OASIS

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Operations And Service Infrastructure for Space

Executive Summary

Space Studies Program 2012

International Space University | Florida Institute of Technology | Kennedy Space Center

OASIS

Operations And Service Infrastructure for Space

Executive Summary

25th Anniversary
INTERNATIONAL SPACE UNIVERSITY
ISU

The SSP 2012 Program of the International Space University was convened at Florida Institute of Technology, Melbourne, Florida, USA in collaboration with National Aeronautics and Space Administration, Kennedy Space Center.

This Executive Summary and the Final Report are the results of the Spaceports Team Project undertaken by 34 participants from 19 different countries over approximately 6 weeks.

The OASIS logo represents the launch between spaceport nodes through space; the logo was inspired by the skipping of stones across a body of water.
Design work courtesy of the OASIS Graphics Team.

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OASIS

*"Once you get to earth orbit,
you're halfway to anywhere in the solar system."*

~Robert A. Heinlein

Vision

Humans are explorers by nature, striving to reach new heights and expanding horizons. The need for adventure pushes us to break our assumed limits and reach higher than ever before. In the age of technology, it is time to break the chains of Mother Earth and build a new home throughout the Universe.

The ultimate goal is not limited to the Moon, an asteroid, or Mars; these are waypoints in the venture of humans. Advancement occurs by creating stepping stones between existing civilizations and new frontiers. Spaceports are not limited to terrestrial applications anymore. Orbital and planetary surface spaceport nodes at strategic locations are the answer to making space more accessible and affordable.

The OASIS team provides the international, intercultural, and interdisciplinary solution of an ever-growing, evolving multi-purpose logistics network of spaceports. This network will provide necessary mission services to enable human and robotic expansion into the hostile space environment within 50 years. In situ resources will be utilized to create propellant, materials and solar energy.

A phased approach allows smaller steps to effectively build a successful pathway to the never before explored corners of space. The first node of the network, located in Low Earth Orbit (LEO), is a stopover safe haven with propellant for refueling, primary subsystem services, and an intermediate launch and staging location. As a building block for inexpensive travel beyond LEO, each subsequent node, whether Moon or Mars based, has unique resources and services, while also providing an additional step to further the reach of future missions.

Mission Statement

"Develop a ***progressive network of spaceports*** using the most ***cost-effective resources*** to enable space ***exploration and commercial activities***, and ultimately to ***extend humanity*** throughout the solar system."

The Market

Potential services provided by the spaceport network are based on current and future market trends. In the short term, there is an evident market of over 20 commercial GEO satellites launched per year. The potential services are phased in time in three periods:
Short *(2015-2025)*, Medium *(2025-2045)*, and Long *(2045 – onwards)*.

Tugging satellites from LEO to GEO

A tug service from low orbits to GEO is similar to the way a tugboat is designed to move ships across a bay. A reusable tug unit provides commercial satellites with an efficient means of transport from low orbits to GEO.

On Orbit Refueling at LEO

This service offers interplanetary and/or exploratory missions, whether corporate, agency, or tourism, the ability to send a larger mass to their respective destinations.

Additional Capabilities

The tug is able to perform additional tasks to meet the customers' future needs: repair, geostationary orbit slot change, deorbit, salvage, and storage capabilities.

Future Markets

Human exploration of Moon/Mars, Cis-lunar services, tourism, and space-based solar power infrastructure deployment

Benefits

	Without a Spaceport Network	With a Spaceport Network	Cost Reduction for the Customer
Performance to GTO	4.85t	9t	
Price per Kg to GTO (Falcon 9)	$11,134	$10,963	2%
Price per Kg to GTO (Ariane)	$15,789	$10,963	44%
Payload to Mars	1t	10t	

Business Case

The core service and value enabled by the first spaceport node in LEO is a tug service for GEO satellites from LEO to GEO. By providing a service to tug satellites from LEO to GEO, including eventual orbit inclination change, the client is able to use a smaller and cheaper launch vehicle because it does not need to carry the extra propellant to reach GEO by itself. The reusability of the tug allows for a compounded cost savings in meaningful mass to GEO orbit.

