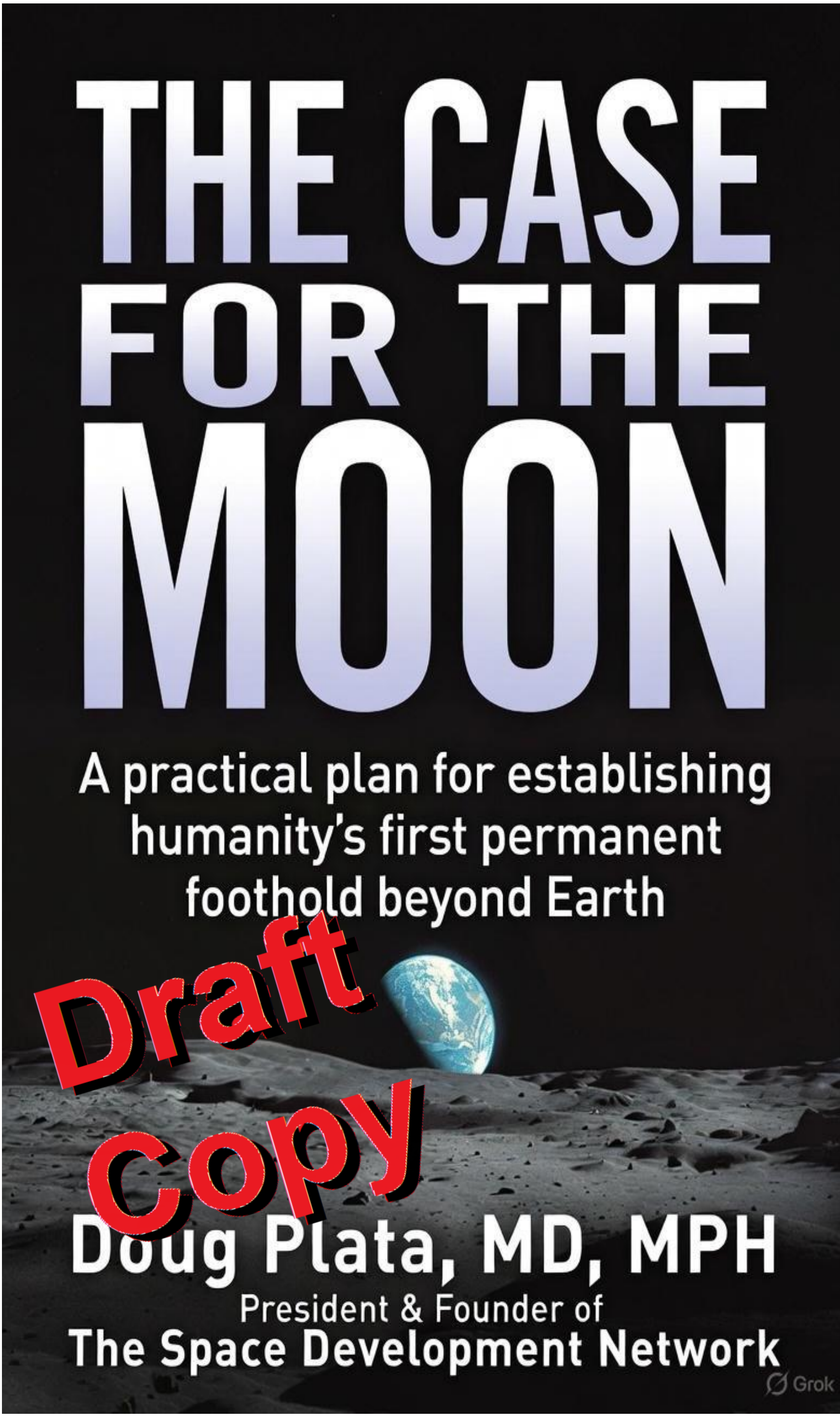
THE CASE
FOR THE
MOON
A practical plan for establishing
humanity's first permanent
foothold beyond Earth
Draft
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Doug Plata, MD, MPH
President & Founder of
The Space Development Network
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The Case for the Moon

January 2026 version (1.0)

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Famous Quotes

"If God wanted man to become a spacefaring species, He would have given man a Moon."

- Krafft Arnold Ehricke

"The Earth is the cradle of humanity, but one cannot live in the cradle forever."

- Konstantin Tsiolkovsky

"The Moon is not simply an object of scientific curiosity; it is the nearest place in space where we can learn to live and work productively away from Earth."

- Paul Spudis

Foreword

I have written this book, at this point in time, in the hope that America's space policy decision makers will stop and realize the significance of the moment we are now approaching. For the first time, we are about to have cheap access to space (CATS) in the form of fleets of reusable heavy lift vehicles. The implications of such capability demand that our current plans be fundamentally changed to take advantage of this opportunity while remaining within our current budget.

What can be achieved is truly remarkable. This book describes how we can establish humanity's first permanent foothold (technically off-Earth settlement) in the form of an Initial Permanent Crew. It also describes how America can lead the world in both the establishment of a large and growing International Lunar Base (ILB) and gain a significant foreign policy win by coordinating with the other nations for their national astronauts to explore the Moon on behalf of their own people. As flight rates go up and costs come down, private individuals can settle down by taking advantage of the technical foundation that the ILB established.

Consider the inspiration that such achievements would have on upcoming generations and how such approaches will ensure that the values which Americans cherish will be the same values that bases and settlements beyond Earth operate with.

That said, the default is to continue current programs and to enter into expensive, decades-long activities until we come to the realization that it isn't achieving anywhere what we could hope for. We have been doing that since the 1980s. It is my hope that, by reading this book, our space policy decision makers will come to understand the remarkable opportunity before us and to have the vision and courage to choose the Innovative Plan.

Doug Plata, MD, MPH
President and Founder
The Space Development Network

Acronyms & Terms Used in This Book

AGRx	Artificial gravity prescription
AgWG	Agriculture Working Group
Atm	Atmosphere of pressure (1 atm = 14.7 psi)
BMD	Bone mineral density
GCR	Galactic cosmic rays
CATS	Cheap access to space
CLPS	Commercial Lunar Payload Service
CNC	Computer numeric control
COTS	Commercial Orbital Transportation System
DexBot	Dexterous (tele)robot
DV	Delta-v (change in velocity)
EML1	Earth-Moon Lagrange point #1
GDP	Gross domestic product
GEO	Geostationary orbit
HSF	Human spaceflight (program)
ILB	International Lunar Base
ILEP	International Lunar Exploration Phase
InstaBase	Instant (inflatable) base
iSAS	Intensive Space Agriculture Session
ISRU	In Situ Resource Utilization
ISS	International Space Station
KREEP	Potassium (K) rare earth elements and Phosphorus
LCROSS	Lunar Crater Observation and Sensing Satellite
LEO	Low Earth Orbit
LogWG	Logistics Working Group
MSTS	Modular Surface Transport System
mSv	Millisieverts
NASA	National Aeronautics and Space Administration
NRHO	Near Rectilinear Halo Orbit
OST	Outer Space Treaty
PELs	Peaks of Eternal Light
PSR	Permanently shadowed regions
SANS	Spaceflight-Associated Neuro-ocular Syndrome
SDN	The Space Development Network
SHLV	Super Heavy Lift Vehicle
SLS	Space Launch System
SPE	Solar particle event
StarHab	Starship habitat
Tonne	A metric ton (1,000 kg)
VR	Virtual reality

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01 – Introduction / Innovative Plan

THE PURPOSE OF THIS BOOK

Dreams Becoming Reality

Although the Case for the Moon necessarily makes arguments for the Moon in comparison to Mars and elsewhere, it is not a case against any other destination. Indeed, the argument of this book is that we are entering a window of opportunity in which all these things will become possible. Specifically, the capability of the Starship fleet will make these visions possible within reasonable public and private budgets.

The dreams of space advocates are coming true. But for many, it seems hard to believe. But keep this book close at hand. As Starships dock and transfer propellant, as they land cargo on the Moon and eventually Mars thereby buying down the risk before sending crew, the vision described in this book will become increasingly close and still relevant. It may be that the capability of the Starship fleet will become unavoidably obvious or another country will start taking the lead by securing missions that utilize them. Either way, the relevant factors underlying the scenarios described in this book won't be denied forever. This remarkable vision is a choice. We would be stupid not to seize that opportunity sooner than later.

WHO IS THIS BOOK WRITTEN FOR?

Target Audiences

Because we are approaching a point where cheap access to space (CATS) is becoming a reality thanks to fully reusable heavy lift vehicles, a point is approaching where space policy makers will need to decide whether to take full advantage of this emerging capability. The whole vision including American leadership, worldwide inspiration, the historic prize to be seized, and indeed, the future of humanity on the Moon hinges on whether these decision makers recognize and take advantage of the opportunity.

A second target audience are those space advocates with some useful skills who would like to play their part in advancing the cause of space development. Since crew will be settling down and residing in lunar habitats, the broad range of living begins to become relevant. Crew will be growing food, cooking, dancing in 1/6th gravity, producing metal parts, speaking various languages, driving surface vehicles, and so many other things. Most everyone can contribute voluntarily in some way. Chapter 39 describes how space advocates can join together for free in Zoom working groups to coordinate work in support of the effort to advance the vision of space development.

THE INNOVATIVE PLAN FOR SPACE DEVELOPMENT

In a Nutshell

The Innovative Plan described in this book envisions fully using the emerging reusable heavy lift vehicles with Starship being the leading example. After Artemis 3 it envisions an Initial Permanent Crew entering a horizontalized Starship (i.e. StarHab) and expanding the living space into the propellant tanks. While making history as the first humans to move indefinitely beyond Earth, further cargo Starships will deliver the beginnings of the International Lunar Base (ILB). As international astronauts arrive, they will be conducting missions of lunar exploration while expanding the ILB. As flight rates go up and the Base becomes more self-reliant, private individuals will begin to arrive resulting in true settlement.

A Realistic Vision

Plenty of books have been written laying out some far future vision. The High Frontier comes to mind with its vision of millions of people living in spinning colonies near the Moon and beyond. Yet 50 years later, we seem to be no closer to those visions.

This book is different. It attempts to be realistic in terms of what is not just possible but probable. It attempts to position itself between what will actually likely happen (the probable) and then what becomes possible given that capability.

For example, given the current reality (very successful Starship Flight 11) and the probable future (continued production of engines and Starship bodies) the probable future is one where a fleet of Starships becomes reality. Then, given that probable reality, what becomes possible when that fleet is used?

If 100+ metric tons of cargo can be delivered to the lunar surface per cargo ship launch then 100+ tonne inflatable habitats can be delivered to the lunar surface. Are inflatables habitats probable? Yes, three are in space now (Genesis 1, 2, and BEAM). Is there a leading company working on surface inflatable habitats? Not that I'm aware of. So, our identification of a possible development also identifies a needed company and hence identifies a task for space advocates to work on (contacting people who can establish such a company). It also identifies work that we as advocates can do to promote the vision (i.e. render an International Lunar Base composed of large inflatable habs).

So, it is this space between the probable and the possible where this book describes.

The Innovative Plan is based upon four principles:

- Cost-effective
- Near-term tech
- Reasonable risk
- Remarkable outcomes

Cheap access to space accounts for most of the cost-effectiveness but recycling, ISRU, and competition between companies will contribute as well.

Near-term tech means new surface systems but nothing beyond what's already been done in other settings.

Reasonable risk means that we are not going to unnecessarily risk human life but, at the same time, we shouldn't settle down into a decades-long development program before establishing a permanent base on the Moon.

If you get anything from reading this book, it is that very remarkable outcomes are possible if we just choose to take advantage of the emerging capabilities, start developing surface systems that will be needed starting about 2030, and not allowing our space policy to be trapped by expensive programs lasting decades.

Evolution

This book also seeks to describe the modest, incremental, evolutionary process by which we go from the present to a truly grand vision. Every step is not only small but predictably likely.

For example, if countries are funding their companies to compete against each other to produce goods and services at an International Lunar Base, then will the price of those goods and services come down over time after the development costs have been amortized. From the perspective of time, economies of scale, and competition, it would seem inevitable. Contrarily, it would be odd if the prices didn't come down.

Then there will be a point where wealthy individuals could afford the next increment of a good or service. Again, that would seem inevitable. Then, as the scale of those goods and services increase, will their prices continue to decrease? Again, that seems inevitable. So, the transition from a governmental base to private settlement seems to be a natural probability if it is competing companies that provide those things in the first place. And so, this book promotes that specific approach. This is an example of how this book seeks to describe each step in the most probable way possible while guiding the decisions needed towards the greatest possible outcome.

COMPARING PLANS

The Traditional Plan

The Traditional Plan (or the plan of record) is NASA's current plan for lunar exploration. It is currently composed as follows:

- **Artemis 2 -** Sept. 2026 - Crewed lunar flyby
- **Artemis 3 -** Late 2027 - US returns to the Moon. Includes first woman
- **Artemis 4 -** Sept. 2028 - Gateway module and second crewed return
- **Artemis 5 -** March 2030 - Gateway module and third crewed return

It will use SLS and the Orion capsule for each mission and the Starship lander for Artemis 3 and Blue Origin's lander for Artemis 4 and 5.

At an estimated $93 B spent up to Artemis 2 and an estimated $16.4 billion total for Artemis 2-5, outcomes would include:

- A lunar flyby (repeat of Apollo 8)
- First woman on the Moon (maybe first person of color)
- Three lunar surface missions (repeat of Apollo surface missions)

The Innovative Plan

The Plan described in this book would instead spend the money on surface systems and lunar surface missions.

Surface Systems (Median AI estimates - for what it's worth)

$500 M - Solar Drapes
$900 M - Specialty hab (inflatable)
$700 M - Robotic ice-harvesting vehicle
$700 M - Life support systems
$2,500 M - Agricultural systems
$1,000 M - Modular surface vehicles
$900 M - Specialty hab (inflatable)

$7.2 B - Total

Flights and Flight Hardware

$2,900 M - Modify Starship to be a StarHab
$6,000 M - Six, Starship-only lunar missions

$8.9 B - Total

$16.1 B - GRAND TOTAL

The point is that the Innovative Plan, although achieving remarkable results, doesn't necessarily require increased spending. Indeed, no single surface system will cost as much to develop will have already been spent developing the reusable launch vehicles.

But the greater comparison is in the outcomes. Whereas the Traditional Plan results in a few government astronauts repeating Apollo by picking up more rocks and establishing a small, four-person outpost, the Innovative Plan described in this book results in a very large International Lunar Exploration Phase, International Base, and eventually private settlement. It is a choice whether we continue in the expensive, moderately inspiring current path or whether, within existing budgets, we instead seek to make history by laying the foundation for humans to start spreading beyond Earth.

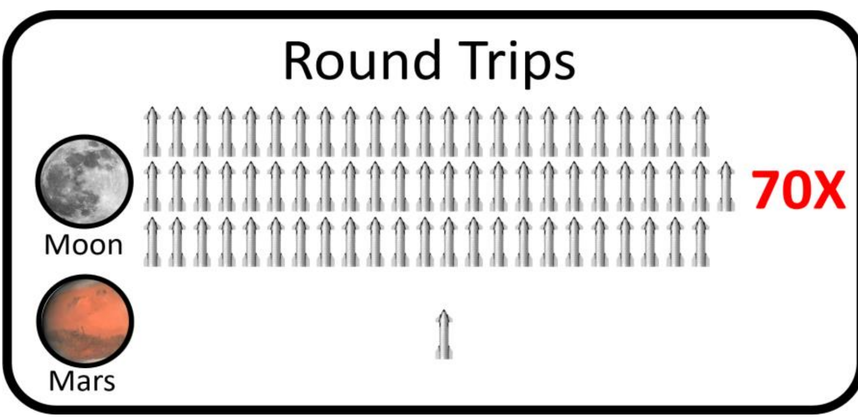
02 – Why the Moon?

Why should lunar development be a space policy priority?

To be clear, this book isn't arguing for limiting our program only to lunar exploration. The argument isn't that we should send a few government astronauts to pick up some more rocks to add to the Apollo collection, pat ourselves on the back and then abandon the Moon for Mars.

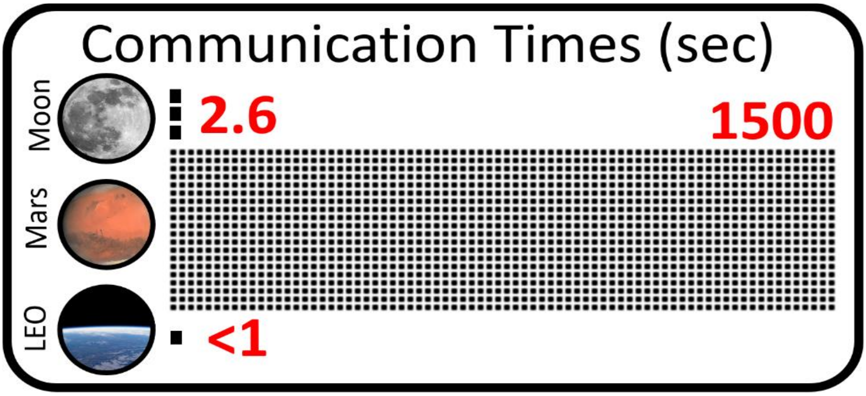
Rather, this book argues that the time is ripe, the Starship fleet is being built, and that America should take full advantage of this unique opportunity to lead the other nations in establishing humanity's first, permanent foothold off Earth. Subsequently, we should then lead the other nations as we establish an International Lunar Base which will quite naturally transition to the largest and rapidly growing off-Earth settlement. America needs to seize this opportunity. It won't happen unless our space policy leaders recognize the opportunity and then marshals Congress and NASA to establish a space policy that ensures that it becomes a reality that not only inspires the next generation but will amaze the other nations and draw them to follow our lead.

Here I succinctly lay out the nine reasons why the Moon should become a space policy priority.

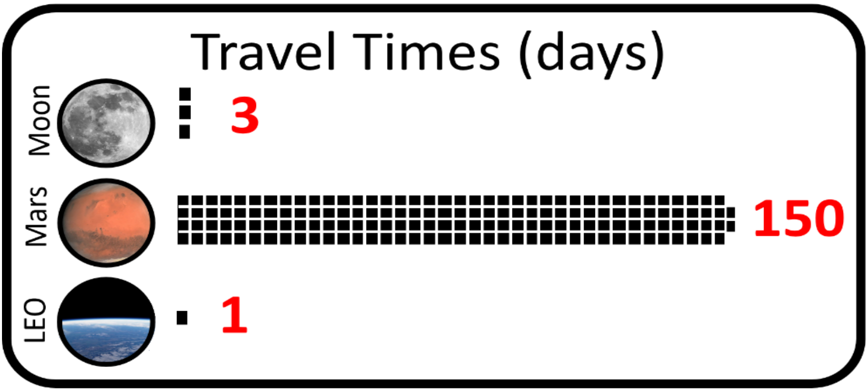


Because it is Close / Safe

The Moon is only three days travel time away and is only 2.6 seconds away by speed-of-light communications. As seen in the first infographic, this means that each translunar transport system can complete 70 round trips to the Moon for each round trip to Mars. This practically guarantees that the lunar base / settlement with be developed faster than anything Mars. Does America want to be in the lead when it comes to establishing the rules in humanity's largest off-Earth base / settlement? Then we'd better recognize the opportunity that the Moon represents.

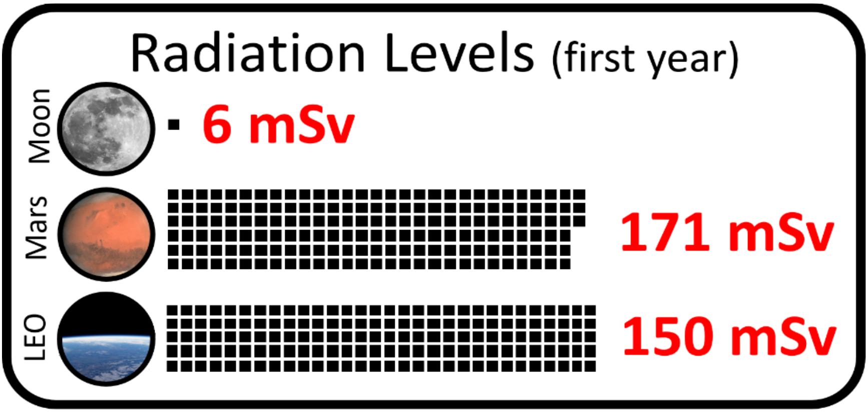


Also, because this close, people living on the Moon will be able to remain in telepresence contact with their loved ones. Any regular advocate attending space conferences knows that we need to be mindful of the ladies and their differing interests. And older couples who've lived long enough to save enough to go will include a spouse who will like to be virtually present in family gatherings and with her friends back on Earth. Occasional video emails aren’t quite the same. It's not a factor that husbands will be allowed to brush aside -- nor should we.



Going to Mars means losing a small chunk of one's remaining life. Returning to Earth means losing a second chunk of life. But by settling on the Moon, one always retains the option of returning to Earth quickly. If a family / health emergency arises, that is still an option.

Also, because the Moon is close, passengers will experience only a brief, 3-day trip exposed to space radiation before landing and entering a radiation-shielded base. However, passengers to Mars will experience far greater radiation exposure. In LEO, passengers orbiting at an inclination that will give them views of most of the earth will daily be exposed to the trapped radiation in the southern Atlantic anomaly. As a result, they will have significant radiation exposure over time.



Because it can be Done Soon

In Chapter 4, "How Soon?" I make the case that the time is ripe to develop the Moon. After decades of waiting for cheap access to space (CATS), it is finally arriving in the for of SpaceX's Starship fleet and the lunar-specific vehicles by Blue Origin. The space policy decision-makers in DC need to stop the old way of thinking (a few government astronauts on incredibly expensive science missions) and fully embrace the remarkable opportunities that the Starship fleet offers. It is only somewhat forgivable that they hesitate until Starship demonstrates every last capability before changing the policy. During the Apollo Program space policy embraced the Saturn V system even before it was demonstrated. Starship now has enough demonstrations and the remaining hurdles are sufficiently small. It is past time to embrace what this capability represents and align space policy likewise.

From a China policy standpoint, it matters more how many nations we are working with on the Moon than who got back to the Moon first. If we make it about large scale, international exploration and base using the Starship fleet then we can't lose.

Because the Cost is Reasonable

This book doesn't call for an increase to NASA's budget. But rather, NASA's budget be re-oriented to cut the fat and replace it with systems that are far more cost-effective. In the process, the American taxpayer will get far more bang for their buck.

If one looks for places to save money in NASA's budget, it is a target rick environment. At an estimated $4.1 billion per mission, SLS, Orion, Gateway, and Mobile Launcher 2 don't represent a cost-effective approach. Previously Acting Administrator Sean Duffy called the current Artemis Program "unsustainable". That's stating the obvious. But what should replace it. This book describes an alternative scenario that is entirely doable and would yield remarkable achievements.

Also, because the trip to the Moon is so short compared to a trip to Mars, more people can fit into one Starship. They need fewer consumables and they need less "elbow room". For this reason, the ticket price will be substantially lower than the ticket price for Mars. And for many people on the lower end of the wealth curve, they won't really have a choice. They can afford to go to the Moon but not to Mars. And for many, that will be the determining factor.

Finally, shipping bulky items like counters, bathtubs, furniture, floors, etc. will not only be costly but those items will displace passengers thereby reducing revenue for the transport companies. So, there will be a strong incentive for the International Lunar Base to start producing these things from local resources. Chapter 29 describes how metals can be extracted from the lunar dirt and processes into sheet metal and other pieces of equipment.

Because Elon Won't Pay for it

The SpaceX Starship's design is optimized for Mars and not the Moon. It will work fine for the Moon because it is so over-sized. And SpaceX is fully willing to fly to the Moon if paid to do so. But SpaceX is rightfully focused on their goal of Mars with Elon pledging Starlink revenue to go towards Mars infrastructure.

If a large and growing International Lunar Base is going to be developed, we need a space policy for that purpose. NASA can still do Mars by partnering with SpaceX's Mars program. But the lunar base won't develop itself. The space policy decision makers need to decide that lunar development should be one of the main objectives of our space program at this time and partnering with SpaceX for Mars being the other main objective.

Because of the Historic Opportunity

There will be only one first woman on the Moon, only one first astronaut exploring a lunar lava tube, only one first permanent base on the Moon, only one first puppy born on the Moon, and only one story of the first humans to sell their homes on Earth and be the first if humanity to settle down off Earth. These are the type of things that we know will go down in history. All these historic firsts are within our reach if we only choose to seize those opportunities. The book is a call for us to not miss those opportunities while we stupidly watch other countries seize those firsts.

Because it Will be Inspiring

What will be the first words spoken by the first woman to set foot on the Moon? Billions of people will one day know the answer to that question. What will be the name of the female dog that is part of the Initial Permanent Crew? A billion children worldwide will know its name. And what will its puppy be named? America has the opportunity to astonish the upcoming generation of young people with what we can do. Don't we want that? Wouldn't that foreign policy coup be worth directing a part of NASA's human spaceflight budget towards that goal? Chapter 12 describes the sort of life that the Initial Permanent Crew will be able to demonstrate to the watching world.

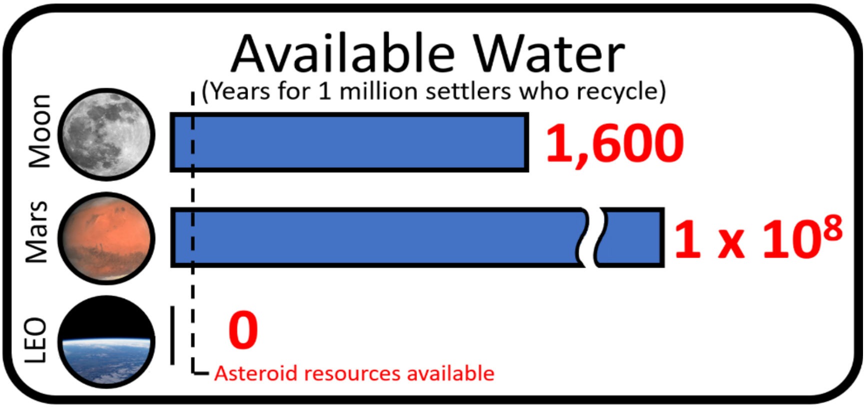
Because America Can Lead the Way

As of this writing, 60 nations have joined with the United States is signing the Artemis Accords. These are a set of principles that the nations have agreed to abide by when going to the Moon. The large number of nations agreeing to these Accords demonstrates American leadership as we start to move beyond Earth.

The NASA Administrator needs to meet with the other Artemis Accords countries and figure out what comes next in terms of a coordinated International Lunar Exploration Phase (ILEP) and International Lunar Base and then carve out portions of its budget dedicated to purchasing Starship missions to the Moon and Mars.

Because the Moon has Abundance

Mars advocates often point to the huge (volatile) resources on Mars relative to the scant resources on the Moon and therefore conclude that Mars is the only place where off-Earth settlement can have a future. They routinely cite the parts per million concentrations of water in the sun exposed lunar dirt (regolith) while ignoring the copious amounts of water and carbon and nitrogen-containing chemicals published in NASA's 2009 LCROSS experiment. To show how wildly off their data picking is off, consider one more infographic:



If a settlement has grown to the size of a million people and the recycling of water has advanced no more than it is today on the ISS, how long until the lunar water ice runs out?

So, each settler requires about one kg of water per day after recycling. The current best estimate of how much water there is at the shadowed areas of the lunar poles comes to about 600 million cubic meters. How long would that last the higher settlement? The answer is 1,600 years. You could easily fit the history of the development of the United States more than six times into that space. And do you think that during those 1,600 years, alternative resources could be developed and imported such as from asteroids and comets? In other words, the Moon will never run out of resources. What it has is far more than enough.

Because the Largest Settlements Will be There

With flights to the Moon being as much as 70 times more frequent than for Mars, it seems apparent that the fastest growing base will be on the Moon and with increased flight rate, that it will be able to transition to a private settlement sooner. For these reasons, the Moon will take the lead in off-Earth settlement and remain that way for decades to come.

In other words, the future is on the Moon.

03 – What About Mars?

SUMMARY

Like the Moon, Mars is a legitimate destination in its own right. Given that the Starship is specifically designed for Mars and SpaceX has the Starlink revenue to fund Mars development, Moon and Mars development will occur simultaneously. But, because of the much greater distance, Mars will be developed much more slowly.

Mars' greater resources itself is not a big argument in its favor because the Moon has more than enough resources. But the ease of accessibility of its volatiles is a definite plus. But, once ice harvesting operations have been set up on the Moon, the production of the next increment of volatiles will be fairly cheap.

To be clear, there is no need to be opposed to the exploration, development, and settlement of Mars. Indeed, we should be very enthusiastic and supportive of it. But the Moon will likely be developed and settled a few years prior to the same happening on Mars and also, the growth rate of a lunar base / settlement will be substantially greater than that on Mars primarily due to the much shorter round-trip time to the Moon. So, the case for the Moon is more of a question of where the bulk of development and settlement will occur in the early decades. It seems apparent that the Moon will be the location where this will happen.

There is a supportive relationship between the Moon and Mars. Martian development and settlement could still occur whether the Moon existed or not, certainly. And yes, much of the testing of Martian habitats and systems could be done more cheaply in environments on Earth than on the Moon. But the Moon is there and it will be developed a short while before Mars. So, systems implemented long-term on the Moon in its vacuum and in the logistically challenging setting will yield some lessons which can then immediately be applied to Mars where many of the systems will be nearly identical.

However, this is not to say (as so many do) that the purpose of the Moon is only as a steppingstone to Mars -- that Mars is the ultimate and only truly valuable goal and so lunar development should essentially be paused after initial development and then we'll move on to the "real" destination which is Mars. No, the Moon is a legitimate end destination in its own right. As we will see later in this book, its resources are more than sufficient to support a very large population for a very long time. And its proximity to Earth means that it will grow substantially faster than any development on Mars.

Finally, it would seem prudent to have humanity's eggs in three baskets ASAP and not just two including a basket substantially further away than the Moon is from the Earth.

THE PROS

Mars has some substantial advantages which deserve to be acknowledged.

Resources

The first thing that should be mentioned is its atmosphere. Although only about 1/200th the density of Earth's atmosphere, it none-the-less is a very convenient source for propellant, air, plastics, and other organic compounds.

A second, and related pro, is the availability of fairly pure water in an easily accessible form. The form is that of very large glaciers at high latitudes. Sites being identified for initial bases make sure to be on those glaciers. A good source of hydrogen, combining this with the CO_2 and N_2 in the Martian atmosphere, any number of useful organic molecules are possible given the right chemistry equipment. Given enough power, plastics could be produced which would be of great value for structural material for use in things like furniture, counters, shower stalls, etc.

Radiation Protection

It is true that the Martian atmosphere provides some protection against space radiation. It is probably sufficient by itself to prevent plants from dying from a solar particle event (SPEs, i.e. solar storm). The thickness of the Martian atmosphere would be sufficient to prevent the immediate death of unprotected crew for most SPEs.

But it would be unhealthy in the long term for crew to work within unshielded greenhouses. We can also give SPE warnings to crew wherever they are so it’s a convenience and not an essential.

“Oceans of Water”

Yes, we know that Mars has oceans’ worth of water in the form of glaciers and this fact is highlighted by many a Mars advocate as to why only Mars can support settlement. But it is not the amount of water that matters. The Moon has at least 600 metric tons of water sufficient to support a million-strong city that recycles for about 1,600 years. Rather, the advantage that Mars has in terms of water is its relative ease of access. Using what is called a “Rodwell” a pipe could be drilled into the glacier. By simply pumping heated water down the pipe, an increasingly large void is melted into the glacier freeing up more liquid water. By contrast, on the Moon, the water must be heated out of icy regolith in cryogenically cold craters. This process is doable but does require a more involved operational process.

Life

Another major pro that Mars has to offer is the potential for the discovery of fossil and/or extant life. This is of far greater scientific interest than questions mostly of geology which the Moon has to offer. Whereas this scientific potential is supportive of a program of scientific exploration, it is not a great rationale for private Martian development or settlement.

Gravity

The higher gravity of Mars (3/8ths gee) is often put forward as a pro compared to the gravity of the Moon (1/6th gee). The logic usually stated is that we don't know how much gravity is needed for long-term health, but more is undoubtedly better than less.

Inspiration

It should also be acknowledged that Mars, for some reason, has a greater hold on the imagination than the Moon in terms of exploration and settlement. There are more movies, books, pieces of art, etc. about Mars than there is for the Moon. Mars also offers more interesting sights including the largest canyon and volcano in the solar system.

THE CONS

Cost

Will this interest be sufficient to overcome the substantial barrier of travel time and cost? Probably not. The 60 times greater travel time to Mars is a real bear that will give many second thoughts. But probably the greater factor is the increased cost of traveling to Mars. The greater cost of travel to Mars is affected by:

- Lunar craft being reused 70 times more frequently than Martian craft
- Longer travel times require more provisions thereby eliminating more passenger space
- Passengers will require more "elbow room" for the long trips thereby also eliminating more passenger space
- Fewer passengers per flight means a higher ticket price.

There are more passengers on the low end of savings than the high end. A certain percentage of passengers will only be able to afford to move to the Moon than to Mars. And for those who could afford to go to Mars, doing so will consume more of their savings than if they go to the Moon instead.

Gravity

It is certainly true that more gravity is better than less for health. But we have some indication that even Martian gravity is going to lead to long-term consequences. So Martian gravity will likely only slow the deterioration rather than stop it altogether.

A study was done in which the tail of laboratory rats was partially suspended so that the forces on their hind legs were the same as they would experience on Mars. The result was that they lost bone mineral density. One should presume that the same level of force on the limbs in the Martian environment would yield the same results as these lab tests have shown. Artificial gravity (e.g. indoor centrifuges) might sufficiently mitigate these results. But the inconvenience of such an approach would largely negate the gravity advantage of Mars.

And there is the flip side, the lower level of gravity on the Moon would allow for significantly increased freedom of action (e.g. dancing up the walls to the ceiling). Most settlers would probably prefer more freedom of action than less.

Separation From Loved Ones

Mars advocates rarely acknowledge the relative separation from loved ones that moving to Mars would require. About 85% of the attendees of Mars Society Conventions are males. Even for those who are married, their wives often do not join them as they don't have as much interest in Mars as their husbands do. It seems to me unlikely that men who would like to move to Mars will essentially divorce their wives to do so. Perhaps the reluctant wives would be willing to move with their husbands if their husbands were dead set on going. But limiting connection to family and friends to only video emails pose a substantial barrier which deserves to be acknowledged by Mars advocates.

In contrast, two-way, real-time telepresence is possible from the Moon with only an annoying but bearable 2.6 second time delay. Lunar settlers could be virtually present at their family's holidays gatherings and their grandkids' graduations and marriages. If still participating in business, the Moon would allow for teleconferencing while Mars wouldn't.

Life

The potential discovery of life on Mars is very exciting. But it is a two-edged sword. Even if solid, scientific arguments against planetary protection concerns can be made in a compelling manner, it simply remains to be seen whether logical, emotional, and political arguments based upon these concerns will manifest themselves as a substantial barrier to the exploration, development, and settlement of Mars. There's a real risk as to how this will play out the closer that we get to being able to go to Mars.

Telerobotic Workforce

The Moon allows for the presence of a very large, robotic workforce, teleoperated 24/7 by operators on Earth. This is not possible for Mars. The obvious solution is for robots on Mars to be autonomous. This seems not only possible but inevitable in the years ahead. So, teleoperations would only be an advantage for the Moon in the early years.

CONCLUSION

The primary advantage of Mars is the accessibility of its resources, particularly its air. The other advantages seem uncompelling and have associated disadvantages. When comparing the resource advantage to the increased cost of going to Mars, the inconvenience of traveling to Mars, and the loss of interactive communication with loved ones, it is likely that the Moon will be the favored destination for settlers for the next several decades such that it will have the largest and leading off-Earth settlements.

WHAT ABOUT FREE SPACE SETTLEMENTS?

Within the space advocacy community, people typically divide themselves into one of three categories when it comes to destinations for space settlement: The Moon, Mars, and free space (or O'Neillians). The term "free space" doesn't mean that it costs nothing or is necessarily democratic. Rather the term is used to mean empty space free of large gravitational bodies such as the Moon or Mars. So, free space can include Earth orbit, a gravitational balance point (i.e., the Lagrange points), orbits around other planets, or in the asteroid belt.

These settlements are typically envisioned to be very large spinning structures which produce their own artificial gravity. Settlers can walk around in one gee while apparent centrifugal force pushes them down on the floor.

Free space settlement must, by necessity, be very large. When one resides in a spinning structure it creates a situation where one experiences Coriolis forces whenever one turns their head. The Coriolis forces become less the larger the radius and hence the slower the rate of rotation necessary to achieve one gee. Just how many RPMs residents can adapt to over time is debated but it is probably between 3 and 6 RPMs. Given these numbers, it appears that the smallest spinning habitat would be at least 110 meters in diameter.

GERARD O'NEILL'S VISION

The person who really did the most to promote this vision is Princeton professor Gerald (Jerry) O'Neill. Immediately after the end of the Apollo Program, he famously posed the following question to his students, "Where would be the best location for a growing, industrial, settlement in space". As the story goes, the students and he ultimately decided that spinning settlements in free space was the correct answer to that question. Dr. O'Neill proceeded to write a very influential book titled, "The High Frontier" which described in fair detail what a spinning settlement would be like and how it could be constructed. There were some obvious, big challenges to O'Neill's vision. For starters, free space habitats would be exceedingly large and massive.

Gerard's vision was written out many times in the popular press and even on TV. He had the opportunity to present his vision before Congress and even NASA considered the vision. But the magnitude of what it would take to accomplish the vision left many with the view that it was implausible. Indeed, the NASA Senate subcommittee chairman, William Proxmire, once quipped about O'Neill's proposals by saying "…not a penny for this nutty fantasy." There were studies, annual Space Manufacturing conferences, and even some hardware built but until the present, that funding never did come through and the O'Neillian vision remains just that, a vision. Unfortunately, Gerard O'Neil died in 1992 at only 69 years of age after a seven-year battle with leukemia.

But O'Neill's vision never died. Indeed, many of the early members of his space advocacy organization, the L5 Society, went on to become long-term leaders in the succeeding National Space Society (NSS). And when the NSS conducts space settlement design for students, it's rarely Moon or Mars settlements but free-space settlements.

What's more, the free space settlement vision has received some very needed updates. In particular, Al Globus has significantly simplified the vision by identifying a low radiation orbit (Equatorial LEO or ELEO). This prevents the need for millions of tons of material to be launched from the Moon or imported from asteroids to provide radiation shielding for very large, spinning settlements.

A second major improvement that Al Globus has identified is that the Coriolis effect can, to some extent, be adjusted to in a relatively short period of time. He believes that the evidence points to people being able to adapt to as much as 6 RPMs.

Put together, Al has proposed relatively small spinning settlements which he has termed Kalpana One and Kalpana Two with the latter having a diameter of 110 meters and with a population of about 500 people. That's a large habitat but much, much smaller than O'Neill's original vision.

THE ADVANTAGES OF FREE SPACE SETTLEMENTS

Before we get to the problems with free space settlement, we do need to acknowledge some of the main reasons that some advocates argue for them over settlements on the Moon and Mars.

Proximity to Earth

Earth is where the bulk of humanity's markets are and will be for a long time. O'Neill's original case for free space settlements envisioned that the settlers would earn a living construction massive power satellites. That was probably yet another unrealistic aspect of his vision. Most likely things in space will be assembled at much lower labor costs on Earth and then simply launched and deployed to space. Telerobotics can do any remaining assembly.

A better argument is that settlers in LEO will be able to continue their business provided that it is telecommuting in nature. Clearly, this is an advantage over Mars with its average of 14 minutes' time-delayed communication. For the Moon, the time delay is only 2.6 seconds, so LEO doesn't have that much of an advantage on this point. But who will be putting the money down to move off Earth? Only those who have lived long enough to save up enough money. Many of those people will be retirees who…want to retire.

Rather, the stronger argument that favors LEO and lunar settlements over Mars is that, in both cases, settlers can be telepresent at important family gatherings on Earth. This may especially be true for spouses. Advocates who are excited about becoming an off-Earth settler tend to be males as any attendee at a space conference can tell you. Convincing their wives to significantly cut ties with friends and family (including those grandkids) could be a pretty hard sell.

So, what's the problem with free space settlement?

THE DISADVANTAGES OF FREE SPACE SETTLEMENTS

Lack of Local Resources

The leading problem with free space settlements is exactly that -- they're in free space where resources are lacking. Both the Moon and Mars have immediate resources. Free space advocates think that proximity to Earth is an advantage. But in free space you must transport all your material up from Earth's very deep gravity well or you have to develop the systems from scratch to import material from either the Moon or from asteroids. On the contrary, for the Moon and Mars, you don't need to transport materials using rockets. The materials are there on the surface and can be transported to the base via electric vehicles.

To help better understand this issue, free space advocates often point out that it takes less energy to deliver material from the Earth to LEO as compared to delivering material from the Earth to the Moon or Mars. That's true, but entirely irrelevant. Let's say that you were to launch four kilograms of material to LEO. That's four usable kilograms. But if one wants to transport that to the lunar surface, about three of those kilograms would need to be propellant to push and land that last kilogram on the surface of the Moon. But, if that one-kilogram part was a motor that kept a 10 kg telerobot working and that telerobot produced 100 kg of material (e.g. water or metal) before needing to be replaced then that one kilogram resulted in 100 kg of usable material. That 25 times greater usable material than was possible for the same launch to LEO. The same holds true for Mars. And the lack of immediately available resources prevents the potential for the exponential growth of a telerobotic workforce like is conceivable on Mars and especially on the Moon.

The lack of immediately available material is a major reason why free space advocates generally agree that it will be a very long time before settlements will be established in free space. And therein lies the rub. Moon and Mars advocates can agree that O'Neillian settlements will sprinkle the solar system one day. But that day won't come anytime soon. And so, for now, our attention would best be focused on where settlement will begin.

When Gerard O'Neill testified before Congress about his vision for free space settlement, that vision was so far out there that the chairman of the Senate Subcommittee responsible for NASA's budget responded "It's the best argument yet for chopping NASA's funding to the bone .... I say not a penny for this nutty fantasy". He then went on to succeed in eliminating spending for research on space colonization from the budget. It has been approximately 45 years since that time and O'Neill's original vision still seems pretty far out there.

Seeing the Sea

Equatorial LEO is the orbit with the lowest radiation levels. But if one is living in orbit, it would be nice to have a better view. An equatorial orbit is over ocean 85% of the time. And there's not a lot of highlights along the equator either. People who settle in ELEO likely won't ever orbit over their home country, see the boot of Italy, see the Hawaiian islands, use a telescope to see the pyramids or the Great Wall of China, etc. The view would still be beautiful but repetitive. By contrast, people who settle on the Moon and Mars will likely first launch to a hotel in an inclined LEO orbit which, in time, will pass over much of the inhabited Earth. After staying there for a few weeks taking in the views, they will then transfer to an interplanetary craft and head to their final destination.

Orbital Debris

Another big problem with having a large settlement in LEO is all the orbital debris that will eventually puncture the settlement. One could bulk up with shielding but that would add a great deal of mass to the structure and wouldn't be effective against the largest of orbital debris. O'Neillian advocates recognize this problem. And they agree that LEO would have to be cleared of orbital debris before long-term settlements could be established there. Again, we're talking about something that pushes space settlement far down into the future.

By contrast, on the Moon and Mars, there is little orbital debris to be concerned about, and micrometeorites are naturally addressed by placing lunar dirt on top of habitats which one would be doing anyhow for radiation protection.

THE ARTIFICIAL GRAVITY ARGUMENT

The one major, and legitimate argument that the advocates of O'Neill's vision is that, for natural growth (i.e., settlers reproducing themselves), it would require that children be born from the settlers. The fair question is, can people successfully reproduce in lunar and Martial gravity levels? O'Neillian advocates reason that, because we know that a full gee 24/7 is natural and hence healthy then we should just pursue O'Neill's vision regardless of the cost because, maybe, we won't be able to have children on the Moon and Mars.

There are several problems with this reasoning. First is the definition of settlement. Many space advocates argue that settlement isn't settlement unless there are children. Similarly, they argue that a settlement cannot be sustained unless a settlement can grow by having children.

SETTLEMENT DEFINED

But technically, settlement doesn't necessarily require having children. This would be like saying that communities on Earth can't be communities without having children. Well, what about active retirement communities? They can have thousands of people, involved with all sorts of community activities, and even have their own local governance. Are we to say that they are not a community because they are not able to have children? Of course not.

But can retirement communities grow? Yes, active retirement communities typically grow continuously and can grow to be very large. But obviously, it is not from natural growth but from retirees entering the community in greater numbers than they "leave" the community. And this analogy is fair. The initial settlements will most likely be composed primarily of those who have lived long enough to have saved up enough money to go. And most will be freed from childrearing and occupational responsibilities. So, retirees are the prime candidates for off-Earth settlement.

The key to understanding this matter is to simply recognize that there isn't just one type of space settlement but several different types. There can actually be government settlements, retirement settlements, company towns, and general settlements (with children).

However, just because all settlements don't require having children, this doesn't mean that having off-Earth children isn't something worth pursuing. It's very important to the full scope of space settlement. Chapter 24 describes the steps to determining the artificial gravity prescription for healthy gestation and childhood.

WHAT IF THE AG Rx DOESN'T WORK OUT?

There is the very real possibility that, after the animal studies are completed, that we will find out that the reduced gravity of the Moon and Mars will have unacceptable health consequences for gestation and childhood even given full artificial gravity in a centrifuge for a few hours a day. Proposals exist to create large settlement railroad cars continuously moving around large, circular tracks. Whereas this is technically possible, it is not a near-term solution, nor would it be particularly enjoyable to grow up in a train of railroad cars. At that point, we should accept that the O'Neillian vision is the only practical option for a naturally growing settlement even if it would take many decades to realize. But even if this turns out to be the case, very large settlements of adults will be established on the Moon and Mars first.

CONCLUSION

So, given the significant challenges that free space settlements face, the question that Gerard O'Neill asked his students seems to me to be the wrong question. We should now be more concerned with what the next steps should be rather than what the situation might be a century down the line if the near-term path doesn't work out perfectly. And for the near-term it is clear to me that, given the immediate resources and the proximity of the Moon, then the Moon is where large settlements will develop first.

04 – Why Now & How Soon?

SUMMARY

Starship development is moving along nicely. Full reusability of heavy lift vehicles is a complete game changer. And not only this but both SpaceX and Blue Origin have the factories to produce fleets of reusable ships. We need space policy to take full advantage of this capability.

This chapter makes the case that landing cargo on the Moon will start occurring about 2027 and, when successful, crew will start landing in about 2028. Attempts to land cargo on Mars will occur about simultaneously with crew on Mars occurring somewhat after the Moon. We should aim for an Initial Permanent Crew about 2030. Buildup of an International Lunar Base will occur starting in the early 2030s with a transition to a private settlement being in the late 2030s. A large International Lunar Exploration Phase (ILEP) will occur in the mid to late 2030s. Populations of ethnic/national and religious groups will become large enough by the end of the 2030s such that the 2040s will witness the establishment of people-specific colonies.

WHY NOW?

Many books have been written about our future in free space, the Moon, and Mars. But most of these were written many years ago. But can we so confident that the next ten years will demonstrate to all that it is starting to become a reality?

The single most important factor is the emergence of two specific companies, SpaceX and Blue Origin who have the specific vision and sufficient funding to turn those visions into actual reality. Each share the same vision of large populations of humans living beyond Earth. This is a vision that NASA has never adopted and so they never designed nor pursued a path towards that goal.

Both companies realized that, for their vision to become reality, they needed to achieve fully reusable rockets in the (super) heavy lift vehicle class. It has taken 20 years for them to get there but they are both within just a few years of achieving that goal. And once achieved, humanity will find itself at a turning point in that it will be the first time that humanity will begin spreading beyond Earth. This isn’t sci-fi fantasy but a probable reality.

But can these companies overcome the remaining challenges to fully reusable rockets? The fact that SpaceX's has landed more than 400 of its Falcon 9 first stages, twice caught its Super Heavy booster on the launch tower, and twice completed pinpoint landings at an imaginary tower in the ocean gives considerable confidence that full reusability is likely. And if SpaceX can show the way, others will inevitably follow.

From the funding side, two of the wealthiest people on Earth (Musk and Bezos) are committing their considerable wealth towards off Earth settlement. And when they bring the cost of access to space down dramatically through full reusability, the halting progress of national space agencies will be swept away by rapid and large-scale progress led by these visionary companies.

I wish that more people understood the historic transition point that we are facing. The younger generation will have their Apollo moments as the first woman sets foot on the Moon, the first humans set foot on Mars, the first permanent foothold beyond Earth is established, and the first human is born off Earth. I am convinced that young people alive will witness all of these things.

HOW SOON?

In this chapter, let's attempt to estimate when different things will happen. Why do so? The main reason is so that you, the reader, will have the sense that the Innovative Plan described in this book is not some far out science fiction vision but an option that is just an optional path given the developments in progress.

BUT FIRST SOME CAUTIONS

The safest thing would be to make no specific predictions whatsoever. No estimate, no chance of being wrong! Yet, how can we be confident that the proposals laid out in this book are realistic. By not just speculating but looking at the relevant factors involved, we can understand what is probable.

Predicting the Future

But it was actually Niels Bohr who is quoted as saying, "Prediction is very difficult, especially if it's about the future". Especially as we consider the development of reusable heavy lift rockets, setbacks and easily happen that throws off the timeline. And setbacks are bound to happen. We just don't know how many or when.

Also, the timeline of the near-term future (e.g. when actual Starlinks will be dispensed) is much more likely to be accurate than something in the distant future (e.g. when an international base will reach a certain size). So please grant some grace when the future unfolds and indicates how far off the predictions were from reality.

Pending Full Funding

Obviously, the Innovative Plan proposes some new steps which will not be possible without being adequately funded. If the space policy decision makers don't adopt these proposals, then things like the Initial Permanent Crew, International Lunar Exploration Phase, and International Lunar Base will not occur. So, out timeline describes when these things will likely happen but that is completely dependent upon timely adoption and funding of these proposals. Any delay in policy will result in a delay of the timeline. If this Administration doesn't adopt these policies and there is, say a three to four year delay, then China's plan on developing a Starship knockoff could affect whether the United States could achieve something like the Initial Permanent Crew described in this book.

"Elon Time"

It has become somewhat of a meme about how Elon Musk predicts the future too optimistically. And there is certainly truth to that. However, how about "NASA Time", or "Boeing Time", or "Bezos Time", or just about anyone else? Like they say, "Space is hard" and so we should expect that things will develop slower than desired. But Elon Time applies more to development than operations. Right now, Falcon 9s are launching every two to three days -- no more delays. The delays that SpaceX experienced in the mid to late 2010s are now past and operations are running a lot more smoothly and frequently. We can likewise expect that Elon Time will wind down after Starship matures through launch tests and they get more into the routine of launching, catching, refueling, and relaunching.

Setbacks

It is highly likely that there will be setbacks which in turn will throw off the timeline. This is especially the case when attempting to perfect reusable heavy lift rockets. So, setbacks are bound to happen. We just don't know how many or when. Like they all say, "Space is hard".

SpaceX hasn't been particularly lucky. (3 failed F1 launches, two F9 explosions, multiple F9 landing failures, Starship prototype crashes, Starship development). But other times they have been lucky including their flawless, first F9 launch and first Starship catch attempt.

ASSEMENT OF LAUNCH INTERVALS

In the Space Development Network, we have developed an on-line spreadsheet in which we attempt to estimate the order and timeline of when different developments will be achieved. You can check out that spreadsheet via the QR code to the right. This book addresses developments occurring now and in the immediate future and so, like many parts of this book, our timeline will need to be updated on an ongoing basis with estimates changing as events play out. The timeline represents our best guess which helps us make policy recommendations in a timely manner.

Findings From the Timeline

As the Space Development Network has developed the probable timeline, three things jumped out at us as a result.

First, cargo to Mars in Nov 2029 is likely off the table. Could they launch a minimal payload to Mars without refilling? How much could they send with just one refilling? Caveat: Quick ChatGPT rocket equation calculation suggests 10-30 tonne payload on surface of Mars without LEO refilling. Consistent with Elon's presentation. So, still might be possible.

Second, flight frequency is critical. They will need to reach a launch cadence of Starship far faster than it took to achieve today's Falcon 9 launch frequency of 3.3 per week. Catching on the tower really helps. Experience with turnaround time also helps.

Third, propellant launches will compete with Starlink launches. Hard to imagine that they will forgo generating more revenue by delaying Starlink launches.

SpaceX already knows these issues and so is likely actively working to overcome them. They must ramp up launch rate very quickly. This is why they chose the tower over oil rigs. An example of why we are surprised by a decision that SpaceX makes but they are looking ahead in detail.

STARSHIP DEVELOPMENT

Cheap access to space (CATS) is <u>the</u> fundamental factor upon which other developments depend. Although Starship isn't the only reusable fleet of heavy lift vehicles in development, it is the one that we know the most about, the most capable, and likely the one that is currently in the lead in terms of being able to support lunar base development.

Progress to Date

Up to the present time, Starship development has lived up to the promise of "excitement guaranteed". We've seen multiple types of explosions, out-of-control spinning rocket stacks, and exploded Starships streaking though the sky. But also, we've seen successful launches, pinpoint ocean landings, and (most amazing of all) the booster being caught three times by the arms of the launch tower. Amazing. But the path to this point has taken 2.5 years which is longer than expected, and we are still waiting for several development milestones to be achieved before it becomes operational.

Upcoming Hurdles

Looking forward, there is still a lot of Starship developments to accomplish while the timeline is beginning to run out. The single hardest hurdle is probably the heat shield being thin enough to ensure that enough payload gets to orbit but thick enough to ensure that the Starship can be reused multiple times. They have been working on this problem for a few years now but haven't completely solved it yet. Truth be told, reusability of the upper stage tanker isn't technically necessary for Artemis or any other program. Expending the upper stage Starship would still mean a cheaper $ per kg to LEO than the SLS. But if SpaceX is going to be launching Starships for other reasons, then they might as well take advantages of those launches to conduct upper stage reusability efforts.

But there are additional challenges that absolutely must be overcome before Artemis 3. These include a Starship fitted out to be an orbital depot, the full refilling process, and a cargo mission to the lunar surface.

Orbital Depot

Transferring propellant to a lunar Starship in LEO is a requirement before Artemis 3 can occur. The full process includes: constructing, testing, and launching the depot, docking, making good connections, transfer of cryogenic propellants, and storage without boil-off. Already these processes have been demonstrated either in orbit or sufficiently in the laboratory setting (e.g. zero boil off using cryocoolers). For example, during Starship flight test 3, about 10 tonnes of propellant were transferred between tanks using a small ullage burn.

How SpaceX plans on first demonstrating partial propellant depot capability will be to launch a target Starship to LEO and then launch a tanker

Starship which will dock with the target, connect, and transfer propellant. This one test will go a long way to reassuring NASA and the space policy decision makers that SpaceX can keep to the timeline of Artemis 3 before the end of 2028. We estimate that this will probably occur during the 3rd and 4th quarters of 2026. This would mean that two years of test flights would remain until the end of 2028 Artemis 3 deadline arrives. This timeline is dependent upon the latest Starship upgrade (Version 3) doesn't suffer a series of setbacks like Version 2 experienced.

Lunar Cargo Landing

Successful Starship HLS cargo landing and lunar ascent is required to be demonstrated before NASA precious astronauts are sent to land in that hardware. We have witnessed multiple small lunar landers crash or tip over after landing. However, it would not be accurate to presume that, because other landers failed to land, that this means that Starship will likely also experience such problems. SpaceX has far more money and workers to work on the problem than these much smaller companies. Also, SpaceX has extremely extensive experience landing its boosters. Finally, from the standpoint of physics the angular momentum of tall, heavy objects is actually a lot easier to control than shorter, less massive objects. For example, consider how difficult it is to balance a pencil compared to a broom.

Tentative Conclusion

Put all together, it will be challenging but not feasible for Starship HLS to deliver crew to the surface of the Moon by the end of 2028. When that is accomplished, it then mostly comes down to ramping up the scale and rate of operations rather than the challenge of developing the Starship.

PERMANENT BASES

Initial Permanent Base

NASA does plan on establishing a permanent presence on the Moon and SpaceX has even rendered both an image of a vertical Starship as a base with lots of windows as well as inflatable habs at their base which looks surprisingly like our InstaBase concept. Unfortunately, this is pretty much the extent of NASA's vision. Their vision is limited to a few government astronauts for increasingly long stays conducting more science missions by collecting more rocks to add to the Apollo collection. Given the full capability of the Starship and Blue Moon fleets, we believe that the vision should be far greater in order to match with the expected capability.

It is our view that the establishment of humanity's first permanent foothold beyond Earth (on the Moon) should be considered a much higher priority than Artemis 4 and 5. Specifically, we propose that the StarHab with the Initial Permanent Crew with all of that historic significance follow as the next mission after Artemis 3. It's not a good idea to delay the establishment of an Initial Permanent Base and Crew resulting in a temptation for China to seize that historic prize.

