High Frontier

Columbia: A Permanent Lunar Base

FINAL REPORT to NASA Office of Space Flight

December 17, 2003

Klaus P. Heiss
Principal Investigator

"Our journey into space will go on. The work of the crew of the Columbia and the heroic explorers who traveled before them will continue."

President George W. Bush
August 29, 2003

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"Now it is time to take longer strides – time for this nation to take a clearly leading role in space achievement, which in many ways may hold the key to our future on Earth."

John F. Kennedy
May 25, 1961 before a joint session of Congress

"America's Space program will go on. This cause of exploration and discovery is not an option we choose. It is a desire written in the human heart. We are that part of creation which seeks to understand all creation. We find the best among us, send them forth into unmapped darkness, and pray they will return."

George W. Bush
February 7, 2003 at NASA's Lyndon B. Johnson Space Center, Houston, Texas at the Memorial Service of the STS-107 Crew of the Space Shuttle Columbia

This report assesses the current technology base and recommends a comprehensive program to reaffirm and reorient the U.S. Human Space Flight Program and reach a succinct goal:

Columbia, The First Lunar Base Within A Decade.

Achieving this worthy goal would give the American taxpayer, every night, an easily seen visual symbols of civilian U.S. effort and accomplishment, with continuous recognition and admiration by all peoples on our planet.

Foreword

"The U.S. space effort has moved forward for more than 30 years [since Apollo] without a guiding vision, and none seems evident. In the past, this absence of a strategic vision in itself has reflected a policy decision, since there have been many opportunities for national leaders to agree on ambitious goals for space, and none have done so. . . . We believe that the White House, Congress, and NASA should honor the memory of Columbia's crew by reflecting on the nation's future in space and the role of new space transportation capabilities in enhancing whatever space goals the nation chooses to pursue."

COLUMBIA **ACCIDENT INVESTIGATION BOARD**
Report Volume 1, August 2003

The recent *Columbia* Accident Investigation Board, chaired by Retired Admiral Harold W. Gehman, focused on the physical and organizational causes of the *Columbia* accident and recommended actions for future safe Shuttle operations. Most profound is the Board's realization, stated on page 209, of two key missing causal realities that undermine the nation's ability to sustain a viable, vibrant manned space program:

- "The lack, over the past three decades, of any national mandate providing NASA a compelling mission requiring human presence in space;" and, following the lack of such a clearly defined long-term space mission,
- "The lack of sustained government commitment over the past decade to improving U.S. access to space by developing a second generation space transportation system."

For over three decades technical experts have differed little about what should be the space exploration steps after the American flag was placed on the Moon in response to President Kennedy's historic 1961 charge to send Americans to the Moon and return them safely "before this decade is out." What has been missing is the same kind of political commitment and will to empower NASA to take the next logical step beyond program Apollo.

Under growing adverse political and fiscal pressures associated with the Vietnam War, President Nixon rejected NASA's 1969 proposed strategic vision and detailed technical plan for a post-Apollo effort that involved full development of low-Earth orbit, permanent outposts on the Moon, and initial journeys to Mars. Since then, these objectives have reappeared in numerous proposals for the long-term vision of the U.S. space program, for example:

- The 1986 National Commission on Space, following the *Challenger* accident, proposed "to lead the exploration and development of the space frontier, advancing science, technology and enterprise, and building institutions and systems that make accessible vast new resources and support human settlements beyond Earth orbit, from the Highlands of the Moon to the plains of Mars."

- Following President George H.W. Bush's 1989 call for a Space Exploration Initiative on the 20th anniversary of the first Lunar landing, the National Space Council's 1990 Advisory Committee on the Future of the U.S. Space Program observed that the primary justification for the space station is to conduct research to plan missions to Mars and other distant destinations. In 1991, former astronaut Retired Air Force Lt. General Thomas Stafford led The Synthesis Group in examining four architectures for President Bush's proposed Space Exploration Initiative: 1) Mars Exploration; 2) Science Emphasis for the Moon and Mars; 3) The Moon to Stay and Mars Exploration; and 4) Space Resource Utilization.

Regrettably, no particular architecture was pursued – leading to another decade without a strategic vision to guide NASA in making policy or day-to-day program decisions. And, as the adage goes, " When you don't know where you are going, any road will take you there."

This report takes the perspective that 'Going to the Moon to Stay' is preferred and, after explaining the reasons for this choice, assesses the current technology and recommends a specific program for NASA to pursue such an enterprise. Based upon the wealth of available background material from studies, technology programs, and associated recommendations dating to the Apollo program and earlier – particularly to the 1969 Space Task Group, this report assesses the current technology base and recommends costs and schedules for a comprehensive program to reaffirm and reorient the U.S. Human Space Flight Program and reach a succinct goal:

Columbia, The First Lunar Base Within A Decade.

This report builds upon the original High Frontier Report of 1981, which comprised major goals and technology opportunities for both civilian and military space activities. It helped to build the base for President Reagan's Strategic Defense Initiative, but had little follow-through or programmatic impact regarding major civilian activities and goals then outlined. Hopefully, this report will help rectify three decades of a lack of a national vision for Human Space Flight Program.

Ambassador Henry F. Cooper
Chairman, High Frontier
December 17, 2003

Executive Summary

A Historic New Goal for NASA

This report gives a cogent rationale for Human Space Exploration, assesses the technology base, and recommends a specific program to pursue a specific objective – to establish a permanent Lunar base within a decade. In honor of the lost crew of Columbia, we propose to name this permanent Lunar Base, Columbia.

The proposal to return to the Moon and establish a permanent Lunar base is based on the consistent findings of many studies and reports dating back to the 1940s and 50s; the comprehensive post-Apollo program recommended initially by the 1969 Space Task Group[1]; the Space Shuttle and later Space Station decisions of the 1970s and 80s; the various Space Commission efforts of the 1980s and early 1990s; and the recent Gehman Board report – and the associated conclusions and recommendations[2].

This wealth of materials and past assessments strongly suggest that establishing a permanent Lunar base within a decade is a succinct, clear, achievable goal for Human Space Flight for the next decade. For three decades, the extant technology base has provided the basis for this major reaffirmation and reorientation of the U.S. Human Space Flight Program, at acceptable costs and a set schedule. As Columbus opened the sea-lanes to a new world over half a millennium ago, so will Moon base Columbia open ‘Space lanes’ for human exploration and enterprise.

Assessment Criteria

The detailed assessment and recommendations elaborated in the following pages were molded by the following constraints on the program for Human Space Exploration:

1. **Accomplish within a decade** – anything longer is beyond the attention span of U.S. political decision-making in trading off budget requirements.
2. **Require no substantial increase in NASA budget** – a major challenge will lead to major reorientation, but should not more than double the NASA budget.
3. **Capitalize on past technology achievements and knowledge base** – including for the Apollo, Shuttle, and Space Station components, space operations know-how, and related experience of U.S. industry.
4. **Significantly increase civilian and national security uses of space** – by opening and exploiting Cis- and Circumlunar Space for U.S. space activities.

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[1] The 1969 Space Task Group was composed of the Vice President (Chairman), the President’s Science Advisor, the Air Force Secretary, and the NASA Administrator – and included as observers, the Director of the Bureau of the Budget, the AEC Chairman and the Undersecretary of State for Political Affairs. See T.A. Heppenheimer, *The Space Shuttle Decision,* NASA SP-4221, p. 125.

[2] For example, see *Pioneering the Space Frontier: Report of the National Commission on Space,* Bantam Books, 1986; *America at the Threshold: America’s Space Exploration Initiative,* The Synthesis Group, U.S. Government Printing Office, 1991; and *Columbia Accident Investigation Board Report,* U.S. Government Printing Office, 2003.

5. **Assure manageable risk** – by reducing long duration space travel uncertainties: effects of micro gravity, cosmic heavy particle radiation, and prolonged isolation.
6. **Make a historic contribution to the expansion of human enterprise** – in particular, to develop an Earth-independent technology base for human habitation outside and ultimately independent of Earth.
7. **Encourage a new regime for human and economic activities in space** – to allow for free enterprise in pursuit of Space activities.
8. **Conform to the "iron laws" of economics: transportation and time (interest) costs** – to accommodate the inescapable "delta-V" and investment interest requirements which increase geometrically with distance from the Earth.
9. **Stimulate the Nation's youth and their enthusiasm for exploration, science and technology** – requiring complementary programs to involve students and academia along with industry, beyond usual Federal grants and contracts.
10. **Be a U.S.-led program** – with welcome participation of other nations.

The GOAL: Columbia, A Permanent Lunar Base

When numerous past studies are considered, their recommendations can be grouped to compose three possible goals for NASA's near-term Human Space Exploration program: 1) Abandon Human Space Flight, 2) Go to Mars, and 3) Establish a human presence on the Moon. The first is unimaginative and unresponsive to the human thirst for exploration; the second fails several of the above assessment criteria – particularly that the goal be accomplished within a decade – but could be a logical extension of the third, which is, in any case, a precondition for further human exploration of space.

This study concludes – consistent with the 1969 Space Task Group – that establishing a Lunar base on the Moon within a decade is the logical next step in space exploration. We propose to name that Lunar base "Columbia," in honor of the crew of Columbia and all those who have given their lives in seeking to explore the last frontier of space – and for Columbus, who over 500 years ago opened the sea lanes to the New World.

The MEANS: Technology Building Blocks

1. **Upgrade current Space Infrastructure Investments**, starting with an upgrade of the Space Shuttle system to "2000" technology, including replacement of SRBs with pressure-fed liquid (LOX/LH2) boosters – resulting in major reductions in flight costs, schedules and risks, increased payload capabilities, and a full range of STS technology modules for cargo and Human Space Flight.
2. **Develop reusable upper stage** (Space Tug) for Cis- and Circumlunar operations. A modular approach should allow for the accommodation of all foreseeable manned and unmanned requirements as well as rescue and abort capabilities to/from/beyond Shuttle and Space Station orbits.
3. **Develop in-orbit fuel storage and transfer capabilities**, allowing Space Station uses as a "Space Port" or refueling/logistics station.
4. **Develop a Lunar Closed Ecological Life Support System (CELSS) Lunar Habitat** as NASA's primary space goal for the next decade.

Figure 1 – Closed Ecological Life Support Systems (CELSS)

Costs, Risks and Schedules

Based on several independent best judgments, a "first order" assessment of the costs of providing this "infrastructure" for human exploration of Space – on the Moon within a decade – involves a realignment of and an increase in the NASA budget well within the criteria set forth above. The benefits from this investment will exceed many times the "up-front" cost, even when considering only the "narrow" effects on the communications, information and energy sectors of the global economy.

This is thought to be a high-confidence assessment, since most required technology is well within the state-of-the-art – no fundamental advances in Space technology are needed. All anticipated needed advances are incremental – in fact, extensions beyond NASA's capabilities that have existed since the early 1970s. No overriding technology risks are involved and this initiative will substantially reduce immediate human Space flight risks: A substantial part of the required investments will fulfill the requirements proposed in the Gehman Commission report, as discussed in Chapter 3.

And yes, human Space flight will remain fraught with risk and loss of life, just as all exploration over ages past was and will remain so.

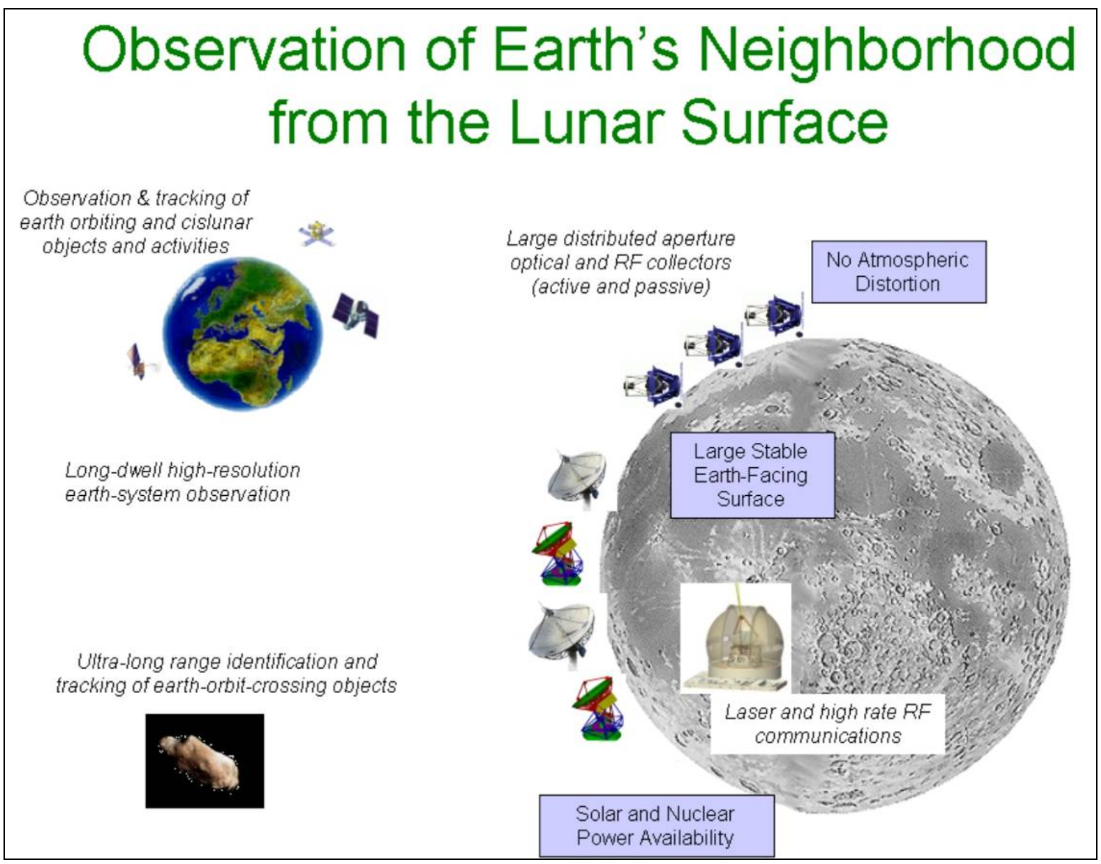
Critical to establishing a permanent Lunar base within a decade within these costs will be a single minded implementation of technology options outlined in this report, building on the existing Space Shuttle, Space Station and Life Sciences technology base.

Equally important will be that NASA be held to the requirement to accomplish this historic mission within the decade – by 2014; any 'slack' in this ironclad requirement would lead to an inexcusable squandering of taxpayers' resources.

Last and not least, in the pursuit of these opportunities while containing the costs to the public sector and taxpayers, will be the forging of a constructive partnership between NASA and the vast resources of the private sector. Critical will be defining the 'rules of the road' for opening Space for Human enterprise, with a reaffirmation of strong private property rights – similar to the original 1775 Declaration of Rights of Virginia.

PROSPECTIVES Following From This Near-Term Space Goal

Generations to come will remember this first Earth-independent Human settlement, which will far outshine the historically important settlement of Jamestown by English settlers in 1607. Indeed, Columbia will become the Jamestown of Space civilization. This overarching goal for the U.S. Space program for the next ten years will move mankind out of the 'single point failure mode' of planet Earth and revive the prospect of unknown new frontiers, the moving force in human exploration.



As illustrated in Figure 2 above, ‘Columbia’ will also add to our perspectives of Earth – just as the first “Full Earth” images from Apollo 8 fundamentally changed mankind’s awareness of Earth and its ‘vulnerability,’ giving rise to an ecological movement worldwide. So will the first permanent settlement on the Moon change our awareness of Cis-Lunar Space – and add to the myriad uses of satellites already in operation, affecting our daily lives, well-being and security interests. New uses of Space and the resources of Space for and on Earth will undoubtedly follow.

Examples of areas of exploration with major improvements for planet Earth include:

- **Communications and observation platforms** for information activities worldwide.
- **Large Geosyncronous and High Earth Orbit (HEO) structures**, including at various libration points.
- **Security provided by Columbia’s “High Ground”** – in Cis- and Circumlunar Space – may develop similarly to the **“Rock of Gibraltar,”** which contributes to observing and controlling access to and from the Mediterranean.

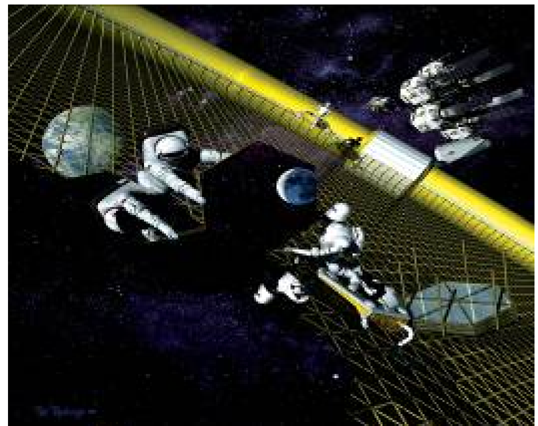


Figure 3 – Large HEO Structures

- **RDT&E of inexhaustible new Space energy resources** for use on the Moon, in Space and possibly on Earth. **For example, more Solar energy ‘hits’ the surface of the Moon in but 10-days than the energy from all known global fossil fuel resources accumulated over eons past on Earth.** A 10 Giga-Watt solar power plant can be built on the Moon with ‘proven’ technology. Such a concept is shown in Figure 4 [Solar Arrays (1), Microwave Transmitters (2), Reflectors (3) – all made from lunar soils by various production equipment (4, 5 and 6)].

Figure 4 – Solar Energy Production on the Moon for Cis-Lunar Space

- **CELSS feedback to husbanding resources on Earth** – possibly similar in its economic and environmental effects in the 21st century to the effects of electronic miniaturization and computation in the 20th century. The ability to sustain life and a community of astronauts independent of Earth by recycling waste materials and the use of “local” Lunar resources will have deep implications as to technologies and systems available on Earth, leading to a parsimonious ‘husbanding’ of resources.

Looking toward Earth and Cis-Lunar Space will produce the most immediate practical applications and 'paybacks' for the investment to establish a permanent Lunar base. Looking outward – toward continuing the journey into Space – will address man's thirst for information on the worlds beyond our direct experience. Specific initiatives could include:

- **Large astronomical observatories on the 'back side' of the Moon –** a decades old dream of astronomers, allowing ultra-large, distributed aperture observatories looking into the innermost processes of the universe, its origin and ultimate destination;
- **"Earth Independence" –** the Moon is the 'natural' testbed for Human exploration missions beyond the Moon in subsequent decades, such as Mars, the Asteroids and eventually the outer planets. In the long run, certainly such 'independence' of human existence must be regarded as an 'ultimate' technological achievement of mankind – wherever the journey may take us.

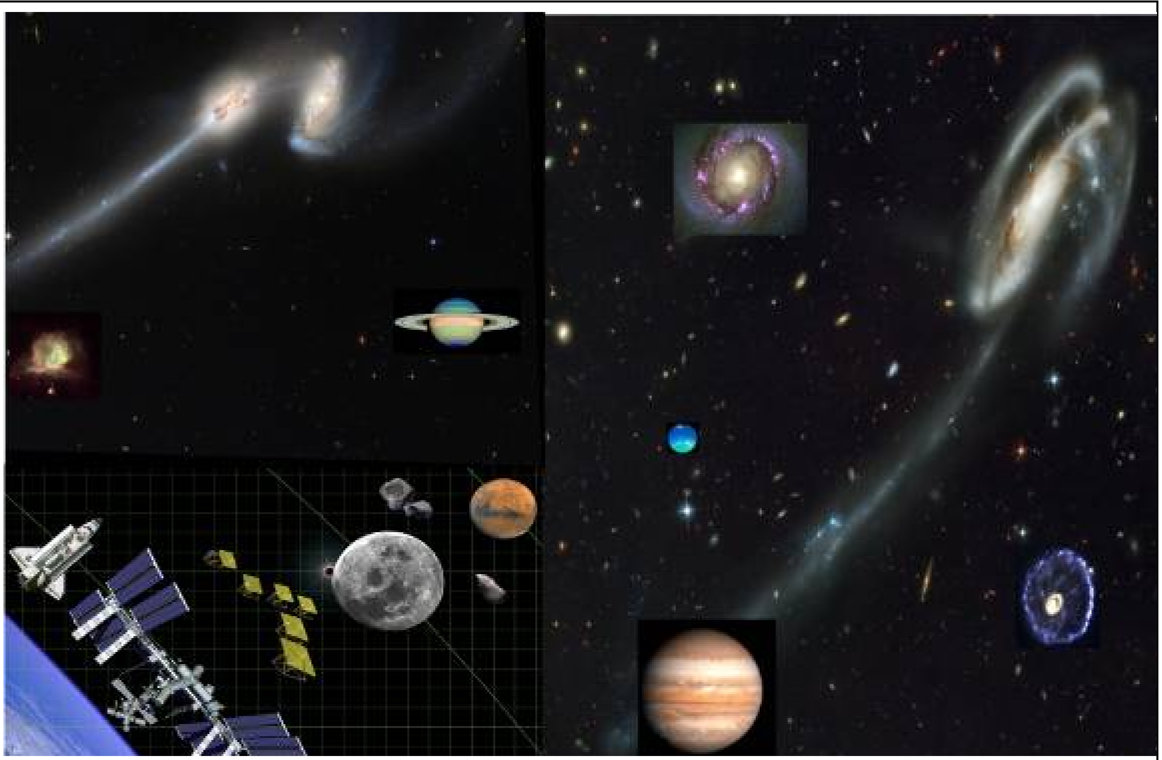


Figure 5 – The Moon: Platform for Solar System Exploration and Beyond

"[With future rocket developments], ***it will be possible to go to other planets, first of all to the Moon. The scientific importance of such trips is obvious."***

Wernher von Braun – Memorandum to the U.S. Army – Spring 1945
(See Appendix D)

Profound Education, Science and Technology Implications

Science and technology do not happen in the 'abstract,' as percentages of GNP or from incantations of the need for more Ph.D.s, engineers, technical workers and educators, more science, statistics and mathematics, high school students and college graduates.

Incantations or lamentations about America's deteriorating technology base will go unanswered without agreed goals that challenge our imagination and make us take the hard road of sweat and tears and work and risk. The "Columbia" Lunar base challenge will bring entirely new opportunities, with applications in the next decade requiring untold numbers of enterprising new employment prospects. Recent downward trends can be reversed, and not only will many Americans seek a future of opportunity but also an influx of untold thousands worldwide will join us in Space enterprise. Furthermore, the innovative spirit of free enterprise, encouraged by policies that reward risk-taking by venture capitalists and entrepreneurs, can complement and supplement NASA efforts to multiply the technological gains from seeking to establish a Lunar base within a decade.

We know of no goal or enterprise – including the Manhattan Project – that have had or will have more profound impacts and open more opportunities for generations to come than this single initiative: to return to the Moon within a decade – and this time to stay.

But beyond all these considerations, there is the spirit of the human mind and human enterprise, the historical imperative to expand into the 'void' of Space:

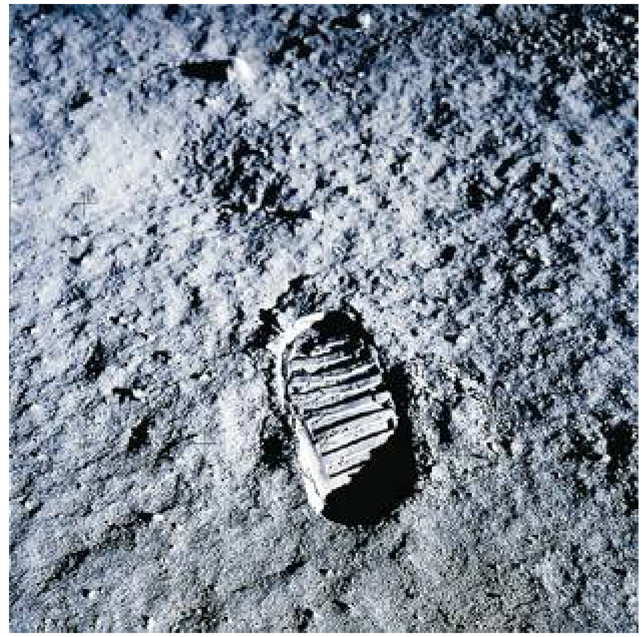
Let the first child born outside Earth, on the Moon, be from America, of a mother who risked her life in pursuit of flight. Let that child be named for all those who died in the quest for exploration, from Kitty Hawk to Columbia, and those yet destined to die – for all explorers of ages past, and of ages yet to come. Let that child be a messenger of freedom, a witness to the spirit of exploration and enterprise, for all generations that will follow that child on our journey into Space and, ultimately, to the stars.

"We choose to go to the Moon. We choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win, and the others, too."

President John F. Kennedy
Rice University, Texas – September 12, 1962

"Here's one Small Step for a Man –
One Giant Leap for Mankind"

Neil Armstrong – On the Moon
July 20, 1969



Why the Moon?

"Earth's closest neighbor in space, the Moon, is surprisingly complex. It is an object for detailed exploration, a platform from which to observe and study the universe, a place to live and work in the environment of space, and a natural source of materials and energy for an emerging space-based economy.

"The Moon offers a record of four billion years of planetary history. Its violent birth and history of bombardment from space is closely related to events on the early Earth. The Moon provides a natural laboratory for detailed study of geology and planetary formation, the output of our Sun over its lifetime, and the elements of our universe. The Moon's 14 Earth-day night, crystal clear, airless sky and stable ground provide a superb platform for astronomy.

"The Moon is the nearest object in space where people can live under conditions similar to those we face on other planets. Thus, the Moon is a natural test bed to prepare for missions to Mars through simulation, system testing, operations and studying human capabilities.

"The Moon is a rich source of materials and energy for use in space. Abundant metals, ceramics and recoverable amounts of hydrogen, carbon, and oxygen can provide propellants and human life support from the lunar surface. The 14 Earth-days of a lunar daytime provide abundant solar energy. Our Moon provides a rich scientific and economic way station for human expansion into the Solar System."

America at the Threshold
Report of the Synthesis Group on
America's Space Exploration Initiative
Chaired by Retired Air Force LGen. Thomas P. Stafford
May 1991

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The Next Ten Years in Space:

Assessment of Possible new Goals and Technological Opportunities for the U.S. Space Effort

FINAL REPORT to NASA Office of Space Flight
December 17, 2003

Klaus P. Heiss
Principal Investigator

Main Report

" I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to Earth. No single space project … will be more exciting, or more impressive to mankind, or more important … and none will be so difficult or expensive to accomplish …".

President John F. Kennedy
May 25,1961

With these words President Kennedy initiated our journey to the stars, with the first milepost clearly set – the Moon.

John F. Kennedy will be remembered a thousand years from now for this single, inspired decision, taken when few of the hardware systems needed to accomplish the indicated mission existed – nor in some cases were there even the very concepts on how the Apollo mission would or should be accomplished. Would it consist of a "brute force" approach with a direct landing on the Moon and return to Earth, or a Low Earth orbit transportation node to affect a direct landing on the Moon and return to Earth, or a Command Module to Lunar orbit with a Lunar excursion module therefrom and later rendezvous and return to Earth? This last approach, which was eventually adopted to accomplish the mission set by President Kennedy, had not even been conceived when the Apollo program was initiated.

Since this historic goal was achieved ahead of President Kennedy's schedule, the U.S. has floundered in its civil space enterprise, as noted by the recent Columbia Accident Investigation Board, chaired by Retired Admiral Harold W. Gehman. President Kennedy's concise, imaginative easily understood goal was not replaced with an equally imaginative challenge for America's post-Apollo civil space programs. As important as are the many uses of Space, the U.S. civil space program has failed to invigorate the imagination of America's youth, and the prospects of the future efforts have deteriorated as NASA's efforts meandered in an uninspired Space program that seems devoid of clear purpose and historic destiny.

The following pages argue that it is time to resume the journey and complete the effort initiated by President Kennedy: return to the Moon and stay on that 'Rock of Gibraltar' to the Sea of Space that awaits us "out there." At the same time, we should assure America of the full beneficial uses of Cis- and Tran-lunar Space for decades and centuries to come by establishing "Columbia" Base on the Moon within a decade: the first extraterrestrial and ultimately autonomous human settlement.

After Chapter 1 reviews the logic for NASA selecting this mission as the goal for its human Space flight program for the next decade, Chapter 2 discusses the available means of returning to the Moon "to stay"' within a decade – our proposal based on numerous extensive studies that date to the recommendations of the Apollo management and technical team in the late 1960s. Chapter 3 discusses why the risks associated with this recommended program should be considered to be acceptable. Notably, this program would address most problems that the *Columbia* Accident Review Board identified as contributing to the *Columbia* accident. Not the least of the Board's judgments was that a major contributor to the problems in the NASA program was the lack of such a mission as recommended here.

Then Chapter 4 considers the immediate benefits of establishing such a permanent Lunar base and its supporting infrastructure – benefits that potentially justify the investment in purely economic terms. Several classes of benefits are evident, including: potentially innovative Life Sciences and other science and technology advances; aids to service, repair and update spacecraft in Low Earth Orbit (LEO), Geosynchronous Earth Orbit (GEO) and other orbits; a variety of Earth-oriented applications by looking from the Moon toward Earth; and the potential of using the Moon base to "look outward" in preparation for future efforts to explore our solar system. A most intriguing prospect for a Lunar base is to harness its enormous solar energy potential.

Chapter 5 discusses cost and schedule possibilities, concluding that a modest increase – on the order of 30-50-percent – in NASA's budget is required to establish the Columbia Lunar base within a decade. This conclusion is based on several independent examinations of the proposed program.

Chapter 6 reviews the legal regime needed to encourage free enterprise in Space commensurate with the potential benefits of a permanent Moon base and a continuing viable Space exploration program. After a few final comments in Chapter 7, several appendices further elaborate the key matters in the body of the report. In particular, Appendix A reviews the 1971-72 Shuttle decision and the history of subsequent events that led to a loss of the vision evident in the 1969 Space Task Group report, which recommended for the immediate post Apollo space program much the same space transportation system that is recommended here.

Chapter 1 – THE GOAL for U.S. Space Exploration:
"Columbia," A Manned Lunar Base within a Decade

"And while many memorials will be built to honor Columbia's crew, their greatest memorial will be a vibrant space program with new missions carried out by a new generation of explorers."

Vice President Dick Cheney
February 6, 2003

Since a sustained U.S. Space exploration effort was initiated, its overarching goals and rationale have been extensively considered and debated, as considerable investments have been made.

Prior to Sputnik's 1957 wake-up call, U.S. aerospace efforts were conducted efficiently through a loose amalgamation of Research Centers administered through NACA. To focus a determined national effort to match the spectacular Russian achievements, the 1958 Space Act created NASA to pursue U.S. civil Space activities. President Dwight D. Eisenhower and Congress specifically emphasized the non-military potential and uses of manned and unmanned Space exploration.

With the 1961 decision by President John F. Kennedy to land an American on the Moon and to return him to Earth by the end of the decade, human Space flight became NASA's central theme for the 1960s. Kennedy's mandate was spectacularly met with time to spare. Since that millennial achievement, it is fair to say that NASA's efforts and goals have meandered – largely undefined for the past three decades, though there were repeated specific proposals for a focused manned space program:

- The 1968-69 Space Task Group on the Post-Apollo Program first recommended continuing the journey initiated by President Kennedy to explore the Moon and, by the 1980s, to continue to Mars and beyond with unmanned missions for a budget not to exceed $100 billion. But in the face of growing resistance from Congress and debates over the budget and Vietnam, the Nixon administration sharply scaled back NASA's proposal and cancelled the remaining Apollo program, leaving the three unused Saturn V rockets now on display at NASA centers[1]. The recommendation was 'muted' to one of 'technical feasibility' and that was the end of that: additional manned missions to the Moon and extended space exploration of Mars were laid to rest; the Space Station was cancelled and the 'battle' for a New Space Transportation System led to the Space Shuttle. But NASA's recommended program in 1968-69 was – and still is – technically sound, and its proposed schedule of key events is given below in Figure 1.1.

[1] The major political considerations surrounding the curtailing of the NASA recommended post-Apollo program are discussed in detail in T.A. Heppenheimer, *The Space Shuttle Decision, NASA, SP-4221, 1999. See also,* John Ehrlichman, *Witness to Power: The Nixon Years,* New York: Simon and Schuster, 1982; and Space Task Group, *The Post-Apollo Space Program: Directions for the Future,* September 1969, reprinted in NASA SP-4497, vol. I, pp. 522-543.

- The 72 Space Shuttle decision was made independent of any goal for manned Space exploration. See Appendix A for a discussion of the principal author's involvement in the 1971-72 debate that led to the 1972 Space Transportation System decision. Hundreds of different Space programs were analyzed, including entirely novel commercial, scientific and defense applications; but none included a return to the Moon or a mission to Mars.

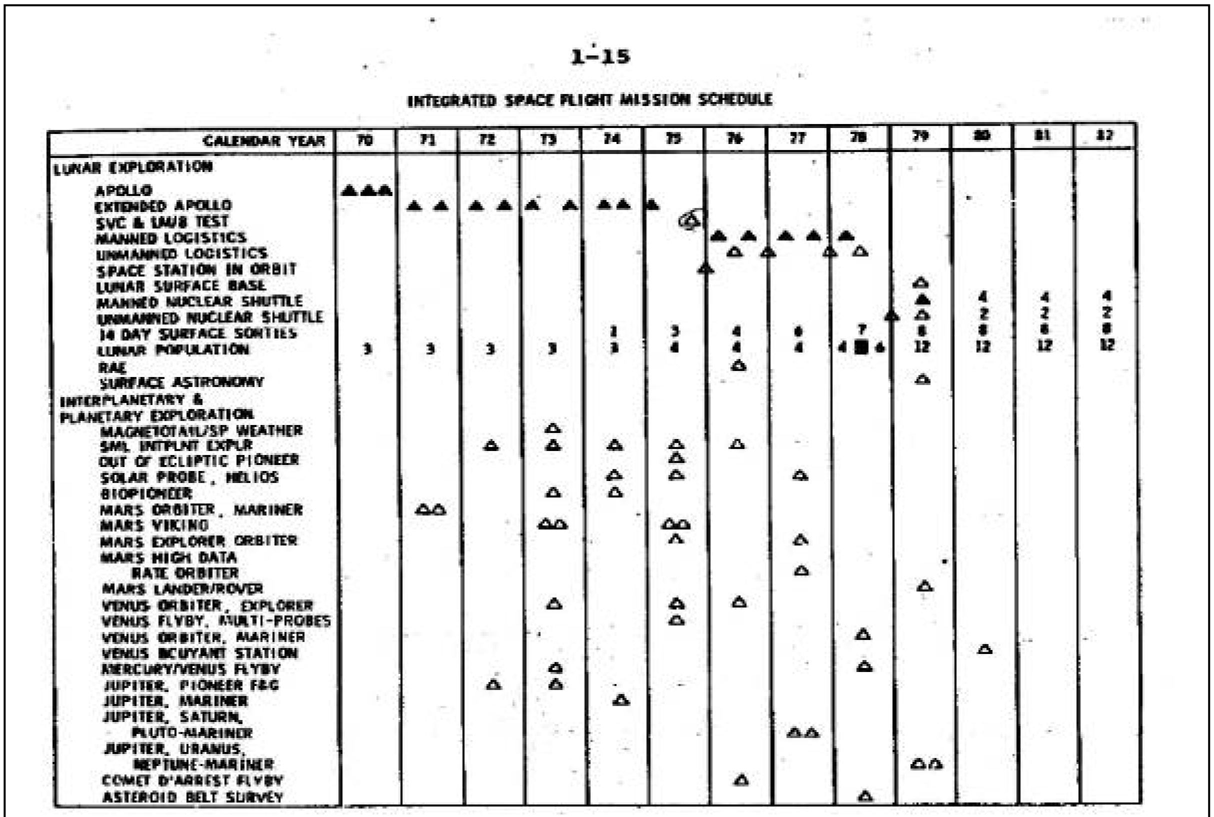

Figure 1.1: Integrated Space Flight Mission Schedule (From 1969 Space Task Group Report)

- SkyLab – the U.S. Space "Station" of the Apollo era – had a larger internal volume than today's International Space Station (ISS), and was allowed to decay from orbit in the late 1970s for want of a few $100-million. It was to be supplanted by the ISS program of the 1980s and 90s, with tens of billions of dollars to fund important technical achievements in manned Space operations and life sciences research, yet with no destiny defined beyond Low Earth Orbit (LEO).
- Numerous Space Commissions, Task Forces and Congressional Hearings since 1972 have outlined a myriad of possibilities for Space enterprise and manned Space flight, but despite the talent and excitement put into these efforts, a U.S. vision for its civilian Space effort remains undefined. Particularly of note was the most recent high-level reiteration of the proposals of the 1969 Space Task Group given by the 1991 Synthesis Group led by former astronaut and Retired Air Force General Thomas Stafford. The Synthesis Group examined four architectures for

President George H.W. Bush's proposed Space Exploration Initiative: 1) Mars Exploration; 2) Science Emphasis for the Moon and Mars; 3) The Moon to Stay and Mars Exploration; and 4) Space Resource Utilization[2].

Regrettably, no particular architecture was pursued following the Stafford Commission – leading to another decade without a strategic vision to guide NASA in making policy or day-to-day program decisions. The recent Gehman Commission presciently observed:

> *"The U.S. space effort has moved forward for more than 30 years [since Apollo] without a guiding vision, and none seems evident. In the past, this absence of a strategic vision in itself has reflected a policy decision, since there have been many opportunities for national leaders to agree on ambitious goals for space, and none have done so. . . . We believe that the White House, Congress, and NASA should honor the memory of Columbia's crew by reflecting on the nation's future in space and the role of new space transportation capabilities in enhancing whatever space goals the nation chooses to pursue[3]."*

Thus, the time has come to reassess what we know about the potential of Space and narrow the many choices down to one significant step for this next decade – which in and by itself constitutes a significant, even historic advance and at the same time significantly contributes, rather than forecloses, all the other options and potentials beyond. At a minimum this goal should also help to clarify the role of humans in the exploration and development of Space and the Solar system in particular. After all, a large part of the NASA effort is expended on manned Space flight: the Nation needs to know what for, beyond generic platitudes.

Assessment Criteria

So as not to reinvent the wheel, this report draws heavily from the numerous studies by NASA and various commissions to make specific recommendations. The assessment and recommendations elaborated in the following pages were molded by constraints that the U.S. Human Space Flight Program should:

1. **Be accomplished within a decade.** JFK set the example. Anything beyond a decade is outside the attention span (seriousness test) of U.S. political decisions and the horizon of public interest when trading off budget requirements.
2. **Require no substantial increase in the NASA budget.** Obviously a major reorientation of NASA priorities may/should ensue with a major new challenge, but in no case should the goal set require a doubling or more of the current NASA budget.
3. **Capitalize on past technology achievements and knowledge base.** These include the Apollo program, Space Shuttle and Space Station technologies,

[2] *America at the Threshold: America's Space Exploration Initiative,* The Synthesis Group, U.S. Government Printing Office, 1991.
[3] Gehman, Harold W., Chairman, *Report of the Columbia Accident Investigation Board*, U.S.Government Printing Office, October 2003.

propulsion and space operations know-how, and commercial and other infrastructure.

4. **Significantly increase civilian and national security uses of Space for the benefit of the United States.** The opening and control of Cis- and Circumlunar Space for U.S. Space activities would clearly accomplish this.
5. **Be accomplished with manageable risks.** Clearly Human Space Flight for the foreseeable future will involve substantial risk, including the loss of life; but such has been the case for all major milestones in Human exploration throughout the ages. Most technology required for Cis- and Circumlunar Space operations is a limited extension of technology demonstrated three decades ago. Still, major uncertainties may affect Human Space flight for longer durations, such as the effects of micro gravity, cosmic heavy particle radiation and prolonged isolation – all of which are as yet not fully understood or tested.
6. **Make a historic contribution to the expansion of Human enterprise.** One such overriding goal has to be to realize an Earth independent technology base for Human habitation outside – and ultimately independent – of Earth.
7. **Encourage a new regime for Human and economic activities in Space.** To assure the benefits of free enterprise, the legal regime for Space operations should pursue the principle of full sovereignty, including private property and enterprise. Under the current, often undefined, legal and regulatory regime, Lewis and Clark would still be lingering East of the Mississippi.
8. **Conform to the 'iron laws' of the economics for the cost of transportation and the cost of time (interest).** The transport costs of mass ("delta-V" requirements) and the cost of time (interest) are inescapable, increase geometrically with distance from Earth and hence will confine Human activities to near-Earth space in the foreseeable future – particularly when considered in combination with the uniquely adverse, unknown Space environment effects on astronauts from extended activities in Space.
9. **Stimulate our Nation's youth and their enthusiasm for exploration, the sciences and technology.** Whatever the goal, it should be complemented with programs that actively involve students, academia, and local government, i.e. beyond the well-trodden paths of Federal contracting and grants.
10. **Be accomplished as a U.S.-led program.** Other nations will be welcome to pursue programs of their own, conforming to their various priorities and desires, or to join the U.S. effort subject to the criteria outlined herein.

Applying these Criteria: A Clear and Unambiguous Choice

Much has been said since the Columbia accident – and will be repeated in future weeks – about the promise and cost of the Space Shuttle and of Space Enterprise. It is sad that it takes tragedy to focus our affluent society on the core issues of human enterprise and on the core importance of Space to America's future – in Space and on Earth.

2003 saw the launch to and return from Space of the first astronaut by China, which has a focused, technologically maturing Space program. Someday America may see a major challenge from China as a major space power. Hopefully, the Columbia disaster will prompt a renewed U.S. commitment to Human Space Exploration and Enterprise, which will again spur U.S. technological advances that assure America continues as the World's preeminent Space power.

In addition to this overriding "Human Destiny and Survival" rationale for Space Enterprise, there are also strictly utilitarian reasons for the Space Shuttle and Human Space Flight. As the one in charge of the independent assessment effort of the Space Transportation System directed by the White House for NASA in 1970-72, the principal author of this report discusses in Appendix A the rationale considered then and – equally important – how it responds to today's needs, thirty years later[4]. Conclusions:

- That 1972 assessment was right then, and continues to be right, without modification except to account for technological advances since 1972; and
- That recommended Space Transportation Infrastructure – of reusable vehicle(s) access to space – is still right and will remain so as long as we persist in human Space enterprise around Earth and beyond.
- Also correct was the observation communicated to the NASA Administrator: "Any expenditure of public funds must be justified . . . by the aims and purposes of the expenditure. Technological possibilities alone carry no conviction, though they often bring new possible aims into sight and reach. Whatever their nature and origin, the different aims must be hierarchically ordered and must find their place in the system of national priorities."

The cost-efficiency case made in 1971 is summarized in Appendix A – and combined with an analysis of what went wrong that undermined U.S. efforts to realize the fundamental promise of Space as seen in 1969-72 – and as still seen today. This review again emphasizes the need for a clear, national priority goal for Human Space Flight. The Gehman Commission recently noted the important impact of this conclusion on assuring astronaut safety.

Many options and destinations are outlined in the various reports of the past decades, ranging from an exclusively robotic exploration of Space around Earth, the Solar System and beyond, by many preferably based on Earth without the expense of Space launches and payloads to an all-out effort to establish free floating Space colonies at various libration points near Earth and beyond, ultimately for presence of humans throughout the Solar system and beyond.

Among wide-ranging choices, the options can be narrowed down to three themes:

- Abandon the quest of human Space flight, with a minimal pro-forma continuation of ongoing activities and programs to be slowly phased out over the next decade(s). At the extreme, abolish NASA as we know it and revert to the model

[4] Documented in Klaus P. Heiss and Oskar Morgenstern, *Factors for a Decision on a New Reusable Space Transportation System,* Memorandum for Dr. James C. Fletcher, NASA Administrator, October 28, 1971; and *Economic Analysis of the Space Shuttle System,* Study directed by Klaus P. Heiss and Oskar Morgenstern for NASA under contract NASW-2081, January 31, 1972 – Executive Summary and three Volumes.

of NACA of the 1950s for aerospace technology and NSF for the science components of the NASA programs.
- Go to Mars as the next goal for manned Space flight and then proceed to establish a permanent manned presence on Mars.
- Return to the Moon and establish a permanent manned presence there.

Option I: Abandon Human Space Flight

One of the first papers on Space given by the principal author of this report was titled "The Fallacies of the Anthropocentric Approach to Space Exploration." This paper, given at the 1968 IAF meetings in New York[5], argued that, for the same expenditure – or less, the Apollo program then to be completed within a year (in 1969) could have obtained the same sample returns through robotic technologies and extended these capabilities throughout the Solar system. A close reading 'between the lines' of NASA's current long term plan would lead one to similar conclusions.

How right in the abstract theory of the ivory towers of scientists and the world of accountants; how wrong in the quest of human exploration and historic advancement. Here is why. The question is: "Can Man establish a presence in Space – ultimately independent of support from Earth?" This clearly must be seen as an ultimate question of mankind, with profound philosophical, psychological, societal implications.

Today, mankind lives in a 'no back-up' single mode failure system called Earth. Our planet and civilization can end for a variety of reasons; e.g., from pestilence, global catastrophes and wars, and entirely natural events either on Earth or through cosmic events – such as witnessed worldwide via television when the July 16-22, 1994 multiple impacts of the Shoemaker-Levy comet on Jupiter released much more energy than in all the nuclear arsenals on Earth. The geologic record is replete with such cataclysmic events over the 'brief' history of the past 600 million years and more can be expected.

Beyond these violent events – whether manmade or natural – for the first time in the history of mankind our world has become 'closed.' Whereas but a few decades ago large areas of Earth were expanses of unknown regions and territories, today's events in even the remotest corners of the world are experienced 'live' in our living rooms; ours now is a world without unknown frontiers yet to be explored and opened. At the same time – according to some – our world has limited resources to be shared among a vastly exploding global population. It is a world destined for fights of redistribution of scarcity with mankind assembled all around the same watering hole. It is a world of zero-sum thinking, a world of wars, a world of irreconcilable conflicts.

And worse: a self-centered civilization without challenges from outside and the unknown can regress in self-centered satisfaction of its own perceived superiority and degenerate in a regression of boredom and – ultimately – cultural retardation.

[5] "Fallacies of the Anthropocentric Approach of the U.S. Space Program", Annual Meeting of the International Astronautics Federation Annual Meeting New York, New York, 1968

It has happened before – 15th century China, then the world's leading, dominant nation, was the world's leading shipbuilding nation. Chinese voyagers set out to reach shores throughout Asia Pacific and Africa – and British investigators recently suggested even of the Americas – and to complete a round trip back to Asia, to return through the straights of Magellan. Just as for the circumnavigation of Africa (and accidental side trips to the shores of South America under Pharaoh Necho 600 B.C.), these tales of enterprise largely go untold. In the 15th century the future of mankind China's to take, but it was the Europeans who indeed set out to do so.

The reason for China's abject failure: some quirk in the succession of emperors and empresses and the sway of eunuchs when empresses reigned. 'Bean-counters' of ages past argued, "Why spend all this treasure to visit barbarians and wastelands at the rims of civilization? If these barbarians and other lowlife are interested let them come to visit us at their expense." So said the 'Luddite accountants' in 15th century China.

As they say, "The rest is history." Europe brought 'civilization' to the rest of mankind in the centuries that followed. For America to fall prey to a repetition of China's history lesson, now on a grand interplanetary scale, we must say resoundingly, "No!"

To forgo the quest for answers to ultimate questions and opportunities for our and future generations would be to abdicate America's founding spirit – namely to explore the unknown, to open new frontiers and to settle and develop these for generations to come. While many of the visions and expectations along this journey of exploration and settlement have gone unfulfilled, accompanied often by untold suffering, courage and sometimes desperation, it is this quest itself that has maintained our positive, dynamic, diverse community. That same spirit needs to be extended and maintained in our quest for Space, at least until we learn about barriers too difficult to overcome.

The "costs" to the free world of not going to the Moon and, potentially, later to proceed to other places in the Solar system could exceed by far the small investment asked of us now, however large these amounts may sound in the disputes of the moment.

If we abandon this quest, others will take it up. Let that day of infamy not arise in our lifetime.

Option II: Go to Mars and Establish a Permanent Presence of Humans on Mars

Manned exploration of Mars was an 'obvious' destination for those who first considered space travel within the Solar System and beyond. It was considered in a 1609 letter from Johannes Kepler to Galileo Galilei. Human exploration of Mars also was tied to the initial recommendations for post-Apollo manned space exploration – the 1969 Space Task Group Report recommended the full development of LEO, permanent manned outposts on the Moon and initial, mostly unmanned, exploration of Mars. NASA Administrator Tom Paine emphasized the long-range objective of manned exploration of Mars – and President Nixon, under growing adverse political and budgetary pressures, rejected this ambitious goal. In 1991, President George H.W. Bush again emphasized the long-term goal of a manned mission to Mars – and NASA's program again floundered. We might again consider a manned mission to Mars as the next goal for U.S. Space enterprise.

This long-term goal, though desirable, may be too ambitious to sustain the needed political support – e.g., it fails the first criteria of being achievable within a decade. Serious obstacles and uncertainties must be resolved before commitment to such an enterprise is viable. Critical challenges to traveling to Mars within a decade, include:

- The effects of heavy particle radiation on the human body during prolonged Space flight. They are ubiquitous and difficult to shield against, other than through massive amounts of Water/Hydrogen, which would increase the mass, cost, and time of manned flights to Mars and back. When traversing the Earth's magnetic field, the Van Allen belt and beyond, astronauts on each Apollo mission to the Moon were exposed to such radiation, with persistent effects, including 'flashes,' whenever another 1,000 neurons or so were eliminated by the crossings of such heavy particles through their neuro-system, hitting the optic nerves. Extended over many months or years the effects of such exposure can be devastating.
- The effects of prolonged micro-gravity on the human body, leading to effects not dissimilar to aging and affecting within hours the whole human body in a myriad of ways. Prolonged Space flights over many years – or presence in severely diminished gravity – may be 'showstoppers' to such prolonged presence.
- The effects of prolonged isolation on the human psyche and body. Prolonged isolation, even on Earth, can have devastating effects on the mental health and physical well being of humans. The effects of mental well-being on the immune system is as yet not completely understood. Several incidents of 'burn-out' in orbit are documented. While these effects may be relatively 'easy' to cope with in near Earth environments – permitting relatively quick returns to Earth, long distance flight may pose entirely different perspectives and effects. Similarly, human judgment may be affected – sensory or otherwise.

While each of these effects may be serious – and a showstopper all by itself, the combination of 'synergistic' effects of less than disabling proportions of these effects must also be understood. There is considerable experience obtained from human Space flight missions in Low Earth Orbit (e.g., Space Stations, Space Shuttles, Soyuz flights). However, Apollo provided the only missions beyond the protective envelop of the Earth's magnetic field and the Van Allen Belt. Thus, there are only very limited data involving an environment like that to be experienced on interplanetary flights.

Each of these parameters can seriously add to – or mitigate – the cost and time of human missions to Mars. For example, if a 1-g environment were required throughout the mission, this requirement would substantially increase the mass and complexity of the mission. Similarly, if vast protective water enclosures are needed to protect against heavy particle radiation this requirement will increase mission mass as well. When both combine, mass requirements may increase by orders-of-magnitude, adversely affecting spacecraft design and mission parameters.

Two other key factors that limit confidence in committing to a Mars mission within a decade are the costs of transportation and time (i.e. interest). What may make sense with a few weeks' turn-around time for the Moon may become unfeasible – technically or economically – with roundtrip schedules of a few years for a single mission. This sad fact would not be ameliorated by assumed breakthroughs and advances in propulsion, nuclear rocket programs to reduce trip times and some of the listed bottlenecks in manned flights to Mars. Neither do we have such means of transportation today, nor can we be assured of measures to address associated health concerns.

