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DEFINING THE FUTURE

NWO Servicing

NGST

Chuck Lillie

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Design for Servicing

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- Future space observatories should be designed to enable on-orbit servicing to:
  - Replenish expendables
  - Replace limited-lifetime items
  - Replace degraded or failed components
  - Upgrade with newer technology
- Guidelines include:
  - Design for servicing from the beginning
    - Standard interfaces with kinematic mounts, blind mating connectors
    - Ease of access with external mounting or easily opened panels
    - Grapple fixtures, handholds and foot restraint fittings for EVA servicing
    - Fittings for propellant replenishment
  - Create modular designs
    - Package subsystem components together where possible
    - Replace at subsystem and/or component level
    - Orbital Replaceable Units (ORU's) for units most likely to wear out or fail
    - Parts kits to allow other units to be fabricated if necessary

Replaceability Options

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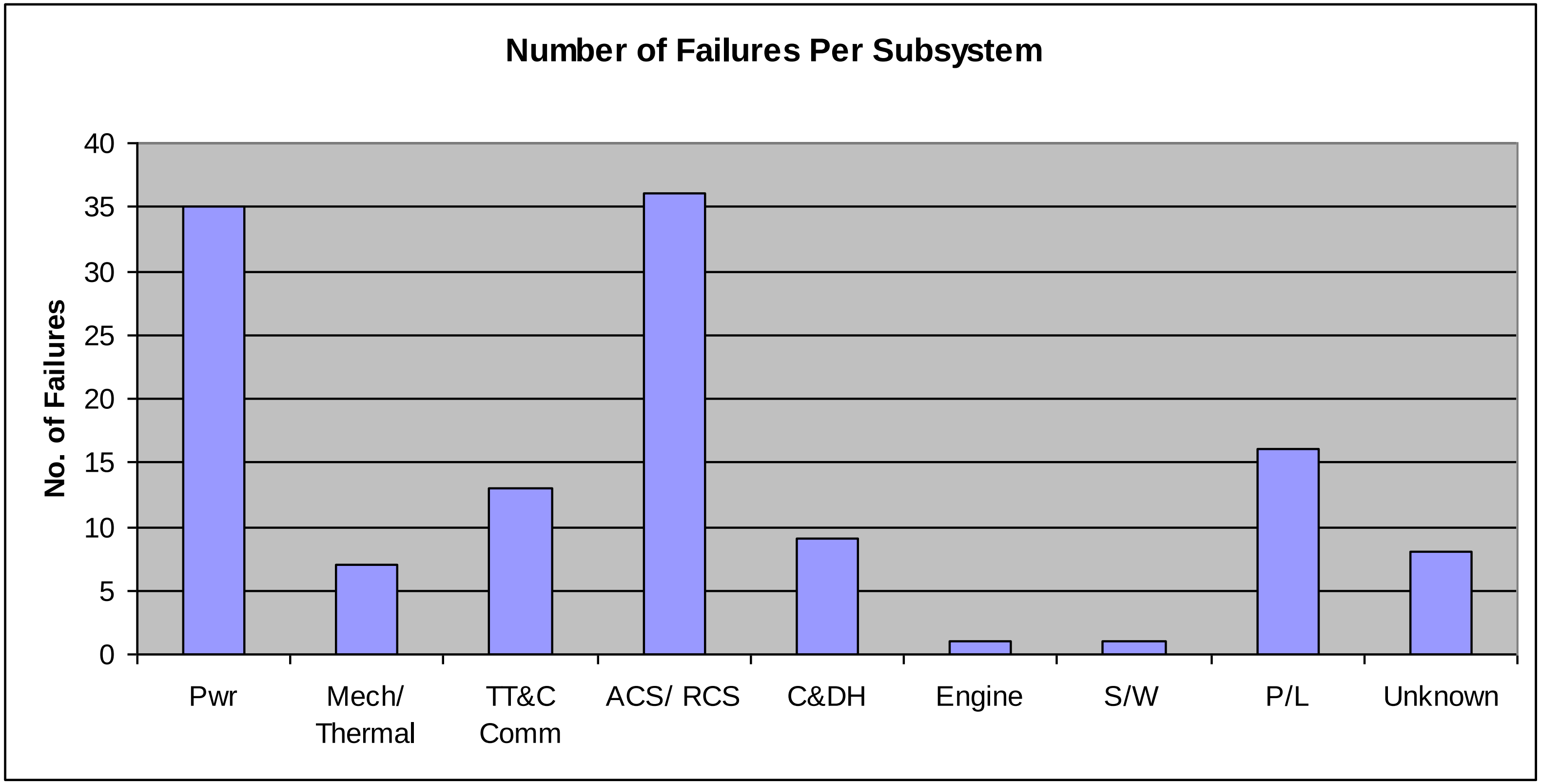
- Replace Entire Bus
  - Pro: Ability to update all systems with future technology
  - Con: Requires new bus to fix one component
- Replace individual subsystems
  - Pro: Lower cost, Spare selection based on statistical failure modes
  - Con: Inability to update all systems with future technology
- Replace individual components
  - Pro: Maximum flexibility
  - Con: More ORU attachment componentry
    - Requires more sophisticated replacement robot
- Carry Replacement components on only flight
  - Pro: No service vehicle needed
  - Con: Unable to update systems with future technology, higher mass, limited lifetime extension

Subsystem Failure Statistics

- Data below is from every satellite launched from Earth between 1990 and 2008



Trade Evaluation Criteria

- Impact of number of replaceable units on Cost and Mass
  - More units = more ORU interfaces
  - How should we include servicing vehicle and future launch cost?
- Statistical evaluation of unit spare philosophy
  - Redundancy vs. Replaceability
- Servicing approach and location location
  - Robotic, EVA or Crew Assisted
  - Cis-Lunar (EM L1) or Sun-Earth L2

The Necessary Technologies

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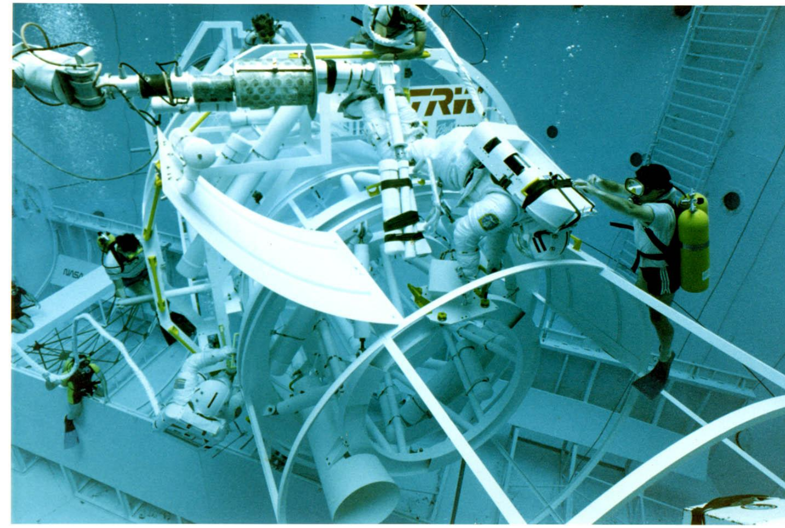
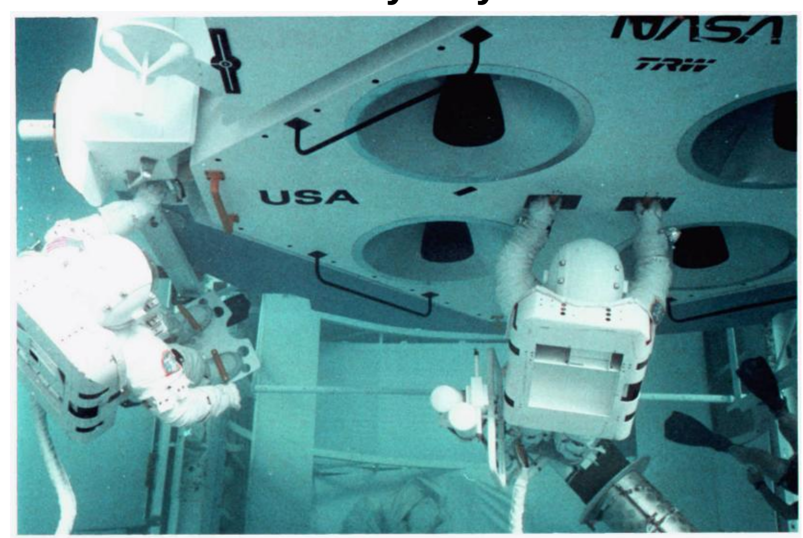
- Access to space
  - Launch Vehicles
  - Manned Spacecraft
- Rendezvous and Docking
  - Proximity operations
- EVA Capability
  - Spacesuits
  - Tools and crew aids
  - Work platforms
  - Crew Training facilities
- Robotics
  - Remote manipulator systems
  - Dexterous manipulators
  - Machine vision
  - Autonomous Operations
- Telerobotic
- On-Orbit Servicing Facilities



