

CHAPTER 5 – COST AND SCHEDULE CONSIDERATIONS

Rough Order of Magnitude (ROM) Costs, Schedules, Budgets

As described in Chapter 2 (The Means), the ‘vision’ of a new, reusable Space transportation system remains to be completed. Part of what was recommended in the late 60s and early 70s has been accomplished with the Space Shuttle: the cost and risk estimates presented in the early 70s have been borne out, including the two tragic losses of Shuttle Orbiters. The predicted failure rate (two failures in 100 flights) – using solid boosters – was slightly higher than the record to date. The predicted costs per flight were also close to those later experienced in operations. What went wrong in the past three decades is described in Appendix A in some detail, the principal cause being an essentially dysfunctional Government and Interagency ‘management’ structure and process, ill suited to achieve specific goals on a specific schedule.

Based on the analysis of literally hundreds of Space programs in the early 1970s and after exploring dozens of different possible approaches to the ‘infrastructure’ for deploying and sustaining a first permanent base on the Moon within a decade, the most cost-effective structure that emerges is the one outlined in Figure 2.2, an evolution of the Space Shuttle toward a full re-usable Space Transportation System. In addition, the specific implementation requires considerable trajectory analyses to outline mission support, communications and software infrastructure – so much so that Moon orbiting ‘mission support’ satellites are required for cost-effective operations.

Among the myriad possibilities but within, again, the constraints – budgetary and schedule in particular – one basic solution stands out, with two different possible mission profiles: in Figure 2.2 one Basic Mission and Technology profile is shown, with a Lunar Tug directly proceeding from LEO to the Lunar surface (the original Apollo mission profile), whereas in Figure 5.1 a LEO to Low Lunar Orbit Space Tug is matched with a Lunar Ascent and Descent Tug to accomplish the same mission.

For costing purposes, a specific mission and trajectory analysis was performed using the mission profile shown in Figure 5.1 [see Appendix B]. Based on these designs and assumptions, two separate and independent, fairly detailed, first order estimates were obtained – one accomplished in-house by NASA JSC and another accomplished independent of the NASA costing base, but using the best and most extensive available data base and technology status assessment within the Government and Aerospace

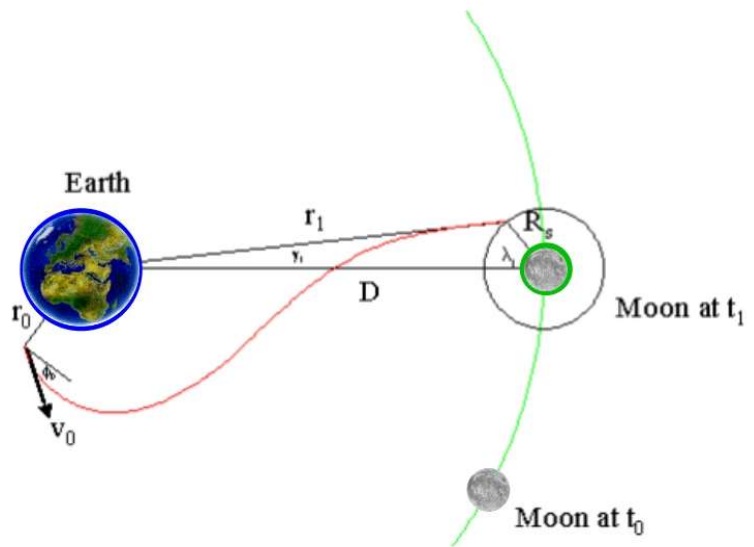


Figure 5.1 – Lunar Base Deployment Mission for Requirements and Costing Analysis

industry. Both assessments came up with a close to identical infrastructure, the one depicted in Figure 2.2; the other in the detailed Summary Cost Table 5.1 below.

