Station for Exploratory Analysis and Research Center for Humanity

Jasmine Wong[1], Matthew Decker[1], Joseph Lewis[1], and Megerditch Arabian[1]
California State University, Northridge, CA, 91330

and

Peter L. Bishay[2]
California State University, Northridge, CA, 91330

Fractional gravity and microgravity present many obstacles that hinder mankind's ability to expand permanently beyond Earth. In addition to the well-documented harmful health effects of microgravity, it is likely that natural human reproduction may not be feasible on the fractional gravity of extraterrestrial planets. A long-term, earth-independent, space-based architecture that can provide a continuous 1G environment may be the only viable solution to mankind's expansion. The Station for Exploratory Analysis and Research Center for Humanity, SEARCH, provides an Earth-independent architecture for a Lunar-orbit-based community of 16-24 people in a 1G environment. Advancements in technology, data on human reproduction in an artificial 1G environment, and knowledge of the physiological, psychological, and sociological effects due to long term community isolation are priceless benefits that will result from SEARCH's 55 year mission. Design aspects covered include mission scheduling, budget, technology development, transportation systems, synergistic commercial and NASA technology applications, utilization of scientific data from planned NASA exploration missions, an Earth-independent resource plan, station manufacturing and LEO assembly, life support and power logistics, as well as emergency system and return to Earth strategy.

I. Introduction

THE required duration of manned space flight is increasing. With exploration goals extending to Mars and beyond, the prospect of permanent human expansion into space is on the horizon. However, the physiological detriments of extended time in microgravity are a significant limiting factor. Muscle and bone atrophy due to a lack of mechanical loading on the body is the focus of a number of research projects and NASA design objectives[1,2]. A study on returned astronauts in 2011 suggests that permanent visual-impairment experienced by some of the astronauts who had long-duration (>6 months) missions aboard the ISS was caused by an increase in intracranial pressure which, in turn, swelled the optic nerve and flattened the eyeball[3]. A myriad of medical and technological research and development projects have had the goal to mitigate these, and other biomedical risks caused by microgravity. It has been proposed that a regiment of exercise[4], negative lower-body pressure[5], nutrition, and medications will allow for expedition-type missions to Mars. However, in order for permanent human expansion into space to be viable, humans must be able to reproduce and raise offspring non-terrestrially.

Multiple reproduction studies have been performed on various species, including mammals, during space flight and simulated microgravity (μG) using 3D rotating clinostats. Findings suggest mouse fertilization is possible in microgravity via in vitro fertilization (IVF) but that the development of the embryo is impaired by only one day of μG conditions[6]. While no study has been published that has tested early mammalian pregnancy during space flight, the

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[1] Student, Mechanical Engineering Department, College of Engineering and Computer Science, 18111 Nordhoff Street, Northridge, CA 91330, Student Member AIAA.
[2] Assistant Professor, Mechanical Engineering Department, College of Engineering and Computer Science, 18111 Nordhoff Street, Northridge, CA 91330.

first mission carrying pregnant mice into orbit found lower weight gain, prolonged labor, "lower birth weights, and increased perinatal mortality"[7]. To date, no testing has been performed on the viability of mammalian birth in space.

With more research to be done, it is possible that the effects of a microgravity environment on the human reproductive process will inhibit mankind's ability to establish a permanent colony in space. Partial gravity may also be insufficient to produce and raise viable offspring. The only remaining solution is a continuous 1G artificial gravity environment. While this will solve a great number of the health concerns associated with μG exposure, numerous design challenges arise which we, at our current technology readiness level, are unable to address.

This paper proposes a 1G space station that will provide the capability to support a crew of 16-24 people in a Lunar-orbit for 30 years. Beginning the experiment in 2040, the Station for Exploratory Analysis and Research Center for Humanity (SEARCH) will provide data on human reproduction and child rearing in an artificial 1G environment and the effects of long term community isolation. SEARCH is designed to be completely independent of Earth resupply during the 30 year experiment. The proposed design includes the mission architecture, 55-year timeline, NASA-based budget, spacecraft design specifications, technology readiness considerations and suggested secondary missions for SEARCH.

II. Mission

A. Architecture

SEARCH's primary mission includes four phases; research and development, manufacturing and assembly, reliability verification, and independence. Independence includes the birth and maturity of a single generation and the birth and adolescence of a second generation. Fig. 1 shows these phases and their duration beginning in 2015.

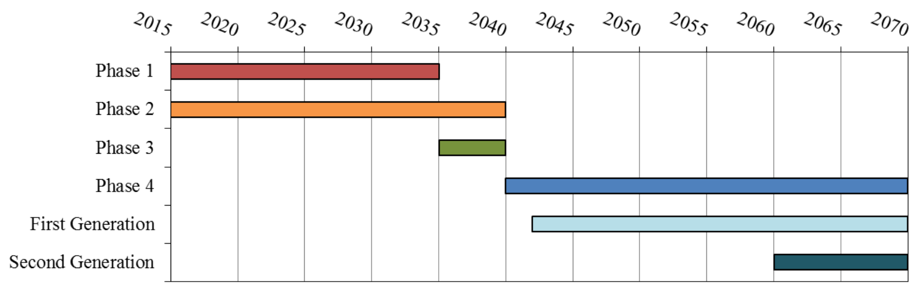

Figure 1. SEARCH mission architecture timeline.