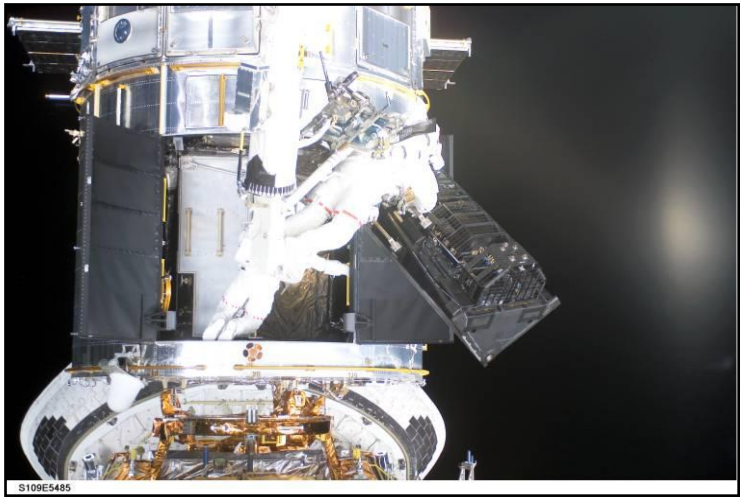
AXAF Neutral Buoyancy Tests at MSFC



OMV Servicing

Servicing the Hubble Space Telescope

- EVA servicing missions for HST have clearly demonstrated the ability of on-orbit to repair, maintain and enhance observatory performance
- The four servicing missions conducted to date have
  - corrected the optical performance of the telescope,
  - replaced failed components,
  - increased the wavelength coverage of its instruments and
  - increased the observatory's productivity by several orders of magnitude.



Removing the Faint Object Camera

Power Control Unit Replacement

Compton Gamma Ray Observatory (CGRO)

Launched April 5, 1991, Incorporated GSFC specific replaceable ORUs

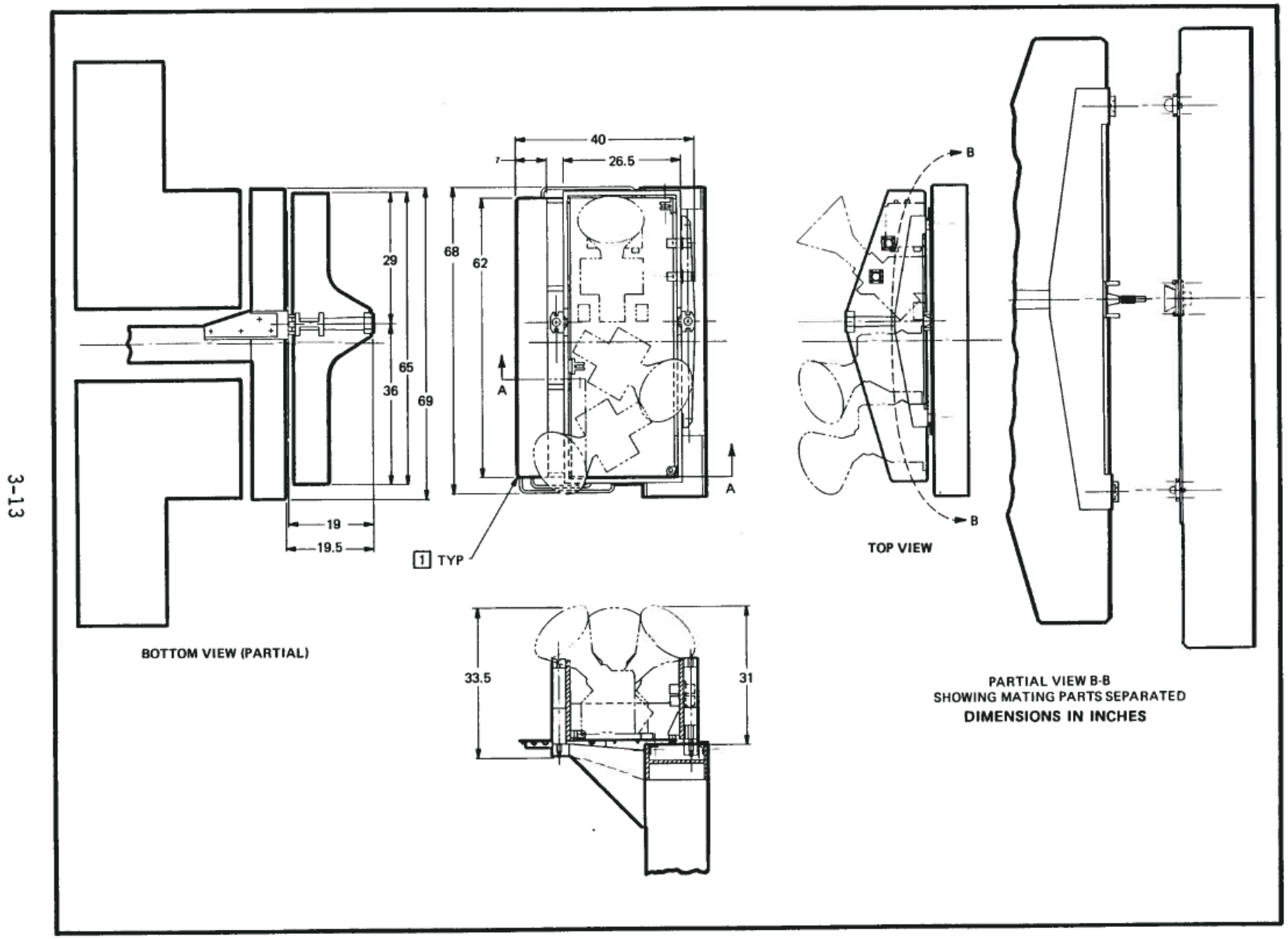
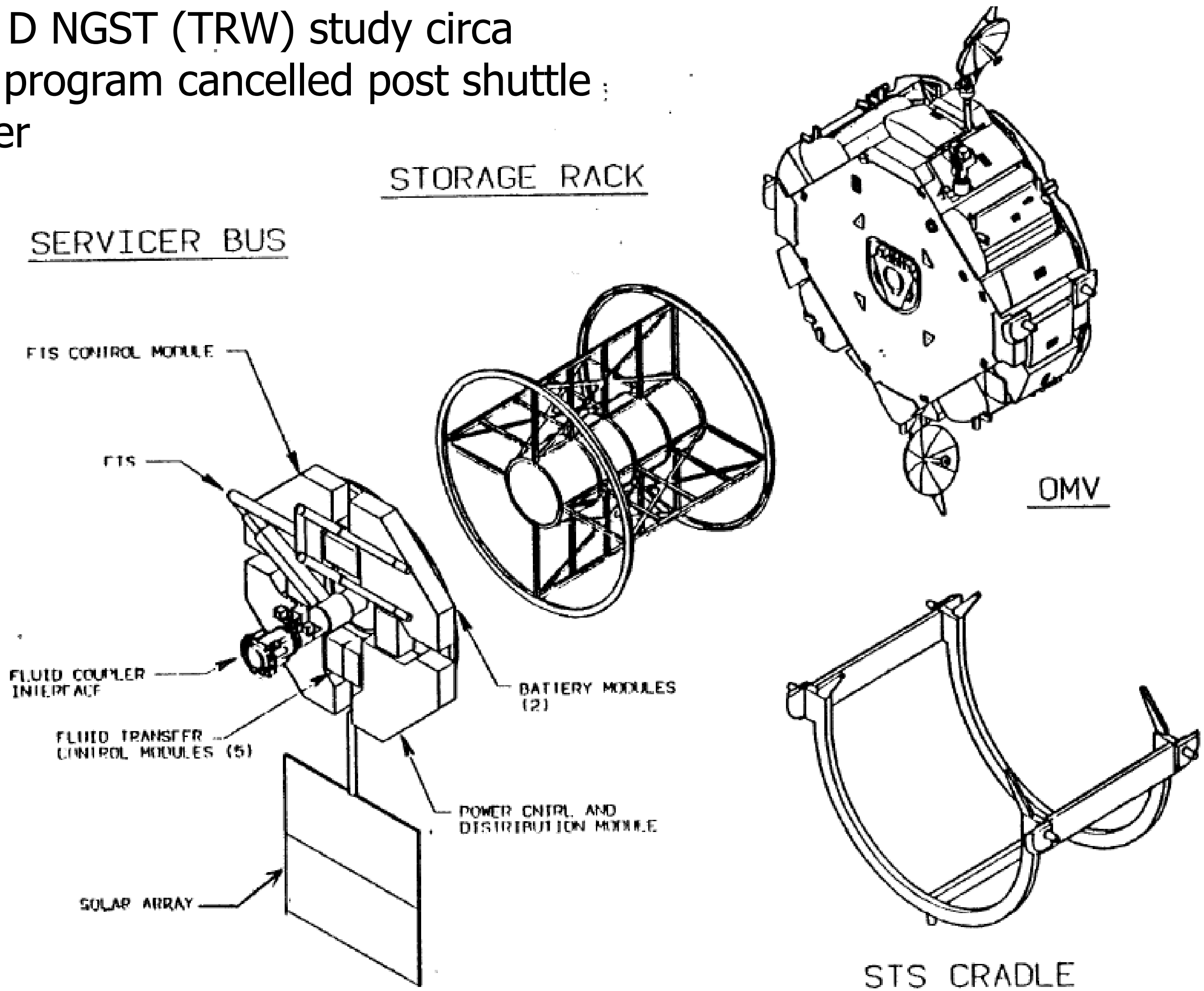


