The Use of Small Logistics Containers for Crewed Lunar Exploration Campaigns

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The capability to deliver pressurized logistics to the lunar surface is key to the success of any lunar exploration campaign. A driving factor for this is the choice of the container system for delivering pressurized supplies. This paper is focused on efficiency and flexibility as major metrics for the container system. The efficiency of a container system can be measured through use of an effective tare factor which is the ratio of aggregated container mass to aggregated useful cargo mass. The flexibility of a container system can be measured based on the number and type of flights in a given campaign that pressurized logistics can be delivered on. NASA's current plan for the container system is to use Pressurized Logistics Modules (PLMs), which are similar to the Multi-Purpose Logistics Modules (MPLMs) used to supply the International Space Station (ISS). This is a relatively efficient concept for delivery of cargo to the ISS, but is relatively inflexible when used for the lunar campaign. The authors introduce an alternative concept to the PLM called the Small Logistics Container (SLC). This concept is meant to counter the inflexibility of the PLM by creating a container, which at less than 300 kg fully-loaded, can be delivered to the lunar surface on any flight in the campaign. The disadvantage of the SLC concept is that the efficiency of the system is less due to its higher tare factor. A hybrid option for logistics delivery, which uses both PLMs and SLCs, is presented at the end of the paper as an approach for a container system that is both highly flexible and efficient.

Nomenclature

CxAT	=	Constellation Architecture Team
ISS	=	International Space Station
LAT	=	Lunar Architecture Team
MPLM	=	Multi-Purpose Logistics Module
PLM	=	Pressurized Logistics Module
SLC	=	Small Logistics Container

I. Introduction and Motivation

IN response to the announcement of the Vision for Space Exploration, NASA is working towards returning humans to the lunar surface by 2020. In contrast to the Apollo missions, the goal of these new lunar missions is to establish a sustained human presence on the lunar surface with the ability to have crews of four people living and working on the Moon for long-duration stays of up to 180 days[1].

To support crews during these long-duration stays, a substantial amount of pressurized logistics must be delivered to the lunar surface. These pressurized supplies include daily consumables for the crew, scientific equipment, as well as pressurized spares to maintain surface infrastructure elements. These supplies must be

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delivered in containers that provide a stable, pressurized environment during Earth launch, in-space transit, landing, and the lunar surface stay.

The challenge of delivering the required pressurized logistics is compounded by the constraints placed on the logistics system by the capabilities of the transportation system. NASA is currently considering utilizing a combination of Ares I and Ares V launch vehicles, shown in Figure 1, to send both crew and cargo towards the Moon[1]. The Ares V will carry either a cargo-version or a crewed-version Altair lander, which is also shown in Figure 1. Both versions use a common descent stage; the difference between the two is that the crewed version carries a crew compartment and ascent stage, leading to a significantly reduced cargo capability. The cargo capability of the crewed version if further reduced due to the need for the descent stage to capture the CEV into lunar orbit prior to descent. Current estimates for the cargo capabilities to the lunar surface are: 4,269 kg for a crewed flight and 17,378 kg for a dedicated uncrewed cargo flight[2]. Given that these estimates are for a "minimal-functioning lander" it can be assumed that these values will be reduced due to the addition of equipment mass to reduced loss of mission and loss of crew risks. For this study, the authors assume that the crewed lander will only be able to deliver 1 mt of cargo and the cargo lander will deliver 14.5 mt. However, not all of this cargo capability will be available for pressurized logistics: several of the cargo flights will also need to deliver unpressurized cargo and large infrastructure elements such as habitats and pressurized rovers. This means that the amount of mass available for the pressurized logistics and corresponding container system will vary greatly from flight to flight within the campaign.

Figure 1. Artist impressions of the Ares I (left)[3], Ares V (middle)[4], and Altair lander (right)[2].

Developing a container system for pressurized logistics that can deliver the highest amount of pressurized cargo to the lunar surface for a given tare mass is very important given that the overall crew duration during the campaign is directly related to the amount of consumables available. By creating an efficient container system that is flexible enough to work within the constraint of the varying lander cargo mass capabilities, the amount of pressurized logistics that can be delivered will be maximized while maintaining the ability to always deliver pressurized logistics on any flight. The following section discusses the metrics of efficiency and flexibility, which can be used to assess different logistics container systems for the lunar exploration campaign.

II. Metrics for Analyzing Pressurized Logistics Containers

The performance of a pressurized logistics container system can be assessed using two metrics: its efficiency and its flexibility. The efficiency of the system is measured based on how much cargo can be delivered to the lunar surface for a given container mass. For a given amount of available cargo mass on an Altair lander, the more actual pressurized logistics that can be delivered, the better the efficiency of the container system. The flexibility of the system is measured based on how easily the container system can be integrated on various flights during the campaign. The greater number of flights the pressurized logistics can be delivered on the greater the flexibility of the container system. The following subsections describe these two metrics in more detail.

