SICSA Mars Project

Space Architecture
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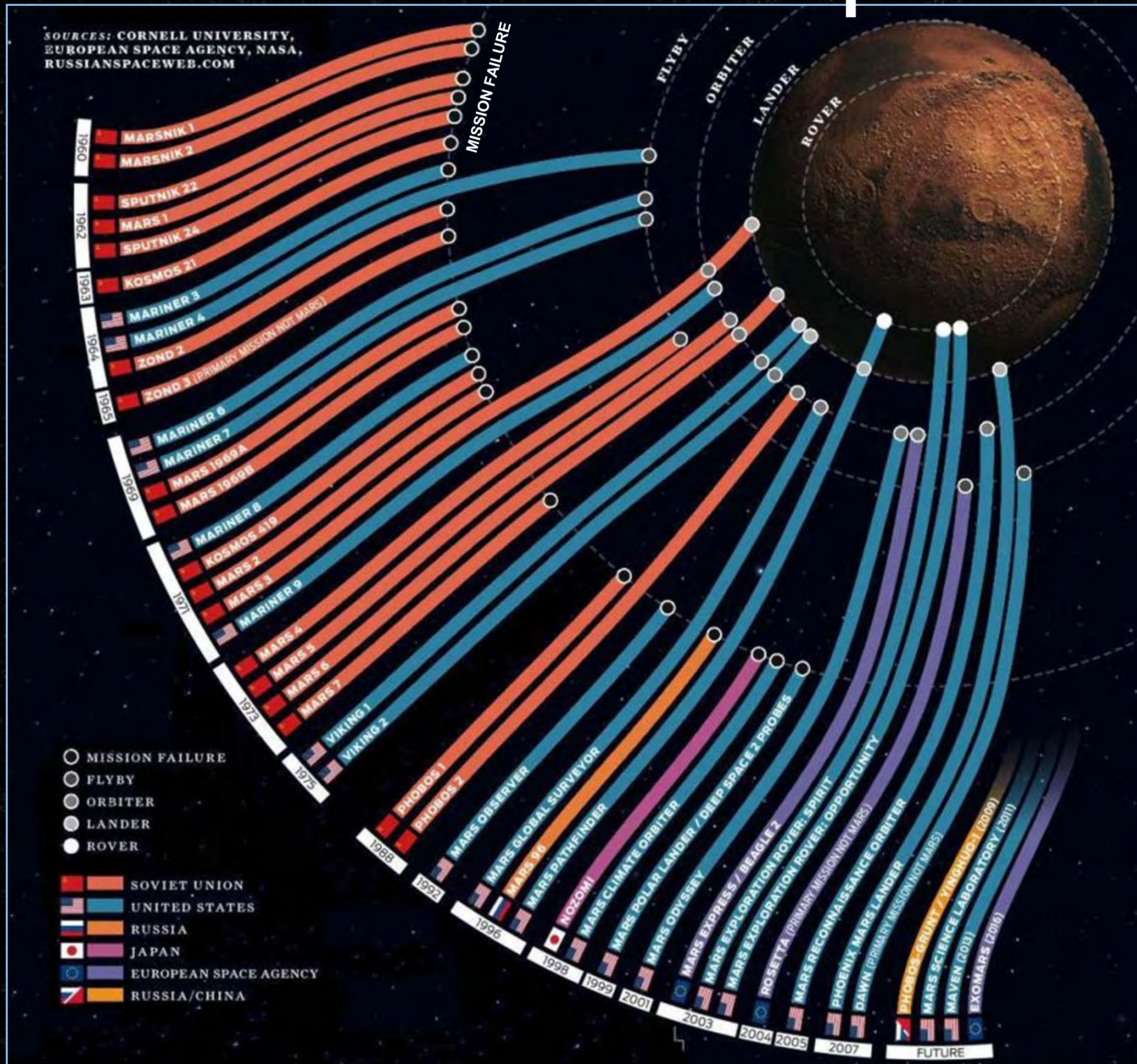
Mission Statement: Student Project

- Explore and define an architectural framework through which to study space architecture, space operations and mission planning, and functional relationships of systems, elements and people
- Facilitate multi-disciplinary and cooperative study involving numerous students pursuing discrete aspects of the architecture

Mission Statement: Mars Architecture

- Provide sustainable, scalable and expandable capability to access and operate throughout the Martian system
- Enable human visitation and Earth-return from Martian system, including orbits, natural satellites and eventually to the surface
- Enable recovery of Martian artifacts
- Contribute to the continued evolution

Context of Mars Exploration



Deployment Strategy

- Earth Region
  - Surface
    - Industry
    - Academia
    - Politics
    - Launch facilities
  - Orbital
    - LEO construction
    - L4/L5 depot
    - Departure trajectory
- Interplanetary Region
  - Outgoing
    - Crew
    - Cargo
  - Incoming
    - Crew
    - Artifacts
  - Solar Orbit
    - Communication Satellites
- Mars Region
  - Approach
    - Braking
  - Orbital
    - OMV Ops
    - Depot
  - Moons
    - OMV Ops
    - ISRU

Earth Surface

- Manufacture all new components
- Acquire all existing components
- Assemble some components
- Tap into communications infrastructure
- Use various launch sites & vehicles
  - All Components to LEO
  - Multiple launch options:

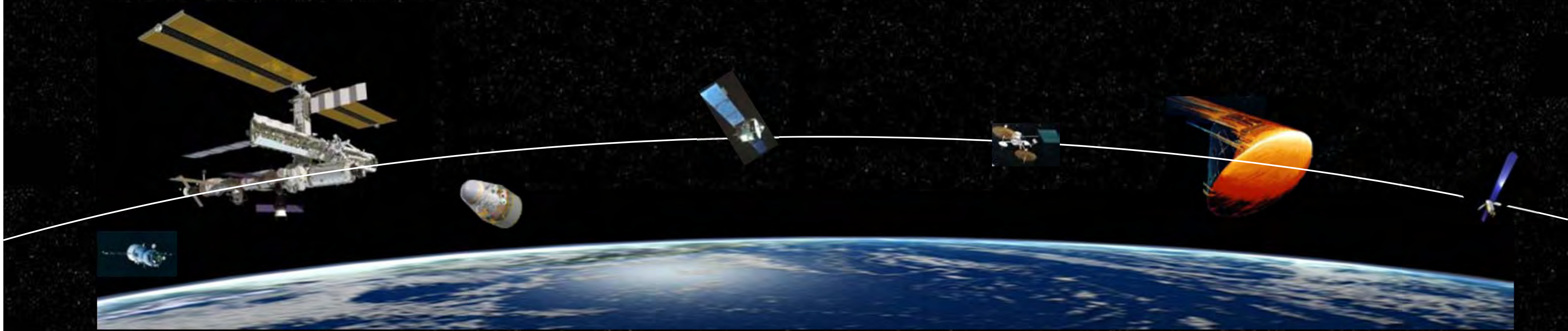
Current Launch Vehicle	Launch Site	P/L Mass to LEO
Ariene 5	Kourou, French Guiana	21 MT
Atlas V	KSC, Vandenberg AFB	20 MT
Delta 4 Heavy	KSC, Vandenberg AFB	25.8 MT
H-II	Tanegashima, Japan	19 MT
Proton M	Baikonur, Kazahkstan	22 MT
Soyuz FG/ST	-Baikonur, Kazahkstan -Kourou, French Guiana	7.8 MT
Zenit 3SL	-Baikonur, Kazakhstan -Sea Launch Facility (equator)	5 MT

Future Launch Vehicle	Launch Site	P/L Mass to LEO
Angara	Vostochny, Russia	24.5 MT
Falcon 9 Heavy	KSC	32 MT
GSLV Mark 3	Sriharikota Island, India	10 MT
Long March (CZ-NGLV)	Hainan Island, China	25MT
Taurus 2	Wallops Island, Virginia	5.5 MT

Low Earth Orbit

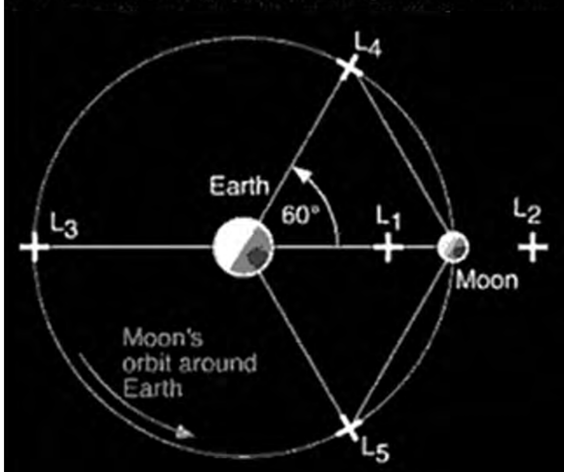
- Depot
  - ISS
  - Fuel
  - Assembly/Repair/Refurb
  - Logistics
- Crew Vehicle/Habitaxi

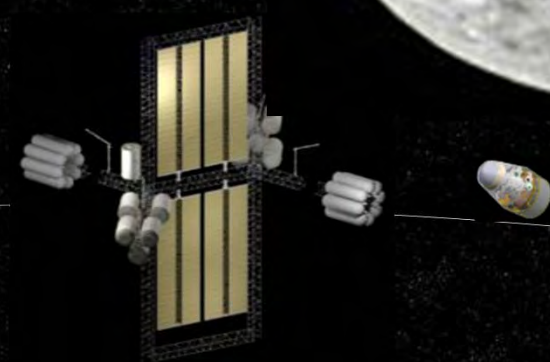
- Orbital Maneuvering Vehicle (OMV)
- Existing communication structure
- Earth re-entry



LaGrangian Point 1. 4 or 5

- OMV
- Depot
  - Staging
  - Fuel
  - Assembly/Repair/Refurb
  - Logistics
- Crew Vehicle/Habitaxi



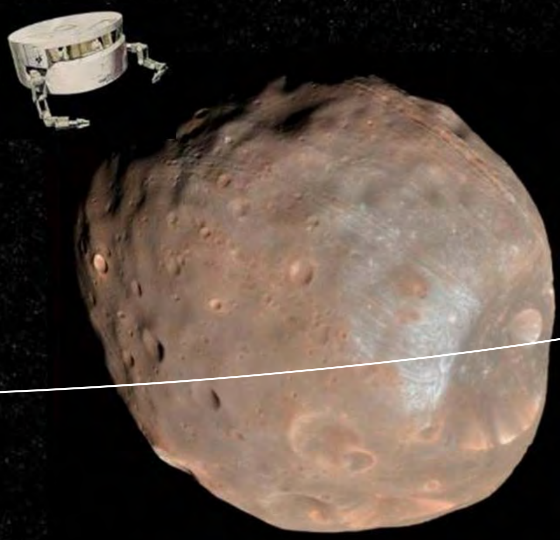


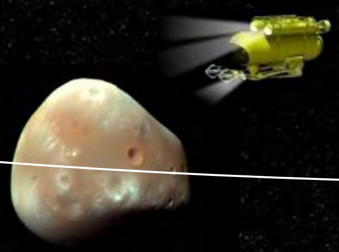
Trans-Mars/Trans-Earth

- Communication Satellites
- Trans-Mars/Trans-Earth Vehicle
  - Propulsion System
  - Payload Spine
  - Propellant
  - Power System
  - Communication Components
  - Payload Elements

Martian Moon Orbits

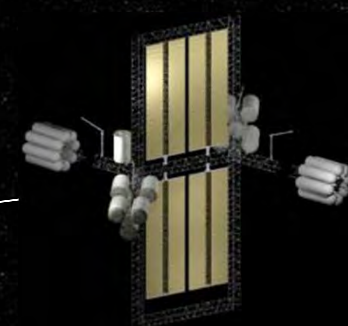
- Robotics
- Robotic Insitu Vehicle
- ISRU option
- Depot / Mars Observation





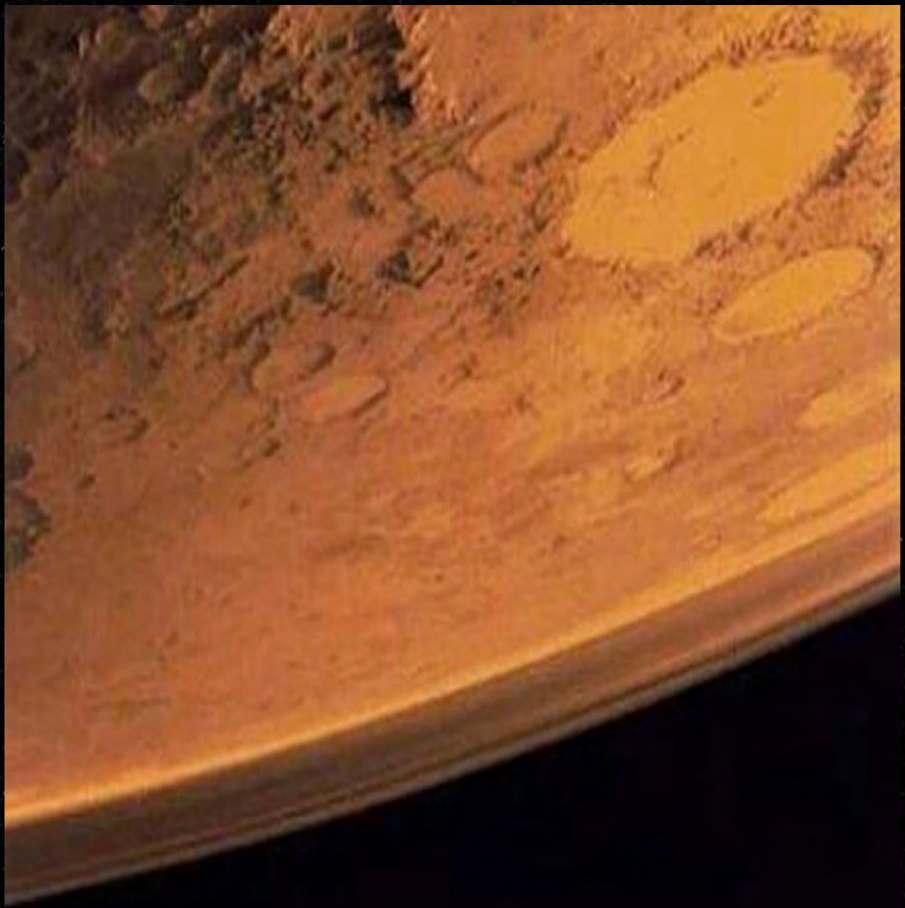
Low Mars Orbit

- Depot
  - Staging
  - Fuel
  - Assembly/Repair/Refurb
  - Logistics
- OMV
- Crew Vehicle/Habitaxi
- Satellites
  - Communications
  - Navigation
  - Surveillance
  - Power beaming
- Descent/Ascent Vehicle



Mars Surface

- Descent/Ascent Vehicle
  - Human
  - Cargo
- ISRU
- Robotics Capability
- Communications/ Navigation
- Surface Mobility
- Habitation Modules
- Surface Depot/Outpost
- Environmental Robustitude



Mission Enabling Capabilities

- Delta-V Capability
  - Low Thrust/High Efficiency
    - VASIMR – ISR Argon
  - High Thrust/Low Efficiency
    - Chemical Propellant – ISR Methane
  - Aerobraking
  - Gravity assist
- Energy Production
  - Electrical
  - Chemical
  - Thermal
  - Nuclear
- Fuel (transportable Energy)
  - Production
  - Storage
  - Transportation
- Energy Management
  - Thermal Management
  - Storage Capacity
  - Delivery Capacity & Methods
- Logistics
  - Consumables
  - Expendables
  - Recyclables
  - In-Situ Producibles
  - Transformables
- Communications
  - Satellites
    - Solar Orbit
    - Mars Orbit

Mission Enabling Capabilities

- Knowledge Capture
  - High-speed Data
  - Low rate Data
  - Long Range
  - Local Area Networks
  - Trans-Martian Network
  - Cameras
  - sensors
- Attitude Control
- Navigation
  - Intra-Planetary
  - Orbital
  - Surface
- Command, Control and Synchronization Capability
- Payload Capability
  - The stuff that's above and beyond what's needed to just get there and back
  - Discretionary mass with needs
  - Provides end-products or expanded capabilities

Mission Enabling Capabilities

- Robotic Capability
  - Scale
    - Size
    - Quantity
  - Location
    - Mars, Phobos & Deimos
    - Orbital
    - Surface
  - Interoperability and intra-operability
- Human Presence Capability
  - Places to be, work, live, and survive
  - Abilities to transition between environments
- Surface Mobility
  - Stuff
  - People
  - Materials
  - In-Situ Materials
- Telepresence
  - The ability to virtually transcend space

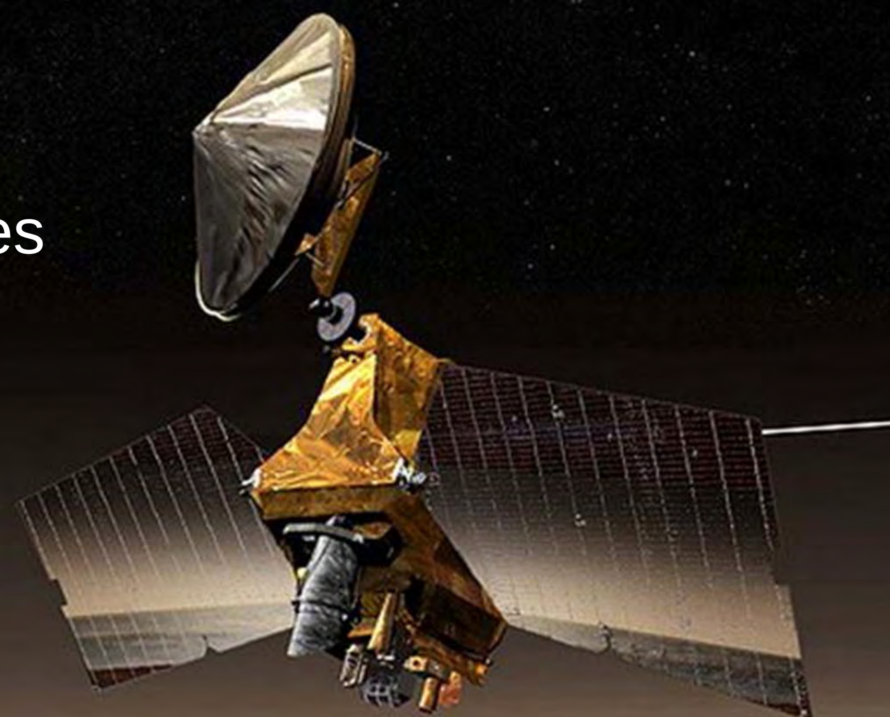
How We Achieve This Architecture

Operational Phases

- Precursor Reconnaissance Missions
- Cargo/Infrastructure
- Human Transfer
- Operations in Martian System
- Return Home

