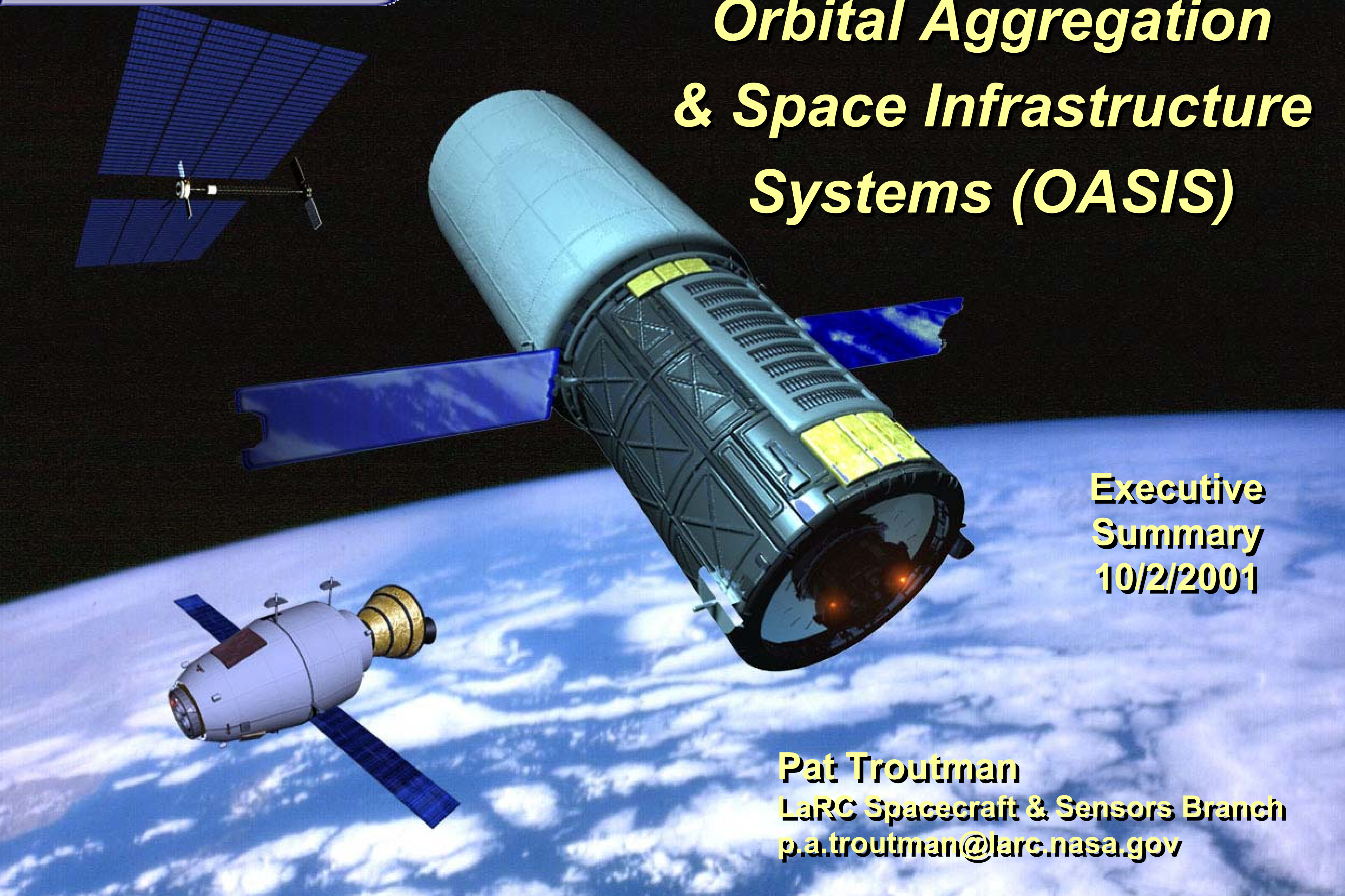
RASC

Orbital Aggregation & Space Infrastructure Systems (OASIS)



Executive Summary
10/2/2001

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Orbital Aggregation & Space Infrastructure Systems (OASIS)

Objectives:

- Develop robust and cost effective concepts in support of future space commercialization and exploration missions assuming inexpensive launch of propellant and logistics payloads.
- Infrastructure costs would be shared by Industry, NASA and other users.

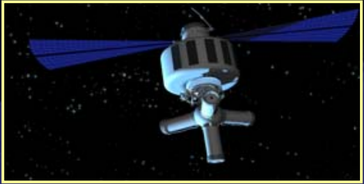
Accomplishments:

- A reusable in-space transportation architecture composed of modular fuel depots, chemical/solar electric stages and crew transportation elements has been developed.

Hybrid Propellant Module

Infrastructure Elements:

Lunar Gateway



Space Station

Crew Transfer Vehicle

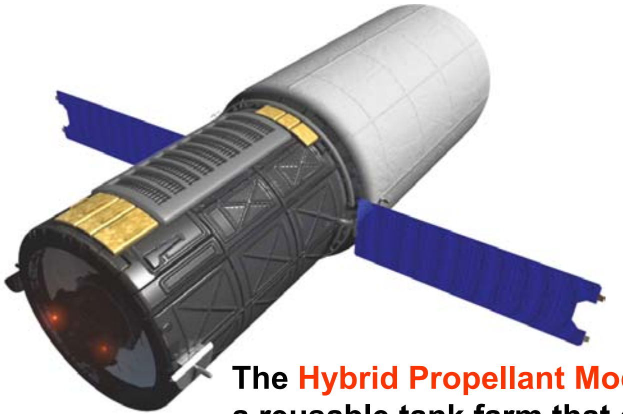
Solar Electric Propulsion

Chemical Transfer Module

The Revolution!

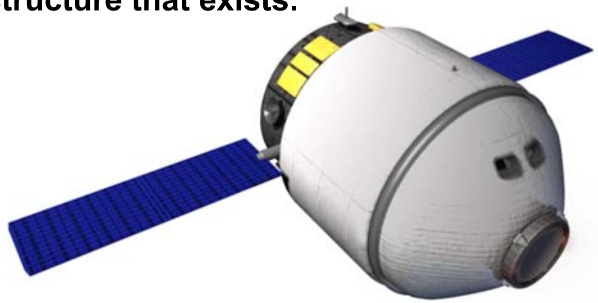
Minimize point designs of elements in support of specific space mission objectives and maximize modularity, reusability and commonality of elements across many missions, enterprises and organizations.

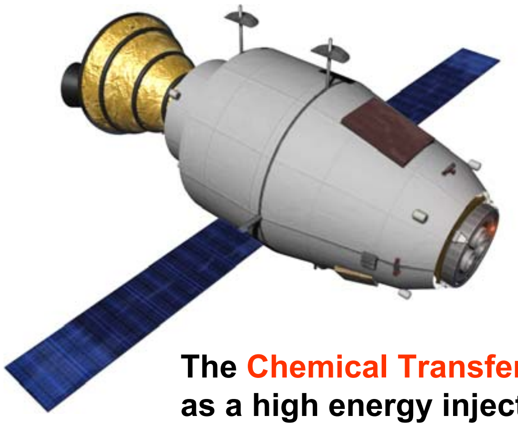
OASIS Supporting Concepts



The **Hybrid Propellant Module (HPM)** is a reusable tank farm that combines both chemical and electrical propellant in conjunction with modular transfer/engine stages.

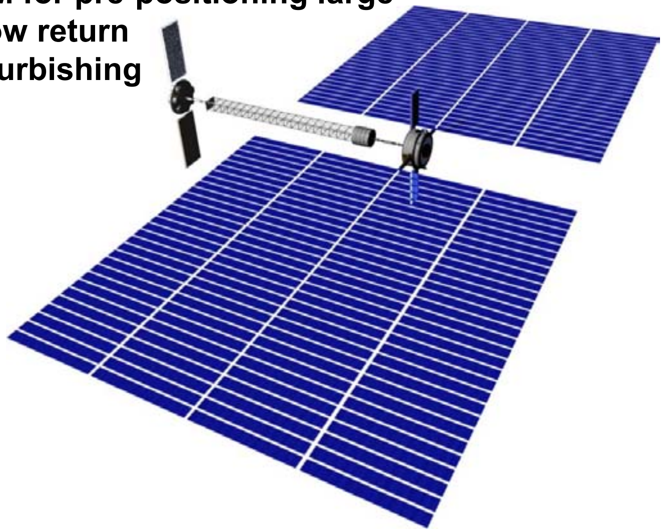
The **Crew Transfer Vehicle (CTV)** is used to transfer crew in a shirt sleeve environment from LEO to L1 and back as well as to the ISS and any crewed orbiting infrastructure that exists.





The **Chemical Transfer Module (CTM)** serves as a high energy injection stage when attached to an HPM and an autonomous orbital maneuvering vehicle for proximity operations such as ferrying payloads a short distance, refueling and servicing.