Before discussing the rough cost estimates, it is remarkable to note that both assessments came up with essentially the SAME Space Transportation System infrastructure as the most cost-effective way to reach the historic goal—establishment of a Lunar Base within a decade. Based on the existing know-how and knowledge base today, the most effective approach was judged to be by incorporating more current technology and then completing the other parts of the original Space Transportation System vision of the early 1970s in nearly identical ways.

Obviously many details remain to be worked out and clearly further ‘optimization’ can and must occur at a system and subsystem level – but the basic parameters are set and obvious. They constitute a fundamentally different approach than the ‘brute force’ approach of the Apollo program, with a much more flexible and useful infrastructure deriving therefrom for future operations throughout Cis-Lunar, Trans-Lunar and future planetary missions.

Based on these assumptions and qualifications the cost estimates for all major infrastructure components are listed in Table I below. Based on Table I and the second, NASA in-house cost estimate, it is anticipated that the total cost for returning to the Moon and establishing an operational presence there would be **between \$50 billion and \$75 billion**, with \$50 billion as the best estimate. The \$75 billion estimate includes not only additional infrastructure elements, such as Moon-orbiting satellites, but also a hefty 30% uncertainty factor.

It should be noted that the **\$50 billion best estimate** may be reduced as further mission parameters are optimized and refined, as was the case in the Apollo days. At the time of President Kennedy’s decision to go to the Moon in 1961, none of the infrastructure components had been built, nor had been conceived the alternative actually employed to orbit and land on the Moon. This later accepted approach helped to reduce substantially overall mission costs. Costs can also escalate, but contrary to widely held beliefs such escalations are not ‘inherent’ to aerospace industry. In many cases cost growth has resulted from undue delays and ‘stretching’ and what can be called ‘inside the beltway program management’ – a unique system between NASA, Space Interagency Groups, other entities such as OMB, Congress and sometimes even the Judiciary. A sad example is the ‘management’ of the Shuttle development and operation resulting from this unique ‘management’ setup [see Appendix A].

When government and industry have been committed to the achievement of a set goal within a specified time, U.S. aerospace industry has performed quite well, often ahead of schedule and within budget – in some cases giving rise to true legends such as the ‘skunk works’. Very often these unique achievements are never made known, or can be revealed only decades later. It is this management spirit that has to be brought to achieving this proposed goal.

Table 5.1
 Summary of ROM Estimates of Lunar Base Costs within a Decade

ELEMENT	Build	Total		Total		Missions in 1st 10 years	Guess At Cost Per Flight	Total Recurring	Total 10 Year Cost
		Non-Recurring Inc 12% I&T	Non-Recurring Inc NASA	Non-Recurring Inc NASA + 30% Uncertainty	Non-Recurring Inc NASA				
		M 2006 \$	M 2006 \$	M 2006 \$	M 2006 \$		M 2006 \$	M 2006 \$	M 2006 \$
Shuttle C	6	11210	14570	18940		4	300	1200	20140
Sep Crew Module + Liq Boosters	4, 12	8280	10770	14000		4	500	2000	16000
Mod to Orbiters for SCM	4	1200	1560	2030					2030
Certification of new Orbiter	4	2000	2600	3380					3380
Cis-Lunar Chemical Tug	6	4240	5510	7160		4	50	200	7360
Lunar Ascent/Descent Stage	4	3000	3900	5070		4	50	200	5270
Initial Lunar Habitat	3	470	610	790					790
Airlocks, Dock Mech & S/W	20, 20, 3	1180	1530	1990					1990
Lunar Satellites	12	1110	1440	1670		6	70	420	2090
Lunar Truck	4	3160	4110	5340					5340
Lunar Nuc Power System	1	4260	5540	7200					7200
SEP Tug	NA	870	1130	1470		0			1470
Total		40980	53270	69040				4020	73060

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These overall costs break down as follows:

A. Improving and modifying the Space Shuttle, including

- **Separable Crew Module (SCM)** for Shuttle, also usable for manned Tug/Lunar Lander and ISS rescue. Such an SCM will be able to get off the stack and save the crew in case of an emergency during launch and can be mated in-orbit with the chemical propulsion Tug. The SCM will have it's own solid rocket propulsion system (for abort), parachutes (parafoils) and be able to accomplish non-powered water and runway landings. The costs include design and production of a new separation system;
- **Liquid Boosters** to replace the Solid Rocket Motors (SRMs)
- **Upgrade Shuttles** to current technology
- **Modifications and Certification** of four Orbiters;

The RDT&E (Research, Development, Testing and Evaluation) and the build of 5 (five) SCMs and 12 (twelve) Liquid Boosters is estimated at about \$2.6 billion in RDT&E and \$5.6 billion in production costs. The costs of modifying the existing orbiters are estimated roughly at \$1.2 billion; and the cost of certifying Orbiter with Separable Crew Cabin is estimated at \$500 million per orbiter for a total of \$ 2 billion for four orbiters.

B. Shuttle – C (Cargo Shuttle): to transport large systems components beyond the capabilities of the Shuttle to LEO a cargo version of the Shuttle is a logical evolution and extension of this unique technology base. The basic requirements to accommodate all the volume and mass requirements deriving from the requirement to deploy a permanent Lunar Base within a decade are:

- Three SSMEs (Shuttle Main Engines) on the rear end of a payload support sled and fairing
- Liquid Boosters
- A 5 (five) ft stretch to the Liquid Hydrogen Tank
- Capability to lift ~185,000 pounds payload, consistent with Evolved Shuttle Class system (93.5×10^6 tons to 30X150nm ellipse at 28.5 degrees inclination)

Technical analogies and experience base: Shuttle Orbiter and past Shuttle-C designs.

The estimated costs for RDT&E and procurement of 6 (six) Shuttle-Cs are

- Non-Recurring \$2.1 billion
- Recurring \$9.1 billion

C. Cis-Lunar Chemical Tug (CLT), with basic design capabilities as follows:

- Re-usable LOX/LH2 Upper Stage capable of cargo or crew transfer from LEO to LLO (Low Lunar Orbit)
- With aero-break capabilities when returning to LEO
- Assumed mass fraction of 0.8, assumed to accommodate crew support, Thermal Protection System for aero-braking, and a highly reliable, robust, reusable design
- Approximately 115K lbs of propellant, 29 K lbs inert weight

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- Starting with 181K lbs (82 ton) in LEO (delivered by Shuttle C) Tug can deliver
 - A maximum payload of 32K lbs to LLO and return to LEO, sized for an initial rigid Habitat; and
 - Nominal operations assume delivery of Lunar Descent/Ascent Stage propellant of + 15K lbs from LEO to LLO and return 11K lbs to LEO from LLO using aero-capture.

Technology analogies/base: Tanks from Shuttle External Tank experience, engine heritage an RL-“X” from Centaur RL-10, Avionics from Orbiter, Thermal Protection System for aero-braking from Orbiter.

The resulting RDT&E and procurement costs for 6 (six) CLT Tugs (two for development) are:

- Non-Recurring Costs \$2.4 billion
- Recurring Costs (Production) \$1.8 billion

D. Lunar Ascent/Descent Stage (LADS): with basic design characteristics as follows:

- LOX/LH2 LADS for transportation between LLO, Lunar surface and back initially the Cis-Lunar Tug carries LADS propellant for one round trip on each of its nominal operations flight requires fuel transfer in LLO
- Once SEP Cargo Hauler and Propellant Depot are established LADS will not require Cis-Lunar Tug to bring propellant
- Mass fraction is 0.8, sufficient to support crew and of highly reliable, reusable design approximately 23K lbs of propellant and nearly 6K lbs of inert weight
- Maximum Payload from LLO to Lunar surface and empty return is 32K lbs
- Nominal operations assume down payload of 15K lbs and return (up) payload of 11K lbs to LLO

Technology analogies/bases: derived from parameters and assumptions for LOX/LH2 Cis-Lunar Tug (i.e. same as stated above).

