

Comparative Configurations for Lunar Lander Habitation Volumes: 2005-2008

Marc M. Cohen

Northrop Grumman Corporation

Copyright © 2009 SAE International

ABSTRACT

This paper presents an overview of the progression of the contemplated candidate volumes for the Lunar Lander since the beginning of the Vision for Space Exploration in 2004. These sets of data encompass the 2005 Exploration Systems Architecture Study (ESAS), the 2006 Request for Information on the Constellation Lunar Lander, the 2007 Lander Design Analysis Cycle -1 (LDAC-1) and the 2008 Lunar Lander Development Study (LLDS). This data derives from Northrop Grumman Corporation analyses and design research. A key focus of this investigation is how well the lunar lander supports crew productivity.

INTRODUCTION

Under the Constellation Program for exploration systems, NASA has engaged with the industry and academic communities on the analysis, design, and development of concepts for the crewed Lunar Lander. This interaction has followed two-year cycles of NASA publishing a concept, followed by the industry responding with a review of the design and innovative ideas. Northrop Grumman's approach defines crew productivity as how well the system supports the crew to perform their mission. The first order metrics for crew productivity are how efficiently the crew can use their time and how safely they can do their jobs.

In the first cycle, in 2005, NASA published the Exploration Systems Architecture Study (ESAS), which

focused upon the Orion CEV but included a substantial chapter on the Lunar Surface Access Module (LSAM). In 2006, NASA issued a Request for Information for the Lunar Lander Concepts Requirements Description, based largely upon ESAS, to which industry responded (which soon became known as the Constellation Lunar Lander or CLL). In the second cycle in 2007, NASA published the Lander Design Analysis Cycle – 1 (LDAC-1). In 2008, industry responded to a NASA Broad Area Announcement for the Lunar Lander Development Study (LLDS) based on LDAC-1.

This paper identifies the habitable volume allocation in each of these four studies of the Lunar Lander and examines the design assumptions for each lander option. As these study cycles progressed, there has been considerable variation in functional allocation and total volume. In the 2005 ESAS, NASA allocated 16 m³ for the habitation function in addition to the Ascent Module (AM). In our 2006 CLL RFI response, Northrop Grumman recommended a 23.2 m³ habitation volume. In the 2007 LDAC-1, NASA proposed a bare-bones minimum functionality of 10 m³ for the entire Ascent Module, including all habitation functions. In the 2008 LLDS, Northrop Grumman recommended a 19 m³ Ascent Module, incorporating the habitation functions. TABLE 1 presents these volumetrics. The Summary presents a comparative break-down and analysis of these volumes.

This paper traces the progress of the Lunar Lander habitation concepts through this formative period of analysis and design. It makes some observations and

remarks about the amount of free circulation volume necessary for the crew of four to live and work in the Ascent Module in space and on the lunar surface for the mission durations specified by NASA.

THE LUNAR MISSION TIMELINES

The lunar lander story begins with NASA's publication of several sets of lunar mission timelines. TABLE 2 shows these timelines specifying the durations for the mission segments, which can vary substantially over the contemplated time spans. The most detailed set of data came from NASA Exploration Systems Mission Directorate (ESMD) at the December 2006 2nd Space Exploration Conference in Houston (Lavoie, 2006). It is the only set of mission profiles to date that addresses

the Outpost Construction missions from 14 to 30 days. The 2008 Exploration Life Support Metric (Yeh, 2009) is the most recently published, and is consistent with the Exploration Conference for both Sortie and Outpost Occupancy missions.

Although the relationship between mission duration and volume is well-established in an empirical sense (Cohen, 2008), it has yet to be reflected in design concepts for the "extended duration" lunar landers shown in TABLE 1 or in the Lunar Surface Outpost. However, the designs of the lunar lander until now focus upon the transportation aspect of the mission requirements, while neither yet addressing the requirements for the crew to carry out the mission, nor the integration of the vehicle with the habitation systems for longer outpost missions.

TABLE 1. Pressurized volume in meters³ for various recent Lunar Lander baseline concepts.

