Small Rocket/Spacecraft Technology Platform

SMART

Micro-Spacecraft Prototype Demonstrates Modular Open Systems Architecture for Fast Life-Cycle Missions

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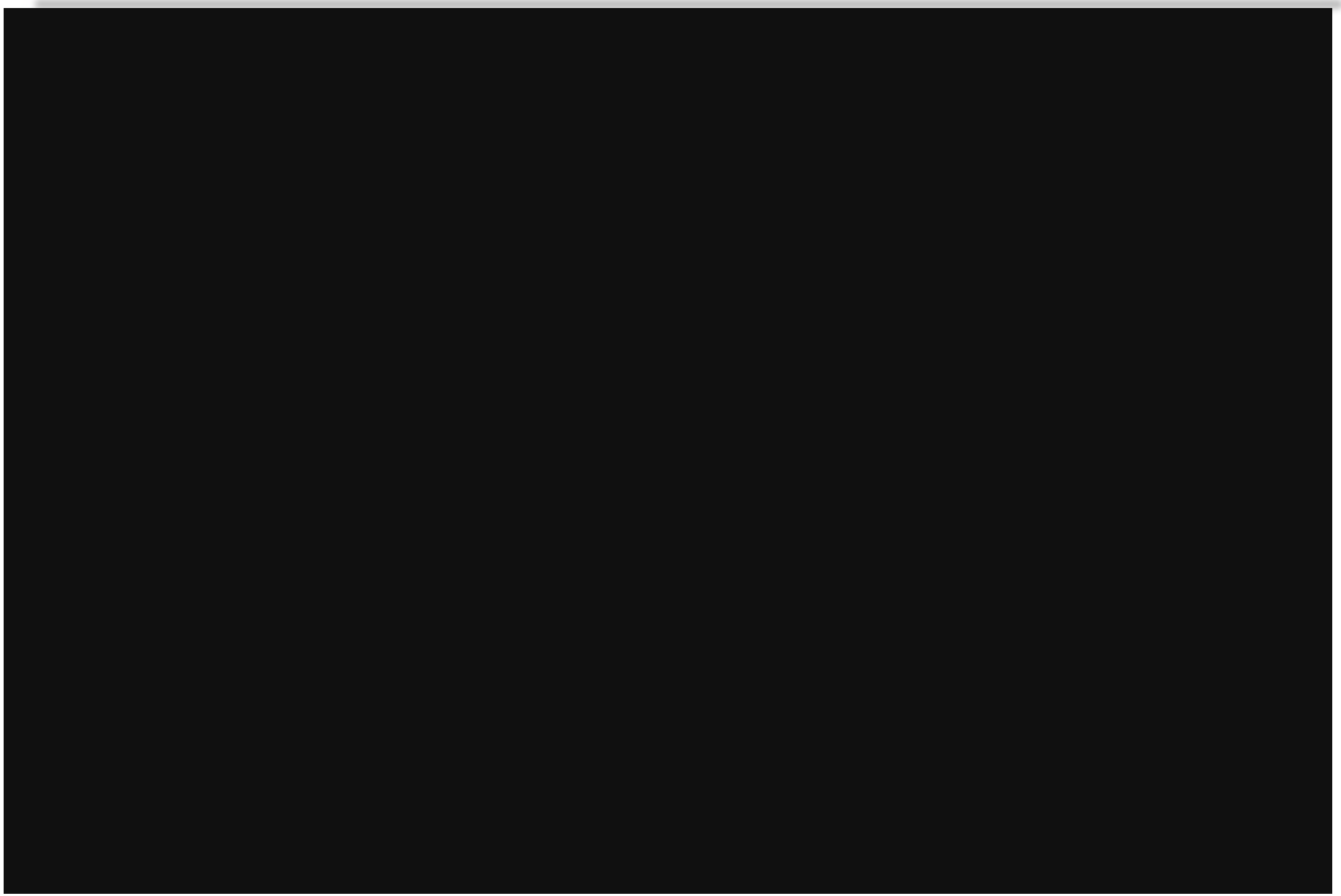
Motivation

- **A gadget is easily understood as enabling when:**
  - It is a sensor that can detect radiation with the utmost quantum efficiency.
  - It warms up a system that must operate at 87K, and it takes the heat from its surrounding environment.
  - Protects the spacecraft from 3000° C surface heating.
  - Let us get to our nearest star in say, 1,000,000 years.
  - Revision to the latter: it gets us there in 4 years … at the speed of light.
  - Revision to the revision: it gets us there NOW!
  - Etc., etc., etc.
- **But what if I introduced you to an architecture, a system, a process, and a derived gadget child that can accomplish science that could not be accomplished in a million years with our resources and operating cook-book? By the sheer fact that it will be flown, and often, and inexpensively? And do a great job at it?**
  - Would the child of that architecture be considered an “enabling”, “game changing”, gadget?

Motivation

- **Scientists and engineers can spend their career in one worthy mission … but what about the science and technology that gets grounded in the mean time?**
- **There is room for all: large expensive spacecraft with multiple instruments trained in concert to understand physical phenomena. Or requiring large apertures either of monolithic design, or distributed design. Or reaching far away, inhospitable locales that require exacting performance and reliability.**
- **There is also room for: smaller spacecraft trained to our neighborhood, specifically designed to enable missions that cannot be done with larger systems either because of cost or science needs, that require distributed and frequent observations, that cannot tolerate technology obsolescence, that are flexible, and that are ideally suited for focused science and technology validation and demonstration (but not the one prodigal system never to be flown again).**