Finally, extensive human experience on the Moon is a precondition to human Space trips to Mars, and lessons learned from this experience may provide new ways to execute missions to Mars. Preliminary missions to the moons of Mars, Deimos and Phobos, are also a prelude to human Space flight to Mars. Thus, we can develop solutions to key problems by returning to the Moon and establishing a permanent base of operations for study and exploration of that space environment.

Option III: A First Human Settlement on the Moon within a Decade

Under the above constraints on the characteristics and parameters for meeting the next major goal for Human Space exploration, **the only realistic Goal for the next decade is to establish the first human settlement outside Earth on the Moon.** From the standpoint of risk, transportation costs and travel time alone, the Moon is the first logical step to address the fundamental questions of the scope and limits of Human Space Flight beyond Earth throughout the solar system.

As Figures 1.2 and 1.3 make clear, the Moon is also the **'natural' platform to operate in Cis-Lunar space** – to GEO, to HEO and NEO, even to LEO. Once such an operational capability has been established, the 'energy' distance (the amount of propulsion needed) to reach even low earth orbits from the Moon is substantially less than reaching that same location from the 'much closer' Earth. The same holds true for any and all other locations in Cis and Trans-Lunar Space.

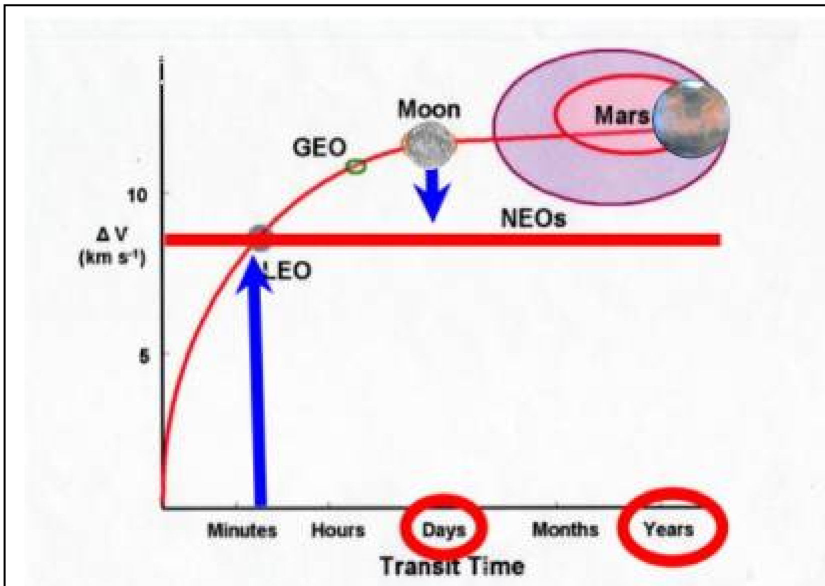

Figure 1.2 – "Delta V" and Time Budgets from Earth to Moon and Mars

At the same time it is also clear that whereas the Moon is within a few days of Earth in case of emergencies of whatever kind – or simple re-supply operations before reaching 'Lunar autonomy' – travel to and from Mars will take years. Once having set out for Mars one can not just 'turn around' in mid-flight, a gravity assist from Mars is needed for such 'turn-around'.

As discussed below, there will be many new practical applications that result from a Lunar habitat that permits exploitation of the Moon's physical environment. Human involvement in such exploitation will be critically important. The same 'operational advantage' holds for the moons of Mars, Deimos and Phobos, when considering 'Cis-Martian' Space missions. Again, the moons may be the 'natural' initial destination, until technologies and experience beyond Earth Space mature.

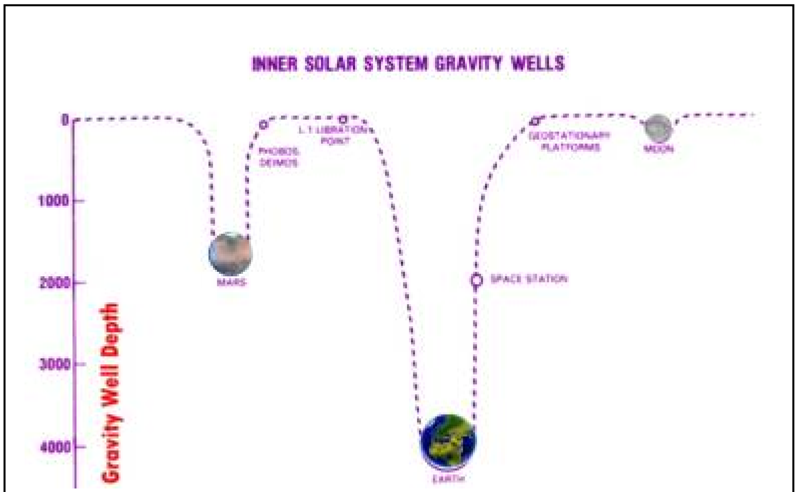

Figure 1.3 Inner Solar System Gravity Wells

Key among these innovations is a **revolution of Space transportation and Space operations** in Cis- and Trans-lunar Space and for missions into the solar system, once the aerospace community grasps the unique characteristics of Lunar resources, e.g.,

- The **abundance of energy** beyond any resource ever imagined on Earth;
- The **absence of any significant 'atmosphere;'**
- The **stability of the Lunar 'platform;'** and
- The abundance of **mineral resources** given the apparent 'cogeneration' of Earth and Moon in their infancy billions of years ago.

One example: Once the energy resources on the Moon have been tapped, a new era of Space transportation will open – with propellant-less propulsion options, **totally changing** the 'delta-V' driven location speculations of Cis-, Trans-lunar and planetary exploration missions in and around diverse libration points. Indeed one may ask, "What good are mathematical 'optimization' exercises if propellant mass is no issue?" Thus are the potential changes wrought by a human presence on the Moon.

Finally, as pointed out in the discussion of obstacles confronting a national goal for human exploration of Mars (Option II), there are many issues concerning **ecological health and closed ecological life support systems** (Heavy particle radiation, micro-gravity, human factors among them). The place to find the answers to these myriad of Life Sciences issues, the environmental health of humans in interplanetary space flight and the feasibility of Closed Ecological Life Support Systems (CELSS) is outside the Van Allen belt, yet close enough for rescue and early returns should environmental and health data indicate incipient problems. That place is the Moon, which also can supply/provide a variety of shielding and protective strategies not available in the 'void' of interplanetary space flight. The results of these Lunar *in-situ* efforts could significantly reduce costs and risks of eventual future human Mars mission exploration.

Of paramount importance in this context is the question of the relative abundance or not of H_2O on the Moon. This is a hotly discussed topic, with indications from the Clementine mission that indeed such resources exist near the polar regions of the Moon. However, a more detailed assessment of the extent of these water resources on the Moon is needed, first with additional remote sensing missions, then – as in the good old days – by on-site old-fashioned geologic prospecting by humans on the Moon.

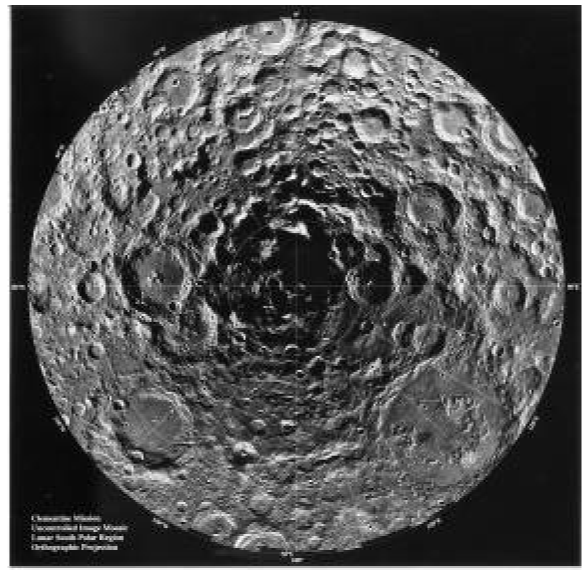

Figure 1.4 – Clementine Composite Image of Lunar South Pole

Of course, once solar energy resources are tapped on the Moon, then hydrogen can be literally 'squeezed' out of the regolith 'stones', where hydrogen and helium-3 have been 'implanted' by solar winds for billions of years. [See Chapter 4.]

Such a fundamental goal can make use of an extensive existing technology base, with some crucial system development components to enable such a mission by a decade after go-ahead. These include four core components, discussed further in Chapter 2:

- **Space Shuttle:** Evolutionary steps toward modular, reusable liquid assist and unmanned systems options.
- **Space Tug:** A LEO-to-Lunar Surface-and-return manned Reusable Upper Stage, again modular in its various components.
- **On-Orbit fuel storage and transfer capability**: For example, oxygen, hydrogen, and water that accrue in various Space missions to and from LEO (Shuttles, ISS) can be used to refuel LEO-based Space Tugs to increase efficiencies and reduce costs of missions above LEO to HEO, GEO and beyond, all the way to the Moon and back. Thereafter, these technologies can enable the use of Lunar water resources and their cracking into H_2/O_2 for Space Tug (and CELSS) operations. Solar Electric Power Space stations can provide power to Space Tugs with missions beyond the primary pull of Earth's gravity.
- **Closed Ecological Life Support Systems ("CELSS"):** The key technology for ultimately Earth-independent, autonomous human settlements on the Moon and in Space, with untold 'technology feedback' to Earth. The impact on the global

economy of such drastically advanced recycling of resources may be similar to the effects of miniaturization in electronics, image processing and computation from the Space program of the 20th century.

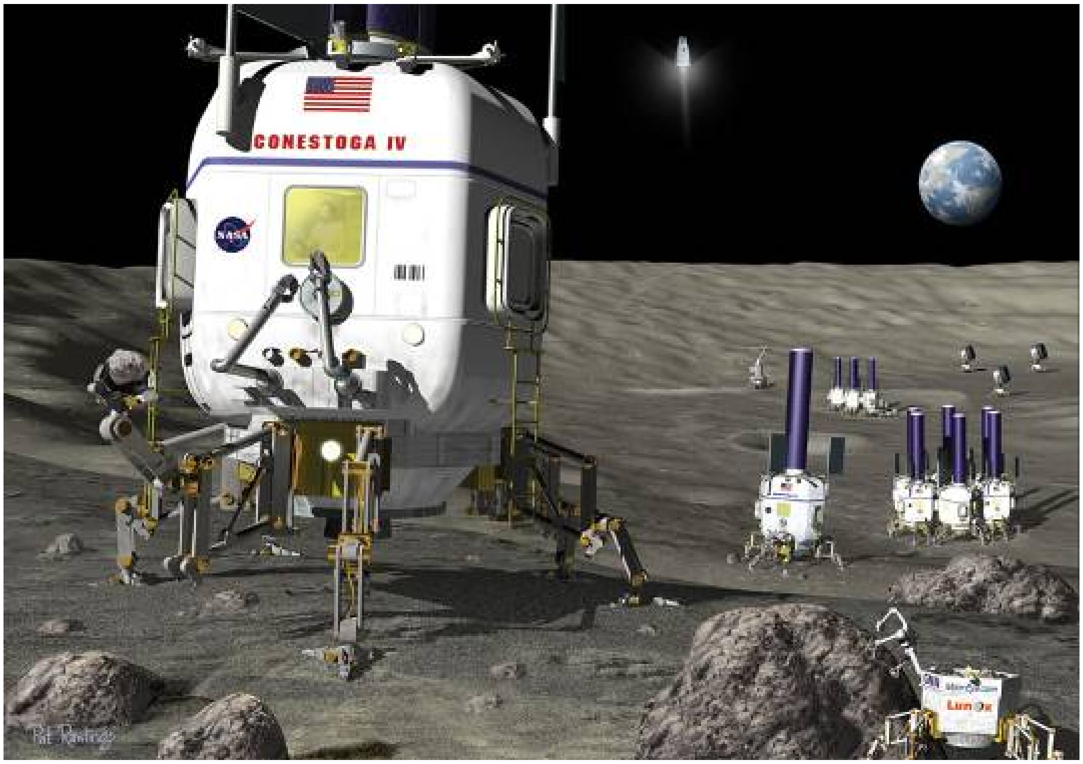

Figure 1.5 – Autonomous Lunar Utility Vehicles

Profound Science and Technology Implications

One of the foundations of the vigor of free market economies – and the U.S. economy in particular – is the immense drive for innovation, which in turn is based on the ‘human resources’ of education, the sciences and technology.

Currently, the U.S. is experiencing a serious erosion of the foundations of its wealth, in aerospace in particular. Things we could do but a few decades ago are, in fact, today outside of our immediate reach, including the ability to return to the Moon – or even to replicate a Space Shuttle, much less to improve its design to 2000 technology. A new generation must learn again how to repeat these feats of decades ago – preferably while a few of the pioneers are still available to help. These resources – ultimately key human resources: engineers, scientists, aerospace workers – should be mobilized, maintained and expanded, not through ‘make work’ programs that reinvent the wheel (e.g. one more ‘expendable’ launch system) but through challenges that open new frontiers, such as exploring and exploiting the Moon.

Entirely new applications, technologies, and missions are outlined in Chapter 4, based on the work of literally hundreds and thousands of innovators, scientists and engineers of decades past. Many others will expand that list of ideas over the next months and years. This portfolio of opportunities encompasses all areas of technology and the sciences, across literally the whole electromagnetic spectrum, all the life sciences, the communications and information economies (well over 50% of all economic activities in advanced economies), material sciences, and human factors. With the prospect of an inexhaustible energy base – be it solar, be it nuclear – there are no limits to the expansion of this new frontier other than our failure to set out to explore, breach and expand this frontier as well.

These conditions will pose an exciting challenge to the next generation of aerospace engineers and scientists. **Science and technology do not happen in the 'abstract'** – as percentages of GNP or in response to incantations of the need for more Ph.D.s, engineers, technical workers and educators; more science, statistics and mathematics; more high school science and college graduates. Such incantations and lamentations will go unanswered in the void of goals that challenge our imagination and make us take the hard road of sweat and tears, work and risk – justifying all the long and lonely hours of studies and tests and failures, and here and there the thrill of success.

The "Columbia" challenge will bring about entirely new opportunities of the Frontiers of Space, with **real life applications in the next decades.** If but a fraction of all the opportunities are pursued – requiring untold numbers of enterprising new employment prospects, the downward trend in aerospace science and engineering can be reversed, leading to an influx not only of America's youth toward a future of opportunity but an influx of untold thousands worldwide to join us here in Space enterprise.

We know of no goal or enterprise – including the Manhattan Project – that has had or will have more profound impacts and open more opportunities for generations to come than this single initiative: to return to the Moon within a decade, this time for keeps.

And – lest a goal be set – NASA cannot answer the question as to what technologies are needed in the pursuit of Space enterprise. Based on the list of criteria in the previous section, the only realistic goal for NASA to be given for the next decade is to establish a Manned Lunar Base within ten years from go-ahead.

> ***We have taken to the Moon the wealth of this nation, the vision of its political leaders, the intelligence of its scientists, the dedication of its engineers, the careful craftsmanship of its workers, and the enthusiastic support of its people. We have brought back rocks, and I think it is a fair trade. . . . Man has always gone where he has been able to go. It's that simple. He will continue pushing back his frontier, no matter how far it may carry him from his homeland.***
>
> **Apollo 11 Commander Michael Collins**
> **Before Congress on September 16, 1969**

Let the first child born outside Earth – on the Moon – be from America,
of a mother who risked her life in pursuit of flight.

Let that child be named for all those who died in the quest for exploration,
from Kitty Hawk to Columbia – and those yet destined to die;
for all explorers of ages past – and of ages yet to come.

Let that child be a messenger of freedom,
a witness to the spirit of exploration and enterprise
to all generations that will follow that child –

On our journey into Space and
to the stars.

Chapter 2 – THE MEANS: Technology Building Blocks

The INFRASTRUCTURE to Enable Cis- and Trans-lunar Space Applications

The object of your mission is to explore the Missouri River, & such principal stream of it, as, by it's course & communication with the waters of the Pacific Ocean, may offer the most direct & practicable water communication across this continent, for the purposes of commerce.

President Thomas Jefferson
Instructions to Lewis and Clark
June 20, 1803

As summarized in Chapter 1, establishing the first human settlement on the Moon within a decade requires evolutionary improvements in four important technology components: 1) the Space Shuttle, 2) a Space Tug, 3) Space based Refueling and Storage Stations and 4) a CELSS Lunar Base Module building on ISS technology. Other existing mission-critical technology will improve as a byproduct of a comprehensive program focused on establishing the Columbia Lunar base – and various technologies will be advanced to accomplish this goal more effectively and to help accomplish numerous missions that will inevitably follow for Cis-Lunar and other applications.

Just as was envisioned by the 1969 Space Task Group, the first three of these four components compose a Cis-Lunar "Space Transportation System" and the fourth is the basic habitat for sustaining productive human life and operations on the Moon. To emphasize the consistency of the concept of operations proposed here, consider Figure 2.1, taken from the 1969 Space Task Group report[1]. The primary needed space transportation vehicles, as illustrated in Figure 2.2, are:

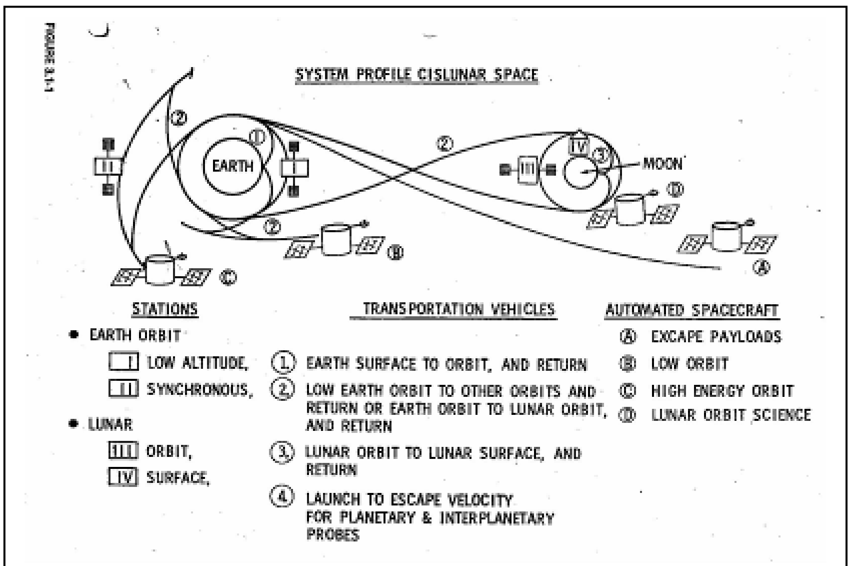

Figure 2.1 – 1969 Space Task Group Cis-Lunar Systems Operations Profiles

[1] See Appendix A for a discussion of a key 1971-72 economic study of concepts considered by the 1969 Space Task Group and various decisions made 30-years ago – and since – all of which need to be revisited in light of the proposed mission to establish a manned lunar base within the next decade.

- Shuttles, which carry material and people between the Earth's surface and LEO, there to be transferred to orbiting habitats and/or storage stations. (Shuttle-derived Heavy Lift Launch Vehicles – HLLVs – could also be important.)
- Space Tugs, which transport personnel and/or material 1) in LEO between LEO habitats and storage and 2) between LEO and Lunar orbit or the Moon's surface.
- Mission-critical stations in LEO, between LEO and the Moon, and around the Moon – including space-based LOX/LH2 refueling stations to provide fuel for the Space Tugs and Lunar operations. (Liquid-fueled rockets are desired to reduce costs and life-threatening risks – including for future Shuttle concepts.) Solar Electric Power (SEP) Space stations can also provide power to conduct space missions once the Tugs are beyond the primary pull of Earth gravity.

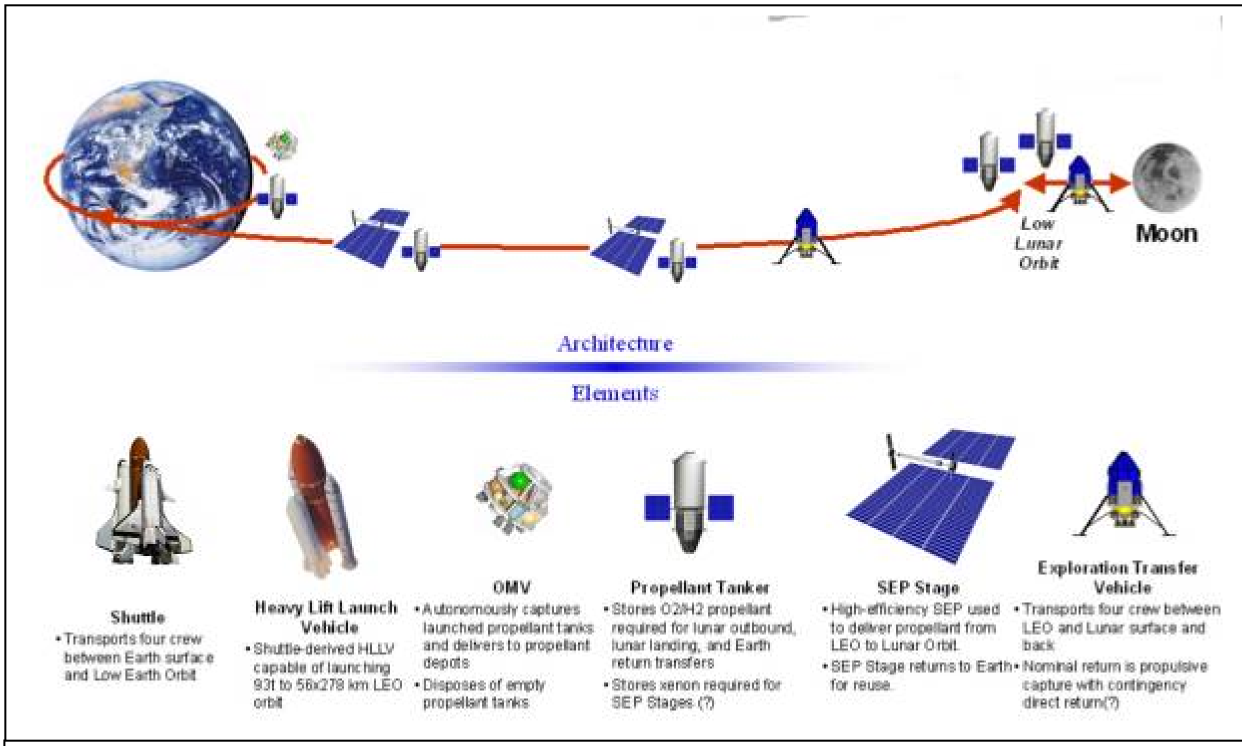

Figure 2.2 - A Shuttle Derived Reusable Space-based Systems Approach

This proposed Space Transportation System could be used to repair and service failing LEO, HEO and GEO satellites, to improve their efficiency/effectiveness and to extend their life – a fundamentally new capability. But its primary purpose is to establish and maintain a viable Lunar base – Columbia – the primary objective proposed here.

This goal will be achieved by, in effect, executing the plan conceived in 1969 toward the end of the Apollo program but regrettably abandoned in the face of the political and budgetary pressures of the Vietnam era. Where appropriate, it will exploit technological advances of the past three decades. In some cases it will take different directions because of the needs of achieving this focused goal. The following sections discuss the essential building blocks to building a Lunar base within a decade.

Building on the Space Shuttle Technology Heritage –
Shuttle and Shuttle-Derivative Space Transportation Systems

Needed now is to complete the architecture and technology vision of the late 1960s and early 1970s (See Appendix A.), while incorporating subsequent progress on associated technology – which, during the past three decades, advanced more in the military and commercial sectors with a veritable explosion in computing and software capabilities, micro-miniaturization, and material sciences. The key to any and all STS designs is – as it was 30-years ago – standardization, modularization and robust interchangeability.

If the extensive results of the late-1960s and early-1970s analyses are applied to the current situation, the outline of STS components needed to meet the criteria and goals outlined above remains as illustrated by the building blocks in Figure 2.3.

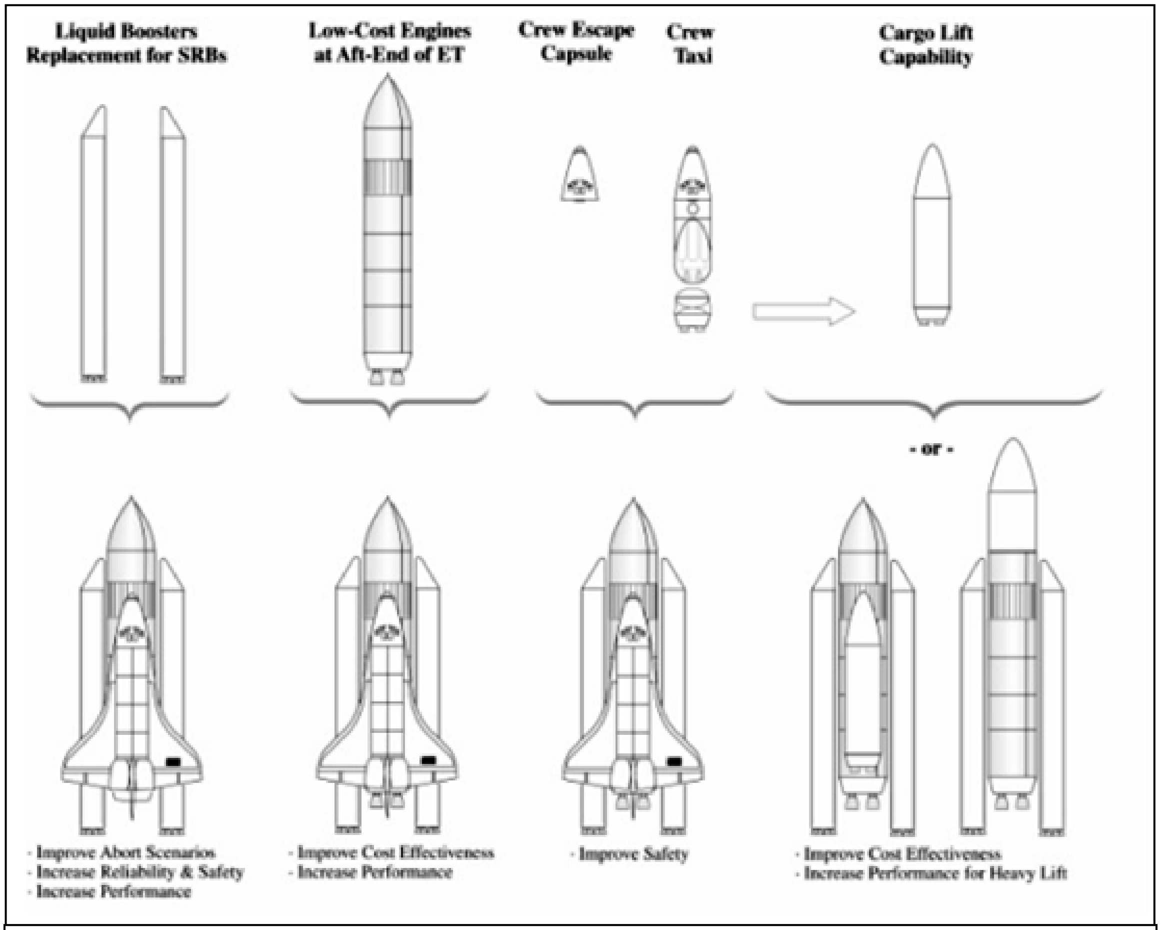

Figure 2.3 – Evolutionary Modular Shuttle System Upgrades

The Space Shuttle of the 1970s can evolve into a robust component of future Space transportation infrastructure if the above 30-year-old recommendations for Shuttle operations are accepted – and this approach would implement the risk-reduction spirit of the recent Gehman Commission report (See Chapter 3.) as follows:

- **Upgrade Space Shuttle Systems and Subsystems to "2000" Technology** – including with a 'Modular' Crew Escape Capsule for the Shuttle that at the same time can also be used for in-orbit Crew Taxi missions in Cis-Lunar Space, including Crewed Orbit Transfer Vehicles (see below);
- **Replace SRBs with Liquid Boosters** – with the following benefits:
    - Substantial launch cost reductions – incremental and infrastructure costs;
    - Substantial reduction in launch risk – allowing for the first time intact abort capability at launch and substantially increased 'failure' recovery capability through 'cross-feed' between the various liquid tanks and engines; and
    - Increased performance – particularly when storing 'excess' LOX/LH2 fuels in orbit for OTV operations beyond LEO by maximizing Liquid Booster use and 'excess' fuel in External Tank (ET) on each mission;
- **Evolve the Shuttle toward a Cargo Version ("Shuttle C") –** including adding modular engines at Aft-End of the External Tank and 'automated' operations of Shuttle launch and return capabilities. This enabling step toward Shuttle class Heavy Lift Vehicle(s) will reduce risk and improve future launch/lift capabilities.

	Shuttle Class	Shuttle Class- Evolved	In-line HLLV	2 Stage In-line
Concept Configuration				
Concept Description	• 1.5 Stage Vehicle • Side mount Payload Carrier - 4.6m x 25m Pld envelope • ET - LOX/LH2 Core • 3 SSME Boat tail on Carrier • 2 - Four Segment SRBs	• 1.5 Stage Vehicle • Side mount Payload Carrier - 7.6m x 27.4m Pld envelope • ET LOX/LH2 Core - 5 ft. stretch LH2 tank • 3 SSME Engines on Carrier • 2 - Five Segment SRBs	• 2.5 Stage Vehicle • Inline Payload Shroud - 9.4m x 27.4m Pld for Mars - 7.3m x 27.4m Pld for Near Earth • ET Derived, LOX/LH2 Core • 3 RS-68 Engines • 2 - Five Segment SRBs • Large LOX/LH2 Upper Stage - 2 J-2S Engines or - 1 SSME	• 2 Stage Vehicle • Inline Payload Shroud - 9.4m x 27.4m Pld for Mars - 7.3m x 27.4m Pld for Near Earth • LOX/RP First Stage • 8 RD-180 Engines • LOX/LH2 Second Stage - 4 J-2S Engines or - 2 SSME
GLOW	2041mt	2449 mt	2871 mt w/ J2S(2) 2876 mt w/ SSME(1)	2223 mt w/ J2S(4) 1991 mt w/ SSME(2)
Performance (Destination)	88.6 mt (30 x 150 nmi Ellipse.. @28.5°)	93.5 mt (30 x 150 nmi Ellipse.. @28.5°)	108.5 mt w/ J2S(2) 113.5 mt w/ SSME(1) (30 x 150 nmi Ellipse.. @28.5°)	102.0 mt w/ J2S(4) 102.0 mt w/ SSME(2) (30 x 150 nmi Ellipse.. @28.5°)

Figure 2.4 – Shuttle Class Evolved and HLLV

- **Spin-off Shuttle-Derived (Modular) Heavy Lift Vehicle –** can deliver heavy and bulky payloads to help build Large Space Structures throughout Cis-Lunar Space as an alternative to assembling them in LEO operations. Liquid boosters and upgraded External Tanks, including retrofits with modular (reusable?) engine capabilities, can help support a flexible, unmanned Heavy Lift capability.
- **Provide a standardized Recoverable Crew Module** – to improve crew survivability in case of catastrophic failure of Shuttle flights, develop a "Separable" Crew Command Module suitable for the Space Shuttle and manned

Space Tug operations throughout Cis-Lunar Space. When combined with the other upgrades of the Space Shuttle, this is as close to "assured" crew survival as one ever can come in human Space Flight.

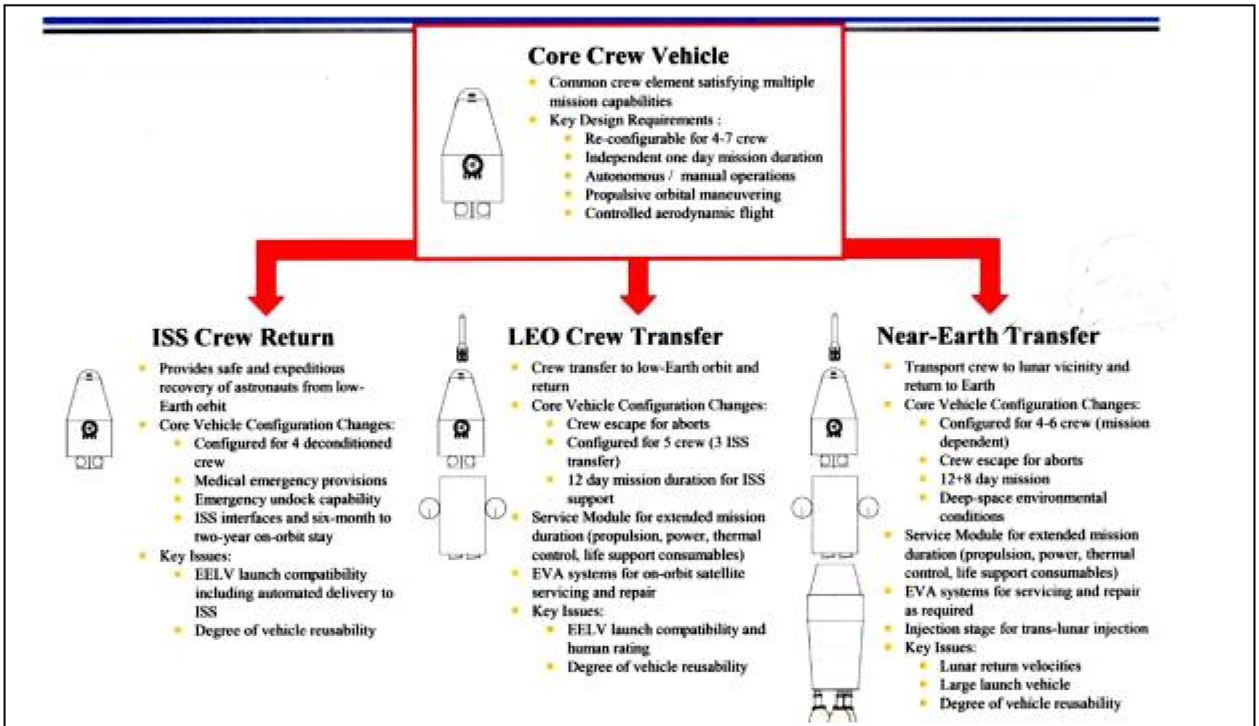

Figure 2.5 – Modular Core Crew Vehicle

A Modular ("Lego") Family of Space Tugs

Cargo orbit transfer operations throughout Cis-Lunar Space and/or Crew Operations up to and including Lunar Landings and restarts were envisioned as part of the STS recommendations of the late-1960s and early-1970s. See Figure 2.6. Key to achieving flexible operations will be to revive the Apollo era engine technology base – particularly restartable LOX/LH2 engines. Then **that technology base can be used to 'modularize' a family of diverse orbit transfer Space Tugs throughout Cis- and Trans-Lunar Space**, up to and including Manned Space Tugs to go from LEO to the Moon's surface and return[2].

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[2] As discussed in Appendix A, Space Tugs – as well as liquid boosters and the other components recommended above – were key elements in NASA's architecture considered by the 1968-69 Space Task Group and evaluated by an independent economic analysis of the space transportation system to support the Space Shuttle decision of 1972. Without the context of a Lunar mission as a goal, pressures for short term cost savings led to a less than optimum Shuttle design with greater recurring costs and risks. Future NASA programs should avoid this danger from shortsighted planning objectives.

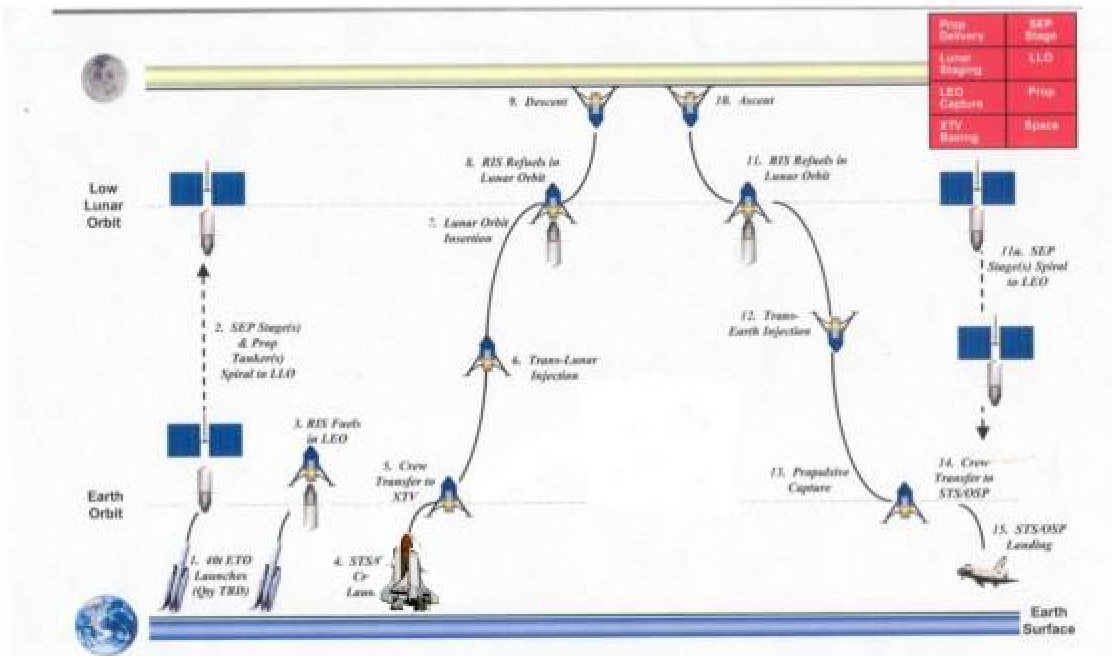


Figure 2.6 – LEO to Lunar Surface Space Tug Capabilities

An overriding reason for a reusable upper stage – a Space Tug – will be its ability to refurbish, repair, update and otherwise tend various payloads throughout Cis-Lunar orbit, just as the Shuttle has done for LEO missions – as demonstrated in repairing the Hubble Space Telescope. A past example where a Space Tug could have made a tremendous difference – with who knows how many benefits to astronomy alone – would have been to repair the $1.5 billion Compton Gamma Ray Observatory (CGRO), which was lost due to four of its six gyros malfunctioning. It could easily have been revisited and repaired – or recovered – with a Space Tug capability. Instead CGRO was 'de-orbited' after failure of Gyro 3 and splashed down June 3, 2000.

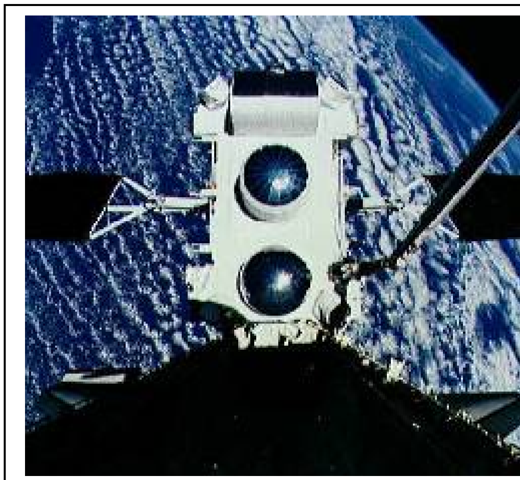


Figure 2.7 – CGRO being deployed from Space Shuttle

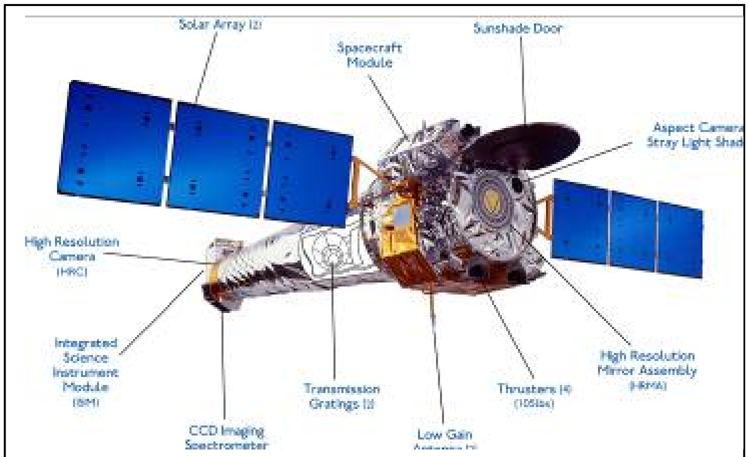


Figure 2.8 – Chandra X-Ray Observatory

Similarly, Chandra, another $1.5 billion astronomy spacecraft – where the optics seem subject to unexpected 'fogging up,' probably due to spacecraft related leaks – could be repaired, refurbished and improved by a Space Tug visit, just as the Shuttle has serviced Hubble. Just as the CGRO was left to 'decay' – and like the MIR Space Station (and SkyLab earlier), Chandra is left untended and degraded. A Space Tug capability can end this *de facto* policy of benign neglect in prematurely ditching accomplishments of the past. Optimum Space Tug design would employ modular building blocks, including a robotic "Mini-Tug" and a Manned Cargo Space Tug.

The Autonomous Space Transfer & Robotic Orbital Server (ASTRO) program is the first step toward a robotic Mini-Tug capability to refurbish, replace, repair and update Spacecraft throughout Cis-Lunar Space. (See Figure 2.9.) The goal of a Mini-Tug Space Operations Architecture program is to validate the technical feasibility of robotic, autonomous on-orbit refueling and reconfiguration of satellites to support a broad range of future U.S. national security and commercial space programs.

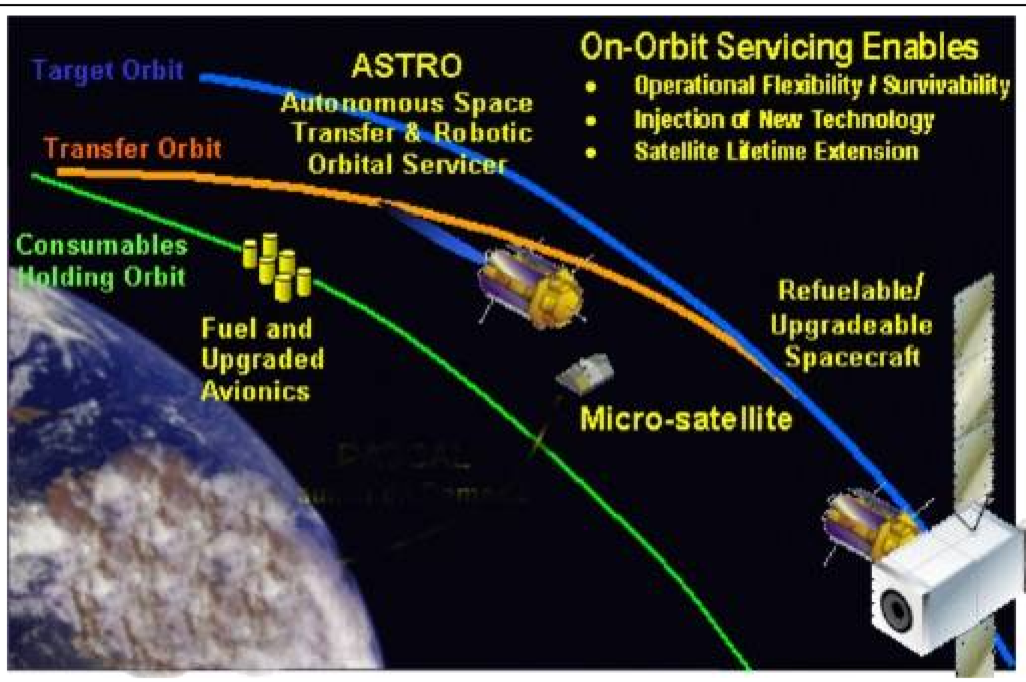


Figure 2.9 –Autonomous Space Transfer & Robotic Orbital Server (ASTRO)

Refueling satellites will enable frequent maneuvers to improve coverage, change arrival times to counter denial and deception, and improve survivability, as well as extend satellite lifetime. This modular approach to Space Tug capabilities will include an engine with reboost capability to make use of ‘excess’ LH2/LOX from LEO and later from Lunar Base(s). Electronics upgrades on-orbit can provide "Moore's Law" performance improvements and dramatically reduce the time to deploy new technology. In addition, a refueling service port can act as a "mother-ship" for micro-satellites, supporting micro-satellite deployment and operations for missions such as space asset protection.

An ASTRO advanced technology demonstration can design, develop, and test on-orbit a prototype servicing Mini-Tug, a surrogate next generation serviceable satellite (NextSat), and the SPAWN Space Awareness prototype micro-satellite escort to provide near-field space situation awareness for U.S. satellites deployed in geo-stationary orbits. SPAWN, designed with a modular satellite bus architecture, can enable rapid integration of payloads for responsive launch. Elements of an ASTRO demonstration, tied together by non-proprietary satellite servicing interfaces (mechanical, electrical, etc.), can facilitate an industry-wide on-orbit servicing infrastructure. NASA can apply the sensors and software developed for autonomous rendezvous and proximity operations to enable future commercial resupply of the International Space Station.

The ASTRO program plans include efforts to:

- Develop and validate software for autonomous mission planning, rendezvous, proximity operations and docking.
- Design, fabricate, and test on-orbit robotic satellite servicing, including fuel and electronics transfer, deployment of and operations with a micro-satellite.
- Design, fabricate, and test on orbit a modular micro-satellite for protection of stationary satellites. Perform utility assessments of on-orbit servicing in conjunction with operational customers and plan for technology transition.

Figure 2.10 provides illustrations of space tugs from the 1969 Space Task Group report. Such Manned and Cargo Space Tugs can transfer cargo and/or astronauts from LEO to the Lunar surface and back to LEO, as illustrated in Figure 2.6.

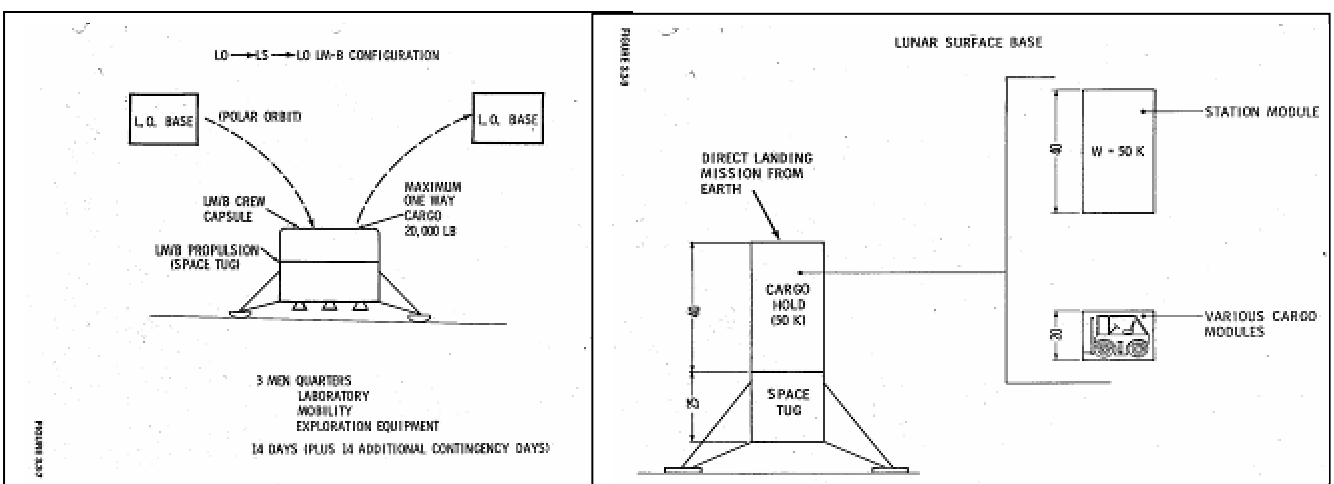


Figure 2.10 – STF Modular Manned/Cargo Space Tugs – 1969 Concepts

In the manned version, the Crew Module is common to the Shuttle Crew Escape Module which, when retrofitted with an ablative heat shield, can also be used for crew emergency returns from any LEO / ISS or emergency Space Tug direct return from Lunar Base(s). The cargo version should be capable of automated operations from LEO to Lunar landings and similarly, once refurbished by the crews on the Moon, automated returns to LEO operations base(s). The capacity of the cargo Space Tug should accommodate the largest component of the Lunar CELSS Base, estimated in 1969-72 to be about 50,000 pounds.

This basic modular space tug concept incorporated in the architectures considered in the late 1960s continue to be viewed as a key element in current space transportation concepts, as illustrated in Figure 2.11 from a recent study. Thus, a modular use of multiple engines could combine to provide a flexible Space Tug capability with ample redundancies to allow for select engine failures. This philosophy followed the Russian approach to expendable launch systems, where a bundling of V-2s and a number of Valiers led to a remarkable cost effective and reliable performance record. Other solutions should be explored as well, up to and including the Nuclear Tug proposed for Cis- and Tran-lunar operations in 1969 for late 1970s operations.

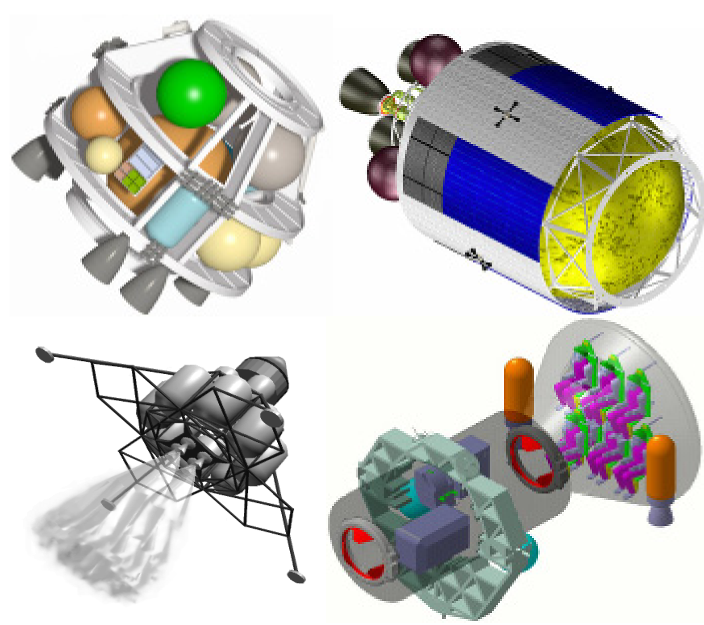


Figure 2.11 - Modular (Manned/Cargo/Propellant) Space Tugs – 2003 Technology

To minimize cost and schedule risks, Lunar Base components will initially be deployed using ‘brute force’ – old fashioned – LOX/LH2 technology (i.e. chemical propulsion). But as the Lunar Base is established the logistics requirements between LEO and LLO and Lunar surface can be met in a very efficient, new way – solar power can supply the energy needed to propel the Cargo using on-board ‘expulsion material’ – in this case Xenon – to propel the spacecraft.

A Solar Electric Propulsion Lunar Tug (SEP-LT), illustrated in Figure 2.12, can be operated continuously in Cis-Lunar space to deliver propellants from LEO to LLO – and can be refurbished and updated in-orbit or, when necessary, returned to Earth. The ISP – the specific impulse (determining the speed with which ‘expelled’ material issues from the spacecraft) – is a multiple of that achievable by chemical propellants. A ‘drawback’ is that relatively little material is expelled at any one moment – hence requiring a much longer time for speeding up and slowing down on the desired transport trajectories.

However, as long as the cargo ‘pipeline’ is planned along ‘just in time’ management principles the additional 80 to 90 days are close to irrelevant for all the cargo that can be transported from LEO to LLO and back, thereby dramatically reducing the total mass requirements to accomplish the logistics of the Lunar Base (propellants, re-supplies, spare parts, expansion modules to the Moon and return samples, research products, modules) from LLO to LEO.

