Cislunar Space: The Next Frontier

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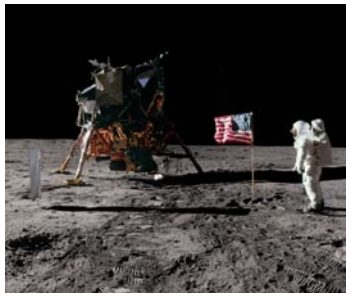
Three Ages of Spaceflight

The "Space Race" Age

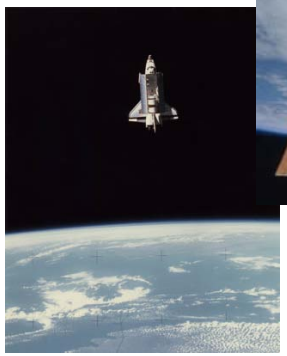
- Racing the Russians
- To the Moon and back
- The Value of Space





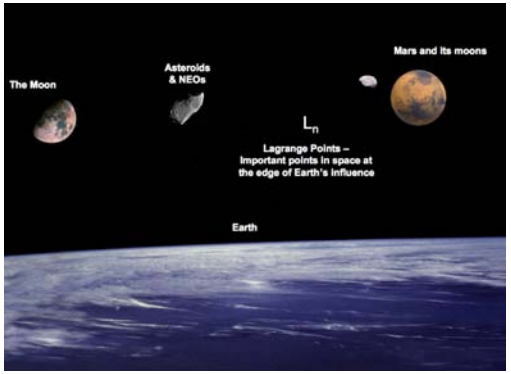
The "What now?" Age

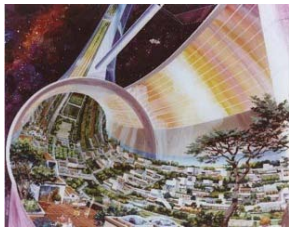
- Space Shuttle: hammer looking for a nail
- ISS: Jumping off platform or dead end?
- Robots or People?



The "Beyond LEO" Age

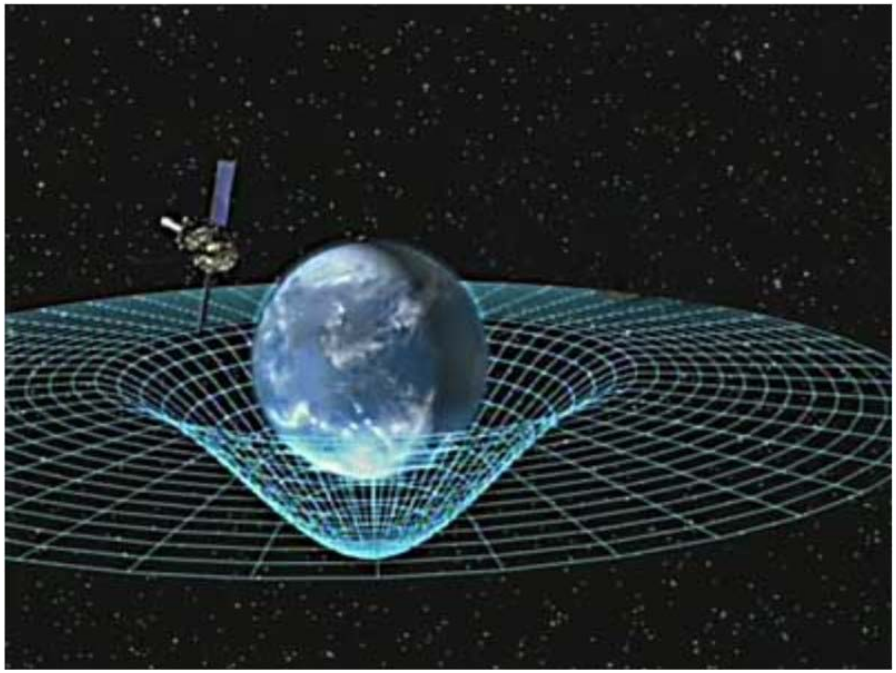
- Destination where?
- Purpose what?
- The New Value of Space



The Problem

- The ultimate goal in space is to go anywhere, anytime with as much capability as we need
- Spacecraft are mass- and power-limited and thus, capability-limited
- They will remain so as long as we are restricted to what can be lifted out of Earth's gravity well
- This restriction negatively impacts scientific capabilities, economic health, and national security



To extend reach and capability, we must learn to use what we find in space to create new space faring capabilities

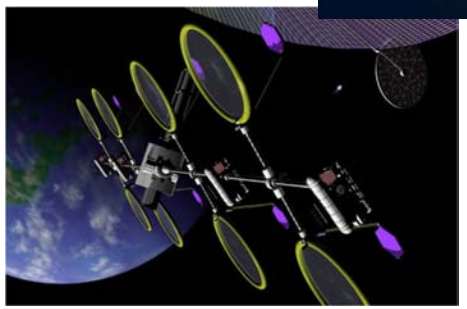
Space faring: Changing the Rules

Current template

- Custom-built, self-contained, mission-specific spacecraft
- Launch on expendable vehicles
- Operate for set lifetime
- Abandon after use
- Repeat, repeat, repeat

New template

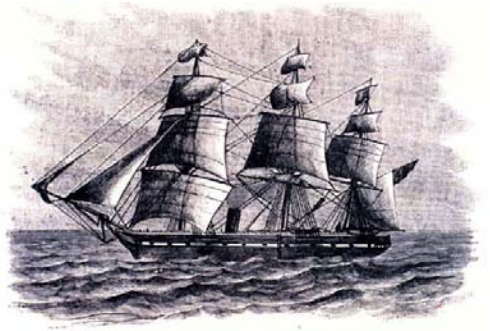
- Incremental, extensible building blocks
- Extract material and energy resources *of* space to use *in* space
- Launch only what cannot be fabricated or built in space
- Build and operate flexible, modular, extensible in-space systems
- Maintain, expand and use indefinitely



What's the value of exploration?