So, if we assume that Artemis 3 is followed by a StarHab mission, when could that be accomplished? Our timeline indicates that it could be achieved approximately in mid-2028 with the Initial Permanent Crew landing on the Moon in late 2028. If we factor in unanticipated delays, then it could be pushed into early to mid-2029.

International Lunar Base

We propose that no other crew be sent to the Moon for the first 6 to 12 months of the Initial Permanent Crew (IPC) to make that history the focus of America's lunar program. But, during that time there certainly can be routine cargo landings in preparation for the International Lunar Base (ILB).

So, according to our estimated timeline, about four, 100-tonne specialty habs could be delivered to the lunar surface by the end of the IPC phase. So, by the end of 2029, NASA astronauts could be sent to quickly establish the American core of the ILB. Throughout 2030, additional specialty habs could be sent interspersed with international partner (e.g. ISS) astronauts. Then, throughout the 2030s, there would be the International Lunar Exploration Phase parallel with the growth of the ILB.

MARS MISSIONS

We are guessing that SpaceX will not be able to accomplish cargo missions to Mars using the November 2026 window. But they would be very well positioned to conduct a larger set of cargo landing attempts in the 2029 window. Our guess is that it might be as many as ten cargo landing attempts. If one crashes, the telemetry will be sent back and the landing software adjusted for the next attempt. Historically, less than ten attempts were needed to master the ability to land:

- Seven - Falcon 9 attempts
- Four - Starship prototype landing attempts
- Four - Starship booster soft splashdowns
- Five (so far) - Starship upper stage soft splashdowns

Although there is some uncertainty, our best guess is that SpaceX will succeed in reliably landing cargo with the 2029 window so that they will attempt crew landing on Mars in 2031. Even if they are unlucky and it is 2033 or even 2035, that's less than 10 years from now -- still amazing!

PRIVATE SETTLEMENT

The earliest, most expensive kilograms and seats will be purchased by those with the deepest pockets which are government and not private individuals. So, the first habitats will be established by countries in the form of an ILB. But, if our proposal that an Artemis 2.0 coordinates countries to fund their own companies to competitively provide hardware, soft goods, and services, then the International Base will begin to receive very wealthy, private individuals and eventually the 75 million millionaires on Earth will have the opportunity to move to the settlement portion of the International Base. So, when will those arriving will be more private settlers than government residents? That's really hard to estimate because it is further out in time. But our estimate is that this crossover point would occur perhaps in the late 2030s (for fun let's say 2038). And when will there be enough of one people group (e.g. Japanese speakers) such that they would pay those companies to construct the new habitat as little colony separate from the ILB? Again, a wild guess but perhaps right about 2040. Since the Moon is 70 times closer than Mars in terms of round trip, we estimate that a million people (not all in the same settlement) would be established on the Moon by perhaps 2045.

What do you think? Is this pure fantasy or based upon a reasonable consideration of the relevant factors?

05 – A Turning Point in Human History

SUMMARY

This chapter makes the case that a permanent lunar base represents a transition point in human history. Starting with the Initial Permanent Crew, humanity will start to spread beyond Earth first with the permanent bases on the Moon and Mars. We will know that we are watching history being made.

HISTORY IN THE MAKING

We are approaching a point in time that could prove to be very historic -- at the level of Christopher Columbus or Plymouth Rock. The moment that humans began moving beyond Earth will be looked back upon as when it all started. We are all very privileged to be living at this time.

Those older space advocates who have been working towards this day can take comfort that they lived long enough to see the picture emerging of how large, off-Earth development and settlement will happen. For those of us too young to remember the amazing Apollo Program, this will be our moment. And what a moment it will be. Neil and Buzz walking on the Moon was truly amazing. But how much more amazing will it be to witness the first humans selling their homes and beginning settling down beyond Earth!

A Historic Moment for All of Humanity

America has a space budget larger than any other in the rest of the world and a couple of American companies are well in the lead in developing fully reusable heavy lift vehicles. So, America will lead in the establishment of large, permanent bases on the Moon and Mars leading to settlement. But because of the rapidly dropping launch costs, many other countries will be able to follow America's lead. So, other countries will likewise point to the near future as the time when they send some of their citizens to represent their own people in new branches of humanity.

The Historic Significance of the Starship Fleet

SpaceX is developing its Starship super heavy lift vehicle in Boca Chica, TX and has constructed a factory positioned to crank out a fleet of these vehicles once they become reliable. This capability makes possible the turning point in human history where humanity first begins moving beyond Earth. Each Starship will be able to transport perhaps 120 people to the Moon at a time. Given a fleet of hundreds of Starships each completing round trips in less than two weeks, one can imagine an international base growing rapidly into the thousands and from that infrastructure foundation, a private settlement becomes possible. It all depends upon the capacity and frequency of the Starship flights and the per-seat and per-kg costs. And this is where the Starship really shines because it was specifically designed for this very thing.

Star Factory in Boca Chica, TX.

CHOOSING TO WRITE HISTORY

The goal of the Apollo program was to land astronauts on the Moon and to safely return them to Earth. People walking on the Moon! How amazing is that? And that is exactly what happened. No doubt those working on the Apollo program understand that those first steps on another world and the words spoken would go down into history. Words such as:

President Kennedy - *"We choose to go to the Moon in this decade..."*

Neil Armstrong - *"One small step for man...one giant leap for mankind".*

When we return to the Moon, will it be history making or just a ho-hum repeat of something that happened over 50 years ago? Well, it all depends upon how we do it.

Just like, during the Apollo Program, we can and will know that we are writing the history of when humanity began to spread beyond Earth. This book describes how we can write that history by how it is conducted, especially the Initial Permanent Crew phase. And it ought to be conducted in such a way that parents in the future will have a clear and positive story to tell their children.

It would be disappointing if we were to muddle forward without intentionally thinking about writing history the best we can. Imagine a history where there were some government astronauts picking up more rocks to add to the Apollo collection, and then some more astronauts arrived, and then there was a small base with astronauts spending increasing time on the Moon, and then at some point, a private individual arrived but then returned after a few weeks, and then someone stayed for an extending time. That would make an indistinct story that future generations would have a hard time relating.

Rather, the story proposed in this book is that, early on, there were specifically eight private workers that sold their homes on Earth and were the first of humanity that moved beyond Earth. We would know their names, their backgrounds, their jobs, and their personalities. We could relate some of the amazing firsts that they did like the time that two of them did an amazing dance performance in 1/6th gravity, and how these eight people set the stage for the International Base where the nations of the world began sending their representatives. This is the historic prize to be seized, IF we choose to do it in such a way that would be amazing and memorable.

PRIVATE WORKERS FROM THE START

The key to writing a truly historic program comes from the true understanding of the term "settlement". Fundamentally, settlement is when one settles down, meaning that one is establishing a new home there.

Setting down means establishing one's permanent residence. If one has a family, then one is living with one's family with the simplest form of family being a couple. Settlement also requires that it goes on to become a larger community. This is why 1607 (Jamestown) is cited as when the English settled North America and not 1587 (Roanoke) because the latter disappeared and so never became an established community.

It is generally agreed that off-Earth settlement should be a private matter and not government in nature albeit there could be a partnership. It should be noted that, from a technical standpoint, a government base and a settlement are nearly identical. In both cases, one needs: power systems, permanent habitats, life support, growing food, and mechanisms to utilize local resources. Whereas private individuals settling down can constitute a settlement, a government facility where the residents are only living there because of the job means that a government base is just that, a base (or outpost) but not really a settlement.

Because of the historic significance of people settling down off Earth, it is here proposed that the first settlers be a handful of individuals (i.e. Initial Permanent Crew of eight) working for a private company that has a contract with NASA for its Crew to conduct a set of demonstrations of use in a follow-on American base as the first habitats of the International Lunar Base. So, whereas ultimately the funding comes from NASA, the company employees can be considered private workers and hence the first humans to begin settling beyond Earth.

During the Initial Permanent Crew phase, the focus should be on those eight people. So, even though we would, at that time, have the capability of landing crew on the Moon, we should hit the pause button and deliver only cargo so that the story that the people on Earth are watching for six to twelve months is only the story about these historic crew. But the cargo deliveries could include the first habitats of the International Lunar Base (ILB). Then, after the Crew lives out the story, American and other astronauts will start arriving, be greeted by the Initial Crew and then start setting up the ILB and conducting missions of lunar exploration. The private, Initial Crew would remain until other private individuals (paying their own way) start arriving to grow the private areas of the base.

So, the historic story will be about that Initial Permanent Crew, what they did, and then how American and astronauts from other countries began arriving. It would include how the countries worked together to establish an international base while extensively exploring the Moon. Later, private individuals arrived and as their numbers grew, they began establishing small settlements (colonies) in the polar areas and eventually settled territories around the Moon. Chapter 16 goes as far as to describe how continued growth of people groups on the Moon will likely lead to the establishment of independent settlements with self-governance perhaps one day resulting in fully independent countries.

TRANSPORTATION

06 – The Starship Fleet

SUMMARY

The focus on this book is the fleet of fully reusable Starships because its development is so much in the public's eye. It is currently the best example of how very large-scale development will occur on the Moon. The evidence is clear that a fleet of Starship is well neigh inevitable. Cheap access to space (CATS) really is the game-changer it has always promised to be.

Three key assumptions underlying this book are that:

- The Starship rocket will be developed to the level of capability intended by SpaceX.
- A fleet of Starships will eventually be produced in the hundreds to thousands.
- Flight turnaround times will increase until each Starship is being launched from the Earth or Moon at a rate of about once a day.

Together, by the end of the 2030s, this capability represents an increase over our current capability of at least two orders of magnitude greater than our current launch capability with the resulting decrease in cost per kg and per crew. The result will be the ability to simultaneously send tourists to LEO and develop large and growing bases on both the Moon and Mars.

What is Starship?

"Starship" is the name of the rocket system being developed by SpaceX. SpaceX's primary goal is that a Starship fleet will eventually deliver cargo and crew to the surface of Mars in such large quantities that a self-sustaining city would be established there with a million residents by 2050 - 2055. Yes, it does sound like science fiction, but if one looks at the remaining milestones, engine production rate, factory producing the Starship bodies, and revenue from the Starlink satellite constellation, it seems as though SpaceX could be on track to achieve that goal.

For the purpose of this book, I focus on the Starship fleet rather than the alternative Earth-Moon transport system being developed by Jeff Bezos' company, Blue Origin. More is publicly known about the Starship, it will be more capable, and it should likewise be capable of delivering cargo and passengers to the surface of the Moon.

The Starship is composed of the booster first stage called the Super Heavy and then its upper stage is confusingly also called the Starship. One must rely on the context to determine whether one is talking about the whole system or just the upper stage when using the term "Starship".

As of this writing, the Super Heavy booster has 33 engines giving it more thrust than even the Saturn V that took astronauts to the Moon. It has also been designed to return to and be caught by its launch tower about eight minutes after launch. This was first demonstrated on November 22, 2024. The significance is that 33 out of the stack's total of 39 engines was retrieved to be used again resulting in dramatic savings whether or not the upper stage Starship eventually achieves reusability. When the upper stage also achieves reusability, the cost of sending large payloads to space will have decreased to between 20x and 100x what it has been costing to date. It would truly represent a revolution in space access completely negating expectations based upon past experience.

The upper stage Starship currently has six engines although that may increase to nine. However, different variants may have a different number of engines. For example, variants that will remain in space (depot and lunar lander) won't need the sea level engines with their smaller nozzles.

Propellant Depots and Tankers

One variant of the Starship will be the propellant depot in low Earth Orbit (LEO). This "gas station" will allow cargo Starships to launch their heaviest possible payloads into LEO with very little residual propellant in their tanks. The cargo Starships would then dock with the depot and completely refill their propellant tanks before heading to the Moon or Mars with their full payload. It is hard to overstate how important this is for building up and sustaining large and growing bases and even settlements beyond Earth. In the "How Soon" chapter, we'll get into the question of how difficult it will be to develop and operate the depot in LEO including storing propellants without boil-off.

Another essential variant will be the one that delivers propellant to the Starship depot in LEO. These will be reused and so will have a heat shield. They will have docking and alignment mechanisms to allow tankers to dock, connect, and transfer propellant from tanker to depot.

LUNAR HUMAN LANDING SYSTEM (HLS)

NASA has it lunar HLS program that is funding both SpaceX and Blue Origin to develop lunar landers to return NASA astronauts to the lunar surface before 2030. This is an important program because, without it, NASA will only have the capability to send its astronauts to high lunar orbit.

The program is also important for the participating companies because it gives them the cash to do what they already want to do which is to develop their vehicles. In the case of SpaceX, it has been funded to modify their upper stage Starship to land on the Moon. Since Starship is fundamentally a Mars rocket, it is perhaps surprising that it was selected as a lunar lander. It is certainly much larger than is necessary to land just a few astronauts to repeat Apollo's scientific exploration. But the ability for Starship to land 120 or more metric tons of habitat, equipment, etc. at a time is right in line with this book's proposal that governments fund the development of a large and growing International Lunar Base.

As for Blue Origin, they have a logical stepwise development plan for landers of increasing size. Because, from the beginning, it has been designed as a lunar lander and not for Mars, it will be able to source all of its propellant from lunar resources -- perfect for a lunar ferry. And the non-propellant portion of the lander (aka its dry mass) will likely be proportionately less than that of Starship. Whereas SpaceX gets all the attention, Blue Origin is a company worth keeping an eye on. They are progressing well and, having chosen a simpler lander and chosen our nearby Moon as their ultimate destination, they may surprisingly take the lead in how quickly an International Lunar Base will grow to the level of settlement.

Other Variants

Other Starship variants could include one with a clam shell fairing that would open to deliver very satellites such as large telescopes. SpaceX even talks about using Starship to do deliveries of cargo and crew from one point to another (e.g. Los Angeles to Shanghai in 30 minutes).

CAPABILITY

We don't yet know for sure how much payload that Starship will take to orbit. But it is likely to achieve 120 tonnes to orbit in full reusable mode. SpaceX hopes to get it up to as much as 150 tonnes. In fully expendable mode the Super Heavy doesn't return but splashes down into the Atlantic and Starship has no heatshield nor remaining propellant and so burns up on re-entry. SpaceX estimates that, by so doing, they would be a one to deliver as much as 250 tonnes to LEO. This is far above the typical 13 +/- tonnes sent to LEO by SpaceX's partially reusable Falcon 9 rockets.

Crew Capability

A fair question is whether Starships will be able to safely launch passengers into space. The Starship is not designed with a launch abort system. This makes many space advocates very nervous. But commercial airlines also don't have abort systems. How does that work.

It appears that SpaceX believes that they can get the reliability of launch high enough such that it would meet and exceed NASA's level of risk acceptability. A key part of that is engine out capability which has already been demonstrated on previous flights. It is like commercial airplanes having two engines. Even if they lose one engine, the remaining engine has sufficient power to fly and safely land passengers.

SpaceX has described the Starship as large enough to transport 100 people at a time to Mars. Many space advocates feel as though this is a bit on the tight side. Perhaps by having passengers on a sleep schedule and by spreading awake passengers throughout the floors even among the provisions and equipment it might be possible. But, for the purpose of making the case for the Moon, one can envision more than 100 passengers taking a limited three-day flight to the Moon.

THE STARSHIP FLEET

At Starbase, TX, SpaceX has buildings designed to construct and assemble not just individual Starships but an assembly line to produce a fleet of Starships as though they are an airline fleet. In a short video posed by Elon musk within the Starship Factory, the nose cones for twelve Starships are seen. So, SpaceX has the facility to mass produce Starships.

In his May 2025 presentation titled, "Mars Game Plan" Elon stated that they hope to eventually produce 1,000 Starships a year. To put this into perspective, in 2023, Boeing delivered 528 airplanes. But those require significantly more sophisticated manufacturing, materials, tolerances, and suppliers. So, it seems that a fleet of Starships is in the works.

Quick Launch Turnaround

In order to launch many tanker and passenger ships leading up to and during an Earth-Mars departure window lasting 45 to 60 days, launches need to be happening multiple times a day. Anticipating this need, SpaceX has developed its launch tower with two arms affectionately called the "Mechazilla" named after the monster in five different Japanese movies. This tower was intended to literally catch the returning stages of a Starship. And catch it, it did! On October 14, 2024, the world was stunned to watch the first ever catch of a Super Heavy booster. As of this writing, an upper stage Starship has not been caught but a couple have conducted pinpoint landings in the ocean indicating that they are getting close. When that happens, history will be made by proving that full reusability is now possible.

07 – The Lunar Ferry and Spaceports

SUMMARY

Let's not ignore the reusable vehicles that Blue Origin is specifically developing. Although its Blue Moon Mark 2 lander doesn't deliver the cargo mass anywhere close to SpaceX's lunar Starship, with on-orbit refilling and sourcing its propellant from the Moon, Blue Origin can establish a lunar ferry greatly reducing the number of refilling required in LEO.

LUNAR FERRY

The Blue Moon Landers

This book talks a lot about SpaceX's Starship fleet because it will likely become a growing reality by 2030, because of the implications of so much capacity, and because we know more about it because of their greater openness. But Starship is designed for Mars and not the Moon.

But there is a heavy lift vehicle being developed specifically for the Moon -- namely, the Blue Moon landers by Blue Origin, Jeff Bezos' company. Significantly, its propellants are hydrogen and oxygen which can both be resourced from lunar resources specifically, the water ice whose existence NASA proved in their 2009 LCROSS Mission. They found a spot where concentrations were at one part per 18 which is certainly high enough for use as propellant. The best estimate is that there is at least 600 million metric tons of water ice on the Moon. If one were to launch the equivalent of a Shuttle external tank from the Moon every day, propellant from lunar water would last for more than 2,200 years -- plenty of time to develop and import propellant from alternate sources (e.g. asteroids). So, in practice, the Moon will never run out of water.

A Lunar Ferry

Why is it so valuable to source propellant from the Moon? One can imagine a lunar ferry on the lunar surface being refueled with lunar-derived propellant. It ascends to about EML1 (an Earth-Moon gravitational balance point), retrieves a cargo or crew module from a vehicle coming from the Earth, and then brings it back down to the lunar surface.

To understand the significance of the lunar ferry, one only has to ask how much would it take to deliver that same propellant from the Earth. Rocket scientists measure the difficulty in moving to different orbits and locations with the term delta-V (DV). This indicates how much a rocket needs to accelerate a payload in order to change its orbit. To get lunar ascent and descent propellant from the Earth to the lunar surface, the DV is about 16 km/sec. Think about that, increasing the speed by 16 kilometers each second! Whereas the DV for ascent and descent propellant from the Moon is, in a way, 0 km/sec because you don't need rockets to transport water from a permanently shadowed region to the lunar ferry.

Now, that said, the Blue Moon Mark 2 lander has a dry mass (meaning mass without propellant) too high to be a good lunar ferry. We will have to wait to see if Blue Origin comes up with a Mark 3 lander specifically designed to be a ferry. If so, then the Blue Origin "tortoise" (not known for its speed) could ironically take the lead by having chosen a much closer finish line (the Moon) than SpaceX's "hare" which never stops running but has chosen a finish line (Mars) 70 times further away in terms of round-trip time. For the sake of lunar development, a lunar ferry would be tremendously helpful.

LANDING PADS

Sandblasting While Landing

Concern has been raised about vehicles landing on the Moon. The exhaust velocity of such landers is actually greater than lunar escape velocity. Some have commented that dust and rocks kicked up during the landing process could be traveling so fast that they would pose a danger to the orbiting Gateway. They also point out that the dust and rocks thrown up would be traveling in an orbital ellipse and as such they would tend to come back to the exact same landing point. But whether these scenarios happen or not, it is incontrovertible that the dust kicked up during landing would sandblast nearby objects whether solar drapes, habitats, outdoor equipment, rovers, or whatnot. It would certainly seem prudent to prevent this.

This latter point is not a theoretical concern. Apollo 12 intended to land close to Surveyor 3, which was an unmanned lander which arrived on the Moon just a few years before. The Apollo 12 crew did such a good job conducting a pinpoint landing that they actually saw Surveyor 3 even before landing and landed so close that they were able to walk over to it. Upon inspection (and they returned with a piece of it) they found evidence of it having been sandblasted by their own exhaust blast.

Landing Pads

One obvious solution to this challenge is to construct landing pads so that only gaseous exhaust and no pebbles are blasted outward. Circular berms constructed around the landing pad would redirect any exhaust away from local structures. A fair concern would be about whether an "off-nominal" landing where the lander misses the mark and conducts an emergency landing off the landing pad thereby kicking up unprotected regolith. This situation could be partially addressed by locating landing pads at the bottom of natural craters so that there is a large, natural berm protecting distant structures.

An additional solution would be to locate landing pads away from structures but within easy driving distance. It has been suggested that a two-kilometer distance from structures should be sufficient. These would be the regional spaceports that the Space Development Network advocates.

Work has been done looking into whether pavers could be produced via microwave sintering and then the telerobotic placement of the pavers to make a landing pad. As can be seen in the image to the right, this was demonstrated in an experiment conducted in Hawaii.

Another quick and low-energy approach would be to deliver tarps for the outer lander zone. These thin tarps would prevent the gaseous flow from the exhaust from interacting with the lunar dust. Telerobots could secure these tarps into the ground using spikes.

Yet another (and rather ingenious) proposed solution to the initial landing would be to inject aluminum powder into the exhaust of the lander. This aluminum would be immediately melted and so would spray onto the landing site providing a type of metallic mortar to hold the regolith together just prior to landing.

All things considered, we believe that some combination of the proposed sandblasting and landing pad solutions will adequately address the challenge.

SPACEPORTS

Location of Spaceports

Given the ability of spaceports to be connected to bases and structures via roads, it then follows that a single, well-placed spaceport on the Moon could serve a region. And once one spaceport is created, that experience could be used to duplicate the construction of spaceports elsewhere on the Moon. So, where should the spaceports be located?

It seems that there are logical locations for spaceports namely, places that people will want to routinely visit. Probably the site most desired to visit would be the Apollo 11 landing site where humanity first set foot on another planetary body. So, one could look around there to find some feature that could act as a natural shield to protect the Apollo 11 site from blast from an off-nominal landing. This could be something like the cluster of craters 5 km to the northwest called the Cat's Claw.

Visiting Tourist Sites

One could imagine lunar spaceport and tourism companies establishing and operating regional spaceports and the roads connecting them to local sites of interest. Roads could snake along the terrain to logical overlook points where sintered platforms and tourist facilities with large windows could allow the tourists to have a relaxed environment overlooking the point of interest. In particular, on the rim of major craters, beautifully architected centers could give tourists views looking out at dozens or hundreds of kilometers of pristine view to view the central peak and distant crater walls.

A student group in the Space Concepts Studio class at the University of Southern California Viterbi School of Engineering proposed a very promising idea. He envisioned two towers being erected on either side of the Apollo 11 landing site. Between the tips of the towers there would be a cable from which a gondola would take visitors directly in front of the descent vehicle and over the footprints from Neal Armstrong and Buzz Aldrin. In this way, visitors could get a very close view of that history without risking that their own footprints would obscure those historic footprints.

Tourists viewing the Apollo 11 site.

08 – Logistics and Surface Transport

SUMMARY

In this chapter, a comprehensive system of modular surface vehicles is described for just about every application needed. Also described is an end-to-end logistics transport system that is largely automated and launcher/lander agnostic.

LOGISTICS

The transportation of cargo from the Earth to the Moon opens up the interesting question of what sort of logistics system makes the most sense.

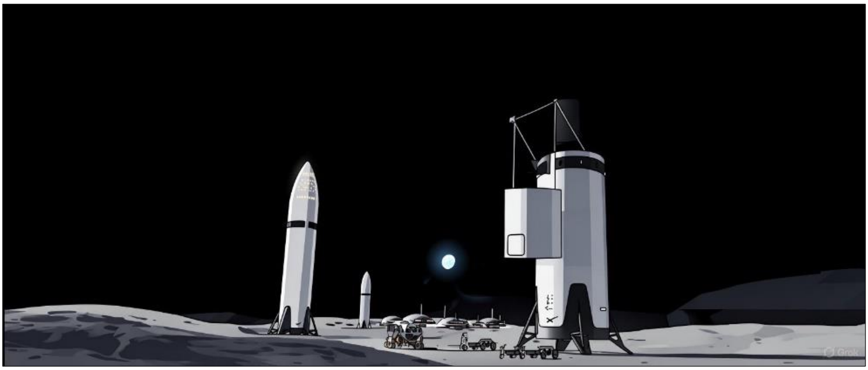
The Network's Logistics Working Group (LogWG) has met via Zoom several times to discuss this matter. Among the attendees include individuals who have served in military logistics and so bring that experience with them.

Our inspiration is the Intermodal shipping container system that has thoroughly revolutionized international trade. One shipping container can start in a factory overseas, be closed and sealed, transported to the dock loaded on a ship, transported across an ocean to another dock, transferred by train to a regional distribution center, redistributed and then finally driven to the final store. Could something like this be implemented for transport from Earth to bases on the Moon and Mars?

Choosing the right in-space shipping solution is tricky business as there are several tradeoffs. My view is that, at a distribution facility at Kennedy Space Center, cargo should be secured in pallet containers within unitary containers shaped to roughly conform within the fairing of the launch vehicle. For example, the Starship's fairing is 9 meters in diameter so the container could be 8 meters and roughly cone shaped. Blue Origin's New Glenn rocket has a fairing of 6 meters so the container could be 5 meters in diameter. After exiting Earth's atmosphere, the fairing could come off (to be retrieved) and the upper stage could be docked with a propellant depot so that the entire mass of the unitary container

"StarShuttle". Credit: Adapted from SpaceX image.

and its contents could be sent to the Moon.



Concept of a modified Starship logistics system. Adapted from SpaceX image.

Once having landed on the Moon, a crane system could remove the unitary and drop it onto two connected MSTVs which would transport it to the Logistics Hab (LogHab) at the main base. If one side of the unitary container is flat, then any size of container could dock with the LogHab. Each pallet with tracking devices would be unloaded from the unitary containers and individually, automatically transported to the correct department using automated pallet jacks like Amazon is starting to do in some distribution l centers. For those pallets needing to be transported to another base/settlement, the automated pallet jacks would transport those to other airlocks in the LogHab attached to standardized container to be transported to more distant bases. All containers may themselves be more valuable as resources than shipped back empty. For example, copper is very hard to come by on the Moon so a reinforced copper shipping container would be of great value to lunar settlements.

But intelligent minds can disagree with our proposed logistics system and all views are welcome.

SURFACE TRANSPORT

We have seen how private American companies are solving the rocket transportation system between the Earth and Moon. But it doesn't stop there. How will goods and crew be transported on the surface once they get there?

Several countries and companies have developed surface vehicles. We can start with NASA's Crew Surface Vehicle (CSV). This was developed during the early Constellation Program before the Shuttle money was freed up.

Crew Exploration Vehicles

There are several interesting features which stand out. One is that they conceived of a side docking mechanism that would allow crew to go from a habitat directly into the short sleeve environment of the cabin. This would partially eliminate the need to do decompression procedures when transitioning from a habitat to the surface vehicle.

Another interesting characteristic is that they included a glass hemisphere at the front center of the cabin -- rather like the Plexiglass domes allowing dog to look through fences. This would allow crew to remain inside the cabin while driving up to, examining rocks, and using manipulators to bring samples through a small port into the cab -- all without ever having to exit the cab.

But national astronauts actually want to get out and walk. So, on the back of the cab, they had rear-entry space suits. In this way, none of the dust would get into either the CSV or the habitat. The challenge would be how to clean the suits and how many different ports would be needed given all the different sizes of the crew.

Rear-entry suits.. Credit: NASA

Lunar Cruiser

The Japanese Space Agency (JAXA) has also been working on the Lunar Cruiser with automotive giant, Toyota. It also is a pressurized vehicle, but the difference is that it has door that open on the side for easy exiting of suited astronauts.

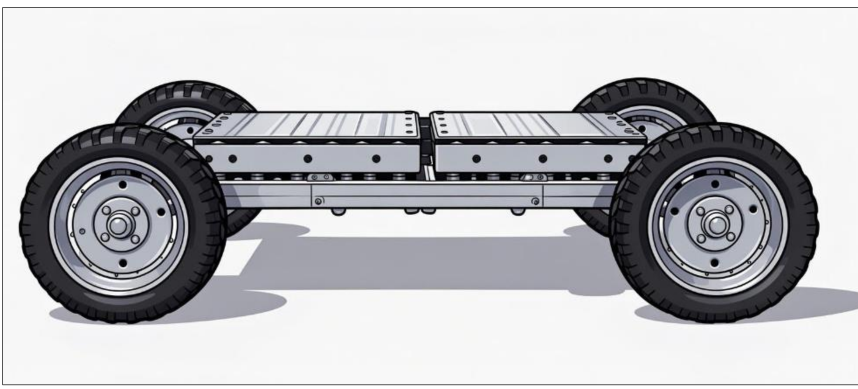
Open Vehicles

Several companies have developed concepts for open "air" vehicles. In this way, astronauts can drive right up to a rock of interest, the front gate lowers, and the astronauts step out a few meters to examine the rock, collect the specimen, and get back into the rover. It wouldn't be a shirt sleeve environment, but it would have maximum accessibility while being lower mass to launch from Earth.

The Network's Vehicle Concept

As we survey the vehicle concepts put out by others, we immediately recognize that they are designed for the government paradigm that doesn't take into full account the inevitable reality that the Starship fleet is going to bring. Rather, they are typically designed to meet (and often funded by) government requirements. And governments are currently confined by the vision of just a few government astronauts conducting geologic exploration and collecting more rocks to set next to the Apollo samples.

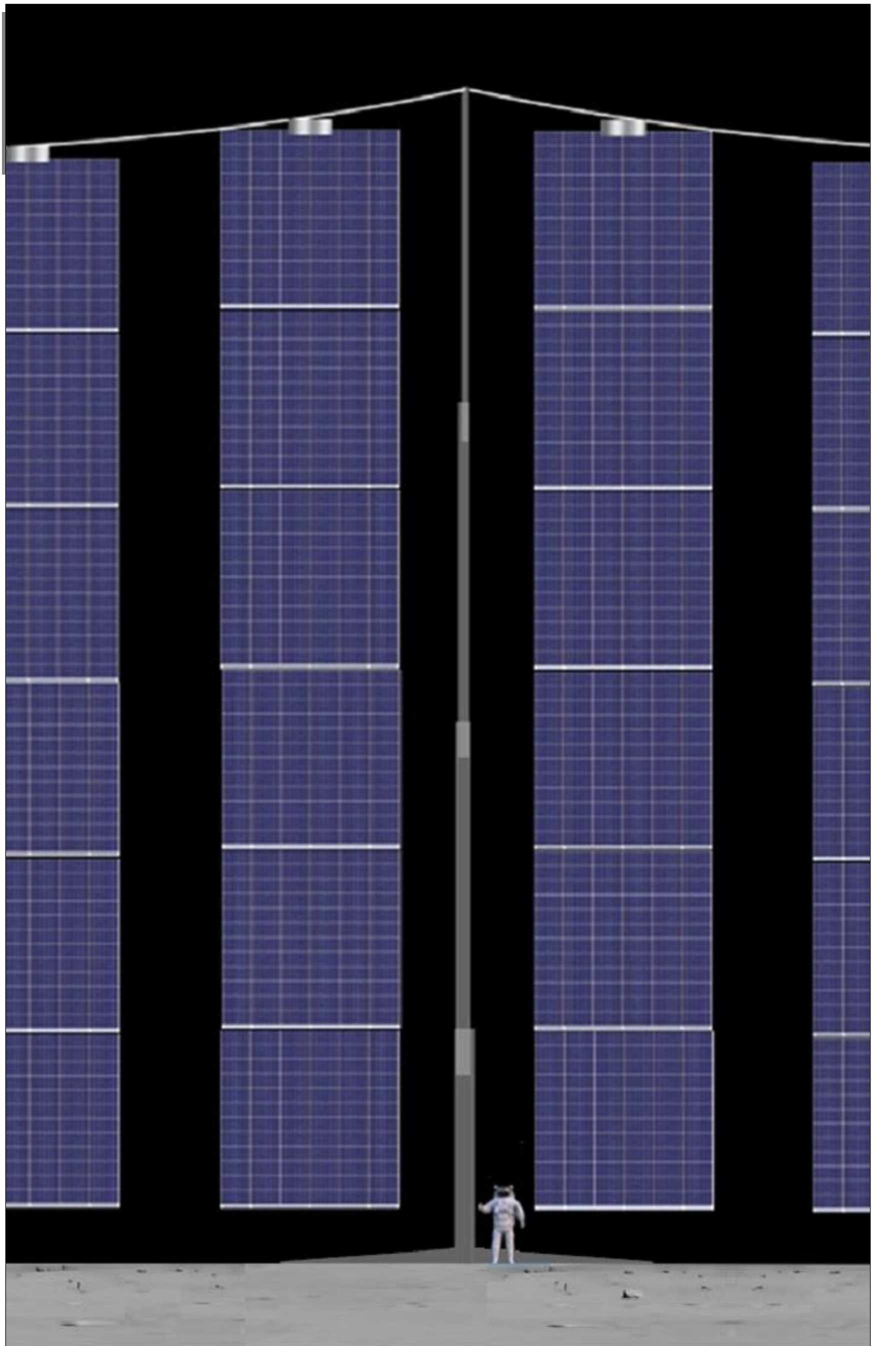
From our perspective, when you have a fleet of Starships, countries will naturally take advantage of that reality. Vehicles will be used for large-scale exploration (see Chapter 13). But they will also be used to transport volatiles probably tens of kilometers to be processed at a Peak of Eternal Light. With time, they will be traveling long distances making resources from any part of the Moon available at bases in order parts of the Moon. So, they will need basic compacted dirt roads (see Chapter 10). Given these circumstances, what sort of requirement would drive the design of surface vehicles?



The electric chassis onto which will slide various modules and implements.

The Network believes that surface vehicles should be modular with the basis being an electric chassis that can travel roughly the distance of a standard Model 3 Tesla. The platform / battery pack of this chassis should rise above the tops of the wheels so that crew and (open and closed) cargo modules can slide between chassis. There should also be anchor points on the front and back of the chassis to turn it into a tractor. Crew modules can be open or closed depending upon the need. We also believe that it should be designed so that portions of it could be produced from in situ (local) resources. We call this concept the Modular Surface Transport System (MSTM).

It may be that someone reading this chapter has an interest in moving this concept forward on a space advocate level. It could be the development of a 3D design and the animation to help get the concept out. Or perhaps it may involve tracking down and contacting university EV clubs and pitching the concept. Let us know by visiting our website.



INFRASTRUCTURE

09 – Power System (Solar Drapes)

SUMMARY

This chapter discusses solar and nuclear power on the Moon. It highlights the Solar Drapes concept which uses the maximum Starship payload capacity to deliver a whole array of thin film PV drapes suspended by a line of telescoping poles. In this way, an average of 5.1 MWs is produced from a single payload delivery. This is industrial scale power providing enough for any of the following: Ongoing food for 230 people, or 37 tonnes of propellant per day, or 29 tonnes of iron per day, or 8 tonnes of aluminum per day. These high-power products would be produced at the poles and the results shipped overland within three days to anywhere else on the Moon. Nuclear power would be useful during brief times of shading or during the long nights away from the poles.

PEAKS OF ETERNAL LIGHT

Because the Moon always points its face at the Earth, it rotates on its axis only once a month as it orbits the Earth. For this reason, towards the equator, the Moon's day lasts for two weeks, and its night also lasts for two weeks. If an initial base was located near the equator it would have to have a power system such as nuclear power to provide the base with enough power to survive the two-week night.

Fortunately, the Moon is barely tilted compared to its orbit around the Sun. As a result, there are locations near the north and south poles where sunlight shines for greater than 80% of the time. These have been originally given the term, "Peaks of Eternal Light (PELs)". Additionally, these locations tend to be close to certain regions where the sunlight never hits the ground. We call these, "Permanently Shadowed Regions (PSRs)". In 2009, NASA's LCROSS mission conclusively demonstrated the presence of water ice and organic chemicals in one of these permanently shadowed craters in useful concentrations.

SOLAR DRAPES

The Space Development Network puts forward a concept for solar power at the lunar poles which represents what we believe would be the least mass, maximum power system for the PELs.

The concept of operations is that a lander would land away from a specific PEL. The lander would lower a robotic tractor pulling on a wagon filled with telescoping poles and rolls of thin solar drapes. As the wagon drives to the PEL and then drives along its ridge. It would tilt up telescoping poles and deploy long footings. Precise adjustments would be made to ensure that these telescoping poles remained directly vertical. As the wagon pulled forward, a suspension line connected between the tips of the poles would be pulled out of the wagon until the next telescoping pole was erected. This process would continue until all poles and drapes were placed on the ground.

After this set-up was complete, all poles would simultaneously start telescoping vertically causing the suspension line between them to raise up and the thin film sheets would unroll. The result would be a very large wall of solar drapes arising up to 60 meters high which would be perpendicular to the incoming sunlight. Motors between the suspension line and the drapes would ensure that the drapes are always pointing directly at the sunlight as it moves across the horizon during the month.

We have calculated that a 100 metric ton payload of solar drapes delivered by a cargo Starship would provide industrial levels of power. It would be enough to electrolyze 37.6 metric tons of water each day for propellant, or 28.8 tonnes of iron per day, or 7.9 tonnes of aluminum each day. And that is from a single Starship payload! Alternately, that much power could be used to grow enough food continuously for 230 people. See our poster below.

TRANSMITTING POWER

For ice-harvesting operations, vertical solar drapes could be set up outside of the periphery of the PSRs while ice-harvesting vehicles operate within. So, how could the power from solar panels get down to the ice harvesters? There are several possible solutions which people in the field have discussed. Small robots with a spool could lay out a wire from the drapes to a base station that the vehicles would periodically return to recharge. That part of the wire in the permanently shadowed areas could be superconducting tape given the very low temperatures there. Alternately, power could be beamed from the drapes to the vehicles using either microwaves or lasers. The advantage of this approach is the savings of the mass of the wire.

Some have proposed placing a transparent tent over icy regolith and then using mirrors on neighboring ridges to redirect sunlight onto the tent to heat the regolith to steam out the volatiles into rovers with tanks where the volatiles could be condensed. But this approach seems to be complicated when it comes to laying out the tent over uneven ground, sealing the periphery, and then uncovering and moving the tents. Given the LCROSS results showing fairly high concentrations of water, it would probably be simpler just to transmit the power to excavating vehicles and to use electrical power to steam out the volatiles within the harvesters themselves.

POWER STORAGE

Most lunar advocates along with NASA recognize the great value in starting the first base at the southern lunar pole where there are both the so-called Peaks of Eternal Light and high concentrations of volatiles. But even at these peaks there will be nights lasting for several days. And as one establishes a base anything more than a few hundred kilometers away from the poles, very quickly the nights become 14 days long. If each facility doesn't have its own nuclear power source, there will need to be an energy storage solution.

Types of Power Storage

Perhaps the easiest and most straightforward storage solution would be to simply use batteries. But they have significant mass and may be difficult to produce cheaply using local materials. Alternately, electricity during the day electrolyzes water into hydrogen and oxygen and then runs them back through a fuel cell during the night. Alternate forms of power storage could include flywheels (using local material) or thermal wadies where head is stored in the regolith during the day which then powers equipment that produces electricity at night.

Reducing Power Consumption

It is likely that one wouldn't run operations during the night at the same level of energy consumption that one does during the lunar day. So, during the night, energy intensive operations would come offline and activities would turn from operations to low-power activities such as maintenance, cleaning, food processing, and recreation.

SOLAR CONCENTRATORS

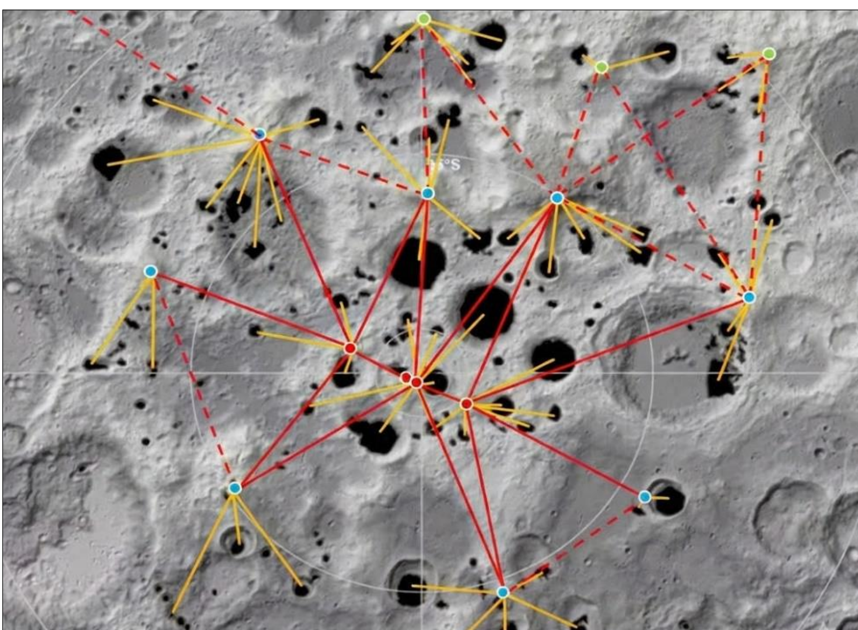
Solar concentrators are parabolic mirrors that concentrate sunlight to a point or line. This concentrated sunlight can heat a liquid which transmits that heat to an engine that can produce power or electricity. Since they are just mirrors, they could be somewhat thinner than solar panels and, more importantly, they could be constructed using local aluminum found in the rocks of the lunar highlands.

The concentrated sunlight can be used directly for certain processes including melting, sintering, cooking, and in support of some chemical processes.

These solar concentrators could be connected to Stirling engines which are highly efficient. These engines could be connected to electrical generators to produce electricity.

REGIONAL POWER GRID

The PELs are limited areas even in the polar regions. There are many areas at the poles that don't have these peaks. One could imagine setting up, over the long term, a network of towers on regional peaks that would use microwaves to transmit power between them. Alternatively, aluminum is abundant in the lunar regolith whereas there are no known copy ore bodies on the Moon. On Earth, high tension, high-voltage, long-distance wires tend to be made of aluminum not copper. By using connecting different PELs, each pole region could supply power 24/7 including operations down in the permanently shadowed craters.



NUCLEAR POWER

Different types of power systems will be needed for the different phases of development at different locations. Starting at the lunar poles, photovoltaics and concentrated sunlight will be the dominant source of power.

Later, facilities will be established away from both poles perhaps at sites that are frequently visited (e.g. tourism sites), a people group has established a settlement, or where specific elements are being mined. In this case, the lunar nights would last for about 14 Earth days during which no solar power could be produced on the surface. Nuclear reactors would be ideal for providing power especially during the long nights.

Shipping nuclear fuel from Earth to non-polar areas would be the obvious thing to do initially as a whole lot of power could be shipped as a small amount of mass. Fissile material can be launched safely from Earth but would need to overcome politically driven pushback. With time, nuclear fuel could be produced from resources on the Moon. In particular, there are a few locations on the Moon that are known to have higher concentrations of thorium which can be used as a safe source of nuclear fuel. NASA is developing the Kilopower system which would be very useful for powering habitats.

Concept of Operations for the Establishment of Solar Drapes at the Lunar South Pole

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Space Development Network

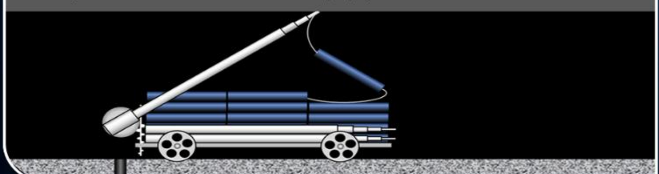
Introduction

It is well recognized that the lunar south pole would be a good location for the establishment of an initial permanent base due to the presence of permanently shadowed regions near locations with nearly continuous solar illumination. If a permanent base is established and grows into a large international base, high energy activities will require the maximum exploitation of the solar power available at these high sunlight locations. These high energy processes could include: the electrolysis of lunar polar ice for propellant, the growth of food, the production of surface structures, and the extraction of metals from the lunar regolith. The concept of solar drapes is here proposed along with a method for how they could be erected.

Delivery & Set-out

A large payload is delivered to the lunar surface via a reusable lander. A motorized wagon with the solar drapes packed within drives out of the lander to the deployment site. An auger located at the back of the wagon drills vertical holes to a depth of approximately 20% of the height of the drapes. Automated mechanisms tilt up the first telescoping pole and places it into the hole. The holes will need to be dug as vertical as possible.

Between the tips of each telescoping pole is a suspension line onto which approximately five solar drapes are attached in series. As the wagon moves forward, the solar drapes are pulled out of the wagon and onto the ground at regular intervals. The wagon then drills the second hole, tilts up and drops the second pole and moves forward, and so on until the entire solar drape payload is set out.



Erection

The erection of the solar drapes would be as simple as activating the telescoping poles at the same time. The suspension lines between them would begin to pull up and hence deploy all solar drapes at the same time so that a long wall of solar drapes arises simultaneously. Each drape would track the sun by means of a motor between the top of each drape and the suspension line.

Power Uses

Assume 100 metric ton Starship payload with 50 tons for solar drapes including support and electrical management, 30 tons reserved for surface deployment, and 20 tons of margin during design. We estimate a specific power of 150 W/kg. The total power delivered would thus come to 7.4 MW. Starting at the best lunar south polar peak of persistent light with an average of 83% illumination through the solar year and 20% loss due to self-shading brings the power to 5.1 MW. This amount of power would be able to provide any one of the following capabilities.

The total energy to electrolyze water comes to 17.8 MJ/kg at 90% efficiency, meaning we can electrolyze 37.6 metric tons of water to hydrogen and oxygen per day. If certain metals were to be extracted directly from lunar rocks or regolith then iron can be produced in a molten oxide cell for 15.25 MJ/kg plus heat yielding 28.8 tonnes per day, or aluminum can be produced in a molten salt cell for 55.33 MJ/kg plus heat yielding 7.9 tonnes per day.

Each person consumes about 4.42 kg of food each day. It has been estimated that it takes 22 kW of lighting to produce that amount of food. So, we calculate that the full payload of solar drapes would provide enough lighting to produce food for about 230 residents.

REFERENCES & CALCUALTIONS: DevelopSpace.info/drapecalculations

10 – Lunar Roads

SUMMARY

This chapter describes how long-distance roads could be established early on by simply robotically smoothing and compacting the lunar dirt. Self-driving cargo and crew vehicles would need periodic way stations / motels where cargo and crew modules could slide from a depleted electric chassis to a fully charged one. Crew vehicles would need to carry their own water shielding to protect against radiation.

Information in this chapter was developed with the assistance of Taylor Abernathy, Principle Civil Engineer, City of Lake Forest, CA.

THE VALUE OF LUNAR ROADS

Mobility Within a Region

Roads will obviously become an immediate need just as soon as the first lunar infrastructure. The first roads will be constructed from the regional spaceport to infrastructure and habitats (likely at a Peak of Eternal Light -- PEL). Ideally, the landing pad and infrastructure and habitats will be located kilometers away so that these things will not be sandblasted by any off-nominal landing / crash near the spaceport.

Also, there will be worksites in permanently shadowed regions (PSRs) and surface vehicles will need to traverse between these sites and processing facilities (likely near a PEL). As multiple, separate bases are established, roads will likely connect them. So, for a variety of reasons, a network of roads will be established probably starting in the south polar region.

Access to Global Resources

Looking a bit further out in time, nations will likely wish to establish bases away from the poles towards the equator. It would be desirable for these bases to have overland connection to the polar base(s) in order to benefit from access to the resources located there and high-energy products produced at the PELs. One may think that roads from the poles to the equator will be excessively long -- 2,730 km (1,700 miles). Yes, that is a fair distance but, as will be shown shortly, it is within the realm of feasibility. Once such roads are built, it would take only three days of continuous driving at 40 kph (25 mph) for products and people to get from the poles to the equator.

Think about it for a moment. When pole-to-equator roads are built, bases near the equator will have access to propellant, water for various purposes, food, and metals. In other words, they will not be lacking just because they are not near the volatiles found in the PSRs. This greatly enhances their viability because the cost of overland transport using electrical vehicles will be a relatively small portion of the production costs.

Much Lower Energy Requirements

It is understandable for one to think that it would just be better to do suborbital flights from a pole to the equator rather than driving all that way. No. The difference in the amount of energy is huge when comparing the need to produce the propellant to accelerate on the suborbital trajectory and then slow down for a safe landing at the equator versus the battery charges necessary to drive the same distance. The rocket equation is tyrannical because one needs to accelerate not just the dry mass of the rocket but the propellant as well. Consider that the kinetic energy is 1/2 mv^2 so the much faster flight will increase the energy needed as a proportion of the square of velocity. And then you must burn a substantially large amount of propellant to reverse that velocity to zero. Also, water consumed for suborbital hops would mostly not be replenished. There's a great amount of water on the Moon but still, we may want to conserve it especially that water near the PELs at the poles.

The Tesla Model 3 Extended Range can drive 584 km on Earth using a full charge. However, it must deal with a significant amount of air resistance and road resistance due to Earth's full gravity. On the Moon, range will be extended due to lack of air resistance and reduced weight. But compacted dirt roads are softer than hard surfaces so, all combined, electric vehicles on the Moon should be able to get about 900 km range. Compared to the 2,730 km distance from pole to equator, one might think that the vehicle would need about three segments with two waystation stops to recharge. But since the 2,730 km distance is a straight line, deviating somewhat around large craters would increase the total distance by perhaps 10%. So, the lunar EVs may need three waystations between a lunar pole and the equator. Battery pack sizes are a design choice and so their size may be influenced by the distance between equally spaced waystations.

Environmental Benefits

Given that the Moon has thick layers of powdered rock and no life, one might be tempted to think that the Moon has no environment. True, it has no biology to harm nor rivers or air to pollute. But it does have a visual environment that can be significantly defaced. Specifically, because the Moon has no air nor rain, any tire tracks made there will last a very long time. In fact, scientists estimate that tire tracks could last up to 10s or even 100s of millions of years. By having roads and sticking to them, tire tracks can be minimized.

Exploration and Tourism

A network of roads could also assist with both exploration and tourism. By creating very smooth / non-bouncy roads, travel time could be minimized. If one needed to drive off the road system to explore new locations, one could conceive of a different type of electric undercarriage that the crew module could slip on to. This is what I call the StickWalker approach where wheels are replaces with walking legs that are poles with poke vertically into the ground. At an angle, these small holes would be practically invisible.

LEVELS OF ROADS

One can imagine a logical progression from very basic roads to advanced roads with the latter taking much more energy and time to construct.

- **Level 1** - Compacted Dirt Roads - This is where it will start and what will be described in the rest of the chapter. These include telerobotic tractors smoothing paths and compacting the lunar dust so that it is less likely to be kicked up when a vehicle drives over them.
- **Level 2** - Gravel Roads - Also very simple to produce and in fact a potential competitor for compacted dirt roads as the initial form of roads. This would involve a tractor implement what would rake out and sort rocks of various sizes. Gravel size rocks would be placed on the dirt creating a cover over the very fine dust.
- **Level 3** - Sintered Roads - Sintering means using microwaves or concentrated sunlight to melt and fuse together the lunar dirt. The lunar dirt is covered with what is called nanophase iron

which makes it easier to heat. The result is like road pavers but they need to be thick enough to bear the weight of the heaviest passing vehicle. Given how much energy sintering requires, it would take a very long time before significant portions of even a regional network of roads could be constructed using this means.

- **Level 4** - Paved Roads - The Moon has no fossil fuels and water is precious, so asphalt and regular cement is a non-started. Shipping binders from Earth would be cost prohibitive. Ideas like using astronaut urine and blood to create concrete is so stupid it's hard to know why such research is done in the first place (way too little quantities of these materials). But sulphur is present on the Moon and could be used as a binder. But such material would need to be mined and transported. So, this is not a near-term solution.
- **Level 5** - Railroad Tracks - Recently the idea has been promoted to create railroad tracks on the Moon. The clear advantage to doing so is that one can avoid the lunar dust altogether. However, one pair of steel tracks from the lunar pole to equator would require an estimated 6-20 TWh - That's terawatt-hours of energy! That's an incredible amount of energy required just to avoid dealing with dust.

All things considered, compacted dirt roads seem like an easy, early solution to the need for road networks on the Moon.

THE PROCESS OF MAPPING ROADS

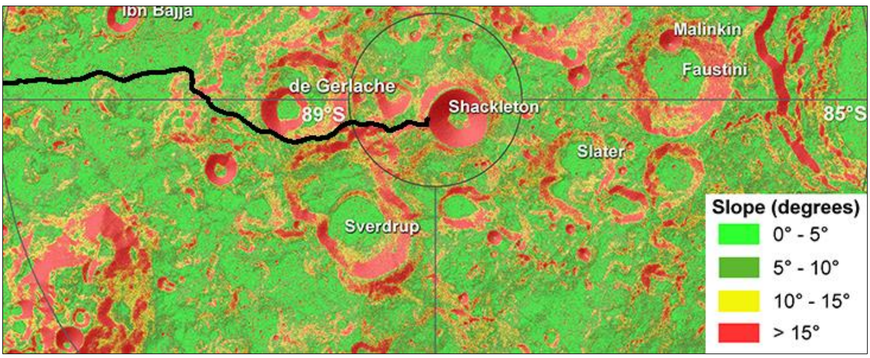
Regional Maps

Locations can and should be identified now about where landing pads, infrastructure, and habitats should best be placed. Given the high-resolution elevation data from the Lunar Reconnaissance Orbiter (LRO), we have, for years now, been able to tell where the PELs are located and where to find relatively flat areas for habitats. A network of roads avoiding steep areas between these locations can be identified. When one looks closely at the LRO images, it becomes apparent that nearly everywhere, lunar dirt has been kicked up and spread all around giving even ridges soft, rounded features. By filling in small craters and driving around the bigger craters, we should be able to create roads avoiding steep areas between any of places where we will have assets.

However, the many PSRs of the lunar south pole have not yet been prospect with on-the-ground data. So, which PSRs contain sufficiently high levels of volatiles making it worthwhile to harvest those locations? We don't know. So, there will need to be a robotic prospecting phase, and the results of those studies will identify which areas will become volatile harvesting "mines". So, the regional roadmap will be incomplete until after we get that data.

Global Maps

Slope angle is probably the most significant factor determining where a lunar road can go. It is not reasonable to have vehicles driving up or down steep slopes no to have to cut into a side hill to make a road more level (high side to low side). So, we would start with the LRO data that has a resolution of 25 to 50 cm. From the elevation data, the Space Imaging Center at the University of Arizona (Tucson) has produced slope maps. These maps would be particularly useful in identifying what path deviations would be needed to avoid areas of excessive slopes. Very high resolution from one of the RoadBots could be used to refine the original global maps.



SMOOTH DRIVING

Very Smooth Roads

The keys to making compacted dirt roads work would be to ensure that they are very smooth and compacted as much as possible. Smoothing largely involves removing rocks (which can be done with a rock rake implement), filling in small craters (which are ubiquitous), compacting, grading, and compacting again. The hope is to make roads so smooth and compacted that vehicles can quickly drive along the road without significantly bouncing.

Self-driving Vehicles

Practically all vehicles on the Moon will be self-driving. It will be very easy to implement this because lane keeping is now fairly common and, on the Moon, there is no traffic, stop lights, dogs running onto the street or any such thing. So, just driving along a road will be quite simple.

Autonomous Transport of Resources

The Innovative Plan for Space Development foresees telerobots preparing and compacting a network of Level 1 dirt roads on the Moon. Automated vehicles could drive on those roads and record the ups and downs and any loss of traction while going around corners. This recording could be used by later vehicles to safely traverse the road at a maximum but safe speed.

These vehicles could take international astronauts and tourists to regional destinations without having to consume a tremendous amount of energy electrolyzing water into propellant for a suborbital hop. Traveling at about 25 mph from a polar base to the equator would take about 3 days. There would need to be solar-powered charging way stations. Perhaps cargo and crew modules could be transferred between electric undercarriages to eliminate waiting times.

But also, these vehicles could be used to transport water and other volatiles from the poles to bases or settlements in other parts of the Moon. Likewise, autonomous vehicles could transport mined materials such as potassium and phosphorus fertilizer from mines to other bases including to the poles. In this way, no part of the Moon would be without the resources they need for settlement.

Driving Speeds Using Accelerometer Recordings

So, one can fill in small craters but there will be areas that have bumps that are too large to be bulldozed down. So, there will be unavoidable ups and downs and, if the vehicle is driving too quickly, in 1/6th gravity, it will be easy for the vehicle to "catch air" and potentially lose control resulting in tumbling over. That, of course, would be very bad. So, how can this be prevented? Specifically, there are several ways that vehicles on the Moon can know where along the course they are. Previous vehicles traveling along the road can record and transmit results from the accelerometer and later vehicles can slow down in those areas where they are about to lift off the ground if they go too fast. In this way, good traction can always be assured while traveling at a relatively fast but safe speed.

Tilting Platform

Since long-distance travel can last for up to three days, passengers could sleep while the self-driving vehicle is moving. If the vehicle is driving up or down or tilting a bit to the left or right, then sleeping passengers could end up rolling around insider their vehicle. To avoid this, an active leveling system could ensure that the platform that the crew module is attached to always remains level within the angle limit that the roads are designed to meet.