The **Solar Electric Propulsion (SEP)** module serves as a low thrust transfer stage when attached to an HPM for pre-positioning large elements or for slow return of elements for refurbishing and refueling.

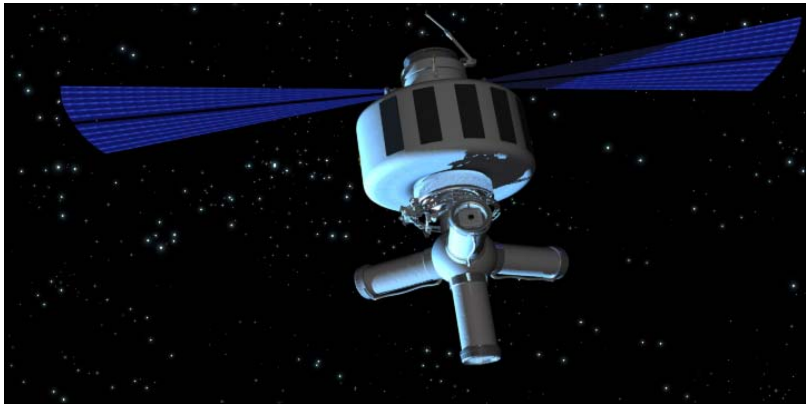


Exploration Mission Architecture:

Earth-Moon L1 Gateway Missions

Deploy L1 Gateway:

- Combined Gateway and SEP launched on Delta IV variant.
- Hab section inflates and docking tubes deploy.
- Rendezvous with Lunar lander (launched on Delta IV variant).
- SEP fires and stack travels towards L1.



Deploy First Hybrid Propellant Module:

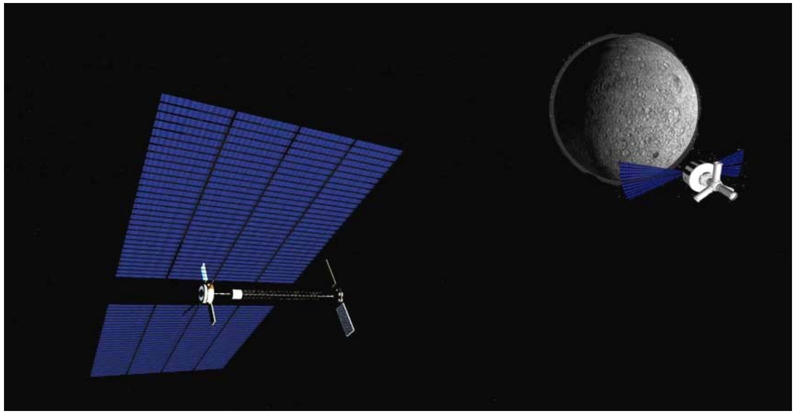
- The first Hybrid Propellant Module (HPM) is launched on a future shuttle or ELV into LEO.
- The HPM will be used to pre-position chemical propellant at the L1 Gateway.
- Deploy and test HPM systems.
- HPM will wait for a SEP module to dock with it and transfer it to the Gateway at L1.

Exploration Mission Architecture:

Earth-Moon L1 Gateway Missions

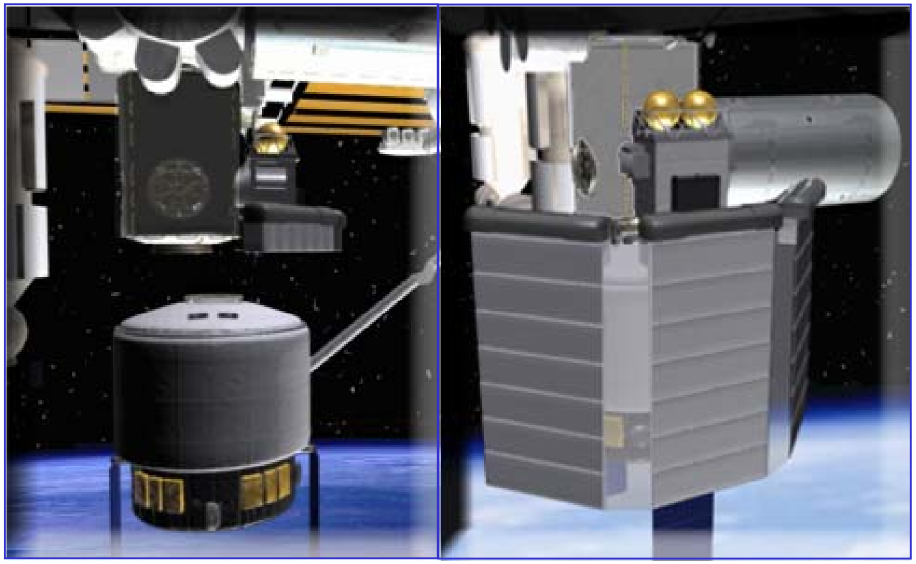
Deploy L1 Gateway:

- SEP deployed from STS or ELV.
- SEP solar arrays deploy in LEO.
- Rendezvous and dock with previous HPM
- Ferry crew return propellant (HPM) to Gateway at L1
- Gateway is now ready to receive the crew



Launch & Ready the Crew Transfer Vehicle:

- Future shuttle docks to the ISS carrying a Crew Transfer Vehicle (CTV) and perhaps a Chemical Transfer Module (CTM)
- Robotic arms berth the CTV/CTM stack to the station via an International Berthing & Docking Mechanism (IBDM).
- The CTV is then configured and outfitted for the journey to the L1 gateway.
- The CTM undocks from the ISS to rendezvous with and bring back a newly launched HPM that contains the propellant to send the crew to L1.



Exploration Mission Architecture:

Earth-Moon L1 Gateway Missions

Crew Transfer to L1 Gateway:

- The CTM rendezvous and docks with the second fully fueled HPM.

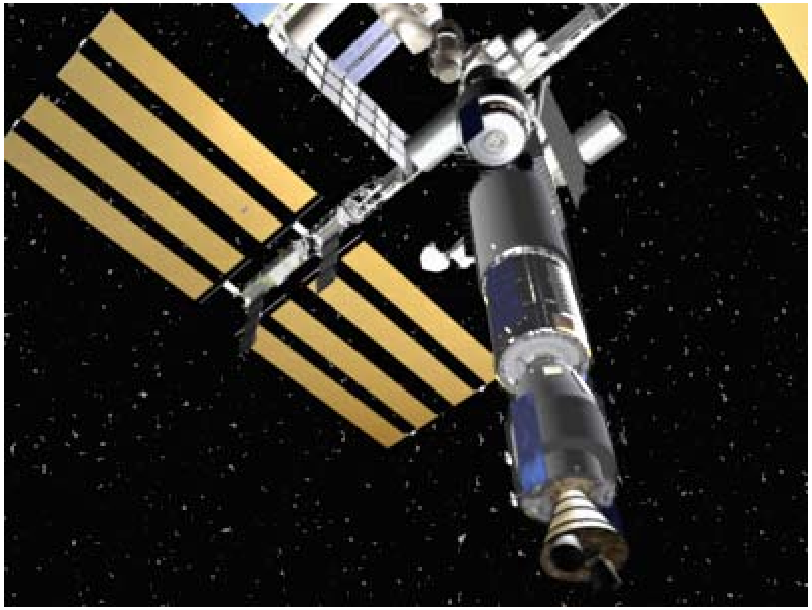
- The CTM docks the CTM/HPM stack to the CTV on the ISS. The crew enters the CTV from the ISS.

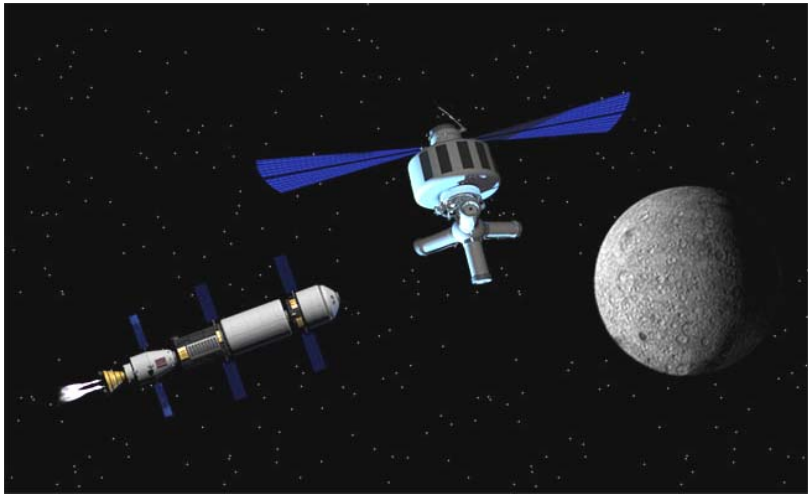
- The CTM/HPM/CTV stack backs off from the ISS.

