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Starting and Growing Lunar Settlements

USC ASTE 523, Spring 2023

Design of Low-Cost Space Missions

A Near-Term, Income-Generating, Lunar Settlement

Part 5

Living on the Moon in the next decade

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Topics

- The goal – Creating Near-Term, Low-Cost Lunar Settlements
- Objectives
- Getting Started
  - On the Earth
  - On the Moon
- Who are the First People on the Moon
- Real Estate Development – the first Business on the Moon
- Subsequent Development Phases
  - Creating Income and Reducing Cost
  - Spreading Cost Among Multiple Groups
- How Does the Lunar Population Grow with Time?

Settling the Moon is no different than settling California or Alaska, only a bit easier because there is constant communications and resupply. It's not a "techie" activity. It's a people and business activity—with a mix of entrepreneurs, service workers, engineers, scientists, explorers, and very busy Maytag repairmen.

How do we get started?

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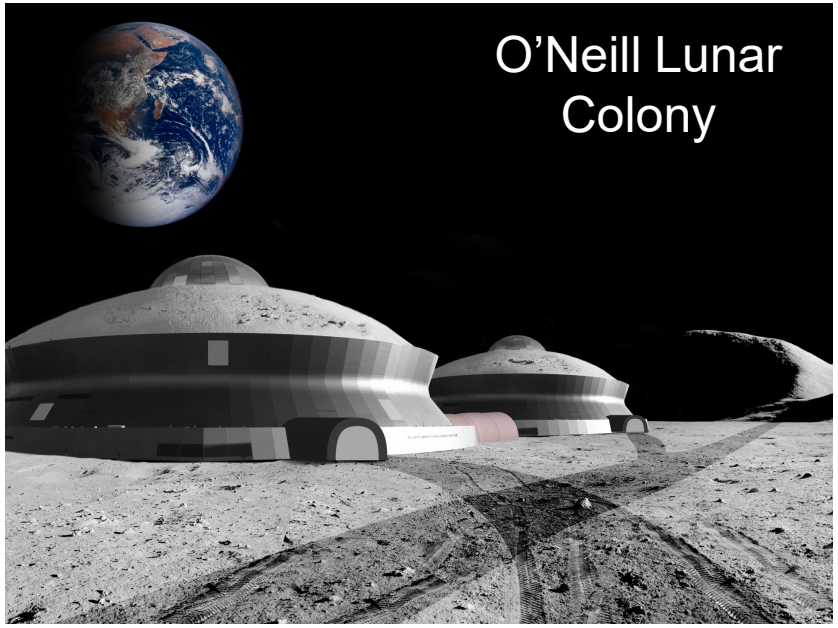
The O'Neill Lunar Colony – Dramatically Reduce the Size of an O'Neill Space Colony and Move It to Surface of the Moon



- 2 domes for 1,000 people, each with twice the area of a 100,000-person stadium
- Excellent living conditions for an extended stay in 1/6th g
- Nearly all the raw materials are already on the Moon
- Can do most of the work inside, rather than outside
- Can use everyday commercial equipment brought from Earth
- Many sources of *external income* from work not required to support the colonists
  - ^{3}He for Earth
  - Entertainment/Sports
  - Space Tourism
  - Co-branding
  - Space Burial
  - Many more

An interesting idea, but how do we do it and what are the risks?

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What Are the O'Neill Lunar Colony Objectives?

1. **Near Term**
   - Want to start work on the Colony today
   - Want to start building it within 3-4 years
   - Want income generation to start as soon as we start building it (or possibly sooner)
   - Want a full-scale Colony on the rim of Copernicus within 10 to 15 years
2. **Low Cost**
   - Estimate for a 1,000-person lunar colony: $3B to create, $13B to get to the Moon over several years, and $2B/yr to support, with no more than 10% from one company or country
   - Will work very hard to drive down cost. May not meet the objective above, but I expect that we can come close
   - Will work from the outset in an "industrial" mode – finding the right balance in what we undertake and doing it quickly, safely, and at low cost, but not "optimally"

We want to build on the remarkable work that NASA and the space community (US and international) have done over 50 years and create a robust environment for human expansion to the Moon to benefit all of us, and particularly those who help to do it.