B. Timeline

The majority of research and development occurs before 2025 to ensure technology readiness for manufacturing and Low Earth Orbit (LEO) assembly. System integration is scheduled to begin in year 2031. Once assembly is complete in LEO and life support systems are operational, the first four members of the experiment crew will launch, board SEARCH, and finish the system integration and testing. In 2035, the station is "spun-up" to the rotational speed required for 1G environment. After this time, 1G-dependent systems will be installed, the remaining 12 members of the crew will launch to SEARCH, and reliability verification of all Earth-independent systems will occur between 2035 and 2040. This phase takes place while SEARCH is in LEO so that backup supplies and food can be launched to the station before the Earth-independent experiment begins in 2040.

C. Budget

The Human Exploration and Operations Mission Directorate (HEOMD) budget and a maximum of 20% of all non-HEOMD program budgets are the primary sources of funding for SEARCH. NASA's budget is assumed to be flat at $16B (2016 dollars) per year. The International Space Station (ISS) is fully funded through 2024 while the SLS and Orion budgets are assumed to be fully funded through 2030, they are then considered allowable sources of income for the SEARCH project.

The available annual budget and mission operating costs are shown in Fig. 2. SEARCH's budget will utilize 20% of the non-HEOMD program budgets from 2015 to 2020, totaling to \$5.0B annually. From 2025 to 2031, SEARCH will utilize an additional 16% from the ISS budget, totaling \$5.5B annually, with the remainder of the ISS budget applied towards keeping the ISS operational as an assembly platform. From 2031 to 2040, SEARCH's budget will reduce to 10% of the non-HEOMD program budgets and 8% of the ISS budget, resulting in \$2.7B annually. To determine the available funds, the assumption is made that surplus funds from the previous fiscal year are available the following year.

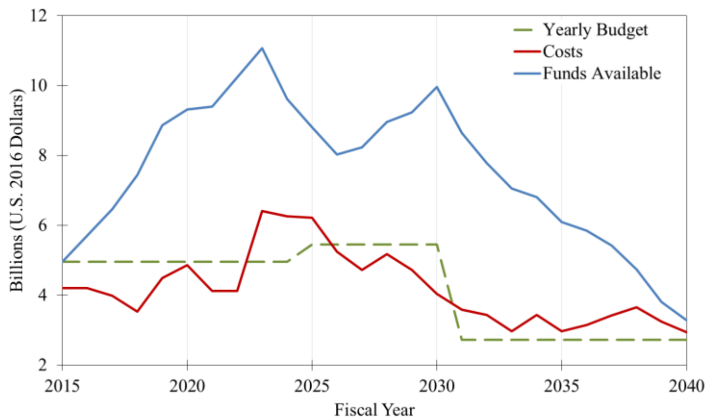

Figure 2. SEARCH budget and cost overview.

III. SEARCH

The full station, with a center hub length of 54.6 m and an envelope diameter of 142 m, is shown in Fig. 3. Major components of the station include the 1G Habitat Ring, microgravity hub, solar arrays, propulsion, restraining cables and transport trusses.

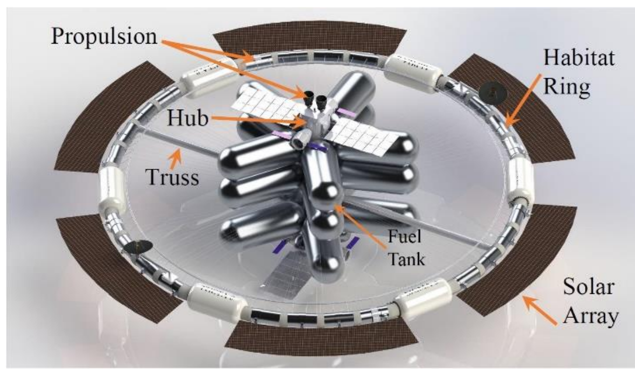

Figure 3. SEARCH assembly.

A. Location

A 56.2° polar lunar orbit was chosen for SEARCH's 30 year Earth-independent experiment. When the experiment concludes, SEARCH will remain in lunar orbit and facilitate secondary missions. Though a sun-synchronous orbit would have been most preferable for power generation using SEARCH's six solar arrays, the fuel requirements to maintain the orbit disqualified the option. The 56.2° inclination is considered the most stable lunar orbit as it requires little or no active station-keeping[8].

