Small Spacecraft

- The Promise and Potential of Thinking Small

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November 12, 2009
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"Small" is Essential to Success

- **"Key to strong walls are the smaller stones that fill the spaces and lock together the larger elements"**

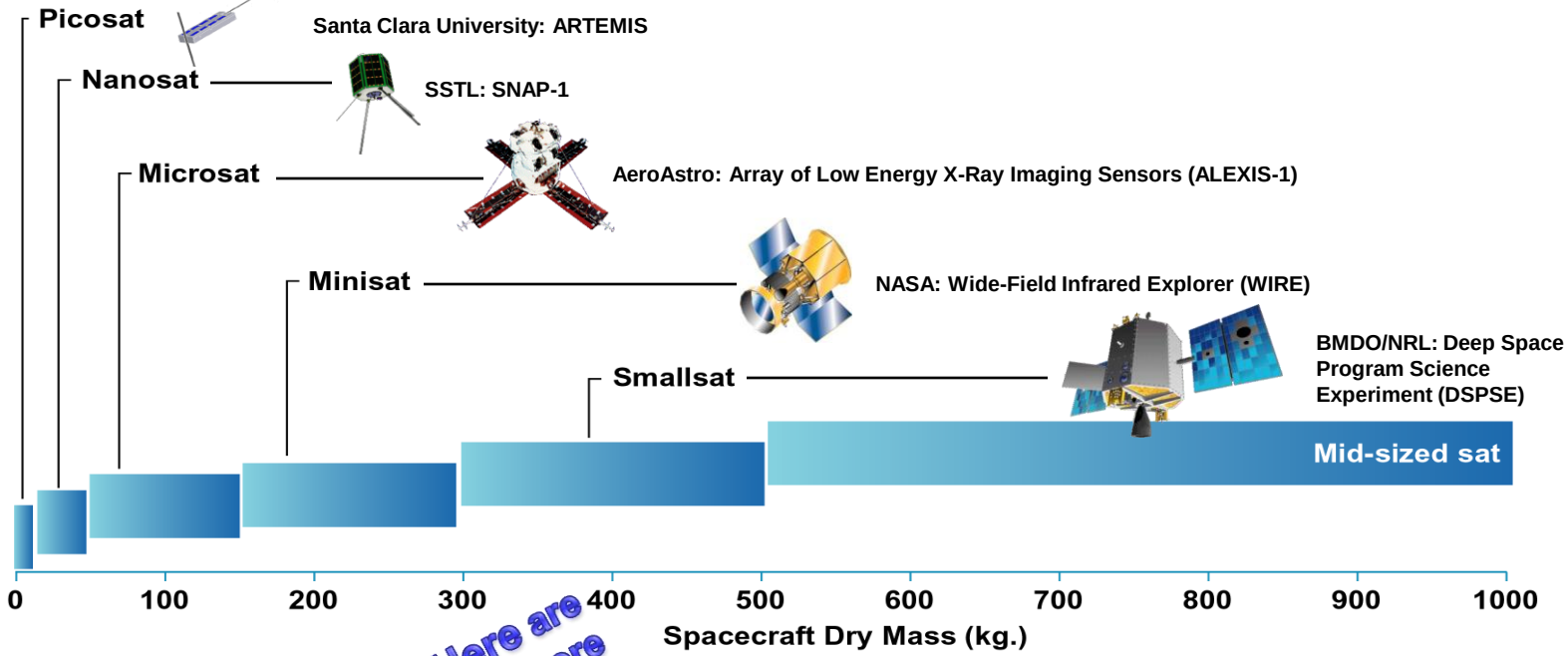
"Irish Stone Walls"
by Pat McAfee

- **A decade ago the power of small spacecraft was questioned:**
  - **In the mid-80s NASA faced a 'going out of business' problem – big, expensive missions = fear of failure and lengthy periods between results**
  - **Commercial (and some government) pioneers saw great human benefit in a proliferation of small space missions (*"The Logic of Microspace" by Rick Fleeter*)**
  - **It was slowly realized that a portfolio approach using s/c of various sizes and types was best in terms of return on investment and maintaining pace**

- **Small spacecraft don't eliminate the need for larger ones, but they have proven to be extremely capable**

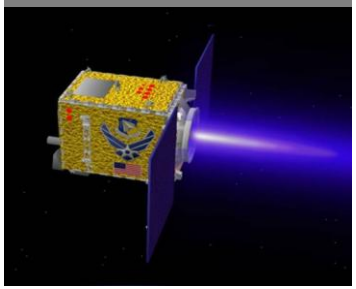
How many American's can name a person on the Space Station?
How many American's remember Spirit and Opportunity?