A little warm-up video



Back in 2002 and 2004

Shopping Cart Approach to Implementation

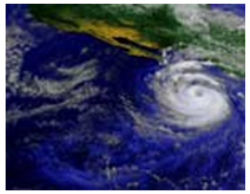
MODULAR

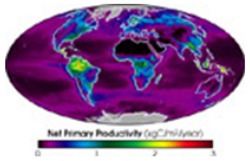
RECONFIGURABLE

RAPID

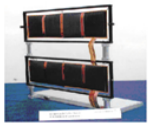
Process: days to months

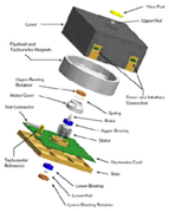
1 **Mission Requirements**

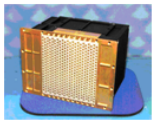


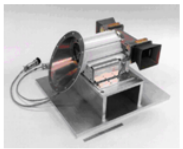


2 **Select components from inventory**

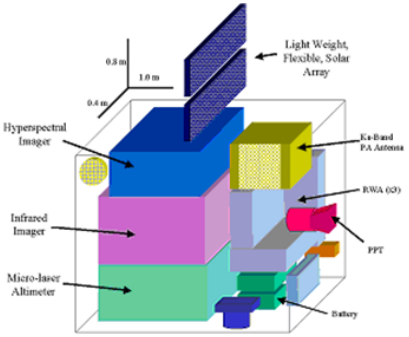




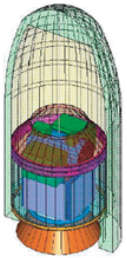


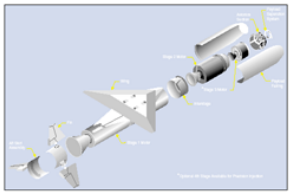


3 **Payload and System Integration**



4 **Launch vehicle integration & launch**





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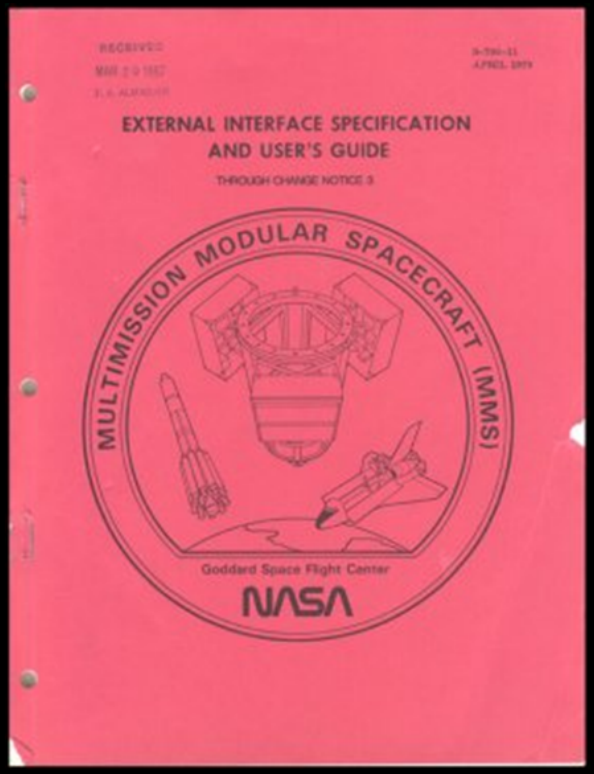
Multi-mission Modular Spacecraft

MMS Makes it to ebay®



Description- External Interface Specification and User's Guide" (160pp., soft) According to this report, this proposed spacecraft "will support a variety of remote-sensing earth orbiting missions requiring solar, stellar or earth pointing. Additionally, it will benefit special-purpose programs such as space manufacturing or low-G biological missions. It can be launched by Delta or the Space Transportation System (STS). It can also be accommodated on the Atlas- Agena with an eight foot diameter or larger fairing or the Titan. It can be used at orbital altitudes from low earth to geosynchronos. It is available to support U.S. Government, foreign government and commercial space programs. It presents a standardized telemetry and command interface both for integration, test and on-orbit operations with the Ground Space Tracking and Data Network and the Tracking and Data Relay Satellite System...". Literally a spacecraft for all uses. Must be why it was never developed further. Minor faults to cover, otherwise excellent condition. FLOWN? YesEstimate:**$50 - $75** [currency USD]

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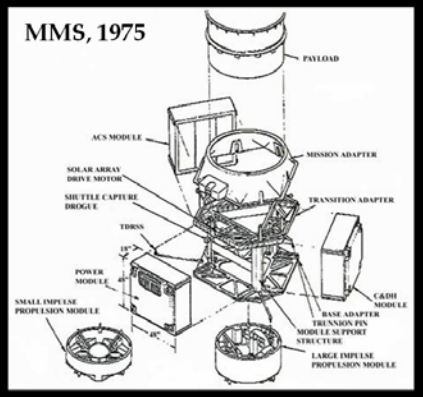
More on MMS

The Multimission Modular Spacecraft



MMS was a *standard*, three-axis stabilized spacecraft design conceived to accommodate the largest number of missions, whether in low Earth, or in geosynchronous orbits

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Interface Standards, 1970's – '80s

- A basic premise of the MMS design included the use of *interface standards*, permitting module exchange between spacecraft.
- Backward-compatibility would permit the re-fitting of operational spacecraft with subsystems produced at a later date.
- AT least six spacecraft flew under the MMS umbrella:
  - Solar Max Mission (SMM) in 1980
  - Landsats 4 and 5 in 1982 and '84, respectively
  - Upper Atmospheric Research Satellite (UARS) in 1991
  - Ocean Topography Experiment (TOPEX/Poseidon) in 1992
  - Extreme Ultraviolet Explorer (EUVE) in 1992.