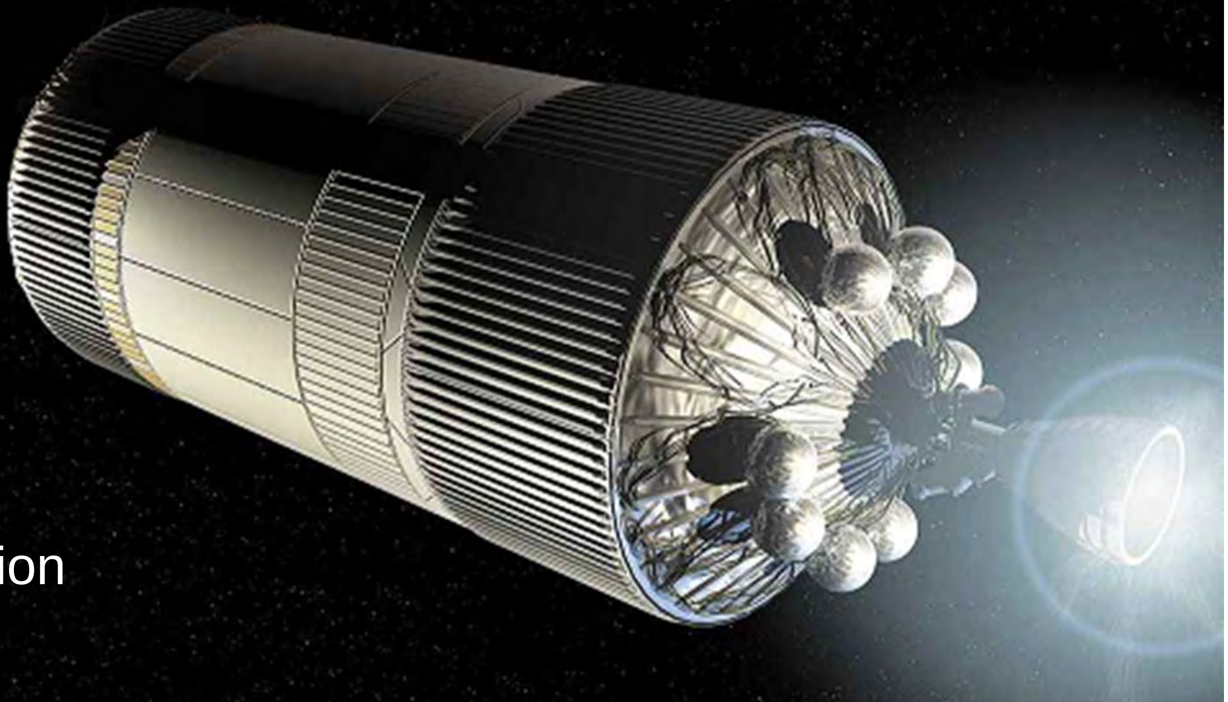
Phase 1: Preliminary Missions

- Satellites form communications infrastructure
  - Mars Orbiting
  - Solar Orbiting
- Robotic missions characterize landing sites
  - Orbital Reconnaissance
  - Surface Missions
- Sample return mission demonstrates ISRU



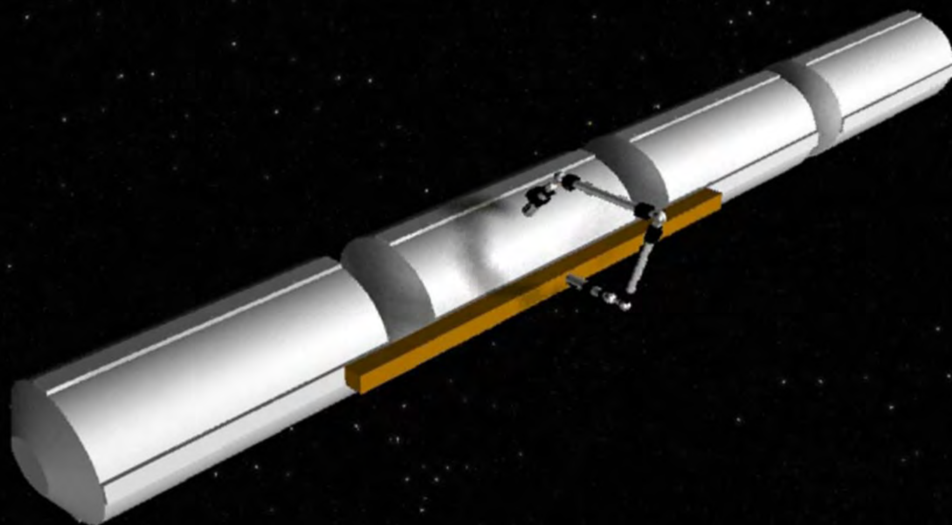
Phase 2: Cargo Delivery

- 20-30 Mt commercial launch vehicles
- Autonomous rendezvous & docking
- Propulsion
  - Chemical
  - Plasma
- Braking into Mars orbit
  - Aerobraking
  - Propulsive deceleration



Phase 3: Propellant Production and Systems Checkout

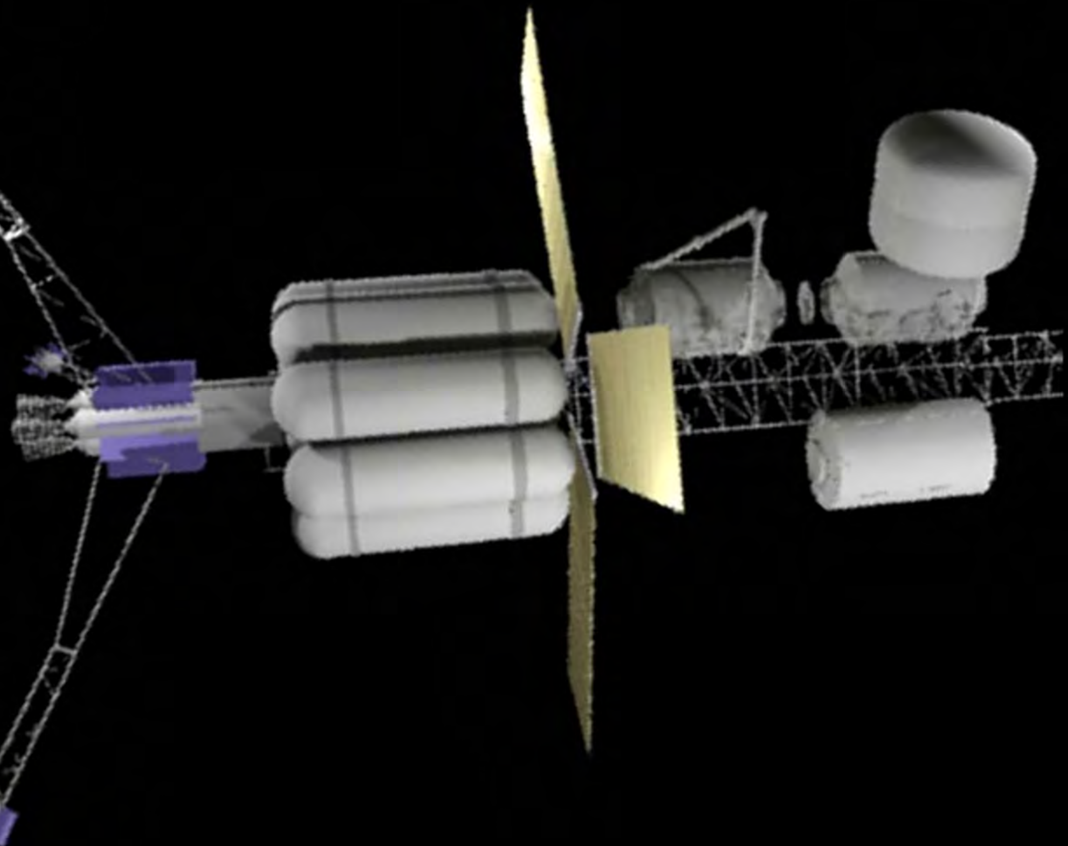
- Begin multi-functional depot assembly in LMO
- Deploy ISRU plant on Martian surface
- Begin placing surface infrastructure



- Test out mission architecture at all levels

Phase 4: Crew Transfer

- Minimize crew transfer time
- Protect against radiation
  - Avoid Van Allen Belt
  - Use “storm shelters”
    peak events
- VASIMR
  - Needs lots of power
  - Requires spiral out period



Phase 5: Operations in Low Mars Orbit

- Rendezvous with multi-functional depot
- Begin exploration of Phobos
- Tele-operation of near real-time rovers & robots

Phase 6: Surface Operations

- Flexible surface mission durations
- ISRU
  - Oxygen for breathing
  - Oxygen used with hydrogen feedstock to create water
  - Oxygen used with methane for combustion

Phase 7: Return Home

- Methane and oxygen powered ascent vehicle
- Rendezvous and docking with crew transfer vehicle
- Argon VASIMR propulsion
  – 4 day Mars spiral and 85 day transit to Earth
- Return to surface
  – Direct entry
  – LEO recovery

Crew Operations Throughout

- Housekeeping
- Health maintenance
- Science
- Public outreach
- Personal communications

Crew Operations by Mission Phase

- Outbound
  - Training
  - Maintenance
- Mars Vicinity
  - Remote operations of robots
  - Observations
  - EVAs
- Inbound
  - Debriefing
  - Analysis of samples

Maintaining Public Interest

- "Wow" Factor
  - Making it continuously interesting
  - Maintaining the return on investment in the form of value-added outposts
  - Keeping it sold
- Vicarious Presence
  - Taking it to the people
- Commercialization
- Investment
- Education outreach

Architecture Elements

Propulsion – James Doehring

Depots – Michael Fehlinger

Element Concepts – Frank Eichstadt

LMO Command & Control Module – Kristine Ferrone

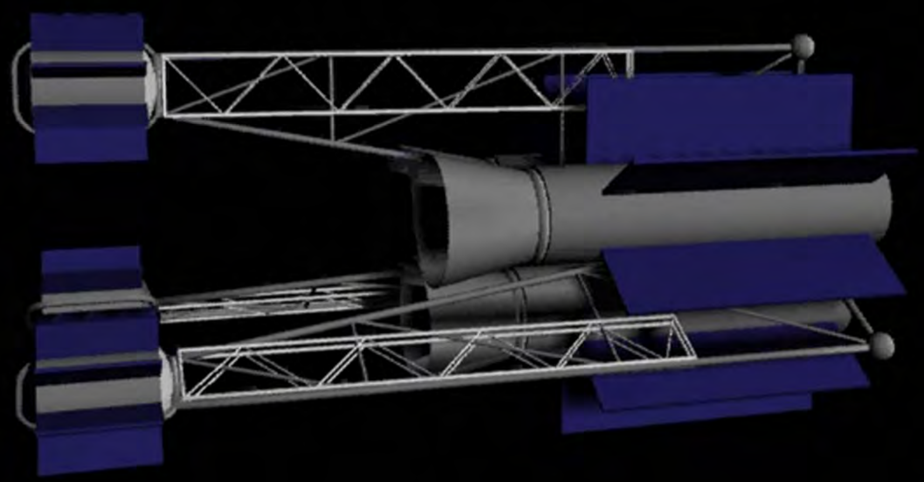
Launch Vehicle Options – Loi Nguyen

Propulsion

•Hybrid fuel currency
 high thrust vs.
 high efficiency

•Long-term payoffs
 Methane & Argon
 “economy”

•Power plants
 Design for launch



Depot

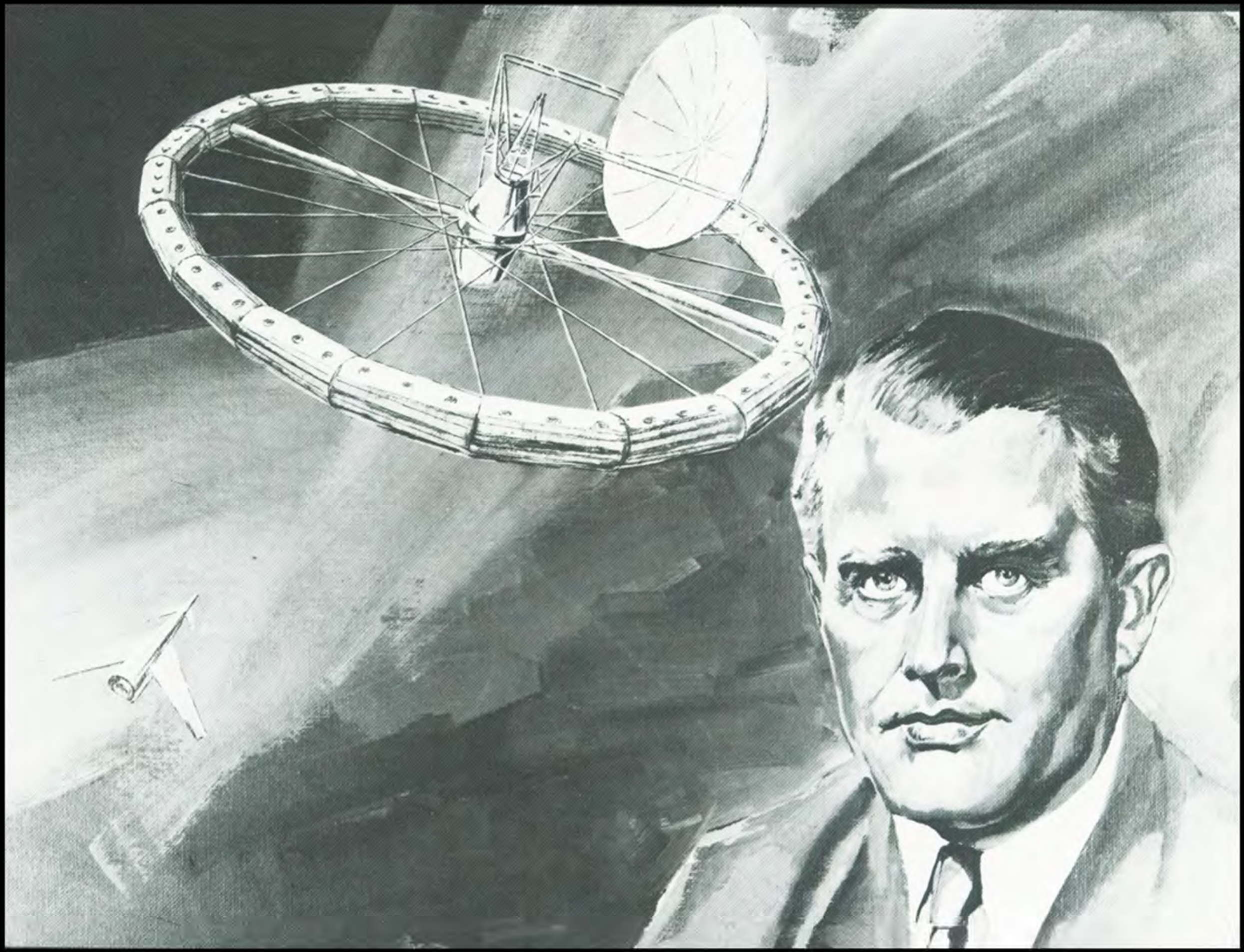
Michael Fehlinger

Station Concepts
Fuel Depot
Configurations

With the development of a Space Statation, what will it look Like?

Some of the first examples come from ideas of Von Braun. Much notably is the "big Wheel" that appeared in the movie 2001: a Space Odyssey. First presented on April 30, 1954.

But the 1990's perception of a space station would have one or more long spars or arms with living quarters, workshops, laboratories, solar collectors, radiators, platforms for experiments, communications antennas, and docking ports.



Wernher von braun : Conceptual Space Station

Station Concepts
Fuel Depot Configurations

The following images are platforms designed to carry various types of scientific instruments, with periodic servicing by the Space Shuttle, as well as communications platforms in geosynchronous orbit. Some of these were designed to grow into space stations through the addition of pressurized habitat modules.

