurance —but that hasn't happened
- **Traditional "mission assurance" focuses on the spacecraft and launch system to ensure that they will always work, but the real mission assurance is whether the information is available when the end user or person in need of help needs it**
- Potential mission failure from multiple sources cannot be eliminated
  - Launch failures (OCO, Columbia, Glory) — on the average, 10% of launches fail
  - System failures (USA 193)
  - Collisions (Iridium 33/Cosmos 2251 which left millions of untrackable debris particles)
  - Operator errors (Huygens Titan probe wind experiment, Mars Climate Orbiter)
  - Assembly errors (Genesis)
  - Data unavailable due to cost or schedule overruns or program cancellation
    - Extended delays (Chandra, JWST)
    - Program cancellation due to cost (T-Sat, Constellation)
- **This means that systems must be sufficiently low-cost to have back-ups**

To the end user, it doesn't really matter whether there was a parts failure, a system failure, the program was delayed, or it was cancelled —
The system has a reliability of ZERO for every day the data isn't there.

Even if We're 100% Successful, We Lose

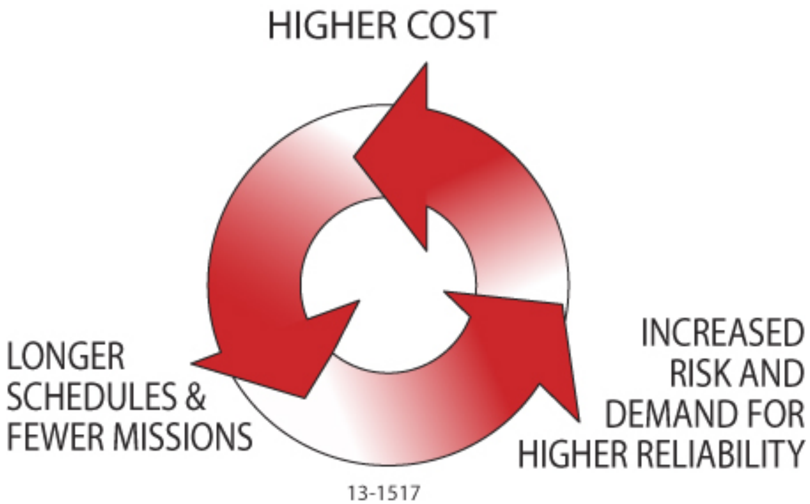
- For traditional LargeSats, the consequences of a launch failure (Glory), system failure (USA 193), collision (Iridium 33/Cosmos 2251) or enemy attack (Chinese ASAT) are that the asset isn't available for any current need and takes years and lots of $$$ to replace, if it's ever replaced
- **In addition, 15 years after a successful launch of a traditional large satellite with <u>no</u> on-orbit failures, <u>no</u> system failures, <u>no</u> assembly or operator errors, and <u>no</u> collisions, we have**
    - **A satellite built with 25 year old technology to meet 25 year old mission needs and trying to cover the entire world**
    - **No production line and no one who knows how to build a replacement**

Culture is dramatically hard to change and the current culture wants to guarantee that each individual spacecraft will succeed, rather than allow options or back-ups to current, very expensive space assets.

This has created a system that is too expensive, too fragile, too slow, and not responsive to changes in the world around us or to advances in technology.

How Did We Get Here in the First Place?

- In the Apollo program we put a man on the Moon in 8 years, including building the largest (and most reliable and lowest cost/lb) rocket ever built
- Today it takes 8 yrs to get a program underway and 10–20 yrs to get a satellite on orbit
- Why?
  - The **Space Spiral** at right drives both cost and schedule



- **Nobody starts out to create an expensive, long term program with cost and schedule overruns, but we get there much of the time**
  - Essentially everybody is trying to do a good job within the constraints they have — but that doesn't necessarily meet the needs of the warfighter, mitigate the modern terrorist threat, or get us to Mars in the near term
- The Space Shuttle was originally sold as being able to reduce cost to $10M/launch (~$30M in today's $$)
  - At the end of the Shuttle program, it cost about $1.3 billion/launch, not counting repaying any of the $50 billion non-recurring development cost

The current constraints, oversight, and processes have been put in place for good reasons, but that doesn't mean they shouldn't be changed or abandoned.

Welcoming Chart from RS1, April Fool's Day, 2003, titled “The Challenge for Today”

“I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to Earth.”

– John Kennedy, before a joint session of Congress, May 25, 1961

“The U.S. Air Force has kick-started a major study on quick-to-launch boosters capable of enhancing the nation’s warfighting abilities,... Given a Pentagon go-ahead and funding, the Air Force could first fly a multi-stage system by 2014.”

