Small, Flexible, Low-Cost Earth Science Missions

June 30, 2006

NASA GSFC

Agenda

Overview

Launch Vehicles

ALI - Lightweighted

Spacecraft Comparisons

MR2 Spacecraft

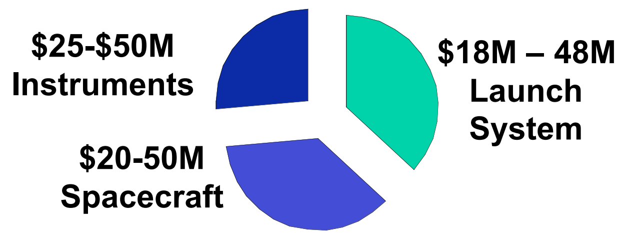
Spacecraft Quad Charts

Summary

Four Principal Elements for Low-Cost, Earth Science Missions

Small, highly capable, low-cost missions can be developed by:

1. Substantially reducing the cost of launch and launch services by use of Taurus/Minotaur/Falcon-class launch vehicles.



W/Taurus/Minotaur/Falcon L/V

2. Leveraging NASA & DOD's latest lightweight technology (>TRL6) -- maximizes the payload to orbit.
   - I.e., incorporate mature technologies into an operational system
   - Allows for investing in specific technologies for specific applications

Selecting a spacecraft architecture
   - RSDO catalog
   - Design a "one-of" Science observatory
   - Modular, Reconfigurable, and Rapid (MR2) Spacecraft based on heritage augmented with new technology and with Plug-and-play interface technology

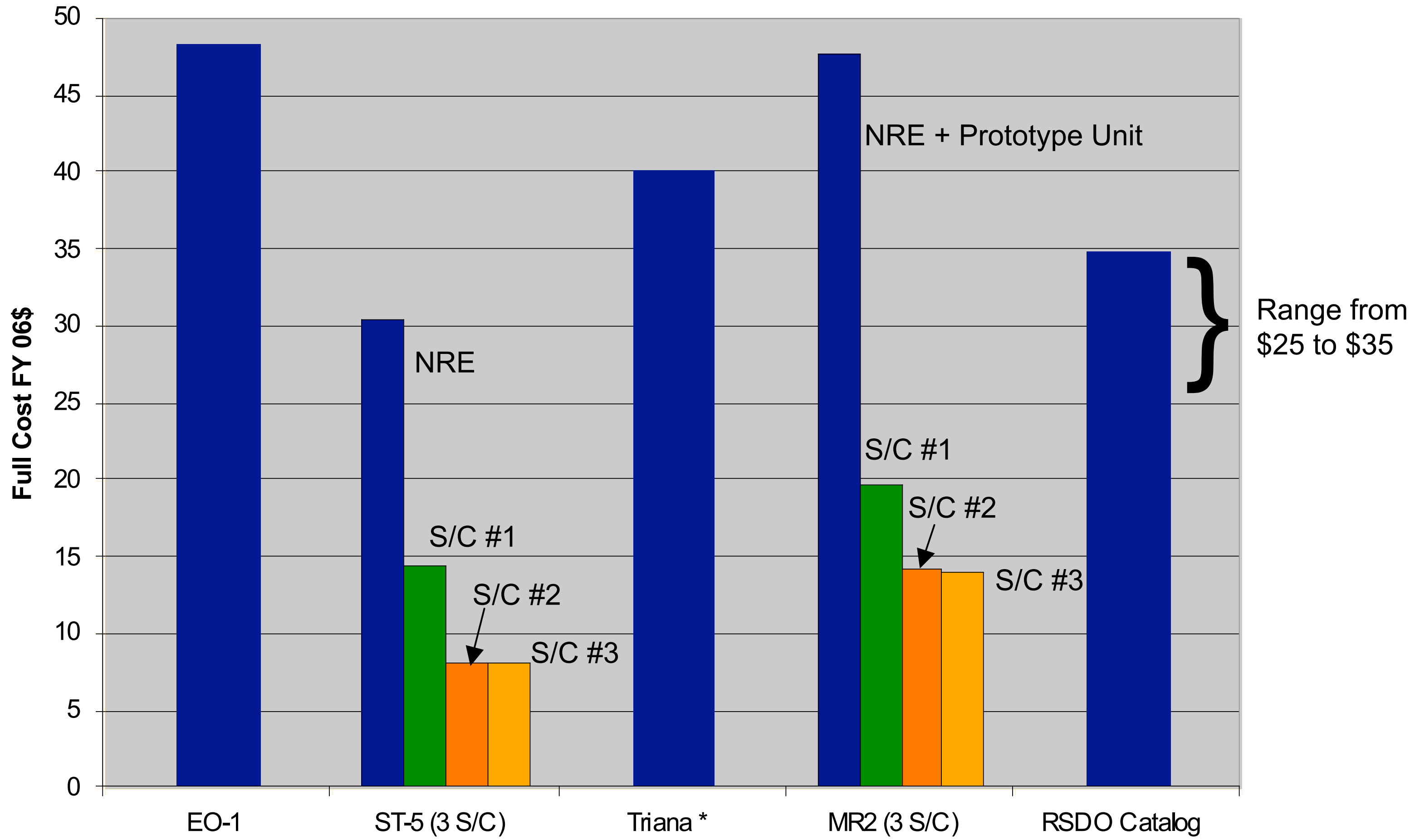
4. Correlating the science measurements from multiple missions flying in formation