Figure 3-7. Orbit Replaceable Attitude Determination Module.

Orbital Maneuvering Vehicle (OMV)

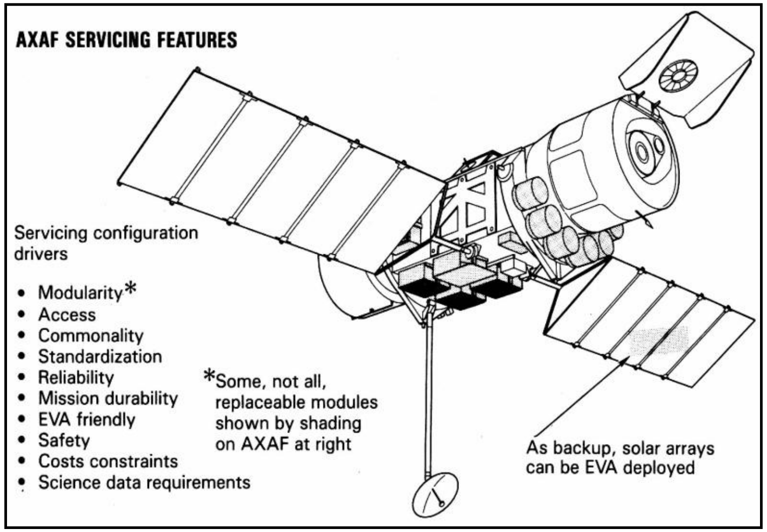
Phase D NGST (TRW) study circa 1985, program cancelled post shuttle disaster



AXAF was Designed For Servicing

- The Advanced X-Ray Astrophysics Facility was designed in the 1980's as a serviceable observatory in Low Earth Orbit
- Components likely to wear out were housed in easily accessible Orbital Replacement Unit, i.e.:
  - Avionics modules on the bottom of the observatory
  - Solar arrays
  - Cylindrical reaction wheel containers at the front of the observatory.
  - Science instruments at the rear of the observatory