Humans explore because it conveys an evolutionary advantage

- Exploration broadens experience and imagination, permitting better prediction of the future, ensuring better odds for survival
- Curiosity and its satisfaction is intellectually and emotionally satisfying



H.M.S. Challenger preparing to Sound, 1872.

Exploration improves our ability to solve problems

- Increased imagination and knowledge base permits recognition of innovative approaches and solutions
- Helps focus energies on posing the right questions, or, questions that can be addressed and answered

Exploration excites and inspires the creative, productive segment of society

- Permits intellectual connections and relations that might not otherwise occur (the 'ah-ha!' syndrome)
- Inspires effort; attempts to achieve things previously thought to be out of reach
- Frontiers are unknown, mysterious places that stimulate imagination and illustrate new possibilities

Exploration ≠ Science

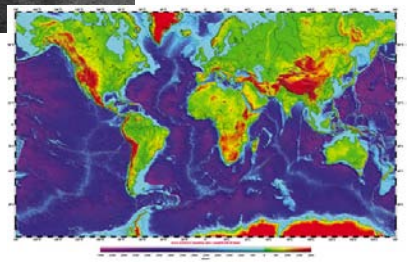
Exploration **is going into the unknown, probing the frontier, looking over the next hill.**

- It has structure, but is not directed
- Discoveries sometimes build on each other, sometimes are isolated

Science **is the process by which we explain nature**

- It has a well-defined, directed structure (observation, hypothesis, experiment, verification)
- Scientific knowledge is cumulative and self-correcting

Both are dynamic, not static. Science accompanies and follows exploration.



Exploration precedes and enables science

Exploration and Science

"Exploration without science is tourism" – A famous NASA Official

Exploration is *broader and richer* than science – knowledge acquisition PLUS:

- Security and asset protection
- Wealth creation
- Settlement and infrastructure development

Exploration *enables* science

- Access to remote locales and exotic environments
- Exploratory infrastructure permits scientific investigation

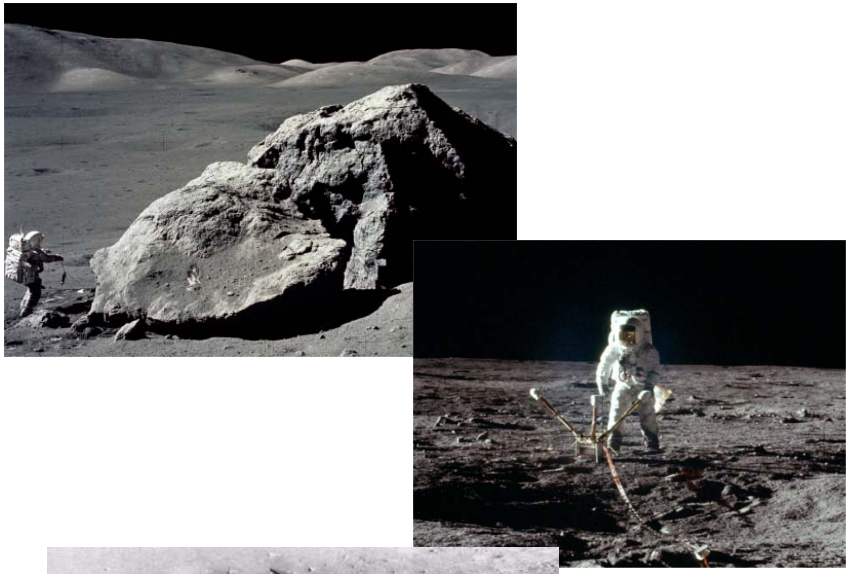
Why Human Spaceflight?

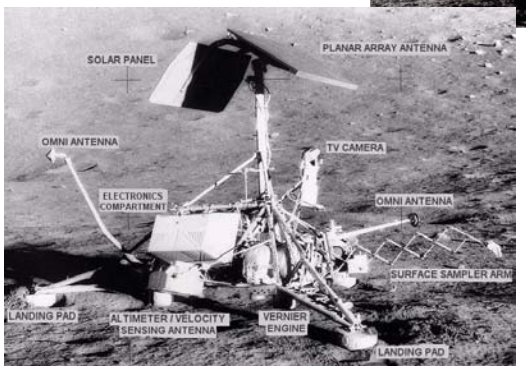
People bring unique capabilities to space exploration

- Intuitive and flexible - recognize problems and improvise solutions
- Repair and maintain complex equipment and installations
- Conduct field science, requiring intense interaction of humans with environment

Machines alone do not and will not possess intelligence of necessary magnitude to explore and utilize space

- Robots are good for remote, hostile environments to provide first-order reconnaissance
- Robots can be designed to answer focused questions (hypothesis testing) or make precision measurements





We don't always know ahead of time what measurements are significant and which are irrelevant