B. Artificial Gravity

Centrifugal force provides the artificial gravity. The rotating reference frame produces two important design considerations, the Coriolis Effect and gravity gradient. These drive the size of the habitat ring. The Coriolis Effect causes dizziness, disorientation and nausea. This effect arises at certain speeds when the inhabitant moves towards or away from the axis (e.g., squatting or standing up). A rotational speed below 2 rpm is believed to be required to live without need of an adjustment period, whereas a speed above 7 rpm is typically not acceptable regardless of adjustment period[9]. The gravity gradient experienced by an inhabitant is inversely proportional to the radius of the station. A large gradient would cause the motion within the station to be awkward. The rotational speed was chosen as 4 rpm to reduce the adjustment period required and shift the 1G line to an achievable radius of 56 m. This speed and diameter results in a module gravity gradient below 5% from floor to ceiling.

C. Structures

The Hub contains fuel and water tanks, main propulsion systems, Reaction Control System (RCS) thrusters, flywheels, and Common Birthing Mechanism (CBM) docks. Four Space X Dragon capsules are also docked on the Hub.

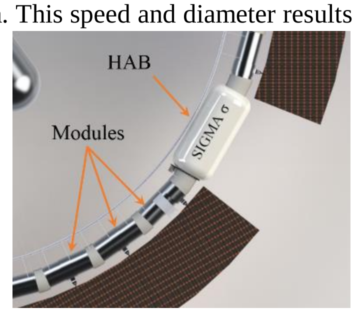

Figure 4. Modules and HAB.

All living and working quarters, life support systems, water tanks, aquaponics, flight and systems control, the additive manufacturing shop, and structural batteries are located within the 1G Habitat Ring. The Habitat Ring is composed of six inflatable Habitats (HABs) and 24 hard modules as shown in Fig. 4. All aluminum structural components of the station are 7075 alloy. The modules contain the food, water, air systems, sleeping quarters, and laboratories while the HABs house the majority of the living quarters, systems control, and recreation components. The HABs were arbitrarily assigned a Greek letter naming convention in order to differentiate them.

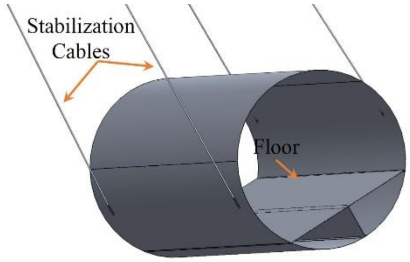

Figure 5. Individual module view.

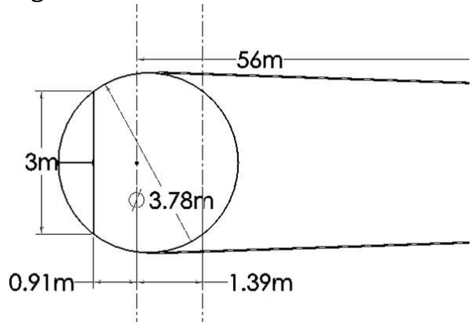

Figure 6. Module cross-section view.

1. Modules

An individual module is shown in Fig. 5. Each module's aluminum shell is 8.45 m in length and 3.78 m in diameter. A cross-sectional view of a module is shown in Fig. 6. The 56 m 1G radius is designed to be in the center of an average, 1.83 m tall, astronaut. The aluminum floor is 3 m in width and 6.35 mm thick. The floor is supported in the center with an I-beam and fixed at each end with a wedge to the outer shell. Due to imprecise, semi-autonomous assembly in LEO, flexible coupling sleeves made of heat shrink material are used to ensure integrity under pressure.

2. Stabilization Cables

Due to the flexible coupling sleeves, each module requires four steel cables anchored to the hub to restrain radial motion. Each cable is a 16 mm diameter, 6x25 IWRC filler wire with a design factor of 5.

3. Inflatable Habitats

Six HABs provide the necessary volume for the crew, while still being able to launch in NASA's SLS Block 2B[10]. Each HAB has a length of 16.0 m and 6.7 m diameter when inflated. Fig. 7 shows a cross-section view of the HAB along with the layered wall design. Nomex, Kevlar, polyurethane open cell foam and Nextel layers protect against fire, micrometeoroids, and radiation. A Combitherm layer is used to inflate the HAB.

Figure 7. HAB cross-section view.

The HABs are designed with the option to rotate 180° about their axis. This provides two invertible spaces that can experience 1G within a single HAB. A 1500 HP motor, seen in Fig. 8, is used to rotate the HAB with a design factor of 3.

4. Hub

The 7075 aluminum alloy Hub contains and supports the fuel, nitrogen and water tanks, main propulsion systems, RCS thrusters, flywheels, and docks. Five CBMs are located on the hub. Four of them are docking locations for Space-X Dragons that deliver the crew to SEARCH, these capsules will stay with the station throughout the experiment. The fifth CBM is located along the hub center axis at the end of the hub opposite to the main propulsion system and will be for assembling crew and cargo deliveries.

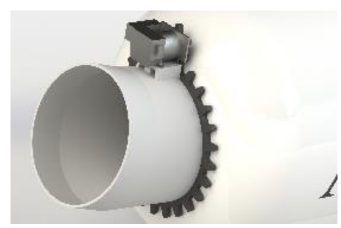

Figure 8. HAB motor.