– Leonard David, in *Space News*, March 28, 2003

“If it takes us 11 years to create a Responsive Space capability, we all oughta find a different line of work.”

– Jim Wertz, Challenge to the First Responsive Space Conference, April 1, 2003

It's 2018, and low-cost, quick-to-launch boosters and the low-cost spacecraft to put on them are still a bit hard to find.

The Famous Words of Walt Kelly

- We have created the circumstances which have allowed both cost and schedule to spiral out of control

- It should reasonably be our job to fix it

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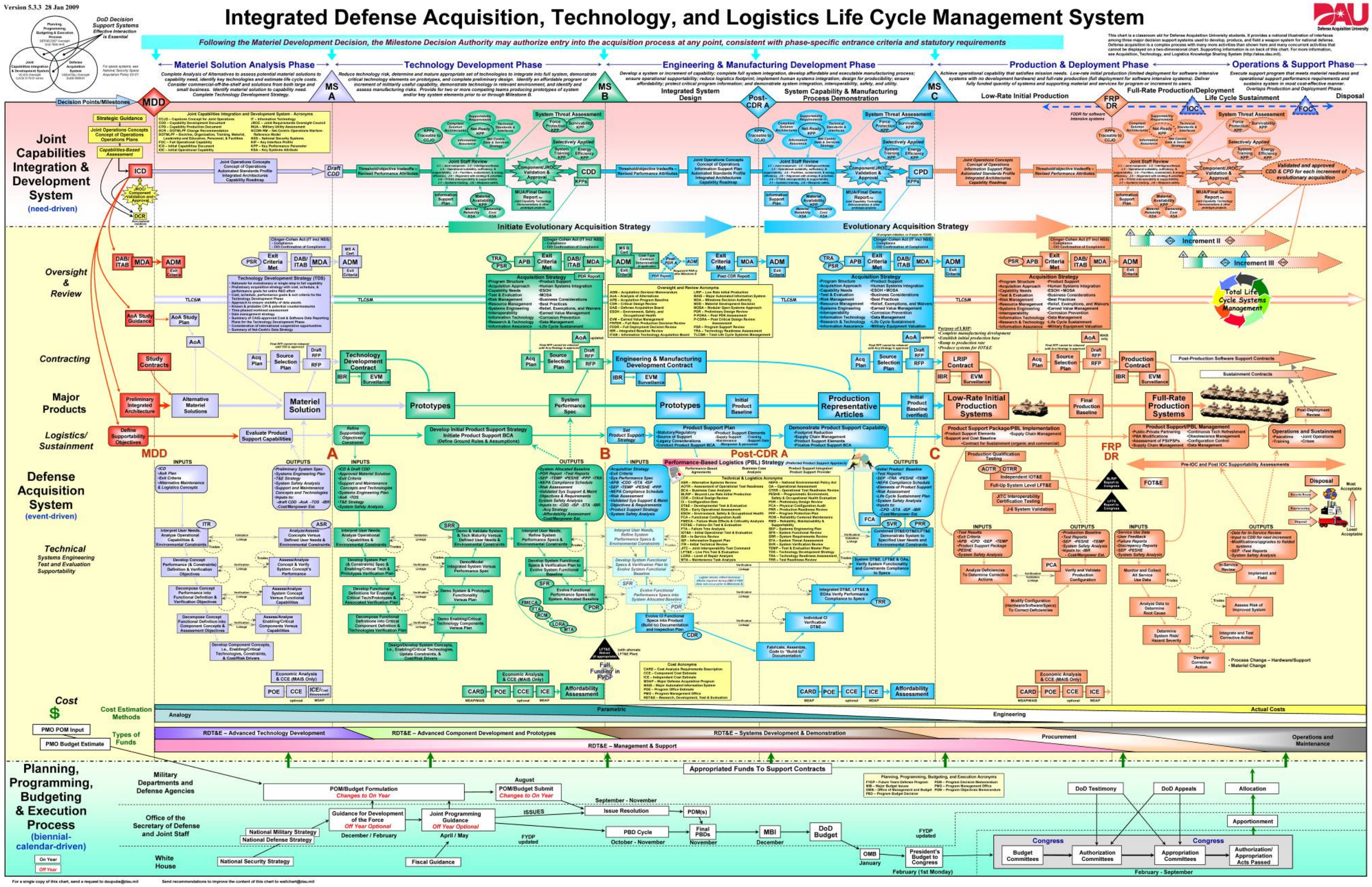
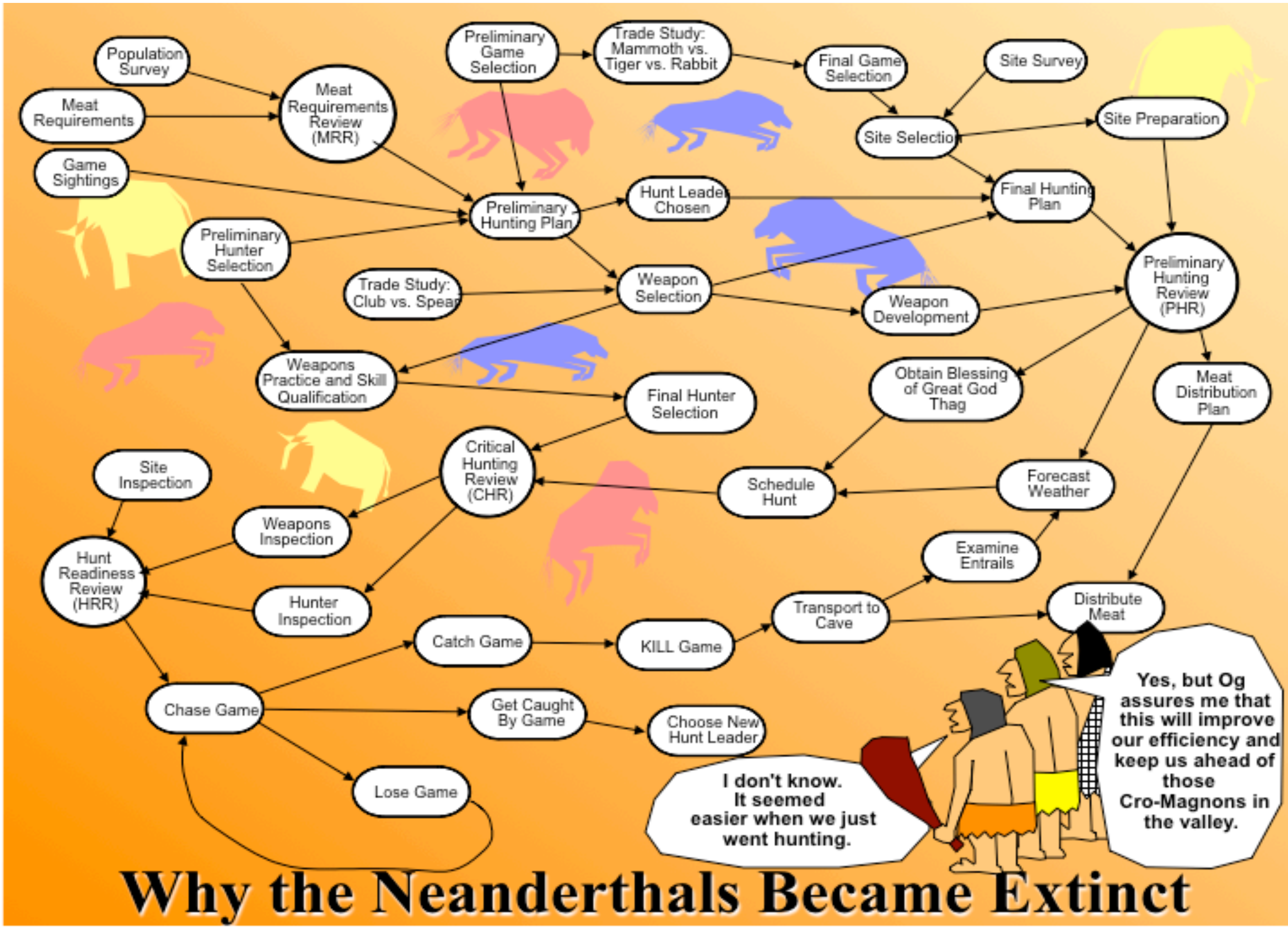
The DoD Acquisition Process