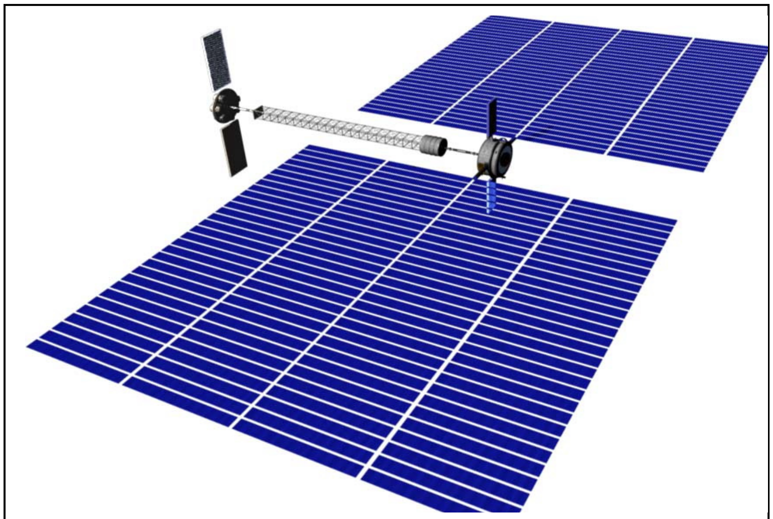


Figure 2.12 – High Power Solar Electric Propulsion Tug for Cis-Lunar Cargo Transports

To transport very massive future payloads, much more massive energy supplies will be required, from the Moon or from Cis-Lunar space. However, once such supplies are available on the Moon (say, a 10 GW LSP plant as shown in Chapter 4 – Prospectives), Cis-Lunar transport and orbit management will be totally revolutionized, opening a new age in space transportation – the era of zero propellant Space transportation. This is only one of the ‘prospectives’ opened up by the establishment of the Lunar Base and to be pursued in decades to follow. For future interplanetary missions, nuclear energy propulsion (NEP), which should be the subject of continuing R&D, would be a primary source of needed power as well.

SEP technology will also be synergistic with the early development of Lunar Solar Power (LSP) systems. For purposes of the Infrastructure cost and schedule estimates RDT&E for such missions, a SEP Lunar Tug stage might be assumed to have the following design parameters: 1 (one) MW – probably magneto-plasma-dynamic, 50,000 lbs dry weight, using Xenon at 3800 sec ISP (specific impulse) which results in an average LEO-to-LLO trip time for propellant re-supplies of about 90 days.

Space Based LOX/LH2 Refueling Stations

Key to Cis-Lunar Orbit Transfer Operations will be In-Orbit (LOX/LH2) Refueling Port(s) to allow Space Station uses as a “Space Port” or refueling/logistics station, as illustrated in Figure 2.13. Among their missions is ‘husbanding’ excess LOX/LH2 fuel and other excess supplies from Earth missions to LEO (e.g., via Shuttle) and storage for Space Station and Cis-Lunar operations/missions, including for Lunar-based Space Tug operations to and from LEO and/or re-supply from Lunar LOX/LH2 production and inventories. Shuttle missions today return to Earth with considerable amounts of water. Similarly, the ISS is producing considerable ‘waste water.’ Using in-orbit ‘re-fuelling and storage depots' to retain and reprocess in Space such 'excess' or 'waste' water, hydrogen and oxygen supplies will improve the logistics of Cis-Lunar operations.

Costs and logistics requirements for initially deploying and operating the Space Transportation System were conservatively estimated without counting on such benefits. It is intended that actual experience be used to realize savings from such operations – resources too valuable, in 'delta-V' alone, to let go wasting. In the decades to follow these fuel storage facilities will be all the more important when LOX and LH2 are produced on the Moon for Cis-Lunar and Trans-Lunar space transportation.

Figure 2.13 – LOX/LH2 Modular Fuel Depot

CELSS Lunar Base Module

Development, testing, and deployment on the Moon of an autonomous Closed Ecological Life Support System (CELSS) capability is the proposed primary NASA space goal for the next decade. (See Figure 2.14.) This key technology and systems achievement for the next decade of Space flight by humans should make extensive use of all system components of the ISS of the 1980s and 90s, SkyLab of the 1970s and other NASA, NSF and U.S. Navy experience in long duration autonomous crew operations and technology.

Although official NASA studies of Lunar bases ceased in 1972, the NASA community has continued to examine the issue of permanent habitats on the Moon and how to make best use of Lunar resources.[3] These studies have made extensive use of the data and experience of the Apollo missions of the 1970s and, as regards human Space flight, the extensive experience gained in the Space Shuttle and International Space Station (ISS) programs and missions. A detailed roadmap on resolving Life Sciences issues and – most important – risk reduction and management for human space flight has been defined for the next decade.[4] Appendix C provides a detailed summary list of the critical issues to be resolved to support long-term human exploration.

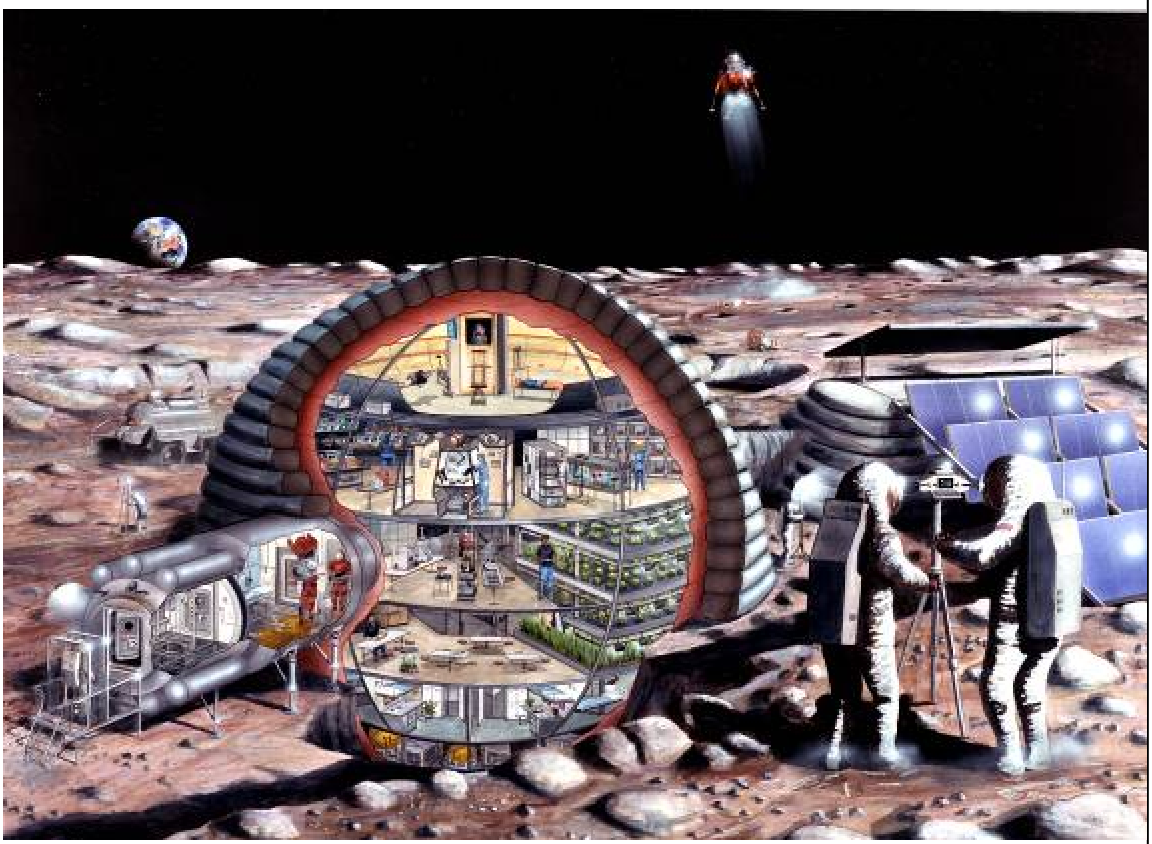


Figure 2.14 – Closed Ecological Life Support Systems (CELSS)

Most critical is a resolution of the issues surrounding stay-times of astronauts in various space environments and the autonomy of operations – an overriding issue in determining overall mission costs for journeys not only to the Moon, but much more critical for any future human exploration missions beyond the Earth-Moon system.

The only realistic and credible way that these important issues can be resolved is by first establishing a permanent outpost on the Moon, as a testbed on these and probably many more issues that may arise (see Chapters 3 and 4 on Risks and Prospectives).

[3] Mendell, W.W. Editor, *Lunar Bases and Space Activities of the 21st Century,* Lunar and Planetary Institute, Houston, Texas, 1985.
[4] NASA Baseline Document "Bioastronautics Critical Path Roadmap – An Approach to Risk Reduction and Management for Human Space Flight", July 30, 2003.

The principal elements of an appropriate comprehensive Lunar exploration program were defined by the 1969 Space Task Group – then seeking to continue to the next logical stage the very successful Apollo program. Three objectives of the 1969 proposed program, which intended to culminate within a decade (See Figure 1.1.) in an extended human presence on the Moon, were to:

1. *Understand the Moon in terms of its origin and evolution, search its surface for evidence related to the origin of life, and apply new data on the differences and similarities between the Earth and Moon to the reasonable prediction of dynamic processes that shape our planet;*
2. *Develop the technology essential for a continued Lunar program which will permit the effective utilization of the Moon; and*
3. *Extend man's domain to include the Moon.*

Reaching the first objective implied a broad spectrum of Lunar-wide scientific investigations to determine structural features, the variability of chemical composition, and correlation of such features in the context of the history of the Moon and the Earth-Moon-Solar System; search for organic compounds, fossil life forms and micro-organisms; and comprehensive studies of all factors of the Lunar environment, including geologic/geophysical processes, one-sixth Earth gravity effects and associated gravitational field variations, solar winds, etc.

It was assumed that humans would be involved in these investigations through an extension of the Apollo program – which, regrettably, was not to be. Three Saturn V rockets were built for exploration by manned missions, but not employed – and instead were located at three NASA centers as historical memorabilia. There was a 25-year hiatus of any direct contact with the Lunar environment – until the 1994 Clementine mission returned to orbit the Moon, mapping its entire surface in over 1.7 million frames of data in 13 spectral bands – more such data than was taken in the Apollo program, the initial analysis of which composed the subject of the entire December 17, 1994 issue of *Science*. Among other things, Clementine pointed to the existence of H_2O in the Polar Regions, an important finding confirmed by the 1998 follow-on Lunar Prospector mission to the Moon. More recently Arecibo radar data failed to confirm the Clementine and Prospector findings, and work on this issue is ongoing.[5]

The lack of manned missions also blocked accomplishing the second objective, which would have developed and demonstrated long range operations across the Lunar surface with reliable vehicles during both day and night operations; a variety of supporting equipment and supporting systems (e.g., shelters, power, communications and data processing) to support Lunar operations – including, where feasible, initiatives for manufacturing processes on the Moon and to exploit the Moon's vantage point to support Earth applications and future planetary missions; long-term independence from Earth consumables by reliance on Lunar resources and closed ecological systems –

[5] As one researcher put it: "If there is ice at the poles, the only way left is to test it is to go there directly," Bruce Campbell of the Center for Earth and Planetary Studies at the Smithsonian Institution, November 12, 2003.

including to minimize problems and risks of long-term survival and/or provisions for rescue or escape; etc.

To reach the third objective, it was judged necessary to determine if Lunar materials can be used to reduce man's dependence on Earth to an acceptable level. If they exist in sufficient quantity at acceptable Lunar sites, utilization methods must be developed and proven – e.g., techniques for extracting hydrogen and oxygen from Lunar raw materials must be demonstrated, and methods must be devised to gather/mine raw materials and use these materials for construction, consumption and operations.

In 1969, it was projected that Lunar exploration could progress to the point where Lunar exploitation could have begun by 1975 (within five years) and exploitation activities could have grown over the next decade. The key elements of the exploration phase were 1) to conduct sufficient scientific experiments to determine the desirability of subsequent exploitation and 2) to assure that there was a sufficiently low-cost Earth-Moon transportation system to support a large long-term manned activity.

Our proposed approach to assuring a cost-effective Earth-Moon transportation system (via Shuttle improvements, a system of Space Tugs and a system of Space stations) was discussed above, Beyond that, it remains necessary to conduct much of the three phases of Moon exploration proposed by the 1969 Space Task Group, namely:

1) Additional landings and Lunar exploration then planned by the Apollo program between 1970 and 1975 – none of which has since occurred;
2) Lunar orbiting missions – a few of which have occurred, e.g., the 1994 Clementine and 1998 Lunar Prospector unmanned missions which returned a wealth of information; and
3) A Lunar base to operate in as autonomous a mode as possible – then thought to compose much of the planned project for the next decade between 1975 and 1985. The Lunar surface base was expected to be established by 1979; and, after major Lunar exploration from that base, it was expected to be a permanent base by the mid-1980s.

Much this same program is recommended today – obviously with the added value of relevant accomplishments since 1969, but with the burden of lost efforts and technology advances that would have occurred, most notably the loss of the Saturn V and related launch capabilities and a systematic development program aimed at Lunar exploration.

Key technology developed by public and private funding of biosphere experiments during the past three decades should be included in establishing mankind's first foothold outside Earth. The proposed system components are basic concepts that have been examined in detail for more than three decades. Still, each of them needs refinement to exploit the best of today's technology – which would be best accomplished thorough competition among various aerospace entities before a final selection of the design for key components of the space transportation system and the Lunar habitat.

However, the basic finding holds: the first permanent Base on the Moon – Columbia – can be established with the means outlined herein, namely:

- An evolution of the Space Shuttle to include Liquid Boosters;
- A modular Crew Rescue/Vehicle Capsule for use on the evolved Space Shuttles, Space Tugs and ISS Crew rescue missions;
- Modular LOX/LH2 Space Tugs for Cis-Lunar and Moon surface missions;
- LOX/LH2 in-orbit fuel port facilities; modular Solar Electric Cargo Tugs for Cis-Lunar operations; and
- The first Closed Ecological Life Support Moon Base – Columbia – all well within proven, tested and existing technology.

A systematic program aimed at establishing a permanent Lunar base is needed to reduce these goals to practice. The establishment of the first Earth-independent Human settlement will far outshine the historic settlement of Jamestown by English settlers in 1607 and all it meant for the subsequent history of the United States.

Cost and Reliability Benefits of Modularity and Standardization

Transportation costs constitute only one third of total Space program costs. The rest has to do with spacecraft, instruments, data and their processing – in space and on the ground. Assuring the viability of such infrastructure is key to reducing costs and risks and improving reliability.

Studies 30-years ago showed that costs can be minimized if spacecraft and Space systems are standardized and modularized at a subsystem level[6]. This idea was revolutionary in the early 1970s and still has to be implemented today – and a reusable Space transportation capability to all orbits would encourage such innovation, which would lead to fundamentally new scientific, commercial and military Space programs.

Costs could be cut by up to 70-percent for small, medium and large Spacecraft. Standardization would facilitate the repair and updating of these spacecraft at a subsystem level. Exchanging, so to say, blue, green, pink and whatever other color boxes would compose tasks requiring minimal training – without prerequisite graduate degrees in aeronautical or other engineering fields. Improved quality control would result from such an approach, improving overall system reliability.

Three decades ago, only a few very select Space missions were found to be "outside" the scope of such standardization. Instead of handcrafting each satellite like ultra-expensive Swiss clockworks, the age of standardization could have been introduced in

[6] The following discussion draws from the 1970-71 independent review performed by the principal author and Professor Oskar Morgenstern, as reported in Klaus P. Heiss and Oskar Morgenstern, *Factors for a Decision on a New Reusable Space Transportation System,* Memorandum for Dr. James C. Fletcher, NASA Administrator, October 28, 1971; and *Economic Analysis of the Space Shuttle System,* Study directed by Klaus P. Heiss and Oskar Morgenstern for NASA under contract NASW-2081, January 31, 1972 – Executive Summary and three Volumes. See also Appendix A.

Space, just as it was in the decades after 1970 in automobile manufacturing and other industries. In fact, private industry's successful development of Iridium – a constellation of 66 communication satellites – demonstrated that such an approach is also viable for Space systems. During the 1990s, that constellation was deployed in five years for $5 billion and today is operated by a half-dozen individuals to support defense missions.

The ability to revisit any and all satellites in Earth orbit to maintain, repair and modernize them at the component level will improve reliability and reduce costs/risks.

- Reliability and assurance of service would be increased dramatically by the STS proposed here. With the ability to revisit, repair and update on-orbit spacecraft provided by the modular architecture recommended here, high assurance of service may be increased to levels customary in ground based operations (twelve sigma or better in electronics), while at the same time reducing drastically the number of spacecraft needed for such assurance of service.
- With a modular, standardized subsystem design, replacement and repair capability, the prospect exists of updating expensive assets in Space, rather than replacing whole systems or letting old technology linger in Space providing obsolete services.

Benefits of New Space Missions via Large Space Platforms

To give a conservative evaluation of the benefits of NASA's proposed Space Transportation System, our economic studies 30 years ago excluded manned missions. We did not want to rationalize the Space Shuttle simply and solely on the basis of man-in-Space – that would tilt the analysis much too much in favor of the Space Shuttle.

So we set out to define an entirely unmanned Space mission program, making use of the extensive new capabilities that the Space Tug and Space Shuttle opened up: structures larger than could be carried by any expendable system, standardized and designed for maintenance, repair, replacement, and updates. The large size of many of these platforms, their costs and potential technological improvements with advancing technology, and their amenability of direct access for maintenance, repair, and modernization would provide assurance of high reliability – 99.999-plus percent.

Considered also would be entirely new classes of spacecraft for science, commerce and defense, whether in LEO or beyond GEO. Dozens of new Space application missions were outlined for NASA, the DoD and private enterprise to pursue once the Space Shuttle and Tug were fully operational. For example, we proposed:

- **Advancing Space Science.** One of our first visits in Princeton was to the astronomy department, then chaired by Prof. Spitzer. These meetings led to the Hubble Space Telescope. Were it not for the unique capabilities of the Space Shuttle, this telescope could never have been built, launched, repaired, maintained and modernized, up to and including previously unanticipated capabilities. The myriad of discoveries made with this magnificent instrument justifies the cost of the entire Space Shuttle program, including the tragic death of the crews of Challenger and Columbia. What nobler cause than to die in pursuit of the ultimate questions of why we exist, where we came from and where the journey will take us in the future? Beyond Hubble, we defined half-a-dozen other scientific spacecraft, ranging from radar to infrared to multi-spectral instruments of a size and capability preciously unknown and unimagined.

- **Encouraging Commercial Applications.** Some suggested communications and navigations applications would develop with or without the Space Shuttle – such as GPS, a variety of Global resources sensing satellites, and low and high Earth orbit communication satellites at a variety of frequency bands. Thirty years ago, we also foresaw an entirely new class of satellites, with vastly expanded capabilities, requiring precisely the same type of engineering approach as for the Hubble Space Telescope. For example, we envisioned communication platforms in geo-synchronous orbit, with on-board switching capabilities, vastly expanded power-requirements, on-board data processing and storage, with tens of thousands of spot beams, with satellite-to-satellite optical and laser communications. Once deployed, this system would provide point-to-point communications to any place in the world, without any ground communications capabilities, allowing access to any and all data and information bases with simple, handheld devices.
- **Benefiting Defense Applications**. At least one third of all applications foreseen for the new STS were defense related. They included some of the applications realized since then in navigation (GPS), in observations, in communications, albeit not to the extent possible if we had truly developed the full Shuttle and Tug capabilities, with vistas as to expanded uses of Space very similar to those cited for commercial uses above. Other applications have not benefited from the potential cost/risk reduction and improved reliability fostered by the modular STS recommended here.

For remote sensing of the Earth resources, we envisioned a Global Resources Information System (GRIS) described in detail in the NRC papers of the Snowmass meetings of 1974. The effect on the distribution of world food supplies through the commodities markets alone accounted for billions of dollars in annual benefits. Environmental, energy, geologic and other resource observations benefited as well, including such arcane applications as archeology. Many of these have become reality to date, as they can also be achieved with smaller spacecraft, not requiring the capabilities of the Space Shuttle and Tug system.

Closure

Because of our decision to exclude manned missions in the evaluation of the economic benefits of NASA’s 1969 proposed Space Transportation System – reiterated here as this current report’s primary recommendation, we did not include important applications of that architecture.

For example, large Solar Power Satellites of up to 100 square miles in area, as first proposed by Peter Glaser of Arthur D. Little in 1968[7], provided a truly spectacular vision of future energy supplies from Space to Earth. As envisioned by Glaser, one such platform alone would be able to supply up to 10 GW of electric power to any point on Earth within its 'line-of-sight'. Such concepts would benefit greatly from a Lunar base and the exploitation of Lunar resources to help harness such energy resources.

Also not included in the analyses were any Human Space flight missions such as a Space Station, or Lunar missions or missions beyond. The reason, once again, was not to co-mingle the obvious missions and requirements of manned Space Flight with an analysis of whether a Shuttle and Tug were needed even without such missions – a question which was answered in the affirmative.

Our vision in 1972 included the fact that these space-based capabilities would not be subject to totalitarian government controls, and would be able to make available the complete Library of Congress as if entering that Library, its catalogues and volume retrievals "on site". We projected these capabilities could bring about the collapse of such totalitarian systems that to a large extent were built on the control of information. Alas today we are still a long way from reaching that lofty goal, with many a trend recently taking us in a somewhat different direction of more control and less access.

The bottom line of this assessment of the technological building blocks for returning to the Moon to stay is that the new horizons provided by both manned and unmanned missions are truly astounding – and well worth the investment, as was demonstrated to be the case in 1972. The key question is whether the current political leadership agrees to make the necessary monetary and political investment.

"The future is purchased by the present."

Samuel Johnson

We conclude this memorandum with the observation – though by now trivial and obvious, but nevertheless fundamental – that any expenditure of public funds must be justified, precisely [the same] as expenditure of private and business funds, by the <u>aims</u> and <u>purposes</u> of the expenditure. Technological possibilities alone carry no conviction, though they often bring new possible aims into sight and reach. Whatever their nature and origin, the different aims must be hierarchically ordered and must find their place in the system of national priorities.

Klaus P. Heiss and Oskar Morgenstern
October 28, 1971 Memorandum to NASA Administrator James C. Fletcher

[7] Glaser, Peter E., "Power from the Sun: its Future", *Science*, 162, 857-866 (1968)

Chapter 3 – REDUCING RISKS

"Politics is more difficult than physics."
Albert Einstein

As with all worthy enterprises, returning to the Moon within a decade requires creative technical and management innovation and involves risks. The technical risks were acceptable to take this logical follow-on to the Apollo program over 30 years ago – as elaborated in the 1969 Space Task Group Report and discussed in Chapter 2.

However, the proposed program to achieve this goal was not politically viable in 1969, in the heat of the Vietnam debates over national priorities and budgets. Nor has it been politically viable in several subsequent attempts to take this logical next step. Perhaps now, in the wake of the Columbia accident – and consistent with the council of the Columbia Accident Investigation Board[1] (the Gehman Commission) – that political condition has changed. Unless the political condition has changed, a discussion of technical risk is little more than a futile exercise.

This observation is not intended to ignore that some technical risks important to building a Lunar habitat have been reduced by NASA's continuing manned space programs and principally unmanned missions to explore Space. For example, the 1994 Clementine mission returned to map the entire surface of the Moon after a 25-year hiatus – and the December 17, 1995 issue of *Science* is devoted to analysis of 1.7 million frames of Clementine data. Clementine data suggested that there is water in the polar regions of the Moon – if confirmed, this finding will siginficantly help establish a viable Lunar base.

Meeting the Gehman Commission's Requirements

Other risks are largely unchanged because there has been no serious program to solve, in a timely way, the key technical problems confronting human enterprize in Space. As observed on page 209 of the Gehman Commission's review of the physical and organizational causes of the *Columbia* accident, two key missing causal realities undermine the nation's ability to sustain a viable, vibrant manned space program:

- "The lack, over the past three decades, of any national mandate providing NASA a compelling mission requiring human presence in space;" and, following the lack of such a clearly defined long-term space mission,
- "The lack of sustained government commitment over the past decade to improving U.S. access to space by developing a second generation space transportation system."

[1] The *Columbia* Accident Investigation Board, chaired by Retired Admiral Harold W. Gehman, focused on the physical and organizational causes of the *Columbia* accident and recommended actions for future safe Shuttle operations.

As outlined in chapters 1 and 2, these conditions, which have prevailed for over three decades, can be rectified by a national goal meeting the criteria set out as a basis for this assessment: Establish a Lunar Base within a decade, Space Base “Columbia”. What better memorial to the loss of the seven *Columbia* astronauts than to put the safety requirements and concerns arising out of the Columbia disaster to positive use toward the achievement of a truly historic goal for human Space flight and exploration?

The Gehman Commission was unanimous in its support for a continuation of Human Space Flight; e.g., their report states on page 210, **“The United States needs improved access for humans to low-Earth orbit as a foundation for whatever directions the nation’s space program takes in the future”.** The program discussed in the previous two chapters will significantly reduce the risks identified by the Gehman Commission. Developing the technology building blocks outlined in Chapter 2 to support a Space Transportation System and a permanent Lunar base will importantly comply with – and in many ways go beyond – the specific recommendations set out by the Gehman Commission for the short and mid-term, as discussed below.

Upgrade Space Shuttle System and Subsystems to 2000 Technology. Many of the technical corrections for the current Space Shuttle system – near-term and mid-term – recommended by the Gehman Commission can be accommodated under this initiative (p. 225-227 of Commission report), including:

- Thermal Protection System Recommendations
- Imaging
- Orbiter Sensor Data
- Wiring
- Bolt Catchers
- Closeouts
- Micrometeoroid and Orbital Debris
- Foreign Object Debris
- Scheduling, and
- Training

The Gehman Commission also called for recertification of Shuttle (p. 209): “Prior to operating the Shuttle beyond 2010, develop and conduct a vehicle recertification at the material, component, subsystem, and system levels. Recertification requirements should be included in the Service Life Extension Program.” Specifically, we propose to:

Replace Solids with Liquid Boosters. As reviewed in Appendix A, liquid boosters should have been part of the initial Space Shuttle decision in 1972 – based on an examination of full life-cycle cost – but solid rocket boosters (SRBs) were selected because of their lower non-recurring (development) costs.

Unless the SRBs are replaced by liquid boosters, ‘intact abort’ can never be achieved. The most spectacular Space Shuttle ‘launch’ was when a flight was terminated on the pad after ignition of the Space Shuttle engines but before the ignition of the solid boosters when a problem was indicated by various instrument readings. Had either of the Solid boosters ignited, such an abort would not have been possible, nor is intact abort possible at present for the initial minute(s) of flight well into a Space Shuttle mission. Indeed the 'worst' Space Shuttle accident – a 'cartwheel' on the launch pad when only one of the Solids were to ignite – has not yet happened, but cannot be excluded.

With Liquid Boosters several significant – indeed mandatory – advantages accrue in launch operations:

- Single LOX/LH2 fuel system for all launch components (tank and boosters);
- Intact abort at launch;
- With cross-feed among the various LOX/LH2 engines (SSMEs, Liquid Booster engines, future Tanks engines) intact mission termination may be possible throughout ascent by significantly increased capability of correcting failures of one major system component (fuel tanks, fuel links, engines) with remaining capacities;
- Significant reduction in pre-launch complexities and flight preparation issues and costs (single fuel system and technology); and
- The Challenger disaster would have been avoided.

Evolve the Shuttle toward a Cargo Version. An (unmanned) Shuttle C (cargo) can evolve within the proposed evolutionary Shuttle upgrade program envisioned originally (in 1972) and readily accommodated with the need to retrofit an eventual Crew Rescue Module (CRM, see below). Such a cargo version would substantially increase unmanned payload capabilities to LEO and significantly decrease payload / Shuttle related costs from the manned aspects of mission specifications. Included can be LOX/LH2 refuelling modules to LEO for in-orbit fuel depots for Space Tug operations, making economic use of any excess launch volume or mass budgets.

Develop Shuttle derived (Modular) Heavy Lift Vehicle. By adding LOX/LH2 engines to the External Tank ("ET") and implementing the other ET related recommendations of the Gehmann Commission, a modular Heavy Lift capability can evolve from the current Space Shuttle system components, including expenable launches with recovery/reuse of high value items (e.g. engines), up to and including "Twin-Parallel-Burn" Shuttle launches, increasing STS cargo capability well beyond any currently foreseen launch mass or volume requirements.

Develop a Recoverable Crew Module. Such a capability would have allowed rescue of the Columbia crew during ascent and later from orbit, particularly if Space Tug capabilities also were operational in orbit. Such modules when added with 'reserve' heat shields would also allow an efficient, low cost ISS crew evacuation capability.

Deploy a Modular ('Lego') Family of Space Tugs" and "Re-Fueling Port(s) for Cis-Lunar Operations with Mini-Tugs, Cargo Tugs, Crew Module Tugs and Re-Fueling Ports.

A new era in Cis-Lunar Space operations will open with these components added to a Recoverable Crew Module, which would have allowed rescue of the Columbia astronauts in/from orbit. Never again should the temptation arise not even to ask for data due to an assumption that nothing can be done if the worst fears were confirmed by the data. Some operating capacities of the Space Tug fleet have to be set aside for such refurbishment, repair and – if nothing else – rescue of astronauts stranded in Cis-lunar orbit.

The Columbia disaster might not have happened with a successful refurbishment (including prolonged crew stay in orbit, if necessary) and repair mission and certainly the astronauts could have been rescued.

Indeed, the requisite technology components go significantly beyond the Gehman Commission's recommendations and could allow, for the first time, intact abort or crew rescue throughout LEO – something clearly lacking with a continuation of SRBs or the palliatives of what euphemistically is called a Space Plane, an 'option' clearly rejected even in 1971/72.

Beyond Gehman: Reducing the Risks of Human Space Flight Exploration of the Moon and the Solar System

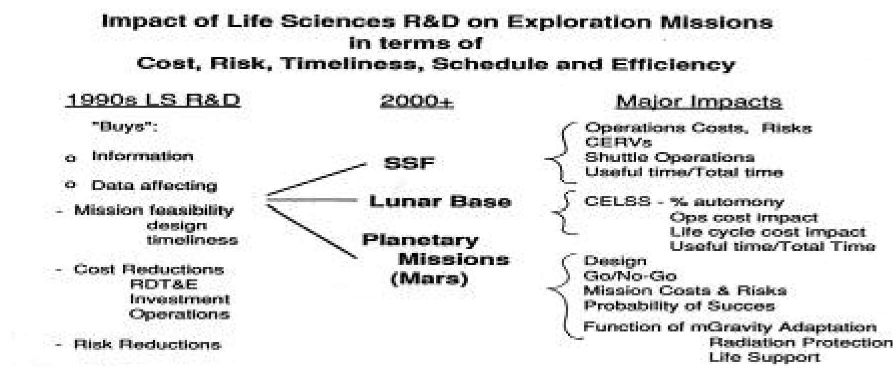
The testing, development and deployment on the Moon of such a Closed Ecological Life Support Systems capability – evolved from the ISS Technology Base – must be considered the primary NASA space goal for the next decade. Establishing the first Earth-independent Human settlement will far outshine the historic settlement of Jamestown by English settlers in 1607 and all it meant for subsequent U.S. history.

At the same time, the initial design for an autonomous Closed Ecological Life Support System – the key technology and systems achievement for the next decades of Space flight by humans, ultimately throughout the Solar System – should make extensive use of any and all system components of the ISS of the 1980s and 90s, Skylab of the 1970s and extensive other NASA, NSF and US Navy experience in long duration autonomous crew operations and technology.

Reduce Risks via Robust Life Sciences Program. Lest we forget, the tragic last flight of Columbia was a Life Sciences flight, dedicated to finding out how organisms are affected by key aspects of the Space environment – low gravity, increased radiation, and the effect of both combined on living organisms. Also part of their work and that of the Life Sciences program is an evaluation of countermeasures to overcome any adverse effects and protocols on how to manage any of the remaining risks.

The interdependence of the various life sciences research fields and the impact these results have on potential mission costs, risks and schedule are schematically shown in Figure 3.1:[2]

Figure 3.1



This research can be thought of as 'buying' information and data on the feasibility of various exploration missions; the needed design parameters such as shielding, artificial gravity, exercise regime; scheduling issues of the ISS; potential Lunar Bases; and missions beyond to Mars, asteroids or other Moons and planets. Substantial work has been accomplished in the 1990s[3] and early 2000s[4]; a comprehensive review of the current status of many of the outstanding questions is summarized in Appendix C.

Figure 3.2 - RDT&E Testbed on Earth for Lunar and Planetary CELSS

As suggested in Figure 3.2, some of the necessary Life Sciences research can be conducted on Earth, including biosphere experiments supported by private funding and in various Life Sciences facilities at NASA centers and elsewhere. Additional such facilities are proposed for testing various aspects right here on Earth. But to understand

[2] Heiss, Klaus P. and Francis Sand, *Exploration Missions and Life Sciences: Issues and Linkages*, Report to Frank M. Sulzman, NASA, February 20, 1992.
[3] NASA Advisory Council – Aerospace Medicine Advisory Committee, *Strategic Considerations for Support of Humans in Space and Moon/Mars Exploration Missions*, June 1992.
[4] NASA Baseline Document, *Bioastronautics Critical Path Roadmap – An Approach to Risk Reduction and Management for Human Space Flight*, July 30, 2003.

the impact of the adverse environmental factors of Space on the human body, one has to gain practical experience in real flights in space. The extensive flight experiences gained from Shuttle operations and the ISS over the past two decades have considerably extended our experience base, the duration and to some extent the autonomy of human space flight.

Important questions have to be answered beyond what can be gained from Near Earth missions: (a) understanding the effects of reduced gravity (such as 1/6 of Earth Gravity on the Moon) vs. a near absence of gravity (Shuttle, ISS) along with radiation and ‘isolation’ effects; (b) an ability to operate on other celestial surfaces (the Moon); and (c) the extent to which ‘local’ resources can be used to increase *in-situ* autonomy and decrease the need for re-supply and support from Earth. Figure 3.3 shows one evaluation of potential use of Lunar resources for in-space support/operations.

Applications \ Resources	Moon and Asteroids	Sunlight	Unprocessed Materials	Bricks	Metals	Ceramics	Oxygen	Silicon	Volatiles	Slag
Shielding			x	x	x_1					x
Reaction Mass, Propellants, and other consumables					x		x	x_2	x	
Structures				x	x	?				
Projectiles				x	x	?				
Targets and Decoys	x	x	x	x	x	x	x	x	x	x
Stabilizing Inertia			x_1	x						x
Heat sinks					x				x	
Energy Storage					x	x	x	x	x	
Energy Productions and Distribution	x_4	x						x		
Strategic Materials		x_6								
Lunar/Base Platform	x	x_6			x_5					
Space Manufacturing	x	x	x	x	x	x	x	x	x	x

KEY

X – potential match of resource to military applications deserving study. Potential application; utility depends on engineering details of military requirements

- most likely drivers

1 – These two applications are most likely (in terms of total tonnages needed) to drive NTMs for defense application.

2 – Reaction mass could be dust; propellants could be liquid oxygen/hydrocarbon/hydrogen; more advanced propulsion systems (e.g.,Electric Propulsion using Ammonia).

3 – Lunar Water returned to GEO may provide an early high-leverage return from NTMs.

4 – Solar arrays constructed on the lunar surface may provide a viable power source for high power systems in cis-lunar space.

5 – Independent source of these materials may be sufficiently important that standard cost/benefit considerations may not apply.

6- Solar Energy may be collected on lunar surface for transmission

Figure 3.3 - Potential Applications of Lunar and Near Earth Asteroid Resources

Also important will be real (live) testing of such technologies as tele-medicine and other tele-operations, allowing effective combination of terrestrial capabilities with Lunar and later planetary habitats. Timely information saves lives, reduces costs, and increases autonomy and productivity of the ‘on-site’ crews.

In addition to the overriding Trans-Lunar ‘mission enabling’ character of Life Sciences research in the three areas already outlined above (micro-gravity, heavy particle radiation and long isolation human aspects of prolonged Space flight), the following research areas will be advanced by CELLS and evolved ISS capabilities:

- Improved Crew capabilities and performance in Space operations, including increased automation of systems, self-repair, tele-robotics, tele-presence etc.;
- Advanced Crew interfaces;
- Reduced ‘Outside’ (Earth) Re-supply;

- Maximize closed loop life support;
- Micro/miniature sensors, processors and wireless technologies; and
- Advanced fabrication, repair and self-repair technologies.

To accomplish these tasks – reducing risk and increasing the autonomy and the duration of ‘in Space’ stay times – comprehensive RDT&E has to be conducted on Lunar materials and structures deployment and re-supply technologies for Cis-Lunar and (later) Trans-Lunar Space. As indicated in Figure 3.3, many synergistic effects exist between various future Space applications in Cis-Lunar Space and the material resources of the Moon. How to use these to increase the autonomy of Lunar and Cis-Lunar Space operations will be a central theme over the next decades.

<u>Evolve ISS to a LEO and/or Lunar CELSS Base</u>. Increasing the autonomy of ISS and Lunar Base operations through RDT&E and deployment of a truly autonomous – without external re-supply – Closed Ecological Life Support Systems will significantly extend any ‘emergency’ crew stay time on the ISS or on the Moon, whenever extended unexpected interruptions of normal space operations and logistics should occur.

The impacts and benefits of information and data to be gained from *in-situ* (on site, in Space) life sciences research at a Lunar CELSS facility are substantial – and critical to human exploration of the Solar system. Detailed Monte Carlo simulations of specific risk network analysis models using Life Sciences RDT&E parameters and U.S. Navy submarine data showed a significant impact of expected CELSS results on ISS operations, crew emergencies and autonomy. The basic model life sciences inputs and interactions are shown in Figure 3.4[5]:

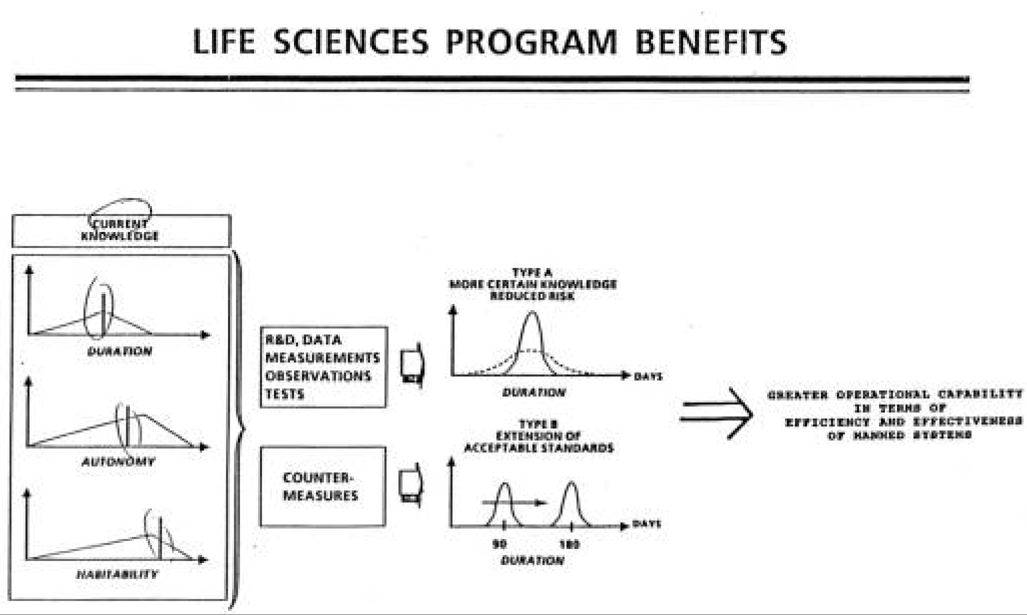


Figure 3.4 – Life Sciences Parameters impacted by CELSS Research.

[5] Klaus and Sand, *op.cit.*

In the 1990s the principal author and Francis Sand conducted extensive simulations to evaluate the contributions to be expected from various projects, extending real life experience of two key parameters critical to planetary exploration such as missions to Mars: duration ('stay-times' of astronauts before a need to return) and autonomy – the ability to sustain the crew with diminishing 'from-Earth' support and supply requirements. As one steps up the 'delta V mountain' of solar system exploration missions, the more distant and massive are the selected destinations, the higher are the rewards to increasing the autonomy and the duration of stay-times. The notional impact of extending the autonomy of ISS operations from CELSS research is shown in Figure 3.5[6]:

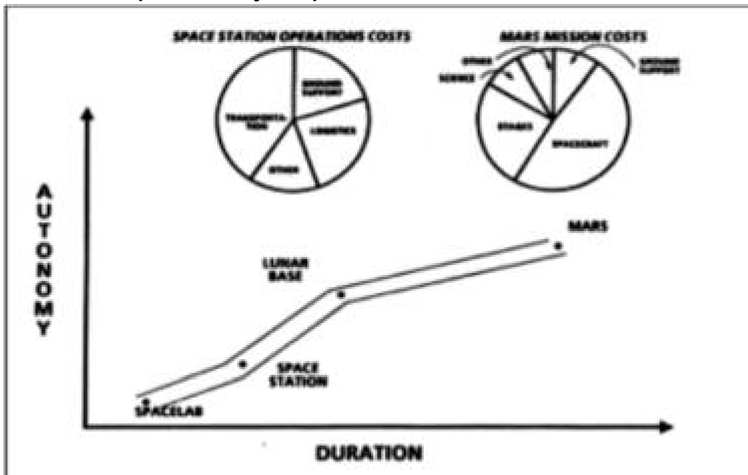


Figure 3.5 – The Impact of Life Sciences R&D on Human Space Exploration Mission

Hundreds of simulation runs varied crew sizes, number of flights, and stay-times using actual U.S. submarine data on the impact of 'unforeseen' health emergency events. As stay-times in orbit are increased due to advances in Life Sciences CELSS capabilities the number of flights and rescues are substantially reduced, in this case to and from the International Space Station. See Figure 3.6.

REPRESENTATIVE EXAMPLE OF IMPACT OF LIFE SCIENCES RESEARCH ON SPACE STATION OPERATIONS

TABLE E1

OPTIMIZED STAYTIMES SUBJECT TO LIMITED % RESCUES

MTBE = 200 days

LIMIT %	3	4	5	6	7
FLIGHTS	184	137	109	90	76
RESCUES	6	5	5	5	5
STAYTIMES	45	62	81	202	126

MTBE = 500 days

LIMIT %	3	4	5	6	7
FLIGHTS	74	55	44	36	30
RESCUES	2	2	2	2	2
STAYTIMES	112	155	203	255	314

Figure 3.6 – Results of Monte Carlo Simulation Runs of extending Autonomy and Duration of On-Board Stay Times using U.S. Submarine Data

[6] Klaus and Sand, *op.cit.*

Applied to the question of human exploration missions to the Moon and beyond, the simulation data indicate a not-insignificant risk from health emergencies – random and unpredictable. Rescue and return missions from the Moon to Earth are a matter of a few days, and 'manageable' – whereas missions at substantially greater distances from Earth currently could not be accommodated with confidence.

ISS operations and the design of the first Lunar habitat will be strongly affected by on-going Life Sciences R&D. With the deployment of an actual facility on the Moon, the very question of the role and scope of humans throughout the Solar system can be addressed with considerable confidence, with expected substantial 'savings' in potential planetary exploration costs and reduced risks.

Closure

When contemplating risks, it should be understood that establishing a Lunar habitat within a decade was judged feasible over 30-years ago with then extant technology. On page 1-29 of its report summary, the 1969 Space Task Group noted their recommended program continued the Apollo mode and equipment for five years, judged "adequate time to develop firm information before committing to the Lunar orbit station mode" – in turn intended to help establish Lunar sites for further observation and for a Lunar base. This section concluded, **"In fact it is quite possible to have a surface base well established before the end of this decade [i.e., the 1970s] without making a significant commitment before 1975."** Given the subsequent advance of technology and additional information on the Moon, the technical risk is less today.

While it is not possible to allocate 'precisely' the individual technology block components of the identified Space Goal – a manned Lunar Base within a decade – it is certainly clear that the above discussed technology and capability in combination amply meet the concerns and recommendations set out by the Gehman Commission. Indeed in some important ways the requisite technology components go significantly beyond the Commission recommendations. For example, they would allow, for the first time, intact abort or crew rescue throughout LEO space flights by astronauts, which would be lacking with a continuation of SRBs or the palliatives of what euphemistically is called a Space Plane – an 'option' clearly rejected even in 1971-72.

"The U.S. space effort has moved forward for more than 30 years [since Apollo] without a guiding vision, and none seems evident. In the past, this absence of a strategic vision in itself has reflected a policy decision, since there have been many opportunities for national leaders to agree on ambitious goals for space, and none have done so. . . . We belsieve that the White House, Congress, and NASA should honor the memory of Columbia's crew by reflecting on the nation's future in space and the role of new space transportation capabilities in enhancing whatever space goals the nation chooses to pursue."

***COLUMBIA* ACCIDENT INVESTIGATION BOARD**
Report Volume 1, August 2003

"Far better it is to dare mighty things, to win glorious triumphs, even though checkered with failures, than to rank with those poor spirits who neither enjoy not suffer much, because they live in the gray twilight that knows not victory nor defeat."

Theodore Roosevelt

"They had a hunger to explore the Universe and discover its truths. . . They, the members of the Challenger crew, were pioneers. . . The future doesn't belong to the faint-hearted. It belongs to the brave. The Challenger crew was pulling us into the future, and we'll continue to follow them."

Ronald Reagan – 1986

I believe without question that if a nation misses the great movements of its time it misses the foundation on which it can build the future. The high technical requirements for success in space are so fundamental that spin-off rewards are almost automatic. . . No one today can even guess the limits of either the personal items or the industrial which might accrue from the basic scientific work that has to be done in a space program. This is the great unknown ocean of the universe and we . . . are as obligated to probe it and use it and participate in its control as the nations of Europe were obligated to explore their terrestrial oceans in 1483. I believed that there are moments in history when challenges occur of such a compelling nature that to miss them is to miss the whole meaning of an epoch. Space is such a challenge.

John A. Michener

Chapter 4 – THE 'PROSPECTIVES'

The Space 'Rock of Gibraltar'

Looking at Earth from the Moon – From Exploration to Enterprise.

> ***"More Solar energy 'hits' the surface of the Moon in but 10 days than the energy from all known global fossil fuel resources accumulated over eons past on Earth"***
> **This Report – page ix**
>
> ***The object of your mission is to explore the Missouri River, & such principal stream of it, as, by it's course & communication with the waters of the Pacific Ocean, may offer the most direct & practicable water communication across this continent, for the purposes of commerce.***
> **President Thomas Jefferson**
> **Instructions to Lewis and Clark**
> **June 20, 1803**

No single image has changed our lives more than the one shown on the cover of this report: a lonely Earth floating precariously in the 'emptiness' of Space over the horizon of the Moon. This 'one' image has driven home the beauty, the vulnerability and the uniqueness of the planet we call Earth, more than all the volumes and libraries full of informed discussions, concerns and recommendations.

Indeed, looking again at this image, it is surprising and 'shocking' that some of that awareness has 'receded,' at least in the minds of some of us swamped by everyday concerns and issues.

Establishing a permanent human presence on the Moon will forever change the reality and our perception of the world we live in. There is no other point of 'real estate' from which Earth and the space around Earth can be so easily observed and managed. The Moon is our 'natural' Space Station, waiting to be explored, developed and used.

It remains for many others to 'fill' the list of opportunities that will come with this change in perspective. What is done here is but to sketch out some basic areas that are profoundly affected by a decision to establish a Lunar Base.

Profound Science and Technology Implications. One of the foundations of the vigor of free market economies – and the U.S. economy in particular – is the immense drive for innovation, which in turn is based on the 'human resources' of education, the sciences and technology.

There has been a serious erosion of these foundations of U.S. wealth, in aerospace in particular. Things we could do a few decades ago today seem to be outside of our immediate reach, including an ability to return to the Moon, or even to replicate a Space Shuttle, much less improve its design to exploit '2000' technology. These resources (ultimately one and all human resources – engineers, scientists, aerospace workers) should be mobilized, maintained and expanded, not through 'make work' programs that reinvent the wheel (e.g. one more 'expendable' launch system) but through challenges that open new frontiers, such as on and from the Moon.

A portfolio of entirely new applications, technologies, missions are outlined in this report, based on the work of literally hundreds and thousands of innovators, scientists and engineers of decades past – to be expanded by ideas and concepts of many others over the next months and years. This portfolio of opportunities encompasses all areas of technology and the sciences, across literally the whole electromagnetic spectrum, all the life sciences, the communications and information economies (well over 50% of all economic activities in advanced economies), material sciences and human factors. With the prospect of an inexhaustible energy base – be it solar, be it nuclear – there are no limits to the expansion of this new frontier other than our failure to set out to explore, breach and expand this frontier as well.

Most important: **science and technology do not happen in the 'abstract'**, as percentages of GNP or incantations of the need for more Ph.D.s, engineers, technical workers and educators, more science, statistics and mathematics high school students and college graduates. All these incantations and lamentations will go unanswered if there are not goals that challenge our imagination and make us take the hard road of sweat and tears and work and risk and all the long and lonely hours of studies and tests and failures – with here and there the thrill of success.

This downward trend can be reversed by a challenge to bring about new opportunities of the Frontiers of Space, with **real life applications in the next decades** and – if even a fraction of the opportunities are pursued, requiring numerous enterprising new employment prospects. We will see the influx not only of our own children toward these new opportunities, but also thousands worldwide will join us in Space enterprise.

Unique 'Cis-Lunar' Properties of Space Station Moon. The 'locational' advantages of "Space Station Moon" include that:

- It is a massive, 'airless', stable platform.
- It has an unlimited supply of solar energy hitting its surface and immediate surrounds – an energy potential of about 1.3 KW per square meter (!) at an average of 1 AU. More 'impressive' is that in but ten days more solar energy 'hits' the surface of the Moon than all the known global fossil fuel resources accumulated over eons past on Earth! Without an atmosphere the energy is there for the taking.
- It can serve as an ideal platform for emplacing nuclear reactors and missions using these power sources in a variety of novel Space missions. Use of any number of Prometheus size reactor modules will allow any level of foreseeable power supplies as an alternative to or complement to solar power plants.
- It could also serve potentially as an ideal testbed for 'clean' fusion RDT&E using the 'captured' He3 in Lunar soils – 'clean' insofar as fusion processes using He-3

generate as their major byproduct deuterium rather than the exceedingly volatile contaminating byproduct tritium associated with ‘conventional’ fusion processes.[1]
- It has only a sixth of Earth’s gravity enabling major reductions in transport energy required (and associated delta-V) for many important operations.
- It has most material resources needed for Space and Lunar structures and operations, including some of the direly needed water resources (hydrogen in particular).
- Last but not least, it is only a very short distance from Earth, indeed the Moon is part of ‘Earth Space’ and an ideal platform to observe all of Cis-Lunar space across the full electromagnetic spectrum.

A ‘Portfolio’ of different applications, projects and missions can be assembled to illustrate many diverse technologies and concepts proposed in previous decades. With a renewed and specific commitment to return to the Moon – this time to stay, the portfolio will expand in the sciences, applied technology areas, exploration missions and practical applications on the Moon, in Cis-Lunar Space and on Earth. These will be stimulated throughout academia and the research and technology community, as well as in industry and the private sector. ‘Rules of the Road’ have to be defined to facilitate such co-operation and participation.

Last and not least, many of these seed technologies and programs can first be tested as to their components and critical lead items on the ISS and Low Earth Orbit, as well as laboratory simulations on Earth where appropriate.

While nobody can predict today which applications and concepts will come to fruition, what is certain is that many more and totally new uses will be found for Space, on the Moon and on Earth – with untold and likely unanticipated benefits to mankind’s journey into Space towards independence from planet Earth. When such a ‘Declaration of Independence’ is proclaimed by communities outside Earth, then we shall know that our journey into Space has been successful.