Human Spaceflight

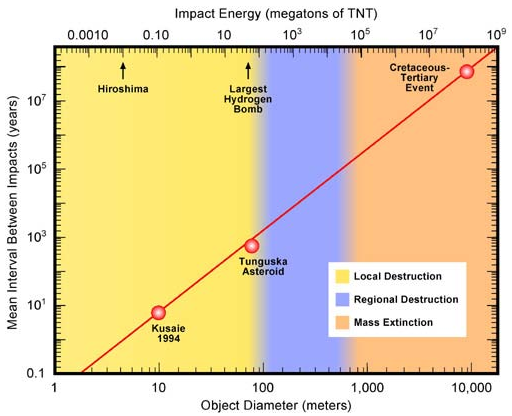
The Ultimate Rationale

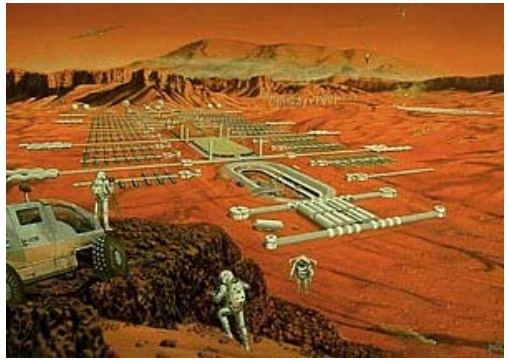
Study of Apollo samples taught us key signs of large-body impact

We now know that large objects collide with Earth on a quasi-regular basis

Not a question of *if*, but *when*

Conclusion: **We're doomed**





Needed: Multiple reservoirs of human culture

A Key Policy Document

Speech by OSTP Director and President's Science Advisor John Marburger at Goddard Symposium, March 15, 2006

Critical Points:

- Ultimate goal is *to use* space for benefit of mankind
- Incorporate Solar System into our economic sphere
- Moon is of unique significance -- closest and most accessible source of materials and energy out of Earth's gravity well
- Development of off-planet resources makes entire Solar System accessible
- Critical architectural consideration: Space exploration budget must grow at low level to be sustainable

Office of Science & Technology Policy
Executive Office of the President

44th Robert H. Goddard Memorial Symposium
Greenbelt, Maryland
March 15
Keynote Address

John Marburger
Director, Office of Science and Technology Policy
Executive Office of the President

It is a privilege for me to speak in this Symposium. My first job as a scientist, before I went on to graduate school, was at Goddard Space Flight Center. I had worked there during the summer of 1961, and returned as a full time employee in what was then called the Thermal Systems branch in the summer of 1962. Goddard was booming in those days, and the challenge of making scientific instruments work in the space

http://www.spaceref.com/news/viewsr.html?pid=19999

What's the Mission?

Common themes from space policy documents:

- Sustainable and affordable program
- Explore with robots *and* humans
- Test bed for systems and procedures on the Moon
- Learn resource utilization on the Moon
- Create new space flight capability

We are going to the Moon to learn the skills we need to live and work productively on another world

What Are These Skills?

Arrive

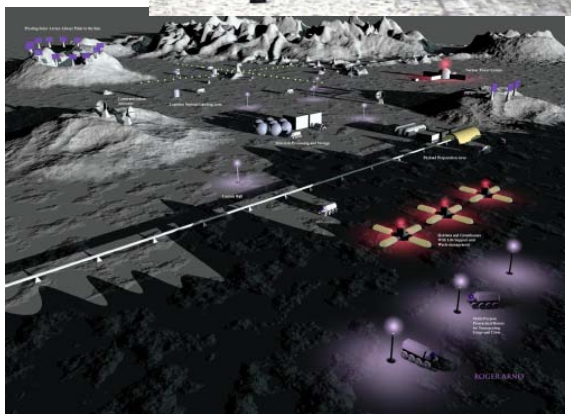
- Create transportation system to take humans to and from the Moon
- Use this system to access cislunar and translunar space

Survive

- Build habitat to safely house human explorers
- Protect from environmental hazards
- Extract consumables from local materials

Thrive

- Create new infrastructure and capabilities by using the material and energy resources of the Moon
- Extend this economic zone first to cislunar, then to translunar space



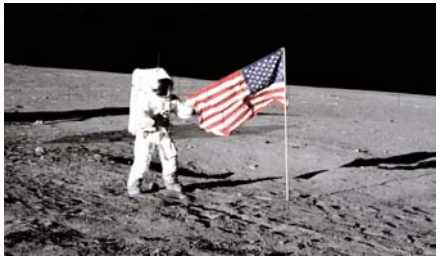
What Kind of Space Program?

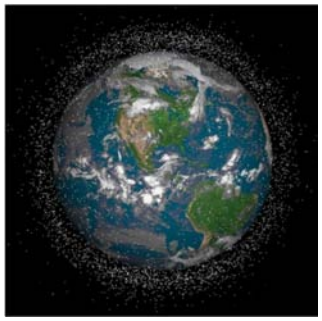
Space program originated and grew in response to geopolitical pressures

We then found it to be useful for other purposes (technical innovation, national drama)

Despite the documented value of space, we are still wedded to PR stunts as goals

Space must be relevant to national scientific, economic, and security needs





Waning Influence

Geopolitical landscape is shifting

- American sense of urgency, shared sacrifice of Apollo is a mere memory today
- Emerging signs of a “space race” with new space powers