Mass is One Dimension of Thinking Small



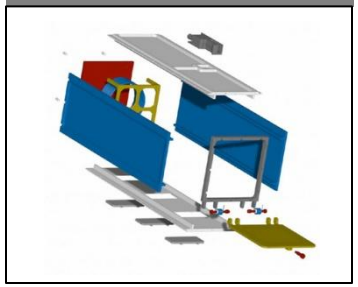
Here are two more

XSS-11



~100kg

Cubesat



Complexity (~100 parts)

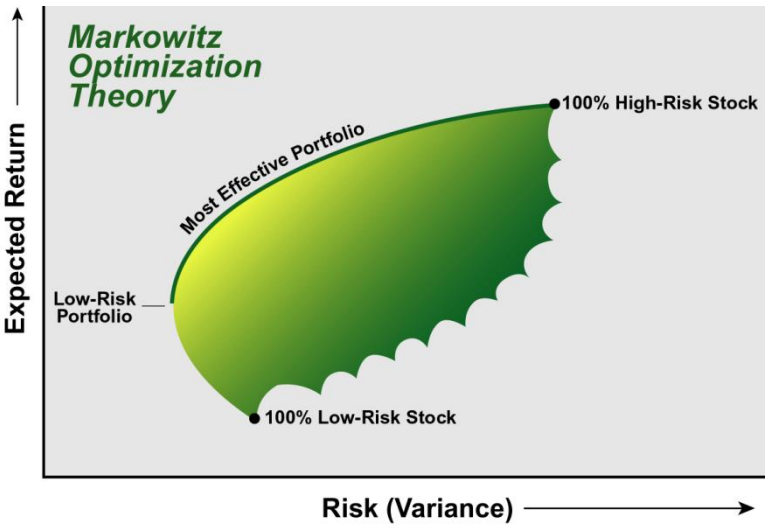
GeoLITE

Cost (~$100M)

www.rand.org/pubs/monograph_reports/MR864

Risk is a Key and Essential Dimension in the World of Small

- **Risk is essential – consider a stock portfolio:**
  - **The "most effective" portfolio *must* contain high-risk elements, even at the lowest desired levels of risk**
  - **The *least* desirable option contains only low-risk elements**
  - **The key to optimizing a portfolio is to include high-risk elements and ensure a high return per dollar spent**



- **Risk comes in many flavors: cost, schedule, technical, programmatic, cultural, etc…**
- **Complexity ≠ risk**
- **The goal when designing a small mission is to properly blend cost, benefit, and risk to achieve <u>a great result</u>**

THOUGHT EXPERIMENT: a 100 kg microsub enters the ocean of Europa and is eaten by a 50 ft long silicon fish – small spacecraft/infinite return

Ten Roles Where Thinking Small Can Pay Off

- **#1 – Building a Portfolio**
- **#2 – Achieving "First Results"**
- **#3 – Challenging Established Culture**
- **#4 – Acquiring Precursor Scientific and/or Operational Data**
- **#5 – Exploring Risky Markets/Destinations**
- **#6 – Maintaining Programmatic Pace**
- **#7 – Demonstrating Technology**
- **#8 – Training Future Leaders**
- **#9 – Establishing Cooperative Ventures**
- **#10 – Ensuring Full Exploitation of Resources**

Even NASA Can Think Small… to Great Effect!

- NASA design (JSC), ESA contribution, vendor fabrication
- Prototype vehicle built to Class A specs
- Small focused team (100 CS employees) using modern tools
- Complex OML
- Demonstration of streamlined, fast track development

X-38

- NASA design (ARC airframe, GRC propulsion), Boeing fabrication
- Modified Buffalo (C-8A) (airliner sized)
- Blown wing demonstrator
- 3X lift increase over conventional aircraft
- Unassisted aircraft carrier (Kittyhawk-class) landing and takeoff!
- Design database for C-17

Quiet Short-Haul Research Aircraft (QSRA)

- NASA design (JSC), DARPA/NASA funding, vendor fabrication
- "Buy by the Limb" strategy
- Sophisticated upper body system with 47 DOF
- Mission focused – develop augmenting capability
- 25 person in-house team
- Mobile, dexterous, and teleoperated

RoboNaut

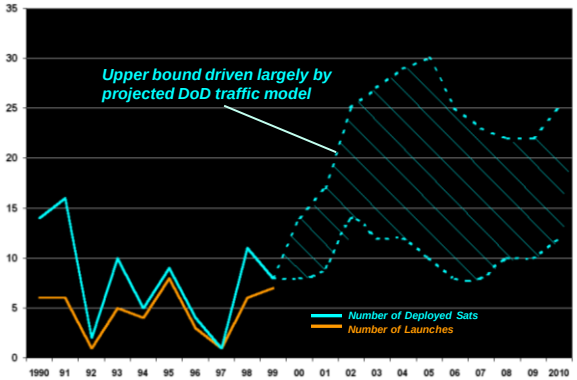
- NASA design (ARC/DFRC), Rockwell detailed design and fabrication
- Fly-by-wire RPV subscale (.44) demonstrator
- Graphite-epoxy structures – 2X g loads of conventional aircraft
- Provided control laws for production systems