Lunar and Cis-Lunar Enterprise Outlook. Literally hundreds if not thousands of scientists and engineers have done impressive work on the feasibility and scope of Lunar activities needed to establish a first presence on humans on the Moon. Many were documented in 1985 in “Lunar Bases and Space Activities in the 21st Century”, edited by W.W. Mendell. We do not start with a ‘blank page’.

One of the most imaginative – and at some future time realistic – works on the role and scope of the Moon in mankind’s future has been described by Krafft Ehricke, in papers dating to the late 1960s and early 1970s and summarized in “Lunar Industrialization and Settlement – Birth of a Polyglobal Civilization[2].” The Moon can be an integral part of the Cis-Lunar and planetary economy. The question is, “How do we get from here to ‘there’”.

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[1] *Report of the NASA Lunar Energy Enterprise Case Study Task Force*, NASA Technical Memorandum 101652, July 1989, 171 p.

[2] Mendell, W.W. Editor, *Lunar Bases and Space Activities of the 21st Century,* Lunar and Planetary Institute, Houston, Texas, 1985; see also the *Partial Bibliography* in Appendix E.

Most of the major Space policy assessments and exercises of the past sixty years are 'unidirectional, with the Moon as a stepping-stone to other places in the Solar system. Among the large mass of articles, papers, writings only a few deal with the beneficial uses of the Moon for Cis-Lunar Space and, even fewer with significant direct benefits that could be derived from investments and operations on and from the Moon.

Indeed, many space experts are astonished at having 'missed' this inward looking perspective for Space exploration from the Moon. "Thinking within the Cis-Lunar box," while everybody has been scrambling to move and think outside that box, requires in this sense a reversal of paradigms.

Figure 4.1 - "Never, ever think outside the box!"

Transportation costs and the **cost of time** (interest) will limit the 'economic' uses of Space. Because of transportation and interest costs, the commodities (goods and services) delivered from Space to Earth will need to have near zero mass and travel close to the speed of light. In addition, if one allows for the 'demand-price' relationship, then the price of such physical goods would collapse with a large supply from Space.

These 'iron laws' of economics combine to 'limit' commodities for use on Earth to essentially data and energy. '**Data**' in the form of **observations**, **communications** and **location** compose the 'information economy' – well over 50% of all economic activities of advanced economies and societies. "**Energy"** is in the form of light (optical) or other forms across the electromagnetic spectrum.

Similarly, the region where these activities will be located will be principally in near-Earth Space. Following the 'location' theory of economic activities based on 'marginal' advantages' and 'marginal costs' first described by von Thünen in the 19th century[3], these activities will be limited to near-Earth space at least until communities and settlements independent of Earth are established elsewhere – with the same 'economic laws' applying 'there' as well, wherever that may be in the universe.

The enthusiasm of Krafft Ehricke and others in exchanging material supplies and goods between a Lunar and a 'terrestrial' economy is mistaken. Similarly, the idea of physical travel outside the Solar system is beyond reach currently. It is much easier to transmit data and information (as well as DNA – i.e., human genome 'data') than large quantities

[3] Thünen, Johann Heinrich von, *Der Isolierte Staat in Beziehung auf die Landwirtschaft und die Nationalökonomie,* [The Isolated State in Relation to Agriculture and the Economy], Hamburg 1826 and 1850, wherein von Thünen explained the location of various economic activities as a function of transport cost, including the cost of time (interest) based on marginal costs and marginal benefits.

of 'humans,' mostly in the form of water. (These same 'laws' lead us to transport orange juice concentrate from Florida to other locations, even within the United States.)

The **"Space Economy"** for some time to come will be a Cis-Lunar economy, comprising and affecting large parts of the terrestrial **information** sectors first; and later the global energy sectors, with in-space **energy** supplies as the first significant step toward the development of energy supplies in and from Space.

Due to transportation costs (delta-V), economics will favor extensive use of **lunar mineral resources** for in-orbit Cis- and Trans-Lunar applications and projects, leading to possibly 'massive' infrastructures to make use of the information and energy potential of Space – and the Moon in particular.

<u>The Cis-Lunar Information Economy</u>. One cannot overstate the importance and scope that the Space age has brought to revolutionizing the information sector of the economy – globally, regionally and locally. Few are aware that when asking 'the computer' for driving and location directions these data have been gathered from Cis-Lunar Space – some in real time and some in laborious work over many decades, such as topographic and thematic map information. Similarly, when each day about $1 trillion circle the global economy looking for investment opportunities or trade, these monetary flows are enabled by satellite communications to many remote areas in the world.

Agricultural resources, crop data, land use information, water resources, forestry, desertification, urban sprawl – all these subjects and more have been vastly affected by Space. Today, when a U.S. farmer operates his harvester, the location of his vehicle is determined by GPS; crop quality, soil moisture and yield information is transmitted 'real time' via satellite links into various data banks; and synthesized analysis returns to the farmer for decision-making on fertilizing that specific field in that specific location, with those specific soil conditions and for a specific crop – which he selected based on all the global crop data collected and transmitted, again globally via satellite.

All these processes today occur continuously, 24 hours a day, 365 days a year. At any time, crops are harvested in either the Northern or Southern hemispheres, ranging from tropical zones all the way to the Arctic. There is not a single month in which some wheat somewhere in the world is not harvested, given winter and spring wheat and all the 'zones' where wheat is grown. Today's trading department in many a commodity company looks more like the Houston Apollo mission command center than the idyllic images of bespectacled 'desk' traders of centuries past.

And depending on the season, anywhere from 10% to 40% of all the 'news' reporting on media world-wide has to do with weather and climate – daily schedules are affected as are a myriad of decisions, many based on 'forecasts' rather than on 'facts.' We act upon such forecasts today because the quality of these forecasts has advanced substantially since the days of the farmers' almanac. Data and information derived therefrom are mostly gathered again from Space.

For example, instruments on the TIROS series of weather satellites (the MSU) have taken ~30,000 atmospheric temperature measurements around the globe for the past 25 years (since 1979), aggregated daily at 1:30 a.m. and at 1:30 p.m. astronomical time. Each dot in the image in Figure 4.2 represents an actual temperature measurement at the ‘precise’ astronomical local time of 1:30 a.m., with the color of each dot denoting the temperature measured between 230K and 280K degrees (Kelvin). These data provide a true, accurate, ‘measured’ assessment of eventual temperature and climate change – an effective counter to fear mongering and ‘precautionary measures’ with untold costs to the economy and trade world-wide amounting to billions of dollars and untold regulatory constraints. [See Figure 4.3.]

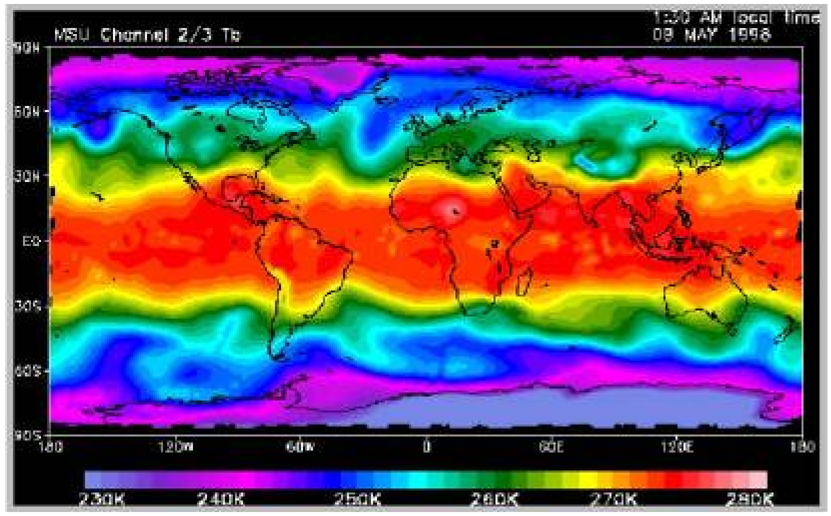

Figure 4.2 – TIROS MSU Data of May 8th, 1998 at 1:30 a.m.

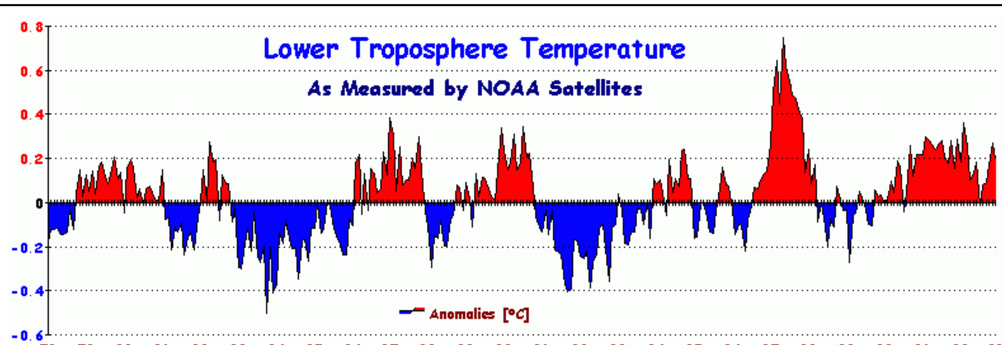

Figure 4.3 – Lower Troposphere MSU Temperature Data over past 24 Years

Similar examples of data gathered and distributed globally from Space now exist in an untold variety of areas too numerous all to be listed. Yet many gaps in our observations continue to exist and many of the data, valuable as they could be, are still being gathered, collected and distributed often in a haphazard way and often to a select few.

<u>Observations of Cis- and Trans-Lunar Space</u>. The Moon as an operational platform from which to observe Earth and all of Cis-Lunar and Trans-Lunar Space will again revolutionize “Earth Observations” capabilities, especially when integrated with other Cis-Lunar capabilities. Just as with the Hubble Space Telescope, entirely new vistas and possibilities will be opened with the ability to deploy and tend large observatories across the full electromagnetic spectrum and with hitherto unheard of apertures – on the 'front side' of the Moon for Cis-Lunar Space and Earth and on the 'back side' of the Moon for hitherto unimaginably detailed astronomy observations of the universe.

The 'Earth oriented' applications listed in Figure 4.4 include large active and passive optical and RF collectors for 'long dwell' high resolution earth-system observations; ultra-long range identification and tracking of Earth orbit crossing objects; observation and tracking of Earth orbiting objects and activities; and ultra precise measurements of Earth and Cis-Lunar parameters such as the gravitational Earth 'surface' (the Geoid), topographic data, and other real time, continuous measurements.

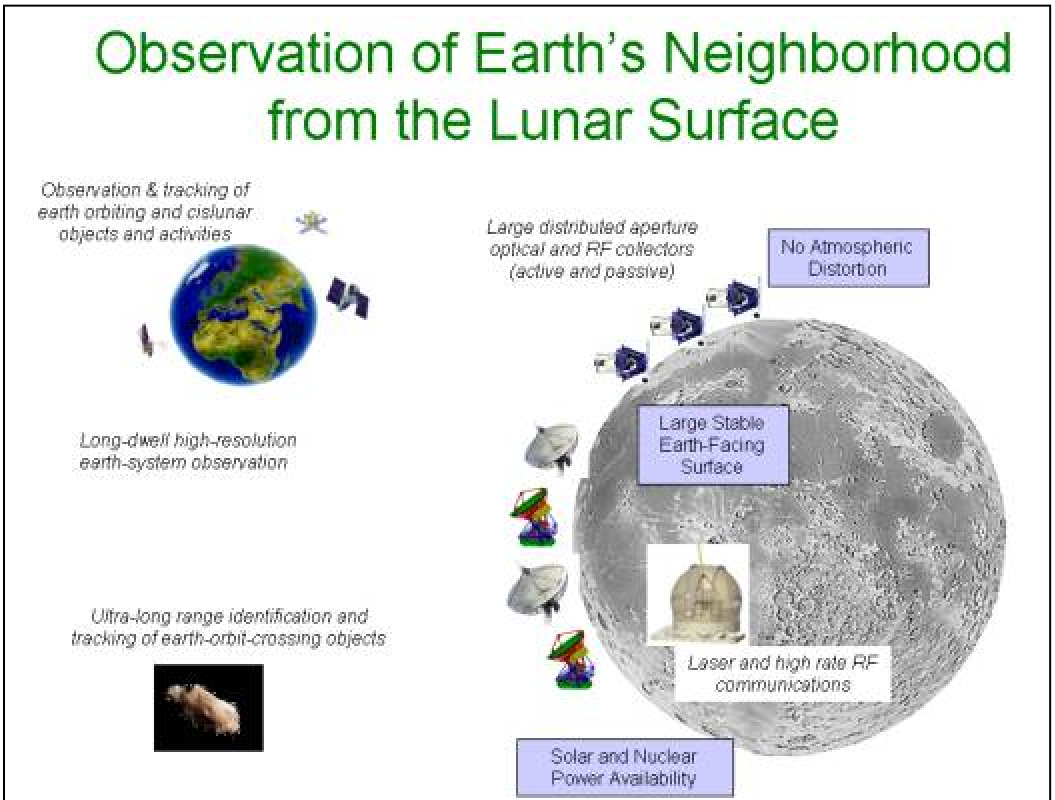

Figure 4.4 – Changing our Perspectives of Cis-Lunar Earth-Space

With the use of entirely new orbit capabilities and locations enabled by support from Lunar bases, other applications will be enabled – including large and unusually complex structures. Included are real time continuous high resolution applications for the Lunar polar zones (North and South poles). These applications were not 'newly invented' here to justify some expensive Space scheme. As applied to astronomy, they were part and parcel of the 1969 Space Task Group recommendations, as illustrated in their summary of space applications reproduced in Figure 4.5. These recommendations included four large observatory initiatives:

- **A Lunar Based Optical Interferometer**. See Bernard F. Burke, "Astronomical Interferometry on the Moon (1982)," who made the case for high angular resolution, aperture synthesis and a Lunar VLA for a maximum baseline length of

10 km. Adopting radio wavelength Interferometry to an optical VLA would lead to a qualitative advance in our understanding of the universe.

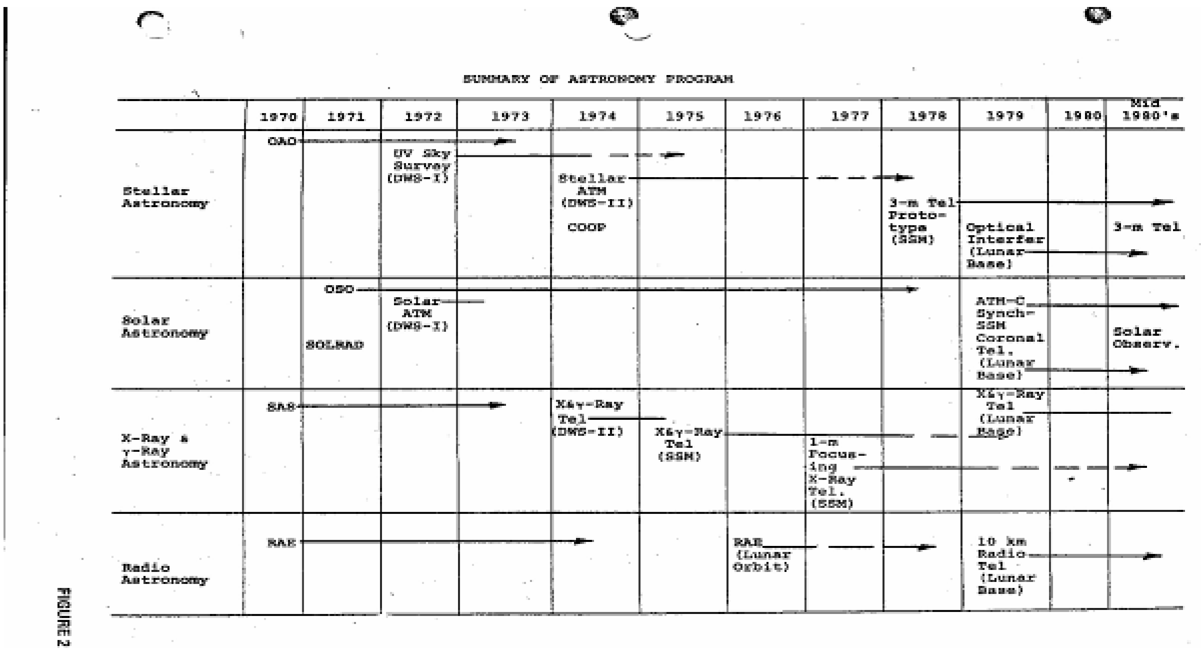

Figure 4.5 – 1969 Space Task Force Lunar Astronomy Recommendations

- **<u>A Lunar Based large Solar (Coronal) Observatory and Neutrino Observatory</u>**. Again, in the latter case – neutrino observations – the severe background over a large range of energies can be alleviated by making such observatories on the Moon [M.M. Shapiro, R. Silberberg, M. Cherry, K. Lande, A.G. Petschek, among others].
- **<u>Large Scale Lunar Based X-Ray and Gamma Ray Observatories</u>**, making use of the Moon's advantageous low radioactive environment when compared with the Earth's surface or atmosphere. Background radiation from surroundings will be lower on the Lunar surface than it in satellites in orbit around Earth. The Moon is well beyond the regions where the geomagnetically trapped particles exist, nor will there be activation by the intense particle fluxes encountered in the South Atlantic Anomaly.
- **<u>A Ten Kilometer Radio Telescope</u>**. As expanded on by Jack O. Burns [" A Moon-Earth Radio Interferometer", 1982], enabling significant advances in astrometry via the measurement of the celestial coordinate system – thereby improving celestial navigation and astronomical timekeeping and synthesis mapping for the mapping of radio bursts of stars, our galactic center as well as other galaxies to orders of magnitude greater accuracies and detail. A more recent concept of one such observatory is shown in Figure 4.6.

Figure 4.6 – One Lunar Far Side Observatory

These structures cannot 'assemble themselves' in the abstract, nor can they be operated, maintained and updated without substantial, continuous human participation in their deployment, maintenance and operation.

Assembly, Testing and Deployment of Large Space Structures. Indeed, the ability to assemble and operate in Space large structures – such as the assembly of International Space Station – opens up entirely new perspectives in the scope and scale of Space observations and Space applications – on the Moon and in all of Cis-Lunar Space, including at various libration points. The implications and 'derivatives' of these vastly expanded or entirely new applications in communications, observations, navigation and information activities worldwide can hardly be imagined, much less quantified, other than to state that the impacts will be enormous and utterly beneficial to all mankind. One such future deployment and operation is shown in Figure 4.7.

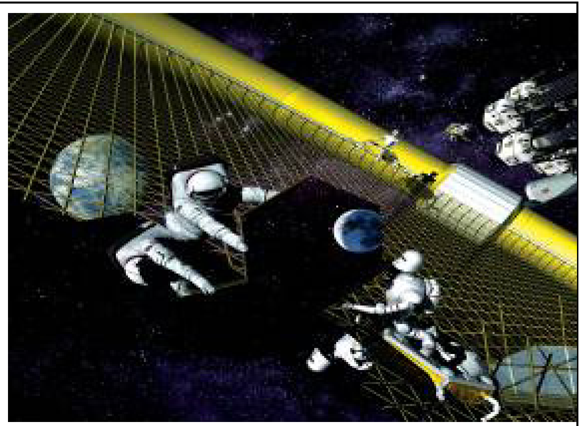

Figure 4.7 – Assembly of Large Structures in Cis-Lunar Space

It is not the purpose of this report to highlight and identify all potential applications – a task for years to come and part of a 'dynamic' portfolio of Space applications and sciences opportunities that should be assembled as part of this initiative. Figure 4.8 is but one example, ultra-large interferometers deployed in this case in geo-synchronous orbit.[4]

[4] Bekey, Ivan, *Advanced Space System Concepts and Technologies: 2010 – 2030,* The Aerospace Corporation, El Segundo, California and AIAA Inc., Reston, Virginia, 2003.

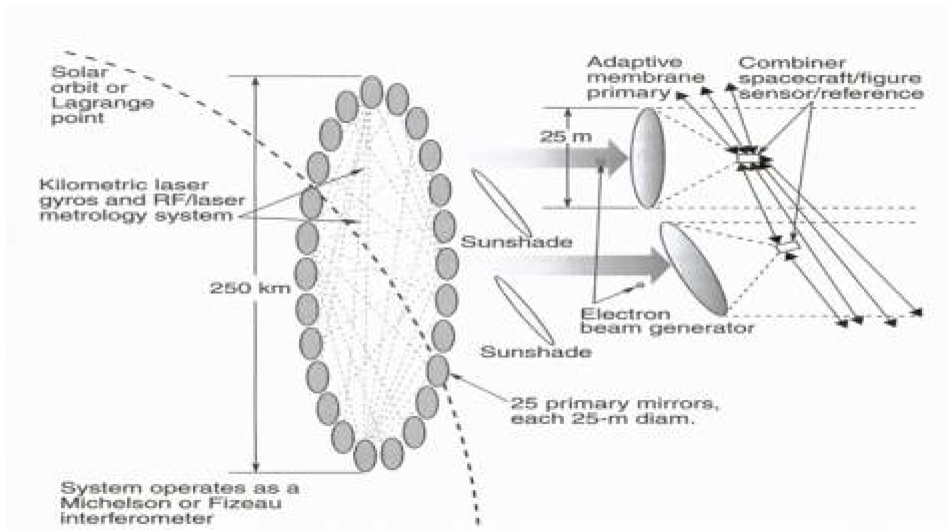

Figure 4.8 – Ultra Large Interferometer - Extra Solar Planetary Systems (250 km in Diameter)

There are dozens more proposed concepts that need investigation and reevaluation in light of their being enabled and supported from a Lunar base. For example, the abundance of energy on the Moon and the ready availability of most material resources on the Moon can dramatically transform the 'economics' of Space transportation in Cis- and Trans-Lunar Space. Once energy is no longer a limiting factor, building the energy supplies for these new modes of in-Space transportation on the Moon will be preferable to other locations such as the various libration points – which are of mathematical and esthetic importance.[5]

Testbed for Revolutionary Concepts, Including Production of Energy and Other Resources

The Lunar base will serve in subsequent decades as a testbed for Human Exploration beyond the Moon – to Mars, the Asteroids or further in the future the outer planets. As time passes, reductions in risk/cost and time optimization for viable mission designs are expected for Trans-Lunar crewed missions in the future. CELSS and related Environmental Health RDT&E on Space Exploration should be directed toward achieving critical milestones to support NASA Exploration Missions beyond the Lunar base, including for interplanetary missions[6]. In the most primitive sense, components of the ISS could be deployed on the Moon with minimal adaptations as a first step.

[5] Among the many studies on lunar energy related matters: *Report of NASA Lunar Energy Enterprise Case Study Task Force,* NASA Technical Memorandum 101652, July 1989 171 p.
[6] Heiss, Klaus P. and Francis Sand, "Exploration Missions and Life Sciences: Issues and Linkages", *op.cit.*

Results from detailed Monte Carlo simulations of the effects of CELSS derived benefits on issues of microgravity[7], radiation and human factors advances on Mars missions (using the mission requirements of the Mars "Sprint" mission proposed in the 1990s as a specific example are shown in Figure 4.9.

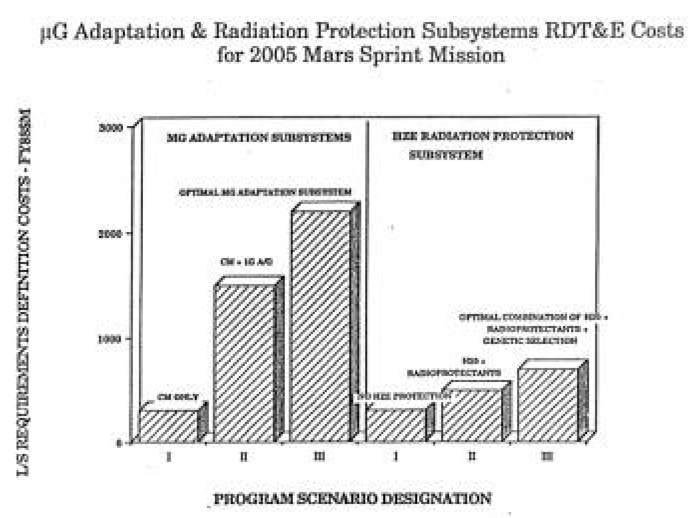

Figure 4.9 – Monte Carlo Simulations of Effects of Life Sciences Parameters on a hypothetical Mars Sprint Mission

Depending on the outcome of the Environmental Health and CELSS assessments and advances, the cost (and risk, schedule) impact on but one relatively simple Mars Mission (Sprint) would be in the billions of dollars.

The benefits of finding out about these critical enabling parameters for future missions beyond the Moon to Mars or other planetary bodies are large indeed. Without this practical experience in near-Earth space – including the ability to rescue and intervene when unexpected health and safety problems arise, any commitment today, or even serious consideration, to proceed responsibly to Mars or anywhere else would occur with very limited knowledge and empirical data and experience.

In that sense, the Moon is the 'natural' Space Station for Earth, an ideal and economic platform to find out the answers to some of the most fundamental questions as to the feasibility of sustained human presence at, and possibly even independent settlements of, Lunar outposts on a continuing journey in Space.

For sure we owe posterity these investments into the future 'prospectives' of the United States and of mankind to find out whether our world is 'closed' – or is open for further unlimited exploration and expansion.

Many conceptual studies have been inspired by the pioneering contributions by Peter Glaser dating back to 1968 – or for that matter the very first writings on practical Space applications by Hermann Oberth in his seminal work of the 1920s. Still, much work remains to be done. Yet what is certain already is that energy on the Moon, and at later times from the Moon, is abundant, indeed inexhaustible.

[7] *ibid.*

In the initial build-up to these capabilities, the Prometheus nuclear Space power capabilities can more than suffice. The next significant step will be to build the first significant Lunar solar power generating capacity, say to achieve a 10 GW Solar Electric Prototype for Moon based Cis-Lunar Applications and Operations [See Figure 4.10.][8]:

To provide 10 GWe for Lunar and Cis-Lunar uses, about 2340 km^2 to a depth of 30 cm have to be moved and processed – the equivalent to moving 1.4 billion tons (at 1/6 Earth gravity). Lunar machines to process 10^6 tons per year have been designed to produce glazed solar cells entirely with lunar materials.[9] A total of about 800 km^2 would be prepared. Abundant thermal energy for glazing is available as well.

Figure 4.10 – Energy Distribution to Earth via Large Space Reflectors: #1 Solar Arrays, #2 Microwave Transmitters, #3 Reflectors; All made from Lunar soils by Production Equipment #4, #5 and #6 [Criswell]

The science, technology and economic implications of having 10 GWe available are enormous for any number of Cis- and Trans-Lunar applications. Practically unlimited power could be supplied to all Earth orbiting spacecraft (when compared to to-day's miserly power budgets in Space operations) – i.e., it would herald the advent of propellantless Space transportation technologies near Earth and to destinations throughout the Solar system and beyond, with entirely new orbits enabled around Earth and, when combined with Space Sail technologies, the ability to reach up to a third the speed of light with Hybrid Electric Impulse Space Sails.

Equally important, the RDT&E and subsequent implementation of Lunar Solar Power plants will have significant major "side" benefits. The maturing of technologies for the

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[8] Criswell, David R., "The Initial Lunar Supply Base," in *Space Resources and Space Settlements,* eds. J. Billington, W. Galbreath, and B. O'Leary, pp. 207-224, NASASP-428 and testimony by David Criswell to the U.S. Senate, November 2003 (to be published).
[9] Criswell D. R., "Solar Power Systems: Review of the technology base of an operational LSP System," *Acta Astronautica (2000)*, Vol. 46, No. 8, 531 – 540, Elsevier Sciences Ltd.

use of Lunar resources could lead to 90% or higher independence from Earth-based supplies.

The material composition of the Moon is quite similar to that of Earth – not surprising given their common origin – with only hydrogen as a truly scarce element. But here again the same material processed for the construction of the LSPs, regolith, also contains significant amounts of H_2 and – possibly equally important as to energy futures – He3, a helium isotope. Both elements are readily recoverable in regolith processing, the simplest method being through microwave irradiation. Pepin found that heating Lunar regolith (obtained from the Apollo missions) caused the He3 to be evolved above 200° C – and by 600° C about 75% of the He gas could be removed[10]. It is anticipated that if heating to 600°-700° is achieved, various other volatiles can be collected in addition to He3 – e.g., H_2, He4, H_2O, C compounds and N_2. The relative amounts of "by-products" from the production of a single ton of He3 are shown in Figure 4.11[11].

For every metric ton of ^3He, 6,100 tons of H_2 and 3,300 tons of water would be produced, in addition to 500 tons of nitrogen, 4,000 tons of CO and CO_2 and 1,600 tons of methane – all of these elements are important to establishing an autonomous Lunar agricultural base and "bio-environment". The 6,100 tons of hydrogen alone would cost billions of dollars if transported from the Earth to the Moon.

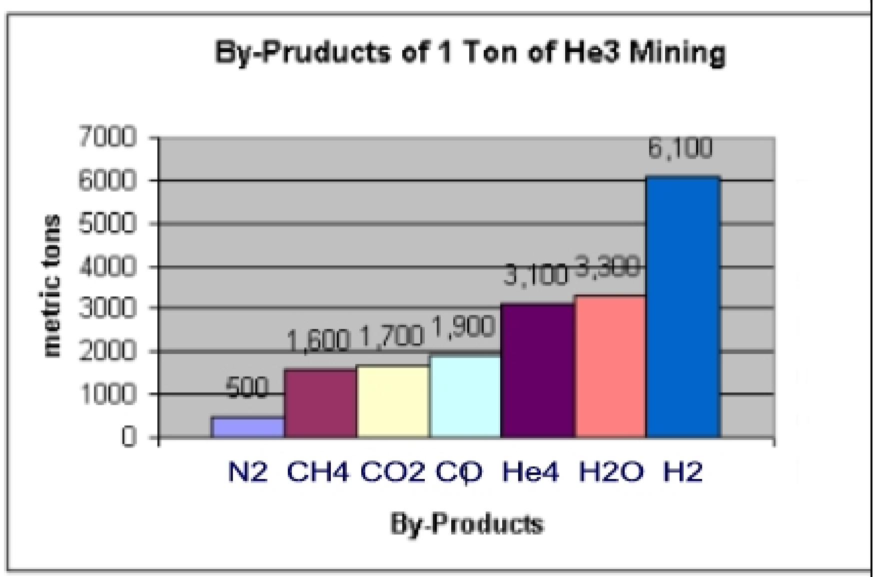

Figure 4.11 – By-Products of Helium 3 Production from Lunar Regolith

This is in addition to any water that might be found e.g. at the poles as indicated by data from the Clementine mission.

Once the "in-situ" Lunar materials processing and LSP technologies have been developed, they can be extended to support Cis- and Trans-Lunar missions and Space structures to: (a) provide power supplies for varied space operations; (b) enable propellant-less Space transportation and station keeping capabilities and (c) provide large parts of "future generation" large Space structures. The most ambitious scheme was proposed by Peter Glaser in 1968[12], inspiring most of the derivative opportunities

[10] Pepin R. O. et al., *Proceedings of the 11th Lunar Scientific Conference*, Vol. 2, 1435 (1970)
[11] Cameron E. N., University of Wisconsin Report, WCSAR-TR-AR3-8708 (1987)
[12] Glaser P. E., "Power from the Sun: ist Future," *Science*, 162, 857 – 866 (1968).

described here. The use of Lunar materials for the economic deployment of such structures – or power relay stations from the Moon to Earth – was identified in the Minority Report of the NRC on SPS in the early 1980s and studied in detail in 1989, as depicted in Figure 4.12[13].

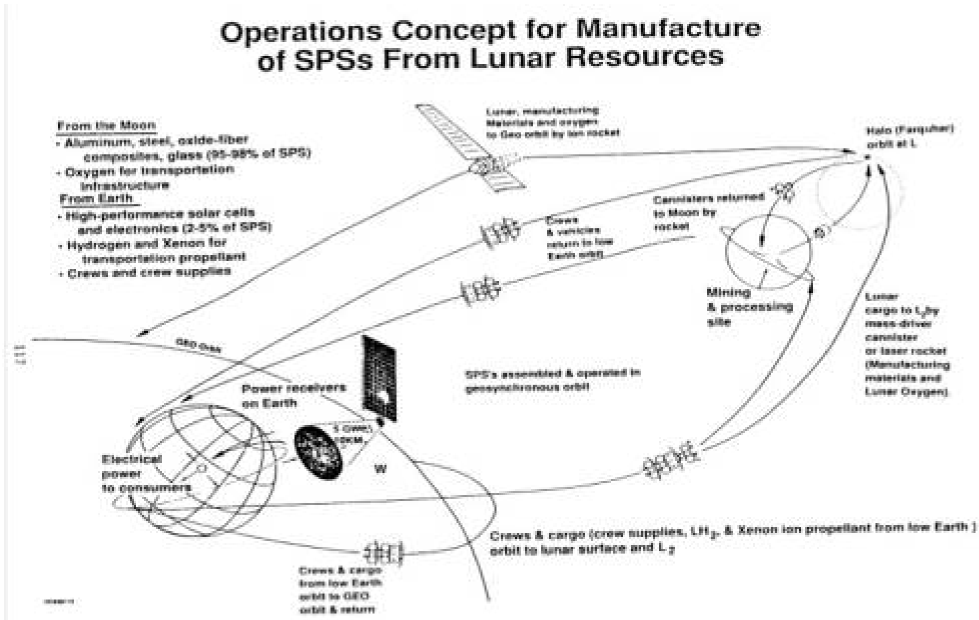

Figure 4.12 – Manufacture of Solar Power Satellites from Lunar Resources

“Looking out” toward Trans-Lunar Space, the Solar system and beyond, the Moon – combined with the power supply systems outlined herein – will be the natural “Rock of Gibraltar,” providing the jumping-off point to any and all destinations beyond Earth orbit. This is NOT because of some esoteric properties of Lagrangian equilibrium points – interesting as these might be for the mathematically challenged – but because of the Moon’s unique ‘locational’ combination of resources, ‘platform stability’, vast real estate for deployment of instruments and facilities and, last but not least, inexhaustible energy supplies. An era of ‘propellant-less’ Space transportation can be enabled by the Moon and from the Moon.

The LSP technology and production infrastructure can be used with equal effectiveness and synergistically for the deployment of distributed aperture observatories across the electromagnetic spectrum (infrared, optical, microwave, x-ray and gamma ray, active or passive). As suggested by Criswell, one can combine any number of these with LSP facilities. One such base could provide a 15,000 km^2 Lunar front- or backside-collector-observatory area. Specifically, comets and asteroids capable of endangering Earth could be detected – and possibly intercepted –in advance of a threat of impact. As calculated by Criswell and others, a Lunar Power base of 100 km apparent diameter, operating at 0.1 cm wavelength can focus solar intensity beams to a less than 100 km

[13] Lunar Energy Enterprise Task Force, *Report of NASA Lunar Energy Enterprise Case Study Task Force,* NASA Technical Memorandum 101652, July 1989, 171 p.

spot size out to 10^{10} km – twice the distance from the Earth to Saturn. By irradiating incoming comets these would be gradually heated, giving off ejected gas and dust. Their trajectories can be thus modified to 'side-step' the Earth or the Moon. Comets of less than 100m diameter may be obliterated completely.[14]

Figure 4.12 – First Space Sail – February 5, 1993 – NPO Energia – Vladimir Syromiatnikov – Columbus 500 Entry

The same power and technology can be used to propel vast Space (Solar) Sails of 100 km diameter – via laser or microwave beams – to any point in the Solar system and to points beyond. More than half a dozen viable schemes for such sails were proposed and identified in the 1992 Columbus Space Sail competition, which led to the flight of the first Solar Sail into Space on February 5, 1993, as indicated in Figure 4.12.

Equally interesting – at least for near-Earth applications – will be RDT&E and possible deployment of "Space Elevators" to L1 (for Cis-Lunar missions) and L2 (for Trans-Lunar missions), a concept first proposed by Artsutanov[15]. If combined with electromagnetic launch capabilities on the Moon to reach L1 and L2, both locations might help assemble ultra-large Space structures extending potentially over 100 miles to then be relocated from there to destinations around Earth and throughout the Solar system. [See Figure 4.13]

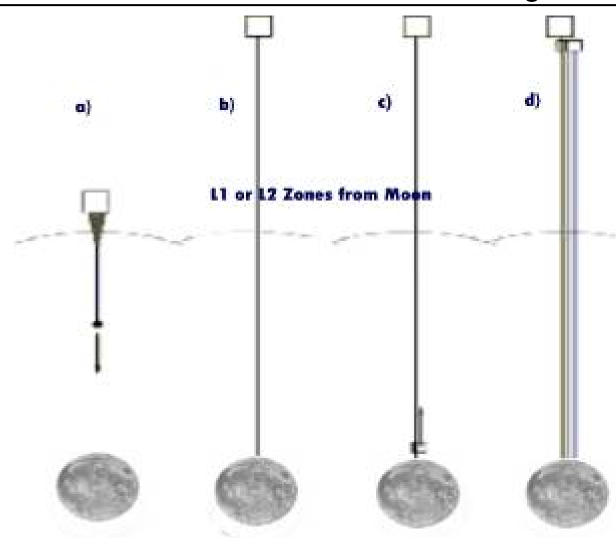

Fig 4.13 – Illustration of the Deployment Scenario for Space Elevators

Whereas any deployment and use of such elevator concepts from the Earth are totally outside known materials technology capabilities (not to mention the impact of the severe adverse atmospheric and environmental conditions around Earth), the Moon presents an ideal testbed for their exploration and implementation.

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[14] Weaver H. A., "HST and VLT investigation of the fragments of comet C/1999 S4 (LINEAR)," *Science*, 292, No. 5520, 1329 – 1333.

[15] Artsutanov Y., *Into Space without Rockets: A New Idea for Space Launch*, AFSC Foreign Technology Division Report ADA084597, Air Force Systems Command, Wright-Patterson AFB, 1969 (first published in Russian on July 31, 1960).

Closure

The technology and science vistas opened by the development of a Lunar resources infrastructure are truly breathtaking: Once the ‘mental block’ of thinking about the Moon as nothing but a way-station to destinations beyond the Moon – barren of any interest and potential of its own – has been overcome, a world of vast new opportunities for Earth and for human exploration throughout the Solar system will have been opened.

This “Portfolio of Opportunities” remains to be filled out and described and then implemented where warranted by science, technology and the market. Should we desist in leading, others will eventually lead, like the barbarians’ of centuries past when China was evaluating its exploration options and their costs in 1423.

We should take the first step, as a few colonists did in Jamestown about 400 years ago – to establish the first habitat and provide the necessary energy supplies that enable all other uses of resources and life support. In the long run, that may be the most significant impact and consequence of establishing a ‘Columbia’ Base on the Moon – to answer the question of the ability of humans to live and sustain themselves in Space. The direct benefits of such a base will go a long way to allow us an informed judgment.

“With the sharp instruments , they could recognize every detail on the Earth and could give light signals to the Earth through the use of appropriate mirrors. They would enable telegraphic connections with places to which neither cables nor electrical waves can reach. . . The station could observe every iceberg and could warn shipping. . . The disaster of the Titanic of 1912, for example, could have been prevented in this way.

Hermann Oberth
***Rockets to Planetary Spaces,* 1923, NASA TT F-9227, pp 92-97.**

CHAPTER 5 – COST AND SCHEDULE CONSIDERATIONS
Rough Order of Magnitude (ROM) Costs, Schedules, Budgets

As described in Chapter 2 (The Means), the ‘vision’ of a new, reusable Space transportation system remains to be completed. Part of what was recommended in the late 60s and early 70s has been accomplished with the Space Shuttle: the cost and risk estimates presented in the early 70s have been borne out, including the two tragic losses of Shuttle Orbiters. The predicted failure rate (two failures in 100 flights) – using solid boosters – was slightly higher than the record to date. The predicted costs per flight were also close to those later experienced in operations. What went wrong in the past three decades is described in Appendix A in some detail, the principal cause being an essentially dysfunctional Government and Interagency ‘management’ structure and process, ill suited to achieve specific goals on a specific schedule.

Based on the analysis of literally hundreds of Space programs in the early 1970s and after exploring dozens of different possible approaches to the ‘infrastructure’ for deploying and sustaining a first permanent base on the Moon within a decade, the most cost-effective structure that emerges is the one outlined in Figure 2.2, an evolution of the Space Shuttle toward a full re-usable Space Transportation System. In addition, the specific implementation requires considerable trajectory analyses to outline mission support, communications and software infrastructure – so much so that Moon orbiting ‘mission support’ satellites are required for cost-effective operations.
Among the myriad possibilities but within, again, the constraints – budgetary and schedule in particular – one basic solution stands out, with two different possible mission profiles: in Figure 2.2 one Basic Mission and Technology profile is shown, with a Lunar Tug directly proceeding from LEO to the Lunar surface (the original Apollo mission profile), whereas in Figure 5.1 a LEO to Low Lunar Orbit Space Tug is matched with a Lunar Ascent and Descent Tug to accomplish the same mission.

For costing purposes, a specific mission and trajectory analysis was performed using the mission profile shown in Figure 5.1 [see Appendix B]. Based on these designs and assumptions, two separate and independent, fairly detailed, first order estimates were obtained – one accomplished in-house by NASA JSC and another accomplished independent of the NASA costing base, but using the best and most extensive available data base and technology status assessment within the

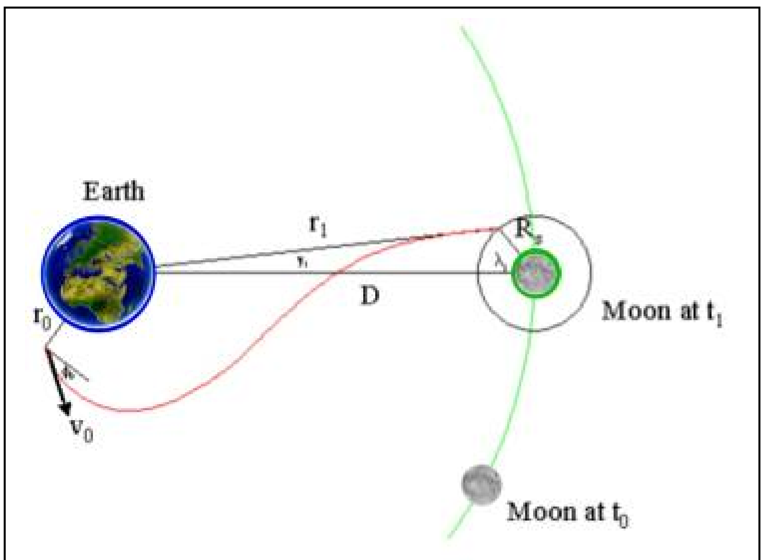

Figure 5.1 – Lunar Base Deployment Mission for Requirements and Costing Analysis

Government and Aerospace industry. Both assessments came up with a close to identical infrastructure, the one depicted in Figure 2.2; the other in the detailed Summary Cost Table 5.1 below.

Before discussing the rough cost estimates, it is remarkable to note that both assessments came up with essentially the SAME Space Transportation System infrastructure as the most cost-effective way to reach the historic goal–establishment of a Lunar Base within a decade. Based on the existing know-how and knowledge base today, the most effective approach was judged to be by incorporating more current technology and then completing the other parts of the original Space Transportation System vision of the early 1970s in nearly identical ways.

Obviously many details remain to be worked out and clearly further ‘optimization’ can and must occur at a system and subsystem level – but the basic parameters are set and obvious. They constitute a fundamentally different approach than the ‘brute force’ approach of the Apollo program, with a much more flexible and useful infrastructure deriving therefrom for future operations throughout Cis-Lunar, Trans-Lunar and future planetary missions.

Based on these assumptions and qualifications the cost estimates for all major infrastructure components are listed in Table I below. Based on Table I and the second, NASA in-house cost estimate, it is anticipated that the total cost for returning to the Moon and establishing an operational presence there would be **between $50 billion and $75 billion**, with $50 billion as the best estimate. The $75 billion estimate includes not only additional infrastructure elements, such as Moon-orbiting satellites, but also a hefty 30% uncertainty factor.

It should be noted that the **$50 billion best estimate** may be reduced as further mission parameters are optimized and refined, as was the case in the Apollo days. At the time of President Kennedy’s decision to go to the Moon in 1961, none of the infrastructure components had been built, nor had been conceived the alternative actually employed to orbit and land on the Moon. This later accepted approach helped to reduce substantially overall mission costs. Costs can also escalate, but contrary to widely held beliefs such escalations are not ‘inherent’ to aerospace industry. In many cases cost growth has resulted from undue delays and ‘stretching’ and what can be called ‘inside the beltway program management’ – a unique system between NASA, Space Interagency Groups, other entities such as OMB, Congress and sometimes even the Judiciary. A sad example is the ‘management’ of the Shuttle development and operation resulting from this unique ‘management’ setup [see Appendix A].

When government and industry have been committed to the achievement of a set goal within a specified time, U.S. aerospace industry has performed quite well, often ahead of schedule and within budget – in some cases giving rise to true legends such as the ‘skunk works’. Very often these unique achievements are never made known, or can be revealed only decades later. It is this management spirit that has to be brought to achieving this proposed goal.

Table 5.1
Summary of ROM Estimates of Lunar Base Costs within a Decade

ELEMENT	Build	Total Non-Recurring Inc 12% I&T	Total Non-Recurring Inc NASA	Total Non-Recurring Inc NASA + 30% Uncertainty	Missions in 1st 10 years	Guess At Cost Per Flight	Total Recurring	Total 10 Year Cost
		M 2006 $	M 2006 $	M 2006 $		M 2006 $	M 2006 $	M 2006 $
Shuttle C	6	11210	14570	18940	4	300	1200	20140
Sep Crew Module + Liq Boosters	4, 12	8280	10770	14000	4	500	2000	16000
Mod to Orbiters for SCM	4	1200	1560	2030				2030
Certification of new Orbiter	4	2000	2600	3380				3380
Cis-Lunar Chemical Tug	6	4240	5510	7160	4	50	200	7360
Lunar Ascent/Descent Stage	4	3000	3900	5070	4	50	200	5270
Initial Lunar Habitat	3	470	610	790				790
Airlocks, Dock Mech & S/W	20, 20, 3	1180	1530	1990				1990
Lunar Satellites	12	1110	1440	1670	6	70	420	2090
Lunar Truck	4	3160	4110	5340				5340
Lunar Nuc Power System	1	4260	5540	7200				7200
SEP Tug	NA	870	1130	1470	0			1470
Total		40980	53270	69040			4020	73060

These overall costs break down as follows:

A. Improving and modifying the Space Shuttle, including

- **Separable Crew Module (SCM)** for Shuttle, also usable for manned Tug/Lunar Lander and ISS rescue. Such an SCM will be able to get off the stack and save the crew in case of an emergency during launch and can be mated in-orbit with the chemical propulsion Tug. The SCM will have it's own solid rocket propulsion system (for abort), parachutes (parafoils) and be able to accomplish non-powered water and runway landings. The costs include design and production of a new separation system;
- **Liquid Boosters** to replace the Solid Rocket Motors (SRMs)
- **Upgrade Shuttles** to current technology
- **Modifications and Certification** of four Orbiters;

The RDT&E (Research, Development, Testing and Evaluation) and the build of 5 (five) SCMs and 12 (twelve) Liquid Boosters is estimated at about $2.6 billion in RDT&E and $5.6 billion in production costs. The costs of modifying the existing orbiters are estimated roughly at $1.2 billion; and the cost of certifying Orbiter with Separable Crew Cabin is estimated at $500 million per orbiter for a total of $ 2 billion for four orbiters.

B. Shuttle – C (Cargo Shuttle): to transport large systems components beyond the capabilities of the Shuttle to LEO a cargo version of the Shuttle is a logical evolution and extension of this unique technology base. The basic requirements to accommodate all the volume and mass requirements deriving from the requirement to deploy a permanent Lunar Base within a decade are:

- Three SSMEs (Shuttle Main Engines) on the rear end of a payload support sled and fairing
- Liquid Boosters
- A 5 (five) ft stretch to the Liquid Hydrogen Tank
- Capablility to lift ~185,000 pounds payload, consistent with Evolved Shuttle Class system (93.5 x 10^6 tons to 30X150nm ellipse at 28.5 degrees inclination)

Technical analogies and experience base: Shuttle Orbiter and past Shuttle-C designs.

The estimated costs for RDT&E and procurement of 6 (six) Shuttle-Cs are

- Non-Recurring $2.1 billion
- Recurring $9.1 billion

C. Cis-Lunar Chemical Tug (CLT), with basic design capabilities as follows:

- Re-usable LOX/LH2 Upper Stage capable of cargo or crew transfer from LEO to LLO (Low Lunar Orbit)
- With aero-break capabilities when returning to LEO
- Assumed mass fraction of 0.8, assumed to accommodate crew support, Thermal Protection System for aero-braking, and a highly reliable, robust, reusable design
- Approximately 115K lbs of propellant, 29 K lbs inert weight

- Starting with 181K lbs (82 ton) in LEO (delivered by Shuttle C) Tug can deliver
    - A maximum payload of 32K lbs to LLO and return to LEO, sized for an initial rigid Habitat; and
    - Nominal operations assume delivery of Lunar Descent/Ascent Stage propellant of + 15K lbs from LEO to LLO and return 11K lbs to LEO from LLO using aero-capture.

Technology analogies/base: Tanks from Shuttle External Tank experience, engine heritage an RL-"X" from Centaur RL-10, Avionics from Orbiter, Thermal Protection System for aero-braking from Orbiter.

The resulting RDT&E and procurement costs for 6 (six) CLT Tugs (two for development) are:

- Non-Recurring Costs $2.4 billion
- Recurring Costs (Production) $1.8 billion

D. Lunar Ascent/Descent Stage (LADS): with basic design characteristics as follows:

- LOX/LH2 LADS for transportation between LLO, Lunar surface and back initially the Cis-Lunar Tog carries LADS propellant for one round trip on each of its nominal operations flight requires fuel transfer in LLO
- Once SEP Cargo Hauler and Propellant Depot are established LADS will not require Cis-Lunar Tug to bring propellant
- Mass fraction is 0.8, sufficient to support crew and of highly reliable, reusable design approximately 23K lbs of propellant and nearly 6K lbs of inert weight
- Maximum Payload from LLO to Lunar surface and empty return is 32K lbs
- Nominal operations assume down payload of 15K lbs and return (up) payload of 11K lbs to LLO

Technology analogies/bases: derived from parameters and assumptions for LOX/LH2 Cis-Lunar Tug (i.e. same as stated above).

Estimated costs for the LADS for an initial build of 4 (four – of which 2 for development):

- Non-Recurring $450 million
- Recurring (Production) $2.5 billion

E. Initial Lunar Habitat: probably the 'Infrastructure' item most open to change with further study of optimization and expansion due to desired missions from the scientific, technical and user community in start-up phase. The specific initial tasks and missions can and will be determined over the first part of the decade, and can be expanded as the initial habitat grows and expands with the myriad of scientific, technical and user community demands identified. For purposes of costing the initial Habitat and making use of the ISS technology base and experience, the requirements were based on a Rigid Cylinder analogous to ISS MPLM with a mass changed from 10.500 lbs for ISS MPLM to 30.5. lbs for an initial Lunar Habitat and a length of 60 ft.

Based on these analogies and technology experiences the estimated costs of RDT&E and initial built of 3 (three) for the Habitat are

- Non-Recurring $210 million
- Recurring (Production) $260 million

F. Lunar Satellites: to meet the necessary communications, navigation and positioning requirements for real time Lunar space transportation and lunar surface operations a number of such satellites will be deployed around the Moon. For costing purposes, the technical analogies and experience base were 'scaled' GPS satellites, with the mass scaled from 1.850 lbs to 1.110 lbs (60%).