Benefits of this Strategy

- Low cost Earth Science Missions with significant performance capability
- Short development phase (3-5years) = frequent launches
- Incorporates existing or emerging NASA and DOD technologies (TRL 6 or above) at low cost.
  - Maximizes payload to orbit using small ELV's
  - Provides a low cost platform for technology.
- The Agency benefits: Using NASA technologies retains core competencies, and trains our younger personnel.

This is a viable approach to enable high performance, rapid missions at a low cost.

<$25M Spacecraft are Achievable



Our recent experience with small, highly capable spacecraft indicates that this approach is achievable.

* ST-5 successful, Triana: fully qualified, SMEX-Lite spacecraft, awaiting launch opportunity

Small Expendable Launch Vehicles

Existing & Near-Term Small Launch Vehicle Options

- **Existing & under-development small ELV providers can provide Sun Synchronous/LEO responsive launch opportunities for moderate costs.**

Vehicle	Estimated SS/LEO Payload (Kg)	ROM Recurring Price
Pegasus	220	$30M+
Taurus	900-1500	$40M+
Minotaur I	340	$18M
Minotaur IV	1100	$22M
Falcon 1	420	$7M (TBR)

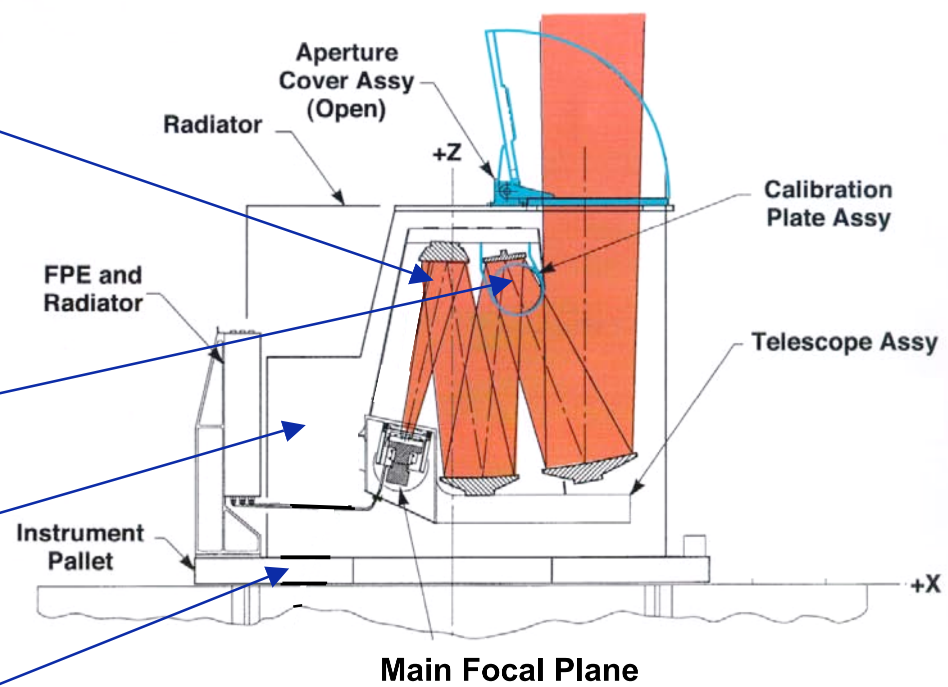
- **Other longer-term or less mature options include:**
  - **Minotaur V**
  - **Taurus 3113**
  - **SpaceX Falcon 5 and 9**
  - **AirLaunch QuickReach**

