Life Support Systems for a New Lunar Lander

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A life support system concept has been developed for a new NASA lunar lander concept. The ground rules and assumptions driving the design of this vehicle are different from the Constellation Altair vehicle, and have led to a different design solution. For example, this concept assumes that the lander vehicle arrives in lunar orbit independently of the crew. It loiters in lunar orbit for months before rendezvousing with the Orion Multi-Purpose Crew Vehicle (MPCV), resulting in the use of solar power for this new lander, rather than fuel cells that provided product water to the life support system in the Altair vehicle. Without the need to perform a single Lunar Orbit Insertion burn for both the lander and the MPCV, the modules do not have to be centered in the same way, so the new lander has a smaller ascent module than Altair and a large habitat rather than a small airlock. This new lander utilizes suitport technology to perform EVAs from the habitat, which leads to significantly different requirements for the pressure control system. This paper describes the major trades and resulting concept design for the life support system of a new lunar lander concept.

I. Introduction

THE top level requirements that a life support system must fulfill stay very similar throughout all human spaceflight and exploration, but the designs necessary to efficiently meet those requirements can vary significantly depending on the mission type and other vehicle design choices. At the end of the Constellation program, NASA considered the broader options now available for performing lunar exploration, which is still an important destination for NASA and part of the campaigns considered as part of the International Space Exploration Coordination Group. The mission requirements for exploration were very similar to the Altair lunar lander. Changes that began at the mission architecture level with launch vehicle capabilities enabled configuration changes in the lander vehicle, and resulted in an updated life support system concept.

II. A New Mission Architecture

The new architecture under consideration was referred to as "Lunar Orbit Rendezvous", but perhaps might better be named "Two Lunar Orbit Rendezvous". The Orion vehicle and the lunar lander would each reach lunar orbit separately and rendezvous for crew transfer. After that, the mission progressed much like the Constellation or Apollo designs. The lander would descend to the surface with the crew to perform their mission. An ascent stage would return to lunar orbit to again rendezvous with the Orion vehicle. After the crew transferred back to Orion to return home, the ascent vehicle would be left for disposal.

A. Lunar Orbit Insertion

In the Constellation architecture, the lunar lander's descent stage engines had to perform the lunar orbit insertion burn to move both the lander and Orion vehicles while they were docked together. This led to two major effects in the design that had great impact on the operation of the vehicle for lunar exploration.

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First, the descent stage propulsion for the lunar lander was very large. With a constrained diameter, it was very tall, making EVA access difficult and placed the center of gravity at landing (when the tanks were close to empty) very high.

Second, there was a large force that had to be transmitted through the lander structure into the Orion vehicle. This resulted in a lander design that was essentially symmetrical so that the loads could be passed through a central path to the Orion centerline. This constrained the way mass could be distributed through the vehicle, and led to a large ascent module/habitat on the centerline, and smaller removable airlock that could be left behind.

Without these constraints, design options opened up that had the potential to improve the usability of the vehicle for human exploration of the lunar surface.

B. Lunar Orbit Loiter

The option to launch Orion and the lunar lander on the same kind of launch vehicle created difficulties at the same time that it opened up new options. The new launch vehicle was large and powerful, but it was assumed that the US could only perform so many of these launches each year for facility and cost constraints. The assumed rate was one every six months. From a safety perspective, it doesn't make sense to risk the launch of a crew if you're not sure the launch of the lander will be successful. Therefore, the lunar lander was to be prepositioned in lunar orbit six months before the arrival of the Orion vehicle and the crew. While this is clearly the right choice for human safety, the long loiter introduced new challenges for the lander vehicle.

C. Technology

The Constellation program was open to using new technology when it provided benefits, but constrained by schedule and the risk that using a new technology in the baseline design would introduce. In this new study, some technologies had matured to a higher technology readiness level than when they were considered for implementation in Constellation. Later dates for System Requirements Review (SRR) and Preliminary Design Review (PDR) meant that exceptionally promising technologies could be pushed to maturity,

III. Configuration Decisions

The requirements for life support system components are largely driven by the duration of time for which the crew uses the vehicle. For the lander system, the habitation, ascent, and EVA functions each presented different challenges. The design of the life support system components depends on how these functions are grouped into different modules. The other subsystems must also respond to the new requirements. The design of propulsion, power, structures, and EVA are interconnected with the life support system.