5. Truss

Two trusses contain elevators that are used for resource and crew transport between the hub and habitat ring. Each 7075 aluminum alloy truss is 51.37 m long with a 1.98 m diameter. The elevators are specified to a 900 kg maximum load and use a 3 kW electric motor and 2:1 rope system.

D. Power

Fig. 9 shows SEARCH's power distribution system. The most significant loads are the life support systems and HAB motors. Solar arrays, with a solar cell area of 700 m^2, are the primary source of power generation. For use during eclipse or array malfunction, the station is equipped with two means of energy storage, flywheels and structural batteries. An emergency flywheel system is available in the case of primary and secondary system failure.

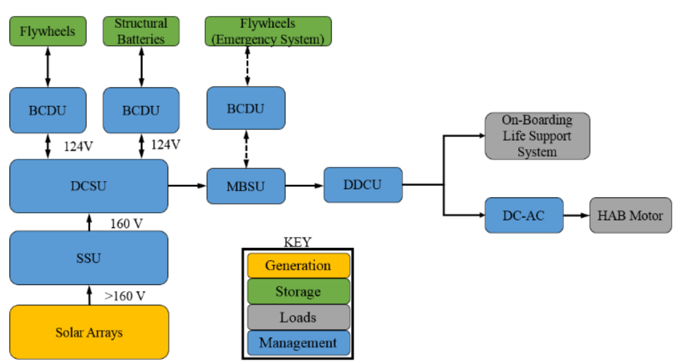

Figure 9. SEARCH power distribution system.

With the exception of a laser transmitter, all power calculations are assumed to have a 15% transmission loss and design factor of 1.3. The storage systems are assumed to have an additional overall 15% loss during each charging and discharging cycle. Using the volume ratio between the ISS and SEARCH along with the ISS power requirement of 83.6 kW, the total power requirement of SEARCH is presumed to be 297.4 kW.

During solar exposure, the solar arrays provide this 297.4 kW of power to the orbital and orientation control system, the life support and control systems, and to charging the storage components. Presuming 50% solar cell efficiency, the arrays produce 449.9 kW. The power output of the solar arrays are determined using Eq. (1). Where R_{sun} is the radius of the sun, D is the distance from the sun to the lunar orbit, H_{sun} is the sun's surface radiation intensity, η is the solar cell efficiency, and A_c is the total solar cell surface area.

$$P = \eta A_c \left(\frac{{R_{sun}}^2}{D^2} H_{sun} \right) \tag{1}$$

SEARCH has two sets of 9 fused silica fiber composite flywheels, each with a lifespan of 15 years, that provide the primary means of energy storage. A set of the 200 kg flywheels are capable of providing the nominal 119.0 kW power for the life support and control systems during 6 hours of eclipse. An additional 2 flywheels (1 for every 15 years) are available to provide emergency power at 70% of the nominal value. Each 79.9 cm diameter flywheel is supported by magnetic bearings and has a rotational speed of 60,000 rpm, density of 2200 kg/m^3, and thickness of 18.1 cm.

A secondary storage system of lithium-ion structural battery walls lining the modules provides power required to run a single HAB motor and the robotic maintenance system during solar exposure. The multifunctional structural batteries line the interior of the module walls for easy repair access. The fiber-reinforced polymer-based composite has a high energy density and working voltage. With a maximum energy density of 2.23 GJ/m^3, the walls provide 852.5 kW power, supplemented by 178.5 kW provided by the solar arrays, to run a HAB motor for the 2 minute rotation. To maximize the battery wall lifespan, four modules-worth of batteries are utilized at a time per charge/discharge cycle, with a battery wall nominal thickness of 0.52 cm. Summarized load and generation requirements are tabulated in the Appendix.

A laser power transmitter is available to provide power to the outboard robotic maintenance and repair system in the event that the wired transmission lines are damaged. The laser transmitter is located on one of the modules and the transmission is assumed to have loss of 45%.

E. Thermal and Radiation Shielding

A dual-loop coolant system utilizing water as the inner coolant and ammonia as the outer is used to regulate station temperature. Ammonia is replenishable via human waste processing. Twelve expandable carbon-fiber radiators, shown in Fig. 10, are used to dissipate excess station heat. These radiators have a high heat flux density[11], and therefore have smaller required dimensions than their aluminum counterparts. This minimizes the overall mass of the station and stress on the Hub.

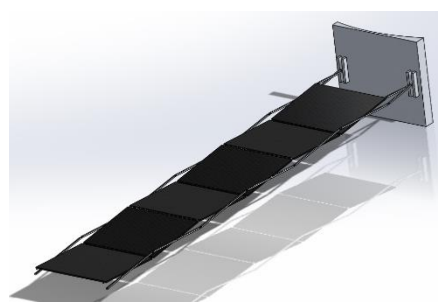

Figure 10. Carbon fiber radiator.

Quest Thermal's Micrometeoroid and Orbital Debris – Integrated Multilayer Insulation (MMOD-IMLI) protection system provides micrometeoroid shielding and passive thermal control for the Habitat Ring modules. A 10 layer IMLI blanket has a heat leak of 1.58 W/m^2 and a thermal conductivity of 0.12 mW/m-K. A 120 layer blanket is able to stop a 5.4 mm particle traveling at 6.6 km/s[12].