Proprietary Data – Government Use Only

LDCM Follow-on Mission's
Lightweight Advanced Land Imager
(LALI)

Potential Areas for Mass Reduction

- Reduce mass of telescope optics truss and housing
  - Light-weight ULE glass mirrors
  - Composite structures
  - Eliminate fold flat
  - Reduce f/#
- Eliminate solar calibration mechanisms
- Reduces size of housing and pallet
- Use composite material for pallet
- More efficient and up-to-date electronics, packaging, and wiring



Actual ALI and Estimated LALI Mass Distributions (kg)

	ALI	LALI
• Telescope (truss, diffuser, wiring)	34.5	14.0
• Housing (structure, mechanisms, wiring)	13.6	6.0
• Pallet (structure, wiring)	18.3	9.1
• Focal plane radiator (structure, wiring)	7.3	6.4
• Focal plane electronics (structure, wiring)	7.7	7.7
• ALICE (including filter box)	8.6	6.8
Total	90.0	50.0

LALI Technologies to Study

1. Develop on-board computational capability to reduce downlink rate and storage requirements
2. Cabling:
    1. Digitize signal on the chip and use fiber-optic cable for data transfer to on-board storage.
    2. Replace wiring harness with other technologies (i.e., “blue-tooth”)
3. Combine and miniaturize electronic functions
4. Reduce radiator size with improved coatings and lightweight structure
5. Build-up bread-board model of new ALI optical configuration
6. Qualify focal plane detectors (commercial devices currently available)

Spacecraft Options

Spacecraft Type Comparison

The difference between RSDO, SMEX-Lite, and MR2 class spacecraft can be highlighted in terms of mission/application flexibility.

RSDO	SMEX-Lite	MR2
Missions: • Excellent for single missions • Ideal for multi-missions that fit current design, without major modifications Attributes: • System-level modularity (complete spacecraft) • Accepts performance "option" changes	Missions: • Excellent for single missions • Ideal for multi-missions that use legacy interface technologies Attributes: • Modularity at the box / subsystem level • Monolithic Structure • Legacy interface standards • Flexible enough to re-use modules	Missions: • Ideal for multi-missions with maximum flexibility in applications (orbit, number of instruments, etc) Attributes: • Modularity at the card, box, subsystem, and system levels, according to needs • Scalable, modular structure • Plug-and-play interface standards, with self-discovery and cross-system recognition/ compatibility • Rapid integration and test

Increased Flexibility →

Spacecraft Mass Comparison

Spacecraft Mass (Kg)

EO-1	RSDO	SMEX-Lite	MR-2
462	160-400	180	100-130

Lowest S/C Mass = Lowest S/C Cost

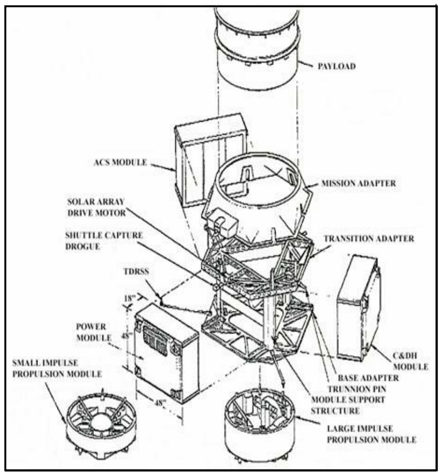
Lower Mass = Smaller Launch Vehicle = Lower Transportation Cost

MR2 provides the best combination of low mass, low cost and the flexibility for a wide range of science programs

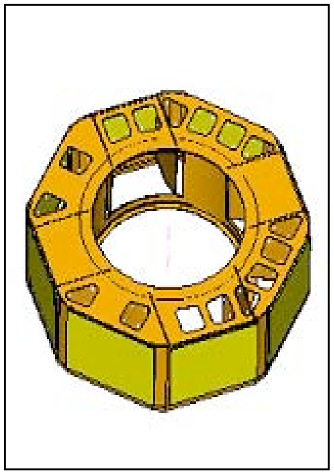
Modular, Reconfigurable, Rapid (MR2) Flight Systems Evolution