A. Propellant and Power

In previous lander designs for Altair, fluids were shared between the propulsion and power systems and the life support system. Those choices had to be re-evaluated as subsystems changed their designs. The long loiter time in lunar orbit meant that cryogenic fluids were more difficult to store and maintain. A methane-oxygen system was selected for the descent stage propulsion. Oxygen ullage could be scavenged after landing for use in the life support system. The power system design uses solar panels for the long loiter period. Solar power is also used on the surface since the panels are already present. There is no fuel cell to generate product water that the life support system can use, but at the same time, the power system does not scavenge any propellant for fuel cells.

B. Module Definition

Any mass that returns from the lunar surface to orbit is some of the most expensive in terms of fuel required over the mission. As a result, it's desirable to minimize the ascent stage design as much as possible. In the Altair design, performing LOI while docked to Orion meant that the ascent module had to be strong enough to transmit the loads and centrally located. That didn't leave room for a separate habitat, so the ascent module also served as the crew habitat, and the airlock was left behind to reduce ascent mass. In this design, no module needed to be centrally located, so a small ascent module was placed off center, leaving room for a larger habitat with airlock functionality. The life support system in the ascent stage can be optimized for short duration, while functions for habitability only need to appear in the habitat life support system. Some functions may be duplicated if it is more mass efficient than expanding the ascent module systems to supply the long duration

C. EVA Interfaces

EVA access and suit use were both impacted by the change in module configuration, and had to be considered while the decision was being made. The EVA suit architecture was still assumed to include a larger, more rigid suit with mechanical joints for surface exploration, and a more malleable soft suit for crew survival and landing. Some parts may be shared between both configurations. Crewmembers wearing the larger surface exploration suit will not fit in the small ascent module. Emergency strategies had to include the capability to change from the surface suit to the crew survival suit under many different conditions. Being able to group the habitat and airlock functions together in a module allowed the team to examine the use of a suitport architecture, rather than a traditional airlock. While propulsion may not seem directly tied to EVA, the removal of the requirement to perform LOI for the lander and CEV together and the propellant selection reduced the amount of propellant required for the descent stage. A shorter descent stage, and the ability to more freely manipulate the module location allowed the distance to the surface for EVA crewmembers to be greatly reduced compared to the Altair design.

