Using ISS and Micro-Satellites in Support of Exo-Planet Detection and Characterization

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MIT

How to Use ISS

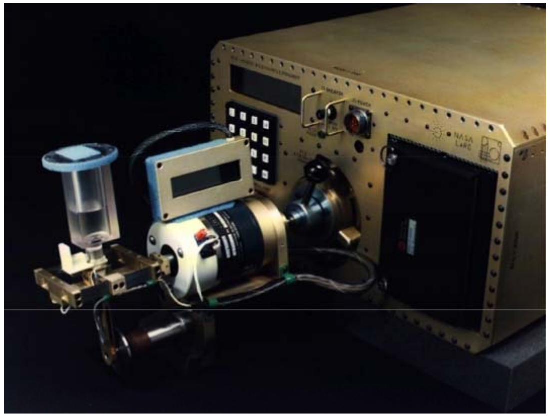
- As a platform for making observations
  - ISS provides power, data links, coarse ACS
  - ISS is very accessible: Shuttle, Progress, ATV, HTV, COTS
  - Crew can provide IFM and up-grade
  - However, contamination can be an issue (e.g., vibration, glint)
- As a platform for deploying systems (e.g., Kibo airlock)
  - Could retrieve and/or deploy micro-satellites, analogous to SPAS
  - Possibly perform check-out inside/outside ISS prior to deployment
  - Hybrids
- As a platform for maturing the needed technology
  - Test staged control systems, complex dynamics, deployment, micro-propulsion, optics, thermal control, material exposure

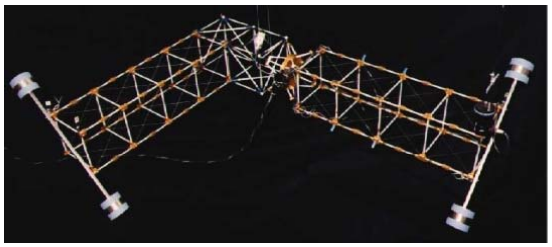
MIT-PSI/AFS μ-G Laboratories

- **Mid-deck 0-g Dynamics Experiment (MODE)**
  - [STS-48, September 1991]
- **Mid-deck 0-g Dynamics Experiment Reflight (MODE-Reflight)**
  - [STS-62, March 1994]
- **Dynamic Load Sensors (DLS)**
  - [MIR Space Station]
- **Mid-deck Active Control Experiment (MACE)**
  - [STS-67, March 1995]
- **Mid-deck Active Control Experiment Reflight (MACE-Reflight)**
  - [ISS, September 2000 to August 2001]
- **Synchronized Position, Hold, Engage, Reorient Experimental Satellites (SPHERES)**
  - [ISS, April 2006 to present].

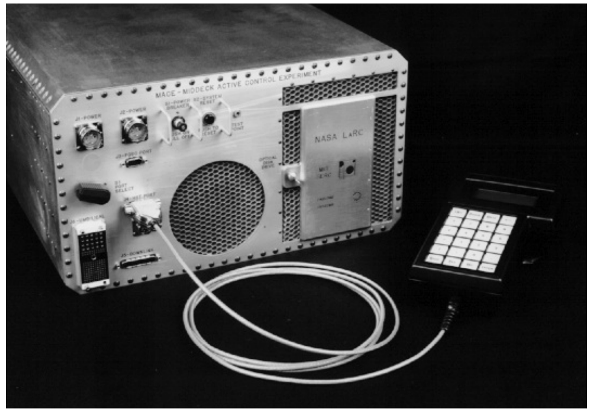
These programs averaged $2.0M + 2.0 years from initial design through fabrication-test-integration to initial phase of on-orbit operations.