Highly Maneuverable Aircraft Technology (HiMAT)

- ***NASA can run at the bleeding edge through in-house innovation… when allowed to!***

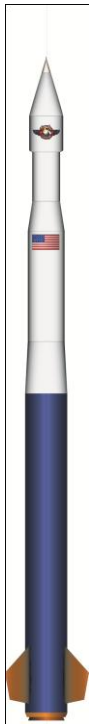
Small Spacecraft Can Address Many Markets

- **Government generally remains focused on large programs that feed <u>institutional need</u>; in the small world:**
  - **USAF has long been a source of advocacy**
  - **NASA thinks small (or commercial) with great reluctance**
  - **OGAs not there yet (though NOAA might become interested in the wake of N-POESS)**
- **Commercial and academic sectors better matched to thinking small, especially really small:**
  - **Entrepreneurial ventures focused on high capacity microsats designed to exploit technology (MEMS, high-power solar, IP comm,..)**
  - **Government should not compete in this market – nurture with modest funding and support (access to SMEs, tools, facilities)**
  - **A decade ago I predicted modest growth in this sector… not sure it ever materialized**



Access to Space Continues to be a Vexing Problem

- **On the cost dimension, transportation can quickly become the dominant factor in the project budget**
- **Opportunities remain limited:**
  - **Primary P/L (dedicated or shared LV) – most expensive option, but you own the resource**
  - **Secondary P/L (custom carrier or multiple carrier) – cheapest ride but sacrifice autonomy, must track to primary P/L schedule, and trajectory is often constrained**



So… why hasn't anyone built a dedicated small launcher?

Challenge	Opportunity
• Small rockets are notoriously difficult to develop	• Lots of technology available and amatuer rocket community getting close to needed capability
• Need $20-30M to do the job right	• Commercial ventures have raised far more in the past
• Requires a very well structured team with egos in check	• Talent is available
• A flexible launch range is needed	• Wallops has MARS (commercial) and range assets are pre-negotiated with cleared ascent area
• The government has to allow it to happen	• Favorable Administration

A fresh look at the technology and the market should demonstrate the potential for a profitable company focused on microsat launches

What's Possible: a Small Mission Left Unfinished…

- **Imagine exploring the Moon commercially with small spacecraft:**
  - **A MER-sized lunar rover remotely operated from Earth using IP nets and designed to survive repeated lunar nights**
  - **Built by young people in a garage using existing tools – a diverse team operating in close partnership with schools**
  - **Watched by millions via a reality TV venue**
  - **Pre-mission revenue generated by advertising sales, product placement, gaming, product sales, video sales, etc.**
  - **Revenue augmented during launch and ops through web traffic, feed pricing, technology IP, data purchases, mission-related events, etc.**
- **When the Moon is done the team next lands on an asteroid**

The best way to make "small" work is to think BIG!

EXTRA CREDIT

[NOTE: the following charts present only a NASA perspective

Small Spacecraft – Myth Busting

MYTH	REALITY	IMPLICATION
• Smallsats are new	• NASA started with smallsats (e.g. Explorer 1) and has had an on-again, off-again love affair ever since	• NASA has had to periodically retool, reinvent, and retrain to incorporate smaller missions in the overall portfolion
• Smallsats are not "main mission" investments	• If correctly matched to scientific/technical requirements and sociopolitical needs, a smallsat mission can deliver startling results	• Good mission design is very important when smallsats are concerned - David can slay Goliath IF you choose the right rock and aim very carefully
• Smallsats do what big sats do	• Technology enables ever more capable smallsats, but a balance of large, medium, and small missions is still the best bet	• Tendency to oversell the role of smallsats and to create programmatic imbalances, much the way "faster, better, cheaper" did in the 90s
• Smallsats are built with off-the-shelf component	• They can be, but more often they are just as customized as larger satellites	• Excess tendency to treat smallsats as an "assembly job" of pieces and parts rather than a complex spacecraft
• Technology is driving by the larger missions, not the smallsats	• Often it's easier to incorporate new technologies on a smaller spacecraft if the gain in performance more than offsets the technical risk (it usually does)	• NASA has not invested much in spacecraft technologies and will likely have to shop far afield to find the systems needed to build smallsats to meet VSE goals
• Smallsats can be complex because it takes a lot of design to jam things into a small volume	• For the type of missions smallsats will be fairly complex, but this need not be a barrier to meeting cost or reliability targets	• Choosing the right level of complexity is critical to meeting cost and performance goals
• Smallsats represent high-risk to the overall mission	• Smallsats PERMIT the incorporation of "appropriate risk" into an overall mission portfolio - these risks should be clearly stated to everyone involved	• A "dumb failure" is unwanted in a mission of any size - all types of risks must be adjudicated when designing a smallsat mission to maximize mission success factors

