Commercial Transportation Mission Overviews

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Someday commercial lunar transportation will exist. What would the commercial lunar transportation firm look like if it were available today or were to emerge in the future? It would start small and attempt to grow on revenues to minimize up-front costs. It would separate and focus on the 99% unmanned cargo rather than the 1% human cargo, understanding the difference in cost to satisfy the requirements of each type of mission. It would use the space adventure tourist as the sizzle of the steak they are selling. It would have expansion and evolutionary growth milestones that could be financed by private capital with incremental returns on investment. It would attempt to only meet 80\% of early government requirements rather than the 20\% that cost the most money to develop. It would offer incremental payload increase capability to minimize the up front cost. It would use a team approach with equity partners drawn from aerospace, finance, customer, industrial and international organizations. It would have a start-up team containing members with a history of developing previous successful space ventures plus on-loan participants from NASA, finance, international and commercial customer prospects. It would focus on unmanned, non-critical cargo from government customers and innovative cargo from entrepreneurs to realistically prove the reliability of the systems used before manned missions are attempted. It would attempt to generate interest from international, customer and finance to broaden its hardware cost options, increase its market base and enhance private financing avenues. It would have a commercial nuclear option well in mind and on the team, so it fits within the lunar transportation node system at the right time and is available for future destinations. It will have already determined that Helium3 is worth $6 billion/ton on earth to specific team customers and might impact global energy strategies including the need for oil. It will understand previous remote resource development locations on earth, like the North Slope oil and remote mining, to understand the economic drivers, like inbound tonnage to earth will eventually far exceed outbound tonnage. Such commercial companies exist today, but may not know it or realize the potential of the Moon, Mars and Beyond initiative. NASA can stimulate this emerging entrepreneurial sector with the potential of their Space Exploration Program.

\textbf{Nomenclature}

\begin{tabular}{ll}
ACS & = Attitude Control System \\
AR&D & = Automated Rendezvous and Docking \\
ATP & = Authorization to Proceed \\
ATV & = Automated Transfer Vehicle \\
CEV & = Crew Exploration Vehicle \\
EELV & = Evolved Expendable Launch Vehicle \\
ELV & = Expendable Launch Vehicle \\
ETO & = Earth to Orbit \\
GNC & = Guidance, Navigation, and Control \\
GPS & = Global Positioning System \\
LEO & = Low Earth Orbit \\
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L1 = Lagrangian point 1  
LTS = Lunar Transportation Systems, Inc.  
MEO = Medium Earth Orbit  
OMS = Orbital Maneuvering System  
RFP = Request for Proposal  
SOW = Statement of Work

I. Summary

The word "commercial space" means different things to different people. NASA has its own view of what "commercial space" means. The aerospace industry has another view of "commercial space". Even within the field, different constituencies give different meanings to those words. To us, "commercial space" means "private investment in 'for profit' companies stimulated by future government purchases of goods and services and expanding later to non governmental customers."

The White House¹, the Congress², and the Aldridge Commission³,⁴ have made it clear that our efforts to return to the Moon, go on to Mars, and explore the Solar System during coming decades will not happen without the significant involvement of entrepreneurs with innovative ideas, non aerospace industry companies, and new ways of doing business. Lunar Transportation Systems, Inc. has created innovation⁵,⁶,⁷ and would like to bid the CEV RFP, but without changes to the draft Statement of Work a company from the commercial sector like ours can not propose. Even though Sean O'Keefe and the Exploration Systems Mission Directorate have stated that they are open to concepts from small companies and private individuals, NASA's recent draft CEV RFP⁸ Statement of Work does not mention commercial space at all, except to say "The Government does not intend to acquire a commercial item using FAR Part 12 ⁸,⁹." 

The company believes innovation is needed not only in how NASA develops its program requirements, the use of the existing commercial EELV's¹⁰,¹¹ and how NASA creates and manages procurements, but also in a concerted effort to pay more than lip service to involving small companies and entrepreneurs with innovative concepts. How can good ideas from individuals and small companies compete with the juggernaut of big aerospace and entrenched NASA bureaucracy?

First, this paper discusses "commercial space" involvement in NASA's new Vision for Space Exploration and the normal methods that "Commercial Space" attempt to enter the existing traditional aerospace procurement environment. Second we discuss the development of the current NASA CEV procurement. Third, we discuss one example of a new Earth - Moon architecture that we believe has significant benefits over traditional and evolving architectures. This commercial lunar transportation mission overview is based on the innovation Lunar Transportation Systems, Inc. (LTS) point design done over the last year, but includes the early innovation of one company. This innovation expanded further could provide a basis for a commercial transportation architecture capable of varying amounts of unmanned cargo moving affordably in both directions and evolving into greater capacity over long period of time to include resources from the moon. This return cargo could be Helium-3 in sufficient quantities to change our dependence on foreign oil. Innovation can come from many different locations.¹²-²⁶ Innovation can come from many different locations.²⁷-³⁶

Our company suggests an open environment where many innovative ideas are considered by more sources so more than one commercial company can participate. The commercial industry with some interest shown by government would provide a variety of innovative solutions, which could be matured with technical discussions with NASA and possibly other agencies to accomplish an early potential early landing on the moon and later a sustaining interest in the moon’s development. This process of opening the procurement to commercial companies can be accelerated, if the NASA procedures for cooperation can be part of the innovation. The gain for NASA in pursuing the commercial path as suggested by Aldridge and others is a maturing of the best innovation for Moon, Mars and Beyond and the potential of part of the funding originating in the private sector.

II. "Commercial Space" Involvement in NASA's new Vision for Space Exploration

The President’s Commission on Implementation of U.S. Space Exploration called upon NASA to make a concerted effort to transform its culture to enable the private sector to become more involved in the development and operation of its space programs, to improve its procurement methods and ways of doing business, and to seek out and encourage entrepreneurial and small business innovation. In the six months since the release of the Commission's report, we have not witnessed very much change in the way NASA pursues its business. A case in point is NASA's recently released Draft NASA CEV SOW. These documents reflect old methods of doing business. They reflect old strategies for accomplishing NASA's goals. And they reflect traditional aerospace industry procurement policies.

American Institute of Aeronautics and Astronautics
In order to attract the best ideas from private individuals, from small companies and university departments, NASA must become as innovative in reaching out and soliciting new ideas as the innovative technologies they wish to attract.

III. Comments on the NASA's Current Draft CEV Procurement

The definitive architecture that will best enable the return to the moon and then on to Mars has not yet been identified and the technologies that enable the architecture must be demonstrated prior to establishing the permanent capability. LTS recognizes that the timetable for this technology demonstration will require a significant number of years to accomplish. LTS has identified a near term architecture that, while not able to initially meet all the CEV manned requirements, meets the logistic and cargo needs. This architecture requires minimum technology development and can be used by NASA to establish the infrastructure that supports and enables the final architecture.