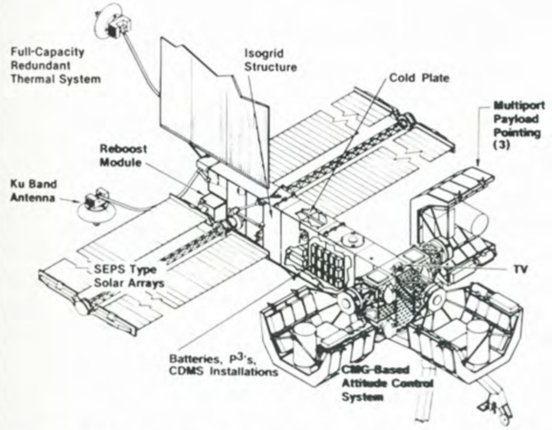


Figure 1.7 Space platform concept designed by McDonnell-Douglas. *Courtesy of McDonnell-Douglas.*

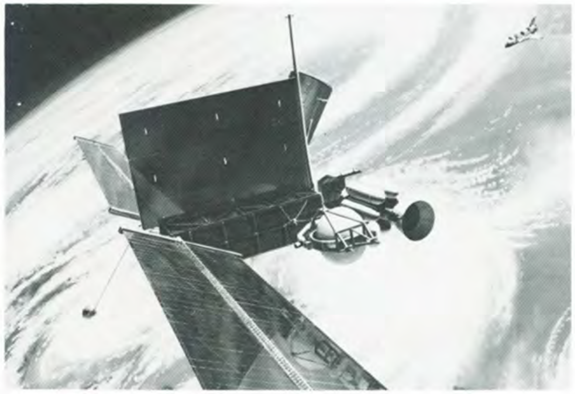


Figure 1.8 The TRW space platform concept as a long-term host vehicle for scientific payloads. *Courtesy of TRW.*

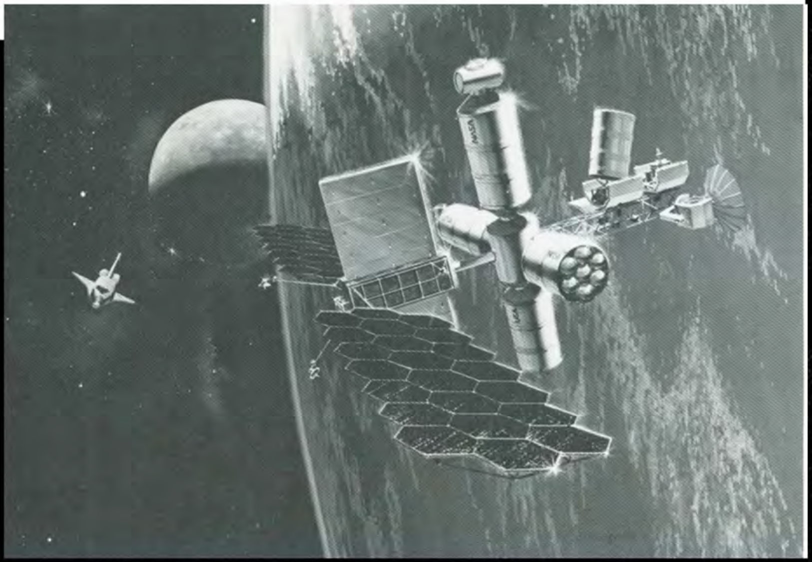


Figure 1.9 MSFC concept for evolution of a space platform into a manned station through addition of manned modules. *Courtesy of MSFC.*

Station Concepts

Fuel Depot

Configurations

In 1979 , the NASA JSC undertook studies of a new space station, the Space operations Center (SOC). SOC studies were contracted to JSC in 1980 and continued for about two years.

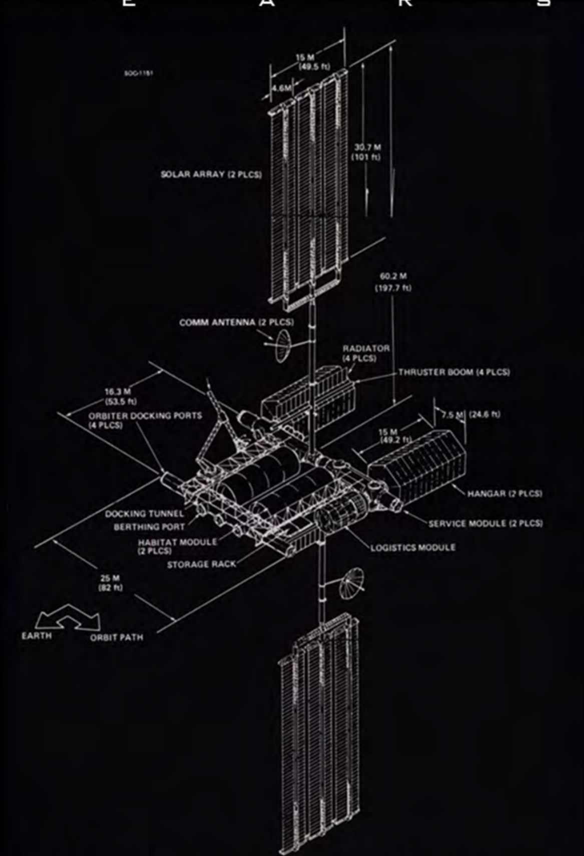


Figure 1.10 The "Space Operations Center" space station concept. *Courtesy of Boeing.*

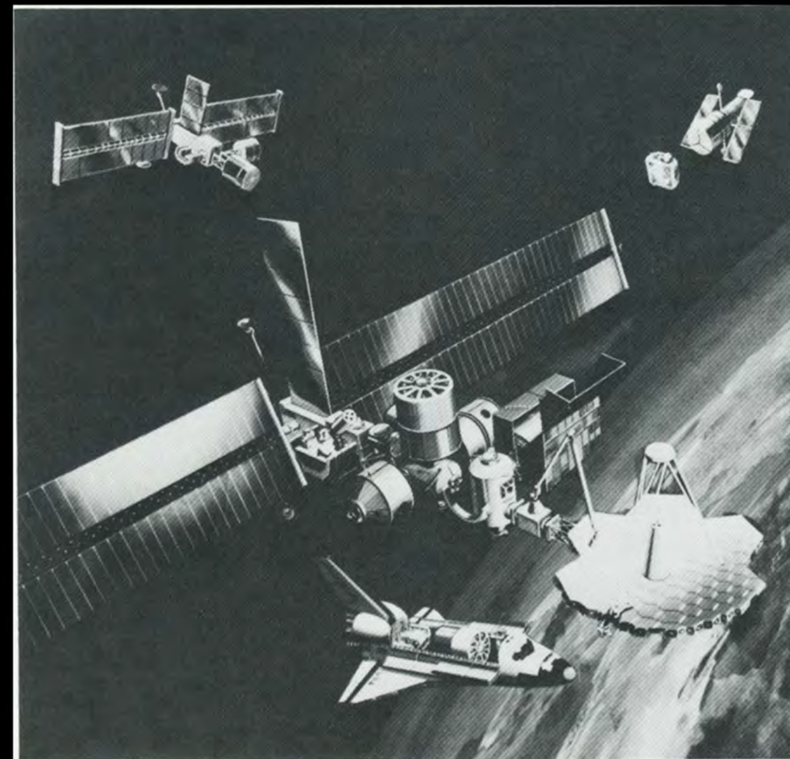


Figure 1.11 MSFC space station concept circa 1982. *Courtesy of NASA-MSFC.*

At the same time, the Marshall Space Flight Center (MSFC) was refining its designs for a manned platform that would evolve from earlier unmanned platforms. Above is a typical MSFC concept.

Both approaches had many attractive and disputable features which caused NASA headquarters to take control of the emerging program.

Station Concepts
Fuel Depot
Configurations

Two concentrating solar collector power units are attached at the ends of the keel to increase the available power to 125 kilowatts. The drag from additional solar panels would cause the station's orbit to decay quickly. Therefore, concentrating collectors, which produce more electricity with a smaller area, are used as the station expands.

This model space station is designed to accommodate six to eight crew members engineers, scientists, technicians, and others. the Space Shuttle and unmanned cargo ships will haul the sections and modules into orbit.

Fuel Depots Configurations

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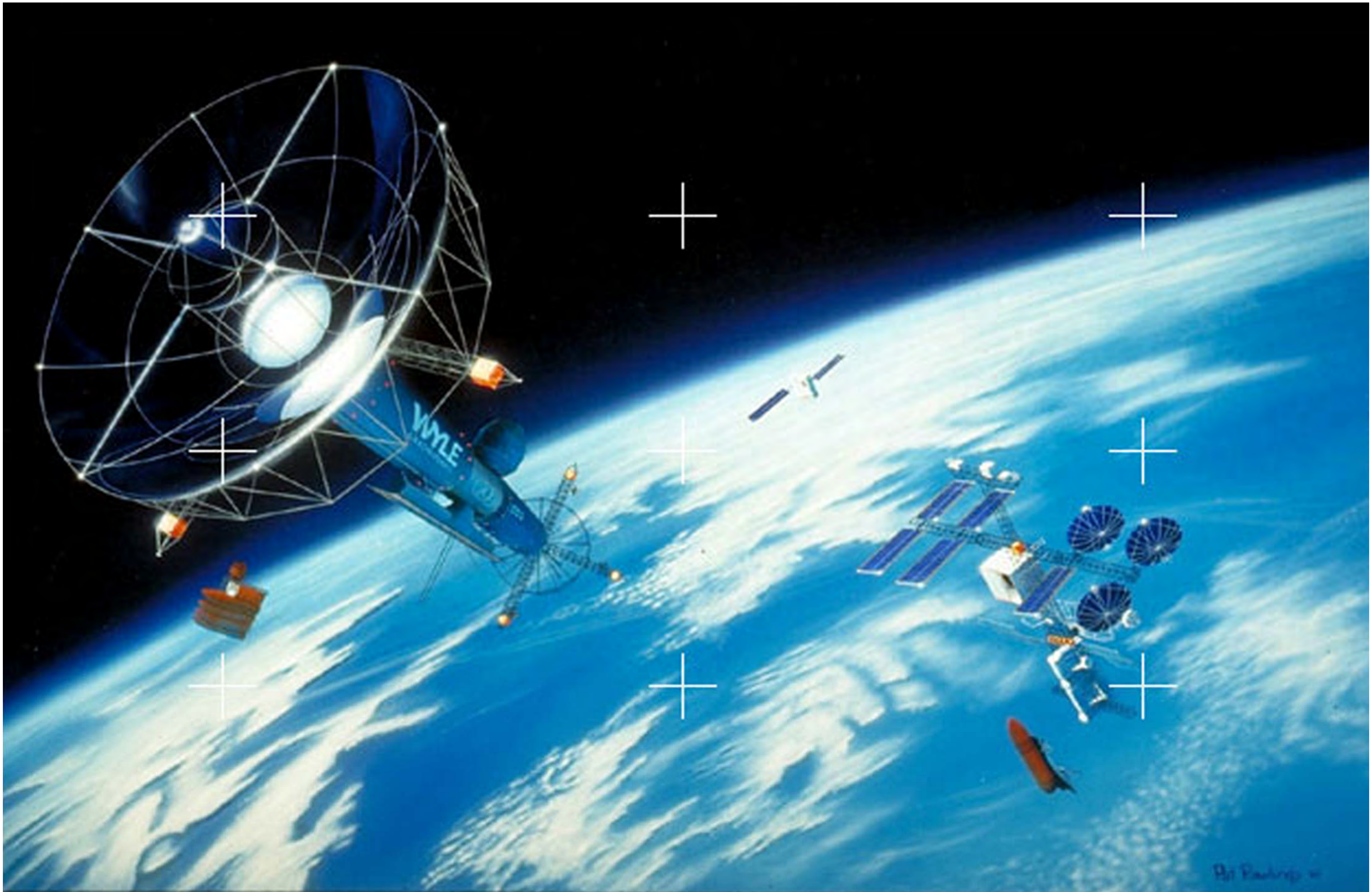

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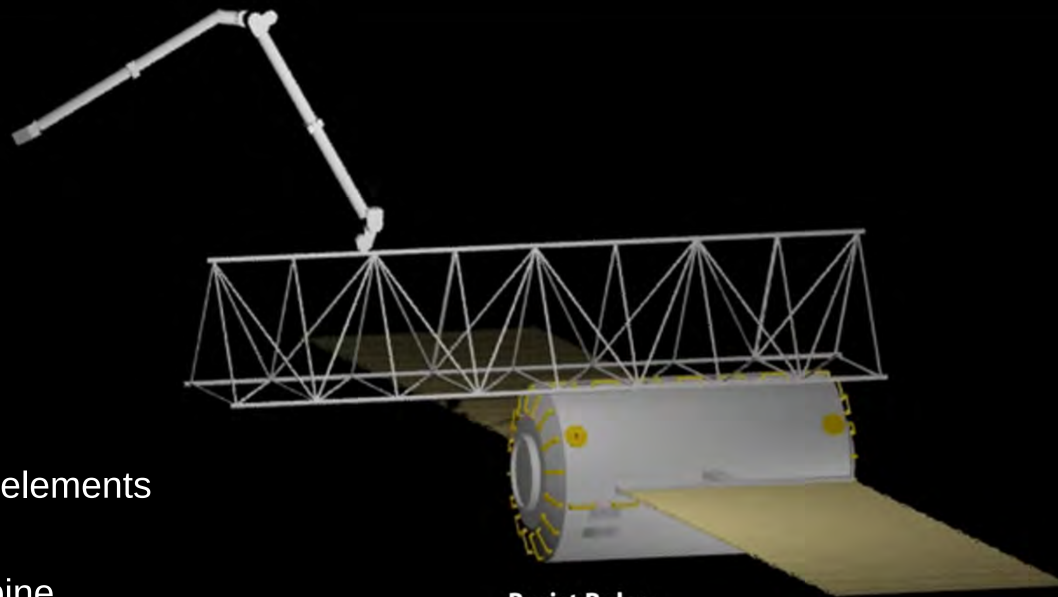
Depot

- Flexible, open-ended and expandable for future missions.
- Low Earth Orbit or L4/L5 Depot
  - Initially minimalistic
  - Temporarily holds all fuel and payload elements
  - Assembles Trans Mars Vehicle (TMV)
  - Loads payload elements onto barge spine
  - TMV disembarks for Trans Mars trajectory
- Low Mars Orbit (LMO)
  - Initial depot consists of first TMV components
    - Propulsion
    - Spine structures
    - Module elements
  - Follow on missions contribute to depot
    - Spine structures
    - New elements
- Overall design may vary between the Earth and Mars Depots, but they will consist of same language of architecture



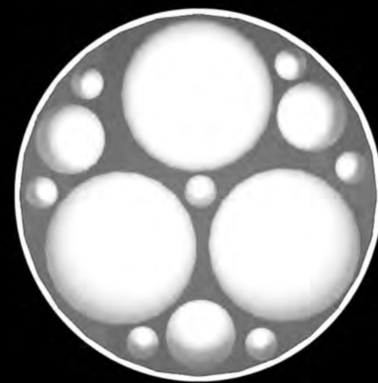
Purist Rules:
to refine and simplify design dispensing with ornamentation

Shroud Capacity

ARIANE 5

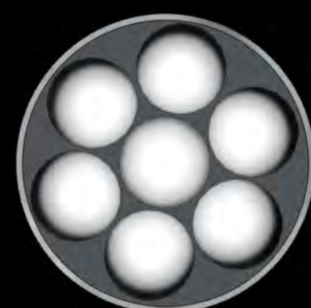
Length 17m
Diameter 7.4m

Basic foundational elements/systems to the development of the chosen architecture.

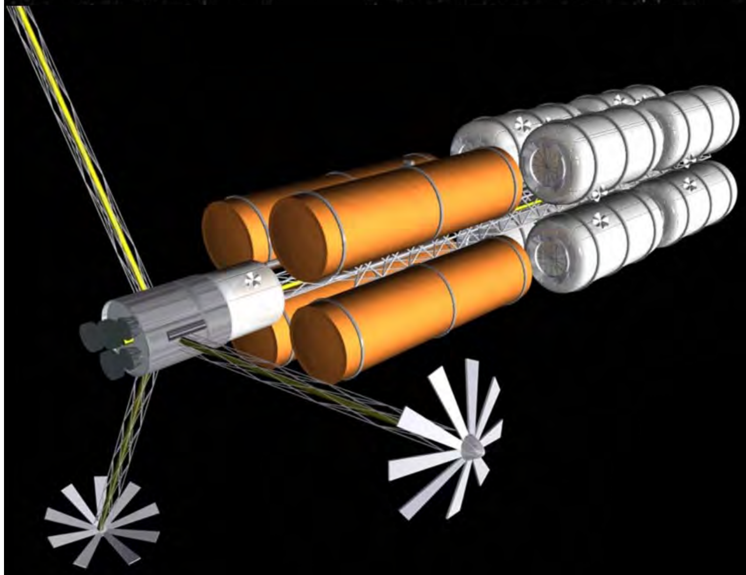


PROTON M

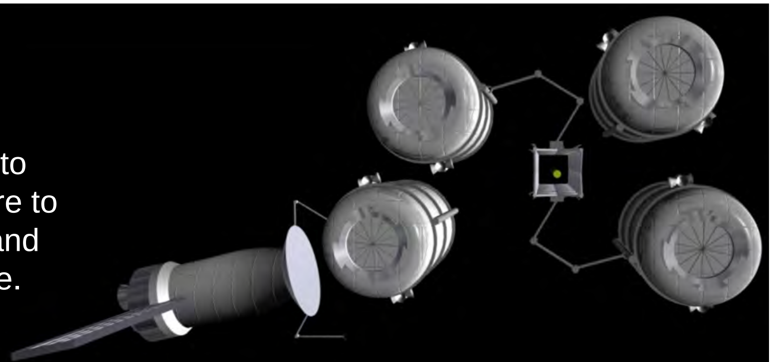
Length 15.25m
Diameter 5m



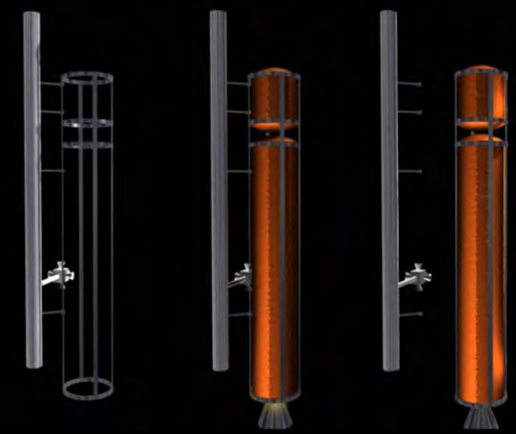
Schematic: Vehicle Orbital Assembly



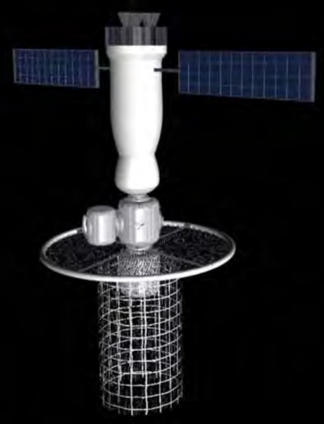
ATV can be used to move infrastructure to the robotic arms and eventually to spine.