- The CTM/HPM/CTV stack begins a series of engine burns that will transport the crew from LEO to the L1 Gateway.

- The CTM/HPM/CTV stack arrives and docks to the L1 Gateway after 4 days of travel.

- Everything required to perform a Lunar excursion is now at the Gateway.





Exploration Mission Architecture:

Earth-Moon L1 Gateway Missions

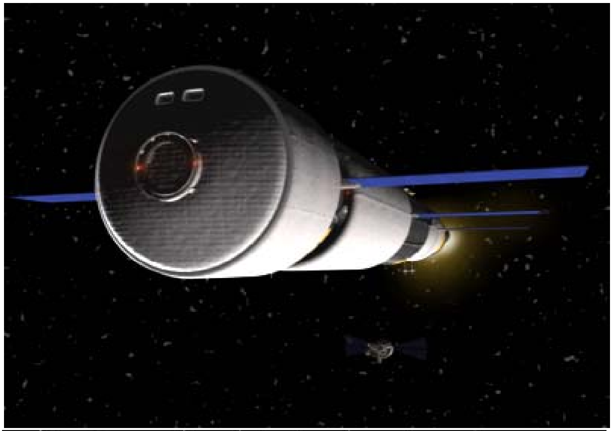
Before the Lunar excursion is performed, The CTM, SEP and HPMs must be repositioned such that the HPM with the full load of liquid hydrogen and oxygen is connected to the CTV & CTM and the HPM with the full load of Xenon propellant is attached to the SEP module.

Gateway Swap:

- **The CTM pulls the HPM full of Xenon off of the CTV.**
- **The SEP utilizes its RCS to transfer the HPM full of liquid hydrogen & oxygen to the Gateway port where the CTV is docked.**
- **The HPM stacks approach the desired ports on the gateway in sequential order.**
- **The HPM full of hydrogen & oxygen is now attached to the CTV.**
- **The CTM and SEP exchange places so that CTM is attached to the HPM full of Hydrogen & Oxygen and the SEP is attached to the HPM full of Xenon.**
- **The Crew transfer stack is ready for the return voyage to LEO. The Lunar excursion can now be performed.**

Exploration Mission Architecture:

Earth-Moon L1 Gateway Missions



Return of Crew & Elements to LEO:

- The crew boards the CTV from the Gateway. The CTM pulls the CTV/HPM stack from the Gateway.

- The CTM then propels the HPM and crewed CTV back to LEO, the stack docks to the ISS where the crew will catch a shuttle to Earth.

- The SEP attached to the HPM full of Xenon leaves the Gateway for its return to LEO.

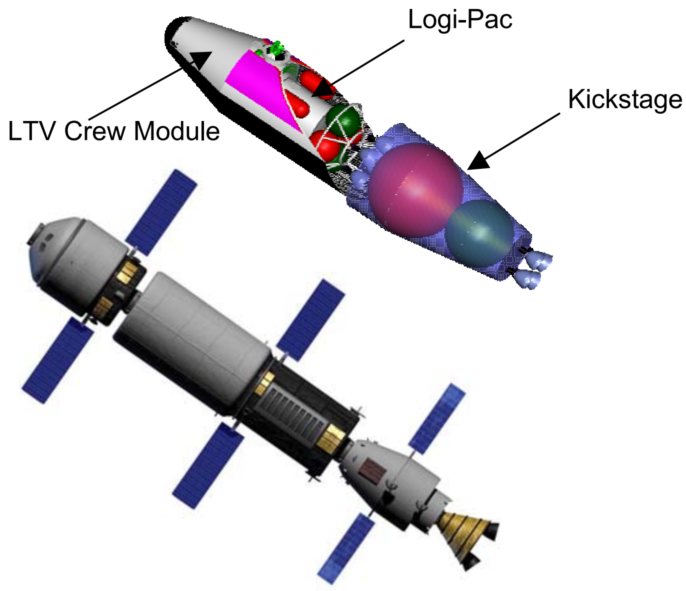
- Once back in LEO, the elements are refueled and refurbished.

All of the elements that were utilized to transfer crew and supplies with the exception of the Lunar lander have returned to LEO and are ready to support another mission.

Comparison to Baseline Exploration L1 Architecture

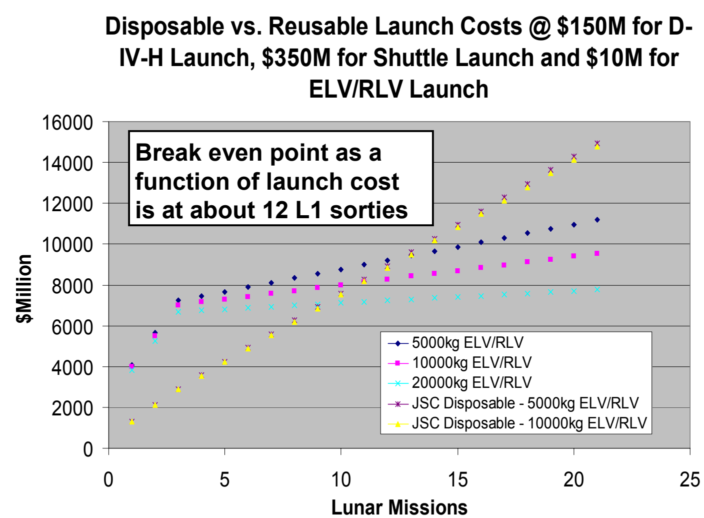
Similarities:

- Both architectures use the same Gateway, Solar Electric Propulsion, and perhaps Lunar Lander systems.



Differences:

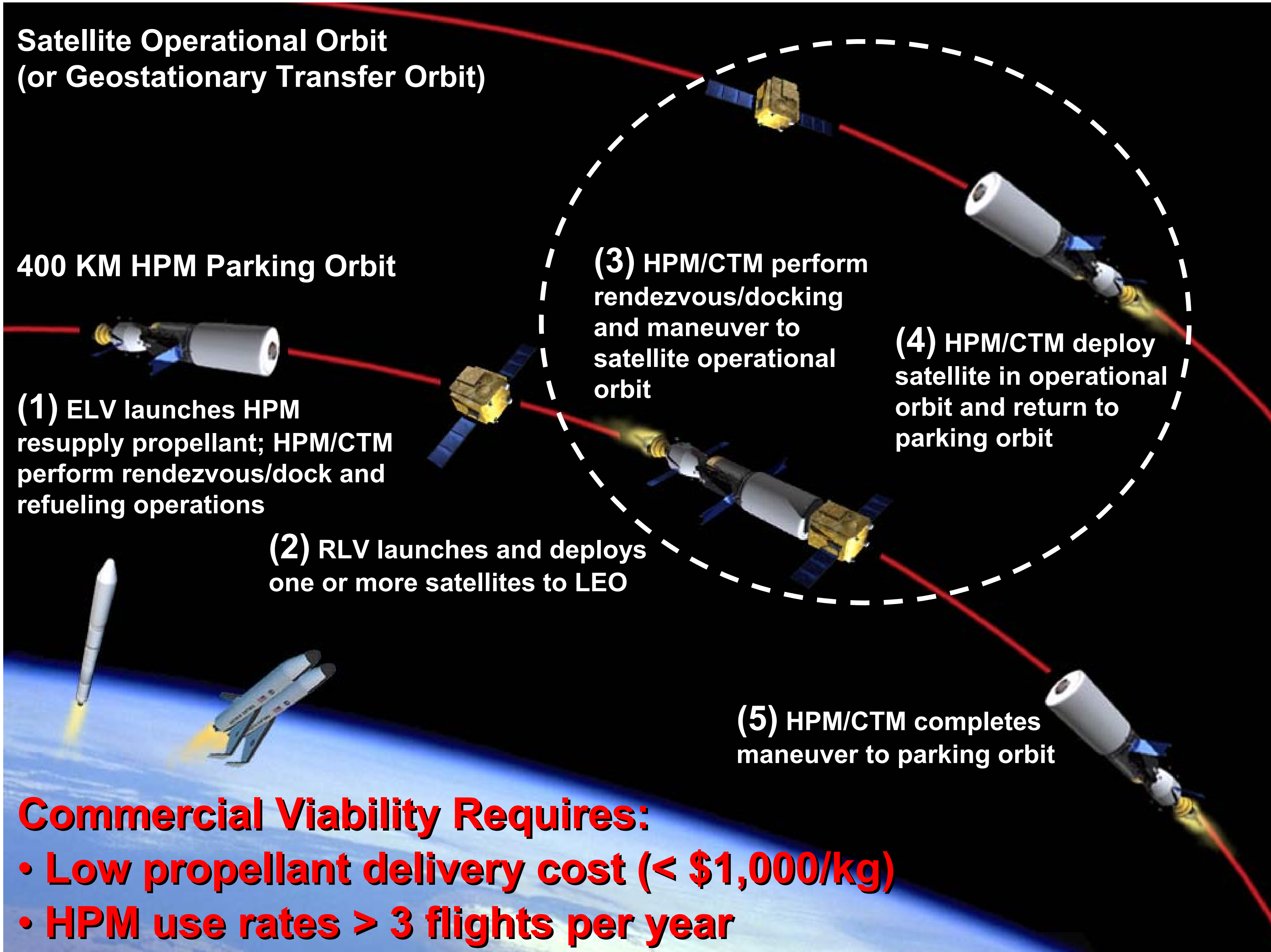
- The OASIS architecture is entirely reusable, vs. the expendable kick stage and refurbish requirements for the Logi-Pac and aeroshell.
- Aerobraking is not required in the OASIS architecture
- The HPM architecture requires inexpensive ETO launch for propellant resupply