- **Past NASA concepts provide the evolutionary background for Modular, Reconfigurable, Rapid Flight Systems:**
  - **These have resulted in successful spacecraft implementations.**
  - **Lessons-learned are readily applicable.**
  - **The MR2 architecture represents the best sum-value of each experience.**
    - **Concept was originally developed using ESR&T and GSFC IRAD funds.**

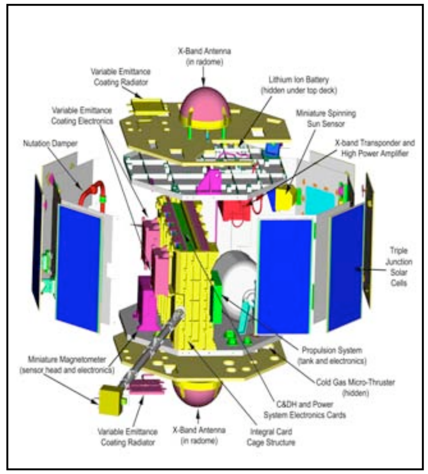
1970s and 1980s - Multimission Modular Spacecraft (MMS)



1990s – Small Explorer (SMEX-Lite)



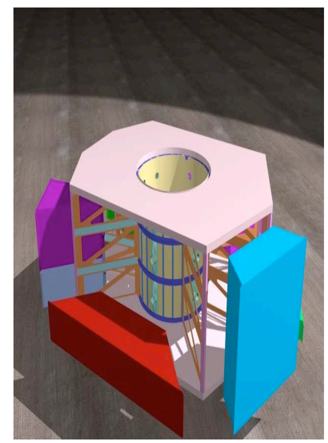
Late 1990 early 2000 – Space Technology 5 (ST5)



2000s and beyond – MR2

MR2 leverages work over the last 4 years:

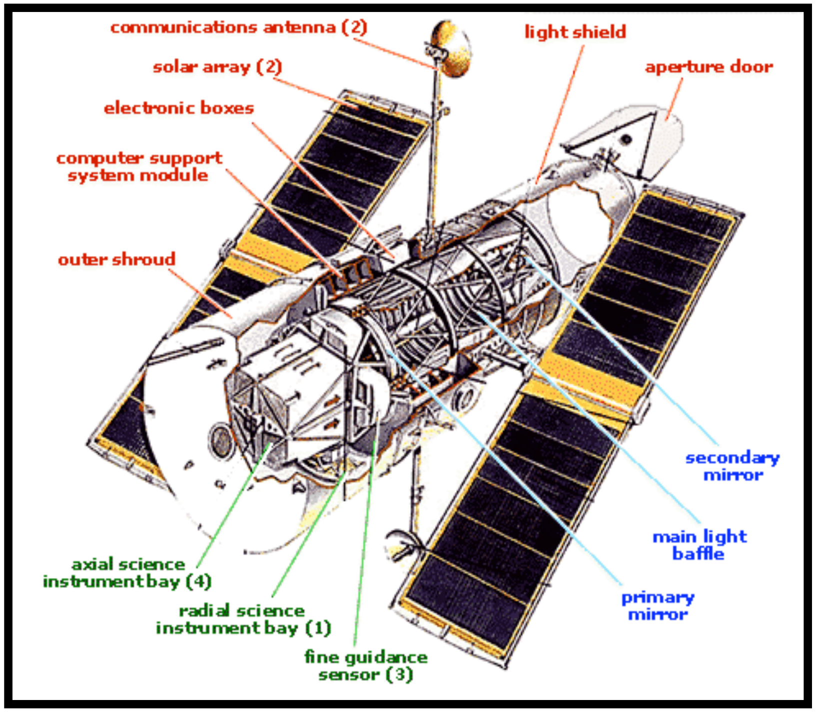
-GSFC FY04 IRAD
-NASA HQ (ESR&T) Funding.
-Collaboration with AFRL, LaRC, JPL, and others

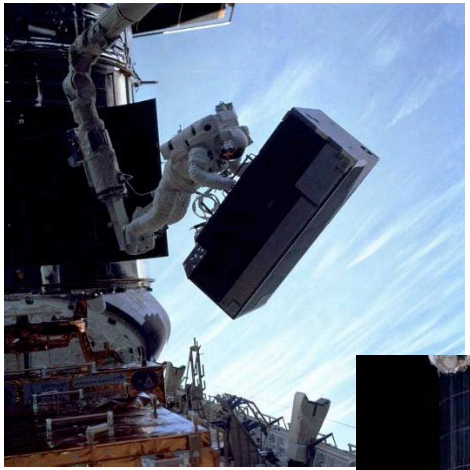


Given this successful experience, we have high confidence that the MR2 approach is achievable.