Radiation is the limiting factor in most deep space exploration and colonization. Where Solar Energetic Particles are mostly mitigated by SEARCH's external structure, Galactic Cosmic Rays (GCRs) pose a unique and difficult design challenge. Hydrogen can both fragment some of the larger ions in GCRs and shield against the secondary radiation that results[13]. Due to weight and the required Earth-independence, water walls are not a viable solution. Hydrogenated Boron Nitride Nanotube (BNNT) composites are an option to integrate passive shielding into the structure[13]. Thermally stable up to 800°C with a density of 1.3-1.4 g/cm^3 and a Modulus of 1 TPa[14], BNNTs have properties well suited for space applications. However, current projections state that BNNT composite shielding will only be safe for a mission of up to 1000 days[15]. Due to this limitation, active GCR magnetic shielding is also required. Both the passive BNNT shielding and active magnetic shielding are scheduled for extensive research and development.

F. Human Systems

1. Resource Plan

Supplemented by non-perishable items from Earth until the crops and fish stabilize, aquaponics provides the crew diet once 1G is achieved. This symbiotic system between fish and crops allows for a natural nutrient exchange in a limited space. A water volume of 13,627 liters supports a basic crop system of beans, corn, squash and tilapia. The main diet is supplemented with various vegetables that are also capable of being raised in water.

Station water revitalization is conducted through a Vapor Phase Catalytic Ammonia Removal (VPCAR) system with a projected 98% recycling rate. To sustain the crew for the duration of the experiment, a total 29,784 kg of water is required for human use. This results in a total SEARCH water requirement (human use and aquaponics) of 100,199 kg with a design factor of 1.3.

The cabin pressure of SEARCH will be kept at 14.70 psi with an air mixture of 78% nitrogen, 21% oxygen and 1% trace gases[16]. While the crops will assist in removing excess CO_2 from the environment, a Carbon dioxide and Moisture Removal Amine Swing-bed (CAMRAS) system will additionally be utilized. This system also removes surplus humidity from the environment. An S-Series Bosch system disassociates the CO_2 into water and carbon. Trace contaminant analysis is performed by the Spacecraft Atmosphere Monitoring (SAM) system while the Common Cabin Air Assembly (CCAA) filters the environment and collects humidity[17]. The total supply of liquid oxygen required for the life support system is 181,215 kg with a design factor of 1.17. Based on the ISS nitrogen requirements[18] and presuming that SEARCH's crew uses ten times that amount over the duration of the experiment, 4300 kg of liquid nitrogen is required.

Due to the length of SEARCH's mission, new clothing is 3D printed using filaflex material. EVAs are performed using NASA's next generation Z-series suits validated by year 2025.

2. Waste

Waste removal is accomplished via a plasma gasification process in the Plasma Arc Waste Destruction System (PAWDS), which uses Argon as an ignition gas. The products of the process are syngas, solid inert waste and 13.06 MW per year of power. Syngas can be recycled as the ignition gas so that the Argon does not require replenishment.

3. Healthcare

Plant-based nutrition is the primary means of healthcare. However, non-plant-based medical supplies are stocked. A regiment of anti-radiation medication is utilized to offset the effects of radiation exposure. Crew doctors will be assisted in routine medical procedures and surgeries using a pre-programmed Robonaut 2.

G. In-space Propulsion

After SEARCH assembly in LEO is complete, four MR-107Ns spin-up the station to the rotational speed required for 1G environment in the Habitat Ring. The amount of hydrazine fuel required for station spin-up is 543,000 kg.

A Hohmann transfer is utilized to efficiently transfer from LEO to the target lunar orbit. Presuming orbital interjection at the lunar orbit apogee, the total ΔV of the Hohmann transfer is 3.42 km/s. The time of flight is approximately 183 days. Two of Aerojet Rocketdyne's RL-10, LOX/LH_2 fueled rocket engines are used to achieve the necessary ΔV. A Variable Specific Impulse Magnetoplasma Rocket (VASIMR) is utilized for orbital changes and corrections once in lunar orbit. With a 5.0 N thrust and specific impulse of 5000 s, the VASIMR requires a 200 kW power source. Xenon, due to its reliable tankage properties and relative ease of ionization, will fuel the VASIMR.

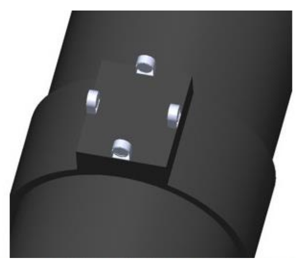

Figure 11. NSTAR cluster.