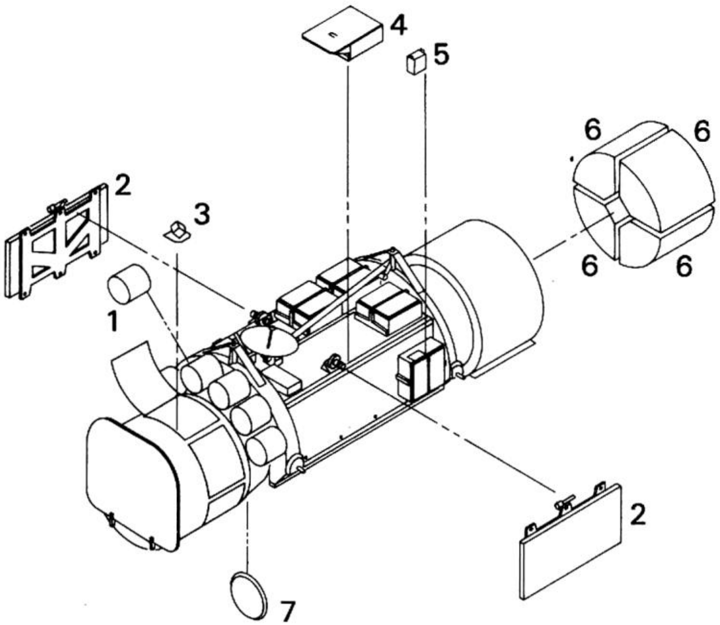
Low-Earth Orbit Version of AXAF



AXAF Servicing Features

AXAF Servicing Concept

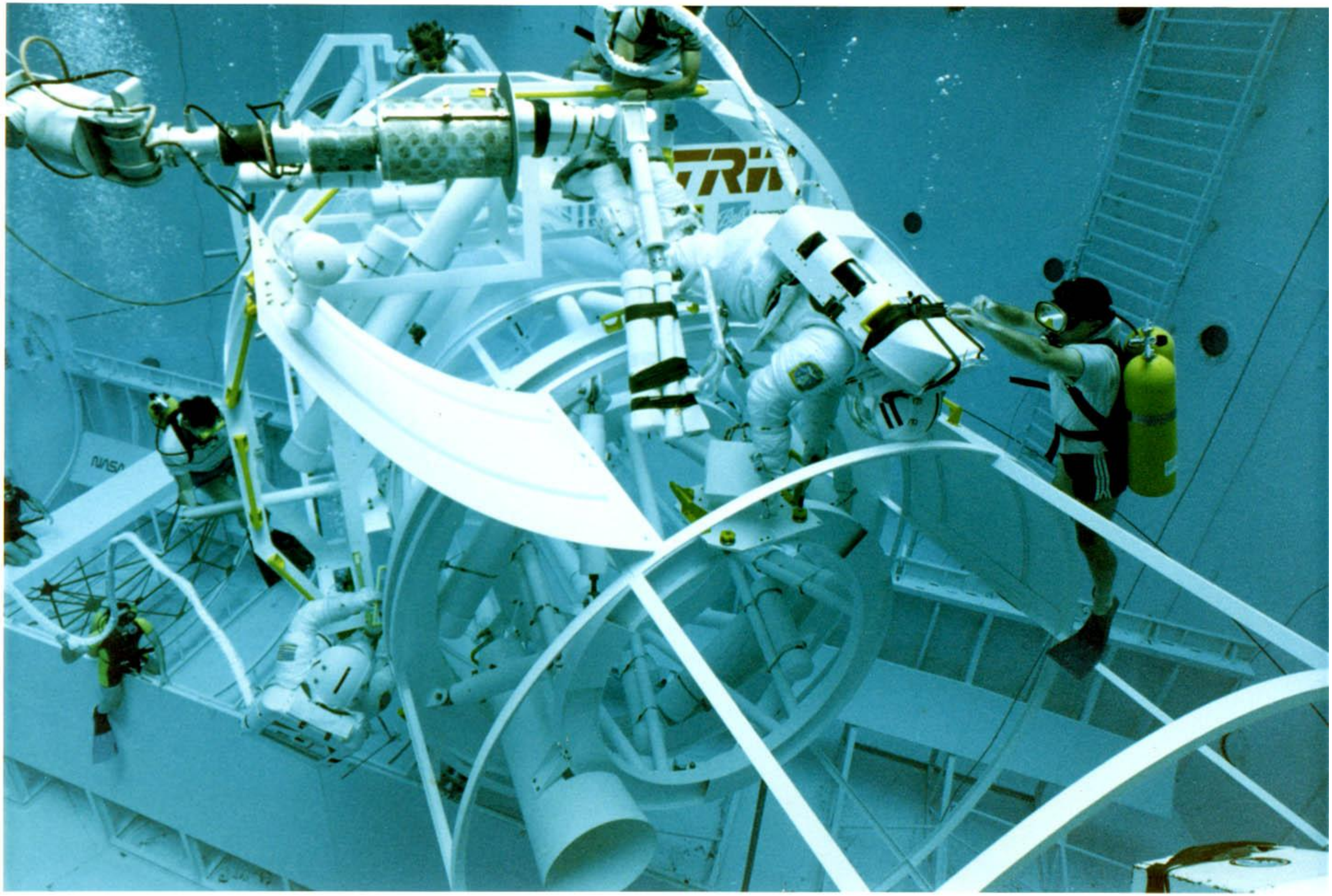
DESIGNED FOR SERVICEABILITY, AXAF ORUs, CRUs ARE LOCATED FOR EASE OF ON-ORBIT SERVICING



DESCRIPTION		QUANTITY ON SPACECRAFT	SPARES
ORUs	1. Reaction wheel assembly	6	3
	2. Solar array wings	2	2
	3. IRU (gyros)	2	1
	4. Battery module	1	1
	5. Tape recorder	2	2
SIs	6. Focal plane experiment	4	—
	7. Objective transmission grating (OTG)	2	—
Typical CRUs	1. Aspect camera	1	—
	2. Power supply electronics module (MMS type)	3	—
	3. Solar array switching unit (SASU)	2	—
	4. Electronic integrating assembly (EIA)	1	—
	5. Instrument switching unit (ISU)	1	—
	6. CDM module (MMS type)	1	—
	7. Drive electronics assembly (DEA)	2 (redundant units)	
	8. Attitude control electronics (ACE)	2 (redundant units)	
	9. Reaction wheel electronic assembly (RWEA)	6	—
	10. HRMA actuators and related electronics	6	—
	11. HGA dish	1	

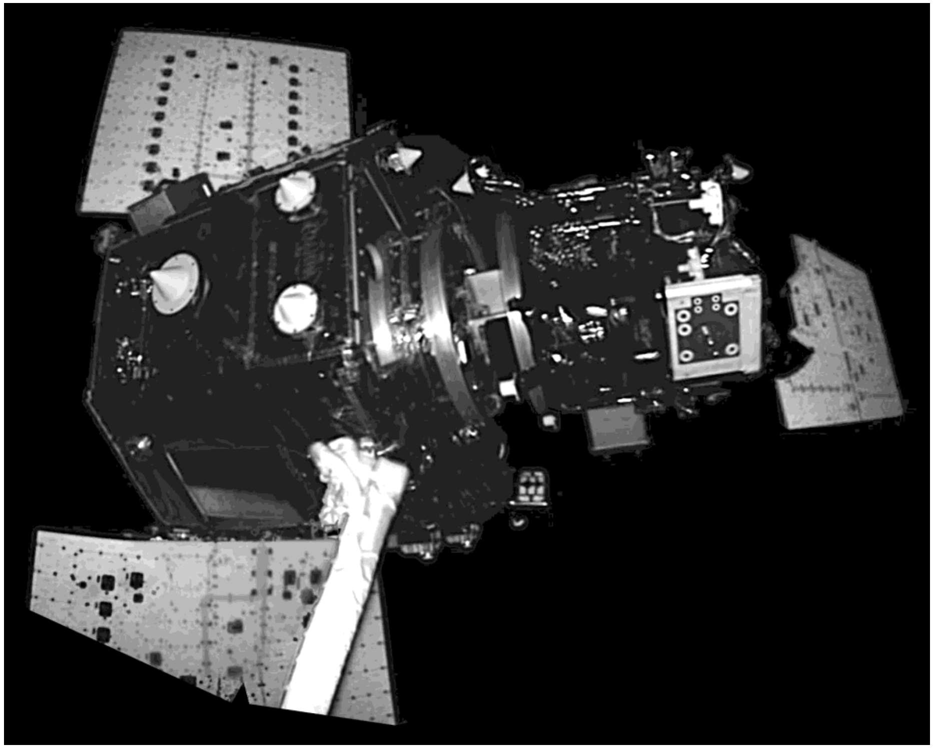
- Concept circa 1989 for servicing with the shuttle or at the space station customer servicing facility

AXAF Mockup in MSFC's Neutral Buoyancy Facility



Orbital Express Overview

- DARPA demonstration program to advance technologies for satellite serving
  - Rendezvous and Docking
  - Fluid Transfer (propellant re-supply)
  - ORU (orbital replacement unit) Transfer
- General Program
  - ~5 years from program award to end of flight operations
  - NGST provided the Fluid Transfer and Propulsion Systems to Boeing/Ball
  - Class C+ (limited redundancy)



Self portrait of the two docked vehicles (ASTRO servicing vehicle on left; NextSat client/ commodities spacecraft on right)