Based on this analogy the RDT&E and an initial build of 12 (twelve) satellites are

- Non-Recurring $160 million
- Recurring (Production) $950 million
- The Launch costs to Lunar orbits, assuming 2 (two) satellites per launch, are 6 (six) Launches at $70 million / launch, or $420 million

G. Lunar Utility Vehicle (LUV, Truck): the Lunar Utility Vehicle is used to transport cargo and crew from Lunar surface LADS landing site(s) to the Habitat, off-load the LADS and place payload(s) at appropriate site(s). The LUV will also be the initial Lunar Excursion Vehicle for trips from the Habitat for various exploration missions.

Technical analogies and experience base: the Apollo Lunar Rover, with the mass scaled from 509 lbs to 10.200 lbs (twenty times larger). Based on these requirements the estimated costs for RDT&E and initial build of 4 (four) are estimated to be

- Non-Recurring $2,2 billion
- Recurring (Production) $950 million

H. Solar Electric Propulsion Lunar Tug (SEP-LT): a key technology component, enabling a new era in Cis-Lunar Space transportation and high synergism with the early development of Lunar Solar Power (LSP) systems. For purposes of the Infrastructure cost and schedule estimates RDT&E for such a SEP Lunar Tug stage is included based on the following design parameters

- (one) MW – probably magneto-plasma-dynamic)
- 50K lbs dry weight
- Xeon at 3800 sec ISP (specific impulse)
- Trip time ~ 90 days

Based on these design requirements the RDT&E (excluding production) is estimated at $870 million.

I. Lunar Nuclear Power: for initial start-up a nuclear power plant is considered (another possibility being an immediate Lunar Solar Power (LSP) facility. Such a nuclear powered electric generator is assumed to provide 100KW electric.

Technical analogies and knowledge base: Power systems being postulated by the Prometheus program and from the Cassini RTGs. Based on these requirements and assumptions the estimated RDT&E and initial build

- Non-Recurring $670 million
- Recurring (Production) $3.6 billion (including 40 kg of reactor grade plutonium)

J. Docking Mechanisms and Airlocks: extensive transfers of crew/cargo in LEO and LLO are required, necessitating a full development of appropriate interface systems.

Technical analogies and knowledge base (albeit Russian – Vladimir Syromiatnikov) are Apollo-Soyuz, Shuttle-Soyuz, Soyuz-ISS and Shuttle-MIR and US experience with Shuttle/ISS. Based on these assumptions and analogies the estimated RDT&E and initial build of 20 (twenty) each are

- Non-Recurring $20 million
- Recurring (Production) $160 million

K. Software: one of the most demanding and difficult parts of estimating costs. Based on technical analogies and experience with the Shuttle avionics, the RDT&E and Production Non-Recurring cost of the requisite software is estimated to be $1.0 billion.

L. Other Cost Estimates. Many variations in the design parameters, mission profiles, technical assumptions are possible. Many elements in this Shuttle-derived Space Transportation System can be 'optimized', changed, and improved upon. Yet, the estimates presented above are believed to be a good first cut based on a solid, 'bottoms-up' approach, minimizing risky or speculative advances or programs wherein the schedule may be questionable. For example, a start-up Lunar power supply system using a Nuclear 100KW plant is included, although it may be entirely possible to immediately deploy a Lunar Solar Power plant of this capacity. If so, one significant saving can be affected, particularly when considering the synergies with an SEP-LT.

A significant part of these investments will be incurred if recommendations from the Gehman Commission for Shuttle operations are carried out over the next decade.

One other significantly, detailed estimate on such an evolved reusable STS is shown in summary form in Table 5.2. The estimate is based on NASA in-house efforts at JSC.

Table 5.2

LUNAR COST ESTIMATE SUMMARY (RY$)

- **•OMV/CTV/XTV Modular Space Tugs**
- **•STS-Derived Launcher- Liquids**
- **• 2014 IOC Estimate: $ 40 to 55B**
- **•Estimate per mission: $ 10 to 12B**

In Scope: OMV/CT Lunar Crew/Cargo Space Tug(s), PPM, Stage, Lunar Rover and Initial EVA C Derived Ops & Facilities,

Out of Scope: Shuttle, ISS mods,

NGLT Estimate: $3.0B (FY03-FY08)

SLEP Estimate: $2.0B (FY03-FY08)

Many basic elements in this cost estimate are similar to the assumptions in Table 5.1; nevertheless significant other elements are included – such as an Orbiting Maneuvering Vehicle Tug in addition to the Lunar Cargo and Crew Tug. On the other hand, SEP Tug costs are not included herein, nor are Shuttle modifications and recertification.

The two estimates are remarkably similar in the basic finding, namely that building on the existing U.S. Space Transportation technology base provided by the Shuttle and the ISS the U.S. can commit to the deployment of a First Lunar Base within a decade for an estimated cost of between $5 billion to $7 billion additional annual funding of NASA – or a 30% to 50% increase in the current, eroded funding of the U.S. Space effort of the past decade – for a total of about $50 billion.

"[Within a decade], the Space Station module continues in polar orbit, and a Space Station Module is emplaced on the Lunar surface, while a nuclear shuttle provides four trips per year from Earth orbit to Lunar orbit. The space base is now permanently manned, and the LM-B [Lunar Module-B] provides large payload capabilities between Lunar orbit and surface. In-depth geological exploration near the base now begins, including very deep drilling, and exploration of Lunar resources – especially hydrogen and oxygen from water or minerals – can begin. Large optical, x-ray, and gamma ray telescopes can be erected near the base.

"The planned program leads toward the goal of the Lunar Exploration Program – To explore and utilize the Moon for the benefit of mankind.

"If this goal is pursued with a suitably supported program of exploration, it is possible that the following levels of achievement could be reached [within another five years]: To have explored all major regions of the Moon; and To have established a permanent Lunar base.

". . . The establishment of a Lunar base would provide a center for continued exploration activity and furnish laboratory space for specialized science, applications and technological research that requires or utilizes the Moon's unique environment or its isolation from Earth. It would permit, for example, erection and operation of large radio, x-ray and optical telescopes on the surface. This would be an important milestone in the effort to utilize the Moon for the benefit of mankind.

"In looking forward to man's possible future in space exploration, the base could also be used to develop man's capabilities to operate for extended periods of time on another planet and for training for manned planetary exploration. The availability of laboratory facilities would also furnish opportunities cooperative participation by other nations."

An Integrated Program of Space Utilization for the Decade 1970-1980
The Space Task Group, June 19, 1969, p. 2-131-132

CHAPTER 6 – RULES OF THE ROAD

DECLARATION OF PRINCIPLES AND PROPERTY RIGHTS

(Legal, Institutional, Space Property and Enterprise Issues)

> ***"Wherever possible the private sector [should] be given the task of providing specified services or products in Space, and be free to determine the most cost-effective ways to satisfy those requirements . . . "***
>
> **Pioneering the Space Frontier**
> **Report of the National Commission on Space, p. 11**
> **Chaired by Thomas O. Paine**
> **May 1986**

The most challenging – and in some ways the most important – part of our renewed journey into Space will be a clear, simple statement of principles that guide U.S. and worldwide policy as to the role of enterprise, risk taking, costs and rewards when pursuing ventures in Space, be these of nations or of private enterprise, of explorers or merchants, of innovators or service providers.

Over the decades an impressive regime of international cooperation in Space exploration and the uses of Space has developed – some through explicit statutory provisions and international agreements, some by explicit or tacit understandings, some by deliberate non-specificity. In some cases, these practical steps have helped to give appropriate guidance for Space activities. In other cases, various agreements are unenforceable and have little to do with developing a regime that supports the desired role of entrepreneurs, private enterprise and innovative Space exploration.

Space activities have proceeded under defense, civil and industrial sponsorship and direction. The policies have been dominated by defense and civil considerations, rather than the private sector, as reflected by the makeup of the space interagency process summarized in Figure 6.1. But recently private

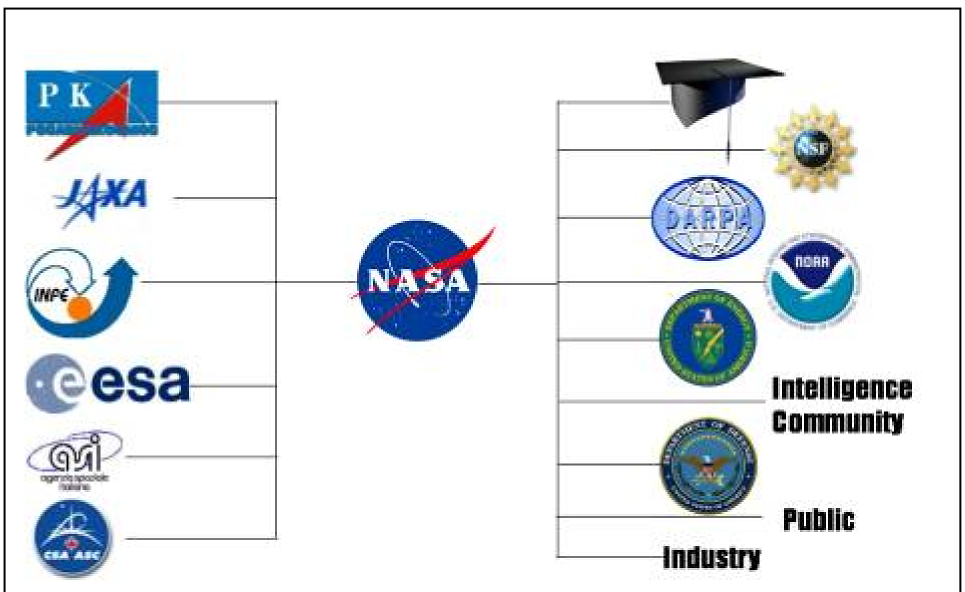

Figure 6.1 – NASA Interagency and International Cooperation

industry has begun to play a much more significant – and in some cases, a dominant – role in funding the design, deployment and operation of space systems – because that course is profitable. This trend should be encouraged in the proposed effort for NASA to establish a Lunar habitat within a decade, with incentives for entrepreneurs and private enterprise.

Thus, the policies of the past – both the international 'understandings' and the interagency practices – need to be reviewed and updated to reflect that new reality. Such a serious updating should conform to the basic principles that have traditionally guided U.S. spirit and practice in exploring new frontiers, including the ideas embodied in the U.S. Constitution.

In formulating such new 'rules of the road' for renewed Space enterprise, it is instructive to consider some of the most remarkable passages in human thought, written by a refugee from National Socialism, a guest of British hospitality in London in 1942. Of particular note are the concluding remarks by Friedrich Hayek in his "The Road to Serfdom," written in exile in London on the foundation of free societies. These remarks addressed to his host country, England, on the inherent dangers of totalitarianism, whether national or socialistic or both, are timeless and should be heeded as various U.S. authorities consider the policy issues of Space enterprise today. (pp.177f):[1]

> *"The purpose of this book has not been to sketch a detailed programme of a desirable future order of society. If with regard to international affairs we have gone a little beyond its essentially critical task, it was because in this field we may soon be called upon to create a framework within which future growth may have to proceed for a long time to come. A great deal will depend on how we use the opportunity we shall then have. But whatever we do, it can only be the beginning of a new, long, and arduous process in which we all hope we shall gradually create a world very different from that which we knew during the last quarter of a century. It is at least doubtful whether at this stage a detailed blueprint of a desirable internal order of society would be of much use - or whether anyone is competent to furnish it. The important thing now is that we shall come to agree on certain principles and free ourselves from some of the errors that have governed us in the recent past. However distasteful such an admission may be, we must recognize that we had before this war once again reached a stage where it is more important to clear away the obstacles with which human folly has encumbered our path and to release the creative energy of individuals than to devise further machinery for 'guiding' and 'directing' them - to create conditions favorable to progress rather than to 'plan progress'. The first*

[1] Europeans, including Hayek, all too easily overlook that these same ideals were the foundation of the 18th century American revolution and the VIRGINIA DECLARATION OF RIGHTS of 1775 in particular, drafted by Messrs. Mason and Lee and recognizing the Pursuit of Property Rights specifically, adopted by Mr. Jefferson a year later in drafting the Declaration of Independence and ultimately included in the U.S. Constitution. The spiritual roots of these ideas can be traced, beyond John Locke, well back to scholastic thought, including the idea of the social contract foundation of all Government powers and the role (preference) of private property over common property. (Thomas Aquinas, Duns Scotus, and Marsilius of Padua - who would extend the social contract foundation even to matters of theology (c.1270 - 1342).

> *need is to free ourselves of that worst form of contemporary obscurantism that tries to persuade us that what we have done in the recent past was all either wise or inevitable. We shall not grow wiser before we learn that much that we have done was very foolish.*
>
> *"If we are to build a better world we must have the courage to make a new start - even if that means some 'reculer pour mieux sauter'. It is not those who believe in inevitable tendencies who show this courage, not those who preach a 'New Order' which is no more than a projection of these tendencies of the last forty years, and who can think of nothing better than to imitate Hitler. It is indeed those who cry loudest for the New Order who are most completely under the sway of the ideas which have created this war and most of the evils from which we suffer. The young are right if they have little confidence in the ideas that rule most of their elders. But they are mistaken or misled when they believe that these are still the liberal ideas of the nineteenth century, which in fact the young generation hardly knows. Though we neither can wish, nor possess the power, to go back to the reality of the nineteenth century, we have the opportunity to realize its ideals - and they were not mean. We have little right to feel in this respect superior to our grandfathers; and we should never forget that it is we, the twentieth century, and not they, who have made a mess of things. If they had not yet fully learned what was necessary to create the world they wanted, the experience we have since gained ought to have equipped us better for the task. If in the first attempt to create a world of free men we have failed, we must try again. The guiding principle, that a policy of freedom for the individual is the only truly progressive policy, remains as true to-day as it was in the nineteenth century."*

Had England only listened to Hayek! Let us not fail in Space, where the stakes, one may dare say, are much larger.

The need to revisit, reformulate and innovate U.S. Space Policy to conform to new opportunities and capabilities is a paramount requirement, not only for the U.S. but for all free market nations worldwide. This is necessary to assure substantial, productive and profitable (i.e. beneficial) uses of the vast investments made to-date by various governments, often with no regard nor incentive as to any practical uses.

What comes to mind is not dissimilar to the situation in the Colonies over 200 years ago. With the opening of the vast new territories West of the Appalachians, who and how should one decide on property and property rights – some abstract entity in distant London or the people who dared to go out and open up these new spaces for civilization? What is needed is an application of these same principles of homesteading and property rights that guided our forefathers then: the **Principles of the U.S. Constitution applied to a Declaration of Independence to and in Outer Space.**

A new Space Doctrine is needed along with any decision to establish the first permanent outpost on the Moon, assuring thereby the High Frontier for Space Enterprise. Critical amongst these principles – which should be established as a matter of statutory rights – are the indicated in the following proposed draft "Statement of Principles of Space Enterprise."

Obviously this draft Declaration can be improved upon, but the core principles expressed herein have to be part of any such new Declaration – without which Space enterprise for sure will be destined to fail: we might as well burn our Space ships – just as the Chinese bureaucracy did in 1423 and let the 'barbarians of Space' visit us.

Absent such a Declaration of Rights: why should we have spent our precious resources to go West into the new territories; why would we have set out for Oregon and the Pacific? Indeed, why now risk our treasure on Space Exploration and Enterprise?

Hopefully, the United States will not repeat the mistake of the Chinese World Empire of the 15th century – and leave the 'new territories' to others to explore and develop.

PROPOSED DRAFT STATEMENT OF PRINCIPLES FOR SPACE ENTERPRISE
A Declaration of US Space Property Rights and Independence
(Williamsburg, Virginia)

Whereas the United States has been founded on a set of well understood principles fundamental to the pursuit of property [Virginia Declaration of Rights, 1775] and freedom of man and

Whereas these principles have served the United States and the community of free nations well over centuries past

Whereas, in addition, the very discovery and development of these United States and the Americas were founded on the principles of the freedom of the seas, including the freedom to appropriate land and resources unclaimed or unused by others

The United States hereby declare:

(1) FREEDOM OF NAVIGATION – The new "Sea of Space" shall be open for anyone to navigate in and to undertake whatever enterprise in analogy to the freedom of the seas; the United States shall not agree to or be party to any treaty, policy, regulation or understanding that limits this freedom in whatever form; the United States sees no difference between the Open Seas of Earth and the 'Open Seas' of Space and hence no new principles have to be invented or agreed to that would limit such freedom of navigation and enterprise - for whatever purpose.

(2) THE RIGHT TO PRIVATE PROPERTY – Private property is fundamental to the pursuit of enterprise, investment, exploration and freedom of man, be it on Earth or in Space; the United States shall not agree to or be party to any treaty, policy, regulation or understanding that limits any proprietary rights of land, resources, services, data or other economic and intellectual goods in Space or derived from Space. In particular, the

United States want to re-affirm that nothing in the 'Outer Space Treaty' prohibits or contradicts full private property rights by any citizen of Earth, nor any and all uses of such property for whatever private or public gain. This all the more so as 'private property' is the foundation of all free societies and has existed throughout known history at least since the inception of agriculture 5,000 or more years ago. On the other side 'national property rights' are a rather recent artifact promoted by the French revolution, giving rise to 'nationalism' and 'socialism' with a concurrent notion that such 'nations' are free to steal or infringe on any such private property. The devastating consequences of these artifacts, when combined, were seen in the 20^{th} century. Specific provisions in the Constitution of the United States prohibit any 'taking' of such private property by government(s) without due compensation, nor can the United States be any party to a treaty or agreement that directly or indirectly were to lead to such a 'taking'.

Again, the United States see no difference between activities of free man on Earth and in Space for whatever purpose, and in particular reaffirms the right to private property of any and all means in the pursuit of exploration, science and commerce to be inalienable and fundamental to such freedom.

To the extent that the United States de-facto or unwittingly may have been a party to different understandings and treaties, these shall henceforth be declared null and void to the extent that they infringe on such property rights.

(3) SPACE HOMESTEADING RIGHTS – To foster the early and broadest possible exploration of Space and use of its vast resources the United States hereby proclaim Space Homesteading rights whereby - in analogy to the principles that opened the vast reaches of the United States to development for the benefit of their people and world markets.

The United States will recognize the appropriation of any surface and underlying mineral and resource rights by anyone on the Moon or on any other Celestial body, with the size of homesteading rights to be determined for each of these bodies separately. Asteroids and Space debris can be appropriated in *toto*.

Such Homesteading rights are granted to any person that takes physical possession of such surface or object, himself or through ventures financed by him at his risk and benefit. The proprietary rights have to be exercised through use within 99 years or revert to unclaimed Space status.

Lands and resources claimed as private property in Space under the Homesteading principle by US persons shall be subject to the rights and obligations of the United States constitution.

(4) LOW COST ACCESS TO SPACE FOR PRIVATE ENTERPRISE – Based on the principle that Government is formed to serve the individual, his rights, pursuit of freedom and property, the United States Government will henceforth make available at additive costs any facilities, services, hardware and intellectual Government rights in the pursuit of private U.S. Space enterprise.

By 'additive costs' are meant the costs added by each specific private activity to Government Space program, project or facility costs, and proven by Government to have been added by those specific activities to any one annual government budget appropriation. Similar access will be granted to any other free market nation that grants similar rights and access to its facilities and which participates in significant co-operative programs in Space with the United States.

(5) COMPETITION – Earth and Space are best served by open competition of ideas and enterprise in free markets, so that the best may succeed. Consonant with this premise the people of the United States will pursue their goals and interests in Space as they see fit: ‘anticipatory’ regulations, license requirements, laws and other provisions that stifle enterprise in open markets serve no purpose.

Nor is the exploration and use of Space served by 'co-ordinated' or co-operative programs for the sake of co-operation, if such programs deterred or stifled competition and enterprise by any nation and its people. After all, Spain and Portugal did not set out jointly to open the world for Europe. And the Soviet Union did not set out jointly with the United States to launch the first satellite or the first man into Space. Nor did President Kennedy set out to put man on the Moon and return him to Earth by the end of the 1960's jointly with the Soviet Union. Duplication - if any - is a low price to pay for enterprise and freedom in Space.

(6) EXERCISE OF RIGHTS AND CLAIMS – Consonant with the positive principles of international law, the United States shall claim and recognize property rights in Space only to the extent that such rights are vested in persons that control or provide services, resources, land or goods anywhere in Space. The United States will not recognize any claims or rights based on abstract, theoretical notions of others that would infringe in any way on free enterprise by the United States or any other Space faring nation or person of mankind, or other civilizations yet to be encountered.

We cannot foresee the ingenuity that companies, established or entrepreneurial, will bring to the building of new industries in the 21st century based on the Highway to Space. Nor can we know the individuals whose names will rank with Douglas, Boeing, Sikorsky, and the other pioneers of the aeronautical industry. But looking back for analogies, we know that one of America’s heroes, Charles Lindberg, practiced the skills of piloting in heavy weather, prior to his Atlantic crossing, by flying the U.S. mail.

Pioneering the Space Frontier
Report of the National Commission on Space
Dr. Thomas O. Paine, Chairman, 1986, p. 21

Chapter 7 – Closure

"The U.S. space effort has moved forward for more than 30 years [since Apollo] without a guiding vision, and none seems evident. In the past, this absence of a strategic vision in itself has reflected a policy decision, since there have been many opportunities for national leaders to agree on ambitious goals for space, and none have done so. . . . We believe that the White House, Congress, and NASA should honor the memory of Columbia's crew by reflecting on the nation's future in space and the role of new space transportation capabilities in enhancing whatever space goals the nation chooses to pursue."

***COLUMBIA* ACCIDENT INVESTIGATION BOARD**
Report Volume 1, August 2003

This report urges that the White House, Congress and NASA support a focused effort to return to the Moon within a decade to establish a permanent, manned Lunar Base – named "Columbia" in honor of the crew of Columbia and all others who have given their lives in pressing our frontier outward into Space.

The resulting Space operations will benefit U.S. citizens much more than NASA's accumulated efforts since Apollo's historic first Lunar landing – and is currently beyond the reach of any other known or potential Space faring nation.

Stated another way: These capabilities in the hands of an enemy nation – if not matched by at least equivalent US capabilities – would signify the demise of the United States as the leading engine for innovation, economic growth and security.

Or stated yet another way: Since the last significant Space Transportation Systems decision in 1972 – the decision to develop the Shuttle – the United States and NASA have spent about $450 billion with little to show for it when compared to what might have been achieved for the $100 billion investment requested by the 1969 Space Task Force Report to pursue essentially the program advocated here.

It is time that NASA be given this historic goal, from which significant advances in technology, opportunities for innovation and economic and social wealth will be derived.

"Only 24 individuals have traveled as far from Earth as our nearest neighbor in Space, and only 12 have landed upon it. The total time spent by humans on the Lunar surface was less than two weeks, all of it in the Apollo years from 1969 to 1972. In those brief journeys a remarkable amount was learned: more than 800 pounds of soil and rock were returned to be analyzed on Earth; equipment was set up to measure heat flow from the Moon's interior, and to report Moonquakes and meteorite impacts. Laser reflectors were set up, which have allowed us to measure changes in the Earth-Moon distance to a few inches. Metal foils were stretched like sails to catch the wind of protons and heavier elements streaming from the Sun. And with electric roving vehicles, astronauts explored outward from their landing sites. But the 12 men who trod the Lunar surface in the course of six Apollo missions could not venture more than five miles from their landed spacecraft. Quite literally, they could do no more than scratch the surface of the Moon. We therefore recommend that: We return to the Moon, not only for brief expeditions, but for longer, systematic explorations; eventually, we should come to stay.

"As in the exploration of Earth, our exploration of the Moon can best proceed by a combination of visits to specific points, and the establishment of permanent outposts at locations of continuing interest. Separation of sites by purpose is more likely than the concentration of all activities at one "lunar base." Seismologists will need locations remote from mining, to achieve seismic quiet. Prospectors will need to make a series of land traverses, as is customary in resource exploration, and the promise of the Lunar poles may draw prospectors at an early stage of Lunar exploration. The first expeditions will make use of transfer vehicles as temporary camps on the Moon, just as the shuttle serves on each flight as a temporary space station. As more is learned and we find reasons to zero in on specific points, the temporary camps will be enlarged. Caches of food, fuel, water, and oxygen will be left there between visits and, finally, explorers will "overnight" at outposts through the Lunar darkness that lasts 15 Earth days. We will return to the Moon for diverse reasons. As the first stage of the return to the Moon, we recommend: Establishing human-tended Lunar surface outposts, primarily for a variety of scientific studies."

Pioneering the Space Frontier
The Report of the National Commission on Space
Chaired by Dr. Thomas O. Paine
A Bantam Book, May 1986, p. 63.

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Appendix A
NASA Directions Since Apollo[1]

The proposal to establish a permanent presence of humans on the Moon is as old as the Space program itself. In fact, it predates development of the necessary rocket technology. For example, Wernher von Braun's wrote in a1945 Memorandum to the Army that with future rocket developments beyond his V-2, *"It will be possible to go to other planets, first of all to the Moon. The scientific importance of such trips is obvious[2]."*

Dr. von Braun's contributions are well known – both in launching America's first satellite and in NASA's pioneering efforts leading to the Mercury, Gemini and Saturn rockets that carried our astronauts into Space and to the Moon. That historic achievement – with the first manned Lunar landing a year earlier than President Kennedy's visionary goal – was not followed by a systematic program to fully exploit a Lunar Habitat. But not because there were no plans for doing so.

The most detailed and precise plan to bring about such a historic achievement dates back to the late 1960s, when the best minds in science and technology set out to propose developing the transportation technology components for all of Cis- and Trans-Lunar Space. Based on these studies, the 1969 Space Task Group[3] outlined a comprehensive Space Transportation System for Cis-Lunar operations capable of routine missions throughout near-Earth and the Moon, as illustrated in Figure A-1.

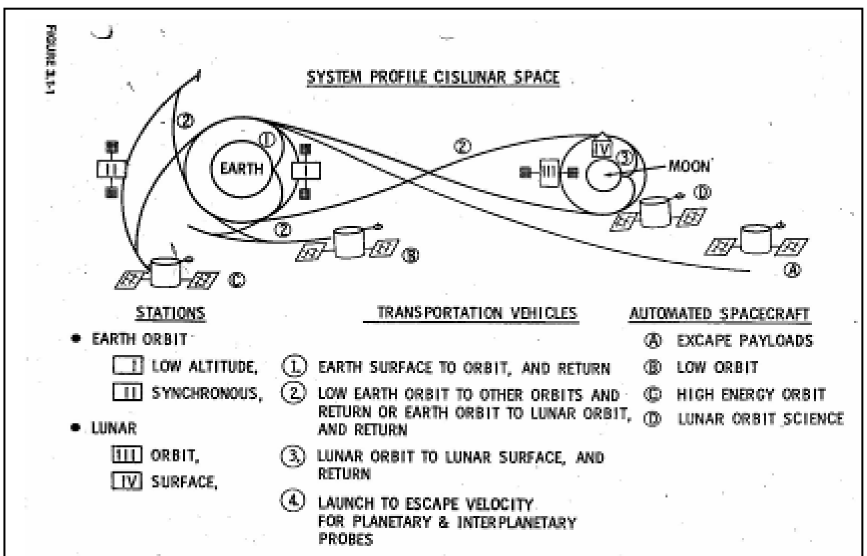

Figure A-1 - The 1969 Space Task Force Cis-Lunar Svstems Profile

Then, as now, the key technology components to establish the first human settlement on the Moon within a decade are the same key items discussed in the body of

[1] This Appendix builds upon Klaus P. Heiss, *Some Thoughts on the Columbia Disaster and How to Proceed from Here*, Mimeograph, April 18, 2003.
[2] "Survey of Development of Liquid Rockets in Germany and Their Future Prospects, " Prof. W.von Braun, Chief, Engineer, Penemunde Group, Mimeograph to US Army, Spring 1945.
[3] Space Task Group, *The Post-Apollo Space Program: Directions for the Future,* September 1969, reprinted in NASA SP-4497, vol. I, pp. 522-543 ["Space Task Group" report].

this report, namely a Space Shuttle, reusable Space Tug(s), Space based Refueling and Delivery Systems and a CELSS Lunar Habitat.

Some important parts of the key technology were developed in the 1970s and 1980s: e.g., the Space Shuttle, the life sciences, large structures assembly, operating experience acquired in the Space Station program, and advances in information technologies and numerical control systems. Other important components remain to be developed – and some technology efforts need to be redirected because they did not proceed during the 1970s and 80s with a Lunar mission in mind. In particular, the 1972 Space Shuttle decision was made without serious consideration for its important role in a Space Transportation System designed for establishing a Lunar habitat.

As the one in charge of the independent assessment of the Space Transportation System, directed by the White House for NASA in 1970 through 1972, the author will review the rational put forth then and – equally important – how that rationale compares to the "facts" thirty years later. The 1971-72 conclusion was and remains correct. The following sections discuss 1) the cost-efficiency case made in 1971 – combined with an analysis of what went wrong subsequently; 2) the promise of Space seen by the author in 1971 – and still today; and 3) the need for a clear, single goal for manned Space flight – as discussed in this report.

INPUTS TO THE 1972 SPACE SHUTTLE DECISION

Contrary to perceptions, the case for the Space Shuttle – and also for the Space Tug then an integral conceptual part of a reusable Space Transportation System (STS) to service to all Earth orbits – was NOT based on transportation cost savings[4]. Important presentations by the independent assessment team in 1970-71 started with the realization that the Space Shuttle <u>cannot</u> be justified solely with the narrow argument of transportation cost savings[5].

Indeed it is this statement – that the Space Shuttle System could NOT be justified on the basis of transportation cost savings – and the logical exposition of the REAL case for the Shuttle that won the author the award to do the independent outside assessment by NASA in 1970 to begin with. Imagine: a $3 million contract, limited explicitly to five pages of substantive exposition AND a full day cross-examination as to the rational AND to start out the presentation with the statement: "The reusable Space Transportation System (Space Shuttle and Space Tug) can NOT be justified on transportation costs!"

So what WAS the logic for having a Space Shuttle and Space Tug – other than reducing the cost of Space transportation?

[4] This misperception may occur because the 1972 Shuttle decision was made to reduce near-term, non-recurring costs – but that selection was for the more expensive (in terms of life cycle costs) and higher risk choice and was not the selection recommended by the author, as the following paragraphs discuss.
[5] Heiss, Klaus P. and Oskar Morgenstern, *Economic Analysis of the Space Shuttle System*, 3 volumes NASW – 2081, Princeton, NJ, January 1972.

The very first Table in our 1971 Executive Summary and our Main Report to NASA clearly and simply stated that the life cycle costs would be less for New Expendable (rocket) systems than for a Space Shuttle and Tug – some $11 billion vs. $12 billion, NOT counting the costs for manned Space flight missions!

However one “massaged” the NASA and DoD mission models (we reduced the mission numbers given to us by the agencies by up to 67%) there was no way to “justify” the Space Shuttle based on transportation costs over a 10-year, 20-year or even “infinite” time horizon – where “infinity” has a way of shrinking drastically when reasonable discount costs are applied to “future” savings, which we did[6].

In Figure A-2, the various Shuttle configurations considered in the 1971-72 assessment are shown and compared in terms of Total non-recurring costs (RDT&E, initial fleet of five orbiters) vs. the cost per flight of the various options. These ranged from a fully reusable version (A “707” sitting atop a “747” taking off vertically with all internal LOX/LH2 tanks), to Thrust Assisted Orbiter Shuttles (TAOS) and a “Reusable Crew Module” launched on expendables, nowadays called ‘Orbital Space Plane’.

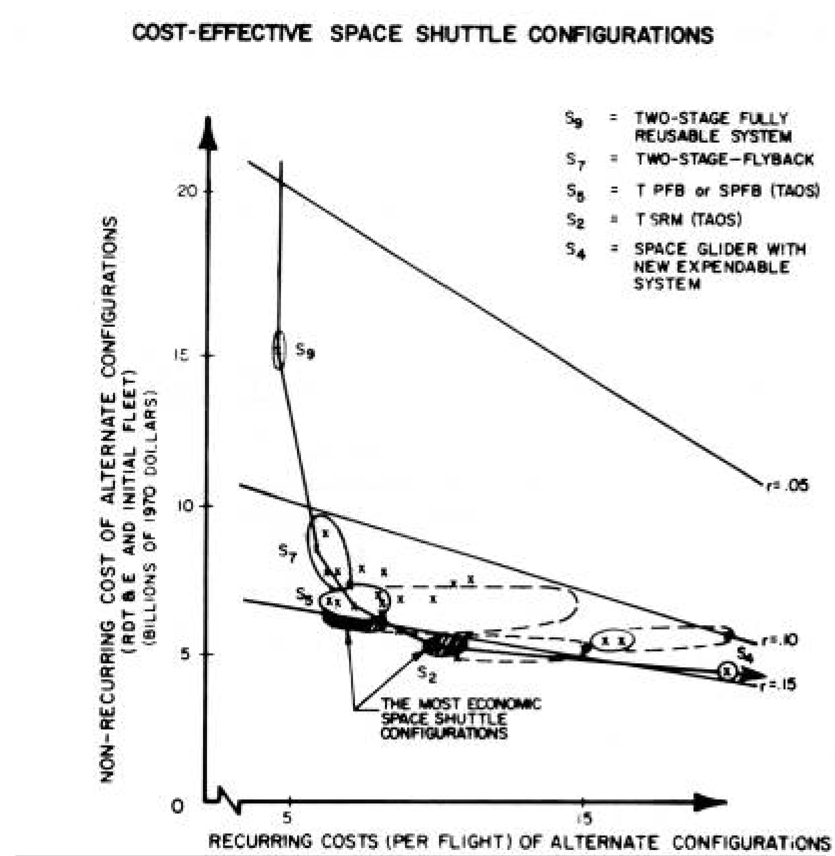

Figure A-2 - The 1971 Space Shuttle Decision – The Thrust Assisted Orbiter Shuttle (TAOS) Selection

Figure 0.10

Also shown in Figure A-2 is the effect of interest rates on technical system choices: were funding, costs and risks no issue, then a case could have been made for a fully reusable Shuttle. However, given those constraints the TAOS set of configurations emerged as the choice. The ‘Orbital Space Plane’ was rejected out of hand, as with the intended uses (with a reusable Space Tug) for carrying all payloads to low, high and

[6] Heiss, Klaus P. and Oskar Morgenstern, *Economic Analysis of the Space Shuttle System* (Executive Summary and 3 volumes), Mathematica, [NASA – NASW 2081] Princeton, N.J. January 31, 1972

geosyncronous orbit and the ensuing 'payload effects' the basic rationale for the new Space Transportation System was foregone.

Also noteworthy in this context was the fairy tale of the "assumed" $5 million cost for each Shuttle launch. The range of launch costs was clearly identified in ALL reports and testimony to Congress and in three separate GAO 'in-depth' reviews in the 1970s – and was stated as shown in Figure A-2.

- For TAOS with Solid Boosters (the configuration ultimately chosen by NASA) these costs ranged anywhere from $15 million to $30 million (in 1970 dollars – or about $60 to $120 millions in today's dollars) depending on assumed launch rates of up to 24 per year, with a clearly stated launch risk of 2% (98% success rate).
- In contrast, TAOS with Liquid (Pressure Fed) Boosters would reduce these costs and risks by about half – and would permit the possibility of intact abort throughout launch.

Furthermore, moving toward a fully reusable STS (using modular designs with standardized spacecraft components) would open up totally new ways of operating and assuring space missions – collectively called 'payload effects',[7] e.g.,

- The ability to revisit any and all satellites in Earth orbit would allow for cost effective **maintenance, repair and updating** of components of these spacecraft. Transportation costs constitute only one third of total STS costs. The rest has to do with spacecraft, instruments, data and their processing – in space and on the ground – and a modular design with standardized components offers great benefits in further reducing costs of the other two-thirds of total STS costs.
- **Standardization of Spacecraft and Space systems at the subsystem level** was a revolutionary idea in 1970 (still unimplemented, by the way) that promised up to 67% cuts in support costs for spacecraft. Standardization would facilitate repair and updating a satellite subsystem level – permitting relatively untrained personnel to exchange blue, green, pink and whatever other color boxes. As in 1970, only a few Space missions are "outside" the scope of such standardization.
- **Reliable On-orbit service** reducing the costs of required high confidence capabilities of key national security satellites, which is very expensive to achieve through redundancy of expensive satellites.
- **In-orbit modernization made feasible** by such replacement and repair capability. This prospect of updating expensive satellites **in Space at the component level,** is much to be desired over replacing whole systems or – worse – letting old technology linger in Space providing obsolete services.

In this context, our 1971-72 study examined both manned and unmanned missions. We did not want to rationalize the Space Shuttle simply and solely on the basis of man in Space: that would tilt the analysis much too much in favor of the Space Shuttle.

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[7] In support of Study: Lockheed Missile and Space Corporation, *Payload Effects Analysis Study* CASI 71-37496.

We observed that Space Tug and Space Shuttle would open up extensive new capabilities, e.g., structures larger than could be carried by any expendable system could be standardized and designed for on-orbit repair, replacements, updates, maintenance, etc[8]. We identified entirely new classes of Spacecraft for science, commerce or defense – in Low Earth Orbit, intermediate orbits, and up to and beyond Geo-synchronous orbits. Dozens of new Space application missions where designed and outlined for NASA, the DoD and private enterprise – once the Space Shuttle and Tug were fully operational, e.g., for

- **Space Science:** one of our first visits in Princeton was to the astronomy department, chaired at that time by Prof. Spitzer. The result of these meetings was what today is known as the **Hubble Space Telescope**. Were it not for the unique capabilities of the Space Shuttle, this magnificent instrument could never have been built, launched, repaired, maintained and modernized. We also defined half a dozen other scientific Spacecraft, some in LEO, some in HEO and some in GEO, ranging from radar to infrared to multi-spectral instruments of a size and capability hitherto unknown and unimaginable.
- **Commercial Applications:** particularly for communications and remote sensing. Some applications would develop with or without the Shuttle, e.g., a vast range of communications and navigation satellites, including GPS, a variety of Global resources sensing satellites, low and high Earth orbit communication satellites at a variety of frequency bands. We also foresaw an entirely new class of satellites with vastly expanded capabilities, e.g., a new generation of **communication platforms in geo-synchronous orbit** with reduced power-requirements, on-board switching, data processing and storage; **tens of thousands of spot beams**, and satellite-to-satellite optical and laser communications allowing point-to-point communications to any place in the world. Direct access to repair, maintain and modernize these platforms was critical to providing 99.999-plus reliability. We envisioned a Global Resources Information System (GRIS) described in detail in the NRC papers of the Snowmass meetings of 1974. The effect on the distribution of world food supplies through the commodities markets alone accounted for billions of dollars in annual benefits. Environmental, energy, geologic and other resource observations benefited as well, including such arcane applications as archeology. Many of these have become reality today, as they can also be achieved with smaller spacecraft, not requiring the capabilities of the Space Shuttle and Tug system.
- **Defense Applications**: at least one-third of all applications foreseen for the new STS were defense related. They included some of the applications realized since then in navigation (GPS), in observations, in communications, albeit not to the extent possible if we had truly developed the full Shuttle and Tug capabilities, with vistas for expanded uses of Space very similar to those cited for commercial uses above. Building on the considerations of “Bambi” and a seminal 1968 paper by Max Hunter – a member of our team – showing the technical feasibility (in principle) of a Space based laser defense against ballistic missile attacks, we included BOTH options in our analyses of 1971-72. While not necessary for a

[8] In support of Study: Aerospace Corporation, *Integrated Operations/Payloads/Fleet Analysis Final Report*, CASI 72N-26790.

positive Space Shuttle decision, these possible space missions would have significantly added to the benefits of the STS then proposed.

Not included in the cost-benefit analysis was a vision of future energy supplies from Space to Earth, e.g., large **Solar Power Satellite Platforms** of up to 100 square miles in area, first proposed by Peter Glaser of Arthur D. Little[9]. One such platform alone will be able to supply up to 10 GW of electric power to any point on Earth. Also not included were any **manned Space flight missions** such as a Space Station, or Lunar missions or missions beyond. While these possibilities were recognized, we chose not to co-mingle them unmanned Space missions which alone justified the Shuttle-Tug STS on the basis of a cost comparison. Their inclusion would open new horizons, indeed.

Analyzing literally hundreds of different Space program scenarios, with any and all mixes of foreseeable Space missions and applications, we concluded by the end of 1971 that a STS employing a Space Shuttle and Space Tug was in the interest of the United States, at a substantially reduced cost from the original plans of NASA (a two stage fully reusable design roughly a 707 on top of a 747 taking off vertically with internal hydrogen tanks etc.) saving the country billions of dollars in the development phase (cutting the RDT&E costs by 50% or more) AND allowing a cost effective, new range of Space operations and uses. The author presented this result to the NASA Administrator in an October 29, 1971 Memorandum (to assure consideration in the Final Design Selection process set for early November and still limited to two stage designs only)[10]. This memorandum was followed in January 1972 by a three volume report and separate Executive Summary, documenting the extensive work done by our group in Princeton with support from Aerospace Corporation (Mission modeling) and Lockheed Missile and Space Corporation, the leading contractor for military[11]. Notably, this report explicitly stated that the risk of Shuttle Missions failure was one in fifty.

The variation of cost-effectiveness vs. flight rate is shown in Figure 2.3[12] – 'break even' for the TAOS Shuttle configuration was/is around 25 flights (again including all launches out of East and West coast sites) to all orbits. Two broad 'families' of Space programs were analyzed: ballistic missile and other DoD programs (the upper range of results depicted in Figure 2.3) and scenarios without such advanced uses. Obviously the case for the Space Shuttle system was better with additional uses in low earth orbits.

Contrary to perceptions held by some, NASA did not 'assume' 600 or more space flights to 'justify' the Shuttle. This is simply not the case as indicated by all of the testimony throughout the Space Shuttle decision hearings before Congress in the 1970s.

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[9] Glaser, Peter E., "Power from the Sun: its Future", Science, 162, 857-866 (1968).
[10] Heiss, Klaus P. and Oskar Morgenstern, „Factors affecting a Space Shuttle Decision", Memorandum to James C. Fletcher, NASA Administrator, October 29th, 1971.
[11] January 1972 Report to NASA., op. cit.; Lockheed Missile and Space Corporation, *Payload Effects Analysis Study* CASI 71-37496; Aerospace Corporation, *Integrated Operations/Payloads/Fleet Analysis Final Report*, CASI 72N-26790.
[12] Heiss, Klaus P. and Oskar Morgenstern, *Economic Analysis of the Space Shuttle System*, *op.cit.*, Executive Summary..

However one “massaged” the NASA and DoD mission models (we reduced the mission numbers given to us by the agencies by up to two-thirds) there was no way to “justify” the Space Shuttle based on transportation costs over a 10year, 20 year or even “infinite” time horizon – where “infinity” has a way of shrinking drastically when reasonable discount costs are applied to “future” savings, which was done. Transportation costs were at best a “draw”.

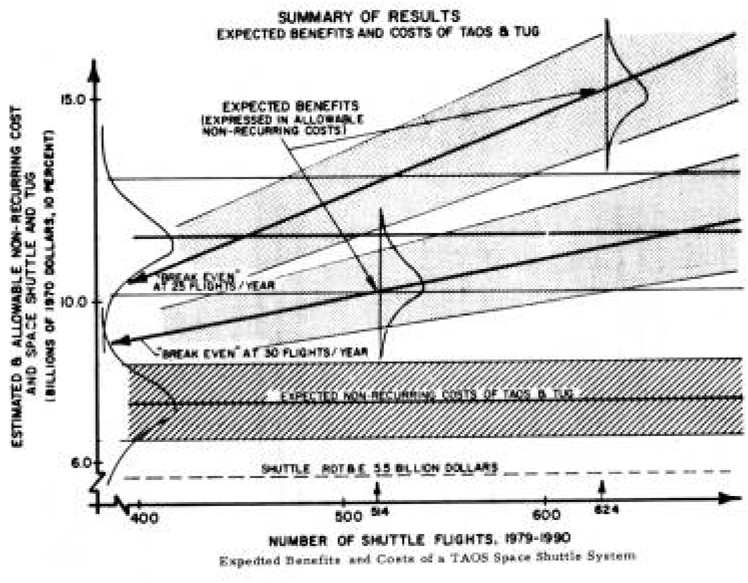

Figure 2.3 - Space Shuttle Flights and ‘Breakeven’: With and Without Advanced Space Applications

The real reason for reusable STS capabilities – to LEO, GEO and beyond, ideally including Lunar orbits – is in the profound effect these capabilities would (will) have on the very conduct of Space missions, their reliability and capabilities. They would lead to a fundamental change in how to conduct ‘Near-Earth’ Space missions.

Thus, the opening up of the Moon as our ‘natural’ Space Station and Operations base for Cis- and Trans-Lunar activities will transform and change forever on how we operate and use Earth and Near Earth Space.

Today, thirty plus years later, the author would not change a single sentence, conclusion or recommendation made in 1971. The concluding observations to NASA deserve highlighting: **The economic basis for the Space Shuttle and Tug were sound and solid – AS LONG AS NASA AND THE NATION HAD AN ACTIVE SPACE PROGRAM ALONG THE SCALED BACK SCENARIOS OUTLINED AND USED BY US.**

Never, ever would it have occurred to us, that NASA and the nation would abdicate the pursuit and conquest, indeed domination of Space.

A 30 YEAR ROAD TO DISASTER

The initial Space Transportation System Recommendations of 1971 – The 1972 decision to proceed with a new Space Transportation System – including the TAOS Shuttle and the Space Tug – was the last significant, courageous and strategic Space program decision assuring an aggressive U.S. Space strategy for the rest of the century to well into the next millennium: all this at an affordable budget profile substantially less than that expended on the Apollo program of the 1960s, the vision for which President Kennedy and his generation will be remembered in millennia to come. The salient technical transportation components recommended at that time were :

- **TAOS instead of Two Stage Fully Reusable Shuttle.** The TAOS Orbiter Shuttle represented a substantial reduction in development costs, risks and schedules over the desire by NASA to develop a two stage fully reusable Orbiter AND Booster – with the estimated development costs reduced by a factor of three to four (from 50 to $60 billion in 1970 dollars to 15 to $20 billion for TAOS, a savings of at least $40 billion
- **A reusable Space Tug** To assure access to all Earth orbit missions to the new STS and its new philosophy of payload standardization for in orbit repairs, refurbishment, updating and rescue for high mission availability;
- **An Ambitious Unmanned Space Missions program**, including all “conventional” DoD programs then deployed; two novel DoD missile defense missions, one “kinetic” (then called ‘killer bees’), one laser based (Max Hunter’s concept of 1968); “conventional” science and commercial programs such as communications, observations, navigation and life sciences programs; an entirely new class of science and commercial space capabilities (such as Large Astronomy Observation platforms – e.g. the Hubble Space Telescope and several others which availed themselves uniquely of the new STS capabilities – and large geosyncronous Space communications platforms of entirely new dimensions allowing global point to point communications without ground networks.); and
- Enabling whatever **Manned Space Program** the U.S. might wish to pursue as a “side benefit” of these capabilities.

Had NASA and the nation fully pursued these programs in the afterglow of the Apollo program achievements, the dominance of the United States in Space would have been absolute. Some of these programs have immensely contributed to changing the strategic perceptions and relations anyhow, others, indeed most still languish to be implemented. The course charted out then still remains to be taken. Most notably in manned Space flight.

Early Open Questions and Compromises 1972

After having identified the TAOS as the most cost-effective of “hybrid” Space Shuttles, I the top experts from industry and NASA met in Princeton in June/July of 1971 for a week of meetings on all the critical issues. The meeting pitted all the different engineering approaches and groups against one another in a truly historical debate, sometimes reaching rather high decibel levels. The following were notable findings:

- **Solids vs. Pressure-fed "assists"** to the Shuttle at take-off eliminated the need for NASA's proposed 747-size reusable booster with parallel rocket boosters for needed "extra lift." Two principal options were considered: either solid rockets, such as those produced by Thiokol for expendable rockets, or – like the main external tank – two additional pressure fed rockets using the same fuel (oxygen and hydrogen) as the Main Space Shuttle Engines. The former had an "irreducible risk", among others as to simultaneous ignition and the inability to cut off such ignition should problems develop at or during launch. Pressure Feds not only could be shut off in case of emergency, but with "cross-feed" from the other tanks (Main tank and/or the other parallel burn booster) ALL engines could be fed from whatever tank(s) were available or operable. Indeed of all the Shuttle launches the most impressive was the one that did not take off AFTER the SSMEs had ignited (Shuttle Main Engines) but BEFORE the Solids had ignited, quite a feat to avoid disaster on the Shuttle's maiden launch. The worst Shuttle accident has not happened: ignition of only one of the Solids and a "cartwheel" of the Shuttle and tanks and solids right on the take-off stand. After discussion of these considerations, we left the choice open because pressure-feds with cross-feed had not been tested operationally and required an additional $500 million in RDT&E costs when compared to solids. Still, it was noted that Solids would double the cost per launch. The agreed group consensus was that, if NASA decided on Solids initially, they should move quickly to adding pressure feds to Shuttle operations to reduce risk and the high cost per flight.
- **Thermal Tiles vs. Metallic Composites Heat Shields** to provide for the tremendous heat arising during re-entry into the atmosphere was the other big issue. Grumman was considering an ingenious scheme related to tiles. The other major option was to develop new metallic/composites able to withstand these stresses and environs. The tiles approach was more immediate, requiring less new materials development. The metallic protection, while requiring a significant materials development and testing program would dramatically reduce turn-around times, refurbishment needs and thereby launch costs and times.
- **Space Shuttle Main Engines** – With ignition at lift-off and burn all the way to Earth orbit, significant new requirements were imposed on rocket engine technology. Indeed, the development and total success of the SSMEs to this date constitutes the major technology achievement in the Space Shuttle program, a feat no other space-faring nation has accomplished to-date. Yet the uncertainties at the meetings in that June/July week were significant, the RDT&E inescapable and hence committed to.
- **Gradual Evolution of Space Shuttle** to a fully reusable Spacecraft was the core component to the review group's considerations – but this would lead NASA to give up on its dream of a fully reusable, two stage Space Shuttle of incredible technological challenge in favor of a "hybrid" TAOS approach. This vision was as follows:
    - **Initial fleet size and subsequent procurements**: Based on launch requirements, anticipated "attrition", material and technical obsolescence

an initial procurement of five Orbiters was proposed with additional Shuttles to be procured at a rate of about one a year, for **a total of between nine to twelve for the initial decade** of full operations.

- **Two launch sites – ETR (Kennedy Space Center) and WTR** (Edwards in California for polar orbit launches) were anticipated.
- **Gradual Technology Upgrades:** As the experience and technology progressed certainly the solids would be replaced by pressure feds, the tiles with metallic composites and payload capacities could be dramatically increased with e.g. a dual parallel launch of two Shuttles simultaneously, with the tanks between them, vastly expanding the mass and size of payloads to be transported to LEO.
- **Evolution toward a Fully Reusable Shuttle:** Ultimately even more radical innovations could evolve from the TAOS, such as the "Stage-and-A-Half" envisioned by the team member Max Hunter, with up to sixteen Shuttle engines and delta wing shaped fuel tanks attached (and recovered).

The October 1971 Compromise on Solids vs. Pressure-Feds:

The author prepared a Memorandum of the group's conclusions concerning the Space Shuttle, configurations and options – intended to support a possible November 1971 NASA decision[13].