	2005 NASA ESAS LSAM	2006 NGC Constellation Lunar Lander RFI Response	2007 NASA Lander Development Analysis Concept (LDAC-1)	2008 NGC Altair Lander Development System Study (LLDS)
Ascent Module (AM)	10	8	10	8
Habitat Module (HM)	16	23.2	none	11***
Airlock (AL)	8*	10*	7.5 to 8**	8**
TOTAL Pressurized Volume	34	41.2	18	27

* Requirement for four crew members to transit the airlock at one time.

** Requirement for two crew members to transit the airlock at one time.

*** Habitat function combined with Ascent Module in one module.

TABLE 2. Candidate Lunar Exploration Mission Durations

Mission Type	2005 ALS Metric pp. 7- 42.	2005 ESAS pp. 200-209.	2 nd Exploration Conference pp. 19, 34-41.	2006 ELS Metric, p. 40.	CxP-70007 Lunar DRM pp. 13-16.	2008A ELS Metric pp. 29-31.
CEV-Cislunar Transit	14 days	14 days	N/A	18 days	N/A	N/A
Lunar Sortie	6 days	7 days	N/A	5 days	7 days	N/A
Outpost Build-up, Years 1-2	N/A	N/A	7 days	N/A	N/A	N/A
Outpost Build-up, Year 3	N/A	N/A	14 days	N/A	N/A	N/A
Outpost Build-up, Years 4-5	N/A	N/A	30 days	N/A	N/A	N/A
Outpost Occupancy	98 days, "Destination Surface System"	6 months	6 months	181 days "Lunar Outpost"	N/A	3600 days
Maximum Surface Mission Duration	118 days	~194 days	> 6 months	204 days	210 days	180 days (no contingency)

LUNAR LANDER CONFIGURATION VOLUMETRICS

TABLE 1 shows the pressurized volume results from four baseline studies for the lunar lander. It explicates the designations of the modules and the allocation of functions and volumes to them for these four efforts:

- 2005 NASA ESAS LSAM
- 2006 Northrop Grumman RFI Response
- 2007 NASA LDAC-1 Lander
- 2008 Northrop Grumman LLDS concept.

2004-2005 CONCEPT EXPLORATION AND REFINEMENT STUDY

Soon after President Bush announced the Vision for Space Exploration (VSE) in February 2004, NASA solicited proposals and awarded 11 contracts for the Concept Exploration and Refinement Study (CE&R). While most of this study addressed the Crew Exploration Vehicle (CEV, later named Orion), part of it addressed the lunar lander that would become part of the Constellation Systems to carry out the VSE. The lander requirements in the CE&R were rather flexible, and did not afford a rigorous treatment of pressurized volumes for the crew.