A. Efficiency

The quantitative measure of the efficiency of a container system is its tare factor, which is the ratio of the mass of the container system to the mass of the pressurized cargo delivered. This ratio is governed by several factors as shown in Equation 1:

$$\text{Tare factor} = \frac{\text{Container Mass}}{\text{Cargo Mass}} = \frac{(\text{Structural Mass} + \text{Nonstructural Mass} + \text{Packing Mass})}{\text{Volume Available} \times \text{Packing Factor} \times \text{Cargo Density}} \quad \textbf{Equation 1}$$

The geometrical properties of the container, the thickness of the walls, and the characteristics of the materials determine the structural mass of the container. The nonstructural mass consists of all the components required to maintain and monitor the environment inside the container. Unlike the structural mass, the non-structural mass does not scale noticeably with the size of the container, which means in general, for containers made of similar materials: the smaller the container, the higher the tare factor.

The packing mass consists of all the components that are used to store the actual useful cargo within the container. Current logistical containers, such as the Multi-Purpose Logistics Module (MPLM), use a combination of racks such as the International Standard Payload Rack (ISPR) and bags known as Cargo Transfer Bags (CTB)[5]. These internal containers can add as much mass as 10% of the cargo being delivered[6].

The volume available for cargo is determined by the geometry of the container, whereas the packing factor is determined by how much of this volume is actually utilized for cargo storage. The packing factor can be as high as 0.95 for densely packed, small containers. The packing factor can never be equal to 1.0 because of the required volume for nonstructural and packing components. As the container's volume is increased, thought must be given to how the crew will access the increasing amount of cargo within the container. For large, room-size containers, the crew will require walkways and space to manipulate the cargo within the container.

The final factor in determining the amount of cargo that can be delivered is the density of the actual cargo. In order to determine an average cargo density, the authors carried out a systematic experimental analysis of the density of logistics items. For items that could be shaped into any form such as some dried foods, hygiene fluids, and packaging, the bulk densities were used. For solid items, the densities are for a rectangular envelope that would include the entire item. For densities that could not be determined experimentally, we relied on Ref. 7, which includes information on logistics (and densities) for NASA's First Lunar Outpost. Based on our analysis, which is summarized in Table 1, the achievable average density was determined to be approximately 358 kg/m^3; however, to account for further packaging inefficiencies, a value of 300 kg/m^3 is used for this study.

Table 1. Density of Pressurized Logistics Items.

Category	Mass, kg/p/d	Density, kg/m^3	Source
Dry food	0.75	335	Measurement
Health care	0.1	180	Measurement, Ref. 7
Packaging	0.3	2700	Aluminum
Galley supplies	0.1	229	Measurement, Ref. 7
Waste management	0.3	264	Measurement, Ref. 7
Personal hygiene	0.2	233	Measurement, Ref. 7
Housekeeping	0.25	516	Measurement, Ref. 7
Clothing	0.25	218	Measurement
TCC	0.06	478	Measurement, Ref. 7
Pressurized spares	0.61	500	Ref. 7
Pressurized science	0.19	500	Estimate based on pressurized spares
Total	**3.11**		
Average density		**358**	

B. Flexibility

The second measure of a suitable pressurized logistics container system, its flexibility within the campaign, is not as easy to quantify as efficiency. For lunar exploration campaigns, the flexibility of the system is an important consideration due to the varying amount of cargo mass capability on each lunar flight. As mentioned previously, dedicated cargo flights can deliver approximately 14.5 mt of cargo to the lunar surface, however, on a number of flights, the available cargo mass will be consumed by the delivery of key surface infrastructure elements and unpressurized logistics, thereby creating cargo flights with capabilities to carry as little as 1 or 2 mt of pressurized cargo, which must include the required containers[5]. Crewed flights to the lunar surface are estimated to have 1 mt of cargo capacity, which must be shared by both pressurized and unpressurized logistics.

Due to the varying cargo capacities of the landers over the campaign, flexibility can be taken as a measure of how many flights pressurized cargo can be delivered on. One measure of the flexibility of a container system is the number of flights a fully loaded container could be delivered on. While offloading cargo (i.e. not packing a container to its maximum capabilities) can lead to increased flexibility, if the container is sufficiently large, it is conceivable that not even an empty container could be flown on certain flights (e.g. crewed flights). Another disadvantage of offloading cargo is that the cargo mass is decreased for a given container, the tare factor is increased, thereby reducing the efficiency of the system.

The flexibility of the container system can also be measured by the minimal amount of mass (and volume) available for pressurized logistics varies when a single container is added or subtracted to the campaign. The smaller this amount is, the easier it is to match the available cargo capabilities of the system with the actual demand based on the specifications of the lunar campaign.

C. An Example: The Multi-Purpose Logistics Module

To further clarify these metrics, the example of the Multi-Purpose Logistics Module (MPLM) will be presented here. The MPLM is a pressurized cylinder, which is used to transport pressurized logistics to the International Space Station. As described in Ref. 5, this module has a length of 6.25 m and an external diameter of 4.52 m. While its has 75 m^3 of total internal volume, only 25 m^3 of this is available for the payload giving the MPLM a packing factor of 0.33. The total mass of the container (i.e. its structural plus non-structural mass) is approximately 4500 kg and the mass available for the combination of cargo mass and payload mass is 9072 kg. Summarized in Table 2, these parameters give the MPLM a tare fraction of 0.65.