Existing GEO launchers charge the full price of the launcher to the GEO satellite operator regardless of the actual mass launched. The price per kilogram for a 4.85 metric ton satellite to GEO is 11,134 U.S. dollars, totaling approximately 54 million dollars. On the other hand, if the GEO satellite is only 4 tons, the price per kilogram increases 21% to 13,500 U.S. dollars.

To offer a competitive price per kilogram for its customers, Ariane maximizes the mass used per launch by offering a dual launch to GTO with a maximum mass of 9.5 tons. Unfortunately, the number of GEO satellites launched per year is limited to about 20 satellites. As a result, finding two GEO satellites with similar mass fitting into the Ariane fairing remains a challenge for Arianespace.

The tug service offered by the LEO node of our network solves those limitations. It launches single or dual GEO satellites in LEO and fills the remaining space/mass in the launcher with either LEO satellite(s) or water to refill the depot in LEO. This ensures a minimum launching cost per kilogram from Earth to LEO for any selected launcher. As a result, the spaceport network will be able to offer lower launching cost to GEO satellite operators and even to LEO satellites that also cannot always use the maximum mass offered by the selected launcher. In addition, the spaceport network using LEO satellites or water to fill the remaining space/ mass on the LEO launcher ensure that the GEO satellite does not have to wait for another GEO satellite to be launched with.

Largest payload mass to GEO (9t)
- Eliminates need to launch upper stage
- Orbital circulization by tug instead of satellite bus

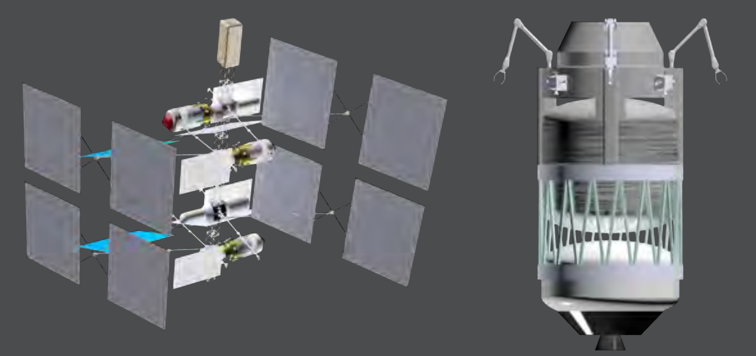
Cost/mass savings
- Two 4.5t satellites for the current price of one

Reduction of the cost of propellant and less hazardous ground processing operations
- Utilizes water as propellant for upper stage rather than hypergolic or solid fuels

Flexible architecture to support all missions
- Support scientific exploration and commercial missions as well as contingency and repair operations