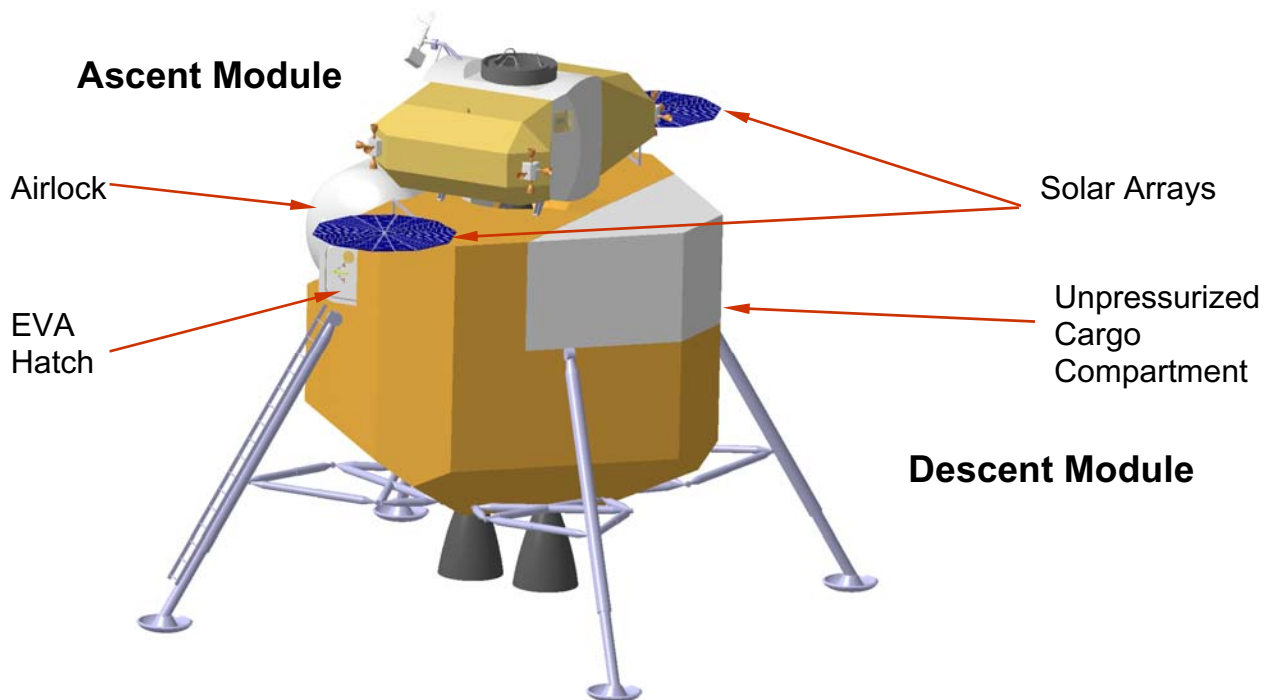


FIGURE 1. Northrop Grumman sketch of a lunar lander concept for the 2004-2005 CE&R study. Drawing credit: Bruce Rouleau.

In performing the CE&R study, Northrop Grumman began to address some of the broader configuration issues such as minimizing the distance the crew would need to climb for access to the lunar surface and accommodating cargo on the descent stage so that it too would be closer to the surface for easier unloading. FIGURE 1 shows one Northrop Grumman concept from the CE&R, with a split in the pressurized volumes between an Ascent stage and a separate EVA airlock that is part of the Descent module. A flexible tunnel would connect the Ascent Stage to the EVA Airlock.

2005 ESAS LUNAR SURFACE ACCESS MODULE CONCEPTS

NASA published its first family of concepts for the Lunar Surface Access Module (LSAM) in the Exploration System Architecture Study (ESAS) report. This chapter designated a fixed volume of 10 m³ for the piloting and ascent function, 16 m³ for the habitation function and 8 m³ for the airlock. ESAS decomposed the problem of assigning these volumes to three configurations of pressurized volumes. These three configurations appear in FIGURES 2a, 2b, and 2c.

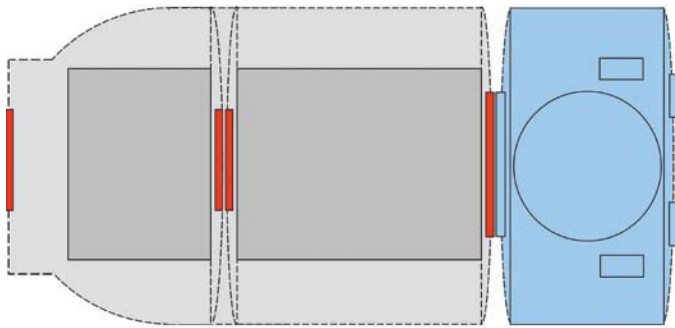


FIGURE 2a. NASA ESAS Concept A for the LSAM combined Airlock/Habitat Module on the left in grey and the separate Ascent Module on the right in blue, connected by the red tunnel.

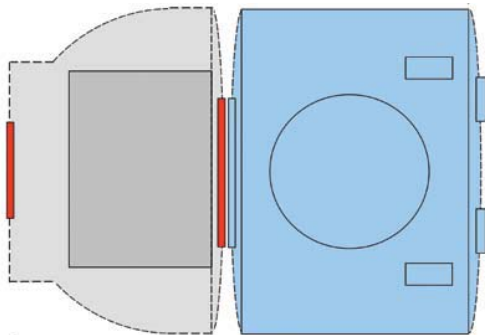


FIGURE 2b. NASA ESAS Concept B for the LSAM combined Ascent Module and Habitat Module on the right and the separate Airlock module on the left, connected by the red tunnel.

