LSA

Luna Station Alpha

Realizing NASA's Vision for the Moon, Mars, & Beyond

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"Astronomy compels the soul to look upward, and leads us from this world to another"
- Plato, 342 BC

Introduction

This paper introduces Luna Station Alpha (LSA), Earth's moon-based spaceport supporting missions for the exploration of Mars and beyond, mining the moon for a fuel source, generating water from lunar resources, growing food in greenhouses, and providing laboratory facilities for scientific study. The LSA station is designed to accommodate a crew of 40 persons, for stays of two years each. This will be our planet's first lunar station, providing work, fitness, and recreation facilities, allowing a moderate-size crew to live comfortably for long durations. Luna Station Alpha will provide laboratories and areas for experiments in both moon-gravity (g/6, or one-sixth that of earth) and artificial-Earth-gravity (1-g) environments. The Habitation, Recreation, and Laboratory modules provide the crew with a 1-g gravity environment for the comfort and health needed for long-duration missions.

A primary task of the LSA station is to support missions to Mars, and to mine the lunar soil, and extract and store Helium-3 for use as an energy source in nuclear fusion reactors. These fusion reactors are much safer and cleaner than today's fission reactors.

Initially, extracted helium-3 will be used as a fuel for a nuclear-powered Mars spacecraft propelled by an ion engine, shortening the time to Mars from six months to about 40 days. Spacecraft bound for Mars will stop at the moon to be fueled with helium-3, and take on water and food. The LSA station will operate shuttles for delivering supplies to spacecraft waiting in lunar orbit.

Later in the LSA program, helium-3 will be produced in larger quantities and sent to Earth – a new global energy source. Fuel tankers, capable of holding perhaps 25 tonnes of helium-3, will be filled in lunar orbit and will return to Earth to deliver the fuel.

A secondary mission of the LSA program will be to develop and deploy some of today's most advanced robotic systems. The entire helium-3 extraction process will be automated, with autonomous (unmanned and intelligent) robot vehicles roving the lunar surface. Scout vehicles will test soil samples for helium-3 levels, and driller and extraction vehicles will remove helium-3 and other gasses from large areas of the lunar surface, periodically returning home to fill large storage domes near the LSA station. A central computer and communication system in LSA will manage the entire process.

NASA’s Constellation Program

We need to begin by discussing current and future plans for space transportation. NASA’s Constellation Program was created to develop efficient methods for space travel, replacing the space shuttle program. Its goal is to safely carry space explorers to the International Space Station, the moon, and other destinations within our solar system, including Mars.

The crew exploration vehicle, the Orion spacecraft, is one part of the Constellation program, which also includes new Ares I and Ares V launch vehicles (rockets), and the Altair Lunar Lander. Orion is a retro capsule design that looks like a larger version of the familiar Apollo capsule, but Orion is able to carry a crew of four for a lunar mission, or up to six for a Low-Earth-Orbit trip to the International Space Station [1, 2].

The name Ares is a synonym for Mars, and the numbers I and V are honoring the Apollo program’s Saturn I and V rockets [3]. The name Orion comes from Greek mythology, and is also the name of a constellation. The name Altair is derived from an Arabic phrase meaning “the flying one,” and is also the name of a star [4].

Fig. 1a. Altair docked to Orion

Fig. 1b. Altair on the lunar surface

Ares I Launch Vehicle and Orion Crew Exploration Vehicle

A primary component of the Constellation Program is the Ares I launch vehicle, and the Orion crew exploration vehicle. This system uses a rocket (Ares I) to lift a capsule (Orion) into Earth orbit to dock with the International Space Station, or to prepare for travel to the moon or other solar system destinations. Ares I is designed with a two-stage rocket system topped with the Orion capsule (and its Service Module rocket), which will carry up to 24 tonnes (52,000 pounds) of crew and cargo.

The beauty of the Ares I project is that it takes the most successful elements that NASA has put into various projects over the years and combines them to form an amazing innovation in space travel. The Ares I first stage rocket, for example, is a five-segment reusable solid rocket booster, based on the four-segment boosters successfully used in the Space Shuttle Program. It also uses the same formulated and shaped solid propellant called polybuadiene acrylonitrile, or PBAN for short. A new section was designed to connect the first stage rocket with the second stage. It is called a frustum. It will have a special motor that separates the first stage rocket after Ares I has reached an altitude of about 58 km (36 miles) and a speed of Mach 5.7. This will take place about two and a half minutes after blast off. Once the first stage rocket has separated, the second, or upper stage, rocket will ignite. It uses a J-2X main engine that runs on liquid oxygen and liquid hydrogen. The J-2X is a variation of engines from two of NASA's earlier projects: Saturn IB and Saturn V from the Apollo era, which launched missions to the moon in the late 1960s and early 1970s. This upper stage propels the rocket until it reaches about 129 km (80 miles) above the Earth's surface, when it separates from the top portion, Orion, where the crew and cargo reside. Then Orion's service module engine takes over, sending the craft into a circular Low-Earth Orbit of about 298 km (185 miles).

Fig. 2. Launch of Ares I-X, Oct 28, 2009

At that point, the crew can direct Orion to go wherever they need. Orion may dock with the International Space Station, or with the Altair Lunar Lander and Earth Departure stage from Ares V — another great part of NASA's Constellation Program [5, 6, 7].

Ares V Launch Vehicle and Altair Lunar Lander

Ares V is the heavy lifter of NASA's Constellation Program. All major cargo is transported in Ares V. It will basically serve as the pantry for the space explorers—all the things they need to survive will be transported in it including: food, water, and all other necessities needed to live in space. Additionally, it will carry big items such as the lunar landing module (Altair), which will be used for missions to the moon, as well as transport materials needed to build a base on the moon. Where Ares I can only carry up to about 24 tonnes (52,000 pounds), Ares V can carry 188 tonnes (414,000 pounds) to low Earth orbit, or 71 tonnes (157,000 pounds) all the way to the moon!

Fig. 3. Ares V Reusable-Solid-Rocket-Booster Separation

Like Ares I, Ares V uses a design with a two-stage rocket system derived from previous NASA successes. The first stage uses two reusable solid-fuel boosters very similar to the Ares I first stage rocket. Having solid-fuel booster hardware in common with Ares I is beneficial because it keeps production costs lower. These solid rocket boosters are a refined version of the Space Shuttle's reusable booster design. Also, like the shuttle design, these two boosters mount to the sides of a central liquid-fueled first stage core, the fuel tank of which is derived from the Saturn V. Ares V's first stage liquid-hydrogen/oxygen core uses six RS-68B rocket engines modeled after the engines used in the Air Force's Delta IV program, for its Evolved Expendable Launch Vehicle.

Above the first stage rocket is a cylinder containing a motor that separates the first stage propulsion section from Ares V and allows the second stage rocket, known as the Earth Departure stage, to take over. The Earth Departure stage uses a J-2X rocket engine, an updated version of the engine that took Apollo to the moon and back. The first (Core) stage pushes Ares V into low Earth orbit, and the second (Earth Departure) stage places it into a circular orbit. At this point, the Payload Shroud separates to expose Altair, and Ares V is then in position for its central purpose: rendezvous with Orion, the crew-filled capsule put into orbit by an Ares I rocket.

The Orion capsule docks with both the Altair lunar lander, and the Earth Departure rocket stage. After they are successfully docked to one another, the Earth Departure engine reignites in order to gain enough velocity to escape the gravitational pull of Earth, at which point the Earth Departure stage disconnects, and Orion and Altair are on their way to the moon. Once the astronauts are in orbit around the moon, up to four crewmembers transfer from Orion into the lunar module Altair, disconnect from Orion, and descend to the lunar surface. When their mission on the surface of the moon is completed, they return to Orion, which can remain in lunar orbit for up to 210 days during a lunar mission. When the astronauts return to Orion, they separate it from Altair, reignite Orion's Service Module rocket, and head back to Earth. Finally, back at Earth, the Service Module is jettisoned, and the Orion capsule is positioned for reentry through Earth's atmosphere and parachuting the astronauts to a safe return [8, 9, 10].

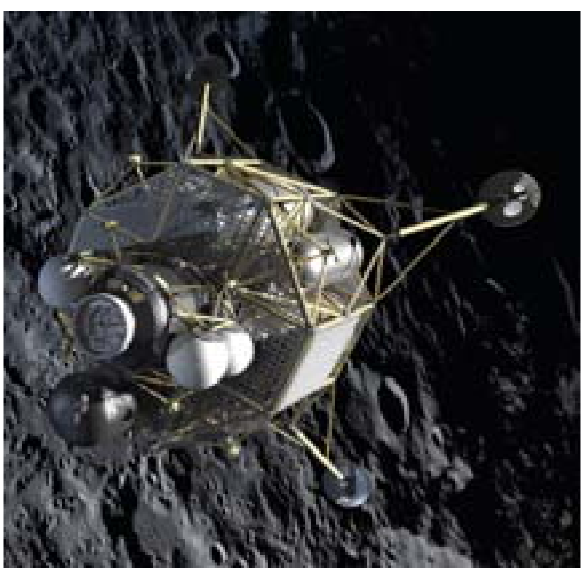


Fig. 4. Altair in Lunar Orbit

Fig. 5a. Ares I with Orion

Fig. 5b. Ares V with Altair

Missions to Mars – Current Plans

The first few missions to Mars were brief flybys; spacecraft zoomed past the planet, snapped a few pictures, and were on their way. A little later, we began sending up orbiters, which discovered features on Mars that were a lot like Earth's surface, such as canyons, volcanoes, craters, gullies and runoff channels, clouds, weather patterns, rocks, hills, polar ice caps, eclipses, and many other characteristics. Orbiters also give us information on Mars' atmosphere and weather. As we advance even more, scientists send up landers and rovers, which cruise around and explore the surface of Mars.

Scientists are also looking into using Mars airplanes to fly around over Mars' surface without a human inside to fly it. These airplanes would take more focused pictures and cover more surface area than rovers or orbiters. Another possibility is the use of balloons, which could travel closer to the surface.

Fig. 6. Mars Airplane

Subsurface explorers will help find water on Mars by traveling underneath the surface of Mars. They could find water in either frozen or liquid form. The Mars Express will be the first subsurface exploration of Mars, and it is built to map a 3D vision of how much, and where, water is distributed on Mars' surface.

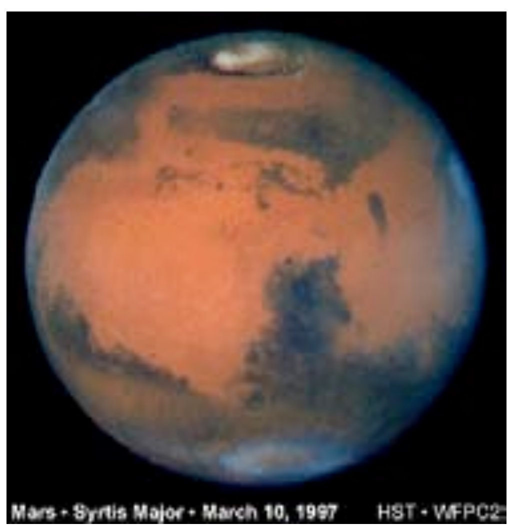
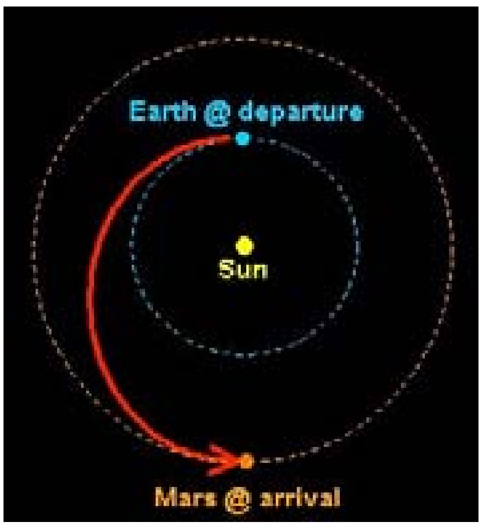


Fig. 7. Mars as seen from the Hubble Telescope

Manned missions from Earth to Mars present special problems for the crew: the long-durations of trips to and from Mars, a long stay at the planet, cosmic rays and solar radiation, zero-gravity during travel and a low-g environment on the surface (about 1/3 of Earth's gravity), dust storms, and a delay in communication of 8 to 40 minutes (depending on the positions of Earth and Mars).

Cargo for Mars trips can be sent ahead of the crew, using unmanned missions carrying surface habitation equipment, exploration gear, a Mars lander, a nuclear power source to provide surface power, and supplies [13, 14, 15].



Mars and Earth pass close together about every two years. Both planets are moving in different orbits at different speeds, so to get from Earth to Mars, spacecraft follow Transfer Orbits (see Fig. 8). These curved paths are designed so the craft and Mars arrive at the same point together in space [16].

Fig. 8. Earth-Mars Transfer Orbit

Rocket travel to Mars using normal chemical engines, such as Cryogenic or Cold-gas designs, will take about six months each way. It will also require the crew to wait about a year on Mars before making the return trip to Earth during the next close pass of the planets. Cryogenic (super-cooled) engine systems use liquid gases like LiH and LOX (liquid hydrogen and liquid oxygen). You have to super-cool hydrogen and oxygen to make them liquids. Cold-gas motors are simpler and lighter, having a high-pressure tank with a nozzle that can open and shut, like a can of spray paint [17]. To minimize the boredom and duration of travel, the crew may someday be placed into a state of hibernation, and sleep through the trip [18].