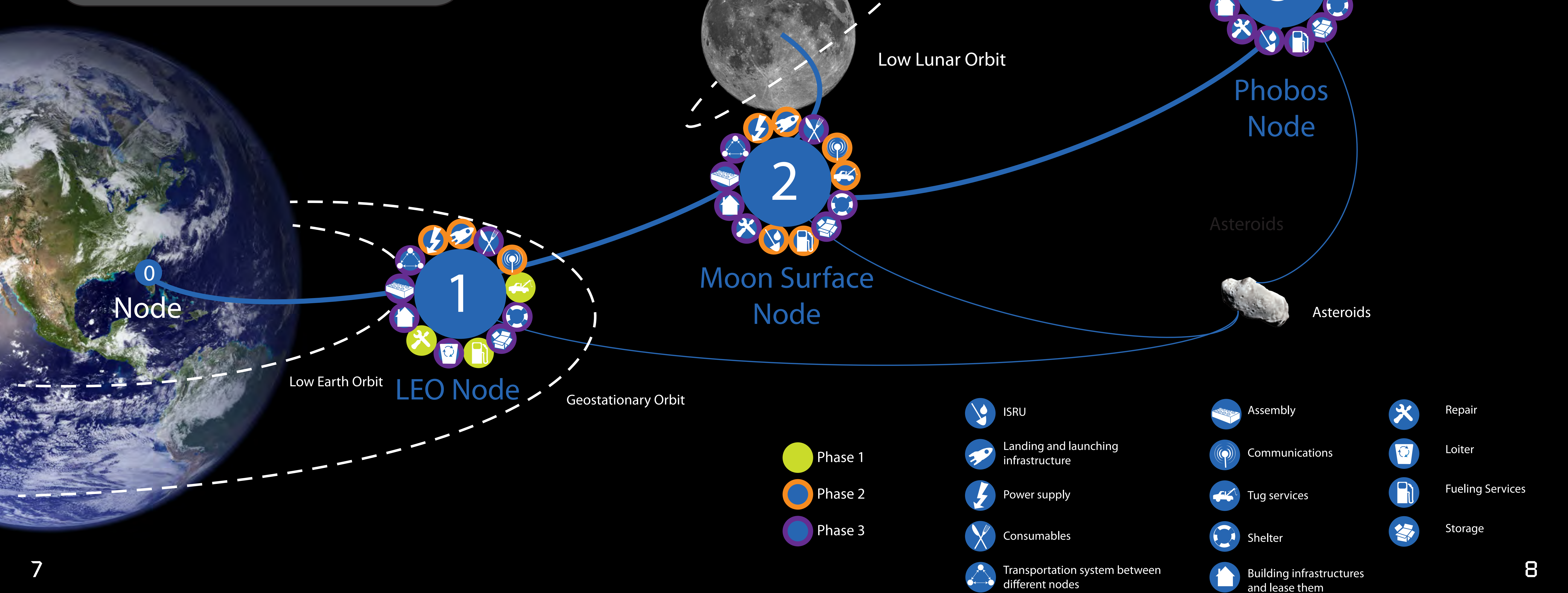
Profitable business case
- Supports a wide customer base of public and private space operators

Network Of Spaceports



A **Spaceport** is an infrastructure waypoint providing services for space vehicles and facilitating departure and arrival.

A **Tug** is a reusable unmanned teleoperated spacecraft able to transport satellites from LEO to GEO and perform servicing tasks with its robotic arms.