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O'Neill Lunar Colony Objectives – 2

3. **Low Risk**
   - **Low technical risk – using primarily existing technology, most of it inside the colony**
   - **Low risk to people – Most of the work is done inside with everyday equipment and multiple safety backups available**
   - **Low to moderate financial risk – High profit margins with 20+ ways to generate income**
4. **High Income – even as we start out**
   - **Intended specifically as a business that generates income from the start and grows rapidly over time**
   - **Estimated income at the outset = $10B/year (minimal profit at the start)**
   - **Estimated income when we're up and running = $100B/year with lots of profit for lots of companies and individuals**
   - **Some businesses will make money, some will not. (If McDonald's fails, Burger King takes over that slot)**

These are good objectives. The real question is how do we achieve them? Perhaps most important, how do we get started?

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Steps in Getting Started

- Create a detailed economic and physical model -- starting this semester
  - The goal is not to follow it, but to show what is possible and what the principal alternatives are
- A "real estate developer" begins creating real estate on the Moon
  - Build a small lunar colony which serves as the base for creating a larger one and as a "safe haven" for the next larger colony
  - Begin to need regulations at this point to avoid price gouging
- Create a Lunar Government
  - Need zoning ordinances, regulation of utilities and prices, and safety regulations
- "Lunar Air, Water, and Electric Corp." starts building the utilities infrastructure
- Begin development of the settlements themselves
  - Properties within the settlement are bought and built by governments, companies, and individuals within the limits of local zoning restrictions
  - Businesses develop to satisfy unmet needs, within regulations

Settling the Moon is no different than settling California or Alaska, only a bit easier because there is constant communications and resupply. It's not a "techie" activity. It's a people and business activity—with a mix of entrepreneurs, service workers, engineers, scientists, explorers, and very busy Maytag repairmen.

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Getting Underway – On the Earth

I'm convinced that Graduate Students are a key to making lunar settlements work.

- Create the USC Near-Term Lunar Settlement Research Group (N-TLSRG)
  - Want to start by the end of Spring Break
    - Will ask whether USC is supportive within the next two weeks
  - Want an inclusive organization that can look for multi-element solutions
  - The biggest single objective is to find ways to make money from the outset
- Representative research topic areas
  - Economics – build an economic model of cost vs. income
  - Law – Is it legal to own and sell lunar property or materials?
  - Marketing – How do I sell lunar sports, tourism, products, and sex on the Moon?
  - Business – Create a business case for multiple lunar businesses
  - Real Estate Development – How do we build and sell or lease lunar settlements?
  - Government – How do we create and set up a lunar government
  - Architecture – How do we design a lunar settlement with all of these businesses
  - Gravitational Biology – Plants, animals, and humans in 0 g, 1/6th g (Moon), 0.4 g (Mars), 0.6 g, 1 g, 1.2 g, 1.5 g and the gravitational biology wheel
  - Education – teaching students of all ages about the Moon
  - Sports and Entertainment – What are the major activities to generate income?
  - Science and Exploration – Tremendous potential for long term growth

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Getting Underway – On the Moon

- We anticipate that the first active lunar company will be a for-profit Real Estate Developer (RED)
  - Will build the first lunar colonies and then sell, lease, or rent the real estate that was created to business, governments, or individuals
  - Process begins by delivering all of the material and then the people to put it together – assembly process not automated
    - Serves as a test of the lunar delivery process
- First products (before the colony is complete, or even started) are O_2 sent to LEO to dramatically reduce the cost of subsequent flights and water for use on the Moon
  - Plants for growing food on the Moon will start quickly
- First small colonies (2 for safety) will be a "House" for people to live in and a "Garage" for working in
  - Could be inflatables or could be built on the Moon out of aluminum
  - Likely sold, leased, or rented before they're built
- The House will be about 100 m in diameter (85,000 ft^2) and 10 m high; the garage will be smaller; CisLune will build a small landing pad on the regolith
- Probably located where power is available and water has been found near the pole

The first people on the Moon will be builders and business start-ups, getting stuff set up and getting underway on things the colony needs or that make a profit.

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Who Are the First People on the Moon?

- Quite a few folks living in the rocket that delivered them
  - Lousy living and working conditions and long hours
- Who are the first folks on the Moon
  - Construction workers – building the first small settlement and then the stuff inside that settlement
  - Structural, mining, and manufacturing engineer
  - Comm engineer – Making sure everybody and everything is always connected
  - Medical personnel and scientists – Begin monitoring everybody's health and, of course, handling any medical problems
  - Physical trainer -- Provide the right training to keep people in shape
  - Farmer and cook – Begin growing and experimenting with raising and cooking food on the Moon
  - Gravitational biologist – likely graduate students beginning to look at how plants, animals, and people are influenced by 1/6th g
  - Facility manager – Decision making for the whole process
  - TV Reporter – Recording and broadcasting what the Moon is like
  - Entrepreneur – selling oxygen, water, and products for Earth and Moon
  - Tourists – who wants to be the first tourist on the Moon?