Technical and Programmatic Quandaries

- Technical modification for MMS technologies was left to individual projects by design.
- There was no central "technology program" in place that would advance modular components, or maintain a selection of options that could be used by a particular customer.
- Projects had no incentive of using "someone else's design".
- Competitive forces also encouraged industry to propose "best" or "better" designs.

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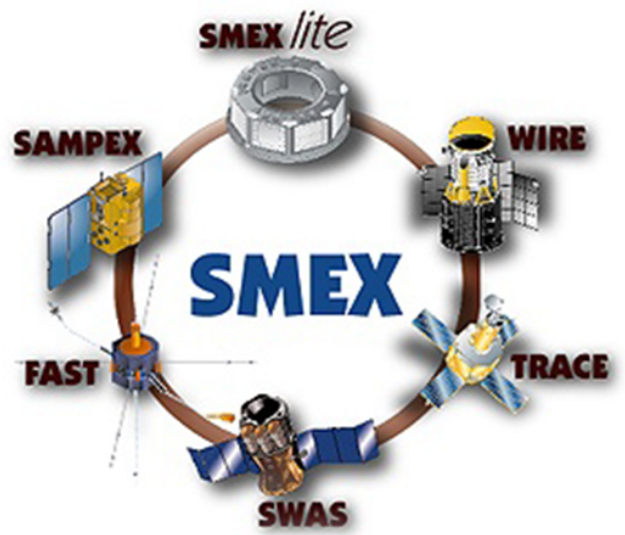
What about SMEX

National Aeronautics and Space Administration
Goddard Space Flight Center

Small Explorer Program Spacecraft

SMEX, 1990s



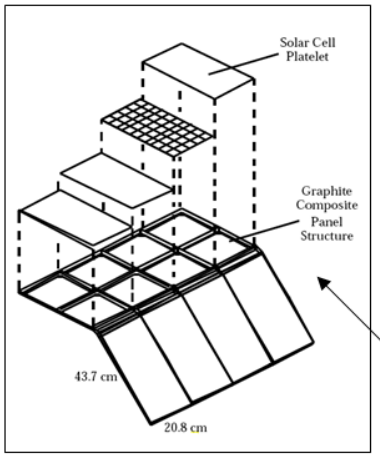
SMEX was a NASA program started in 1988 to provide frequent flight opportunities for focused and relatively inexpensive space science missions.

SMEX-Lite … too good?

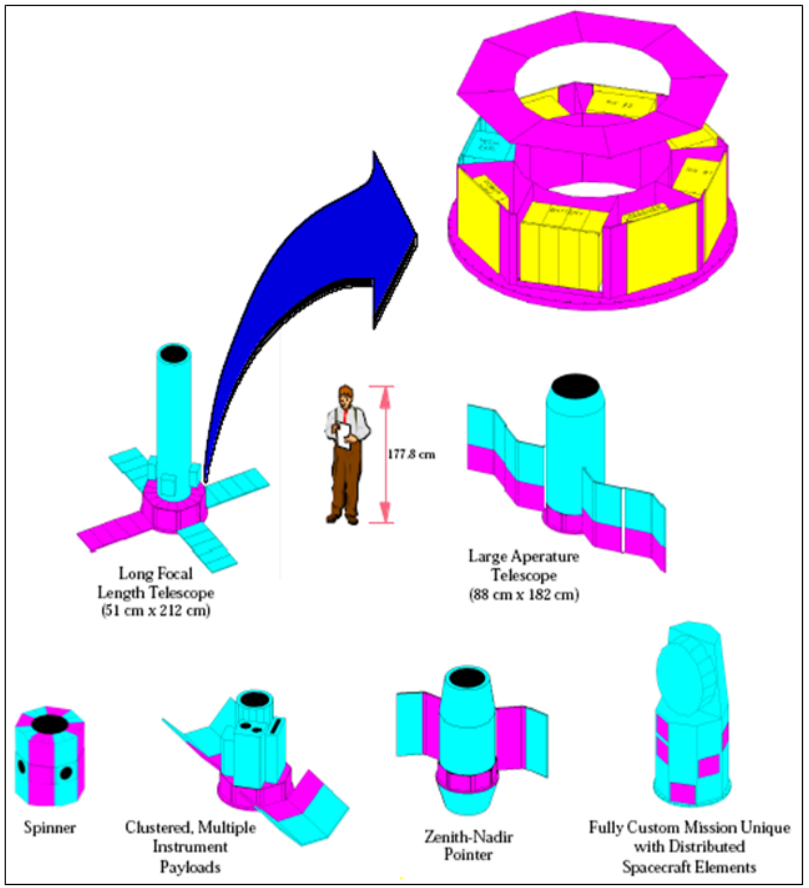
National Aeronautics and Space Administration
Goddard Space Flight Center

SMEX-Lite Modular Architecture Flexibility

- The SMEX-Lite structure and modular (sliced) subsystem architecture provided for multiple instrument configurations and mission implementations.



Modular "platelet" solar array architecture



AFRL Operational Responsive Space Meeting – Logan, Utah 2006

National Aeronautics and Space Administration
Goddard Space Flight Center

Concept/Architecture Comparison

Defining Characteristics			
Characteristic	**MMS**	**SMEX / SMEX-Lite**	**MARS**
Modularity	Implemented primarily at the subsystem level.	Drop-down one level from the "box" to the "functional slice".	Uses *levels of integration*, where a module can be a MEMS device, electronic chip, card, box, subsystem, system, or system-of-systems.
Adaptability	Not implemented.	Not implemented.	System *capable of learning* and acting either a priori, or real-time from its environment.
Reconfigurability	System designed to service a specific class of missions.	System designed to service a specific class of missions (small explorers). Drop-down in modularity provides more flexibility than MMS.	The system is *entirely morph-able* in order to apply to a host of missions. Made possible by modular levels of integration and adaptability.