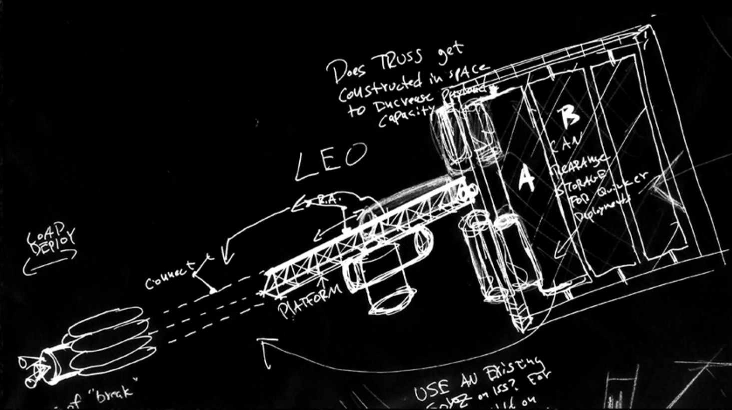


Schematic approach to secure tanks to a “spine”.



Early vision of a depot for logistic transfer and the ability to repair or construct architecture in an inflatable enclosure.





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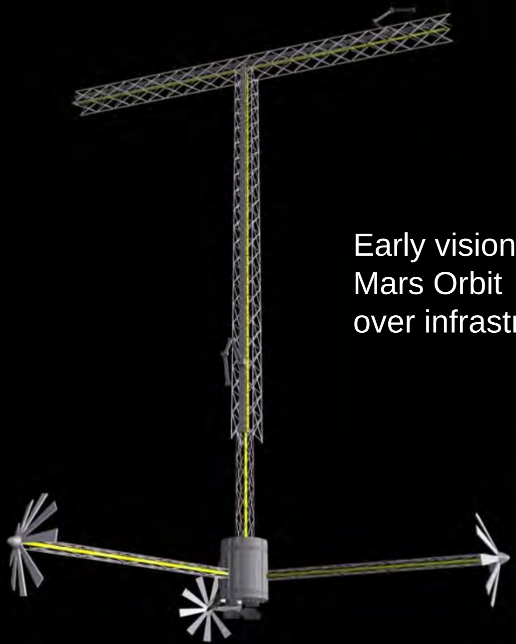
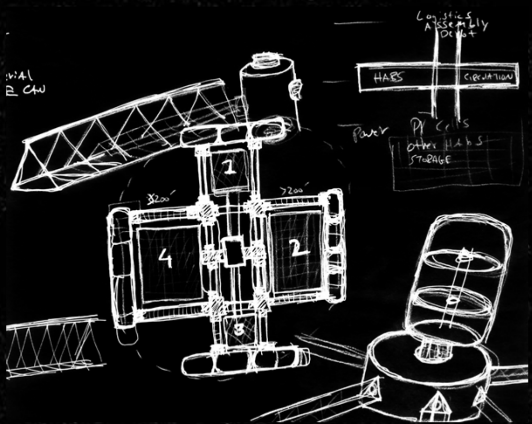
Schematic: Vehicle Orbital Assembly

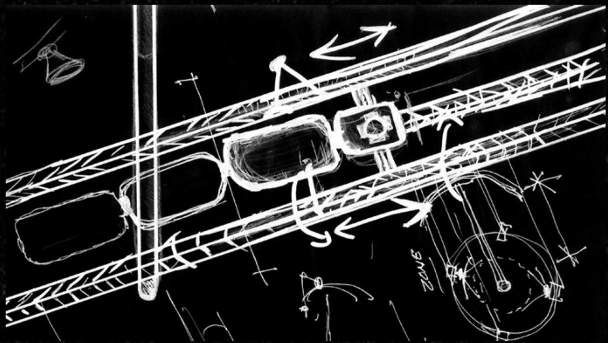


Early vision of Lower Mars Orbit Depot of left over infrastructure

A possible scenario where the construction of a vehicle or depot can be assembled through a series of rings that can store and place material on a spine or structure as it is handled by robotic arms .



Creation of a void to begin to understand an organization to the layout of an open ended depot.



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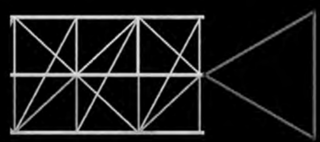
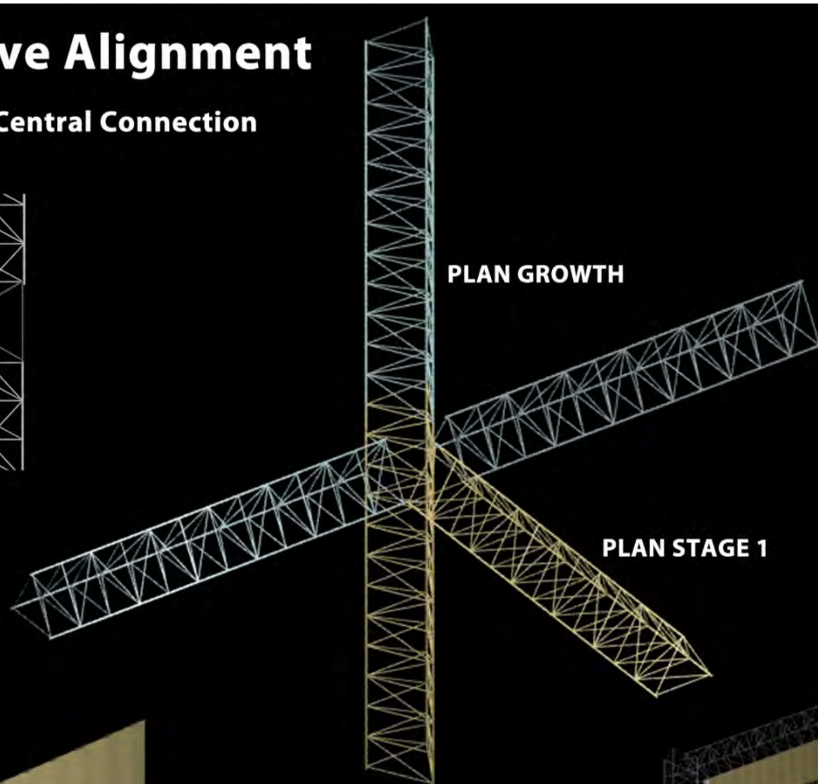
Depot: Various Alternative Alignment

Scheme 1- Vertical Truss with a Central Connection



PLAN STAGE 1

PLAN GROWTH



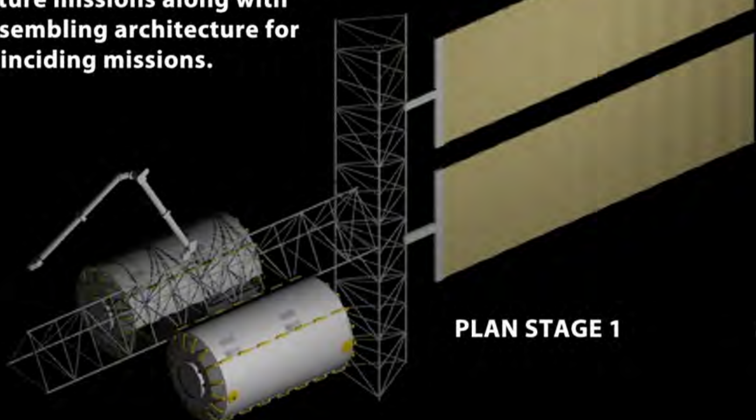
PLAN GROWTH

PLAN STAGE 1

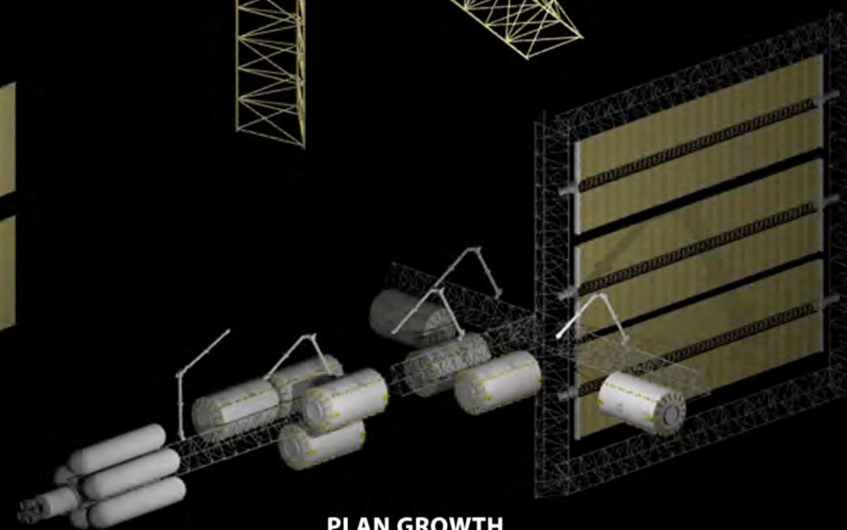
The connection will only be stable once all 4 elements are positioned.

Each depot has the same outcome, these studies are more focused on the begining elements/ connection with the truss.

To limit dead end architecture, the depot is to store infrastructure for future missions along with assembling architecture for coinciding missions.



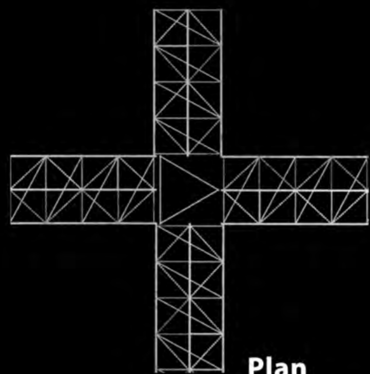
PLAN STAGE 1



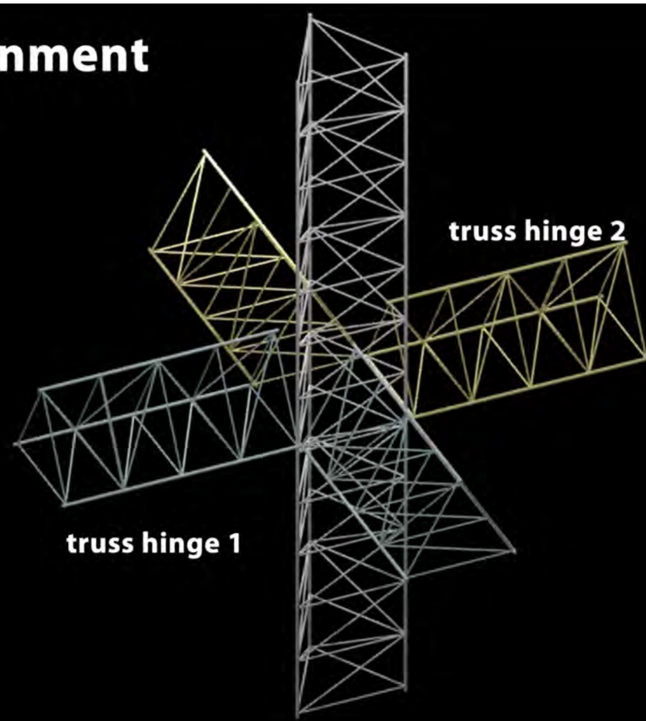
PLAN GROWTH

Depot: Various Alternative Alignment

Scheme 2- Hindge With Vertical Truss

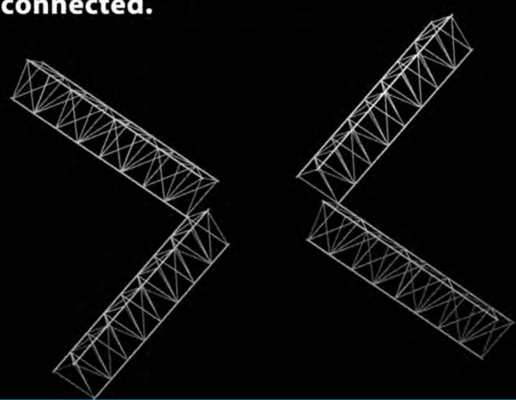


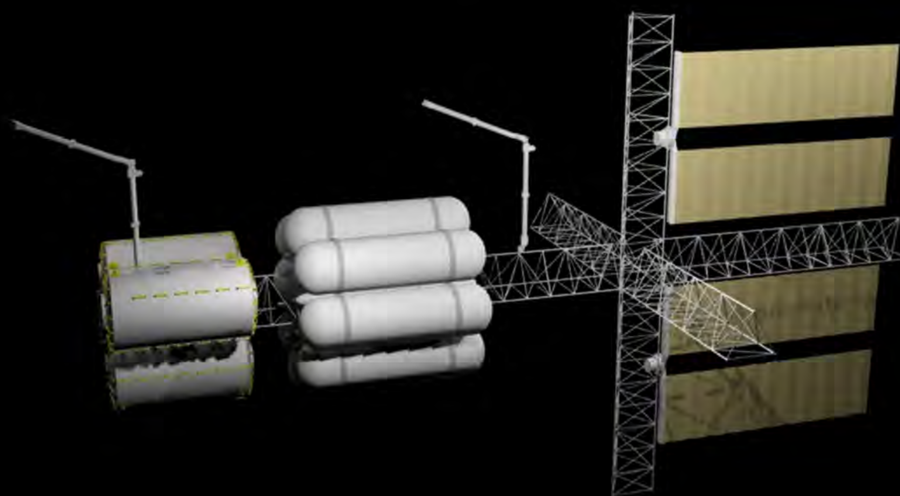
Plan



This scenario was first conceived to have a truss hinged during launch and then connected to be fulled erected . This hinging was carried through the depot design for the expansion of infrastructure.

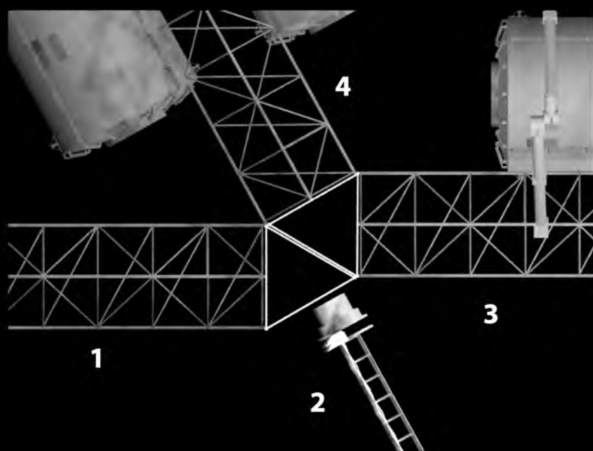
To be stable both hinges must be connected.

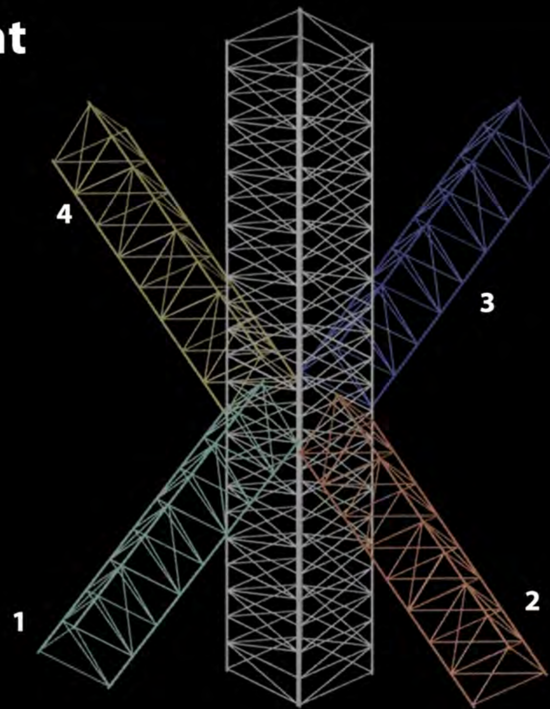




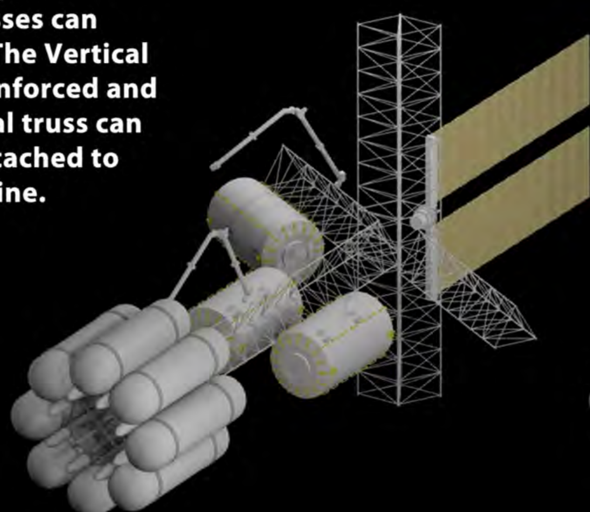
Depot: Various Alternative Alignment

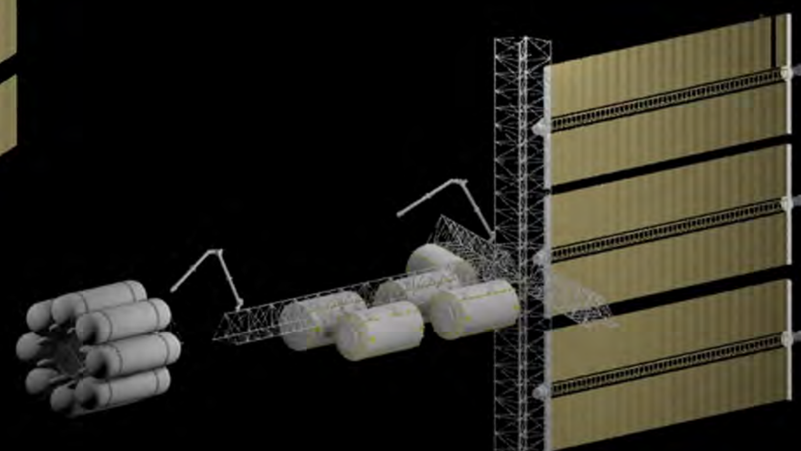
Scheme 3- Hindge With Vertical Truss





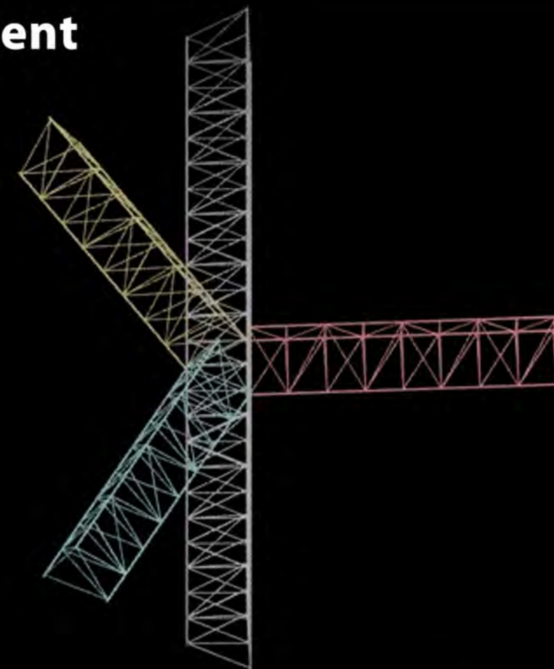
In an attempt to create a square, joining two triangular trusses can achieve this. The Vertical Spine is well enforced and each horizontal truss can be securely attached to the vertical spine.