We need to generate both income and popular interest in what the Moon is like.

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Real Estate Development – How Do We Get Started on the Moon?

- On the Moon – we anticipate that the first active lunar company will be a for-profit Real Estate Developer (RED)
  - Will build the first lunar colonies and then sell, lease, or rent the real estate that was created to business, governments, or individuals
    - These transactions likely will be done well before the settlement is built
  - First products (before the colony is complete, or even started) are O_2 sent to LEO to dramatically reduce the cost of subsequent flights and water for use on the Moon – plants for growing food on the Moon will start quickly
  - First small colonies (2 for safety) will be a "House" for people to live in and a "Garage" for working in
  - The House will be about 100 m in diameter (85,000 ft^2) and 10 m high; the garage will be smaller; CisLune will build a small landing pad on the regolith
  - Probably located near the pole where water and nearly continuous solar power are, but may be elsewhere depending on an analysis of need vs. cost
- Real Estate Development then proceeds to build more small colonies and, of course, larger ones as they are needed
  - How do we allow enough land ownership to create settlements, without granting a monopoly on owning the Moon?

The first people on the Moon will be builders and business start-ups, getting stuff set up and getting underway on things the colony needs or that make a profit. There may be a few tourists and graduate student researchers as well.

Development Phases and External Income (Income not Associated with Living on the Moon)

- Once first settlements are built, initial external income is estimated to be in the range of $10B to $35B per year, rising quickly to $100B to $800B
- However, settlements will generate income even before the first settlement is built, depending on the Phase of Development:

Phase 0: Planning only; no work being done on the Moon; some income available

Phase 1: Lunar start-up; setting up small initial settlement to begin work on the Moon

- 2 settlements (for safety) adjacent to water and power sources near the pole
- 1 settlement for living, 1 "garage" for working, building, and repair
- Beginning low level of commercial activity – tourists, ^3He, O_2 for travel

Phase 2: Initial development small settlements in multiple locations

- Tycho facility for lunar burial
- Start of substantial services for Earth (^3He, mining, diplomats, science, tourism); building the large settlements at Copernicus and elsewhere

Phase 3: Large settlements up and running, 2 or 3 on the rim of Copernicus

We don't want to ignore science or exploration, but the first activity on the Moon is to start businesses that serve basic objectives on the Moon and on the Earth.

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Initial Annual External Income in Phases 1-3 (Income not Associated with Living on the Moon)

- **Some external income will be created even before the first colony is built**
  - **Initial external income is estimated to be in the range of $10B to $35B per year**

Source	How sold	Basis	Pre-Sale*	Amount
Tourism	"In-House" stay	6 tourists/mo @$4M each	Yes	$0.3B
Space Burial	Collect on Earth	10K@$5K to $20K	Yes	$0.05–$0.2B
Helium-3	Per ton	0.5–2 toms/yr @ $3B/ton	No	$1.5B–$6B
Diplomats	No paid activity		No	
Entertainment	Various	Various	Yes	$0.2B
Mining	Experimental	Varying experiments	Yes	$0.1B–0.3B
Science	Lunar Grav Biology Wheel	$0.5B–$2.0B	Yes	$0.5B–$2.0B
Solar System Exploration	Per mission		No	
Solar power satellites	Per satellite	$8.5B each	No	
Knowledge preservation	Per GB	In set-up phase	No	
Manufacturing	Per sq ft	Infrastructure building	Yes	$2B–$5B
Co-branding	Various	Various	Yes	$5B–$20B
Initial Yearly External Income				**$9.6B–$35B**

* Pre-sale are those products for which some income is available even before the product is built or used.

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More on Getting Underway

- After getting the small polar settlement up and running, the next step in construction is likely a nearly identical small settlement near the first set or near the crater Copernicus where the first full-size settlement will be
  - We want to start building the large O'Neill Lunar settlement as soon as possible
    - We also want a small facility at the crater Kepler to begin to prepare for space burial
  - We also want to proceed promptly with projects that will either reduce cost or make money
- Reducing Cost
  - Food for the colonists
  - Nitrogen for the atmosphere
- Making money
  - Looking for ^{3}He in the lunar regolith
  - Begin tourism as soon as possible – essentially immediately

Main question to think about: What else can we do on the Moon that can begin to generate immediate income?