NGST Fluid Transfer Demonstration System

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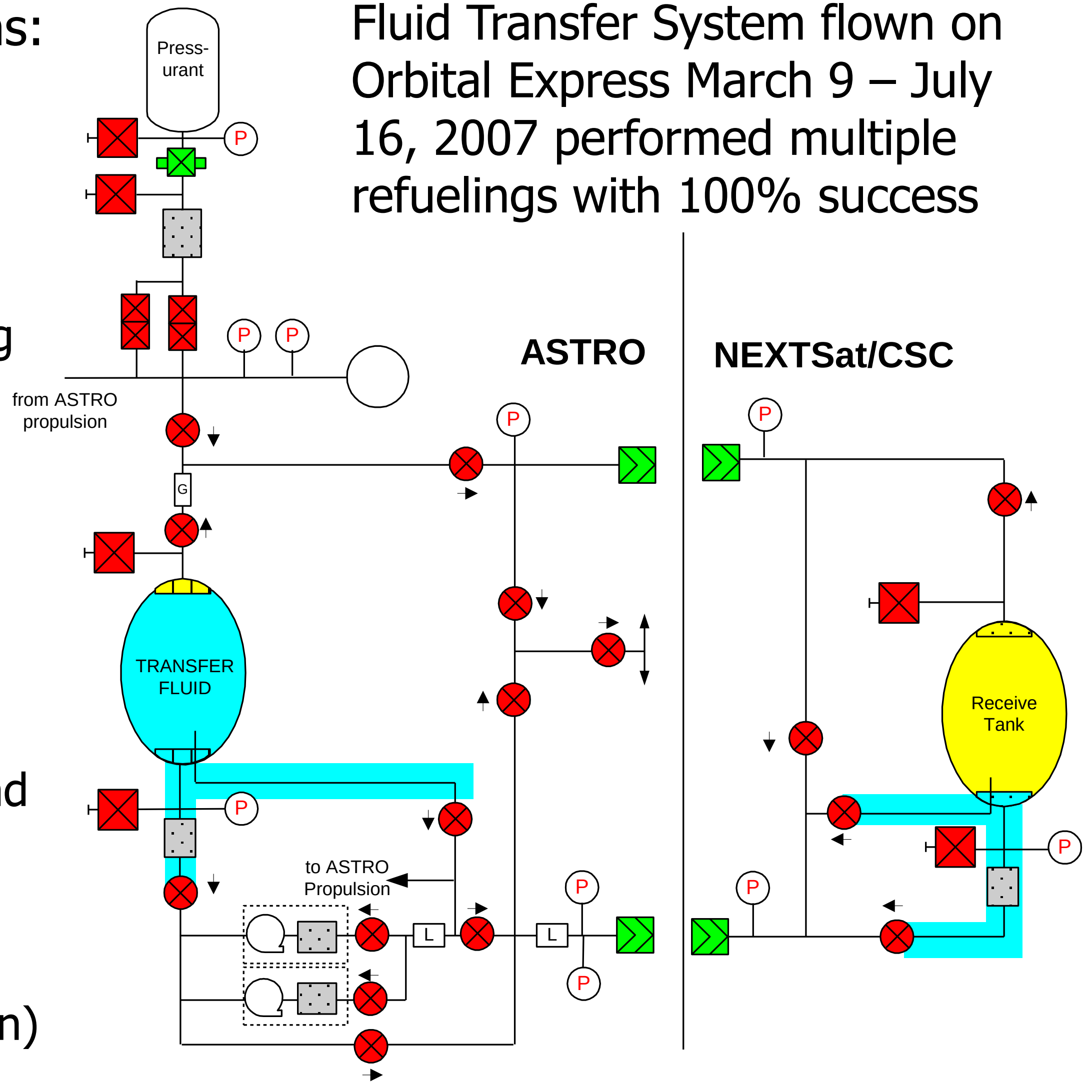
- Key on-orbit demonstrations:
  - Closed loop transfers - propellant in, pressurant back using fluid pump
  - Ullage recompression - no pressurant exchange using pressure supply
  - Fluid gauging - multiple methods
  - Autonomous fluid transfer operations
- Future Client Impacts:
  - 1 to 3 additional valves and two pressure transducers
  - Addition of a passive side coupling and passive side capture system (not shown)

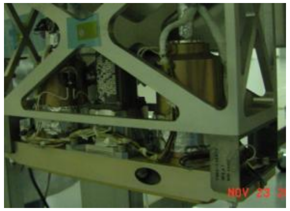
Fluid Transfer System flown on Orbital Express March 9 – July 16, 2007 performed multiple refuelings with 100% success



Development Hardware

Component	Innovation
Variable speed hydrazine (N2H4) pump (0.23 lbm/sec)	Motor-driven adaptation of turbine Shuttle APU pump
Fluid coupling/bellows Assembly	2-path/redundant seal couplings with ~4" travel, rotating-cover thermal protection, axial/lateral misalignment tolerance
Propellant/fluid transfer tanks	Surface tension ullage gas bubble positional control to 95% fill fractions
Flow sensors	Passive fluid flow measurement
Non-propulsive catalytic vent	Operates from 100% liquid to 100% gas along with any combination in-between

Coupling



Tank PMD

Flow Sensor

Pump

Potential Propellant Resupply Benefits

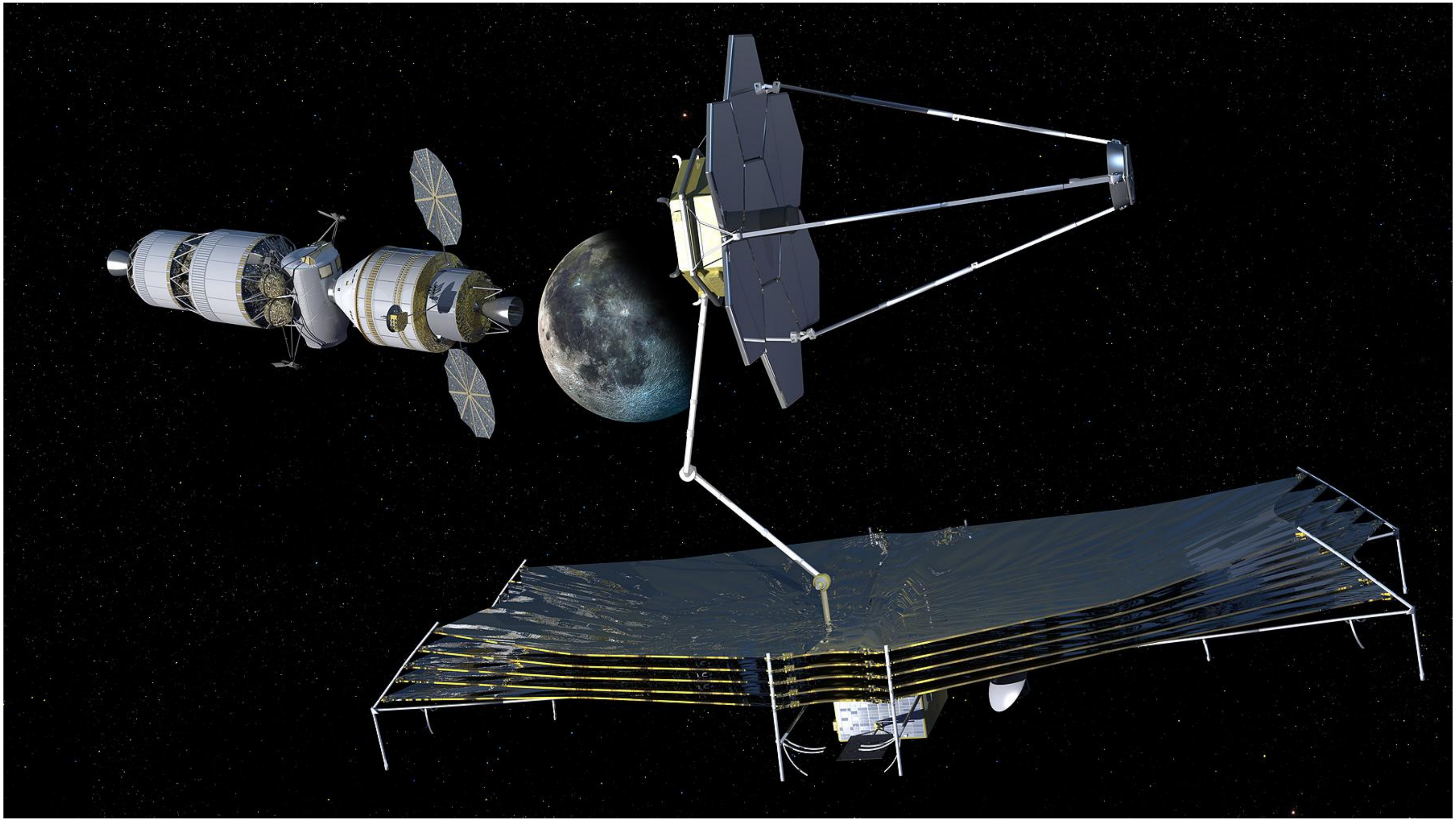
- Early mission: reduced launch weight
  - Launching without mission propellant load could allow an extra spacecraft or more payload to be launched
- End-of-mission: reduced launch weight, system efficiency (reduced mission weight)
  - Particularly for those missions with orbits below 2000 km requiring end-of-life disposal, the savings in propellant mass and tank volume can be substantial
- Mid-life: generally life extension, system efficiency, contingency refuel, and maneuverability. Maneuverability can have mission-improving and mission-enabling benefits, including:
  - Increased coverage, threat avoidance, unpredictability, and imagery resolution (i.e., orbit shifting, reduced perigees)