Management bloat and legal impediments

- “Overhead” exceeds hardware and operations costs

Post-Cold War deterioration of technical industrial infrastructure and knowledge

Budgetary environment

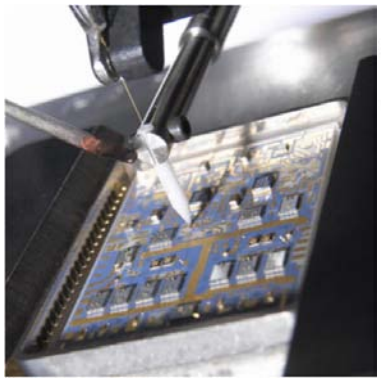
- “blank check” vs. COLA

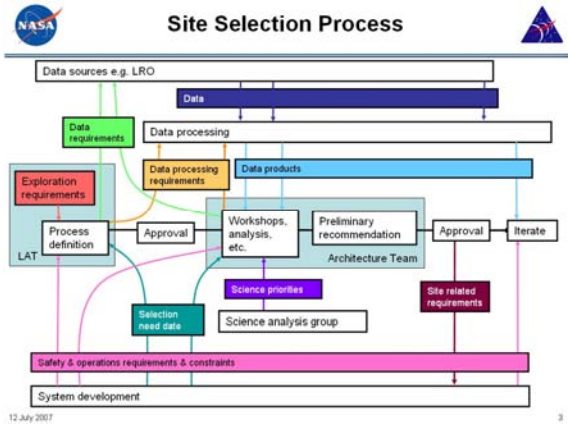
Risk aversion

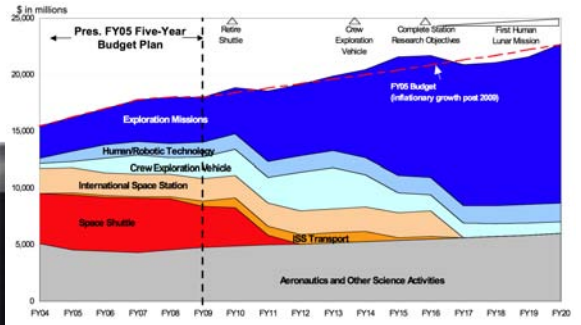
- Societal and individual
- “Safety is our first priority” -- Really? Then don’t go

Goal aversion

- Result of all of the above







Cislunar Space: A New Strategic Arena

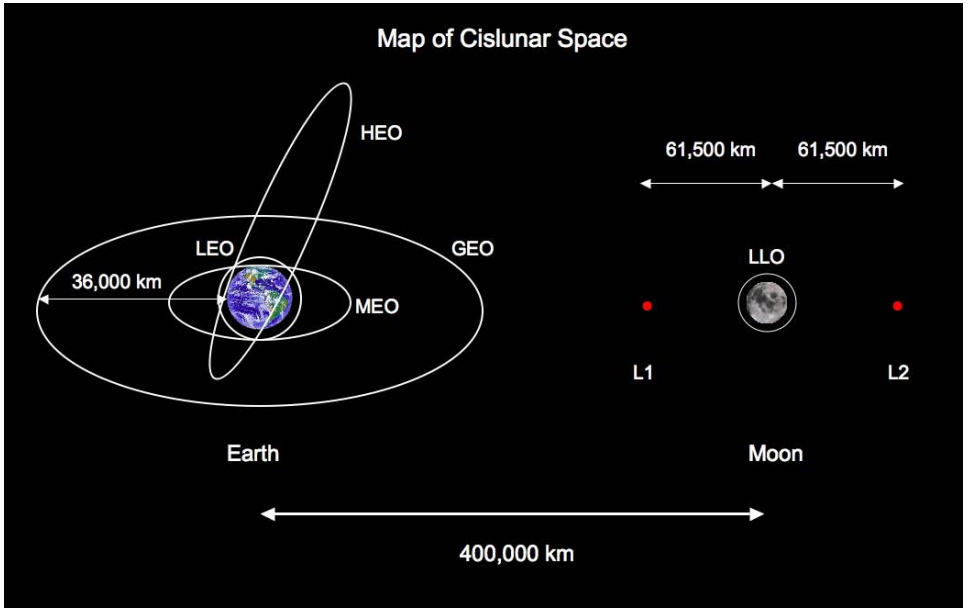
Cislunar: the volume of space between Earth and Moon

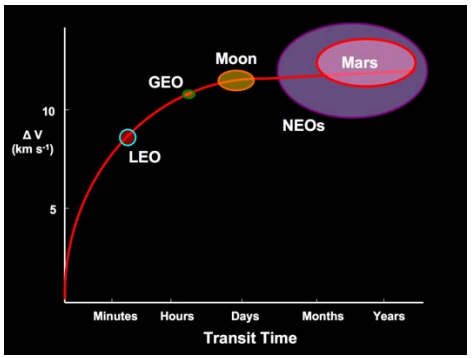
Zones of cislunar space

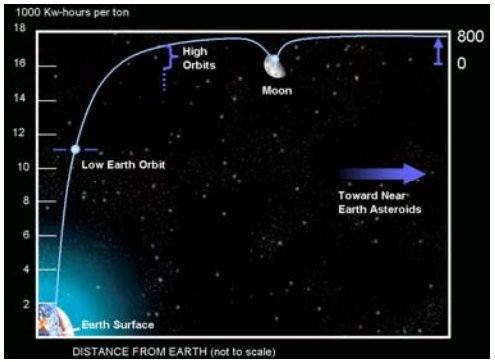
- LEO, MEO, GEO, HEO, L-points
- Different assets located at various levels of cislunar
- Access by machines and people vital to national interests