Ion engines are newer engines, which can run continuously during the flight. A Mars spacecraft using ion engines could make the trip in as short as 40 days. This would allow a trip to Mars, and back again, to occur during one close pass of Mars and Earth. Also, smaller spaceships could be used, since fewer supplies would be needed to support the shorter mission. Using a chemical rocket, the engine is fired for perhaps 10 minutes, and then the craft coasts for six months towards Mars (with a few course-correction burns). With ion propulsion, the engine runs for the entire trip. An ion engine uses a gas such as xenon or argon, which is "ionized" by giving it an electrical charge. The gas ions are electrically-accelerated and pushed out the exhaust of the spacecraft. Even though the thrust is small, the engine continues to run and the craft continues to go faster. Electricity to power an ion engine may use solar power, or a nuclear reactor. Bimodal Nuclear Thermal Rockets use a nuclear reaction in an engine similar to those used in nuclear submarines [19, 20, 21].

Fig. 9. Earth and the moon as seen from Mars [22]

Solar Conjunction is the term for when a planet or other object is on the opposite side of the Sun from the Earth (it is behind the Sun). Communication is generally not possible when the object is behind the Sun. Conjunction of Earth and Mars happens about every 26 Earth months. One solution to the communication problem during the conjunction time is to position one or more satellites to relay messages [23, 24, 25].

Fig. 10. Exploration on Mars

NASA's current vision for travel to Mars, Design Reference Architecture (DRA) 5.0, is for direct trips from the Earth. Multiple cargo ships will launch using Ares V rockets, and send up a six-person descent/ascent lander (similar to the Altair lunar lander), which is landed unmanned on the Martian surface, a surface habitat lander (which supports a crew of six for up to 550 days), that stays in orbit around Mars, surface exploration gear, and supplies. Twenty-six months later, the crew will depart Earth for a six-month trip to Mars, where they will dock with the orbiting surface habitat lander and descend to the surface. The crew is equipped for an 18-month stay on Mars. It will take the crew another six months to return to Earth. This DRA 5.0 program is based on conventional chemical rocket engines in the Ares I and Ares V family [13].

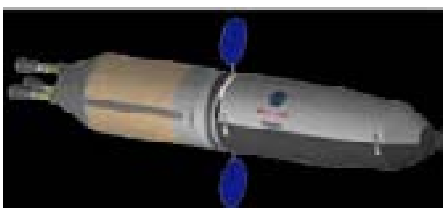


Fig. 11a. Mars Cargo Vehicle

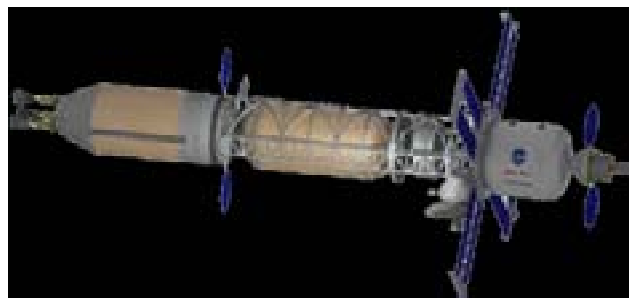


Fig. 11b. Mars Crew Transfer Vehicle

As part of the cargo delivery phase, equipment is landed on Mars for In Situ Resource Utilization (ISRU) – this means taking advantage of existing Resources on the planet, to extract something which is needed. In this case, the ISRU equipment will extract oxygen from the Martian atmosphere, for use in the rocket engine used to lift off of Mars at the end of the mission. There is also water produced in the process. The ISRU is powered by a small nuclear reactor, which, for safety, is placed 1 km away from the habitation area. The ISRU oxygen must be completely produced before the crew leaves Earth. The nuclear reactor also provides surface power for the duration of the mission.

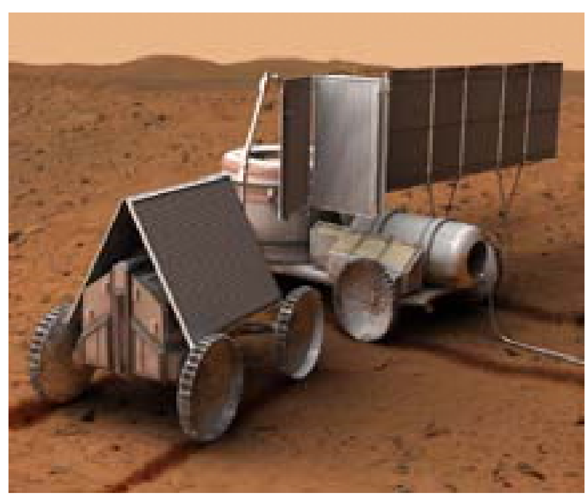


Fig. 12. Nuclear Reactor and 1 km Extension Cord

Helium-3

Here on Earth, what we usually call plain-old helium (He) is actually the isotope helium-4. Isotopes are different versions of an element's atom, each having different numbers of neutrons. Helium-3 is a rare isotope of helium, which is lighter than the common isotope helium-4. On Earth, we find both of these isotopes of helium: helium-4, which makes up 99.99986% of the helium on the planet, and helium-3, which makes up the rest. Helium-3 is essentially impossible to find on Earth in useful amounts.

Helium-4 is the gas we use to blow up party balloons. The helium-4 (He-4) atom has a nucleus with two protons and two neutrons – an atomic mass of 2+2=4. Helium-3 (He-3) has two protons but only one neutron – an atomic mass of 2+1=3. There can actually be other isotopes of helium, but they are not stable, which means that even if they are created in a laboratory, they will quickly change into different substances. This means He-4 and He-3 are the only stable isotopes of the element helium.

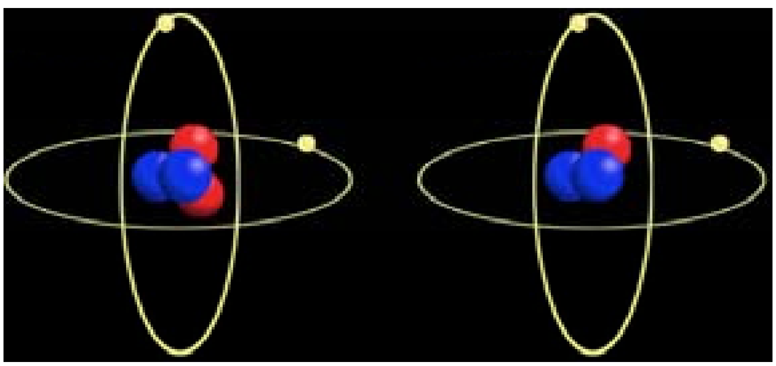


Fig. 13a. Helium-4 Fig. 13b. Helium-3

While He-3 is rare on Earth, it is believed to be much more common on the moon. He-3 is emitted from the Sun, and deposited in the lunar dirt (regolith) over billions of years by the solar wind. He-3 in the solar wind does not reach Earth, since our magnetic field and atmosphere pushes it away. About half of the moon's helium-3 is located in the lunar maria (lunar seas), occupying about 20% of the lunar surface [26, 27, 28, 29].

There is estimated to be about 1 million tonnes (2.4 billion pounds) of He-3 on the moon, in just the first few meters of lunar soil.

To extract 1 tonne of He-3, we will need to mine and process an area of the lunar surface 4 km square, to a depth of about 2.5 meters.

Apollo 17 astronaut Harrison Schmitt is a major advocate for extracting Helium-3 from the moon. The reason He-3 is interesting to us, is that it can be used as a fuel in a nuclear fusion reactor. If we can extract He-3 from the moon's surface, and have a way to store and transport it, we can use He-3 as an energy source for both spacecraft and Earth power needs.

One cargo craft, designed to transport 25 tonnes of He-3 from the moon to Earth, would provide enough fuel to power the US for about 1 year, at our present rate of energy consumption.

Worldwide energy demand could be met with about 100 tonnes of He-3 per year. With about 1 million tonnes of He-3 on the moon, we could have a source of energy that lasts ten thousand years!

While we may not be able to mine all of the lunar He-3, there is certainly a potential to provide a new energy source for thousands of years to come. This new fuel, once delivered to Earth, would be worth billions of dollars per tonne (the replacement value of current fuels). Of course, environmentalists will complain that we are destroying the natural beauty of the moon, and every nation will be demanding its share of the moon's resources, which could quite possibly lead to a major world war, but these are not topics we will explore in this technical paper.

Helium-3 could significantly reduce our dependence on dwindling earth-based fossil fuels (such as coal and oil), and will not only provide a new source of energy for Earth, but will also lessen the global warming effects caused by burning fossil fuels [30, 31, 32, 33, 34, 35, 36].

A promising nuclear fusion reactor design uses He-3 and deuterium (an isotope of hydrogen, having one neutron). When these atoms combine in the reactor, energy is produced, and helium-4 and free protons are left over, allowing electricity to be generated. Combining 1 kg of helium-3 with 0.67 kg of deuterium will provide about 19 megawatt-years of energy.

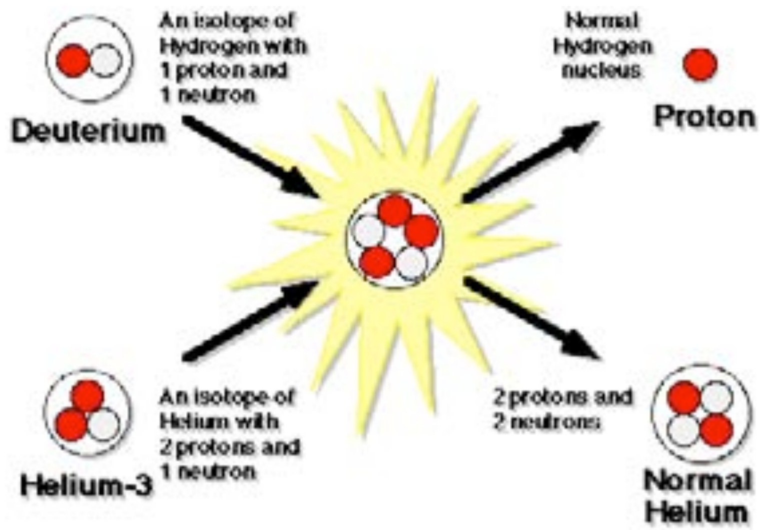


Fig. 14. Nuclear Fusion Reaction with Helium-3 and Deuterium

For spacecraft propulsion, this reactor produces expanding gasses for propulsion, and can generate electricity as well. The electricity can provide power for crew in the spacecraft, or can power a separate ion engine for additional thrust [37, 38, 39, 40].

A New Plan for Mars and Lunar Missions – DRA 6.0

This paper introduces version 6.0 of NASA's Design Reference Architecture (DRA) for travel to Mars and the moon. Previous versions of this plan laid the groundwork for successful missions based on Ares launch vehicles, the Orion crew exploration vehicle, and Mars landers derived from the Altair lunar lander. Key improvements of DRA 6.0:

New Spacecraft:

- **Andromeda, a 5-to-15-person crew exploration vehicle (extended Orion)**
- **Imsai, a refined and larger lunar/Mars lander based on Altair**
- **Ares V-2, an updated Ares V, utilizing the same core and four RSRBs**
- **Ion propulsion engines for Space-Transit service modules (Mars trips)**
- **Use of He-3 fuel for nuclear fusion reactors powering ion engines**
- **Mars missions now stop at the moon for He-3 fueling, water, and food**

New Lunar Support Vehicles:

- **Spaatz, a lunar-based He-3 tanker, fuels Andromeda in lunar orbit**
- **S-Cargo, a locomotive for moving landers between the moon and orbit**
- **Traax, a powerful crawler platform, for moving cargo around LSA**

Current Project Constellation lunar missions will launch a lunar crew on Orion/Ares-I, and launch the earth-departure stage and Altair on a separate Ares-V flight. Current Mars missions based on NASA's DRA 5.0 rely on multiple Ares-V cargo flights, and a multi-rocket crew launch two years later. Mission durations are lengthy, due to use of chemical rocket motors [13].

With DRA 6.0, we return to our Apollo legacy, placing crew/lander components into a single rocket, and add ion propulsion powered by He-3, reducing Earth-to-Mars trips from six months to just over one month.

Fig. 15. Ares V-2 Supports Crew Operations for Mars DRA 6.0 Missions

The new Andromeda crew exploration vehicle and its service module sit atop the new rocket. Below the service module stage is the Earth-Escape stage, and below this is storage for an Imsai lunar/Mars lander.

The more-powerful **Ares V-2 launch vehicle**, first and second stages, sits at the bottom of the rocket. The second stage of the Ares V-2 and the Earth Escape stage used above the lander shroud are identical, using J-2X liquid-fuel engines. These stages are similar to the Earth Departure stage used in Ares V. The Ares V-2 first stage uses the same liquid-fuel center core section as Ares V – for additional lifting capacity it has four Reusable-Solid-Rocket-Boosters instead of two.

The rocket will launch into Low-Earth-Orbit (LEO) using the first and second stages of Ares V-2. Once in LEO, the second stage and the lander shroud will detach, and Imsai will float free. Andromeda, still attached to the Earth Escape stage, will turn around and dock with Imsai. After positioning the craft to face the moon, the Earth Escape stage will fire to put the craft on a path to the moon. The Earth Escape stage is jettisoned after its fuel is exhausted; the trip to the moon will take about three days.