The Pros and Cons of Small Spacecraft

The programmatic perspective

PRO	CON
• When all benefits are weighed, a smallsat mission can be designed to yield results that capture the imagination and deliver	• Larger spacecraft have the advantage of delivering more "bang for the buck"
• There is a great deal of experience in the arena of designing, building, and operating smallsats	• Most of the experience base is no longer within NASA - the Agency will likely have to rely on support from external community to build SOTA spacecraft
• Smallsats provide programmatic flexibility and the ability to respond to changing requirements	• It's critical to tightly integrate smallsat mission requirements to ensure that each mission provides the right answer at the right time in the overall mission sequence
• NASA owns a low-cost launch facility at Wallops (with a commercial partnership) with a long history of launching spacecraft at low-cost and high reliability	• Use of WFF requires NASA to cooperate closely with commercial entities for LV and launch complex
• There has been an explosion of smallsat and related technology over the past decade - you can even buy a satellite kit	• Most of the action in the smallsat arena has not been in the U.S.
• Several smallsat projects can be combined and launched on the same rocket	• LV providers often shy away from "piggy-backed" payloads and sometimes a failure of one payload can effect all others
• Smallsats programs tend to attract very capable staff and managers	• It's hard to keep teams small and focused because so many people want to "help"

The Pros and Cons of Small Spacecraft

The cost perspective

PRO	CON
• If simplicity is maintained during design and development, smallsat cost can be built at very low cost	• Per kg., smallsats are often carry a premium price - some economy of scale does exist
• Complex spacecraft capable of meeting significant science and technology objectives can easily be built for <$100M	• Existing cost models generally are poor predictors of cost in the micro- and nano-sat realm; more work is needed
• Opportunity exist to reduce NASA costs by partnering with others, including commercial firms	• To make best use of high-reliability, lower cost components developers might be forced to shop off-shore
• Opportunity for relatively low-cost launch exists as either secondary/tertiary payloads, or as primary on vehicles like Minotaur	• LV usually is higher proportion of mission cost when compared to larger missions - tends to encourage secondaries and multiple payloads per launch
• Exisiting subsystems/components/parts are available so that modular approaches to design and fabrication are truly feasibility	• Modularity, "serial design," design reuse," and "common bus" are concepts that are difficult to employ in practice unless Agency maintains a "product line" strategy
• Smallsats require small teams, lean development, novelty in testing, and other creative developmental approaches and, as a result, can achieve low cost	• Very difficult to maintain low-cost profile within the NASA environment where the culture is adverse to lean and mean developments
• Smallsats will become even more abundant when launch costs come down	• Cost and price are not the same thing, and there's not much pressure to reduce launch prices

The Pros and Cons of Small Spacecraft

The risk perspective

PRO	CON
• The ability of a smallsat to achieve a given mission objective is nearly the same as larger spacecraft - smallsat are getting more reliable	• NASA risk management procedures are poorly matched to the development of smallsats since the Agency's focus has been on much larger investments
• Smallsats can represent the high-risk portion of the overall mission portfolio	• Higher risk must carry a commensurately higher return and this requires exceptionally thorough mission planning and spacecraft design when planning smallsats missions
• Launchers for smallsats have achieved high-levels of reliability - vehicles like the Minotaur have a great track record because of their heritage	• Not all LVs enjoy the track record of vehicles like Minotaur - the history of other rockets show a stepwise evolution to acceptable levels of reliability
• Smallsats can be built using high-reliability methods if lessons-learned are incorporated into design and development practices	• NASA has a tendency to discard streamlined processes used in the past to develop low-cost missions (Spartan, Hitchhiker, SMEX, etc.)
• Investment exposure is less with smaller missions - if you lose one it's less noticeable	• If the small mission does what it's suppose to it suddenly becomes precious - does JPL take risks with Spirit and Opportunity, or are they treated more like Cassini despite their much lower cost?
• Smallsat teams tend to form highly effective and interactive teams that are nimble in terms of spotting mistakes during development	• Because lean oversight is a necessary element of smallsat design it is essential to have especially effective reviews to catch errors that could lead to mission failure
• The importance of testing tends to be elevated in smallsat development programs since fewer up-front inspections are conducted	• NASA must resist "uncosted work" levied on the smallsat program that could divert monies being held for testing late in the development cycle
• A small spacecraft often has a single purpose - this allows the team to focus on the primary payload and it is therefore less likely to fail	• A larger spacecraft often has multiple payloads and can suffer failures without being labled a "mission failure"