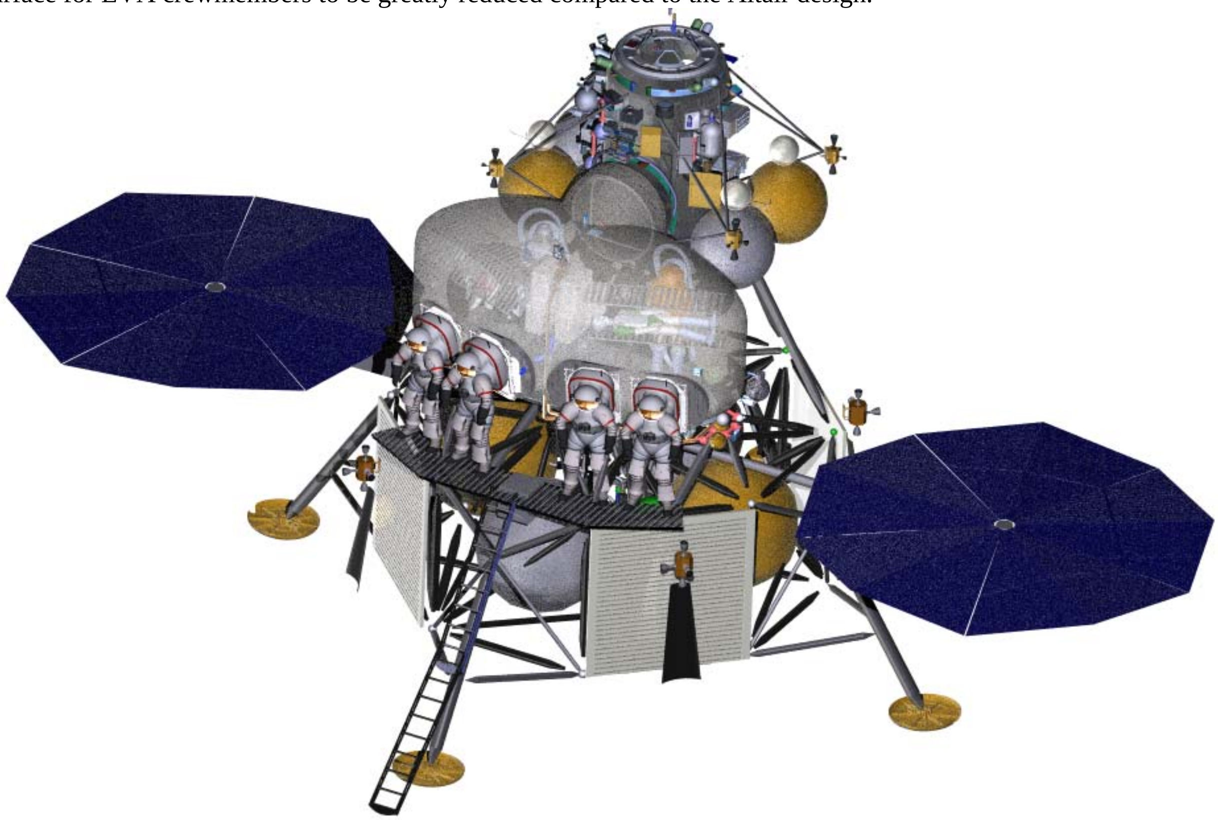

Figure 1: Lunar Orbit Rendezvous Lander Configuration

IV. Ascent Module Life Support

The ascent module life support system is designed most of all to minimize mass, power, and volume. It supports the crew for only 5 hours for descent to the lunar surface and 5 hours for ascent from the lunar surface. The crew is expected to be wearing spacesuits at all times, though visors may be up when not in actual powered flight phases.

A. Air Revitalization

The air revitalization system in the ascent module must control CO2 and humidity both in a suited mode, and in an open cabin in case crewmembers need to use the volume to change into their suits after an emergency. Thus, the air revitalization system has both suit connections and cabin vents. CO2 and humidity are removed by amine swing beds using a common canister design shared by the EVA Portable Life Support Systems (PLSSs). A small cabin fan helps mix the air, which is important when the lander is docked to the Orion vehicle and receiving low flow rates of clean air.

B. Pressure Control

The ascent module must be able to control oxygen and nitrogen pressure in nominal and emergency situations. Oxygen can be supplied directly to the suited crew members with a demand regulator. Nitrogen and oxygen can be introduced to the cabin. Besides metabolic makeup, driving requirements for the PCS include repressurizing the vestibule between the Orion vehicle and the ascent module, as well as a “Feed the Leak” scenario. For the ascent module, crewmembers should be suited whenever it is operating independently. The PCS was assumed to only need 15 minutes capability to allow the crew to secure visors and gloves, rather than 60 minutes to don suits. Overall, this results in a system very similar to the Altair ascent module PCS, but with reduced consumable quantities required.

C. Water

The ascent module has greatly reduced water system functionality compared to the habitat. Since the crew only occupies the ascent module for short periods of time, and is already wearing spacesuits, drinking water and waste management functions are assumed to be performed by the suit. The ascent module does have to support the liquid cooling garments for the suits. A pump to recirculate water, a heat exchanger, and a gas separator to remove bubbles are all included. These functions are considered important, but not necessarily critical survival, so redundant components are not included. The life support system does have to maintain water for use by sublimators in the thermal system. Overall the system carries no potable water for crew consumption, and only uses water for thermal management of the spacesuits or rejection of heat from the vehicle.

D. Conclusion

The ascent module supports suited crewmembers whose movements and activities are highly constrained by the small volume. Cabin pressure, gas composition, and temperature can be controlled. But in many ways, the ascent module performs functions very similar to a portable life support system. This design saves mass and better configures the volume by having the crewmembers share a system, rather than requiring the full capability for crewmembers wearing PLSSs sized for maximum metabolic rates.