Back to 2004

Modular, Reconfigurable, Rapid Space Systems

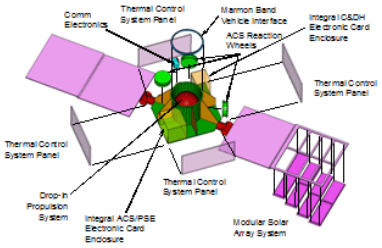
MR²: Addressing the need for revolutionary transformational improvements in the design, architecture, and processes involved in the production of current flight systems for the new *Vision on Space Exploration*

- **Modularity**:
  - Allows for interchangeable components
- **Re-configurability**:
  - Allows for functional flexibility

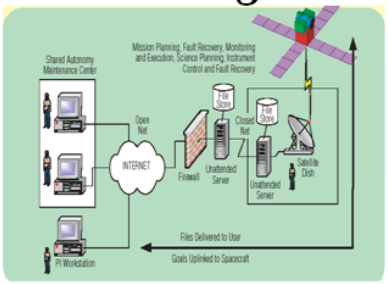
MR²

- **Rapid response**:
  - Allows for fast life-cycle and reduced cost

Space Segment



Ground Segment



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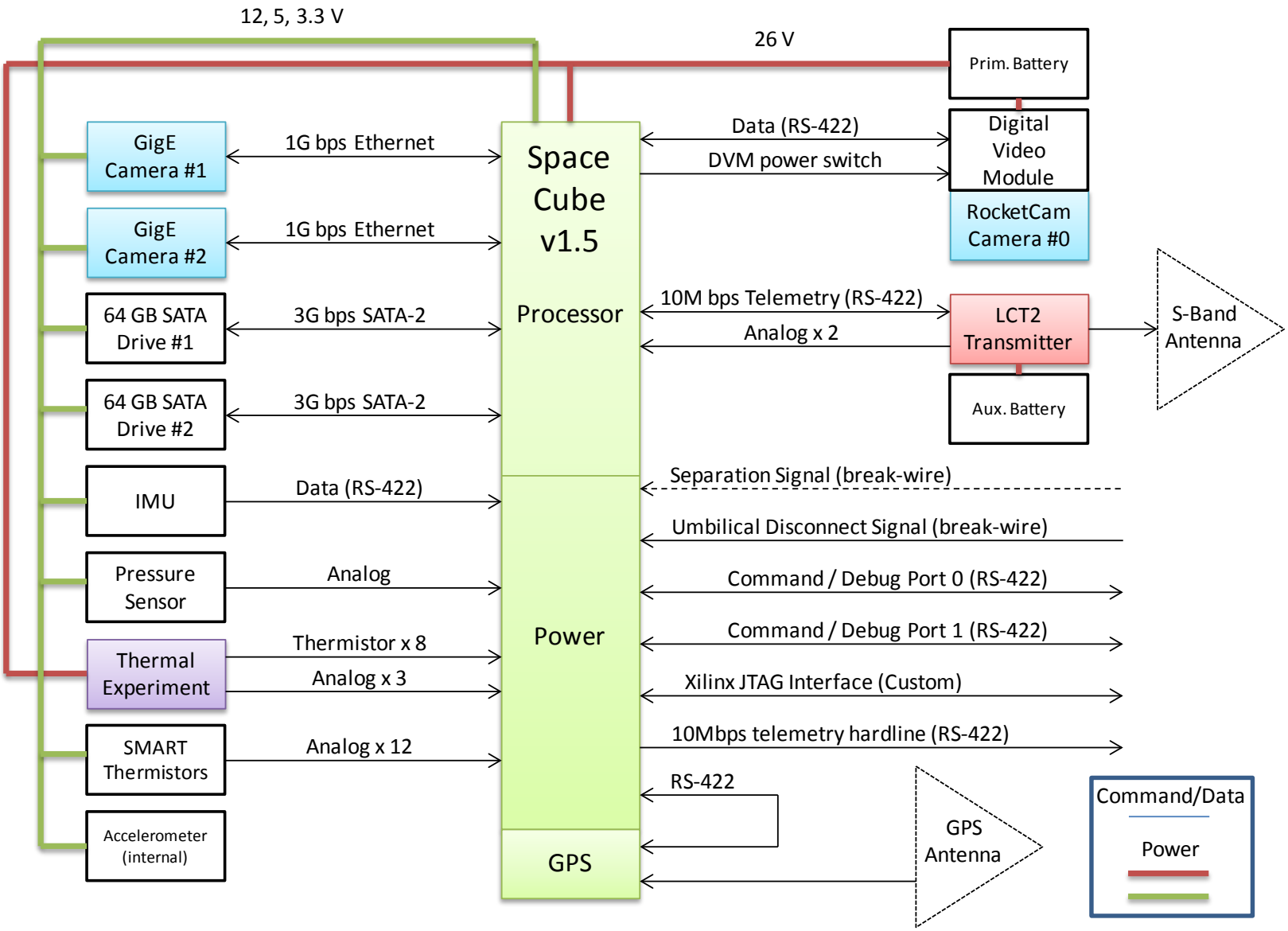
SMART Objectives

- Demonstrate a point design instantiation of a Modular, Open Systems Architecture micro-spacecraft prototype.
- Build and flight-validate a miniaturized high-performance, power-efficient processing avionics for small expendable launch vehicles, and small orbiting spacecraft (Space Cube V1.5).
- Demonstrate a modular, reconfigurable structure.
- Incorporate the Wallops Flight Facility's (WFF) Low Cost TDRSS Transmitter as a component of Space-Based Range.
- Provide a basis for the possible adaptation of WFF's Autonomous Flight Safety System (AFSS).
- Demonstrate tunable thermal technology to accommodate varying orbital environments.