Because of cost-per-flight and risk -- including intact abort requirements during launch and throughout flight, the ideal option was the pressure-fed version of TAOS. Every aspect of Space flight operations indicated this preference. That should have been the recommendation, because if NASA were given a "choice," Solids would be the outcome for two reasons: 1) Solids meant $500 million less in funding requirements in the 70s and, 2) Thiokol produced the solids and was from Utah, as were the Chairman of the Senate Committee presiding over these issues (Senator Moss) and the Administrator of NASA. No other component subsystem of the Shuttle could be produced there. So NASA would invariably come to a preordained (wrong) conclusion in this matter.

The author wanted his professor, Oskar Morgenstern, to co-sign the proposed memorandum. But after having the need for such an input and the various attendant open issues explained, Morgenstern agreed to co-sign the Memorandum only if the two options left open. In 2002, the author learned upon a visit to Princeton at dinner with the President Nixon's Science Advisor, Mr. Edward E. David, that NASA Administrator Fletcher had come to him in early 1972 on this very issue and that David had not recognized the need for him to intervene, for which Dr. Fletcher was basically begging, not realizing that if left to NASA there was no choice. Fletcher's words to David: "There was all this pressure to go for Solids while pressure feds clearly held promise". David did not intervene and asked Fletcher to resolve matters "in house". So was the "Solids" decision ordained.

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[13] Klaus P. Heiss and Oskar Morgenstern, *Factors for a Decision on a New Reusable Space Transportation System,* Memorandum for NASA Administrator James C. Fletcher, October 28, 1971.

The other major component of that Memorandum assumed that NASA and the nation would have a manned Space program to go with the Shuttle.

Thereafter success was nearly total. An effort was mounted by OMB to “downsize” the Space Shuttle to less than what was required to carry the whole range of civilian and military payloads. To thwart that attempt, we literally “camped out” at NASA for ten days, day and night, working with our support teams in Princeton, El Segundo (Aerospace) and San Jose (Lockheed MSC) with the central point being that no costs would be “saved” with smaller configurations. Indeed, re-entry by a larger delta winged spacecraft was less problematical than smaller craft, since the total mass was not that much reduced by downsizing whereas the protective area slowing down the Shuttle during reentry indeed was reduced by such variations. We won that battle hands down.[14]

The Senate and House hearings were equally extensive and – in the end satisfying. The lead opponent of the Space Shuttle program was Senator Mondale, who in the footsteps of Senator Proxmire tried to make a “name” for himself as a big aerospace program ‘killer’. After everything was presented and reviewed, including “showdown” sessions with the proponents led by the author and opponents led by Mondale, Proxmire turned to the author and said – in front of Mondale: “I would like to compliment you for the work done and the thorough analyses. While I will not come out in favor of this vast program I will certainly not oppose it.” That meant the approval of the program.

Numerous investigations and exams by GAO and others followed, including a later Ph.D. thesis by Hum Mandel, demonstrated that, despite serious delays in procurement schedules, our 1971 estimates of RDT&E costs of the Shuttle program came within 5% of the actual costs realized.

But all was not well.

Price Controls, Inflation and the Shuttle Development Impacts

To finance the war in Vietnam while opposing tax increases in an up and coming election year, President Nixon demonetized the Dollar and imposed price controls. What resulted after 1972 was a period of the worst inflation ever experienced by the U.S. – and NASA had made a “pre” inflation budget deal with OMB. OMB directed the Shuttle be developed according to the budget profiles, so inflation required that programs be cut. “Non-destructive” testing was invented to replace reality simulations and, at every junction where NASA had the choice to do more expensive technologically advanced components, the cheaper way was chose: On Solids vs. pressure-feds, on heat tiles vs.

[14] Call of George Shultz to Klaus Heiss and Oskar Morgenstern, Monday, January 3rd, 1972 and 6 pm meeting on same Monday between James Fletcher and George Low with George Shultz, Caspar Weinberger, Don Rice, Edward David and Peter Flanigan; in: T.A. Heppenheimer, *The Space Shuttle Decision: NASA’s Search for a Reusable Space Vehicle*, NASA-SP 4221, 1999, pp.408-415.

metallic/composite shielding on upper stages, etc. The program was stretched, another "fund-raising" mechanism in Government accounting and procurement.

Notably, the "European" Space Tug: was cancelled, with devastating consequences for the vision propounded by the 1969 Space Task Force and the comprehensive 1971-72 review discussed above. Over 60% of all Space missions are above LEO, the orbits reachable by the Shuttle alone. To implement the vision for a reusable Space Transportation System required a reusable Stage – the Space Tug. But NASA had inadequate funding.

So the first attempt to recover a Space Tug program was to talk the Europeans into joining us in the development of the STS, with the Europeans (ELDO, a predecessor of ESA) developing the Space Tug. After a 12-month crash program, things were coming together: ELDO agreed to fund and build the Space Tug in co-operation with NASA. Less than six months later, NASA was directed by the Space Interagency Group to cancel any such agreement with ELDO/ESA.

Instead the DoD undertook a "long march" to nowhere, in the next decade spending $3-5 billion – some of it with and through NASA – with all programs failing either in infancy or in technological stillbirths, e.g., the IUS (interim upper stage), the TOSS, the Centaur-in Shuttle, etc. So no such stage exists today – meaning that over 60-percent of all the potential Space missions envisioned in the 1969-72 period were aborted. Further, the infrastructure to maintain the launch capability for these "out-of-reach" missions was retained, and became a reason not to pursue a fully reusable upper stage. With the loss of the Space Tug went a range of innovative new military, scientific and commercial Space applications. The negative impact of this single decision – and its consequences for the decades to follow, cannot be overstated. Few are aware of this even today.

The disaster for the Space Shuttle program solidified with the advent of the Carter administration. With Vice President Mondale's "experts' in key "second-tier" positions throughout the government, particularly in OMB – a blood bath set in for the Shuttle program. Mr. Mondale made sure he would be proven right as to the deficiencies of the Space Shuttle. The components of this demolition effort was varied and devastating:

- **Cutback of Shuttle launch sites** from two (East and West Coast) to one (East Coast). These "savings" were arrived at by some obscure logic that fewer launch sites would mean lower costs – however, it meant was that no polar launches could be made with the Shuttle, again leading to a further loss of applications and traffic. Of course, the Vehicle Assembly Building at Vandenberg had already been started and a billion dollars invested therein. In addition, it also meant critical DoD "bureaucratic" support in annual budget battles. Somebody in SIG and the White House did not like the Shuttle.
- **Cutback of Shuttle Orbiters** from five to four – after initially attempting to cut the fleet to three. This decision, combined with the closing of the Western launches of the Shuttle – practically meant the end of the Space Shuttle long before its first launch. Not only were the missions for the Shuttle cut back substantially to a debilitatingly low level, negating most advantages, if any, for reusable systems –

but by “freezing” the procurement the technological evolution of the Shuttle beyond the initial compromises was foreclosed.

- **Disastrous budgetary implications** were that the end result of this “policy” would be substantially added expenditures, if only the additional $2 billion per year for maintaining the Titan launch infrastructure and capabilities, leaving aside for the moment the several billions already spent on the Western Test range to actually launch Shuttles from there. The U.S. could have procured Two Space Shuttles a year just for the Titan closedown and saved money!
- **Lack of Space missions making use of Shuttle capabilities –** Once NASA had the task of developing the Shuttle and was mired in the yearly battles for the budget to see to its development, all other programs were subordinated or forgotten in favor of this single development.

While astronauts were completing the spectacular missions to the Moon – through Apollo 17, NASA launched a Space Station larger than the “current” ISS – called Skylab – but did not sustain it. NASA was unable even to raise $100 million or so to boost Skylab to a higher orbit and so preserve our Space station capabilities into the 1980s – a failure of titanic proportions in its shortsightedness. The “conjecture” was that – without a Space Station in orbit the “next” program for the 1980s would be – you guessed it – a Space Station for the 1990s, albeit smaller than Skylab. This alleviated NASA and SIG from any and all thinking of truly new missions and applications, such as the ones outlined by the 1969 Space Task Group or our [Heiss/Morgenstern] 1971-72 comprehensive study based on the work of hundreds and thousands of the best aerospace minds. All this occurred before even the first Space Shuttle launch in 1981.

Attempts to Salvage STS after Fatal Cutbacks in Shuttle Program (Private Funding for Orbiter V)

Round I of the private funding for Orbiter V. Fresh from the “mandate” to arrange private funding for Orbiter V (with OMB convinced no such effort would succeed), the author arranged an aerospace consortium around Boeing as the main (or lead) investor. Boeing had been “left out” of the Space side of the aerospace business, having done the Saturn II stage in the Apollo program and playing a significant role in the Skylab program. Also, Boeing’s capital and sales base, when compared to that of the rest of aerospace industry, was firmly grounded by then in commercial markets. In addition, Boeing had the largest operating experience and data base on aircraft operations, which might be applicable to Space Shuttle operations.

The consortium formed around a Space Transportation Company concept not dissimilar to the Comsat model established in the 1960s for Civilian Space Communications. It included Boeing in a lead role, and included Martin-Marietta, United Technologies, Thiokol, North American Rockwell and some other companies.

But just as the venture was about to take off, “infighting” began within the consortium, each contractor trying to grab a larger share of the pie, with each of the Space Shuttle contractors asserting that Boeing had little, if anything, to contribute; forgetting that none of the other companies had Boeing's capital base nor its operations experience.

A Trip to Paris and the Founding of Arianne Space. Having raised the prospect of private funding of the Fifth Orbiter and the formation of a Space Transportation company to see to the marketing of this capacity, French aerospace and government officials invited the author and Boeing officials (Gil Keyes) for a one week meeting in the French Senate to explore what Europe should do in operating the Arianne launcher program. Our proposal was simple: form a company under private corporate law, involve banks, financial institutions, aerospace companies and government institutions and keep Government oversight functions via the Board, basically the Comsat example set under President Kennedy for Space communications in the early 1960s. Any other approach was not likely to succeed in the market place. The French and the Europeans formed what today is known as "Arianne-Space" within six months of that meeting. Arianne Space is today the most successful Space launch company in the world.

Reorganizing

On February 29th 1980 the author along with others from High Frontier briefed "Candidate" Ronald Reagan on the technical prospects of ballistic missile defenses and the associated need. At lunch, Reagan said that should he become President he would initiate such a program. The author came away from this meeting determined to save the Space Shuttle program from the debilitating path set for it by the Carter/Mondale reign re. Space matters. I had come to the conclusion that an aerospace consortium was not likely to succeed for the reasons stated above. Given the strong and positive financial case for the Fifth Orbiter, the facts supported the need to continue, with Aerospace in a leading contractor role.

To such purpose the author incorporated the Space Transportation Company and brought a group of investment bankers into the venture – former partners of Morgan Stanley, White Weld and Co. Eastman Dillon and various legal and accounting talents. After the business analyses were completed and a framework of understanding worked out with competent NASA officials, Prudential came on board, with William Field Prudential had to reinvest every year about $6 Billion, or $30 Million each business day. The case for the Shuttle, subject to reaching agreement with NASA, was ironclad. Prudential had an additional motivation: being the largest insurance company, invariably Prudential was also the premier financing entity of any and all commercial Space ventures, principally communications satellites. What good were these "investments" if they could not be launched to orbit?

This led to an additional "complementary" investment: commercial launch back up with expendable rockets. After a survey of available options, and aware of the need to back up any and all Space Shuttle payloads that also might develop in the future, there was one and only one system fulfilling such requirements: the Titan family of launch vehicles. After intense negotiations we signed an exclusive worldwide agreement with

Martin Marietta on October 29th at Cape Canaveral in Florida on occasion of the first launch of the Titan 34 D, later to be christened the Titan III.

In 1982 Federal Express joint the SpaceTran venture and President Reagan formed the Space Commercialization task force. The road to substantial private funding and involvement in U.S. Space transportation seemed open and imminent. At the UNISPACE meetings in Vienna, Austria in the Summer of 1982 we celebrated the agreements in principle and the then NASA administrator, Jim Beggs, seemed ecstatic.

However, we had not checked with the “hidden” Government structure, the Space Interagency Group, a group determined to “save” the United States and mankind from any such undertaking. And the “obstacles” to such enterprise were NOT buried in the Department of Defense, the usual villain of the academic community of “experts” and “cognoscenti”, but the civilian side of the Space government community.

Worse yet, whereas the President and the White House clearly were on our side and the side of more commercial involvement, it was this civilian government core of bureaucrats who saw their “well earned” spot in the sun of government power whittle away just at the point of “fruition”, e.g.,

- **On Expendable (“Rocket”) Space transportation:** Instead of following the Comsat example on how to organize U.S. Space activities in areas of commercial potential and of national security concerns (and Intelsat for international uses) – or the example just set by Arianne Space (a combination of financial, industry and government investments), the USG set out to splinter US Space activities and invented yet another bureaucracy at the U.S. Department of Transportation which swiftly set out to foster all U.S. expendable rockets aerospace companies and systems and incentivise – in a rush of hubris – even new ones, all of which subsequently failed or cost the sponsoring companies untold billions in unrecovered costs, or costs burdened to government contracts. Of course, Space Shuttle operations and marketing were to stay a monopoly of the US Government, in this case NASA.
- **On Privatizing or Commercializing Remote Sensing**: Again, rather than follow the Comsat precedent set in the 1960s and despite the explicit desire and intent of President Reagan, the SIG set out to sabotage the privatization of remote sensing, be it of land and ocean resources, be it of weather satellites. The very day President Reagan announced his desire to commercialize and privatize these government activities (Spring of 1984), all the media (newspapers and special television reports) had lead articles on how stupid any such endeavor was judged to be by worldwide comments and reactions well orchestrated by SIG and their ideological co-brethren. How could it be that even before the President had announced his policy U.S. and world reaction was negative to any such restructuring of USG monopolies?

  Yet worse was to come: as some of us in industry had organized an international consortium to do exactly what President Reagan advocated – commercial remote sensing using the Space Shuttle and combining Comsat, private U.S. investors and international aerospace firms – in a panic of regulatory overreach SIG imposed what euphemistically was titled the Landsat Commercialization Act of 1984 wherein Title 4 of that same act outlaws any and all private ownership of original Space data (!) this despite the fact that we already had a signed contract with NASA wherein under specific and explicit standard agreement all those data indeed were to be our private property. The SIG had to revert to such constitutionally suspect brutality since otherwise they had no “handle” on our making untold millions from applications and technology SIG was negligent of having thought about or implemented. (In a meeting in the Roosevelt Room of the White House in 1984, it dawned on SIG that they had totally missed the fact that we did not need U.S. Government frequency approvals as we put all the data on other media – hence SIG could not dictate to us “fair pricing” policies set to ruin any attempted private activity). The fact that the same legislation also outlawed the operation of any and all television cameras in Space and from Space in clear violation of first amendment rights was of little, if any, concern to this policy group.

Now, TWENTY YEARS LATER, the same Space bureaucracy finally has come around to conclude that indeed it is advantageous and efficient for the US Government to avail itself also of commercial, private remote sensing capabilities. How much further could we have advanced by now, at what untold savings to the U.S. Government: NIMA and its predecessors in the 1980s would have saved up to $1 billion in multispectral and panchromatic imaging and map making alone had they allowed the Stereo MOMS venture to proceed in 1984.

- **Turning Down Private Funding for the Space Shuttle:** Instead of jumping at the opportunity to provide a “zero Government cost” back up and continuation of Shuttle production capabilities NASA did everything imaginable to sabotage the venture. First it did not believe that such a venture could be funded on the merits, then – with Prudential Insurance and Federal Express joining SpaceTran – NASA went to infinite length to “study” the economics of the venture, while all along we were not asking for any government guaranties except an assurance of six launches a year from the fleet of Shuttles with all incremental costs reimbursed to NASA. After years of negotiations and deliberations NASA turned down our proposal for funding the Fifth Orbiter (at a negotiated price from Rockwell of about $1 billion) because NASA alleged we would be making too much money and not taking enough risk – like loosing an orbiter: that is the NASA testimony in March 1986 after the Challenger explosion. Orbiter V would have been rolled out in July 1986. Instead the US could not launch any spacecraft for over two years and the Fifth Orbiter cost US taxpayers about $3 billion.

- **The 1992 Columbus 500 Space Sail Competition.** Having failed to bring about substantial private and commercial involvement in the U.S. Space program I made a final attempt to foster and bring about such independent and market based involvement of non USG people. The Columbus 500 Space Sail Cup was conceived by me and the Hon. James Symington, former Chairman of the House

Space and Sciences committee in the 1970s. Needless to say, despite overwhelming US participation and proposals NASA could not be moved to facilitate or support any such effort. As a result the only group actually launching such a sail was a Russian team led by the very same Vladimir Syromiatnikov of Apollo Soyuz fame: on February 4th 1995 the first Space Sail set out and stayed in orbit for several days, substantially longer than a similar first, the flight of the Wright brothers nearly 100 years before.

Many other examples and many other ventures could be added to this “honor roll” of ill conceived, self-serving , if not mean spirited, policy decisions of SIG in their pursuit of preserving the USG monopoly on Space and access to Space: any venture likely to fail SIG would consistently support, any venture likely to succeed outside the boundaries of absolute and total USG control they would set out to sabotage, prevent, if necessary by ex-post-facto legislation.

WHERE DO WE GO FROM HERE?

Looking now at the shambles and ruins of 30 years of ill-begotten SIG policy and NASA management of the U.S. Space program, where should we go from here? As argued in the body of this report, **A worthy program, at little extra cost would include:**

- **The First Step** on the road to reclaiming leadership in Space by setting a firm, overriding goal for Manned Space Exploration, namely the establishment of a **Permanently Manned Lunar Base** to test out the full range of Closed Ecological Life Support Systems **(CELSS)** leading ultimately to the capability of totally autonomous, Earth independent Homesteads of mankind in Space. This can all be accomplished efficiently and safely on the Moon, without any need to proceed further at immense costs, risks and potential loss of life. Any discussions of “plans” or “programs” or “missions” beyond such a Lunar Base should be considered as smokescreens to detract from a viable manned Space program. One first has to learn how to take these first steps before setting out to unrealistic, possibly fatal, interplanetary missions. Once this has been set as the driving goal the other decisions follow logically:
- **Upgrade Space Shuttle to 2000 Technology** – The technology upgrades and choices are clear: the SSMEs (Space Shuttle Main Engines) work great – the major accomplishment of the initial Shuttle RDT&E. What needs upgrading are
    - **Thermal protection technology:** replace the “tiles” approach with new metallic/composites suitable for routine reuse;
    - **Thrust assist – replace the solids with pressure feds/liquids**, allowing intact abort, cross feeding, redundancy, and substantially lower transportation costs;
    - **Continuous procurement of new Orbiters**, allowing thereby the upgrade of U.S. low Earth orbit space transportation capabilities;
    - **Evolution toward fully reusable Space Shuttle Technology** as technology and operational experience evolve a gradual evolution toward a fully reusable Shuttle is possible; and

    - **In Orbit Crew Rescue Capability –** this capability already exists with the Soyuz-Shuttle docking capability demonstrated in the 1980s. All that needs to be done is implement it operationally, at little cost.
- **A Reusable Upper Stage (Space Tug) –** as a central piece of the 1969 Space Task Force recommendations and the 1972 STS review decision, this key technology should now be implemented, including a capability to Lunar Orbit, Landing and Return missions.
- **Significant New Space Science and Application Mission Platforms –** some of these missions have been outlined in the 2003 NASA strategic plan, but key applications technology initiatives are missing, e.g., in the information technology areas. Large geo-synchronous platforms – and beyond - building on our Space infrastructure should be a principal component, in applications but also in the sciences.

These goals can be achieved over the next decade and form a real basis for future U.S. manned missions throughout the Solar system. More important, the United States will be able to set the historic precedent of a homestead outside Earth, able to, ultimately, function without any support or input from Earth – a true **"Independence Base" –** crucial for the survival and expansion of mankind throughout our Solar system and ultimately beyond.

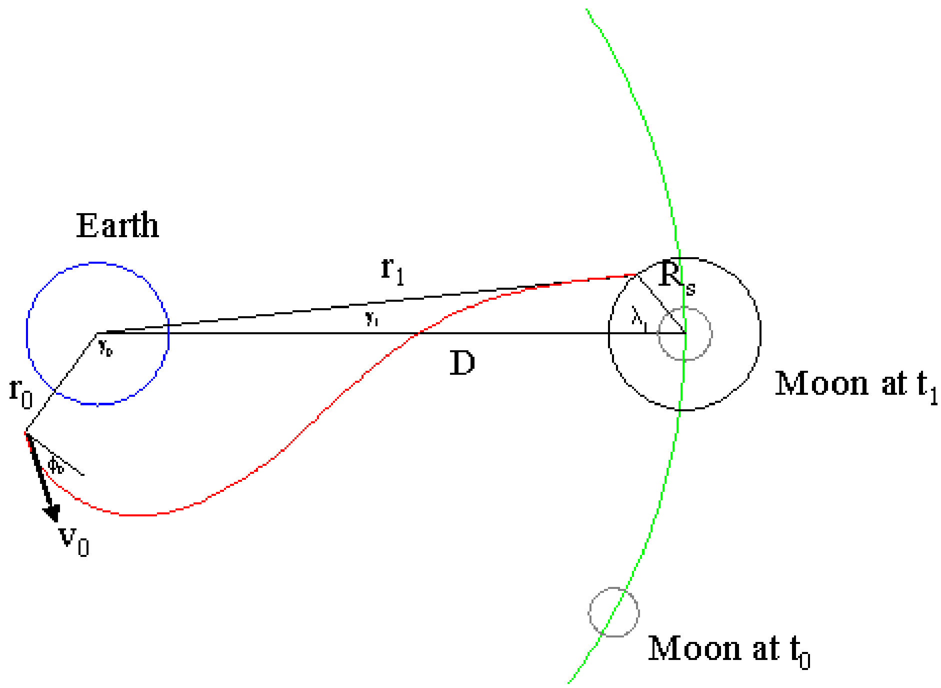
Everything else should be secondary to this NASA STS program; science and technology: aeronautics, astronautics, life sciences, astronomy and many of the other areas of innovation – important as they are – should be funded at levels commensurate with their support to achieving the goal of establishing a Moon base within a decade.

NASA's rationale – its *raison d'etre* – is Manned Space Exploration.

NASA seems to have forgotten this and – at least for the past three decades – has been meandering around, apparently not knowing what to do and where to go. It is time for a new day.

Appendix B
Lunar Transportation Planning for Initial Habitat Deployment Within a Decade
5 DEC 03

References
[1] Bate, R., Mueller, D., and White, J., *Fundamentals of Astrodynamics*, Dover, 1971.
[2] Chobotov, V., *Orbital Mechanics*, AIAA,1991.
[3] Isakowitz, S., *International Reference Guide to Space Launch Systems*, AIAA, 1991.
[4] *Delta II Payload Planner's Guide*, McDonnell Douglas, 1995.



Gravitational const. => $G := 6.67259 \cdot 10^{-11} \cdot \frac{m^3}{kg \cdot sec^2}$

Physical const. for Earth:

Mass => $M_E := 5.98 \cdot 10^{24} \cdot kg$

Radius => $R_E := 6.378 \cdot 10^6 \cdot m$

Gravitational Parameter => $\mu_E := 3.986 \cdot 10^5 \cdot \frac{km^3}{sec^2}$

Physical const. for Luna:

Mass => $M_L := .0123 \cdot M_E$

Radius => $R_L := 1783 \cdot km$

Gravitational Parameter => $\mu_L := 4.9028 \cdot 10^3 \cdot \frac{km^3}{sec^2}$

Distance from Earth => $D := 384400 \cdot km$

Angular Rate => $\omega_L := 2.649 \cdot 10^{-6} \cdot \frac{rad}{sec}$

Orbital Speed => $v_L := D \cdot \omega_L$ $\qquad v_L = 1.018 \frac{km}{sec}$

Patched-Conic Lunar Trajectory [1,2]:

Lunar Sphere of Influence => $R_S := D \cdot \left(\frac{\mu_L}{\mu_E}\right)^{\frac{2}{5}}$ $\qquad R_S = 6.618 \times 10^4 \, km$

Select initial Earth departure conditions:

$r_0 := R_E + 185 \cdot km$

$v_0 := 10.95053177207593 \frac{km}{sec}$

$\phi_0 := 0 \cdot deg$

Calculate conditions at arrival at Lunar SOI:

Select desired intersect angle => $\lambda_1 := 35 \cdot deg$

$$r_1 := \sqrt{D^2 + R_S^2 - 2 \cdot D \cdot R_S \cdot \cos(\lambda_1)} \qquad r_1 = 3.324 \times 10^5\,\text{km}$$

$$\varepsilon := \frac{v_0^2}{2} - \frac{\mu_E}{r_0} \qquad \varepsilon = -0.777\frac{\text{km}^2}{\text{sec}^2} \qquad H := r_0 \cdot v_0 \cdot \cos(\phi_0) \qquad H = 7.187 \times 10^4 \frac{\text{km}^2}{\text{sec}}$$

$$v_1 := \sqrt{2 \cdot \left(\varepsilon + \frac{\mu_E}{r_1}\right)} \qquad v_1 = 0.919\frac{\text{km}}{\text{sec}}$$

$$\phi_1 := \text{acos}\left(\frac{H}{r_1 \cdot v_1}\right) \qquad \phi_1 = 76.386\text{deg}$$

$$\gamma_1 := \text{asin}\left(\frac{R_S}{r_1} \cdot \sin(\lambda_1)\right) \qquad \gamma_1 = 6.558\text{deg}$$

$$p := \frac{H^2}{\mu_E} \qquad p = 1.296 \times 10^4\,\text{km} \qquad a := -\frac{\mu_E}{2 \cdot \varepsilon} \qquad a = 2.564 \times 10^5\,\text{km} \qquad e := \sqrt{1 - \frac{p}{a}} \qquad e = 0.974$$

Calculate Time of Flight:

$$\nu_0 := 0 \cdot \text{deg}$$

$$\nu_1 := \text{acos}\left(\frac{p - r_1}{r_1 \cdot e}\right) \qquad \nu_1 = 170.491\text{deg}$$

$$E_0 := \text{acos}\left(\frac{e + \cos(\nu_0)}{1 + e \cdot \cos(\nu_0)}\right) \qquad E_0 = 0\,\text{deg}$$

$$E_1 := \text{acos}\left(\frac{e + \cos(\nu_1)}{1 + e \cdot \cos(\nu_1)}\right) \qquad E_1 = 107.705\text{deg}$$

$$TOF := \sqrt{\frac{a^3}{\mu_E}} \cdot \left[\left(E_1 - e \cdot \sin(E_1)\right) - \left(E_0 - e \cdot \sin(E_0)\right)\right] \qquad TOF = 54.351\text{hr}$$

Convert to Lunar Reference Frame:

$$\gamma_0 := \nu_1 - \nu_0 - \gamma_1 - \omega_L \cdot TOF \qquad \gamma_0 = 2.343\text{rad}$$

$$v_2 := \sqrt{v_1^2 + v_L^2 - 2 \cdot v_1 \cdot v_L \cdot \cos(\phi_1 - \gamma_1)} \qquad v_2 = 1.112\frac{\text{km}}{\text{sec}}$$

$$\xi_2 := \text{asin}\left(\frac{v_L}{v_2} \cdot \cos(\lambda_1) - \frac{v_1}{v_2} \cdot \cos(\lambda_1 + \gamma_1 - \phi_1)\right) \qquad \xi_2 = 4.129\text{deg}$$

$$\varepsilon := \frac{v_2^2}{2} - \frac{\mu_L}{R_S} \qquad \varepsilon = 5.437 \times 10^5\,\text{m}^2\,\text{sec}^{-2}$$

$$H := R_S \cdot v_2 \cdot \sin(\xi_2) \qquad H = 5.297 \times 10^3\,\frac{\text{km}^2}{\text{sec}}$$

Calculate Velocity and Altitude at Perilune:

$$e := \sqrt{1 + \frac{2 \cdot \varepsilon \cdot H^2}{\mu_L^2}} \qquad e = 1.506 \qquad p := \frac{H^2}{\mu_L} \qquad p = 5.722 \times 10^3\,\text{km}$$

$$r_4 := \frac{p}{1 + e} \qquad r_4 = 2.283 \times 10^3\,\text{km} \qquad r_4 - R_L = 500\text{km}$$

$$v_4 := \sqrt{2 \cdot \left(\varepsilon + \frac{\mu_L}{r_4}\right)} \qquad v_4 = 2.32\frac{\text{km}}{\text{sec}}$$

Calculate Δv Required for mission:

Translunar injection=> $\Delta v_0 := v_0 - \sqrt{\frac{\mu_E}{r_0}}$ $\Delta v_0 = 3.157 \frac{km}{sec}$

Lunar Orbit Capture => $\Delta v_1 := v_4 - \sqrt{\frac{\mu_L}{r_4}}$ $\Delta v_1 = 0.855 \frac{km}{sec}$

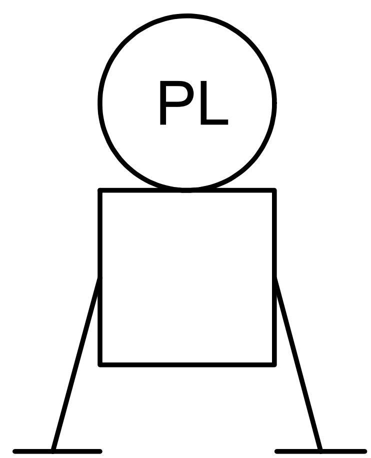
Decent Burn => $\Delta v_2 := \sqrt{\frac{\mu_L}{r_4}} \cdot \left(1 - \sqrt{\frac{2 \cdot R_L}{r_4 + R_L}}\right)$ $\Delta v_2 = 0.093 \frac{km}{sec}$

Landing Burn => $\Delta v_3 := \sqrt{\frac{\mu_L}{R_L}} \cdot \sqrt{\frac{2 \cdot r_4}{r_4 + R_L}} - \frac{R_L \cdot 2 \cdot \pi}{28 \cdot day}$ $\Delta v_3 = 1.753 \frac{km}{sec}$

The total delta-V required for the mission is:

$\Delta v := \Delta v_0 + (\Delta v_1 + \Delta v_2 + \Delta v_3) \cdot 2$ $\Delta v = 8.558 \frac{km}{sec}$

Spacecraft Design



Lander Design

Payload Down Mass => $m_{PL1} := 7 \cdot tonne$

Payload Up Mass => $m_{PL2} := 5 \cdot tonne$

Specific Impulse => $Isp := 465 \cdot sec$

Structural Coefficient => $\varepsilon := .2$

Lander Δv requirement for each mission leg => $\Delta v := \Delta v_2 + \Delta v_3$ $\Delta v = 1.85\frac{km}{sec}$

Landing Mass Ratio => $MR_1 := \exp\left(\frac{\Delta v}{g \cdot Isp}\right)$ $MR_1 = 1.499$

Liftoff Mass Ratio => $MR_2 := MR_1$

Structural Mass:

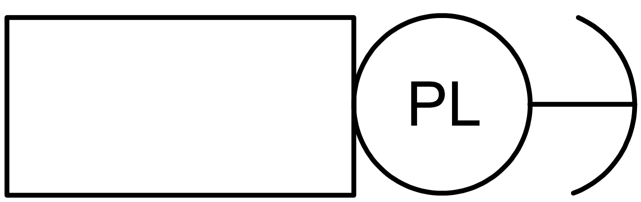
$$m_s := \varepsilon \cdot \frac{MR_1 \cdot MR_2 \cdot m_{PL2} - MR_1 \cdot m_{PL2} + MR_1 \cdot m_{PL1} - m_{PL1}}{1 - MR_1 \cdot MR_2 \cdot \varepsilon}$$ $m_s = 2.627\text{tonne}$

Propellant Mass => $m_p := m_s \cdot \frac{1 - \varepsilon}{\varepsilon}$ $m_p = 10.51\text{tonne}$

Gross Decent Mass => $m_s + m_p + m_{PL1} = 20.13\text{tonne}$

Gross Rendezvous Mass => $m_s + m_{PL2} = 7.63\text{tonne}$

Interorbit Ship Design



Payload Up Mass => $m_{PL1} := 7. \cdot \text{tonne} + m_p$ $m_{PL1} = 17.506\text{tonne}$

Payload Down Mass => $m_{PL2} := 5 \cdot \text{tonne}$

Specific Impulse => $Isp := 465 \cdot sec$

Structural Coefficient => $\varepsilon := .2$

First Leg Δv => $\Delta v := \Delta v_0 + \Delta v_1$ $\Delta v = 4.01 \frac{km}{sec}$

First Leg Mass Ratio => $MR_1 := \exp\left(\frac{\Delta v}{g \cdot Isp}\right)$ $MR_1 = 2.41$

Return Mass Ratio => $MR_2 := \exp\left(\frac{\Delta v_1}{g \cdot Isp}\right)$ $MR_2 = 1.206$

(Assumes aerobraking)

Structural Mass:

$$m_s := \varepsilon \cdot \frac{MR_1 \cdot MR_2 \cdot m_{PL2} - MR_1 \cdot m_{PL2} + MR_1 \cdot m_{PL1} - m_{PL1}}{1 - MR_1 \cdot MR_2 \cdot \varepsilon}$$ $m_s = 12.98 tonne$

Propellant Mass => $m_p := m_s \cdot \frac{1 - \varepsilon}{\varepsilon}$ $m_p = 51.94 tonne$

Gross Departure Mass => $m_s + m_p + m_{PL1} = 82.43 tonne$

Gross Returned Mass => $m_s + m_{PL2} = 17.98 tonne$

"*Present tentative plans call for major reductions or change in NASA, by eliminating the last two Apollo flights (16 and 17), and eliminating or sharply reducing the balance of the Manned Space Program (Skylab andf Space Shuttle) and many remaining NASA programs.*

"I believe this would be a mistake.

1. The real reason for sharp reductions in the NASA budget is that NASA is entirely in the 28% of the budget that is controllable. In short we cut it because it is cuttable, not because it is doing a bad job or an unnecessary one.

2. We are being driven, by the uncontrollable items, to spend more and more on programs that offer no real hope for the future: Model Cities, OEO, Welfare, interest on the national debt, unemployment compensation, Medicare, etc. Of course, some of these have to be continued, in one form or another, but essentially they are programs not of our choice, designed to repair mistakes of the past, not of our making.

3. We do need to reduce the budget, in my opinion, but we should not make all our reduction decisions on the basis of what is reducible, rather than on the merits of individual programs.

4. There is real merit to the future of NASA, and its proposed programs. The Space Shuttle and NERVA particularly offer the opportunity, among other things, to secure substantial scientific fall out for the civilian economy at the same time that large numbers of valuable (and hard to employ elsewhere) scientists and engineers are kept at work on projects that increase our knowledge of space, our ability to develop for lower cost space exploration, travel, and to secure, through NERVA, twice the existing propulsion efficiency for our rockets.

5. . . .

6. "[Canceling Apollo 16 and 17] would have a very bad effect, coming so soon after Apollo 15's triumph. It would be confirming, in some respects, a belief I fear is gaining credence at home and abroad: That our best years are behind us, that we are turnings inward, reducing our defense commitments, and voluntarily starting to give up our superpower status, and our desire to maintain our world superiority.

"America should be able to afford something besides increased welfare, programs to repair our cities, or Appalachian relief and the like. . ."

Casper Weinberger
Bureau of the Budget Deputy Director
August 12, 1972 Memorandum to President Nixon

Appendix C

Bioastronautics Critical Path Roadmap

Summary Table on Risks, Rank Order, Type and Discipline Area

Table 1: BCPR Risks, Rank Order, Type and Discipline Area

ID[1]	Risk Title[2]	Rank[3]	Type[4]	Discipline Area[5]
1	Inability to Maintain Acceptable Atmosphere in Habitable Areas	1	II	Advanced Life Support (ALS)
2	Inability to Provide and Recover Potable Water	2	II	ALS
3	Inadequate Supplies (including maintenance, emergency provisions, and edible food)	2	II	ALS
4	Inability to Maintain Thermal Balance in Habitable Areas	3	II	ALS
5	Inability to Adequately Process Solid Wastes	3	II	ALS
6	Inadequate Stowage and Disposal Facilities for Solid and Liquid Trash Generated During Mission	4	II	ALS
7	Inadequate Nutrition (Malnutrition)	1	II	Food & Nutrition
8	Unsafe Food Systems	2	II	Food & Nutrition
9	Acceleration of Age-Related Osteoporosis	1	I	Bone Loss
10	Fracture & Impaired Fracture Healing	2	II	Bone Loss
11	Injury to Soft Connective Tissue, Joint Cartilage, & Intervertebral Disc Rupture w/ or w/o Neurological Complications	3	III	Bone Loss
12	Renal Stone Formation	4	III	Bone Loss
13	Occurrence of Serious Cardiac Dysrhythmias	1	II	Cardiovascular Alterations
14	Impaired Response to Orthostatic Stress	1	II	Cardiovascular Alterations
15	Diminished Cardiac Function	2	III	Cardiovascular Alterations
16	Manifestation of Previously Asymptomatic Cardiovascular Disease	3	III	Cardiovascular Alterations
17	Impaired Cardiovascular Response to Exercise Stress	4	III	Cardiovascular Alterations
18	Human Performance Failure Because of Poor Psychosocial Adaptation	1	I	Human Behavior & Performance
19	Human Performance Failure Because of Sleep and Circadian Rhythm Problems	2	II	Human Behavior & Performance
20	Human Performance Failure Because of Human System Interface Problems & Ineffective Habitat, Equipment, Design, Workload, or Inflight Information and Training Systems	3	III	Human Behavior & Performance
21	Human Performance Failure Because of Neurobehavioral Dysfunction	4	III	Human Behavior & Performance
22	Immunodeficiency/Infections	1	III	Immunology, Infection & Hematology
23	Carcinogenesis Caused by Immune System Changes	1	III	Immunology, Infection & Hematology
24	Altered Hemodynamic and Cardiovascular Dynamics caused by Altered Blood Components	1	III	Immunology, Infection & Hematology
25	Altered Wound Healing	2	III	Immunology, Infection & Hematology
26	Altered Host-Microbial Interactions	3	III	Immunology, Infection & Hematology
27	Allergies and Hypersensitivity Reactions	3	III	Immunology, Infection & Hematology

28	Loss of Skeletal Muscle Mass, Strength, and/or Endurance	1	II	Muscle Alterations & Atrophy
29	Inability to Adequately Perform Tasks Due to Motor Performance, Muscle Endurance, and Disruption in Structural and Functional Properties of Soft & Hard Connective Tissues of the Axial Skeleton	1	II	Muscle Alterations & Atrophy
30	Inability to Sustain Muscle Performance Levels to Meet Demands of Performing Activities of Varying Intensities	2	II	Muscle Alterations & Atrophy
31	Propensity to Develop Muscle Injury, Connective Tissue Dysfunction, and Bone Fractures Due to Deficiencies in Motor Skill, Muscle Strength and Muscular Fatigue	3	III	Muscle Alterations & Atrophy
32	Impact of Deficits in Skeletal Muscle Structure and Function on Other Systems	NR	III	Muscle Alterations & Atrophy
33	Disorientation and Inability to Perform Landing, Egress, or Other Physical Tasks, Especially During/After G-Level Changes (Acute spontaneous & provoked vertigo, nystagmus, oscillopsia, poor dynamic visual acuity)	1	II	Neurovestibular Adaptation
34	Impaired Neuromuscular Coordination and/or Strength (Gait ataxia, postural instability)	2	II	Neurovestibular Adaptation
35	Impaired Cognitive and/or Physical Performance Due to Motion Sickness Symptoms or Treatments, Especially During/After G-Level Changes (Including short term memory loss, reaction time increase, drowsiness, fatigue, torpor, irritability, ketosis)	3	III	Neurovestibular Adaptation
36	Vestibular Contribution to Cardioregulatory Dysfunction (Postlanding orthostatic intolerance, sleep and mood changes)	4	III	Neurovestibular Adaptation
37	Possible Chronic Impairment of Orientation or Balance Function Due to Microgravity or Radiation (Imbalance, gait ataxia, vertigo, chronic vestibular insufficiency, poor dynamic visual acuity)	5	III	Neurovestibular Adaptation
38	Carcinogenesis Caused by Radiation	1	I	Radiation Effects
39	Late Degenerative Tissue Effects including Non-Cancer Mortality, Cataracts, and Central Nervous System (CNS) Effects	2	II	Radiation Effects
40	Synergistic Effects from Exposure to Radiation, Microgravity and other Spacecraft Environmental Factors	3	II	Radiation Effects
41	Early or Acute Effects from Radiation Exposure	4	II	Radiation Effects
42	Radiation Effects on Fertility, Sterility, and Heredity	5	III	Radiation Effects
43	Trauma and Acute Medical Problems	1	I	Clinical Capabilities
44	Toxic Exposure	2	II	Clinical Capabilities
45	Altered Pharmacodynamics and Adverse Drug Reactions	3	II	Clinical Capabilities
46	Illness and Ambulatory Health Problems	4	III	Clinical Capabilities
47	Prevention, Development and Treatment of Space-Induced Decompression Sickness	5	III	Clinical Capabilities
48	Difficulty of Rehabilitation Following Landing	6	III	Clinical Capabilities
49	Post-landing Alterations in Various Systems Resulting in Severe Performance Decrements and Injuries	1	II	Multisystem (Cross Risk) Alterations
50	Allergies and Hypersensitivity Reactions from Exposure to the Enclosed Spacecraft & Other Environmental Factors	3	II	Environmental Health
51	Inability to Maintain Acceptable Atmosphere in Habitable Areas Due to Environmental Health Contaminants	1	II	Environmental Health
52	Inability to Provide and Recover Potable Water Due to Environmental Health Contaminants	2	II	Environmental Health
53	Inadequate Nutrition (Malnutrition) Due to Inability to Provide and Maintain a Bioregenerative System	3	II	ALS
54	Difficulty of Rehabilitation Following Landing Due to Nutritional Deficiencies	4	III	Food & Nutrition
55	Human Performance Failure Due to Nutritional Deficiencies	3	II	Food & Nutrition

1 Risk Identification number: Unique number assigned to each risk (1-55) used to track/identify each risk

2 Risk: The title of each risk

3 The Rank Order assigned to each risk by discipline experts in each Discipline Area; a Discipline Area may have more than 1 risk with the same risk ranking (risk order)

4 The Type assigned to each risk by experts; a risk may be Type I, Type II, or Type III depending upon the level of uncertainty regarding both knowledge of the risk itself (its occurrence and severity), and its mitigation status

5 The specific Discipline Area representing the risk; there are 12 Discipline Areas in the BCPR

Memorandum

by

Wernher von Braun

To the US Army

"Survey of Development of Liquid Rockets in Germany and their Future Prospects"

Spring 1945

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Spring 1945

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SURVEY OF DEVELOPMENT OF LIQUID ROCKETS IN GERMANY AND THEIR FUTURE PROSPECTS

By Prof. W. von Braun
Chief, Eng. Peenemunde Group.

We consider the A4 stratospheric rocket developed by us (known to the public as V-2) as an intermediate solution conditioned by this war, a solution which still has certain inherent shortcomings, and which compares with the future possibilities of the art roughly in the same way as a bomber plane of the last war compares with a modern bomber or large passenger plane.

We are convinced that a complete mastery of the art of rockets will change conditions in the world in much the same way as did the mastery of aeronautic and that this change will apply both to the civilian and the military aspects of their use. We know on the other hand from our past experience that a complete mastery of the art is only possible if large sums of money are expended on its development and that setbacks and sacrifices will occur, such as was the case in the development of aircraft.

A few private groups of inventors started serious work on liquid rocket development in Germany in the years 1929-1930. One of these groups, called "Rocket Flying Field Berlin", located at Berlin-Reinickendorf, had Prof. Dr. von Braun as a student among its members. Simple fundamental tests with rocket combustion chambers were carried out there, and small uncontrolled liquid rockets were fired, which reached heights up to 1000 meters, and landed by means of a parachute. At the end of 1932 the work of these groups was slowed down by lack of cash, but the Army Weapons Department was interested in carrying on the work, and took over the services first of Prof. von Braun, and later of most of the other engineers.

This special division of the Army Weapons Department was put under the direction of Dr. Ing h.c. DORNBERGER, and the first rockets developed by them were designed solely for experimental purposes, and were of no military value. In 1934, liquid rockets of the "A-2" type were successfully tried out. They had a thrust of 300 kg., were directly stabilized by means of a large gyro, and reached a height of approximately 2000 meters. In 1938 the first trials were carried out with liquid rockets of the "A-3" and "A-5" types, which were fitted with an automatic control system and rudders in the gas stream. These rockets reached a height of 12 km. when fired vertically, and had a range of 18 km. when fired at an angle. They could land in both cases by means of parachute, and be used again.

In view of the successful results achieved with liquid rockets, it was decided in 1936 to begin with the construction of a large experimental establishment for rocket development at Peenemunde on the Baltic. It was already recognized at that time that the development of rockets showed great promise in the field of aeronautics as well as in that of artillery, and it was therefore decided to build two separate establishments at Peenemunde, one for the Army and one for the Air Force, which are two distinct branches of the Wehrmacht in Germany. At Peenemunde-Ost, comprehensive test beds and work-shop facilities were set up for the construction and testing of rocket drives and controls, whilst at Peenemunde-West an airfield was built for testing rocket aircraft, and pilotless rocket propelled aircraft, as well as auxiliary drives for standard aircraft, such as rocket assisted take-off devices. The cost of construction of the complete installation at Peenemunde totalled approximately 300,000,000 Marks after completion. This close proximity of the rocket development work to the aeronautical developments is one of the principal reasons for the success of the work undertaken at Peenemunde.

The following considerations were decisive in the choice of Peenemunde, and these considerations will always be important when choosing a site for rocket development work:

a. Secluded position, far away from large towns (Safety during launching, nuisance caused by noise of large test beds.
b. Favorable weather conditions (during firing and flight trials of rocket and rocket aircraft blue skies are always desirable.
c. Reasonably satisfactory communications. The development work necessitates constant close compact between development engineers and certain branches of industry.

The successful experimental rocket "A5", previously mentioned had a thrust of 1500 kg. lasting 45 seconds. Basing on the results obtained with the rocket, the order was given to develop a long distance rocket with a range of 250 km., as high and accuracy as possible, and a warhead weighing 1000 kg. This rocket, known as "A4" was first launched successfully in October 1942. The "A4" has a thrust of 25 tons, for combustion period of 68 seconds max. It is fired vertically from a firing table, without guides of any sort, as was the case with all the previous rockets. The steering of the rocket to an inclined position is effected by means of a "programme" apparatus. The lateral direction is determined by the exact setting of a turn table on the firing table. The exact range is determined by shutting off the propulsion unit upon reaching a previously calculated speed.

The development of the "A4" required a great number of preliminary scientific investigations, the most important of which are briefly outlined below:

a. Wind tunnel tests at all ranges of air speeds between 0 and 1500 meters per second. During these tests, such factors as the stability of the rocket, the distribution of the air pressure, the working of the rudders and several more were investigated, apart from the drag measurements, both with and without exhaust gas stream. Both the supersonic wind tunnel and the measuring methods had to be developed over a period of years of hard work.
b. Test bed investigations on the combustion chamber of the rocket, and on the complete propulsion unit. This too necessitated the development of appropriate test beds and measuring methods.
c. Investigations connected with the steering of the rocket at all ranges of air speeds covered by the rocket. For this purpose, a special technique of models, reproducing the attitude of the rocket in flight, was developed.
d. Development of measuring methods for plotting the complete flight path of the rocket.
e. Investigation connected with the influence of the exhaust gas stream on the wireless communication between rocket and ground, etc.

In view of the increasing strength in the numbers of light aircraft in England, and the resulting increased losses of bombers operating against England, orders were given at the end of 1942 to produce the "A4" rocket in quantities. The accuracy of aim was still unsatisfactory, and limited the use of the rocket to large area targets, foremost of which was London. Nevertheless, some 50 to 65000 drawing modifications were required before the first experimental A4 rocket became a real serious production job. This indicates how many absolutely new problems arose during the trials of the A4, which was subjected to hitherto unknown physical conditions.

Meanwhile the development side was attempting to improve the accuracy of aim of the rocket. To this end, radio guide beam devices were developed to improve the lateral direction, and improved propulsion unit cut off devices to reduce the dispersion in range. These improvements however were incorporated operationally on a small scale only, and were in use chiefly in the attack on the harbour of Antwerp.

The original objective of further development was to produce long distance rockets of greater range. It should be noted here that the maximum ranges up to 480 km. were achieved thanks to certain improvements, which however never came into operational use.

Certain A4 rockets were used to carry out vertical trajectory trails, and a maximum ceiling of 172 km. was reached during these trials.

It was planned in the spring of 1945 to give vertically from an Island situated near Peenemunde a few A4 rockets equipped with special instruments for research into the top layer of the atmosphere. The measuring instruments were set in a watertight container capable of floating, which was to have descended by parachute. This project, all preparations for which were completed, could not be carried out on account of military events. It could be done in a short time, however, with some of the A4 rockets still at hand.

The problem of increasing the range of the A4 after completion of the A4 development programme could only be carried on at a greatly reduced rate, as the development of a guided anti-aircraft rocket was given first priority and absorbed most of the personnel, in consequence the increasing air superiority of the Allies. A rocket for this purpose was developed at Peenemunde, bearing the code name "Wasserfall." This rocket was also propelled by liquid fuel and could be guided by radio from the ground on to flying targets. Various successful tests were carried out, but serious production of the weapon was not achieved.

A further development of the A4 long distance rocket is the "A9", on which work was done as far as the priority work on "Wasserfall" would allow. The propulsion unit was the same as for A4. The A9 rocket however had wings, which enabled it to glide through the stratosphere. This enabled the flight path to be increased to such an extent that the range of the A9 was nearly double that of the A4, v.e. approx. 500 km., notwithstanding the fact that the fuel consumption of the A9 was no greater than that of the A4 owin development could not be completed on account of the end of the war. Special control devices would have given the A9 at least the same accuracy as the A4. It was proposed that the weapon should go into a vertical drive at the end of the glide, similar to that of the V1.

As a further development, it was intended to design the A9 winged rocket to carry a crew. For that purpose the rocket was to be equipped with a retracting undercarriages, a pressurized cabin for the pilot, manually operated steering gear for use when landing, and special aerodynamic aids to landing. The landing speed of this piloted A9 rocket would have been as low as 150 km per hour, as it would have contained very little fuel on landing, and would consequently have been light. This piloted A9 rocket would cover a distance of 500 km. in approx. 17 minutes.

The range of the A9, both in the piloted and the pilotless versions, could be increased considerably if the propulsion unit were switched on only after the rocket had obtained a certain initial velocity. There were two possible ways of achieving this end:

1. Use of a long catapult with only a slight gradient, which would have given the rocket an initial velocity of approx. 350 m/sec. There was experience of this type of catapult to hand at Peenemunde, as such a catapult developed by an industrial firm for launching the V1, was tried out at Peenemunde. Experience showed that catapults could be built for launching at supersonic speeds. These high speeds are essential for rockets such as A9, because the rocket is completely filled with fuel at the start and would not fly if it left the catapult at lower speeds.
2. Development of a large assisted take off rocket of 200 tons thrust, on which the A9 rocket would be mounted, and which would give the latter an initial velocity of 1200 meters per second. After the assisted take off rocket has exhausted its fuel, the A9 would become separated from it, and its own propulsion unit would be switched on. The maximum speed of the A9 at the end of its power drive under these conditions would be approx. 2800 meters per second, which would mean that this combination could give the A9 a range of approx. 5000 km., both in the piloted and the pilotless versions. The large assisted take off rocket, called "A10", was to be equipped with air brakes and a special parachute, which would have enabled it to be used again after alighting on water.

   It was proposed to launch the A9/A10 combination vertically this obviating the necessity of erecting large ground launching devices.