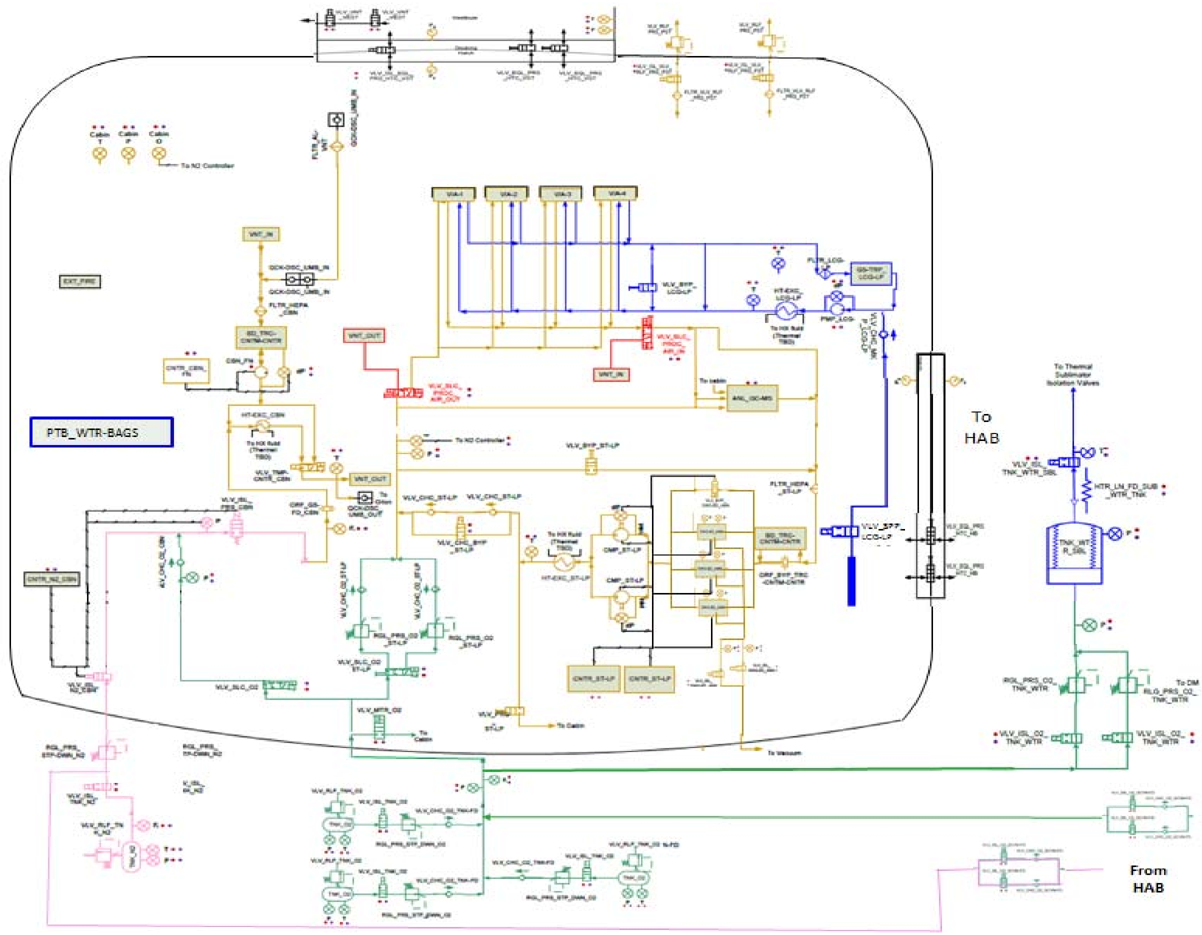

Figure 2: Ascent module life support system schematic

V. Habitat Module Life Support

The life support system for the habitat and EVA functions has much more functionality required than the ascent module. While mass is still important, usability and performance can be given more importance. Power is still important, but volume is not as strong of a constraint in the generously sized habitat module. The habitat supports the crew for half a day after landing, for six days of surface activity with EVA exploration, and for another half day before ascent, for a total of 7 24-hour days.