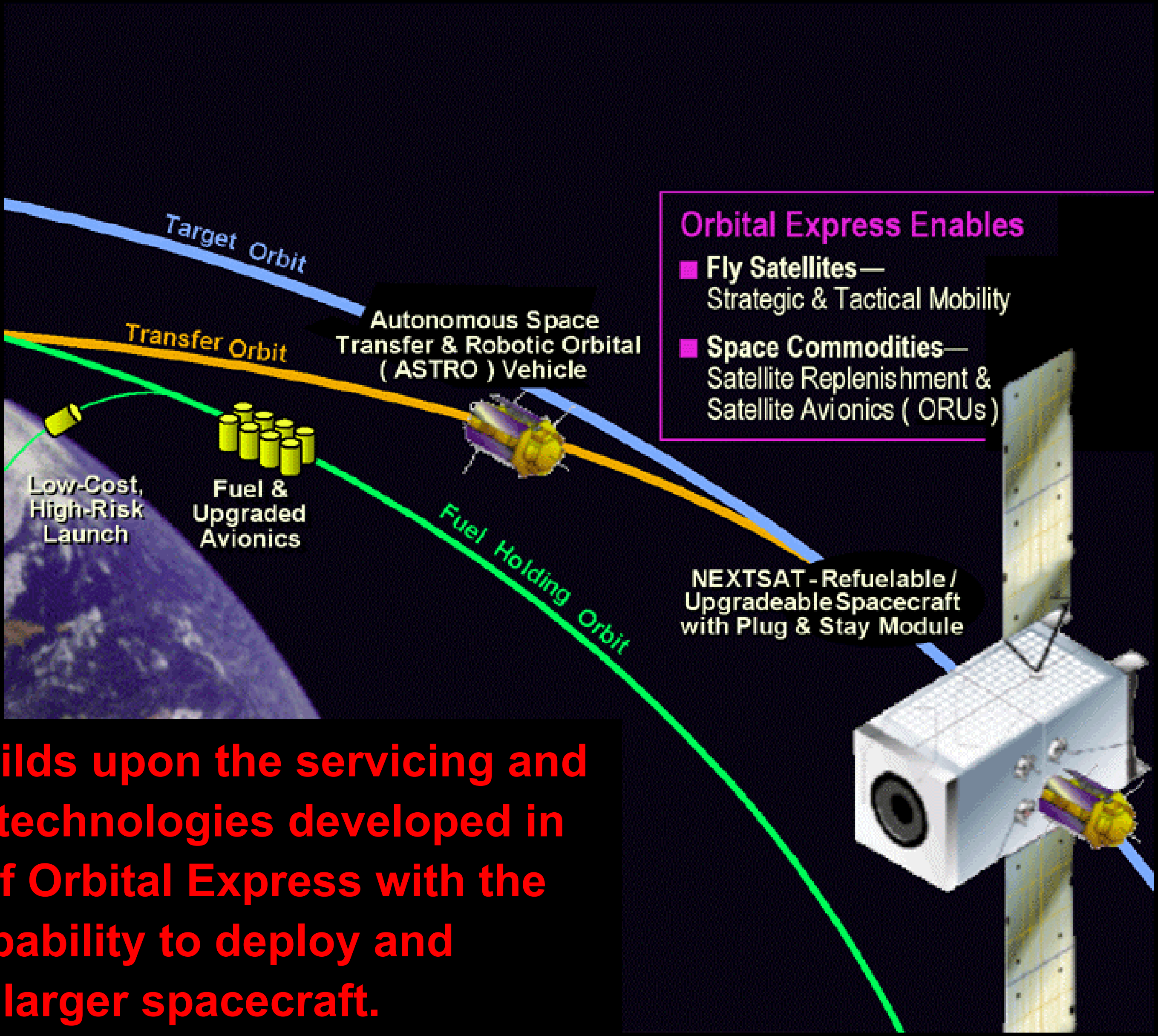
Benefits of HPM/OASIS:

- The OASIS architecture frees up the shuttle to support other HEDS and commercial LEO activities.
- OASIS architecture can potentially be adapted to other missions (Earth-Sun L2, Mars, etc.) with minimal changes.
- OASIS architecture can be adapted to commercial and military missions.

HPM Commercial Satellite Deploy Scenario

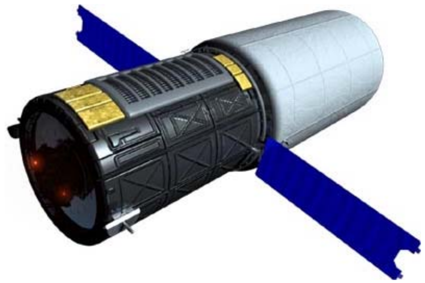


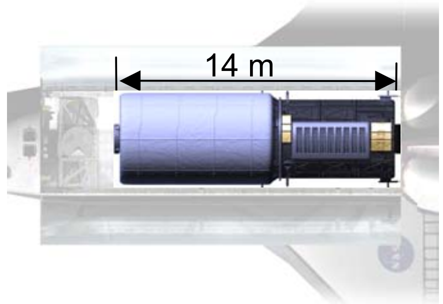
HPM Military Applications

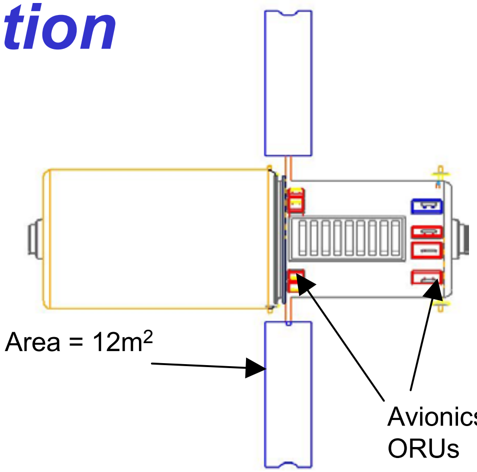


OASIS builds upon the servicing and refueling technologies developed in support of Orbital Express with the added capability to deploy and transport larger spacecraft.

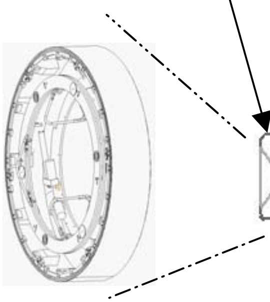
HPM Configuration

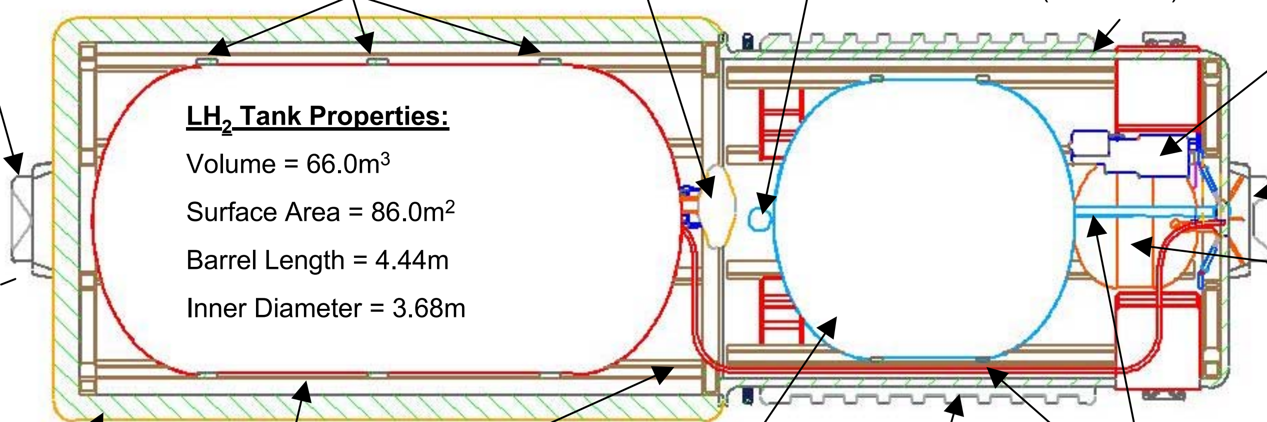






Intl. Berthing Docking Mechanism (IBDM)[1] (2)
Max Dim's: 1.4m dia x 0.25m thick
Hatch Pass Through: 0.80m