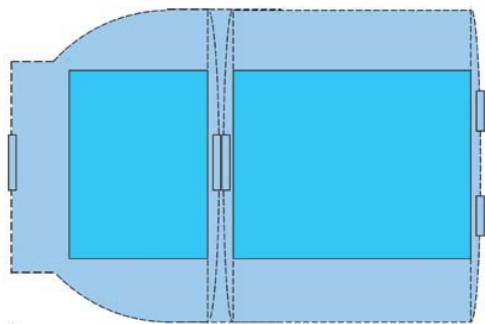


FIGURE 2c. NASA ESAS Concept C for the LSAM as an “all-in-one-module” combining Airlock, Ascent and Habitat Module; all three functions share a single outer envelope, although the Airlock and Ascent Module comprise separate pressure vessels.

The ESAS approach assumed that the functionality and volume to accommodate the crew and their mission would be exchangeable from one configuration to the next. Northrop Grumman’s analysis indicates that both functionality and volumetric allocation must adapt and change in response to the ways in which the designers assign and configure the modules. As an etiological note, where the CE&R Study employed the Apollo Lunar Module nomenclature of Ascent Stage and Descent

Stage, the ESAS used Ascent Module, Habitation Module, Descent Module and Airlock (module), making it linguistically possible to distinguish the piloting station from the living environment. FIGURE 3 shows an interpretation of the module configuration that represents ESAS Concept A (FIGURE 2a) as developed by NASA’s in-house Lunar Architecture Team (LAT) atop a full lander configuration.



FIGURE 3. NASA Lunar Architecture Team LAT-1 concept for LSAM Concept A with combined Airlock and Habitat; it has a separate Ascent Module. Credit: NASA.

FIGURES 4 and 5 show the interior of the 2006 Ascent Module Mockup by Kriss Kennedy at NASA-JSC. This design exercise began during the ESAS deliberations using the same volumetric value of 10 m^3 , but it is not constrained by the ESAS assumptions about geometry shown in FIGURE 2. Rather, the mockup in FIGURE 4 shows an effort to understand the architectural design problem of the lunar lander ascent stage on its own merits. FIGURE 4 shows two side-by-side pilot stations with different candidate window geometries and potential locations for controls and displays. While flying this lander, the two pilots would stand in front of the flight deck and the other two crewmembers would stand behind them. One notable feature is the shallow ledge below the window that could accommodate switches, other controls, or small displays. The two hand controllers (joysticks) appear both in the right hand position in front of each window.

FIGURE 5 shows a detail of the interior, including the protrusion of the engine head cover rising through the floor deck. Behind the engine cover is the EVA hatch, about the same size and in roughly the same position relative to the floor as the Apollo LM EVA hatch. The

main difference is that the LM EVA hatch was on the front side of the LM, below the two windows whereas Kennedy's is opposite the windows and control consoles.



FIGURE 4. Interior of 2005 Ascent Module Mockup by Kriss Kennedy at NASA-JSC. Photo credit: author, December 2006.



FIGURE 5. Detail of the Interior of the Ascent Module, 2006, showing the EVA hatch in approximately the same position as on the Apollo LM, behind the top of the ascent engine head shell. Photo credit: author, December 2006.

2006 CONSTELLATION LUNAR LANDER RFI

In May 2006, NASA released the Lunar Lander Concept Requirements Description Request for Information, better known as the Constellation Lunar Lander (CLL) RFI. The RFI defined several “concept study products,” of which the two most relevant to crew habitation and operations were:

- Innovative lander design concepts
- Concepts for integration of the lander and surface systems, e.g., deployment of surface outpost habitation

The goal of integrating the lander with an outpost led the Northrop Grumman team to identify functional allocations that would serve not only the primary flight and landing function of the CLL, but also its continued

life as part of the lunar surface infrastructure. In formulating these concept study products, the RFI stated these “fixed requirements:”

- Dual Rendezvous mission mode, Earth Orbit Rendezvous plus Lunar Orbit Rendezvous (EOR+LOR).
- Cargo Launch Vehicle (CaLV) Trans-Lunar Injection (TLI) capability from 296 km (160 nmi) circular (assuming 20 mT CEV at TLI) for the payloads and shroud diameters shown in TABLE 3.
- Cargo mission (single launch) TLI mass: 53.6 mT.
- Low-Impact Docking System (LIDS).