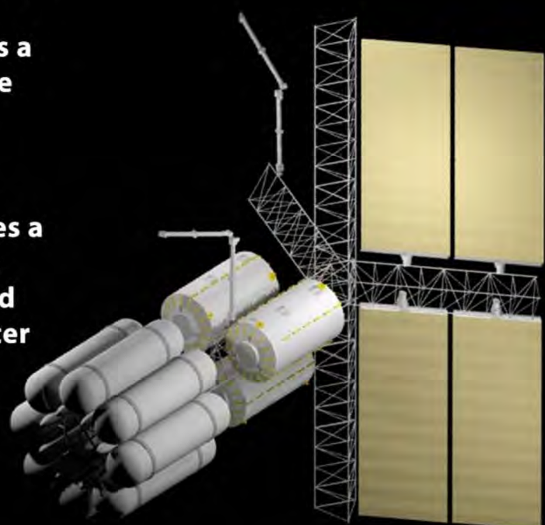
Depot: Various Alternative Alignment

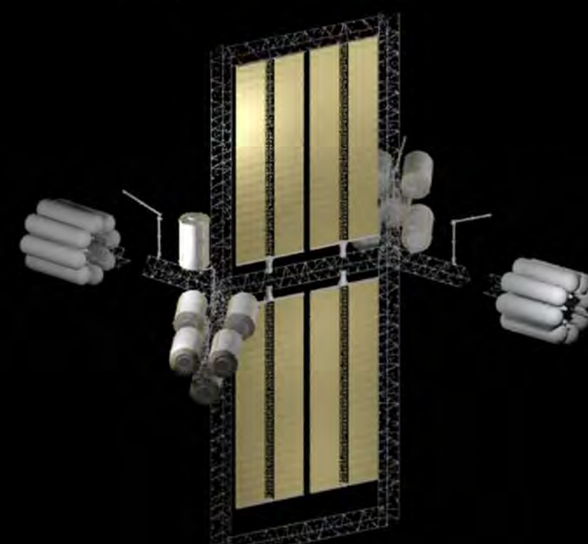
Scheme 4- 3 Sides 1 Vertical



With 1 vertical truss three horizontal trusses can be securely connected and gives a scenario with a more direct connection.

Scheme 4 with the triangular truss gives a larger degree angle between corners and appears to be a better choice.

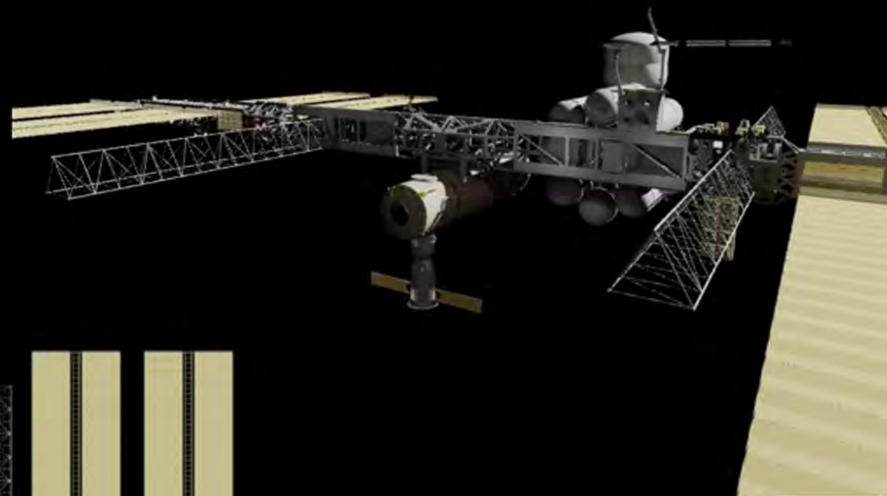


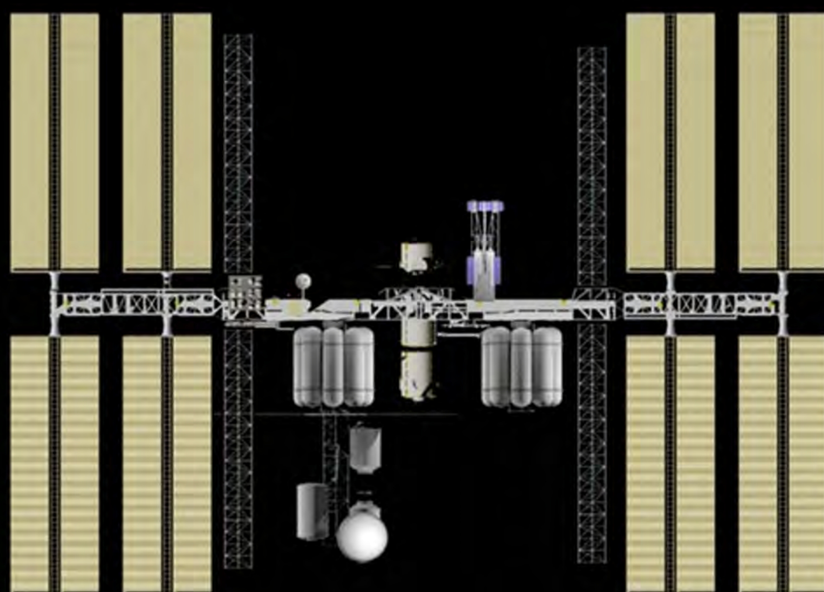


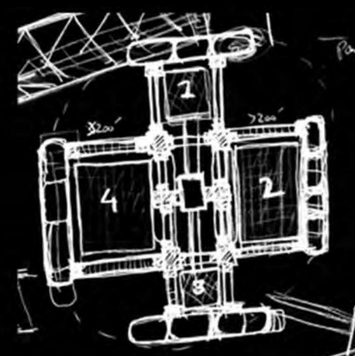
International Space Station: Alternative Alignment

Schematic rendition of the use of the solar panels and main structure.

The removal of Modules create a void for operation.



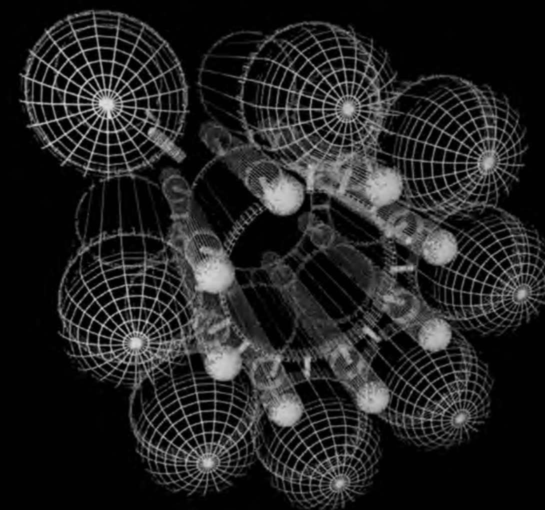


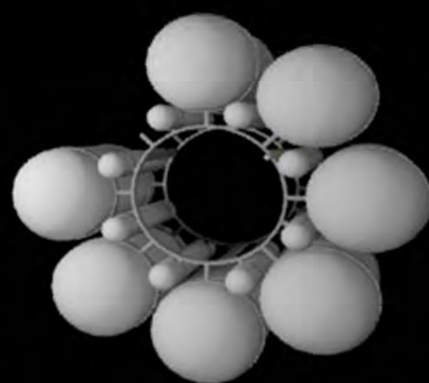


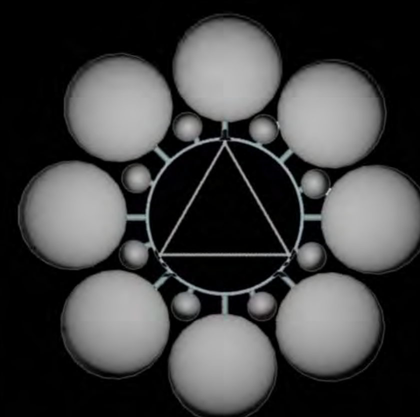
FUEL TANK STUDY:

SCHEME 1: FUEL TANK STRUCTURE

The amount of fuel is an unknown. This study includes a fuel structure capable of holding a variety of tank sizes and fuel.







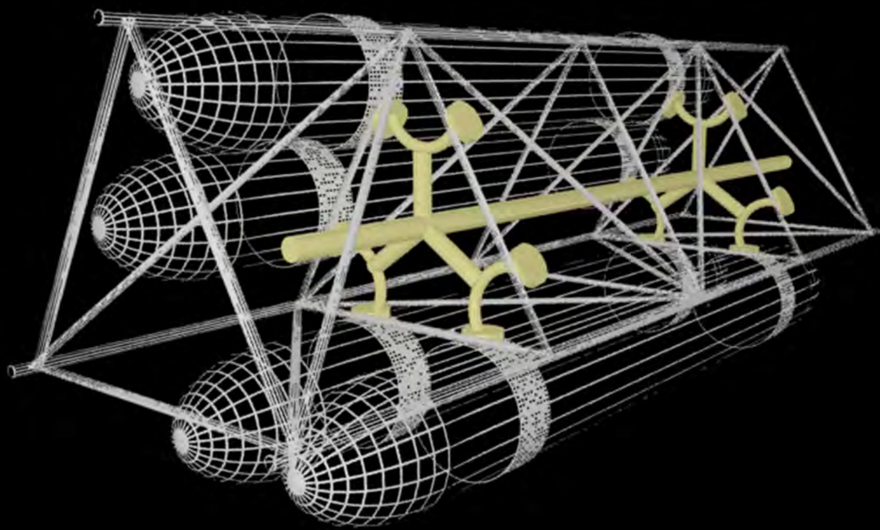
FUEL TANK STUDY:

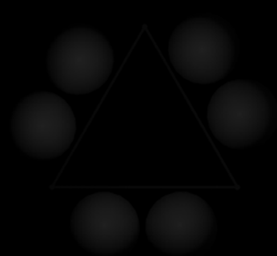
SCHEME 2: FUEL TANKS ON TRUSS

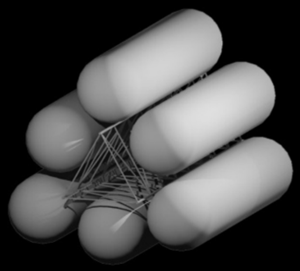
Fuel Tanks can be connected directly to truss

This truss would then be considered a fuel truss

The arrangement depends on amount of fuel and what types of fuel







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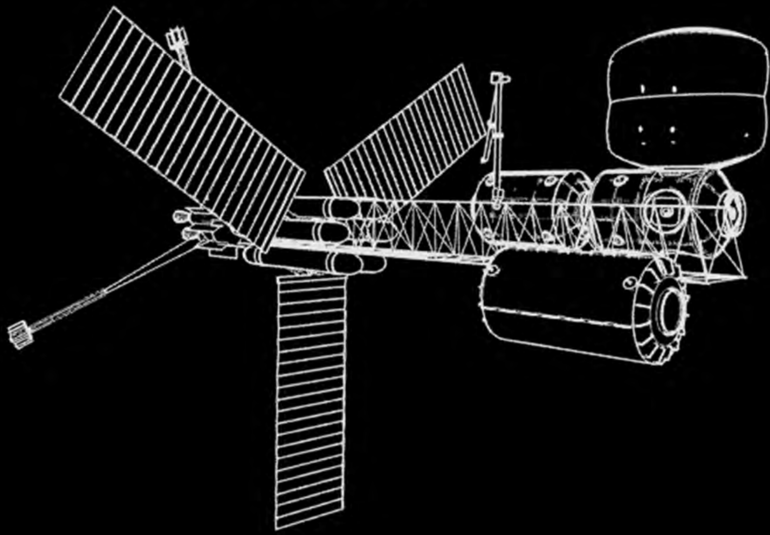
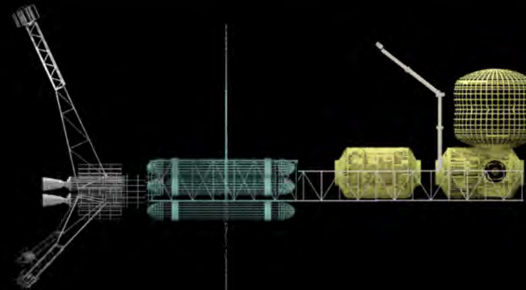
TRANS MARS VEHICLE:

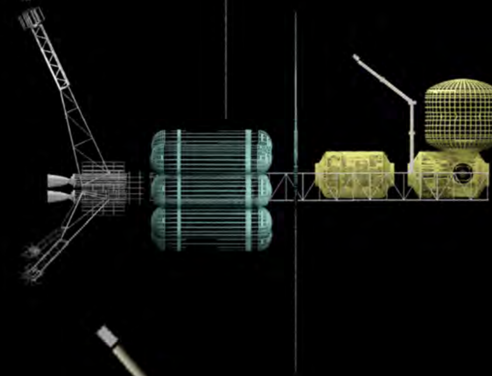
Vehicle Study



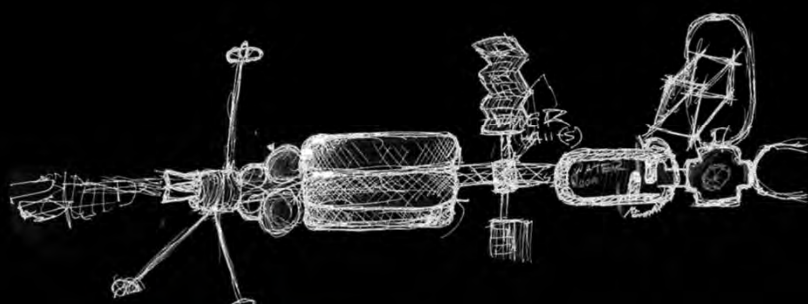
Fuel tanks connected directly on truss with solar panels located in between the tanks

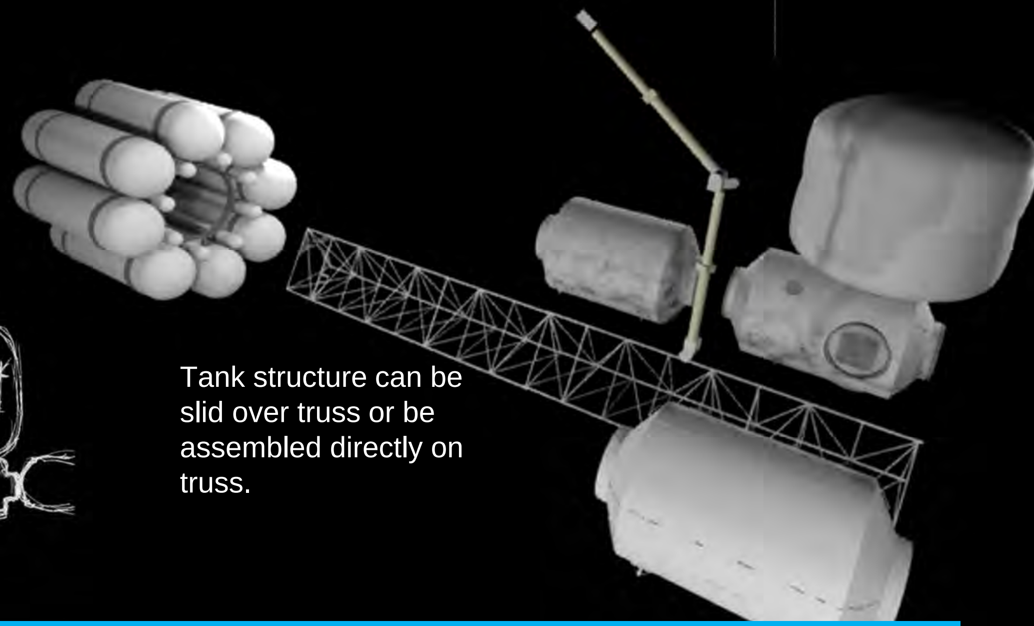


Fuel tanks with fuel tank structure, solar panels located in front of tanks.