System Description

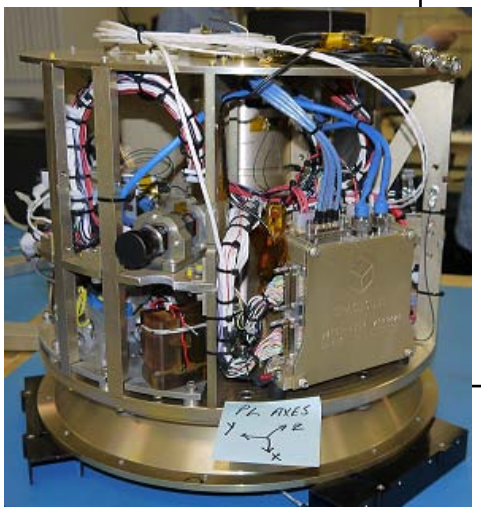
- As a low-cost "class-D" micro-satellite prototype, SMART has a mix of heritage and ruggedized COTS components chosen judiciously ***and tested extensively***. For mission durations lasting up to a year (more is possible), the current system can prove adequate, given its limitations and constraints (every system has them).
- Major functional components and their interfaces exercised in SMART included the SpaceCube avionics, the reconfigurable structure, instrument sensors, and the telemetry system.
- Sensors (including the optical cameras) were used to monitor deployment, temperature, pressure, and acceleration environments, as well as position and inertial attitude.
- Sensor integration into the avionics provided for an account of the flight. Interface testing and sensor data was essential in assessing the avionics and overall system performance.
- A combined rate of ~90 fps of optical data, plus additional sensor data totaled approximately ~93 Mbps of information that had to be processed on-board in real time. After processing, data was stored on-board SATA II SSD drives at about ~240 Mbps. A total of about ~360 Gbits of data was collected during the mission. Not a small data processing rate, and not a small amount of data either, for a "modest" system… and all while taking a rather brutal pounding during its 25 minute mission (from launch to ocean rocking).

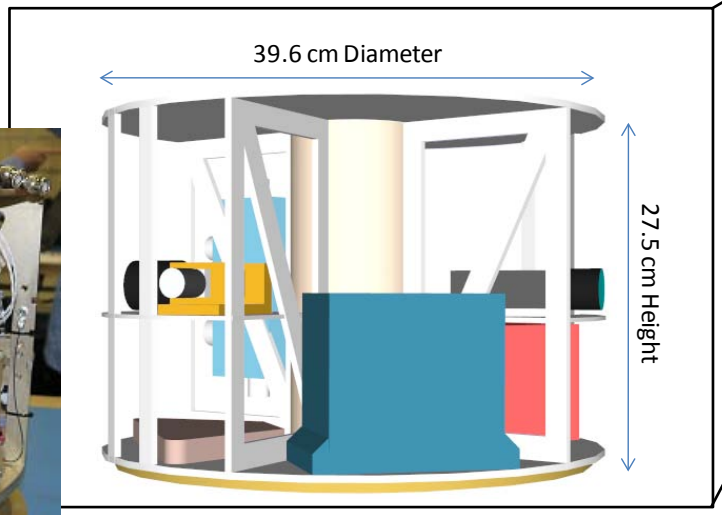
Functional Block Diagram

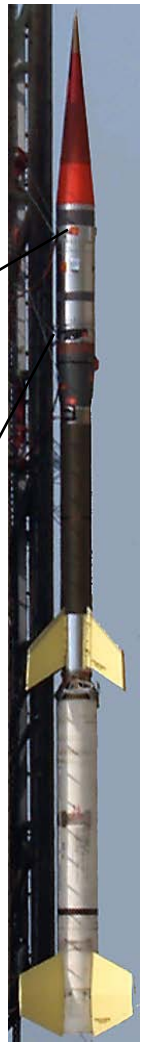


Micro-spacecraft prototype

- **Micro-Spacecraft Prototype Demonstrates Modular Open Systems Architecture for Fast Life-Cycle Missions. Designed as free-flyer.**
- **For NASA, rapid mission implementations represent an opportunity to find creative ways for reducing mission life-cycle times with the resulting savings in cost.**