Modularity Enables System Evolution with Changing Technology

- **The Hubble Space Telescope represents an early implementation example of this architecture, enabling serviceable spacecraft.**



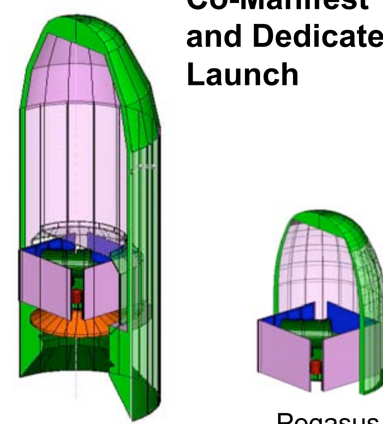


HST Servicing Mission 2 (1997)

- **Interface standards accept new technologies as they become available.**

MR2 Taxonomy and Scalability

- **Spacecraft *scalability* is valid for a defined performance envelope.**
- **Mission size classes lead to broad mission application range.**
  - **Six *mission size classes* identified (IMDC 2003) to cover those most commonly used in aerospace business today, with allocations for spacecraft mass, volume, and power.**
  - **Scalability may jump across launch vehicles.**
    - **It is realistically constrained to a set of mission size classes defined by major launch vehicle class differences.**
    - ***Work continues to identify the "break-points" in scalability.***



Near-Term Emphasis

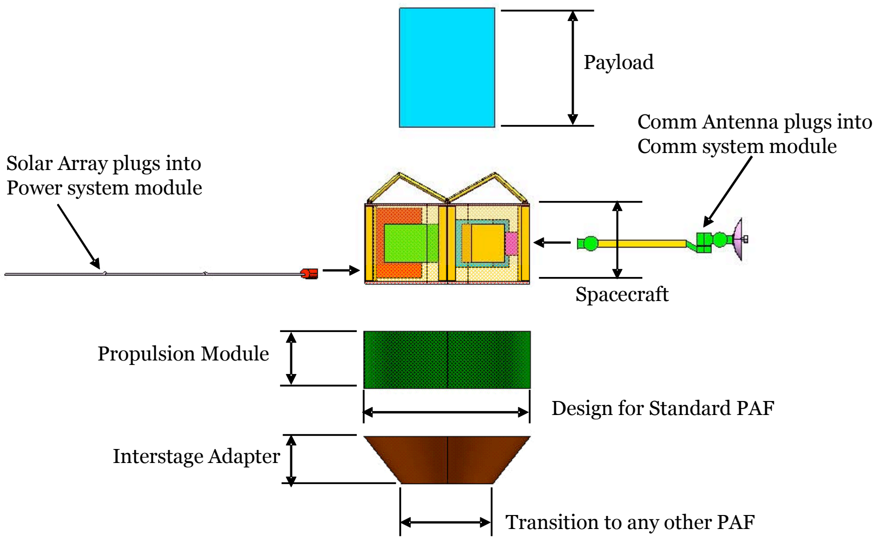
		MR2-25 Series Secondary Payload Class	MR2-50 Series Shared Pegasus Class	MR2-100 Series Pegasus Class	MR2-200 Series Taurus Class	MR2-300 Series Delta II Class	MR2-500 Series Delta IV Class
Not To Exceed Values							
Observatory Size	m	.5 m dia x .5 m	1 m dia x .5 m	1 m dia x 2 m	2 m dia x 5 m	3 m dia x 10 m	5 m dia x 15 m
Typ. Launch Mass to LEO	kg	40	120	400	1200	4000	8,000

Scalability

Break Point **Continuum** **Break Point** **Break Point**

Note: Mass scale shifts for lunar missions

MR2 Spacecraft



Spacecraft design features

- Mission flexibility: Interchangeable science instruments and orbits
- Interchangeable, modular components that are reconfigurable, and rapid I&T (standard Plug-and-Play interfaces)
- Re-sizable spacecraft/structure for various applications
- Electrical, mechanical, software Plug-and-Play interface standards (not technologies)
- Simple assembly and disassembly for efficient trouble-shooting during I&T