LH$_2$ Tank Properties:

Volume = 66.0m^3

Surface Area = 86.0m^2

Barrel Length = 4.44m

Inner Diameter = 3.68m

LOX Tank Properties:

Volume = 24.2m^3

Surface Area = 40.1m^2

Barrel Length = 1.27m

Inner Diameter = 3.30m

Xe Tank Properties (per tank – 2 total):

Volume = 2.14m^3

Surface Area = 8.1m^2

Barrel Length = 0.42m

Inner Diameter = 1.5m

(Max Diameter = 4.4m – Total Length = 14m)

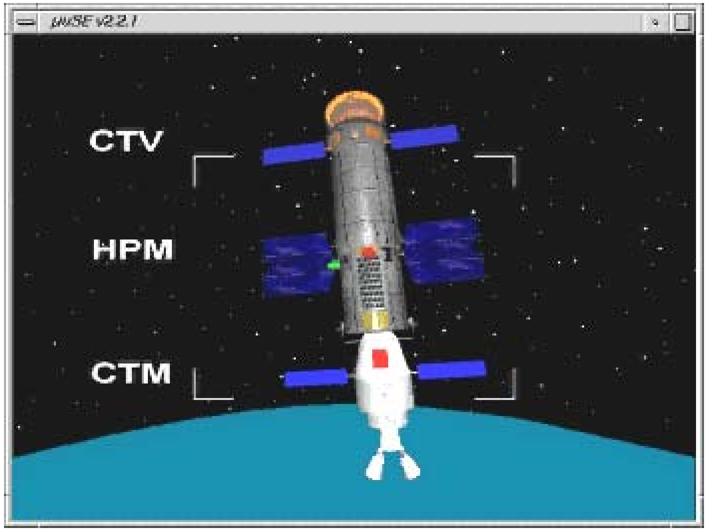
[1]IBDM in development, estimated year 2005 operational date

Docking Simulation

Thrusters:

RCS - LOX/LH2 556N (125 lbf) @385 sec s.s. with a minimum pulse duration of 30 ms.

Cold Gas - LH2 cold gas 111N (25 lbf) @ 100 sec s.s. with a minimum pulse duration of 20 ms.



Overall Technology Summary

Key Technologies	HPM	CTV	CTM	SEP
Integrated flywheel energy storage system	3-axis control	possible	3-axis control	3-axis control
Advanced triple junction crystalline solar cells	> 30% eff	>30% eff	>30% eff	NA
Large deployable thin film arrays	NA	NA	NA	167W/m**2, rad hard
Zero Boil-Off (ZBO) system	Multistage	NA	NA	NA
Integrated primary multifunction structure, radiation & meteoroid and orbital debris shielding	Also provides thermal Insulation	Also provides radiation shielding	Also provides thermal insulation	Yes
Autonomous operations including rendezvous and docking	MANS/AFF	MANS/AFF	MANS/AFF	MANS/AFF
On-orbit cryogenic fluid transfer	LH2/LO2/Xenon	NA	LH2/LO2/Xenon	Xenon/GH2/GO2
Lightweight cryogenic propellant tanks	Composite	NA	Aluminum	Composite
Graphitic foams and syntactic metal foams	YES	YES	YES	YES
Carbon-carbon composite radiators	YES	YES	YES	YES
High performance, high cycle life LH2/LOX main engine	NA	NA	50-100 Starts 0.995 reliability	NA
Integrated GH2/GOX Reaction Control System (RCS)	NA	NA	Yes	YES
Advanced ECLSS CO_2 removal system	NA	YES	NA	NA
High Power Gridded ion engines	NA	NA	NA	>15k-hours life

Summary & Forward Work

- The HPM concept in the OASIS framework could reduce costs and enhance mission robustness across a wide spectrum of future space activities.

- Economic sensitivities for NASA and commercial applications have indicated that inexpensive launch of propellant on the order of $1000/kg is the threshold for making a space based transportation infrastructure viable.

- Technologies supporting spaced-based cryogenic transfer and storage of propellants are critical for enabling on-orbit transportation infrastructure.

- Solar Electric Propulsion technologies (high performance, radiation resistant arrays, long-lived high performance gridded ion engines, large deployable systems) are key to making the infrastructure totally reusable in support of exploration class missions.

- Follow-on activities under RASC have been proposed for FY02:
  - Refined commercial and DOD applications
  - Increased detail assessments for other supporting concepts (SEP, CTM, CTV, etc)
  - Applications beyond the Earth-Moon system

Backup

Future Assumptions: 2015 and Beyond

Low Earth Orbit (LEO) & Beyond:

- NASA/International Space Exploration
  - NASA has deployed a gateway facility at the Earth-Moon L1 point.
  - ISS has evolved into a transportation hub & servicing facility.
- Commercial Possibilities
  - Commercially viable in-space manufacturing of pharmaceuticals and materials resulting from ISS research has begun on automated and crew tended platforms
  - A commercially owned upgraded Shuttle features a payload bay passenger module for commercial crews and other paying passengers.
  - The first hotel in space (based on the NASA gateway facility and catering to the elite) has opened in LEO.
- Military
  - The United States military dominates the space theatre.

Available Earth-to-Orbit Transportation:

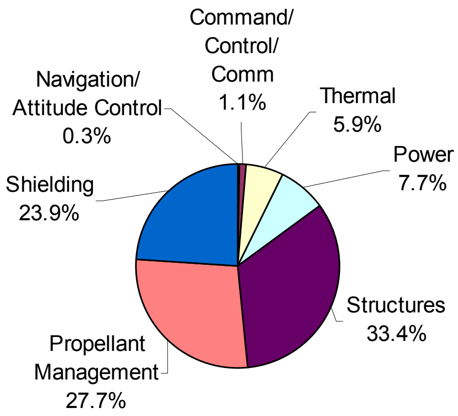
- Upgraded Shuttle - operations overhead cut in half with the same performance.
- Large reliable ELV - 35,000 kg to LEO with a 6 meter shroud.
- Inexpensive ELV - weekly launch of 10,000 kg or more of logistics to LEO.
- Revolutionary RLV eventually replaces weekly ELV launches.

Elements

Hybrid Propellant Module (HPM)

Mass & Technology Summary

Subsystem	Calculated Mass (kg)
Navigation/Attitude Control	12
Command/Control/Comm	42
Thermal	234
Power	305
Propellant Management	1,089
Structures	1314
Shielding	943
Calculated Dry Mass	3939
Dry Mass Margin	165
Dry Mass Target Mass	4,104



HPM Advanced Technology Requirements

Integrated Flywheel Energy Storage System
- Combination energy storage and attitude control

Advanced Triple Junction Crystalline Solar Cells
- Provide >500 W/kg (blanket)
- >30% efficiency

Zero Boil-Off System
- Cryogenic propellant storage system (up to 10 years of storage without boil-off)

Integrated Primary Multifunction Structure & Meteoroid and Orbital Debris Shield
- Non-metallic hybrids to maximize radiation protection

Autonomous Operations including Rendezvous and Docking

On-Orbit Cryogenic Fluid Transfer

Lightweight Composite Cryogenic Propellant Storage Tanks

Graphitic Foams and Syntactic Metal Foams

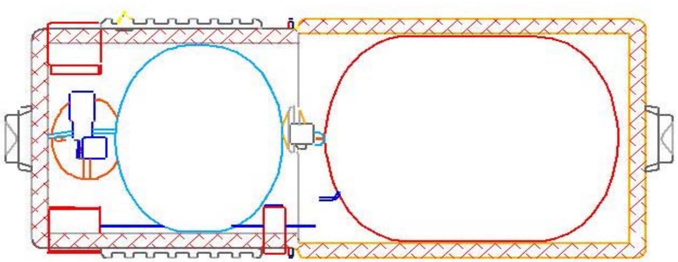
Carbon-Carbon Composite Radiators

HPM ELV Configurations

Shuttle Capacity Equivalent

Delta IV Heavy Payload Envelope Dia=5.0m X Length 12.2m

HPM Packaging Size: Max Diameter = 5m, Total Length = 11.5m

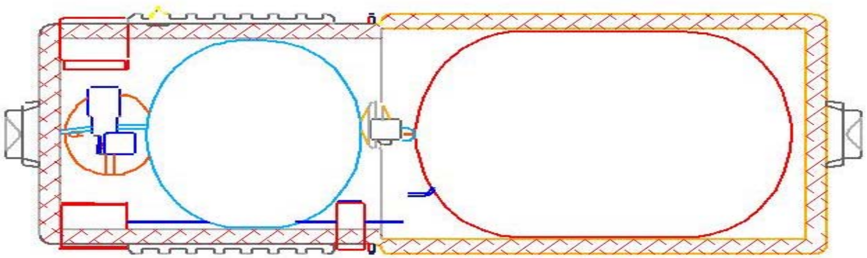


The shuttle capacity equivalent HPM can be launched with a full load of propellant in support of any L1 transfer mission.