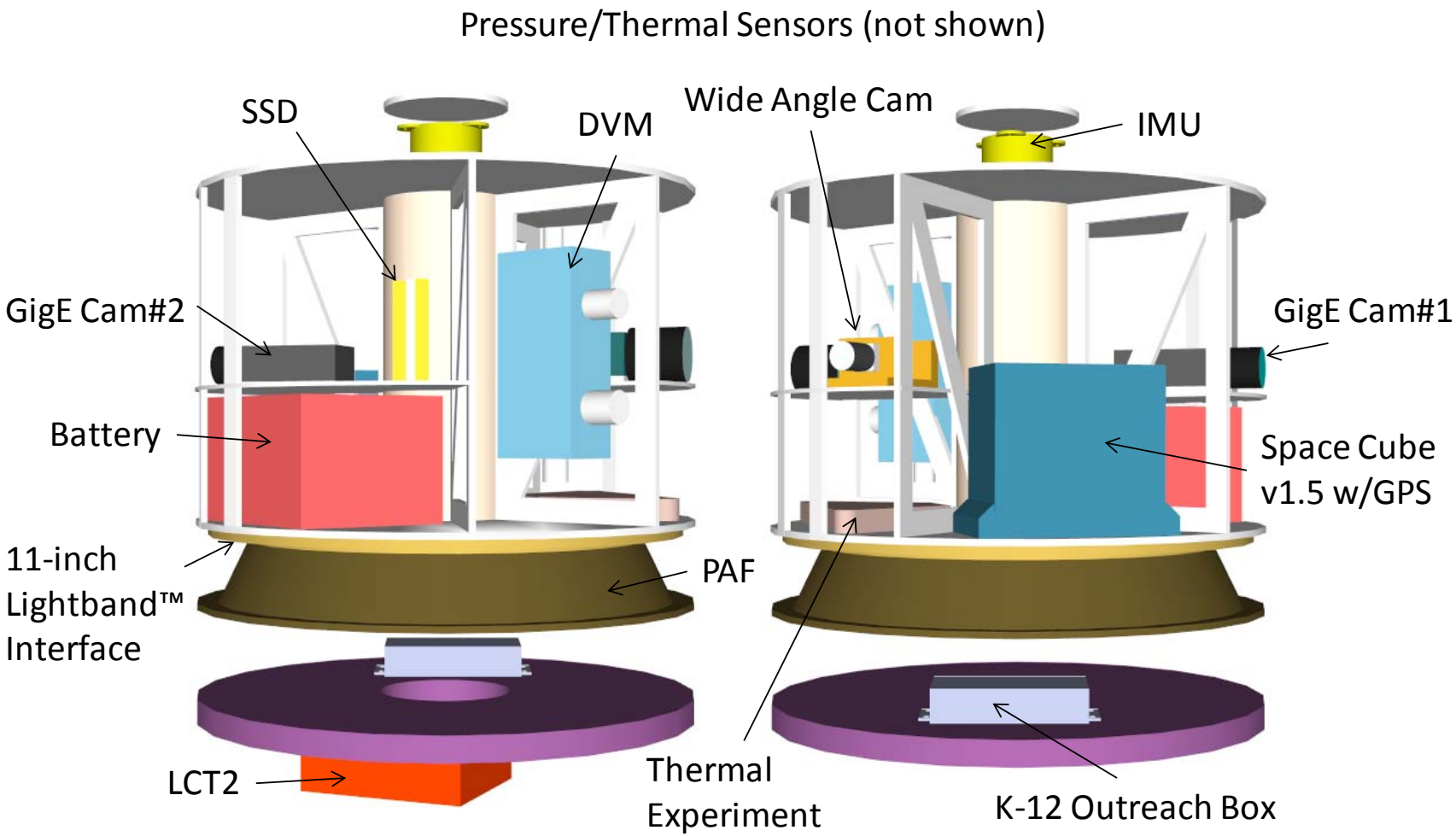




WFF SubTec-5

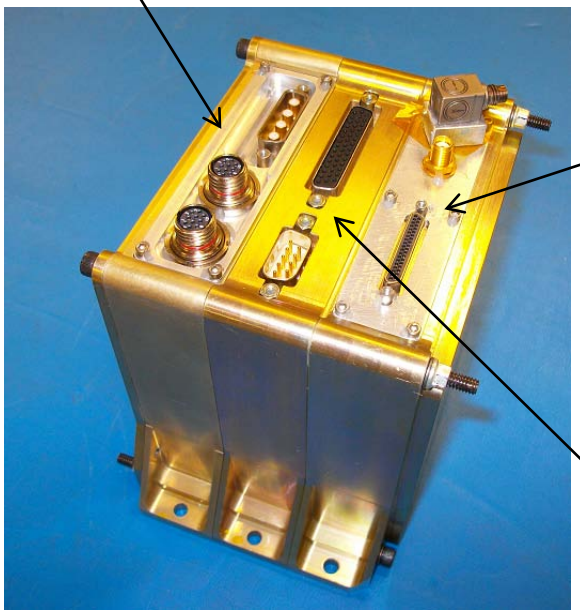
As Flown Layout

- **SMART provides flexibility in layout, and two were flight qualified. Layout details for the version flown is given here.**



Space Cube v1.5

- **Provides inherent redundancy through multiple processor cores, high computational capability, and relatively low power consumption.**



Box Volume

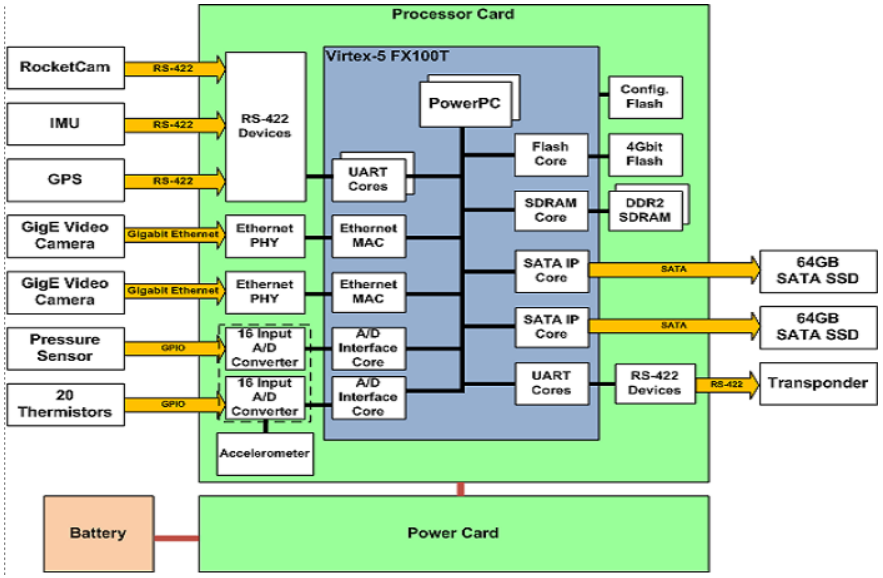
10.9 cm (l) x 11.7 cm (h) x 9.2 cm (d)

(4.3 in x 4.6 in x 3.6 in)

Box footprint

14.2 cm x 9.2 cm

(5.6 in x 3.6 in)