Estimated costs for the LADS for an initial build of 4 (four – of which 2 for development):

- Non-Recurring \$450 million
- Recurring (Production) \$2.5 billion

E. Initial Lunar Habitat: probably the ‘Infrastructure’ item most open to change with further study of optimization and expansion due to desired missions from the scientific, technical and user community in start-up phase. The specific initial tasks and missions can and will be determined over the first part of the decade, and can be expanded as the initial habitat grows and expands with the myriad of scientific, technical and user community demands identified. For purposes of costing the initial Habitat and making use of the ISS technology base and experience, the requirements were based on a Rigid Cylinder analogous to ISS MPLM with a mass changed from 10.500 lbs for ISS MPLM to 30.5. lbs for an initial Lunar Habitat and a length of 60 ft.

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Based on these analogies and technology experiences the estimated costs of RDT&E and initial built of 3 (three) for the Habitat are

- Non-Recurring \$210 million
- Recurring (Production) \$260 million

F. Lunar Satellites: to meet the necessary communications, navigation and positioning requirements for real time Lunar space transportation and lunar surface operations a number of such satellites will be deployed around the Moon. For costing purposes, the technical analogies and experience base were 'scaled' GPS satellites, with the mass scaled from 1.850 lbs to 1.110 lbs (60%).

Based on this analogy the RDT&E and an initial build of 12 (twelve) satellites are

- Non-Recurring \$160 million
- Recurring (Production) \$950 million
- The Launch costs to Lunar orbits, assuming 2 (two) satellites per launch, are 6 (six) Launches at \$70 million / launch, or \$420 million

G. Lunar Utility Vehicle (LUV, Truck): the Lunar Utility Vehicle is used to transport cargo and crew from Lunar surface LADS landing site(s) to the Habitat, off-load the LADS and place payload(s) at appropriate site(s). The LUV will also be the initial Lunar Excursion Vehicle for trips from the Habitat for various exploration missions.

Technical analogies and experience base: the Apollo Lunar Rover, with the mass scaled from 509 lbs to 10.200 lbs (twenty times larger). Based on these requirements the estimated costs for RDT&E and initial build of 4 (four) are estimated to be

- Non-Recurring \$2,2 billion
- Recurring (Production) \$950 million

H. Solar Electric Propulsion Lunar Tug (SEP-LT): a key technology component, enabling a new era in Cis-Lunar Space transportation and high synergism with the early development of Lunar Solar Power (LSP) systems. For purposes of the Infrastructure cost and schedule estimates RDT&E for such a SEP Lunar Tug stage is included based on the following design parameters

- (one) MW – probably magneto-plasma-dynamic)
- 50K lbs dry weight
- Xeon at 3800 sec ISP (specific impulse)
- Trip time ~ 90 days

Based on these design requirements the RDT&E (excluding production) is estimated at \$870 million.

I. Lunar Nuclear Power: for initial start-up a nuclear power plant is considered (another possibility being an immediate Lunar Solar Power (LSP) facility. Such a nuclear powered electric generator is assumed to provide 100KW electric.

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Technical analogies and knowledge base: Power systems being postulated by the Prometheus program and from the Cassini RTGs. Based on these requirements and assumptions the estimated RDT&E and initial build

- Non-Recurring \$670 million
- Recurring (Production) \$3.6 billion (including 40 kg of reactor grade plutonium)

J. Docking Mechanisms and Airlocks: extensive transfers of crew/cargo in LEO and LLO are required, necessitating a full development of appropriate interface systems.

Technical analogies and knowledge base (albeit Russian – Vladimir Syromiatnikov) are Apollo-Soyuz, Shuttle-Soyuz, Soyuz-ISS and Shuttle-MIR and US experience with Shuttle/ISS. Based on these assumptions and analogies the estimated RDT&E and initial build of 20 (twenty) each are

- Non-Recurring \$20 million
- Recurring (Production) \$160 million

K. Software: one of the most demanding and difficult parts of estimating costs. Based on technical analogies and experience with the Shuttle avionics, the RDT&E and Production Non-Recurring cost of the requisite software is estimated to be \$1.0 billion.