A. Air Revitalization

The air revitalization system in the habitat must support the crew during sleep, wake, and exercise periods. Since the occupied time is similar to the Altair mission, amine swing bed technology was again selected. Instead of units common with the Orion design, small units common with the PLSS components were selected so common spares could potentially be used. Initially, it seemed that a suit loop would not be required in the habitat. But in the even that the habitat cannot hold pressure, crewmembers will need to be able to stay in a suit while moving into and out of the ascent module, so they can pressurize it and change from the surface suit to the soft suit that would be worn for ascent. The crewmembers will not fit in the ascent module with PLSSs on. Since only two crewmembers will likely fit in the ascent module with two suits each, they must take turns. Umbilicals are needed to support those who have already changed to the soft suits while the third and fourth crewmembers change. This contingency drives the need for umbilical connections for air revitalization.

B. Pressure Control

Much of the habitat pressure control system in the habitat is the same as the ascent module design. The primary changes are to support frequent EVA exploration. Scavenged oxygen pulled from propulsion tanks must be compressed and stored so that it can be used to quickly refill PLSS tanks. The scavenged oxygen boils off slowly, so it must be gathered slowly during the day. The PLSSs are refilled as soon as the crew returns from an EVA. More oxygen can be scavenged slowly overnight. Before beginning an EVA the next day, the crew uses nearly half of the oxygen in the PLSS tank to purge the suit til it reaches >95% O_2. The oxygen that had been scavenged overnight is used to quickly refill the tanks before the crewmembers depart from the habitat. A mechanical compressor is used to gather the oxygen from the 30-50 psia propulsion tanks to 3500 psia in the storage tank, so that the PLSS tanks can be filled to 3000 psia. The gas stored in the tank up to 3000 psia is always available for emergencies in the habitat or a suit. With this design, the pressure control system can provide oxygen in both nominal and emergency cases without the mass for tanks to deliver and store large quantities of oxygen.

C. Water

The habitat module must store all the water required for the mission, and deliver it to the crew for potable water and EVA use. Since all the water must be provided at launch, a silver ion residual biocide would be added when the tanks are filled. Stored water either needs to be conditioned to prevent freezing. Since the habitat has a large volume, the water is stored inside, rather than outside. Water can be delivered through a valve with septum, one of which is placed for food rehydration and drinking water, and one is placed closer to the hygiene area. A small reservoir of water is fed from the storage tank and heated for use in rehydrating certain kinds of food. The water system also must supply water to the EVA PLSSs. Water must be supplied to refill water tanks, but until the PLSS can operate its own thermal control, water can be recirculated and cooled.

D. Waste

NASA engineers intend to keep the human interface to waste collection systems as common as possible across future vehicles for sharing parts and keeping training simple and usability as easy as possible. Solid waste is collected in canisters that can be left behind when the crew returns to the Orion vehicle in lunar orbit. In the Altair lander design, the urinal on the ascent module was intended to vent urine directly overboard to minimize mass. After more detailed analysis, it was determined that an orifice sized to vent liquid waste without allowing it to vaporize and cause freezing issues would restrict flow to rates lower than the rate at which the human body can generate urine. Venting urine would require at least a holdup volume to contain urine so that it could be vented more slowly. A venting system needs to be made of metallic components to be compatible with heaters that can prevent freezing blockages in the lines. Instead, a storage tank made of a lightweight nonmetallic material was selected as the lightest weight system. From a user perspective, the waste collection system should be very similar to the Orion system. But inside, it can be simplified to remove fans because gravity can be used to manage phase separation, and wastes will be stored in the habitat and left behind on the lunar surface.

E. EVA

The habitat EVA interfaces are focused around the suitports used to provide access to don the surface exploration suit, and go out onto the surface to be explored. The small volume of gas trapped between the suitport hatch and PLSS cover does not significantly disrupt the habitat pressure control, unlike the large airlock in the Altair volume. PLSS recharge occurs in much the same way as before, but the location of the connections may actually be external to the vehicle. There is still some debate as to whether the suits can be launched already configured in position in the suitports. If they can be, they will need thermal conditioning and physical support. For the life support system, the worst case is that they must be shipped inside, requiring an initial EVA out a side hatch with complete habitat depressurization in order to dock them into the suitports.