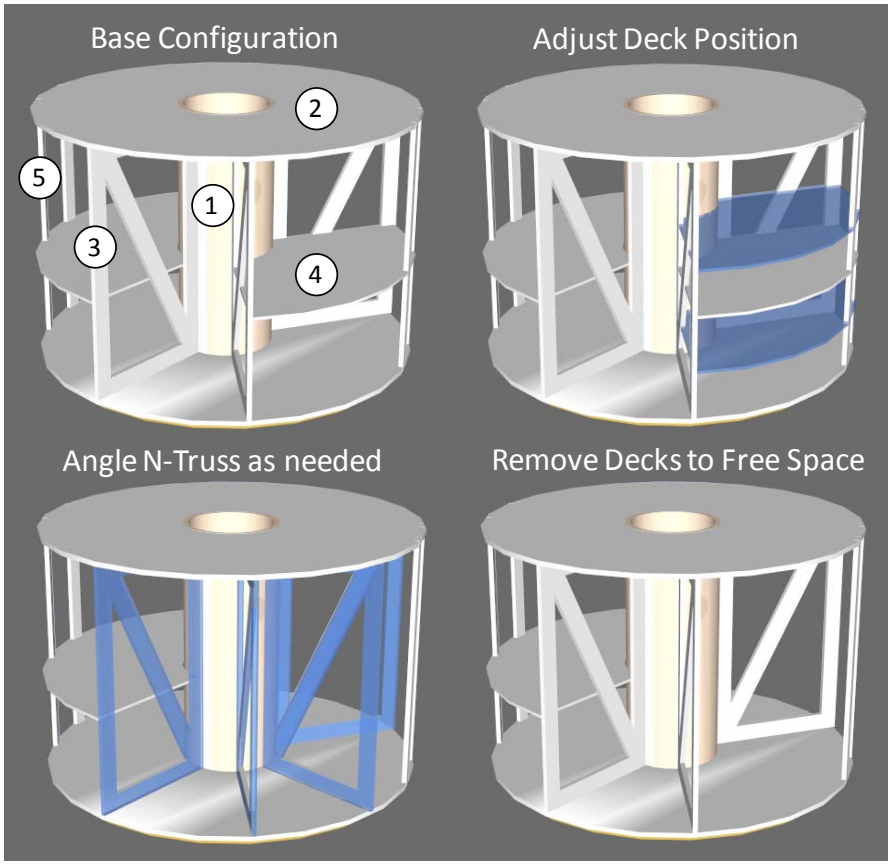
Interfaces: Gigabit Ethernet (GigE) + RS422 + SATA II + Analog (Spacewire will be added in Space Cube Mini)

Mass: 1.3 kg

Power Consumption: 17 Watts (approx.)

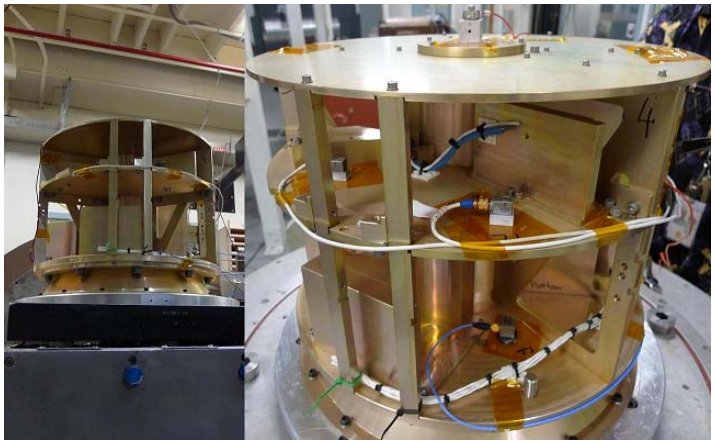
Modular, Reconfigurable Structure

- **The objective is to allow for layout changes using some basic components.**
- **Robust mechanical design for tough launch environment.**



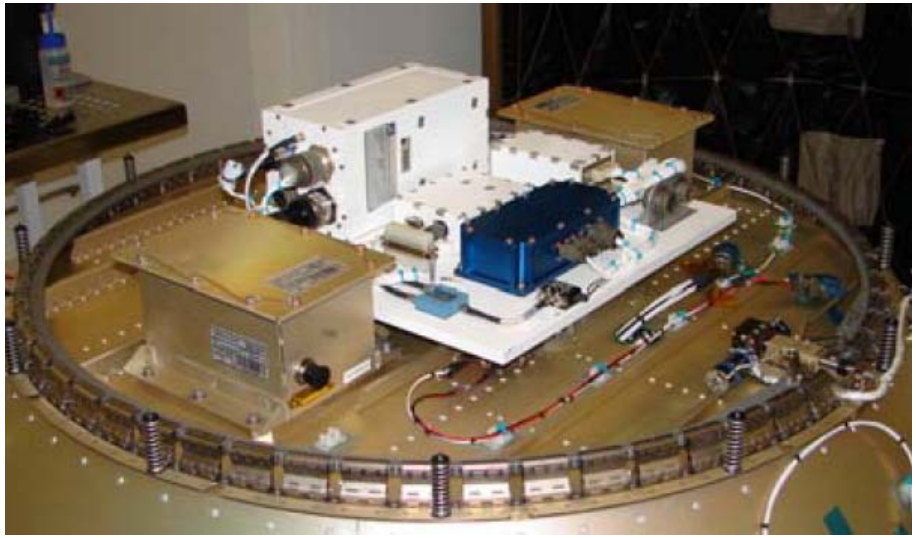
Structural Components:
(1) Thrust Tube; (2) Closeout Deck; (3) N-Truss; (4) Mid-Deck; (5) Longeron

Flight qualification successfully completed in July 2010, with two configurations tested.