Figure 2. Outside view of a Multi-Purpose Logistics Module[6].

Table 2. Suitability metrics for the Multi-Purpose Logistics Module.

Variable	Value	Comments
Structural + Non-Structural Mass, kg	4500	Reference 5
Packing Mass, kg	825	Estimated as 10% of the payload mass
Container Mass, kg	**5325**	
Volume Available, m^3	75	Reference 5
Packing Factor, -	0.33	Reference 5
Cargo Density, kg/m^3	330	Cargo mass of 8247 kg & a volume of 25 m^3
Cargo Mass, kg	**8247.2**	
Tare Factor [-]	**0.65**	

A tare fraction of 0.65 means that the MPLM is a relatively efficient pressurized logistics container; however, it would not be optimal for the lunar exploration campaign as it exhibits low flexibility in the campaign. With a fully-loaded mass of over 13 mt, the MPLM could only be flown on cargo flights that are not carrying any other cargo. In fact, as a certain amount of unpressurized logistics and pressurized fluids must be delivered on a regular basis, the MPLM would be difficult to manifest on any flight. To make it more flexible, the MPLM could be flown with less cargo, but this would increase its tare faction and reduce its efficiency as shown in Figure 3. Adding or subtracting one MPLM from the lunar campaign changes the amount of mass available for pressurized cargo by over 8 mt, which is inflexible if it is desired to only add 100 – 500 kg of scientific equipment to the manifest of the campaign.

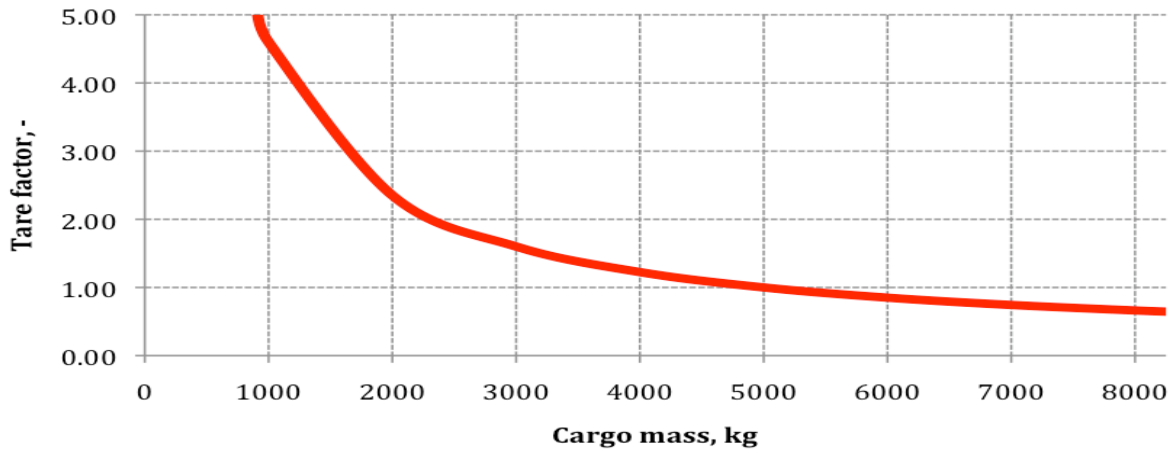

Figure 3. Tare factor vs. cargo mass for the MPLM.

III. The Pressurized Logistics Module

NASA is currently investigating several architectures for the lunar exploration campaign. Each of these campaign plans on using a pressurized logistics container system known as Pressurized Logistics Modules (PLMs) to deliver pressurized cargo. Work by the Constellation Architecture Team (CxAT) is currently ongoing on lunar surface systems architectures, but no public information has been made available at the date of writing. However, there are results available from previous architecture studies, the campaign put forth by the Lunar Architecture Team (LAT) and the initial architecture concept and campaign presented publicly by CxAT[8,9].

LAT focused on an architecture using a concept of surface infrastructure elements known as Mini-Habs that would be offloaded and assembled on the lunar surface. Reference 8 discusses a PLM that was created for this architecture that consisted of a 2.7 m diameter and 5 m long horizontal, pressurized cylinder. This cylinder is estimated to have a tare mass of 2181 kg and would be able to be able to transport 176 single CTBs or 3019 kg of cargo. This information is summarized in Table 3.

Table 3. Efficiency of the LAT PLM.

Variable	Value	Comments
Structural + Non-Structural Mass, kg	2181	Reference 8
Packing Mass, kg	302	Estimated as 10% of the payload mass
Container Mass, kg	**2483**	
Volume Available, m^3	33	Calculated from Ref. 8
Packing Factor, -	0.25	Calculated based on 176 CTBs of 0.0462 m^3
Cargo Density, kg/m^3	371	Cargo mass divided by volume of CTBs
Cargo Mass, kg	**3019**	
Tare Factor, -	**0.82**	

As presented at the 3rd Exploration Conference, an early architecture studied by the CxAT departed from the Mini-Hab concept slightly by using larger modules to assemble the outpost[9]. Figure 4 is a flight manifest for this architecture, which shows that the habitation elements and the PLMs have increased in size from the LAT studies. While no data has been released on the PLM for this new campaign, an estimate can be made based on the MPLM and the original PLM.