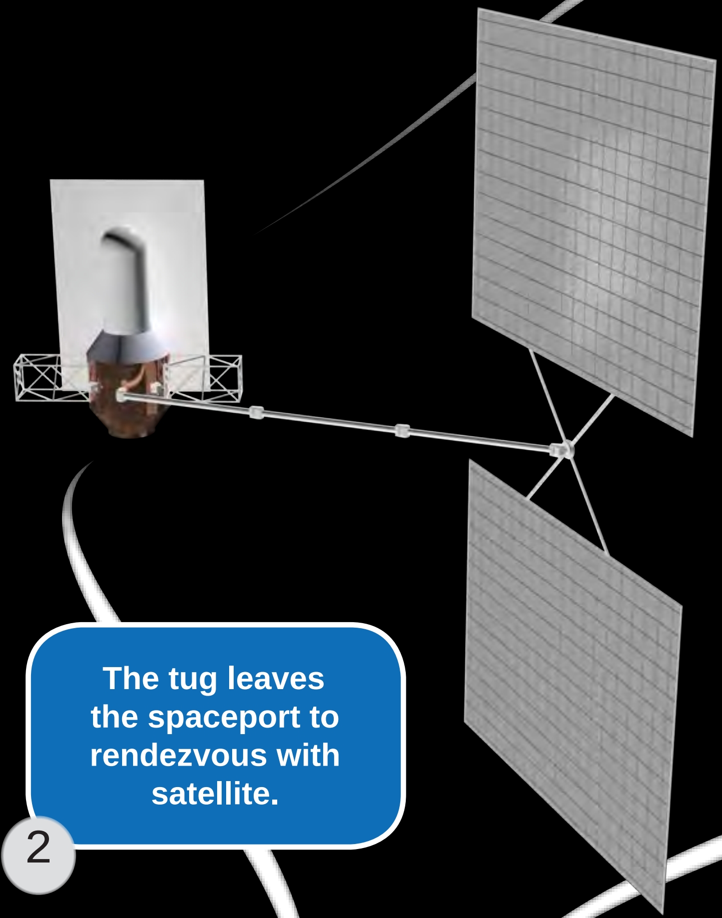


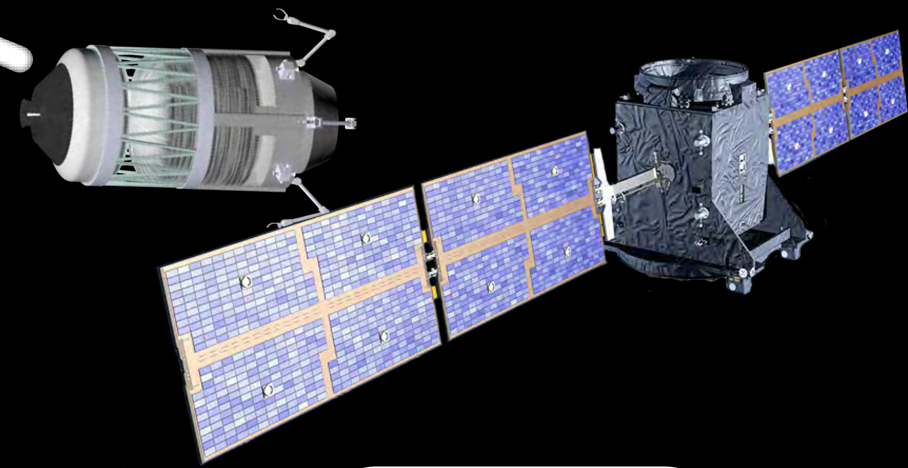
Phase 1: 2015-2025

Node 1 of the spaceport network is located in Low Earth Orbit (LEO). As most of a rocket's mass at launch is propellant, a spaceport in LEO with refueling capability would support any kind of missions from the Earth into the solar system.

The LEO location allows the creation of a new range of on-orbit services, contribution to commercialization of space, and enables a foundation for further development of the network.

The spaceport allows satellites to be tugged from LEO to GEO, consequently reducing their launch costs and on-orbit refueling for interplanetary or exploratory missions.





1 A launch vehicle from Earth delivers the client's satellite to LEO.

2 The tug leaves the spaceport to rendezvous with satellite.

3 The tug docks with the satellite and transfers it to GEO.

4 The tug releases the satellite in the appropriate orbit.

5 The tug returns to the spaceport in LEO and docks for refueling.

"... allows satellites to be tugged from LEO to GEO...reducing their launch cost..."

The spaceport at Node 1 supports primary services such as power generation, station keeping, communication, navigation, and docking services to other elements. Standard interfaces, like an international docking adapter, will allow different spacecrafts to dock. Additionally, the spaceport has modular components to increase its capabilities.

In phase 1, the spaceport is refilled with water from Earth. Cryogenic propellant is produced from the water on-demand via electrolysis and transferred to the the tug tanks.