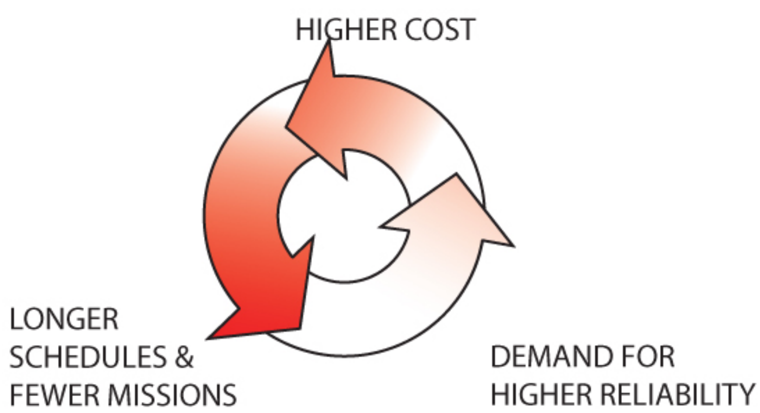


It is probably impossible to get from the upper left to the lower right in one human lifetime.

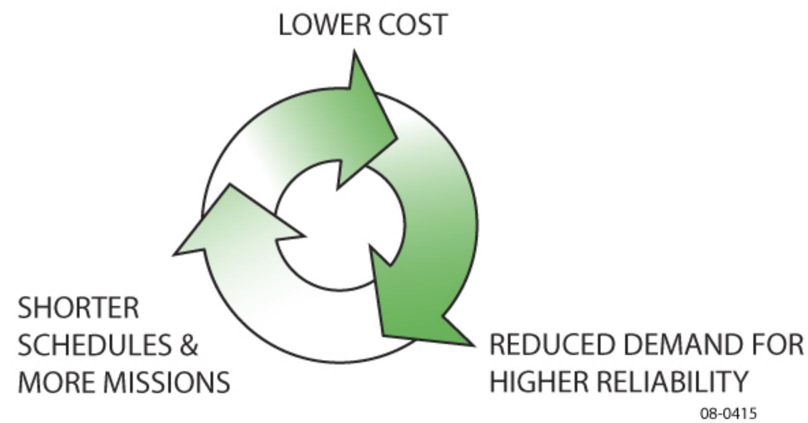
Another View
of the Federal Acquisition Process



Our Goal Should be to Reverse the Space Spiral



(A)



(B)

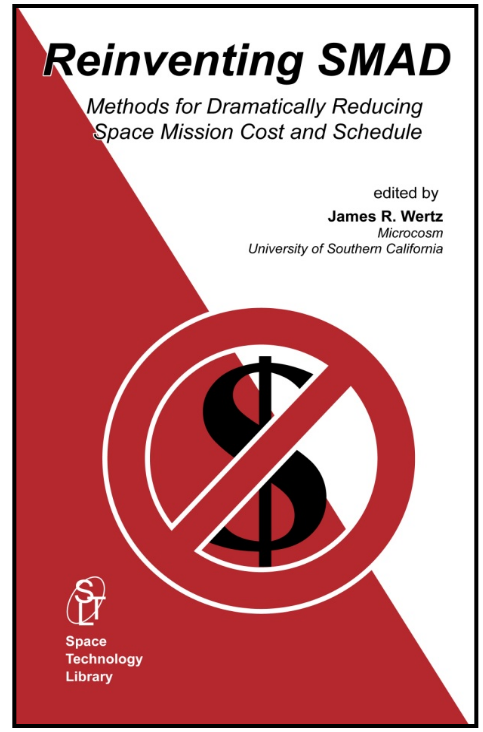
- What do we want to do?
  - **Reduce mission cost — by a factor of 2 to 10**
  - **Shorten schedule — from decades to years or months**
  - **Build smallsats and small launchers to inventory for launch-on-demand**
  - **Increase the number of missions (by a large amount)**
  - **Reduce the demand for 100% reliability on each flight in favor of mission reliability**
  - **Create a system that is more flexible, less fragile, less vulnerable, and far more responsive to the needs of industry, the government, and the end user**
  - **Create sustainable, ongoing business opportunities**

We want a practical and pragmatic program aimed at creating high utility, much lower cost, more rapid, robust, and responsive space missions.

Reinventing SMAD

We Also Need to Reinvent SMAD

- The book ***Space Mission Analysis and Design***, ***SMAD***, first appeared in 1991, and set out the broad process of defining and designing robotic space missions
  - In many ways, SMAD became the de facto standard used throughout the world
  - In 2011, we updated SMAD to ***Space Mission Engineering, SME***—"the process of defining mission parameters and refining requirements so as to meet the broad and often poorly defined objectives of a space mission in a timely manner at minimum cost and risk."



- ***SMAD and SME are about engineering and our goal here is to dramatically reduce space mission cost and schedule which is about more than just engineering***
  - It's also about attitude, personnel, programmatic approaches, the acquisition process, perceived risk, and a willingness to look at ways to share cost or generate income
  - ***Reinventing SMAD, R-SMAD,*** is the process of going about changing how we do business in space in order to achieve our objectives

We want to look at something broader than space mission engineering per se. We want to Reinvent SMAD in order to create newer, more useful, lower risk, more responsive, and much lower cost space programs.