Modern national strategic needs depend critically upon ability to use our satellite assets

Space power projection involves both protection of assets and denial of assets to an adversary



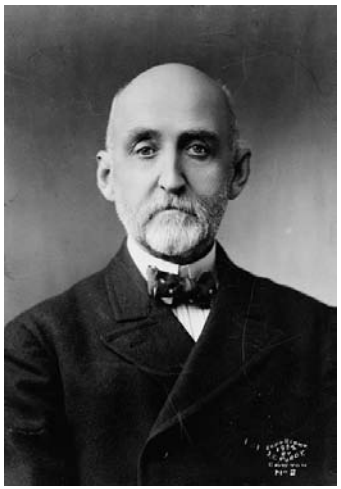


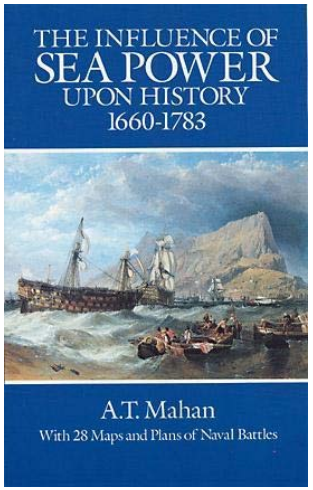


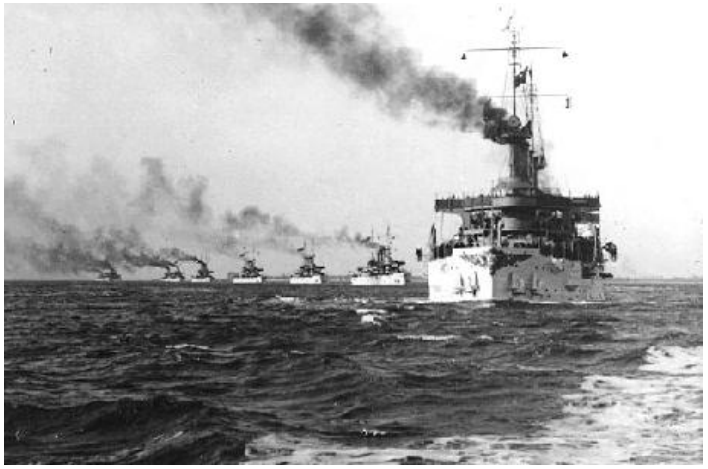
Historical Analogy for Cislunar Space:

Alfred Thayer Mahan and *The Influence of Sea Power on History (1890)*

- Mahan studied history of the rise and fall of nations
- Nations who control the sea control their destiny
- The converse is also true
- Power projection is morally neutral; it can be for the benefit or to the detriment of nations
- Power projection can ensure or deny commerce and freedom of the seas



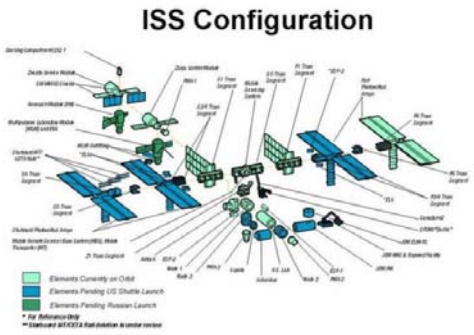




The “Great White Fleet” of the United States Navy 1907-1909

Lessons from Shuttle and Station Programs

- Large, distributed systems too big to be launched from Earth can be assembled in space
- Humans and machines working together can assemble, service and maintain complex space systems
- Applying this paradigm to trans-LEO (cislunar) space requires development of a transportation system that is affordable, extensible, and reusable



Developing the resources of the Moon enables the creation of such a system (if you can reach the lunar surface, you can access any other point in cislunar space)

The Solution

The Goal

Expand human reach* beyond low Earth orbit

*Reach = the ability to send people and machines to any point within a given volume of space to perform whatever tasks are envisioned

The Mission

Establish a robotic and human presence on the Moon to learn how to use local resources of material and energy to create new space faring capabilities

An Affordable Lunar Return Architecture

(Spudis and Lavoie, 2010)

Mission

Create a permanent human-tended lunar outpost to harvest water and make propellant

Approach

Small, incremental, cumulative steps

Robotic assets first to document resources, demonstrate production methods

Teleoperation of robotic mining equipment from Earth. Emplace assets and build outpost remotely

Investigate, develop, and demonstrate metal and ceramic fabrication for habitat and tool equipment use

Use existing LV, HLV if it becomes available

Cost and Schedule

Fits under existing run-out budget (< $7 B/year, 16 years, aggregate cost $88 B, real-year dollars)

Resource processing outpost operational halfway through program (after 18 missions); end stage after 30 missions: 150 mT water/year production

Benefits

Permanent space transportation system

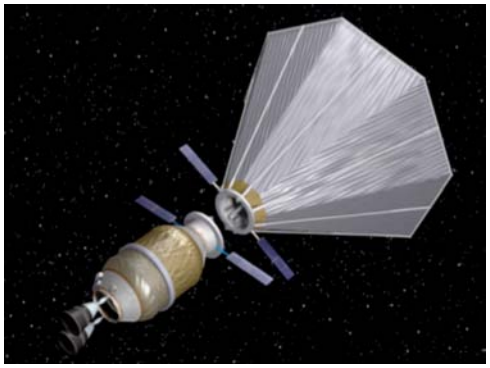
Routine access to all cislunar space by people and machines; flexibility of purpose and operations