It is our charter to establish a near term capability and improve our system as the NASA technologies are ready to be incorporated through technology transfer. This will allow a commercial/government partnership that will benefit and enhance NASA goals and objectives, as well as those of LTS.

There may be other commercial or academic entities that have valuable capabilities that will also be shut out of the CEV development effort because the primes do not consider them as key to their competitive advantage. We would like to have the CEV SOW modified to include the capabilities of commercial entities, like ourselves, so that our existing technology system can become part of the "toolkit" to allow the demonstration of the technologies for the definitive system in the exact environment and at low cost to benefit both the NASA effort and LTS's commercial system.

Another option is to have a separate commercial CEV development track where commercial companies could propose to provide some or all of the CEV capability on a commercial basis. In this approach industry would provide private capital to finance the development of their products and services and would sell these to the government according to a pre-arranged agreement. The Space Act which chartered NASA does provide such flexibility in working with industry and universities.

LTS believes it would be beneficial to NASA and the nation to modify the SOW to allow commercial entities, like ourselves, that can offer unique benefits and opportunities for rapid technology demonstration to the major prime contractors to bid supporting services and infrastructure as part of the CEV procurement. The other option is a separate parallel commercial track as described previously.

This would enable participation by smaller, more nimble commercial companies that could lead specific tasks or develop specific systems such as robotic lunar landers for precursor missions and as those mature, to compete for other system elements. While this may make the program a bit more complex to integrate, we believe the payoff is significant because some of these capabilities could become available to NASA quickly with relatively small up-front cost.

IV. LTS Technical and Political Strengths for the NASA

Lunar Transportation Systems, Inc. (LTS) presents NASA with an opportunity to strengthen national support for the NASA's Moon, Mars and Beyond initiative. The shared cost, low risk, and early operations of the system can provide the incentives to achieve NASA's long-term goals for space exploration.

Table 1 presents some of the strong points of the LTS system.

Table 1. LTS Technical and Political Strengths

- Innovative technical and business approach.
- Satisfies Congress's interest in promoting commercial space and commercial innovation.
- LTS views the first leg of the transportation cycle as COMMERCIAL already and intends to purchase from commercial firms for the transportation from earth to LEO.
- LTS can deliver lunar robotic and cargo payloads in support of Project Constellation.
- The major elements of the LTS system are reusable.
- LTS views propellant transfer as a tank transfer operation performed by manufacturing plant technology robotics in a telerobotic manner rather than a cryogenic liquid transfer from one large tank to another in space.
• The LTS systems is scalable and LTS spacecraft can be scaled up to fit into the payload capability of Delta IV Heavy launch vehicles to carry the CEV with crews and transfer of large payloads to the Lunar surface to support a Moon base.
• The LTS approach provides 800 kg early payload landed on the moon’s surface gradually increasing with enhancement of the system and logistics support to 10 tons landed with the reusable vehicle returned to service.
• LTS focuses on early unmanned cargo to confirm the reliability, propellant logistics and abort recovery systems, and may later be capable of transporting CEV type payloads.
• The LTS approach leads to a transportation node system expandable to each orbit around each planet to provide increasing transportation support and allow the emergence of commerce on each node.
• LTS can explore technologies that can enhance lunar operations.
  • Cryogenic propulsion for lunar descent and ascent operations.
  • Control of propellant boil-off rates on the lunar surface. Refueling by tank transfer.
  • Potential robotic experiments to verify lunar oxygen processes.
  • Cost savings through commercial investment in needed capabilities.
  • Uses existing launch capability (cost effective, low technical risk)
  • Enhances early flight program content and operational learning.

V. LTS’s Potential Role in the CEV Procurement

LTS, Inc. understands that the CEV Statement of Work is intended for major aerospace contractors with the resources and experience to develop such an extensive system. We do not seek a prime contract, but would like the opportunity to propose the LTS system as a test-bed for CEV technology demonstration and operations. A contractual relationship and involvement during the preliminary design phase would allow LTS concepts and commercially based support activities to be integrated into the program in ways that would be mutually beneficial to NASA and to LTS, Inc. Participation in the Moon, Mars and Beyond program would enhance the ability for LTS to raise the necessary capital for this commercial venture.

VI. LTS Potential Role in Constellation Systems

Lunar Transportation Systems concepts require no significant technology development and use existing expendable launch vehicles and infrastructure from Earth to LEO. Preliminary system development schedules provide for an operational system as a precursor to Constellation architecture. Table 2. Itemizes some LTS applications to support the Constellation Program.

Table 2. Lunar Transportation System Applicability to the Constellation Systems

• On-orbit test-bed for Constellation systems technologies and operations
• Early payload delivery to the lunar surface
• Potential candidate for Earth Departure Vehicle, the (EDS)
• Potential candidate for the Lunar Surface Access Module (LSAM)

VII. Lunar Transportation Systems, Inc. (LTS) Introduction

A. LTS Concept Summary

Lunar Transportation Systems (LTS) uses a system of systems approach that will enable the sustainable future exploration of space. The LTS architecture is effective, affordable, safe and reliable because of our methodologies for leveraging existing technology and private sector financing to meet NASA’s strategic technical challenges in the near and far term. The result will be the equivalent of an “Earth - Moon highway” with “filling stations” at critical nodes in cislunar space. Once the highway and its operational processes are put in place it can be used as many times as desired to support a variety of operations.

B. The LTS Architecture

LTS is developing a new Lunar architecture concept that, we believe, is better suited for a state of the art Lunar transportation system. This architecture is characterized by modularity and extreme flexibility leading to reduced development cost and evolves more effectively into the commercial business model capable of drawing private capital investment and providing a return on that investment. A hard look at this architecture will show
that it enables NASA to meet its strategic objectives, including sending small unmanned payloads to the Lunar surface in a few short years, sending larger payloads to the Lunar surface in succeeding years, and sending crews to the Moon and back to the Earth by the middle of the next decade. LTS's Lunar architecture is based on the concept of refueling a fleet of fully reusable spacecraft at several locations in cis-lunar space, which creates the equivalent of a two-way highway between the Earth and the Moon. Over the long term earth based resource recovery operations in remote environments depend on logistics capable and affordable logistics transportation systems. These transportation systems move more mass from the remote site than to the site over a fifty year period. This means the transportation system must be affordable and capable of growth over the long term use.

C. The LTS Spacecraft

The LTS architecture is based on four spacecraft. The spacecraft are delivered to Low Earth Orbit (LEO) by existing ELVs and operate only in space; one of the four spacecraft, the Lunar Lander, also operates on the lunar surface. All spacecraft incorporate active guidance and control systems. Key elements of the architecture are automated rendezvous and docking systems, automated payload transfer systems, robotic propellant tank transfer systems, robotic propellant tapping systems, autonomous Lunar landing systems, and robotic Lunar payload offload systems. These spacecraft produce a space highway for repetitive and cost effective trips to the lunar surface and back to the Earth.