OE has laid the groundwork for future mission planners to evaluate the benefits of propellant re-supply for a variety of mission needs

Hubble Robotic Servicing Vehicle

- The HRSV consists of an Ejection Module (EM) and Deorbit Module (DM)
  - The EM holds the robot arm, ORUs, new instruments and servicing tools
  - The DM contains the propulsion system that will be used to deorbit HST
  - The “skirt” at the bottom of the EM is made up of solar panels that provide electrical power to the vehicle.
- The key element of this design is servicing arm tipped with a flight qualified robot developed for the International Space Station.
  - “Dextre” (the Special Purpose Dexterous Manipulator) has 7-degrees-of-freedom in each of two arms, and a 23-foot total arm span.
  - In tests at GSFC it has demonstrated its ability to perform the servicing tasks scheduled for SM4 autonomously and/or telerobotically.

Manned Servicing Concept



- Servicing in Cis-Lunar Space with an ORION/CEV baced servicing vehicle

Summary

- HST servicing missions clearly demonstrated the desirability of on-orbit servicing, and further developed NASA’s EVA capabilities
- The Orbital Expr3ess robotic servicing mission demonstrated the feasibility of autonomous rendezvous and docking, fluid transfer, and equipment replacement.
- Many options for human and robotic servicing are now available and should be considered in the design of future space observatories.\
  - Orion/CEV derivative servicing vehicles
  - Orbital Express and Hubble Robotic Servicing Vehicle derivative vehicles
- Servicing NWO at L2 or the Earth-Moon L1 point could extend its operational lifetime and enhance its performance
  - Xenon and bi-propellant replenishment would greatly enhance the number of targets that could be observed
  - Instrument replacement could also enhance performance and increase the science return

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DEFINING THE FUTURE

For NWO

- Servicing location
  - L2, L1 (EM) servicing at L1 may cause shadowing & therefore need larger batteries
- Serviced components
  - Starshade: Propellant (Xenon & Hydrazine), thrusters, whole propulsion module, whole bus!
  - Telescope: instruments, electronics, gyros, RWA, propellants, instrument module, bus
- Wireless bus servicing: see F6, open questions regarding cg migration, navigation & calibration
- Servicing mission scenario
  - Just telescope, stays attached, or service and depart
  - Just starshade, stays attached, or service and depart
  - Both
  - Service other assets
  - $400M bogey (INCLUDES launch)
- Needs to be less expensive & risky than another starshade (if just servicing starshade)
- ORUs & CORUs a la AXAF/LEO
- Yes, we're thinking about servicing