FireSat Reinvented

- SMAD and SME used an example mission called FireSat
  - The goal was to create a small, low-cost mission to support forest fire detection and monitoring throughout the US, possibly throughout the world
  - FireSat took images of forest areas and sent them to a central ground station, where fires were identified, and the forest service was notified
  - The end user that needed the data was a firefighter in a pick-up truck with a shovel in the back that wanted to know where the fire was and where it was headed
  - **The cost estimate was $300M to $400M for two "low-cost" FireSats**
- **FireSat Reinvented is a smallsat with a total on-orbit recurring cost of $7M to $10M**
  - **Forest Fires are detected on board the spacecraft**
  - **Geographic coordinates of the fire (and other fire data) are sent from FireSat to the end user's iPhone for display in real time on his or her FireMap App**
    - **Total message is a few kilobits**

We're not there yet, but we know where we want to go, and we're not far away.

Can It Be Done?

Can We Really Dramatically Reduce Space Mission Cost and Schedule and Improve Mission Reliability?

Absolutely

- It is not easy, but using a combination of modern microelectronics, modern software, design for manufacturability, low-altitude smallsats as supplements and tech demos, and other other techniques

We can maintain or improve performance and dramatically reduce cost, risk, and schedule

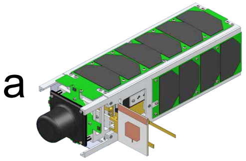
- To achieve this, we need to
  - Fund new approaches (they are very low cost, but not free)
  - Create low-cost, responsive launch (also very low cost)
  - Embrace new ways of doing business in at least some elements of the space program

Greater use of smallsats is 1 of approximately 150 techniques for reducing space mission cost and risk.

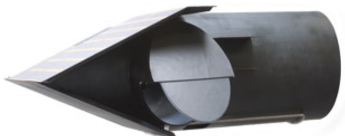
Many methods are available. In some way, they all require changing the way we do business in space.

Examples

- Traditional space systems are designed and built by some of the best and most capable engineers in the world
  - **You can't get the same spacecraft, built the same way, for far lower cost**
- **However, there are many examples of high utility, much lower cost systems:**
  - **NigeriaSat** (~$10M), part of the Surrey Disaster Monitoring Constellation, took the first photos available from space of the aftermath of Hurricane Katrina
  - RadCal was a very low cost ($10M) radar calibration mission of the 1990's -- now replaced by U of Hawaii **Ho`oponopono** mission for $0.1M
  - **NanoEye** Earth observing system ($2M) has comparable performance, greater agility, and far more maneuverability than GEOEye-2 ($800M)



Ho`oponoponno

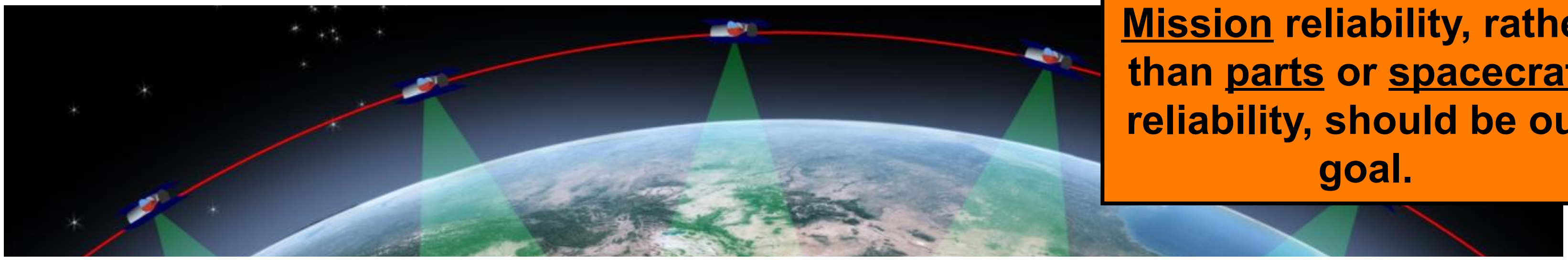


NanoEye

- **Better performance for less mass and less $$$ is common in all modern electronics -- TVs, phones, tablets, and toys -- it can also happen in space**
- **Recent USC study shows that for Earth observing systems you can get the same performance at far lower cost and risk by flying at lower altitudes**
  - Also mitigates the problem of orbital debris

Dramatic space mission cost reduction is not easy, but it is possible. The best result is most likely a mix of very low cost smallsats at low altitudes plus somewhat lower cost, more capable traditional systems at higher altitudes.

Advantages of Using a Responsive SmallSat Constellation to Supplement or Augment Traditional Systems



Mission reliability, rather than parts or spacecraft reliability, should be our goal.