The four LTS spacecraft right to left, illustrated in Figure 1, are the Lunar Lander, the Payload Dispenser, the Propellant Transporter and the Propellant Dispenser. The Propellant Dispenser, the fourth spacecraft, is nearly identical to the Propellant Transporter except it does not contain a main rocket engine because it only operates in LEO.

Figure 1. Conceptual designs for Lunar Transportation Systems (LTS) Spacecraft: Left to right, the Propellant Dispenser, the Propellant Transporter, the Payload Dispenser, and the Lunar Lander.

The Payload Dispenser is a payload carrier that provides a common interface with the Lunar Lander. The Propellant Dispenser is a rack for six hydrogen and six oxygen tanks with the subsystems necessary to perform autonomous rendezvous and docking and tank transfer to either Propellant Transporters or Lunar Landers. The function of the Propellant Transporter is to deliver propellant tanks to Lunar Landers in cis-lunar space as required. Propellant Transporters contain the subsystems necessary to navigate between the Earth and the Moon, to perform autonomous rendezvous and docking, and to transfer propellant tanks to Lunar Landers.

The function of the Lunar Lander is to transport payloads from LEO to the surface of the moon and back to LEO, see Figure 2., next page.
D. Delta II Heavy Flight Demonstration Missions Summary

LTS, Inc. is planning a full scale Flight Demonstration program to demonstrate operations and validate new technologies. The LTS demonstrators will be launched from Earth to LEO on Delta II Heavy class rockets. Figure 3, below, shows the Lunar Lander with two propellant tank sets but no Lunar payload yet, being deployed by a Delta II Heavy in LEO.

The purpose of the Flight Demonstration Program is to test systems and new technologies being developed by Lunar Transportation Systems, Inc. in LEO, at L1, in Lunar orbit, on the lunar surface, and on return missions from the Moon. Delta II Heavy launch vehicles provide reliable launchers to test and validate LTS systems and technologies. All LTS spacecraft, as well as their subsystems, their rendezvous and docking systems, their payload transfer systems, their propellant tank transfer systems, their propellant tapping systems, and their payload lunar offload/on-load systems are being designed to fit on Delta II Heavy launch vehicles.

The 1st series of Delta II Heavy Flight Demonstration missions only operate in Low Earth Orbit to test and validate LTS systems and technologies.

Table 3. Flight Tests - Systems Validation

1) Delta II Heavy launch integrity and LTS LEO spacecraft deployment.
2) Autonomous rendezvous and docking between two LTS spacecraft.
3) Autonomous transfer of Lunar payloads between two LTS spacecraft.
4) Transfer of cryogenic propellant tanks between two LTS spacecraft.
5) Tapping of propellant tanks.

The 2nd series Flight Demonstration missions further test and validate LTS systems and technologies in LEO but also send small payloads to the lunar surface. The 3rd series of Flight Demonstration missions refine tests and validate LTS systems and technologies in LEO and send larger payloads to the lunar surface. The 4th series of Flight Demonstration missions further refine tests and validate LTS systems and technologies in LEO, send sizable payloads to the Lunar surface, and return Lunar payloads from the Moon to LEO or to the Earth.
VIII. Summary of the LTS System

A. A New Lunar Architecture

Most of the concepts for Lunar transportation architecture that are being considered today by NASA and aerospace industry are based on decades of study of early spaceflight history and keep going over the same ground. In our view these architectures are not an acceptable solution for a new Lunar transportation system that will be required to support an emerging Lunar colony at reasonable cost. Genuine innovation is needed to achieve the goals of affordability and sustainability called for by the President.

LTS is presenting an innovation outline for a new Lunar architecture that could become a Lunar transportation system to support unmanned and later manned operations over a long period possibly extending into the recovery of resources from the moon’s surface. On the earth surface this recovery of resources of value has been the reason for a private company or consortium of companies to invest the amount of private capital to justify the trip and the development of the remote region. These architectures are characterized by modularity and extreme flexibility leading to reduced development cost and a greater ability to grow and evolve with the introduction of new technology. It seems logical, for example, to imagine nuclear technology to replace chemical propulsion on the longer distance segments of the trip to and from the moon. On earth technology is overtaken by better technology as part of the normal market forces of a transportation industry. A hard look at this architecture will show that it enables NASA to meet its strategic objectives, including sending small payloads to the Lunar surface in a few short years, sending larger payloads to the Lunar surface in succeeding years, and sending crews to the Moon and back to the Earth by the middle of the next decade. This transportation technology system is also appropriate for the transportation to locations beyond the moon and leaves room and capability for the emergence of commercial operations on the nodes as it does on earth when trade routes cross. Our new Lunar architecture is based on the concept of refueling a fleet of fully reusable spacecraft at several locations in cislunar space, which create the equivalent of a two-way highway between the Earth and the Moon. These refueling locations later become the centers of space commerce.

B. A Potential International Consortium

The financing method of creating a commercial transportation system parallel to the totally funded government system is to work the market side and pull together the customer groups able to profit from the recovery and transport of Helium 3 from the moon. In Prudhoe Bay, for example, the oil companies focused on the trillions in recoverable oil assets by going to one field by starting the total process of recovery by transporting only some oil south. Later natural gas was added as a revenue source with other costly facilities and other fields were developed, which took hundreds of billions. The first $12 billion was the toughest to raise and the only development money not paid out of early oil revenue. The same financing can be used on the moon with the correct, directional, expanding, evolving transportation system and an international consortium with a profit motive as a potential long term customer.

Helium 3 is worth approximately $ 5 billion per ton to various customer groups of different sizes from smaller medical uses to large energy producers on the grid, but it is not naturally occurring on earth. It has small uses, but the big financial kicker is the ability to jump-start the nuclear grid power industry by potentially creating a power plant with almost no radioactive properties and a cost effective alternative to the fusion power plant. It might actually jump start the fusion power research by creating an alternative that actually moves our country into economical power. Proof of Helium 3’s value can be confirmed by a relatively affordable lab experiment.

C. Use of Existing ELVs

This new Lunar architecture utilizes current ELV’s, EELVs to bring a new fleet of reusable LTS spacecraft, Lunar payloads, propellants, and eventually crews from the Earth to LEO. The first leg of the trip from the earth surface is already commercial. To ignore that fact seems to be contrary to what an industrial company or consortium of resource companies would do. A consortium would use the most effective and affordable transportation available. The LTS reusable spacecraft do the rest of the job to and from the moon. The LTS system of transportation moves payloads from LEO to the Lunar surface and can bring payloads back to Earth from the Moon. This strategic roadmap permits a "pay as you go" and a "technology development pathway" that allows NASA to achieve a series of its strategic objectives as funding and technology developments permit. The suggested commercial route parallels CEV techniques and uses some NASA budget to stimulate the investment of private money by others on a parallel path. Commercial interests using their own non-NASA money develop an unmanned cargo route and pursue valuable resources on the moon. Our approach reduces mission recurring cost by advancing in-space transportation technology, and later, resource utilization, because this is less costly than investing in new ETO transportation.