Station orientation is achieved by 16 NSTAR ion engines mounted as clusters of 4 on the Habitat Ring, as seen in Fig. 11. A sensory feedback system will determine which NSTARs need to fire and the duration of burn to achieve proper orientation. A Reaction Control System uses SpaceX Draco Thrusters mounted on the Hub. The RCS thrusters assist in orbital corrections, but their primary purpose is to flip the station during the Hohmann transfer from Earth so the RL-10s can perform the retrograde burn for entry into the lunar orbit. The Draco thrusters use nitrogen tetroxide and monomethyl hydrazine as fuel. Both the NSTARs and VASIMR use Xenon as propellant. The amount of Xenon required for the duration of the experiment is 277,000 kg.

1. Hohmann Transfer Fuel Requirements

The Tsiolkovsky Rocket Equation, Eq. (2), is used to calculate the required fuel, m_f, for the Hohmann transfer. The equation is a function of engine specific impulse (I_{sp}), the gravitational constant (g_0), the empty mass (m_e), and total ΔV. Empty weight of the station is determined to be 2.809×10^6 kg using the SolidWorks model, gravitational constant is presumed to be 9.81 m/s^2, and the RL-10 engine specific impulse is 465 s. Based on these parameters, total required fuel mass is found to be 3.141×10^6 kg.

$$\Delta V = I_{sp}(g_0)\ln\frac{m_f}{m_e} \tag{2}$$

Utilizing an oxidizer-to-fuel ratio of 85-15%, the required masses of liquid oxygen and liquid hydrogen are 2.670×10^6 kg and 471.2×10^3 kg, respectively.

H. Communications

SEARCH is equipped with high gain antennas (HGAs), low gain antennas (LGAs), and ultra-high frequency (UHF) antennas. The HGAs are for primary communications via X and Ka band frequencies for high data rate information transfer while the LGAs are used for basic engineering, telemetry, and emergency backup communications. The UHF antennas are utilized in communication with future planned lunar bases, in-situ resource units, and rovers using the Electra Lite Transceiver package. Communications with Earth are carried out through NASA's Deep Space Network (DSN).

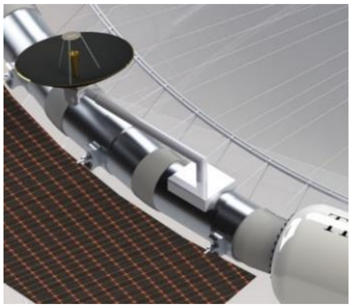

Figure 12. HGA on Habitat Ring.

The HGAs are designed with 2-axis gimbals mounted on the Habitat Ring to maintain line of sight with Earth during uplink and downlink data transfer. A Cassegrain HGA design was selected for SEARCH. The Cassegrain design utilizes a sub-reflector to redirect incoming signals from the reflector dish to the feed horn minimizing signal blockage from the feed horn that is typical of Axial Feed parabolic antennas. Figure 12 shows an 8 m Cassegrain HGA utilized on SEARCH. LGA and UHF antennas are mounted on the Habitat Ring in addition to the two designed HGAs.

Internal communications within SEARCH are modeled after the ISS's Communication and Tracking Subsystem (C&TS). This system provides two-way audio and video communication within the station and with those performing Extravehicular activities (EVA).

I. Outboard Maintenance and EVA

Due to the rotational velocity of the Habitat Ring, EVA in this section of SEARCH is significantly more dangerous than microgravity EVA. A 7075 aluminum alloy track is connected to the modules, seen in Fig. 13. Two robotic arms, one shown in Fig. 14, are capable of performing telerobotic maintenance on the solar arrays, antennas, HAB motors and NSTAR engines. With interchangeable end effectors, a variety of maintenance and repair tasks can be performed.

Figure 13. Robotic arm assembly.

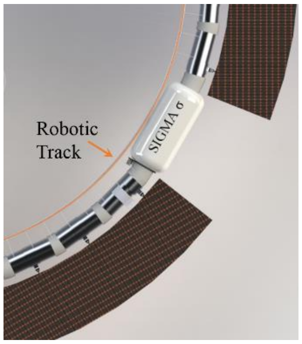

Figure 14. Robotic track location.

Onboard manufacturing is required to replace or repair tools and machinery. The technology development of 3D manufacturing in both polymers and metals makes this a viable option to facilitate long-duration Earth-independent missions. All tool material and possible replacement parts must be considered prior to the experiment and the raw materials must be stocked onboard SEARCH.

J. Assembly

The size of SEARCH requires unique assembly methods. While the ISS was built with complete modules being launched to orbit and assembled to the truss and each other, SEARCH utilizes in-orbit welding to construct the modules, trusses, and hub.

1. Strategy

Utilizing the ISS as an assembly platform allows the use of the Mobile Base System, including the Canadarm2 and Dextre. The ISS also serves as a lifeboat and EVA platform for assembly crews. These crews will be launched to the ISS for 1 to 2 year-long missions beginning in 2020. While the ISS is fully funded and operational, these crews will be responsible for assembly part-time while also pursuing the scientific goals of the ISS. After 2024, the crew aboard the ISS will be fully dedicated to SEARCH assembly. Early launches of fuel, orbit control mechanisms, power systems, and thermal structures ensures that SEARCH's orbit will remain stable as the central hub is under construction.