Maximum Shroud Configuration

Delta IV Heavy Payload Envelope Dia=5.0m X Length 14.8m

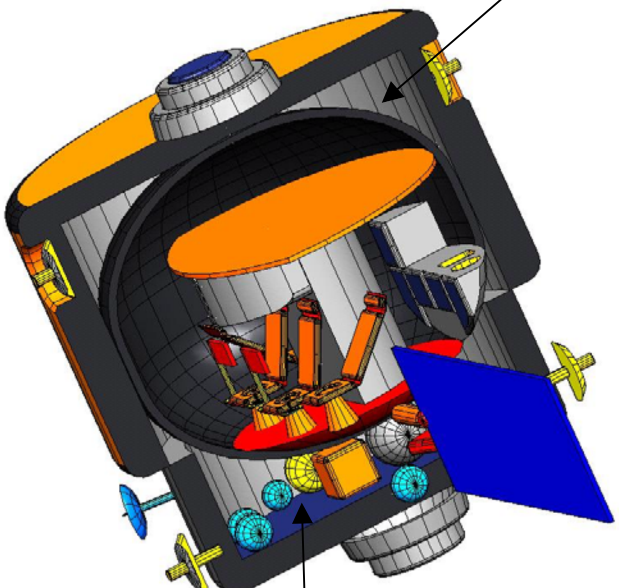
HPM Packaging Size: Max Diameter = 5m, Total Length = 14.8m



An HPM configured to utilize the maximum allowable shroud could offer enhanced performance for both exploration and commercial missions.

Crew Transfer Vehicle (CTV) Configuration

Total Pressurized Volume = 25.1m^3



Storage Area for:

Atmosphere Control and Supply, Atmosphere Revitalization, Temperature and Humidity Control, Fire Detection and Suppression, Water Recovery and Management

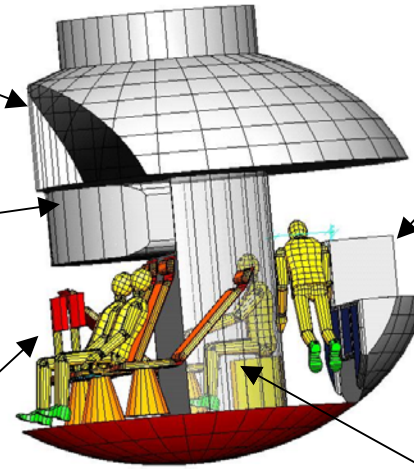
CTV Crew Sleep and Entertainment Area = 5.14m^3

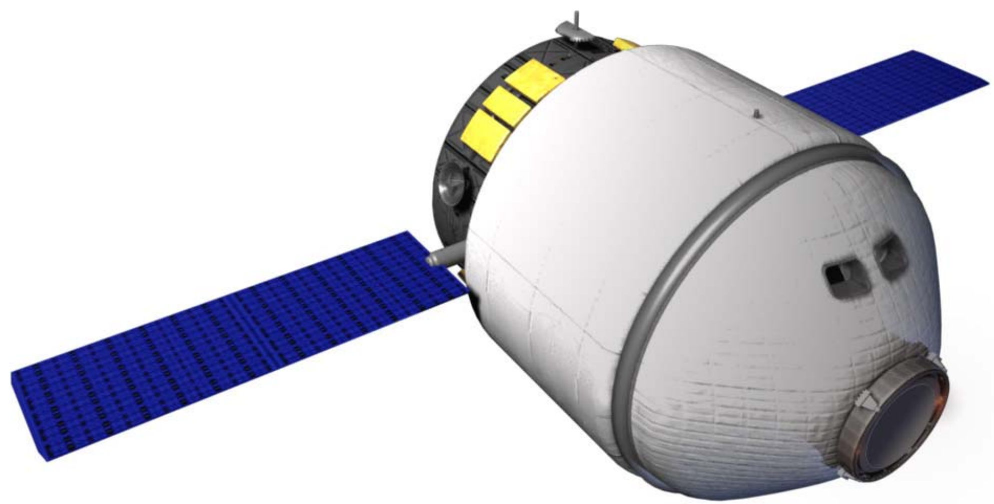
Galley Storage Area = 0.56m^3

System and Crew Storage = 0.58m^3

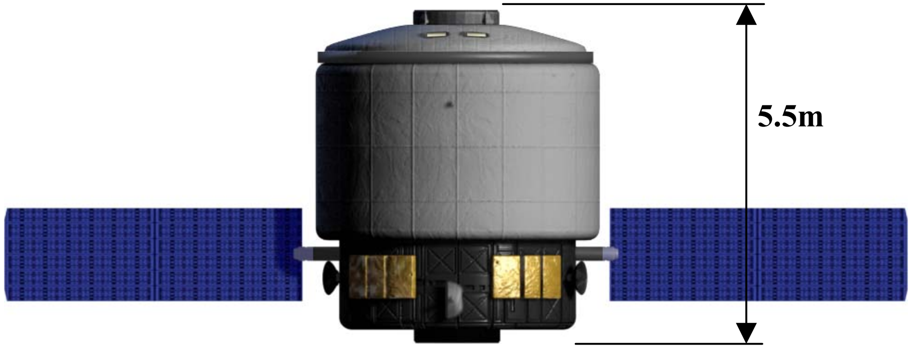
Command and Control Chairs (Provides roughly 0.28m of leg room)