D. Enabling Technologies
This state of the art architecture, as described in some detail in this White Paper, does not depend on the development of any new launch vehicles. It does depend on the maturing of six emerging technologies: 1) an autonomous rendezvous and docking system, 2) an autonomous payload transfer system, 3) a spacecraft to spacecraft cryogenic propellant tank transfer system, 4) an autonomous propellant tank tapping system, 5) an autonomous Lunar landing system, and 6) an autonomous payload offload system. Maturing these technologies appears less risky and less costly than investments in Earth to Orbit (ETO) transportation or cryogenic propellant transfer technologies. These emerging technologies, except AR&D, are developable by ground test and our program plan includes flight demonstration on early robotic missions to the Moon.

E. Lunar Payload Capabilities

The initial fleet of reusable spacecraft is designed to fit the payload capabilities of Delta II Heavy class launch vehicles. Lunar Lander spacecraft can deliver payloads of up to 8 metric tons from LEO to the lunar surface; depending on where and how frequently they are refueled on their way to the Moon. This architecture is capable of delivering 800 kg to the lunar surface directly from LEO without the need to refuel in space. It is capable of delivering payloads of 3.2 metric tons to the lunar surface with refueling at L1 only. Comparable payloads can be returned from the lunar surface to the Earth with refueling at one or more of those locations. While this initial system is not meant to transport crews to and from the Moon, it is meant as a technology development test bed for a crewed Earth – Moon transportation system.

F. Scalability

This new Lunar Transportation system is scalable. A follow-on fleet of larger spacecraft, designed to fit the payload capabilities of Delta IV Heavy class launch vehicles, can transport payloads of up to 30 metric tons from LEO to the Lunar surface, depending on where and how frequently they are refueled on their way to the Moon. These larger spacecraft are capable of transporting crews to the lunar surface and returning them to the Earth. They also have the capability to provide heavy cargo transportation to support a permanent lunar base.

G. Crew Safety

A very important element of our lunar architecture is crew safety. Commonality of modules and subsystems increases flight operations experience rapidly, leading to greater safety. Backup Lunar Landers can be pre-positioned at L1, in lunar orbit, or even on the Lunar surface to provide crew rescue capability in case of a mission abort situation.

H. Cost Reduction

The non recurring costs to develop this Earth – Moon transportation system are much lower than the cost of developing systems that use more traditional architectures, because there are fewer unique developments and it relies on maturing existing launch systems. A significant reduction in lunar mission costs comes from the reusability of the major elements of this system. The largest cost in operating this system is the delivery of the spacecraft, the propellants, and the lunar payloads from the Earth to LEO. LTS plans to bring the Earth – Moon transportation infrastructure from the Earth to LEO on existing expendable launch vehicles. Perhaps as much as 70% of the cost of each Lunar mission will be to transport the LTS infrastructure from Earth to LEO. While these are expensive to fly, the development cost of significant new launch capability represents at least 100 launches of existing EELV’s and many years of lunar transportation operations. When propellants can be manufactured on the Moon, Earth – Moon mission costs may be reduced by 60% or more. If and when reusable Earth to LEO launch vehicles becomes available, lunar mission costs may be reduced by a further 60% or more.

I. Schedule

Because this system relies on existing technologies and existing ELVs and only requires the maturation of several enabling technologies, it can deliver payloads to the Lunar surface relatively quickly and well within NASA's schedule for robotic and human Lunar exploration.

J. The Bottom Line.

This Lunar architecture is based on concepts that reduce Lunar mission life cycle costs and technical risks, improve reliability and crew safety, accelerate Lunar mission schedules, and allow for the routine delivery of Lunar payloads on a two way highway between the Earth and the Moon.

IX. A Description of the LTS Earth – Moon Transportation System

This system builds a two-way transportation highway between Low Earth Orbit and the Lunar surface, either from LEO directly to the lunar surface for smaller payloads, or from LEO by refueling in cislunar space for heavier payloads and for payloads returning from the Moon. The system uses a small fleet of reusable spacecraft, supported by a small fleet of expendable spacecraft, to transfer payloads in LEO, to transfer
propellant tanks at specific locations in cislunar space, and to transport payloads to and from the Lunar surface. The system uses existing ELV’s to transport its entire infrastructure from the Earth to Low Earth orbit.

A. Reusability
A key feature of this Earth – Moon transportation system is that the two principal spacecraft, the Lunar Lander and the Propellant Transporter are fully reusable. The Lunar Lander transports payloads from LEO to the Lunar surface and back. The Propellant Transporter transports cryogenic propellant tanks from LEO to any place in cislunar space where the Lunar Landers need to be refueled.

B. Earth – Moon Payload Capabilities
The size of the payloads delivered to and from the Moon depends on where and how many times Lunar Landers are refueled on their way to and from the Lunar surface. This system is capable of delivering 800 kg to the Lunar surface directly from LEO without the need to refuel in space. It is capable of delivering 3.2 metric tons to the Lunar surface with refueling at L1 only. And it is capable of delivering up to 10 metric tons to the Lunar surface with refueling at MEO, at L1, and in Lunar orbit. Comparable payloads can be returned from the Lunar surface to LEO or to the Earth with refueling at one or more of those locations.

Lunar Lander Payload Capability
From LEO to the Lunar Surface and Return

Lunar Lander
Empty Spacecraft Mass - 1 metric ton
Propellant Mass - 5 metric tons
Total Mass - 6 metric tons
Spacecraft Size - 3.0 m height, 2.7 m diameter
Payload Mass - Up to 10 metric tons
(Total 800 kg in LEO)
Launch Vehicle to LEO - Delta II Heavy class

Mission Profile 1 - LEO to Lunar Surface Direct - 800 kg
Mission Profile 2 - LEO to L1, Refuel, to Lunar Surface - 3.2 tons
Mission Profile 3 - LEO to MEO, Refuel, to L1, Refuel, to Lunar orbit, Refuel, to Lunar Surface - 10 tons

Figure 4. Lunar Lander payload capability from LEO to the Lunar surface and return.

C. Translunar and Lunar landing spacecraft
The LTS system is based on the development of a fleet of two reusable spacecraft and two expendable spacecraft. The reusable spacecraft, which make up the heart of the system, are the Lunar Landers and the Propellant Transporters. These Two types of reusable spacecraft perform different functions and are equipped with different means for sensing and motion. The weight of the spacecraft structures also varies. Three of these spacecraft, the Payload Dispenser, the Propellant Dispenser, and the Payload Transporter, only operate in space. The third spacecraft, the Lunar Lander, operates in space as well as on the Lunar surface.

The structures of the two reusable spacecraft consists of an inner aluminum tube which carries three aluminum plates, one at each end and one middle plate located below the mid section of the spacecraft. Six sets of cryogenic propellant tank sets, arranged in a circle fit between the plates. These tank sets are so attached that they can be robotically transferred from one spacecraft to another. Each tank set consists of a tall hydrogen tank.
and a shorter oxygen tank, with the six hydrogen tanks located on top of the central plate and the six oxygen tanks located on top of the bottom plate.

