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Depot for Martian and Extraterrestrial Transport Resupply (DeMETR)

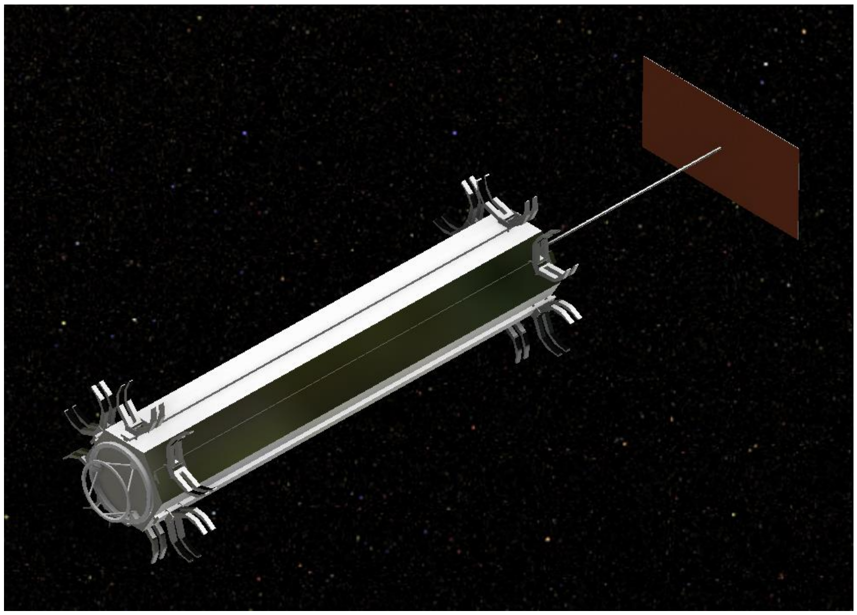
Emily Beckman
University of Tennessee-Knoxville, ebeckma1@vols.utk.edu

Ethan Vogel
University of Tennessee-Knoxville

Caleb Peck
University of Tennessee-Knoxville

Nicholas Patterson
University of Tennessee-Knoxville

PROPELLANT RESUPPLY CAPABILITY



DEPOT FOR MARTIAN AND EXTRATERRESTRIAL TRANSPORT RESUPPLY (DEMETR)

UNIVERSITY OF TENNESSEE

Faculty Advisor: Dr. James Lyne

I. INTRODUCTION

This mission architecture was designed to meet the requirements of the NASA RASC-ALs propellant resupply capability theme. The Depot for Martian and Extraterrestrial Transport Resupply (DeMETR) station and the High-orbit Resupply Module for Exploratory Spacecraft (HRMES) will deliver 19.6 T of Xenon and a combined 8.1 T of dinitrogen tetroxide (NTO) and Monomethylhydrazine (MMH) oxidizer to the Deep Space Transport in cis-lunar space [1]. DeMETR is a station placed in Lunar Distant Retrograde Orbit (LDRO) which stores propellant for transfer in between refuel missions for reasons discussed further in this paper. HRMES is a taxi which is capable of carrying propellant from the launch vehicle to the station and from the station to the Deep Space Transport. This mission architecture is capable of supplying the deep space transport with a full load of propellant at every opportunity beginning in 2033.

II. MISSION STRUCTURE

The mission begins with the launch of the entire DeMETR station with one full load of propellant on the Space Launch System (SLS) Block 2 in 2029, one year after the SLS Block 2 is predicted to be available according to the SLS Planner's Guide [2]. The SLS will propel the spacecraft until exploration upper stage (EUS) separation which will put the DeMETR station on course to enter lunar orbit using the weak stability boundary (WSB) method, discussed in the trajectory design section. Engines on DeMETR will complete the maneuver to insert the station into lunar distant retrograde orbit (LDRO). HRMES, with a full load of propellant for the deep space transport and up to 11.4 metric tons of commercial partner propellant, is also launched on an SLS Block 2 rocket in 2030, and will follow the same trajectory as DeMETR to reach LDRO. The taxi will then rendezvous with the station in orbit. This is illustrated in Figure 1.

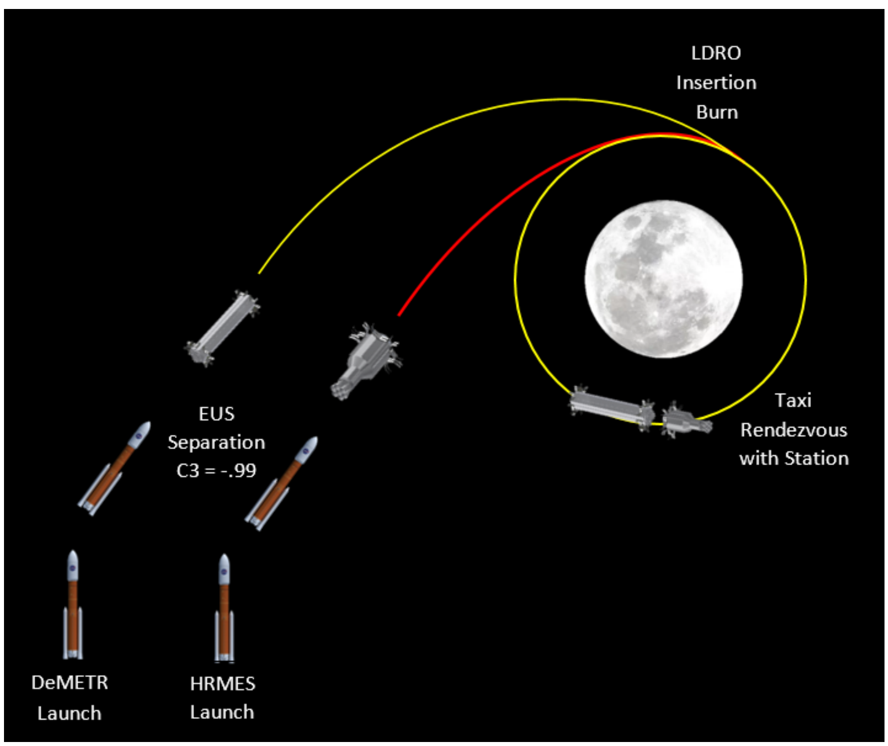


Fig. 1 General early mission architecture. Orbits and transfer trajectory not shown to scale.