- **Nearly 100% mission reliability because of graceful degradation plus rapid replenishment**
  - A SmallSat lost for any reason represents only a partial loss for the constellation
  - SmallSats can be replaced essentially immediately to restore lost capability
- **Can launch in time to impact the outcome of current world events**
- **Provides capabilities, such as persistent surveillance, that traditional systems can't**
- **Can rapidly incorporate new technology**
- **Very low risk** (recall that risk = probability of failure x cost of failure)
  - Spacecraft cost (both in $$ and schedule) is very low and problems can be fixed
- **Reduces the need for on-orbit spares**
- **Can create new systems on a dramatically shorter schedule**

A low-cost, SmallSat constellation can reduce mission cost, risk, and schedule and increase mission reliability, robustness, performance, and responsiveness.

Rapid Reconstitution and Resilient Space

- Responsive Space is not required to achieve Resilient Space
  - We could, for example, build spacecraft and launch systems that never fail and cannot be shot down, but historically that option has been expensive and less successful than we would like
- Deputy Director of the NRO and former SMC Vice Commander, Brig Gen Mark Baird, has expressed a strong interest in Rapid Reconstitution
  - **"Having a bad day, does not relieve the mission commander of the duty to deliver the data that they were assigned to deliver"**
- **Rapid Reconstitution is the best Resilient Space**
  - Does not need to reproduce the original satellite, but does need to reconstitute the most important elements
  - Needs to be low cost in order to be practical in today's cost constrained environment

Being able to launch a replacement spacecraft in a day and at low cost is the most effective resilience available.

The Value of Responsive Space

Go from:

Cover all the world all the time with all of the sensors you might want.

To:

Put the sensors you need where you need them, when you need them there at low cost.

How Do We Get Started?

How Do We Get Started?

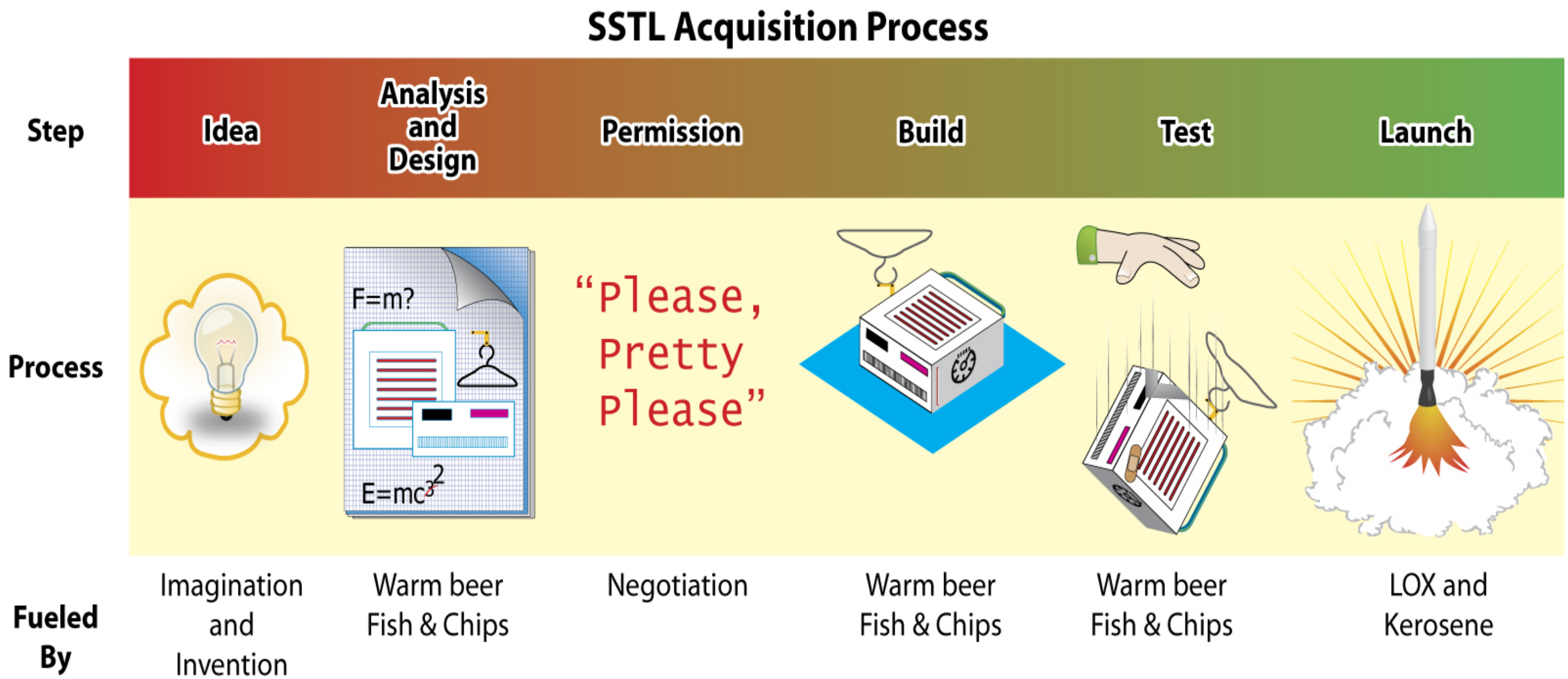
- **The key step in reducing cost and schedule is to <u>get started</u>**
  - Program managers are much too busy (remember the DoD acquisition chart) to take the time to figure out how to reduce cost and schedule
- How do we get underway?
  - **Recognize that the need is real**
    - There are lots of reasons to not do it, but none that are compelling
  - **Start a cost reduction program and fund it**
    - Everything costs money to get started, cost reduction is no exception
  - **Make it a priority**
    - Containing cost is always a priority, but usually the last priority
    - The first priority should be "meeting most of the broad mission objectives in the near term at dramatically lower cost"
  - **Make it somebody's job to see that it gets done**
    - If it's not somebody's job, it never gets reported up the management chain
    - It has to be important to senior management, or it won't happen