1) The Reusable Lunar Landers
Lunar Landers deliver payloads from LEO to the Lunar surface and can return payloads from the Lunar surface to LEO or directly to the Earth. Lunar Lander spacecraft receive payloads from Payload Dispenser spacecraft in LEO, receive propellant tank sets from Propellant Dispensers in LEO, and may receive propellant tank sets from Propellant Transporters at MEO, at L1 and/or in Lunar orbit, depending on the size of the payloads they are transporting to the Lunar surface. Lunar Landers are propelled by a single liquid hydrogen/oxygen engine located at the bottom end of their aluminum tubes.

Lunar Landers have a mechanism to autonomously transfer propellant tank sets from either Propellant Dispensers or Propellant Transporters. They also contain mechanisms to autonomously tap into propellant tanks to create propellant flow to their rocket engine. A set of retractable landing legs folded back along the tube allowing the Lunar Lander spacecraft to land on the Moon and take off from the Moon. Lunar Landers provide reliable two way transportation between Earth orbit and the Lunar surface.

Figure 5. Left: Lunar Lander empty structure concept.
Right: Lunar Lander with two propellant tank sets.

2) The Reusable Propellant Transporters
Propellant Transporters are brought from the Earth to LEO on ELV’s. Propellant Transporters bring propellant tank sets beyond Earth orbit to any location where Lunar Landers require refueling in cis-lunar space. They can travel to MEO, L1, and/or Lunar orbit to provide refueling stations for the Lunar Landers.

Propellant Transporters are almost identical to Lunar Landers but have no landing legs since they are not designed to land on the Moon. Propellant Transporters have a single rocket engine, ACS thrusters, a fuel cell power source, computers, an inertial guidance system, and a Videometer rendezvous and docking system. Propellant Transporters and Lunar Landers are reusable and form the backbone of this Earth-Moon system.

Figure 6. Propellant Transporter Concept with full tank sets.
3) The Expendable Propellant Dispensers

Propellant Dispensers bring propellant tank sets to LEO on ELVs. Once in Earth orbit Propellant Dispensers rendezvous and dock with either Lunar Landers or Propellant Transporters and transfer cryogenic propellant tank sets to their receiving spacecraft. Propellant Dispensers are simple, relatively inexpensive spacecraft that are discarded after a single use.

Propellant Dispensers do not have rocket engines nor are they able to tap into the propellant tanks they carry. Propellant Dispensers contain videometer systems for rendezvous and docking, Orbital Maneuvering Systems (OMS) to reach their proper designated locations in LEO for rendezvous with a receiving spacecraft, and an Attitude Control Systems (ACS) to achieve proper attitude for docking. Propellant Dispensers have the capacity to carry up to six propellant tank sets.

4) The Expendable Payload Dispensers

Payload Dispensers bring payloads to LEO on ELVs. They provide a common interface with Lunar Landers, rendezvous and dock with Lunar Landers and transfer their payloads to Lunar Landers in LEO for transport to the Lunar surface. Payload Dispensers are then discarded and enter the Earth’s atmosphere after a single use.

Payload Dispensers do not have rocket. They contain AR&D systems for rendezvous and docking, Orbital Maneuvering Systems (OMS) to reach their proper designated locations in LEO for rendezvous with a receiving spacecraft, and an Attitude Control Systems (ACS) to achieve proper attitude for docking.

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Figure 7. Payload Dispenser concept
Showing the Lunar payload on top of Its payload carrier.

D. The Rocket Engines

The Lunar Lander and Propellant Transporter are the two space vehicles that are rocket powered. The required H2-O2 engine can be of relatively low power since it has only to overcome the lunar gravity which is 1/6 of the Earth’s gravity. With a weight of 6 tons for the fully fueled Lunar Lander, and assuming the maximum payload of 8 tons, the minimum theoretical rocket thrust would only be 2.4 tons. Considerably greater thrust however is desirable in order to keep fuel consumption as low as possible.

The specific impulse of the engine is an important characteristic since it has a significant affect on the performance of the system. A value of 440 sec. has been assumed in our computations. An engine that comfortably meets all those requirements is of version of the Pratt & Whitney RL 10 that has a thrust of 7 tons, a vacuum ISP of 444 and a weight of 140 kilograms.

To fit the size limitations of the fairing of the Delta 2 rocket, the rocket engine will have to be slightly modified to fit into the 0.9-meter space available in our vehicles. And the exhaust nozzle will have to slightly protrude below the base of the vehicles.

Another question that has to be addressed is the ability to throttle the engine. Theoretically, an engine should be able to do the required job working at 100% thrust only. However start and stop of a rocket engine are not
instantaneous with time lags that are not totally predictable. To compensate for this a small modulation of thrust of a few percent should do the job as required for lunar landing.

E. The Use of Expendable Launch Vehicles

One of the requirements of this Earth–Moon transportation system was to size all spacecraft for the payload envelope and payload capability of existing expendable launch vehicles. The Delta II Heavy was chosen because of its long history of reliability and its payload carrying capacity.

Figure 8. LTS spacecraft are carried from Earth to Low Earth Orbit on Expendable Launch Vehicles. Shown here is the Delta II Heavy on the Launch pad with a cut away showing how an LTS spacecraft fits into its fairing.

F. Enabling Technologies

This Earth–Moon transportation system is made possible by the development of a small fleet of reusable spacecraft that can transport cryogenic propellants to any location in cislunar space to refuel Lunar Landers that can deliver small to moderate size payloads to the Lunar surface. The system is made possible by developing six autonomous robotic technologies:

1) An autonomous rendezvous and docking system.
2) An autonomous spacecraft to spacecraft payload transfer system.
3) An autonomous cryogenic propellant tank transfer system.
4) An autonomous cryogenic propellant tank tapping system.
5) An autonomous Lunar landing system.
6) An autonomous Lunar payload offload system.

G. Rendezvous and Docking

All LTS spacecraft will use the French developed Videometer, a new technology device, to ensure very precise automatic rendezvous and docking operations. Based on the design of a star tracker, the videometer is the first automatic optical system ever used for spacecraft navigation. This state-of-the-art rendezvous technology was developed for the ESA Automated Transfer Vehicle (ATV). For the final rendezvous maneuvers, the vehicles use their videometer sensors, combined with additional parallel measurement systems, which allow automatic docking with centimeter precision. The videometer is able to analyze images of its emitted laser beam automatically reflected by passive retro reflectors serving as targets installed on the LTS spacecraft. During the last 200 meters of the final approach maneuver, the videometer automatically recognizes the retro reflectors target patterns and then calculates the distance and direction to the docking port. This precise tracking of the relative motion between the two spacecraft as they get closer provides information to the on-board Guidance, Navigation and Control (GNC) system, which automatically pilots them together.
Fig. 9. The EADS Sodern "Videometer" on the LTS "Propellant Dispenser" approaching the Lunar Lander to transfer propellant "tank sets" in Low Earth Orbit.