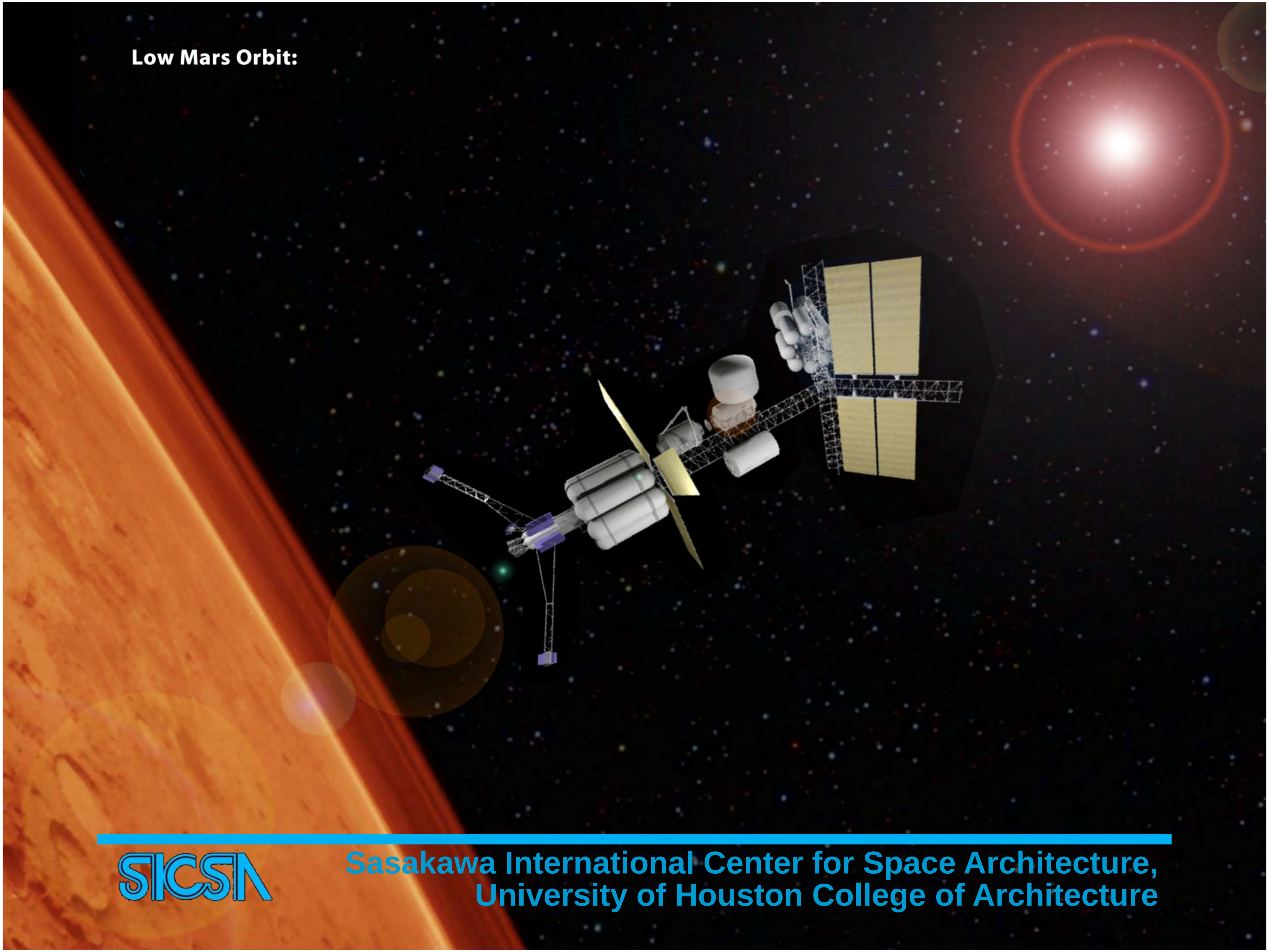
Trans Mars Vehicle with the same type of architecture as a depot can be disassembled and become a depot.



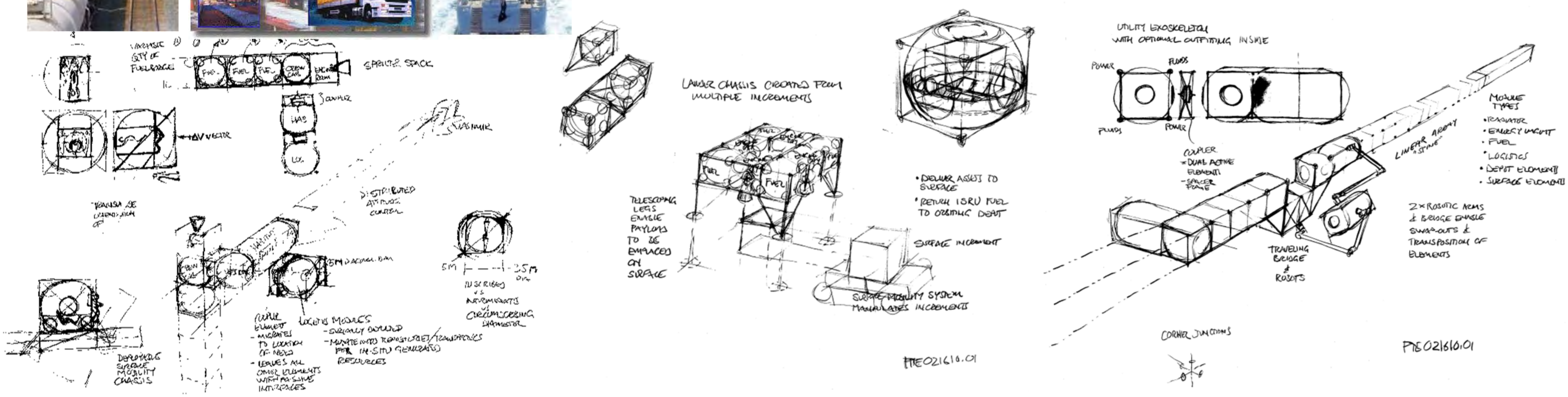


Tank structure can be slid over truss or be assembled directly on truss.

Low Mars Orbit:



Reconfigurable Modular Vehicle Concepts



- Cubic increments and corner interfaces enable elements to interconnect along three axes
- Versatile modular elements recombine to create phase-specific capabilities
- Mobile robotics provide “switching yard “ capability (animation)

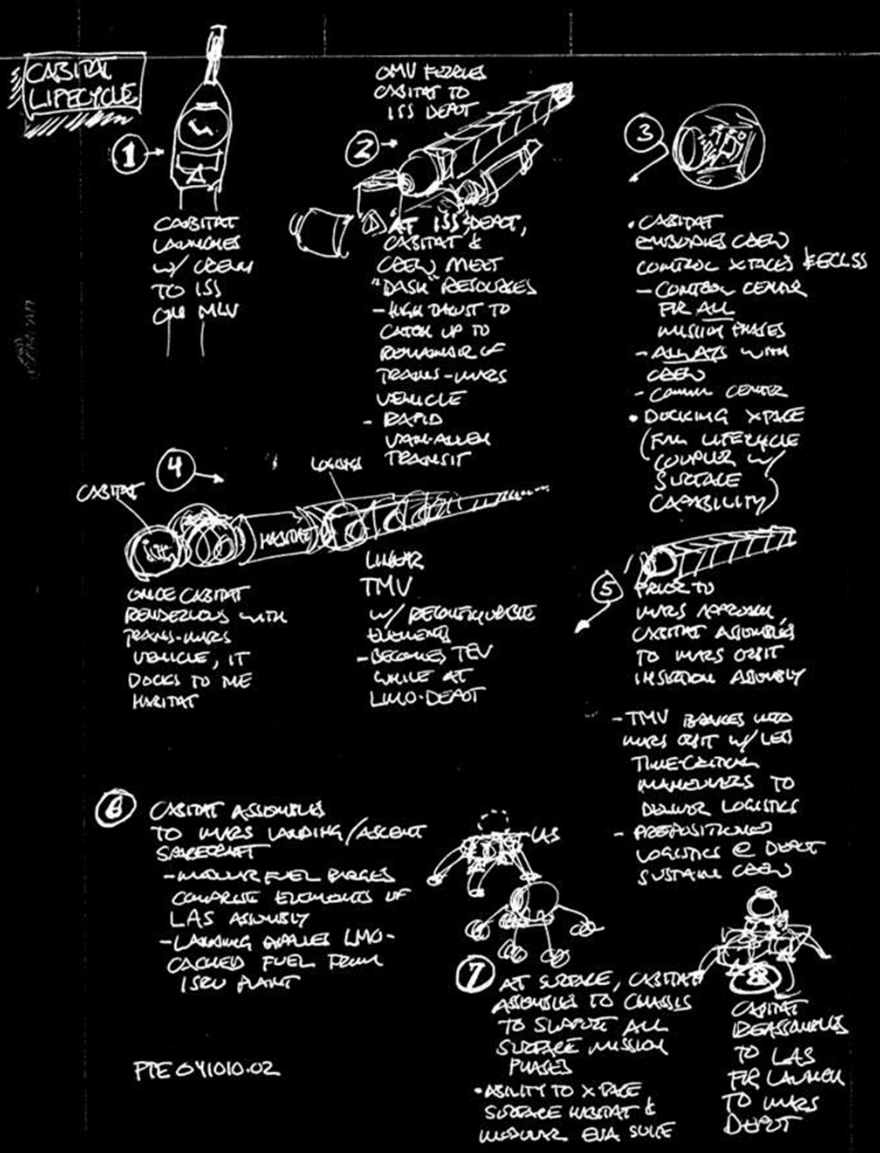
Fuel Barge

An element that stores, transports and delivers fuel and is interoperable with:

(in order encountered during lifecycle):

- Launch vehicle
- LEO OMV
- LEO or L4 Depot
- Mobile Bridge (in flight reconfiguration)
- TMV/TEV
- "Dash" Vehicles
- Propulsion Elements
  - VASIMR (Argon Barge)
  - Chemical Prop Element (Methane Barge)
- Mars OMV
- LMO Depot
- Mars Lander
- Mars surface mobility
- ISRU plant
- Mars Lander/Ascent vehicle

Standard "Stack" interfaces support all applications



Habitaxi

An element that accommodates crew during all transitional mission events

- Standard “Stack” interfaces support all applications
- On-board ECLSS capable of sustaining four crew for duration of all “stand-alone” phases
- Provides control interfaces for all mission phases/events
- Serially attaches to all elements via a single pressurized coupler

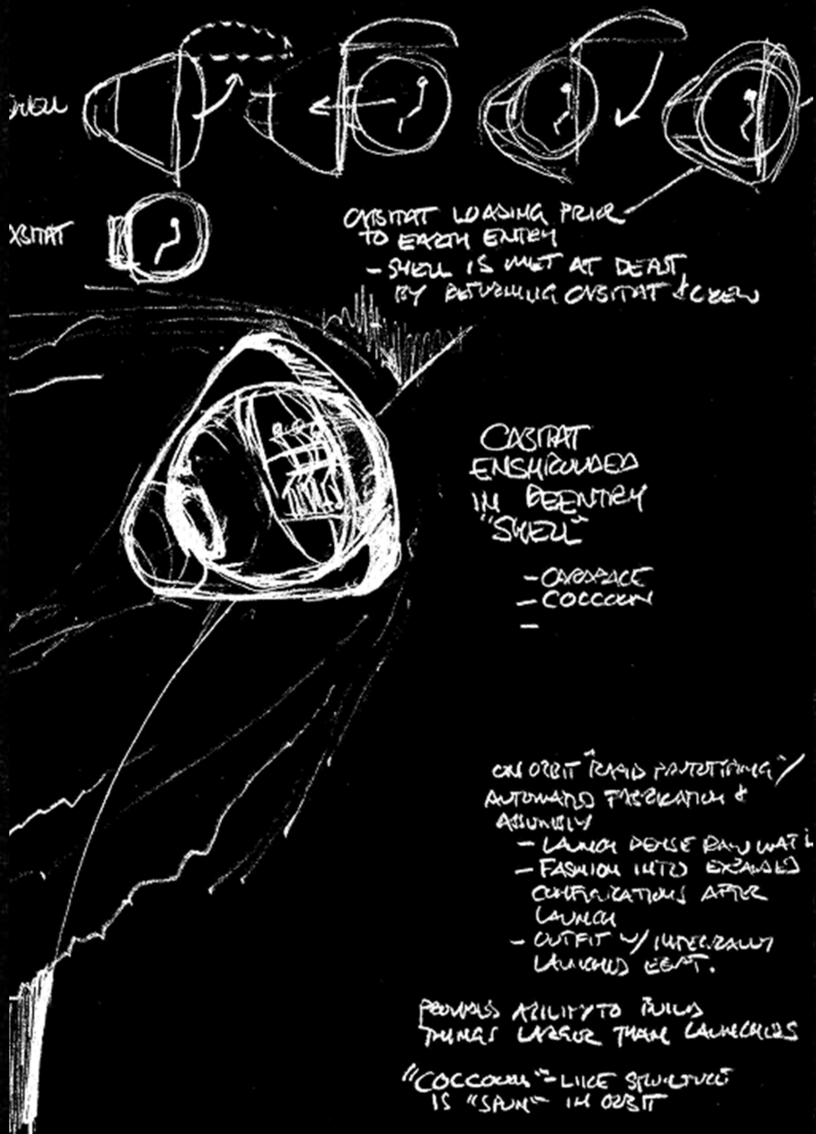
Serial Interoperability

- Launch to LEO
- Ferry via LEO OMV to Depot
- Transfer to “Dash” vehicle
- Rendezvous and interoperability with TMV
- LMO insertion
- LMO Depot rendezvous
- Transfer to Mars Descent Stage
- Transfer to Mars Surface Mobility System
- Interface with Surface EVA Vestibule
- Rendezvous with Mars Surface Habitat
- Transfer to Mars Ascent Stage

Habitaxi:

Serial Interoperability (cont.)

- Rendezvous with LMO Depot via LMO OMV
- Transfer to Earthbound “Dasher”
- Rendezvous with TEV
- Interface with TMV Habitat and logistics elements
- Assemble with Earth Capture Stage
- Rendezvous with LEO Depot
- Encapsulate in reentry shroud at LEO Depot
- Reentry and recovery



Habitaxi (cont.)

Habitaxi combines with Earth Entry Shroud at LEO Depot

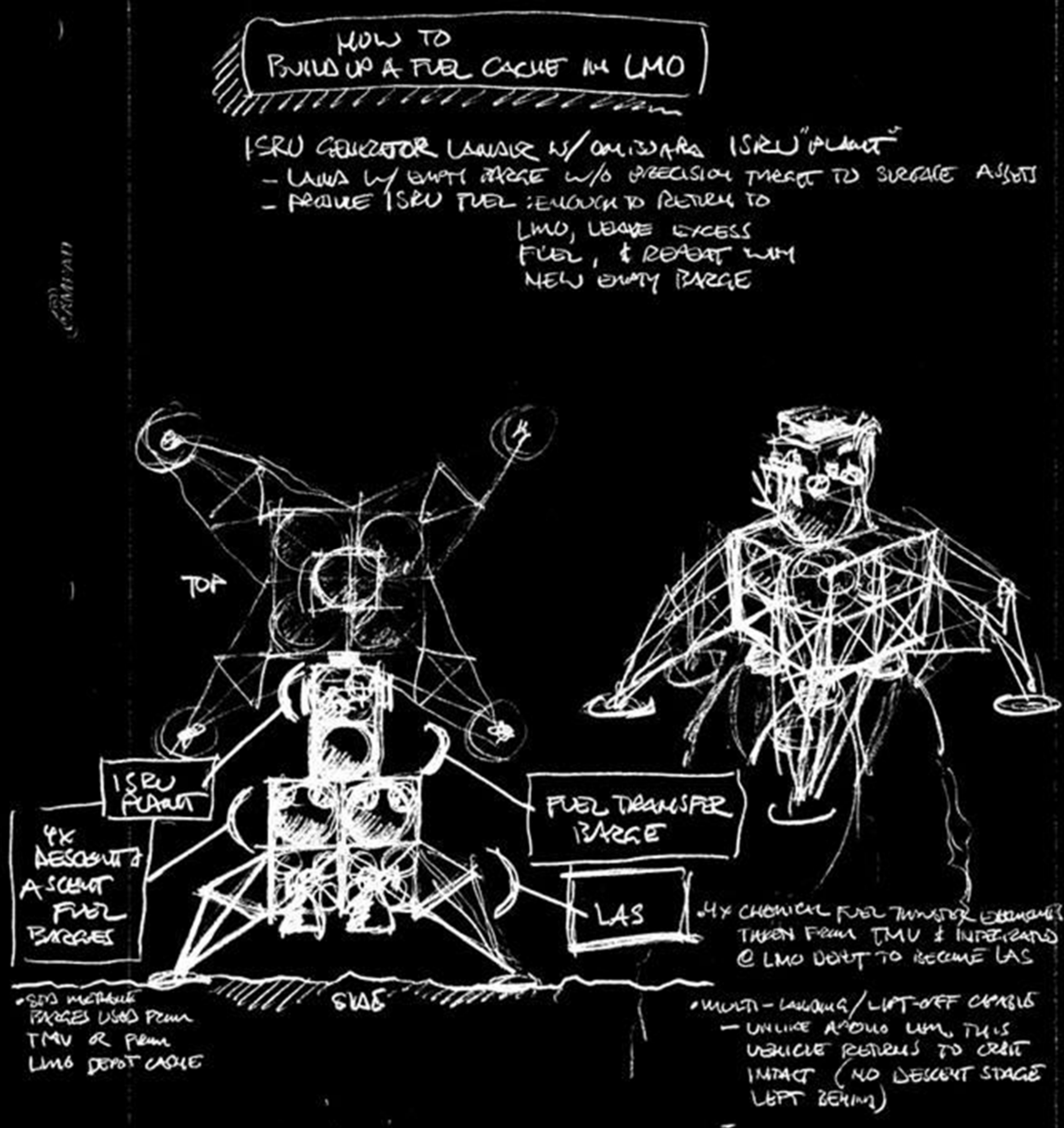
Avoids sending reentry –related mass all the way to Mars and back