The Right Attitude

- For over 25 years, the leader in very low cost, capable missions has been SSTL (Surrey Satellite Technology Limited) founded by Sir Martin Sweeting in 1985
  - What has kept them on top for that extended period?
    - They have excellent engineers and managers, but so do lots of companies
  - The major difference has been their attitude
    - They take great pride in creating very low cost, capable space systems and are anxious to compete in that arena with anyone
- Creating the right attitude
  - **Make reducing cost important** – to the engineers, the managers, and the customer
  - **Avoid "Designing to a Reliability of Zero"**
    - To the soldier who was killed because the system wasn't there, it doesn't matter that it would have been a great system when it was finally launched
    - "For every year the system isn't there it has a reliability of zero" ["Design for a Reliability of Zero," Mike Hurley and Bill Purdy, NRL]
  - **Recognize that reducing cost has a price** – nothing comes for free
  - **Recognize that virtually any technique can increase or decrease cost**
    - We have to look for the intelligent compromise that meets our objectives

The most important element in reducing cost is the attitude of the group that's doing the work and that of the people they report to.

The SSTL Acquisition Process (My View)



In the end, we need to change not only how we build spacecraft and launch systems, but also the mission analysis and design process and how we use space systems to meet the needs of the end user. (It's all about the firefighter in the pickup truck.)

Conclusions

- Our original objectives can be accomplished:
  - **Reduce space mission cost — by a factor to 2 to 10**
    - **Initial cost reductions within 12–24 months**
    - **Major reductions within 24–36 months**
  - **Reduce the schedule for new programs — from decades to months or years**
  - **Reduce the cost of access to space — by a factor to 2 to 5 initially, 4 to 10 or more in the longer term**
  - **Provide responsive launch (within 8–24 hours) for natural or man-made disasters**
  - **Provide frequent, low-cost access to space for education, innovation, and testing**
- How do we do it?
  - **Begin a proactive program to drive down cost and schedule**
  - **Make it somebody's job to see that it gets done**
  - **Use new, much lower cost technology, strong system and mission engineering, and learn from the experience of others**
  - **Try a capabilities based design, rather than a design to requirements**

Bottom Line – the Need is Real and It Can be Done.
What's required is a change in culture – and that's US.

Sources of Additional Information

Sources of Additional Information

- The cost reduction methods summarized here are from the text and reference, ***Space Mission Engineering: The New SMAD***, which provides additional details on all of the methods
- An updated version listing about 150 approaches in multiple categories is contained in the paper ***"Methods for Achieving Dramatic Reductions in Space Mission Cost"*** available on the Microcosm website, www.smad.com/Space2018Conference. A sample of these methods related to Systems Engineering is in the next 2 charts. This briefing is also there.
  - Another round of updates is in process for the forthcoming book ***Reinventing SMAD: Methods for Dramatically Reducing Space Mission Cost and Schedule***.
- A somewhat older, but relatively complete ***Bibliography of Reducing Space Mission Cost*** and other reference material is also on the Microcosm website above
- To continue the discussion (or add elements to the bibliography), get in touch with us at jwertz@smad.com