At this point in the mission there will be two supplies of propellant in orbit for the Deep Space Transport in addition to any commercial fuel. These launches are slated early in the schedule to allow for delays in SLS development and difficulties with launching the SLS Block 2 with the frequency listed in the literature, two per year [2]. When the Deep Space Transport is ready to be refueled in 2033, HRMES will depart DeMETR with one load of propellant and rendezvous with the Deep Space Transport. The fuel tanks are transferred to the Deep Space Transport and the waste is transferred to HRMES. HRMES again rendezvous with DeMETR and transfers the waste to the station for processing in the bioreactor. A new HRMES taxi is launched and repeats the same process as its successor. After the new taxi arrives in LDRO but before docking, the old taxi departs the station and returns to Earth via the WSB method. This ensures that at least one load of propellant and one HRMES taxi is available in LDRO at any time in the event a new launch may not be completed at the time the Deep Space Transport arrives for refueling. Because HRMES is a relatively inexpensive vehicle, it is expendable and will be allowed to burn up in the atmosphere. HRMES will always deliver the propellant which has been on orbit longest to the Deep Space Transport to prevent age-related failures of the propellant tanks. The mission structure and event sequence is given in Table 1.

Table 1. General mission schedule. Two-year cycle repeats for as long as necessary to supply the deep space transport and future missions.

Date	Event	Hardware in LDRO at End of Event
2029	Launch of DeMETR	-
2030	DeMETR Enters LDRO	DeMETR, 1 Propellant
	Launch of HRMES 1	DeMETR, 1 Propellant
2031	HRMES 1 Enters LDRO	DeMETR, HRMES, 2 Propellant
	HRMES 1 and DeMETR Rendezvous	DeMETR, HRMES, 2 Propellant
2033	HRMES 1 and Habitat Rendezvous	DeMETR, HRMES, 1 Propellant
	HRMES 1 Rendezvous with DeMETR, Deliver Waste	DeMETR, HRMES, 1 Propellant
	Launch of HRMES 2	DeMETR, 1 Propellant
2034	HRMES 2 Enters LDRO	DeMETR, 2 HRMES, 2 Propellant
	HRMES 1 Returns to Earth	DeMETR, HRMES, 2 Propellant
	HRMES 2 and DeMETR Rendezvous	DeMETR, HRMES, 2 Propellant
2035	HRMES 2 and Habitat Rendezvous	DeMETR, HRMES, 1 Propellant
	HRMES 2 Rendezvous with DeMETR, Deliver Waste	DeMETR, 1 Propellant
	Launch of HRMES 3	DeMETR, 1 Propellant
...	...	...

III. LAUNCH VEHICLE

Due to the large mass of the propellant needed for supply to the hybrid Mars campaign, the best candidate for launch vehicle at the time of the mission is likely the SLS Block 2. Multiple flights will increase the chances of failure, so a single flight is preferred. The SLS Block 2 is estimated to be able to lift 45 metric tons of payload to a C3 of -0.99 km^2/s^2 which is sufficient to lift the entire station and propellant for one refueling mission in one flight [2]. While it is possible that there will be further development of commercial heavy lift vehicles before this mission, the lift capabilities of all other current and planned heavy lift vehicles to this C3 are too low to launch the entire needed mass of 27.7 metric tons of propellant for refuel in one mission [3], [4]. Therefore, the SLS Block 2 is the preferred launch vehicle.

However, because the SLS Block 2 is not yet developed, an alternate launch strategy was also determined as a backup. The Delta IV Heavy is the current vehicle with the highest launch capability, approximately 10.5 metric tons to a C3 of -0.99 km^2/s^2 [3]. Using the current design for the DeMETR station, the first launch may only carry 6.3 metric tons of propellant for delivery. In order to launch the required propellant mass, three subsequent launches of a HRMES with approximately 7.13 metric tons each will be required. For each subsequent refueling, four launches of a modified HRMES taxi with approximately 7 metric tons of propellant would be needed. This would require redesign of the HRMES taxi for smaller loads and is not optimal due to the high frequency of launches.

IV. TRAJECTORY DESIGN

DeMETR and HRMES both use the weak stability boundary (WSB) method to reach LDRO to take advantage of the low values of ΔV required to insert into LDRO orbit [5]. The SLS Block 2 will launch the station or taxi into a trans lunar insertion (TLI) with a C3 of approximately -0.99 km^2/s^2 [2]. This trajectory sends the spacecraft on a trajectory which reaches well beyond the Moon's orbit. At this point the sun's gravity begins to have a greater effect on the spacecraft and will raise the perigee of the orbit to a point where it intersects the desired lunar orbit. When the spacecraft arrives at the moon, it is already moving in the correct direction and closer to the velocity required for the orbit. Therefore, lower values of ΔV are required to insert into LDRO. Figure 2 shows one of many possible trajectories which may be used. The WSB method is highly dependent on the location of the Sun and the Moon with respect to the Earth and therefore has many possible solutions [6]. NASA literature states that approximately 80 m/s of ΔV will be required to perform an insertion into LDRO using the WSB method [5]. To keep estimates more conservative at these early stages in the mission design, a ΔV of 100m/s was assumed to be required for the insertion.