The modules, hub, and trusses require welding in LEO. This is performed via friction stir welding (FSW) which can join any aluminum alloy. FSW is achieved by a pin rotating between 10,000-15,000 rpm heating and stiring the material together at the joint, without requiring oxidizer. The walls of the modules are assembled by joining three wall segments while the hub and truss sections are complete cylinders. Figure 15 shows a wall segment with its layers. Manufactured and launched as layered module sections, the wall structures consist of the battery walls, aluminum module shell, and MMOD-IMLI layer.

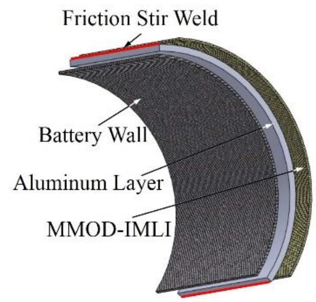

Figure 15. Module wall structure.

2. Launch Vehicles and Schedule

The SEARCH mission launch schedule is shown in Fig. 16. The red line after 2035 indicates the 1G spin-up. All crewed launches will be done using Space X's Falcon 9 and Dragon capsule. NASA's SLS Block 2B, with a maximum payload of 130.0 mT, is presumed to be available for two launches per year for payload deliveries to LEO. Space X's Falcon Heavy, with a maximum payload of 53.0 mT, is presumed to be available for three launches per year. The Falcon 9, with an unmanned payload maximum of 13.2 mT, is also utilized for component and supply transport.

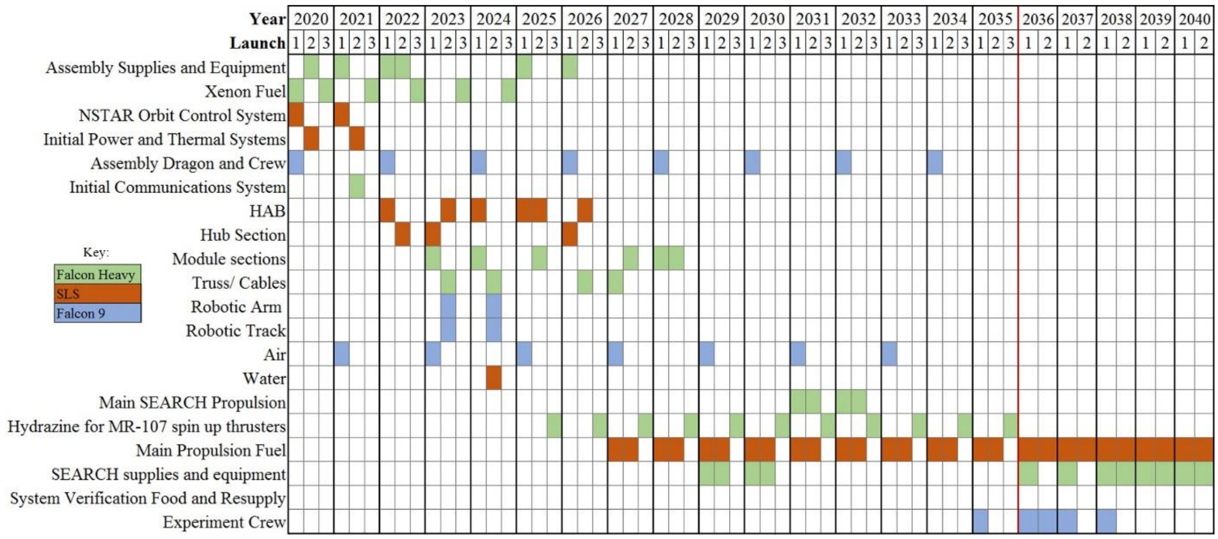

Figure 16. SEARCH mission launch schedule.

The fuel for the RL-10s requires 28 launches. Each LOX launch will consist of 125,000 kg LOX held in a 3,956 kg spherical aluminum tank with a diameter of 6.0 m. Each LH_2 launch will consist of 104,000 kg LH_2 in a 26,668 kg cylindrical aluminum tank with a diameter of 9.5 m and length of 28.9 m. The fuel for the MR-107Ns requires 11 Falcon Heavy launches and the Xenon required for the NSTARs and VASIMR require 6 Falcon Heavy launches.

IV. Emergency System and Return to Earth

In the case of a catastrophic structural or life support system failure, the four Dragon capsules that the crew arrived in can accommodate the original 16 member crew plus any offspring, up to a total crew size of 28. The ability to return to Earth in these Dragons is made under the presumption that the Dragon technology has been developed to achieve functionality beyond LEO by the beginning of the experiment. In the event that the Dragons are determined to be have deteriorated or received micrometeoroid damage during the duration of the experiment, partially-filled capsule crew rotations from Earth can be made to replace the unsafe capsule. This capsule and crew rotation can also be used to remove any severely ill crew members from the experiment.

V. Technology

A. Readiness

Table (1) shows the key technologies utilized in SEARCH with low (≤5) Technology Readiness Levels (TRLs). It is assumed that a technology with a TRL greater than 5 will certainly be developed in time for use in SEARCH.