The **Andromeda crew exploration vehicle** is larger than Orion, **carrying a crew of five to fifteen**. For lunar missions, it is used for transporting a crew of up to fifteen (lunar missions only needing a crew of four will be carried out using the smaller Orion vehicle). For missions to Mars, Andromeda will typically hold a crew of five – extra seats are removed and replaced with a small recreation/exercise area to make the 40-day trip to Mars more comfortable. **The bottom heat shield is 5 meters in diameter, identical to Orion**. Attached below Andromeda is its service module engine.

Andromeda's **service module** is available in two versions: the Lunar-Transit version, for moon trips only, is smaller and has a chemical engine but no ion engine. The Space-Transit version is a larger model for missions to Mars and beyond, using a newly-designed **He-3/fusion/ion engine**, along with two J-69 chemical rockets for initial thrust.

For missions to Mars, Andromeda will go into orbit around the moon to get its He-3 tank fueled by **the unmanned Spaatz fuel truck**. Spaatz will dock to a special fueling connector on the side of the service module, and will transfer He-3 into a tank inside the service module. This Space-Transit service module holds enough fuel (for both the chemical and ion engines) to support trips to Mars and back again. The Spaatz ascent/descent engines are refilled at the LSA station. It is about 16 meters in diameter. **Spaatz can lift 6 tonnes of He-3 from the moon to fuel a spacecraft in lunar orbit.**

Fig. 16. Spaatz Leaving the Moon to fuel Andromeda in Lunar Orbit

Missions to Mars benefit not only from lunar fueling, but also from moon-supplied food and water. The main advantage of using lunar-provided fuel, food, and water, is the lower takeoff weight from Earth, and the cost-savings this brings. Less launch weight from Earth means smaller rockets are needed to escape Earth's gravity.

Andromeda brings with it to the moon, an Imsai lander docked to its nose. However, this Imsai is empty of fuel, oxygen, food, and water supplies. While Andromeda is in lunar orbit, it swaps this Imsai for another Imasi that has been loaded at the LSA station with fuel for its engines (hydrogen and oxygen), oxygen for life support, water, and food from the lunar greenhouses. The fully-loaded Imsai will be lifted from the moon to the waiting Andromeda craft by **an unmanned locomotive called S-Cargo** (Space-Cargo), a spacecraft which uses the same refillable ascent/descent engines as Spaatz. While it may move at a snails-pace, S-Cargo is a vital lifting platform with special clamping mechanisms to hold a variety of freight of different shapes and sizes. At about 20 meters in diameter, **S-Cargo can lift up to 25 tonnes**.

When a new Andromeda craft enters lunar orbit to be prepared for a Mars mission, a fueled and stocked Imsai is loaded onto S-Cargo, which lifts it into lunar orbit and releases it. Andromeda separates from the empty Imsai craft it just brought from the Earth, and docks to this fully-loaded Imsai. S-Cargo latches onto the empty Imsai and brings it back down to the LSA station where it will wait to be prepared for the next Mars mission. A crane lifts this empty Imsai off of S-Cargo and places it onto **Traax, a crawling platform** for moving items around the station. Having a platform that is about 30 x 30 meters, **Traax can move loads up to 25 tonnes.**

To prepare an Imsai for a Mars mission, Traax will take it over to the greenhouses to be loaded with food, and then to the storage depot to be loaded with water, oxygen, and hydrogen. Once Andromeda's empty Imsai has been swapped for a fueled and stocked Imsai, and its He-3 tank has been filled (the deuterium fuel tank is filled on Earth before it leaves), Andromeda uses its chemical engines to accelerate towards Mars, then shuts then off and fires the ion engine for the duration of the trip to the red planet.

Like DRA 5.0, multiple Ares-V cargo flights will launch two years before the crew. However, **with Andromeda's ion propulsion, crew transit time between Earth and Mars is shortened to about 40 days**. Since the lander is included in Andromeda/Ares-V-2, there is only one rocket launch for crew departure. The shorter transit time not only makes the trip more comfortable for the crew, but the mission now has the flexibility of either a short or long stay on Mars, either returning quickly while the Earth is still close, or waiting for the next planetary alignment. Shorter trips also are a big advantage for rescue operations, should an emergency occur.

These new DRA 6.0 vehicles add to and expand the Constellation program, using many common components, and make a variety of different rocket designs possible. The new Ares V-2 rocket system is designed so it can mount either the new Andromeda, or the current Orion, crew exploration vehicles. Likewise, the center section is designed to hold either the larger Imsai, or the current Altair, lander craft.

Our DRA 6.0 plan evolved from discussions within our project team, where we explored designs to provide a *single* rocket for both the crew exploration vehicle and the surface lander, and add capacity for a larger crew. This is for both lunar and Mars missions. We believe that using two rockets to deploy crew and lander, as in the Constellation program's Orion/Ares-I and Altair/Ares-V plan, is less-efficient than simply using an Apollo-inspired all-in-one rocket design. It certainly makes sense to have a small Orion/Ares to service the International Space Station in Earth orbit, but for lunar or Mars missions we feel that DRA 6.0 will be a more efficient approach, and will still keep many components in common with the current Constellation program.

One of our team members had the good fortune to spend some time, at a recent private event, talking with Apollo 11 astronaut Buzz Aldrin. It was enlightening for her to hear his thoughts on Project Constellation, rocket designs and lunar missions, and it helped us choose our direction for Mars DRA 6.0.

Fig. 17. Kennedy Prock discusses the Constellation Program with Buzz Aldrin

Luna Station Alpha Overview

Luna Station Alpha (LSA) is designed to mine the moon for helium-3 fuel, support missions for the exploration of Mars and beyond, and provide laboratory facilities for scientific study. Luna Station Alpha will provide laboratories and areas for experiments in both moon-gravity (g/6, or one-sixth that of earth) and artificial-Earth-gravity (1-g) environments. The LSA station is designed to accommodate a crew of 40 persons, for stays of two years each, providing work, fitness, and recreation facilities to allow the crew to live comfortably. LSA is truly a worldwide effort, utilizing funding and cooperation from all partners of the international community.

Artificial gravity is a prominent design feature of LSA. A large upper rotating section of the lunar station produces 1-g of artificial gravity (the equivalent of Earth's gravity) for three spherical modules mounted in a wheel-like design. This 1-g gravity environment provides the crew with the comfort and health needed for long-duration missions. The Habitation module (HAB), Recreation module (REC), and the Laboratory/Office module (LAB) each connect to the central Hub by a tube containing an elevator. Tensioned cables tie the modules to each other. Thrusters on the three modules are used to initiate and maintain rotation of this wheel. Solar panels mounted on the upper surfaces of each module provide power.

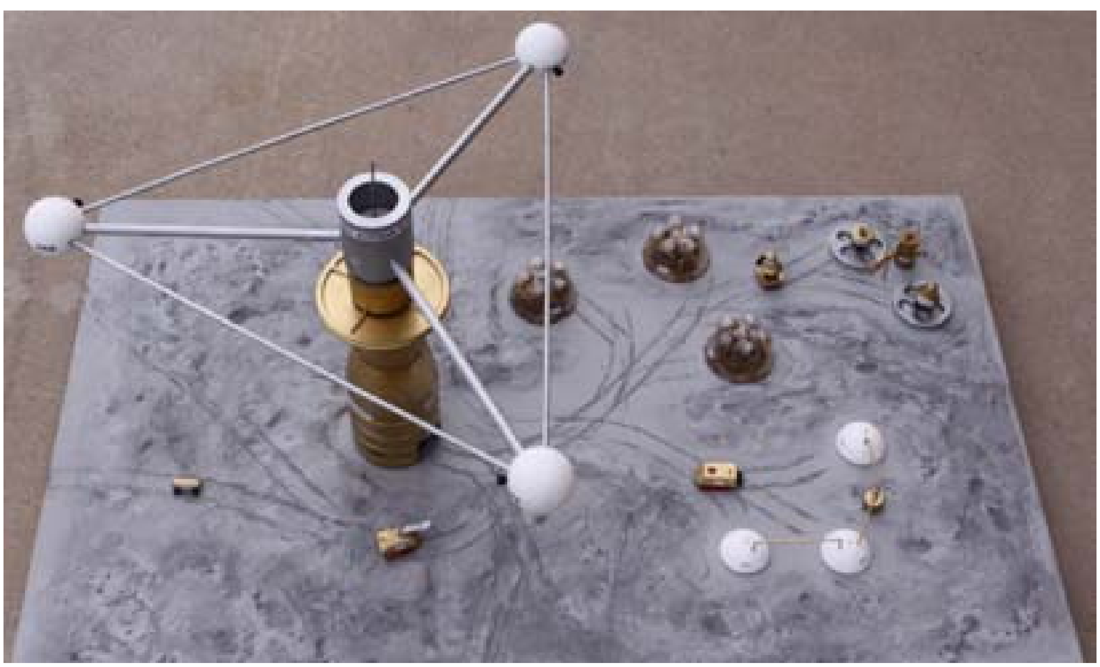


Fig. 18. Luna Station Alpha

The non-rotating part of the central Hub will be mounted to a foundation on the lunar surface, and has an axle on the top on which the upper wheel section rotates. Personnel, moving from one wheel module to another, travel via the elevators and through passageways in the rotating top of the Hub. For access to the g/6 laboratory, storage, and maintenance bay areas, the Hub also includes passageways and airlocks from the wheel hub into the lower non-rotating section of the station. Smaller airlocks will allow spacesuit-clad crewmembers direct access to the lunar surface. The lower Hub section houses the primary air and water storage tanks, with additional tanks located in each of the HAB, REC, and LAB modules.

The Habitation module will be self-sufficient, since air/food/waste/water facilities will be included. HAB will also double as an emergency lifeboat, and the crew will be able to seal off the elevator tube and survive for up to 60-days while waiting for a rescue craft to arrive from Earth.

There will not be specific work modules at LSA, since operations for helium-3 production, storage, and spacecraft fueling will be supported by a variety of robotic vehicles. We will be providing maintenance bays (large garages) for repair and upkeep of the roving vehicles. Even the unmanned fuel truck and the freight locomotive, (Spaatz and S-Cargo), will fit inside the largest bay – they will land on top of the tractor platform Traax, which then crawls to the maintenance bay to bring Spaatz or S-Cargo inside. These maintenance bays are located in the Hub (below the rotating section), so all bay operations will be carried out in moon gravity. However, the bays can be pressurized with air, so the crew can work in a shirtsleeve environment.

A landing and launch pad is provided near the station to support crew landers and cargo trips between LSA and lunar orbit. These vehicles are fueled automatically via an intelligent lifting/fueling robotic arm, Crane-ium. The fuel comes through pipes from the large storage domes at the nearby depot. The robotic vehicles roaming the lunar surface extract vital gasses and automatically fill the storage domes.

Greenhouses are used to grow food for both the LSA crew and for Mars crews. A large airlock allows crewmembers to drive into the greenhouse, and for Traax to bring an empty Imsai lander inside to be stocked for a Mars trip. Once inside a greenhouse, the crew can work in a shirtsleeve environment. The greenhouses are supplied with nitrogen for fertilizer, carbon dioxide for plant consumption, while oxygen is extracted.

Selection of Base Location

Just like early settlements in Arizona, a vital consideration of where to place a lunar base is water. For years, researchers have speculated that there was water on the moon in the form of ice. Now, we now this is a fact. Researchers have also thought that the highest concentrations of ice are at the poles of the moon where there are several deep valleys that never get sunshine and remain terribly cold and therefore frozen. The location we have chosen for our base is beside **the Shackleton Crater (which is 19 km dia, and 2 km deep)**, and contains the moon's southern pole. Radar studies have shown there are significant deposits of hydrogen, possibly in the form of water or ice in this region. The LSA station will be located on the rim of the crater. This area is not in total darkness like the inside of the crater, and is not always frozen. It is almost always in sunlight, beneficial for providing solar energy to the base. Another benefit to this location is the proximity (about 190 km) to Malapert Mountain, a 5 km tall mountain that is always visible from Earth, and will later be used to erect a radio tower for communication to Earth.

Fig. 19. The Shackleton Crater is the site for Luna Station Alpha

Ground Support from Earth, Cargo, and C-Pods

Luna Station Alpha will have supply and maintenance support from Earth, but LSA will be as self-sufficient as possible. Solar panels and batteries will provide power to the rotating modules, and small nuclear reactors will power the helium-3 extraction robots. Greenhouses will provide some of the station's food and oxygen, and waste will be recycled as much as possible. There will be periodic flights from Earth to bring food, water, oxygen, medicine, mail from home, and other important supplies. Occasionally, a flight will even bring fresh vegetables, fruit, and meat, since the crew deserves a special meal every now and then.

Some supplies will need to be replenished periodically, and quite a bit of building material will need to initially be brought from Earth. Rather than using throwaway cargo containers to be tossed in a lunar landfill, we are going to rely on two basic shapes of recyclable cargo containers: the sphere, and the icosahedron (ahy-koh-suh-hee-druhn).

We need a lot of spherical high-pressure tanks for storing various gasses extracted from the moon. Many of these will be used in the storage domes at the fuel depot, and others will be needed for air and water storage in the LSA hub, and in the HAB, REC, and LAB modules. When we start building the LSA station, most of these spherical tanks will be filled with water or oxygen before being sent to the moon. When the water and oxygen has been consumed by the station-building crew, and the tanks emptied, they will then be moved to their final destination for gas or water storage.