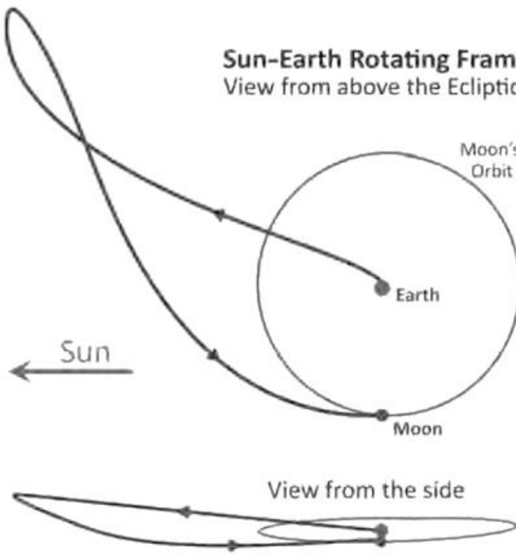


Fig. 2 One possible solution to the WSB problem [6].

LDRO requires very little station keeping because it is a highly stable orbit. Previous literature estimates that a spacecraft may stay in an LDRO orbit for approximately 50 years with no propulsive maneuvers required [5]. The duration of this mission is not expected to be longer than 50 years so no station keeping should be required. RCS engines are available on DeMETR in case station keeping and corrections after docking are required.

Rendezvous in LDRO requires small amounts of ΔV. Because the time between missions is large, trajectories may be planned well in advance and significant time built in for phasing to rendezvous. If rendezvous must be completed within 50 days, the maximum ΔV required is approximately 30m/s if the spacecraft are at the maximum distance, a separation of seven days [5]. This is illustrated in Figure 3 [5].

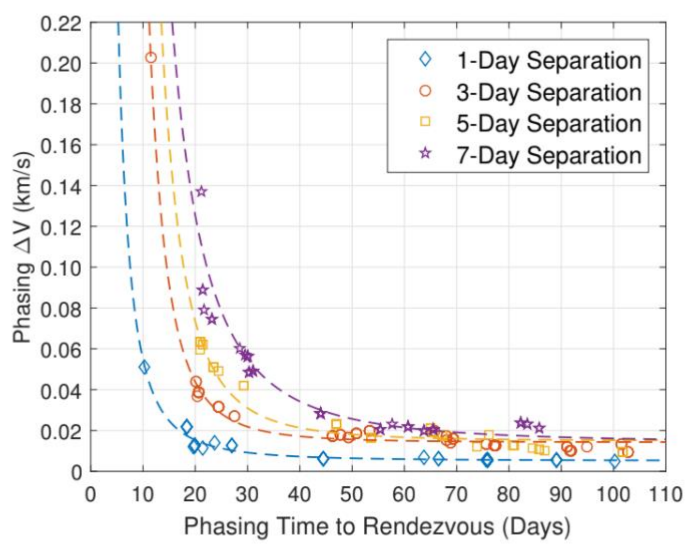


Fig. 3 ΔV required by phasing time for various separation distances [5].

V. GROUND INFRASTRUCTURE

Hazardous propellant will be transferred by rail from suppliers already packaged in the tanks in which it will be launched [7]. Potential suppliers were identified based on location, experience in aerospace-grade propellant manufacturing, and volumetric manufacturing ability. While suppliers are still being identified, Arch-Lonza is the current frontrunner in the search for an MMH supplier. Arch-Lonza operates several production facilities in the US and manufactures space-grade MMH [8]. Xenon availability may present a significant challenge. The world produces approximately 53 t of xenon annually, so procuring the called for 19.6 t of xenon via short-term contracts would represent a buy-up of 37% of the world's xenon [9]. According to the NASA Glenn research center, any short-term procurement of xenon in excess of 10 t may drive propellant costs to prohibitive values. To alleviate this concern, it will be necessary to begin buying and storing smaller quantities of xenon as early as is feasible. Due to the extended duration of the Martian orbiter campaign, this strategy will likely not be sufficient to prevent price destabilization for the duration of the campaign. Therefore, it is necessary for in-house production of xenon to take place. This can be done by building air separation units (ASUs) or by purchasing and retrofitting older ASUs to increase their production rates. One advantage of this approach would be that, irrespective of market prices, NASA would have access to a known quantity of xenon per year. This approach may present the additional long-term advantage of reducing transport overhead, as new ASUs could be built at locations convenient for missions which would require large quantities of xenon.

VI. SYSTEM DESIGN

A. DeMETR

The body of the DeMETR station is an extruded regular hexagonal shell with interior diagonal of 2 m and skin thickness of 4 mm. The interior of the station houses the International Docking System Standard (IDSS) internals, guidance and control computers, motors for driving the onboard rail systems, four control moment gyros (CMGs), the bioreactor apparatus (described below) including a waste storage tank, batteries for high-power operations, and fuel storage for RCS thrusters. The station holds the passive IDSS port [10]. To place the station in LRDO, a sacrificial upper stage must be selected to supply the ΔV required after leaving the SLS fairing. This stage has not been selected, but the estimated mass of propellant required to make this maneuver has been included using a representative specific impulse. This stage will be joined to the station via the IDSS, but brace against the flat side of the station to avoid placing high loads on the docking port. The flat face opposite the IDSS port will serve as the attachment point for the solar panel and radiator arrays which will be used for power and heat management. A CAD drawing of the DeMETR station is given in Figure 4.