Phase 1 Critical Technologies

In-Space Propulsion Technologies
Low boil off cryogenic propellant tanks
On orbit refueling
Reusable cryogenic rocket engines

Space Power & Energies
300kW solar power systems

Robotics, Tele-Robotics and Autonomous Systems
Radiation tolerant electronics
Autonomous rendezvous and docking

Human Exploration Destination Systems
Production of LH2 and LO2 in orbit

Entry, Descent and Landing
Flexible aero-braking thermal protection system

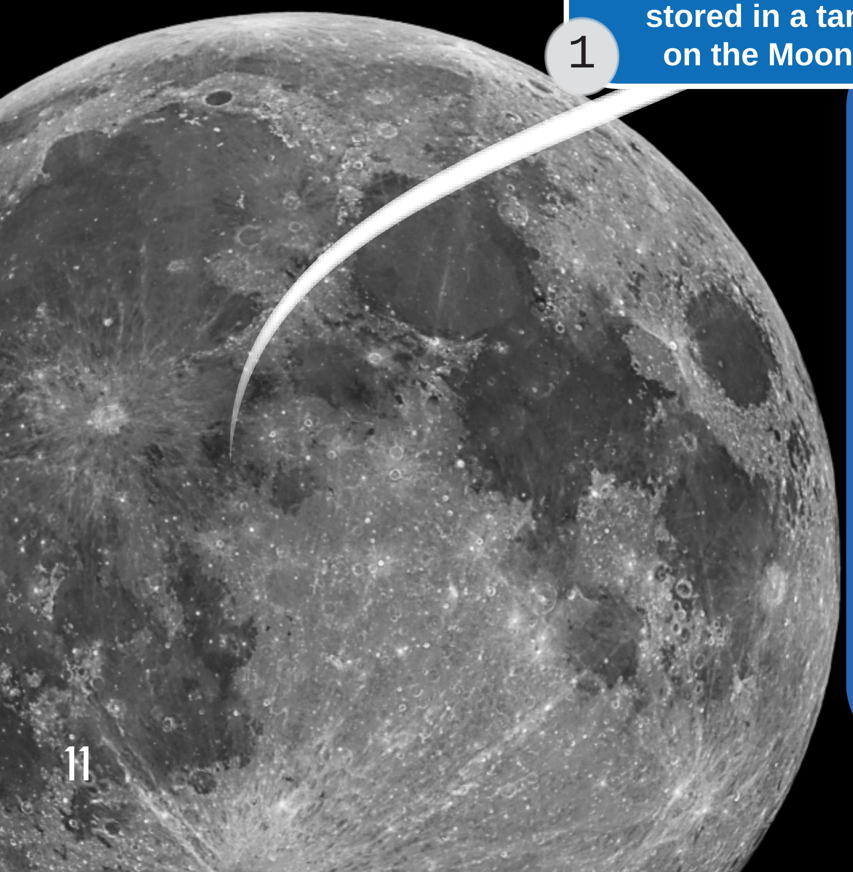
Phase 2: 2025-2045

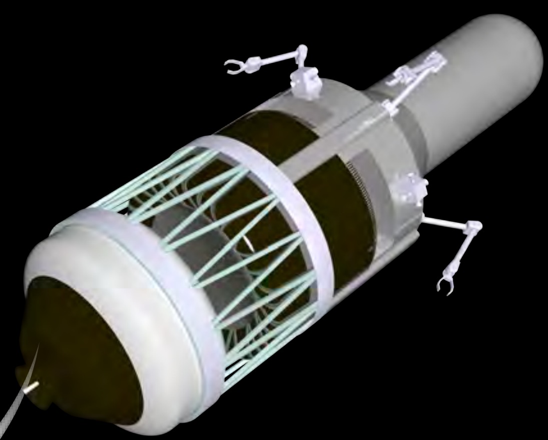
Node 2 is located on the surface of the Moon. The resources available enable the possibility of in situ production of propellants, solar panels and habitation modules.