The icosahedron [46] is an enclosed structure made from twenty identical equilateral triangles. We chose this shape for use as a general-purpose cargo pod, since we can reuse the triangle panels as a building material. **We call these icosahedron cargo crates C-Pods** (since the obvious name iPod was already taken). At about 16 meters in diameter, **a C-Pod can hold up to 3 tonnes of cargo**. When a shipment of supplies or materials has been emptied from the C-Pod, the triangle panels are separated and moved to a building site.

Fig. 20. The C-Pod uses the Icosahedron Shape

Many parts of LSA are designed around a geodesic dome structure [47, 48, 49]. The HAB, REC, and LAB modules are geodesic spheres, and the storage domes and greenhouses are also geodesic designs. A geodesic dome design actually uses non-equilateral triangles, however, a tapered framework can be designed such that the equilateral triangles we get from C-Pods can be used as panels to enclose the structure's openings.

Fig. 21. A Geodesic Design can be used to Build Domes or Spheres

Cargo flights from Earth will be unmanned, using the heavy-lifting Ares V or Ares V-2 rocket systems. The nosecones in these rockets will hold an array of C-Pods, spherical tanks, or larger components used for building the LSA station.

The lifting platform S-Cargo launches from the station's Pad into lunar orbit, where it latches onto a C-Pod or other cargo load. S-Cargo then brings the cargo down to the surface. S-Cargo lands, and the pad's intelligent lifting/fueling robotic arm, Crane-ium, lifts the cargo off, and loads it onto the Traax crawler. **Traax will then take the cargo to a specific work area, or bring the cargo into the maintenance bay in the station Hub, which is then pressurized. This allows the crew to access the cargo without spacesuits.**

Landing/Launch Pad, Transportation, and P-Pods

Landers, such as Altair and Imsai can land anywhere around the LSA station. When these landers use their conventional descent/ascent engines, the lower section of the lander remains on the lunar surface, **littering the landscape**. However, this is the basic method for bringing crew down to the surface, and back up to orbit.

For flights simply for crew delivery or crew exchange, **a simpler people-only pod, the P-Pod**, may be docked to either Andromeda or Orion, in place of a lander. At about 6 meters in diameter, **P-Pod can carry fifteen people**. P-Pod (which uses the same engines as Spaatz and S-Cargo) launches from the station's pad into lunar orbit and then docks to Andromeda or Orion. The crewmembers transfer into the P-Pod, which then undocks from the orbiting capsule. The P-Pod returns to the lunar surface, and can simply land on the pad, requiring the crew to don spacesuits before getting out. However, **P-Pod, full of crew, can also land on the Traax crawler. Traax will bring them directly into the maintenance bay in the station Hub, which is then pressurized. This allows the crew to move from their orbiting capsule, into the P-Pod, and then walk right onto the floor of the station – no spacesuits required!**

These Landing/Launch Pad systems at Luna Station Alpha rely on advanced robotics, not only for lunar crew movements using P-Pods, and cargo delivery using C-Pods, but also to support missions to Mars by providing supplies and fuel to orbiting spacecraft.

A bay in the station Hub holds two Nit-Picker Crew-Transport Vehicles. This general-purpose lunar exploration truck can carry a crew of eight and cargo in the back. Robotic arms on the front of the vehicle allow the crew to perform delicate lunar-surface operations from the comfort of their heated front seats. These robotic arms have a long reach, a lot of range of motion, and powerful fingers.

Fig. 22. The Nit-Picker Crew-Transport Vehicle

The crew can stay in the pressurized interior for travel and work with Nit-Picker, or they can put on spacesuits, de-pressurize the vehicle, and go onto the lunar surface to work. Nit-Picker provides the crew with a very flexible surface vehicle which has a long-range of operation. The crew will need to check on mining operations, maintain the robotic systems around the station, and other tasks on the lunar surface.

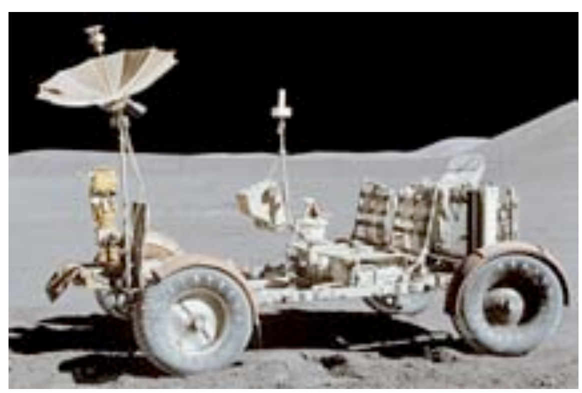


Fig. 23. Early Lunar Vehicles: Soviet Lunokhod (left), and USA Lunar Roving Vehicle (right)

Helium-3 Mining and Processing

A primary task at Luna Station Alpha is the mining, processing, and storing of Heluim-3 from the surface of the moon, for use as a fuel. In phase one of our lunar helium-3 extraction program, He-3 will be produced to fuel Mars-bound spacecraft. Phase two of the program, which will not begin until we have some experience with the He-3 extraction process, will be to increase production and begin shipments of He-3 back to Earth, for use in power-generating nuclear fusion plants.

Since the processed He-3 will be a gas, it is simply stored in sealed tanks, and is easily moved between tanks using hoses and pumps. **He-3 tanks will be filled to a maximum pressure of 10 MPa, which stores about 13 kg of He-3 per cubic-meter** [41, 42, 43]. The He-3 will be moved from mobile tanks on extraction vehicles, to large storage tanks near the lunar base, and finally to the unmanned Spaatz fuel truck, which shuttles fuel to a spacecraft waiting in lunar orbit. **Spaatz can lift 6 tonnes of He-3 from the moon to fuel a spacecraft in lunar orbit.**

Spaatz will lift off from the LSA base into lunar orbit, where it will dock to a fueling connector on Andromeda's Space-Transit service module. This Space-Transit service module includes the He-3 fuel tank, fusion reactor, and ion propulsion engine used for Mars missions. Later, in phase two, Spaatz will also fuel tanker craft for transporting He-3 back to Earth. These tankers have not yet been developed, but since they will hold a lot of helium-3, it will take multiple Spaatz loads to fill one up (Spaatz can hold 6 tonnes of He-3, whereas the Earth-bound tankers would probably be designed to hold at least 25 tonnes of He-3).

Extraction of He-3 from the lunar soil requires heating it to about 600 degrees C to cause the helium atoms to form into a cloud of gas. This gas is then cooled, and passed through a special membrane (filter) to separate He-3 from He-4. If we heat the soil further, to 900 degrees C, oxygen can also be produced. **Other useful gasses may also be produced in this process, including nitrogen and carbon dioxide (which can be used to grow plants), and hydrogen (which can be used as a fuel)**. The extracted gasses are easily pumped into storage tanks. We will agitate (shake) the soil during the heating phase to recover the maximum amount of gasses. This processing should be done in mobile extraction trucks – we want to avoid transporting a large volume of lunar soil [28, 29, 30, 31].

Helium-3 Extraction Vehicles and Storage Domes

Several specialized vehicles have been designed to search for and extract helium-3 from lunar soil. All of these vehicles are autonomous, or unmanned. Computers in the vehicles and at the LSA station control movements and operations. Initially, crew will be deployed with the vehicles, but as we get more experience and confidence in their automated operation, the vehicles will simply be left to operate by themselves. When we wish to increase production of He-3, we can add many additional vehicles to our extraction fleet, each working different areas of the lunar surface, in a round-the-clock operation.

Each of these vehicles is powered by a small nuclear reactor. All vehicles have a radio communications link to the central computer in the LSA station, which constantly tracks vehicle position and movement. Since craters and mountains will block the line-of-sight radio signals, we have a small communications satellite in lunar orbit, specifically for LSA/vehicle communication. It takes the satellite about two hours to complete an orbit, so the vehicles must be able to operate on their own and will phone-home every couple of hours. The central computer maintains a master lunar map of surface areas which have been processed, and areas targeted to be processed, and directs the vehicles to their next processing area.

To search for and identify soil areas rich in He-3, we deploy the **Helium-3 Scout, or H3S**. This is a small multi-wheeled device capable of drilling a fixed-size soil sample two meters deep, pulling the sample into a test chamber for the heating/cooling extraction sequence, and measuring the quantity of He-3 and oxygen produced. The results are sent to the LSA central computer.

Fig. 24. The H3S (Helium-3 Scout)

The **Helium-3 Driller, or H3D**, will be used to loosen up dirt and rocks since He-3 can be several meters deep in the Moon's surface. There are large treads on the bottom of the vehicle similar to treads on a tank. Treads give the vehicle the ability to drive across rugged lunar terrain. At the rear of the H3D, is a large movable drill, connected to an arm. The whole arm can move up and down, and the middle joint can also move up and down. Also, the drill itself can rotate on its axis. The drill can be positioned many different ways to allow it to loosen up a large section of ground by drilling multiple holes. The H3D will then move forward a bit, and the drill will loosen up a new section of lunar surface.

After H3D has loosened up the lunar soil, the **Helium 3 Extractor (H3X)** will move into position. This vehicle also uses treads on the bottom of it for handling the cratered terrain of the moon. H3X will then scoop up a section of the loose soil and move it into an internal extraction furnace (a large oven), which will heat the soil to about 600 C to free the helium atoms into a gas. This gas is filtered to separate the lighter He-3 from He-4, and the helium-3 is then pumped into a storage tank in the vehicle. The furnace temperature is then raised to 900 C so we can get oxygen and other gasses out of the soil as well. All of the gas tanks are large enough for H3X to move over a very large surface area before it needs to return to the lunar base storage depot to empty its He-3 and other gasses into tanks in the large storage domes.

We will experiment with two versions of H3X, which have different mechanisms to move the soil into the furnace. One version uses a large excavator claw attached to the front of the vehicle, mounted on retractable and jointed arms, so it can pick up the dirt and then rotate the load up and dump it into the top of H3X. A second version uses a rear scoop design on the back of H3X, with a spiral soil-mover that pushes the soil up into the furnace chamber. When its tanks are full, the H3X will return to the base, lock onto the storage transfer connector, and pump the gasses into the domed storage tanks. Then it will return back to join the H3D at the excavation site. This extraction process will be fully robotic after the trial period and will be going on 24/7.

Fig. 25. H3X (Helium-3 Extraction) Vehicles at Work on the Lunar Surface

The H3X vehicle has storage tanks for the extracted gasses, the most important of which is the He-3 tank – a sphere 4.2 meters in diameter, which has a volume of 40 cubic meters. When filled to the maximum pressure of 10 MPa, **the H3X tank holds about 500 kg (one-half tonne) of He-3.** During the extraction of He-3, we also plan to extract oxygen, and other useful gasses we can get from the soil: nitrogen and carbon dioxide (which can be used to grow plants), and hydrogen (used as a fuel for Spaatz's and S-Cargos' engines). H3X will have additional storage tanks for these gasses as well.

The main storage depot tanks are covered with a protective dome 30 meters in diameter. Inside the dome, sixteen spherical tanks hold the processed He-3 gas. Each of these tanks is 6.6 meters in diameter, having a volume of 150 cubic meters each. When filled to the maximum pressure of 10 MPa, each tank holds about 2 tonnes of He-3. **If all of the He-3 tanks in the storage dome are completely full, the dome holds about 32 tonnes** [41, 42, 43, 44]. To hold the oxygen and other extracted gasses, additional tanks are located above the main He-3 tanks. We have three storage domes currently, and can add more as He-3 production is increased in the future. When H3X returns to a storage dome, it automatically hooks up to a special sort of docking connector, which connects to each of the H3X gas tanks. Pumps at the dome empty all of the tanks in H3X, pumping the gasses into the proper tanks in the dome. Pipes between the storage domes and the landing/launch pad are used to fill the Spaatz tanker with He-3 (and hydrogen and oxygen for the engines). Pipes are also used to send needed gasses to the LSA's hub and greenhouses.

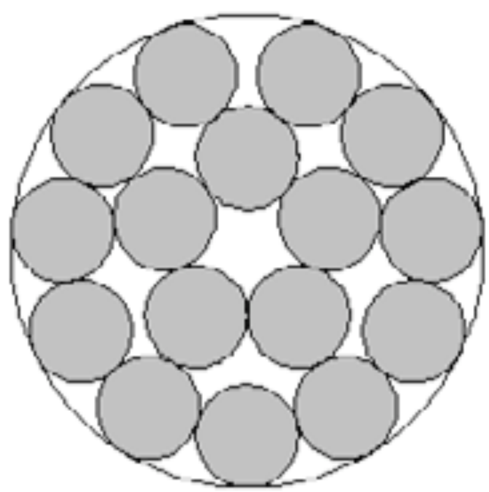


Fig. 26. Helium-3 Storage Dome, and Spherical He-3 Tank Packing

Work Areas and Robotics

There will not be specific work modules at LSA, since primary work operations for helium-3 production, storage, and spacecraft fueling will be supported by a variety of unmanned robotic vehicles. All of the robotic vehicles will be autonomous (operating independently) for long durations, but the main computer, CenSer (Central Services), ultimately controls them.