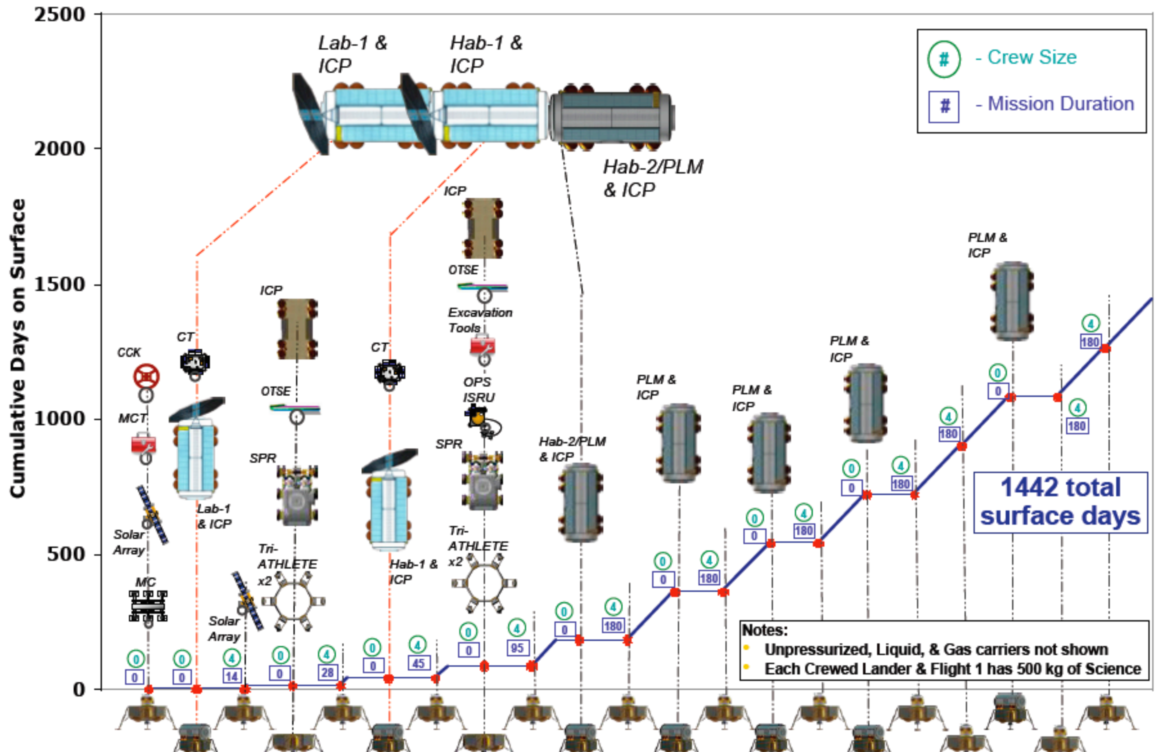

Figure 4. Notional campaign plan from CxAT study[9].

Knowing the tare factors and total mass of both the original PLM and the MPLM and estimating that the new PLM will be approximately 10 mt to allow cargo space for unpressurized logistics on the later cargo flight on which they are delivered, we can estimate the parameters of the new PLM using Figure 5. While not required, we can estimate the volume of the container based on a packing factor of 0.30. The parameters of the new PLM are shown in Table 4.

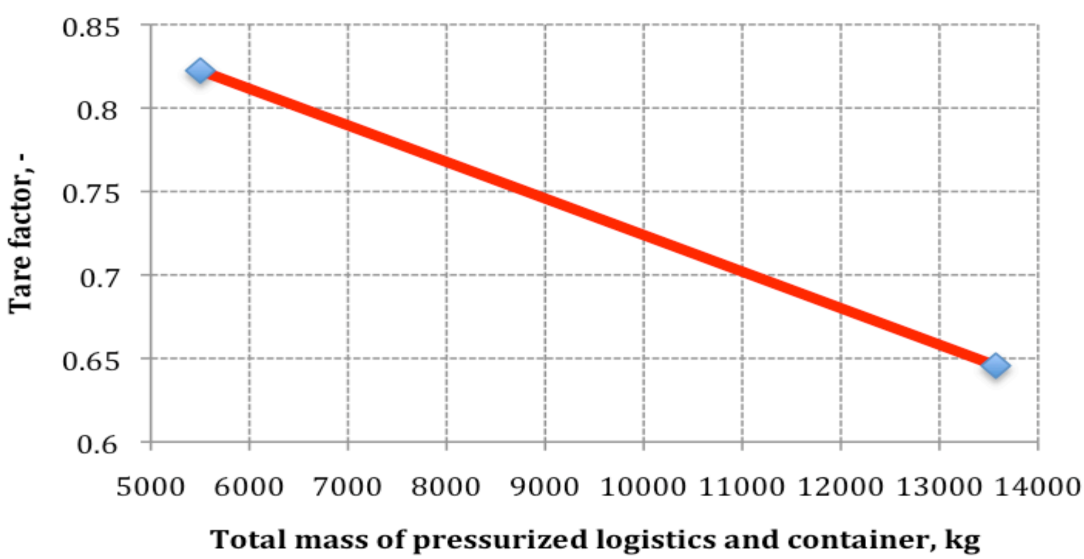

Figure 5. Tare factor vs. total mass for the new PLM.