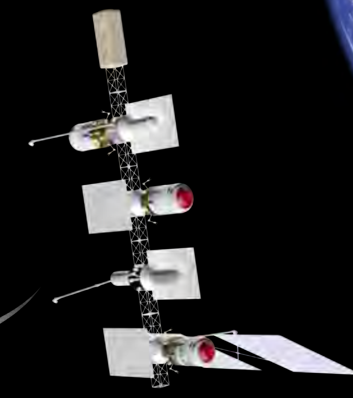
On the Moon's surface, a power generation and communications system will be setup first. Additional ISRU elements will be added later. An excavator will gather resources, and a processing unit will transform it into water. Small quantity of propellant will be generated for the Moon surface shuttle, which will be used to carry the water tank into orbit.

Another part of the Moon surface infrastructure will be a spaceport Vertical Takeoff Vertical Landing (VTVL) pad that will enable spacecraft to launch and land safely and accurately through the use of navigation beacons.

In the long term, consumables for life support systems (Oxygen, fresh water and food) will be provided for a human presence.







1 Water is extracted from Lunar regolith and stored in a tank on the Moon.

2 The moon surface shuttle carries the water tank to low lunar orbit and rendezvous with the tug.

3 The tug swaps an empty water tank from low earth orbit with the full water tank from the Moon.

4 The tug transports the water tank to the spaceport in LEO.

5 The Moon surface shuttle returns to the moon with an empty water tank.

Phase 2 Critical Technologies

In-Space Propulsion Technologies
Stoichiometric radio (8:1) engines

Robotics, Tele-Robotics, & Autonomous Systems
Tele-operated robotics for lunar base operations

Communication & Navigation
High bandwidth communication (e.g. optical)

Human Exploration Destination Systems
Ultra-cold lunar ice excavator
Regolith processing facilities

Entry, Descent & Landing Systems
Reusable lunar lander

"...resources available enable the possibility of in situ production of propellants..."

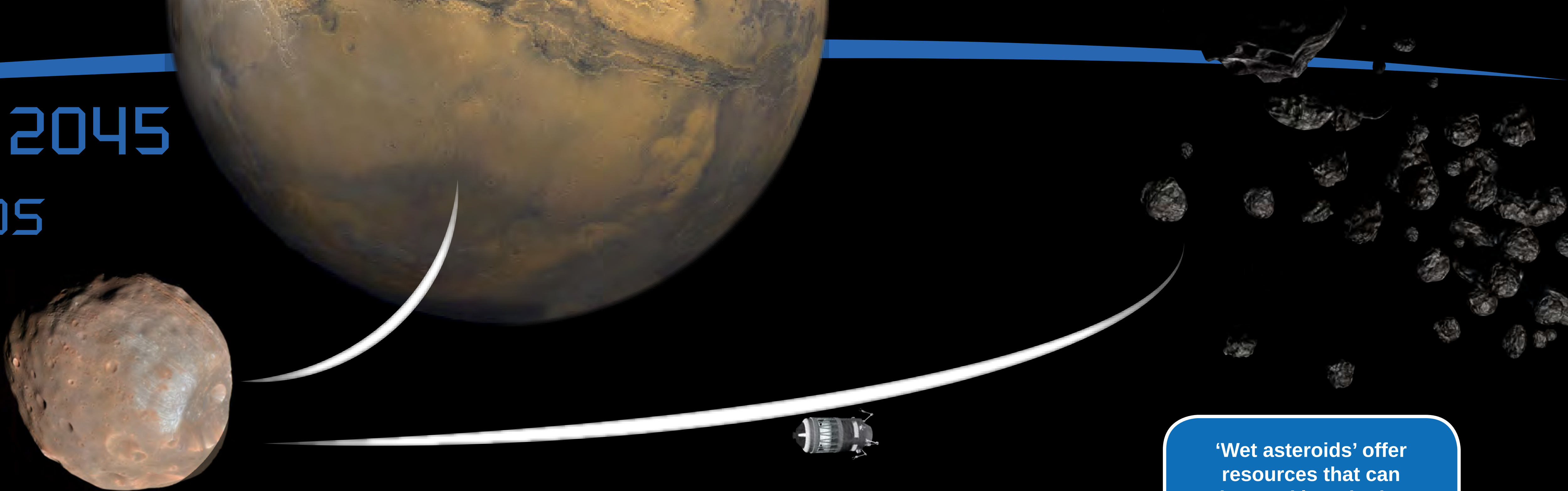
In phase 2, the LEO spaceport is refilled with in situ resources from the moon. Water is excavated from lunar regolith. Some of it is used to produce cryogenic propellant to operate the moon surface shuttle and refill the tug. The rest is stored in a tank on site.