Crew Privacy (lavatory, hygiene) = 2.0m^3

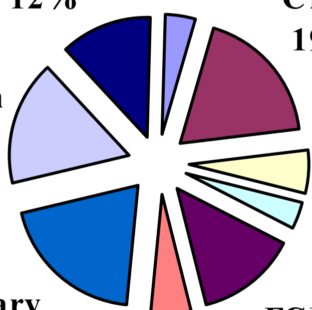




Crew Transfer Vehicle (CTV)
Mass & Technology Summary



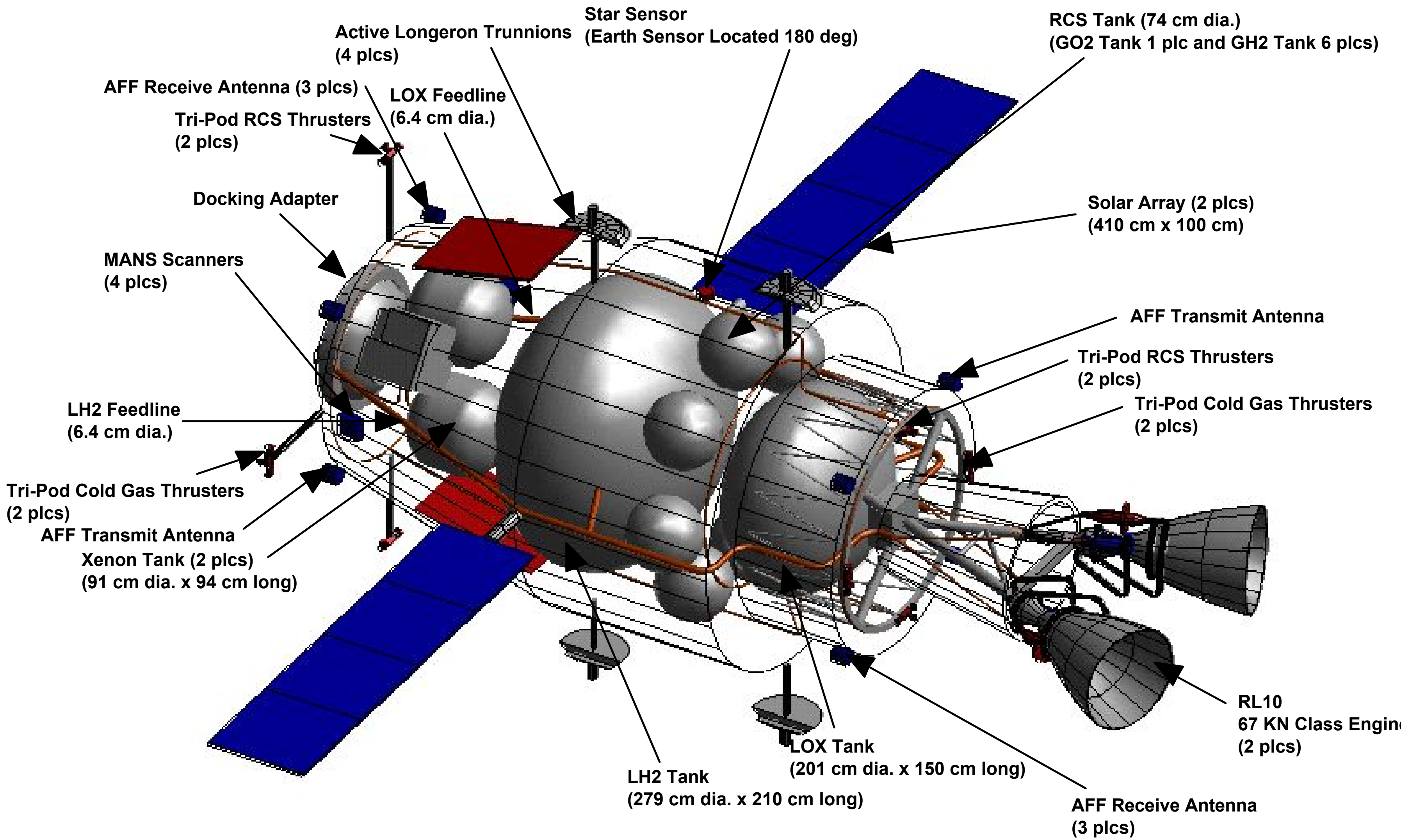
Mass of Full (CTV) = 5282 kg



Technologies Currently Used in CTV

- **Advanced Triple Junction Crystalline Solar Cells**
  - Provide >500 W/kg (blanket)
  - >30% efficiency
- **Integrated Primary Multifunction Structure & Meteoroid and Orbital Debris Shield**
  – Non-metallic hybrids to maximize radiation protection
- **Autonomous Operations including Rendezvous and Docking**
- **Lightweight Composite Cryogenic Storage Tanks**
- **Graphitic Foams and Syntactic Metal Foams**
- **Carbon-Carbon Composite Radiators**
- **Advanced ECLSS CO_2 Removal System**

Chemical Transfer Module (CTM) Configuration



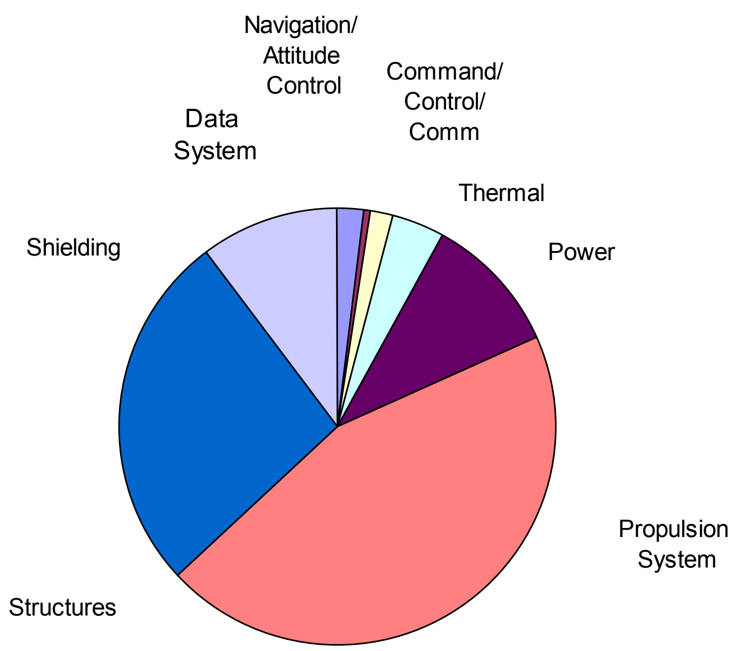
Overall Deployed Dimensions: 9.4 m long x 12.6 m width

NOTE: MMOD SHOWN TRANSPARENT FOR CLARITY.

Chemical Transfer Module (CTM)

Mass & Technology Summary

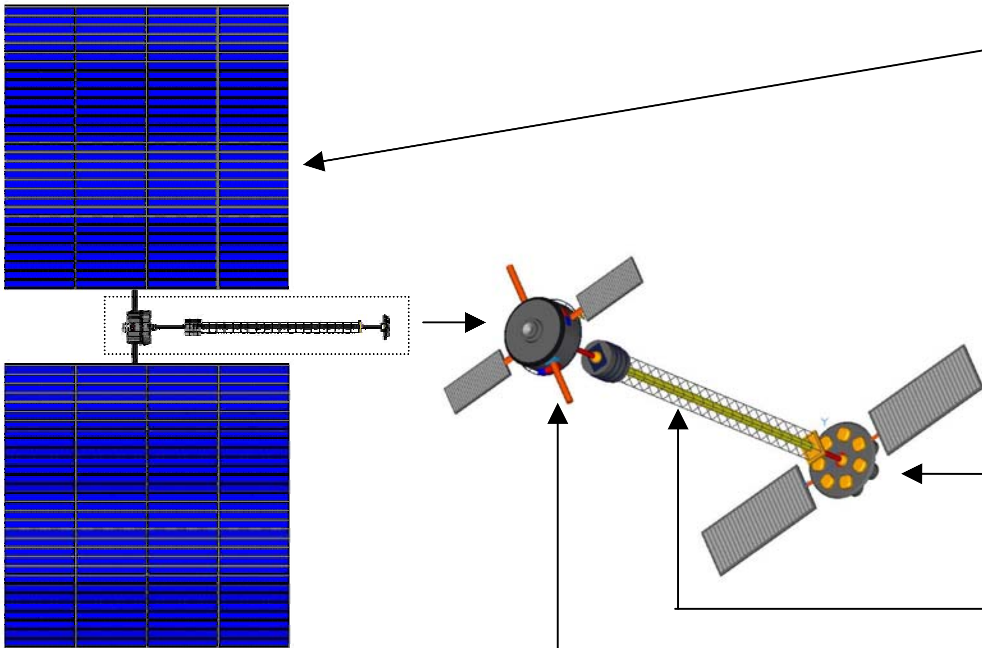
Technology	Summary Description of Desired Technology and Key Performance Metrics	Current TRL	Where	Who	Current Funding (K$)	Increase in Funding Required (none, small, large)	Applications Other than HPM/CTV
High Performance, High Cycle Life LH2/LOX Main Engine	Main propulsion engine w/ Ispvac> 445 sec, capablible of > 50 on-orbit starts over a 10 yr. Period w/ reliability > 0.995	5		Pratt&Whitney, Rocketdyne	TBD	TBD	Any Upper Stage Applications
Integrated GH2/GOX Reaction Control System	Two-fault tolerant system to gassify and maintain RCS propellants, w/ Thruster Ispvac >385 sec (ss) and 100,000 cycle life	6	MSFC/JSC	Space Station Freedom, SSTO	TBD	TBD	Upperstage, HEDS, SSTO, Space Station, applications
Electro-Mechanical Valve Actuators	Light weight, high-efficiency, electro-mechanical valve actuators and engine gimble motors	6	MSFC	Pratt&Whitney, MOOG	TBD	TBD	Upperstage, HEDS, Launch Vehicle



Subsystem	Calculated Mass (kg)
Navigation/Attitude Control	**18.80**
Command/Control/Comm	**73.70**
Thermal	**138.40**
Power	**356.50**
Propulsion System	**1,583.00**
Structures	**951.00**
Data System	**72.60**
Shielding	**360.01**
Calculated Dry Mass	**3554.01**
Dry Mass Margin	**+845.99**
Dry Mass Target Mass	**4,400.00**

Solar Electric Propulsion Module (SEP)

Mass & Technology Summary

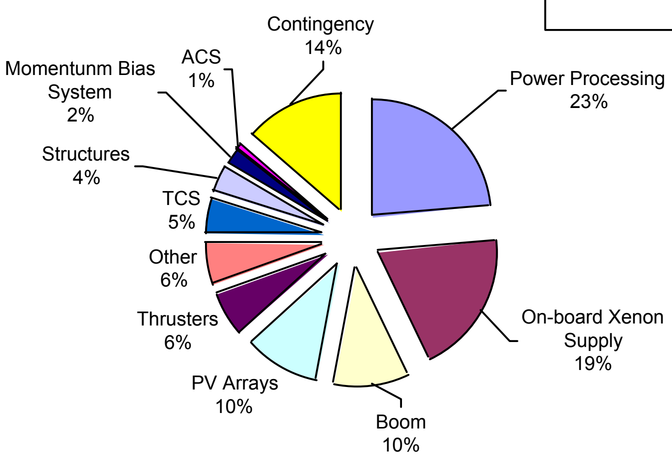


Photovoltaic Arrays: 2 square-rigger style wings (rad hard as possible)
- Thin film cells, Array area = 2700 m^2, Power produced = 450 kW

Thrusters: 9 Gridded Ion Engines, operating at 50 kW
- Xenon, 3,300 s Isp, 2.0 N thrust per engine, 15 khours lifetime (Minimum)

Articulated boom for thrust vectoring

Base Palette containing
- Extra Xenon for free-flying operation
- Arrays mounts
- Power processing
- Reaction Control system
- Attitude Control system
- HPM docking & Fluid Transfer interfaces