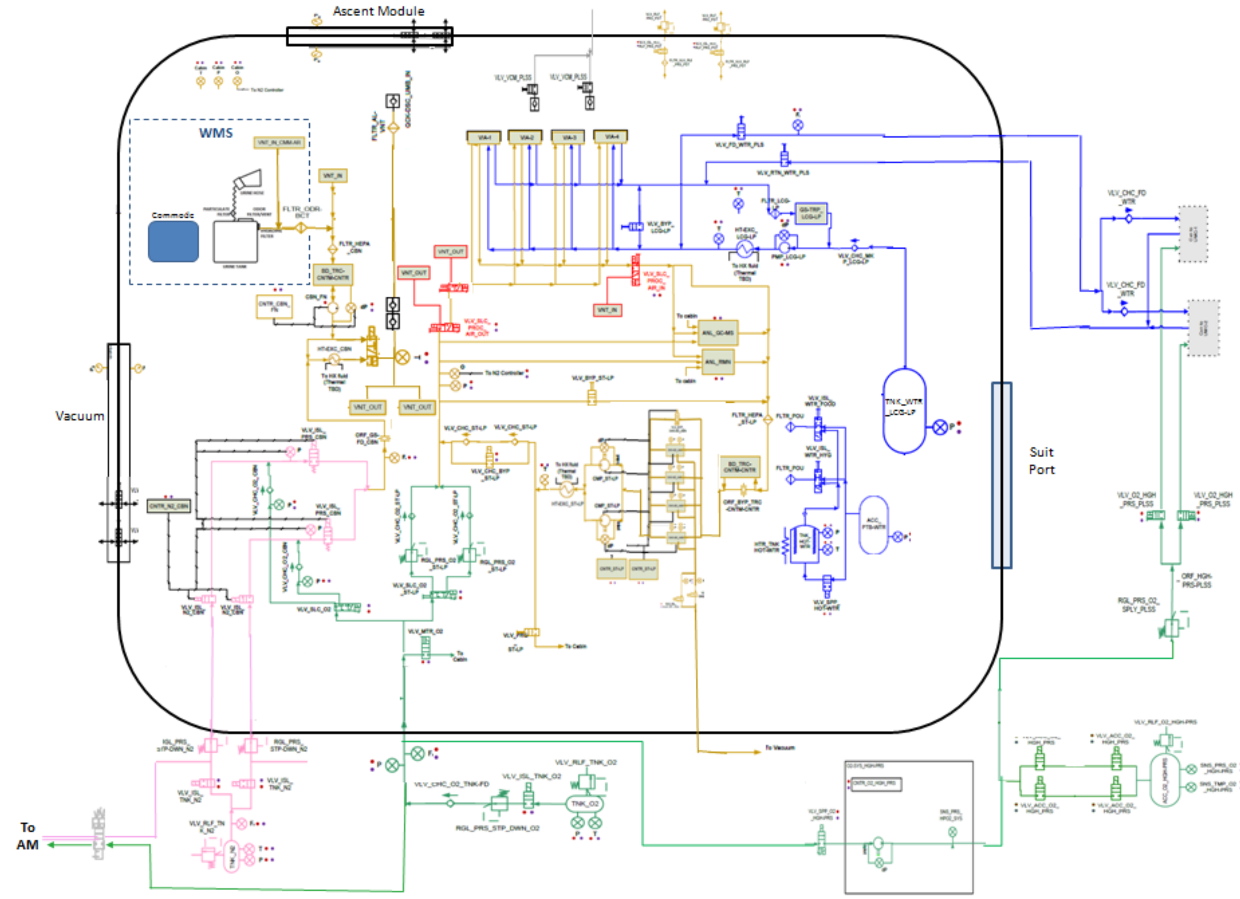

Figure 3: Habitat life support system schematic

VI. Conclusion

The life support system for the new lunar lander organizes life support functions differently from both Apollo and Altair lunar landers. Leaving the habitat on the surface slightly reduces the importance of mass for those systems, and allows more attention to functionality and usability in the design process. But since many functions have to be duplicated, it is very important to truly minimize the ascent module mass. The overall lander design studied in this design concept would likely be updated for changes to structural design and shape of modules, but the life support design was an efficient solution and would be unlikely to change significantly, unless new technology became available.

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Acronyms

ACDC Altair Conceptual Design Contract

EVA	Extravehicular Activity
LOI	Lunar Orbit Insertion
NASA	National Aeronautics and Space Administration
PCS	Pressure Control System
PDR	Preliminary Design Review
PLSS	Portable Life Support System
SRR	System Requirments Review