Completes Habitaxi life-cycle

Provides accommodations for recoverable Mars artifacts

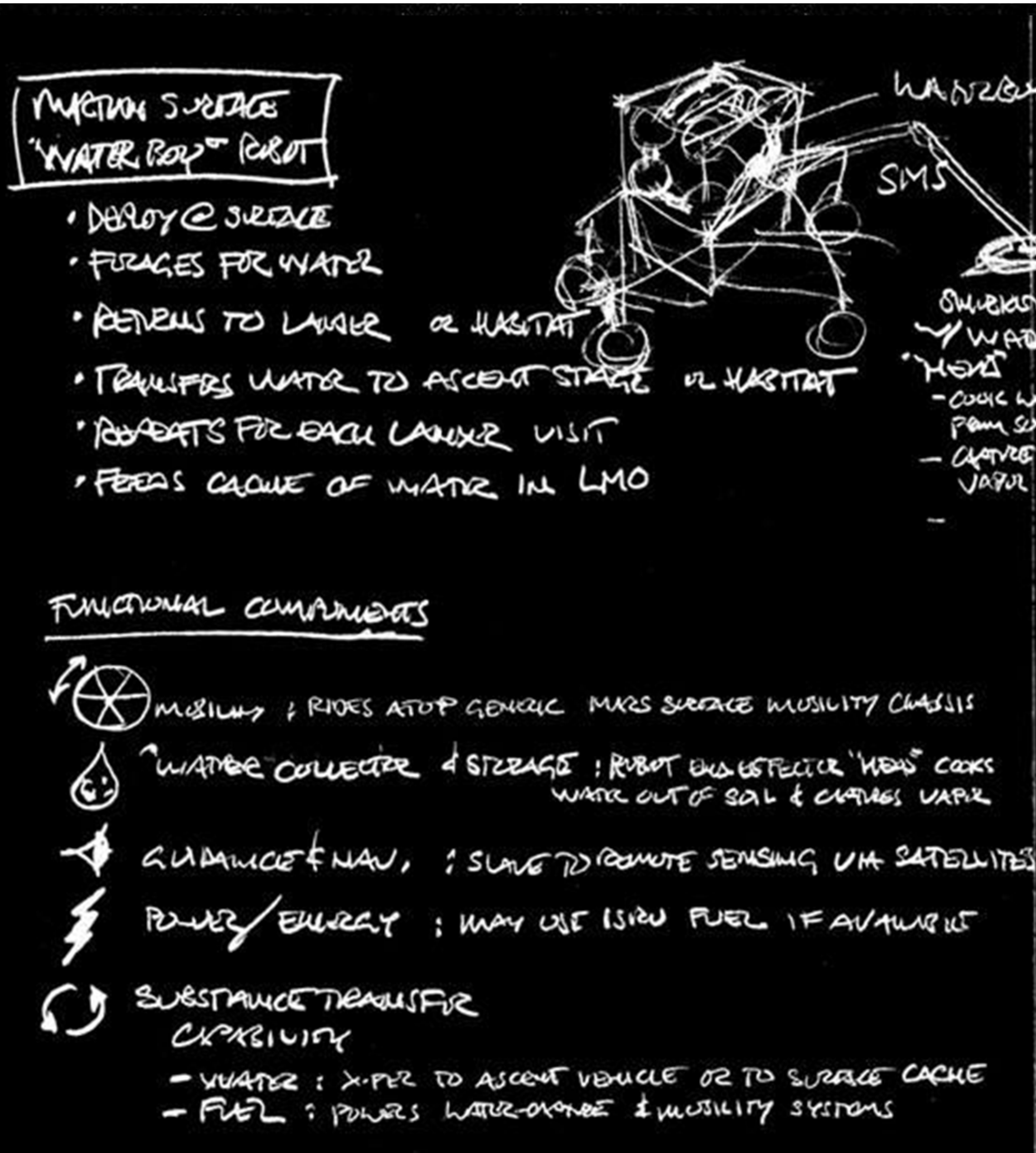
Becomes historical artifact of the mission

Initial round-trip validates entire lifecycle and returns Mars artifacts to Earth



Fuel Ferry:

- Assembled in LMO from elements of a TMV integrated with a Mars ISRU Fuel Plant
- Descends to Mars surface
- Generates methane and/or Argon from atmosphere
- Delivers fuel to surface-based cache or to cache at LMO Depot
- Capable of executing multiple transits between LMO and Mars surface
- LAS chassis is scalable and repurposable
-



"Waterboy":

- Delivered to Mars surface via LAS
- Integrates onto Mars Surface Mobility System chassis
- Roves to locate water concentrations
- "Cooks" water out of the soil
- Captures resulting vapor
- Fills reservoir
- Transfers water to surface assets of delivers to LMO Depot
- Runs on ISRU Fuel

LMO Command & Control Concepts

Kristine Ferrone & Loi Nguyen

Final Presentation

May 12, 2010

Overview

- Thought Experiment
  - Role Comparison
  - Organization Chart
  - Operational Definitions
- Design Concepts
- 3D Examples
- Conclusion

Thought Experiment

- *Objective:* Use Innovation Tools to define the functions of a command and control (C&C) module for Mars vicinity mission
- *Tools*
  - Role Comparison
  - Organizational Chart
  - Operational Definitions

Remote vs. Local Control

- Remote Control
  - Current Mission Control Centers do the majority of commanding to ISS systems to reserve crew time for maintenance and science activities
- Local Control
  - Paradigm shift for Martian missions due to comm delay between the two planets. Crew will become more autonomous and therefore will be responsible for nominal commanding for systems

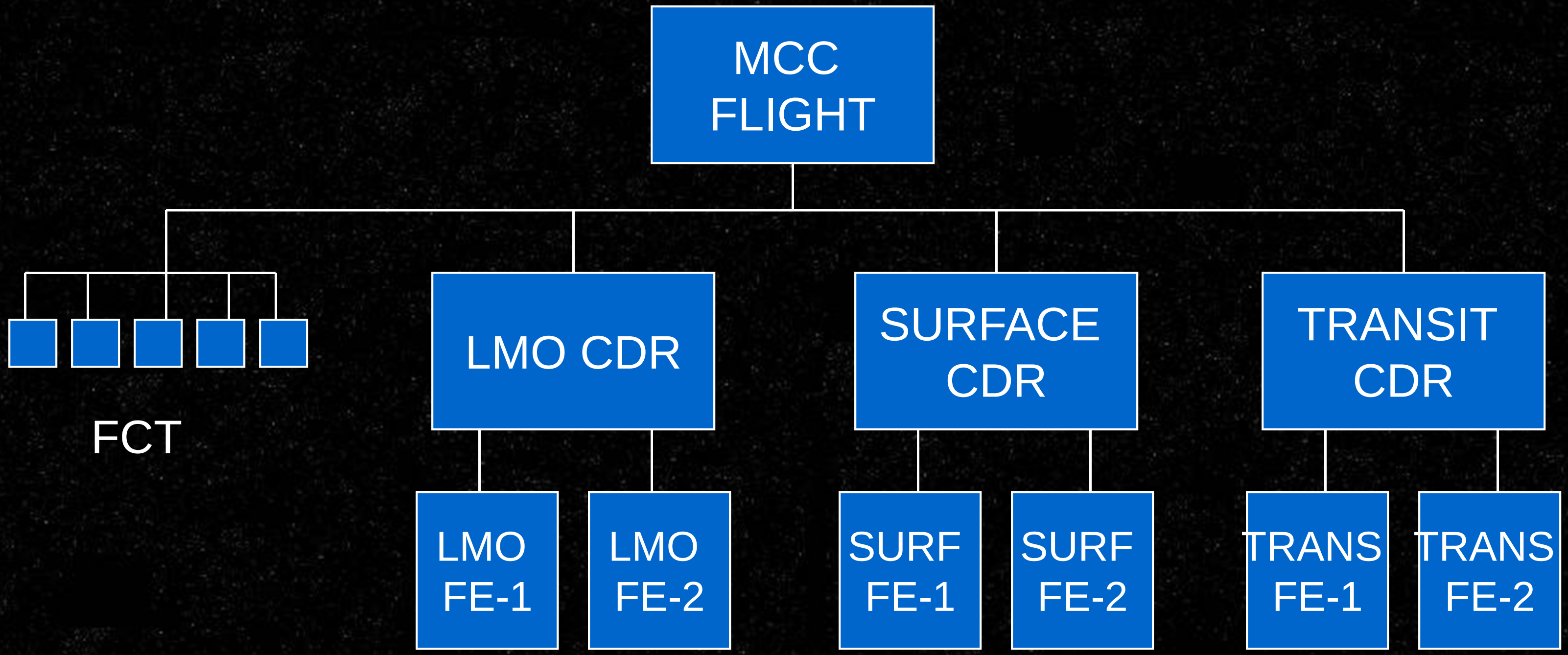
Remote vs. Local Control

- Remote Control
  - Flight Control Team of system experts spending an entire shift monitoring & commanding to a small subset of the station
  - Unified under Flight Director direction
  - DVIS voice loops for inter-system communication
  - Each console has multiple system-specific displays
  - Big command board, clocks, map of station trajectory for whole team to monitor/view
  - Each position also leverages 'back room' support

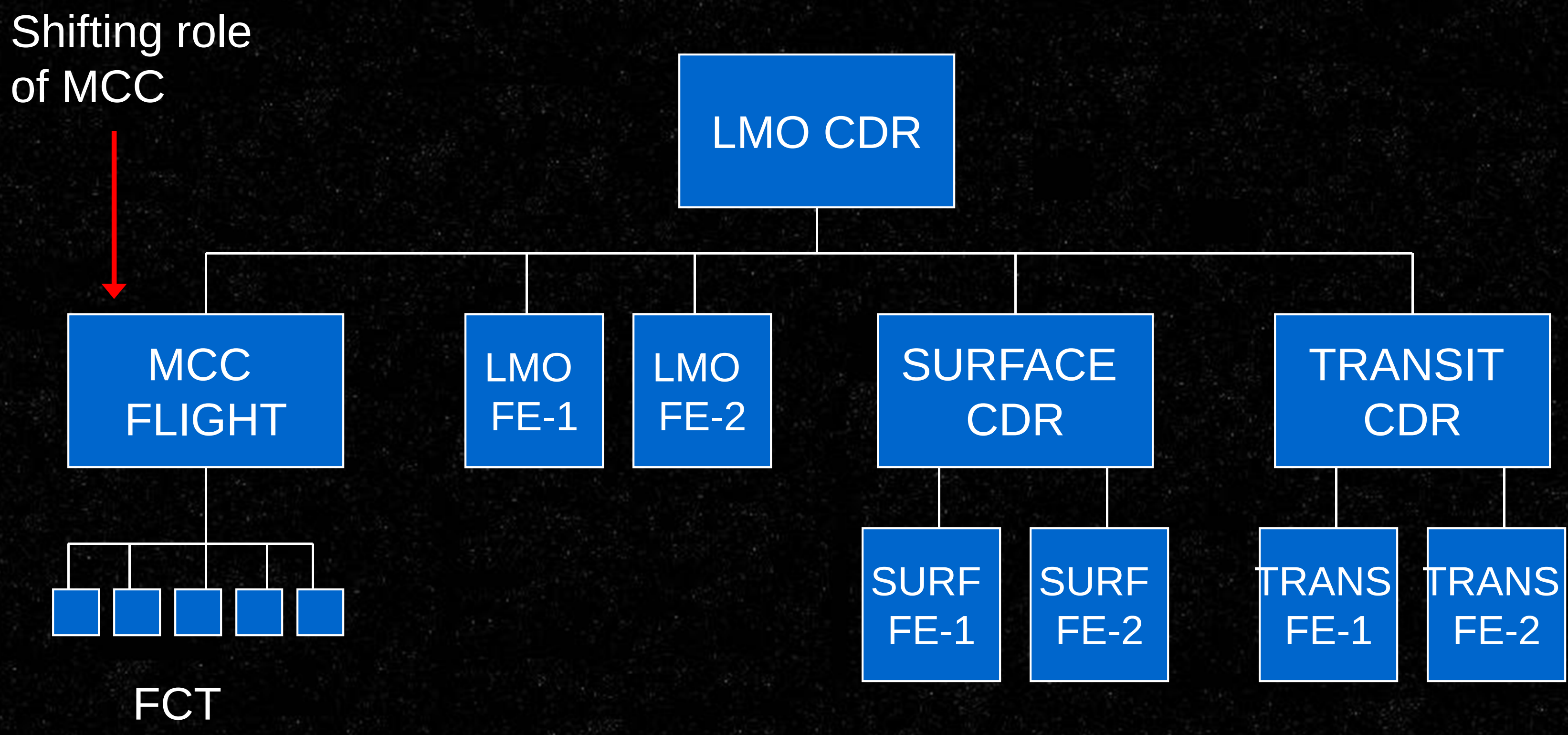
Remote vs. Local Control

- Local Control
  - Team of jack-of-all-trades astronauts with breadth but not necessarily depth systems knowledge
  - Unified under Commander direction
  - PDA/Intercom communication
  - Each console has overview displays
  - Big boards for better situational awareness??
  - MCC is the back room support

Remote Control Organization Chart



Local Control Organization Chart



Operational Definitions

- Define “CONTROL” in this context -
  - *Power Systems*
    - array position, telemetry analysis, commanding, load shed & distribution of power
  - *Thermal Systems*
    - array position, telemetry analysis, commanding, beta angle, thermal effects to transfer vehicle, EVA, experiments, etc.
  - *Communication Systems*
    - antenna position, telemetry analysis, commanding, AOS/LOS status with Earth & surface teams, file transfer, audio/video, satellite status and positioning
  - *Attitude/Trajectory*
    - station orientation/position, docking & undocking maneuvers, reboost
  - *Life Support Systems*
    - Status of atmosphere, consumables, temperature control, C&W and response
  - *Housekeeping*
    - Planning, task distribution, food, clothing, exercise, sleeping arrangements
  - *Radiation*
    - Autonomous solar flare warning and response due to comm delay with Earth
  - *Payloads*
    - Health & status of racks and payload experiments, science data transmission, reports
  - *LAN & Electronics*
    - Control services, routers, network, laptops, PDAs, etc.

Operational Definitions

- Define “OPERATOR” in this context –
  - 3 person crew in LMO – 1 Physician, 1 Engineer, 1 Scientist or Pilot (?)
  - Highly intelligent and skilled astronauts with breadth of knowledge and training on all systems
  - Autonomous in near term
    - Can receive expert advice in ~40 min, but at minimum will need to safe systems in an anomaly situation
  - Highly vested in performance/repair of vehicle since no lifeboat exists

Design Concepts

- Isolated Module
  - Provide adequate focus
  - Reduce noise level
  - Reduce crowd and distractions
  - Reduce the risk of bumps or damage to the critical equipment in microgravity
  - Partition out every day activities (sleep, meals, etc.)