Table 4. Efficiency measurement for the new PLM.

Variable	Value	Comments
Structural + Non-Structural Mass, kg	3675	
Packing Mass, kg	575	Estimated as 10% of the payload mass
Container Mass, kg	**4250**	Based on total mass of 10 mt and tare factor of 0.74
Volume Available, m^3	64	
Packing Factor, -	0.3	Estimate between PLM and MPLM
Cargo Density, kg/m^3	300	From experimental analysis
Cargo Mass, kg	**5750**	Based on total mass of 10 mt and tare factor of 0.74
Tare Factor, -	**0.74**	**Calculated linearly from original PLM and MPLM**

This new PLM has a lower tare mass than the previous version due to its larger size. This system provides a more efficient pressurized logistics container system, but it is still relatively inflexible. The flight manifest above shows that the PLM is only delivered on four flights in the later part of the campaign (not including the Hab-2 module). It can be assumed that all the pressurized logistics for the build-up phase of the campaign are delivered inside pressurized surface infrastructure elements such as the habitats and the Small Pressurized Rovers. This is not only a relatively inflexible system, as pressurized cargo can only be delivered on nine of the twenty-one flights listed, but the system is also highly dependant on the amount of cargo that can be carried on habitats and rovers.

IV. The Small Logistics Container

The Small Logistics Container (SLC) was developed to counter the limited flexibility of the PLM-based logistics approach by providing a smaller container size that could deliver pressurized supplies both on crewed and on cargo flights (possible in conjunction with PLMs for the latter). The concept of using man-sized containers for re-supply of planetary outposts is not entirely novel: it was proposed as the primary means of logistics for repeat visits of NASA's First Lunar Outpost architecture[10]. The primary motivation for using a smaller container was the ability to carry it along on crew transportation flights which are typically more limited in cargo capability.

The initial concept for the SLC is a small, pressurized cylinder (about the size of a person) with elliptical end caps as shown in Figure 6. The length of the vessel is 1.5 m and its diameter is 0.75 m. The structural mass is made up of the outer shell of the container and internal rails for structural support. The outer shells of the container consists of two half shells built of 3 mm thick aluminum 2219 and 10 mm of MLI blanket. There are two circular rails, one in each end cap and 16 linear rails running along the length of the cylinder sections of the vessel halves. These rails are intended to keep items stored internally in place and transmit loads from the cargo through the outer shell to the lander, in particular during Earth launch and propulsive maneuvers.

The thermal control concept for the SLC was based on a passively cold-biased system with actively controlled heating when necessary. The MLI insulation results in very small heat flux (in or out) during any of the mission phases, and the vessel and cargo mass provides thermal inertia that further decreases temperature changes inside the vessel. The critical mission phase from a thermal control perspective is prolonged exposure to the cold lunar surface environment; in this case a sustained power demand of 1-3 W is required to keep the air inside the container at acceptable temperatures.

The non-structural mass of the SLC consists of the equipment to monitor and maintain the environment inside the container when sealed: this includes sensors to measure pressure and air temperature in the container, a pressure equalization valve for unloading, and air heaters to regulate the air temperature during eclipse periods. Twenty-five percent margin was added to the structural components and 30 percent was added to all components to allow for mass growth during detailed design of the vessel. The packing mass of the SLC consists of three types of internal containers of varying geometry and volume. There are two rectangular prism containers in the center of the outer shell. Each end cap houses a custom built container and eight side containers are placed in the cylinder length surrounding the center containers (see Figure 7). The masses of all these components are shown in Table 5.

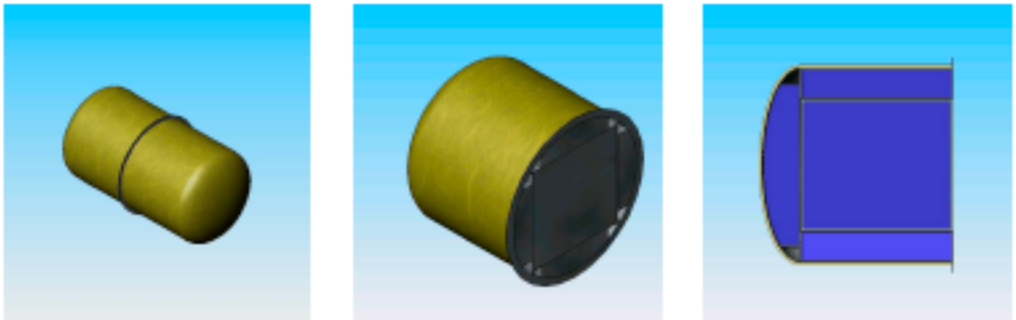

Figure 6. Different views of the Small Logistics Container: entire SLC vessel on the left, vessel half in the center and in cross-section on the right-hand side.