Shifts philosophy to think about using local resources first for propellant and materials

Experience living and working on another world

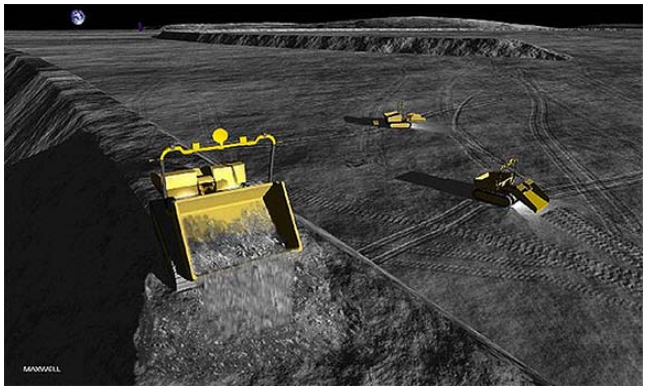
Goals and Principles

- Extend human reach beyond LEO by creating a permanent, extensible space faring infrastructure
- Use the material and energy resources of the Moon to create this system
- Lunar return by small, incremental, cumulative steps
- Proximity of Moon permits progress prior to human arrival via robotic teleoperations
- Innovative space systems: fuel depots, robotics, ISRU, reusable spacecraft, staging nodes
- Paradigm shift to local production of propellant and materials as part of any mission design
- Fit under estimated budget run-out of Augustine Committee (2009)
- Schedule is free variable; constant, steady progress but no deadlines



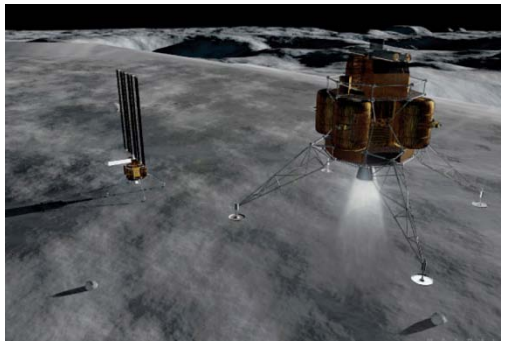
Initial Steps

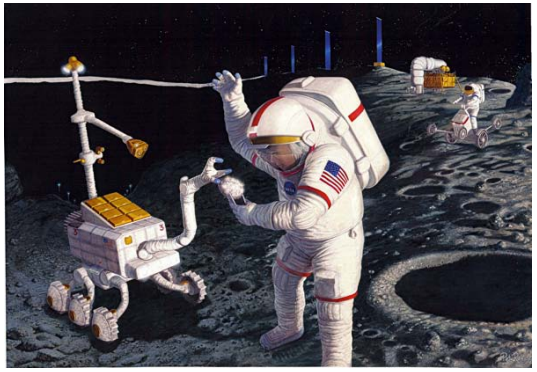
1. Communication/navigation satellites
   - Polar areas out of constant Earth LOS; need comm, positional knowledge
2. Polar prospecting rovers
   - Study and characterize water deposits, other substances, environment
3. ISRU demo
   - Heat icy regolith to extract water; purify and store as ice in cold traps
4. Digger/Hauler rovers
   - Excavate regolith, transport feedstock to fixed stations for water extraction
5. Water tankers
   - Purify and store extracted water

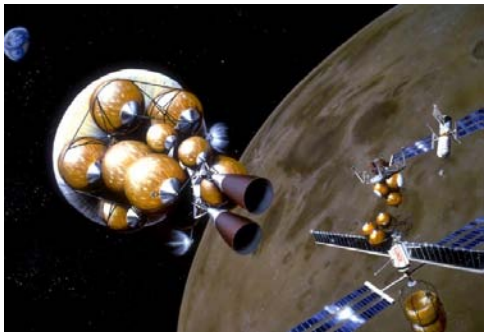


Next Steps

6. Electrolysis units
    - Crack water into hydrogen and oxygen; liquefy into cryogens
7. Supporting equipment
    - Robotic Landers - medium (500 kg payload), heavy (2 mT payload)
    - Power plants - extendable solar arrays, steerable on vertical axis to track sun at poles
    - Cryo storage - store LOX, LH_2 (use cold traps, 25 K)
    - Material Fabricators - Process regolith for rapid prototype products and parts
8. Space-based assets
    - LEO depot - fuel lunar departure stages
    - LLO depot - staging node for reusable cargo and human landers