Located in the LAB module, **CenSer is a supercomputer which tracks all vehicle positions and controls movement** via a radio communications network. Since craters and mountains will block the line-of-sight radio signals to the vehicles, a **communications satellite, TelStar**, is in lunar orbit specifically for relaying CenSer/vehicle communication. It takes the satellite about two hours to complete an orbit, so the vehicles must be able to operate on their own during quiet time. The computer maintains a master lunar map of surface areas which have been processed, areas targeted to be processed, and directs the vehicles to their next processing area.

Fig. 27a. CenSer, a Yarc-1 Supercomputer

Fig. 27b. The TelStar Lunar Communication Satellite

The crew can connect to CenSer from any of the ASR33 terminals around the station, by typing HAL (He3-Auto-Login). These terminals allow interactive control, hardcopy, and local file storage and upload.

To search for and identify soil areas rich in He-3, CenSer deploys the Helium-3 Scout (H3S) vehicle. This device drills a fixed-size soil sample, tests and measures the quantity of He-3 and oxygen produced, and sends the results back to the computer.

Once CenSer has determined a plan for mining He-3, it will direct two vehicles to follow a mowing-the-lawn path to cover a specific lunar area. First, **the Helium-3 Driller (H3D) is used to loosen up the lunar surface. The Helium 3 Extractor (H3X) follows behind, extracting He-3 and other gasses from the soil**, and pumping them into its storage tanks. H3D and H3X will move over a very large surface area before H3X has a full 1/2 tonne load of He-3 and needs to return to the lunar base storage depot to empty its He-3 and other gasses into tanks in the large storage domes.

When H3X returns to a storage dome, it automatically hooks up to a special sort of docking connector, which connects to each of the H3X gas tanks. Pumps at the dome empty all of the tanks in H3X, pumping the gasses into the proper tanks in the dome. **This entire helium-3 mining/processing/storage operation is fully automated, thanks to state-of-the art robotics systems, and advanced computing and communication equipment.**

Pipes from the storage domes to the LSA's Hub and greenhouses, automatically transport oxygen, nitrogen, and carbon-dioxide for air and plant-growth use. Pipes from storage domes to the landing/launch pad, and the **robotic arm Crane-ium, are used to fill the tanker Spaatz with He-3, and to fuel its ascent/descent engine system with hydrogen and oxygen gasses. S-Cargo and P-Pod also get their engines automatically fueled with hydrogen and oxygen with the Crane-ium fuel arm.**

The LSA station includes maintenance bays (large garages) for repair and upkeep of the roving vehicles H3S, H3D, and H3X. Even Spaatz, S-Cargo, or P-Pod will fit inside the largest bay – they first need to land on top of the Traax platform, which will then crawl to the maintenance bay to bring them inside. These maintenance bays are located in the Hub (below the rotating section). Airlocks lead from the station passageways to the usually-unpressurized maintenance bays. Crew will get into their spacesuits in the airlock, depressurize the airlock, and enter the bay. Bay doors open to allow vehicle access from the lunar surface. Most work in the bays will be performed in the vacuum of space, the crew wearing spacesuits, but there may be times when it is desirable to pressurize the work bays for other uses. For extensive vehicle maintenance, the bay doors can be closed and the bay pressurized, allowing the crew to work in a shirtsleeve environment.

Also in the lower section of the station Hub, are various pressurized (but moon-gravity) areas: offices, a g/6 laboratory for research and experiments, the moon gymnasium (just for some g/6 fun), and storage areas. In addition to the g/6 laboratory and office space in the Hub, a large 1-g laboratory/office area is available in the LAB module. Researchers may choose to carry out experiments in either g/6 or 1-g environments. The LAB module also houses offices for scientists and technicians, the CenSer supercomputer, and communications equipment for connecting to the TelStar satellite, which allows CenSer to stay in contact with all of the unmanned roving vehicles.

The Landing/Launch Pad systems at Luna Station Alpha rely on advanced robotics, not only for crew movements using P-Pods, and cargo delivery using C-Pods, but also to support missions to Mars by providing supplies and fuel to orbiting spacecraft.

The Spaatz He-3 fueling vehicle is unmanned and fully automated. Spaatz can lift 6 tonnes of He-3 from the moon to fuel a spacecraft in lunar orbit. When a spacecraft, such as Andromeda, enters lunar orbit and requires He-3 fueling, it contacts CenSer. Once the desired amount of He-3 fuel is determined, CenSer directs a filled Spaatz tanker to launch and rendezvous with the orbiting spacecraft. A special docking connector on the side of Andromeda's Space Transit service module allows Spaatz to dock and transfer the He-3 fuel (Andromeda's deuterium fuel tank is filled on Earth before it leaves). **The unmanned S-Cargo platform lifts an Imsai lander, pre-loaded at the LSA station with supplies, into lunar orbit.** Andromeda undocks from the empty Imsai it brought from Earth, and docks to the one just delivered by S-Cargo. Once Andromeda's tank is filled and it has a prepared lander, it leaves lunar orbit for Mars, and Spaatz and S-Cargo (with the empty Imsai) return to the LSA's landing/launch pad. **The P-Pod people shuttle automatically ferries up to fifteen crew between orbiting spacecraft and the LSA station. These are all examples of the advanced automation at Luna Station Alpha.**

Habitation Module

One spherical pod in the rotating artificial-gravity wheel is the Habitation module (HAB). This module has **individual personnel rooms for forty crewmembers**. These personnel rooms are reasonably-sized, and provide each crew member with privacy, as well as a work desk with computer station, a seating area having an audio/video system for both research and entertainment, a personal refrigerator, a beverage dispenser, as well as a comfy bed and pillow of their choice.

At the work desk, crew can log into their personal computer space. Each crewmember wears a radio ID badge, which allows the main LSA computer to track them at all times. When a person sits at their work desk, personal information and files stored in their ID badge is available to them on the work desk's computer station. The computer stations in the Media Center work the same way.

The personnel rooms are clustered on four inner floors of the HAB module, each floor also providing two **restroom/shower stations** to be shared by the ten residents on that floor.

At the top of the habitation module is a spacious **Dining Room with a domed ceiling** (which is the top of the spherical module), having windows with motorized shutters to provide a pleasant view outside. The elevator tube is transparent where it extends down from the ceiling of the dining room to allow an exit to the dining room floor. A second elevator stop at the floor below is used to deliver food and supplies to the **Galley** (kitchen) and warehouse level located just below the dining room. It is believed that having a large, full-gravity open area for dining and socializing will offset the smaller quarters to which the crew is subjected in most of the station – since personnel are deployed to the station for two-year periods, every opportunity to alleviate stress will result in a happier, more-productive crew, and it is expected that the HAB module dining area, personnel quarters, as well as the REC module features, will alleviate most crew anxiety and stress.

Also located in the HAB module is the **Medical Center**, which contains a waiting room, doctor and nurse offices, an operating room for basic surgery, and a comprehensive storeroom for medicines and supplies. Should a doctor or nurse not be on duty at the center, a fully stocked, self-serve first aid station is available for crew use.

The HAB module will also have storage for **emergency oxygen and water tanks**, located in the cavities between the crew areas and the spherical outer wall of the module. Complete life-support systems are also built into the HAB module, including oxygen generator systems, carbon-dioxide scrubbers, water-recycling facilities, and **waste management**. The Habitation Module will be self-sufficient, and will double as an **emergency lifeboat**; the crew will be able to seal off the elevator tube, if necessary.

Recreation Module

The Recreation module is a very important part of the space station, as all of the crew need a break, and to relax from their workday. The REC module contains the Media Center, Game Room, Movie Theater, Music Room, Stargazing Center, Chapel, Gymnasium, Workout Room, and the Outdoors Simulator.

The **Media Center** will not have books, since everyone can look up books on the main station computer system, or the Internet, which is, of course, connected over a satellite link. There are ten work desks where the crew can log into their personal computer space, for research or recreation. Each work desk has a printer and scanner, and a public poster-size printer is available, so people can print out things to decorate their rooms. Each crewmember wears a radio ID badge that allows the main LSA computer to track them at all times. When a person sits at a work desk, personal information and files stored in their ID badge is available to them on the work desk's computer station. The computer station in their private HAB room works the same way.

For relaxation, the **Game Room** offers chess, checkers, scrabble, card games, and many board games. There are multiple large-screen video monitors with wireless headphones, where people can watch movies, TV shows, or play video games.

The **Movie Theater** seats forty people, and is available at all times for movies-on-demand. Crewmembers may reserve the theater by logging into the main computer. Popcorn and beverages are available at the back of the theater. Musician crewmembers will enjoy the **Music Center**, a soundproofed group of rooms, stocked with a full collection of acoustic and electric instruments. People can get together to jam, or use the recording equipment to save and re-mix their songs. A small dance floor is available, and people can dance to a live band, DJ, or recorded music.

Offering a chance to enjoy space from a spectacular vantage point, the **Stargazing Center** contains powerful telescopes, as well as a comfortable seating area, positioned under the retractable moon roof. The crew can go there to do some research, casual stargazing, or enjoy a romantic evening. Cameras built into the telescopes allow people to save pictures, or print them out on the center's photo-quality printer.

The **Chapel** can hold up to forty people. All faiths are represented, and regular services will be held. Crewmembers may also enjoy an Earth-based live service, on the large video monitor at the front of the Chapel.

It is very important for the crew to maintain good muscle-tone and cardiovascular fitness. The **Gymnasium** is a large multi-purpose room where people can play everything from basketball and tennis, to rock climbing, running, or just tossing around a baseball. Connected to the gym are separate stations for a baseball batting cage, and a golf driving cage.

There is also a separate **Workout Room**, which contains a treadmill, and a full collection of weight lifting equipment. The weight lifting machines use springs instead of actual weights, since they will be much lighter to get into space.

The **Outdoors Simulator** has a small pool, plants, flowers, grassy areas, and sun lamps. This will be a pleasant place to visit to go for a swim, take a walk, or just relax on the grass, so people can feel like they are back home. The simulator will have sun lamps, so people can get the vitamin D needed for a healthy lifestyle.

The crew may express their artistic abilities, and entertain each other as well. Crewmembers who paint, may set up a gallery showing in one of the REC module rooms. Those who wish to recite poetry may likewise set up a reading. The dramatic folks may wish to put on a play, and the dancers can dance. Some of the crew may wish to offer classes to others. These are just some of the ways in which the crew may express and enjoy the artistic side of life on Luna Station Alpha.

Artificial Gravity

The LSA station uses rotation to produce artificial gravity due to centrifugal force. When the main wheel section is rotating, objects will be forced radially outward. This means that people will be standing in the modules with their heads pointed toward the hub.

Weightlessness (microgravity) can cause physiological problems for humans; long-durations in a weightless, or even low-gravity, environment can lead to muscle atrophy, bone loss, cardiovascular problems, and balance disorders [50]. By providing artificial gravity in the LSA's HAB, REC, and LAB modules, we will minimize these ill effects for lunar station personnel, who will be spending up to two years aboard the station.

People in a rotating artificial gravity environment will be subject to the "Coriolis Effect," which affects the inner ear and can cause dizziness, nausea and disorientation. According to studies, an artificial gravity environment rotating above 7 revolutions-per-minute (rpm) will be completely disorienting to humans. However, rotation rates of 2 revolutions-per-minute (rpm) or less will prevent people from feeling the Coriolis Effect [51]. Therefore, the LSA space station will use 2-rpm for the rotation rate (rotating any slower would require a larger wheel radius, and there is no advantage to making the station larger than necessary).

In order to get the equivalent of Earth's gravity (1-g), at 2 rpm, we need a radius of rotation of 224 meters (a diameter of 448 meters) [51]. We will place this point somewhere in the center of the spherical modules -- module gravity will be slightly less than 1-g on floors above this (closer to the hub), and slightly more than 1-g below this point, but this difference will be minimal, and we can just approximate the modules' gravity to be about 1-g (Earth's gravity). Note that gravity will decrease as you take the elevator towards the hub, where gravity will drop to about zero from the wheel rotation – at this point the crew will be pulled towards that moon by its g/6 gravity.

Since the LSA station is not out in space, but is on the moon, we not only have the centrifugal force of artificial gravity pulling outwards at 1-g, but also the moon itself pulling down vertically at g/6. What will happen is that as people are standing with their feet to the outside of the wheel, the moon will be pulling them slightly sideways. However, we can simply tilt the pod floors to be perpendicular to the angle of the net gravity force, and this problem goes away.

The net gravity force, a combination of 1-g horizontally, and g/6 vertically, is found using vector addition [52]. The net gravity force has two components, a magnitude and an angle. For our paper, we found these numbers using a graph paper method. Our coach verified the numbers using the proper vector addition equations.