THE PROCESS OF CONSTRUCTING ROADS

The RoadBots

To construct the roads, there would be a team of tractor-like robotic vehicles. Ideally, they would conduct their work autonomously but if that technology hadn't been developed yet, the work could also easily be done telerobotically. RoadBots would consist of robotic tractors with:

- A tall mast with lidar to scan many meters ahead allowing the identified road path to be adjusted to bypass craters too large to be filled in.
- A front blade to push regolith into small craters and to create a generally smooth path.
- A rock rake to remove rocks leaving behind compactable material.
- An electric steamroller to compact and smooth the road.
- Repeat use of the front blade and compactor would ensure that the path is as perfectly smooth and compacted as possible.

Grading the Roads

As previously mentioned, the terrain through which the road will be placed may be at an incline forward and back or left and right. Going forward and back we largely have to drive at that angle. We can do a bit of cutting and filling to level out the path but not very much. But we can cut into a right-left incline a bit, perhaps as much as 15 degrees which would come to about one tonne of material removed for each meter going forward.

Teams of RoadBots autonomously constructing compacted dirt roads.

Simultaneous Teams

An important point is that the speed of how fast a lengthy compacted dirt road can be constructed is how many teams of RoadBots are constructing the road simultaneously. So, if there are five RoadBot teams working on a 1,900-mile pole-to-equator road simultaneously and each team is moving forward at 1 mph then it would take 80 days to finish the road. That comes to 5.7 lunar daylights (14 Earth days) to complete the road which is a reasonable amount of time for such an important project. Of course, one could fiddle with the variables such as increasing the number of RoadBot teams and/or choosing a different project time.

Maintaining the Roads

The problem with dirt roads is that, as vehicles drive over them, they can develop longitudinal ruts or wash boarding. Self-driving vehicles could be directed to drive on one side or the other of previous ruts to prevent ruts from deepening. But eventually the roads will need to be fixed. But the solution is simple. As needed, have two RoadBots drive along the route. One would use a blade and the other would compact the road again. In this way, the roads could be adequately maintained indefinitely.

PONY EXPRESS WAYSTATIONS

Swapping Cargo and Crew Modules

As mentioned before, way stations are where electric chassis can be charged while crew or cargo vehicles are incoming. At the waystation, depleted vehicles can drive up next to a fully charged electric chassis. Then, the crew or cargo module can slide between the two chassis so that those modules can immediately continue their journey. This is analogous to the Pony Express mail system in America's old West where mail-carrying riders could swap fresh horses and continue their rapid journey. Alternately, passengers could dock with the waystation and spend a while resting and stretching their legs or even spending the night.

Waystation Design

Given the charging needs, the way station will certainly need a large field of solar panels that could charge a bank of batteries during the lunar day (15 Earth days). The scheduling of trips will need to consider the vehicular traffic and battery sizes to take into account the demand for charging and different parts of the lunar day.

Also, given the accommodation needs of passengers, the waystation should be designed to have lounge and kitchen areas, bedrooms, bathrooms, and the ability to provide life support and handle human and other wastes.

The diagram below shows how a sintered turnout would have a parking spot where robots could dust off the vehicle before it advances to dock with the way station. Passengers could then move from the pressurized vehicle into the way station. Waste would be stored in an exterior container which would be periodically removed and transported to where that valuable waste could be processed back into useful materials. As the traffic increases, additional solar panels, batteries, and motel space could be added.

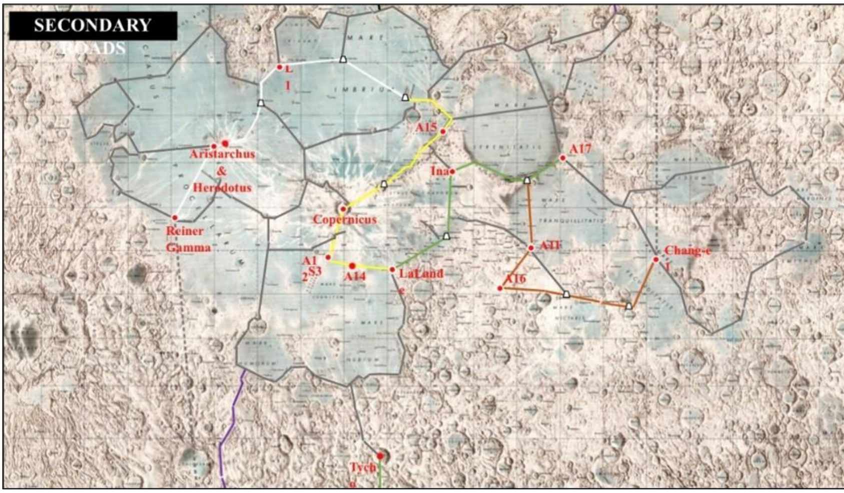
A conceptual diagram of a waystation.

A ROAD NETWORK

So, what would drive the design of the global road network? In the long run, it will probably be what places on the Moon will be repetitively visited by explorers and tourists. Certainly, sites with historic artifacts such as the Apollo landing sites would be on the list. Also, certain sites with dramatic landscapes like the edge of large craters hundreds of kilometers wide would be of great interest. Certainly, the opportunity to safely explore lava tubes would be fun. And remarkable hotels, a day's ride between sites of interest would be something to look forward to.

The Lunar Grand Tour

In the image below, the Space Development Network has imagined a network of roads connecting major sites of interest. Then, secondary roads often following the edge of mare basis would allow travelers to drive along relatively smooth roads while having dramatic basin walls to one side. Overall, this Lunar Grand Tour would connect points of interest while allowing options for taking paths that would see some impressive sites.



Hypothetical map linking likely tourist sites with secondary roads. Credit NASA

11 – The Role of Robots

SUMMARY

An AI-humanoid robot could be a member of Initial Permanent Crew conducting useful tasks 24/7. Other dexterous robots would plant, harvest, process, and maintain the greenhouse areas. They could also continuously clean and maintain facilities. Indeed, robots would probably outnumber human crew at every level of development.

ROBOTS VS HUMANS

Categories of Roles

In space advocacy circles there is a recurring argument about who is better for space -- robots or humans. The advocates for robots argue that robots are cheaper and don't require life support. The advocates of humans argue that humans are much faster than robots and have better judgement.

But these arguments miss the point. Robots are better for some things and humans are better for other things. This page will detail what situations are best for each.

But first, let's clarify the three settings in question. Those are:

- Exploration
- Development
- Settlement

The debate and confusion most often result from not distinguishing between those settings.

Exploration

The greater speed of humans notwithstanding, robots are almost always better than humans for scientific exploration. For probes exploring the outer solar system this is a given. Only robotic probes can currently explore places beyond Mars. The radiation during transit and long-duration life support requirements make exploration by humans impossible in these locations.

For the Moon and Mars, robots still easily beat humans for several reasons. On a per-mission basis, they are far cheaper than sending astronauts. If we were to mass produce Spirit and Opportunity rovers for Mars, each mission would cost about $400 million whereas the first human mission to Mars would typically cost about $150 billion. So, we could conduct about 375 robotic missions for each crewed mission. Most importantly, those robots could go to 375 different locations whereas humans could only go to one location or just a handful if they were to drive around. Science return is highly dependent upon where one goes. So, the more places one goes the more unique science is returned. And scientific rovers are lasting for many years. So, even though they are slower each telerobot could cover a substantially equivalent distance as human explorers.

Understanding Context

Those that argue for humans say that robots are not smart enough to understand the context of what they are looking at. They say that, until we have true AI, only geologists in the field can interpret what they are looking at. This completely ignores how teams of our best geologists on Earth can be virtually "present" on the Moon or Mars via telepresence. Those robots that we have on Mars are as smart as the scientists who operate them. So, that argument doesn’t fly.

No Exploratory Role for Humans?

However, even though there are strong practical reasons for why robots beat humans for exploration in almost every context, there is nonetheless a strong reason why we shouldn't "let the robots have all of the fun" but should hold them back in favor of astronauts conducting scientific exploration.

For both the Moon and Mars, there could be a very extensive International Exploration Phase provided that the per-seat price was low enough. This extensive phase, driven by the motivation of national pride, could be just the thing needed to increase flight frequency and so further reduce the cost of passenger transport thereby opening the way for private settlement.

It is the position of the Space Development Network advocates that NASA's Commercial Landed Payload Service (CLPS) should limit small "commercial" landers to prospecting and perhaps small-scale demonstrations and NOT to visit exciting science sites prior to international astronauts visiting them.

Telerobotics Versus Autonomy

Workers on Earth controlling lunar telerobots would experience a 2.6 second speed-of-light round trip time delay. This means that the telerobots could perform tasks with full human intelligence controlling them. With the time delay, actions would be slowed but, operating 24/7, considerable work could be accomplished telerobotically prior to crew arrival.

But If a task could be safely, fully automated and done with about the same efficiency of teleoperations then those robots would be allowed to operate autonomously. A hybrid would be supervised autonomy where the teleoperators (perhaps controlling multiple telerobots) give high-level instructions and the robot determines the individual steps to accomplish those goals. Driving while avoiding hazards is one task that now could probably be fully automated. And if a robot gets stuck, a fellow robot could free it.

Development

Space development means building up infrastructure including the systems to utilize local resources. Teleoperated robots could set up power systems, harvest and process ice, and set up inflatable habitats, dock equipment into ports, and perhaps even start growing food in the greenhouse.

Dexterous telerobots could remove worn parts designed with quick release mechanisms and replace them with new spares. In this way, small mass spare parts could keep telerobots working thereby producing products (e.g. water or metals) at quantities perhaps 100X the mass of the spare part.

After crew arrival, the relationship between them and robots becomes very interesting. The crew would maintain the telerobots, assemble more of them, and even extract metals from the lunar dirt and process them into more telerobotic parts. A small crew could maintain a very large telerobotic workforce and development would scale very large very quickly. Telerobots harvesting and processing metals could expand the number of their fellow telerobots and hence get onto an exponential curve.

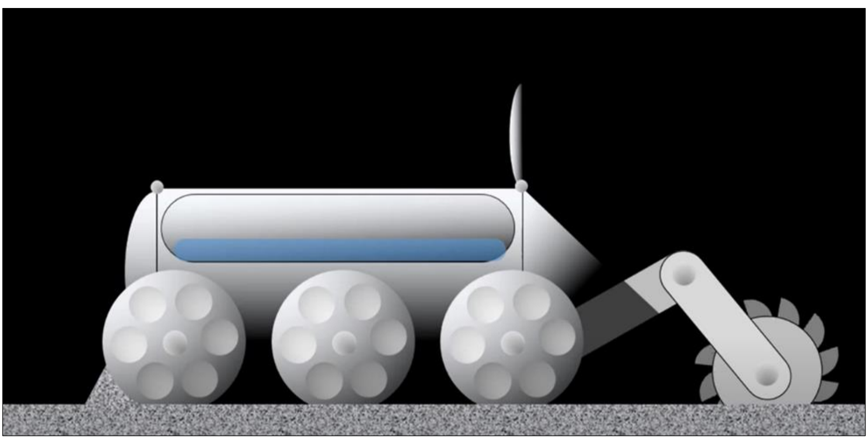
Settlement

Robots cannot do human settlement, but they can be an integral part of keeping the settlement running. There would be a division of duties. Everything that the robots could do the robots would do. Those tasks that humans could do much better than telerobots from a dexterity (not logic) standpoint the humans would do.

SPECIFIC ROBOTS

The Ice Harvester

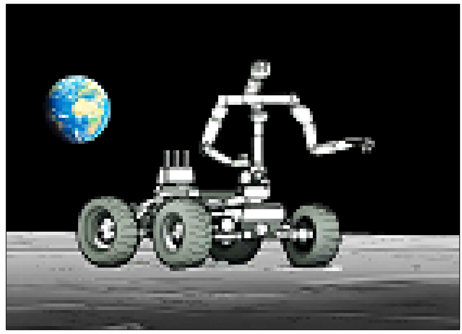
The key robot to harvest and process the ice will be the Ice Harvester. It could be designed to perform the function of multiple pieces of hardware thereby reducing the amount of equipment mass needed to be transported to the Moon. Depending upon the vertical distribution of the lunar polar ice, this robot could use a bucket wheel excavator to scoop up the icy dirt into its body. After closing a lid, the telerobot would tumble the icy dirt and heat it thereby causing the volatiles to steam out and into a container on its body. After drying the dirt, it would open a lid and "poop" out the dry dirt, move a few meters forward and repeat the process. The Ice Harvesters would probably be operated autonomously but with oversight by people on Earth doing shifts so that they could work 24/7.



The Ice Harvester combines several functions into a single vehicle.

After its volatile tanks are full, it could back up to and connect to a power station receiving beamed power from solar drapes at which time the volatiles could be reheated and the water and organics separated through the process of distillation. The water would be transported to a PEL where it would be electrolyzed into propellant. The frozen organics would be transported to the International Base where the chemists would convert them into useable products.

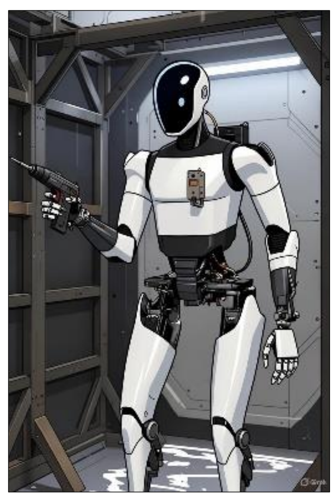
Dexterous Telerobots


The DexBot.

It is inevitable that the robotic parts will wear out with time. What to do? Here's where the dexterous telerobot (DexBot) comes in. Somewhat humanoid, the dexterous telerobots would have a head with eyes, arms and hands, and could move around not on legs and feet but on a rover body. Its uses would Include: setting hardware in place after a habitat is inflated, connecting power cables, swapping out spare parts on other robots and vehicles, and preparing the habitat prior to crew arrival.

How can the Ice Harvester be kept going when breakdowns are inevitable? Initially, the DexBot would not do actual repairs to the Ice Harvesters and other robots but rather only swap out spare parts. Parts should be so designed so as to be easily swapped out using quick release mechanisms. An example of this is the modern bicycle tire that requires no tools. With a simple tug of a lever and spinning it around, the wheel can be disconnected from the forks.

Robotic Crew


Robots will likely outnumber humans

Robots can also be part of the Initial Permanent Crew. Indeed, a humanoid robot (e.g. Tesla's Optimus) could be the tenth member of the team (after the dog). It could have a name, voice, personality, and be continuously upgraded to perform more and more useful tasks. It could be a high-profile demonstrator of what a domestic and working android robot could do. As a major product placement, it could generate revenue for the mission.

Specialty robots could also be present such as robots helping in the agricultural and kitchen sections of the Initial Permanent Base. Operating 24/7, much of the day-to-day work could be offloaded to these robots. Being specialty robots, they could have swappable appendages optimized to harvesting, processing, and cleaning.

Perhaps a robotic pet could be present as well. But I haven't yet seen one that's realistic.

There could also be a CameraBot for the Moonday night TV show. It could provide a third-person perspective of the crew whether indoors or outdoors.

WorkerBots

Eventually, when it makes economic sense, robots will begin constructing habitats using local resources. Likely by that time, robotic development on Earth will be advanced enough such that training the lunar WorkerBots in the tasks needed to construct habitats will be figured out.

PHASES OF DEVELOPMENT

12 – The Initial Permanent Crew

SUMMARY

This chapter describes a scenario of the first permanent crew to settle down on the Moon. Ideally, these would be four couples without children back on Earth and so, free to sell their homes on Earth and move indefinitely to the Moon. In other words, they are the first humans to begin spreading beyond Earth -- true settlers. Their jobs, hypothetical national origins, languages, and talents are described. If chosen well, the Crew of eight should be able to speak to at least 75% of the world in a language that they would be able to understand.

HUMANITY'S FIRST PERMANENT FOOTHOLD

The Initial Crew

We need to understand just how close we are to humanity taking its first permanent steps off Earth. It doesn't take as much as many people presume. The Plan for Sustainable Development laid out in this book describes a proposed Initial Permanent Crew and how such a group could be the very historic, first of humanity beginning to spread beyond Earth.

While the lunar lander is becoming human-rated by landing cargo on the Moon, it could either land as the StarHab and then be horizontalized as described in chapter 17 or it could deliver a large, inflatable InstaBase. Telerobots would cover either with lunar dirt prior to crew arrival. With the indoor centrifuge providing a full gee of artificial gravity several hours a day, the very first crew should be able to remain on the Moon for at least three years and quite possibly much longer. If crew are able to move off Earth for an indefinitely long period of time, then this is the beginning of human migration beyond the Earth.

This Initial Crew (let's say eight people) will go down in history at the level of Christopher Columbus and the Pilgrims. We would know up front that we are writing history. What story will we choose to write?

Social Status

Biosphere 2 in Tucson, Arizona served as a two-year experiment from September 1991 to September 1993. During this experiment, there were eight "biospherians" who lived inside this hermetically sealed facility. At the time, two of the biospherians were dating and went on to get married. Why are the social statuses of the Initial Permanent Crew so important?

If we are going to intentionally write the story of how the first humanity started expanding beyond Earth, then the social status of that very first crew would begin to dominate how long they could remain on the Moon. If a crew member had a dependent child or even a spouse back on Earth, they would likely feel the need to return to Earth even before their radiation levels or bone density required them to. Sending a bunch of single individuals to work and live together for years could result in some interesting situations which could negatively affect crew morale. Two gals showing an interest in the same guy (or vice versa) could make for some great reality TV but could seriously harm the ability of the crew to do their work.

Eventually, as the population of the base grows, there will be all types of people moving to the Moon. But initially, the people to go down into the history books as those humans to first move off Earth need to be those who can stay there essentially indefinitely. Ideally, they would go as couples in which their social status is resolved. Just like on Earth when a job requires someone to move away for years, they take their family with them. Same situation here. What we're talking about is the beginning of actual space settlement -- on a small scale.

Crew Diversity

The Plan envisions that the Initial Crew be private workers of a company that is funded by NASA using American tax dollars. As such, the crew should be Americans, and the common language should be English. But the crew members would not necessarily have been born in the United States because many Americans are naturalized citizens enjoying all of the same legal privileges of American born citizens. Doing so would illustrate that being American isn't based upon one's ethnicity or national origin but is based upon our shared values and beliefs. Indeed, it would be to the distinct advantage of the program if the crew members could broadly represent the world through their diversity of backgrounds and speak to as many people in the world as possible in languages that they understand. It would also be beneficial if there was a diversity of faith, personalities, and talents. Talents could include musical abilities, dance, gymnastics, and arts. So, even though the Crew are Americans, they would be broadly representative of the world.

Selection Criteria

So, the educational and talent criteria for selection should be specified to people of a certain age around the world. As people pass through the process of selection, at some point they would need to become naturalized American citizens. The educational criteria would be published but training in the specific protocols needed would be provided to the finalists. A process somewhat like that followed by the Mars One organization could be employed. This could include the submission of video pitches, video interviews, but also videos of athletic performances, live video music performances, and the results of language proficiency tests.

INTRODUCING THE CREW

Right now, we don't know who would make up the initial crew of eight. But let's imagine an ideal, hypothetical scenario where the first crew of eight have been selected. Here they are:

- **The Commander-Farmer -** Your prototypical astronaut. He's former military. A pilot. Great at organizing people and managing the team. But he's also a farmer and his day-to-day job is working in the hydroponic greenhouse section.
- **The Biologist -** The Commander's wife, is going to be the primary one responsible for animal studies including those designed to determine how much artificial gravity is needed for healthy gestation and childhood. She is cross-trained in the medical protocols. She and her husband own the dog which is the ninth team member.

- **The Engineer -** He is responsible for setting up and maintaining all of the hardware. He also works with the Machinist-Metallurgist as they develop replacement parts from local resources.
- **The Physician -** Responsible for the health of the crew. She monitors everyone to determine if they exceed certain biomedical criteria requiring them to return to Earth. She works with the Biologist in the animal studies.

- **The Machinist-Metallurgist -** The patron saint of blue-collar workers. He extracts metallic micrometeorite bits from the regolith, melts them using concentrated sunlight, removes the dross, casts and machine the metals to make basic metal parts. He works with and is cross-trained to do the work of the roboticist. Only he knows what will be his first CNC machined and 3D-printed pieces.
- **The Chemist -** Demonstrating the small-scale production of new chemicals nearly every day from the organic chemicals in the ice and from the geologist's samples. Later, as the base grows and there are dedicated manufacturing habitats, she works to set up larger-scale chemical processing facilities. She is cross-trained with the Geologist.

- **The Geologist -** Receives rock samples from telerobotic missions from selected sites around the Moon. Besides being the first to closely examine the samples, he works with the chemist to extract elements and chemicals from the rocks for use producing and increasing array of materials.
- **The Roboticist -** In charge of the primary job of the base which is to maintain and expand the telerobotic ice-harvesting workforce

to grow the propellant-producing system to increase the quantity and lower the cost of all follow-on travel to the Moon.

- **The Android -** Perhaps the tenth member of the team would be a bipedal, humanoid robot whose AI would allow it to perform helpful tasks and interact with crew while having its own personality.
- **The Dog -** And if that is not inspiring enough, a female dog could be the ninth member of the team. Later, the dog's mate could be sent leading to you know what -- Yes, Moon puppies!

LANGUAGES

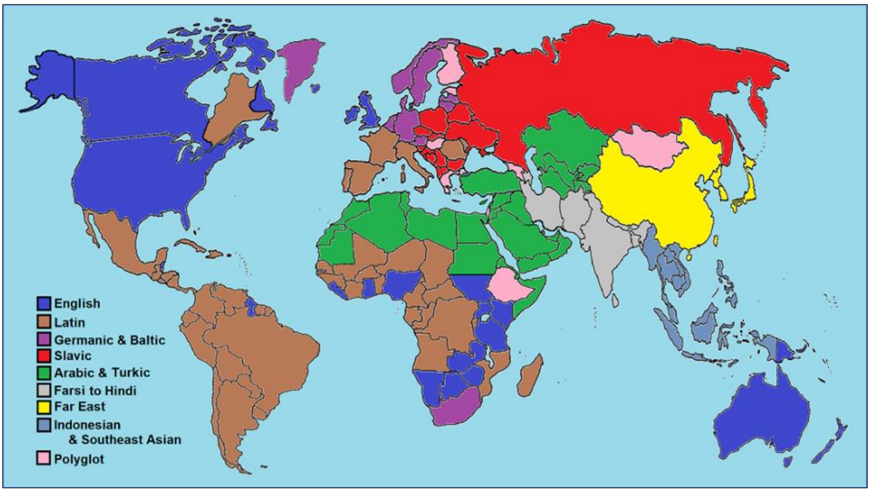
The Advantage of Diverse Languages

The Plan proposed in this book includes that the Initial Permanent Crew each know a set of languages. The purpose of doing this would be to further enhance the world's connection to this American led and funded phase. Although Americans are taking the lead, in a sense this diverse Initial Crew including with their wide variety of languages means that these first permanent steps are being taken by the representative of humanity. Through the crew's languages, each country would, in a sense, have their representative connection within the Initial Crew. The two ways that the Crew's languages would connect them to the countries would be through news interviews and being broadcast within the classrooms of those countries.

The benefits of connecting the Initial Crew with countries throughout the world include:

- Demonstrating that the United States is a country based not upon ethnicity but upon principles applicable to people around the world.
- Demonstrating that American leadership in space is something not to be feared but a blessing to the other nations.
- Similarly, preventing other nations whose nationalism poses some dangers from taking the lead in space.
- The crew demonstrating the point that Americans of diverse backgrounds can get along together.

- Eliciting international goodwill and influence as young people from around the world know that America is providing them with a (small) chance of establishing humanity's first, permanent, off-Earth foothold.
- Providing representatives from the Initial Crew which can communicate in the language of follow-on international exploration teams.
- Just the enjoyment of watching a crew whose diversity provides variety.



Language Groupings

All crew members would need to speak English as the common language within the Team. If young people from around the world knew what languages would increase their likelihood of being selected, they could pursue the acquisition of those specific languages. Gifted students could become fluent in several different languages. Here is a scenario of what other languages each of the crew could speak if this were a selection criterion:

- Commander: Indonesian-Malaysian, Indochinese languages
- Biologist: The major Latin-based languages
- Engineer: Polyglot (e.g. Amharic, Greek, Hungarian, Mongolian, etc.)
- Physician: Arabic & Turkish
- Machinist-Metallurgist: Mandarin, Japanese, Korean
- Chemist: Hindi, Pashto, Farsi
- Geologist: The Germanic languages
- Roboticist: The Slavic languages

A polyglot (someone who can easily pick up another language) could significantly increase the number of languages represented among the initial crew. So, what percentage of the world's population could a crew of eight speak to in their language? In conversations with linguistics faculty, it is estimated that the Initial Crew knowing the above languages would be able to speak to about 75% - 80% of the world.

Special thanks to linguistics professors Heidi Harley (University Arizona – Tucson) and Armin Schwegler (University California Irine) for concepts included in this section.

EXTENDING CREW STAY

The Benefits of Extending Crew Stay

If we can extend the length of how long the crew can remain on the Moon, this would result in several benefits. It could either cost less since there would be fewer launches necessary to maintain (or grow) the population of the base. Secondly, each time we rotate crew, there is a danger to their lives and consequently a danger to the program. The Challenger and Columbia accidents illustrate this concept.

Biomedical Return Criteria

How long can we remain on the Moon and how can we know when the crew must return. Several biomedical criteria could be established. The crew should be periodically monitored for these biomedical indicators by the Physician. If they are nearing any of the criteria, then they are sent back to Earth. Bone mineral density is a good example but there are several other indicators that would be monitored. On the Moon, we wouldn't need to know beforehand how long the crew could remain before the criteria are met. They would remain as long as possible until they are met. With exercise and artificial gravity, perhaps the crew could remain on the Moon for a long time. See the author's paper on this topic by scanning the QR code to the right.

Radiation Not the Limiting Factor

Between 50-70 cm thick of uncompacted lunar dirt on top of the UniHab would provide full protection against solar storms and would reduce the radiation levels of the galactic cosmic rays by about 30%. This would allow for the crew to remain on the Moon for about years before they reached a notional career limit of 1,000 mSv. They would then have plenty of time to maintain the telerobots to push even more dirt on top of the habitat. Therefore, it is not the radiation exposure which would limit the length that the crew could stay. Rather, it is the health effects of reduced gravity of the Moon that would likely determine how long the crew could stay.

13 – The International Lunar Exploration Phase (ILEP)

SUMMARY

In our scenario, immediately following the Initial Crew Phase lasting between six and twelve months, a large phase of international exploration would commence. A follow-on agreement to the Artemis Accords would coordinate the participating nations so that their astronauts would each have newsworthy missions. This would be a huge foreign policy achievement for the United States naturally leading to the establishment of an International Lunar Base.

OVERVIEW

Thanks to commercial launch companies dramatically lowering the cost of space access, we can imagine that soon, the per-seat price in a mission of lunar exploration will come down to the point where most countries could afford to purchase at least one seat. If wealthier countries were charged about 10% more per seat and there was cost-shifting in favor of poorer countries, then all countries could afford to purchase at least one seat. The opening of the Moon (and indeed the solar system) to the nations of the world would generate tremendous goodwill towards the US for having made it possible.

There are many artifacts, natural features, habitats, and activities which international astronauts could explore and participate in which would be at a newsworthy level. The pride of citizens watching their national astronauts exploring the Moon on their behalf and in their own language would provide the necessary motivation for countries to set aside a very small amount of their national budgets to purchase those seats thereby funding this Phase.

As countries choose to leave some of their astronauts on the Moon, a growing International Lunar Base (ILB) would form the first off-Earth settlement and provide the transportation and infrastructure foundation upon which private settlement could grow.

PER SEAT PRICE MAKES ALL THE DIFFERENCE

Space Launch System (SLS)

The SLS is NASA's Shuttle-derived super heavy lift vehicle (SHLV). It is very expensive both in terms of overall development costs as well as per-flight costs. Yet, it is the most developed, human-rated heavy lift vehicle. Additionally, the SLS would launch the expensive Orion capsule designed for deep space missions and would have to go through the Gateway station around the Moon which would utilize several SLS launches to be set up. If one assumes a per-mission, incremental cost of about $4.1 B each for a surface crew of two, then this would come to about $2 B per seat. At that cost, nine missions (through Artemis 9) would cost about $37B for eight missions and perhaps 20 astronauts on the surface of the Moon. Most of the seats would go to American astronauts and only up to seven other nations would be able to watch their astronauts exploring the Moon. This chapter proposes an American initiated program of lunar exploration far greater than that.

Starship

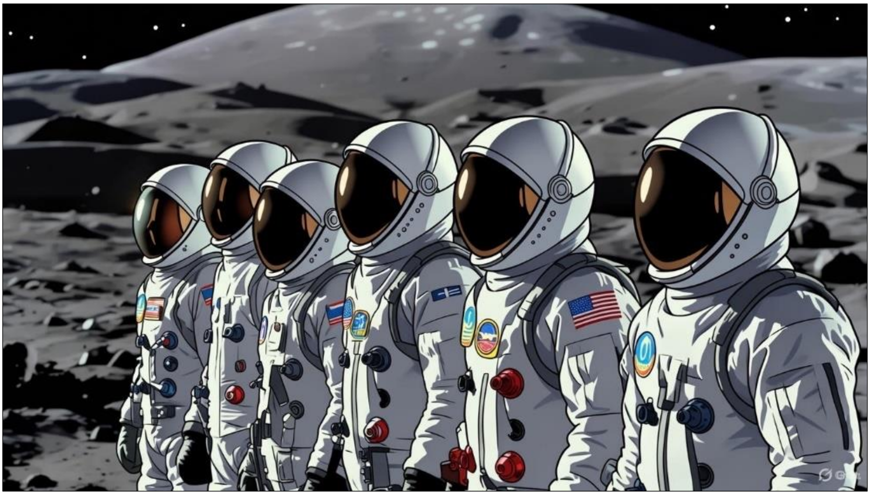
If SpaceX's Starship becomes a reality (likely) then it will be a complete game-changer for humanity. Intended to be the first, fully-reusable, orbital-class rocket, the cost would be just the refueling of the rocket. The decision makers in Washington DC should pay attention to the development of the Starship and be willing to transition to a public-private program with SpaceX if the Starship shows that it will likely be more cost-effective and about as capable as the SLS (i.e. the moment Starship refuels).

HOW MANY NATIONS COULD AFFORD A SEAT?

Assumptions

In policy chapter 33, it is proposed that initial lunar missions take full advantage of the Starship fleet starting as soon as it demonstrates LEO depot filling and storage (likely in late 2026). This chapter also assumes lunar missions using only SpaceX hardware (as Elon has indicated via an X post). In the early years to assure launch safety, it is assumed that six astronauts would fly to LEO on a Falcon 9 – Dragon and transfer to a cislunar Starship and then proceed to the Moon while refilling around EML1.

Estimates for such a mission run to a median point of about $1 B. So, for six seats, this comes to about $167 M per seat. With a high flight rate (aka Starlink launches) and already proven engine-out capability, crew safety can be better than the one in 300 level that NASA's ASAP safety committee set for commercial crewed missions. This is vaguely analogous to how passenger jets need no escape system because even one remaining engine is enough to safely land. So, if crew can launch on Starship, then the number of crew can be increased well above six in a Dragon capsule. One could theoretically stuff as many as 120 – 200 astronauts into a lunar Starship payload bay but let's choose a conservative crew of 50. This would bring the per-seat cost to $20 M per astronaut.



Teams of international astronauts during their "Apollo" moments.

Affordability

How much would nations be willing to pay for one seat on a mission of lunar exploration? The United States spends only 0.1% of its GDP each year on civil space. So, let's assume that other countries would be willing to set aside that same, small about of their smaller GDP and that they would be willing to set aside that amount each year for four years to save up for one seat on a mission. The QR code to the right links to a spreadsheet which shows the calculations. It turns out that nearly all countries (98%) would be able to afford at least one seat and nearly two-thirds of nations would be able to purchase an entire 50-person Lunar Starship.

Think about it, the United States could really benefit all of the other nations of the world by providing the leadership necessary to open up not only the Moon but the inner solar system to humanity. This is the legacy that is possible in the next few years. However, if we continue down the expensive SLS approach then, instead of 211 nations being able to go to the Moon, only about seven would be able to do so. The choice is ours to make.

INTERNATIONAL LUNAR EXPLORATION SCENARIO

The next QR code below illustrates a very hypothetical scenario of two years' worth of international lunar exploration expeditions at one mission per week. The specific series of missions included the following design choices:

Less naturally newsworthy locations and activities are done earlier and the more exciting ones later. In this way the firsts in each category will be exciting because they are first whereas the latter will be more exciting because they are naturally so.

Countries are matched to a site or activity if there is a natural association with them. So, for example, the crater named after Nicolaus Copernicus who was from Poland. Therefore, the choice of who gets to be the first to visit the crater named after him would be determined by Poland. Similarly, for example, Sweden (with its famous IKEA store) might choose for its team to set up the first HomeHab including specially designed furniture easily set up.

Certain activities are clustered to create a month-long theme. So, for example, the eleventh month of the second year would be the month that astronauts from different countries would be exploring ridges. This helps the world public pay attention to what is happening on the Moon rather than just being a random set of activities.

WHICH NATIONS VISIT WHICH SITES?

It would seem inappropriate for the first nations to visit the Moon to get to visit all the really cool sites and to leave less newsworthy sites for later, poorer nations. For example, one could imagine that, during the Artemis and American Phase, the United States could visit their Apollo sites, the Soviet rovers, be the first to enter a lava tube, the best magnetic and irregular patches, and conduct the first lunar race. That would be great for America but would leave it to other nations to only repeat what America had already done.

Rather, it is here proposed that the expeditions in the American and International Exploration Phase be assigned in an organized manner so that each mission would include enough unique elements to ensure that they were newsworthy. If nations are going to set aside something like 0.1% of their national budgets for four years it would need to be worth it. So, making sure that the missions are newsworthy would be important to have an ILEP large enough to ensure that the flight rate is high, per-seat prices low, and that the International Lunar Base be large enough to provide the foundation for private settlement. Our Google spreadsheet (visit the QR code to the right) shows our current list of sites and activities and their levels of newsworthiness.

So, what might the process of assigning mission locations and activities look like? An international committee should be set up that looks to assign missions in a fair manner and in an order that maintains newsworthiness. Letters of interest (LOIs) should be sought to determine how many missions to plan for.

Dr. Stooke and I have identified about 160 sites and activities for an estimated 130 missions. There are about 70 nations that could afford to purchase more than 1 full mission (where they buy six seats). In the case of the largest nations like the United States, they could afford to purchase as many as 267 complete expeditions. There just are not that many newsworthy sites and activities to support that many expeditions. So, it is suggested that the bigger nations be limited to the number of missions that they could perform during the ILEP. After the ILEP, nations could be free to conduct as many missions as they wish.

As part of the process of assigning missions, certain nations can be identified that should be given the right to assign specific missions. For example, Russia has several artifacts on the Moon. We can imagine that they would love to visit their Lunokhod rovers and it would seem inappropriate for the international committee to assign those missions to other nations. So, for example, they could choose which of their rovers to visit and then they could assign the missions to visit their other rover to a nation of their choice. Likewise, certain craters are named for historic astronomers from certain nations. Perhaps those nations would like to visit a crater that had been named after their historic astronomer. And if a nation has multiple such craters, then perhaps they would be allowed the choice to assign other of "their" craters to nations of their choice.

The Apollo Program demonstrated that the public's interest can wane as missions repeat the same sort of activities. So, missions should be assigned in a manner that maintains newsworthiness. This could be done by a variety of strategies. Missions within a category could be clustered in order to make a set of related missions. For example, the category of lunar pits includes: depressions, a larger pit, areas where pits are clustered, fractures, a small skylight, a large skylight, a small lava tube, the likely largest, accessible lava tube, and the one and only arch on the Moon (DevelopSpace.info/arch). This order is a sequence of increasing newsworthiness. These missions could be clustered within a two-month period and by ordering them in this manner, newsworthiness could be maintained in the public.

Also, six-person missions could be either of a single nation or a collection of nations. So, for example, there could be a mission involving six different Pacific island nations. In the spirit of the Apollo-Soyuz mission, even rival nations could join together in a mission as a step towards generating friendly relations.

WATCHING INTERNATIONAL EXPLORATION MISSIONS

Many of the international lunar exploration missions would be very newsworthy with people around the globe watching. But some percentage of the missions would get reported in the international news but wouldn't be top-of-the-page stuff. But, within the countries that had astronauts on the missions, the interest would likely be so strong that time would be taken out of classes for students to watch certain moments live.

TV Series

The TV series would start by following the Initial Crew. It could continue by showing the latest developments with the latest international team doing field exploration as well as any new developments at the International Lunar Base (ILB).

Live video from the current mission would likely be fed via the Internet for space advocates wanting to follow such things as well as for citizens within the country whose astronauts were doing the exploring. But mostly, people would follow the daily or weekly highlights to keep up with what was going on.

The choreography of the camera work would need to be planned well in advance and with the team during their training. If done well, even the live program could be done in such a manner to make for an interesting show.

Virtual Reality (VR)

Again, the virtual reality programming started during the Initial Crew Phase could be continued. During the ILEP, it may be mostly citizens within the country who are currently doing exploration who would be willing to pay in order to be virtually present along with their national astronauts to experience such missions as though they were there.

CameraBots

Telerobots specifically designed to be cameramen could follow the international crew as they explore. They could have telescoping poles to get different views from different heights.

HoverCams

Conceivably, each field mission could have a rover with safe propellant that a rocket drone craft could periodically refuel from. Then these rockets could fire their small rocket engines and perform fly-overs and hover in order to get perspectives that could be obtained in no other way.

VISITING ARTIFACTS

Apollo Landing Sites

Probably the expeditions of greatest interest would be a revisit of the Apollo mission landing sites. There was a total of six such missions (Apollo 11, 12, 14, 15, 16, & 17) that occurred between 1969 and 1972. Each site has the descent module remaining on the surface while the ascent module is missing due to the astronauts having departed in it.

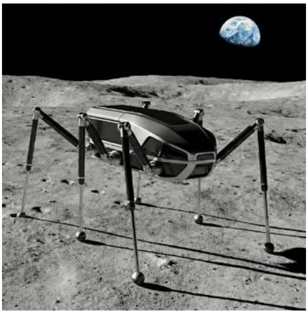
There are a set of artifacts associated with each site including footprints, flags, scientific instruments, and other items including even golf balls. These artifacts should be preserved and indeed the surrounding area should be preserved. Yet, international astronaut teams should be able to visit them while preserving the historic appearance of the site for future generations to visit. Chapter 42 describes how present and future landing and exploration sites could be managed in such a way to ensure their preservation while also ensuring that future visitors could get an up-close look at the artifacts. Using a crew-sized StickWalker, international astronauts could visit artifacts up close without leaving any evidence behind.

Obviously, the Apollo 11 missions (the first time humans set foot on the Moon) would be of great interest. Would it put the conspiracy theory to rest that we never visited the Moon? Yeah...probably not. But still, such a return mission would be watched by the whole world.

It is worth noting that the Apollo 12 mission landed very close to the Surveyor 3 lander. Whichever nation visited this site would get a "twofer".

The Apollo 14 mission site was located at the Fra Mauro formation. It was at this location that astronaut, Alan Shepard (first American in space in 1961) famously hit a couple of golf balls. In the 1/6th gravity they went pretty far. But photograph analysis has identified exactly where one of those balls probably is. Using the StickWalker, return astronauts could confirm their location.

The Apollo 15 site visited a very visually interesting site with a winding trough which is a collapsed lava tube. It was also the first site where the lunar rover was used.



During the Apollo 16 mission, the astronauts drove their rover nearly 27 kilometers (17 miles) leaving extensive tracks. During this mission, astronaut John Young jumped very high while performing a salute. We could imagine that the international astronauts visiting this location would also like to repeat this gesture perhaps to a world record height -- ok, a lunar record height.

The Apollo 17 site was at Taurus-Littrow valley. It was the only mission with a geologist (Harrison (Jack) Schmidt). They visited a large rock which later astronauts and tourists would like to visit. Return visitors could also go to the site where the original astronauts found orange dirt later to be identified as resulting from volcanic activity.

Landers & Rovers

There are currently 28 landers of which eight deposited rovers which drove the surface. Missions to visit these artifacts would be inherently newsworthy. Would these countries like to replace those vehicles with exact replicas and return the original to their national space museums? Maybe but probably not. But just the thought shows some of the possibilities.

By the time humans return to the Moon, there could well be more landers and rovers on the surface. In particular, NASA's CLPS program will likely already have delivered a few landers and rovers by then.

Impact Sites

Perhaps the least interesting of the artifact sites are the 40+ impacts caused by the probes and upper stages impacting the surface of the Moon. The speed of impact was so great that no pieces would be expected to remain to be discovered. The sizes of the impacts vary depending upon the size of the impacting piece of hardware. After dedicated missions visiting the first couple of impact sites, other impacts sites could be visited as a bonus side-show during other missions.

VISITING VOLCANOES AND LAVA TUBES

The Moon has had volcanic activity in the past resulting in some interesting features for international astronauts to visit.

Volcanoes

There are several volcanoes including the classic cinder cone-shaped volcanoes. International astronauts hiking up and reaching the peak of such volcanoes would be of interest to the viewing public. There are also regions with multiple volcanoes clustered together. In the floor of certain craters there are fractures from which volcanic material has vented.

Rilles

As volcanic lava flowed on the surface of the Moon, they exhibited a phenomenon of having channels of lava flowing like a stream. The upper surface of that stream, being exposed to the vacuum of space, cooled down the roof of the flow. If the lava drained out, then hollow channels would remain behind. With meteorite impacts causing fractures, the ceiling of the stream could collapse over time leaving behind trenches which are called rilles (rhymes with thrills). Imagine international astronauts driving their rover along such a winding rille.

Lunar Pits

If the lava tube remains intact, meteorite impacts could destabilize a lava tube's roof causing a localized collapse of the tube's ceiling. This could be partial or complete leaving either a depression or puncturing a skylight. Depressions are not as exciting as skylights which open into tubes to be explored. But their initial investigation would still be of interest.

Lava Tubes

One of the most striking missions would be when astronauts rappel down into such a lava tube for the first time. What will they see? To keep the excitement and glory reserved for humans instead of robots, it is here proposed that CLPS missions with rovers not be allowed to reveal the secrets of certain sites but leave those for humans to discover. Let's not let the robots have all the fun!

Lava tubes are often identified as potential good locations for a base or settlement. So, the explorations of lava tubes could act as the first surveys of what would eventually be settled. An international astronaut team could even set up a small inflatable habitat as the first non-polar base. Being under the ground, the temperatures would tend to be constant thereby making long-term habitation safer.

CRATERS YOUNG AND OLD

It is obvious that any program of lunar exploration would want to visit craters. There are so many of them and they would make for some dramatic footage. Imagine a crew as they just crest a ridge and get to see the whole inside of the crater for the first time. Then there is the footage of the crew walking or driving along the crater's rim. Then also imagine as they descend the inside wall of the crater, drive across the floor and then climb and reach the central peak.

An example of a young crater is Necho. This crater was named after an Egyptian pharaoh, and so Egypt should probably be given first dibs for visiting it. Necho sponsored an expedition to sail around the continent of Africa. It took three years. This crater has well-preserved geological features and a series of landslides that looks sort of like a bolt of yarn. Part of one of its walls is slumped.

One of the more dramatic pairs of craters is the Aristarchus & Herodotus set of large craters in the Moon's northwest region. From Herodotus comes the Moon's largest rille producing a large valley. Together, Herodotus and its valley have been termed the "Cobra Head".

Copernicus is one of those craters that has bright ray patterns extending from it in every direction. Rocks thrown out from this crater were visited by Apollo 12. It has very dramatic landscape including a large mountain ridge in the center of the crater.

Lalande Crater may be an important crater due to the potential resources that it contains. LaLande Crater is believed to have one of the highest concentrations of the KREEP rocks. This stands for potassium (K), phosphorus (P), and rare Earth elements (REE). It also contains thorium which could be very useful for fuel for nuclear reactors on the Moon. Potassium and phosphorus are key components of fertilizer (NPK) needed for the growth of plants for food.

The largest crater known in the solar system is the South Pole - Aitken (SPA) crater. As its name indicates, this crater extends from near the lunar south pole up to a Aitken Crater by the equator. The impact was so large and so deep that it is believed that the floor of this crater exposed the Moon's mantle.

On the back side of the Moon, one crater particularly stands out. Tsiolkovsky Crater is named after the famous Russian physicist who formulated the rocket equation and really began to help us understand how space travel could be done. Because the Moon always shows only one of its faces towards us, the backside of the Moon (incorrectly termed the dark side of the Moon) was completely unknown. That was until the Soviets were the first to fly a probe behind the Moon. For this reason, the craters, including Tsiolkovsky, tend to be named after Russians. This crater really sticks out visually because it is one of the few craters on the back side which was so deep that it created a lava flow which is much darker in color than the surrounding highlands. In this crater is a central peak which stands out because it is so bright compared to the floor.

Probably one of the most dramatic expeditions visiting a crater would be the one visiting Cabeus Crater. This is at the lunar south pole and is a permanently shadowed crater. Its ambient temperatures get down towards absolute zero (Kelvin). So, exploring it could be rather hazardous. Special measures would be needed to ensure that all equipment and crew in the mission was being heated throughout the mission. Could this be done simply by internal heaters? Could telerobots accompany the crew heating them with infrared lamps on top of poles? Could sunlight reflected by mirrors (or beamed energy) on neighboring peaks warm up the area where they are traversing? Or is all this just crazy thinking with such a crewed mission being impossible? Time will tell.

But, if possible, the crew could explore that environment to see if the water ice discovered by NASA's 2009 LCROSS mission is a general phenomenon throughout the crater floor. Such findings would be of value to future mining companies.

Perhaps my favorite young crater is Tycho. This is a very dramatic site as it is a relatively young crater with rays streaming out from it. Its floor is filled with lava but with a prominent central peak. At the very top of the peak is a large boulder about a football field across. Imagine the dramatic footage that could be obtained as international astronauts visit that boulder. Imagine as the cameras show them as they come up over the edge of the boulder, the view of the whole crater from that perspective, the group photo, and then the HoverCam flying up and away from the team as they wave to the camera. The TV crew would have a marvelous time planning and executing such footage.

VISITING MOUNTAINS AND VALLEYS

Mountains

Mountains on the Moon don't form the way that they do on Earth (i.e. mostly tectonically). Rather, the primary process for mountain formation on the Moon is due to large impacts. Certain mountains suggest themselves as locations for international exploration.

The central peaks of large craters can be considered as mountains which would be explored in the process of exploring the craters.

The Rumker mountains are a series of volcanic domes. It is a low shield-shaped plateau with multiple volcanoes on top. They are in the northwestern corner of the near side. The Chinese sample return will be from the plains around this area.

Malapert is a very important mountain which is directly in the direction of the Earth from the lunar south pole. For this reason, it could serve as an important communications relay station because it is always within view of the Earth, but it is also within view of much of the south pole area.

Ridges

The rims of craters could be considered ridges. Any crater is going to look dramatic when you look down from its ridge. Rims are rocky especially for the younger craters and so care would need to be taken when driving along them. Perhaps rovers could be sent ahead to scout a safe path.

The Smirnov Ridges are in Mare Serenitatis. These ridges fall into a category of ridges that formed when lava plains were put under pressure by the heavy lava flows. This one is one of the biggest and most dramatic.

There is a connecting ridge between Shackleton and De Gerlache craters. Being near the south pole, it is a ridge that is illuminated for a large part of the lunar year. This area will be a high priority site for development and is my preferred location for the ILB.

The rim of Peary Crater near the lunar north pole has several points that are highly illuminated. This ridge is immediately adjacent to permanently shadowed area with potentially valuable volatiles such as water and carbon and nitrogen-containing compounds. So, it too would be a high-priority site for development.

Valleys

On Earth, valleys tend to form by the process of erosion -- mainly due to water. But on the Moon, there is no such erosion. So, valleys on the Moon are rare but they do exist.

Schroteri is a giant sinuous rille. But it is far larger than most rilles and so it is placed in the valle category. It is so large that it is doubtful that it was ever roofed over.

The Alpine valley runs outwards from the Imbrium system. It is the largest valley on the Moon.

RATHER STRANGE FEATURES

Magnetic Anomalies

Reiner Gamma is by far the most prominent of the magnetic anomalies on the Moon. These may have formed when a lava tube solidified when the Moon had a magnetic field thereby creating a very large permanent magnet. Over time, as charged solar particles impacted the Moon, they were directed by the local magnetic field to strike some areas and were diverted away from other areas. As a result, an aurora pattern was created in the lunar dirt.

This feature is so large that it would probably not be apparent from the surface. So, to properly visit this site an incoming international team should come in for a landing over this feature so that they could see it from above. Upon landing, they would explore the area with instruments to measure the magnetism.

Irregular Mare Patches

We're not quite sure what created the irregular mare patches (IMPs). Current thinking is that volcanic gases came up from below and deposited material in very strange patterns. Crew visiting these sites would be exploring a very visually interesting location. In particular, Ina is the largest of the IMPs and so should be particularly interesting to visit. There are other IMPs that are less spectacular and so should probably be visited first in order to have a build-up of interest in the news.

ACTIVITIES FOR ASTRONAUTS

Expeditions don't have to be limited to visiting some distant location on the Moon. Very newsworthy activities could be conducted that don’t involve visiting an artifact or natural feature.

Habitats

A growing International Lunar Base would need astronaut teams to set up quite a number of specialty habs. Each of these would be newsworthy because of the usefulness of each of these habs to the base.

So, for example, Iraq is the country where, historically, the kingdom of Babylon was located. One of the seven wonders of the ancient world was Babylon's hanging gardens. So, perhaps they would be interested in being the country that set up the base's GardenHab with all the details about what that involves being the basis for a series of news reports.

Chapter 19 describes the ten categories of habs. The InstaBase at the lunar south pole would already have been set up prior to the ILEP.

Activities

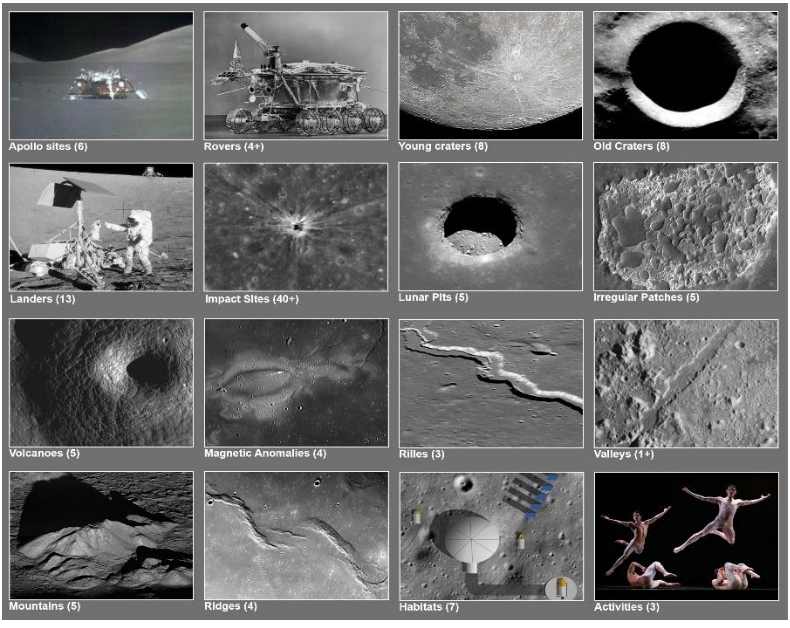
We can imagine some of the activities that international astronauts might engage in.

Performing Arts - Music would likely be a popular and common activity. Likewise, dance in 1/6th gravity would be explored with new styles of dance developed.

Sports - With 1/6th gravity, athletes could perform spectacularly, and it is likely that new types of sports would be invented to take advantage of the unique environment.

Races - These could also occur with the natural irregularities of the surface and the 1/6th gravity resulting in some pretty exciting moments!

And undoubtedly, more creative thinkers could come up with many more noteworthy activities.



Categories of lunar exploration: DevelopSpace.info/international

14 – The International Lunar Base

SUMMARY

During the Initial Crew Phase, cargo landers would deliver components of the International Lunar Base. As international astronauts explore the Moon, many of them will remain behind in a growing international base to represent their nations. Besides continuing to explore, they will also work to set up the International Base and develop ISRU to make the base increasingly Earth independent. The International Base may have three internal time zones to keep the residents roughly in touch with their home countries. English will likely be the common second language.

TRANSITION FROM THE INITIAL CREW

During the six to twelve months that the Initial Permanent Crew make history, Starships would be landing cargo on the Moon in preparations for the International Lunar Base (ILB). For interest's sake, perhaps the Crew could set up one of the habitats but mostly, it would be professional astronauts who would do that.

STARTING THE BASE

American Habitats

Because America has its greater space budget and international leadership, it seems likely that it would be the country to set up the first habitats of what will eventually become the ILB. The initial collection of habitats could therefore constitute an American base but, with the addition of specialty habs from other nations, the American base would then simply become the American section of the ILB.

The American base probably needs to have a certain set of functions to ensure that it can operate as a complete base. As such, it may be that the specialty habs making up the American base will have not just one but two or more functions within each specialty habs. As later, single-function specialty habs from other nations arrive, the American habs can transition to more efficient, single-purpose habs.

Intergovernmental Agreement

The ISS Intergovernmental Agreement (IGA) is a successful example of how this can be done. This agreement is a treaty signed in 1998 by the US, Russia, ESA member states, Japan, and Canada and does a good job regulating ownership, jurisdiction, responsibilities, and cooperation. Something like this would ensure that the base operated well.

There is, however, the need for the agreement to have one different aspect to it compared to the ISS treaty. Namely, it should be anticipated that the ILB will eventually grow to be a settlement that is mostly privately owned. Rather than establishing government-only rules that inhibit the growth of the private sector, it should be recognized, encouraged, and enabled for private settlement and private companies to establish their footholds at the ILB.

MASTER PLAN FOR THE ILB

There needs to be a practical master plan for the ILB. This can't be some bespoke, conceptual design bordering on science fiction. Function needs to take priority over form and the master plan needs to assume near-term likelihoods such as Starship payload capacity, ease of Earth-based manufacturing, that the time, energy requirements, and safety of in situ (e.g. 3D printed) means that these won't be near-term probabilities. The master plan shouldn't show just the end state but also include the plan for how the base can meet its needs at every stage of growth and an estimated timeline given assumed transport capability from heavy lift fleets.

If you, the reader, are into space architecture, facilitating other architects to develop this master plan would be a valuable contribution to the cause of lunar development.

ASSEMBLING THE BASE

Solar Power

Power production needs to scale as the base grows as part of the master plan. Rather than a large field as shown in SpaceX's illustration of Moonbase Alpha, the base would more likely be located at the lunar south pole with long lines of vertical Solar Drapes localized at high points of the topography. Wires would connect the Solar Drapes to American and then International Base.

Corridors

A key component on the International Base would be the corridors that connect everything together into a single base. There are different ways that this could be done including:

- Set out the entire corridor first and then attach specialty habs one by one.
- Add segments of the overall corridor as the base grows in size.
- Each specialty hab could also have its section of the corridor integrated with it

The first approach of inflating the entire corridor first means that the base would have its skeleton visible for years while the specialty hab "meat" is being added on. Functionally that would be fine but aesthetically, the base would look unfinished for a long time. Perhaps an approach where the tubular corridors were folded in on itself (folded intussusception) could solve that problem. We do want to try and minimize the number of mechanical connections, each of which can pose a risk of breach.

Although the amount of time spent in the corridors would be less than that spent within specialty habs, it would still be necessary to shield them against solar particle events (SPEs). Above ground, with regolith poured between outer walls is an easy solution from the aesthetic and practical standpoints.

Attaching Specialty Habs

The master plan would describe the sequence and steps for how arriving specialty habs would be attached to the corridors. This would need to include how utilities would be connected such as electricity, air, water, sanitation, and industrial liquids. Testing would be necessary to confirm that all is safe before inhabitation and usage.

COMMERCIAL COMPETITION

International companies

It is here proposed that the specialty habs and services needed by the International Base be provided by private companies and not by governments. Unlike the ISS, the plan for the ILB is that it would eventually become primarily a private settlement. Given the general inefficiencies, high costs, and non-enlightened, governmental politics the approach should be for each country to fund its own companies to design and develop that specialty hab that the country has chosen will be their contribution. After the R&D is completed, the intellectual property becomes that of the company, and the company operates largely independently with the hope that a small commercial ecosystem will be established at the ILB. This ecosystem will then be available to private customers at (hopefully) reasonable price so that private settlement can really take off.

Coopetition

This is a fun term combining cooperation and competition. In the last couple of decades, America's space program has been emphasizing and experimenting with various forms of so-called "commercial space". It is a mix of straight purchases where the commercial sector has a product or service to buy all the way to where NASA provides most all of the development and operational funding, but where it is hoped that it will ultimately lead to the companies being able to serve other customers thereby placing NASA as being just one of several customers. This approach has had mixed results but has certainly been better than the old "all government all the time" approach.

For the ILB, it is important to have at least two companies providing each good and service. In case one company fails, has poorer quality, or higher price, purchasers will still be able to choose. But the ILB will start as governments being the customers and with a pretty small market. So, we need to be realistic. This won't be a pure, mature commercial marketplace.