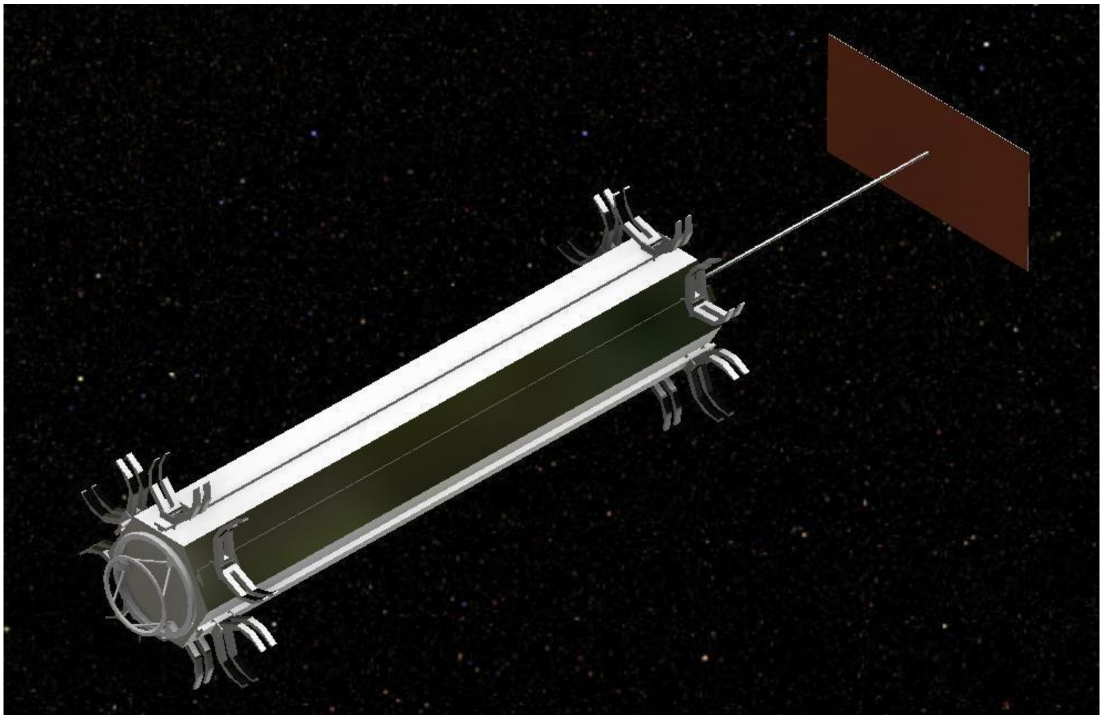


Fig. 4 CAD model of the resupply station DeMETR including IDSS docking port, clamps, and solar panels.

B. HRMES

HRMES is a lightweight aluminum craft designed to transport fuel from DeMETR to the target interplanetary habitat in LDRO. The main structure, shown in Figure 5, is 4.8 meters long and has a mass of about one metric ton. To be compatible with DeMETR, the rails for the clamp holders sit on a cylinder that is 1.732 meters in diameter. The cylinder is 2 meters long which provides enough space for the fuel pod transfer from DeMETR and subsequent holding of the pods during the delivery. Inside the main cylinder will be the waste container which will store the human waste that will be collected during the exchange with the target craft. This transfer occurs through the IDSS docking port [10], which is why the waste container must be directly on the other side of the port. An adapter which houses the electronic and control components of the taxi will connect the main section to the engines and fuel bay. The fuel bay is 1 meter in diameter and holds the MMH and NTO fuel that supplies the cluster of seven Aerojet R-42 engines that propels the taxi. These restartable engines have a thrust rating of 890N and a specific impulse of 303 sec [11]. When fully loaded to supply the habitat with fuel, the taxi has a mass of roughly 30 metric tons. In this configuration, all engines must be used to provide an acceleration of 0.208 m/s^2 towards the target craft. However, during the return trip to DeMETR, the expected mass is to be only 2000 kg. Therefore, only the center engine will need to be used to propel the taxi back to the station with an acceleration of 0.445 m/s^2. Assuming the maximum ΔV of 30 m/s per transit operation, one resupply mission will require approximately 75 kg of fuel. Using an oxidizer/fuel ratio of 1.73:1 [12] and enough fuel to conduct two resupply missions, the MMH fuel tank will store 64 kg of fuel, while the NTO fuel tank will store 111 kg. There is a 1.17 factor of safety for the amount of fuel in case emergency maneuvers must be done for a total of 175 kg of fuel.

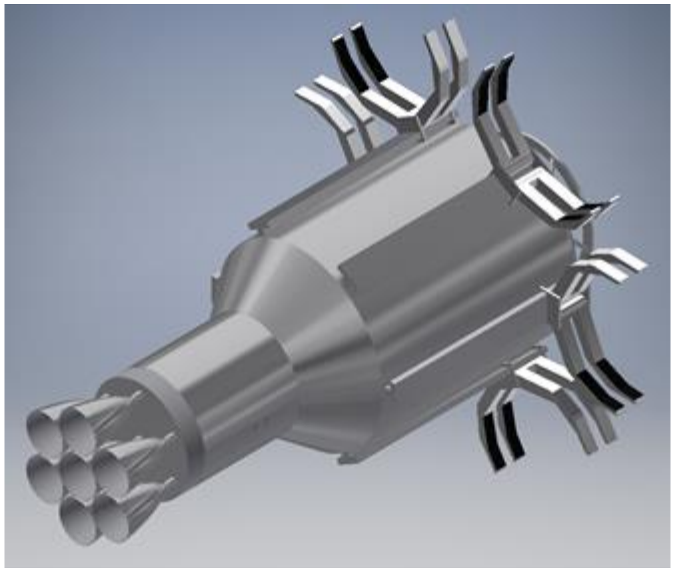


Fig. 5 Rear isometric view of HRMES.