H. Transferring Payloads in Low Earth Orbit

Lunar bound payloads are integrated on top of special Payload Carriers, which are installed on the top plate of Payload Dispensers and are robotically transferred to Lunar Landers in LEO prior to the Lunar Lander’s departure to the Moon. After two spacecraft have been brought in very close proximity within a couple of centimeters of proper position and attitude with respect to each other, the lead spacecraft will order a last gentle push from the thrust control jets to bring the two spacecraft in full contact. Tapered pins protruding from one vehicle’s top plate will then engage tapered holes in the second spacecraft’s top plate. Electromagnets will then be energized in order to keep the two spacecraft solidly locked together. The top plates in the two spacecraft carry diametrical recessed grooves, which contain at least one geared pinion inside the groove. The payload, which carries a similar plate with a dented rail fitting inside the recessed groove, is held solidly by the rims of the groove and is prevented from sliding along the groove through the geared pinion.

After the two spacecraft are docked and connected the payload transfer is initiated. An electric motor actuates a geared pinion of the transferring spacecraft and slowly moves the payload along the grooves of the first vehicle so it engages the groove in the receiving vehicle. At this point a geared pinion of the receiving spacecraft takes over control and moves the payload to its exact position in the middle of its top plate and keeps it solidly in this position. This is achieved by locking the driving mechanism. The magnetic locks can now be released and the Lunar Lander can proceed to the Moon.

Figure 10. Payload Transfer from the Payload Dispenser to the Lunar Lander in Low Earth Orbit

I. The Payload Carrier

While docked, the Payload Dispensers transfer their Lunar payloads using Payload Carriers that contain a built in transfer mechanism which works as follows: The Payload Dispenser and the Lunar Lander both feature recessed grooves running diametrically across their top plates. The Payload Carrier has a toothed rail running across its bottom plate that fits into the recessed grooves. The Payload Dispenser and the Lunar Lander are docked so that the two grooves line up. Gears inside the grooves engage the rail and move the Payload Carrier and Lunar payload from one spacecraft to the other, and then the Payload Carrier is locked solidly in place. Payload Carriers also provide a means to unload their payloads and gently place them on the lunar surface after landing on the Moon. The payload carrier system will mature further in its movement to become the containerized cargo like system of space transportation by maturing the transfer, the stacking capability and ultimate use on the moon. Instead of encouraging expensive integration on each payload, the commercial system tries to move to a standard system that eliminates expense.
J. In-Space Refueling

The heart of this Earth-Moon transportation system is the use of self contained propellant tank sets that are brought up from the Earth in Propellant Dispensers and Propellant Transporters on expendable launch vehicles. Propellant tank sets are robotically transferred in LEO from Propellant Dispensers in Low Earth Orbit to Propellant Transporters or Lunar Lander spacecraft. The tank sets contain liquid hydrogen and liquid oxygen propellant. This propellant transfer system is what makes this transportation system concept possible.

Propellant Dispensers also transfer propellant tank sets to Propellant Transporters in Low Earth Orbit. Once fully fueled, Propellant Transporters can travel to MEO, to L1, or to Lunar orbit to transfer propellant tank sets to Lunar Landers, both on their way to the Lunar surface and, if needed, on their way back to Earth from the Moon.

K. Refueling the “Propellant Transporter” and the “Lunar Lander” in Space

The heart of this Lunar transportation system is the use of pre-filled, self-contained propellant tank sets. These tank sets are transported from the Earth to Low Earth Orbit on ELVs in Propellant Dispenser spacecraft. Propellant Dispenser spacecraft then transfer their propellant tank sets to either a Propellant Transporter or a Lunar Lander. Fully fueled Propellant Transporter spacecraft can travel to MEO, L1, and/or Lunar orbit where they are positioned to transfer tank sets to Lunar Landers both on their way to the Moon and returning from the Moon.

Both meeting spacecraft are guided by their GPS to the pre-defined location using their thrusters. The approaching vehicle will use its Orbital Maneuvering System engine for rendezvous and docking. The attitudes of the two spacecraft will be aligned using their inertial guidance systems. After the receiving spacecraft has moved to the proper location, it uses its gyro and videometer to achieve proper attitude and position near the Propellant Dispenser vehicle. A telescoping hand now extends from the central column of the Lunar Lander, grabs a single propellant tank set and pulls it into position in the receiving spacecraft. The locks are then released, the receiving spacecraft rotates around the dispensing spacecraft and the procedure is repeated until all tank sets are transferred from one storage spacecraft to the working transportation vehicle.

The angles of rotation around the longitudinal axis will be controlled so that the empty tank berth in the receiving spacecraft faces the occupied berth of the donating spacecraft. Once the spacecraft are sufficiently close (about 100 meters) and with a very small closing velocity, an optical system like the Videometer, will take over control of docking. Once the vehicles are docked, magnetic clutches will temporarily lock them together. At that point, a telescoping arm with a gripper will extend from the central tube toward the receiving spacecraft, grab the facing tank in the donor vehicle, and pull the tank to its assigned place in the receiving spacecraft and solidly hold it there. The same transferring action will proceed simultaneously with the upper row of hydrogen tanks. Once this operation is completed, the Payload Dispenser is discarded in the Earth’s atmosphere or becomes part of the emerging transportation node in LEO and the Payload Transporter or Lunar Lander can proceed, fully fueled, to the Moon.

L. The Propellant Tank Sets

A key element of this Earth-Moon transportation system are the cryogenic propellant tank sets. A tank set consists of two propellant tanks, a larger liquid hydrogen tank that fits between the top plate and the center plate of the spacecraft and a smaller liquid oxygen tank that fits between the center plate and the bottom plate of the spacecraft. The liquid hydrogen tanks are 3.0 m in height and .9 m in diameter. The liquid oxygen tanks are 1.25 m in height and .9 m in diameter. These can vary with the shroud diameters available on vehicles from earth.

The propellant tanks are light-weight, cylindrical containers similar to simple coca cola cans. Strong but very light. They are designed to withstand an internal pressure of at least one atmosphere in empty space and will be tested to a pressure of 3 atmospheres on Earth. They are fitted with an H-shaped waistband for attachment along the periphery of the spacecraft. Sealed orifices are provided at both ends, an upper one for helium pressurization and a lower one for connection to the propellant lines. These orifices are sealed through a welded, thin diaphragm that is only pierced when a propellant flow is required to feed the rocket engine. The propellant tanks will then be completely emptied and then discarded. The tanks are held in place through telescoping grippers that grab the tanks by their waistband and hold them on their support plate. The propellant tanks can easily be released from their telescoping grippers and discarded in space.
M. Propellant Tank Transfer

After two vehicles are solidly connected, the transfer of the fuel tanks can proceed. In weightless space the tanks are held only loosely between the two vehicles plates. They are also loosely constrained laterally through vertical bars arranged between the tanks. Very little push is now required from the telescoping grip to move the tanks from one vehicle to the other. When a tank arrives midway between the vehicles, the telescoping arm from the receiving vehicle extends toward it; its gripper grabs the tank by its waistband and pulls it into its new berth. This process has to be repeated, until all the tank sets have been transferred.