THE INTERNATIONAL LUNAR BASE

As the American base is being set up, the ILB will grow with probably the typical ISS partner countries. There will probably be the ESA, Japanese, Indian, etc. sections growing over time. Individual smaller countries will contribute their specialty habs perhaps as part of interstitial international areas.

Time Zones

The Moon is tidally locked with the Earth such that one side always faces the Earth. As a result, the Moon rotates on its axis only once a month meaning lunar days (and nights) last for about 14 Earth days. So, the Moon's sunlight will be a very poor way of dealing with people's sleep cycle. Rather, the moonbase will need to use its own artificial lighting to set the base's day/night cycle. As such, it will undoubtedly be on a 24.0-hour cycle.

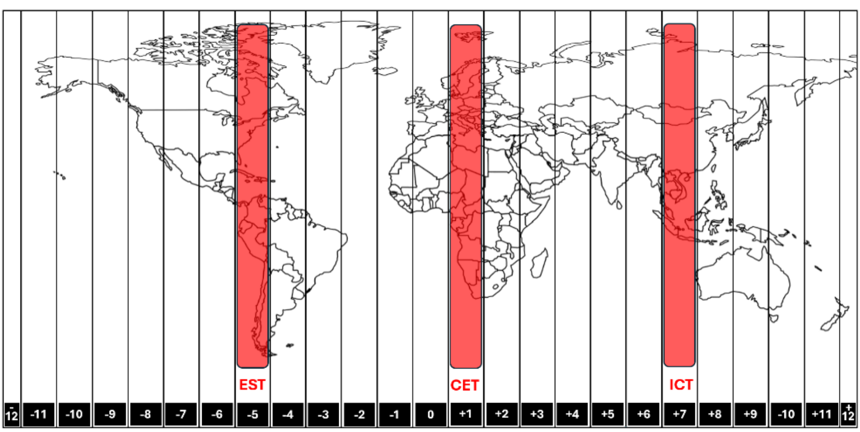
But what Earth time zone should the base be in?

The Moon is only 2.6 light seconds round trip to the Earth. So, residents on the Moon will likely remain in contact with friends, family, and colleagues from their home country. As a result, they will probably prefer to live within the approximate time zone of their home country. Yet they will be within a base with residents whose home countries have different time zones. What to do?

Probably, the ILB should have three time zones. The midpoint between California and Rio de Janeiro is about Eastern Standard Time (EST)and so lunar citizens of countries in the Western Hemisphere can live with that time zone.

Western and Eastern European, African and the Middle Eastern countries can probably agree to live within the Central European Time zone (CEST). When the entire base wants to get together, probably noon CET would be a good time to do so.

Eastern Asia is a bit more challenging since India is a large population but then so is China and Japan. A reasonable compromise would be Indochina Time (ICT).



Proposed time zones for a lunar base covering most of the world.

Languages

As is common in the world, English would probably be the choice for the common language in the base. But as you walk past each section, you will probably mostly hear that language being spoken. But on-person, local AI translation will probably help people communicate with each other verbally because, especially among private settlers, not everyone will know English as the common language.

EXPERIENCING THE BASE

Design

Walking through the mature International Base will be quite something. Designed with aesthetics in mind, the architectural designs will be pleasing. Interior decorators will have figured out numerous, creative elements using space, form, line, light, color, and textures. Well selected plants will help the base not be so technically sterile. Ambient music and nature sounds will please the ear. Perhaps thought could be applied to what smells one might experience in different sections. And when it comes to sound and smell, some of this might be remedial given the environment such as that on the ISS.

International Experiences

As one walks through the base's different areas, you would find yourself passing by the Indian section, then the African section, then the Australian section, etc. Each will have its own styles, sounds, and smells. Would you like some Hawaiian BBQ? You know that you can go to the south pacific section! You want to go to the Samba party tonight? Let's head over to the Brazilian section. You will have the opportunity to meet very interesting people from all over the world. Certainly, life in the ILB will be nothing short of very interesting.

Work Environments

To your right, you are walking past the GardenHab. To your left there is the MedHab. And up ahead is the life SupportHab. You see workers going into the FabHab producing equipment from local resources. There are new specialty habs arriving, being set up, and with their "grand openings". It will be an active, industrious environment.

Religion

People will bring their religious faith with them so there could well be a section of the base with very beautifully constructed religious houses of worship. Initially they may share meeting places with the ability to transform the trappings between services. But eventually there will be a church, mosque, temple, etc. Prominent ministers will be broadcast from Earth. Special services (e.g. Christmas program) might be of general interest with the residents having greater opportunity to be exposed to religious activities than they probably had on Earth.

Community Activities

And finally, the base will have its own community life. In the MeetingHab, there will be musical programs, dance performances, and the latest movie releases. Conceivably, the residents could have some role in self-governance with town halls and elections.

CONCLUSION

When it comes to the ILB, we need to think beyond just a government-centric, McMurdo-style science station. There will be plenty of that. But the ILB will be humanity's first, large, off-Earth community.

15 – Private Settlement Phase

SUMMARY

As described in the Introduction chapter, competing companies would first serve governments in the International Base and then be naturally positioned to serve private settlers as the base expands into a settlement. People from certain wealthy nations will be over-represented and they will likely cluster in parts of the International Base until they become numerous enough to consider branching off into their own colony.

WHAT IS SPACE SETTLEMENT?

As mentioned previously, private settlement will be the natural outgrowth of the International Lunar Base. As flight rates go up and as the companies at the base transition to routine production, wealthy private settlers will begin to afford to settle down in some portion of the base.

What is Space Settlement?

When one thinks about "space settlement" one often thinks of something very large and expensive. Who's going to pay for such large infrastructure? How will the settlement pay to sustain itself? Will they mine some valuable mineral? Will they pay for themselves by producing intellectual property?

But private settlement won't be anywhere as difficult as many presume. Perhaps a historic reference point will help.

When did English people start settling North America? All Googling of that question yields the specific date of 1607. But why?

In 1607, English people landed at a place which they called Jamestown, Virginia. They numbered 104 settlers. More people arrived and their little town grew to about 1,000 before settlers began moving to other towns. So, that's a pretty straightforward explanation for why 1607 is the answer to when the English settled North America.

But wait a minute. Those weren't the first English there. In 1587, Roanoke, VA was settled by 107 people, but, because it vanished within a couple of years, it is not credited with being the first settlement because settlement requires permanence.

Now, Jamestown didn't have a child born in 1607 but rather, a baby girl, Virginia Laydon was born two years later in 1609. So, why does Google say that English settlement started before there were births? Simply because, when you settle down, that's settlement.

Now, isn't 104 people too few to be called a settlement? Apparently not. There is really no lower limit for when settlement starts only that it grows and becomes permanent.

So, the actual definition of "settlement" is this:

A place, typically one that has hitherto been uninhabited, where people establish a community.

There's no requirement for children and there's no specification of the minimum necessary size. So, what exactly does "space settlement" mean?

At its core, settlement means "to settle down". And what does that mean? It means to establish one's home. It is not a transient place where one lives, but one's home for an indefinite period of time. Yes, one may eventually move away...but then one may not. Bases in Antarctica are well established, but no one sells their home and moves to Antarctica. Rather, that is a base, and people’s families remain back at home.

"Settling down" is also often used to refer to starting a family. For example, someone might date around and not commit. But, when they have found "the right one", tie the knot, and establish a family, they are often described as having "settled down".

Settlement Without Children?

But what is a family? Yes, families can include children, but they don't necessarily have to have children. Couples who are married but have no children are still a family. Retired couples whose children have "flown the coup" are still a family. And if those retired couples move to a retirement community that community can grow even though no one is having children. To say that a large retirement community with many homes, community activities, and whatnot is not a "settlement" because they don't have children is just not being reasonable.

Sun City – Summerlin, NV (pop. 12,500)

Above is an image of Sun City – Summerlin, NV (population 12,500). There are no children here but there are groceries stores, restaurants, community activities, and they are governed under city ordinances, and they elect their own local officials. If a community of this size existed on the Moon or Mars, it would clearly be considered a true space settlement.

But we do want space settlements to encompass the entirety of the human social possibilities including children. But, until we conduct animal studies to determine how to safely have pregnancy and childhood, then the first private settlers may well include a disproportionate number of older, wealthy retirees.

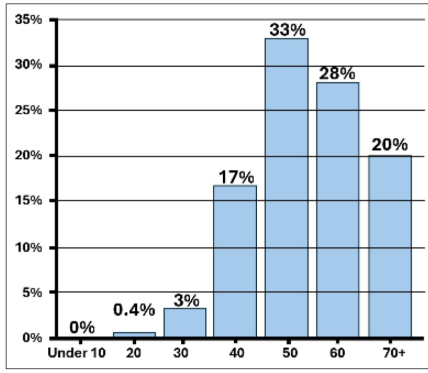
So, these pages propose that actual space settlement could start with as little as a few couples who move off Earth for an indefinite period and that this humble start be the beginning of an increasingly large community. These couples are called the Initial Permanent Crew.

The Historic Significance of Space Settlement

To be historically significant, an initial, small settlement must go on to become a large, sustained settlement. Roanoke Island is a historic footnote because the little colony there didn't survive or go on to play a significant historic role. The history of the founding of Plymouth Colony on the other hand is celebrated each year in America during Thanksgiving. The difference is that the latter went on to be part of something much bigger.

These pages describe how an Initial Crew of four couples could be a small, tentative, initial settlement. But that scenario won't become historically significant unless the population there grows in an increasing manner. The Innovative Plan describes an immediate follow-on phase with an International Lunar Base and Exploration Phase. This would provide the revenue to the participating companies and the flight rate to bring down the costs to the point where wealthy individuals might be able to move and settle down on the Moon. With mastering the development of even more in situ resources beyond water, the amount of material needing to be shipped from Earth would become increasingly less thereby reducing the cost to sustain the settlement.

RETIREES



Millionaires tend to be older.

Over-Represented Among Settlers

Who will the initial settlers be? Most of them will have three characteristics in common:

- They will have lived long enough to save up enough money to afford the ticket and living costs.
- They will be free of child-rearing responsibilities.
- They will be free of occupational responsibilities.

Retirees fit this profile perfectly. There can be little doubt that retirees will be over-represented among the first settlers.

Off-Earth Retirement

It is anticipated that private settlers will start arriving on the Moon and during the International Lunar Exploration Phase. They will not only pay for their own transport but would have to pre-pay for their housing and life support for the remainder of their life (freeloading one's oxygen is not an allowable option). These private settlers could arrive in two phases:

1) **The Early (Founder) Private Settlers:** This would be a unique and very historic group of people. They would fully pay their way and be willing to contribute their skills (usually voluntarily) for the purpose of playing a historic role in getting the settlement ready to grow its population. Those private settlers with certain anticipated needed skills (e.g. dentists) would find themselves being pushed towards the front of the line.
2) **The Later (Regular) Private Settlers:** This group includes those who may have higher quality of life requirements and/or who would rather be fully retired than be doing a lot of work in their retirement. And/or it may be that their spouses will want to wait until the lunar settlement has a lot of amenities.

Staffing

It is understandable that some will question how an initial settlement would be able to provide the services needed and desired by settlers, especially retirees who may be used to having a lot of conveniences. To understand how this can be addressed, consider the likely order in which settlement will occur. It would start with the Initial Crew who are highly trained and who require no amenities but are happy to be fulfilling their life dream. The next phase would be up to 1,000 international astronauts, also fairly young, healthy, and happy to suffer some deprivation for the purpose of building up the infrastructure necessary for settlement. Likewise, the Early Private Settlers will be a select group of people. They would need to be healthy to not burden the lunar medical system with conditions that it is not prepared to meet. Paying their own way, they would need to be wealthy. But they cannot be part of this group unless they are also willing to give their skills and experience for the growth of the base in preparation for the next phase. An organization would determine which settler goes when based upon a roadmap of what skills are needed at what point of development and settlement size. Later settlers can be more typical of retirees with higher expectations and poorer health. By the time that they arrive the quality of life and medical care will be at a level which they expect.

Quality of Life

Some people object that retirees would not want to settle the Moon because the quality of life would be so poor that it couldn't compete with the quality of retirement opportunities on Earth. But the belief that off-Earth settlement must be cramped, dangerous, deprived lifestyle fails to take into the account the many things which could easily be done to address the quality-of-life issues in an off-Earth settlement. There are also several unique experiences that only a lunar settlement could provide which would not be available on Earth. Then, there is the common mistake of presuming that off-Earth retirees would be typical of on-Earth retirees. There are about 1.4 billion people between the ages of 55 and 70. Certainly, among such a large group are those with wealth and who would be attracted to the opportunity to play a historic role in helping humanity start to move off Earth.

For later settlers, they could have very large living areas, be part of a community more exclusive than any on Earth with the best entertainment and fine dining. From the Moon, they could attend their loved ones' events on Earth via telepresence. Large habitats could provide many of the activities found on Earth such as swimming, golfing, and visiting the spa. And the 1/6th gravity would allow older people to have a mobility and to do feats which they were unable to do even in their youth (e.g. effortlessly leaping to great heights).

Partial Gravity & Older Settlers

Older people would receive special benefits from living in the 1/6th gravity of the Moon. For starters, the pain of arthritis would be relieved by having less weight bearing down on their feet, knees, and backs. They would be able to more easily arise from a seated position. But more than this, older people on the Moon would be able to do unimaginable feats such as back flips.

Very importantly, older people would be able to be active in a manner that they had never been before. They would be able to jump higher than they've ever been able to jump before. The dance classes would be particularly popular as everyone would be able to be airborne longer than even Baryshnikov (literally!). Physical activity is very important for maintaining health during older age.

Certainly, osteoporosis is a concern in the elderly and 1/6th gravity could speed this process. But the increased activity including impact exercise would help and momentum is maintained on the Moon so the impacts should have the same effect as on Earth. With exercise being more fun, the amount of exercise done each day would likely increase and, with the new type of exercise equipment being used on the International Space Station, bone mineral density loss has almost stopped.

MOTIVATIONS FOR SETTLING SPACE

Given that it is cheaper to retire on Earth and there are many wonderful places on Earth to retire to, what would motivate retirees to settle down on the Moon? Certainly, the activities described above would be attractive, but attractive enough to justify the expense? And certainly, retirees don't retire to make a profit. They retire expecting to spend money not make money.

There are three non-economic but still powerful reasons that would attract certain people to retire on the Moon:

- **Personal significance:** People who are part of the initial settlement will know that their story will be going down into history. Later generations would know what their ancestors did to help humanity move off Earth. So, one can retire on Earth to relative insignificance or retire on the Moon and literally make history. For some, this will be fairly strong motivation.

- **Prestige:** Not everyone is wealthy enough or skilled enough to be part of the first settlers to move off Earth. Thousands of people apply to a few astronaut slots. Here is an opportunity for someone who has "made it" to demonstrate to their peers and family the ability and courage to do what few can do. Off-Earth settlements can only be populated by the wealthy and successful. The typical net worth of the settlement citizenry will likely be higher than any community on Earth. Being part of such a community would be noteworthy and hence attractive to many.
- **Unique Experiences:** Living on the Moon would allow the settler to not only do unbelievable activities such as flying but to tour the Moon as well.

For Retirees, the Moon Has the Advantage

Compared to Mars, the Moon offers retirees certain advantages. The most significant will be proximity to the grandkids. This factor alone will probably make settlement on Mars less likely than settlement on the Moon. The round-trip time delay for telecommunications between the Moon and Earth is about 2.6 seconds. This is short enough to allow telepresence at family events such as graduations, weddings, and holiday gatherings. For Mars, it averages 25 minutes which limits communications to sending video emails. Business consulting is likewise better from the Moon than Mars. Also, the Moon's 1/6th gravity allows for more amazing activities than can be done on Mars (38% of Earth's gravity). Finally, anyone would find the six month-long confinement in a craft going to Mars pretty inconvenient. For the Moon, the trip is only for three days. And more passengers on a shorter trip means a cheaper ticket.

16 – From Base to Lunar Countries

SUMMARY

Looking out to the 2040s, we can anticipate that, as people groups start setting up their own colonies, thoughts will naturally start moving toward the idea of self-governance. To prevent future border conflicts, inspiration can be drawn from the Northwest Ordinance Act to pre-draw borders and set criteria for a vote of independence after reaching a certain population size. It is unlikely that anyone on Earth will take physical action to stop self-governance and so it will happen.

Undoubtedly, any Plan for lunar settlement imagined at this early date will have to change when confronted by reality. But the attempt to figure out how things will probably play out is useful for two reasons:

- It inspires people with a vision of what is possible,
- It serves as a reference point to help planners think through the relevant factors.

The Plan laid out here is based upon the idea that there are natural factors which will drive the direction of development. Being natural, we may be able to understand how they will likely play out.

THE INITIAL BASE

Most everything starts small before growing large. A lunar base will be no different. The first habitat will likely not be a specialty hab but a general hab in which all of the major functions would be provided within a single habitat. This could be either the StarHab or the InstaBase.

These pages argue that the Initial Crew should be private workers for companies in a public-private partnership with NASA. These crew would help establish the infrastructure needed for the following phase -- the International Lunar Base.

THE INTERNATIONAL LUNAR BASE

US Habitats

Even during the Initial Permanent Crew phase, cargo landings will still be occurring including very large inflatable habs and equipment which will constitute the beginnings of the International Lunar Base.

With NASA having the largest space budget in the world by far, the initial habitat would probably be followed by several large US habitats consisting of some of the most foundational specialty habs. These would be habs such as the DormHab, (life) SupportHab, and StorageHab (with food supplies prior before food is grown. American astronauts would arrive, move into the initial base habs and then, from those, continue to receive and set up more specialty habs. Astronauts from allied (e.g. ISS) countries would start to arrive and set up those specialty habs designed by their countries.

Specialty Habs for International Astronauts

This phase is the main phase in which a permanent base becomes reality. The pages dealing with the International Lunar Exploration Phase goes into some detail showing that most all countries could afford at least one seat on a mission of lunar exploration. The result is that somewhere around a thousand, highly-trained international astronauts could populate the growing international base. It is during this phase that most of the specialty habs would be set up and adjusted until they work well.

It is proposed that the specialty habs not be developed directly by the countries but that the countries would fund their companies to develop their specialty habs but that companies from other countries developing competing habs wither the same function. In this way, there will be competition on both price and quality thereby reducing the incremental costs as private settlers start arriving.

An international base would also need to have clarity on certain governance issues, and the reality of a coming, permanent base would give the specific push necessary to get people to finally make decisions regarding off-Earth property rights, resources, and eventually, political independence of future colonies. I have doubts that these agreements will necessarily come through some United Nations committee but rather would be intergovernmental agreements like the ISS agreement or a follow-on to the Artemis Accords.

National Sections

Retirees will undoubtedly make up a disproportionate percentage of the initial private settlers. These older people may find it difficult to learn the common language (i.e. English) of the international base. For this reason, we can envision language-specific sections of the international base developing in which different languages are commonly spoken in different areas of the base. Advanced language translators will help with communications but for everyday conversations, people would rather not have to constantly go through translation. These linguistic, national, religious, and philosophical sections would lay the foundation for small, separate colonies probably located in the polar region, but within easy driving distance to the International Lunar Base.

POLAR COLONIES

The south lunar pole has hundreds of square kilometers of areas with increased sunlight throughout the lunar day. About 13 distinct areas have been identified each having areas of increased sunlight and with nearby permanently shadowed craters potentially having elevated concentration of ices. Colonies in each of these areas would probably still be connected to the international base and to each other via compacted dirt roads, covered tubes, or even rails. These colonies could grow as large as tens of thousands of residents with sufficient space, water, organics, and other resources from the local region. Access to local volatiles may be considered a constitutional right for the colonies (the right to life).

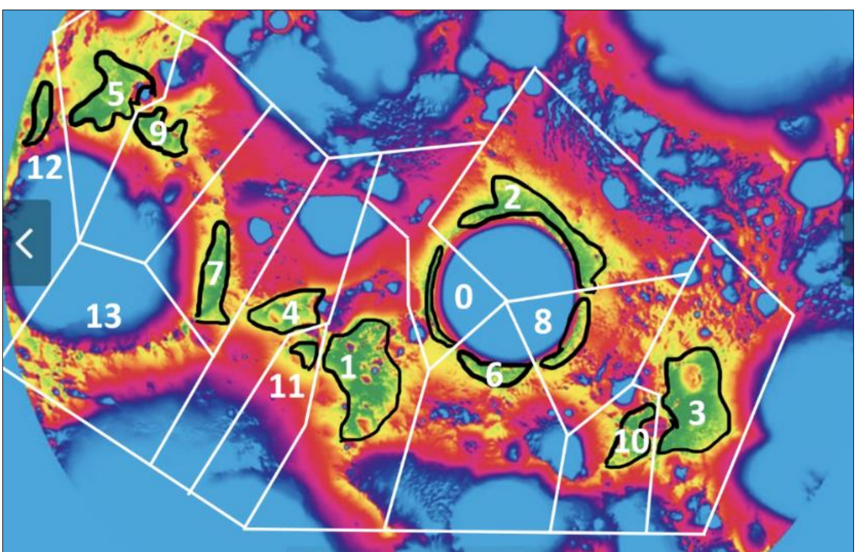
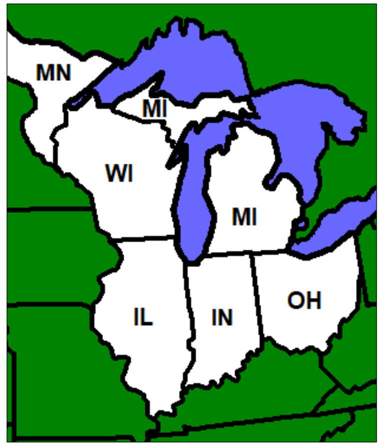


Illustration of polar areas containing both high sunlit areas and PSRs.

TERRITORIES & COUNTRIES



The Northwest Ordinance.

The term "territories" is used to describe pre-defined areas of the Moon that could, one day, become an independent lunar country. If there are no boundaries pre-drawn for colonies at the poles nor boundaries pre-drawn in the rest of the Moon, then people groups could grow up intertwined with each other and future border disputes could arise. America's history of how it handled the Northwest Territories demonstrates a rational and peaceful way of establishing future, political entities. Before different people groups start settling on the Moon or Mars, we need to have enough foresight to realize that, one day in the future, where borders are drawn will be a significant issue. It is best to prevent conflict then by establishing boundaries now while there is little at stake.

Whereas the Outer Space Treaty (OST) prevents signatories from claiming property for national sovereignty, it is unreasonable to believe that, in the future, people living on the Moon or Mars will never wish to become politically independence. They will. And when they do, those new political entities will not be signatories of the OST and so it would be entirely reasonable for them to claim sovereignty over the land that they reside on. It is also unreasonable to believe that countries such as the United States will be so opposed to people on the Moon (many coming from the US) issuing their own Declaration of Independence. Will the US boycott supply launches thereby resulting in their deaths? Will the US send the marines to stop these moves towards independence? Not only would the US not do any such thing, but they would also welcome their compatriots deciding to become independent branches of humanity spreading common values beyond Earth.

It is impossible to determine with exactness what those countries might be. But it is reasonable to guess that they might be based upon the same factors that people group themselves on Earth including: linguistic, national, religious, and political differences. It may be that countries on the Moon or Mars will arrange themselves into a federation in which they govern themselves and yet have some body representing all the people on the planetary body.

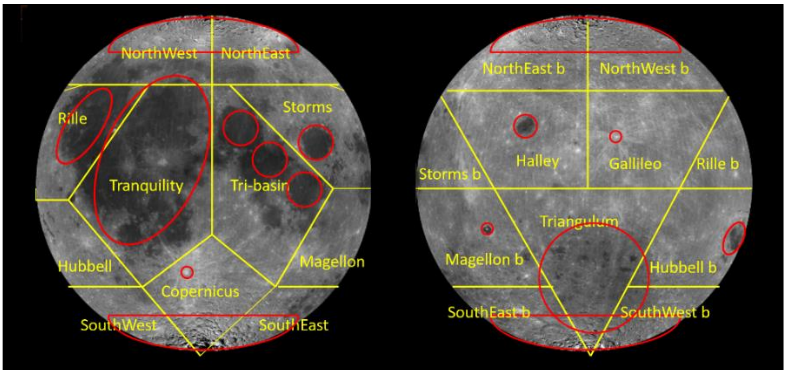


Illustration of pre-drawn territorial borders on the lunar front and back.

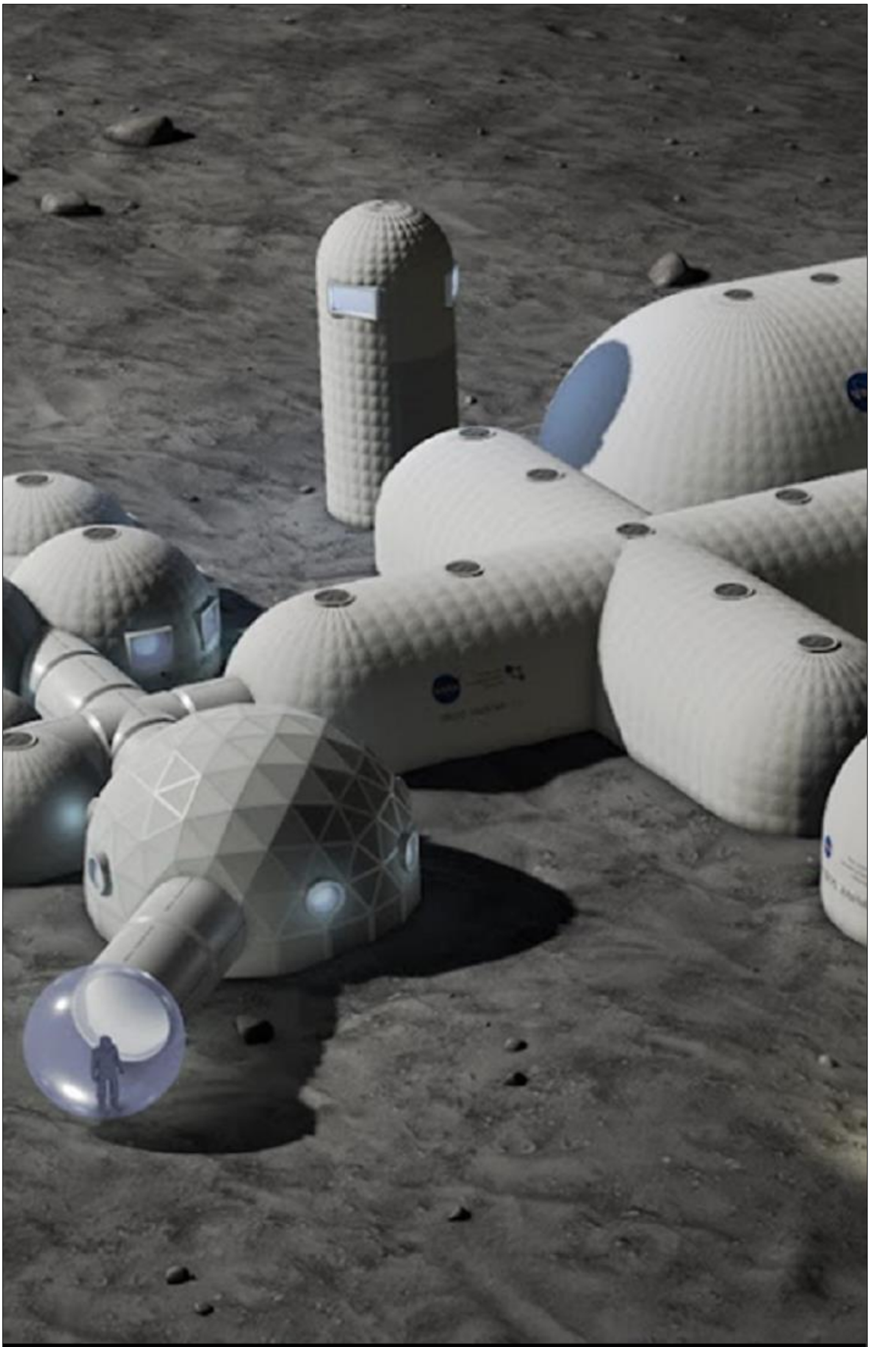
Repeat on Mars

Whereas few point to the Martian poles as the logical starting point for Martian colonies, most of everything else would follow similarly to how the colonies play out on the Moon.

ESTABLISHING BORDERS

It may be that UN agencies will be unable to develop sufficient consensus to propose future borders on the Moon and Mars. But perhaps an international, self-appointed group could be the first to identify proposed borders. An example of something similar is the Geneva Convention setting standards for how war was conducted. It was first established by the non-governmental International Committee of the Red Cross. But those standards were so useful, they have been broadly adopted internationally as customary law to where countries who haven't signed the Geneva Conventions are nonetheless held to them. Until anything better is established, the suggested borders will remain as the only ones proposed.

An international committee proposing borders.



HABITATS

17 – StarHab

SUMMARY

The concept of StarHab is of a Starship landing on its tail and then tilted over, using tethers, onto a large, inflatable pillow. This concept is proposed as a simple way of establishing the first permanent habitat on the Moon for the Initial Permanent Crew. The Crew would land separately, enter, clear the propellant tanks, and then cut doorways through the methane tank. Using pre-welded attachment points, they would move floor sections, walks, doors, furniture and equipment from the payload bay throughout the rest of the StarHab. The end result would be a habitat, 2.5 times more voluminous than the ISS. StarHab would be thoroughly networked. This Chapter goes into what each section would contain.

What would be the simplest, most logical first habitat whether it was on the Moon or Mars?

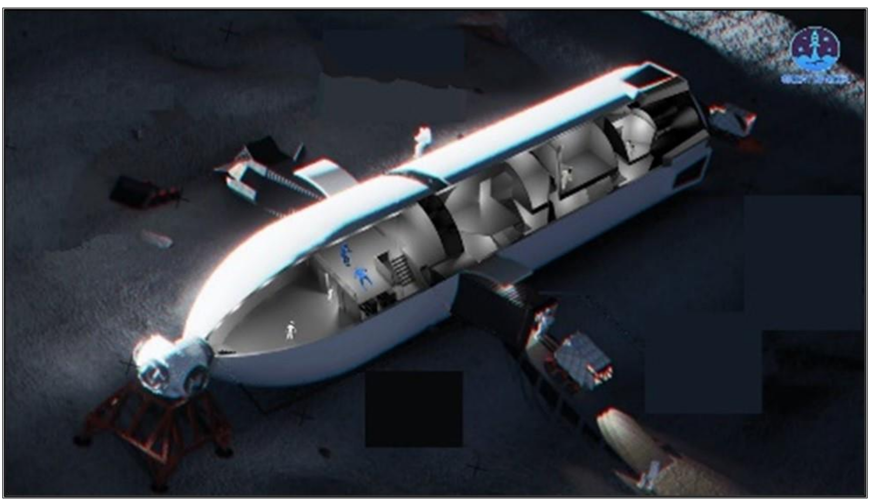
Many space advocates have imagined any number of different types of habitats. There's the aluminum cylinder that we have lots of experience with on the ISS. There's the inflatable habs concept perhaps located within a lava tube. Then there's the ever-so-popular 3D printed habitat.

But the first habitat could be practically no habitat at all (the best hab is no hab?). Instead of the Initial Crew exiting their lander and setting up a habitat, they could just remain in their lander and call it home. After all, it's already set up with power systems, life support and thermal control systems. And indeed, SpaceX's artists have rendered this concept, and it was shown after the ninth Starship test flight.

However, providing a vertically oriented Starship with enough radiation shielding for a long-term, Initial Permanent Crew is somewhat of a problem. One could imagine robots filling bags with lunar dirt to be winched up and placed around the crew compartment. Also, in the vertical orientation, a lot of the floor space would be taken up with the stairway (or ladder) to the next floor. And if one were to utilize the propellant tanks for habitable space, there would be about fifteen, 3-meter high stories -- that's a lot of climbing for a single habitat.

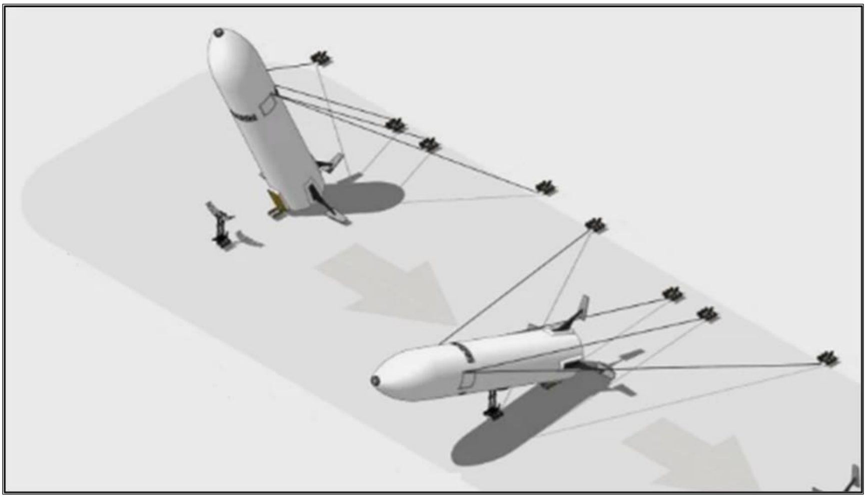
But the Space Development Network working with graduates from the International Space University are proposing that a Starship be designed to become a horizontal habitat (aka StarHab).

The StarHab concept is that of an upper stage Starship modified to where the payload section has been outfitted with three horizontal floors with sections of flooring, walls, equipment, and furniture stacked in the payload bay between the floors. Prior to launch, anchor points would have been welded into the sides of the methane and oxygen propellant tanks to which flooring panels could be affixed thereby resulting in three floors throughout the entirety of the StarHab. By using all three sections of the Starship it would be turned into a habitat with a volume 2.5 times that of the ISS (all from a single Starship landing!).



Cutaway rendering of the StarHab.

Upon landing on the lunar surface, the liquid methane and oxygen would be removed and any residual completely vented to the infinite vacuum of space. Next, dexterous robots would be lowered from the cargo bay doors. Then, three long tethers would be dropped down, and the robots would take the ends of the tethers and use ground anchors to secure them into the ground at three points of a triangle around the StarHab. Perhaps deep penetrating helical anchors would work best like that used in NASA’s Lunar Anchoring Device Concept (LaRC, 2011).



The StarHab being horizontalized using tethers.

Next, using electric winches, the StarHab would be slowly tilted over in a very controlled manner. After being tilted down to perhaps 35° above the lunar surface the tethers would be released with the StarHab tilting over to the ground in a controlled manner using either a scissor lift or large inflatable pillow. The result would be a completely horizontalized Starship.

Subsequently, robotic vehicles would pile loose lunar dirt on top of the StarHab to provide shielding for space radiation and micrometeorites and thermal insulation. Later, the Initial Permanent Crew would land in a separate Starship a short distance away and would drive to the StarHab and enter it via an airlock.

Once inside the StarHab, the Crew would cut doorways through each of the three floors of the central methane tank. The crew would move flooring sections from the payload bay through the cut-out doorways of the methane tank and secure the bottom, middle, and top floors to the welded anchor points. They would then return to the payload bay and move and attach vertical walls, doors, electrical/comms lines, equipment, and furniture. The final result would be a large habitat with plenty of space for the Initial Permanent Crew to live and work within.

The Network has completed our own design of the StarHab as follows and we welcome additional work by professional space architects.

From aft to front, the upper floor would contain a kitchen, pantry, dining area, living room, and Agriculture1 area. The middle floor would contain four bedrooms, a fitness/performance area, centrifuge, and storage area. The bottom floor would contain office space, utilities room, and Agriculture2 area. Below the bottom floor would be a basement with storage area.

From the ISU team's detailed estimate, we think that the internal set-up phase would take the Initial Crew of eight working regular astronaut hours (10-12 hours/day) about two weeks. Likely there would be an "Commissioning Day" as this little Team, this representative of humanity, begins settling down and operating their modern, little homestead.

To see how the Initial Permanent Crew would live and work in the StarHab, read chapters 20-22 and 28-31 respectively.

18 – The InstaBase Concept

SUMMARY

The InstaBase concept is simply an initial base composed of inflatable modules all connected together. As a compacted payload, it would be lowered from a Starship to a vehicle that would transport it to a robotically prepared site. Setting it up would be a simple matter of inflating it with condensed air. The InstaBase would be either an alternate to StarHab or an intermediate phase between StarHab and the International Lunar Base. SpaceX has rendered an inflatable base looking very much like the InstaBase.

When the first permanent crew arrives on the Moon, what sort of habitat will they live in?

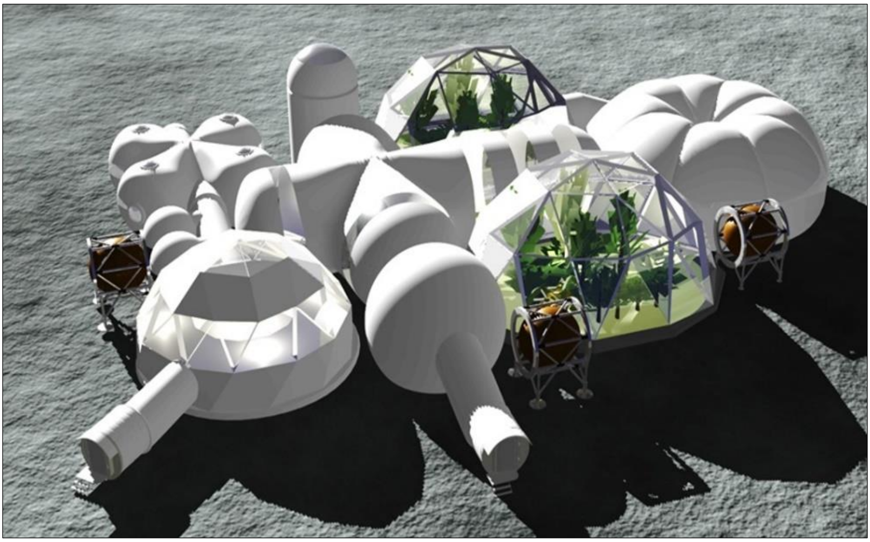
INTRODUCTION

The name InstaBase comes from the concept of an inflatable base that can be set up very quickly simply by opening the valve on a tank containing liquified air. It contrasts with other construction concepts that take a great deal of time and energy assembling habitats using local resources.

The InstaBase is proposed as an alternative or an immediate follow-on to the StarHab concept where an Initial Permanent Crew would reside for six to twelve months in a small but fully functional base. It would precede the very large specialty habs and so would not be replicated in large numbers. Both the StarHab and InstaBase concepts are equally applicable to both the Moon and Mars.

Although the Space Development Network came up with the InstaBase concept several years ago, we are pleased to see SpaceX has apparently conceived of a very similar concept as evidenced by their artistic rendering of a very similarly sized, inflatable concept during their Starship test launch #9 pre-flight show.

Please see Chapter 19 where the pros and cons of inflatable habitats are discussed.



Artist rendering of the instaBase.

COMPARISON WITH OTHER HABITATS

Why is the InstaBase a preferred base option for the Initial Permanent Crew? Here, we'll go one by one through the other options.

StarHab - StarHab (horizontalized Starship habitat) is a perfectly good alternative to the InstaBase. But later we will be moving on to very large, inflatable specialty habs which would constitute the initial habitats for the International Lunar Base. The volume of the InstaBase was sized for an Initial Permanent Crew of eight. As a result, it came to about 2,500 cubic meters which coincidentally is almost the exact volume of the StarHab after the propellant tanks are vented, cut into, and set up for habitation. However, if we wanted to increase the size of the InstaBase, the payload mass of the Starship would allow for it to be even larger.

Aluminum Cylinders - We have a lot of experience with aluminum cylinders on the ISS. So, there's that. But assembling a large base with numerous cylinders would require a corresponding numerous launches and hence price. At this point, if we were to launch a Starship next to the ISS and utilize its propellant tanks for habitable volume then it would have 2.5 times the internal volume of the ISS in a single launch! Just because we did things a particular way before doesn't mean that we have to continue that same approach. Capabilities are moving forward and so should we.

3D Printed Habs - As discussed in some detail in the Specialty Hab chapter, 3D printed habs have significant disadvantages compared to the inflatable InstaBase. Time for construction, large power requirements, risk of equipment breakdown, safety issues when not using the best materials, and lack of off-Earth experience all make this option not a realistic probability.

In Situ Produced Habs - Habs produced from locally produced metals or bricks suffer similar disadvantages to 3D printed habs. Let's just leave it at that.

Lava tubes - Very popular in some quarters is the idea that the best first location for a lunar base would be within a lava tube. The advantages include natural shielding from micrometeorites, radiation, and thermal extremes. All true. However, there are no known lava tubes near the lunar south pole where the very valuable Peaks of Eternal Light (PELs) and permanently shadowed regions (PSRs). This includes having to deal with the 14-day night when one has a base away from the poles. In the shielding section of this chapter, it is shown how providing sufficient shielding to any initial habitat is not particularly difficult.

UniHab - This concept preceded the InstaBase concept. Both have roughly the same internal volumes for each habitat section but the UniHab (as the name suggests) is a unified habitat where all of the sections are rooms within a single structure. The overall structure is shaped like a thick pancake with a roof held flat by internal walls and tethers. The diameter of the UniHab is 36 meters with an indoor centrifuge of 15 meters diameter. It was specifically sized to accommodate an Initial Permanent Crew of eight composed of four couples. With a relative flat (air mattress-like) roof, the UniHab can be unfurled via inflation, deflated flat, and the robotic tractors could push regolith onto the top of the UniHab which would then be inflated thereby easily lifting the regolith shielding via enormous air pressure. The tractors could then push regolith on the sides thereby providing complete protection. But the reason why our Network moved on to the InstaBase concept is because the end result would be a flat mound of dirt not "worthy of a great nation". In other words, aesthetics won out. But from the standpoint of ease of shielding, the UniHab is a bit superior. And also, to construct our own, full-scale mock-up of such a base, it would be eminently easier to compose if of individual modules rather than have to roll up and pull the entire base into a trailer in one move.

DELIVERY AND SET UP

The InstaBase would be delivered to the lunar surface as a standard payload in a Starship and lowered to the ground. Surface vehicles would transport it to a spot where robotic tractors had pre-prepared the surface. The straps on the InstaBase package would be cut and small amount condensed air would very quickly inflate the InstaBase giving it its final shape but at significantly less than the final 1/2 atm. Robots would drive around the periphery and anchor the edges of the InstaBase's floor to the ground using ground anchors. The InstaBase would then be inflated to the final 1/2 atm.

SHIELDING

Teleoperated robots with a stacking conveyor would pour regolith into holes at the top of each module. These holes would be propped up via large springs. The regolith would slide down between the outermost layer and the inner layer of each habitat. Tethers would maintain a consistent width between the inner and outer layers. A device within the habitat would vibrate the air inside to vibrate the inner wall thereby facilitating the regolith to slide between the two layers of the wall. The result would be a layer of regolith of a consistent width providing shielding against radiation, micrometeorites, and wide thermal swings.

DESIGN

The InstaBase is a conceptual design to accommodate an Initial Permanent Crew of eight. More professional improvement of the design is welcome. The habitats involved with crew living were sized to rooms within a typical house with common areas sized for up to eight people. There are four bedrooms and two bathrooms. The GreenHabs were sized to provide for the full nutrition needs of the Crew of eight using work done at the University of Arizona (Tucson) Prototype Lunar Greenhouse. The centrifuge diameter is somewhat arbitrary. Obviously larger is better but there has to be a reasonable limit. A lookout town is mostly an aesthetic design choice.

MODULES

The InstaBase would be composed of 10 attached modules including:

● BedHab	● WorkHab
● BathHab	● GreenHab1
● LivingHab & Kitchen	● GreenHab2
● The Bubble	● SpinHab
● ArtsHab	● StorageHab
● The Tower	● The Garage

- **Living Quarters -** The BedHab would have four bedrooms, each with a king-size bed for a couple. There would also be the typical furniture in a bedroom. The BathHab would be composed of two bathrooms allowing different couples to utilize the facilities at the same time. The Kitchen would have everything that you would expect in a home kitchen but scaled up for eight people. In an overhead track would extend robotic arms that could help with food preparation thereby offloading cooking workloads. Above the kitchen would be the Livingroom where all eight crew could sit in couches and other furniture with a large screen for entertainment or communicating with Mission Control as a group. It would also be the room where board and floor games would be played. Extending from the Kitchen is a clear tube leading to a clear sphere. Two people could "exit" the InstaBase and stand in this sphere while still in the InstaBase's environment. In this way they could "go outdoors" without having to suit up.
- **ArtsHab / FitnessHab -** The ArtsHab would be a dual-purpose facility. Normally portable exercise equipment would be there. But on occasion, that equipment would be moved into neighboring modules to clear the floor. At that point the ArtsHab would turn into a PlayHab for things such as music and dance. The ceiling of the ArtsHab is a hemisphere. With "sticky" footwear, crew could run up the walls and even across the ceiling as part of their gymnastic or dance routines.
- **WorkHab -** The WorkHab has several different wings. The largest wing is for machining with a set of equipment to machine block of metal and work with sheet metal as well. Another wing would be dedicated to chemistry processing including organic chemistry using the organics extracted from ice in the PSRs. The GeoBio

wing would house animals used in the centrifuge studies and well as receive, store, and process rocks brought in by robots. Finally, the last wing would be for robotic assembly and repair. Specifically, some of the large

- **GreenHabs -** As mentioned above, these large modules are specifically sized to provide the full nutrition for the IPC on an ongoing basis. This volume of plants also can process the air and water needs for more than the crew of eight.
- **SpinHab -** This would contain a spinning cylinder with four rooms allowing crew to comfortably experience a full gee provided that they are conducting "sedentary activities" where they are not moving their head -- think of screen time. It would also be used to conduct animal experiments for the artificial gravity prescription (AGRx) for healthy gestation and childhood.
- **The Tower -** Crew could easily climb up in this lookout to windows and view more distant locations.
- **Storage Hab -** Certain food items, spare parts, and produced parts would be stored here.
- **The Garage -** Although not part of the current design, a garage with a large airlock could allow autonomous vehicles to be brought into the InstaBase so that they could be cleaned, repaired, and even assembled in a short sleeve environment.
- **Tanks -** There would be several tanks for fluids located at certain locations around the InstaBase. This would include tanks for water, nutrient solutions, waste, CO_2, etc.

OUTDOOR SPACES

- **Air Locks -** Strategically placed around the base would allow ingress and egress. They should also allow for crew vehicles to attach to the InstaBase.
- **Metallurgy -** A purely outdoor area somewhat away from the InstaBase is where teleoperated robots could conduct metallurgy. Alternatively, the metallurgy work could be done next to the Parabolic Drapes. Read about metallurgy in Chapter 29.
- **Walkways / Driveways -** Microwave sintering could create dust-free paths by fusing together the regolith. This would allow limited EVAs in spacesuits without the risk of exposing the suits to the abrasive regolith.

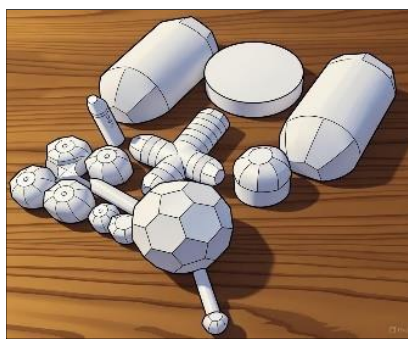
PROGRESS

The Space Development Network has constructed a full-scale mock-up of the InstaBase to illustrate the concept. Using inexpensive sheet plastic and a high school gymnasium we assembled the entire base measuring 30 m x 52 m (100 ft x 170 ft). We have conducted displays to the community and at that National Space Society's annual ISDC conference.

The Network's inflatable InstaBase mock-up and SpaceFair.

To take it to the next level, professional space architects would need to completely redo and improve the design. Our concept serves as a conceptual starting point.

Download a file to print your own papercraft version of the InstaBase.



19 – Specialty Habs

SUMMARY

The most logical form of habitat for the International Lunar Base would be the largest possible inflatable habitat that could fit as a payload in the Starship. At 100 tonnes, it would be something like a very large, square air mattress of about 70 meters on a side and three floors in height. Its double walls would be filled with regolith shielding. To give some perspective on its size, that floor space is the equivalent of 69 average American homes!

Countries and companies could choose which specialty hab they wanted to design. That could be their contribution to the International Lunar Base.

THE ADVANTAGES OF INFLATABLES

Volume and Mass

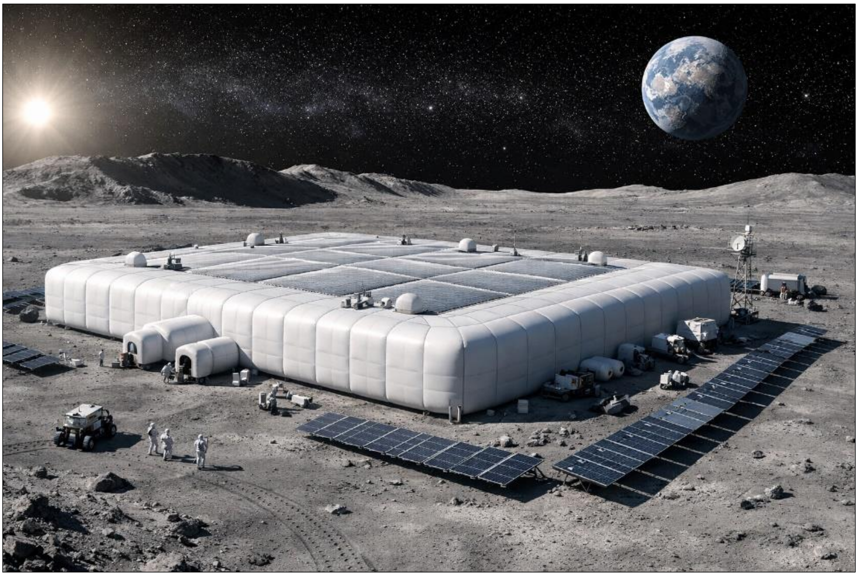
The most obvious advantage of inflatable habitats is that one can tightly pack them into a payload and yet, after inflation, the interior volume can be far greater than their payload volume. By contrast, you are stuck with the volume of rigid structures. For example, SpaceX listed the payload volume of a Starship as being 1,000 cubic meters. By contrast, after the InstaBase payload is removed from the Starship and inflated, the volume of all its modules would total a bit over 2,500 cubic meters.

Ease of Set-up

Whereas 3D-printed habitats will take a lot of time and energy to construct without manufacturing with all of the safety practices available on Earth, inflatable habitats can be constructed using the best materials and tested before launch. The next major section in this chapter describes the process of set-up. It's not that difficult.

Experience

Did you know that there have been three inflatable habitats launched to space, and by a single company - Bigelow Aerospace? They launched Genesis 1 and Genesis 2 which remained in orbit for up to 18 years. Currently on the ISS, their BEAM module is attached and will continue with the ISS until it deorbits for a total of probably 14 years. Several commercial LEO companies expect to have inflatable modules. But what we need is for one of the companies to develop surface inflatables.



Single delivery of a 100 tonne payload for the empty structure.

Risk of Collapse

Many would have the automatic concern about inflatables rupturing due to orbital debris or micrometeorites. Well, at lunar distances, orbital debris is practically non-existent. That risk is too low to worry about. Micrometeorite impacts are a risk and have hit the ISS before. But the Plan described in this book involves shielding the habitats with local regolith. This effectively prevents micrometeorites from reaching the interior surface of the inflatable habitat. Sure, in theory habitats could be struck by much larger meteorites. But this would be equally likely for the ISS and it operated in LEO for 27 years with far less shielding than being proposed here for lunar habitats. Again, the risk is just too low.

Frankly, the greater risk is failure of material resulting in a catastrophic rupture along a seam. One is reminded of such an incident in the fictional movie, “The Martian”. We would want to test to beyond the safety factor (2.5 – 4). So, for example, while being developed, an inflatable habitat could be inflated to 2.0 atm or even all the way up to failure (as is commonly done).

There are processes to reduce the risk of rupture. One common one is to include rip-stops into the inflatable materials. These are particularly strong threads every so often in the fabric. If a rip starts, its propagation will be stopped when it reaches the thread. If a 1 cm tear were to occur through both air-proof layers, the crew would have about 20 minutes to find and easily patch the hole. At the University of Maine, a study was done showing that microphones could triangulate the hissing sound to rapidly identify the location of the leak.

Inflated habitats have so much internal pressure that the walls are rigid and the modest amounts of regolith shielding proposed would literally not make much of a dent in the walls. Think about how the four wheels of your car counter the 1.5 tonnes of mass.

Finally, if there remains a concern about sudden collapse, one could easily erect an internal metal skeleton to hold up the roof with regolith shielding which, on the lunar surface, weighs only $1/6^{th}$ than if it was on Earth.

THE DEPLOYMENT OF SPECIALTY HABS

After telerobots have prepared a surface for an inflatable habitat, it is delivered as a payload and transported on the back of an electric vehicle to the center of the prepared site. After straps are cut, “set-up” is quick and easy. It is a matter of remotely opening a valve of condensed air and the inflatable payload unfolds and expands until inflated to perhaps 0.5 atmosphere of pressure. Telerobots would need to use ground anchors to anchor the peripheral and internal tethers in order to increase the amount of flat floor on the ground.

There would need to be a master plan for what habitats will go where and in what sequence. Each module would need to have connectors allowing it to be connected to other current and anticipated specialty habs and airlocks.

THE DESIGN OF SPECIALTY HABS

Layers

For habitats in orbit, the most massive layer by far is the outer layer to break up and spread any orbital debris that may strike the module. But on the surface of the Moon, our regolith shielding makes this layer unnecessary. That saves 10 kg / m2.

There are five additional layers that we will need. The outer and inner most layers are abrasion-resistant layers to protect against abrasive regolith and crew walking on the floor. The next outermost layer is the pressure restraint layer made of very strong material such as Dynema. Then, there are two bladder (air proof) layers so that, if one develops a tear, it gives time to be patched.

The mass of each layer is as follows:
- 1.00 kg/m2 - Abrasion-resistant exterior surface
- 2.50 kg/m2 - Restraint layer
- 0.60 kg/m2 - Bladder 1
- 0.60 kg/m2 - Bladder 2
- 1.30 kg/m2 - Abrasion-resistant interior surface

= 6.00 kg/m2 - TOTAL

Unneeded for Covered Surface Habs
- 0.60 kg/m2 - Thermal layer
- 10.0 kg/m2 - MMOD layer (micrometeorite / orbital debris)

Special thanks to Judith Watson who worked with inflatables at NASA-Langley for graciously responding with list and mass of inflatable layers.

In addition to the South Pole InstaBase and/or StarHab, the International Lunar Base would be composed of many different variants of specialty habs.

Utility Habs: Maybe not so glamorous, but entirely essential. Utility habs could include things like life-support, sanitation, a larger centrifuge, farms, chemical processing facilities, a machine shop, etc. These would be dedicated habitats, each of which would mean that much less would need to be shipped from Earth thereby allowing more of the payload to be crew thereby increasing growth rate of the base.

Transportation Habs: Think of space ports. Passengers would need to land somewhere. So, they would land on a landing pad (to prevent dust being blown everywhere), a transfer rover would dock with the lander and the passengers would transfer into the vehicle. That vehicle would drive to one of these transportation habs where the vehicle would dock with the hab and the passengers would exit into the hab where they would be formally welcomed including any ceremony that the base might think should be standard -- sort of like welcome at Hawaii.