Performance Data (***representative sample only: system is reconfigurable)***

General Performance Parameters	
Payload Envelope (m^3)	>1
Payload Mass (kg)	>50
Average Payload Power (w)	>100
Solar Array	GaAs
Payload Thermal Restrictions	None
Launch Vehicle (can change)	Pegasus, Taurus/Minotaur
Command & Data Handling	
Architecture Heritage	MMS, SMEX, ST5
Processor	PPC RAD 750 / SpaceCube
Telemetry & Command Storage (Gbits)	>50
Data Bus	Ethernet, Spacewire
Downlink Rate (Mbps, X-Band / Ka-Band)	>150
Software System Heritage	SDO/LRO
Telecommunications Protocol	CCSDS/IP
Autonomy	Enabled
Guidance, Navigation & Attitude Control	
Control Strategy Inertial and Nadir Pointing	3-Axis Stabilized
On-Board Navigation and Timing to 1 usec	GPS Compatible
Independent Safehold Processor	Implemented
Structure	
Modular, Re-Sizable Structure	Aluminum (may change)
Instrument Interface	+Z Deck
Launch Vehicle Interface	- Z Deck
Mass Total (w/cont.) - typical for type mission	
Payload - LALI (kg)	50
Bus Dry Mass (kg)	130
Propellant (Hydrazine) - 1 year mission (kg)	7
Total Spacecraft (observatory) mass (kg)	187

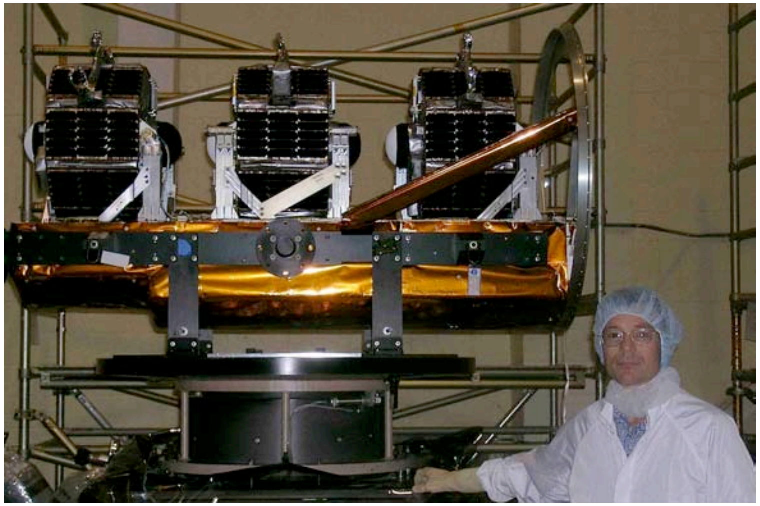
Table represents a *sample* of system capabilities *only*. The architecture allows for flexible accommodation of mission requirements / application.

Technology Development Needs

- Further the modularity concept
- Demonstrate the flight system plug and play technology (has been incorporated mission operations center)
- Mechanical and Thermal design
- Incorporate low weight ACS sensors/mechanisms and I/F
- Further lightweight power and communication systems

ST-5 Spacecraft

ST5 spacecraft (x3) in deployment cradle



Spacecraft design features

- Light-weight highly integrated system architecture
- High-density, small package design optimizes performance for class of spacecraft
- Advanced technologies include low-power electronics, miniature x-band transceiver, cold gas thrusters
- Production-line principles and experience in manufacture of three identical spacecraft
- Deploys the constellation from its own cradle