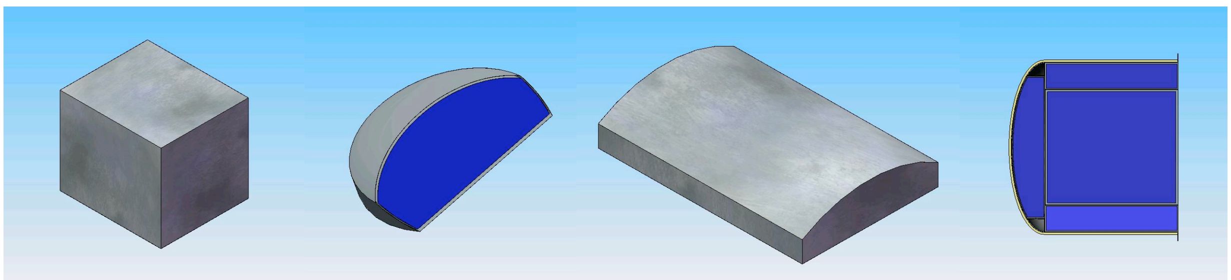

Figure 7: Overview of cargo storage containers and arrangement inside the SLC (right)

Table 5. Mass breakdown for the SLC.

Component	Unit mass, kg	Number of units	Mass, kg
Half shell (3 mm thickness, Al 2219)	18	2	36.1
MLI blanket - half shell (10 mm)	6.2	2	12.4
Linear rail (Al 2219)	0.4	16	6.4
Circular rail (Al 2219)	1.4	2	2.9
25% Structural Uncertainty on Half Shell, MLI, and Rails	--	--	14.4
Rectangular container (10 mm honeycomb w/ 0.3 mm Al 2219 walls)	3.8	2	7.6
End cap container (5 mm honeycomb w/ 0.1 mm Al 2219 walls)	0.7	2	1.3
Cylinder segment container (5 mm honeycomb w/ 0.1 mm Al 2219 walls)	0.5	8	4.1
Connecting Interface	0.8	2	1.6
Manual equalization valve + attachment	10	1	10
High pressure transducer	0.4	1	0.4
Low pressure transducer	0.3	1	0.3
O2/CO2/CO/H2 Sensor Package	5	1	5
Strip heater (estimate)	1	8	8
Vessel dry mass including containers, kg			**110.4**
30% design margin on dry mass, kg			**33.1**
Total vessel mass including containers, kg			**143.5**

The total volume available for cargo inside of a single SLC is 0.525 m^3. Assuming a cargo density of 300 kg/m^3, it is estimated that an SLC can transport approximately 157.5 kg of pressurized logistics. This equates to a tare factor of 0.91, which shows that the SLC is less mass-efficient as a bulk cargo delivery system than the PLM. However, the SLC system is considerably more flexible than the PLM because the mass of a full SLC is below 300 kg. This low mass allows the SLC to be manifested on both cargo and crewed flights during the lunar exploration campaign, and it may literally be “carried” around by the crew on the lunar surface (reduced gravity). The available pressurized cargo mass of the campaign will better match the required pressurized cargo mass due to the fact that adding or subtracting a single SLC changes the available cargo mass by only 150 kg, whereas adding an extra PLM changes the overall available cargo mass by over 5000 kg. It would of course be possible to change the available cargo mass by less, but that would mean that the PLM would be partially empty and therefore have a significantly higher tare factor.

Table 6. Efficiency assessment for the SLC.

Variable	Value	Comments
Structural + Non-Structural Mass, kg	127	Outer shell, rails, and instrumentation
Packing Mass, kg	17	Mass of internal containers
Container Mass, kg	**144**	
Volume Available, m^3	0.6	
Packing Factor, -	0.89	
Cargo Density, kg/m^3	300	From experimental analysis
Cargo Mass, kg	**157.5**	
Tare Factor, -	**0.91**	

A. Operational Considerations for the SLC

One of the concerns with the SLC system is how the containers will interface with other surface infrastructure elements. The SLC cannot be assembled and connected to habitat elements in a manner similar to the PLM; instead it must be carried inside the airlock to be used by the crew. This makes the final design of the SLC somewhat dependent on the geometry of the airlock. There are, however, several modifications that could be considered for eliminating these operational concerns. One possible solution is to design the SLC to have an interface to an airlock or suit-port incorporated into the design. This solution would have the negative effects of reducing the efficiency of the SLC, through increased structural mass, thereby increasing the tare factor, as well as the possibility that the size of the SLC may need to be increased, while providing easier access to and storage of supply items. This trade analysis is considered future work.