N. Propellant Tank Tapping System

In order to release the fuel from the containers, nozzles will extend from the top and bottom plates, pierce the seals on the tanks and open the fuel flow.

O. Propellant Access.

The analogy to “beer keg tapping” for access to the propellants is over simplification of the technology LTS envisions, but clearly illustrates the goals of low complexity, low cost, and high reliability. There are many examples of this type of transfer systems for non-cryogenic fluids in an earth environment. The adaptation of these technologies to cryogenic fluids and robotic operations in space is an objective of our proposed project. Tank conceptual designs are being developed in independent system studies. These data will support the propellant access concepts selection for technology demonstrations to provide a TRL-6. Component, subsystem and large scale demonstration testing will be conducted at the Marshal Space Flight Center. The propulsion and robotics laboratories will participate in test article configuration design, test planning and will conduct the tests.

Both the Lunar Lander and the Propellant Transporter must have access to the propellant tank sets in order to feed their rocket engines. Each tank features two orifices covered with a thin diaphragm, a small one on top for helium pressurization and a larger on the bottom to draw the cryogenic fuel. A nozzle with a six bladed knife and flexible seal will then be forced into the two openings to connect them to a helium line and propellant manifold. Only two opposed tank sets will be tapped at a given time while keeping the other tanks for later use or for transfer to another vehicle. Check valves in each manifold will prevent the fuel from being spilled at tank locations which are not in use.

P. Landing on the Moon

While the Lunar Lander descends toward the lunar surface above the selected landing area, a precision altimeter will measure the height of the vehicle above ground as well as its vertical velocity. The onboard computer will trac these values and figure the exact altitude where, at full engine thrust, the two linear relationships of decreasing vertical velocity and decreasing height above ground will converge to zero simultaneously and cut off the engine at that point. The altimeter and computer may not always do a perfect
job, some hard landing has to be expected and the landing gear will be designed to accommodate an imperfect landing.

![Figure 13. Landing on the Moon](image)

**Q. Off-Loading of Payloads**

Payloads brought to the surface of the Moon by the payload carrier may be integrated on top of the Lunar Lander on Earth before launch or may have been transferred in Earth’s orbit from a Payload Dispenser. In either case the payload will be located on the top of the Lunar Lander. The Lunar Lander with extended legs is a rather tall structure and off loading of the payload is a critical task. The payload will be installed on a special Payload Carrier with an extendable overhead arm and a cable, which will enable the payload to be lowered to the Lunar surface. In early missions to the Moon the payload carrier, located on top of the Lunar Lander, will have the ability to gently lower the payload to the ground.

The figure below shows one possible implementation of the idea: the payload is attached through a cable to the telescoping arm. After being detached from it’s carrier, the payload is pulled off it’s support structure and gently let down to the Lunar surface in an upright position. In later operations a mobile crane would be available at the landing sites, tall and stable enough to handle even large payloads mounted on top of a Lunar Lander.

To operate the system, the payload carrier contains a power source, an electric motor and a controller. On signal from the Lunar Lander, the carrier will free the payload, extend an overhead arm, tighten the cable and then gently lower the payload to the Lunar surface. In later flights a crane will be waiting on the Lunar surface to unload incoming Lunar Lander payloads.

![Figure 14. Payload Offload](image)

**R. Returning Payloads from the Moon**

This LTS system is capable of returning payloads from the Lunar surface to LEO or to the Earth. The size of payloads returning from the Moon depends on how many times and at which cislunar locations the return spacecraft refuels on its way from the Moon to the Earth.
X. Earth - Moon Mission Profiles

The LTS transportation system architecture can utilize a wide range of mission profiles, including LEO to Lunar surface direct, LEO to L1 to Lunar surface, LEO to MEO to L1 to Lunar orbit, and then to Lunar surface with refueling at each stage along the way.

Selected profiles depend on the size of the payloads required for specific Lunar missions. The two charts below show a LEO direct to the Lunar surface profile and a LEO to L1 for refueling, to the Lunar surface profile. Mission Profile 1 is capable of putting 800 kg on the Lunar surface. Mission Profile 2 is capable of putting 3.2 metric tons on the Lunar surface.

![Mission Profile 1](image1)

**LTS Mission Profile 1**
From LEO Direct to the Lunar Surface

1. An LTS Lunar Lander is launched to LEO on an ELV.
2. A Propellant Dispenser is launched to LEO on an ELV.
3. The Lunar Lander rendezvous and docks with the Payload Dispenser.
4. The Payload Dispenser transfers its payload to the Lunar Lander.
5. A Propellant Dispenser is launched to LEO on an ELV.
6. The Propellant Dispenser rendezvous and docks with the Lunar Lander.
7. The Propellant Dispenser transfers propellant tanks to the Lunar Lander.
8. The Lunar Lander departs LEO for the Lunar surface.

![Mission Profile 2](image2)

**LTS Mission Profile 2**
From LEO via L1 to the Lunar Surface

1. A Propellant Transportation is launched to LEO on an ELV.
2. A Propellant Dispenser is launched to LEO on an ELV.
3. The Propellant Dispenser rendezvous and docks with the Propellant Transportation.
4. The Propellant Dispenser transfers its “tank sets” to the Propellant Transportation.
5. The Propellant Transportation departs LEO to L1.
6. A Lunar Lander is launched to LEO on an ELV.
7. A Payload Dispenser is launched to LEO on an ELV.
8. The Lunar Lander rendezvous and docks with the Payload Dispenser.
9. The Payload Dispenser transfers its payload to the Lunar Lander.
10. A 2nd Propellant Dispenser is launched to LEO on an ELV.
11. The Propellant Dispenser rendezvous and docks with the Lunar Lander.
12. The Propellant Dispenser transfers propellant “tank sets” to the Lunar Lander.
14. The Lunar Lander rendezvous and docks with the Propellant Transportation at L1.
15. The Propellant Transportation transfers propellant “tank sets” to the Lunar Lander.
17. The Lunar Lander lands on the Moon.

Other Lunar mission profiles are possible using the LTS propellant tank transfer system which can refuel Lunar Landers anywhere in cislunar space. A mission profile that includes refueling at MEO, L1, and Lunar orbit for example, can place payloads of up to 10 metric tons on the Lunar surface.

XI. The LTS Flight Demonstration Program

LTS is planning a Flight Demonstration program to demonstrate operations and validate new robotic technology.
technologies. The Flight Demonstration Program will test systems, procedures, and new technologies in LEO, in MEO, at L1, in Lunar orbit, on the lunar surface. These missions will utilize LTS spacecraft which will be launched from the Earth to LEO on a series of Delta II Heavy rockets.