L. Other Cost Estimates. Many variations in the design parameters, mission profiles, technical assumptions are possible. Many elements in this Shuttle-derived Space Transportation System can be ‘optimized’, changed, and improved upon. Yet, the estimates presented above are believed to be a good first cut based on a solid, ‘bottoms-up’ approach, minimizing risky or speculative advances or programs wherein the schedule may be questionable. For example, a start-up Lunar power supply system using a Nuclear 100KW plant is included, although it may be entirely possible to immediately deploy a Lunar Solar Power plant of this capacity. If so, one significant saving can be affected, particularly when considering the synergies with an SEP-LT.

A significant part of these investments will be incurred if recommendations from the Gehman Commission for Shuttle operations are carried out over the next decade.

One other significantly, detailed estimate on such an evolved reusable STS is shown in summary form in Table 5.2. The estimate is based on NASA in-house efforts at JSC.

Table 5.2

LUNAR COST ESTIMATE SUMMARY (RY\$)

- OMV/CTV/XTV Modular Space Tugs
- STS-Derived Launcher- Liquids
- 2014 IOC Estimate: \$ 40 to 55B
- Estimate per mission: \$ 10 to 12B

In Scope: OMV/CT Lunar Crew/Cargo Space Tug(s), PPM, Stage, Lunar Rover and Initial EVA C Derived Ops & Facilities,
Out of Scope: Shuttle, ISS mods,

NGLT Estimate: \$3.0B
(FY03-FY08)

SLEP Estimate: \$2.0B
(FY03-FY08)

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Many basic elements in this cost estimate are similar to the assumptions in Table 5.1; nevertheless significant other elements are included – such as an Orbiting Maneuvering Vehicle Tug in addition to the Lunar Cargo and Crew Tug. On the other hand, SEP Tug costs are not included herein, nor are Shuttle modifications and recertification.

The two estimates are remarkably similar in the basic finding, namely that building on the existing U.S. Space Transportation technology base provided by the Shuttle and the ISS the U.S. can commit to the deployment of a First Lunar Base within a decade for an estimated cost of between \$5 billion to \$7 billion additional annual funding of NASA – or a 30% to 50% increase in the current, eroded funding of the U.S. Space effort of the past decade – for a total of about \$50 billion.

“[Within a decade], the Space Station module continues in polar orbit, and a Space Station Module is emplaced on the Lunar surface, while a nuclear shuttle provides four trips per year from Earth orbit to Lunar orbit. The space base is now permanently manned, and the LM-B [Lunar Module-B] provides large payload capabilities between Lunar orbit and surface. In-depth geological exploration near the base now begins, including very deep drilling, and exploration of Lunar resources – especially hydrogen and oxygen from water or minerals – can begin. Large optical, x-ray, and gamma ray telescopes can be erected near the base.

“The planned program leads toward the goal of the Lunar Exploration Program – To explore and utilize the Moon for the benefit of mankind.

“If this goal is pursued with a suitably supported program of exploration, it is possible that the following levels of achievement could be reached [within another five years]: To have explored all major regions of the Moon; and To have established a permanent Lunar base.

“. . . The establishment of a Lunar base would provide a center for continued exploration activity and furnish laboratory space for specialized science, applications and technological research that requires or utilizes the Moon’s unique environment or its isolation from Earth. It would permit, for example, erection and operation of large radio, x-ray and optical telescopes on the surface. This would be an important milestone in the effort to utilize the Moon for the benefit of mankind.

“In looking forward to man’s possible future in space exploration, the base could also be used to develop man’s capabilities to operate for extended periods of time on another planet and for training for manned planetary exploration. The availability of laboratory facilities would also furnish opportunities cooperative participation by other nations.”

***An Integrated Program of Space Utilization for the Decade 1970-1980
The Space Task Force, June 19, 1969, p. 2-131-132***