In the more distant future, the development of liquid rockets offer in our opinion the following possibilities, some of which are of tremendous significance:

1. Development of long range commercial planes and long range bombers for ultra high speeds. The flight duration of a fast rocket aircraft going from Europe to America would be approx. 40 minutes. It would even be possible to build very long range bombers, which would turn round at supersonic speeds in a very wide curve after having released their bombs, and return in a glide to land at their point of departure. The high speed of such aircraft would make defence against them ineffective with present day means.
2. Construction of multistage piloted rockets, which would reach a maximum speed of over 7500 meters per second outside the earth's atmosphere. At such speeds the rocket would not return to earth, as gravity and centrifugal force would balance eachother out. In such a case the rocket would fly along a gravitational trajectory, without any power, around the earth in the same way as the moon. According to the difference of the trajectory from the earth, the rocket could complete one circuit around the earth in any time between 1½ hours and several days. The whole of the earth's surface could be continuously observed from such a rocket. The crew could be equipped with very powerful telescopes, and be able to observe even small objects, such as ships, icebergs, troup movements, constructional work, etc. They could also carry out physical and astronomical research on problems which could only be tackled at that altitude, due to the absence of the atmosphere.

The importance of such an "observation platform" in the scientific, economic and military spheres is obvious when the crew of the rocket want to return to earth, all they need do is to reduce the speed of the rocket slightly, which can be done by rocket propulsion. The rocket then enters the upper layers of the atmosphere tangentically, and its speed is gradually reduced by friction. Finally it can land like an ordinary aeroplane by means of wings and auxiliary gear. It would also be possible to relieve the crew and provision the "observation platform" by means of another rocket, which would climb up to the platform and pull up beside it.

3. Instead of having a rocket set up as an "observation platform" outside the earth, it would be possible later on to build a station specially for the purpose, and send the components up into the interstellar spaces by means of rockets, to be erected there. The erection should be easy, as the components would have no weight in the state of free gravitation. The work would be done by men who would float in space, wearing divers' suit, and who could move at will in space by means of small rocket propulsion units, the nozzles of which they would point in the required direction.
4. According to a proposal by the German scientist Prof. Oberth an observation station of this type could be equipped with an enormous mirror, consisting of a huge net of steel wire onto which this metal foils could be suspended. A mirror of this nature could have a diameter of many kilometers, and its component facets could be controlled by the station which would enable the heat and light of the sun to be concentrated on selected points or the earth's surface. This would enable large towns for instance to get sunlight during the evening hours. The weather, too, can be influenced by systematic concentration of the sun's rays on to certain regions. Rain could be induced to fall on regions hit by draught, by concentrating the sun's rays on to distant lakes and seas, and increasing their evaporation. The clouds thus formed could be driven to the required spot by influencing the centres of low andhigh pressure through radiation from other facets of the mirror. If the mirror is made large enough, and it could be of extremely light construction, it would even appear possible to generate deadly degrees of heat at certain spots of the earth's surface.
5. When the art of rockets is developed further, it will be possible to go to other planets, first of all to the moon. The scientific importance of such trips is obvious. In this connection, we see possibilities in the combination of the work done all over the world in connection with the harnessing of atomic energy together with the development of rockets, the consequence of which cannot yet be fully predicted.

To conclude, we think after what has been said above that a well planned development of the art of rockets will have revolutionary consequences in the scientific and military spheres, as in that of civilization generally,much in the same way as the development of aviation has brought revolutionary changes in the last 50 years.

A prophecy regarding the development of aviation, made in 1895 and covering the next 50 years, and corresponding to the actual facts, would have appeared at least as phantas than as does the present forecast of the possibilities of rocket development.

In the same way as the development of aviation was not the work of a single man, but became possible thanks to the combined experience of many thousands of specialists, who concentrated exclusively on this one branch of science for years, so the development of the art of rockets will require a systematic effort by all specialists who have gained experience on this subject.

Appendix E
Partial Bibliography on Lunar Research and Bases

Abrams M. S. (1973) *Compressive Strength of Concrete at Temperatures to 1600°F* RD016.01 T. Portland Cement Association, Skokie, IL I 1 pp.

Ackerman D. (1976) *The Planets: A Cosmic Pastoral.* Morrow Quill, New York. 159 pp.

Ackerman D. (1983) *Lady Faustus.* Morrow, New York 94 pp.

Adams J. H., Silberberg R., and Tsao C. H. (1981) Cosmic ray effects on microelectronics, Part 1: *The Nearearth Particle Environment.* NRL Memorandum Report 4506, Naval Research Laboratory, Washington, DC. 92 pp.

Adams J. H. and Gelman A. (1984) The effects of solar flares on single event upset rates. *IEEE Trans. Nucl. Sci., NS-31,* 1212-1216.

Adams J. H., Letaw J. R., and Smart D. F. (1983*) Cosmic Ray Effects on Microelectronics, Part II - The Geomagnetic Cutoff Effects.* NRL Memorandum Report 5099, Naval Research Laboratory, Washington, DC. 45 pp.

Adams James H. Jr. and M. M. Shapiro Irradiation of the Moon by Galactic Cosmic Rays and Other Particles, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 315 – 327

Adams M. W. W., Mortenson L.E., and Chen J. S. (1981) Hydrogenase. *Biochem. Biophys Acta, 594,105-176.*

Adelberg R. Y. and Ingraham J. (1976) The Microbial World. Prentice-Hall, Englewood Cliffs, NJ. 871 pp.

Bustin P., Kotra R. K., Gibson E. K., Nace G. A., and McKay D. S. (1984) Hydrogen abundances in lunar soils (abstract). In *Lunar and Planetary Science Conference XV* pp. 1 13-114. Lunar and Planetary Institute, Houston.

Adams T. R. (1968) The outer space treaty: An interpretation in light of the no-sovereignty provision. *Harvard J. Int. L.,* 9, 140-157

Adelman S. J. and Adelman B. (1984) The case for Phobos. In *The Case for Mars II.* Astronaut. Soc., Sci. Technol. Ser. Vol. 62, pp. 245-252.

Agosto W. N. (1983) Electrostatic separation of binary comminuted mineral mixtures. In *Space Manufacturing 1983, Advances in the Astronautical Sciences,* pp. 315-334. Amer. Astronaut. Soc., AAS 83-231, Univelt, San Diego.

Agosto W. N. and King E. A. (1983) *In situ* solar furnace production of oxygen, metals, and ceramics from lunar materials (abstract). In *Lunar and Planetary Science* XIV pp. 1-2. Lunar and Planetary Institute, Houston.

Agosto W. N. (1984) Electrostatic concentration of lunar soil ilmenite on vacuum ambient (abstract). In *Papers Presented to the Symposium on Lunar Bases and Space Activities of the 21st Century,* p. 24. NASA/Johnson Space Center.

Agosto W. N. (1984) Electrostatic separation and sizing of ilmenite in lunar soil simulants and samples (abstract). *in Lunar and Planetary Science. XV* pp. 1-2, Lunar and Planetary Institute Houston.

Alford N. M. and Birchall J. D. (1985) The properties and potential applications of Macro-Defect-Free cement. *In Very High Strength Cement-Based Materials, Mater. Res. Soc. Symp. Proc, 42.* pp. 265-276. Materials Research Society, Pittsburgh.

Allen / Nelson, *Space Biospheres.* 1986 Orbit Book Company

Alter A., B. Hagene, Mille et Une Lunes. Presses Pocket, 1991. ISBN: 2-266-03984-9

Alter, Dr. Dinsmore, Ed., Lunar Atlas. Dover Publications, 1964. Lib. Cong. 67-28175

Alter, Dr. Dinsmore, Pictorial Guide to the Moon. Thomas Y. Crowell Co., 1963. Lib. Cong. 63-9198

Altman K. and Gerber G. B. (1983) The effect of ionizing radiations on connective tissue. *Adv. Radiat Biol.,* 10, 237-304.

Allton J. H., C. Galindo Jr., and L A. Watts, Guide to Using Lunar Soil and Simulants for Experimentation, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 497 - 506

Altseimer J. H. (1973) *systems and cost analysis for a nuclear subterrene tunneling machine-* LOS Alamos Scientific Laboratory Report LA-5354-MS, LOS Alamos, New Mexico. 22 pp.

Altseimer J. H. (1976) *Technical and cost analysis of rock-Melting systems for producing geothermal wells.* Los Alamos Scientific Laboratory Report LA-6555-MS, Los Alamos, New Mexico. 37 pp.

Alvarez L W, Alvarez W, Asaro E, and Michel H. V (1980) Extraterrestrial cause for the Cretaceous-Tertiary extinction. *Science, 208,* 1095-1108.

Alvarez W., Alvarez L. W., Asaro E., and Michel H. V. (1982) Current status of the impact theory for the terminal Cretaceous extinctions. *Geol. Soc. Am. Spec. Pap.* 190,305-316.

Alvarez W. and Muller R. A. (1984) Evidence from crater ages for periodic impacts on the Earth. *Nature, 308,* 718-720.

American Astronautical Society (2001, 2-6 December) Final Report, AAS International Programs Committee, Workshop on International Legal Regimes Governing Space Activities, American Astronautical Society, 27pp., Springfield, VA.

Ander Mark E., Surface Electromagnetic Exploration Geophysics Applied to the Moon 271, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 271 – 278

Anderson K. A. , W M. Dougherty, and D. H. Pankow Launching Rockets and Small Satellites from the Lunar Surface, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 177 - 186

Andrews D. G. and Snow W R. (1981) The supply of lunar oxygen to low earth orbit. In *Space Manufacturing Four,* pp. 173-179. American Institute of Aeronautics and Astronautics, New York.

Apollo 7 Mission Report, Prepared by Apollo 7 Mission Evaluation Team, National Aeronautics and Space Administration, Manned Spacecraft Center, Houston, Texas, December 1968 (MSC-PA-R-68-15)

Apollo 7 Press Kit, Release #68-168K, National Aeronautics and Space Administration, Washington, DC, Oct. 6, 1968

Apollo 8 Mission Report, Prepared by Mission Evaluation Team, National Aeronautics and Space Administration, Manned Spacecraft Center, Houston, Texas, February 1969 (MSC-PA-R-69-1)

Apollo 8 Press Kit, Release #68-208, National Aeronautics and Space Administration, Washington, D.C., December 15, 1968

Apollo 9 Mission Report (MSC-PA-R-69-2 May 1969) (NTIS-34370)

Apollo 9 Press Kit, Release #69-29, February 23, 1969

Apollo 10 Mission Report (MSC-00126 November 1969)

Apollo 10 Press Kit, Release #69-68, May 7, 1969

Apollo 11 Mission Report (MSC-00171 November 1969/NASA-TM-X-62633) (NTIS N70-17401)

Apollo 11 Preliminary Science Report, Scientific and Technical Information Division, National Aeronautics and Space Administration, Washington, DC, 1969 (NASA SP-214)

Apollo 11 Press Kit, Release #69-83K, July 6, 1969

Apollo 12 Mission Report (MSC-01855 March 1970)

Apollo 12 Preliminary Science Report, Scientific and Technical Information Division, office of Technology Utilization, National Aeronautics and Space Administration, Washington, DC, 1970 (NASA SP-235)

Apollo 12 Press Kit, Release #69-148, November 5, 1969

Apollo 13 Mission Report (MSC-02680 September 1970/NASA-TM-X-66449) (NTIS N71-13037)

Apollo 13 Press Kit, Release #70-50K, April 2, 1970

Apollo 14 Mission Report (MSC-04112 May 1971)

Apollo 14 Preliminary Science Report, Scientific and Technical Information office, National Aeronautics and Space Administration, Washington, DC, 1971 (NASA SP-272)

Apollo 14 Press Kit, Release #71-3K, January 21, 1971

Apollo 15 Mission Report (MSC-05161 December 1971/NASA-TM-X-68394) (NTIS N72-28832)

Apollo 15 Preliminary Science Report, Scientific and Technical Information office, National Aeronautics and Space Administration, Washington, DC, 1972 (NASA SP-289)

Apollo 15 Press Kit, Release #71-119K, July 15, 1971

Apollo 16 Mission Report (MSC-07230 August 1972/NASA-TM-X-68635) (NTIS N72-33777)

Apollo 16 Preliminary Science Report, Scientific and Technical Information office, National Aeronautics and Space Administration, Washington, DC, 1972 (NASA SP-315)

Apollo 16 Press Kit, Release #72-64K, April 6, 1972

Apollo 17 Mission Report (MSC-07904 March 1973) (NTIS N73-23844)

Apollo 17 Preliminary Science Report, Scientific and Technical Information office, National Aeronautics and Space Administration, Washington, DC, 1973 (NASA SP-330)

Apollo 17 Press Kit, Release #72-220K, November 26, 1972

Apollo Lunar Surface Experiments Package (ALSEP): Five Years of Lunar Science and Still Going Strong, Bendix Aerospace

Apollo Program Summary Report, National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas, April 1975 (JSC-09423) (NTIS N75-21314)

Apollo/Saturn Postflight Trajectory (AS-503), Boeing Corporation Space Division, February 19, 1969 (D-5-15794), (NASA-CR-127240) (NTIS N92-70422)

Apollo/Saturn Postflight Trajectory (AS-504), Boeing Corporation Space Division, May 2, 1969 (D-5-15560-4), (NASA-CR-105771) (NTIS N69-77056)

Apollo/Saturn Postflight Trajectory (AS-505), Boeing Corporation Space Division, July 17, 1969 (D-5-15560-5), (NASA-CR-105770) (NTIS N69-77049)

Apollo/Saturn Postflight Trajectory (AS-506), Boeing Corporation Space Division, October 6, 1969 (D-5-15560-6), (NASA-CR-102306) (NTIS N92-70425)

Apollo/Saturn Postflight Trajectory (AS-507), Boeing Corporation Space Division, January 13, 1970 (D-5-15560-7), (NASA-CR-102476) (NTIS N92-70420)

Apollo/Saturn Postflight Trajectory (AS-508), Boeing Corporation Space Division, June 10, 1970 (D-5-15560-8), (NASA-CR-102792) (NTIS N92-70437)

Apollo/Saturn Postflight Trajectory (AS-509), Boeing Corporation Space Division, June 30, 1971 (D-5-15560-9), (NASA-CR-119870) (NTIS N92-70433)

Apollo/Saturn Postflight Trajectory (AS-510), Boeing Corporation Space Division, November 23, 1971 (D-5-15560-10), (NASA-CR-120464) (NTIS N74-77459)

Apollo/Saturn Postflight Trajectory (AS-511), Boeing Corporation Space Division, August 9, 1972 (D-5-15560-11), (NASA-CR-124129) (NTIS N73-72531)

Apollo/Saturn Postflight Trajectory (AS-512), Boeing Corporation Space Division, April 11, 1973 (D-5-15560-12), (NASA-CR-144080) (NTIS N76-19199)

Apollo/Skylab, ASTP and Shuttle Orbiter Major End Items, Final Report (JSC-03600), March 197

Anderson K. A., Lin P, P., McGuire R E., McCoy 1. E., Russell C. T, and Coleman P. J., Jr. (1977) Linear magnetization feature associated with Rima Sirsalis. *Earth Planet Sci. Lett, 34,* 141-15 1.

Armstrong D. E., Coleman J. S., Berteus B., McInpeer B., Potter P, M., and Robertson E. S. (1962) *Rock melting as a drilling technique.* Los Alamos Scientific Laboratory Report LA-3243-MS, Los Alamos, New Mexico. 39 pp.

Armstrong T. W, Alsmiller P. G., Jr., and Barish J. (I 969) calculation of the radiation hazard at supersonic aircraft altitudes produced by an energetic solar flare. *Nud Sci. Eng., 37,* 337-342.

Armstrong P. E. (1974) *Subterrene electrical heater design and morphology.* Los Alamos Scientific Laboratory Applications to lunar-glass structural components, in Report LA-521 I -MS, Los Alamos, New Mexico. 34 pp

Armstrong, Neil et al, First on the Moon. Konecky & Konecky. ISBN: 1-568-52398-X

Arnold G. W. and Doyle B. L. (1982) Trapping and release of implanted D/H ions in fused silica. *Nucl. Instrum. Method. 194,* 491-495.

Arnold J. R. and Duke M. B. (editors) (1977) *Summer Workshop on Near-Earth Resources.* NASA Conf. Public. 2031. NASA, Washington. 95 pp.

Arnold J. R. and Duke M. B. (editors) (1978) *Summer Workshop On Near-Earth Resource&* NASA CP-203 1. NASA, Washington, D.C. 107 pp.

Arnold J. R. (1979) Ice in the lunar polar regions. J. *Geophys. Res, 84,* 5659-5668.

Arnold J. R. (1984) Lunar materials: Domestic use and export (abstract). In *Papers Presented to the Symposium on Lunar Bases and Space Activities of the 21st Century, p.* 100. NASA/Johnson Space Center, Houston.

Artsutanov, Y.: original is in Russian, "V kosmos na elektrovoze" "Into the Cosmos With an Electric Locomotive," *Komsomolskaya Pravda,* July 31, 1960.

Artsutanov, Y.: "Into Space Without Rockets: A New Idea for Space Launch," AFSC Foreign Technology Division Report ADA084597, Air Force Systems Command, Wright-Patterson AFB, 1969.

Ash P. (1980) The influence of radiation on fertility in man. *Br. J. Radiol.,* 53,271-278.

Atchley Susan V., David J. C. Chen, Gary F Stmiste, Ronald A. Walters, and Robert K. Moyzis Toward the Development of a Recombinant DNA Assay System for the Detection of Genetic Change in Astronauts' Cells, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3
pp. 679 – 686

Atkins J. 0. and Peng S. S. (1974) *Compression Testing of Rock in Simulated Lunar Environment.* RI 7983, Bureau of Mines, Washington. 21 pp.

Atwater, J. E. (1996). Regenerative life support. Retrieved Jan. 13, 2003, from http://ucs.orst.edu/~atwaterj/LifeSupport.html

Auslander D., Spear R, Babcock P., and Nadel M.(1984) *Control and Modelling of a CELSS (Controlled Ecological Life Support System).* NASACR-177324. Berkeley College of Engineering, Berkeley. 85 pp.

Bache H. H. (1981) Densified cement/ultrafine particle based materials. *Papers Presented to the 2nd Intl. Conf. on Superplasticizers in Concrete.* Aalborg Portland, Aalborg, Denmark- 36 pp.

Bahcall J. N., Huebner W F., Lubow S. H., Parker I D., and Ulrich R. IC (1982) Standard solar models and the uncertainties in predicted capture rates of solar neutrinos. *Rev. Mod. Phys, 54,* 767-800.

Bakens, Davis S, editor, *Saturn Illustrated Chronology: Saturn's First Ten Years, April 1957 Through April 1967*, MHR-5, August 1, 1968, George C. Marshall Space Flight Center, National Aeronautics and Space Administration

Baker D. (1981*) The History of manned Spaceflight,* Crown Publishing Co., New York. 544 pp.

Balasubrahmanyan V K. and Ormes J. F (1973) Results on the energy dependence of cosmic-ray charge composition. Ap.J., 186, 109-122.

Baldwin P, P, (1972) Mission description. In *Apollo 15 Preliminary Science Report.* NASA SP-2 89, pp. I - I to I - 11. NASA, Johnson Space Center, Houston.

Baldwin R B. (1949*) The Face of the Moon,* University of Chicago Press, Chicago. 239 pp.

Baldwin R B. (1963) *The Measure of the Moon,* University of Chicago Press, Chicago. 488 pp.

Ball P, C. *et a],,* (1984) Prompt muon-neutrino production in a 400-Gev proton beam-dump experiment. Phys. *Rev. Lett,* 51, 743-746.

Baragiola, R.A., C.A. Duke, M. Loeffler, L.A. McFadden, J. Sheffield, Impact of ions and micrometeorites on mineral surfaces: Reflectance changes and production of atmospheric species in airless solar system bodies. AGU/EGS meeting, Nice France, March 2003.

Basaltic Volcanism Study Project (1981) *Basaltic Volcanism on the Terrestrial Planets.* Pergamon, New York 1286 pp.

Beattie, Donald A. *Taking Science to the Moon*, The Johns Hopkins University Press, 2001

Beeckmans J. M. (1965) The deposition of aerosols in the respiratory tract. (1) Mathematical analysis and comparison with experimental data. *Can J Physiol. Pharmacology., 43,* 157-172.

Bekey, G., Bekey, I., Criswell, D. R., Friedman, G., Greenwood, D., Miller, D., and Will, P. (2000, April 4-7), NSF-NASA Workshop on autonomous construction and manufacturing for space electrical power systems, Chapter 5, Arlington VA

Bell J. E and Hawke B. R (1984) Lunar dark-haloed impact craters: Origin and implications for early mare volcanism. J. *Geophys Res, 89,* 6899-6910.

Benson Charles D. and William Barnaby Faherty, *Moonport: A History of Apollo Launch Facilities and Operations* NASA SP-4204, 1978

Benton E. V, Almasi J., Cassou R., Frank A., Henke R. P., Rowe V, Pamell T A., and Schopper E. (1984) Radiation measurements aboard Spacelab 1. *Science,* 225,224-226.

Berezinsky V. S. and Zatsepin G. T. (1970) Cosmic neutrinos of ultrahigh energy. Sov. *J. Nucl. Phys., II*, 111 - 114.

Berezinsky V S. (1976) Ultra HE neutrinos and detection possibilities by DUMAND. In *Proc. 1976 DUMAND Workshop* (A. Roberts, ed.), pp. 229-255. Univ. Hawaii, Honolulu.

Berezhnoi A.A. About comet origin of lunar ice, Experiment in Geosciences, V. 6, No. 2, p. 76, 1997

Berezhnoi A.A., Dorofeeva V..A. The behavior of sulfur during impact interactions of comets with the Moon, Experiment in Geosciences, V. 6, No. 2, p. 77, 1997

Berezhnoi A.A., Shevchenko V.V., Dorofeeva V.A. Comets-probable source of volatiles on the Moon, 26 Microsymposium on comparatible planetology, October 13-17, 1997, Moscow, Russia

Berezhnoi A.A., Klumov B.A., Lunar ice: Can its origin be determined? JETP Letters, V. 68, No. 2, p. 163-167, 1998

Berezhnoi A.A., Determination of the Main Source of Water in Lunar Cold Traps, 30th Lunar and Planetary Science Conference, Houston, 1999, Abstract no. 1598

Berezhnoi A.A. Collision between Lunar Prospector and the Moon: Interpretation, Abstr. CAMMAC-99 Conference, p. 32, September 1999,Vinnitsa, Ukraine

Berezhnoi A.A., Gusev S.G., Khavroshkin O.B., Poperechenko B.A., Shevchenko V.V., Tzyplakov V.A., Radio Emission of the Moon before and after the Lunar Prospector impact, 4th International Conference on Exploration and Utilisation of the Moon, Abstract book, ESTEC, Noordwijk, The Netherlands, 10-14 July 2000

Berezhnoi A.A., Klumov B.A. Photochemical Model of Impact-Produced Lunar Atmosphere, 4th International Conference on Exploration and Utilisation of the Moon, Abstract book, ESTEC, Noordwijk, The Netherlands, 10-14 July 2000

Berezhnoi A.A., Klumov B.A. Photochemical Model of Impact-Produced Lunar Atmosphere, Proceedings of the Fourth International Conference on Exploration and Utilisation of the Moon, p. 175-178, ESTEC, Noordwijk, The Netherlands, 10-14 July 2000

Berezhnoi A.A., Gusev S.G., Khavroshkin O.B., Poperechenko B.A., Shevchenko V.V., Tzyplakov V.A. Radio Emission of the Moon before and after the Lunar Prospector impact, Proceedings of the Fourth International Conference on Exploration and Utilisation of the Moon, p. 179-181, ESTEC, Noordwijk, The Netherlands, 10-14 July 2000

Bhatt S. (1968) Legal controls of explorations and use of the moon and celestial bodies. *Indian J. Int. L., 8,* 33-48.

Bibring J. P., Burlingame A. L, Chaumont J., Langevin Y., Maurette M., and Wszolek P. C. (1974a) Simulation of lunar carbon chemistry. 1. Solar wind contribution *Proc. Lunar Sci. Conf. 5th,* pp. 1747-1762.

Bibring J. P., Langevin Y, Maurette M., Meunier R., Jouffrey B., and Jouret C. (1974b) Ion implantation effects in "cosmic" dust grains. *Earth Planet Sci. Lett, 22,* 205-214.

Bills B. G. and Ferrari A. J. (1977a) A harmonic analysis of lunar topography. *Icarus 31,* 244-259.

Bills B. G. and Ferrari A. J. (1977b) A lunar density model consistent with topographic, gravitational, librational, and seismic data. *J. Geophys Res,* 82,1306-1314.

Bills B. G. and Ferrari A. J. (1980) A harmonic analysis of lunar gravity. i *Geophys Re&, 85,* 1013-102

Bilstein, Roger E., *Stages To Saturn: A Technological History of the Apollo/Saturn Launch Vehicles*, Scientific and Technical Information Branch, National Aeronautics and Space Administration, November, 1980 (NASA SP-4206)

Binder A. B. (1998) Lunar prospector: overview, *Science,* 281: 1475-1480: September 4. (See also 1480-1500).

Bionta R. M. *et al* (1983) Results from the IMB detector. in *Fourth Workshop on Grand Unification* (H. A. Weldon, P. Langacker, and P. J. Steinhardt, eds.) pp. 46-68. Birkhauser, Boston.

Birch, P., "Orbital Ring-Systems and Jacob's Ladders-I," *Journal of British Interplanetary Society* , Vol. 35, No. 5, pp. 475-497, May 1983.

Birch, P., "Orbital Ring-Systems and Jacob's Ladders-II," *Journal of British Interplanetary Society,* Vol. 36, pp. II 5128, 1983.

Birch, P., "Orbital Ring-Systems and Jacob's Ladders-III," *Journal of British Interplanetary Society,* Vol. 36, pp. 231238, 1983.

Birchall J. D. (1983) Cement in the context of an energy expensive future. *Phil. Trans. Roy. Soc. London, A310,* 31-42.

Birchall J. D., Howard A. J., and Kendall K. (1982) Strong cements. *Proc. Brit Ceram. Soc., 32,* 2 5-32.

Blacic J. D. (1984) Structural properties of lunar rock materials under anhydrous, hard vacuum conditions (abstract). *In Papers Presented to the Symposium on Lunar Bases and Space Activities of the 2stt Century,* p. 76. NASA, Johnson Space Center, Houston

Blacic J. C. (1984) Structural properties of lunar rock materials under anhydrous, hard vacuum conditions (abstract). In *Papers Presented to the Symposium on Lunar Bases and Space Activities of the 21st Century,* p. 76. NASA, Johnson Space Center, Houston.

Blacic J. D. (1985) Mechanical properties of lunar rock materials under anhydrous, hard vacuum conditions: Applications to lunar-glass structural components. Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3

Blainey G. (1968) *The Tyranny of Distance.* St. Martin's Press, New York. 365 pp.

Blanford G., Borgesen P., Maurette M., and Moller W (1984) On-line simulation of hydrogen and water desorption in lunar conditions (abstract). In *Papers Presented to the Symposium on Lunar Bases and Space Activities of the 21st Century,* p. 124. NASA/Johnson Space Center, Houston.

Bluth B. J. (1984) Sociology and Space Development. In *Social Sciences and Space Exploration* (S. Cheston, C. M. Chafer, and S. B. Chafer, eds.), pp. 72-78, National Aeronautics and Space Administration, Washington, D.C

Bock E. (1979) *Lunar Resource Utilization for Space Construction.* GDC-ASP-75-001, General Dynamics Convair Division, San Diego. 109 pp.

Boehm F (1983) Neutrino mass and neutrino oscillations. in *Fourth Workshop on Grand Unification* (H. A. Weldon, P. Langacker, and P. J. Steinhardt, eds.), pp. 163-173. Birkhauser, Boston.

Boeing Company, *Final Flight Evaluation Report: Apollo 7 Mission*, for the office of Manned Space Flight, National Aeronautics and Space Administration, February 1969 (D-2-117017-4 Revision A)

Boeing Company, *Final Flight Evaluation Report: Apollo 8 Mission*, for the office of Manned Space Flight, National Aeronautics and Space Administration, April 1969 (D-2-117017-5)

Boeing Company, *Final Flight Evaluation Report: Apollo 9 Mission,* for the office of Manned Space Flight, National Aeronautics and Space Administration, (D-2-117017-6/NASA-TM-X-62316)

Boeing Company, *Final Flight Evaluation Report: Apollo 10 Mission*, for the office of Manned Space Flight, National Aeronautics and Space Administration, (D-2-117017-7/NASA-TM-X-62548) (NTIS N70-34252)

Bogard D. D. (1977) Effects of soil maturation on grain size-dependence of tapped solar gases. *Proc. Lun. Sci. Conf 8th,* 3705-3718.

Bohor B. E, Foord E. E, Modreski J., and Triplehorn D. M. (1984) Mineralogic evidence for an impact event at the Cretaceous-Tertiary boundary. *Science, 224,* 867-869.

Borg J., Dran J. C., Langevin Y., Maurette M., Petit J. C. and Vassent B., (1982) The planar track model and the prediction of alpha-recoil aging in radwaste materials. *Radiat Eff., 65,* 173-181.

Borgianni C., Capitelli M., Cramorossa F., Triolo L, and Molinari E. (1969) The behavior of metal oxides injected into an argon induction plasma. *Combustion and Flame, 13,* 181-194.

Bova, Ben, Welcome to Moonbase. Ballantine Books, 1987. ISBN: 0-345-32859-0

Boyce J. M., Dial A. L, and Soderblom L A. (1974) Ages of the nearside light plains and maria. *Proc. Lunar Sci. Conf. 5th,* pp. II -23.

Boyce J. M. (1976) Ages of flow units in the lunar nearside maria based on Lunar orbiter IV photographs. *Proc. Lunar Planet Sci. Conf. 7th,* pp. 2717-2728

Bradbury R. (1982) *The Complete Poems of Ray Bradbury.* Ballantine, New York. 288 pp.

Breakwell, J.V. and Andeen, G.B.: "A Hanging Chain in Orbit," AIAA/ASME/SAE]7th Structures, Structural Dynamics and Materials Conference Proceedings, p. 89,1976.

Bridger G. W. and Chinchen G. C. (1970) Hydrocarbon-reforming catalysts. In *Catalyst Handbook* (Industrial Chemicals industries, UK., Agricultural Division, eds.), pp. 64-96. Springer-Verlag, New York.

Briggs Randall and Albert Sacco Jr., Environmental Considerations and Waste Planning on the Lunar Surface, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 423 – 432

British Astronomical Association, Guide to Observing the Moon. Enslow Publishers, 1986. ISBN: 0-894-90085-4

Brooks, Courtney G., James M. Grimwood, and Loyd S. Swenson, Jr., *Chariots For Apollo: A History of Manned Lunar Spacecraft*, The NASA History Series, Scientific and Technical Information Branch, National Aeronautics and Space Administration, Washington, DC, 1979 (NASA SP-4205) (NTIS N79-28203)

Brown W. C. (1992 July) A Transportronic Solution to the Problem of Interorbital Transportation, NASA CR-191152/pt-7452, 168pp.

Browning D. L (1982) Large space structures. In *Space Industrialization,* Vol. 2 (B. O'Leary, ed.), pp. 71-73.

Buckingham, B. (2002). PESTO experiment to produce amber waves of grain on space station. NASA News Release No. 27-02. Retrieved Jan. 16, 2003, from http://spaceflight.nasa.gov/spacenews/releases/2002/27-02.html

Buden D. and J. A. Angelo Jr., Nuclear Energy-Key to Lunar Development, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 85 - 98

Bugbee, B. (1999). Engineering plants for spaceflight environments. *American Society for Gravitational and Space Biology Bulletin, 12,* 67-74.

Bugbee, B. (1996). Growth analysis and yield components. In F.B. Salisbury (Ed.), *Units, symbols, and terminology for plant physiology.* New York: Oxford University.

Bugbee, B., & Koerner, G. (1997). Yield comparisons and unique characteristics of the dwarf wheat cultivar “USU-Apogee.” Retrieved Jan. 13, 2003, from the Utah State University Crop Physiology Lab web site: http://www.usu.edu/cpl/apogeec2.html

Bugbee, B., & Salisbury, F. B. (1989). Controlled environment crop production: Hydroponics versus lunar regolith. In D. Henninger & D. Ming (Eds.), *Lunar agriculture* (pp. 107-129). Madison, WI: American Society of Agronomy.

Bur T P, and Hjelmstad K. E. (1970) Elastic and attenuation symmetries of simulated lunar rocks. *Icarus,* 13,414-423.

Burge T A. (1983) 14,000 psi in 24 hours. *Concr. Intern., 7,* 39-40.

Burgess, E., Outpost on Apollo's Moon. Columbia University Press,1993. ISBN: 0-231-07666-5

Burke Bernard F., Astronomical Interferometry on the Moon, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 281 – 291

Burke James D., Merits of A Lunar Polar Base Location, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 77 – 84

Bums Jack 0., A Moon-Earth Radio Interferometer, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 293 – 300

Burrows A. (1984) On detecting stellar collapse with neutrinos. *Astrophys J.,* 283, 848-852.

Bustin I. L., Kotra P. Y., Gibson E. K., Nace G. A., and McKay D. S. (1984) Hydrogen abundances in lunar Soil (abstract). In *Lunar and Planetary Science XV* pp. 1 12-113. Lunar and Planetary Institute, Houston

Cadogan, Peter, The Moon - Our Sister Planet. Cambridge University Press, 1981. ISBN: 0-521-28152-0

Cameron A. G. W (1973) Abundance of the elements in the solar system. *Space Sci. Rev., 15,* 121-146,

Carrano A. V, Gray J. W, Langlois R- G., Burkhart-Schultz K. J., and van Dilla , Purification of human chromosomes by flow cytometry and sorting. *Proc. Natl. Acad. Sci. USA 76,* 1382-1384.

Carmichael F, S. (1982) Magnetic properties of minerals and rocks. in *Handbook of Physical Properties of Rocks,* pp. 230-287. CRC Press, Boca Raton, FL

Carnes I. G., Strangway D. W, and Gose W A. (1975) Field-strength dependence of the viscous remanent magnetization in lunar samples. *Earth Planet Sci. Lett, 26, 1-7.*

Carpenter J. H. (1970) Electrical methods for the separation of minerals. *Min. Sci. Eng.,2,* 23-30.

Carr G. (1981) Comments from a Skylab veteran. *The Futurist 15,* 38.

Carrier W. D. III, Johnson S. W, Wemer R A., and Schmidt R. (1971) Disturbance in Samples recovered with the Apollo core tubes. *Proc. Lunar Sci. Conf 2nd,* pp. 1959-1972.

Carrier W. D. III (1973) The relative density of lunar soil. *Proc. Lunar Sci. conf. 4th,* pp. 2403-241 1.

Carrier W. D. III, Mitchell J. K., and Mahmood A. (1973) The nature of lunar soil. J. *Soil Mech. Found. Div.,* American Society of Civil Engineers, 99, 813-832.

Carrier W. D. III (1974) Apollo drill core depth relationships. Moon, 10, 183-194.

Carrier W. D. III and Mitchell J. K. (1976) Geotechnical engineering on the Moon (abstract). In *Lunar Science WI, Special Session Abstracts,* pp. 92-95. Lunar Science Institute, Houston

Carroll, J.A., "Tether Applications in Space Transportation," *Acta Astronautica,* Vol. 13, No. 4, pp. 165-174, 1986.

Carroll W. T. (editor) (1983) Research on the use of space processes. JPL *Publication 83-36,* jet Propulsion Laboratory, Pasadena. 200 pp.

Carroll W. T., Steurer W H., Frisbee R. H., and Jones R. M. (1983) Should we make products on the Moon? *Astronaut Aeronaut., 21,* 80-85, Carta M., Ferrara G. E, Del Fa C., and Alfano G. (1964) Contribution to the electrostatic separation of minerals. *International Mineral Processing Congress, 1,* 42 7-446.

Carter J. L (1971) Chemistry and surface morphology of fragments from Apollo 12 soil. *Proc. Lunar Sci. Conf.* 2nd,873-892.

Carter J. L (1973) Morphology and chemistry of probable VLS (Vapor-I-iquid-Solid)-type of whisker structures and other features on the surface of breccia 150 1 5,36. *Proc. Lunar Sci. Conf. 4th,* 413-42 1.

Carter J. L. (1984) Lunar regolith fines: A source of hydrogen (water) (abstract). In *Papers Presented to the Symposium on Lunar Bases and Space Activities of the 21st Century,* p. 27, NASA/Johnson Space Center, Houston

Caruso, K.M., Back to the Moon: Mankind Returns to the Lunar Surface. Aerospace 1 Publications, 2001. ISBN: 0-970-51500-6

Chaikin, Andrew, A Man on the Moon: The Voyages of the Apollo Astronauts, Penguin Books, 1994

Chan, S. (1996, November). NFT growing systems. *The Science Teacher,* 46-49.

Charles P.J. (1959) The strength of silicate glasses and some crystalline oxides. in *Proceedings of the International Conference on Atomic Mechanisms of Fracture,* p. 225-249. MIT Press, Cambridge.

Chenette D. L and Dietrich W. F. (1984) The solar flare heavy ion environment for single event upsets: A summary of observations over the last solar cycle, 1973-1983. *IEEE Trans. Nucl. Sci., NS-31,* 1217-1222.

Cherry M. L., Davidson I., Lande K, Lee C. K., Marshall E., Steinberg R. I., Cleveland B., Davis R., and Lowenstein D. (1983) Physics opportunities with the Homestake large area scintillation detector. *ICOMAN '83: International Colloquium on Matter Non-Conservation,* p. 133-143. INFN, Rome.

Cherry M. L., Corbato S., Kieda D., Lande K., Lee C. K., and Steinberg R. I. (1985) The Homestake large area scintillation detector and cosmic ray telescope. in *Solar Neutrinos and Neutrino Astronomy* (M. L. Cherry, K. Lande, and W A. Fowler, eds.) pp. 32-49. American Institute of Physics, New York

Cherry J. L. and Lande K. (1985) Proposal for a neutrino telescope on the Moon (abstract). In *Papers Presented to the Symposium on Lunar Bases and Space Activities of the 21st Century,* p. 50. NASA, Johnson Space Center, Houston.

Cheston, T. Stephen and Winter, David L. (eds.), *Human Factors of Outer Space Production*, Boulder, CO: Westview Press for the American Association for the Advancement of Science 1980

Chou C. L., Boynton W. V., Sundberg L. L., and Wasson J. (1975) Volatiles on the surface of Apollo 15 green glass and trace-element distributions among Apollo 15 soils. *Proc. Lunar Sci. Conf. 6th,* 1701-1727.

Christol C. Q. (1980) The common heritage of mankind provision in the 1979 agreement governing the activities of states on the moon and other celestial bodies. *Int. Lawyer, 14,* 429-465.

Christol C.Q. (1982) *The Modem International Law of Outer Space.* Pergamon, New York 945 pp.

Chupp E. L. (1976) *Gamma-ray Astronomy.* D. Reidel, Boston. 195 pp.

Cintala Mark J., Paul D. Spudis, and B. Ray Hawke, Advanced Geologic Exploration Supported by a Lunar Base: A Traverse Across the Imbrium-Procellarum Region of the Moon, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 223 – 238

Cisowski S. M., Collinson D. W, Runcom S. K., Stephenson A-, and Fuller M. (1983) A review of lunar paleo intensity data and implications for the origin of lunar magnetism. *Proc. Lunar Planet Sci. Conf 13th,* in *J. Geophys, Res., 88,* A691-A704.

Clark A. C. (1969) *The Coming of the Space Age.* Meredith, New York. 301 pp.

Clarke, A.C.: *Fountains of Paradise,* Harcourt Brace Jovanovich, New York, 1978.

Clarke, A.C., "The Space Elevator: 'Thought Experiment' or Key to the Universe?" *Advanced Earth Oriented Applications of Space Technology 1,* Vol. 1, pp. 39-48, 1981.

Clark, P.E. and McFadden, L.A. "The Lunar Crust as Case Study: A Comparison of Iron Data Derived from Geochemical and Mineralogical Remote Sensing Techniques, Lunar and Planetary Sci. Conf. XXVII, 1996.

Clark P.E., McFadden, L., "The Moon as Case Study, 2: Examining the Relationship Between Surface Chemical, Mineralogical, and Physical Properties." B.A.A.S., 28, 1121, 1996.

Clark, P.E. and McFadden, L.A. "New results and implications for lunar crustal iron distribution using sensor data fusion techniques," J. Geophys. Res., 105, no. E2, 4291-4316, 2000.

Clube S. V. M. and Napier V M. (1984) Terrestrial catastrophism-Nemesis or galaxy. *Nature, 311,* 635-636.

Cocca A. A. (1974) The principle of the "common heritage of all mankind" as applied to natural resources from outer space and celestial bodies. *Proc. 16th Colloq. L Outer Space,* pp. 174-176.

Cole D. M. and Segal R. (1964) Rocket propellants from the Moon. *Astronaut. Aeronaut, 2,* 56-63.

Collar A.R.; and Flower, J.W., "A (Relatively) Low Altitude 24-Hour Satellite," *Journal of British Interplanetary Society,* Vol. 22, pp. 442-457, 1969.

Compton, William David, *Where No Man Has Gone Before: A History of Apollo Lunar Exploration Missions*, The NASA History Series, Office of Management, Scientific and Technical Information Division, National Aeronautics and Space Administration, Washington, D.C., 1989 (NASA SP-4214)

Connors M. M., Harrison A. A., and Akins E A. (1985) *Living Aloft- Human Requirements for Extended Space Missions.* NASA, Washington

Conrad H. M. (1968) Biochemical changes in the developing wheat seedling in the weightless state. BioSci., 18, 645-652..

Cook, Jeremy, Ed., The Hatfield Photographic Lunar Atlas. Springer-Verlag, 1999. ISBN: 1-852-33018-X

Cooper M. P., Kovach R. L. and Watkins J. S. (1974) Lunar near-surface structure. *Rev. Geophys Space Phys,*12, 291-308.

Cordell B. M. (1984) The moons of Mars: Source of water for lunar bases and LEO (abstract). In *Papers Presented to the Symposium on Lunar Bases and Space Activities of the 21st Century,* p. 66. NASA, Johnson Space Center, Houston.

Cordes J. M., Ananthakrishnan S., and Dennison B. (1984) Radio wave scattering in the galactic disk. *Nature, 309,* 689.

Cort G. E. (1973) *Rock heat-loss shape factors for subterrene penetrators.* Los Alamos Scientific Laboratory Report LA-5435-MS, Los Alamos, New Mexico. 12 pp.

Cortright, Edgar, Chairman, *Report of the Apollo 13 Review Board*, National Aeronautics and Space Administration, June 15, 1970

Coulter W. H., (1956) High speed automated blood cell counter and cell sizer. *Proc. Natl. Electronics Conf.* 12, pp.1034-1040.

Crane H. (1966) The Complete Poems and Selected Letters and Prose of Hart Crane (B. Weber, ed.). Liveright, New York. 302 pp.

Crissman H. A. and Steinkamp J. C. (1982) Rapid, one-step staining procedures for analysis of cellular DNA and protein by single and dual laser flow cytometry. C*ytometry, 3,* 84-90.

Criswell D. R., (editor) (1976) *Lunar Science VII, Special Session Abstracts (on Lunar Utilization),* pp. iii-vi. Lunar Science Institute, Houston.

Criswell D. R., (1977) Appendix: Materials packaging. *Space-Based Manufacturing from Non terrestrial Materials* (G. K. O'Neill and B. O'Leary, eds.), *Prog. Astronaut Aeronaut, 57,* 97-123.

Criswell D. R., (1978) *Extraterrestrial Materials Processing and Construction.* NASA CR-18870, NASA, Washington. 476 pp.

Criswell D. R., (1983) A transportation and supply system between low earth orbit and the moon which utilizes lunar derived propellants (abstract). In *Lunar and Planetary Science XIV Special Session Abstracts, pp.* II - 12. Lunar and Planetary Institute, Houston.

Criswell D. R. (1983a) Lunar utilization. In *Extraterrestrial Materials Processing and Construction,* p. 2.2, 2.162.19,4.9,4.12-4.19,4.4. NASA CR-167756, NASA, WashingtorL

Criswell D. R (1983b) Roles of powder metallurgy in the development of space manufacturing. *Prog. Powder Metal J.,* 38,115-146.

Criswell, D.R. (2000) Solar Power System: Review of the technology base of an operational LSP System, *Acta Astronautica* (2000) Vol. 46, No. 8, 531 - 540, Elsevier Sciences Ltd.

Criswell, D. R. (2002, October 10-1 8) Accelerating 21't Century economic growth by implementation of the Lunar Solar Power (LSP) System, IAF-02-R.3.04, 6pp., World Space Congress-2002 & 53 d International Astronautical Congress, Houston, TX. 4.

Criswell, D. R. (2002) Energy prosperity within the 21st Century and beyond: options and the unique roles of the sun and the moon, Innovative Energy Solutions to C02 Stabilization (Ed. - R. Watts), Ch. 9, 345 410, Cambridge Un. Press.

Cron, A.C., "Applications of Tether in Space," *NASA Conference Publication 2365,* Vol. 2, pp.5-55-5-61, Proceedings of a workshop sponsored by NASA, Washington, DC and Marshall Space Flight Center, Huntsville, AL, held in Williamsburg, VA, June 15-17, 1983.

Crosby A. W. (1985) Life (with all its problems) in space. In *Interstellar Migration and the Human Experience* (B. P- Finney and E. M. Jones, eds.), pp. 210-219. Univ. California Press, Berkeley.

Crossland-Taylor P. J. (1953) A device for counting small particle suspended in a fluid through a web. *Nature,* 171,37-38.

Crow L. J. and Bates P, C. (1970) *Strengths of Sulfur-basalt Concretes,* RI 7349, Bureau of Mines, Washington. 21 pp.

Cunningham E. (1910) On the velocity of steady fall of spherical particles through a fluid medium. *Proc. Roy. Soc. London., A-83,357-365.*

Cutler A. H. (1984a) A carbothermal scheme for lunar oxygen production (abstract). In *Papers Presented to the Symposium on Lunar Bases and Space Activities of the 21st Century,* p. 22. NASA/Johnson Space Center, Houston.

Cutler A. H. (1984b) Plasma anode electrolysis of molten lunar minerals (abstract). in *Papers Presented to the Symposium on Lunar Bases and Space Activities of the 21st Century,* p. 23. NASA, Johnson Space Center, Houston.

Cutler A. H. (1984) An alkali hydroxide based scheme for lunar oxygen production (abstract). in *Papers Presented to the Symposium on Lunar Bases and Space Activities of the 21st Century,* p. 21. NASA, Johnson Space Center, Houston

Cutler A. H. (1984) Transportation economics for lunar oxygen utilization (abstract). In *Abstracts Third Cal-Space Investigators Conference,* 55-59. California Space Institute, La Jolla.

Cutler A. H. and Hughes M. L (1985) Transportation economics of extraterrestrial resource utilization. Proc. *7th Princeton Space Manufacturing Conf,* pp. 223-244. AIAA, New York.

Czuppon T. A. and Buividas L J. (1980) Hydrogen for ammonia production In *Hydrogen: Production and marketing* (W. N. Smith and J. G. Santangelo, eds.), p. 47-66. American Chemical Society, Washington.

Dar A. (1983) Atmospheric neutrinos, astrophysical neutrinos, and proton decay experiments. *Phys. Rev. Lett,* 51,227-231.

Dautrebande L. and Walkenhorst W. (1966) New studies on aerosols. IV *Arch. Int Pharmacol., 162,* 194203.

Davies C. N. (1945) Definitive equations for the fluid resistance of spheres. *Proc. Phys Soc. London, 57,* 259268.

Davies C. N. (1972) An algebraic model for the deposition of aerosols in the human respiratory tract during steady breathing. J. *Aerosol Sci., 3,* 297-309.

Davies and Colvin, *Journal of Geophysical Research*, Vol. 105, American Geophysical Union, Washington, DC, September 2000

Davis L. W. and Bradstreet S. W. (1970) *Metal and Ceramic Matrix Composites,* pp. 73- 1 00. Cahners, Boston.

Davis H. R. (1983) Lunar oxygen impact on STS effectiveness. *Eagle Engineering, Inc. Rept #EEI 83-63,* Eagle Engineering 44 pp. Houston.

Davis M., Hutt P., and Muller R. A. (1984) Extinction of species by periodic comet showers. *Nature, 308,* 715717.

Dekanozov R V (1975) juridical nature of outer space including the moon and other planets. *Proc. 17th Colloq. L. OuterSpace,* pp. 200-207.

Dekanozov P, V (1978) Draft treaty relating to the moon and the legal status of its natural resources. Proc. *20th Colloq. L. Outer Space,* pp. 198-203.

Dekker M., International Lunar Farside Observatory & Science Station. Project Report, New York. International Space University, 1993

Delano J. W. (1982) Volatiles within the Earth's Moon (abstract). In *Papers Presented to the Conference on Planetary Volatiles,* pp. 27-28. Lunar and Planetary Institute, Houston.

Dennis W. L. (1961) A formalized anatomy of the human respiratory tract. in *Inhaled Particles and Vapours* (C. N. Davies, ed.), pp. 88-94. Pergamon Press, London.

DesMarais D. J., Hayes J. M., and Meinschien W G. (1974) The distribution in lunar soil of hydrogen released by pyrolysis. *Proc. Lunar Sci. Conf 5th,* 1811-1822.

Dickey J. (1968) "A Poet Witnesses a Bold Mission," Life, November 1, 1968, p. 26.

Dietrich W F and Simpson J. A. (1978) Preferential enhancements of the solar flare-accelerated nuclei carbon to zinc from -20-300 MeV nucleon. Ap.J*, 225,* L41 -L45.

Dolbare F. (1983) Flow cytoenzymology - an update. In *Oncodevelopmental Markers Biologic, Diagnostic, and Monitoring Aspects* (W H. Fishman, ed.), pp. 207-217. Academic Press, New York

Douglas James N. and Harlan J. Smith A Very Low Frequency Radio Astronomy Observatory on the Moon, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 301 – 306

Doyle L. E. (1961) *Processes and Materials for Engineers.* Prentice Hall, New York. 797 pp.

Driggers G. W. (1976) Some potential impacts of lunar oxygen availability on near-Earth space transportation (abstract). In *Lunar Science VII, Special Session Abstracts,* pp. 26-34. The Lunar Science Institute, Houston.

Dry M. E. (1976) Advances in Fischer-Tropsch chemistry. *Ind. Eng. Chem. Prod. Res Dev., 15,* 282-286.

Duke M. B. and Arnold J. P. (editors) (I *977) Summer Workshop on Near Earth Resources.* NASA CP-203 1, NASA, Washington, DC. 105 pp.

Duke M. B., Mendell W. W, and Keaton P. W (1984) *Report of the Lunar Base Working Group.* LALP-84-43. Los Alamos National Laboratory, Los Alamos. 41 pp.

Duke M. B., Mendell W. W, and Roberts B. B. (1985) Towards a lunar base programme. *Space Policy, 1,* 49- 61.

Dukes, C., Baragiola, R.A., McFadden, L.A., Surface Modification of Olivine by H+ and He+ Bombardment, J. Geophys. Res. 104, 1865-1872, 1999.

Dula A. (1979) Free enterprise and the proposed moon treaty. *Houston J. Int. L., 3,* 3-35.

Dupree A. K., Baliunas S. L, and Guinan E. F. (1984) Stars, atmospheres, and shells: Potential for high resolution imaging. *Bull. Am. Astron. Soc., 16,* 797.

Dyal P., Parkin C. W, and Daily W D. (1974) Magnetism and the interior of the moon. *Rev. Geophys., 12,* 568- 591.