V. Integrated Assessment of Logistics Strategies for Lunar Exploration

The previous sections described the advantages and disadvantages of two types of pressurized logistics containers: PLMs and SLCs. When considering the overall lunar exploration campaign, these two containers allow for three strategies for the delivery of pressurized logistics. The first strategy is to only use PLMs. The second option is to replace the PLMs with SLCs throughout the campaign. The third option is to utilize both container types to create a hybrid strategy.

Utilizing PLMs for logistics allows the campaign to benefit from high efficiency due to the containers low tare factor; however, as discussed previously, there are several disadvantages of a logistical strategy that only employs PLMs. The main concern is the limited flexibility of this option: the large tare mass of the container limits the use of the element to dedicated cargo flights in the second half of the campaign. The first half of the campaign is supplied by placing pressurized logistics within various surface infrastructure elements. This leads to two further problems: the amount of logistics to be delivered (and the corresponding surface durations for the crews) in the first half of the campaign is dependent on the amount of mass available to be carried in the habitat elements, and secondly, pressurized logistics cannot be carried with the crew on their flights which means that all pressurized spares, equipment, and consumables must be pre-positioned up to six months ahead of time. If there is a malfunction up to six months before a crew arrives that requires a pressurized component that has not been pre-positioned, the campaign will not be able to continue as planned, resulting in more stringent redundancy and safety stock requirements..

The second strategy for delivering pressurized logistics is to replace the PLMs with SLCs. This allows for the increased flexibility of having the ability to supply pressurized logistics on all flights. This advantage comes at the cost of decreased efficiency through a higher tare factor. This decreased efficiency could lead to reduce surface durations for the crew because the amount of pressurized logistics that can be delivered would be reduced. Figure 8 shows the increased flexibility of SLCs for a sample campaign analysis. The blue bars show the normalized cargo capability of each lander for pressurized logistics and their containers (after accounting for infrastructure, fluids, and unpressurized logistics). The plot is normalized to the total cargo mass capability of a cargo lander. It can be seen that fully loaded PLMs can only fit on four of the flights while fully loaded SLCs can fit on all flights, including crewed flights.

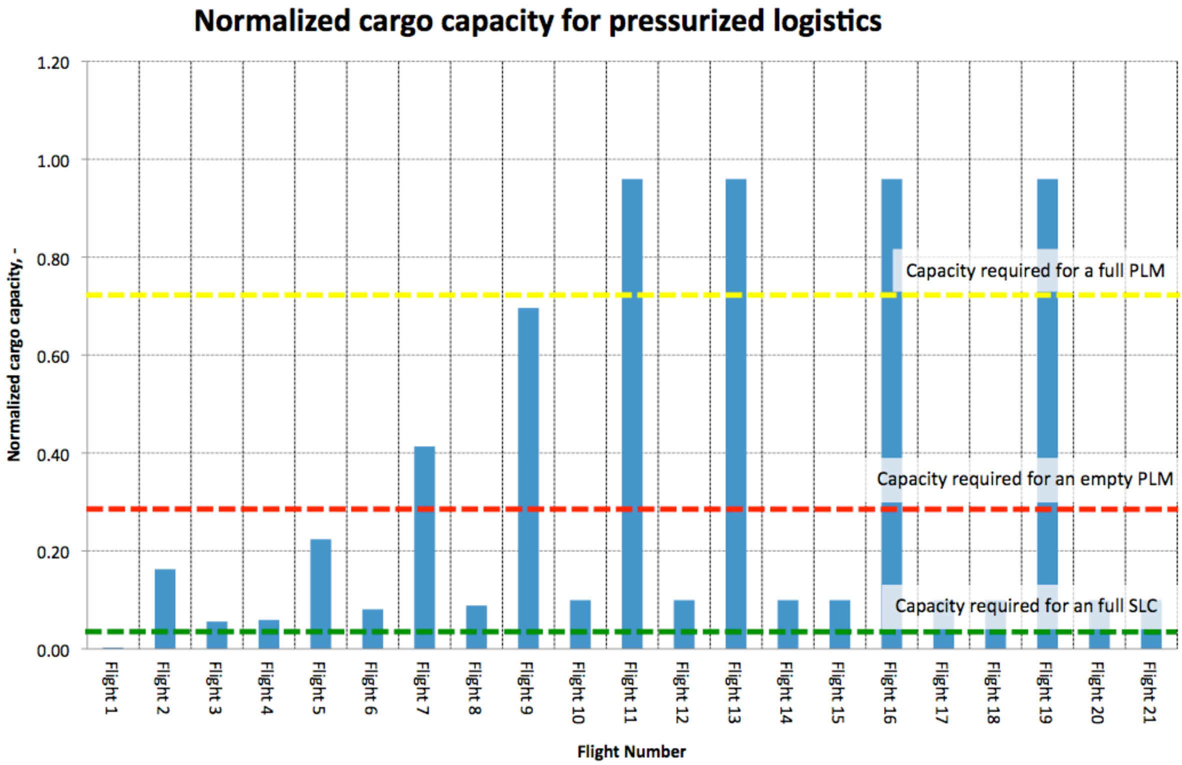

Figure 8. Plot showing the mass capacity for pressurized logistics on flights in a sample campaign.