Research Laboratories in Space

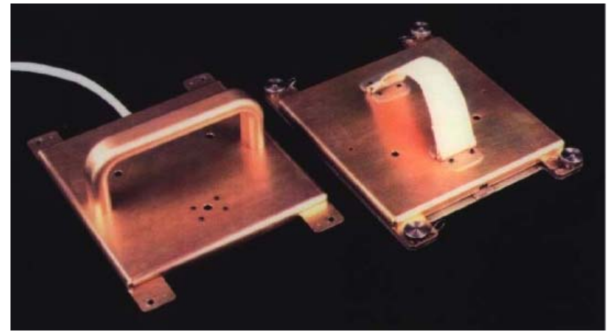




MODE
Shuttle 1991 & 1994



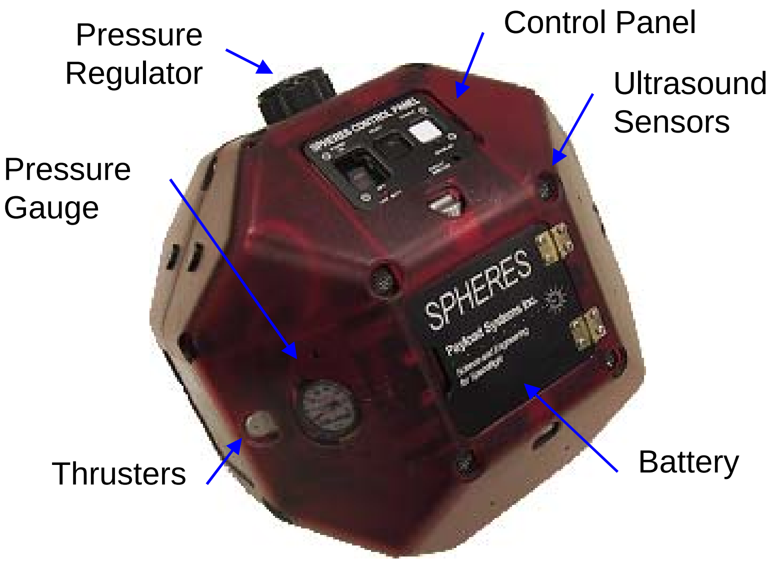
MACE
Shuttle 1995



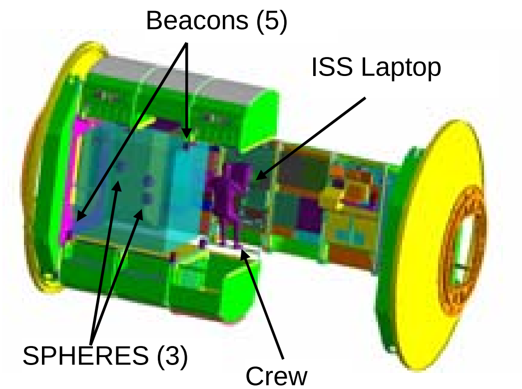
MACE ISS 2000

SPHERES Formation Flight Laboratory

- A ***risk-tolerant***, ***flexible***, ***high-fidelity*** environment to ***develop*** formation flight software
  - 3 6-DOF free-flyer, self-contained nano-satellites; 2 support satellites in ground operations
  - Satellite-to-ground (laptop) and inter-satellite communications
  - Custom pseudo-GPS metrology system
  - Guest Scientist Program supports multiple investigators
  - Extensible via an expansion port



SPHERES nano-satellite



Courtesy Boeing Co

SPHERES ISS Operations

ISS Test Session Accomplishments

- Had a total of 19 science test sessions of ~4 hours each since launch in May 2006
- Conducted one, two, and three satellite operations in full 6DOF
- Accomplishments summary, including estimated percentage of task complete:

	Sessions	Completed	Pending	%
Docking				
- Traditional	2-5,8	Dock to tumbling target	None	100
- “Safe”	5-6,9-10,14	Basic “react to failure” tests	Obstacle avoidance (3 sats)	70
- Assembly	9-13, 17, 19	Basic maneuvers, Some Docking	Dock 2 “assembled” sats to 3rd	50
- Reconfiguration	5-13, 17, 19	Joint thruster firing, Sens. Rcfg	Fuel optimization	50
- Inspection	10-11, 18	Basic Maneuvers, Wall Avoidance	Full plane coverage tests	60
- On-line path planning	8,10,12	Docking to a fixed target	Docking to moving targets	60
- Obstacle Avoidance	9-11, 14	Virtual obstacles avoidance	Real obstacle avoidance	25
- Fuel slosh	13-14, 16, 18	Satellite excitation maneuvers	Addition of fluid tanks	30
Formation Flight				
- Precision Formations	7-8, 11-14, 18	Circles, plane change, Spiral	Fuel balancing, optical maneuvers	85
- Initialization	10-11,13-14, 19	3-sat with collision avoidance	3-Sat & integrated tests	40
- Scatter	10-11	2-Sat demonstration	3-Sat & integrated tests	40
- Path planning	10-11, 15	Real-time guidance algorithm	SPHERES-only path planning	10
- Distributed Control	14,15	Initial demonstrations	Cyclic Pursuit continuation	40
- Collision Avoidance	13, 15, 19	Head-On, 3-Sat, Integrated Tests	Multi-sat control law	80
- FDIR - Recovery	1-8, 14	Independent detection & recovery	Fully integrated FDIR	70
Common				
- Lost-in-Space	7, 18	2-Sat and 3-sat algorithms	3-Sat algorithms	60
- ΔV Control	10-12	Data collection and basic motion	Integration with estimator	70
- Advanced Controls (Hinf)	13-14	1 & 2 Sat basic maneuvers	Use on high-level tasks	50


MIT

How to Work with ISS

- Getting launched
  - Both of my ISS experiments went through DoD SERB/STP
  - The smaller the payload, the easier to find a launch
  - Consider launching in stages: grow the facility
- Getting integrated
  - Engage the Safety Office early
  - Explore innovative ways to adapt to existing interfaces
  - Remember, despite NASA's help, you will have substantial integration work. The ISS Office does not do it for you.
- National Laboratory
  - Permanent facility on ISS with re-supply and upgrade
  - Consider sharing generic equipment, resources, and integration services

Payload Integration Plan

- The Payload Integration Plan (PIP) provides the management roles and responsibilities, and a definition of the technical activities, interfaces, and schedule requirements to accomplish the integration, launch, on-orbit operation, and postlanding operations of the payload with the carrier.
- It is essentially the contract between your payload and the carrier that specifies which services the carrier will provide and to what standards the payload will be designed and operated.
- The PIP lists customer and NASA responsibilities in the integration process
- Supported by a series of Annexes which detail other aspects of the payload development

Payload Integration Plan

- PIP outlines the following:
  - Time required during the mission
  - Hardware to be provided by the customer
  - Data transfer requirements
  - Stowage volume requirements
  - Data requirements
  - Integration review requirements
  - Photographic and video requirements
  - Crew training and on orbit operations requirements

PIP Annexes (Shuttle)

- Annex 1: Payload Data Package Annex
  - Surface level description of the payload properties.
  - Subsequent documents address properties in more detail.
  - Includes data on mass properties, mechanical configuration (internal or payload bay), static and operational envelope definitions, electrical, avionics and crew handling interfaces, and payload and orbiter orientation.
- Annex 2: Flight Planning Annex
  - Defines the timeline by which the experiment will be performed during the mission.
  - Payload requests the blocks of time required to achieve nominal success of the experiment, as well as subsequent time blocks which would be considered desirable, but not vital payload success criteria.
  - Defines constraints with respect to Orbiter attitude and pointing, thruster firings, EVA's and LOS periods.