Table 1. Key technologies utilized on SEARCH with TRLs less than 6.

Component	Key Technology	TRL
Life Support- Medical	Robonaut 2	5
Human Life- Clothing	Objet500 Connex/ Filaflex	3
Radiation Shielding	MMOD-IMLI	3
Structural	Flexible coupling sleeve	3
Power	Structural Batteries	3
Life Support-Air	S-Series Bosch	2
Life Support-Air	CAMRAS	2
Power	High Specific Energy/ High Temperature Flywheels	2
Radiators	Carbon Fiber Base	1

B. Development

NASA's Twins Study is in progress which "looks at changes in the human body in the fields of genetics, psychology, physiology, microbiology, and immunology"[19] that occur over an 11-month duration stay aboard the ISS. NASA also plans to have an asteroid redirect mission in the 2020s and a manned trip to Mars orbit by mid-2030s. With active research occurring on the ISS and exploration in the near future, NASA's missions are driving technology development.

SEARCH's mission has 11 years of technology development, 2015-2025, that will develop the previously tabulated key technologies and processes to the functionality and efficiency required for the 30 year experiment. The first 6 years of R&D is heavily focused on the structural and propulsion systems to enable the manufacture and assembly of these components can begin as soon as possible. The second half of the R&D phase is focused on life support, control, assembly, power, and thermal systems.

Besides the specific technologies and processes previously tabulated, core technologies require advancement in able for SEARCH's mission to succeed. These technologies include GCR protection, solar cell efficiency, power and thermal component life span, advanced EVA technology, additive metal manufacturing, cryogenic fuel management, power management and storage, and chemical propulsion system efficiency.

VI. Secondary Mission

After the 30 year experiment is completed, SEARCH can be outfitted with new technologies and refueled as needed. The station can then be utilized as a lunar-orbit fuel and launch station for manned missions traveling into deep space. With the capability to provide variable G, SEARCH could also be used as a large-scale crew transport vehicle between Earth and other colonized bodies, allowing for astronaut adaptation and training to destination gravity or a healthy 1G environment for extended destinations.

VII. Conclusion

As the duration of manned missions increases and the need for human expansion grows, providing a means for human reproduction in space is becoming critical. Research may find that humans are unable to produce viable offspring without a constant 1G environment. A design was presented for a 1G space station capable of supporting a crew of 16-24 people for a 30 year Earth-resupply independent experiment in lunar orbit. The proposed design included mission architecture, timeline, budget, technology readiness considerations and station design specifications. While each portion of the mission could be an in-depth focus of research and design, this paper sought to address the main considerations in providing a safe, long-duration, Earth-independent space craft.

Appendix

Table A1. Power load and generation requirements.

Load	System Load (kW)	Load Requirements: Solar arrays (kW)	Load Requirements: Batteries (kW)	Load Requirements: Flywheels (kW)	Load Requirements: Emergency Flywheel (kW)	Generation requirements (includes losses): Solar arrays (kW)	Generation requirements (includes losses): Batteries (kW)	Generation requirements (includes losses): Flywheels (kW)	Generation requirements (includes losses): Emergency Flywheel (kW)
"Daytime" Nominal	**297.4**	**349.2**	**0**	**0**	**0**	**522.1**	**0**	**0**	**0**
Life Support & Control	119.0	170.8	0	0	0				
Charging Storage	178.5	178.5	0	0	0				
Daytime + HAB Motor	**1031.0**	**297.4**	**852.5**	**0**	**0**	**444.7**	**1465.7**	**0**	**0**
Life Support & Control	119.0	119.0	0	0	0				
Running Motor	912.0	178.5	852.5	0	0				
Eclipse Nominal	**119.0**	**0**	**0**	**119.0**	**0**	**0**	**0**	**204.5**	**0**
Life Support & Control	119.0	0	0	119.0	0				
Eclipse Emergency	**83.3**	**0**	**0**	**0**	**83.3**	**0**	**0**	**0**	**143.2**
70% Life Support & Control	83.3	0	0	0	83.3				

Acknowledgments

The general supports of California State University, Northridge Mechanical Engineering Department and Associated Students' Student Travel and Academic Research (STAR) Fund are acknowledged. This work was done as a Senior Design Project during the 2015-2016 academic year. The students who participated in this project are acknowledged for their creative ideas and sincere efforts. (Communications): Jorge Ortiz and Gary Sanders. (Life Support): Abdulaziz Alrashed, Ricky Dinger, and Edward Kocharyan. (NASA Missions): Ahmed Alhaila, Mohammed Alkandari, and Ebraheem Allanqawi. (Power): Melissa Aryal, James Chan, Jorge Garcia, Rizel Podadera, and Qianyi Teng. (Propulsion and Orbital Mechanics): Dosan Jyenis. (Robotics): Francisco Tadeo and Maite Lopez. (Structures): Brian Bolves, Claudiu Caldarescu, Jesse Correll, and Josua Werner. (Thermal): Randall Harrington and Josef Staley.

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