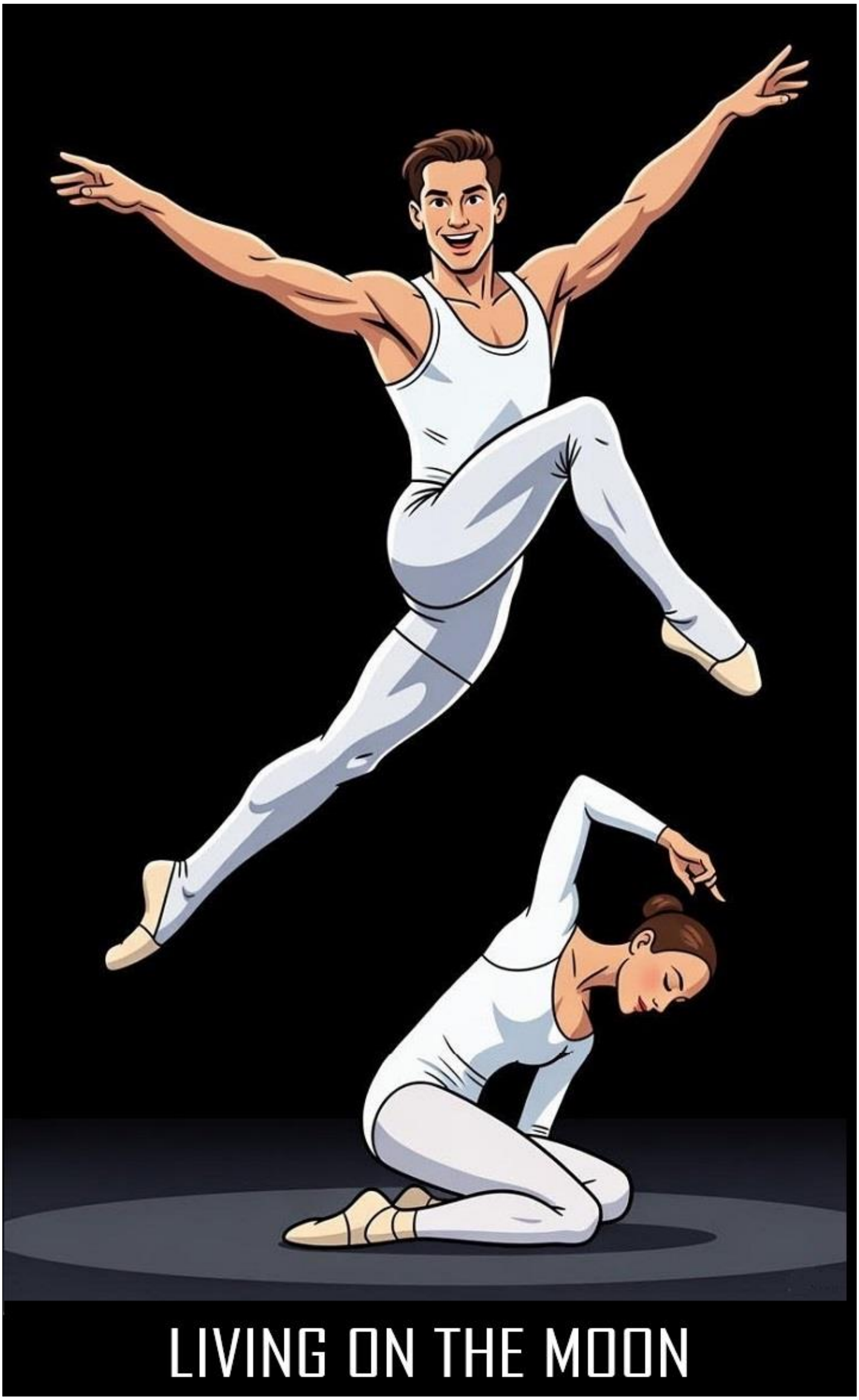
Residential Habs: The number of bedrooms at the base would need to be kept ahead of the population growth in a planned manner. Initially there might be compact male and female dorms favoring single crew. But quickly there would need to be married crew housing with separate rooms and facilities. Later, as private individuals arrive, residential habs might be uniquely, beautifully designed habs according to what the resident could afford.

Recreation Habs: Perhaps the most newsworthy habitats would be the recreation habs. Sports hab allowing for unbelievable gymnastics and such would be fascinating. With 20 metric tonne payload deliveries and delivering just the outermost inflatable layer first followed by deliveries of the inner layers could result in a sports habitat with a footprint of about 3.4 acres. See the sort of things that could be done in that setting.

Community Habs: Community habs could include things such as dining rooms, meeting halls, places of worship, etc.

Medical Habs: Medical facilities of the appropriate capabilities would need to grow according to the medical needs of the residents. Initially just a designated place of the initial UniHab would suffice. But during the International Lunar Exploration Phase, a dedicated emergency habitat should be available to treat things such as serious injuries, dental extractions, or even operations such as a ruptured appendectomy. Eventually as older retirees arrive, full hospital habitats would need to be set up to give the full spectrum of care.

A color-coded illustration of an International Base composed of inflatable habs.


LIVING ON THE MOON

20 – Watching History Happen

SUMMARY

This chapter points out that the first private crew to settle down off Earth will be historically significant. We can choose to knowingly write that chapter in history and make it an interesting story that parents in the future will want to tell their children. Private individuals starting to spread beyond Earth is at least as historically significant as Plymouth Rock is to the American story. And with the Initial Crew being so connected to all parts of the world through their languages, it won't just represent Americans spreading beyond Earth but, indeed, all of humanity.

WRITING HISTORY

The goal of the Apollo program was to land astronauts on the Moon and to safely return them to Earth. People walking on the Moon! How amazing is that? And that is exactly what happened. No doubt those working on the Apollo program understood that those first steps on another world and the words spoken would go down into history. Words such as:

President Kennedy:
"We choose to go to the Moon in this decade..."

Neil Armstrong:
"One small step for man...one giant leap for mankind".

When we return to the Moon, will it be history making or just a ho-hum repeat of something that happened over 50 years ago? Well, it all depends upon how we go about doing it.

History in the Making

We are approaching a point in time that could prove to be a very historic moment (at the level of Christopher Columbus or Plymouth Rock) -- the moment that humans start moving beyond Earth will be looked back upon as when it all started. And just like during the Apollo program we can know that we are writing history while we do it. But it makes a great difference exactly how we do it.

The current default plan is to do a sortie-class mission with a man and the first woman to step on the Moon, establish a small station in lunar orbit, and then continue with sortie missions until a small permanent base is established. Mostly, the plan is for occasional visits to the base to maintain and conduct some science. That permanent base is compared to the McMurdo station in Antarctica.

Frankly, this is not a very historic approach. Yes, the first woman on the Moon will be a big deal. But it probably will be somewhat below the significance of the first man on the Moon -- Neil Armstrong in 1969. Neither McMurdo base in Antarctic nor even the International Space Station are viewed as turning points in human history. In America, each year we celebrate and retell the story of the pilgrims at Plymouth Rock. But some astronauts going back and forth to a permanent base just isn't at that level. But could we write a different story that generations in the future will tell their children?

OFF-EARTH SETTLEMENT

What is Settlement

The key to writing a truly historic story comes from the true understanding of the term "settlement". Fundamentally, settlement is when one sells their home, moves to another place, and establishes a new home there. We call it "settling down". And a home is where your family is.

So, the basic elements to the start of space settlement would be a permanent habitat with life support and such, families starting with the simplest form of couples, the environmental conditions where these individuals could remain at the growing base for an indefinite length of time, and their base eventually growing up to become a large settlement akin to a town.

Base Leads to Settlement

It should be noted that a government base and the start of settlement are nearly identical. In both cases, one needs power systems, permanent habitats, life support, and mechanisms to utilize local resources. Approaches to extending crew stay would help the government both financially and from a risk standpoint and would allow the private settlers to remain "indefinitely" meaning for as long as possible. Those approaches include telerobotically filling the habitat walls with lunar dirt and the use of an indoor centrifuge to provide several hours of full gee each day.

So, the only difference between government astronauts in this setting and the first settlers is that the former are there only for the job whereas the latter are settling down into their new homes while doing their job.

Due to the similarities, it is here proposed that America's space policy intentionally seek to seize the historic prize of establishing humanity's first, permanent, off-Earth foothold (i.e. the first space settlement). NASA should establish a public-private program to fund company crew whose job it will be to establish some infrastructure and demonstrate protocols needed to establish a permanent presence on the Moon. Then, American and international astronauts could arrive to start building up an International Lunar Base. But the history would be lived out by that Initial Permanent Crew.

Private Settlers From the Start

If government astronauts are stationed on the Moon, that is an outpost or a base. It is not a settlement. It is generally recognized that, ultimately, settlement is for the private sector. So, to seize the historic opportunity to write the story of when humanity first began to settle beyond Earth, those first settlers ought to be private individuals. How can that be done at the earliest opportunity so as to secure that prize for the United States?

Chapter 12 of this book describes an approach to developing the Moon including a scenario for how humanity's first, small base could be established. The scenario is that taxpayer dollars fund NASA which in turn funds a company whose private employees settle down into an Initial Permanent Base whether a StarHab or InstaBase. These private individuals would conduct work for their company that has been contracted by NASA. This work would include demonstrations and preparatory work of use to NASA in anticipation of American astronauts landing and establish the first American habitats of the large and growing International Lunar Base. In this way, the first settlers will be private and yet perform work of use to the government thereby justifying government funding.

WATCHING HISTORY HAPPEN

Virtual Reality

There is the real potential of virtual reality (VR) playing a significant role in how the public engages with the program. For example, a pole could be placed near the landing site prior to the arrival of the Initial Crew. On top of the pole would be a high-resolution, 360^0 camera. While the public is watching 2D video of the crew landings, others could pay to be able to don virtual reality headsets which would give them the impression that they are actually standing on the Moon about to witness this historic event. The VR viewers could look up and see the exhaust of the lander as it comes down to land. Even though the pole is within the gaseous blast zone of the vehicle while it lands, the viewer would, of course, suffer no harm. Immediately upon landing, the suited-up crew could exit the lander and walk right past the VR viewers (perhaps pausing and waving at the viewers).

The VR viewers could then instantly pop over to a 360^0 camera near the airlock of the initial base as the crew comes to it. They could next pop inside the airlock during entry and pressurization. Then they could pop into the initial base to see the crew as they settle in.

The 2D video could be made free for viewing around the world. But the VR experience could be charged for by the participating companies. If 1% of the world were to pay $50 for the experience, that would total $4.4 billion in revenue. Whether there would be that many viewers willing to pay that much is a question. But the point is that the public's interest could be a significant source of revenue which should be considered. A portion of that revenue could be used to repay NASA's investment in the participating companies.

Other forms of VR could be strategically placed cameras within the initial base, cameras on the rovers, and perhaps a *DoggieCam*™ too!

TV FROM THE MOON

A space program committed to establishing humanity's first, permanent, off-Earth foothold will have plenty of opportunities to inspire the American public and the rest of the world. For the American public, they will feel as though they are getting their space budget's money's worth. They would also identify with the program in that they would watch the crew establishing their home and doing several activities of human interest. For the children, they will have specific role models trained in specific fields achieving important objectives. And, of course, the kids will simply adore the dog and other animals.

TV Series

Several years of TV programming suggests itself which would cover the various phases of the program. Although it is tempting to think about the cameras inside the initial base as lending itself to some sort of tacky reality TV show, in fact, the show would be more real than the over-dramatized antics of reality TV stars. Here is a hypothetical scenario for a set of TV series:

1st Year Series - The public would probably be interested in the selection and training of the crew who were going to be going on to become humanity's first, permanent, off-Earth representatives. This series would also cover the history of the rocket, habitat, and hardware development.

2nd Year Series - The second year would kick off with the launch and arrival of the historic, Initial Permanent Crew. Then the public would be able to follow their settling in, overcoming any challenges, the steady progress of producing food and equipment using local resources, as well as demonstrating a variety of music, dance, culinary, and other talents.

3rd Year Series - The third year could be the year in which, on a weekly basis, international crew from various countries could arrive, be greeted by our Initial Crew of eight, and share elements of their cultures (e.g. food, clothing, dance, music, and animals). They would then go on to conduct their own Apollo-scale exploration of the Moon using a refueled lander. Meanwhile, some crew would also work to set up large habitats dedicated to specific infrastructure needs for a growing base (e.g. a FarmHab). A sports habitat allowing for activities not possible on Earth could form the basis for several interesting shows.

4th Year Series - During the fourth year, private individuals could start arriving (on their own dime). Their personal stories could be highlighted, and we would watch as the base begins to turn into a settlement. A modest-sized inflatable "Hotel Luna" could be set up with some wealthy and/or famous visitors. Additional large, inflatable habitats providing amenities (e.g. swimming pool, golf driving range) could be set up during the year, setting the stage for additional private individuals (e.g. retirees) who would need a certain quality of life if they are to move to the Moon.

5th+ Year Series - Finally, the development path started on the Moon could be repeated on Mars with StarHabs, specialty habs, and initial crew establishing a base there. We could watch the Martian crew harvesting water, producing propellant, growing food, and producing metals to lower the cost of accessing Mars for all follow-on missions.

Space settlement, even starting at this humble level, is of great historic importance and will be of great interest to the public.

INSPIRATION

Why Have a Space Program?

Is it the purpose of a national space program to "excite" the public?

Adjusted for inflation, in today's dollars, the Apollo program averaged about $34 billion a year. NASA's average space budget (again in today's dollars) since the end of the space program has been about $25 billion a year. So, we have about an average of 74% of the Apollo Program's annual average budget.

Year after year after year, the public's elected representatives choose to fund our space program at about $20B per year +/-. Through our representatives, we choose to have a space program about as large as that of the rest of the world combined. Through our federal budget, we have chosen to spend a modest amount (about 0.4% of the federal budget) on space. Why?

Public surveys indicate that NASA is the most popular of federal agencies. But it is correct to state that the support for the space program is "a mile wide and an inch deep". Both the public and our elected representatives broadly like the space program even if we don't necessarily understand it very well. The space program often survives the cutting board fairly well and it enjoys bipartisan support (a rare quality nowadays). Our representatives would be loathed to end America's space program believing that a great country deserves a great space program.

So, the public, through their representatives, have consistently maintained a decent-sized space program. This is a reflection that the American taxpayer wants to spend a modest amount of our money on space. And why not? We are a democracy and we have the right to spend our money as we choose. But there is an important question. How much value are we getting for our space budget?

Past Space Inspiration

The Apollo program not only successfully achieved the goal of beating the Soviets to the Moon, it inspired generations. It is documented that the pursuit of science at all levels of education increased significantly during this time period. It became common to say, "If we are able to land a man on the Moon, then why can't we _________". The Apollo program gave our nation a sense of confidence and the rest of the world viewed the United States as being very competent and hence the leading country in the world. To this very day we take pride in having placed a man on the Moon.

Inspiration Currently Limited

Ask a typical American to state the name of any American in space now and what they are doing. In general, the public barely knowns that we have an International Space Station and very few know the name of any astronaut on it nor what they are doing. Do you, the reader, even know who is on the ISS now? Is this the best that we can get for a budget three-quarters the size of the Apollo program (adjusted for inflation)?

The Innovative Plan for Space Development proposes a direction for America's space program that wouldn't require any substantial increase in NASA's budget but would deliver a series of accomplishments of historic significance and incredible inspiration not only to our own public but to the rest of the world. We can be far ahead in space leadership if only we choose.

Unfortunately, the Traditional Plan fails in the four principles upon which the Innovative Plan is based. (See page 12.) Although crew return to the Moon seems to be back on the table, the plan for NASA seems to be expensive, and delayed going through a Gateway in lunar orbit, starting with uncrewed landers, and with no clear plan for how crew will go to the Moon in a large-scale, sustainable manner. Meanwhile, a real journey to Mars has to wait for funding to be freed up. It seems unlikely that the current Administration will accomplish only limited achievements in space if they make no significant changes to the current plan. But consider the public impact if this proposed Innovative Plan were pursued.

Lunar Inspiration

It could start with an announcement of the commitment to the full utilization of the reusable heavy lift fleet and all that that entails. The Artemis Accords could be followed on with a new coordinating plan for the International Lunar Exploration and Base phase. This would be realized in the early 2030s, but the participating countries need to start working now to develop the competing surface systems needed.

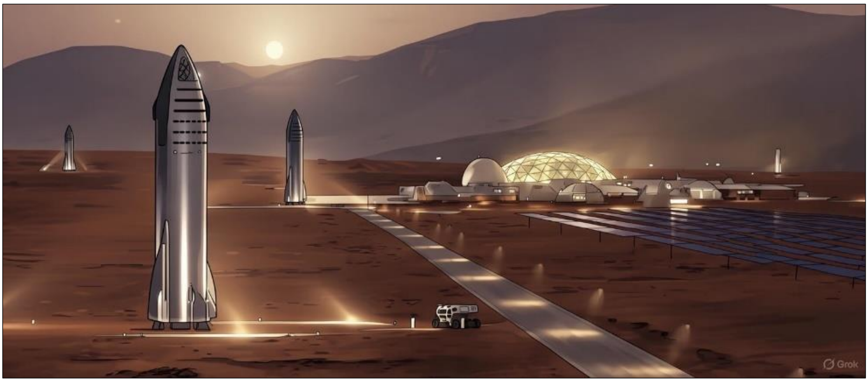
The scenario for the Initial Permanent Crew needs to be articulated and the criteria for who can compete to be part of the Initial Permanent Crew should be set so that young people around the world can start learning and preparing themselves to compete for those slots.

Then, as crew land on the Moon for Artemis 3, it would now be part of a much larger context in which it is understood that this is part of the first steps towards a permanent (even private) foothold for humanity beyond Earth and an American-led, international exploration phase and large and growing base.

The result would be that American taxpayers would see that their space program was about to achieve revolutionary accomplishments and that much of the rest of the world is wanting to follow our lead. They would read ongoing news reports of not just another research project on the ISS but historic steps with people setting the foundation for humanity's spread beyond Earth.

MARS

Meanwhile, NASA needs to enter into formal dialogue with SpaceX for a joint program to send humans to the Red Planet. That could / should include a Mars flyby (or **Ph**obos-**D**eimos) mission to forever resolve the question of which country "went" to Mars first and how many astronauts from NASA and partner countries and how many SpaceX employees would be among the first humans to set foot on Mars.



Mars base. Credit: SpaceX

21 – Cooking and the Culinary Arts

SUMMARY

The Network's Food Working Group (FoodWG) has developed a Plan for how produce from the GreenHab would be converted into ingredients used in recipes to make meals that would meet the nutritional needs of the crew. It is an interesting challenge to produce the right amount of produce at the right time so that food storage is minimized. Automated / robotic systems would be used to free up valuable crew time. Cooking and the enjoyment of regular and special meals will play an important role in crew morale and interest by many in the watching public.

THE FOOD WORKING GROUP

The Space Development Network has a specific group, the Food Working Group (FoodWG) dealing with the point after the Farmer(s) harvest and store produce. So, the ordered steps that the FoodWG covers are:

1) Start with produce
2) Process those into refined ingredients (e.g. flour)
3) Prepare recipes according to a menu
4) Meet the nutritional needs of the crew.

Along the way it includes the culinary arts, which are the creative aspects of cooking including presentation and holiday meals.

One of the main projects of the FoodWG is to produce a sophisticated Lunar Cookbook with recipes using ingredients grown within the Initial Permanent Base or shipped from Earth and stored (e.g. coconut cannot be easily grown in the StarHab).

NUTRITION

Nutritional Needs

Our working group briefly considered what the nutritional needs of the Initial Crew of eight would need. Apart from a higher-than-average caloric need due to a vigorous exercise schedule, we are developing the menu with the basic nutritional needs for people on Earth. At a fundamental level this means:

- 65% - Carbohydrates
- 20% - Fat
- 15% - Protein

There are other nutritional needs such as vitamins and micronutrients which would also need to be satisfied.

Meeting Nutritional Needs with Which Plants?

We have the assumption that all the nutritional needs will be met by what the crew grows. This probably isn't exactly correct since, with the delivery of large payloads, the crew could probably be supplied only with deliveries from Earth if need be. In fact, the delivery of food is a very convenient way of supplementing carbon and nitrogen to the base. Also, there are certain "comfort foods" and certain important ingredients which cannot be easily produced early on the Moon. But to simplify matters, we are sticking with what we believe that the Initial Crew can grow themselves.

Variety

We could theoretically meet the nutritional needs through a monotonous diet of, for example, potatoes for starch, peanuts for fat, and soybeans for protein. But we want to show that people moving off Earth don't have to be deprived but can have a nice variety of recipes. In fact, eating from our Lunar Cookbook would probably give more variety than most people normally get. And with good application of the culinary arts the dining of the Initial Crew could turn out to be very pleasant.

As we have generated an extensive Food List, we have found that, for most all of the foods we can think of, there is a way of growing them even in the initial habitat. It sometimes takes creative approaches like dwarf, fruit-bearing trees in a pot, but it can still be done.

Processing Into Ingredients

There is a step in the from-plant-to-plate process that those of us on Earth often ignore. That is to take a plant and convert it into a useable ingredient. Nowadays, this is typically done at a manufacturing level using large, industrial equipment. We need such equipment but in low mass, small volume forms on the Moon. Typically, these already exist but it is going to add another time-consuming step in the process of preparing a meal that we don't normally deal with. Making soy milk from soybeans is an example of this. On Earth we just run out to the store and buy soy milk in a carton. But on the Moon, we'll need to use those small machines that do that process and spend the time running the machine.

Different ingredients will be processed at different times relative to their consumption. Some ingredients can be made just as soon as they are harvested. Flour from wheat grains is an example of this. Meanwhile, others will be processed closer to consumption. Guacamole is a classic example of this.

Storage

Storage includes:

- Keeping on the plant
- Baskets (e.g. fresh produce)
- Pantry (room temperature storables)
- Refrigerated (perishable but cannot be frozen)
- Frozen (perishable but freezable)

Keeping something like tomatoes on the plant until harvested for immediate use helps extend the period of time that they can be available fresh. If one were to pick all the tomatoes at once and put them in the refrigerator, then they would all start to go bad about the same time.

Food Preferences

As is done with crew traveling to the ISS, professional dieticians will have the crew undergo taste testing of different recipes during their training and before they launch to the Moon. The actual menu for the Initial Crew would reflect those preferences and the Agricultural Plan would be adjusted to reflect the ingredient needs of the recipes in the menu. Since the Initial Crew will be eating from the same produce of the GreenHab, one might think that conflicting food preferences would force some to eat foods that they don't like. But just like we do on Earth one could just avoid one dish and double up on another. So long as each meal has something enjoyable for each of the Crew then it should be OK.

From Nutrition Back to Planting

So, there is a proper order for figuring out what to plant and when. One must work back and forth to figure it out. We start with the nutritional needs and look at what plant ingredients would meet those needs. Then we select or develop recipes which would meet the nutritional needs using those plants. Care must be taken to cluster ingredients between recipes to utilize the full amount of that ingredient that is being produced. So for example, if one grows a pumpkin for Thanksgiving but there is some left over then guess what type of soup you're going to have within a few days?

After figuring out the ingredients needed then one can figure out how many of what types of plants need to be harvested by what time. The time factor can be made more variable via storage. So for example, if one has harvested a lot of strawberries at a given point in time, one could eat fresh strawberries but then consume frozen strawberries in the form of a smoothie weeks later.

After figuring out what the harvest schedule needs to be it is a fairly simple matter to calculate back the planting schedule including any seedling schedule.

Managing Produce / Ingredient Flow

A complicated challenge will be how to ensure enough of an ingredient is available while not having large amounts of ingredients in storage. The easiest approach would be to look at what is currently being harvested and in store and to choose recipes / meals that use those things. But this may mean eating a whole lot of zucchinis in different forms for two weeks -- not exactly ideal! So, correctly managing harvesting and storage can help inform recipe choices to spread when one ingredient is consumed over time thereby avoiding overloading the crew with a particular ingredient all the while keeping an eye on making sure that the nutritional needs are being met. In practice, this could be challenging to figure out. It may be that AI would be used to identify which recipes should be used to manage this process. Trying to explicitly detail this process in a printed cookbook could be an interesting challenge.

Saving Time by Using Robots & Processors

Crew time is extremely valuable. But in the Initial Permanent Base, crew time won't be so tied up doing many experiments like they have to do on the ISS. Rather, the focus of the Initial Base is sustainability and not just science. Instead, they will need to have a lot of time available for doing ISRU, growing food, producing parts, etc. So, any machine that can offload work will pay back the shipping costs very rapidly.

This is also a place where robots could be helpful. There are advanced robotic systems intended to cook in a kitchen setting. They move around on tracks in the ceiling and have two arms and cameras. They can open cupboards, remove containers, open those containers, measure out portions, place ingredients in pots or whatnot, turn on the stove, stir, remove the cooked item and place on a plate. It's really quite amazing. Now, if they would only wash the dishes too! And these robots could be conducting this work just as people are about to wake up or while they are working in the WorkHab before lunch and supper.

But we don't want to let the robots have all of the fun. Cooking food and preparing meals is an important part of living off Earth. So, the robots could act as kitchen assistants that prepare things but the final steps including presentation are being done by whichever crew is on cooking duty for the day. In the eyes of their fellow crew and the people who are on Earth watching, it will be the human cook that will be taking credit for the final meal and its presentation.

But we mustn't get too hyper-focused on robots. Good old, automated equipment can be real time-savers too. Food processors, ingenious choppers, mixers, etc. are time-savers here on Earth and any piece of equipment that can save time up there should be considered too.

Who Does the Cooking?

Besides the assistance of the cooking robots, all crew members would be scheduled to prepare some of the meals. But there could be a couple of Initial Crew members that were selected in part because they are particularly good at cooking. They would be the primary cooks provided that their specialty job allows them the time. So, depending upon what the daily job requirements might be for any given job, there may be some positions that would tend to have more free time than others. When selecting those positions, special preference could be given to either choosing people who have the cooking skills and/or they would be specially trained in cooking and the culinary arts.

The Lunar Cookbook

As mentioned before, we'd like to develop a Lunar Cookbook that would lay out an example menu and set of recipes and even include a planting and harvesting schedule. This cookbook would be useful in simulations in analogues bases. But they could also serve as a unique cookbook for those who would like to have their own garden and recipes that would use those ingredients. Even if someone wasn't attempting to produce food for all their nutritional needs, it would still be interesting to attempt specific recipes.

If you, the Reader, think that you could help develop the Lunar Cookbook and you are willing to work within the guidelines of the Space Development Network we would love to have you join us (for free) and contribute your talents.

THE CULINARY ARTS

Beyond just the work of cooking, the culinary arts include developing new dishes, balancing things like flavor, textures, and aroma, designing thematic menus, and, of course, presentation.

Presentation

A big part of the culinary arts is the presentation of the food. Often, this doesn't take a lot of time to do but simply the knowhow and the motivation to make it special. In the Lunar Cookbook there should probably be a section about presentation in general and details about presentation with certain dishes.

Cooking on TV

Another part of presentation would be conducting an occasional variety spot on the weekly TV show from the Moon, where there could be a cooking demonstration. These segments could help reach out to and inspire a group of people who don't normally think about space. But that's sort of the point here. As we go beyond exploring and start actually living off Earth, it will involve more parts of life than the space program normally has. And as a result, it will spark an interest in space in a more diverse group of people.

Cooking demos will draw a different sort of space advocate.

Holidays

To be sure, holidays will have special meals with all the trappings possible and will likely be broadcast. Traditional dishes (e.g. turkey, pumpkin pie, cranberry sauce) would need to either be grown on the Moon or specifically shipped. There could be special holidays from the country of origin of one of the team members that would be introduced to Americans and others not from that nation. Along with the meal, there could be special aspects of the meal such as the telling of the traditional story. The celebration of holidays in this traditional manner would help make the point that this really is the beginning of humanity spreading out from space. This is home life and not a government outpost.

22 – Dance, Celebratios, and More

SUMMARY

As the Initial Permanent Crew settles down into their Star-Hab, they would not only be working but living life. Aspects of living not normally associated with life on a space station (such as the arts) would now be just a normal part of life. This chapter describes some of the interesting things that the Initial Crew could do.

What would it be like to live on the Moon?

Daily Living

We would all watch as the initial crew settles down and begins doing their primary job but also living daily life. Some of that living would be normal things such as preparing and eating meals and playing with the dog. In the evenings after work, social life could include game night, movie night, and telling stories.

Periodic celebrations such as 4th of July, Thanksgiving, and Christmas would all be special events as they are for us on Earth. Some surprising things could be done on certain holidays that maybe would best not be mentioned here to keep it a surprise. Crew members who grew up in other countries might celebrate and share their holidays with the rest of the crew and the watching people from Earth. For example, a crew member with Indian background could share about how their celebration, Holi, how the tossing things into flames and tossing of colors would all have to be worked out.

Gymnastics and Sports

Indoors, there are several sports activities that would be completely transformed because the Moon has only 1/6th the gravity of Earth. During the Apollo program, astronauts were able to jump unusually high. So, consider a Performance Area in the StarHab and/or InstaBase with a high, rounded ceiling. Prior to being sent to the Moon, they would have been trained (using tethers) on the Earth to do ridiculously amazing feats only possible on the Moon. Upon arrival, they would privately practice their routines until they mastered them in the lunar environment. Then, one evening during our weekly TV show from the Moon, we get to see a choreogra4thphed gymnastics performance with that crew member performing an unbelievable routine.

The Crew, taking advantage of the greater possibilities given the reduced gravity, could engage in several entirely new types of sports. Imagine a type of basketball in which all surfaces could be used. Since one can jump six times higher than on Earth, 3D sports with platforms throughout the Performance Area could be used. Honestly, it's sort of difficult to imagine all of what might be possible.

Use the QR code to the right to see how even human flight could be enabled in 1/6th gravity.

The Visual Arts

The various types of art could be on display, which would turn the Initial Permanent Crew into a phase that would appeal to people who may not be so scientifically but rather artistically inclined thereby expanding those people who consider themselves to be space advocates.

The visual arts include painting, drawing, sculpture, photography, and textile arts. Among the crew of eight, one or two might have been selected because they have natural artistic ability. Special training by an art teacher could improve those skills prior to launch. Once in the Initial Permanent Base, they could choose a subject and produce a piece of art which could be shared on a TV segment. The Machinist, although perhaps not an artist, could none-the-less choose a file that particularly catches his fancy and have the CNC machine produce that object which he would then share. One of the crew should probably also be a trained photographer whose photographs would appear on the TV show periodically and be available for download.

Literary Arts

The literary arts include things like poetry, (stand up) comedy, and drama / acting. One could imagine segments of the weekly TV show in which different members of the crew have such segments. For drama, there could be complete show (April 1st?) in which some sort of fictitious, dramatic situation apparently happens that the crew must deal with.

Music

Perhaps the top selection criteria for the Initial Permanent Crew would be musical talent. A Director of Music for the program could coordinate between several music faculty and students to identify music generas and pieces for different musical segments throughout the entire TV series. It could include musical accompaniment for performances as well. The Crew should be very good but not necessarily professional as their instruments and, with excessive practice of the specific songs before launch, they would probably be able to give pretty good performances. Unique pieces could be premiered for the first time from the Moon.

Much thought would need to go into what instruments should be represented among the crew of eight. One could imagine having two very good vocalists and an excellent pianist and guitarist who could also play the banjo. From the others may be crew who play the violins, and cello so as to create a string quartet. Other instruments could include percussion, harmonica, saxophone, ukulele, bass guitar, regular, pan, and wood flutes, clarinet, oboe, trumpet, and unique instruments such as the Jew's harp and didgeridoo. Obviously, one would probably have difficulty having a crew that small being able to competently play all those instruments. But this is where the Director of Music, working with crew selection to ensure as much musical variety of good quality, is possible.

Special thanks to Brent Fischer, Grammy-winning music producer for concepts incorporated in this section.

Performing Arts

Performing arts is where things would get especially interesting due to the 1/6th gravity. Juggling would, of course, be especially easy such that crew without any special juggling skills could be taught how to juggle by a more talented juggler. Gymnastics would be phenomenal because airtime would be more like what a high diver has and so many more things could be done. The performing arts could also include little segments of theater and a fashion show.

Other activities would be special but still something that we can do on Earth such as four of the crew playing a string quartet.

But there are certain activities which would be different on the Moon than on Earth. For example, any exploration of the Moon such as exploring the Moon's lava tubes would be unique. Also, imagine the crew going outside on the 4th of July to watch the fireworks set off in the distance with the Earth in the background. That would be pretty cool.

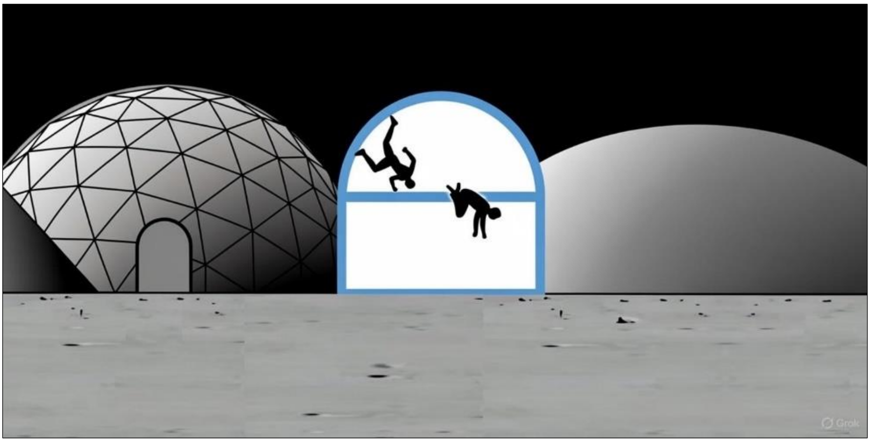
The Initial Permanent Crew on an EVA to celebrate the 4th.

Dance!

But the most remarkable performing art would be dance. In 1/6th gravity, some amazing performances could be delivered like nothing seen before on Earth. What would the physics allow? Amazing feats with new degrees of freedom would become possible.

On Earth, one typically has one hop per beat. But, in the Moon's gravity environment, even the choreography would change. A hop could be on each measure and, while in the air like a high diver, mid-air moves could be timed with the beat.

With high friction (sticky?) socks, the dancers could be free to utilize not just the floor but the walls and even the ceiling as performance areas. Lifting and tossing one's dance partner would be much easier on the Moon than on Earth. The acrobatic moves that could be done while being tossed into the air would be nothing like we've ever seen on Earth. The watching populations on Earth would likely be astonished by what they were witnessing.



In the Moon's $1/6^{th}$ gravity, dance will become a wholly new phenomenon.

Special thanks to the faulty for dance concepts included in this section:

- *Professor Whitney Herr-Buchholz of the University of Arizona (Tucson) School of Dance for input on lunar dance.*
- *Professor Bruce Bayley of the University of Arizona (Tucson) Physics Department for input on the physics of dance.*

Get Involved

More work needs to be done to understand the physics of performance in the lunar environment. A physics paper on lunar dance comes to mind. We need someone within the professional or academic dance fields to develop an imagined lunar dance routine. Then, someone needs to write a paper systematically identifying what would make up a most remarkable series of musical performances given the limited size of crew but with musical abilities having top selection and language mastery being second. The time is coming for when these things will become a present possibility, and we need to be ready to take advantage of those opportunities.

CREW HEALTH

23 – Space Radiation

SUMMARY

Space radiation comes in a few different forms. Of greatest concern are the solar particle events (SPE e.g. solar flares) and galactic cosmic rays (GCRs). The equivalent of 20 cm thick of water shielding is sufficient to protect against the short-term death that a very bad SPE can cause. That an ought of shielding can reduce the GCR radiation exposure by about 40% thereby giving crew about six years before they reach their career limit. Add more lunar dirt to the thickness of the habitat and you buy the crew even more time. Crew driving in vehicles will want to carry their SPE shielding with them.

A common concern, and even objection, to traveling and settling down off Earth is the well-known risk of space radiation. We think of space as being empty and it largely is. But, in that void, there are atomic particles and electromagnetic radiation shooting around. This radiation can strike the molecules in our body causing damage. In this chapter, we will consider the different types of space radiation, see what the risks are, and what can be done on the way to and on the surface of the Moon to address this problem.

TYPES OF RADIATION

There is not just one type of space radiation. There is some space radiation that is of little concern. For example, the solar wind is a type of space radiation, but the particles are so small, and their speeds / energies are sufficiently slow such that any spacecraft, habitat, of space suit skin can stop those particles. But there are some that contain sufficient energy to pose a risk.

Trapped Radiation - The Van Allen radiation belts have solar particles that have been trapped by the Earth's magnetic field within bands around the Earth. Whereas this radiation can be a problem if one remains within the belt, if one simply passes through them, the limited radiation exposure is acceptable.

Solar Particle Events - There are times when the sun lets off relatively slow particles but in large quantities in a short period of time. Events such as solar flares and coronal mass ejections fall into this category. Although their energy of each particle is relatively low, because they arrive in such large quantities, they can actually be lethal. And this is not just a hypothetical concern. During the Apollo Program, between Apollo 16 and 17, there were intense solar flares and coronal mass ejections. It is believed that, if the astronauts were in transit or out on the lunar surface when the flare hit, it would have been lethal. Think about how that would have affected the way that we view the Apollo Program now.

Galactic Cosmic Rays (GCRs) - GCRs are the steady "rain drops" of radiation constantly flying through space. Whereas they only occasionally hit astronauts, they can travel at nearly the speed of light and hence cause significant damage including double-stranded DNA damage which is difficult for cells to repair. These are nuclei with masses up to iron side. So each of these heavy nuclei can pack a significant punch.

Secondaries - When something like high-speed, heavy nuclei hit heavier material (e.g. aluminum or regolith), like a game of billiards, the involved nuclei can break apart into smaller elements which continue and can now hit multiple other nuclei. In this way, a single GCR can end up causing a shower of secondaries.

HEALTH EFFECTS

Cancer Risk - The most common concern about radiation is the risk of developing cancer. When radiation hits DNA, it can cause a break. If the break is of a single DNA strand, then the remaining DNA still contains complementary information, and the body has an opportunity to fix the damage. If, however, something like a high-energy GCR breaks both DNA strands, then the body has greater difficulty repairing cells with the lost information. Either way, the risk of cancer increases as the accumulations of mutations withing the cell may cause the cell to start growing in an uncontrolled manner.

In the United States, radiation workers (astronauts are considered to be) have a career limit of no more than three percent radiation exposure induced death (REID). What this means is that radiation exposure should be limited such that there is less than a three percent chance of developing a lethal cancer at some point later in life.

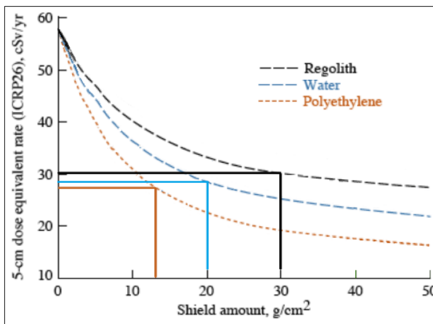
Cell Damage - If a GCR strikes a cell's DNA and disrupts the cell's function, the body will need to replace that dead cell. But certain tissue in the body doesn't replace itself. One such tissue is the brain with its neurons. There are concerns over how much brain function will remain after a 6-month journey to Mars.

SHIELDING

Forms of Radiation Shielding:

Realistically, forms of radiation shielding will include:

- **Water-bearing provisions and waste** - During transit to Mars
- **Regolith -** On top of or within the walls of habitats on the Moon or Mars
- **Water -** In the cab walls of surface vehicles and in the walls of Mars habitats



Adaped from Simonsen, et al. 1997

Applying Regolith

So, how can one cover a habitat with regolith. There are several different possible solutions:

- **Push -** Autonomous tractors can push regolith on the side of the habitat and then drive up on that to push even more regolith on the top of the habitat.
- **Inflate -** If the habitat is inflatable, an even easier approach would be to unfold (e.g. roll out or inflate to unfold) the habitat, have the tractors push regolith on top of the flattened, inflatable habitat, and then inflate the habitat after pushing enough regolith on the top. The upper force of air pressure is far more than the downward weight of the regolith in 1/6th gravity. After inflating, the tractors can then push regolith on the sides. This is an easy approach but does require that the habitats be roughly designed to have flat roofs like air mattresses have.
- **Toss -** Alternately, a "snow blower" type of robotic vehicle could keep driving around the habitat and toss regolith up onto it.

- **Pour -** Finally, robotic vehicles could have a tall conveyor belt / chute that would convey regolith up and pour it into holes at the top of habitats. The holes would be in the outer flexible wall with inner walls being rigidly inflated such that the regolith would slide down between the walls. The result would be an aesthetically pleasing base with the habitats not obviously covered with a bunch of regolith but with all modules having a layer of regolith of set thickness.

CAREER LIMITS

There are several different ways that have historically been used to measure radiation. One of the best ways of measuring it is called Sieverts (daily measured as millisieverts -- mSv). The reason why it is so good is that it includes a biologic adjustment so that different types of radiation have different factors. Certain types of radiation cause more damage compared to other types of radiation even if they have equivalent energy levels.

Radiation limits (to remain within a 3% REID) differ based upon gender and age. For gender, women have sex-specific organ tissue that place them at greater risk of developing cancer. For age, the older one is when exposed to radiation, the fewer years of life remain where cancer can develop before one dies of something else. In other words, older people can be exposed to higher levels of cancer without dying of cancer from that exposure. For convenience's sake, this book using a reference point of a career limit of 1,000 mSv which fits a 60-year-old male. This is an example of one of the first private individuals who has lived long enough to save enough money to afford to move beyond Earth.

LEVELS IN DIFFERENT SETTINGS

Radiation levels are different at different locations in space when considering shielding (either natural or intentionally applied) as well as the effect of Earth's magnetic field.

Radiation Levels

mSv/ day	Years until 1,000 mSv	Location	Shielding
1.80	1.5	Deep space	No shielding
0.40	6.8	LEO-Inclined	No shielding
0.15	18.3	Equatorial LEO	No shielding
1.80	1.5	EML5	No shielding
1.80	1.5	Transit to Mars	No shielding
1.00	2.7	Transit to Mars	Water*
0.90	3.0	Lunar surface	No shielding
0.73	3.8	Martian surface	No shielding
0.60	4.6	Lunar surface	11 cm regolith
0.50	5.5	Lunar vehicle	20 cm water
0.28	9.8	Martian surface	50 cm regolith
0.15	18.3	Lunar surface	100 cm regolith
0.00	N/A	Lava tube	Thick regolith

* Water-bearing provisions/waste around sedentary areas

Out and About

If a scientist based at the ILB with 100 cm lose regolith and conducts eight hours of scientific exploration per week with 20 cm water shielding around their vehicle's cab, then they would accumulate 9 mSv per year while on EVAs and 55 mSv/day while spending the rest of their time in the base. In other words, radiation exposure during EVAs is a relatively small portion of the radiation exposure due to the relatively small proportion of the time spent on EVAs.

HOW BAD IS IT REALLY?

Sometime space cynics emphasize the risk of space radiation, claiming it to be a showstopper. But to be rational, we need to quantify the radiation using the best means of measuring it, consider reasonable measures that can be applied to mitigate the risk (such as shielding), and then calculate the risks of bad outcomes. Excessive alarmism typically results from the lack of quantification and the assumption of worst case scenarios where no measures are employed to mitigate the risk.

From the chart above, one can gain between three and 18 years of time if applying simple shielding strategies. On the Moon, if one covers an initial lunar base with just enough regolith to protect against solar particle events (i.e. about 30 cm) then one buys themselves 4.6 years before reaching the career limit. During that time, the crew can simply maintain the robotic tractors which can then push even more regolith on top of their habitat. By so doing, the time bought will accumulate faster than time goes by. In other words, they will never have to return to Earth because they have exceeded their radiation limits. So, radiation doesn't appear to be a showstopper from the cancer risk standpoint.

As for the direct cellular death caused by double strand DNA damage, this if more of a concern for a 6-month journey to Mars than a 3-day trip to the Moon. And once on either surface, one can enter a well-shielded habitat largely stopping radiation exposure. So, for the Moon, this isn't a significant concern.

COMPARISON TO OTHER LOCATIONS

The following infographic shows the great difference in terms of radiation exposure between the Moon and the other destinations (LEO and Mars). The reason for this is simple. Whereas the major radiation exposure comes from a short, 3-day trip to the Moon, for Mars, the 180-day trip yields a 60 times greater radiation exposure. As for LEO, as mentioned previously, regular exposure to the trapped radiation of the SAA, long-term residents would routinely accumulate radiation exposure.

AGRICULTURE

Finally, how does radiation affect the way that we grow food?

Like any living thing, plants can be harmed by radiation. However, they are much more radiation-tolerant than animals. However, some solar particle events can be particularly severe such as the Carrington event of 1859. However, at Mars distances, the thin atmosphere, and plant's natural radiation tolerance, it seems as though plant growth would be stunted but they wouldn't be killed. So, it appears as though plants can be grown on Mars in an unshielded greenhouse. Crew working in the greenhouse would increase their radiation risk, but the number of hours needed to reach a REID of 3% means that workers should start in their 50s and they can make it to retirement without reaching a career limit.

However, on the Moon, it is a different matter. Even a moderate-sized solar flare could be quickly deadly for plants. Shielding is essential for the greenhouse. So instead of taking advantage of the direct sunlight, the GreenHabs should be shielded with regolith being the most convenient form available. Greenhouses should best be located at the lunar poles where there are areas of power from nearly permanently sunlight. Whereas light tubes are a somewhat complicated solution, perhaps the better solution would be for solar drapes to collect and convert sunlight into electricity which would be passed though the regolith shielding to optimized (magenta) LEDs to where more than one square meter of plants could be grown using just one square meter of sunlight. During the brief (e.g. 3-4 day night) at the poles, plants could be kept alive with a little amount of magenta light from the LEDs using stored power.

24 – Artificial Gravity

SUMMARY

Reduced gravity causes different problems with different organ systems requiring different levels of artificial gravity and exercise regimens. An indoor centrifuge is designed into certain habitats to help extend crew stay and to use to determine the artificial gravity prescription (AGRx) for healthy gestation and childhood. The centrifuge doesn't need to be huge so long as crew don't move their heads while inside and spinning.

OVERVIEW

There are legitimate concerns about whether lunar gravity is sufficient for health for those staying on the Moon for an extended time. Intermittent artificial gravity, by spending time in an indoor centrifuge, could help mitigate the effects of reduced gravity. But we need to conduct animal experiments to determine how much artificial gravity will likely be needed. Studies in a centrifuge on the Moon will probably be the earliest way to determine the amount needed.

QUICK DEFINITIONS

For those readers not particularly familiar with artificial gravity, here's a few acronyms / terms:

- **AG:** Artificial gravity
- **Spin gravity:** Achieving artificial gravity by spinning around such as in a centrifuge.
- **AGRx:** The artificial gravity prescription meaning how much spin gravity exposure is needed to have acceptable health outcomes.
- **Gee:** Meaning Earth's gravity level. 1.0 gee is what we experience standing on Earth. 0 gee is what astronauts experience in orbit. The Moon has 0.16 gee.
- **Microgravity:** The gravity level experienced in orbit. It isn't exactly 0 gee, but it is very close.

THE PROBLEM: HEALTH CONSEQUENCES

We are concerned with the significant effects of reduced gravity on several different organ systems, and each will need different amounts of artificial gravity to treat.

Nervous System (Balance & Circulatory)

Upon arrival in orbit, within a day or two, an astronaut's inner ear will adjust away from Earth orientation to that of microgravity. Upon return to Earth, it takes another couple of days to regain one's "Earth legs". So, this isn't a big problem.

Videos showing returned astronauts being carried away from their landed capsule so many people presume that this means that their lack of exposure to gravity has made them so weak that they cannot stand up and support their weight. This is incorrect. Astronaut Scott Kelley was able to stand up and walk almost immediately after being removed from his capsule after a lengthy stay on the ISS. In the video compilation of him after his flight, it shows him over the next 24 hours having improved balance.

The point is, the coordination of balance is something that recovers very quickly without intervention. Nothing in particular needs to be done about it. And on the Moon, there will always be a down direction. So, it may not be a problem at all.

Similarly, when astronauts spend time in reduced gravity, when they return to Earth, gravity starts pulling their blood away from their head to their legs leading to fainting. Not as with their balance system, the nervous system learns quickly to maintain blood pressure in the brain. Constructive leggings and salt supplements can help during the few days of transition.

Muscular System

Loss of muscle mass is common among astronauts in orbit. But given the exercise equipment that NASA had shipped to the ISS it has largely solved this problem. Indeed, some astronauts have returned with greater muscle mass than they went up with. So again, this doesn't need much in the way of an artificial gravity prescription.

Now we start to get into some organ systems that will likely need artificial gravity.

Skeletal System

It is generally known that astronauts who are in orbit start losing minerals (e.g. calcium) from their bones. In fact, it is said that they lose about 1% of their bone mineral density (BMD) each month. For a 6-month mission on the ISS, it's probably acceptable. But beyond six months, it would start to add up.

A 2020 study by Mortreaux involved partial weight bearing by partially suspending the pelvis of rats to offload forces to Martian levels. The result was the loss of bone mineral density over the two-week study period. I take is as evidence that we may well have skeletal BMD loss over time on Mars needing a regular impact exercise program to prevent that loss.

But as with the muscular system, NASA's fitness equipment on the ISS has shown to largely stop bone mineral density loss. So, using some combination of impact exercise, heel strike equipment, weighted clothing, and possibly medication, BMD loss would be able to be controlled.

Hydrostatic Effects

Here's the real problem. We have fluids in our tissues. It's not just the blood within our arteries and veins. Our arteries can constrict and regulate our blood pressure. But it is the headward shift of fluids that is the problem thereby increasing the pressure in our brains and eyes. The medical term for this is Spaceflight-Associated Neuro-ocular Syndrome (SANS).

There has even been one recorded case of blood clot formation in the neck of an astronaut on the ISS due to the stagnation of venous blood. The concern is that the blood clot could break off and travel to the lungs causing pulmonary embolus, a potentially life-threatening condition.

Exercises won't help. Rather, the hydrostatic fluid needs to be drained away from the cranium to the lower extremities. This can be done in one of two ways. The Russians' chosen method are negative pressure trousers. This works but only while wearing them. Rather a centrifuge is what is needed.

The Centrifuge

This book proposes that a centrifuge be included in lunar habitat designs for two reasons:

- To improve adult crew health and hence to extend crew stay.
- For animal studies to determine how much artificial gravity is needed for healthy gestation and childhood.

However, it is recognized that centrifuges on the Moon or Mars cannot be made half a kilometer in diameter. It is also clear that it is impractical to create a circular train track half a kilometer in diameter nor would it be practical to raise children in shielded train cars going around said track.

Rather, the best that we can do would be to create spinning centrifuge rooms no bigger than the diameter of the largest specially hab (i.e. 90 m diameter).

The Coriolis Effects

The problem with these intermediate length centrifuges is that, for the crew to get a full gee, they will need to spin around faster than the four to six gees that crew can adjust to. Turning their heads while being spun around can induce powerful forces within the semicircular canals in the inner ear instantly creating dizziness and nausea -- not good. But so long as one does not turn their head, there are no Coriolis effects.

In 2016, I and two other space advocates went to our local theme park and had them spin us up to 11 RPMs (full gee at 15 m diameter). Our goal was to conduct up to 10 sedentary activities in the 15 minutes that the operators gave us. We were able to easily conduct all the sedentary activities except for falling asleep (15 minutes wasn't enough time). To us, this proved that one didn't need to have one's head strapped down to avoid the Coriolis effects in an intermediate-length centrifuge.

People will, understandably, often suggest that impact exercise could be done within the centrifuge. Now this idea doesn't work. Any impact exercise inevitably causes one to bounce, inducing a linear acceleration resulting in a Coriolis effect. Alternately they suggest that crew can get eight hours a day of artificial gravity by sleeping in the centrifuge. Again, it is an understandable suggest but it is again incorrect. The hydrostatic pressure distribution has to do with the difference in pressure between the head and the food. Think about if the pressure increases and you swim to the bottom of a swimming pool. When you lay down, the height of the fluid column in your body is no longer very tall -- maybe 30 cm at most. So, the pressure difference will not be very much. The pressure in your cranium will be about the same as in your toes. True, one could sleep tilted up in one of those inclined, seat beds. But it isn't the same as standing and standing while sleeping isn't practical. We want to be lying flat if we are to get a good night's sleep.

Immune System

It has been noted that the immune system is affected by reduced gravity. Unfortunately, there is not enough information to determine how much of a problem this is if at all. Given the mineral changes from the turnover effects on the long bones, perhaps better bone health from exercise will help. We'll have to conduct animal studies to find out.

ARTIFICIAL GRAVITY AND REPRODUCTION

Not everyone moving beyond Earth will want to reproduce. But some will. And there's something good about retirees seeing children running around. We want that.

But (serious question here) will it be safe to do so?

How Healthy is Healthy Enough?

Our bodies are healthiest when they are upright, in full gravity, and active. But is it considered unethical if we don't live up to that standard? Let's say that parents purchase an Xbox for Christmas for their child and, as a result, their child becomes a lot more sedentary due to my game playing all day long. Do we consider that a form of child abuse and throw their parents into jail? No, of course not. Being a reasonable society, we consider that it is not advisable but acceptable none-the-less. So, we can live with some level of unhealthy and still consider ourselves to be unacceptable.

A child spending excessive amounts of time playing video games can become unhealthy, but they are still able to reproduce. We should not fundamentally conclude that, just because settlers are spending some of their time outside of a centrifuge then, necessarily, they won't be able to reproduce.

THE ARTIFICIAL GRAVITY PRESCRIPTION

What we need to do then is to find out how much artificial gravity is needed to be healthy enough. It would be unethical to just wait, have someone get pregnant and just see what happens (aka "Learning on the job"). Rather, we need a set of animal studies.

Components of the AGRxs

Most space advocates have the mistaken view that the AGRx is some specific number between 0 gee and full gee above which reproduction is possible and healthy. However, one can achieve full gee in an indoor centrifuge and, so long as one holds one's head still, no Coriolis effects are induced. Since one can therefore get a full gee in a centrifuge, the variable to be determined is just how many hours of full gee are required for healthy gestation, childhood, and adulthood.

This is a practical question because, if one needs an hour in the morning and an hour in the evening to "drain" fluids from the skull (for example), then this is doable since we spend about 10 hours a day doing sedentary activities. But if one needs to be in a centrifuge 24/7 to survive long-term then this is not practical.

So, the true AGRx is not a single number between 0 and 1 but rather the number of hours one needs to spend in a centrifuge to be healthy enough. It is the total amount of intermittent full AG that is needed for sufficient health.

When Do We Need to Know the AGRx?

Is there a point in time that we need to figure out the AGRx for healthy gestation. Yes, there is.

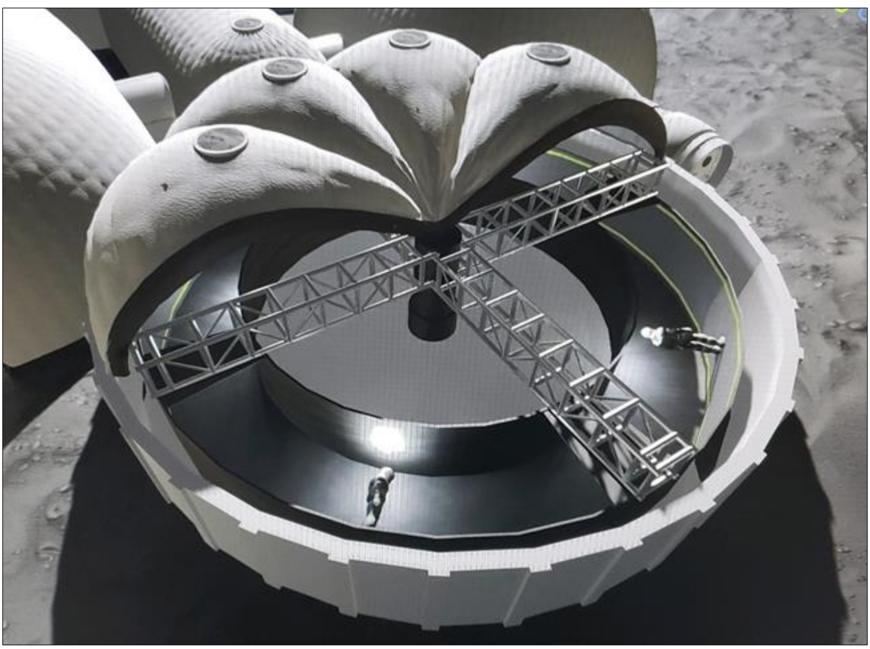
If a woman gets pregnant while on a tourist trip in LEO (something that is likely to happen in time) she can quickly come down to Earth and live out the rest of her pregnancy in Earth's full gee. The same is roughly true with a woman on the Moon who gets pregnant.

But, after a fleet of Starship concludes its trans-Mars injection burn (TMI) there's no coming back. And once a woman gets pregnant on Mars, it would take too long for the planets to line up and then spend six months on the way back. That pregnancy has a good chance of going full term. We need to have the results of the animal studies in hand to infirm that pregnant woman as best we can about how much artificial gravity she needs to have a healthy baby.

That point in time comes when enough people (i.e. more than 500 professional astronauts) have headed to Mars. Based upon Starship development progress, Raptor 3 engine production rate, Starship body production rate, and remaining development hurdles, I would place that date as no earlier than early 2035. As of this writing, that is 9 years away. And I believe that this amount of time is sufficient, but we had better not wait too long to get started on those studies.

In the meanwhile, we should avoid pregnancy among the crew. Based upon our experience with professional astronauts on the ISS, I believe that an unexpected pregnancy will likely be avoided up to the first 250 astronauts (about 2033). But, especially as couples go or crew start firming romantic relationships, we get into a danger zone where it becomes just a matter of time before an unwanted pregnancy occurs. For married couples such as among the Initial Permanent Crew on the Moon, I recommend that the men have vasectomies (highly effective, provable, and mostly reversible) and gave gametes stored back on Earth to ensure they reproduction always remains an option. Yes, it's an awkward topic but necessary.

THE CENTRIFUGE DESIGN



A centrifuge is included in the StarHab, the InstaBase, and in an AG specialty hab called the SpinHab in the International Lunar Base. This design inclusion reflects the importance of artificial gravity to extend crew

Biomedical Indicators:

In order to accurately determine the health impact of reduced gravity exposure, we need to identify measurable biomedical indicators such as: bone marrow density, muscle strength, intracranial pressure, intraocular pressure, blood pressure, density, & viscosity, pressure, immune markers, back pain, presence of venous thrombosis, fetal activity, birth weight & growth curves, and probably others. Deciding what difference is acceptable may be a judgement call.


Middle Articles

Structure of the Scientific Paper

www.DevelopSpace.info/extended

Proposed Protocol for Determining the AGRxs

Given the relatively near-term risk of a woman getting pregnant on Mars, it is proposed that the AGRxs be determined as quickly as possible. To that end, an outline of a protocol is here described while experts are needed to develop a more accurate protocol.