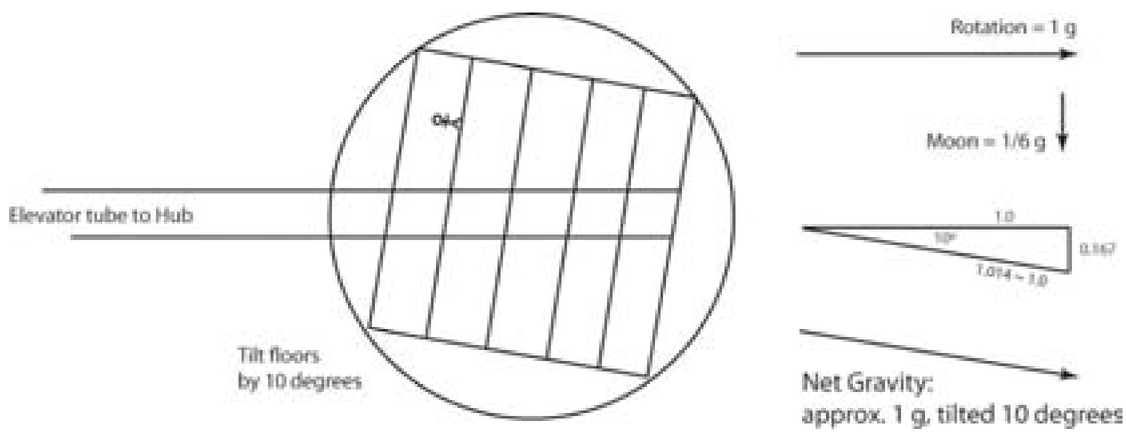


Fig. 28. Tilting the Pod Floors to Compensate for the Moon's Gravity

From our graphical method we found the magnitude of the net gravity force to be barely over 1-g. The result found using the Pythagorean Theorem was 1.01-g. Had the net magnitude been much greater than 1-g, we could have slowed the wheel rotation down, or made the wheel diameter smaller, to get a net force of exactly 1-g. However, 1.01-g is very close to 1-g, so we will just use the original 2-rpm speed and 448 meter diameter wheel. From our graphical method we found the angle of the net gravity force to be about 10 degrees (downward force angle). The result our coach found using trigonometry was 9.46 degrees.

We will tilt the pod floors by 10 degrees to account for the effect of the moon's gravity on our rotating wheel.

Power Systems

Power for the LSA station's HAB, REC, and LAB modules will rely on electricity gathered from solar panels covering the upper surface of each module. Electricity is used to provide lighting, power computers and communication systems, cook food, pump liquids, and generate oxygen (should the primary oxygen supply be interrupted). Solar panels will keep the station running by using the electricity to power the station and charge batteries for use during darkness. New lightweight nickel-hydrogen batteries are being developed specifically for the LSA station [53]. Solar power systems will be installed in each of the modules, providing independent power for each module. The perimeter cable surrounding the wheel will provide for power sharing between modules. **There will be two solar panel arrays on each module, powering redundant systems** – a failure of one solar array (or its battery bank), will not disrupt life-support or critical systems in that module.

Each of the greenhouses has a small array of solar panels on the upper surface to power the airlock doors, gas and fluid pumping, and lights. The crew will drive small electric rechargeable carts through the greenhouses, as they tend to the plants and harvest food. They will use the carts to bring harvested food back to the airlock, where the food is transferred into the Nit-Picker vehicle for a trip to the station Hub, or into an Imsai lander to supply a Mars mission.

A small He-3-powered reactor located at the Landing/Launch Pad provides power for surface operations. Electricity generated by this reactor powers the robotic systems for refueling Spaatz, S-Cargo, and P-Pod with hydrogen and oxygen for their engines. Nit-Picker and Traax are both electric, and are recharged at the Pad as well. This Pad reactor also powers the robotic and pumping equipment at the Storage Domes. For safety, the storage domes, the landing/launch pad, and the He-3-powered reactor are about 1 km from the station's rotating wheel. Electrical cables to the Hub provide the main part of the station with electricity for all Hub areas (maintenance bays, labs, lighting), and pipes provide oxygen and water for crew consumption.

The autonomous He-3 processing vehicles, H3S, H3D, and H3X, are powered by small nuclear reactors. These will initially use conventional fission reactors. As we accumulate and store helium-3 from our mining operation, newer versions of these vehicles may get outfitted with He-3 fusion reactors.

Air and Oxygen

Air inside Luna Station Alpha will have the same basic components as on Earth: nitrogen (~78%), oxygen (~21%), and carbon dioxide (~0.03%). The nitrogen is not consumed, but humans and lab animals breathe in the oxygen, and exhale carbon dioxide. The oxygen must be replaced, and excess carbon dioxide must be removed [54]. The nitrogen will be added to the station air at first, and should not change. There are other chemicals inadvertently added to the air, which must be controlled, such as from laboratory experiments, and the flatulence of forty crewmembers. Charcoal filters help keep the air smelling sweet. Carbon dioxide scrubbers will also be employed to clean the air – recovered carbon dioxide is pumped to the greenhouses for the plants to consume. Equipment that monitors oxygen and carbon dioxide levels, will automatically add oxygen as needed, and will continuously remove carbon dioxide from the air.

Oxygen tanks at the Storage Depot will provide the primary oxygen for the station. This oxygen is extracted from the lunar soil as part of the mining operation, and is automatically added to the storage dome tanks as the H3X vehicles return to the depot to offload their gasses. These depot oxygen tanks supply not only the air systems of the station, but also oxygen for fueling the engines in Spaatz and S-Cargo, and oxygen for the water generators. Visiting freighter spacecraft delivering oxygen pods will periodically recharge the depot's oxygen tanks, as oxygen consumption will exceed current production. **Greenhouse plants will provide a secondary source of oxygen**, which will be automatically pulled out of the greenhouses and added to the storage depot tanks. **For emergency use, oxygen tanks and oxygen generators will be located in each of the HAB, REC, and LAB modules.** The emergency tanks in each module will hold a full 60 days of oxygen for the station's crew of forty. The oxygen generators use an electrolysis process: electricity is used to break liquid water into gaseous oxygen and hydrogen. In another process, the hydrogen is then combined with excess carbon dioxide from the air, resulting in water and methane. The water is reused, and the methane is released to space [54].

We will assume that each person at the station uses 0.9 kg (2 pounds) of oxygen per person per day [55]. For a crew of 40 people, this is 36 kg of oxygen per day. If we presume that our lunar oxygen production provides 50% of our breathing needs, we need to transport about 18 kg of oxygen per day from the Earth. **If a supply ship from Earth arrives every six months, it will need to bring about 3 tonnes of oxygen.**

Water

Water for space station use will initially need to be delivered, and supplies will periodically need to be replenished, but the station will recycle as much water as possible. Humidity in the air will increase as people (and lab animals) exhale and sweat. This moisture in the air is recycled in a device that condenses the water out of the air. People (and animals) will also urinate, and this too is turned into clean water by a recycling device [56, 57, 58, 59]. Water will also be recycled from lab experiments, and personal hygiene uses.

While water must be used carefully, and recycled as much as possible, it is not expected that crew members take only sponge baths for the two years they are on the station. Low-flow timed shower facilities are available, and the crew will be permitted to take a quick shower twice a week. Water from the showers will be, of course, recycled. Water storage tanks, and recycling devices, are located in every module – in larger quantities in the Habitation Modules where the cooking and showers take place, and in modest quantities in the Recreation and Laboratory modules.

NASA's recent success with their Water Recovery System is a model that we will follow. It is a closed-loop water recycling system that successfully purifies wastewater and urine into clean, drinkable water. Additionally, it recovers and recycles moisture from the station's atmosphere. Like water purification on Earth, the drinking water will be periodically checked to insure safety and drinkability. This recycling system will dramatically decrease the amount of water that needs to be sent from Earth and harvested from the Moon.

To produce water at LSA, we will use water generators, which are located in the storage domes. Hydrogen and oxygen are combined in the water generators to create H2O, which is then pumped through pipes and stored in tanks in the Hub. We have the water generators located at the domes, since we don't want explosive hydrogen at the Hub, and it is easy to simply pump the water to the Hub. **The H and O2 gasses are provided by the H3X vehicles** and automatically added to the storage dome gas tanks. Later, we may also extract ice or hydrogen/oxygen resources from the Shackleton Crater to increase our quantity of lunar-generated water.

We will assume that each person at the station uses four liters (about one gallon) of water per day [55]. One liter of water weighs about one kg. For a crew of 40 people, this is 160 liters (160 kg) of water per day. Our goal will be to recycle half of the water we use, harvest a quarter of needed water from the moon with our water generators (combining hydrogen and oxygen from lunar soil, or, later, ice extracted from the Shackleton Crater), and transport a quarter of the needed water from Earth. This means that every day we need to recycle about 80 liters of water, produce about 40 liters, and transport about 40 liters from Earth. **If a supply ship from Earth arrives every six months, it will need to bring 7200 liters (about 7 tonnes) of water.**

Food

Providing food for the LSA station will be challenging. With a crew of 40 persons, there will be a large volume of food needed, and storage space needs to be provided for over a two-month's supply. However, this does not mean that the crew will be squeezing out a chicken dinner from a tube.

Every person living at Luna Station Alpha needs to have the proper amounts of calories each day. The National Research Council recommends a specific caloric quantity for crew members derived from a mathematical expression. It determines the amount of calories needed for basal energy expenditure (BEE). For women, the BEE is $655+(9.6xW)+(1.7xH)-(4.7-A)$. For men, the BEE is
$66 + (13.7xW) + (5xH) – (6.8 x A)$. W is the person’s weight in kilograms, H is the person’s height in centimeters, and A is the person’s age in years [60, 61].

To meet these caloric requirements, crewmembers will choose from menus with a variety of choices. The foods will be stored in several states including frozen, refrigerated, freeze dried, reconstitutable, and thermostablized. Main entrees, vegetables, and dessert items will be stored frozen. Extended shelf-life foods and reconstituted items will be refrigerated. Fruits and stacks will be freeze-dried, and drinks will be rehydratable (powdered). Thermostabilized entrees and fruits are processed in a way that allows them to have a shelf life of a minimum of two years.

Fresher food will be sent up from the Earth occasionally. Prepared vegetables, fruits, and meat dishes will be available from time to time, to give the crew variety during their two-year stay aboard the station. The LSA's greenhouses will grow a variety of fruits, vegetables, and nuts. Greenhouses not only provide a fresh food source, and supplemental oxygen, but the crew will find it quite pleasant to work in the gardens.

The meals will be served in the dining area of the habitation module. Preparation of the meals will take place in the galley (kitchen) within the habitation module. In the galley, there are freezers, refrigerators, hot and cold water dispensers, and air convection microwaves/ovens for cooking and heating foods. The preparation of each meal takes about 5 minutes to assemble and about 20 to 30 minutes to reconstitute or heat.

The food and beverages will be served in disposable, individual serving sized packages that will be opened with scissors – our dining hall's additional utensil. This will eliminate the need for a dishwasher. The packaging will be a flexible material of foil laminate that acts as good barrier for extended shelf life, but is also easily compacted in the galley's trash compacters. Each resident will be responsible for bringing his or her own utensils to and from the dining hall. They will be cleansed with anti bacterial wipes and rinsed with a limited amount of water. With personal utensils, there is less chance of spreading germs.

We will assume that each person at the station uses 1.4 kg (3 pounds) of food per person per day [55]. For a crew of 40 people, this is 56 kg of food per day. We will be growing food in the greenhouses, some for Mars missions, and some for crew consumption. If we presume that the greenhouses will provide 20% of the LSA station's food needs, we need to haul about 45 kg of food per day from the Earth.
If a supply ship from Earth arrives every six months, it will need to bring with it about 8 tonnes of food.

Waste Management and TRDs

As discussed previously, urine is recycled into clean water. For feces, the astronauts can use an air flush toilet like on airplanes. The air keeps the waste away from the body and then will flush it into storage tanks. This solid waste will be processed into fertilizer for the greenhouses.

Every day, each person generates about the following amounts of waste: 3.9 kg liquid, 0.1 kg solid, and 1.0 kg carbon dioxide [55]. The liquid waste is recycled into water, and the carbon dioxide is pumped to the greenhouses.

The solid waste is dumped into the Trash Removal Device (TRD), which is a modified C-Pod connected to a disposable rocket engine. Also loaded into the TRD is trash from the galley's compactors, spent nuclear waste, and any other undesired material.

We will not be trashing up the moon with landfills, so we plan to dispose of our waste in outer space. While it would be great fun to fling our TRDs into a random corner of space using a giant lunar trebuchet, doing so would likely be frowned upon. We plan to rocket our TRDs on a collision course with the Sun. This same technique could be used to deal with nuclear waste on Earth, eliminating a great storage controversy, but that topic is beyond the scope of this paper.

Shielding

Shielding is required to limit space crews' exposure to solar radiation, cosmic rays, and debris. New shielding materials are required, that not only block and/or fragment more radiation than aluminum – the material currently used to build most spacecraft structures – but also are lighter than aluminum. The material must protect the crew from radiation, and it must also deflect dangerous micrometeoroids. The shielding must be durable and long lasting, and able to stand up to the harsh space environment.

Polyethylene is an excellent shielding material because it has high hydrogen content, and hydrogen atoms are good at absorbing and dispersing radiation. Researchers have been studying the use of polyethylene as a shielding material for some time. Reinforced polyethylene is a new material being developed for Luna Station Alpha. It is also a ballistic shield, so it deflects micrometeorites. Since it's a fabric, it can be draped around molds and shaped into specific spacecraft components. A better shield is only half the answer to the problem. If too much shielding material is used, the spacecraft components become way too heavy to get off the ground. So NASA is also working on medical countermeasures that limit the effects of radiation on space crews [62].