PIP Annexes

- Annex 3: Flight Operations Support Annex (FOSA)
  - Describes the on orbit operations and also governs the **flight crew procedures**.
  - Mission control console and equipment requirements, payload checklists, command plans, ground control team responsibilities (customer and NASA), data management plans, and contingency procedures and decisions.
  - Defines **the Joint Operations Interface Procedures** (JOIP). The JOIP are NASA and customer joint responsibilities during the mission. For example, if the payload required downlink of data from the Orbiter, a JOIP would be written to define how the data are downlinked, and what the crew and ground team responsibilities are.
  - One of the most useful of the integration documents, the **Cargo Systems Manual** (CSM), is also spun off from the FOSA. The CSM is a concise overview of the payload. It is intended for the NASA flight controllers as a high level users guide and is referred to frequently during a mission.

PIP Annexes

- **Annex 6: Interface Control Annex**
  - Describes the physical interface between the payload and the Orbiter.
  - Mass properties, stowage configuration and center of gravity are described explicitly.
  - Defines the power, thermal and structural interfaces with the Orbiter in detail.
- **Annex 7: Training Annex**
  - Describes the amount of time required for crew training, the amount of crew support necessary and an overview of which topics will be covered during all training sessions.
  - High level description of the contingency and malfunction procedures

Safety

- Phase Safety Process starts approximately 2 years prior to launch
- Consists of four (sometimes three) reviews
- Data packages are submitted two months prior to actual meeting
- Payload Safety Review Panel has its own staff as well as assistance and representatives from various JSC engineering disciplines:
  - Materials
  - Structures
  - Toxicology
  - Electrical
  - Software
  - Etc.
- PSRP is the last word on what flies on Shuttle/ISS.

LEO - Expendables

- ESPA Ring
  - About 400 lbs

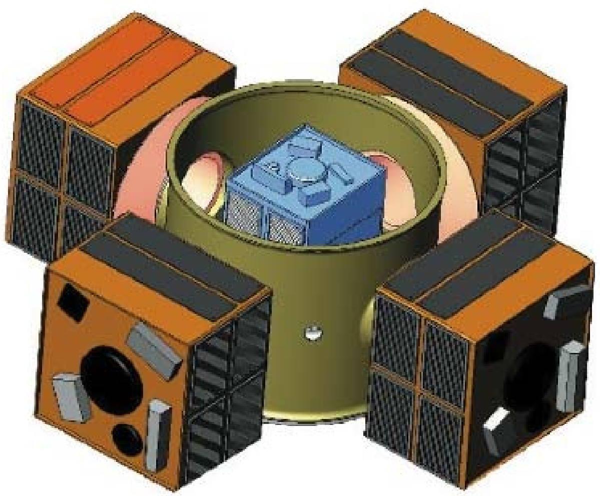
Small Launch ESPA

38.8-inch ring
8- or 15-inch ports
for Minotaur 4, Delta 2,
Falcon 1e, Taurus

Separating ESPA

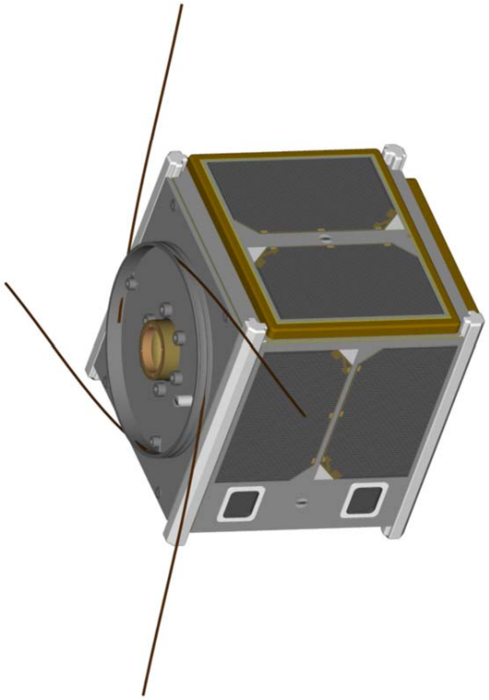
Integrated Separation System
reduces adapter mass and height.
Saab and Lightband separation systems

ESPA Grande



"Stretch" version of standard ring
15- or 23-inch ports
Ring heights to 60 inches

LEO – Cubesat and P-POD



4 inches on a side