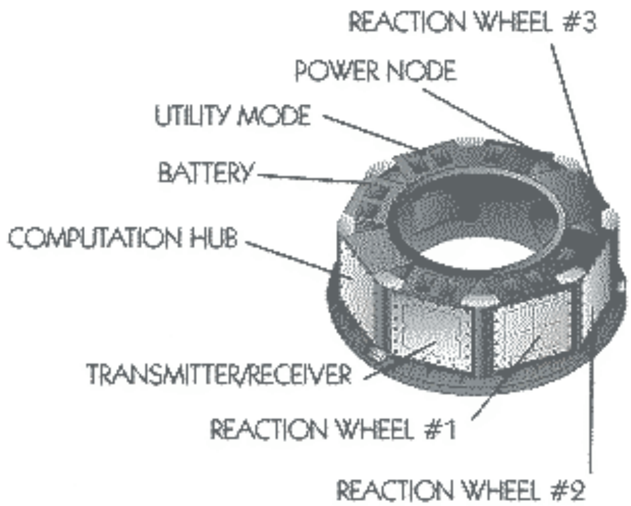
Performance Data

General Performance Parameters	
Payload Envelope (m^3)	None
Payload Mass (kg)	Tech Val
Average Spacecraft Power (w)	<9
Solar Array	GaAs
Payload Thermal Restrictions	None
Launch Vehicle	Pegasus
Command & Data Handling	
Architecture Heritage	Original
Processor	Mongoose V
Telemetry & Command Storage (Mbits)	2
Data Bus	RS-422
Downlink Rate (Kbps, X-Band)	100
Software System Heritage	MAP
Telecommunications Protocol	CCSDS
Autonomy	Enabled
Guidance, Navigation & Attitude Control	
Control Strategy Inertial and Nadir Pointing	Spin Stabilized
On-Board Navigation and Timing to 1 usec	USO
Independent Safehold Processor	none
Structure	
Integrated structure with electronics card-cage	Aluminum
Instrument Interface	None
Launch Vehicle Interface	None
Mass Total (w/cont.) - typical for type mission	
Payload - LALI (kg)	n/a
Bus Dry Mass (kg)	24.33
Propellant (GN2) - 3 month mission (kg)	0.39
Total Spacecraft (observatory) mass (kg)	24.72

Technology development needs

- Change the structural and thermal design
- Modify from spin to three-axis stabilization
- Increase power output, from body-mounted arrays to deployable solar array wing (s)
- Increase power system for 100W instrument
- Replace X-band system to service 500 Mbps downlink capacity
- Replace on-board computer to service increased MIPS requirement

SMEX-Lite Spacecraft



Spacecraft design features

- **Lightweight. monolithic structure**
- **Modularity at the box / subsystem level**
- **Legacy interface standards: MIL-STD-1553, RS-422 for high-speed**
- **Interconnect along a central hub**
- **Instrument can become part of spacecraft structure to drive mass down, but I&T costs increase**

Performance Data

General Performance Parameters	
Payload Envelope (m^3)	
Payload Mass (kg)	
Average Spacecraft Power (w)	25
Solar Array	
Payload Thermal Restrictions	
Launch Vehicle	
Command & Data Handling	
Architecture Heritage	
Processor	Loral RAD-6000
Telemetry & Command Storage (Mbits)	
Data Bus	MIL STD 1553, RS-422
Downlink Rate (Mbps, X-Band)	4
Software System Heritage	
Telecommunications Protocol	
Autonomy	
Guidance, Navigation & Attitude Control	
Control Strategy Inertial and Nadir Pointing	3-axis stabilized
On-Board Navigation and Timing to 1 usec	
Independent Safehold Processor	
Structure	
Monoilithic Structure	Aluminum
Instrument Interface	+Z Deck
Launch Vehicle Interface	- Z Deck
Mass Total (w/cont.) - typical for type mission	
Payload - LALI (kg)	50
Bus Dry Mass (kg)	
Propellant (GN2) - 3 month mission (kg)	
Total Spacecraft (observatory) mass (kg)	50

Technology development needs

- **Lightweight structure**
- **Review electrical design for lightweighting the heritage designs**
- **Modify thermal design**
- **Replace X-band system to service 500 Mbps downlink capacity**
- **Replace on-board computer to service increased MIPS requirement**
- **Modify power subsystem and solar array**

Summary

Next Steps for LDCM Follow-on

- **Produce Strategic Technology Plan to refine the approach for low-cost, LDCM follow-on mission(s)**
  - **Plan includes process for selecting spacecraft architecture**
  - **Includes the mission level development needs, such as on-board computation, autonomous operations, and formation flying**
  - **Includes the development needs for further investment in reducing the ALI mass (LALI).**
- **If MR2 architecture selected, need to advance the architecture design**

Summary

- Launching co-manifested or single missions on SELV's, results in the lowest cost missions
- Technology exists to produce a low-cost, light-weight, modular, reconfigurable (MR2) spacecraft
- Using this technology, co-manifest the LALI on a small launch vehicle for the lowest cost mission
- In addition, the MR2 spacecraft architecture provides SMD with a family of rapidly reconfigurable spacecraft to accommodate a wide range of Earth Science missions
- Using NASA technologies retains core competencies, and trains our younger personnel.

This is a viable approach to enable high performance, rapid missions at a low cost.