The final strategy is to use both SLCs and PLMs to deliver logistics. This hybrid strategy allows for greater flexibility while still benefiting from the increased efficiency of the PLMs. SLCs can be used in the build-up phase of the campaign when PLMs would not be able to be transported to the surface and PLMs could be used in the second half of the campaign. These PLMs could be supplemented with additional SLCs to incrementally increase the pressurized cargo mass as needed until the overall mass capability of the lander is reached. This could lead to extended surface durations in the latter half of the campaign.

Figure 9 shows a plot of the three strategies for delivering pressurized logistics for a sample lunar exploration campaign. The plot is cumulative over the lifetime of the campaign and normalized to the cumulative available cargo mass for pressurized logistics on the landers used. As all three strategies deliver the same amount of cargo, it can be seen that the SLC strategy is the least efficient due to its relatively high tare factor and that the hybrid option is the most efficient, which is because a combination of SLCs and PLMs in the latter half of the campaign ensures that the cargo mass available in the container system better approximates the demand (i.e. no half-full PLMs have to be delivered to the Moon to ensure delivery of all cargo).

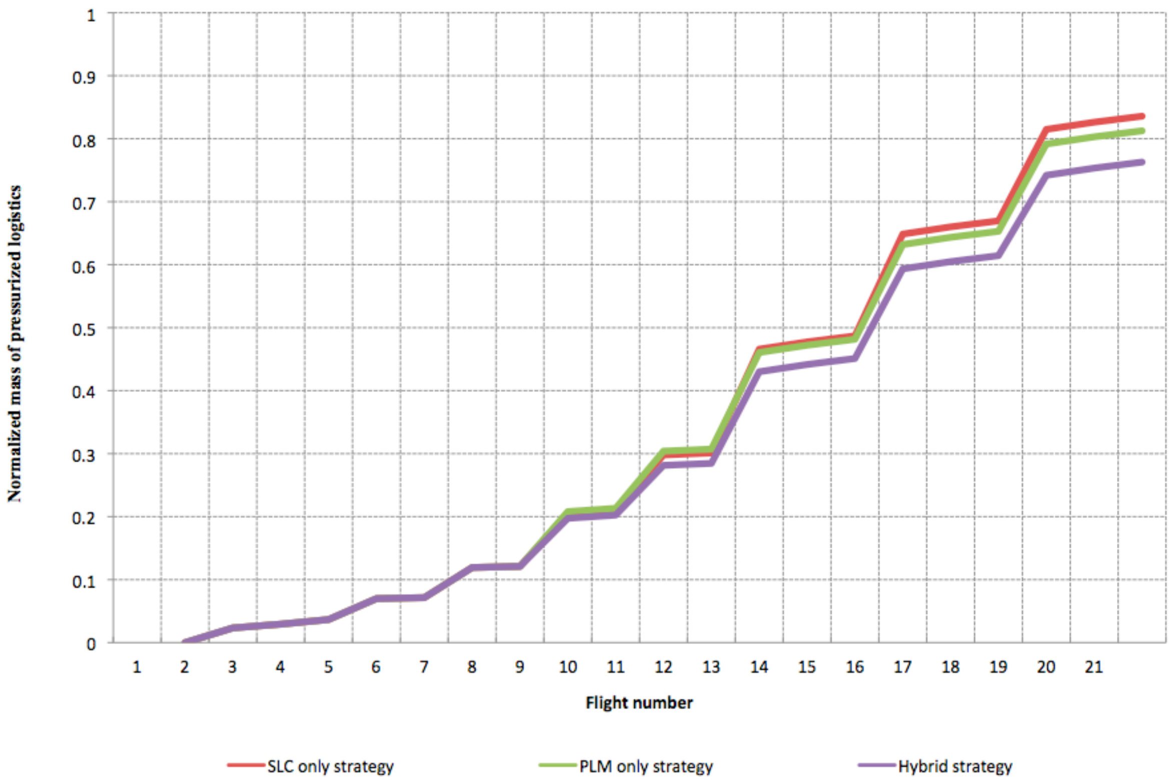

Figure 9. Mass of pressurized logistics (cargo + containers) for a given demand of pressurized cargo.

VI. Conclusion and Future Work

While PLMs provide an efficient system for delivering pressurized logistics to the lunar surface, their limited flexibility within the campaign due to large quanta of delivered cargo is a concern. The concept of the SLC allows for increased flexibility in the delivery of logistics, but at the cost of mass-efficiency if only SLCs are used. A hybrid strategy using both types of containers allows for a balance of mass-efficiency and flexibility, possibly out-performing both "pure" strategies with regard to tare mass delivered to the lunar surface for a given amount and schedule of supply. Further work needs to be undertaken in creating an SLC that does not have to be transported through an airlock and into a habitat, as well as on the exact size of the SLC. One possible solution to this could be the use of modified airlocks to be logistics carriers ("super-SLC").

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