Emergencies and Medical Care

In the case of a station emergency, all crewmembers would go to the habitation module. The modules will be equipped with a 60-day supply of food and water, electricity, and oxygen. The other modules also have an emergency supply of oxygen and water, but the HAB module has the food supplies, medical facility, and other resources needed for longer-duration emergencies. Rockets would be set up on Earth ready to launch at all times so we will be able to get the members of the crew back home.

Due to the long duration of space station habitation, and the time required to descend to Earth, it will be necessary to provide regular and emergency medical treatment on board. The station crew will need to include several medical staff, in order to monitor crewmembers' health, and stabilize any medical emergencies until the crewmember can be returned to Earth.

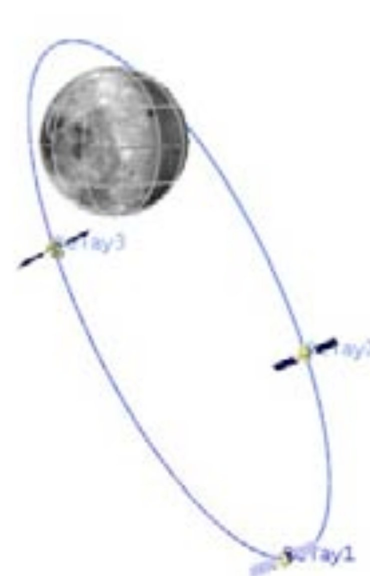
Communications

Radio communication is at about the speed of light, but due to the distances involved in space, there be a noticeable delay – communication latency to the moon is 2 to 3 seconds, which means when someone speaks from the Earth, it will take 2 to 3 seconds before the person on the moon hears it. When they reply, there is another delay before the person on Earth hears it. Communication latency to Mars is 8 to 40 minutes (depending on relative positions)!

Earth to Moon: The ideal form of communication from the moon to Earth would be constant radio contact. For this to be achieved, radio signals would have to travel from the Moon base to Earth without any obstruction. For a radio signal to be received, there can be nothing blocking a line of sight. However, with a base near Shackleton Crater, in the moon's Southern pole, there are some obstacles to overcome.

For starters, the base, depending on its exact location, could be below the horizon of the Earth for as much as 3 weeks per month! This would not allow a direct radio signal to be sent to Earth and back, and therefore will not allow constant radio contact. To fix this problem, we will place radio signal satellites in orbit around the moon to send messages to and from Earth. Unfortunately, the placement of the satellites is not a simple solution, and the reason all comes down to gravity.

In our EarthCom communication system, we place three satellites 120 degrees apart in a circular orbit around the moon, covering the South Pole, it would seem like the problem of having a radio connection without obstruction is solved. The problem is that in order to get a circular obit around the moon, the satellites would need to be set at an altitude of about 1200km above the moon's surface. At this altitude, things orbiting the moon are unstable thanks to good old planet Earth and her gravitation pull. The moon only has about 1/80th of the planet Earth's mass. When things get very far from the moon's surface, the Earth's gravity takes over forcing things to crash back into the moon or spin away in a hyperbolic orbit. If they are at a low circular orbit around the poles, lunar "mascons" pull



on the objects and crash them into the surface. There is a possible stable circular orbit around the moon, but it is at the equator. This is not beneficial to the communication between a lunar base at the Shackleton Crater and Earth. An orbit over the poles is necessary. To fix this problem, the satellites could be set into a highly elliptical orbit around the poles with an eccentricity of 0.6. This is roughly like the shape of a football with the pointed ends rounded off. The angular momentum of the orbit helps keep the satellite in stable orbit around the moon without allowing the Earth's gravity the opportunity to take over [62].

Among Station Residents: Malapert Mountain is a 5 km tall mountain near Shackleton Crater. With the lunar base near this location, Malapert Mountain could be used as a radio tower. This would allow for radios to be the primary form of communication among the Moon's residents, both at the LSA base, and when out and about in a roving vehicle.

Language Translation: In order for language barriers to be kept at a minimum, each country participating in the project would be responsible for bringing one interpreter. The interpreter could translate messages from English to their native tongue for conferences. Another way we can have everyone understanding each another is by providing ear-mounted language translators. Each translator has a button, which changes the language you hear other people speaking, into your language. Let's say you were from China – you could set the button so you hear everything in Chinese.

Station Society and Organization

Many countries from Earth are currently involved in the International Space Station program, and international participation is expected to increase as we open Luna Station Alpha. Member countries will include the United States, Russia, Japan, Canada, many countries in Europe, and Brazil. Crews composed of so many nations will represent not only multiple languages, but many cultural differences as well. People on the LSA station will also be from varied political backgrounds. Politics and cultural differences must take a back seat on the station, where everyone will live in a neutral society. Crewmembers will indeed have loyalties to their countries, but there will be no political divisions on Luna Station Alpha.

The crew of the LSA station will have a minimum age of 25, a maximum age of 75, and a minimum of a master's degree in their field. Everyone onboard reports to the Station Commander – every two years a new Commander is assigned, from a different country. All crewmembers will have specific areas of expertise and responsibility, and everyone is expected to take turns tending to the gardens in the greenhouses, preparing food for the crew, and maintaining the cleanliness of the station. There will always be a minimum of two doctors on board the station at all times.

1	Station Commander
1	First Officer
1	Chief Engineer
2	Medical Doctors/Surgeons
2	Security Officers
8	Helium-3 Processing Specialists
7	Robotics Engineers
5	Spacecraft Operations Specialists
3	Laboratory Scientists
2	Nuclear Reactor Specialists
2	Computer Systems Engineers
2	Communications and Power Systems Engineers
2	Oxygen and Water Systems Specialists
2	Food Systems Specialists
40	Total crew

Appendix A – Conversions

1 kilometer = 0.621 mile

1 meter = (100 cm)/(2.54 cm/inch) = 39.37 inches = 3.281 feet

1 kg = 2.205 pounds

1 metric tonne = 1000 kg = 2205 lbs = 1.1 tons

1 liter = 0.2642 gallons

1 liter of water weighs almost exactly 1 kg

Using 1:800 scale for our model, useful formulas are:

(full-size in meters) = (model dimension in meters) (800)

(full-size in meters) = (model dimension in inches) (800/39.37)
= (model dimension in inches) (20.32)

(full-size in feet) = (model dimension in inches) (800/12)
= (model dimension in inches) (66.67)

(model dimension in inches) = (full-size in meters) / 20.32

Using 1:400 scale for our drawings, useful formulas are:

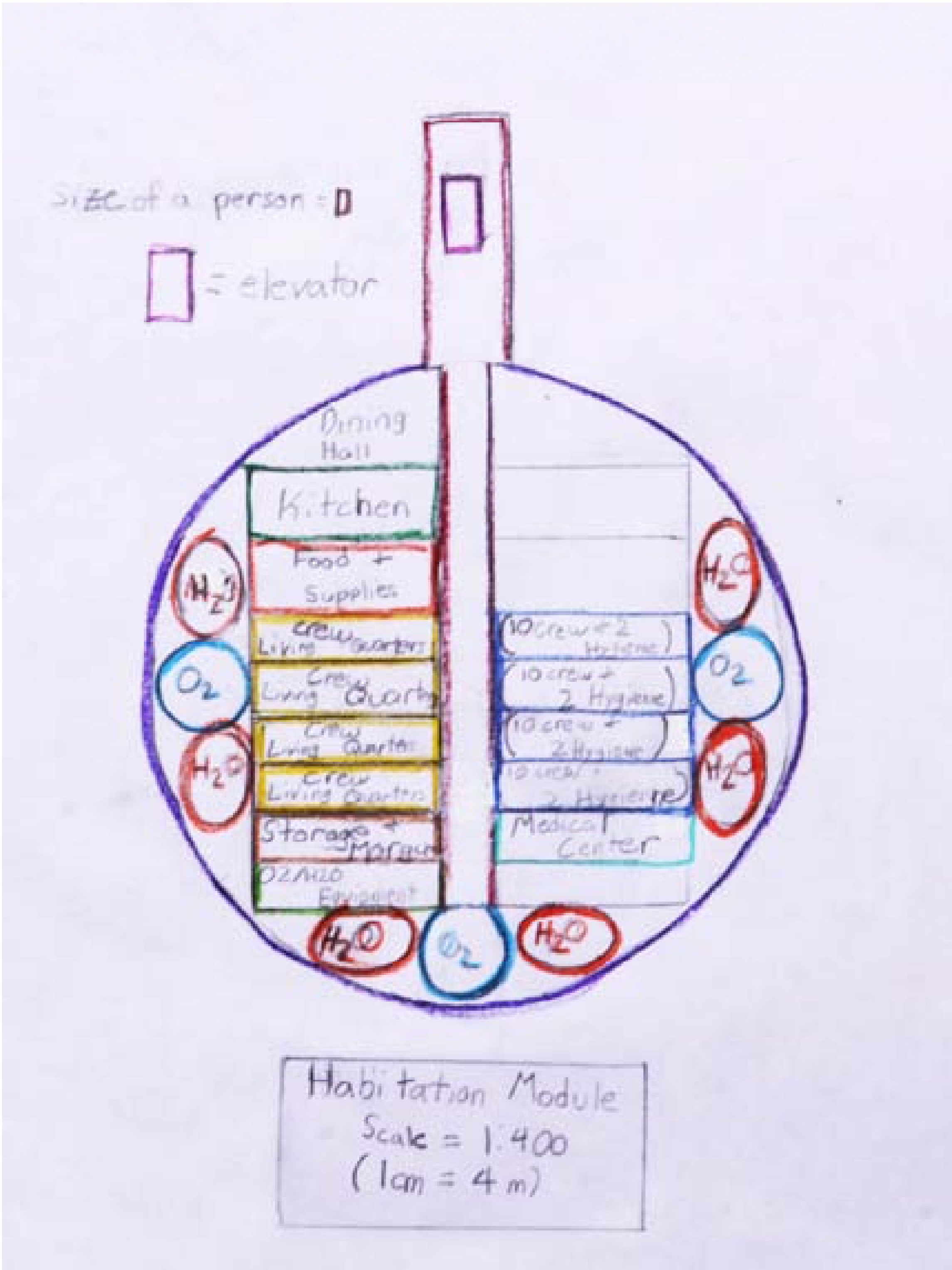
(full-size in meters) = (drawing dimension in meters) (400)

(full-size in meters) = (drawing dimension in inches) (400/39.37)
= (drawing dimension in inches) (10.16)

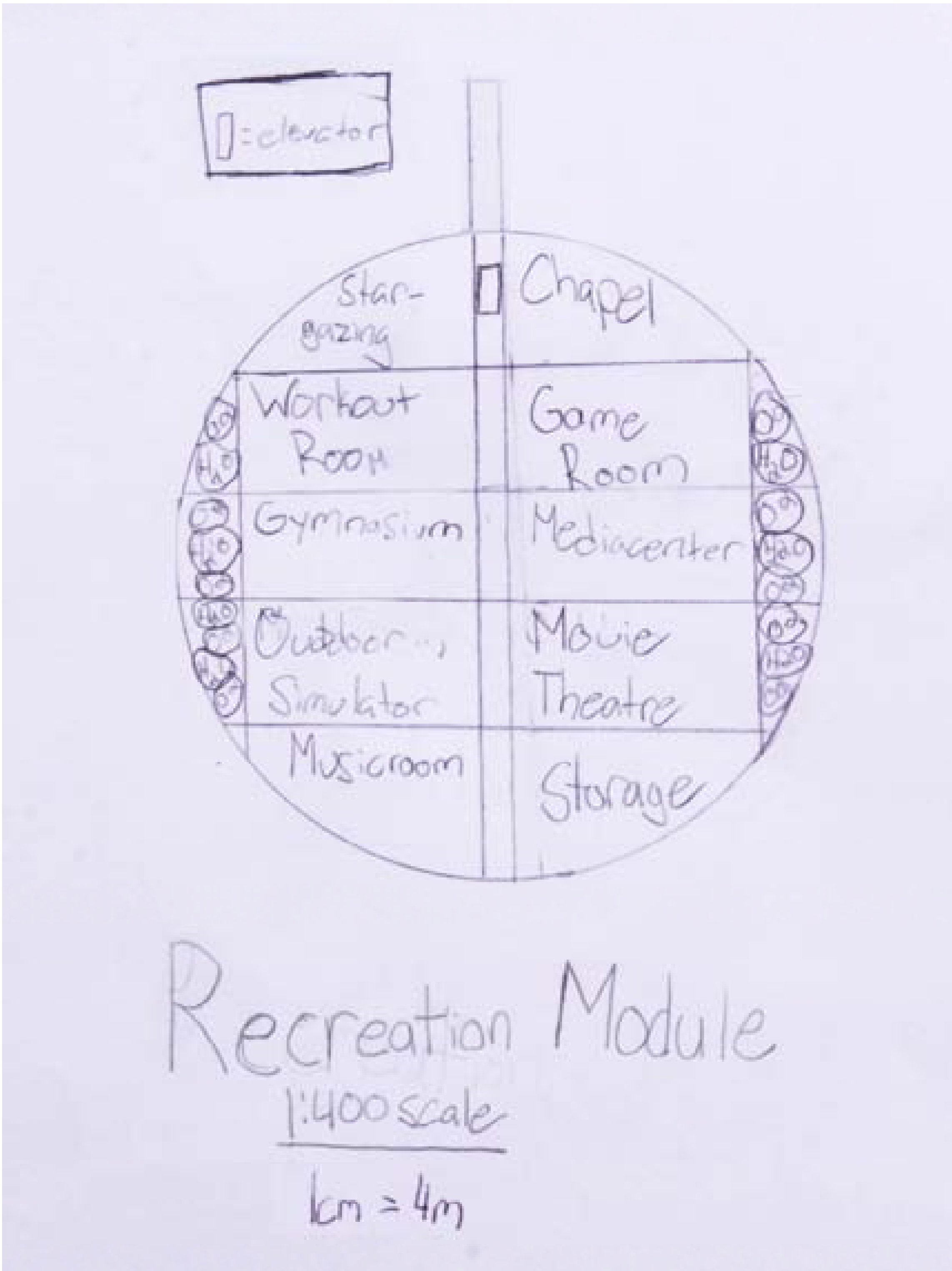
(full-size in feet) = (drawing dimension in inches) (400/12)
= (drawing dimension in inches) (33.33)