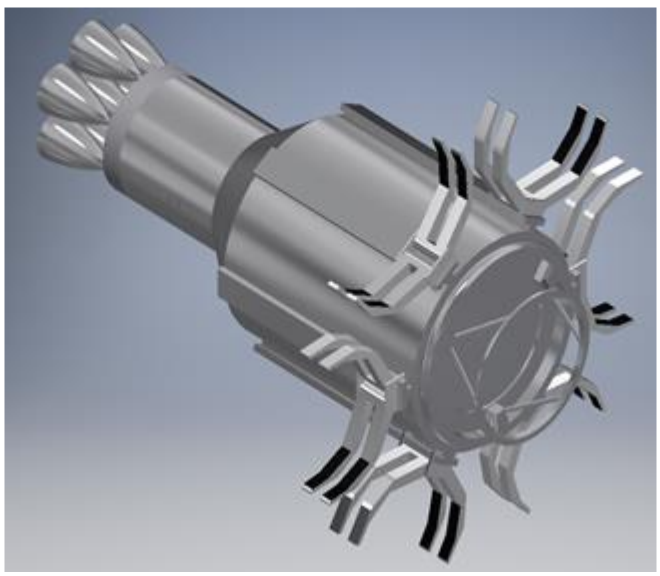


Fig. 6 Front isometric view of HRMES.

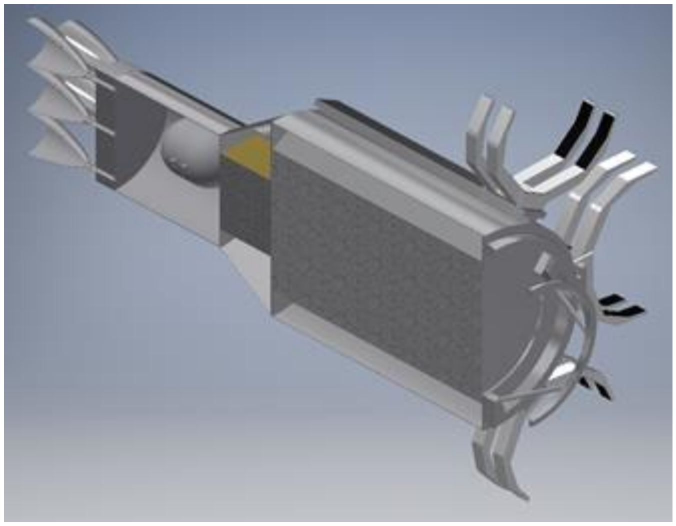


Fig. 7 Cross Section view of HRMES.

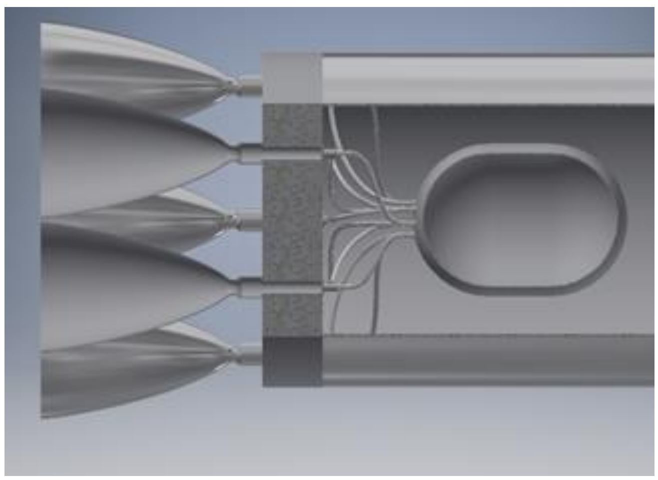


Fig. 8 Engine and fuel plumbing detail drawing of HRMES.

C. Clamps

The exchange of propellant from HRMES to DeMETR takes place via a clamp-and-rail system. This saves weight compared to having tanks stored internally and allows the station to handle tanks of any size. The tanks will be subject to the space environment and therefore are expected to require micrometeorite shielding, and would require radiation shielding if the station were leveraged for projects requiring storage of sensitive cargo (as discussed in the commercial partnership section). The clamp-rail system on HRMES and DeMETR are perfectly aligned, allowing for propellant to be transferred from one to the other by translating the clamps on HRMES forward until the tank is in range of DeMETR's clamps, grasping the tank with DeMETR's clamps, releasing HRMES's clamps, and moving the tank forward. This operation can be repeated between any two clamps to translate the tank forward or backward, and will be used to load and unload propellant tanks from the station.

This scheme allows for easy transfer of propellant from the HRMES to the DeMETR, but would require the baseline propulsion stage design to be modified to allow modular tanks to be inserted and rejected by this method. Further analysis must be performed to estimate the weight change and forces this will put on the design. It is anticipated that this method will be safer than attempting to pump hypergolic and cryogenic propellants in space because the fluids will be stored in separate, self-contained pods for the entirety of the refueling operation. This system is illustrated in Figure 9.

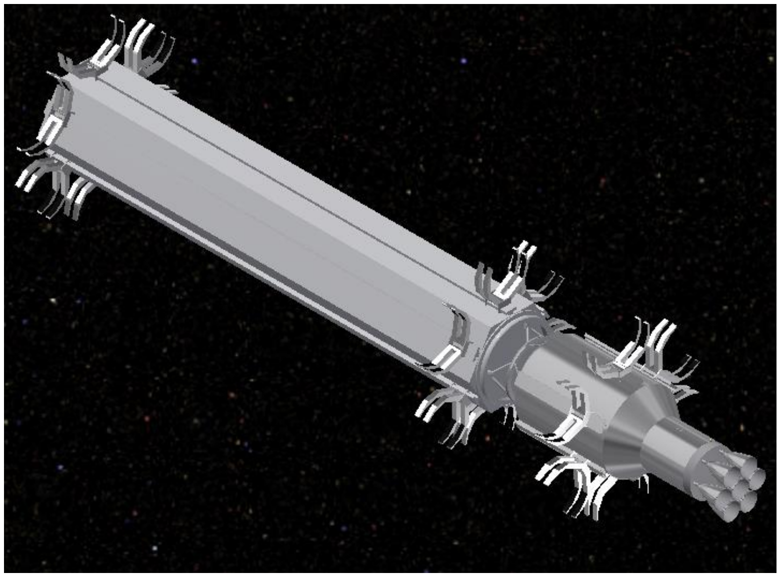


Fig. 9 Docked DeMETR and HRMES with clamps visible.