- LSAM performs attitude control and Trajectory Correction Maneuvers) TCMs during trans-lunar coast.
- LSAM performs lunar orbit insertion, deorbit, powered descent, hazard avoidance, terminal landing, ascent, and rendezvous.
- CEV remains in 100 km (54 nmi) circular Low Lunar Orbit (LLO).
- 4 crew members for lunar missions
- 500 kg minimum science/technology down payload to lunar surface
- 100 kg minimum up payload return from lunar surface to Earth
- Surface airlock [The RFI requirements called for four crewmembers to transit the airlock at the same time].

The 2006 RFI also stated these “desirements:”

- Common systems with CEV
- 2200 kg of additional landed cargo payload on crew flights
- Leaving hardware behind that can be used for incremental Outpost buildup
- Capable of reuse or evolving to reusability
- Unpressurized cargo stowage volume
- Ease of surface access for crew and cargo
- Extensibility to a dedicated cargo lander

The *desirement* for commonality with a dedicated cargo lander gave the lunar lander an aspect of being a robot that can also carry people. From this robot cargo lander, the “derived desirement” for autonomous landing and hazard avoidance suggests that the lander can perform its mission without intervention by the crew. Unfortunately, this construct can lead to overlooking the importance of excellent human system integration for the crew to pilot the lander and to explore from it on the surface. On the contrary, the plan for an autonomous cargo robot vehicle does not reduce the imperative to design a crewed flight vehicle that accommodates the pilot’s requirements to see ahead where he or she is flying, to provide the best flight handling qualities, and to make a safe piloted landing. This crew productivity question is pivotal for the pilot’s performance and the overall safety of the crew and the success of the mission.

The 2006 RFI also provided the values in TABLE 3 to show the relationship between launch vehicle shroud diameter and mass. During the 2006 RFI period of performance, the Northrop Grumman team found that the 8.4 m exterior diameter shroud was sufficient to accommodate the lunar lander concepts. As the

shroud diameter increases, so does the mass. The trade implicit in this table is that by making the lander descent module wider, it may be possible to lower the center of gravity and the top deck height.

The down mass payload of 500 kg and the up mass payload of 100 kg are key attributes of the Altair’s capabilities. These payload figures have stayed in the Altair requirement since first promulgated in May, 2006, so they appear to be stable and well-established within the Altair mission architecture. The *desirement* for 2200 kg in additional down payload remains a greater challenge. TABLE 4 compares these Altair values to their counterparts on the Apollo LM. These Altair payload masses are subject to two questions.

TABLE 3. Lunar Lander Shroud Diameter and Net Lander Payload to Trans Lunar Injection (TLI) from NASA’s 2006 Lunar Lander RFI.

Shroud Exterior Diameter (m)	Shroud Interior “Working” Diameter (m)	Net Lander Payload to TLI (mT)
8.4	7.5	45.0
10.0	8.8	40.7
12.0	10.3	38.0

500 kg Down Payload Mass -- The first question concerns whether this down payload is pressurized or unpressurized. NASA’s statements of vehicle level requirements so far have been silent on this matter. If the design of the Altair flight regime must include an abort during descent that carries 500 kg in pressurized payload, then all the other numbers should reflect it. For example, where in the vehicle would it be possible to stow so much pressurized mass? Given the rules of thumb that pressurized equipment in a spacecraft weighs on the order of 100 to 200 kg per cubic meter, then this 500 kg pressurized cargo would take in the range of 2.5 to 5 m³ of precious cabin volume.

100 Kg Up Payload Mass -- The second question is what are the implications of the 100kg up payload? TABLE 4 shows that it is less than the return mass in the Apollo LM missions, especially if one includes the sample boxes and the EVA suits with Portable Life Support System back packs. The Constellation Program plans two editions of a new space suit. *Configuration 1* is a lightweight space and flight suit attached to life support by an umbilical to the Orion or Altair life support system. This suit is known also as the Flight Operations (FO) or Launch, Entry, and Ascent (LEA) suit. *Configuration 2* is a space suit arranged to carry its own life support system as a PLSS, but that can also plug into Altair life support via an umbilical. This suit is known also as the Lunar Surface Operations (LSO) suit. *Configuration 2* suits will serve for the surface EVAs.