It's important to begin the process of "calling home" on a regular basis to show the world what the Moon is like – preferably in many languages.

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From the Outset, Use Lunar Resources to Reduce Cost

- From the beginning, we want to maximize the use of resources already available on the Moon
  - All construction (except inflatables) done with local materials
    - Metal and glass for structure (weight and strength are not a problem)
    - Soil (after valuable components removed) for insulation and shielding
  - Oxygen and water from the Moon
  - Silicon for solar cells for power generation (or ^{3}He)
- Food production should be done on the Moon as soon as possible
  - Carbon and nitrogen have to come from Earth
  - Lunar manufacturing should be limited to simple, structural products where the mass of the products far exceeds the mass of the equipment to produce it
- Recycling is "In" on the Moon — either fix it, recycle it, use it for something else, or melt it down and start over
  - Additive manufacturing is in vogue today – on the Moon it is most likely to enable the local construction of spare parts which will help reduce the cost of maintenance and repair

Nearly all of the heavy items required for colonization can be mined or built on the Moon.

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Also from the outset, Use of COTS Products is a Major Cost Saver

- **Stuff from Earth is nearly all biological material or manufactured goods**
  - Seeds, computers, voltmeters, iPhones, power tools, LCD TVs, bicycles, clothes, and spare parts
- **Nearly all products used inside can be COTS products direct from Earth**
  - Most manufacturing & construction done inside with normal COTS tools
  - Most electric or mechanical products should work well as built
  - Transportation via bicycles, electric carts, or electric cars (no gasoline)
- **Products for use outside can be COTS products modified for operation in a vacuum environment with lots of dust**
  - Transportation, lifting, and hauling equipment can be light-weight commercial electric vehicles or standard vehicles refitted for electric operation
  - Could explore use of underwater equipment for use on the lunar surface
  - Peopleware for outside is an interesting issue that should be explored
- **Heavy rental business for tourists, visitors, and film makers**
  - Could rent cameras and clothes to tourists
  - Rent professional broadcast equipment to event sponsors
  - If someone brings new equipment, buy it from them for later use by others

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Spreading the Cost Among Multiple Groups

- What did it cost to settle and run California?
  - No one knows, and, in the end, no one cares
  - Hundreds of people, companies, and governments each with their own motives
  - Some made money, others did not
- Similarly, we should not regard lunar settlement as a single project to be funded by "somebody," but as an independent series of related activities
- Governments
  - Diplomatic outposts, exploration, colonization, science, prestige
- Corporations
  - Profit making from virtually any of the activities
    - Example: Building the colonies creates real estate which is then sold, leased, or rented, just like land on Manhattan
  - Advertising and prestige ("Universal Pizza," "Out-of-this-World Lunar Burgers")
- Individuals
  - Tourism, Investment, exploration, and entrepreneurship

Profit and prestige are among the driving motives. Therefore, we may need rules to limit investment, such that no one country or organization gains a monopoly.

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Reducing Ground Operations Cost and Creating Rules and Regulations

Relatively easy to reduce ground operations cost — eliminate it completely.
Sadly, people will still need to meet local rules and home office rules.

- Settlements govern themselves (the people on the Moon likely wouldn't allow any alternative)
  - The settlement makes and enforces rules and regulations, many of which will concern health and safety in a small, closed life-support system
  - Will almost certainly levy taxes for public works
- Independent transportation systems operate under their own regulations, those of their government, and any imposed by the lunar government (just like airlines do)
- Diplomats and government employees operate under control of their own government, just as they do in foreign countries
- Corporate employees operate under their own corporate and management rules
- Individuals are free to do as they like in their free time, although most won't have a lot of free time to do it in—stuff is expensive on the Moon, and you will have to work hard to live there

There are plenty of part-time bureaucrats on the Moon, so, unfortunately, we can expect all of the inefficiencies of any other small metropolis.