D. OTHER COMPONENTS

The station should be able to maintain attitude and make attitude corrections automatically, without interference from ground control. To this end, the station will need an onboard computer. A design similar to the ISS onboard computer [13] should suffice. This will allow the station to make attitude adjustments on its own, while also allowing for adjustments to be made from ground control. The computer will be powered by 10 240-watt class solar arrays made by UNICOR FPI [14], which will take up an area of roughly 16 m^2. These solar panels will supply the approximately 1800 W required by the station during regular operation. System power needs are tabulated in Table 2.

Table 2: Power allocation of DeMETR

System	Passive Power Draw (W)	Active Power Draw (W)
Control Moment Gyroscopes	50	500
Fluid Control Systems	100	500
Thermal Control System	5	55
Communications System	500	750
Total	655	1805

While the station will frequently be in the shadow of both the Earth and the Moon, this will only account for roughly 5% of the total orbit, and thus the solar arrays should be able to feed enough electricity into the station's subsystems. In order to mitigate the situations in which the solar arrays cannot provide the station with enough power the station will also be outfitted with an array of batteries, similar to the batteries used on the ISS [15]. Finally, the station will use SMART (Shape Morphing Adaptive Radiator Technology) radiators to dissipate excess heat being created by onboard electronics and the bioreactor. SMART radiators use thermally activated shape memory technology to adjust their open surface area to increase the amount of heat dissipated from radiation as their temperature increases. SMART radiators that have been produced are capable of dissipating between 90-180 watts per meter of radiative structure added [16].

VII. MASS

The mass of the station and taxi was determined by breaking down the estimated mass of each component and using mass estimated from CAD drawings for the structure. This was added onto the mass of propellant needed to refuel the Deep Space Transport. Tank mass for xenon was calculated using a surface area relationship from literature, modeling the xenon tank as a cylinder with hemispherical caps. The tank mass of the xenon has been estimated to be 1150 kg, which is twice the value calculated this way to account for the exceptionally large xenon mass, and to ensure estimates are conservative. The propellant mass needed to propel the station into LDRO was calculated using Eqn. 1 and the dry mass already computed. A tankage fraction of 0.1 was assumed as a conservative estimate [17].

$$\Delta V = I_{SP} g_0 \ln\left(\frac{m_0}{m_f}\right) \qquad Eqn. 1$$

DeMETR has a dry mass of approximately 2.9 metric tons. With the Deep Space Transport propellant and the propellant needed for transfer, the mass of the system at TLI is approximately 34.6 metric tons, well under the limit for the SLS Block 2. DeMETR has the option of either staying under the mass limit for a factor of safety, launching an extra tank of propellant for the Deep Space Transport to use in the future, or making the remaining mass available to commercial partners. Approximately 10.0 metric tons of mass is available. HRMES has a total dry mass of approximately 1 metric ton. With propellant for delivery, transport to LDRO, rendezvous, and transport back to Earth for disposal, HRMES will have a mass of approximately 33.2 metric tons. Similarly to DeMETR, HRMES also has the option of providing approximately 11.4 metric tons for commercial partners or excess propellant for the Deep Space Transport. A detailed breakdown of mass by component for DeMETR is tabulated in Table 3 and a graphical representation of mass by component is given in Figure 10.

Table 3: Mass breakdown of DeMETR

Part	**Mass (kg)**
Bioreactor	1500
Engines	-
Aestus	111
R-42	31.71
RC Thrusters	35
Structure	850
Control Moment Gyros	112
-Solar Panels (200-240 W)	227
- Batteries	9.52
Communications	33
Onboard Computer	5
Radiators	13.8335
Station Total (kg)	2928
Station Total (T)	2.928

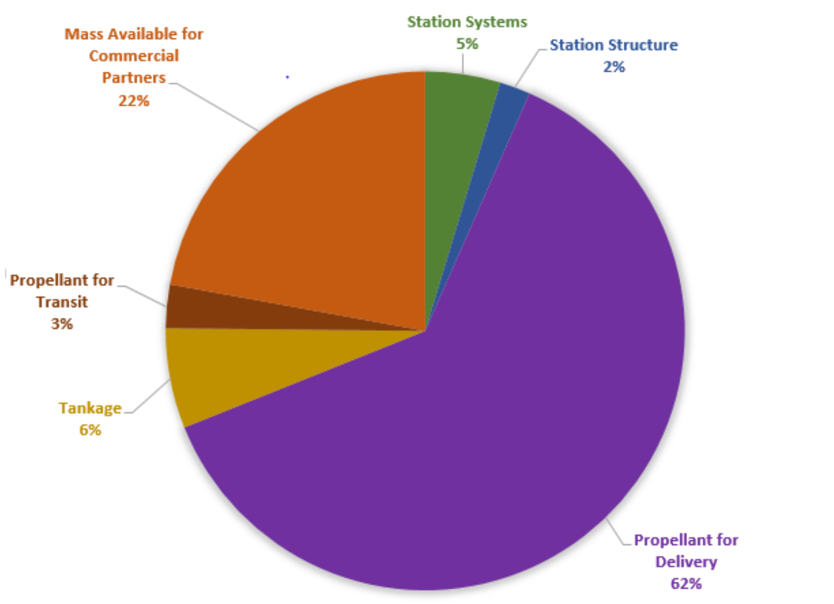


Fig. 10 Mass breakdown of loaded station.