Start with many pregnant laboratory mice, assigning several to different hours of full AG. The length of pregnancy for a laboratory mouse is three to four weeks. After assessing the biomedical indicators, we home in on what appears to be a healthy level of full AG. Next, we increase the number of mice subjects above and below this level and conduct another month's experiment with more pregnant mice while raising the first mice pups in a spectrum of full AG to determine the AGRx for healthy childhood.

Just as soon as one is beginning to develop confidence in the AGRx for mice then one can simultaneously start on studies to determine the AGRx for the next level of animal model. The starting hours of AG for the second animal model will be somewhat below to somewhat above that found for the mice. The next level after large numbers of mice could be either hamster (3 weeks) or rabbit (4 weeks). A similar approach would be used for them as was used on the mice.

Just as soon as one is beginning to develop the AGRx for the second animal model then we begin the AG Rx protocol on the first primate, the marmoset. These have a gestation period of about 4.7 months. Once again, it may take two or three rounds of studies on pregnant marmosets before moving on to the last animal model.

The last model is the macaque monkey. We would prefer to do the study on chimpanzee, but these are excluded from study in the United States. The macaque monkey has a pregnancy length of 5.5 months. After about three rounds of pregnancies, we would have our best idea of the AGRx for humans.

If we add these lengths of time together, we get: (1 mo. x 3 + 1 mo. x 3 + 4.7 mo. x 3 + 5.5 mo. x 3 = 3 years). If the first permanent base is established on the Moon in 2028, then three years after that would bring us to two years before the hypothetical 2033 date when the first Martian pregnancy might occur. This just goes to show just how much we need the centrifuge in the lunar base and how urgent it is that we be ready to seek the AGRx just as soon as the first permanent crew inhabits the first lunar habitat(s).

Making the Decision for the First Off-Earth Pregnancy

The first full gestation of a human baby off Earth should not be taken lightly. But attempting to delay the first off-Earth pregnancy could backfire in terms of the ethical outcomes. In particular, it may be best to intentionally have the first off-Earth baby be conceived on the Moon where careful monitoring could allow early detection of a problem with immediate return to Earth. In this way Martian residents could be better informed to take precautions to avoid pregnancy.

Who should decide whether to become pregnant and remain on the Moon? We will have done what we can to make the decision for pregnancy as well informed as we can given the limited time. Whether or not to become pregnant and remain on the Moon is a very personal decision that we leave up to the parents. They can be advised by experts but ultimately it comes down to those who have the most responsibility for the baby – their parents.

The Significance of the First Off-Earth Baby

Humanity is about to start moving beyond Earth. The first child born off Earth will go down in history as the first of those humans for whom Earth is not their home, but they are from “out there”. We need to work to ensure that this first off-Earth human gets off to a good start and determining the AG Rx is the essential step to ensuring this.

25 – Dust Mitigation

SUMMARY

The best way to deal with dust is to simply avoid it. This chapter describes several easy ways of doing that.

The Moon is covered with dust from meteorite and micrometeorite bombardment. The fluffiest part of the dust is in the top few inches making the surface "squishy" according to the Apollo astronauts.

When landers land, their exhaust velocity can be double lunar orbital speeds thereby causing sandblasting of structures within the area.

Problems with Dust

As astronauts walk in the dust and as rovers drive over it, it kicks up and deposits on everything. This dust is very fine and gets into everything. It can get into the joints of moving parts thereby causing wear and even seizing up. It can be electrostatically charged and so sticks to equipment and space suits.

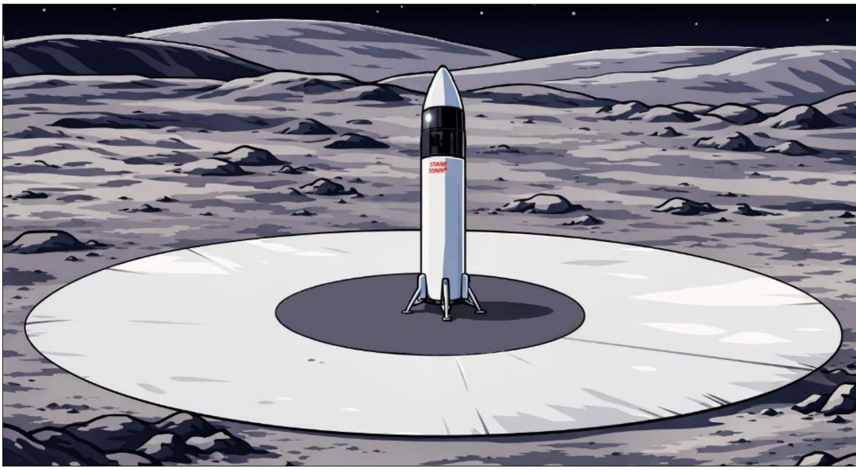
Worse yet, if the dust is tracked into a habitat, it can be inhaled by the crew. Since it is so fine, it can be breathed in and lodged within the lungs causing health problems.

However, one can envision straightforward solutions to each of these problems.

Solution #1: Landing Pads

For the problem of structures being sandblasted with landers, the very first lander won't have this issue due to the lack of anything else being in the area at that time. A lot of concepts are being developed to produce berms and sintered create pavers for landing pads on the Moon.

Conceivably, thin tarps could be delivered as payload and then telerobotically secured to the lunar surface. From the payload, a telerobot could pull out a small, blast-resistant tarp and secure it to the ground underneath the lander. But, for a longer-term solution, telerobots could use microwaves to sinter (i.e. fuse) the lunar dirt or even make bricks and configure them into a robust landing pad. Telerobots could also make berms to help redirect and reduce the blast.



A ceramic pad with peripheral tarp protects from blast and exhaust interactions.

Solution #2: Equipment Wear

For the problem of equipment wear due to the exposure of dust, it is important to remember there is no wind on the Moon. So, instead of dust floating up in the air, it falls in a ballistic (parabolic) trajectory. This helps somewhat.

Telerobots can be designed to move slowly so that the dust isn't kicked up very high. Parts can be designed to keep telerobotic joints far from the dust being kicked up. The speed at which robots drive and work can also keep the dust down. The mining industry on Earth has a lot of experience designing equipment in abrasive environments so it is a matter of iterative engineering to figure out the best designs.

Solution #3: Roads

The Apollo program demonstrated that their crewed rovers would kick up "rooster tails" of dust when their vehicles bounced on an uneven surface. A solution for this would be to create basic dirt roads in which telerobots would smooth out a road and using a vibrating "steam roller" compact the dirt so that, as vehicles drive over it, they don't bounce and kick up dirt. For much more discussion of lunar roads, click here.

Solution #4: Don’t Go Outside

"A clever person solves a problem. A wise man avoids it. -- Albert Einstein

Too much of our thinking of astronauts is about them being in space suits, walking around on the surface, and picking up rocks. Sure, there's a place for that. But if we are going to stay, then much of the work will be indoors and not in a space suit.

Between the Soviet Union (on the Moon) and the United States (on Mars) teleoperated rovers have driven up to 22 kilometers. So, a lot of scientific exploration can be done using rovers at lower cost and must lower risk. With the Moon only three seconds time delay, rovers can accomplish things more quickly than on Mars. So, there isn't going to be that great of a need to send crew out to walk around in the dust.

NASA Surface Exploration Vehicle has a clear bubble in the front where crew, while remaining inside the vehicle, can get a close-up view of a rock and could even use mechanical manipulators to grab samples and bring it into the vehicle through an airlock.

Solution #5: Leave the Suits Outside

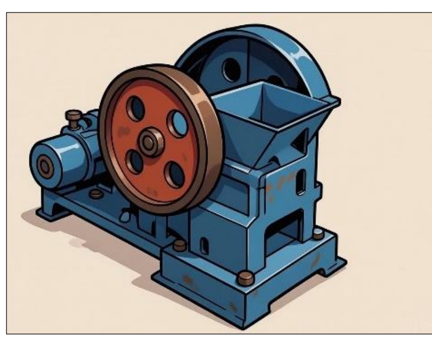
NASA has developed an ingenious solution to prevent dust from getting inside either the crew vehicle or the habitat. Rear-entry space suits ensure that any dust on the suit is left outdoors. This is where the suit is attached to the outside and the crew enters and exits from the back of the suit.

Clear plastic suit liners.

If a network of roads and trails are telerobotically produced, then, even when explorers (such as international astronauts and tourists) do walk out on the surface, dust would largely be limited to the boots. If these paths were sintered using microwaves, little if any dust would be able to get on to the suit. Finally, coveralls could be used to keep dust off the suits.

Solution #6: Gravel Bed Hydroponics

Hydroponics is an approach to growing plants in a controlled environment. Nutrient solutions are used instead of soil. But for things such as fruit trees and tree nuts, non-dusty soil can be produced by taking rocks, washing them from dust, crushing them into dirt, and then tumbling to round their edges.



Rock crusher keeps regolith out of the hab.

26 – Psychology

SUMMARY

Most space advocates err because they talk as though all astronauts will have to bear with very confined spaces basically driving them crazy. Starships and very large habitats will prevent that issue from being a problem. Rather the psychological issues of concern will be crew cohesion related to personality conflicts within the teams, marital issues, and private individuals bringing their pathologies with them. Ways of preventing these problems from arising are discussed.

CHALLENGES MITIVATED BY LARGE VOLUMES

Many psychology studies have been done in analog settings. A lot of these have to do with how the crew perform and get along when essentially locked up in a small volume with a handful of other crews for an extended period.

Confinement

In this book, evidence has been presented that it is likely that, by 2030, there will be a growing fleet of heavy lift vehicles with the full payload capacity able to be sent to the Moon or Mars thanks to full refilling at a LEO depot.

This large capacity will have a significant effect on the psychology of the situation and will be unlike the cramped quarters typically envisioned for small, government crew going to Mars for a scientific expedition. On the Moon, the round-trip time will be as little as two weeks. For Mars, early on, SpaceX is planning on launching dozens of Starships in each window. As the SpaceX fleet grows during the 2030s, fleets going to Mars will reach into the hundreds. Crew and cargo can be mixed so that one doesn't have to pack all passengers in just a few ships. With alternating sleep and sedentary schedules, not all passengers need to be bumping into each other at the same time.

Very Large Inflatable Habitats

Specialty habs consisting of a 100-tonne payload with 6 kilograms per square meter and 10 meters tall (three floors) would have a footprint of 12,241 square meters or 3.0 acres. In other words, early inflatable habitats could be extremely roomy and eliminate problems of confinement from the beginning.

Social Isolation

Analog missions also typically assume that the crew would be isolated from loved ones back on Earth due to time delays in communicating at Mars' distances. Well, that's more of a problem with Mars but not the Moon as the speed of light at lunar distances is only 2.6 seconds round trip.

But, with a fleet of Starships and the rapid growth of the base / settlement on the Moon, the social life will not be spending six months with the same six astronauts. Rather, there will be a community of people from a wide variety of backgrounds. Further, since the lunar base / settlement would be a permanent facility, couples could go or couples could even form within the base. So, the social situation could be a whole lot different than an Apollo 2.0 scenario.

TELEPRESENCE ON EARTH

Because of the Moon's proximity to Earth, one does not have to disconnect entirely from friends and family. One could even be telepresent at family gatherings using Segway-like devices that have screens showing the person on the Moon. So, one could literally be on the Moon yet attend the wedding of one's grandchildren. One could be present at the family Thanksgiving table and carry on a half-way decent conversation across the table. Of course, you can't eat their turkey but...

Keeping in touch with family.

NATURE DEFICIENCY

Some say that you would have to give up the outdoors if you were to move beyond Earth. Technically, this is correct until full terraforming has been accomplished. Yet, from early on, acres-large inflatable habitats could be designed to create natural, outdoor-like environments. We will want to have GreenHabs as part of the base. Couldn't they be designed with walkways, nature sounds, and even the occasional water feature? Greenery can be designed into the base if one so chooses.

GROUP PSYCHOLOGY

For the Initial Permanent Crew of eight, it will be vital for this historically important group of people to get along with each other without significant conflict. Screening, observations, and challenges can help identify which of the competing teams have issues. If during training and simulations some teams seem to get along fairly well then this is a good sign that they will probably also do well on the Moon for the six to twelve months that the world is watching them. And, if they know that the time is limited before the international astronauts start arriving and then the Initial Crew disperses within the larger base, then they will probably be able to bear with irritations since they would know that it was a temporary situation.

MARITAL CHALLENGES


Managing relations.

Six to 12 months for the Initial Permanent Crew is probably not enough time for marital problems to become serious. However, some planning might be advisable to ensure that neither affairs nor divorces occur. That would be quite the dark spot on the story of humanity's first permanent steps beyond Earth. So for example, the team could commit to behaving themselves and nipping any inappropriate attention in the bud. Men could generally work with men and women with women as a partial solution to preventing affairs. Husbands and wives could spend much of their workday separately so that they wouldn't always be "in each other's hair". Etc.

MENTAL CONDITIONS

However, people will bring themselves with them and hence bring some of their mental baggage too. We would like to think that, with proper screening and selection, that, during the ILB phase, international astronauts will be selected to be supremely psychologically healthy.

Yet, from previous experiences in LEO stations and one fairly famous incident of a love triangle gone bad involving an ISS astronaut, screening for psychotically health is not always an exact science. Further, as wealthy, private individuals start paying their way into the base/settlement, they will bring with them their health problems including mental health challenges. Space psychologists will be busy preparing the eventuality and providing needed services to the residents. But just the self-selection of wealthy people will probably create a population of better mental health than the general population on Earth.

By the mid-2030s there will probably be pretty good AI counseling services that will be able to help people process their own issues. And, for the personal touch, psychologists and psychiatrists will be able to serve their fellow residents as their contribution to the base's community.

27 – Lunar Healthcare System

SUMMARY

Initial crew will be selected for peak health and so the healthcare system will focus on potential emergencies. But, as older, private settlers arrive, a broader set of healthcare services will be necessary. The key will be to anticipate the need beforehand and then to push forward healthcare providers, facilities, equipment and medications to ensure that all is available when needed.

A well-organized healthcare system could not only ensure healthcare provision but could proactively prevent dental, medical, and psychological conditions. Public health approaches could also eliminate many infectious diseases from off-Earth settlements.

OVERVIEW

The best approach to addressing the initial medical challenges on the Moon would be to prevent it where possible. This includes proper screening and selection of initial crew to ensure that they are unlikely to experience medical conditions that the facilities are not prepared for. It could also involve regular, voluntary screening and tracking to ensure that problems are picked up earlier when they are more easily treated.

There will be different phases of development with different healthcare needs. The key to ensuring that a growing base has the right healthcare providers, equipment, facilities, and medications is to, as much as possible, anticipate when the need is likely going to arise and then push forward those things to meet the need before they become necessary. The same holds true for equipment, facilities, and medications. Among the international astronauts and early, healthy, private settlers should be those healthcare providers willing to serve their fellow residents freely as part of their contribution to the growing base / settlement. AI and increasingly capable humanoid robots will provide some of the healthcare labor needed.

A unified healthcare system, including a unified, very efficient, and proactive healthcare IT system is described. It would seek to be the central nervous system of a highly capable healthcare system and so could demonstrate to those on Earth how such an excellent and cost-effective healthcare system could look like.

Consideration needs to be put into meeting the healthcare needs of remote EVAs, outposts, and new bases to ensure that likely medical conditions can be adequately addressed. An emergency medical response system would need to be established to identify situations that need rapid response whether within a facility or during an EVA. This could include having a medical Mission Control, having qualified people and/or teleoperated humanoid robots locally available, and the Moon-wide capability for a suborbital response team able to fly from a polar international base to anywhere on the Moon within 20 minutes.

PREVENTION

Crew Selection

As described in Chapters 12-16, it is anticipated that there will be phases of lunar exploration and development. It will start with extremely healthy professional astronauts with few medical conditions. There is already an Aerospace Medicine system in place that can detect and exclude from the astronaut corps those who will pose a medical risk to mission success.

But as private settlers pay for their ticket and start arriving on the Moon, many (most?) of those will be older individuals who have lived long enough to have saved up enough money such that they can afford to move to the Moon. And with age comes and accumulation of health conditions. This is why this book breaks the private settler phase into two parts (early and later). Private settlers who have a history of cardiovascular disease, insulin-dependent diabetes, medication-controlled seizures, or any number of other risky medical conditions should not be out, far away from medical facilities at the International Lunar Base lest they experience a medical incident that the lunar healthcare system is not yet ready to respond to. But it is during the early private settler phase that the final touches of a healthcare system would be put in place. Then, as later, less healthy settlers arrive, there will be facilities and response systems similar to what we have on Earth. So, for private settlers there will need to be a selection process to divide them into the early versus later group.

Preventive Healthcare System

Dentistry is particularly good with regular cleanings and checks to help detect and prevent cavities. Early treatment can prevent small problems from becoming big problems. Really good medical systems are similarly proactive in managing patient's conditions. As branches of humanity begin fresh starts on the Moon and Mars, it would do well for us to think about the healthcare systems that we want to see established. Indeed, if the Moon could demonstrate (and even make available for free) a very well-designed healthcare system then this could be one of the many blessings that lunar development could provide to the people of Earth.

For starters, one's personal health is something that belongs to the individual and doesn't belong to the "system". But a good system should be available should the individual wish to take advantage of it. And as on Earth, the privacy of health information should be strictly maintained.

What would a comprehensively preventive healthcare system look like on the Moon? It would be unified, comprehensive, and would be able to detect and help manage healthcare actions. As one small example, a resident's bathroom scale could be connected to the system and routinely monitored to see how the patient's weight is going. Automated analysis of information could trigger automated and/or AI health education and prompts to help the individual take actions optimized for their health.

TIMING

Push to the Front of the Line

It will be critical to ensure that healthcare providers, equipment, facilities, and medications are available when they are needed at every phase of lunar development. Fortunately, this won't be as difficult as it might first appear.

Take for example the healthcare providers. For even very healthy astronauts, we may expect an incident needing emergency medical intervention including pulmonary expertise. Since those skills will be a high priority, the one physician in the Initial Permanent Crew should probably be both fully trained in these fields and highly experienced. And they should be trained in additional skills that we anticipate needing and be backed up by immediate access to specialists on Earth. For things like nurse midwife, we won't need that expertise until quite a bit later and only after the artificial gravity prescription (see Chapter 24) has determined that having off-Earth children can be done safely. For things like an endocrinologist needed to treat residents with diabetes, they should be pushed to the front of the line but only prior to when we expect that they will be needed (i.e. during the early settlement phase). The same hold true for equipment, facilities, and medications.

Anticipating Needs

It is possible, but would require a lot of work, to formally anticipate what the healthcare needs will be at each phase of base growth. Before very large, inflatable specialty habs start being delivered by a fleet of Starships, some new healthcare organization with the expertise needs to take upon themselves the work of developing a plan for meeting the healthcare needs of a growing base. I presented at the Mars Society Conference on this topic. Scan the QR code to the right to watch that presentation.

Mostly Free Care

Trained, experienced, and expert healthcare professionals certainly deserve appropriate compensation consistent with what they have to offer in the marketplace. But it seems as though the Initial Lunar Base will probably operate differently than private healthcare systems on Earth. As described in these pages, the initial, expensive seats on the Starship fleet will be purchases with those with the deepest pockets (i.e. large countries) so we can anticipate governmental exploration and base phase followed by private settlers. The private settlers will skew older, including retired individuals who will likely want to play their part in the historic establishment of humanity's first permanent foothold beyond Earth. They will likely consider it a privilege to freely contribute their time and expertise for the wellbeing of their fellow settlers.

Retired volunteers.

AI and increasingly capable robots will also be able to provide aspects of healthcare for a relatively low cost. All told, extensive healthcare will be able to be provided at a reasonable cost to governmental and private residents without "breaking the bank". Much later, as the per-seat price comes down and if/when individuals are born off Earth, then the healthcare system may start charging more for services but by that point AI and robotics may be so advanced that all bets are off.

Nursing Homes

Just because private settlers will tend to be older doesn't mean that we are starting a literal nursing home on the Moon. No granny will be pushing her walker to take her place in a Starship.

But older people will get even older and so there will come a time when actual nursing homes will become a thing if those individuals don't return to Earth first. Individuals needing nursing care need a lot of attention. Hopefully, by the time that point comes, nursing home personnel will be greatly augmented by robots capable of providing much of the needed care. Although not the equivalent of the human touch, they will be an essential part of the healthcare team.

CONTEXTS

Astronaut Phases

During the astronaut phases (Artemis, ILEP, & government ILB), governments will select their astronauts the way they have been selected up to now. These are amazing specimens of humans, highly fit physically, and (generally) mentally fit as well. They will not bring much in the way of chronic diseases needing treatment but, theoretically, may need treatment for certain emergencies and injuries. So, that is going to require a certain type of medical care availability. With time, those health astronauts may begin to develop problems resulting from the reduced gravity environment. This may be a bit of a real-time learning process where studies begin to reveal statistics on what the issues are and what healthcare is needed to address the conditions.

Private Settler Phases

As mentioned before, the early private settler phase will select for healthy individuals, but they may develop chronic conditions sooner than younger astronauts. And settlers in the later phase will require the whole gamut of care minus any significant conditions that would better be treated on Earth.

Remote Locations

But the context is not just the health of the residents. Rather, remote outposts or newly started bases will have special healthcare needs that will need to be planned for. It may be that some selection will need to be made to ensure that a new location will not have likely healthcare needs beyond what is available at that location. It may also be that, as they do on Earth, residents will need to travel to receive treatment. This may be to a large international base or even to take the three-day trip back to Earth. But the goal is to make the Moon as medically independent from Earth as early as possible.

HEALTHCARE PROVIDERS

Physicians and Mid-level Providers

In the early phases and in remote locations, there may need to be highly trained, exceptional physicians. For example, the physician among the Initial Permanent Crew may best be a dual-boarded, ER and Pulmonary/ICU physician maybe even with emergency surgical skills additionally trained in other potential conditions. This person could be among the best of the best (aka "right stuff").

As the base grows, a logical sequence of specialists would be pushed to the front of the line to ensure that the expected skills are available. Consultants and telemedicine should also be available. Gynecology would be a relatively early need, but their obstetrics training could wait until pregnancies occur among residents (after the artificial gravity studies on pregnant animals).

Especially as the private settler phases occur, mid-level providers could fill out the ranks of the medical staff.

Nurses and Allied Health

As a physician, I can tend to focus on physician specialties. But, obviously, at the same time we need to ensure that there are nurses with experience in the various nursing fields as well as the allied health professionals such as the various therapists. Pharmacists will be needed in all phases but especially during the later crew phase when people start bringing a wide variety of chronic medical conditions.

Dentistry

We can try screening and early detection but prevent what we can, people will certainly develop dental conditions that will need treatment. Given that a dental emergency could occur during any phase and chronic dental conditions will need care, we will need our dentists as an important part of the healthcare system.

Preventing dental problems.

Mental Health

Practically everyone has at least some mental issues of at various levels and as the selection practices relax especially with the later private settler phase, mental health will assume a larger part of the healthcare system. Counselling can be provided locally, remotely using telemedicine, or AI.

Given the special safety environment of habitats in a vacuum, we need to make sure that a suicidal or delusional resident can't seriously harm others.

LUNAR RESCUE SYSTEM

Mission Control

Given the global, sometimes simultaneous exploratory missions of the ILEP described in this book, we should give thought to how those activities will be overseen by Mission Control. Whether that would be an extension of NASA, an international consortium, or a private company (e.g. former mission control experts) is an interesting question. Either way, when a medical or logistics emergency develops anywhere on the Moon there needs to be a coordinated plan to respond to that emergency in a way that adequately meets the need whatever it might be.

Mission Control will need to be constantly maintaining oversight of EVAs so that the moment there is a problem, they will know the nature of the problem and rapidly respond appropriately. Part of that rescue system will be to ensure that the components of the rescue system are ready to respond on a moment's notice and that assets are in place, at the right place when needed.

Self-Rescue

Lunar expeditions may wish to have more than one vehicle. In this way, if one breaks down or if there is a medical incident (e.g. cracked visor) the other half of the crew could respond immediately. One could also have a robot as a team member that would be able to suffer much more trauma and still be functional compared with human crew. Telerobots on vehicles could also be pre-positioned prior to the landing of international explorers and they could follow the crew. In this way, the landing could be observed and responded to and any incident could have an immediate, teleoperated response.

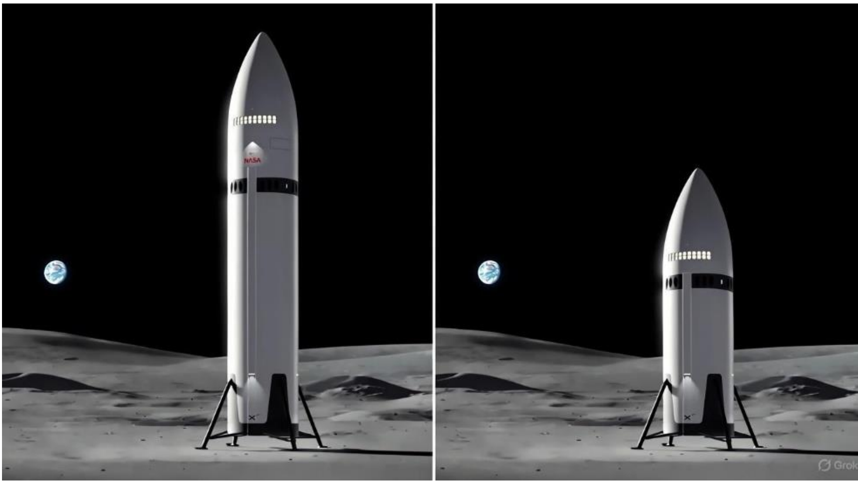
Surface Rescue

Different responses will be applicable depending upon the situation and location. If it happens within a base and the resources are available there then no global response is necessary. If it is during an EVA but there are facilities within quick driving distance then the approach response might be either a crewed, teleoperated, or automated response. For example, say that a crew vehicle has a battery malfunction, the passengers have 36 hours of life support available, and there is a waystation five hours drive away, the solution isn't to risk the lives of a team arriving by a suborbital launch from the polar base but simply to send a charged electric chassis onto which the stranded crew module could slide to and then they complete the trip.

Suborbital Rescue

But, if it is an emergency and it will take too long for surface rescue to arrive, the solution of last resort would be to launch a shortened (stubby) vehicle specifically designed to suborbitally launch from a base with telerobots or crew which would land within driving distance away from the incident, quickly deploy their own vehicle with equipment (e.g. jaws of life) and supplies and arrive at the scene as quickly as possible.

Suborbital flights from a polar base can take about 20 minutes from launch to landing. To be rapidly functional, the suborbital crew may need to already be at no more than 1/2 atm and/or use advanced suits that have good flexibility while operating at 1/2 atm.



Stubby Starship sized to be a suborbital emergency response vehicle.

PUBLIC HEALTH

Population-based Medicine

In a discussion of a lunar base, public health wouldn't normally come up in conversation. For example, that part of public health dealing with disadvantaged people groups wouldn't really apply here. But public health experts tend to excel when it comes to establishing new health systems and data acquisition, and statistical analysis. In the clinical setting they can bring expertise to population-based healthcare management applicable in the setting of a unified healthcare system.

Epidemics

When it comes to infectious disease and epidemiology, it gets quite interesting. Here is another fresh start opportunity. What infectious diseases will we have an opportunity to exclude from a lunar settlement? With proper screening, treatment, quarantine and the segmented nature of off-Earth bases/settlements, one can legitimately consider completely excluding certain organisms from every coming from Earth. Think about viruses as opposed to bacteria. Do we need any viruses for human health or can we seek to prevent them from spreading beyond Earth?

Do we need malaria on the Moon or Mars apart from a study sample? Using quarantine, can we exclude the seasonal flu? When one begins to systematically analyze which pathogens can be excluded, it becomes apparent that large sections of infectious disease can be escaped from using proper public health measures. Now, there are things like athlete's foot whose exclusion is more easily spoken of than achieved. If an infectious agent somehow makes it to a base/settlement, public health professionals could implement protocols to fully eradicate the agent given the unique segmented nature of off-earth facilities.

Will we experience an increasing number of man-made virus pandemics on Earth? Hopefully not but we can't reasonably exclude that possibility. It should be possible to use pre-launch and upon-arrival isolation for the lunar settlement to be largely immune from that risk.

FACILITIES AND EQUIPMENT

The International Lunar Base should initially have a medical specialty hab with sections for different healthcare functions. But, as the population of the base grows, that multi-purpose hab can be converted into a single function hab as more specialized healthcare habs arrive. Eventually, there will be an entire healthcare complex where residents can receive a wide variety of healthcare services. The order of development may be something like: multi-purpose medical facility, DentalHab, ICUHab, ClinicHab, PharmHab, HospitalHab, and later "BabyHab" if children can be safely born off Earth.

Equipment would need to precede the facilities by first being housed in multi-purpose habs until population growth justifies more specialized healthcare habs.

Remote locations such as the start of a new base may follow a similar path that the ILB followed by starting small with a multi-purpose hab and then specializing as the base grows.

MEDICATION

Shipping Costs

For off-Earth transportation costs, the rocket equation means that the cost of transport is directly related to mass. Things that are low mass such as computer chips or medications can therefore be surprisingly low cost to ship. So, for example, an 800 mg ibuprofen contains, yes, 800 mg of pure ibuprofen or just shy of a gram. A gram is 1,000th that of a kilogram. Let's say that, conservatively, when the ILB is established and growing, this is accomplished because the Starship fleet has become fully operational and with full reusability. In that context, it is estimated to cost perhaps $850 per kilogram. So, each gram would cost $850 / 1,000 = $0.85 or less than a dollar -- not a lot. So, instead of going through the hassle of producing medication off Earth, just ship it. And at about $1 per tablet, an entire pharmacy could be shipped.

However, we don't want to waste medication and hence money, so we want to make sure that we have the right selection of medication and in the right quantity without a lot of medication exceeding its expiration date. There are computer systems that assist with "demand forecasting". This will depend upon the expected need, usage rate, how much of the meds are exceeding their expiration date, etc. It is a bit different than what pharmacies are used to dealing with but should be withing their capability to figure out. And it could be a feather in the cap of whichever pharmacy chain takes the lead in becoming the first off-Earth pharmacy.

Pharmacist in the International Lunar Base.

Certain emergencies are rare but critical meds need to be available even if they are likely to expire without being used. That's just the price that one must pay to be prepared for emergency situations.

With a three-day one-way transit to the Moon, maintaining lunar pharmacies is very doable. Far more challenging will the pharmacy on Mars where the minimal wait time will be the six months of travel and the maximum time would be the 26 months waiting for the Earth-Mars launch window to open plus the six months travel time (= 32 months), plus the radiation exposure, storage requirements, and medication expiration dates.

HEALTHCARE IT SYSTEM

Finally, as new worlds are settled, it presents an opportunity for fresh starts when it comes to measurement systems (e.g. let's leave the imperial system on Earth), logistics, electrical & electronic standards, financial, governance, and infectious diseases. Well, another fresh start opportunity may present itself in a brand-new healthcare system including a healthcare IT system.

Given the ability for large language models (LLMs) to greatly increase the speed of computer programming, perhaps we could conceive of a new, comprehensive, integrated, efficient healthcare IT system. There would be time to develop such an IT system as the bases grow and as AI continues to advance.

Especially given the limited staffing in early off-Earth bases, efficiency means extending healthcare while not consuming too much time of the base's residents. IT systems such as electronic medical records (EMRs) should not turn healthcare workers into data entry workers like is so often done. Reducing the burden of EMRs could include the application of microphones and maybe cameras in the exam room and using AI to document and suggest orders. I am aware of at least one company that is working with a major tech company to do exactly this, and I can imagine how the time of clinicians can be more focused on patient care with the AI "scribe / assistant" offloading much of the information work.

It is here proposed that the fresh start opportunity that the lunar settlement presents and the new AI tools be taken advantage of to openly develop a new, comprehensive healthcare IT system that would be broadly available at reasonable cost to enhance utilization uptake not only beyond Earth but on Earth as well.

WORKING ON THE MOON

28 – Lunar Resources

SUMMARY

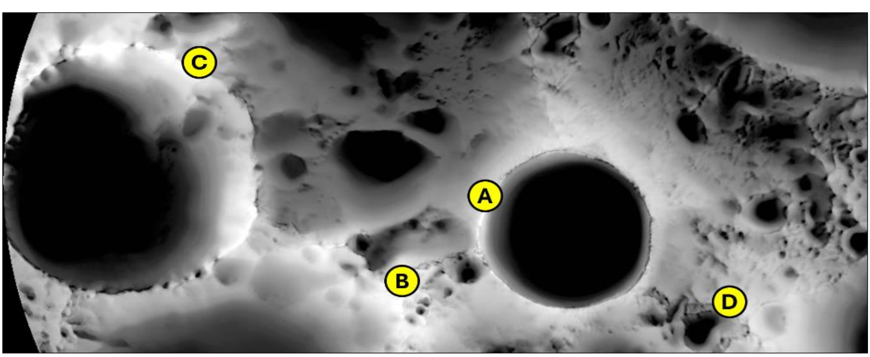
The Moon has some unique resources worth noting. At the top of the list are the so-called polar Peaks of Eternal Light (PELs) and the permanently shadowed regions (PSRs) nearby containing substantial quantities of volatiles. A small percentage of the lunar highland is unoxidized metals. Of particular interest are the results from NASA's 2009 LCROSS mission showing high concentrations of water and substantial amounts of carbon and nitrogen-containing chemicals. Total water could supply a water recycling settlement of a million people for 1,600 years!

The great advantage for planetary destinations is that they have resources readily available unlike free space. As you will see, the Moon has more than enough resources to support not only an initial base but a very large settlement for a very long time.

THE PEAKS OF ETERNAL LIGHT

All the processes involved with establishing an initial permanent base require sufficient power. Fortunately, the poles of the Moon have a particularly favorable power situation.

As the Earth orbits around the sun, it does so with a 23-degree tilt. This is nice in that it gives us the four seasons. Also, as a result, the Earth's poles are exposed to continuous sunlight in the summer and then continuous darkness in the winter.



Four Peaks of Eternal Light on the lunar south pole.

But the Moon is different. It has almost no tilt compared to its orbit around the sun. In fact, the tilt of its axis is only 1.5 degrees. Not only does this mean that it essentially has no seasons but more importantly, there are certain depressed areas including craters where sunlight hit the rims nearly constantly but never hits their floors. As a result, there is the fortuitous situation where locations where solar power can be collected nearly continuously which are relatively close to permanently shadowed dirt where scientists have long speculated that ice may exist over geologic time scales.

Now, some will point out that there are no actual “Peaks of Eternal Light” (PELs) on the Moon. Because of the slight tilt, there are no specific locations that are sunlit 100% of the lunar year. But one of those peaks are sunlit between 87 - 92% of the time on average (ridge between Shackleton and de Gerlache craters). This means that that point has darkness lasting only a few tens of hours. And with solar drapes measuring between 30 and 60 meters in height, the time in sunlight would be increased yet more. That much solar power at one location would still be rather useful.

The use of the lunar pole’s solar power will benefit not only any settlements at the poles but will benefit the entire Moon. This is because, the high-power activities (electrolysis, metallurgy, and growing food) would be preferentially done at these locations and then the product of that production could be shipped from the poles to any other part of the Moon using electric, automated, cargo vehicles with less than a three-day drive.

LUNAR VOLATILES

The LCROSS Mission

Over the years, scientific speculation has led to several craft with a number of instruments attempting to see if water exists on the Moon near the poles. The results were mixed but generally encouraging. Unfortunately, there was always some alternate explanation for the results. So, whereas there was evidence that water ice may exist on the Moon it was never definitive.

Then in 2009, NASA, with the principal investigator, Anthony Colaprete, conducted a rather remarkable study. They were able to add their LCROSS experiment onto an already planned mission which delivered the high-resolution Lunar Reconnaissance Orbiter (LRO) to lunar orbit. The researchers were able to include a shepherding craft and direct the rocket's Centaur upper stage to descend to the Moon at high speed and crash into Cabeus Crater in the south polar region where suspected ice concentrations were particularly high. The impact kicked up dirt from the floor of Cabeus Crater into the sunlight. The trailing shepherding craft was able to spectroscopically image the resulting ejecta. The results were remarkable.

Screenshots from an LCROSS Missions video. Credit NASA.

It was found that 5.7% by weight of the ejecta kicked up was water ice. That is one part per 18. Compared to the bone-dry areas of the Moon towards the equator, this is an extremely high concentration of water.

But it was not only water that was found. The fingerprints of carbon, nitrogen, and sulfur-containing chemicals were found also. Here's the breakdown of those.

Compared to Water:

- 100% - Water
- 16.75% - H_2S
- 6.03% - NH_3
- 3.19% - SO_2
- 2.17% - CO_2
- 1.55% - CH_3OH
- 0.65% - CH_4
- 0.03% - OH

To help with the comprehension of what these numbers mean, I have constructed a set of boxes that show the relative sizes of the lunar regolith and various chemicals discovered by LCROSS. Below is what a cubic meter of icy regolith would look like if the components were broken down into separate cubes. The density of the chemicals in their liquid form is much less than that of the dry regolith. As a result, their volumes appear larger than their weights.

No longer can critics of the Moon claim that there is no carbon or nitrogen on the Moon. There are unmistakable spectroscopic fingerprints of nitrogen-containing ammonia and carbon-contain molecules such as ethylene, methanol, carbon monoxide, and methane. And their relative concentrations mean that any ice-harvesting operation to produce propellant quantities of water would give abundant carbon and nitrogen especially for bases and settlements which recycle those chemicals.

Illustration of lunar volatiles.

Of equal importance is the total quantity of these volatiles. Take water for example. The best data indicate that there is at least 600 million metric tons of water collectively at both lunar poles. If a settlement of a million people were to recycle their water and so have reduced need to replenish those losses, that city would have enough water for over 1,600 years. That would give far more than enough time to develop strategies to import water from asteroids, comets, or other destinations. In other words, settlers on the Moon will never run out of essential resources.

Uses for Lunar Water

Lunar-derived water has multiple uses. By far, the most important use is the refueling of reusable lunar landers thereby turning them into ferries. To achieve this, one simply must electrolyze the water into its constituent parts – hydrogen and oxygen. A variant of Blue Origin's Blue Moon lander is described in chapter 7 which could use this propellant to ferry crew and cargo modules between high lunar orbit and the surface of the moon.

But water could also be used for sanitation, drinking, and to irrigate plants for food and fiber. Electrolyzed water could provide the oxygen necessary for breathing. Finally, if the harvesting of water was achieved relatively early on then it could be pumped between the outer layers of habitats to provide excellent radiation shielding.

REGOLITH

If there is difficulty with harvesting water ice, then the simplest way of getting radiation shielding is to simply have telerobots either push the lunar regolith onto the top of flat-roofed habitats (e.g. like an air mattress) or drop the regolith within their walls. Placing regolith on top of the habitats would be especially easy to do if those habitats were inflatable and if the telerobots were to push the regolith on top of them prior to inflation. This covering would not only protect against space radiation but also from micrometeorites and provide a good amount of insulation to moderate any temperature extremes.

METALS

Although the LCROSS results show ethylene which can be polymerized into polyethylene plastic, the organics would be better used not for plastics but for other purposes (e.g. CO_2 for plants, oils, solvents, lubricants, etc.). That is because, on the Moon, organics are much more limited than metals. For this reason, on the Moon, everything possible should be made from metals than from plastics.

Unfortunately, we don't know if pieces of nickel-iron meteorites would survive the high impact speed impacts on the Moon or whether they would vaporize altogether. There is unoxidized nanophase iron but that is coated all over the lunar regolith grains thereby making lunar regolith attracted to magnets. So, saving energy by separating unoxidized metals may not be particularly easy.

Alternately, one could just "pay the price" and process certain lunar rocks into metals by heating the rocks to the point where the metal oxides in the rocks break down into unoxidized metals and oxygen which makes up the large majority if the mass of propellant.

Given the Moon's relatively simple geologic processes (as compared to that of the Earth's) there are relatively few types of rocks composed of certain minerals on the Moon. There are the mare basalts, highland plutonic rocks such as anorthosite, KREEP-rich rocks, impact breccias, and granites/felsites, and pyroclastic glasses. Regolith is the thick dirt layer which is typically an average of rocks that have been pulverized and mixed up (gardened) from impacts over the eons.

Distinct rocks have somewhat different mineral concentrations compared to each other so one would want to start with the rocks (as opposed to regolith) and crush them up to have greater yields of certain metals.

Given the types of rocks that there are on the Moon, we should be able to produce iron, aluminum, titanium, calcium, and magnesium. However, unlike on Earth, there are no geologic processes that would produce concentrated ore bodies for certain metals such as copper. However, we could easily ship 100 tonnes of copper which should last for a very long time and/or we could utilize alternatives such as aluminum wiring, which is safe provided electrical work is handled according to strict standards. When done so, the risks drop to nearly that of copper.

OTHER RESOURCES

Silicon

Silicon is useful for both solar panels as well as for electronics. As mentioned above, it is very prevalent in certain, readily available minerals on the Moon. To extract the silicon, a process such as molten electrolysis could be used. Multiple groups have demonstrated the production of solar cells from lunar regolith simulant including Blue Origin, a group in Texas, and two in Europe.

KREEP Rocks

There are rocks located by certain craters on the Moon called KREEP. This is an acronym for potassium (K), Rare Earth Elements, and Phosphorus (P). In agriculture, fertilizer is composed of NPK standing for Nitrogen, Phosphorus, and Potassium. So, for full self-reliance the KREEP rocks would be a useful source of potassium and phosphorus. Nitrogen would come from the ammonia in the ice at the permanently shadowed regions at the poles. All of these fertilizers would be diligently recycled so that we would not have to mine and input large quantities of them into our agricultural system.

29 – Metallurgy and Machining

SUMMARY

This chapter describes the extraction of unoxidized metals and how oxidized metals from certain rocks can be extracted while producing oxygen. Given the magnitude of power expected from Solar Drapes, we can expect industrial quantities of metals to be produced fairly early on.

To reduce shipping costs and to become increasingly Earth independent, it is essential to be able to produce metal parts from local resources. This involves a lot of details that experienced machinists can figure out. It appears that there is a straight-forward approach that can be identified to be able to do this.

EXTRACTING METAL FROM REGOLITH

The Sources of Metals

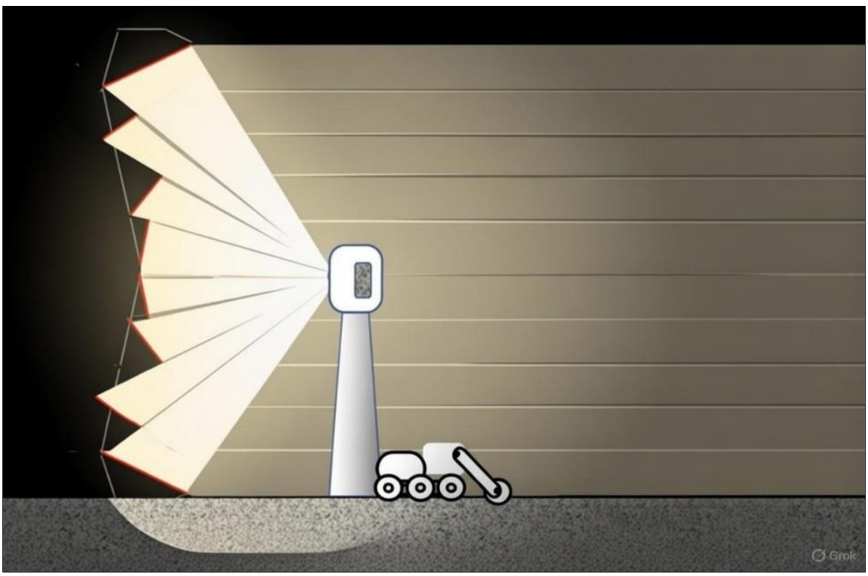
The Apollo Program brought back samples from both the mare and the lunar highlands. Unlike on Earth with its multiple geologic processes, the Moon is much simpler and so has fewer types of rocks and minerals. Nonetheless, the different rocks have different mineral compositions including different ratios of metal oxides. One can envision processing different types of rocks in different ways to get the ratio of metals that one needs.

Beneficiation

A specific rock type can be crushed into powder consisting of different mineral grains. These grains can be separated using different beneficiation processes to increase the concentration of one type of mineral versus another. There are many identified beneficiation processes such as magnetic and electrostatic separation. We are basically making our own ore. Using this relatively low energy approach, one can work with material that requires significantly less energy.

Parabolic Mirrors

We have a concept for a variant of the Solar Drapes in which, instead of photovoltaic sheets hanging from suspension lines, sections of thin mirrors are angled to focus sunlight on a crucible which heats beneficiated material. After achieving a molten state, dross could be removed. The elevated temperature of the material thereby requires less electricity to complete the various chemical and physical processes. Induction heating using electricity from the Solar Drapes could further raise the temperature.



Parabolic Drapes concentrate sunlight to heat beneficiated regolith.

Chemical and Physical Processing

The beneficiated material can then be processed to reduce the metal oxides. Hydrogen reduction can be used to reduce iron. The hydrogen would come from the electrolysis of the water extracted from the PSRs. Carbothermal reduction using carbon monoxide can greatly purify both iron and silicon. Molten-regolith electrolysis is energy intensive but popular to produce oxygen using regolith with the beneficial byproduct of unoxidized metals.

Processing Metals

The molten metal can then be processed by extrusion, sprayed into powder (for 3D printing), cast into forms, rolled into sheets, or cast into chunks to later be machined into useful parts. In every phase of development, metallurgy would be done outdoors and telerobotically using crew in the base. For sheet metal, molten metal blocks could be successively rolled to produce increasingly thin sheets of metal.

REPURPOSING METAL

Shipping containers coming from Earth could be sent one way as those unoxidized metals would be very useful at the International Base. In this way, the shipping containers become part of the payload. And the containers could be made from metals difficult to source on the Moon such as copper. However, one should consider which need is greater, organics or metals, so containers may prefer to be made from carbon fiber. Packaging may want to be made from organics instead of metals. Within the Earth-Moon system, Starships would probably prefer to be quickly sent back to Earth and reused while on Mars, the bodies might stay there with only a few Starships returning with return passengers and engines.

PRODUCTION OF METAL PARTS

Casting

Ceramic molds constructed on Earth and transported to the Moon can be used to produce parts that will be produced in large quantities. For example, brackets to hold flooring together and to connect to attach points will be used in practically all specialty habs. Cast parts may need further processing for their final form.

Sheet Metal

A particularly useful material would be sheet metal. This has a wide variety of uses including equipment housing, storage tanks, and pressure vessels. Some of the uses may be replaced with local basalt slabs.

Extrusion

Metal bars, tubes, and wires can be extruded and cut to specific lengths.

3D Printing

3D printing is a very trendy topic and many space advocates talk as though this is the only process that would be needed to produce an in-situ base. But in reality, 3D printing is only needed occasionally because other processes tend to be faster and require less energy. But undoubtedly 3D printing will be the favored approach when other approaches won't fill the need, an immediate spare part is needed when it is not in storage, or newly designed part for which the forms have not yet been created.

BASALT

Although basalt isn't common at the lunar south pole, it could be quarried elsewhere and transported overland. The distinct advantage is that cutting basalt slabs and transporting it requires far less energy than other processes. The slabs would need to be thick enough with a minimum thickness of perhaps 5 cm.

Basalt material could be used for things like the bottom floor, room walls, dresser and cabinet walls, counters, shower stalls, work benches, desktops, tabletops, sinks, and the main structure for upholstered furniture.

PLASTICS

As mentioned previously, there are enough organics in the lunar polar ice necessary for a large and growing settlement provided that the settlements recycle. However, given the limited supply of organics, it seems best not to use plastics for parts except for very specific cases. Rather, the organics would probably best be used for other organic chemicals as described in the next Chapter.

THE FABHAB

Initial Permanent Base (IPB)

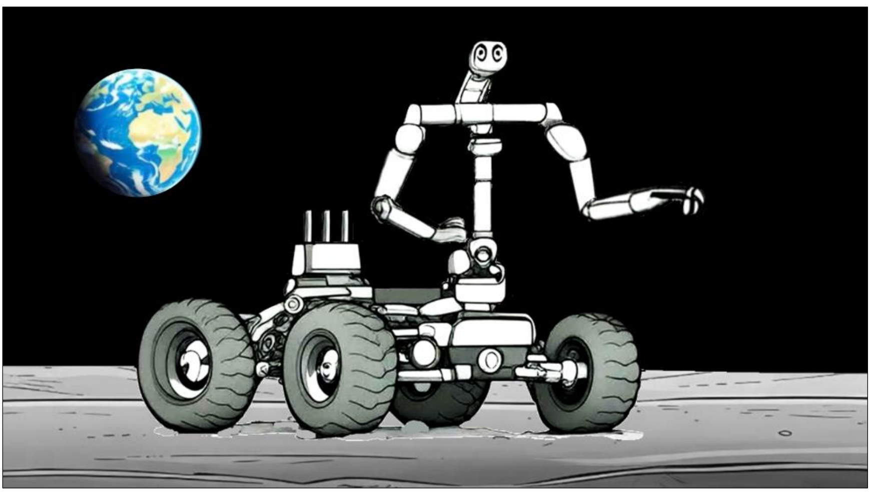
Even within the Initial Base (whether StarHab or InstaBase), there should be areas for fabrication and assembly. So early on, it is unlikely that much of the parts used in the initial habs of the International Base will be produced locally. They will simply be purchased or constructed on Earth and then shipped to the Moon. The Machinist would be the main one responsible for producing parts but with cross-training with the Roboticist.

However, it would still be useful to fabricate parts and assemble equipment to identify if there are any difference in doing so in 1/6 gravity. If it can be demonstrated that it is possible with just a few crew producing a single unit of many different parts, then it would give confidence that it could be scaled up in what could be called the FabHab in the International Lunar Base.

International Lunar Base (ILB)

But the Innovative Plan envisions two specialty hab including the FabHab and AssemblyHab. The FabHab would take gross materials from the metallurgy process and then machine them into parts. Then, in the assembly hab, these parts would be assembled, including with complex shipped parts, into equipment.

TELEOPERATIONS AND AUTOMATION



The DexBot could operate 24/7. Able to do tasks including swap spare parts.

Even though there is a 2.6 second speed-of-light roundtrip between the Earth and Moon, it is not too long to allow most teleoperations. Working in three eight-hour shifts, teleoperators on Earth could control dexterous telerobots (DexBots) for everything from processing metals outdoors to operating the machining equipment within the FabHab. As AI-robots get better, they can be trained on an increasing numb of tasks and so handle them on their own.

Over time, general DexBots will increasingly be replaced with specialty bots who are designed to be maximally efficient doing a few tasks. And ultimately, equipment could be designed to turn the whole process into a highly efficient factory.

Initial Equipment

What would be the key initial pieces of equipment needed to produce the metal parts? Machining equipment tends to be very massive and therefore very expensive to ship from Earth. We believe that the Generation 1 equipment could be made of rigid composite parts, made rigid using tension, and anchored deep into the lunar dirt for stability. That Generation 1 machining equipment would be used to produce much more massive Generation 2 equipment. Analogies to machining and metallurgy on Earth may not exactly apply here. Whereas on Earth economic efficiencies means that these processes are done in huge buildings on a very large scale. In this situation where shipping costs are fairly high and one is not supplying large populations, then the scale on the Moon will be much smaller than such processes on Earth.

Our current thinking is that the metallurgy & processing equipment would be as follows:

- Metal-excavation telerobots
- Solar concentrators and arc furnace
- Ceramic crucible and powder sprayers
- Molds
- Continuous caster for bars and extruders for wires
- Multiple die sets
- Rolling mill to make sheet metal

And the minimal set of machining equipment would be as follows:

- Power hammer
- Hydraulic press
- Sheet metal bake/shear
- Friction stir welder
- Planer
- Lathe
- Multi-axis CNC machining centers
- CNC routers
- Metal 3D printer

EXPONENTIAL BOOTSTRAPPING

Certain metal parts would have an exponential nature in that the resulting equipment would be used to produce more equipment. This would include the production of more automated, metal-extracting robots, and metallurgy and machining equipment. As international astronauts arrived, some of them would be machinists and metallurgists working in habitats dedicated to these processes. The result would be an exponentially growing settlement in which the large majority of the mass was being produced on the Moon and not shipped from Earth.

30 – CHEMISTRY

SUMMARY

Sure, the Moon has the elements needed to support settlement. But are they in their right chemical form. Unfortunately, no. So, there are organic and inorganic chemical processes that need to be done to transform them into the most useful chemical forms.

The focus of chemistry on the Moon is to produce materials from local resources (ISRU) so that less mass must be shipped from Earth. This reduces shipping costs and moves us towards increasing levels of self-reliance.

ORGANIC & INORGANIC CHEMISTRY

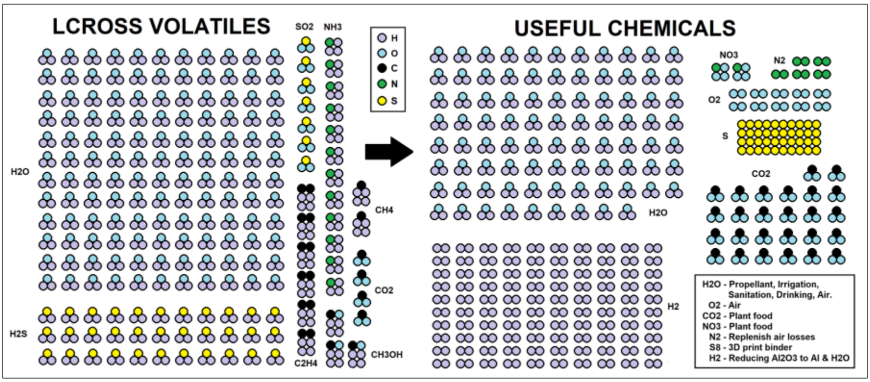
Like chemistry on Earth, chemistry on the Moon can best be divided between organic and inorganic chemistry. This is relevant not only to living things but also because the elements in organic chemistry tend to be volatiles and so it turns out that the volatiles are quite different between the Moon and Mars. In a sentence, volatiles are limited (but sufficiently present) on the Moon, but they are readily available on Mars. For this reason, locally produced objects on the Moon will want to use metals whereas on Mars, organics such as plastics will be commonly used.

SOURCES OF ELEMENTS ON THE MOON

Volatiles

Chapter 28 describes how volatiles such a water and nitrogen and carbon-containing molecules are trapped in permanently shadowed regions (PSRs) around the lunar poles. For lunar bases and settlements that recycle their chemicals, these organics are more than sufficient to support the needs of growing settlements. There are also volatiles embedded by the solar wind into sunlit regolith. But the concentration is so far below that of the volatiles in the PSRs it hardly makes sense to even think about those as a source of volatiles.

Those of us in the Space Development Network have done some preliminary work on how the chemical make-up of the LCROSS results could be chemically transformed into more useful chemicals. Here is a stoichiometric look at how the LCROSS volatiles could be transformed.



METALS

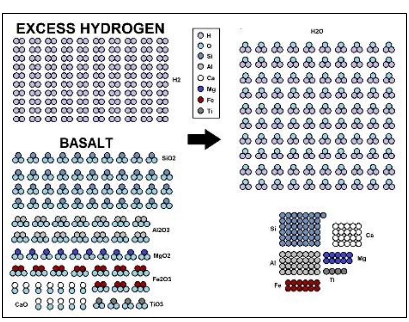
Iron & Steel

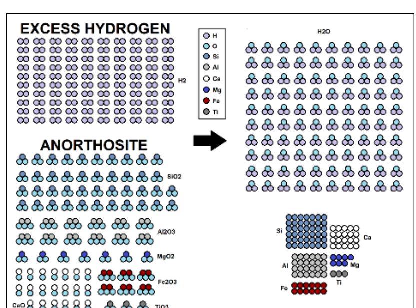
Iron can be extracted from iron-rich minerals such as FeTi)2 found in the common lunar rock, ilmenite. Using hydrogen reduction and carbonyl iron refining. Although energy intense, molten regolith electrolysis can also be used to produce high-purity iron.

Steel uses carbon, which is one of the volatiles found in the 2009 LCROSS results. But, given the relative rarity of carbon, high-carbon steel should be used only where it is essential.

Other Metals

The following stoichiometric diagram shows how the excess hydrogen from the previous diagram could be used to extract metals from different rocks.



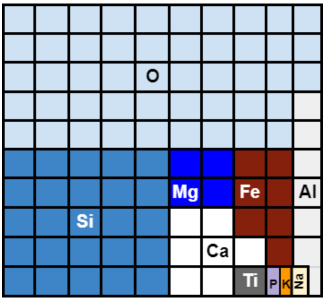


OTHER ELEMENTS

Micronutrients

Micronutrients tend to be in the regolith in the form of metal oxides. Certain single-celled organisms and plants have the biochemistry necessary to incorporate those elements into themselves in a bioavailable form. So, this will be the main way in which the crew will get those micronutrients from local resources.

Potassium and Phosphorus



There is a special case for two elements -- potassium and phosphorus. There is a specific layer of the Moon's crust which tends to concentrate these two elements (along with Thorium) more than in other rocks. Certain areas of the Moon and certain craters tend to be elevated in this type of rock. This rock has been given the name KREEP to indicate potassium (K), rare Earth elements (REE), and phosphorus (P). There is even one such KREEP rock which fell to Earth as a meteorite whose location has been localized to a specific crater (LaLande Crater) on the Earth-facing side of the Moon. This crater has one of the highest KREEP concentrations on the Moon and may be a mining site in the future. For agriculture potassium and phosphorus make up two of the three important elements in plant fertilizer (NPK).