The moon surface shuttle brings it to low lunar orbit where it rendezvous with the tug and swap its full water tank with an empty tank brought by the tug from LEO. It then refuels the tug with cryogenic propellant produced on the moon. The tug flies back to the spaceport in LEO. The moon surface shuttle goes back to the moon surface.

Phase 3: 2045 - Onwards

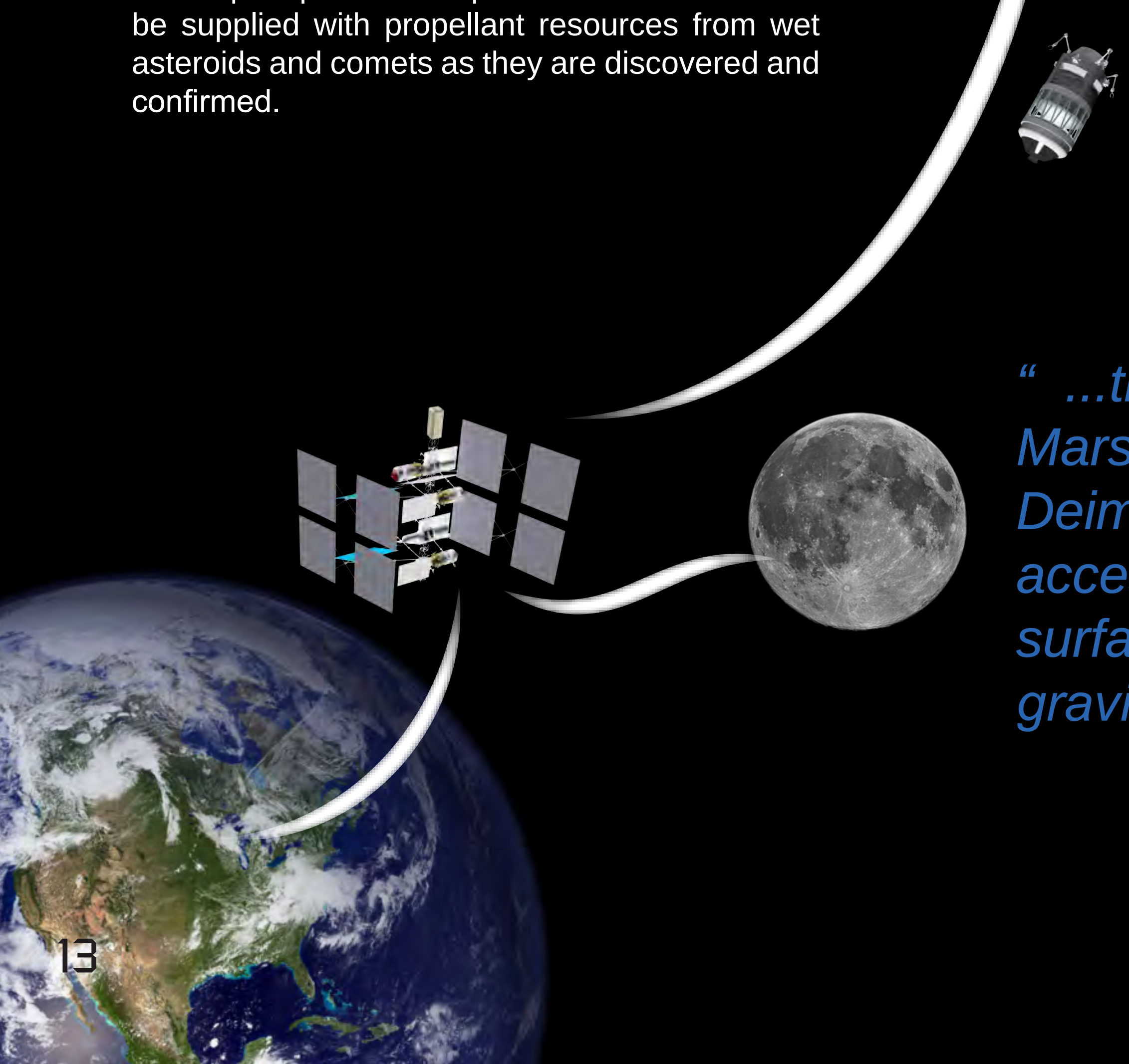
Node 3 is Mars' moon Phobos. The two Moons of Mars, Phobos and Deimos, allow easy access to the Mars surface due to their low gravity field. This provides an advantage when compared to going directly to Mars surface. Even though the presence of resources on Phobos is still not fully proven, the small delta-v that is required to reach locations where the confidence in finding useful resources for propellant is high, makes Phobos a very attractive location for the third node of the network.