VIII. BIOREACTOR

As mentioned in our abstract, the station is equipped with an onboard bioreactor for recycling solid waste produced by astronauts during their time in the habitat. In short, a bioreactor is a chamber which utilizes living bacteria to break down organic molecules into methane and water. [18] The station is equipped with a tank to hold 2 m^3 of solid waste, a methane digester, an electrolysis unit to produce oxygen and hydrogen from water, and a reverse-Brayton cooler to liquify these gases [19]. While the exact design of this device is both beyond the scope of this concept and outside of its focus, the basic function, requirements, and output of the device have been modeled. Assuming the average human produces about .25 kg of waste a day [20], 75% of which is water, and that all this waste is in the form of carbohydrates and water, the bioreactor will produce 875 kg of oxygen, 75 kg of hydrogen, and 150 kg of methane from the maximum 1100-day heliocentric flight duration outlined in NASA literature [1], [21]. It should be noted that this is a ceiling value for design purposes, so missions will be expected to produce less than or equal to these amounts at the same ratio, depending of flight time. This fuel will be used for orbital maneuvering and station keeping. In order to utilize the fuel, it must be separated from the slurry and extracted. On earth, this is done by density driven methods: gaseous methane and low-density water float to the top of the slurry where they are collected. In orbit, density based separation systems which rely on gravity do not work. Instead, passive separation is driven by differences in surface tension of the constituent fluids. Further research would need to be conducted to determine if a fully passive, surface tension-driven separation method would be possible, or if a small amount of artificial gravity would need to be created using a rotating separation chamber, in which case methods like those used on Earth are again viable. The digester is currently planned to use a continuously-stirred configuration because this configuration does not require feedwater. Aluminum is the material planned for use in the digestion and holding tank. As can be seen in an aluminum-water Pourbaix diagram, aluminum forms a passivating oxide film at modest pH in the presence of water [22], limiting further corrosion. Further research would need to be done to determine if protective measures such as sacrificial alloying agents will be required, and if pH control would be necessary.

IX. XENON TANK PRESSURIZATION AND COOLING

The equilibrium temperature for a TiO_2 painted tank at the location of the DeMETR station was calculated to be approximately 237 K from Equation 2. A_C is the cross-sectional area of the tank, A_S is the surface area, S is the radiation from the sun, S_R is the reflected radiation from the Earth, E is the infrared radiation from the Earth, M is the infrared radiation from the Moon, α_V is the absorptivity of the paint, ε_{IR} is the infrared emissivity of the paint, and σ is the Stefan-Boltzmann constant [31]. A high value, 0.5, of A_C/A_S was used to make estimates more conservative.

$$T_{eq} = \left[\frac{\left({}^{A_C}/_{A_S}\right)\left[(S + S_R)\frac{\alpha_V}{\varepsilon_{IR}} + E + M\right]}{\sigma}\right]^{1/4} \qquad Eqn. 2$$

The xenon propellant will be stored at a pressure of 5 MPa and a temperature of 200 degrees Kelvin based on an investigation into the filling of xenon tanks in [23]. If the xenon is stored with only a passive cooling system, the fuel will be subject to bleed-off and will lose mass over time. This is not acceptable due to the long durations the fuel is expected to be in orbit before being sent to the target craft.

Therefore, the fuel tanks will include a cryogenic cooler onboard which will keep the xenon as a liquid and minimize the bleed-off effect [24].

Due to the massive amounts of xenon required, significant attention must be paid to the storage characteristics of it as they relate to tankage fraction. Xenon decreases in density and vapor pressure as temperature is decreased, resulting in smaller, thinner fuel tanks. However, this necessitates large cryocoolers to maintain the fuel at temperature. An optimum point exists at which the competing factors (pressure vessel mass at high temperature and cryocooler mass at low temperature) result in the lowest achievable tank mass for xenon. To do this, vapor pressure and density were found as a function of temperature from tabular data. [25], [26] ASTM standards for pressure vessel thickness were used assuming 10 m long tanks made of 2024 aluminum, adjusting for material property differences between aluminum and steel (which standards assume), and a reduced factor of safety associated with space technology and fabrication methods [27]. Available data on space-based cryocoolers was plotted and analyzed to determine a line of best fit. Using these, a composite mass of the tank and cryocooler was found as a function of the storage temperature of the xenon [28]. Based on this analysis, a tankage fraction of 0.21 is predicted at a storage temperature of 200 K. However, these numbers likely significantly over-estimate the mass of both components. Cryocoolers for most missions are intended to chill small amounts of fuel for satellites or RCTs, and are composed of compressors, heat exchangers, and diffusers. These devices become more efficient as they are scaled up, due to decreased viscous losses relative to heat transfer. Estimates of tank mass are also very conservative; the current expected hoop stress on the optimum tank is much lower than the acceptable stress on aluminum 2024, and it is strongly recommended that composite tanks with much lower overall masses are chosen. This analysis serves as a first-level exploration to determine the approximate optimum storage temperature. A full analysis and tank design would require these factors to be more fully explored. Figure 11 displays the tankage fraction and mass data obtained this way.