Shipping Certain Elements

It may be that there will be certain circumstances in which it will be more cost-effective to simply ship certain elements to the Moon rather than try to extract them from low-concentration sources. An example of this may be copper which is in relatively low concentrations in the Apollo rock samples. We also don't believe that there were ever geologic processes which may have concentrated copper in a manner which has happened on Earth. In that case, the element could simply be shipped as an large payloads thereby meeting the needs for that element for a growing base or settlement for years to come.

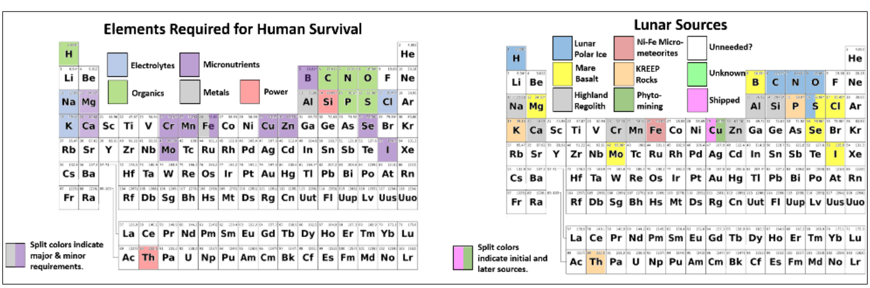
An analogy which might give some idea is that each home on Earth has an average of 50 kg of copper in its wiring. So, a 100 metric ton copper payload would provide the equivalent of the copper needed for 2,000 homes. And we know from renovations that copper wiring tends to last more than a century. But it should be acknowledged that this is an imperfect analogy because there are alternative metals for wiring yet probably a greater need for copper per lunar settler given all of the life support systems needed.

The Elements Needed for Human Survival

Finally, it is commonly stated by Mars advocates that only Mars has all of the resources needed to support a large and ultimately a completely Earth independent civilization. This is not true.

Not all elements are needed for human survival. For example, we like gold and it has many uses. But many human tribes have existed for centuries without working gold mines. It is neither a necessary metal nor a micronutrient. And there are plenty of other elements which are not essential.

The Network investigated this question of what elements exactly are needed for human survival and where they are known to exist on the Moon. As a result, we have produced two periodic tables of the elements which you can see here:



As you can see, every needed element has a known source on the Moon. The challenge then is to identify the processes necessary to transform these elements from their native form into a form usable to the lunar settlers and how they can be recycled in order to reduce the amount that needs to be harvested / mined.

CHEMISTRY IN THE INITIAL BASE

We envision the Initial Crew of eight having one team member who is the official Chemist with another (perhaps the Geologist) who is cross-trained to do the chemistry. The Chemist would receive the organic chemical residue distilled and separated from the water from the ice harvesting operations. This residue would be transported telerobotically from the field distiller to the Initial Base. She would take this organic stew and use an approach (perhaps further distillation) to separate the chemical species from each other. She would then employ a set of chemistry protocols to transform those organic chemicals into more useful forms. She would also produce excess hydrogen in the process and could receive hydrogen from the propellant electrolysis process. Working with the Geologist and the Metallurgist, they would conduct the inorganic chemistry protocols to use the excess hydrogen and electrolysis to extract metals from certain rocks.

The Chemist would routinely make news as she succeeded in demonstrating the production of one chemical after another. Undoubtedly, the Chemist would develop a following by a particular set of young people on Earth who would be inspired by her example to pursue careers in chemical engineering.

CHEMISTRY IN THE INTERNATIONAL BASE

As the International Lunar Base is established and grows, certain chemicals would be needed in increasing quantities. So, a ChemHab would be needed to produce the chemicals needed on an industrial scale. Since chemistry at this level tends to be fairly energy intensive, we would imagine that the chemistry would be conducted at the lunar poles near the Peaks of Eternal Light and then, in their refined form, would be transported to colonies and settlements in other parts of the Moon via automated transport. In this way, all parts of the Moon would have equal access to the water, oxygen, propellant, organic chemicals, and metals as any other part of the Moon.

31 – Growing Food

SUMMARY

We can't ship food forever. Eventually we'll need to grow our own food. This chapter goes into detail about greenhouse designs and the choices that our Working Group (AgWG) made when designing the lunar greenhouses. In a nutshell, they would be very large, multi-floor, shielded inflatables using optimized LED lighting and a hybrid, gravel hydroponic approach completing avoiding the lunar dust.

To have a sustainable base, it needs to be able to grow its own food. Growing some food is fairly straight forward. Growing all one's food is another matter. We take so much for granted every time we run down to the store. But imagine if you had to grow your own wheat to make your own flower to make your own bread. Imagine making your own oil. How about the simple ingredient, cinnamon? How would you grow that? Then, imagine making everything that you eat. It is doable but a daunting task.

THE AGRICULTURE WORKING GROUP (AgWG)

In the Space Development Network, we have established an Agriculture Working Group which met weekly via video teleconference. Space advocates with a "green thumb" have joined together in this working group to discuss and develop the Agriculture Plan. Our ultimate goal is demonstrating a greenhouse demonstrating the production of full nutrition.

Our Agriculture Plan is designed to be consistent with the Network's Innovative Plan for Space Development. As such we start with the context of an Initial Base with a crew of eight on the Moon. Our goal is not only to meet all the nutritional needs of the Initial Crew of eight but to do so with a good about of variety while recognizing that it is not practical to grow certain foods from the beginning (e.g. a coconut tree).

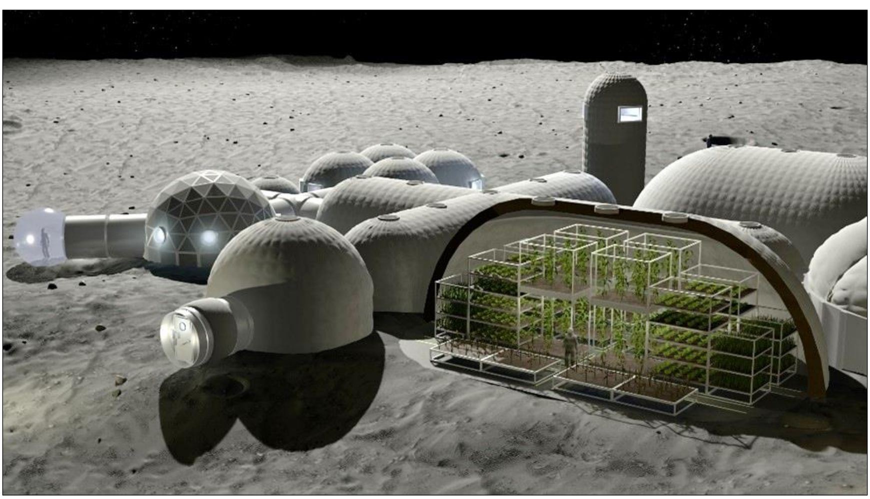
The AgWG has discussed the many aspects of a lunar greenhouse and have, as a group, come to several conclusions about what approach is most practical to start with. But it is a work in progress and could change with more discussion and input from others. But this chapter describes our current thinking. If you, the Reader think that you can contribute to this effort we invite you to join us by joining the Space Development Network (for free) and then indicating your interest in agriculture.

GREENHOUSE DESIGN

Greenhouse Versus the Ecologic Approach

For starters we need to make the fundamental decision as to whether the food grown in the StarHab or InstaBase will be a greenhouse or use the ecological approach. The greenhouse approach is pretty straight forward. You just grow different plants, harvest them, and use them as ingredients.

The ecological approach is more complex in which one is attempting (at some level) to recreate Earth's biosphere by having different species being in a balanced ecological relationship with other species. The Biosphere 2 Project in Tucson, AZ attempted this approach whereas the Prototype Lunar Greenhouse Project at the University of Arizona (also in Tucson) uses the greenhouse approach.



Artistic image of the intensive GreenHab in the InstaBase.

Many people are aware of the initial Biosphere 2 Project in which eight "biospherians" moved into a huge, hermetically-sealed, $150 million dollar facility with five different biomes for two years. The general view is it was a failed experiment with oxygen needing to be pumped into the facility, collapse or overrun of certain species populations, conflict with the crew, and their near starvation. All of that is true even though the experiment yielded useful results and the facility continues to be used to understand agricultural and ecological systems to this day. Unfortunately, this experience has led some to claim that space settlement was shown to be impossible because the Biosphere 2 Project failed.

In contrast, the Prototype Lunar Greenhouse Project goes directly to growing food without the complications of having to figure out ecological relationship between animals and plants. As a result, they have, on a far smaller budget and far smaller facilities, been able to demonstrate the production food for crew in the controlled setting of a greenhouse. Our Agriculture Working Group (AgWG) has compared the two approaches and have settled upon the greenhouse approach for the initial levels of a permanent base. We are open to the more complex ecological approach, but we believe that it would be so far down the line that it doesn't concern us at this time. The partial exception would be with waste management which will be described shortly.

General Design Options

Now that we've settled on the greenhouse approach, there remain several options for how this could be done. These options are not so easily chosen between, and our choices may change with more study.

Related issues have to do with how we use sunlight and the radiation environment within the GreenHab. Specifically, on the Moon, there is no atmospheric protection against either solar particle events (SPEs) or the constant rain of galactic cosmic rays (GCRs). SPEs can be detected and the crew can shelter in time. But GCRs make up most of the radiation dose over time and need to be shielded against for long-term crew.

The easiest way to protect against GCRs is to simply have telerobots cover the habitat with lunar dirt (regolith). But this blocks out the sunlight and so light would need to be transmitted into the GreenHabs in one of several ways:

- Solar drapes producing electricity which runs into the GreenHab via wires to power magenta LEDs optimized for plant growth.
- Solar collectors with fiber optics or light tubes transporting light into the GreenHab without the energy conversion losses.
- An innovative approach using berms and mirrors to block the radiation while bouncing sunlight into the sides of the GreenHab. Since these mirrors could not turn and the Moon rotates on its axis very slowly the long lunar night would be a challenge.

As we have considered the various options, we have settled upon the solar drapes & wires approach to transmitting power into a shielded habitat. It allows for the best control of growing conditions. Also, we have calculated that a 100 metric ton Starship payload could deliver enough solar drapes to power plant growth for about 300 settlers. So, we will have far more than enough electrical power using the Solar Drapes approach.

Moon Versus Mars

We don't feel compelled to have the same agricultural system on Mars as we do on the Moon. If the relevant factors are different so they could lead to different GreenHab designs.

Mars probably has enough of an atmosphere to prevent plants from dying in the setting of an SPE. The great advantage here is that one can consider just having clear walls and ceilings and let the natural sunlight power plant growth without needing the photovoltaic production of electricity. One downside is that plants could not be grown in 3D like they could with interspersed LEDs. As for the radiation issue, we have calculated that, if the agriculture workers are over about age 50 then the radiation levels are low enough such that they can remain within their career limits.

HYDROPONIC OR SOIL-BASED?

Hydroponics is a good way to grow food and there are a wide variety of plants that have been grown hydroponically. But the AgWG feels as though there is an advantage to growing plants in soil due to the favorable microbial environment that soil provides. But using regolith for soil is probably a bad idea. Lunar regolith is a health hazard because it is essentially finely ground glass. Inhaling it is a particular concern, so we'd like to not let any of it into the habs.

But there are a couple of other ways of using lunar material to make soil. Lunar rocks could be crushed down to make particles of the right size. Alternately, telerobots could simply sift the lunar regolith and separate out particles of the right size.

Now, soil is not just bare dirt. A high percentage of soil is organic matter of which lunar regolith has none. So, how could our manufactured lunar dirt be turned into soil? We could simply start with growing plants hydroponically. The inedible waste portion could be further processed using mushrooms and/or biodigestion. The rich organic material can be added to the dirt thereby making it soil.

SOURCING NUTRIENTS FOR PLANTS

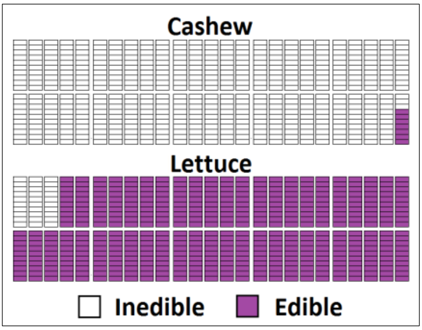
The LCROSS results show that carbon and nitrogen are present in appreciable amounts in the lunar polar ice. (See page 200). These can be converted using well-known chemical processes into the CO2 and ammonia or nitrates that plants need.

For potassium and phosphorus needed as part of the NPK nutrients that plants need, these will likely be supplied from Earth initially and recycled. These are also present in the lunar regolith but would need some processing to free them up. Longer-term, KREEP rocks located near the equator contain appreciable amounts of potassium and phosphorus and could be transported overland in electric vehicles.

As for the micronutrient elements, plants are designed with biochemical mechanisms to extract these from the dirt where they are concentrated in the plant's tissue. This is a process called phytomining. Copper is an example element that can be concentrated and extracted using this method.

WASTE MANAGEMENT

Plants are not entirely edible. There will be much plant waste that will need to be dealt with. So too with human waste. We cannot afford to let any waste product go unrecycled. It is just too precious to lose.



Plant waste can be processed in several different ways. One can simply incinerate it to make basic chemicals. One could also use one of several types of bioreactors to biologically transform the waste into more usable chemical forms. Finally, mushrooms could be grown on top of waste material and then become an ingredient in a recipe.

Human solid waste can be ground up and treated with UV radiation to sterilize it thereby making it safe for later processes. Both waste streams could then be fed back into the nutrient solution which would pass through the soil.

The AgWG has considered the options for waste management and have currently settled on some of the plant waste being used to support mushrooms but with the bulk of it processed by bioreactors with incineration of any remaining waste.

We considered attempting a fully ecologic approach to waste management including an aquaponic set but settled on the above due to the complexity and manhours of managing the aquaponic systems.

GREENHOUSE ENVIRONMENTS

Greenhouses can have their environments highly controlled to optimize production. In a 3D growing environment with magenta LEDs dispersed throughout, production per square meter can be greater than 10 times that done in fields.

Many people are aware that plant growth rates can be increased with elevated CO2 levels. This approach could be used in sections of the GreenHab provided that the gaseous environments could be managed to allow crew to enter those sections as needed. We don't have the luxury of simply venting air with high CO2 levels outdoors.

Lighting can also be highly controlled with some plants able to continuously grow while given light while other plants seem to need the day-night cycle.

Some plants need seasonal environments to come to full fruition. These can include length of sunlight during the day and certain temperatures such as cold snaps. For this reason, some plants would need to be grouped into the same GreenHab chamber, and the dietary menu would have to take into account how this seasonality would yield an abundance of fruit but during a limited period of time.

CHOICES OF PLANTS

We will want to grow as wide a variety of food plants as possible to make living off Earth attractive. But certain plants have a high percentage of the mass edible whereas other plants have only a small percentage edible. This table provides a general summary:

Salad Vegetables
- 90% - Salad greens
- 75% - Bulb vegetables
- 70% - Root vegetables
- 68% - Fruit veggies (tomatoes)
- 65% - Herbs
- 60% - Crucifereous vegetables
- 50% - Pod vegetables

Fruits
- 52% - Melons
- 35% - Banana
- 19% - Strawberries
- 4% - Tree fruits
- 4% - Avocadoes
- 3% - Olives

Beans
- 22% - Soy beans
- 18% - Black beans

Grains
- 30% - Grains

Nuts
- 12% - Peanuts
- 0.3% - Tree nuts

Oils
- 6% - Seeds
- 0.4% - Olives

Other
- 2% - Chocolate
- 1% - Coffee

So, in the early phase, the choice of plants may be something like this:
- Salad veggies
- Root vegetables (e.g. potatoes)
- Tomatoes, Broccoli, Green beans
- Herbs: Basil, Parsley, Cilantro, Oregano
- Fruits: Melons, Bananas, Strawberries
- Grains: Wheat, corn
- Nuts: Peanuts
- Beans: Soybeans & other beans
- Ship: Tree fruits, Nuts, Olives, Avocadoes

MEAT

Meat isn't essential for good nutrition, but many people would really want it on the menu. Since animals are not autotrophs (grow just from sunlight) there would need to be an agricultural step prior to meat production.

Fortunately, some animals consume plant waste and therefore don't need any special feed production system. Tilapia fish and insects are favored for this reason. Chickens also consume plant waste and provide delicious globules of protein and fat in the form of eggs.

As mentioned before, maintaining the equipment necessary for an aquaponics system was considered too much work for an Initial Crew of eight. But, by the time the base gets to about 100 residents, and with economies of scale, we feel that aquaponics make sense.

Chickens too could be introduced fairly early in a base, but we felt that it was not appropriate for the Initial Crew level due to the need for a specialty hab that could address the odors produced by cooped up chickens. Again, chickens and their eggs could be introduced when the base population reaches about 100 and there is a BarnHab that would be capable of addressing odors.

DISTRACTIONS

There are certain food items that some people are almost evangelistic about which we in the AgWG are more reserved about.

Insects

Yes, certain insects can efficiently convert plant waste into high-protein meal. But our goal is off-Earth settlement. We have to bear in mind that, if space settlement is associated in the news with eating fried crickets (and the news would jump all over such a story) that it could discourage a fair percentage of potential settlers (and spouses) if they got the impression that they would have to eat insects if they were to move to the Moon. So, for us, for that reason, insects are off the human menu. No problem if the insects are for fish though.

Marijuana

The most skilled hydroponic experts are in the cannabis industry. No surprise there. And could lunar marijuana be a high-value cash crop? Perhaps. But again, do we want lunar settlement to be all about growing marijuana with all the positive and negative emotions that would elicit. So, we're just leaving that topic alone.

Alcohol

Alcohol isn't a particularly good way to meet one's nutritional needs. But boy does it take over the conversation when it comes up. However, it is a good "social lubricant" and wine goes well with meals. So yes, alcohol is on the menu in modest amounts.

STORAGE

It's not very exciting but we've got to think about how food is going to be stored. Ideally, we would like to harvest the food just as it was to be eaten for the best taste and minimum storage needed. But:

- there will always be a mismatch between production and use,
- storage allows for a varied menu throughout the year,
- and we will want to build up a reserve to maintain food security.

So, storage must be designed into the base from the get-go.

Different foods have different storage requirements. Forms of storage include: dried, canned, refrigerated, and frozen. They have different shelf lives which a flexible menu would have to consider.

THE ROLE OF ROBOTS

Crew time is so valuable. So, every chance we can, we should shift work off to the machines. Telerobots, even with a 2.6 second time delay, could be extremely helpful. It's also most helpful that telerobots could work 24/7 being operated by shifts of crew from Earth. As such, these robots would have human-level intelligence because they would be operated by humans. And they could swap out special implements to harvest specific fruits / produce. But we are rapidly approaching the point where humanoid robots will be able to be trained on an increasing number of tasks. In that case, teleoperations will be unnecessary.

What agricultural tasks could telerobots and autonomous robots do? Could they plant, inspect, and harvest? Probably yes. Not as quickly as humans but then they can work about four to five times more hours per day than humans. Could they process produce and place them in storage? Again, probably yes. Maintain systems by disassembly and repair? That might be pushing it. But if the systems were specifically designed for easy telerobotic manipulation, perhaps even this.

iSAS

The Space Development Network is working towards having an Intensive Space Agriculture Session (iSAS) to demonstrate the full nutrition production starting with a single person and later for an Initial Permanent Crew of eight.

Our concept is for a two-month session with university students led by their faculty who is a space agriculturist. Prior to that session, a variety of food plants would be grown to fruit-bearing maturity. At the start of the session, the first thing that the students would do would be to bring in those fruit-bearing plants into a large inflatable greenhouse with semi-transparent roof allowing in the same photon flux as will be present on Mars.

Then, during the two-month session, plants will continue to grow, bear fruit according to a schedule, and the waste harvested and re-used.

An associated space nutrition group will take the produce, produce ingredients, and through a somewhat complex system of recipes, produce meals that provide for full nutrition while also not requiring a great deal of storage.

The analog Mars GreenHab will be constructed like a very large air mattress and be at a single level without the use of LEDs. According to our Agriculture Consensus Plan, we will start mostly with hydroponics but begin the process of making our own soil using crushed rocks and not toxic regolith. Optimizing the environmental conditions will be the major part of our research goals and defining the processes involved.

FUNDING LUNAR DEVELOPMENT

32 – Funding Lunar Development

SUMMARY

Financing lunar development includes reducing expenses, of which cheap access to space (CATS) is the most important. Fixed-price contracting, recycling and ISRU can all help. Funding will likely start with NASA-led public-private partnerships (PPPs). As prices go down, the savings of private individuals will be a major source of funding.

Resource-based export income (e.g. propellant from ice, He-3, PGMs) will be a difficult business case. Rather, government budgets and private savings will likely dominate funding for the foreseeable future.

REDUCING EXPENSES

It deserves to be mentioned up front that reducing expenses is a legitimate part of balancing a budget, making ends meet, the making of a business case, and sustaining operations. Given the traditionally very high expense of crewed and cargo missions, it makes a lot of sense to see what we can do to reduce costs. The commercial space perspective often emphasizes how money can be generated while neglecting how to reduce expenses. But as they say, "A penny saved is a penny earned".

Dramatically Reduced Space Transportation Costs

By far, the major way that costs will be reduced is with the emergence of fully reusable launch vehicles. SpaceX's Starship fleet is the prime example, but Blue Origin's New Glenn is also working in that direction and we see other companies working towards full reusability if even at the medium lift vehicle level. It is hard to overstate just how huge an impact full reusability will have but we can reasonably say that it will lead to perhaps a 90% reduction in launch costs if not more.

Fixed Price Contracting

For those phases funded by governments, we see that the old way of funding the development of space hardware (i.e. cost-plus contracting) is now being favored by fixed price contracts where any cost overruns is not placed on the government but on the companies that won the bid. And with competitive bidding we are seeing reduction in cost as much as 8-10 times the cost-plus contracting approach.

Commercial Competition

With that sort of savings, NASA has typically been able to afford contracting with two commercial providers whether it is for cargo, crew, or lunar landers. Having multiple commercial providers not only results in lower bids but, after the development phase is completed and operations are ongoing, NASA can split the service contracts between two competing companies giving more launches to the lower bid provider.

Recycling

An often-overlooked secret to reducing the cost of maintaining a permanent base or settlement is to develop ever-increasing levels of recycling. For example, on the ISS, water is being recycled at the 93% level. So, each liter of water can be recycled thereby effectively providing the equivalent of 14.3 liters. Recycling works best for consumables and less so for durable items.

In-Situ Resource Utilization (ISRU)

It is obvious that using local resources could result in large savings by not having to ship them. Mars has the largest quantity of resources, but the Moon has all the resources needed to support a large, growing settlement. (See chapters 28 & 30).

The good news is that the development of a few items (water, metals, and organics) and processed into usable forms can result in a substantial reduction in shipping costs. The Space Development Network believes that significant reductions in shipping costs is possible in the relatively near-term (e.g. within a few years from when the first permanent habitat is established). And recycling and ISRU work together in that, the more one recycles, the less materials one has to produce from local resources.

So, advocates for commercial space development need to pay equal attention to the reduction of expenses and not only on what the source of revenue might be.

Extending Crew Stay

A certain percentage of the cost of maintaining a permanent base will involve the rotating of crew. For the ISS, this is (currently) being done using SpaceX's Dragon capsule at about $55 million per seat. For a permanent lunar base heading towards settlement, if crew stay can be doubled then the cost of crew rotation can be approximately halved. For settlers intending to remain off Earth indefinitely, the cost of rotations may not be such a large issue.

THE FUNDING OF LUNAR DEVELOPMENT

There has been a lot of discussion in recent years about how space development would be funded to the point of economic sustainability. There are many ideas including manufacturing in low Earth orbit (LEO), space solar power, helium-3 on the Moon, etc.

It is clear that uncrewed satellites can turn a profit. Indeed, communications satellites in GEO orbit made up the large bulk of profit made by the space industry. Starlink's "Internet in the sky" is making currently about $11 billion each year (and growing) and the selling of world-wide imagery can also make a profit. But what about human spaceflight? Given the great expense of that, how could it pay for itself? The answer is not so obvious.

Public-Private Partnerships

When NASA originally tried a public-private program in the form of the Commercial Orbital Transportation System (COTS) studies found that NASA was able to reduce its expenses by about 8-10 times compared to if they had used the cost-plus approach. By using the other transactional authority (OTA) they were able to partner with companies in a way in which NASA paid for development and service, but where the companies themselves ended up owning the technology that they developed and then were free to sell those services to other customers. In this way, NASA was able to get access to that service on a more commercial basis. It has been a very successful win-win approach.

What has happened with the reusable heavy lift vehicles is even more remarkable. NASA has been very fortunate to be returning to the Moon and going to Mars while two of the wealthiest individuals are using their own wealth to develop fully reusable launchers that NASA can conveniently take advantage of. As an example, the reason why SpaceX was able to bid an incredibly low about $2.89 billion to develop the lunar lander was that this was the cost not to develop their Starship super heavy lift vehicle but only what it would cost to modify their rocket to meet NASA's lunar lander. By contrast, in today’s dollars, it cost about $41 and $48 billion to develop the Saturn V and Space Shuttle vehicles respectively. Especially given SpaceX's Starlink revenue (easily exceeding NASA's annual human spaceflight budget), the public-private partnerships will be more a partnership of peers rather than commercial companies just fulfilling NASA's requirements.

Similarly, it is likely that there will come a point where NASA's limited vision for returning to the Moon and going to Mars will be faced with the reality that a fleet of fully reusable heavy lift vehicles provides the opportunity to do so much more than just having a few government astronauts picking up rocks. As SpaceX and Blue Origin move forward towards establishing large-scale infrastructure and habitats on the Moon and Mars, there can be little doubt that the space policy decision makers won't be satisfied with standing to the side but will change NASA's plan to coordinate with these and other companies to develop large and growing, American-led international bases which will set the stage nicely for private settlement. The sooner this realization occurs the better.

FUNDING THE PHASES OF DEVELOPMENT

Lunar development could occur in six phases with clear funding approaches for each phase.

- **Phase 0 -** Artemis Exploration Phase - NASA-funded
- **Phase 1 -** Cargo Missions - Largely NASA-funded
- **Phase 2 -** Initial Crew Missions - Mostly NASA-funded with some commercial revenue
- **Phase 3 -** International Lunar Exploration Phase - National space budgets
- **Phase 4 -** International Lunar Base - National space budgets
- **Phase 5 -** Private Settlement - Private savings

Phase 0 - Artemis Exploration Phase

This phase is listed as Phase 0 because it is not actually a phase of development but rather just of exploration. We are currently close enough to these long planned for missions that it seems likely that they will be conducted. But later planned missions (e.g. Artemis 4 and 5) will probably be overcome by circumstances showing that they are not visionary enough given the available of fleets of heavy lift vehicles at that time.

Phase 1 - Cargo Missions

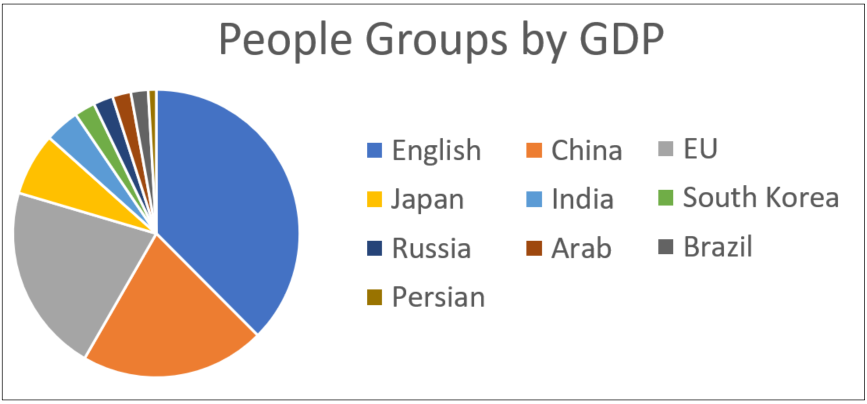
This book advocates that NASA be directed to largely fund Phase 2 which would be the Initial Permanent Crew (IPC) Phase. Immediately leading up to this, several cargo landers would land to human rate them. They will deliver rather large quantities of cargo including infrastructure (e.g. Solar Drapes), habitats, equipment, furniture, etc. so that the IPC will walk into a well-supplied Initial Permanent Base. NASA would fund these missions like their Commercial Resupply Missions to the ISS.

Phase 2 - Initial Crew Missions

These pages advocate that the Initial Permanent Crew should not be a repeat of the Apollo program (i.e. flags and footprints to collect rocks for science) but that the Initial Crew should be private individuals working for companies whose purpose is to set up and maintain the infrastructure later used by astronauts from the US and other countries. Since they would be providing transportation and habitation services starting with NASA it would be appropriate that most of the funding for this infrastructure and the participating companies would come from NASA as part of a set of public-private programs very much like NASA Commercial Crew Program. In addition to this funding, there are several creative side streams of income that are possible.

Phases 3 & 4 - International Lunar Exploration & Base

How can a small, permanent base become a growing settlement? Ultimately, if there is going to be a large private settlement then the cost of traveling to the Moon and sustaining oneself there must be affordable. An interim phase would be very helpful to increase the flight rate and build up the infrastructure until the base is able to support a growing population of private settlers. An International Lunar Exploration Phase



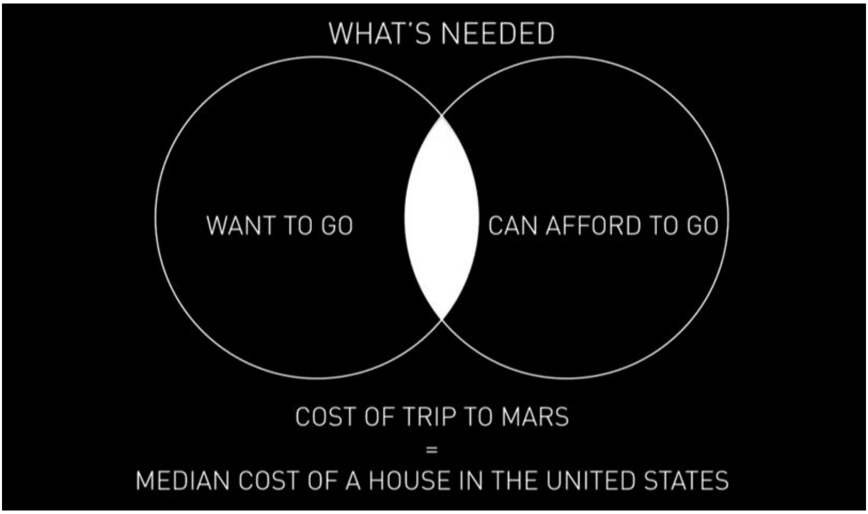
(ILEP) could be exactly what is needed as this interim phase.

It is likely that the initial seats on missions of lunar return will be very expensive. This is obviously true with an SLS-based approach but will also be true even if SpaceX succeeds in developing a fully and rapidly reusable Starship. After all, it would only be expected that SpaceX would want to recover its development costs.

Fortunately, there is a category of customers that can afford seats at these prices -- sovereign clients. Countries have far deeper pockets than even their wealthiest citizens. And there is a range of wealth among countries such that we could guess which countries could afford the early, middle, and then latter seats. From the number of countries that have sent astronauts to either the Mir or International space stations, we can conclude that countries, in general, really want to have astronauts of their own. And what country wouldn't also want to watch their national astronauts exploring the surface of the Moon, on behalf of their citizens, and in their own language?

Now, the participating countries would have a choice as to what they would do with their national astronauts. After their mission of lunar exploration, would they bring them home to serve as in-person heroes to students of the nation? Or would they prefer to leave them on the Moon to represent their country in a growing, international base? Likely it would depend upon the number of astronauts that they sent with a bias towards leaving them behind on the Moon. After all, they could always "Skype" back to be virtually present back in the nation's classrooms.

So, how would the countries pay for the seats for their national astronauts and how would they pay for them to stay and be maintained at the international base? Just like with all nations with space programs, the funding would come through a small portion of their national budgets (1/10th of 1% of their GDP).



The people who will go are those can afford to go and want to – Elon Musk

PHASE 5 – Private Settlement

In his 2016 Guadalajara speech, Elon Musk described how the people who would go to Mars would be at the intersection of those who could afford to go and those who wanted to go. So, who could afford to go? Obviously, they will be people who have saved up enough money such that they could afford to go. In most cases, they would have to have lived long enough to have saved up enough money. Likewise, they would need to be people who go aren't too tied up with raising children or working their career on Earth. Retirees fit these criteria and younger people tend not to. So, it should be obvious that retirees will be over-represented among initial and latter private settlement phases.

Early private settlers will likely be motivated by the opportunity to play a very historically significant role in helping to establish the first, off-Earth settlement. But we may really need to focus on how the settlement could be made attractive for the latter private settlers (and especially their spouses) who might need spacious habitats, entertainment, and a leisurely lifestyle. So, income for early settlement will undoubtedly come not from resource extraction but from the private savings made in Earth markets at other times and places.

ADDITIONAL REVENUE

Beyond the major sources of funding already mentioned, there are potentially a lot of different sources of income.

Chapter 20 includes a description of a multi-year TV series allowing the public to follow developments as humanity starts taking its first permanent steps off Earth. Media rights could generate a significant amount of revenue. Companies could also be charged for product placement in the TV series. Similarly, people could be charged for the virtual reality (VR) experiences of practically being present at these historic events.

But additional revenue from media wouldn't be the only additional source of income. Tourism would probably be a moderate source of revenue. Another noticeable source of revenue could be merchandising (e.g. A toy dog in its space suit, astronaut action figures, lunar habitat doll house, shirts, video games, etc.)

Believe it or not, jewelry made from lunar rocks might actually generate a significant amount of revenue. Consider ten 1 x 1 x 1 meter cubes of rock sent back to Earth as a single payload. Cut to 0.5 x 1 x 1 cm pieces, this payload would yield 50 million pieces of the Moon. This means that only one out of 175 people on the Earth could own a piece of the Moon (or if you prefer, one out of 90 women). Even after shipping 10 cubic meters of rock to Earth, pieces of the Moon would still be rare within one's own, personal, social network. Pieces of the Moon would still be rarer than diamonds. If one charged $300 for each piece of the Moon, the $15 billion in revenue would go far to cover infrastructure costs on the Moon.

Will the mining of lunar polar ice for propellant, helium-3 for fusion power, platinum group metals, or materials for space based solar power or spinning habitats in free space every constitute profitable ventures? We will have to wait and see. But funding from national budgets and private savings will likely form the financial foundation upon which international bases and settlements will be established.

SPACE TOURISM

Internal Vs External Tourism

There is an important distinction between two types of tourism. Traditional tourism is "external tourism" in which people visit the Moon not to settle down there but only for tourism. There will be some of this but probably not a major part of the Moon's income. The reason is because this vacation would be far, far more expensive than any vacation on Earth. One would have to give up most of one's life savings for this one vacation. The situation is even worse for Mars in which one would also have to give up a chunk of one's life for such a "vacation".

But "internal tourism" is where the settlers on the Moon decide to tour the Moon after having settled down. Nearly 100% of the people who settle on the Moon or Mars would want to tour the place that they spent so much money to go to. So, there will be a tourism industry on the Moon and Mars. It is just that most of the tourists might be permanent residents there.

LEO Vs Lunar Vs Martian Tourism

It is an interesting comparison between tourism in low Earth orbit (LEO), on the Moon, and on Mars. As mentioned above, there probably won't be much external tourism on Mars because those tourists would have to spend many months of their life during transit to and from Mars. LEO would be a favored destination for tourism since it takes less propellant to get to LEO than the other two destinations. But there is another relevant factor to bear in mind. Anyone travelling to the Moon and Mars will definitely want to hang out in LEO for several weeks enjoying the view and the experience of zero gravity. And for those travelling to Mars, for a small percentage increase in their overall price, they could throw in a Lunar Grand Tour package as well. So, it could be that many of the LEO tourists will actually be settlers moving on to the Moon or Mars. If propellant is being produced on the Moon to fuel transportation between the Moon and LEO, then the additional cost might be reasonable to throw in a lunar tour to one's LEO tourism package. For these reasons, it would seem that the number of LEO tourists will be somewhat more than lunar tourists and with Mars tourist numbers being substantially smaller despite the spectacular views on Mars.

Is Tourism the Business Case?

The very high price for vacations to the Moon, or Mars would seem to suggest that tourism will not be the major driver for settlement at those locations. And one should assume that, once the settlers are already on the surface of the Moon or Mars, that the internal tourism done using mostly electric vehicles would be a small percentage compared to their moving costs.

But LEO is primarily about tourism, especially with tourist hotels in inclined orbits covering most of the Earth. Yet again, due to the extremely high price tag for this form of vacation, it may be that most of the tourism in LEO will be by settlers on their way to the Moon or Mars.

The Lunar Grand Tour

For those settlers on the Moon or visitors on their way to Mars, they will want to see the best sites that the Moon has to offer. At the top of the list is the Apollo 11 landing site. But the tourists would probably also like to get a taste of the different categories of sites such as a lava tube, a famous crater, an irregular mare patch, a magnetic anomaly, a lava tube trench, and one of the early Russian rovers.

SPACE POLICY

33 – The Impact of New Capabilities

SUMMARY

As fleets of reusable heavy lift vehicles become available, space policy will need to fundamentally change to take full advantage of this new capability. Given the likely ability to transport large cargo and crew, time is running out for countries to fund their companies to develop competing surface systems such as specialty has, surface transport vehicles, life support, agriculture, etc.

NEW CAPABILITIES FUNDAMENTALLY IMPACT POLICY

The Significance of New Capabilities

We are getting very close to having access to fleets of partially or even fully reusable heavy and super heavy lift vehicles. Namely, SpaceX's Starship is already reusing its first stage and is achieving pinpoint landings with its upper stage. As of this writing, Blue Origin has launched its New Glenn heavy lift rocket and successfully landed it downrange on its ship and will likely reuse that stage within a year. Vehicles of these sizes open the possibility of lunar and Martian development on a scale significantly larger than anything that NASA has been planning. The savings of partial and fully reusable commercial launch systems shouldn't be underestimated. We are talking about cost to LEO dropping by something like an order of magnitude and eventually more than that. Continuing with much more costly legacy approaches will soon make no sense.

The systems that NASA is operating and developing were conceived prior to the emergence of these emerging reusable capabilities. Put another way, NASA's current operations and plans won't make sense as these new capabilities become operational. This fundamental fact needs to be acknowledged, and our nationals space policies need to fundamentally change as a result. The sooner that those changes are made, the less of NASA's budget will be wasted and the further ahead we will be.

We need to start transitioning away from old policies based upon old and limited capabilities. This transition won't be easy due to two factors: entrenched powers lobbying for the continuation of the old approaches and the "bird in the hand" phenomenon. By the latter, I mean that it is reasonable to say, "Let's keep moving forward with the old approach that we can be confident will work even though we know that it is very expensive. We can wait until the new capability is fully proven before making the transition". The problem with this is that we can lose billions of dollars and several years waiting for proven capabilities. Those billions of dollars could have been directed at developing the payloads (i.e. surface systems).

There is a tempting approach that I hope no one will advocate for. It may be tempting to say that we need the very expensive government rocket approach as a backup to the reusable fleets just in case the latter runs into a problem. Sorry, that isn't being prudent, it is downright stupid. The consequence of that approach is that so much money will be tied up funding the expensive, slow approach such that there will not be enough money to take full advantage of the hugely better systems. We need to cut our losses -- it is just a question of when.

The Tipping Point Criteria

At what point do we let go of what we have to have the budgetary space to take full advantage of the reusable fleets? That is a policy judgement call. But if we wait too long then we will have wasted a significant amount of money and time. But if we transition too early then we might be risking having an approach that doesn't work.

The correct way of thinking about this question is by thinking in terms of future probabilities and contingency strategies. What is the probability that the reusable fleet will become operational at significantly lower cost than the legacy systems? And, if there are difficulties in the remaining developments, are there smart approaches where we can still accomplish the missions?

The Starship first stage, with its 33 engines, has been caught by SpaceX's launch tower three times now. Two of the recovered boosters have already been reflown. For all practical purposes, the first stage should already be reusable. Reusing the second stage is much harder due to re-entry temperatures. And yet, the upper stage has conducted three pinpoint ocean landings, and the last flight (test flight 11) avoided unexpected burn throughs seen previously. It’s still somewhat away from full reusability but is showing promise. It is true that Starship hasn't yet made it to orbit but that is not because it can't but because they chose to cut the engines 8% early during current testing flights as a safety precaution.

The bigger uncertainty is whether we can be confident that Starship can successfully deliver propellant to and refuel at a depot in LEO. Without that, it cannot replace the necessary functions of the legacy systems for either lunar or Martian transport systems. I interviewed the leading published research engineer on the question of LEO depot probabilities who indicated that all the components of propellant docking, connecting, transfer, and long-term storage (zero boil off) has either been demonstrated in orbit or equivalently in the lab. No single step poses a particular concern. His prediction was that it was most likely to be demonstrated successfully even on the first attempt. Still, it remains a reasonable concern.

Therefore, the Tipping Point Criteria reasonably should be specified as when a Starship docks and transfers propellant and when the depot demonstrates zero boil-off. SpaceX estimates that this will be accomplished by the end of 2026. Our space policy needs to remain flexible enough to allow fundamental changes rather than locking into a policy that quickly makes no sense.

FULLY UTILIZING THE REUSABLE FLEETS

The single most important policy that needs to be established is that the United States should take full advantage of the reusable fleets when they become available. By "full advantage", this means that NASA's budget should be spent in such a way as to get maximum value. So, for example, if each year, a total of two billion dollars is being spent on two "commercial" LEO stations, is it unlikely that the benefits of that amount of money will be equal or more to the value of that money having been spent on missions to the Moon and Mars using the reusable fleets? In my book, it doesn't come close -- the American public will be far more interested in missions to the Moon and Mars than continuing the ISS research in LEO for another 20+ years.

If it becomes the policy to make maximal use of the reusable fleet, then there needs that program needs to be outlined. For example, we know what the plan is for Artemis 2 through 9. Likewise, after the Tipping Point Criteria is met, NASA should be tasked with identifying a program for how that capability can be maximally used. How would surface assets be developed? What categories of missions should be conducted and when? How would the US collaborate with the space agencies of other nations in a coordinated program of lunar and Martian exploration? When can international bases be established? How could NASA collaborate in private partnerships?

COMMERCIAL SURFACE SYSTEMS

Time is Running Out

The reusable heavy lift systems (Starship and New Glenn) are rapidly being developed with lunar cargo capability like in the 2027 to 2029 timeframe. That's a few short years from now. Will we have the payloads to deliver to the lunar surface? Or will we put off using the capacity of those fleets because we haven't gotten around to developing the necessary surface systems?

So, it is here proposed that a space policy that recognizes the emerging capability of these reusable fleets also establishes programs to award companies for the completion of the surface systems necessary. But this shouldn't be a vague approach of giving small grants to small companies to come up with ideas. NASA does a lot of this and yet isn’t completing the development of systems. Time is running out and we no longer have the luxury to turn development programs into commercial space stimulation programs where we are even developing but never coming to conclusions. Like during the Apollo Program we need to have a clear concept of what we are developing and to adequately fund companies to complete that work.

Related to that policy should be to collaborate with other nations to encourage them to fund their own companies to develop competing surface systems or also to choose a specialty hab for their companies to develop. In this way, we can recruit the space budgets of other nations towards a common goal.

34 – Legacy and Leadership

SUMMARY

The Innovative Plan presents a unique opportunity for America to lead the countries of the world as humanity starts spreading beyond Earth. The Artemis Accords are excellent but need to be followed on with coordinating agreements for an International Lunar Exploration Phase and Base. The Initial Permanent Crew scenario provides a remarkable, unique opportunity to seize a historic prize that will inspire the world for generations. The main criterium for identifying the value of the Moon is the foreign policy achievements.

LUNAR LEADERSHIP

Artemis Accords

The Artemis Program, initiated under NASA Administrator Bridenstine during the first Trump administration, is a very successful, American-led agreement on a set of principles as humanity starts expanding to the Moon. It is a set of 10 core principles describing how the signatory nations agree to behave when they go to the Moon. This includes peaceful purposes, formally collaborating with other nations in a friendly manner, preserving space heritage sites (see Chapter 42), and how to view the use of space resources.

There is broad agreement that the Artemis Accords have been a very successful effort. To date, 60 countries have signed the Artemis Accords and that number is likely to grow. Although started during the Trump Administration, the large majority of countries signed up during the Biden Administration and so it has broad, bipartisan support. China subsequently came out with its own intergovernmental agreement for an International Lunar Research Station which 17 countries have signed up to. Interestingly, only about 7% of the countries signing the Artemis Accords can be reasonably considered as dictatorships compared to about 60% of the signers of the ILRS.

Artemis 2.0

Whereas the Artemis Accords have been very successful, they are only a statement of principles and not actually an operational agreement like participating governments on the ISS have. And since NASA's current program only envisions just a few astronauts landing on the Moon every one or two years, most signers of the Artemis Accords have little hope that they will get to see their own astronauts walking on the surface of the Moon as a result.

Given the probability and capability of the fleet of Starships and Blue Moon landers and the potential for an International Lunar Exploration Phase (ILEP) and Base (ILB), there needs to be a follow-on to the Artemis Accords in which countries coordinate the exploration of the Moon to ensure that all participating countries get the opportunity to participate in newsworthy missions of exploration on the Moon. And as mentioned previously, the follow-on agreement could also coordinate which country will develop which competing surface system and specialty habs.

International Lunar Exploration Phase

Chapter 13 describes in fair detail the International Lunar Exploration Phase (ILEP). But currently, America has no policy envisioning or detailing this phase. Given the tremendous goodwill that such a program would bring to the United States as it affords the other nations the opportunity to have their own Apollo moment, it would rise to the level of a significant foreign policy achievement for whichever administrations initiate and carries out the program.

International Lunar Base

Similarly, Chapter 14 gives a description of the large and growing ILB, composed of numerous specialty habs. As with the Artemis Accords it is likely that many (most?) nations will want to be part of the expansion of humanity beyond the Earth. Instead of either the United States or China dominating the Moon, America could play a preeminent but not dominating role with the ILB. Being in that role, America can ensure that the principles being played out including: liberty, democracy, tolerance, economic opportunity, and individual rights. Given a free choice, most people of the world would choose to settle down in a free settlement rather than one controlled by non-free countries.

SEIZING THE HISTORIC PRIZE

As humanity begins to expand beyond Earth, there is a unique opportunity available if the US chooses to seize it. At some point, history will be made as the first permanent crew begins to settle down off Earth. If done correctly, this can be a moment that will go down in history and which humans in the future will refer to.

If there is a small, identifiable group of people that are clearly the first to settle down off Earth, then this becomes a historic story. As with the story of Plymouth Rock which Americans celebrate each year at Thanksgiving, a well-acted out story can serve as such a founding myth story. This book proposes that the United States choose through its space policy to intentionally write this story.

What will be the story of humanity's first settlers beyond Earth?

Private Workers First

Should the first permanent settlers be government or private? Private for sure. If not private, then it will always be debated as to whether they were the beginning of settlement or just working in a government outpost. Also, most civilians can relate to private individuals. Further, people of other countries may not so easily relate to government workers of the United States.

So, it is here proposed that it should be the policy for the United States to fund a private company to operate an Initial Permanent Base whether a StarHab or InstaBase. The first workers would be employees of a private company that is paid by NASA for these employees to demonstrate procedures and maintain telerobotic equipment in support of the establishment of American specialty habs which will be the first habitats of a large and growing ILB. So, whereas the funding comes from NASA (i.e. taxpayer dollars) the workers will be private, diverse, selected for languages, talents, personality, etc. so that they, as private individuals, can represent the first of humanity who sell their homes on Earth and be the first people to move indefinitely beyond Earth.

LEGACY

Whichever administration chooses to set our space policy towards seizing the historic prizes of humanity's first settlers beyond Earth and leading the world to spread beyond Earth, history will credit them for first setting the direction. The analogy is that President Kennedy didn't speak on the phone with the Apollo 11 astronauts, President Nixon did. And yet it was President Kennedy who appropriately gets the credit for initiating the program.

The policy benefits can be achieved immediately. Just like the Artemis Accords are yielding favorable results now with 60 nations having signed up, an Artemis 2.0 program could be established to help coordinate nations as they explore the Moon on behalf of their citizens and NASA could also begin coordinating with them as they fund their competing companies to produce elements of a sustainable International Lunar Base (ILB). It would be very difficult for a later administration to cancel such a program if other countries have already signed up to participate and are working towards an ILB.

CRITERIA FOR THE MOON

Jared Isaacman has been nominated to be the next NASA Administrator and had a good chance of being confirmed. He has attracted a lot of support and certainly would be a very interesting Administrator and has a decent chance of being one of the most influential and consequential Administrators given the capabilities and hence opportunities emerging.

Jared has appropriately indicated that America should be the first to land cargo and crew on Mars. He sets no criteria for whether a base should be established there.

However, for the Moon, he has stated that, after crew are landed on the Moon, it should be determined whether further development of the Moon can be justified based on either science, economics, or national security value. He doesn't seem very confident that any of those criteria can be met as he indicates that "if there is only a 1% chance" that it can, then we should find out rather than let China take advantage of that small chance.

Science: The Moon could occupy planetary geologists for a very long time studying questions of their interest. In particular, the deposition of ice in the permanently shadowed regions (PSRs) could tell a very interesting story of the history of the Earth-Moon system. But, Mars clearly has more interesting geology and of course there is the potential of finding evidence of current or past microbial life. So, with limited budgets, would it be better to spend money doing science studies on the Moon or Mars? From that standpoint, lunar science may not be as compelling.

Economics: In Chapter 32, the evidence is laid out that there won't be much of a market for lunar-derived propellant for sale in cislunar space. He-3 concentrations are very low and there are more cost-effective alternatives for power generation. So, these are not likely to be a source of vast wealth. Just now there is discussion about the production of solar panels on the Moon to be launched in cislunar space for data centers. At this point, it is very speculative so we can't say for sure whether this will be a huge money generator.

Finally, the bases and settlements on the Moon will have needs that business can meet. Funding for those will come from national space budgets and private savings respectively. So, there will be businesses operating on the Moon and making a profit. But the amount of business will be proportionate to the population on the Moon which will be far smaller than markets on Earth. So, some revenue but one wouldn't be able to make a case for a huge economic opportunity. Again, Mars will face the same problems, but no criteria is being set for it.

National Security: This term is more aligned with hard power than soft power. As described in the Chapter dealing with China, it is hard to make the case that the Moon represents a good location for a military base. Any attacking coming from the Moon or cislunar space can be easily seen with radar and would be clear who to attribute it to. The hard power criteria is going to be difficult to establish.

So, my concern about these three criteria is threefold. On the one hand, these criteria don't seem especially, obviously compelling and so are a set-up for failure. Second, it is not clear that the answer to these criteria will be clearly obvious after a few Artemis missions with a few government astronauts picking up more rocks. Thirdly, these criteria miss the greatest value described in some detail throughout this book.

Foreign Policy: Rather, the great national value of lunar development has to do with the foreign policy benefits that the United States gets from playing the preeminent role of leading the other nations in the ILEP and ILB and also the historic value of being the country to write the story of how humanity began spreading beyond Earth. If the space policy makers in DC want for the United States to play a leading role in this 21st century then having the preeminent role in space development starting with the Moon looks like great value for 0.4% of its federal budget.

35 – Is Space Policy Becoming Irrelevant?

SUMMARY

Starlink revenue is now exceeding NASA human spaceflight budget. Given the much greater cost-effectiveness of private launch systems, one must start wondering if NASA will remain relevant when companies have the capability of accomplishing so much more with more money and capability.

The chapter argues that space policy makers need to recognize that our programs need to align with the direction that the leading space launch countries are headed.

WHERE SPACE POLICY IS REQUIRED

Clearly, there are certain activities in space where companies are not able to turn a profit and hence government needs to provide funding. For example, probes and landers on Mars cost billions of dollars and yet it is unlikely that the commercial marketplace is going to pay enough for that information to cover the costs. So, there will always be a place for government space funding and hence space policy.

Human spaceflight has, for decades, been primarily in the domain of governments. Examples are NASA's Apollo Program, Space Shuttle, and International Space Station. Yet, they paid commercial companies to develop and operate the systems but, because the funding was almost completely from the government, then space policy determined the programs and their operations.

WHERE SPACE POLICY IS UNNECESSARY

Yet there are sectors of space operations that don't require ongoing government funding. Unmanned communications satellites are now an example of that. For decades, GEO comm satellites have been highly profitable and not requiring government subsidies to survive. Yes, government can be a customer, but they are just one customer among many.

The more recent example of this is SpaceX's Starlink constellation which is generating now more than $10 billion annually in revenue. Yes, governments also purchase their service but even without that revenue, SpaceX would be able to easily survive. Another interesting example is Planet (Lab) with a constellation of 200 high resolution satellites. They sell images from their frequent overflights for business intelligence and governments.

There has been recent discussions about the establishment of data centers in space. If successful, this would likely be developed using mostly private funding. Another potential example in the medium-term future would be large-scale LEO tourism where NASA-funded CLD stations just aren't sized to receive that many tourists so private LEO station companies would need to step up to that market demand.

THE GRAY ZONE

But nowadays, we find ourselves in a very interesting situation. Increasingly, the desire is to use NASA to stimulate the development of space economies whether in LEO, cislunar space, or on the Moon. The hope is that NASA can pay companies to develop a service which it can use and yet they can also serve the marketplace so that NASA becomes just one customer among many.

The best example of this was the COTS (Commercial Orbital Transportation Services) Program where SpaceX and Orbital Sciences were paid to develop new rockets to launch cargo to the ISS. Studies found that the $ per kilogram savings was between 4 and 10-fold! And the COTS Program resulted in SpaceX not only barely surviving but it has now gone on to returning the launch market back to the United States and now thoroughly dominating the global launch market.

COMPARED WITH NASA'S HSF BUDGET

NASA's Budget Size

Space policy matters to the extent of what it can buy. That is to say that NASA's $7.5 billion annual HSF budget is not peanuts. That amount can accomplish a great deal. But if it is ineffectively spent then it has that much less impact / relevance.

As mentioned earlier, SpaceX's Starlink revenue as of 2025 is greater than $10 billion annually. That grew a whopping 53% compared to 2024. So even now, SpaceX's revenue exceeds that of NASA's HSF budget, and we can reasonably anticipate that in a couple of years, SpaceX's revenue will far exceed NASA's HSF budget. So, how will that affect space policy? Who will set direction when NASA no longer has the greater budget? It's not that NASA will become irrelevant, but that space policy will be localized to those areas for which only government leadership makes sense while other areas transition to private / commercial operations.

GOVERNMENT NEEDS

First, there are certain goals that are specific to governments that do not so strongly apply to private enterprise. Here are a few relevant examples:

Beating China

There is a great power competition between the United States and China, and the stakes are high. Countries around the world are looking as to which country is in the lead and will respond accordingly. As mentioned in the China Chapter (38), the long-term significance is more greatly impacted by who develops the permanent International Base. But it does matter to some extent who wins the battle between who next arrives on the Moon. It seems clear that, without NASA funding, the lunar landers are not going to be built in time if at all. NASA's funding and hence space policy is essential.

Foreign Policy (govt-to-govt relations)

It may be that Blue Origin could eventually develop its own fleet of lunar landers and infrastructure on its own dime. But even if it did that, it wouldn't play the same role with other countries that the United States could play. There is something to government-to-government relations that private companies simply cannot replicate. This is why an explicit policy for the ILEP and ILB phases founded on a policy of full utilization of reusable heavy lift vehicles is critical.

Sending Our Values

Scott Pace (former Executive Secretary of the National Space Council) commonly points out an important point about America's goals in space:

> *"It is not just our machines or our people that we send to space. It's our values. It's who we are. It's things like rule of law, democracy, human rights, and a free market economy."*

One way or another, some country will be the first to establish a permanent and growing base on the Moon. As they develop the infrastructure and the population begins to grow, it is that country that will decide which values dominate. Dear reader, who would you prefer to establish the values of humanity's spread beyond Earth -- The US or the CCP??

SPECIFICALLY, THE MOON

Elon's Interest in the Moon

Elon is absolutely committed to Mars because he believes it is the only planet that has sufficient resources for full self-reliance (FSR). The design of Starship is specifically for Mars entry, and the fleet of Starships is sized to transport enough passengers and cargo to establish a city on Mars with a population reaching a million by 2050. He has publicly committed Starlink revenue towards the Starship development followed by Mars infrastructure.

But, Elon has also clearly and repeatedly indicated that he believes that a government "Moonbase Alpha" (MBA) should be built. Examine, for example, the artistic image that SpaceX has publicly released illustrating a Starship landing at a very large lunar base.