A base on Phobos will be similar to a base on the Moon with operational support, possible propellant generation, propellant storage infrastructure and a port for transportation of resources and people from and to Earth and other spaceports. The operations on Phobos will be supplied with propellant resources from wet asteroids and comets as they are discovered and confirmed.



Mars moon, Phobos, could offer ISRU options for increased payload mass to Mars surface.

'Wet asteroids' offer resources that can be used later in the network to facilitate access further into the solar system.



" ...the two Moons of Mars, Phobos and Deimos, allow easy access to the Mars surface due to their low gravity field...."

Legal Considerations

Creation of a new international governmental authority to contract construction and regulate spaceport network

Transnational private corporation contracted to build and operate spaceport network

Compliance with the debris mitigation guidelines of both Inter-Agency Space Debris Cooperation Committee (IADC) and UNCOPUOS to avoid the creation of new space debris

Establishment of new legal frame work with regards to use of in situ resources

Principle of non-appropriation: distinguish the notion of "land appropriation" and "resource appropriation"

Since radio frequencies and orbits in GEO are strictly regulated, close cooperation with ITU is required

Conclusion

The proposed network of spaceports extends existing transportation and logistics infrastructure of Earth into space with the objective of reducing the overall cost of space exploration and creating a vibrant commercial space market. The primary nodes of the network consist of LEO, the Moon, and the Mars moon Phobos, corresponding to the short (2012-2025), medium (2025-2045), and long (2045 – onwards) term capabilities of the network.

In the short term, the first node of the spaceport network is to be established in LEO, addressing a mature, current market. As a result, the primary services provided in LEO consist of on-orbit refueling and a tug service from LEO to GEO. The tug service is the initial source of business, setting the framework for long term economic viability. Further enabling the market, the second node on the lunar surface will mine lunar regolith/water ice to extract and supply propellant to the LEO node. The second node is a stepping stone to traveling the solar system and development of the third spaceport node on Phobos. Compared to the direct route to Mars, the low gravitational field of Phobos (or any other moon of Mars) facilitates easy access to the Martian surface and further celestial objects such as wet-asteroids.

In order to ensure the feasibility of OASIS, international cooperation is kept as a major driver. For this reason, an international governing authority is established for the network of spaceports, named the International Spaceport Authority (ISPA). To carry out the development of OASIS, ISPA will contract a private, transnational company designated as the Spaceport Company (SPC) to manage and operate the network.

In conclusion, OASIS provides a compelling and viable plan for extending human presence throughout the Solar System with benefits to all of humanity.

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