Design Concepts

- Cylindrical Shape
  - Large volume to surface area ratio to accommodate most crew members
  - Payload shroud considerations for launch
  - Allow for optimal payload racks and screen configuration

Design Concepts

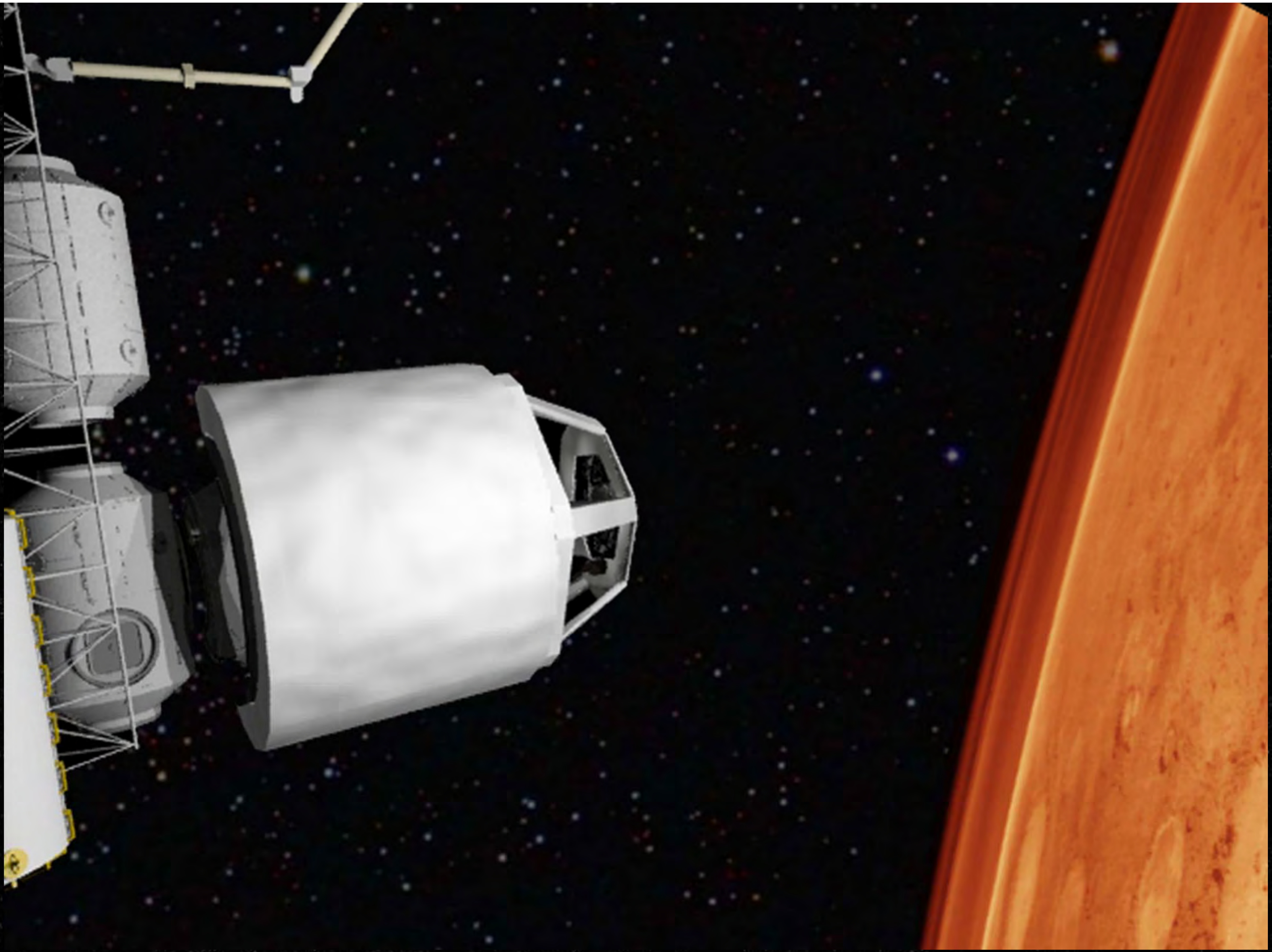
- Cupola Windows
  - Allow for additional views for robotic operations and local environment
  - Allow planetary viewing if module on nadir side of station
  - Enhance crew morale and situational awareness

Design Concepts

- Technological Considerations
  - Large screen with touch controls occupies most of one side of the module
    - Systems status can be configured and customized according to individual crew member, situation, etc.
    - Large size displays data for multiple systems simultaneously, enhancing SA
  - Commanding via PDAs

Design Concepts

- Working Area
  - Retractable table deployed via jointed arm attached to one side of module
  - Translation and rotation of table controlled by operator at table via joystick type controller
  - Provides ease of movement throughout the module in microgravity
  - Table stows against one wall when not in use
  - PDAs or laptops can be deployed on the surface



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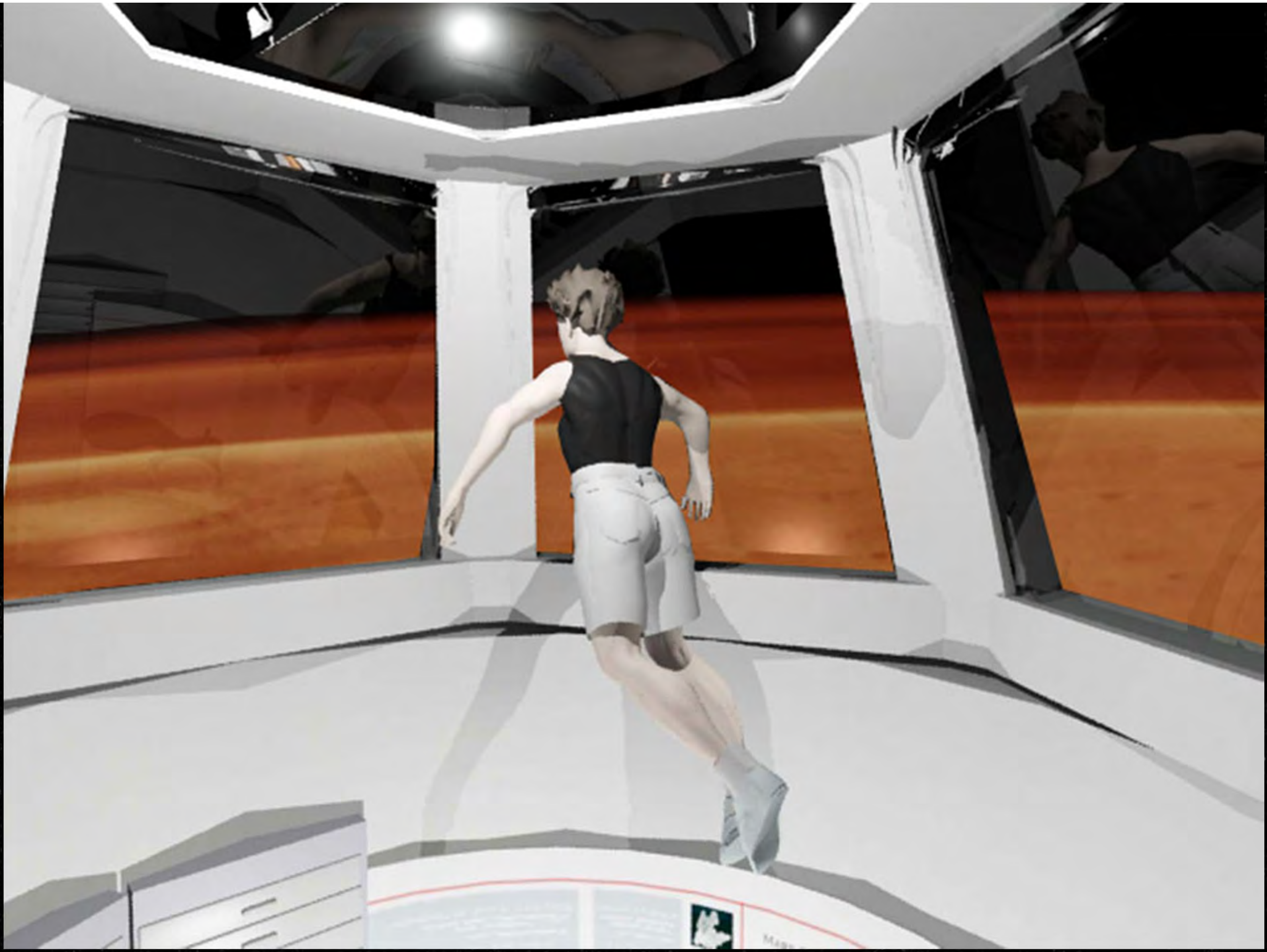

SICSA

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Conclusion

- Thought Experiment
  - Role Comparison
  - Organization Chart
  - Operational Definitions
- Design Concepts
  - Isolated Module
  - Spherical Shape
  - Cupola-Style Windows
  - Technological Considerations
  - Working Area
- 3D Examples

International Launch Vehicle Selection for Interplanetary Travel

Loi Nguyen & Kristine Ferrone
University of Houston
AIAA Region IV Student Conference
NASA Johnson Space Center
April 2, 2010

Overview

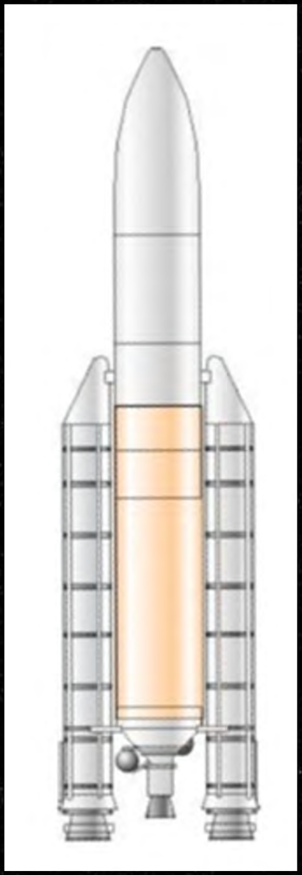
- Discuss Current Launch Vehicles
- Discuss Future Launch Vehicles
- Discuss Launch Vehicle Selections for:
  - Crew Launch
  - Payload Launch
  - Propellant Launch
- Conclusion

Current Launch Vehicles

- ARIANE 5
- DELTA IV HEAVY
- H-II
- PROTON-M
- SOYUZ FG/ST
- ZENIT 3SL

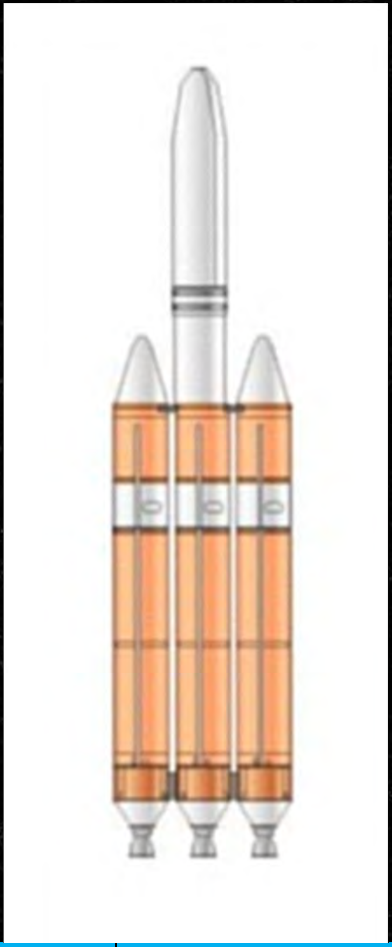
ARIANE 5

- Payload to LEO:
  - 21,000 kg at 51.6 deg inclination
- Launch Site:
  - Kourou, French Guiana (5º10’N / 52º40’W)
- Status:
  - Operational since 1996
  - Success: 21/22
- Dimensions:
  - Height: 53 m
  - Fairing: Length = 17 m, Diameter = 7.4 m



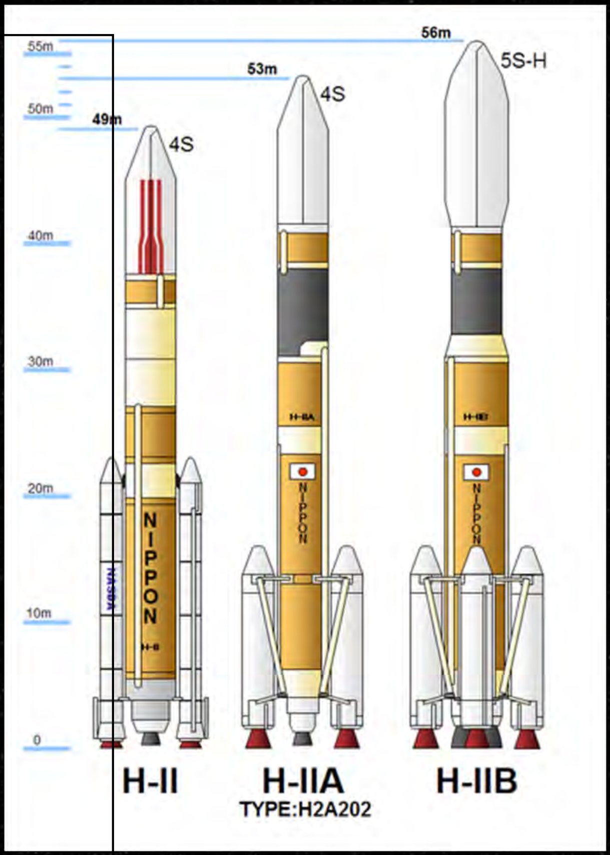
DELTA IV HEAVY

- Payload to LEO:
  - 25,800 kg at 28.5 deg inclination
- Launch Site:
  - Vandenberg AFB (34º36'N / 120º36'W)
  - Cape Canaveral (28º30'N / 80º33'W)
- Status:
  - Operational since 2004
  - Success: 2/3
- Dimensions:
  - Height: 70.7 m
  - Fairing: Length = 19.8 m, Diameter = 5 m



H-II

- Payload to LEO:
  - 19,000 kg at 51.6 deg inclination
- Launch Site:
  - Tanegashima, Japan (30º23'N, 130º58'W)
- Status:
  - Operational since 2001
  - Success: 15 of 16
- Dimension:
  - Height: 56 m
  - Fairing: Length = 15m, Diameter = 5.1m



PROTON-M

- Payload to LEO:
  - 22,000 kg at 51.6 deg inclination
- Launch Site:
  - Baikonur, Kazakhstan (45^{o}54’N / 63^{o}18’W)
- Status:
  - Operational since 2001
  - Success: 18/20
- Dimension:
  - Height: 53 m
  - Fairing: Length = 15.25 m Diameter = 5 m

SOYUZ-FG/ST

- Payload to LEO:
  - 7800 kg at 51.6 deg inclination
- Launch Site:
  - Baikonur, Kazakhstan (45º54’N / 63º18’W)
  - Kourou, French Guiana (5º10’N / 52º40’W)
- Status:
  - Operational since 2001
  - Success: 18 of 18
- Dimension:
  - Height: 50m

ZENIT 3SL

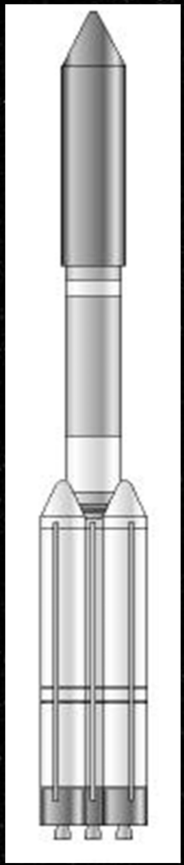
- Payload to LEO:
  - 5,000 kg at 51.6 deg inclination
- Launch Site:
  - Baikonur, Kazakhstan (45º54’N / 63º18’W)
  - Sea Launch Facility (0 to 70 deg)
- Status:
  - Operational since 1999
  - Success: 28 of 30
- Dimension:
  - Height : 59.6 m
  - Fairing: Length = 11.4 m, Diameter = 4.15 m

Future Launch Vehicles

- ANGARA A5
- FALCON 9 HEAVY
- GSLV MARK III
- LONG MARCH (CZ-NGLV)
- TAURUS 2

ANGARA A5

- Payload to LEO:
  - 24,500 kg at 63 deg inclination
- Launch Site:
  - Vostochny, Russia (51º21’N/128º8’E)
- Status:
  - In development
  - Scheduled to begin operations in 2011
- Dimension:
  - Height: 54.5 m



FALCON 9 HEAVY

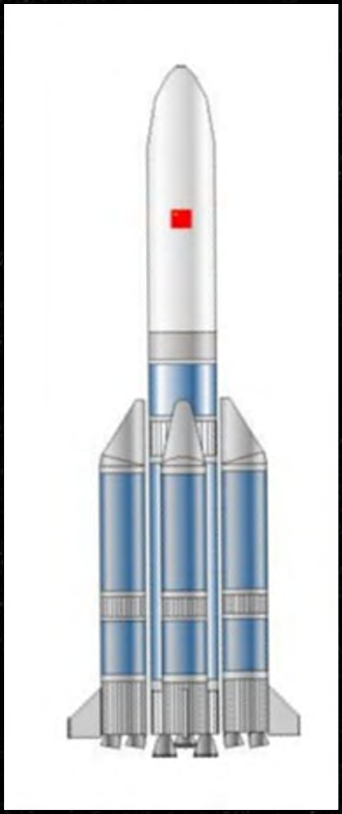
- Payload to LEO:
  - 32,000 kg at 28.5 deg inclination
- Launch Site:
  - Cape Canaveral (28º30'N / 80º33'W)
- Status:
  - In development
- Dimension:
  - Height: 54.9 m

GSLV MARK III

- Payload to GEO:
  - 5,000 kg at deg inclination
- Launch Site:
  - Sriharikota Island, India (13º43’N / 80º13’E)
- Status:
  - In Development
- Dimension:
  - Height: 42.4 m

LONG MARCH 5 (CZ-NGLV)

- Payload to LEO:
  - 25,000 kg at 52 deg
- Launch Site:
  - Hainan Island, China (19º37’N / 110º44’E)
- Status:
  - In Development
  - Scheduled to begin operations in 2014
- Dimension:
  - Height: 55 m



TAURUS 2

- Payload to LEO:
  - 5,500 kg at 52 deg inclination
- Launch Site:
  - Wallops Island, Virginia (37º56’N / 75º27’E)
- Status:
  - In Development
  - Scheduled to begin operations in 2011
- Dimension:
  - Height: 40 m

Launch Vehicle Selection

- Crew Launch
- Payload Launch
- Propellant Launch

Crew Launch

- Only crew launch vehicle in the foreseeable future: Soyuz
- Only rocket capable of launching Soyuz: Soyuz FG/ST
- Keep option for future vehicles as they become operational and reliable

Payload Launch

- After filtering vehicles on issues of cost, effectiveness, readiness, and reliability the options are:
  - Proton M, Ariane 5, Zenit 3SL, and H-II.
  - Makes the most sense to use ALL of these vehicles in some capacity.
  - Rationale: Distribution of cost, risk, and participation over many countries' governments and private industries. Each participating country can contribute as many or as few launches as they can afford in their area of expertise.
- Keep option for future vehicles as they become operational and reliable

Propellant Launch

- Large Fuel Tanks: Any of the payload launch vehicles (Proton M, Ariane 5, Zenit 3SL, and H-II)
- Re-Fueling: Progress, ATV, or HTV vehicles (launching on Soyuz, H-II or Ariane 5)
- Keep option for future vehicles as they become operational and reliable

Conclusion

- Discuss Current Launch Vehicles
- Discuss Future Launch Vehicles
- Discuss Launch Vehicle Selections for:
  - Crew Launch
  - Payload Launch
  - Propellant Launch
- Final Notes on Launch Strategy

Acronyms

- TMV – Trans-Mars Vehicle
- TEV – Trans-Earth Vehicle
- OMV – Orbital Maneuvering Vehicle
- ISRU – In-Situ Resource Utilization
- LEO – Low Earth Orbit
- LMO – Low Mars Orbit
- VASIMR – Variable Specific Impulse Magnetoplasma Rocket

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