Autonomous Flight Safety System (AFSS)

- **The AFSS uses GPS, IMUs, and flight processors to monitor the progress of the launch vehicle with respect to multiple flight termination criteria and, if necessary, terminate the flight without relying on ground-based assets.**
- **SMART SCv1.5 represents a candidate host for this software, in a small package. Its performance will be tested in an upcoming launch in December 2011, on board an UpAero Space Loft sounding rocket.**



Early AFSS Test Hardware on SpaceX Falcon 1

Low-Cost TDRSS/Telemetry Transmitter/Transceiver

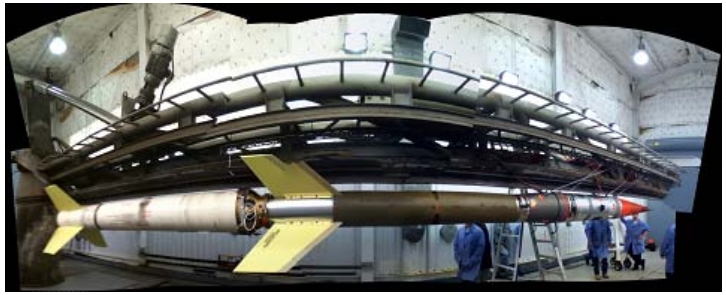
- **The LCT2 was developed at Wallops Flight Facility to provide a low cost space based range solution for telemetering data. The LCT2 follows the roadmap towards a space-based range with the goal of reducing the operational cost of the range while increasing the response time to the launch industry.**
- **LCT2 is a fully programmable software based transceiver and has been used in a range of TDRSS and non-TDRSS applications to achieve not only satellite communications but direct to ground applications (as in SMART).**

LCT2 is a key subsystem of Space-Based Range

LCT2 on SMART's Rear Bulkhead

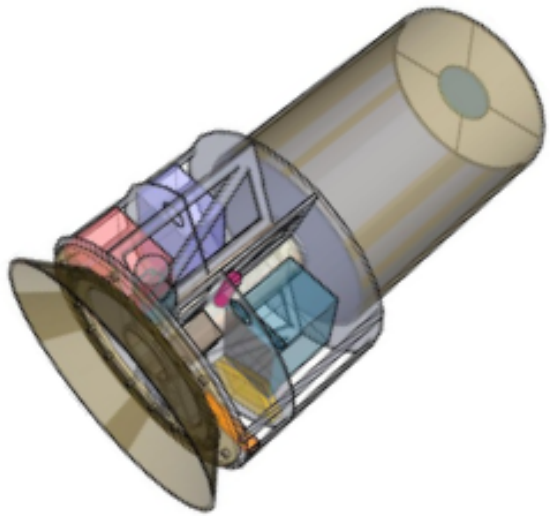
Integration and Test

- **Testing was extensive and thorough: necessary key to success for these systems. However, no "gold-plating" was necessary. A simple pass/fail criteria was the norm.**
- **Several bugs were resolved during testing that may have resulted in mission failure, if unchecked.**

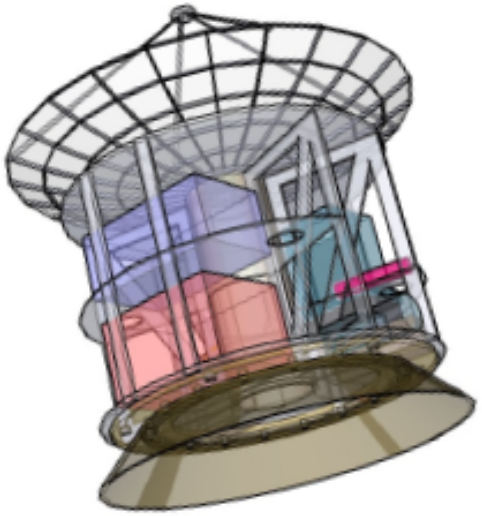


SMART Free-Flyer

- **The next step in the validation of SMART and its architecture is to use it as a fast on-orbit demonstrator. Several options are currently under study, including an ORS risk-reduction exercise, and NASA small satellite applications.**



SMART Optical Application (30 cm aperture, f/1.4 Cassegrain-style telescope)

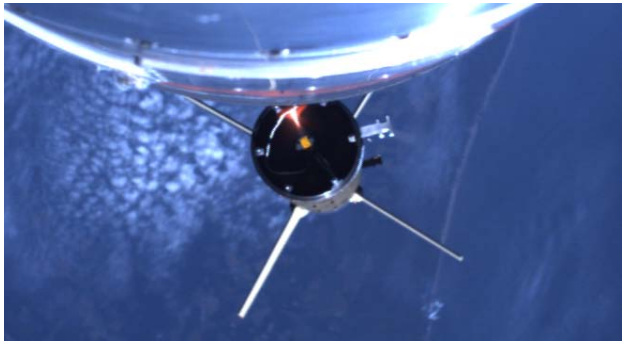


SMART Radio-Frequency Application (50 cm aperture antenna)

- BOL Total Power ~ 51W to 75W
- Available Payload Power ~ 12W to 32W
- Bus Mass ~ 35 kg
- 3-Axis Stabilized
- LEO: Equatorial to Polar Orbits

Conclusions

- From a NASA perspective, SMART provides a step forward in affordable micro-satellites, yielding flexible capability without compromised performance.
- For ORS, SMART also represents hardware validation of critical enabling technologies, not only for hosting AFSS and as a dual-application avionics, but also as a validation tool for Modular, Reconfigurable, and Rapid architectural concepts.
- But SMART is not just a “build one and forget it” system. It is the brainchild of an architectural progression that begs for more, more systems like it, more flights, and more opportunity.



Fasten your seat belts!!