All four LTS spacecraft, the Lunar Landers, the Payload Dispensers, the Propellant Dispensers, the Propellant Transporters, their subsystems, their rendezvous and docking systems, their payload transfer systems, their propellant tank set transfer systems, their propellant tapping systems, and their Lunar payload offload/onload systems will be tested and validated in this program.

Each flight demonstration mission will build on the one before it. The first series of Flight Demonstration missions will test and validate LTS systems and technologies in LEO. Once systems and methodologies are validated in LEO, a second series of flight demonstration missions will be made in cislunar space and, later, on the Lunar surface.

A. LTS Concept Validation in LEO

1) Delta II Heavy launch integrity and LTS LEO spacecraft deployment.
2) Autonomous rendezvous and docking between two LTS spacecraft.
3) Autonomous transfer of Lunar payloads from Payload Dispensers to the Lunar Landers.
4) Transfer of cryogenic propellant tank sets between from Propellant Dispensers to the Lunar Landers, from Propellant Dispensers to the Propellant Transporters, and from Propellant Transporters to Lunar Landers.
5) Tapping propellant tanks in Lunar Landers and Propellant Transporters.

The second series of Flight Demonstration missions will further test and validate systems and technologies in LEO and send small payloads of up to 800 kg to the lunar surface.

A third series of Flight Demonstration missions will refine tests and validate LTS systems and technologies in LEO and send larger payloads of up to 3.2 tons to the lunar surface by refueling Lunar Landers at L1.

A fourth series of Flight Demonstration missions will further refine tests and validate spacecraft systems and technologies in LEO, send larger payloads to the Lunar surface by refueling in MEO, L1, and Lunar orbit, and return Lunar payloads from the Moon to LEO or to the Earth by refueling at one or more of those locations. Refueling frequency and locations will be determined by the size of the payload destined for the Moon or the payload returning to LEO or the Earth from the Moon.

XI. The LTS Development Schedule

Since the LTS Earth – Moon Transportation system relies on existing and proven ELV’s to transport its spacecraft, propellants, and Lunar payloads from the Earth to LEO, the LTS development schedule can be shortened when compared to the development of more traditional Earth – Moon systems.

First LEO flight demonstration missions can begin in year four after ATP. First Lunar landing flights with small payloads can occur by year five after ATP and Lunar landing flights with heavier payloads (requiring refueling at various locations in cislunar space) as well as return payloads from the Moon can begin by year six after ATP. The following chart outlines a planned LTS development and operations schedule.
XII. LTS Trade Studies

LTS has started initiating a series of trade studies in a wide range of technical challenges including conceptual design of LTS spacecraft structures, propulsion systems, ACS systems, cryogenic tanks, propellant tank transfer system, propellant tank tapping system, ground facilities requirements, rendezvous and docking system, LEO payload transfer system, the lunar landing system and the lunar payload offload/unload system.

XIII. Costs

The non-recurring costs to develop this Earth – Moon transportation system are much lower than the cost of developing systems that use more traditional architectures. A significant reduction in Lunar mission costs is the reusability of the major elements of the LTS system, the Lunar Landers and the Propellant Transporters. The largest cost in operating this system is the delivery of the spacecraft, the propellants, and the Lunar payloads from the Earth to LEO. LTS plans to bring its Earth – Moon transportation infrastructure from the Earth to LEO on existing expendable launch vehicles which are very expensive. Perhaps as much as 70% of the cost of each Lunar mission will be to transport the LTS infrastructure from Earth to LEO. When fully reusable Earth to LEO launch vehicles become available in the next decade, Lunar mission costs can be reduced by 60% or more. When propellants can be manufactured on the Moon, sometime in the following decade, Earth – Moon mission costs will be reduced, perhaps, by another 60% or more.

XIV. Scalability

This system is scalable and extendable. A fleet of larger spacecraft that fit inside the payload envelope and utilize the payload capabilities of Delta IV Heavy class launch vehicles would be capable of transporting payloads of up to 30 metric tons to and from the Lunar surface. These larger spacecraft could deliver crews and cargo to support a permanent Lunar base.

XV. Management and Technical Teams

Members of the LTS management and technical teams have over 35 years of aerospace systems experience creating innovative commercial space concepts; founding successful, privately financed space companies; hiring experienced management and technical teams; and, partnering with major aerospace companies in the...
United States and abroad. It is our goal to establish a viable commercial operation to offer the use of all the elements of our system to government users and to any company that has a need to send payloads to and from the Moon.

Lunar Transportation Systems, Inc. was founded by the founders of SPACEHAB, Inc. and Kistler Aerospace Corporation. Those two commercial space companies have raised hundreds of millions of dollars from the private sector during the past ten years. LTS plans to apply the business models used for SPACEHAB and Kistler Aerospace. Seed financing for this project has been obtained and LTS, Inc. has a number of studies underway on the technologies, systems, and architectures required for the successful implementation of its program. Our goal is to raise major financing from the private sector to develop, build, ground test, flight test, and operate the LTS system. These plans could be accelerated by early NASA cooperation and the establishment of non-critical early cargo capable of being transported by commercial companies like LTS and other commercial companies. Our team plans to work closely with NASA and major aerospace industry partners, both in the United States and abroad, on the development and implementation of the LTS system.

**XVI. Conclusions**

Commercial projects evolve differently than government financed systems for space. Privately financed projects are sensitive to the methods that reduced the initial risk money required and to the markets that make up a future customer base. The commercial transportation mission varies in many ways from the traditional aerospace approach. Private companies want to sell services and own their system, when they bring their own money to create a project. In selling services rather than entire hardware systems, the commercial company has a future market that private investors see and can become comfortable with as they invest their private capital. NASA defining and making this unmanned cargo market open and available to commercial companies coupled with “tax credit” based investment incentives under consideration in the Congress could open the doorway to stimulating a broader base within industrial and financial sectors of our economy. The financial sector or private investment would permit NASA to make effective use of “Other People's Money” as well as their existing budget to have more than they have to pay for in exploration systems. The industrial sector interest could include recovery of resources from the moon by international mining consortiums and power grid energy organizations In space entrepreneurship these later commercial markets are many times the early larger than emerging market that tends to define the early transportation, so the entrepreneur is creating a new transportation industry segment along with a new “for profit” company.

NASA and America can gain from using some of the NASA budget to stimulate private investment by others (stimulating Other People’s Investment or OPI). Building a Highway to the Moon could permit other nations to follow using the same hardware and helps position American companies well in the global marketplace. A leader nation must move forward into new markets based on our research, aerospace industry and financial sector strengths rather than trying to recover industries already lost to portions of the world with lower labor rates. Energizing these industrial and financial strengths of America seem to happen in a declared war, but we, as a nation, must use the Congressional legislation and procurement regulations to stimulate this emerging commercial space launch industry and learn to mobilize the American strengths in peacetime for solutions critical to our future energy and resource requirements. Clean nuclear energy might be a goal worth mobilizing our nation to achieve.

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