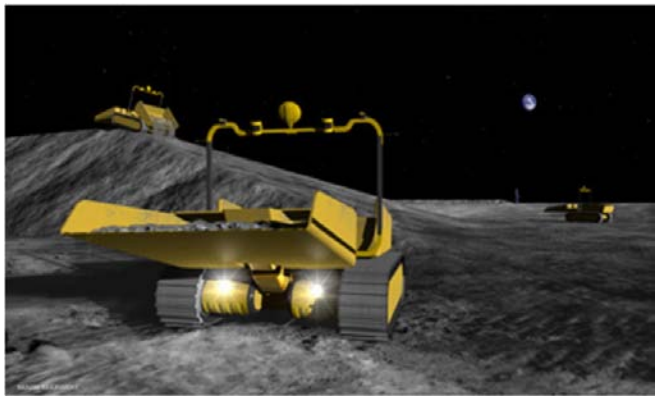


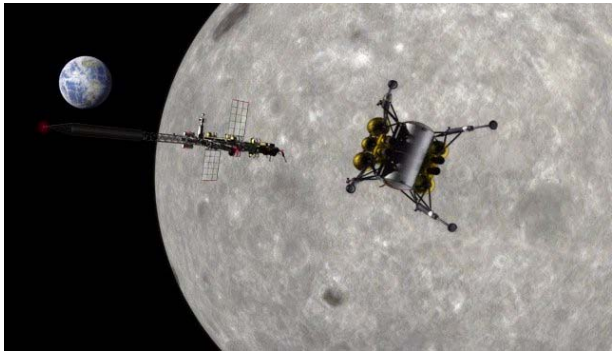




Program Summary

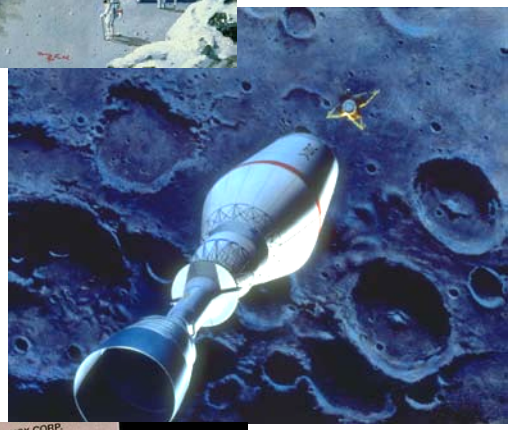
- Create a permanent, cislunar space transportation system based upon the harvest and use of lunar water
- Most infrastructure is emplaced and operated robotically; people come when facilities and budgets are ready
- Small incremental steps that build upon each other and work together
- Progress continually made, regardless of budgetary issues in any given year
- Incremental approach greatly facilitates both commercial and international participation
- Cislunar system is a “transcontinental railroad” in space, opening up the space frontier to science, security and commerce





The Value of Lunar Resources

- Lunar materials can be processed to make aggregate, glass, ceramics, solar cells, and metals for building structures on the Moon and in cislunar space
- Propellant produced from lunar polar water can make travel routine within and through cislunar space
- Off-Earth propellant production will completely change the paradigm of spaceflight
- Routine access to cislunar space has important economic, strategic and cultural implications



Beyond LEO: The Role of the Moon

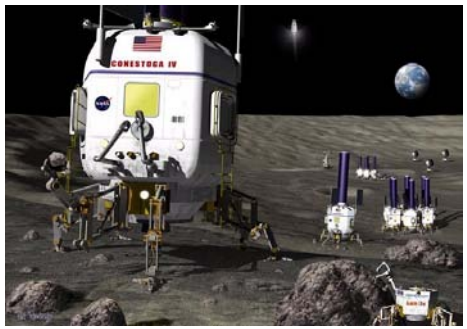
A useful foothold and necessary stepping-stone into the space frontier

A logistics depot for cislunar space

Change paradigm of spaceflight by using lunar products to create a transportation system on the Moon and in cislunar space

A laboratory and platform for science

A planetary space station where we can learn to live and work productively on another world



Affordable?!

Means and Ends

Given the precarious nature of the nation's finances, is any of this realistic?

- Space is intimately woven into the fabric of modern technological life (economy and security)
- For this reason, the complete termination of the space program (or any other government program, for that matter) is unlikely
- The question then is, "What do we do with what we have to spend?"

Need to return value (not "excitement") to taxpaying public

- Creating a cislunar transportation system with multiple uses and multiple users is more viable and sustainable than a series of "stunt" missions to dead-end destinations, regardless of the "excitement" factor (or lack thereof)
- Undertaking this type of lunar return has the potential to eventually *create* wealth rather than consume it

Coping With Limited Resources

Different Strategies

1. **Walk (run) away**

   Brig. Gen. Gideon Pillow, CSA

   The current policy for NASA

2. **Demand more**

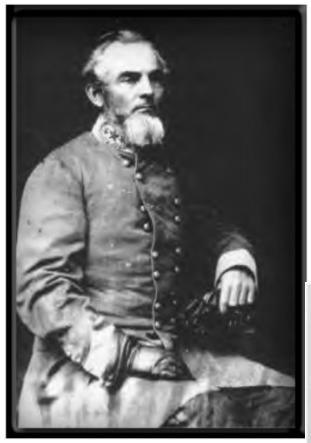
   Maj. Gen. George B. McClellan, USA

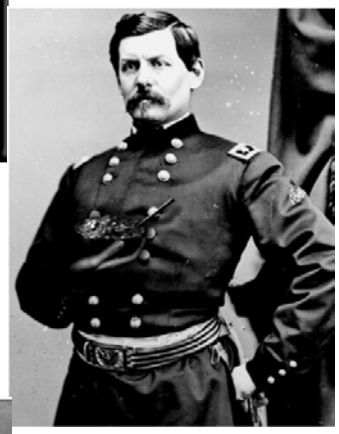
   Augustine: "NASA needs an additional $ 3B/year to go beyond LEO"