Servicing of L2 Missions

Bobby Williams/KinetX
David Dunham/KinetX
Robert Farquhar/KinetX

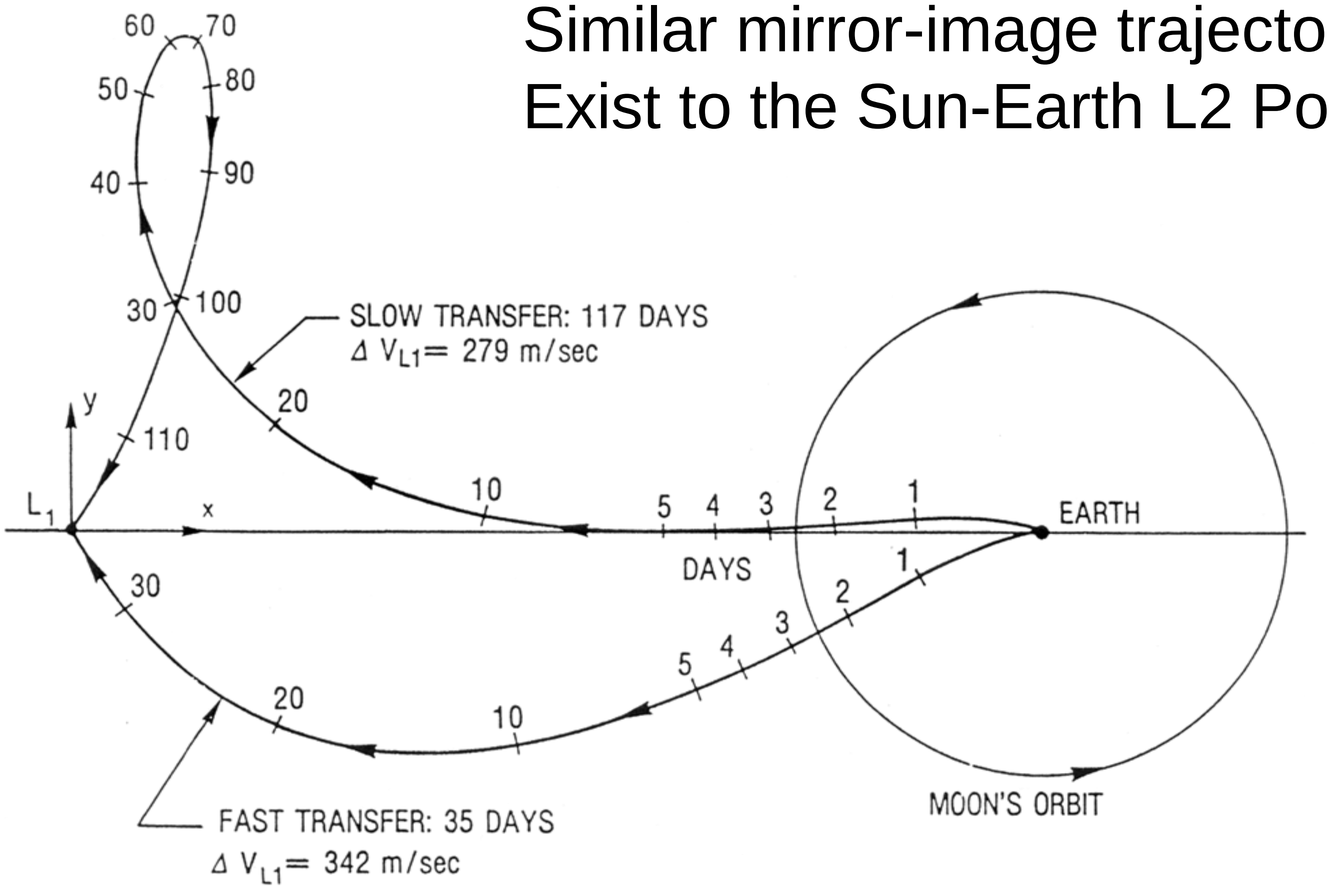
November 6, 2008

Servicing for NWO

- **From “Starshade Spacecraft & Concept of Operations” NWO ITA Review presentation**
- **Replenishing propellant for extended mission, more observations, faster retargeting**
  - Hydrazine refueling demonstrated by Orbital Express mission in 2007
  - Xenon transfer is prime technology development candidate
  - This might be done robotically, but other useful tasks described below would most likely need a manned servicing mission (newly added)
- **Upgrading instruments with the latest technology to increase performance**
  - Detector arrays are prime candidates for technology development, replacement
  - Demonstrated by HST servicing mission
    - Improved sensitivity, field of view, spatial and spectral resolution, and wavelength coverage
- **Replace degraded or failed components**
  - HST capability enhanced with new computers, batteries, solar arrays
  - Gyros, power distribution unit replaced,
  - Fine guidance sensors refurbished and reused

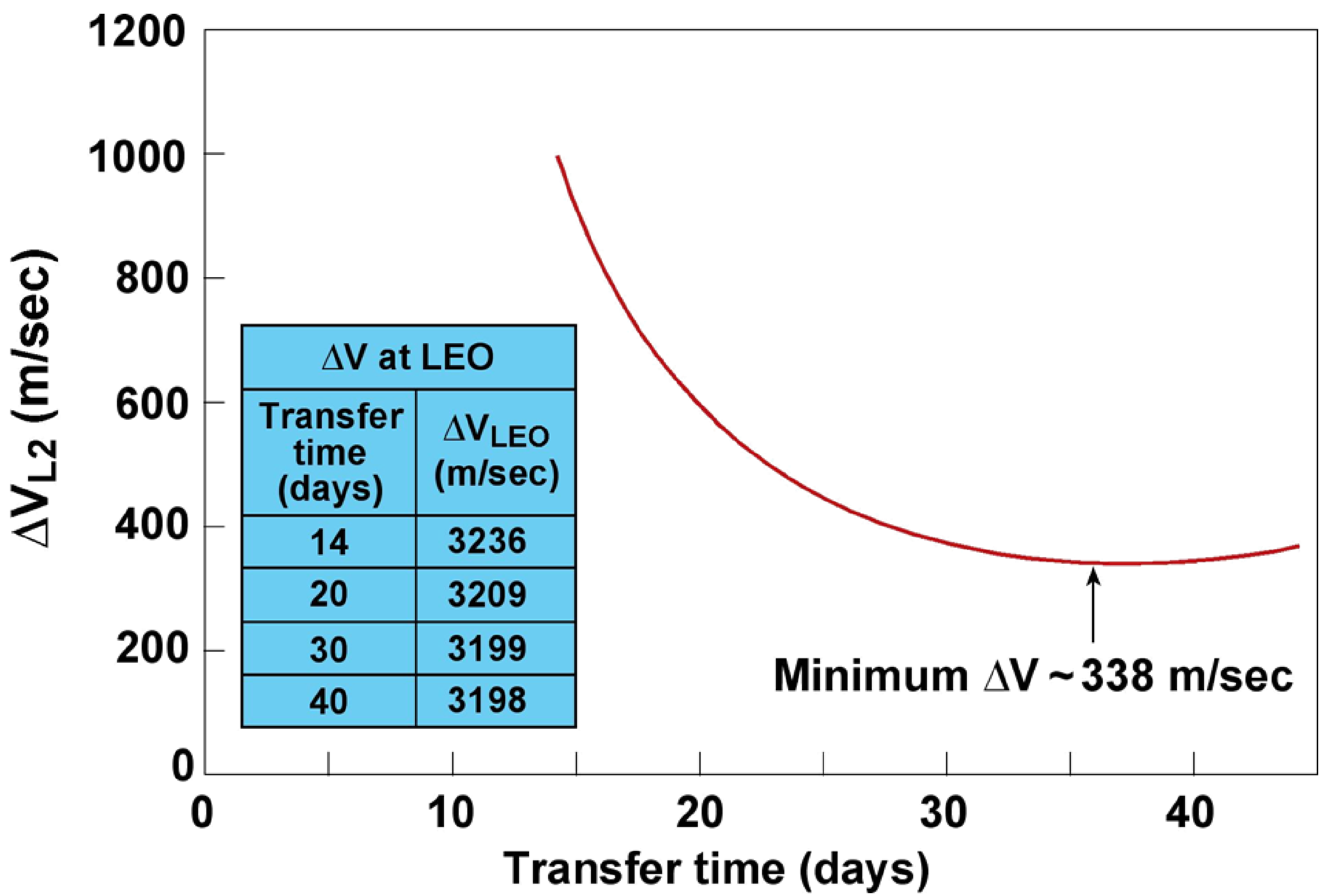
Trajectories to the Sun–Earth L1 Libration Point

Similar mirror-image trajectories Exist to the Sun-Earth L2 Point



Trajectories shown with respect to fixed Sun-Earth line

Fast Transfers: Low-Earth Orbit (LEO) to Sun–Earth L2 Point



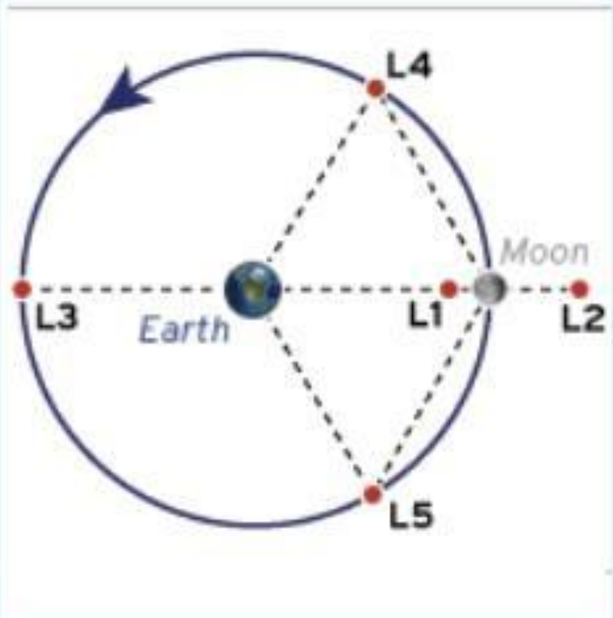
ΔV at LEO	
Transfer time (days)	ΔV_{LEO} (m/sec)
14	3236
20	3209
30	3199
40	3198