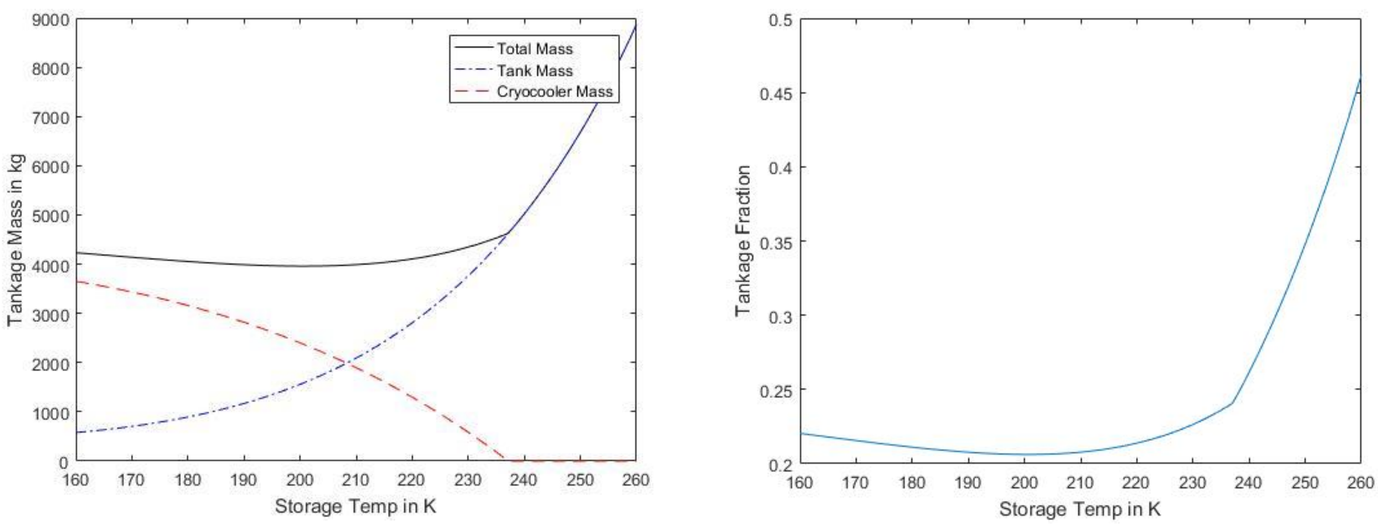


Fig 11: Tank Mass and Tankage Fraction of Modeled Xenon Fuel Tanks

X. COST

A common method of estimating the expense of a space exploration mission is to use correlations between mass and the cost of missions within particular categories. The relationship can typically be modeled as given in Equation 3 where the cost is in millions and the mass is in kilograms. When the station is assumed to fall under the category of a propellant depot and the taxi is assumed to be a storable propulsive stage, the coefficients and total cost for each is given in Table 4 [29]. The cost of design, development, testing, and evaluation (DDT&E) would apply to only the first unit. The cost of the flight unit is the cost of each unit produced after the design is complete. For example, the first HRMES vehicle will cost the sum of the DDT&E and flight unit cost. Each subsequent unit will only cost the value of a single flight unit. These estimated costs have been calculated using fiscal year 2012 dollars as this is the most recent correlation found for these types of missions.

$$Cost = A(mass)^b \qquad Eqn. 3$$

Table 4. Estimated cost of DeMETR and HRMES from mass and cost relations in fiscal year 2012 [25].

	DDT&E			**Flight Unit**		
Category	A	b	Total ($ millions)	A	b	Total ($ millions)
DeMETR	75.492	0.3566	1312	11.487	0.3175	145.9
HRMES	29.125	0.4554	676.8	1.8650	0.4782	50.73

According to the US inflation calculator, there has been a cumulative inflation rate of approximately 8.694% between 2012 and 2018 [30]. This value can be used to calculate the cost of each unit in the current economy. Table 5 gives the cost breakdown of each unit. The DeMETR station is the sum of the DDT&E and flight unit cost because it is only produced once. The first unit of HRMES is the sum of the DDT&E and flight unit costs, and each subsequent unit is only the cost of the flight unit.

Table 5. Estimated cost of DeMETR and HRMES corrected for the current economy.

Unit	**Total ($ millions)**
DeMETR	1585
First HRMES	790.9
All Subsequent HRMES	55.23

XI. OPPORTUNITIES FOR COMMERCIAL PARTNERSHIP AND MISSION EXPANSION

Due to the high maximum launch weight of the SLS Block 2, the DeMETR launch and periodic HRMES launches can support co-manifested payloads. This presents a number of opportunities for private and international cooperation. The initial DeMETR launch can support 10.0 t of co-manifested cargo, and a HRMES launch can support 11.4 t. At present, many startup ventures into asteroid mining, space colonization, and space station construction are in the development phases. These organizations do not necessarily have the same experience or infrastructure for in-space resupply as NASA. The opportunity to leverage NASA resources during the early stages of operation could be very valuable for these enterprises in constructing and maintaining their equipment. Alternately, this extra space could be leveraged to support other NASA operations, especially lunar operations due to DeMETR’s proximity to the moon and the current administration's interest in lunar operations.

XII. FUTURE WORK

Certain aspects of the refueling design concept need further development. Future work should focus on the changes necessary to the NASA baseline to ensure compatibility with the HRMES system. The handoff process will be nearly identical to the handoff process between HRMES and DeMETR, so a second resupply concept will not need to be designed. However, the weight and geometry changes caused by this transition must be determined to effectively compare this system to the existing NASA baseline.

XIII. CONCLUSION

The mission design presented in this paper was designed in accordance with the requirements outlined in the RASC-AL propellant resupply capability prompt. DeMETR and HRMES can supply the Deep Space Transport with the required propellant as detailed in the NASA baseline concept at every opportunity beginning in 2033. Ground infrastructure, launch vehicles, mission schedule, depot and taxi design, propellant transfer, and disposal of the HRMES taxi were all considered and detailed in this report.

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Student Contribution: Emily Beckman

I was the student in charge of determining the orbital mechanics of the spacecraft, including rendezvous in LDRO. From this, I determined the propellant mass requirements for transfer between desired positions. I also analyzed launch vehicles and alternate vehicles should the SLS not develop as expected. These two were combined to create the general mission overview, launch schedule, and docking schedule.

In addition to orbital mechanics related tasks, I computed the equilibrium temperature at the orbital location of the spacecraft to be used in determining the size of cryocoolers needed for the Xenon fuel tanks (this step completed by another student). Finally, I completed the cost analysis and corrected the estimates for inflation to 2018 dollars.