(drawing dimension in inches) = (full-size in meters) / 10.16

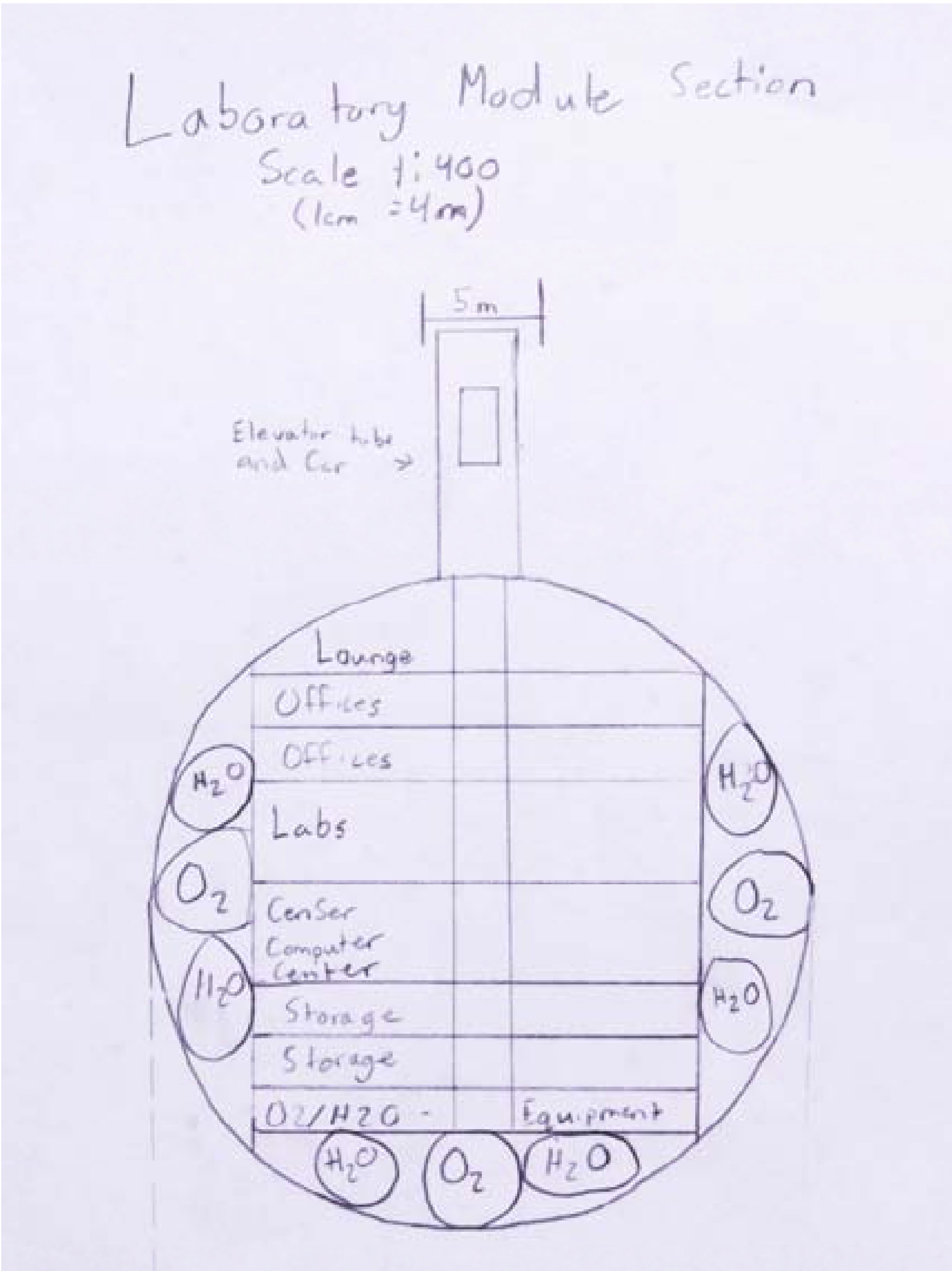
Appendix B – HAB Module



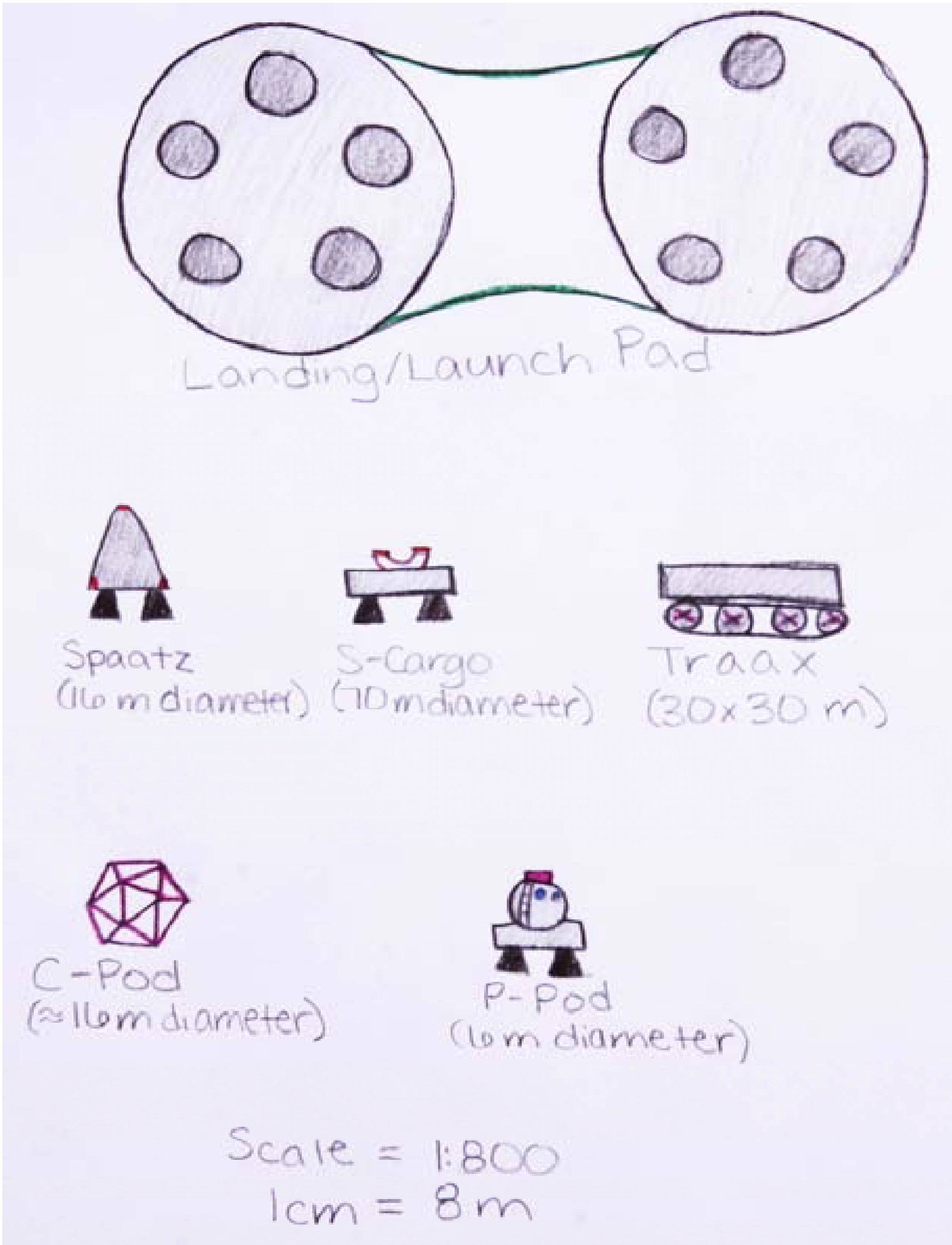
Appendix C – REC Module



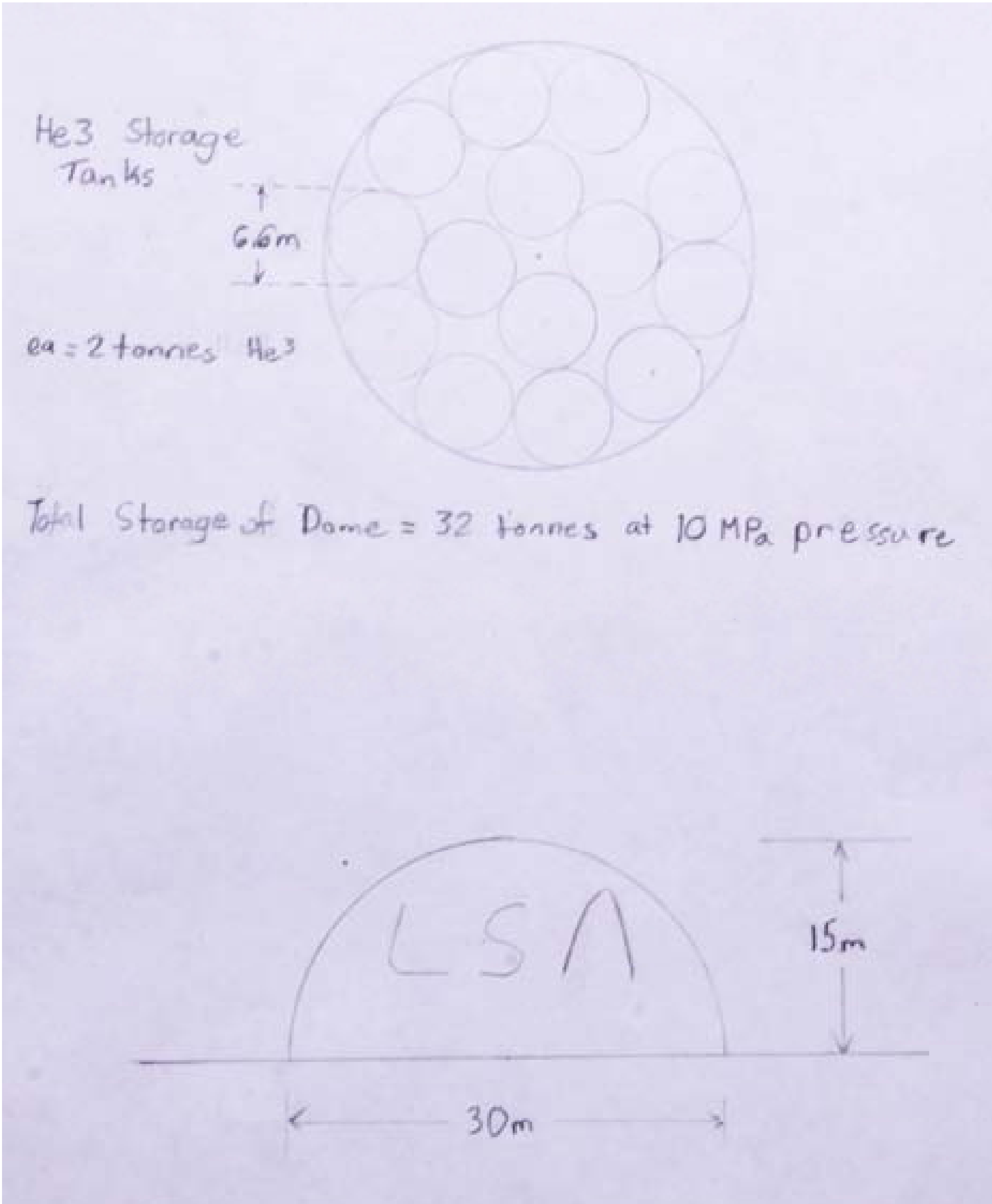
Appendix D – LAB Module



Appendix E – Landing/Launch Pad and Support Vehicles



Appendix F – Storage Domes



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Coach provided some names:
Spaatz, Carl: WWI pilot, WWII General, first Chief of Staff of USAF, early proponent for in-flight refueling
Andromeda: constellation, but really from classic 1971 movie Andromeda Strain
Imsai: Altair's first S-100 8080 competitor (an improved and refined Altair)
Ares V-2: subtle tribute to Wernher von Braun
J-69 Engine: subtle tribute to the 1969 moon landing
CenSer (Central Services): from the 1985 movie Brazil; allusion to censor
Yarc-1: is a Cray-1 supercomputer, circa 1976 (yarc is cray backwards)
ASR33: classic teleprinter/punched-paper-tape machine from Teletype Corp.
HAL (He3-Auto-Login): reference to the computer in the 1968 movie 2001: A Space Odyssey
TelStar: was the first satellite, circa 1962, to relay television pictures, telephone calls and fax images

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