Cost Reduction Example: Systems Engineering Approaches to Reducing Mission Cost

SYSTEMS ENG

Reducing Space Mission Cost—Systems Engineering (SE)		
Technique or Action	**Mechanism**	**Comment © 2017, Microcosm, Inc.**
SE 1. Trading on Requirements	Allows a balance between cost and benefit. Can dramatically reduce cost or avoid program cancelation if requirements are excessively challenging	*Trading on requirements* refers to adjusting the requirements to find the best balance between cost, risk, schedule and performance, much the same way individuals buy a car. Makes traditional competition difficult, but allows the government to become an "intelligent consumer." Example: defining required mission lifetime.
SE 2. Trading among requirements	Allows better performance in one area at the potential expense in other areas. Allows finding the best balance to meeting the end user needs	*Trading among requirements* means accepting less in one area in order to do better in other areas. Example: flying at a low altitude improves resolution, but reduces coverage and possibly mission lifetime.
SE 3. Create tiered requirements	Allows better performance at lower cost.	This refers to creating two or more tiers of requirements to allow optimizing multiple criteria, such as coverage and resolution. Example: multi-tier resolution requirement to prove good resolution when looking straight down and frequent coverage with lower resolution at lower elevation angles.
SE 4. Design capabilities driven system rather than requirements driven system	Allows maximizing performance at low cost (not necessarily minimum cost). May be the best approach to meeting end user needs	Extends concept of "trading on requirements" to minimize or eliminate requirements and concentrate on broad objectives. Allows design to be based on what exists or can be achieved at low cost. Example: building the system around an existing or "easy to invent" set of capabilities.
SE 5. Set functional rather than technical requirements and give reasons for them.	Allows the various requirements trading processes to work	Typically requirements documents specify what is to be done, but not why. Need the "why" in order to be able to conduct requirements trades.
SE6. Allow simultaneous development of critical mission elements	Reduces cost, schedule and mission implementation risk (See also SE 6.)	Classic example is the Apollo program simultaneous development of the Saturn V and the Moon landing elements and mission profile. If systems are to work together efficiently and effectively, they need to be developed in parallel, not in series. (See R&R 4 for addressing problem of added risk.)
SE 7. Concurrent Engineering	Allows schedule compression; increases feedback between groups	Potentially high non-recurring cost. Can achieve "local optimization," but reduces willingness to consider truly different approaches. Typically concurrent engineering refers to components or subsystems, whereas simultaneous development (SE 5) refers to larger elements of the mission.

Cost Reduction Example (Continued): More Systems Engineering Approaches to Reducing Mission Cost

SYSTEMS ENG

Reducing Space Mission Cost—Systems Engineering (SE)		
Technique or Action	**Mechanism**	**Comment** **© 2017, Microcosm, Inc.**
SE 8. Design-to-Cost	Adjusts requirements and approach until cost goal has been achieved	Has rarely been used. Arbitrary cost goals are unlikely to be successful.
SE 9. Large margins	Reduces testing; better flexibility; reduces cost of engineering, manufacturing, and operations	Margins traditionally kept small to maximize performance. Requires balanced implementation—forcing large margins in all components may drive up cost.
SE 10. Fly new component plus same component flown on last mission	Allows use of newer technology with higher capability without the associated risk.	Particularly useful for computer technology. Allows use of newest computer technology—both lower cost and more capability with very low risk. Can be used for other hardware as well.
SE 11. Devalue optimization	Allows multiple cost reduction methods	"Optimized solutions" prevent standardization and use of non-space equipment or processes and require that everything be uniquely designed for each specific application.
SE 12. Used Market-Based System approach for resource allocation	Allows the best possible end result within specific cost and resource constraints	Applicable to missions with multiple payloads. Sets up a market-based system to allow various PIs to trade power, mass, and cost or commodities in limited supply. (See Wessen and Porter [1998].)
SE 13. Use the existing knowledge base	Reduces cost, schedule, and risk by making use of the existing knowledge base Can see what has worked and not worked in prior programs Shortens the "learning curve" for finding approaches that work for your specific program	Reinventing the wheel is rarely economical. According to John Mather, "6 months in the laboratory can save you a week in the library" Specific approaches to building on existing knowledge: a. Books and literature b. Courses, training programs, and conferences c. Commercial software tools d. Become a part of the low-cost community e. Take advantage of the knowledge of others
SE 14. Use a constellation of SmallSats	Reduces the impact of launch & spacecraft failures, allowing much lower cost approaches	Requires very low-cost SmallSats. Provides better persistence
SE 15. Use shorter mission lifetime	Allows more rapid system evolution with newer technology	Must compensate for shorter lifetime. Can have near continuous technology evolution