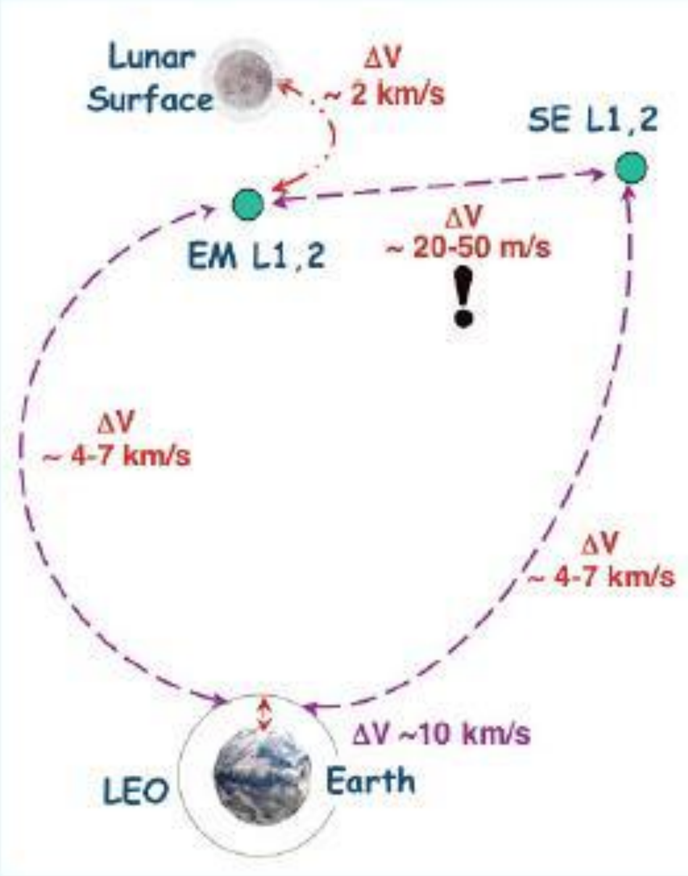
Servicing at the Earth-Moon L1 Libration Point

- **The next 3 slides are from a presentation, "Emerging Pathways for the Single Aperture Far Infrared Telescope (SAFIR) with an Ares V" presented by Dan Lester, University of Texas, at the Ares V Astronomy Workshop held at NASA Ames, April 26, 2008**
- **This would take advantage of infrastructure that would be developed for lunar missions as part of the Vision for Space Exploration**

Servicing Venues -- Importance of EM L1

While Earth-Sun L2 is optimal ops site for many telescopes, Earth-Moon L1 is a nearby jobsite. Transit back and forth is easy -- <u>meters/sec delta V!</u>

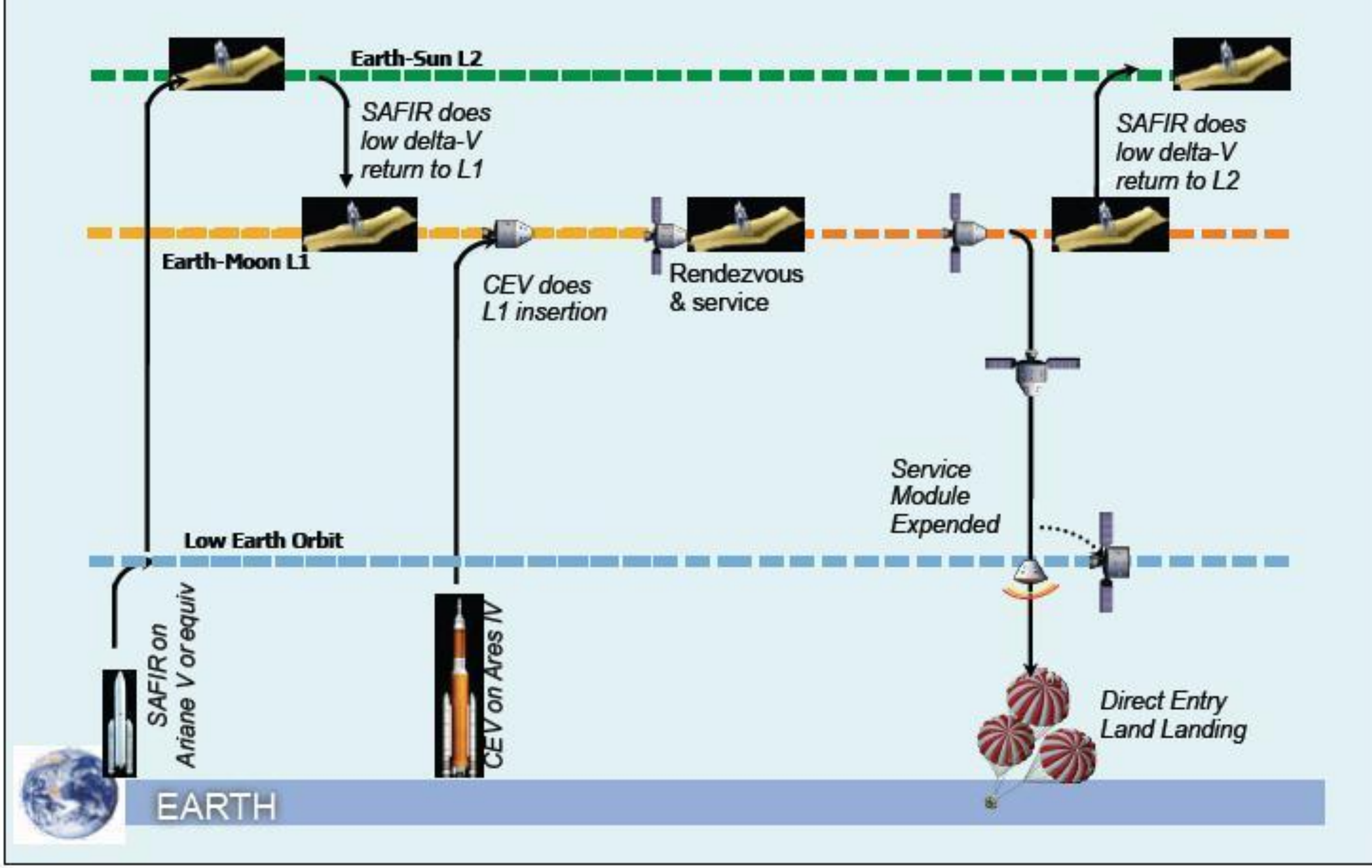




Adapted from Decadal Planning Team documents

Earth-Moon L1 is 84% of the way to the Moon, semi-stable, <u>highly accessible to lunar-capable human space program</u>, and offers low latency to telerobotic efforts from Earth.

Notional SAFIR Servicing Mission Design



So picture this …

John Frassanito & Associates

AGAIN … The value of an Ares V to astronomy may be a lot more than the size of telescope it could lift.

Other Servicing Possibilities

- The ΔV requirements to travel from Low Earth Orbit (LEO) to an L2 orbit and return, are similar to travelling from LEO to the Earth-Moon L1 or L2 libration points, or to Geosynchronous Equatorial Orbit (GEO).
- Consequently, infrastructure designed for one of these other purposes could be used for L2 servicing.
- The International Academy of Astronautics (IAA) has proposed an alternative path for space exploration that, like the Vision for Space Exploration, would have a final goal of a manned mission to Mars.
- The IAA plan involves a gradual approach, “stepping stones” that include servicing of large L2 telescopes, a mission to a near-Earth asteroid, and a mission to Phobos and/or Deimos.
- The IAA plan involves either direct servicing in L2 orbits, or using lunar swingbys.