Recently, there has been the idea that Elon has completely backed away from the Moon by calling it a "distraction". Yes, he did say it is a distraction. But he wasn't saying that Moonbase Alpha shouldn't be built. Rather, he was specifically replying to an X post on January 3, 2025, by Peter Hague who suggested that "Mars people" and "space habitat people" should extract oxygen on the Moon and sell it including to those (i.e. SpaceX) going to Mars. Now, anyone who understands delta-V knows that this idea doesn't stand up under scrutiny. It takes delta-V (i.e. propellant) to slow down to enter a Lagrange point. Further, it takes delta-V to speed back up to get on a trans-Mars injection. But the real killer is the delta-V it would take for said lunar oxygen to be lifted off the lunar surface to the Lagrange point and then the delta-V to return the tanker back to the lunar surface. So, to this bad idea, Elon specifically stated, "No, we're going straight to Mars. The Moon is a distraction..." So, Elon has never wavered from his belief that a base should be established on the Moon. He was only rejecting the idea that lunar-derived propellant would help efforts to get to Mars.

That said, Elon has never indicated that any Starlink revenue would be directed to lunar development. Elon doesn't believe it possible to achieve FSR on the Moon. Rather, SpaceX's involvement would be to provide transportation on a commercial basis for cargo and crew for America and other countries. If US decision-makers direct space policy in that direction, then SpaceX will be there to accept those contracts. If, on the other hand, lunar development is limited to a few astronauts conducting the occasional science mission or if space policy views the Moon as only a steppingstone to Mars, then the Starship fleet won't be used to its full extent for lunar development.

THE PURPOSE OF THIS BOOK

In this book, the Plan has been presented about how America can:

- **SEIZE** the historic prize by writing the story of humanity's spread beyond Earth starting with the Initial Permanent Crew
- **GAIN** tremendous international appreciation by leading other countries in the very broad exploration of the Moon
- **LEAD** the world in establishing a large and growing International Lunar Base
- **FACILITATE** a lunar marketplace of international companies competing to provide goods and services making private settlement possible
- **INSPIRE** upcoming generations with a future beyond Earth filled with potential

A billion young people could watch America's Initial Permanent Crew.

SO, HOW IMPORTANT IS LUNAR SPACE POLICY?

For the Moon, space policy is critical. Without a policy taking full advantage of the fleets of reusable heavy lift vehicles, lunar development could be greatly delayed. Alternately, lunar development could be taken up by other countries who understand the potential leaving America largely out of the picture. The choice is ours. But, considering how much is to be gained by pursuing the Innovative Plan and how much is to be lost by failing to do so, the opportunity should not be missed to provide the necessary policy leadership at this time.

The policy can't be limited to committing to taking advantage of the reusable fleets but not developing surface systems. Rather, space policy needs to lay aside the Tradition Plan to open up the necessary budgetary space.

36 – Space Policies We Need

SUMMARY

This chapter succinctly identifies key space policies that will be needed to capitalize on the emerging capability of the reusable heavy lift vehicle fleets. It starts by identifying ship-to-ship propellant transfer as when space policy needs to recognize that the new capabilities are going to become reality. We need to start developing large surface systems to be ready when heavy cargo is being delivered to the Moon. We need to start soon inviting young people around the world to prepare themselves to be part of America's historic Initial Permanent Crew. And we need to go beyond Artemis Accords to coordinate surface exploration and an International Base with other nations.

POLICY TIPPING POINT

When it becomes operational, the Starship fleet will not only be far more cost effective than the SLS but more capable as well. But that point has not yet come and so it is understandable that stage space policy decision makers in DC will want to continue spending money on the SLS for now. But what would it take for that to change? What achievement will start tipping space policy towards a Starship-based architecture thereby freeing up billions each year for a truly vigorous, sustainable lunar development program?

Starship's first stage has already been caught three times by the launch tower's arms (Mechazilla) starting in October 2024, yet this hasn't led to the policy tipping point.

Starship has not yet reached orbit, but its engines have been turned off 8% short of reaching orbit. Achieving orbit is a trivial next step. But when SpaceX chooses to achieve that step there remains an additional step required to give confidence that the alternate approach will likely work.

That additional step is connecting to a depot, transferring propellant, and storing said propellant with minimal loss. Elon has indicated that ship to ship propellant transfer should occur in 2026.

Zero boil off (ZBO) storage using cryocoolers is mostly a thermodynamic question which is provable in the lab. Indeed, this has been done multiple times including by Blue Origin including for liquid hydrogen. Space policy should reasonably assume that long-term storage is largely a solved problem and so the policy tipping point shouldn't wait for that demonstration.

Policy Recommendation: NASA should start messaging that, once a Starship tanker docks and transfers large quantities of propellant between ships, then we should seriously consider whether the Traditional Plan should give way to a Starship-based system.

TAKE FULL ADVANTAGE OF THE STARSHIP FLEET

The capability that SpaceX and Blue Origin are developing will truly revolutionize the course of human history. This is not an overstatement. It will be on these fleets that humanity will begin to spread beyond Earth.

But, to take the lead in this historic venture, the decision makers will need to direct our space policy to explicitly take full advantage of this capability and to not let other space priorities hog the budgetary resources (see Chapter 37).

Policy Recommendation: NASA's budget should prioritize the full utilization of reusable, heavy lift transport systems just as soon as they become available.

DEVELOP SURFACE SYSTEMS

A cost-effective rocket is useless if it has no payload. In anticipation of reusable heavy and super heavy-lift vehicles, NASA should develop a long-term vision for the ILEP and International Lunar Base (ILB). For the latter, there are a set of technologies that companies need to develop given full funding provided by NASA. Those technologies need to be ready to be used when the time comes rather than being an afterthought.

Policy Recommendation: NASA's needs to envision a Plan for the development of a large and growing International Lunar Base including the surface systems needed. After identifying the necessary components needed, budgetary space needs to be opened up with NASA providing fixed-price contracts with purchase commitments. The US should also encourage other nations to fund their own companies to develop competing components of an international base.

SEIZE THE HISTORIC PRIZE

There will be only one opportunity for a country to intentionally write the story of how humanity began settling down off Earth (see Chapter 5). America should choose to seize it.

Policy Recommendation: It should be America space policy to facilitate the first private crew to achieve the historic prize of establishing humanity's first permanent foothold off Earth. This would be achieved at an Initial Permanent Base with as few as eight people who are able to leave Earth and settle down indefinitely.

THE INTERNATIONAL LUNAR EXPLORATION PHASE

The near-term value of a program of lunar exploration and sustainability is American leadership among the nations, writ large! From a space policy standpoint, this is the great value and justification for a sustained lunar program.

The Artemis Accords have been very successful, but they need to be followed up with an "Artemis Accords 2.0" to coordinate exploration and development of a very large-scale program of lunar exploration.

Policy Recommendation: It should be the goal of NASA's space program to provide international leadership by setting up a framework whereby collaborating nations can coordinate a very large International Lunar Exploration Phase for the benefit of all nations.

INTERNAIONAL LUNAR BASE

Related to the policy for the development of surface systems, US space policy should commit to leading the nations to develop an International Lunar Base on the Moon. This would serve as a base for the exploration of the Moon, a base for industrial-level development, and also the base from which private settlement would arise. By establishing leadership in the development of the international base, the United States can ensure that the principles established are consistent with our values.

Perhaps this would be a good time to note that a large base may seem like a far distant project that space policy doesn't need to address now. But given SpaceX's Starship test flights, engine production rate, and their Starship Factory, now is the time to start developing surface systems for the base and the current administration can establish the legacy for having initiated the vision.

For the base, standard (100 tonnes) inflatable habitat structures can be conceived and then NASA can coordinate with the space agencies of other countries for them to pick which specialty hab they would like for their companies to develop as their contribution to the International Base.

Policy Recommendation: It should be the policy of the United States to lead in the establishment of a large and growing International Lunar Base.

AVOIDING POLICY TRAPS

Chapter 37 describes some policy traps that would constrain NASA's budget for many years, committing to programs that don't yield anywhere near the outcomes as the Innovative Plan described in this book. It is essential to acknowledge that decisions need to be made to open up budgetary space. Yes, one could keep all previous programs and expand the budget. But is that sustainable and is it responsible with the taxpayer's money given the level of debt that the federal government has accumulated?

Policy Recommendation: It should be the Administration's and Congress' policy that our space program should give the taxpayers the best outcome for our space bucks and that there should be no sacred cows.

PARTNER WITH SPACEX ON MARS

Although this book is about lunar exploration, development, and settlement, a policy for Mars should be mentioned because the Moon and Mars programs are often set against each other. If we are conscientious about eliminating wasteful programs from our space program, there should be enough budgetary space to do both programs well.

The space policy decision makers need to come to the realization that any NASA crewed mission plans for Mars will be irrelevant because SpaceX is going to beat them.

The decision makers need to decide if they want NASA to remain relevant when it comes to Mars. Certainly, they do want that. So, for them the question really comes down to, what role will NASA play as SpaceX is developing and sending its fleet to deliver cargo and then crew to the red planet?

The answer seems obvious. There needs to be a public-private program in which NASA (and other leading space partners) funding buys seats on the first mission to Mars alongside SpaceX workers. Both will be interested in establishing permanent facilities from the start and NASA will take the lead when it comes to scientific exploration.

Policy Recommendation: It should be the policy of NASA to partner with SpaceX in a joint program for establishing a permanent base on the red planet.

37 – Avoiding Policy Traps

SUMMARY

This chapter identifies certain popular space policies that risk locking America into programs that will prevent NASA's budget from being able to take full advantage of the emerging capability presented by the reusable heavy lift fleets.

There are certain programs that make no sense as the new capabilities become available. This includes: SLS, Orion, Gateway, and Mobile Launcher 2. There is also the very real risk that NASA's HSF budget will be constrained for decades if we get locked into spending money utilizing the so-call "commercial" LEO stations. Decisions made now will determine if America can seize the remarkable opportunities described in this book.

BUDGETARY SPACE NEEDED

As mentioned in the previous chapter, the International Lunar Exploration Phase and Base will need to be funded by governments and so room needs to be made within space budgets. Elon Musk is appropriately focusing Starlink revenue on Mars and there is no indication that Jeff Bezos has any idea of funding a government lunar base. Obviously, it is the responsibility of governments to fund a government base and the companies that governments set up to provide the goods and services for a government base will be exactly what will be needed as private settlers grow the base and then branch out. So, how can budgetary room be opened up.

No Increase in Overall Budget

If we choose to do it correctly, we don't have to expand the overall NASA budget but rather work within traditional budget levels. The reason why this is possible is primarily due to the significantly lower launch costs that become possible when the capability becomes available of a fleet of fully reusable heavy lift vehicles. Plus also, the use of fixed priced contracts can achieve significant savings. However, all of NASA budget is currently called for so something must give to make space.

What Budgetary Room is Needed For?

To summarize the previous chapter, we need budgetary space to take full advantage of the Starship fleet for transport of cargo and crew to the lunar surface. We need to get busy paying companies to develop full-scale surface systems by the time that we start developing the ILB. The Starship fleet will likely become available before 2030, so time is of the essence. Again, surface systems include: power systems, surface vehicles, large, inflatable habitats, habitat life support, sanitation, a GreenHab, a centrifuge, and ISRU roughly in that order. And there will need to be operational funding to conduct missions of exploration where each national will pay for their own missions.

MAKING BUDGETARY SPACE

Distractions

Mars Sample Return - Terribly over budget and delayed, this program would cost perhaps $5 to $8 billion more going forward. There seems to be sufficient consensus that the program needs to be stopped even though this may well mean that China will get the first pristine Mars sample back before the United States. However, this amount is insufficient by itself to make enough budgetary space for the Innovative Plan. We have to look elsewhere.

Military Space - A few space advocates think only in terms of "great power competition" and how America's civil space (e.g. lunar return) fits within the picture of national security space. There's certainly plenty of reasons for concern about China here on Earth. But, as discussed in Chapter 38, the Moon is far less significant in any way as it relates to our competition with China than things like trade relations, the South China Sea, Taiwan, their military build-up, or such. If we develop some sort of space policy based upon our concerns about China but we don't grasp the rather large advantage of world leadership that international exploration and the Lunar Base, then we will fail to understand how to best use our civil space program to advance our interests vis a vis China.

Orbital Debris and Planetary Defense - Again, these are relatively small budgetary items. The quantitative risk of either is pretty small despite routinely inflated concerns expressed. Again, the foreign policy gains of the Innovative Plan would be a far greater achievement than any policy regarding these two items. These are not bad but shouldn't take precedence over our international leadership on the Moon.

National Space Council (whole of government) - Again, not bad. The space policy directives of the first Trump Administration were consistently good achievements. But, apart from the Moon first directive, such actions are not as significant as policies in support of opening the way for humanity to expand to the Moon and Mars.

Pro-settlement Policy - In the past, some space advocates have promoted the idea that space settlement will only occur if NASA's charter is changed to make space settlement a formal goal. A government lunar base is a legitimate governmental goal not requiring any change to NASA's charter. And from a technical standpoint, both government bases and private settlements require power systems, habitats, life support, agriculture, etc. -- all of the very things that the Innovative Plan proposes. In other words, the best way to achieve settlement is for NASA to pursue a government base with companies able to provide those goods and services and the setting will be in place for private settlement to naturally grow from those capabilities.

Actually Making Budgetary Space

Rather, if we are going to make sufficient budgetary space for the Innovative Plan, once the Starship capability demonstrates itself, several large programs will become unnecessary and will therefore open up the budgetary space needed. Those programs include:

- The Space Launch System (SLS)
- The Exploration Upper Stage (EUS)
- The Mobile Launcher 2
- The Orion capsule
- The Gateway

Just like the ending of the Apollo Program opened enough budgetary space for the Shuttle system to be developed, the ending of the above programs would open up about $3-5 billion annually which would be sufficient for the return to the Moon program.

Cynicism of Government

It is very common for space advocates to reflexively dismiss US space policy transitioning away from the very expensive SLS system to the much more cost-effective Starship-based transport system. The cynical argument that they make is that politicians will never, ever agree to a change that takes away a program from their district.

First, such changes have already happened several times before. When it becomes apparent that a current program no longer makes sense, congress has allowed otherwise painful changes. The Apollo program budget was allowed to come down from its peak. Certain Saturn V contractors lost their business when it was agreed to attempt a transition to the reusable Shuttle system. The orbiter portion of the Shuttle system was shut down (with the resulting loss of certain jobs) after it became obvious that that system was too dangerous. There is agreement that the ISS program will need to shut down in 2030.

The argument here is that, when Starship demonstrates docking and transfer of propellant from a LEO depot then it is obviously a matter of time before it becomes fully operational. That is the space policy tipping point after which it is a matter of time before a transition from SLS to Starship will occur. If the Administration wants to achieve the rather remarkable outcomes stemming from the Innovative Plan in this book, then a fundamental transition to include development of surface systems becomes essential.

Letting Go of SLS

There is another common and somewhat legitimate objection to transitioning from SLS-Orion to a Starship-based Earth-Moon transport system. That objection is, we have a human-rated SLS-Orion system now, but Starship has not yet demonstrated the ability to launch people to space. It's the one bird in the hand versus two birds in the bush argument. Well, Starship can reach orbit now if they just allow their engines to burn for about 8% longer. Also, SpaceX can now safely launch crew to LEO on their Falcon 9-Dragon where they would be able to transfer to a fully fueled Starship. So, an honest approach would be to have NASA put out a request for information (RFI) indicating how heavy lift systems could complete a full Earth-to-Moon mission without SLS, Orion, or the other systems listed above.

From the safety perspective, can Orion really be cancelled when Starship is not designed with a launch abort system? Besides the Falcon 9-Dragon approach mentioned earlier, Elon has also indicated that the necessary level of safety can be achieved via the engine out capability that Starship's first stage has already demonstrated and after numerous Starlink launches, the safety record of the upper stage can be determined. For example, as of this writing, 570 Falcon 9 launches in a row successfully made it to orbit. Rockets will never be perfectly safe but

NASA has revised its criteria of a 1 in 300 chance of loss of crew (compared to Shuttle's 1 in 68). It seems that Starlink launches would be the path to revealing any remaining failure modes to reach the needed level of safety.

On occasion, a really bad suggestion is made that, even after Starship is made operational, the SLS program should be continued as a "back up" in case the Starship system fails. The SLS system is so expensive ($4.1 B/mission) that continuing it would mean that we would have insufficient budget to utilize the Starship capability much at all.

COMMERCIAL SPACE IDEOLOGY

Fixed-price Contracts

NASA is now routinely using fixed-price contracts rather than cost-plus contracts. This places the burden for both cost and schedule overruns on the companies and not NASA. The results have been really pretty good and should be used wherever possible.

The Good Parts of Commercial Space

GEO communications satellites and LEO internet constellations are truly commercial space and obviously good things that don't require large NASA programs. Rather, when commercial space policies are being promoted, it is usually about what government can do to help grow commercial space activities in areas where they haven't been able to already do it on their own. In other words, there is a (correct) assumption that the "smart money" (e.g. venture capitalists) is not convinced that so-called commercial space ventures will be profitable else they would fund the programs using their own money. Rather, government needs to provide grants, contracts, and/or guaranteed usage to stand up commercial entities to provide the service. So, if government funding is absolutely essential, just how "commercial" is it?

Well, actually there is one excellent example of how this approach has worked amazingly well. In 2008, SpaceX was on the verge of going bankrupt. With the COTS, Commercial Cargo, and Commercial Crew programs, SpaceX went from barely surviving to where it is now dominating the world launch market with 90% of the world's payload mass into space in 2025.

Lots of "Commercial" Struggles

Unfortunately, that is a rare example of success. Other so-called "commercial space" programs haven't been anywhere near as successful. People who follow such developments will know of the examples of Boeing's Starliner capsule, Antares rocket that hasn't launched any commercial satellite as its primary payload, Sierra Nevada's Dreamchaser really struggling with reduced NASA funding, CLPS lander companies dependent upon NASA funding for survival, and the dozens to hundreds of companies surviving only on the next NASA grant. Even Blue Origin has survived for 25 years not because of commercial profitability but from Jeff Bezos' willingness to sell $1 billion of his stock per year to fund it. This might better be called "philanthropic space". In the next section, we'll discuss the so-called "Commercial" LEO Destinations and how we really need to make sure that we lose the Moon because we budgetarily got stuck in LEO like we have for the past 25 years.

Government First Then Commercial Later

Commercial space is a very good goal. But we need to be realistic. The Innovative Plan proposed in this book recognizes that there will need to be a government funded phase first for lunar exploration and an international base. Only after cheaper access to the Moon becomes routine and only after companies repeatedly add modules and services to the base can we consider the possibility of private individuals being able to afford incremental goods and services from those companies and hence the base starts to have truly commercial operations.

Commercial Lunar Payload Services (CLPS)

NASA started its small lander program ten years ago and has spent about $2.6 billion over that time. This was well before SpaceX's Starship program was started. Given the significant payloads that Starship is projected to be able to land on the Moon, one could envision dozens of rovers driving perhaps 50 km in every direction for the Starship landing point. The Soviet Lunokhod 2 rover drove about 39 km. Looking at the high-neutron map of the lunar south pole, it appears that about a dozen Starship landings with rovers spreading out from there should complete the prospecting phase of the most interesting sites at the lunar south pole. What then could have been done with the past and future CLPS funding? Well, the development of one of the surface systems needed for the ILB would seem to be a good use of that funding.

AVOIDING NEW BUDGETARY BURDENS

Another large concern is that we will get ourselves stuck with unending budgetary commitments that will hinder NASA's ability to fund lunar development or even a SpaceX-NASA Mars partnership. Namely, the concern has to do with LEO stations.

The International Space Station (ISS)

It is estimated that the ISS has cost perhaps $150 billion to develop, operate, and maintain, of which NASA's contribution has been about $100 billion. That is a crazy amount of money. Additionally, we spend between $3 and $4 billion annually to operate the ISS.

Was that the best use of our space budget over the last 27 years? On the one hand, we got a lot of zero gee research. On the other hand, we therefore didn't have enough funding to rapidly develop a Moon and Mars program. From the public's point of view, do they even know who is on the ISS now? Do you, the reader know that? Are they amazed by the research being produced by that national laboratory? Do you even know what is going on? But, when astronauts were on the Moon, people knew about it.

"Commercial" LEO Destinations

Well, what was done was done. We can't change that. But the concern expressed here is about the desire for a "gapless" transition to so-called "Commercial" LEO Destinations (CLDs). We like to fund two and not just one commercial entities (two cargo, two crew, and two lander providers). So, if we fund two CLD stations in LEO, even if each cost less than the ISS, we may well end up paying for two of them. And for how long?

There is the sunk cost fallacy. If we pay companies to establish their stations, won't we want to pay to use what we paid to establish? Will we utilize the stations conducting another 25 years of research? And how much will that all come to and how many fewer Starship missions to the Moon and Mars will we lose out on?

Considerable effort has been made to try to get commercial activity on the ISS. Analysis of the effort has come to rather negative conclusions. For example, NASA Inspector General, Paul Martin testified;

> *“Candidly, the scant commercial interest shown in the station over its nearly 20 years of operation gives us pause about the agency’s current plans,”*

Despite that failure, there is hope that the CLDs will be different. Most actual investors are not convinced of the profitability of said stations and so are dependent upon NASA funding. There is hope that the killer app will be found for the CLDs. But even if there is, it seems likely that NASA will still be paying for usage for a long time.

If we spend only $1 billion annually for each of two CLDs, there won't be much savings from ISS to apply to the Moon and Mars. Continued, indefinite NASA utilization of stations in LEO is very popular. But maybe we need to set some sort of reasonable limit on how much money we will spend there instead of the Moon and Mars. Perhaps limiting the expense to $10 or $15 B would be reasonable. More than that and we must ask ourselves how much we are losing in lunar and Martian development.

Once we start down the CLD path it will be very difficult to end that expenditure and we need to make sure that another 25 years hanging out in LEO is the best use of our space bucks.

Further, if other countries think that their citizens are more interested in the Moon and Mars than LEO then they could choose to contract with SpaceX whether the United States is able to participate or not. Do we really want to leave it to other nations to collaborate with each other on the Moon and Mars and be the ones to establish humanity's first permanent foothold off Earth without the involvement of the United States?

The Lunar Gateway Station

NASA's Traditional Plan currently includes a small, occasionally crewed station in high lunar orbit. This station is a hold-over from Obama's NASA when they were trying to figure out what they could do in lunar orbit without going to the surface of the Moon. It also resulted from the combination of the Orion capsule being too heavy and the European Service Module being too underpowered to go anywhere other than high lunar orbit. This was all before the Starship development program. Elon Musk has indicated that Starship would be able to do lunar missions all by itself and so not need the Gateway. It seems likely that the Gateway will be recognized as unnecessary as Starship becomes capable of refueling at a LEO depot and conducting lunar missions by itself. Being co-manifested with the Orion capsule, the Gateway won't be dreadfully expensive but will still likely get cancelled nonetheless.

38 – The Challenge of China

SUMMARY

Because so much anxiety is expressed about losing the Moon to China, this chapter points out that, thanks mostly to the lead that the Starship fleet currently has, there is little basis for concern that China will be able to make a credible claim to anything on the Moon -- no one would accept any unreasonable claim and the Starship fleet will overwhelm lunar development anyhow.

IS CHINA A COMPETITOR IN SPACE?

Very often within the space advocacy community China is held up as a reason for an aggressive space policy. The fear is that China is seeking to control space in a way that will block access by other countries, that it will control the "high ground" of cislunar space, and that China will develop the trillion-dollar economy in space.

These views are largely unrealistic for the following reasons:

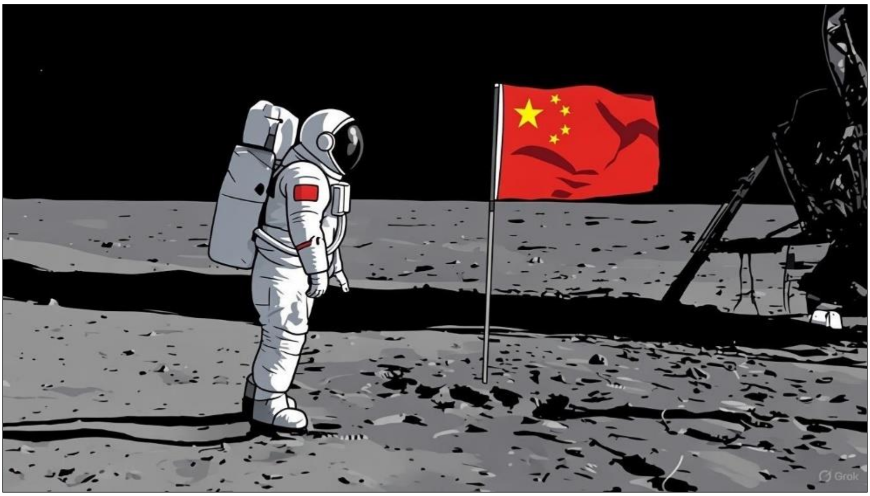
- China is far behind the United States when it comes to a fleet of super heavy lift vehicles.
- In-space resources are expensive to develop, not tremendously valuable, and the market is relatively small.
- It would be difficult for any country, including China, to exclude other countries from accessing space resources including lunar polar resources.

That said, there is a race for national prestige between the United States and China, and it would do well for the US, as the leading free country in the world, to continue in the lead.

Will China Take the Lead?

China's human spaceflight program has gone relatively slowly with only 15 missions since its first crewed mission in 2003. But, in terms of the Moon, it reasonably aims to land its taikonauts on the Moon by 2030. The United States has had an unsteady return to Moon program. As of now, it is more likely than not that the United States will return to the Moon before China first gets there. But this is not a certainty, and for the sake of US leadership, it is reasonable to be concerned about this matter and to take measures to accelerate America's lunar return program.

However, whoever gets back there first, it hardly matters. Just like the Soviets didn't win the space race because they placed the first person in orbit, likewise, it is not who places a person on the Moon next that matters. In the final analysis, what matters is who will establish humanity's first permanent base on the Moon, and which base will grow fastest and largest. And from that standpoint, SpaceX's Starship fleet is well ahead of China with China having little hope of catching up to SpaceX anytime soon.



Whose values will be preeminent on the Moon?

SEIZING CONTROL OF THE MOON

Ye Peijian is the head of the China's Moon program. Much has been made of his statement that, "The universe is an ocean, the Moon is the Diaoyu Islands, Mars is Huangyan Island". Given that these "islands" are central in the territorial dispute in the South China Sea, the assumption is often made that this one statement implies that China's ultimate plan is to claim the Moon and Mars as their own. This seems like quite a logical stretch when the statement could just as easily be viewed as an analogy to distance.

Likewise, China has described their interest in developing space resources. Well, any intelligent space program would want to use in situ resources in support of their space program to reduce the shipping costs involved. Helium-3 is present on the Moon and could be used to power fusion reactors. But the concentration is so low that one would need to process at least 67,000 tonnes of lunar regolith for every tonne of He-3. Considering the cost of doing so and the many alternatives to He-3 fusion, it is not clear this this is an economically viable resource. Further, with He-3 spread all over the Moon, no one is going to prevent another country from accessing it.

Water for propellant is the most cited valuable resource. But the problem is that lunar-derived propellant for vehicles bound for Mars has no identified customers -- Elon has explicitly stated that SpaceX has no interest. And if one looks at the delta-Vs involved, one can see that physics and economics don't make sense.

The Real Value of Lunar Resources

Besides the previously, very speculative lunar resources, there are a couple of resources on the Moon that could lead to competition.

"Peaks of Eternal Light"

There are only a finite set of the so-called "Peaks of Eternal Light" at the lunar poles. These are areas where one can get nearly continuous sunlight and they are conveniently located near permanently shadowed craters. One could imagine a scenario whereby a country such as China could rush to set up operations at those peaks and then claim the right to exclusively use those locations.

The problem with this scenario is severalfold. Unless China is secretly developing a rushed human lunar program, they are not scheduled to be able to establish operations at all the peaks at both poles before NASA, SpaceX, and Blue Origin are planning on sending crew to these same locations. Also, the regions of elevated sunlight (> 70% sunlit) are not small, especially if erecting tall solar panels. Any claim to exclusive control over such large regions would not be accepted by the other nations and would be difficult for China to enforce. Exclusive control over an area on the Moon would also tend to violate the Outer Space Treaty in that it would prevent free access to those locations by other nations. And having solar drapes and ice-harvesting telerobots a kilometer away from another country’s operations cannot logically pose a threat to China's operations. China will not use force to control unreasonably large areas of the Moon thereby causing an incident potentially leading to war. The benefits of controlling large areas of the Moon are too small to justify risking war on Earth.

Lunar Polar Ice

Similarly, lunar polar ice is spread out across many hundreds (perhaps thousands) of square kilometers at each lunar pole. Such broadly spread operations cannot be quickly developed.

THE REAL PRIZE

The real prize for lunar development is two-fold:

- National prestige for that country which leads the rest of the world in opening space for human settlement.
- Establishing the "rules of the road" for how humanity will live off Earth.

Unlike how things have gone in the past, we really are approaching a tipping point where humanity will start spreading beyond Earth. These events will prove to be as historic as any other event in Earth's history. The country that leads out in this process will not only go down in history but will imprint their values on how humans live in the future. It is the position of the Space Development Network that America and not China should lead in the spreading of humanity beyond Earth, but that other countries and peoples will choose in what way that they do so. But if America sets the pattern, then the future of humanity beyond Earth will be one of liberty.

CONCLUSION

In conclusion, we believe that the concerns about China spreading into and controlling space are largely hype. None-the-less, given the historic significance of what is about to happen, we think it prudent for America to boldly open space to humanity and not leave that role to China.

HOW TO GET INVOLVED

39 – Join the Space Development Network

SUMMARY

This chapter is a call for those readers who would like to help realize the vision in this book to join the Space Development Network for free, specify their interests and talents and then participate in Zoom working groups.

The Plan laid out in this book is certainly exciting. But there's no guarantee that the powers that be will choose to adequately fund and pursue such a vision. Is there anything that regular folk can do to increase the likelihood of this happening?

THE SPACE DEVELOPMENT NETWORK

Each Member Contributing What They Can

The Space Development Network was established to organize volunteers to move the Innovative Plan for Space Development going forward. Each person, given their own talents, whether great or small, can contribute something towards moving things forward. For volunteers with formal engineering training, it may be something as significant as writing up a scientific paper describing a cost-effective transportation system to the Moon. For a layperson without professional training, it could be posting a Tweet directing people to one of our web pages describing a concept. Or it could be developing a recipe which would use ingredients from plants which we have identified could be grown in one of the GreenHabs.

Making Progress According to a Plan

The Space Development Network is a new type of space advocacy organization. Most other such organizations are big umbrellas in that they are societies in which people who espouse a categorical view join in undirected collaboration. So, for example, the Moon Society, Mars Society, Space Tourism Society, etc. have their particular focus. But within those societies there are the full variety of concepts which are shared in their conferences but without necessarily having a specific Plan to organize their voluntary work.

The Space Development Network does have a specific Plan -- The Plan for Sustainable Space Development as described throughout the website: DevelopSpace.info. This book covers the lunar development portion of the Plan. Various options at each point of the plan (e.g. habitat options) have been considered and the Network has settled upon what we think is the best solution (e.g. inflatables). Whereas the Network leadership does update aspects of the Plan as better ideas are recognized, the Plan seems to have settled down to that described on the website.

WORKING GROUPS

Specifying Skills and Interests

As individuals join the Network, they complete a form which includes listing their backgrounds, interests, and any skills. Based upon these, they will receive email invitations for recurring working group teleconferences. In these teleconference sessions, members discuss concepts within that category, seek some level of consensus, and then tasks and projects are identified and members of the working group voluntarily accept tasks and work on them with reports of progress being made in later working group teleconferences. Let's consider an example of how this works.

Perhaps the most active working group has been the Agricultural Working Group (AgWG). Ranging from laypeople with limited experience to degreed space agriculturalists, the group discussed the fundamental architecture for growing food on the Moon (and Mars). The Group produced a consensus document describing how we understood how agriculture should be conducted beyond Earth. The results of that work are described in Chapter 31. The result of this work is directly feeding into a follow-on project led by a member who is a published space agriculture faculty. Our goal is to demonstrate the full nutrition production for one individual before scaling that up to production for eight people (Initial Permanent Crew).

Agriculture is just one aspect of space development. There are many other areas including transportation, habitats, robotics, ISRU, health, psychology, chemistry, metallurgy, the arts, music, dance, animals, policy, etc., etc. If we envision space development going beyond just scientific exploration and all that living off Earth involves, then there are many areas that space advocates of nearly any background could contribute to.

NETWORKING WITH OTHER ORGANIZATIONS

The Space Development Network not only networks volunteers but we also would like to network the various space advocacy organizations and collaborate in projects of common interest. We have played the central role in organizing space advocacy organizations to publicly congratulate and draw attention to SpaceX's Starship with each major accomplishment. Likewise, our Moon-Mars Analogue Base (MMAB) concept starting with the InstaBase is something that any space advocacy organization can take advantage of. Many space advocacy organizations don't have their own analogue bases but would benefit by either establishing their own copy of the InstaBase or participating alongside other organizations in a common base.

We believe that the establishment of permanent bases on the Moon and Mars is not far off and so we don't have unlimited time to make the case for the Initial Crew and International Phases nor of the habitation and other surface systems. So, we call upon well-intentioned advocates for space development to join us to work together in an organized manner to do our part to accelerate progress toward the exciting future that we envision.

JOIN THE NETWORK

So, would you the Reader, like to join the rest of us in helping to move forward the Plan for Sustainable Space Development? Check out the Plan and then join us at DevelopSpace.info/join. Joining is free but there is a catch. We don't want members who just join and do nothing. For free membership, we ask members to contribute at least six hours per year of voluntary work. For those who wish, they can join for $20 per year, for which they can be informed about the activity of the Network but without the expectation of volunteer work.

40 – The Analog Visitor Center

SUMMARY

One project that the Network is working on would be the establishment of a new type of analogue base that would be developed rather than exploration-oriented. Located in Florida near KSC and local universities, it would benefit from local support.

OVERVIEW

The Analog Visitor Center (AVC) is a concept for a new type of analog base that would include a lunar focus and be a place that the public could visit. Unlike other analog bases, it would be intentionally located near a populated area (specifically near Kennedy Space Center) to take advantage of existing visitors, local volunteers, launch events, proximity to supplies, and proximity to universities. A set of four phases of development of the AVC is identified starting with very simple (utilizing a mock-up base we already have), to more advanced phases, and with an ultimate vision of a theme park. Starting with philanthropic funding and later having usage fees we believe that the AVC can have adequate funding throughout all of the phases. Finally, the Earth Independence Project is briefly described which would seek to figure out how a small base could produce all of its needs at a rate consistent with natural growth.

COMPARED TO OTHER ANALOG BASES

There are several analog bases, why is there a need for a new one?

Lunar Focused

The Moon is a legitimate destination in its own right. But many of the other analog bases are exclusively Mars oriented. This is a problem since the Moon will likely be developed around the same time as Mars and, given how much closer it is, it will grow much more quickly than Mars. Lunar development is a stated goal of both NASA and SpaceX and so there is a need for the Analog Visitor Center (AVC) to focus on both lunar and Martian development.

Similarly, the local resources of the Moon are fairly different than Mars. For this reason, an AVC will consider the lunar resources in a way that a Mars-only analog base probably won't.

Development and Settlement Oriented

The other analog bases are very much exploration oriented. This book describes a very large exploration phase. But, simultaneous to that, it also advocates the rapid development of a large International Lunar Base setting the stage for private settlement. For this reason, the AVC will be highly focused upon sustainable development and the processes involved with establishing humanity's first, off-Earth foothold.

Proximity to Building Materials and Supporters

The other analog bases tend to be very remote. This is great if one is exploration-oriented with a focus on the crew leaving the hab and conducting EVAs to do geology and searching for evidence of life. But if the emphasis is on increasing independence from Earth by using local resources then this is something that is mostly done indoors. For this reason, being near a Home Depot and local supporters helps to be able to develop the analog base more rapidly.

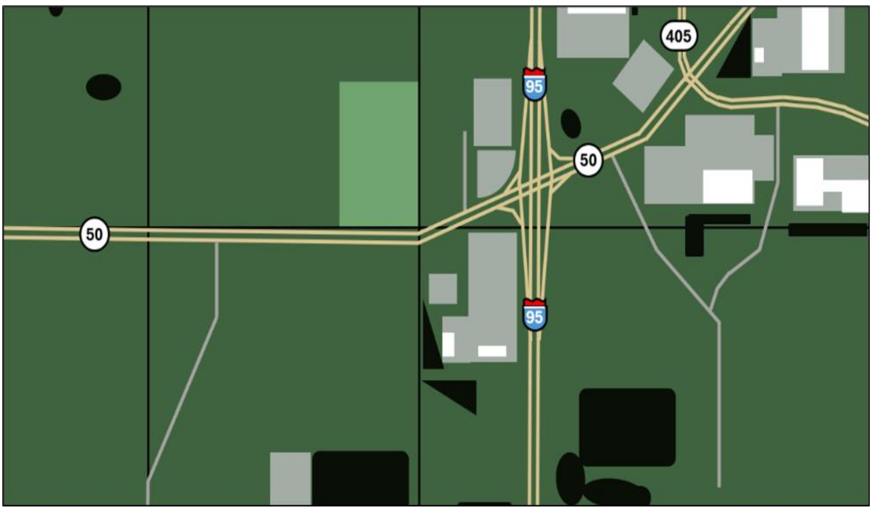
LOCATION

Several analog bases are located in very rural locations with some of them intentionally being extremely remote, even inaccessible by road. If we will be sending just a few government astronauts to repeat geologic exploration like we did during the Apollo Program, then this may make sense. But our expectation is not just government exploration but that a fleet of Starships will allow us to develop government bases even paving the way to settlement. So, a remote, Mars-like setting with just a few simulated astronauts in a small base isn't representative of what we expect with a fleet of large ships. There will be scientific exploration. But the fleet of Starships will rapidly facilitate the establishment of a large base which gets more into development and settlement.

As we look for a place that can engage the public to understand the new era that we are entering and to get excited about our settling down beyond Earth, where should this new type of analog base be located?

To answer that question, we would want to look for where there will regularly be many of the space-interested public. A couple of possibilities present themselves.

Boca Chica has seen large crowds launching test flights ("entertainment guaranteed") although those numbers have gone down significantly since the first launch. But given the very narrow flight corridor north of Cuba, Boca Chica is fine for test flights but not the best for other inclinations. So, will there be crew launched from Boca Chica thereby drawing large crowds? That seems unlikely. And many visitors are drawn locally, and south Texas is not that populated.



Rather, a more interesting location would be in Florida where the highways intersect the Space Coast near Kennedy Space Center. The Network and the Mars Foundation have examined the area and have some ideas of where the analog visitor center would ideally be located. There are some undeveloped properties that would allow the analog center plenty of room to grow into a space-themed park.

Importantly, such a campus should be highly visible to traffic meaning directly off of a major highway carrying tourists going to watch a launch. If our campus had an analog StarHab and InstaBase visible from the side of the road, it would be very attractive to tourists making last-minute decisions to visit.

PHASES OF DEVELOPMENT

We have conceived of a master plan for how the Analog Visitor Center could be developed over time. That plan is, of course, subject to change as circumstances emerge and the speed at which the different phases of development occur will largely be dependent upon funding. One could, for example, even skip to a high phase of development if sufficient funding were provided.

Phase 1 - Minimalist Level

The very first step would be to secure the use of land. It is not necessarily essential to have sufficient money to buy a property outright. Rather, a space supportive philanthropist could purchase the property, make it available for use for a period of time with a minimal lease and then treat the property as a straightforward property investment where the value increases as property prices increase.

At a bare minimum, the property needs to be cleared of brush, road access developed, and basic roadways and parking areas. Groundwork should also include the construction of a Mars yard which could host robotic rover competitions. A storage container could be used to safely store equipment when it is not being used during an event or program.

Immediately, we can conduct events on the campus using our full-scale inflatable InstaBase and Space Fair displays. People could be informed of the events via roadside banner and partnerships with space social media (e.g. YouTube) channels.

Phase 2 - Basic Level

At this level, typical analog activities can begin. A more robust, inflatable InstaBase made from vinyl could be used seasonally for analog missions. A multi-purpose building could host initial research and development work, educational events, and displays. The goal of this level would be to be open daily at a relatively low level while being well staffed with local people during prominent launches. Additionally, during this phase, the Full Self-Reliance (FSR) Project could be conducted such as an intensive Space Agriculture Session (iSAS) and ISRU demonstrations using Mars-equivalent inputs.

Phase 3 - Advanced Level

Should funding and regular staffing be secured, we can consider further growing the AVC to include one or more specialty habs that can be used by different analog teams to develop and demonstrate various projects. An intensive summer session could, for example, demonstrate growing full nutrition. Alternately, fabricators could use a specialty hab to demonstrate the production of plastic or metal parts to demonstrate how, for example, most of the mass of a refrigerator could be produced locally while using only a small portion of the mass in the form of more complex metal parts shipped from Earth.

It is also at this level that daily tourist visits would become possible.

Phase 4 - Theme Park

Whether we make it to this level or not, it doesn't hurt to have an ultimate vision in mind. If Kennedy Space Center becomes an operational spaceport with historic, crewed missions launching to the Moon and Mars, the general public may become very interested in the future of space development. Tourists traveling between Orlando and the Cape may like to visit a facility that provides future-looking experiences in the form of a space-related theme park. For the fun of it, let's call it "SpaceWorld". One could easily imagine opportunities to tour an analog base and watch as uniform staff demonstrate daily processes conducted at the actual bases on the Moon and Mars. Kids will, of course, love to ride in crew rovers over simulated terrain. Perhaps one could suit up, enter a dark dome with regolith floor, be connected to black tethers off-setting 5/6ths of one's weight and listen to Mission Control while having a very realistic experience of being on the Moon. It seems that it would be very easy to imagine any number of educational and entertaining experiences at SpaceWorld.

FUNDING

The AVC will start out small, requiring modest funding but, as it demonstrates interest and revenue, could grow as funding allows.

Property

It all begins with the property. If we were to be in a very rural location, we could probably arrange with the Bureau of Land Management to secure the use of land very cheaply. But near Titusville, FL, our thinking is that the more likely scenario would be that a space-interested philanthropist could secure some undeveloped property and lease it for our use on favorable terms. As property prices naturally increase over time, so would their investment.

Volunteers & Space Advocate Organization Partnerships

Local volunteers (often retirees) could help run operations when there were events thereby greatly reducing staffing expenses especially in the early years. Also, several of the large space advocate organizations do not have their own analog base. Arrangements could be made to allow these different organizations to schedule use of the facilities in exchange for budgetary funding.

Philanthropic Financing

By promoting a realistic but positive view of the future and by offering space-related educational opportunities, we believe that the AVC will appeal to certain space-interested philanthropists. It is tempting to write up a business plan and look to the profit motive to grow the AVC. Although the next two paragraphs fit within this framework, most analog bases don't use this approach but rather relied on philanthropic funding to start and utilization fees to conduct operations. We shouldn't focus only on the commercial approach while ignoring the tried-and-true avenue of philanthropic funding, especially for a project that can appeal to those sources. Philanthropists tend to want to donate to physical things that have lasting value. Fortunately, there are a lot of facilities and individual objects (e.g. telerobots, plastic-making chemistry sets, etc.) that could be funded at different levels.

Utilization Fees

As the AVC develops a setting that begins to look like an actual Moon-Mars base, it will become attractive for use by analog teams. It is customary for analog bases to largely fund their operations by charging small teams to utilize the facilities. Likewise, larger university teams conducting intensive sessions would be charged a utilization fee thereby helping the facility's budget.

Events

Events associated with schools or launches could have a fair-like setting where large crowds are milling about the campus and workers are serving the crowd. In this setting there are many opportunities to generate revenue including: entrance fees, concessions, advanced experiences (e.g. VR), and background replace photos/videos. In the ultimate vision (theme park) entrance fees would form the foundation for revenue.

Public Relations

We have identified many activities that would get positive PR exposure thereby drawing attention to the AVC and making fundraising more likely. These activities could include things such as: A timelapse video of the inflation of the InstaBase. Journalistic tours of the campus. Interviews by space YouTube channels. Reports from (launch) events. Reports of simulations and rover competitions. Etc.

THE EARTH INDEPENDENCE PROJECT

The main purpose of the AVC is to illustrate and demonstrate what a development and settlement-oriented lunar and Martian base might look like. However, an important side project would be to illustrate how a small base could potentially become increasingly or even entirely Earth independent. This means using analog resources of the Moon or Mars to produce materials needed at a growing base. By producing material (e.g. plastics or metals) and then fabricating parts (e.g. a desk made mostly out of plastic), one could help reduce shipping costs or alternatively increase the number of passengers arriving or even figure out how to become fully self-reliant.

Although not discussed in this book, the Space Development Network has developed a concept for how full self-reliance (FSR) could be demonstrated in the analog setting using only Mars-equivalent resources. This would use a first principles approach (what exactly is needed to achieve FSR?) rather than reasoning from analogy (cities on Earth survive therefore we need a city on Mars to survive). We believe that a small team could produce materials, equipment, and even habitats to grow their habitats at the rate equivalent to the natural growth rate.

GETTING INVOLVED

Would you like to play a role in helping to establish the AVC? You don't have to live anywhere near Florida to help. First, please join the Space Development Network and specify your interests. Importantly, please be proactive in this process. Choose an area that you can help and reach out to us. Space advocates of any level of knowledge, training, and skill can help move the ball forward. Thanks!

ADDENDUM

41 – Animals on the Moon

SUMMARY

This chapter describes the different categories of animals that we can expect to show upon the Moon. It starts with a female dog that will have the first, off-Earth puppy (what joy!). There will also be a set of experimental animals that will be used to determine the AGRx for healthy gestation and childhood. Finally, as international astronauts start arriving, they can bring animals unique to their country to add to a growing zoo.

Animals will play several different roles when it comes to space development and settlement. The following write-up describes what we can now imagine.

PET ANIMALS

Rover? FIDO?

In the chapter regarding the Initial Permanent Crew, it is described that one of the crew (and probably the most popular crew member) could be a female dog. It could have its own space suit with helmet and little oxygen tank. Let loose, it would be able to run freely on the surface of the Moon and could even be trained to conduct back flips in the Moon's 1/6th gravity.

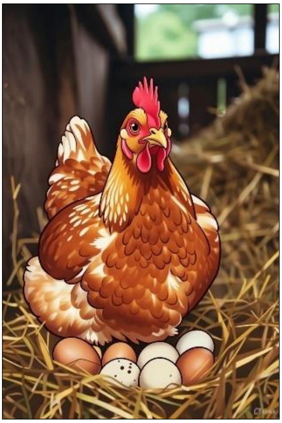
And it wouldn't be long before that dog's mate would be brought up on a following cargo mission. And we all can imagine what a dog and its mate leads to -- puppies! These initial dogs would generate a tremendous amount of attention and excitement by the many dog lovers on Earth.

During the private settler phases, some may be so attached to their pets that it would be necessary for them to be able to bring their pets else they will refuse to move to the Moon. We now live in the era where service pets are allowed to go where only people had previously been allowed to go. This has increased the acceptance of pets living within human society.

FOOD ANIMALS

The consensus of our Agriculture Working Group (AgWG) is that initial food grown would be strictly from plants and not from animals due to the crew time that would be consumed maintaining the system for the animals. But as the population of the base gets into the hundreds, certain animals could start to be grown for food. Given that practically all societies on Earth eat animals, it seems most likely that this practice will continue as people from around the world start moving beyond Earth.

Very early on, just a few types of animals that would provide food for the crew. Initially, fish in a fish tanks fed by algae would be the easiest form of meat possible. Chickens and rabbits will also be early animals for food. The AgWG excluded insects as food because of the "ick factor". It is rather important that we not scare the public from wanting to become settlers. It is inevitable that the media will highlight any idea that you will have to eat insects if you want to be part of the first off-Earth settlements.



Chickens for early protein food.

Waste from the hydroponic greenhouse could be fed to herbivorous fish which could then be eaten by the crew. Likewise, chickens could be an early farm animal -- not so much for their meat but for their eggs. Larger livestock such as cows would come much later after habitats large enough and systems sophisticated enough could deal with them.

Feed

A major consideration for animals would be just how much more food would need to be produced, especially for carnivores such as cats. Certainly, the fish could serve as a source of food for the animals. The good news is that the animals could be smaller than people (e.g. a small dog breed) and so only a portion of caloric intake compared to each human. But, as the number of animals increases there would need to be dedicated FeedHabs and the systems to power them.

MORE ANIMALS

Some additional animals could be periodically brought to the Initial Base to help keep the public's attention on the going ons. Consider how much interest there would be when a finger monkey first arrives wearing his own little jumpsuit with a NASA logo on it! But early on, the number of animals brought in might be limited due to the amount of time it would take for the Initial Crew to care for them except that teleroperated or autonomous robots could offload much of that work.

The finger monkey

International Animals

During the International Lunar Exploration Phase (ILEP), as international explorers arrive, some of them could contribute unique animals from their countries to a growing lunar zoo. The arrival of such animals could well interest the public not only from the country's citizens but from animal lovers worldwide. Some of the animals could be a surprise in that very few would know which animal was going to arrive until it actually did.

BarnHab

Eventually it could be possible to have meat animals such as beef and pigs in habitats specifically designed for them -- a "BarnHab". A pretty good case could be made that modern approaches would make the growing of meat unnecessary because it is inefficient compared to alternatives. The Impossible Burger and Beyond Meat are examples of meat alternatives which are becoming increasingly popular.

ANIMALS FOR REPRODUCTION STUDIES

Chapter 24 describes the use of artificial gravity to determine the artificial gravity prescription (AGRx) for healthy gestation, childhood, and adulthood. For the first two, there would need to be a series of animal studies to generate some data that would inform would-be parents about what effects the reduced gravity would have on their child and how much artificial gravity might be necessary for a good outcome.

As described in the chapter, the set of animals may be: mice, hamsters, marmosets, and finally macaque monkeys. The Biologist would be the main crew member caring for and handling these animals. If the AGRx studies indicate that it would require an unreasonable amount of artificial gravity to have good health outcome then, disappointedly, the settlement couldn't have children. It wouldn't necessarily mean the end of the settlement as there are many (retirement) communities on Earth that don't have children. But in those settings, it may be that pets may provide some of the activity and dependency that children would normally provide.

PRESERVING AND REPRODUCING EARTH'S BIOSPHERE

An Animal Preserve

The BioPreserve is a concept for the backing up of Earth's biosphere in the form of species frozen in their most reproducible forms (e.g. spores, seeds, embryos, etc.). This seems fine until we get to the mammals. Mammals need mothers to carry them during pregnancy. There are only 5,416 different mammal species. A lunar mammalian zoo is discussed here including how the emerging level of reproductive technology (e.g. artificial wombs in centrifuges) could prevent the need to maintain a mammalian zoo and all of the effort it would take.

Paraterraformed Fauna

The very long-term, goal for space advocates would be to fully reproduce Earth's biosphere off Earth. This could be done more quickly using the paraterraforming approach (i.e. large greenhouses) as compared to the full terraforming approach (i.e. open-air approach). In the paraterraforming approach, one would need to figure out how the ecology of different species would work to create stable relationships between them. This is no easy task as the Biosphere 2 project demonstrated. But it is eventually doable.

42 – Preserving Artifacts and the Environment

SUMMARY

Along with the roads chapter, this chapter discusses the need to preserve the lunar landscape by keeping vehicular tracks on roads. Also, new artifacts such as the first exploratory footprints at unique sites deserve to be preserved. How this can be done while allowing later tourist visits is discussed.

Preserving Historic Sites

There is some good work being done by Michelle Hanlon (For All Moonkind) and others seeking to preserve historic artifacts on the Moon. This includes things such as the Apollo landing craft, Soviet landers and rovers, footprints, etc. The Space Development Network joins the many others who support this work.

Various efforts are being made to ensure that the historic artifacts will be preserved for future generations. Ultimately, the goal is to achieve an internationally recognized agreement whereby the historic sites are preserved from damage by the curious who would like to take a little "souvenir" for home.

Landing Blast

As a lunar lander comes down, its exhaust velocity exceeds orbital speed at kilometers per second. The lunar dust is very fine grain such that each landing essentially sandblasts the local area. It is generally felt that vehicles should not land closer than two kilometers from important artifacts lest those artifacts get covered by a layer of dust and in the case of boot prints, go away completely. Telerobots could create sintered (microwaved) landing pads which could help but two kilometers is not too far for visitors to travel by rover after landing.

The Environment

Whereas there is likely no life that needs protection on the surface of the Moon, there is an environment. For example, later visitors might be disappointed to find a landscape covered with rover tracks. Tracks and boot prints on the Moon will remain visible (even pristine) for a very long time. Yet there are historic (e.g. first) tracks and boot prints that would be considered historic as they tell an important tale. What to do to protect these important artifacts?

Making roads to prevent permanent tire tracks everywhere.

A Network of Roads

Keeping the lunar landscape free from a lot of rover tracks is possible using two approaches. The first would be to create a network of roads between locations likely to be those most highly visited. From a preservation standpoint, keeping vehicles confined to roads will be the key to ensuring that the environment isn't defaced with tire tracks going every which way.

Chapter 10 goes into some depth as to how those roads could be made. But in a nutshell, a set of electric RoadBots could smooth out and compact the regolith so that crew and cargo vehicles could drive over them at fairly high speeds allowing for transport from poles to equator in about three days. Groups of RoadBots would follow a pre-determined, low-slope path, deviate as necessary, fill in small craters, rake out rocks, level with a blade, and firmly compact the regolith to ensure a gentle, very smooth, dirt road. Operating 24/7 the groups of RoadBots could complete even long-distance, compacted dirt roads in less than a year.

Stick Walkers

After visitors drive along the road network close to a site that they want to visit, they may wish to leave the road and travel to a new site. So, should the rovers just drive off the road thereby permanently leaving permanent track marks across the landscape?

It is proposed that the crew vehicle pull up to another chassis that, instead of having wheels, it would have six vertical poles what would act as legs. The poles would press vertically down into the lunar dirt for each step. In this way, nearly invisible holes would be pressed into the ground thereby leaving behind little if any track marks. It would definitely be slower than driving on circular wheels, but this approach would preserve the environment.

Protecting Artifacts / Sites

As private individuals land on the Moon and conduct their own tourism in large numbers, systems will need to be set into place to ensure that historically sensitive sites are protected. An internationally agreed system needs to be established to decide what qualifies as heritage sites to be registered and protected.

Sites of interest need to be developed including roads leading to overlooking platforms and walkways. At those locations, there could also be visitor centers with large windows that would allow tourists a relaxed indoor environment to enjoy the view.

Additionally, physical systems need to be put in place to ensure that these space heritage sites are protected from a practical standpoint. Should there be markers, fences, or even robotic protectors and what would that even look like? So, there is more work to be done to ensure that our space heritage is protected.

Potentially Many Artifacts

Currently there are a few recognizable artifacts on the Moon from landers to rovers to impact sites. But, as cost-effective, commercial transportation systems become operational between the Earth and the Moon, then many countries of the world could afford to purchase at least one seat on a mission of lunar exploration. Given the decent number of countries that have had their own astronauts on the Mir or ISS, it seems likely that most countries would take advantage of such an opportunity.

Each time astronauts from a new country land on the Moon, they would be creating artifacts in the form of their boot prints of great interest to later visitors from that country. It would seem a pity if later visitors would deface that historic record. So, what could be done to preserve those many historic features?

Whenever a lander first lands at a new location, it would sandblast an otherwise undisturbed area. But dust being blown on dusty terrain wouldn't change the appearance substantially apart from the immediate blast pattern. But, as the astronauts exit the lander, they will be placing their historic, first boot prints on the ground and towards the destination site. As they get back into the lander and ascend, the blast would destroy their historic boot prints. Yet, an accompanying small telerobotic rover could place little plastic domes over their footprints, thereby ensuring their preservation when the lander takes off again. Later visitors could land on a landing pad away from those historic boot prints and then ride on walking stick chassis to the point of interest as well as to an area overlooking the prints and tracks of the first explorers to that point.

Why the Moon?

The Moon is no longer a distant symbol of exploration – it is a near-term strategic domain in which American leadership, or its absence, will shape the future of space.

For more than half a century, the Moon has been treated as a destination for flags and footprints rather than as the foundation for sustained presence beyond Earth. That assumption is now outdated. Advances in launch capability have quietly transformed what is technically and economically feasible withing the coming years.

In this book, *The Case for the Moon* argues that establishing permanent lunar bases—and ultimately settlements—is not a speculative ambition but a practical policy choice. Drawing on current engineering realities and emerging commercial capabilities, the book outlines how a sustained lunar presence can strengthen America's strategic preeminence creating the setting where the nations of the world will want to follow America's lead in exploring the Moon while establishing humanity's first permanent foothold beyond Earth.

Rather than treating the Moon as an end in itself, the book examines it as infrastructure: a place to develop operational experience, mature off-Earth resource utilization, build resilient space logistics, and develop the framework whereby the values that America promotes will become the values that spread beyond Earth.

Written for policymakers, strategists, and informed citizens, *The Case for the Moon* provides a clear case for why the question is no longer whether the Moon should be developed, but how soon and under what rules. Decisions made in the near term will shape humanity's presence in space for generations.

Doug Plata, MD, MPH is a physician and space advocate in Redlands, CA with a background in biophysics, Family and Preventive Medicine. Doug brings a keen eye to the subject of lunar development starting with the technical foundation and building up to include its impact on the public, international leadership, and ultimately, humanity's future in space.

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