3. **Do the job with what you have**

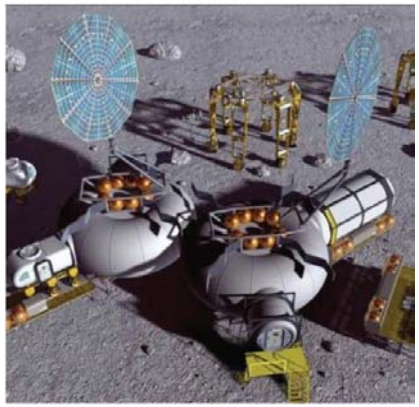
   Lt. Gen. U. S. Grant, USA

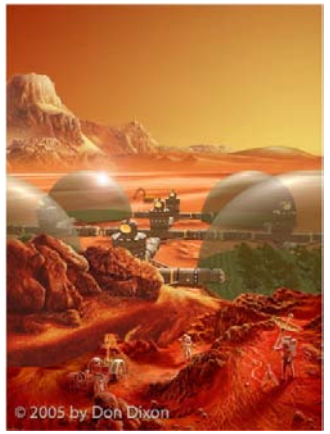
   Small step, incremental program that moves forward under existing budget, no matter how difficult it is or how long it takes



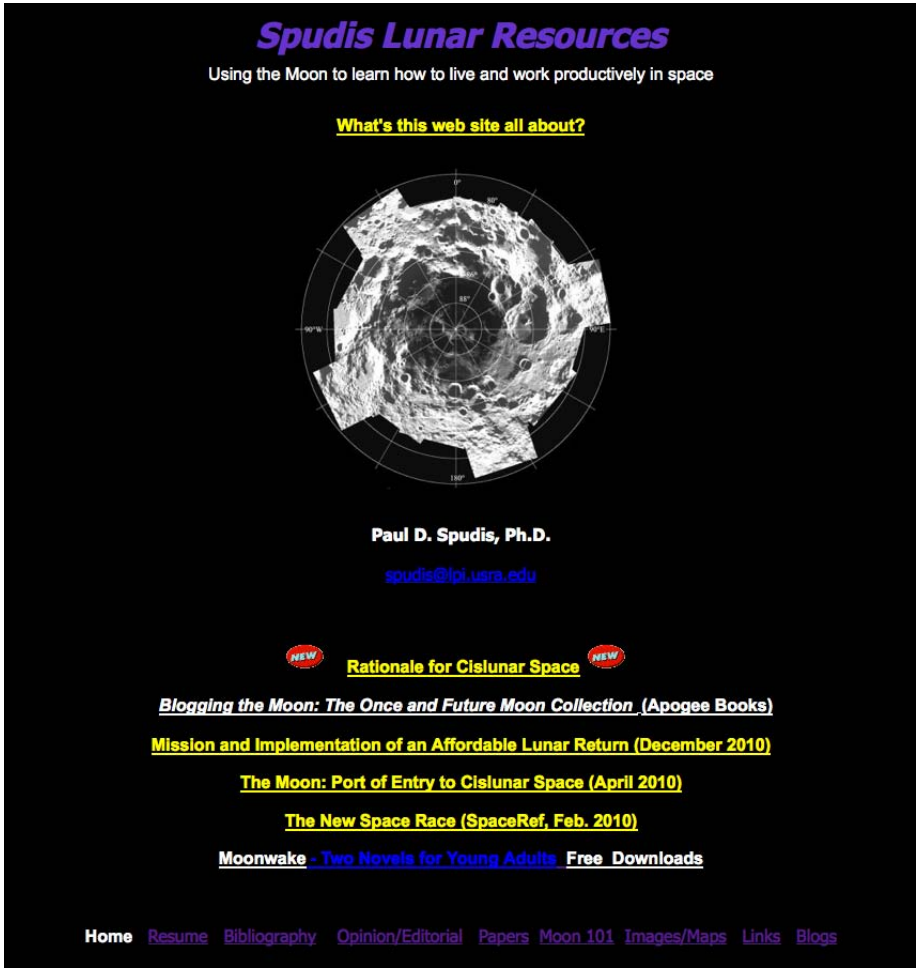


Learning Curve





For more information, go to:
http://www.spudislunarresources.com



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Rationale for Cislunar Space

Space benefits society in many areas, especially the use of satellite assets in orbits beyond LEO.

Earth's deep gravity well is a significant cost deterrent to expanded activities in space. For beyond LEO missions, most launch mass is propellant.

The International Space Station proves that human- and machine-assembled satellites can be as big and as capable as needed and unlimited by launch vehicle size.

We cannot routinely access orbits beyond LEO with people and machines to build and maintain such satellites today.

A system based around the manufacture and use of propellant made from lunar materials can reduce the cost for new space activities, enable routine access to and from the surface of the Moon, access all other points in cislunar space, including GEO and other orbits useful for space assets; and enable human interplanetary flight (i.e., to Mars and beyond).

The Moon also offers other material and energy resources that can be used to create new space faring capability, including regolith aggregate, glass and ceramics, metals and the fabrication of solar cells.

Both robotic and human presence is required on the Moon to enable and maintain production from lunar resources.

By going to the Moon to establish a permanent presence, we create a reusable, extensible and maintainable (thus, affordable) transportation system, a "transcontinental railroad" for cislunar space while expanding human reach beyond LEO.

Undertaking a program to develop and use off-planet resources creates wealth by developing and enabling new technology, opening new and previously unforeseen markets, thereby assuring that free market, democratic pluralism prevails in the new frontier of space (neither totalitarianism nor corporatism).