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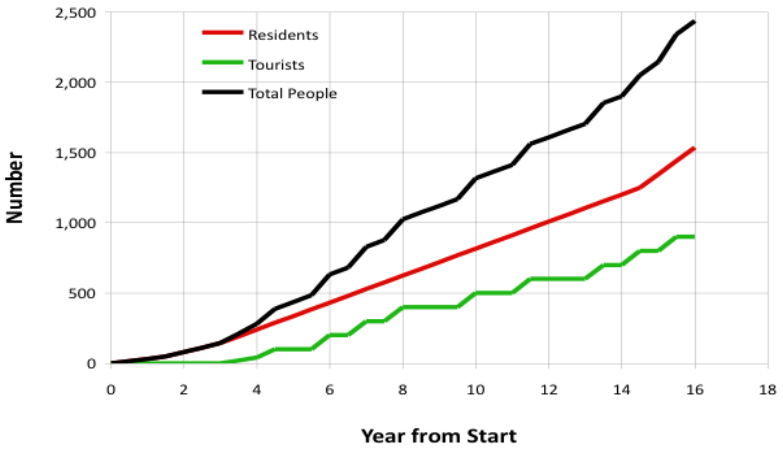
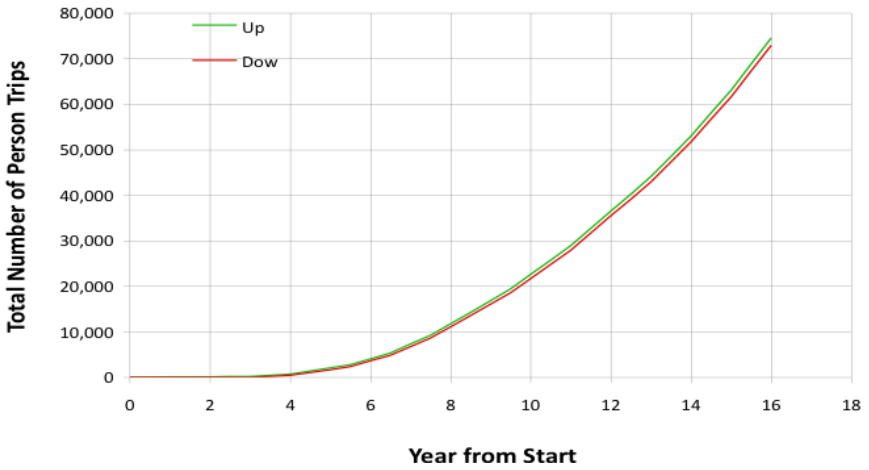
How Does the Lunar Settlement Population Grow with Time?

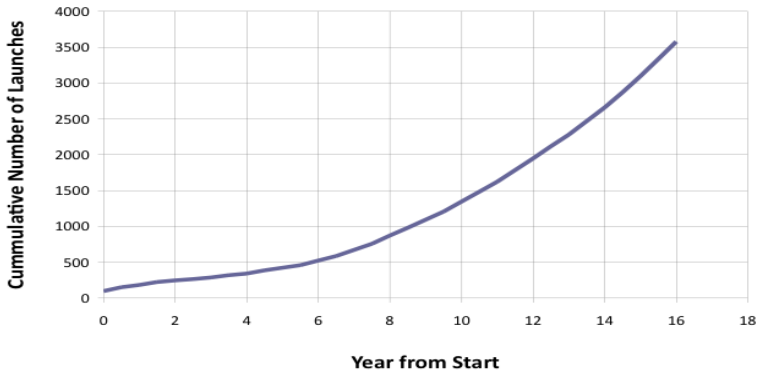
Lunar Population



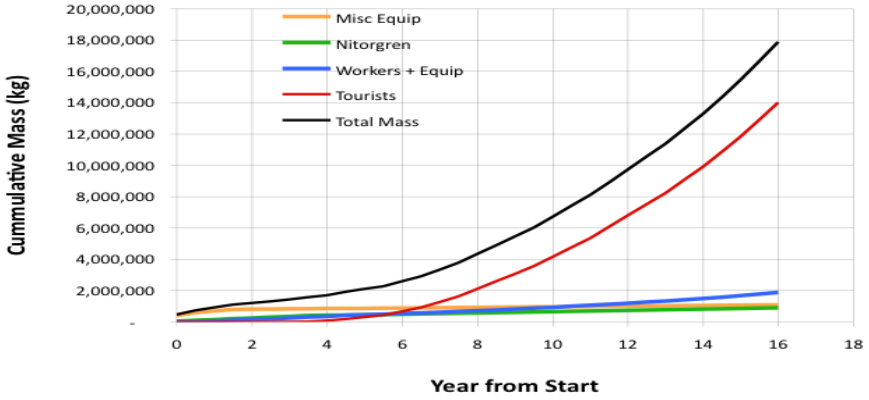
Person Trips to the Moon



Cummulative Launches (At 5,000 kg/launch)



Cummulative Mass to the Moon



The Lunar Settlement(s) reach 1,000 people about 12 years after building begins. We may be able to do it sooner.

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