Mass of Full (SEP) =11,200 kg (includes 2000 KG of Xenon)

Commercial Backup

HPM Commercialization Study Methodology

Inputs

- *HPM Specs*
- *Commercial Satellite Traffic Models*
- *Military Analogs*
- *Ground Rules & Assumptions*

HPM Performance Analysis

- "Speed curves" for LEO, MEO and GEO missions
- Single and multiple HPM operations
- HPM Block I and II

Analysis of Projected Satellites/Constellations

- Potential HPM support roles
- HPM operations strategies
- "Best fit" HPM orbit planes

Refinement of Commercial Traffic Models

Commercial HPM Traffic Model Development

- High and Low Traffic Models
- Integrated Commercial, Military & Exploration
- #HPMs and HPM flight rate per mission type
- ETO estimate for HPM resupply propellant

HPM Economic Viability Analysis

- HPM/CTM allowable recurring cost
- ETO cost targets (satellite delivery and HPM resupply propellant)

Technology and Operations Assessment

- HPM resizing options
- Enabling/enhancing technologies for commercial operations
- Satellite design and operations impacts

Outputs

FY01 Study Products

- *Integrated Commercial, Military & Exploration Traffic Models*
- *Preliminary HPM Economic Viability Analysis*
- *HPM Enabling Technologies*
- *Satellite Design/Ops Impacts*

FY02 Study

Inputs

"Clean Sheet" ELV Concept Development

- Supports HPM resupply propellant delivery to LEO
- Design goal to minimize cost to orbit
- Objectives include definition of ELV configuration concepts; identification of operations concepts, systems and enabling technologies

HPM Commercialization Study

Objective

- Assess the HPM's potential applicability and benefits for Earth's Neighborhood commercial and military space missions in the +2015 timeframe
- Determine common technology development areas important to commercial/military/HPM systems

Goals

- Determine key areas of need for projected commercial/military missions that HPM may support (e.g., deployment, refueling/servicing, retrieval/disposal)
- Quantify the levels of potential HPM commercial utilization and develop ROM estimates for the resulting economic impacts
- Determine common technology development areas to leverage NASA research spinoffs/technology transfers and identify potential cost savings initiatives

Study Drivers

- Projected commercial/military satellite market
- HPM/CTM design (sizing, performance)
- HPM allocation to support identified markets (HPM traffic models)
- ETO transportation costs (trades vs. non-HPM architectures, cost of HPM resupply propellant)

HPM Traffic Models

HPM/CTM Block II Integrated Traffic Models

Mission Area	HPM/CTM Allocation	High Traffic Model Annual rate/HPM	Low Traffic Model Annual rate/HPM	HPM/CTM Allocation	Refined Traffic Model Annual rate/HPM
Near ISS	8	6.4	3.2	8	3.2
Polar	10	4.8	2.4	0	Omitted
GTO	2	17.5	12.5	2	8.8
Exploration	4	1.0	1.0	0	Omitted
Total	24	138 total yearly	79 total yearly	10	43 total missions yearly

"Refined" commercial traffic model based on:

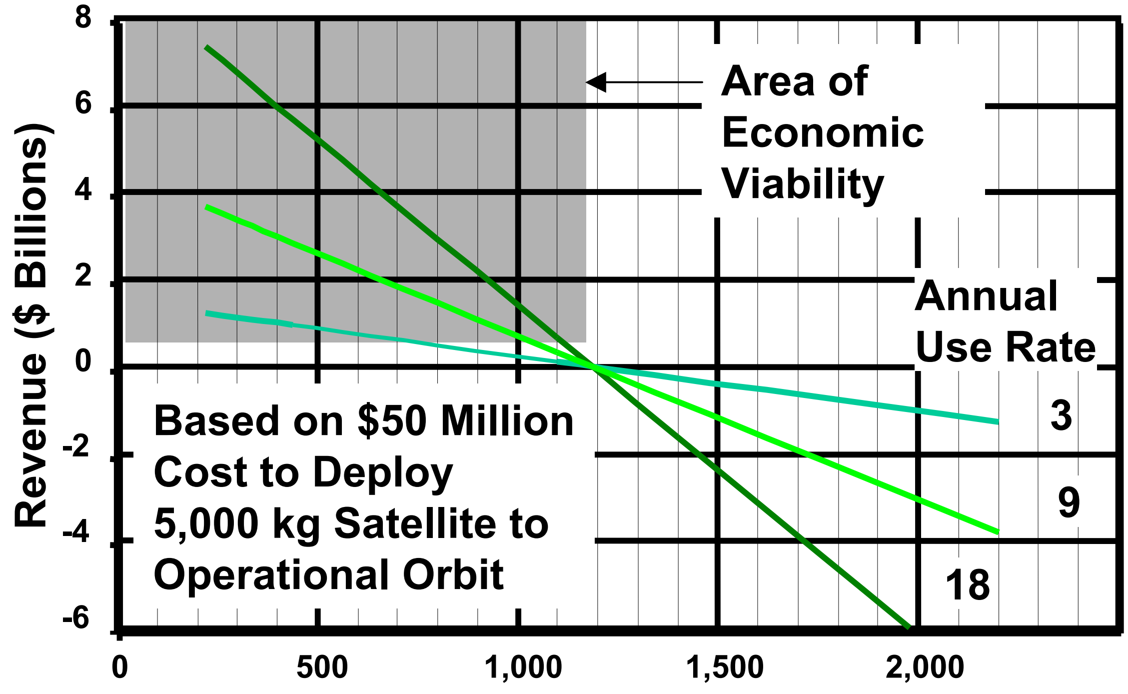
- Higher usage rate missions only (> 3 flights per HPM per year)
- Single launch site from ETR (excludes polar servicing)
- 50% market share (of high traffic model)

HPM Commercial Viability Summary

Commercial viability requires:

- DDT&E funding provided by NASA (and/or DoD)
- Enough life cycle revenue to:
  - Cover start-up costs (HPM/CTM procurement/deployment and infrastructure estimated to be as much as $0.5 billion)
  - Provide desired return on investment
- Low propellant delivery cost to LEO (< $1,000/kg)
- HPM use rates > 3 flights per year

Potential Life Cycle Revenue per HPM/CTM

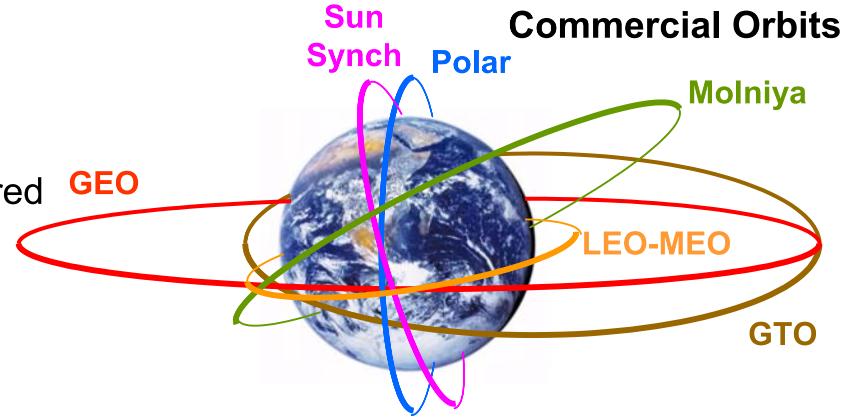


Assumptions:

(1) 10 year HPM/CTM life

(2) Satellite delivery cost/kg to LEO is twice propellant delivery cost/kg

HPM Commercialization Study Summary



Key Assumptions

- Future commercial satellite market mimics existing and proposed market in satellite count and orbits
- A low cost Earth-to-LEO transportation capability is required
  - Low cost, potentially lower reliability ELV for launch of HPM resupply propellant (insensitive cargo)
  - Low cost, high reliability RLV for satellite launch (sensitive, expensive cargo)
  - Cost per kilogram is assessed in HPM viability analysis
- Uses HPM with CTM as defined for Exploration missions
- Satellite launch costs/kg are assumed twice HPM resupply propellant launch costs/kg
- Industry adopts common infrastructure - attach fittings, plug-and-play avionics, other required I/Fs
- Objective is to maximize usage rate (i.e., number of satellites serviced per HPM), minimize number of required HPM/CTMs

Principal Results/Conclusions

- Commercial HPM traffic models are based on satellite delivery; considered the “floor” for potential HPM commercial applications
- HPM commercial viability is highly sensitive to infrastructure costs, mission rates and Earth-to-LEO launch costs
  - Single site for HPM propellant launch is necessary to minimize ground infrastructure costs
  - Required HPM propellant launch costs are consistent with NASA DPT requirements for insensitive cargo
  - Required costs for satellite launch to LEO are consistent with SLI 2nd Generation RLV goals for sensitive cargo
- Future DoD missions may provide additional HPM applications/usage rates