Dyal P., Parkin C. W, and Daily W D. (1976) Structure of the lunar interior from magnetic field measurements. *Proc. Lunar Planet Sci. Con* 7th, pp.3077-3095.

Dyson, Marianne, Home on the Moon: Living on the Space Frontier. National Geographic, 2003. ISBN: 0-792-27193-9

Eckart, Peter *Spaceflight Life Support and Biospherics.* 1996 Microcosm Press / Kluwer Academic Publishers

Eckart, Peter, The Lunar Base Handbook. McGraw-Hill Companies, 1999. ISBN: 0-072-40171-0

Eder, D.: "Canonical List of Space Transport and Engineering Methods," Version 0.76, Unpublished document, August 23, 1995.

Ehleringer J. and Pearcy P. W. (1983) Variation in quantum yield for C02 uptake among C3 and C4 plants. *Plant Physiol., 73,* 555-559

Ehricke K. A.(1957) The anthropology of *astronautics. Astronautics II,* Nov.,26-27. American Rocket Society.

Ehricke K. A. (1971) The extraterrestrial imperative. *Bull. Atomic Sci., Nov.,* 1 8-26.

Ehricke K. A. (1972) Lunar industries and their value for the human environment on Earth. *Acta Astronaut.* 1, 585.

Ehricke K. A. (1979) The extraterrestrial imperative, pan 1: Evolutionary logic. J. *Br. interplanel Sx., 32, 31*1 317.

Ehricke K. A. (1986) The Seventh Continent. Industrialization and Settlement of the Moon. The Krafft A. Ehricke Institute, La Jolla, CA.

Eichler D. (1980) SS433: A possible neutrino source. In *Proc. of 1980 DUMAND Symposium, Vol. 2,* pp. 26627 1. Hawaii Dumand Center, Honolulu.

Eichler B. and Schink B. (1984) Oxidation of primary aliphatic alcohols by *Acetobacterium carbinolicum spp.* nov., a homoacetogenic anacrobe. *Arch. Microbiol., 140,147-152.*

El-Baz F. (1972) New geological findings in Apollo 15 lunar orbital photography. *Proc. Lunar Sci. Conf. 3rd,* pp. 39-612.

Elbert J. W., Gaisser T. K., and Stanev T (1981) Possible studies with DUMAND and a surface air shower detector. In *DUMAND-80* (V J. Stenger, ed.), pp. 222-228. Hawaii DUMAND Center, Honolulu.

Emsberger F. M. (1969) Tensile and compressive strength of pristine glasses by an oblate bubble technique. *Phys. Chem. Glasses,* 10, 240-245.

Erofeeva I. N., Lyotov S. I., Murzin V. S., Kolomeets E. V, Albers J., and Kotzer P. (1983) Detection of solar flare neutrinos. In *Proc. 18th Intl. Cosmic Ray Conf.,* pp. 104-107. Tata Institute for Fundamental Research, Bombay.

Ertel, Ivan D., and Roland W. Newkirk, *The Apollo Spacecraft: A Chronology*, Volume IV, January 21, 1966 - July 14, 1974, Scientific and Technical Information office, National Aeronautics and Space Administration, Washington DC, 1978 (NASA SP-4009)

Etchegaray-Ramirez M. I., Metzger A. E., Haines E. L, and Hawke B. R (1983) Thorium concentrations in the lunar surface: IV Deconvolution of the mare Imbrium, Aristarchus, and adjacent regions. *Proc. Lunar Planet Sci. Conf. 14th,* in *J. Geophys. Res, 88,* A529-A543.

European Space Agency, Proceedings of the Fourth International Conference on Exploration and Utilisation of the Moon. ESA Publications Division SP-462, 2000. ISBN: 9-290-92689-2

Ezell, Linda Neuman, *NASA Historical Data Book, Volume II, Programs and Projects 1958-1968*, The NASA Historical Series, Scientific and Technical Information Division, National Aeronautics and Space Administration, Washington, DC, 1988 (NASA SP-4012)

Ezell, Linda Neuman, *NASA Historical Data Book, Volume III, Programs and Projects 1958-1968*, The NASA Historical Series, Scientific and Technical Information Division, National Aeronautics and Space Administration, Washington, DC, 1988 (NASA SP-4012)

Feingold, H., Stancati, M., Friedlander, A., Jacobs, M., Comstock, D., Christensen, C., Maryniak, G., Rix, S., and Mankins, J. C. (1997), *Space solar power afresh look at the feasibility of generating solar power in space for use on Earth, SAIC* 97/1005, 321 pp.

Ferrari A. J. and Anada M. P. (1977) Lunar gravity,. A long-term Keplerian rate method. J. *Geophys. Res, 82,* 3085-3097.

Ferrari A. J., Nelson D. L., Sjogren W. L., and Phillips R. J. (1978) The isostatic state of the lunar Apennines and regional surroundings. J. *Geophys Res., 83,* 2863-287 1.

Ferrari A. J., Sinclair W S., Sjogren W. L., Williams J. G., and Yoder C. F. (1980) Geophysical parameters of the earth-moon system. J. *Geophys Res,* 85,3939-3951.

Fichtel C. E. (1979) The significance of gamma-ray observations for neutrino astronomy. *Proc. 1978 DUMAND Summer Workshop* (A. Roberts, ed.) p. 289-312. DUMAND Scripps Institute of Oceanography, La Jolla, CA.

Fillius W. and Axford I. (1985) Large scale solar modulation of <500 MeV/Nucleon galactic cosmic rays seen from 1 to 30 AU. *J. Geophys. Res., 90,* 517-520.

Findeisen W. (1935) Über das Absetzen kleiner, in der Luft suspendierten Teilchen in der menschlichen Lunge bei der Atmung. *Pflugers Arch. Ges. Physiol., 236,* 367-379

First Americans In Space: Mercury to Apollo-Soyuz, National Aeronautics and Space Administration (undated)

Fogelson D. E. (1968) Simulated Lunar Rocks. In Proceedings of the Sixth Annual Meeting of the Working Group on Exterrestrial Resources. NASA SP-177, pp. 75-95. NASA, Washington.

Folley, Tom, The Book of the Moon. Courage Books, 1997. ISBN: 0-762-40139-7.

Forssberg A. (1964) Effects of small doses of ionizing radiations. *Adv. Radiat. Biol., 1,* II 7-156.

Forward R. and Maravec, H.R: "High Wire Act," Omni, Vol. 3, No. IO, pp. 44-47, July 198 1.

Forward R.L., *Indistinguishable from Magic,* Baen Books, New York, pp. 59-89, 1995.

Foster T. J. (1983) Plasmid-determined resistance to antimicrobial drugs and toxic metal ions in bacteria. *Microbiol. Rev.,* 9,361-397.

Fraas F (1962*) Electrostatic Separation of Granular Minerals* U.S. Bureau of Mines Bulletin 603. U.S. Bureau of Mines, Minneapolis. 155 pp.

Fraas F. (1970) *Factors Related to Mineral Separation in a Vacuum.* RI 7404, Bureau of Mines, Washington. 13 pp.

Freitas R, A. and Gilbreath W. P. (editors) (1980) *Advanced automation for space missions.* NASA CP-2255. NASA, Washington, D.C. 393 pp.

Freitas R. A. Jr. and Gilbreath W. P. (1982) Nonterrestrial utilization of materials: Automated space manufacturing *facility. In Advanced Automation for Space Missions,* pp. 77-188. NASA CP-2255, NASA, Washington, DC.

French J. R., Nuclear Powerplants for Lunar Bases, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 99 – 108

Frick U., Baur H., Ducati H., Funk H., Phinney D., and Signer P. (1975) On the origin of helium, neon, and argon isotopes in sieved mineral separates from an Apollo 15 soil. *Proc. Lunar Sci. Conf 6th,* 2097-2129.

Friedlander H. N. (1984) An analysis of alternate hydrogen sources for lunar manufacture (abstract). In *Papers Presented to the Symposium on Lunar Bases and Space Activities of the 21st Century,* p. 28. NASA, Johnson Space Center, Houston.

Friedlander A. (1984) *Manned lunar, asteroid, and Mars missions.* Science Applications International Corp., Schaumburg, 82 pp.

Frisbee, R.H., "Earth-to-Orbit Towers," Advanced Propulsion Concepts, http://sec353.jl2l.nasa.gov/al2c/Tethers/03.html Accessed January 27, 2000.

Fruland P. M. (1981*) Introduction to the Core Samples from the Apollo 16 Landing Site.* NASA Curatorial Branch Public. 58. NASA/Johnson Space Center, Houston. 45 pp.

Fruland P. M. (1982*) Catalog of the Apollo 16 Lunar Core 6000916001 0.* NASA Lunar Curatorial Branch Public, 61. NASA/Johnson Space Center, Houston. 155 pp.

Gaffey M. J. and McCord T B. (1977) An extraterrestrial source of natural resources. *Technol. Rev., 79, 50.*

Gaffey M. J., Helin E. E, and O'Leary B. (I 977) An assessment of near-Earth asteroid resources. In *Space Resources and Space Settlements,* pp. 191-204. NASA SP-428, NASA, Washington, D.C.

Gaffey M.J., McFadden, L.A., Nash, D.B., Carle M. Pieters, "Ultraviolet, Visible and Near-Infrared Reflectance Spectroscopy: Laboratory Spectra of Geologic Materials," Remote Geochemical Analysis: Elemental and Mineralogical Composition, C.M. Pieters and P.A.J. Englert, eds., Cambridge University Press, New York, pp. 43-77, 1993.

Gaisser T. K., Stanev T, Bludman S. A., and Lee H. (1983) Flux of atmospheric neutrinos. *Phys. Rev. Lett, 51,* 223-226.

Gaisser T K. and Stanev T (1983) Calibration with cosmic ray neutrinos. *AIP Conference Proceedings #1 14* (M. Blecher and K. Gotow, eds.), pp. 89-97. American Institute of Physics, New York

Gaisser T. K. and Stanev T S. (1984) Interaction rates of atmospheric neutrinos. In *ICOBAN '84: international Colloquium on Baryon Non-Conservation* (D. Cline, ed.), Park City, UT.

Gaisser T. K. and Stanev T (1984) Neutrino induced muon flux deep underground and search for neutrino oscillations. *Phys Rev. D* 30,985-990.

Galloway E. (1981) Issues in implementing the agreement governing the activities of states on the moon and other celestial bodies. *Proc. 23rd Colloq. L. Outer Space,* pp. 19-24.

Galston, A. W. (1992). Photosynthesis as the basis of life support on Earth and in space. *BioScience, 42*(7), 490–493.

Ganapathy P., (1982) Evidence for a major meteorite impact on the Earth 34 million years ago: implications on the origin of North American tektites and Eocene extinctions. *Geol. Soc. Am. Spec. Pap. 190,* 613-516.

Garcia-Munoz M., Mason G. M., and Simpson J. A. (1973) A new test for solar modulation theory. The 1972 May-July low-energy galactic cosmic-ray proton and helium spectra. Ap. *J, 182,* L8 I -L84.

Gault D. E. and Sonett C. P. (1982) Laboratory simulation of pelagic asteroidal impact-. atmosphere injection, benthic topography, and the surface radiation field. *Geol. Soc. Am. Spec Pap. 190,* 69-92.

George A. C. and Breslin A. J. (1967) Deposition of natural radon daughters in human subjects. *Health Phys.,* 13, 375-384.

Gertsch R. E. (1983) A method for mining lunar soil. *Proc. 6th Princeton-AIAA Space Manufacturing Conf., 53,* pp. 337-346. Adv. Astronaut. Sci., Univelt, San Diego.

Gibson E. K. Jr. and Hubbard N. J. (1972) Thermal volatilization studies on lunar samples. *Proc. Lunar Sci.Conf 3rd,* 2003-2014.

Gibson E. K. Jr. and Johnson S. M. (1971) Thermal analysis-inorganic gas release studies of lunar samples. *Proc. LunarSci. Conf 2nd,* 1351-1366.

Gibson E. K. Jr. and Moore G. W (1972) Inorganic gas release and thermal analysis study of Apollo 14 and 15 soils. *Proc LunarSci. Conf. 3rd,* 2029-2040.

Gibson M. A. and Knudsen C. W (1984) Lunar oxygen production from ilmenite (abstract). In *Papers Presented to the Symposium on Lunar Bases and Space Activities of the 21st Century,* p. 26. NASA/Johnson Space Center, Houston.

Ginzburg V. L. and Syrovatskii S. I. (1964) *The Origin of Cosmic Rays.* Pergamon, New Yorlc 426 pp.

Glaser P., Davidson C. and Csigi, K., *Solar Power Satellites.* 1998 Wiley-Praxis 654 pp.

Gloeckler G. (1979) Compositions of energetic particles populations in interplanetary space. *Rev. Geophys. Space Phys., 17,* 569-582.

Godwin, Robert, Apollo 11: The NASA Mission Reports, Vols. 1-3. Apogee Books, 1999-2002. ISBNs: 1-896-52253-X, 1-896-52249-1, 1-896-52285-8

Gofman J. W. (1981) *Radiation and Human Health.* Sierra Club Books, San Francisco pp. 660-699.

Gogotov J. (1984) Hydrogenase of purple bacteria: Properties and regulation of synthesis. *Arch. Microbiol., 140,* 86-90.

Goins N. R., Dainty A. M., and Toks0z M. N. (1977) The deep seismic structure of the moon. *Proc. Lunar Planet. Sci. Conf. 8th,* pp. 471-486.

Goins N. R, Dainty A. M., and Toks6z M. N. (1981) Lunar seismology. The internal structure of the moon. *J. Geophys Res.,* 86,5061-5074.

Goldberg A. H. and Criswell D. R. (1981) The economics of bootstrapping space industries-development of an analytic computer model. In *Space Manufacturing 4,* pp. 137-149. AIAA Publication 81-22787. AIAA, New York.

Goldstein B. E., Phillips R J., and Russell C. T (1976) Magnetic evidence concerning a lunar core. *Proc. Lunar Planet Sci. Conf 7th,* pp. 3321-3341.

Goodbrake C. J., Young J. E, and Berger P, L (1979) Reactions of hydraulic calcium silicates with carbon dioxide and water. J. *Am. Ceram. Soc., 62,* 488-49 1.

Green A. J. and Meizer K. T. (1971) *Performance of Boeing LRV Wheels in a Lunar Soil Simulant. Rep., Effect of Wheel Design and Soil.* Tech. Rep. M-7 I - I0, U.S. Army Engineer Waterways Experiment Station, Vicksburg. 83 pp.

Grieve P. A. F. (1982) The record of impact on Earth: implications for major Cretaceous/Tertiary impact event *Geol. Soc. Am. Spec. Pap.* 190,25-38.

Grieve R. A. F., Sharpton V. L., Goodacre A. I.C., and Garvin J. B. (1985) A perspective on the evidence for periodic cometary impacts on Earth. *Earth Planet Sci. Lett* .

Griffin P, E. and Demou S. G. (1971) Thermal expansion measurements of simulated lunar rocks. *Proc. 3rd Amer. Inst. Phys .Conf on Ther7nal Expansion,* pp. 302-31 1. American Institute of Physics, New York.

Griggs D. T. and Blacic J. D. (1965) Quartz: Anomalous weakness of synthetic crystals. *Science, 147,* 292-295.

Griggs D. T (1967) Hydrolytic weakening of quartz and other silicates. *Geophys. J. Roy. Astron. Soc., 14,* 1931.

Grigorov N. L, Gubin Yu V., Rapaport I. D., Savenko 1. A., Akimov V V, Nesterov V E., and Yakovlev B. M. (1971) Energy spectrum of primary cosmic rays in the 1011-1015 eV energy range according to the data of proton-IV measurements. *Proc. 12th Intl. Cosmic Ray Conf., 5,* pp. 1746-1751.

Grindlay J. E., Band D., Seward E, Leahy D., Weisskopf M. C., and Marshall E E. (1984) The central x-ray source in SS433. Ap. *J., 277,286.*

Grodzka P. (1976) Processing lunar soil for structural materials (abstract). In *Lunar Science VII, Special Session Abstracts, pp.* II 4-115. Lunar Science institute, Houston.

Guiley, R.E., Moonscapes: A Celebration of Lunar Astronomy, Magic, Legend and Lore. Prentice Hall Press. 1991. ISBN: 0-135-41681-7

Gustan, E., and T. Vinopal. 1981. *Controlled Ecological Life-Support System: Transportation Analysis*. Boeing Aerospace Company NASA Contract Report no. 166420, 126 pp.

Haas L A. and Khalafalia S. E. (I 968) *The Effect of Physical Parameters on the Reaction of Graphite with Silica in Vacuum.* RI 7207, Bureau of Mines, Washington. 21 pp.

Hackman R. J. (1966) *Geologic map of the Montes Archimedes region of the Moon.* U. S. Geol. Survey Misc. Geol. Inv. Map I-463.

Halacy Jr., D.S., Colonization of the Moon. Van Nostrand Reinhold Company, 1969. Lib. Cong. 68-54838

Hall, Eldon C. *Journey to the Moon: the History of the Apollo Guidance Computer*, American Institute of Aeronautics and Astronautics, Reston, 1996

Handgartner R. P. and Good N. E. (1982) Energy thresholds for ATP synthesis in chloroplasts. *Biochem. Biophys. Acta, 681,* 397-404.

Hanna A. N. (1977) *Steel Fiber Reinforced Concrete Properties and Resurfacing Applications.* RD049.O1P, Portland Cement Association, Skokie, IL 16 pp.

Hanold R. J. (1973a) *Large subterrene rock-melting tunnel excavation systems. A preliminary study.* Los Alamos Scientific Laboratory Report LA-52 I 0-MS, Los Alamos, New Mexico. 35 pp.

Hanold R. J. (editor) (1977) *Rapid excavation by rock melting-LASL Subterrene Program, September 1973 June 1976,* Los Alamos Scientific Laboratory Report LA-5979-SR, Los Alamos, New Mexico. 87 pp.

Hannigan, Russell J. *Spaceflight in the Era of Aero-Space Planes.* 1994 Krieger Publishing Company

Harland, David M., Exploring the Moon: The Apollo Expeditions. Springer-Praxis, 1999. ISBN: 1-852-33099-6

Harris, Philip R. *Living and Working in Space (Second Edition).* 1996 Wiley / Praxis

Hartmann W K. and Kuiper G. P. (1962) Concentric structures surrounding lunar basins. *Comm. Lunar Planet Lab., 1,* 51.

Hartmann W K. and Wood C. A. (1971) Moon: Origin and evolution of multiring basins. *Moon, 3,* 3-78.

Hartmann W K. (I 983) *Moons and Planets,* 2nd ed., Wadsworth Publishing Co., Belmont, 169 pp.

Haskin Larry A., Randy L. Korotev, David J. Lindstrom, and Marilyn L. Lindstrom, Geochemical and Petrological Sampling and Studies at the First Moon Base, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 199 – 210

Hashimoto A. (1983) Evaporation metamorphism in the early solar nebula-Evaporation experiments on the melt FeO-MgO-SiO_2-CaO-Al_20O_3 and chemical fractionations of primitive materials. Geochem. *J, 17,* 111.

Haskin L A., Jacobs J. W, Brannon J. C., and Haskin M. A. (1977) Compositional dispersion in lunar and terrestrial basalts. *Proc. Lunar Planet. Sci. Conf 8th,* pp. 1731-1750.

Haskin L. A., Toward a Spartan Scenario for Use of Lunar Materials, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 435 – 444

Hawke B. P Head J.W (1978) Lunar KREEP volcanism: Geologic evidence for history and mode of emplacement *Proc. Lunar Planet.Sci. Conf. 9th,* pp. 3285-3309.

Hawke B. R and Head J. W (1977) Impact melt on lunar crater rims. In *Impact and Explosion Cratering (D.* J. Roddy, R. 0. Pepin, and P- B. Merrill, eds.), pp. 815-84 1. Pergamon Press, New York

Haymes Robert C., Lunar Based Gamma Ray Astronomy, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 307 – 314

Head J. W. (1974b) Lunar dark-mantle deposits: Possible clues to the distribution of early mare deposits. Proc. *Lunar Sci. Conf 5th,* pp. 207-222.

Head J. W. (1975) Lunar mare deposits: Areas, volumes, sequences, and implication for melting in source areas (abstract). in *Origins of Mare Basalts and Their Implications for Lunar Evolution,* pp. 66-69. Lunar Science Institute, Houston

Head J. W. (1976) Lunar volcanism in space and time. *Rev. Geophys. Space Phys., 14, 265-300..*

Head J. W. and McCord T B. (1978) Imbrian-age highland volcanism on the Moon: The Gruithuisen and Mairan Domes. *Science,* 199,1433-1436.

Head J. W., Settle M., and Stein R S. (1975) Volume of material ejected from major lunar basins and implications for the depth of excavation of lunar samples. *Proc. Lunar Sci. Conf. 6th,* pp. 2805-2829.

Heiken G. and McKay D. S. (1974) Petrography of Apollo 17 soils. *Proc. Lunar Sci. Conf. 5th,* pp. 843-860.

Heiken G. (1975) Petrology of lunar soils. *Rev. Geophys. Space Phys, 13,* 567-587.

Heiken G. (1976) The regolith as a source of materials (abstract). In *Lunar Science VII, Special Session Abstracts,* pp. 48-52. Lunar Science Institute, Houston.

Heiken, G.H. et al, Lunar Sourcebook: a user's guide to the moon. Cambridge University Press, 1991. ISBN: 0-521-33444-6

Heins P. W. and Friz T. 0. (1967) *The Effect of Low Temperature on Some Physical Properties of Rock.* SPE 1714, American Institute of Mining Engineers, Denver. 8 pp.

Helmreich R. L., Wilhelm J. A., and Runge T E. (1980) Psychological considerations in future space missions. *In Human Factors of Outer Space Production* (T S. Cheston and D. L Winter, eds.), Westview, Boulder, CO. 206 pp.

Helmreich R. L. (1983) Applying psychology in outer space. *Amer. Psychol., 38,* 445-450.

Heppenheimer, T. A. *Colonies in Space.* 1977 Stackpole Books

Heppenheimer T. A., Achromatic Trajectories and the industrial-Scale Transport of Lunar Resources, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 155 – 168

Herald D., "Correcting Predictions of Solar Eclipse Contact Times for the Effects of Lunar Limb Irregularities," *J. Brit. Ast. Assoc.*, 1983, 93**,** 6

Herlevich A., Karpuk M., and Undsey H. (1983) Engineering analysis of potential photosynthetic bacterial hydrogen production systems. *Ann. N. Y Acad. Sci., 413,* 531-534.

Higham D. P., Sadler P J., and Scawen M. D. (1985) Cadmium-resistant Pseudomonas putida synthesizes novel cadmium proteins. *Science, 225,1043-1045.*

Hills J. G. (1984) Dynamical constraints on the mass and perihelion distance of Nemesis and the stability of its orbit. *Nature, 311,* 636-638.

Hirsch P. (1961) Wasserstoffaktivierung und Chemoautotrophie bei Actinomyceten. *Arch. Mikrobiol., 39,* 360373.

Hirsch P., Birchall J. D., Double D. D., Kelly A., Moir G. K., and Pomeroy C. D. (editors) (1983) *Technology in the 1990s Developments in Hydraulic Cements* The Royal Society, London. 207 pp.

Hjorth L. (1983) Development and application of high-density cement-based materials. Phil. *Trans. Roy. Soc London, A310, 167-173.*

Hjorth L. (1984) Silica fumes as additions to concrete. in *Characterization and Perfor7nance Prediction of Cement and Concrete U.* F Young ed.), pp. 165-175. Engineering Foundation, New York.

Ho D. and Sobon L. E. (1979) Exterrestrial fiberglass production using solar energy. In *Space Resources and Space Settlements* U. Billingham and W Gilbreath, eds.), NASA SP-428, pp. 225-232.

Hobbs B. A., Hood L. L., Herbert E, and Sonett C. P. (1983) An upper bound on the radius of a highly electrically conducting lunar core. *Proc. Lunar Planet Sci. Conf. 14th,* in *J. Geophys. Res, 88,* B9 7-B 1 02.

Hockey T.A., The Book of the Moon: A Lunar Introduction to Astronomy, Geology, Space Physics, and Space Travel. Prentice Hall Press, 1986. ISBN: 0-130-79963-7

Hoffman R. A., King P. C., Hansen W P., and Goldstein G. (1980) Simple and rapid measurement of human T lymphocytes and their subclasses in peripheral blood. *Proc. Nat]. Acad. Sci.* USA 77,4914-4917.

Hoffman Stephen J. and John C. Niehoff, Preliminary Design of a Permanently Manned Lunar Surface Research Base, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 69 - 76

Holland H. D. and Trendall A. E (editors) (1984) *Patterns of Change in Earth Evolution.* Springer Verlag Berlin 431 pp.

Hood L. L., Russell C. T, and Coleman P. J. (1978) The magnetization of the lunar crust as deduced from orbital surveys. *Proc. Lunar Planet Sci. Conf 9th,* pp. 3057-3078.

Hood L. L., Coleman P. J., Jr., and Wilhelms D. E. (1979) The moon: Sources of the crustal magnetic anomalies. *Science, 204,* 53-57.

Hood L. L., Russell C. T, and Coleman P. J., Jr. (1981) Contour maps of lunar remanent magnetic fields. *J. Geophys. Res,* 86,1055-1069.

Hood L. L. (1981) Sources of lunar magnetic anomalies and their bulk directions of magnetization: Additional evidence from Apollo orbital data. *Proc. Lunar Planet Sci. 12B,* pp. 817-830.

Hood L. L., Herbert E, and Sonett C. P (1982a) The deep lunar electrical conductivity profile: Structural and thermal inferences. J. *Geophys Res, 87* 5311-5326.

Hood L. L., Herbert F., and Sonett C. P (1982b) Further efforts to limit lunar internal temperatures from electrical conductivity determinations. *Proc. Lunar Planet. Sci. Conf. 13th,* in *J. Geophys Re&, 87, A* 109-A 116.

Hood L. L. and Vickery A. (1984) Magnetic field amplification and generation in hypervelocity meteoroid impacts with application to lunar paleomagnetism. *Proc. Lunar Planet Sci. Conf. 15th,* in *J. Geophys Res., 89,* C211 - C223.

Hood L. L., C. P. Sonett, and C. T Russell, The Next Generation Geophysical investigation of the Moon, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 253 – 264

Hood L. L. and Jones J. (1985) Lunar density models consistent with mantle seismic velocities and other geophysical constraints (abstract). In *Lunar and Planetary Science XVI,* pp. 360-36 1. Lunar and Planetary Institute, Houston.

Hörz F., Gibbons R. V, Hill P- E., and Gault D. E. (1976) Large-scale cratering of the lunar highlands: some Monte Carlo model considerations. *Proc. Lunar Sci. Conf 7th,* pp. 2932-2945.

Hörz Friedrich, Mass Extinctions and Cosmic Collisions: A Lunar Test, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 349 – 360

Hörz F. (1985) Lava tubes: Potential shelters for habitats. In: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3

Howarth D. C. and Codd G. A. (1985) The uptake and production of molecular hydrogen by unicellular cyanobacteria. *J. Gen. Microbic., 131,* 1561-1569.

Howard Y. A. and Wilshire H. G. (1975) Flows of impact melt at lunar craters. *J. Res U. S. Geol. Survey, 3,* 237-251.

Hsu K. J., McKenzie J. A., and He Q. X. (1982) Terminal Cretaceous environmental and evolutionary changes. *Geol. Soc. Am. Spec. Pap.* 190, 317-328.

Hsui A. T. (1979) The bounds of the heat production rate within the moon. *Proc. Lunar Planet Sci. Conf l0th,* pp.2393-2402.

Huntford P., (1984) *Scott and Amundsen: The Race to the South Pole.* Atheneum, New Yory- 576 pp.

Hursh J. B. and Mercer T. T. (1970) Measurement of 212 Pb loss rate from human lungs. J *Appl. Physiol., 28,* 268-274.

Hyde, R.A., "Earthbreak: Earth-to-Space Transportation, *Defense Science 2003+,* Vol. 4, No. 4, pp. 78-92, August/ September 1985.

ILEWG (1997), *Proc, 2ndInternational Lunar Workshop,* organized by: International Lunar Exploration Working Group, Inst. Space and Astronautical Science, and National Space Development Agency of Japan, Kyoto, Japan, (October 14-17), 89pp.

Inazawa H. and Kobayakawa K. (1983) The production of prompt cosmic ray muons and neutrinos. Prog. *Theor. Physics (Japan), 69,1195-1206.*

Inculet I. I. (1979) Electrostatic separation of lunar soil. In *Space Manufacturing 3,* pp. 109-111. American Institute of Aeronautics and Astronautics, New York.

Inculet I. I. (1982) Electrostatic beneficiation of coal. In *Physical Cleaning of Coal.* (Y A. I-iu, ed.), pp. 87-131.

Isaacs, J.D. et al. "Satellite Elongation into a True 'Sky *Hook'," Science,* Vol. 15 1, pp. 682-683, February 1966.

James 0. B. (1981) Petrologic and age relations of the Apollo 16 rocks: implications for the subsurface geology and the age of the Nectaris basin. *Proc. Lunar Planet Sci. 12B,* pp. 209-233.

Jarrett N., Das S. K. and Haupin W. E. (1980) Extraction of oxygen and metals from lunar ores. *Space Solar Power Review,* 1, 281-287.

Jensen, E.A., Vilas, F., Domingue, D.L., Stockstill, K.R., Coombs, C.R., McFadden, L.A., "A Search for Phyllosilicates Near the Lunar South Pole," B.A.A.S. 28, 1123, 1996.

Jett James H., John C. Martin, George C. Saunders, and Carleton C. Stewart, Flow Cytometry for Health Monitoring in Space, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3
pp. 687 - 698

Johnson B. V, Roepke W. W., and Strebig K. C. (1973) *Shear Testing of Simulated Lunar Soil in Ultrahigh Vacuum.* RI 7814. Bureau of Mines, Washington. 18 pp.

Johnson, Dale L., *Summary of Atmospheric Data Observations For 155 Flights of MSFC/ABMA Related Aerospace Vehicles*, NASA George C. Marshall Space Flight Center, Alabama, December 5, 1973 (NASA-TM-X-64796) (NTIS N74-13312)

Johnson C. A. and Volk W. (1965) Reduction of ilmenite and similar ores. U. S. Pat #3,224,870.

Johnson D. M., Frisillo A. L, Dorman J., Latham G. W, and Strangway D. W (1982) Compressional wave velocities of a lunar regolith sample in a simulated lunar environment J. *Geophys Res, 87,* 1899-1902.

Johnson Stewart W. and Ray S. Leonard, Design of Lunar-Based Facilities: The Challenge of a Lunar Observatory, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 413 – 422

Johnston, Richard S., Lawrence F. Dietlein, M.D., and Charles A. Berry, M.D., *Biomedical Results of Apollo*, Scientific and Technical Information office, National Aeronautics and Space Administration, Washington, DC, 1975 (NASA SP-368)

Jones, Dr. Eric*, Apollo Lunar Surface Journal*, Internet: http://www.hq.nasa.gov/office/pao/History/alsj/, National Aeronautics and Space Administration, 1996.

Joseph P., (1966) "These stars distract." *The New York Times,* July 12, 1966, op-ed page.

Josephson J. (1982) Supercritical fluids. *Environ. Sci. Technol., Amer. Chem. Soc.,* 16, 548A-551 A.

Kaplan, Judith and Robert Muniz*, Space Patches From Mercury to the Space Shuttle*, Sterling Publishing Co., New York, 1986

Kaplicky Jan and David Nixon, A Surface-Assembled Superstructure Envelope System to Support Regolith Mass Shielding for an initial-operational-Capability Lunar Base, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 375 – 380

Kato H. and Schull W. J. (1982) life span study report 9, Part I. cancer mortality among atomic bomb 1950-1978. *Radiation Effects Research Foundation Technical Report 12-80.*

Kaula W M. (1977) On the origin of the moon, with emphasis on bulk composition. *Proc. Lunar Planet. Sci. Conf. 8th,* pp. 321-33 1.

Katzeff, Paul, Full Moons: Fact and Fantasy about Lunar Influence. Citadel Press, 1981. Lib. Cong. 80-20922

Kayano H., Karube I., Matsunaga T, Suzuki S., and Nakayama 0. (1981) A photochemical fuel cell system using *Anabacna N-7363. Europ. J. Appl. Microbiol. Biotechnol., 12,1-5.*

Keaton Paul W., A Moon Base/Mars Base Transportation Depot, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 141 – 154

Kelly E. G. and Spottiswood D. J. (1982) Introduction to Mineral Processing. Wiley and Sons, New York. 491 pp.

Kendall K., Howard A. J., and Birchall J. D. (1983) The relationship between porosity, microstructure, and strength, and the approach to advanced cement-based materials. *Phil. Trans. Roy. Soc. London, A310,139-154.*

Kerfin W. and Boger P.(1982) Light induced hydrogen evolution by blue-green algae (cyano-bacteria). *Physiol. Plant Copenhagen, 54,93-98.*

Kessler E. and Maifahrth H. (1960) Vorkommen und Leistungsfähigkeit von Hydrogenase bei einigen Granalgen. *Arch. Mikrobiol., 37, 215-225.*

Kesterke D. G. (1969) Electrowinning of oxygen from Silicate Rocks. In *Proceedings of the Seventh Annual Working Group on Extraterrestrial Resources* NASA SP-229, NASA, Washington. 148 pp.

Kesterke D. G. (1971) Electrowinning of oxygen from silicate rocks. U *S. Bureau of Mines Rept. 7587,.* pp. I-12. U. S. Bureau of Mines, Washington.

Ketchum B. (1984) *Orbital transfer vehicle concept definition and systems analysis study.* General Dynamics, Convair Division, San Diego, 517 pp.

Keys to Space - An Interdisciplinary Approach to Space Studies. Houston / Rycroft, 1999 McGraw-Hill

Khalafalla S. E. and Haas S. A. (1970) Carbothermal reduction of liquid siliceous minerals in vacuum. J. *High Temp. Sci.,* 2,95-109.

Khalili E. N. (1984) Magma and ceramic structures generated *in situ* (abstract). In *Papers Presented to the Symposium on Lunar Bases and Space Activities of the 21st Century,* p. 82. NASA/Johnson Space Center, Houston

Khalili E. N. (1986*) Ceramic Houses* Harper and Row, San Francisco.

Kibler E., Taylor L. W. and Williams R. J. (1984) The kinetics of ilmenite reduction A source of lunar oxygen (abstract). In *Papers Presented to the Symposium on Lunar Bases and Space Activities of the 21st Century,* p. 25. NASA, Johnson Space Center, Houston.

King E. A. (1982) Refractory residues, condensates and chrondules from solar furnace experiments. *Proc. Lunar Planet Sci. Conf. 13th, in J. Geophys. Res, 87,* A429-A434.

King J.H. (1974) Solar proton fluences for 1977-1983 space missions. J. *Spacecraft Rockets, 11,* 401-408.

King-Hele, D. G., D. M. C. Walker, J. A. Pilkington, A. N. Winterbottom, H. Hiller, and G. E. Perry, *R. A. E. Table of Earth Satellites 1957-1986*, Stockton Press, New York, NY, 1987

Klimke, M. (1997), New concepts of terrestrial and orbital solar power plants for future European power supply, in *SPS'97.- Conference on Space Power Systems, Energy and Space for Mankind,* 341 pp.

Knight V., Couch P. B., and Landahl H. D. (1970) Effect of lack of gravity on airborne infection during space flight. JAMA 214, 513-518.

Koppeschaar, Carl, Moon Handbook: A 21st-Century Travel Guide. Moon Publications, Inc., 1995. ISBN: 1-566-91066-8

Korotev R. L (1984) The geologic study of lunar volcanic rocks as supported by a permanent lunar base (abstract). *In papers presented to the Symposium on Lunar Bases and Space Activities of the 21st Century,* p. 14. NASA, Johnson Space Center, Houston.

Krishnaswamy M. P, Menon M. G. K., Mondal N. K, Narasimham V S., Sreekantan B. V, Hayashi Y, Ito N., Kawakami S., and Miyake S. (1983) The KG.F nuclear decay experiment. in *Fourth Workshop on Grand Unification* (H. A. Weldon, P Langacker, and P. J. Steinhardt, eds.), pp. 25-34. Birkhauser, Boston.

Krupka M. C. (1973) *Phenomena associated with the process of rock melting.- Applications to the subterrene system.* Los Alamos Scientific Laboratory Report LA-5208-MS, Los Alamos, New Mexico. 10 pp.

Krupka M. C. (1974) *Selected physiochemical properties of basaltic rocks, liquids, and glasses.* LOS Alamos Scientific Laboratory Report LA-5540-MS, Los Alamos, New Mexico. 24 pp.

Kustenmacher, Werner, Frommer's The Moon: A Guide for First-Time Visitors. MacMillan, 1999. ISBN: 0-028-62869-1

Kyte F (1984) Cenozoic iridium sedimentation: Death of Nemesis? (abstract) *Geological Society of America Abstract with Program. 16,567.*

Laanbroek H. J., Stal L. H., and Veldkamp H. (1978) Utilization of hydrogen and formate by *Campylobacter* spp. under aerobic and anaerobic conditions. *Arch. Microbiol., 119,* 99-102.

Labeyrie A. (1980) Interferometry with arrays of large-aperture ground-based telescopes. *Proc. optical and Infrared Telescopes for the 1990s* (A. HevAtt, ed.), p. 786. Kitt Peak National observatory, Tucson.

Labeyrie A., Authier B., Boit J. L, DeGraauw T, Kibblewhite E., Koechlin L, Rabout P., and Weigelt G. (1984) TRIO: A kilometric optical array controlled by solar sails. *Bull. Am. Astron. Soc., 16,* 828.

Lachs M. (1972) *The Law of Outer Space.* Sijthoff and Noordhoff, Rockville. 212 pp.

LaCourse W C. (1972) The strength of glass. In *Introduction to Glass Science* (L. D. Pye, H. J. Stevens, and W C. LaCourse, eds.), pp. 451-543. Plenum Press, New York.

Land P. (1984) Lunar base design (abstract). In *Papers Presented to the Symposium on Lunar Bases and Space Activities of the 21st Century,* p. 102. NASA, Johnson Space Center, Houston.

Lande K. (1979) Experimental neutrino astrophysics. *Ann. Rev. Nucl. and Part. Sci., 29 U.* D. Jackson, H. E. Gove, and R. F. Schwitters, eds.), pp. 395-410. Annual Review, Palo Alto, CA.

Landis, G.A.: "Compression Structures for Earth Launch," *AIAA Conference Publication AIAA-9S-3737,* 24th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Cleveland, OH, July 13-15, 1998.

Landis, G.A.; and Cafarelli C., “The Tsiolkovski Tower Reexamined,” *Journal qf the British Interplanetary Society ll* Vol. *52,* pp. 175-180, 1999.

Landis, G. (1997), A Supersynchronous Solar Power Satellite, *SPS-97.- Space and Electric Power for Humanity:* 327-328, Montreal, Canada, (24-28 August).

Langevin Y (1978) *L’Etude de l’Evolution des surfaces des petits corps de la systeme solaire.* Dissertation Doctorats Science, Universite de Paris Sud, Paris.

Langham W. H. (editor) (1970*) Radiation Protection Guides for Space-Mission and Vehicle-Design Studies Involving Nuclear Systems.* Radiobiological Advisory Panel, Committee on Space Medicine, Space Science Board, NAS/ NRC, Washington, D.C.

Langseth M. G., Keihm S. J., and Peters K. (1976) Revised lunar heat-flow values. *Proc. Lunar Planet Sci. conf. 7th,* pp. 3143-3171.

Langseth M. G. Jr., Clark S. P. Jr., Chute J. L, Jr., Keihm S. J., and Wechsler A. E. (1972) Heat-flow experiment. *in Apollo 15 Preliminary Science Report.* NASA SP-289, NASA, Johnson Space Center, Houston.

Larson / Pranke, *Human Spaceflight: Mission Analysis and Design.* McGraw-Hill

Lawrence D. J. (org.) (2002 12-14 Sept.) The Moon Beyond 2002: Next Steps in Lunar Science and Exploration, Taos, NM, LPI Contr. # 1128, 68pp. (See J. Head, 23).

Lea F. M. (1971) *The Chemistry of Cement and Concrete.* Chemical Publishing, New York. 497 pp.
Leach C. L, Leonard J. L, Rambaut P. C., and Johnson P. C. (1978) Evaporative water loss in man in a gravity-free environment. J. *Appl. Physiol.: Respir. Environ. Exercise Physiol., 45,* 430-436.
Lattimer, Dick, *Astronaut Mission Patches and Spacecraft Callsigns*, unpublished draft, July 4, 1979, Lyndon B. Johnson Space Center History office

Lee H. and Bludman S. A. (1985) Neutrino production from discrete high-energy gamma ray sources. *Astrophys* J., 290,28-32.

Lehnert B. E., D. M. Smith, L M. Holland, M. I. TIllery, and P, G. Thomas, Aerosol Deposition Along the Respiratory Tract at Zero Gravity. A Theoretical Study, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 671 – 678

Leich D. A., Tombrello T A., and Bumett D. S. (1973) The depth distribution of hydrogen and fluorine in lunar samples. *Proc. Lunar Sci. Conf. 4th,* 1597-1612.

Leich D. A., Goldberg P. H., Bumett D. S., and Tombrello I. *A.* (1974) Hydrogen and fluorine in the surfaces of lunar samples. *Proc. Lunar Sci. Conf 5th,* 1869-1884.

Lemke, E.H., "On a Lunar Elevator," *Acta Astronautica, Vol.* 12, No. 6, pp. 385-396, June 1985.

Letaw J. R., (1983) Proton production cross sections in proton-nucleus collisions. *Phys. Rev. C, 28,* 2178-2179.

Letaw J. R,, Silberberg P., and Tsao C. H. (1983) Proton-nucleus total inelastic cross sections: An empirical formula for E > I0 MeV Ap. *J. Supp., 51,* 2 71-2 74.

Lewis J. S. and Nozette S. D. (1983) Extraction and purification of iron group and precious metals from asteroidal feedstocks. *Adv Astronaut Sci., 53,* 351.

Lewis J. S. and Meinel C. P. (1984) Carbonyls: Short cut from extraterrestrial ores to finished products (abstract). *in Papers Presented to the Symposium on Lunar Bases and Space Activities of the 21st Century,* p. 126. NASA, Johnson Space Center, Houston

Lewis, John S. *Mining the Sky - Untold Riches from the Asteroids, Comets, and Planets.* 1996 Addison-Wesley Publishing Company

Lewis, J. (1991), Extraterrestrial sources for 3He for fusion power, *Space Power, 10:*363-372.

Lewis, Richard S., Appointment on the Moon. Ballantine Books, 1969. Lib. Cong. 68-22871

Lewis William, Lunar Machining, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 519 – 520

Light, Michael, Full Moon. Alfred A. Knopf, 1999. ISBN: 0-375-40634-4

Lin R P (1979) Constraints on the origins of lunar magnetism from electron reflection measurements of surface magnetic fields. *Phys Earth Planet Int.,* 20,271-280.

Lin C. H. and Meyer M. S. (1983) Systems engineering aspects of a preliminary conceptual design of the space station environmental control life support systems. Thirteenth Intersociety Conference on Environmental Systems, Society of Automotive Engineers, San Francisco, CA. 17 pp.

Lin T. D., Concrete for Lunar Base Construction, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 381 – 390

Lindroth D. P. and Krawza W. G. (1971) *Heat Content and Specific Heat of Six Rocks at Temperatures to* 1,000° C RI 7503, Bureau of Mines, Washington. 24 pp.

Lindroth D. P. (1974) *Thermal Diffusion of Six Igneous Rocks at Elevated Temperatures and Reduced Pressure.* RI 7954. Bureau of Mines, Washington. 33 pp.

Lindsay, Hamish *Tracking Apollo to the Moon*, Springer-Verlag, 2001

Lindstrom D. J. and Haskin L A. (1979) Electrochemistry of lunar rocks. In *Space Manufacturing Facilities 3,* 0. Grey and C. Krop, eds.), pp. 129-134. American institute of Aeronautics and Astronautics, New York

Linlor W. I. (1970*) Electromagnetic Exploration of the Moon.* Mono, Baltimore. 246 pp.

Littmann, M., Willcox, K. and Espenak, F. Totality, Eclipses of the Sun, Oxford University Press, New York, 1999

Long, Kim, The Moon Book. Johnson Printing, 1998. ISBN: 1-555-66230

Lorenzini, E.C., Arnold, D.A.; Guilahorn, G.E.; and Grossi, M.D., "Study of an Orbiting Tethered Dumbbell System Having Positive Orbital Energy," Addendum to Final Report: NASA Contract NAS8-35497, February 1985.

Lowman Jr. Paul D., Lunar Bases: A Post-Apollo Evaluation, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 35 – 46

Lowman, Jr., Paul D., Lunar Limb Observatory. NASA Technical Memorandum 4757, 1996

Lunar Development Conference 2000, Return to the Moon II. Space Front Press, 2000. ISBN: 0-970-12780-4

Lvov V., "Skyhook: Old Idea," *Science,* Vol. 158, pp. 946947, 1967.

MacElroy R. D., Harold P. Klein, and M. M. Avemer, The Evolution of CELSS for Lunar Bases, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 623 – 634

Mah R A., Smith M. R, and Baresi L (1978) Studies on an acetate-fermenting strain of *Methanosarcina. Appl. Environm. Microbio., 35,1174-1184.*

Mah P. A. and Smith M. R. (1981) The methanogenic bacteria. In *The Prokaryotes A Handbook on Habitats, Isolation and Identification of Bacteria* (M. Starr *et al.,* eds.) pp. 956-977. Springer-Verlag, Berlin

Malik K. A. and Schlegel H. G. (I 98 1) Chemolithoautotrophic growth of bacteria able to grow under N2-fixing conditions. *FEA4S-Microbiol. Letters, 11,* 63-67,

Malin M. C. (1974) Lunar red spots: Possible pre-mare materials. *Earth Planet Sci. Lett, 21,* 331-341.

Manson, L.A., The Birth of the Moon, Dennis-Landman Publishers, 1978. ISBN: 0-930-42212-0

Mason B. and Melson W. G. (1970) *The Lunar Rocks.* Wiley-Interscience, New York, I 1 7 pp.

Matsuoka H. (1999), Global environmental issues and space solar power generation: promoting the SPS 2000 project in Japan, *Technology in Society,* 21: 1-7.

Matte N. M. (1978) The draft treaty on the Moon, eight years later. *Ann. Air Space L,* 3, 511-544.

Matzke H. J. (1967) Diffusion of tritium in quartz and quartz glass. Z. *Naturforsch. A* 22, 965-969.

Mayer-Hasselwander H. A., Bennett K., Bignami G. E, Buccheri P., Caraveo P A., Hermsen W, Kanbach G., Lebrun E, Lichti G. G., Masnou J. L, Paul J. A., Pinkau K., Sacco B., Scarsi L, Swanenburg B. N., and Wills P, D. (1982) Large-scale distribution of galactic gamma radiation observed by COS-B. *Astron. Astrophys., 105,* 164.

McCord T. B., Pieters C., and Feierberg M. A. (1976) Multispectral mapping of the lunar surface using groundbased telescopes. *Icarus 29,* 1-34.

McCord T. B. and Gaffey M. J. (I 9 7 7) Remote determinations of the compositions of Earth approaching asteroids. *In New Moon: Special Session of the 8th Lunar Science Conference on Towing Asteroids into Earth orbits for Exploration and Exploitation,* pp. 3.1-3.15. Lunar and Planetary Institute, Houston.

McCord, T.B., Clark, R.N., Hawke, B.R., McFadden, L.A., Owensby, P.D., Pieters, C.M. and Adams, J.B., "Moon: Near-Infrared Spectral Reflectance: A First Good Look", J. Geophys. Res., 86, 10883-10892, 1981.

McCord, T.B., Clark, R.N., Hawke, B.R., McFadden, L.A., Owensby, P.D., Pieters, C.M. and Adams, J.B., Remote Detection of Olivine, Pyroxene and Plagioclase: Analysis of Three Lunar Sites., Lunar and Planetary XII, 679-681, 1981.

McCree K. J. (1972) Test of current definitions of photosynthetically active radiation against leaf photosynthesis data. *Agil. Meteor.,* 10, 443-453.

McFadden, L.A., Gaffey, M.J. and Takeda, H., Reflectance Spectroscopy and Mineralogy of a Crystalline LL Chondrite, 7th Symposium on Antarctic Meteorites, National Institute of Polar Research, Tokyo, 66-68, 1982.

McFadden, L.A., Pieters, C.M., Huguenin, R.L., King, T.V.V., Gaffey, M.J. and Hawke, B.R., "Yamato 791197 - Spectral Studies of Another Lunar Meteorite", presented at the American Geophysical Union, May 1985

McFadden, L.A., Pieters, C.M., Huguenin, R.L., King, T.V.V., Gaffey, M.J. and Hawke, B.R., Yamato 791197 - Major Mineralogical Constituents and Its Relation to Remotely Sensed Regions of the Moon from Reflectance Spectroscopy, presented at 10th Symposium on Antarctic Meteorites, National Institute of Polar Research, Tokyo, 1985.

McFadden, L.A., Pieters, C.M., Huguenin, R.L., Hawke, B.R., King, T.V.V. and Gaffey, M.J., "Reflectance Spectroscopy of Lunar Meteorite Y791197: Relation to Remote Sensing Data Bases of the Moon", Memoirs of the National Institute of Polar Research: special issue, No. 41, 140-151, 1986.

McFadden, L. A., G.K. Benedix, D.E. Grosjean, R.E. Johnson, R.A. Baragiola, Alteration of Asteroid Surfaces: Laboratory Simulations of Solar Wind Interactions With Minerals. EOS, Transactions, American Geophysical Union, 74, no.16, p.192, 1993.

McFadden, L.A. Review of Physics and Chemistry of the Solar System by John S. Lewis, Academic Press, Inc. 1995. Icarus, 124, 355, 1996.

McGuire R. E., Goswami J. N., Jha R., Lai D., and Reedy R. C. (1983) Solar flare fluences during solar cycles 19,20, and 21. *Proc. 18th Intl. Cosmic Ray Conf., 44,* pp. 66-69.

McKay D. S., Morrison D. A., Clanton U. S., Ladle G. H., and Lindsay J. F (1971) Apollo 12 soil and breccia. *Proc. Lunar Sci. Conf. 2nd,* 755-772.

McKay D. S., Dungan M. A., Morris P, V, and Fruland P, M. (1977) Grain size, petrographic, and FMR studies of the double core 60009/1 0: A study of soil evolution. *Proc Lunar Sci. Conf. 8th,* pp. 2929-2952.

McKay D. S. and Williams R. J. (1979) A geologic assessment of potential lunar ores. In *Space Resources and Space Settlements U.* Billingham, W Gilbreath and B. O'Leary, eds.) pp. 243-255. NASA SP-428. NASA, Washington, DC.

McKay D. S. (1984) Evaluation of lunar resources (abstract). In *Papers Presented to the Symposium on Lunar Bases and Space Activities of the 21st Century,* p. 21, NASA/Johnson Space Center, Houston.

McKay D. S. and Nozette S. D. (1985) Technological springboard to the 21st Century. *Proc. 1984 NASA-ASEE Summer Study at La Jolla.*

Meek T. T., Cocks, F. H., Vaniman D. T., and Wright R. A. (1984) Microwave processing of lunar materials: Potential applications (abstract). In *Papers Presented to the Symposium on Lunar Bases and Space Activities of the 21st Century,* p. 130. NASA, JSC, Houston.

Meeus, J., Grosjean, C., and Vanderleen, W., Canon of Solar Eclipses, Pergamon Press, New York, 1966

Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3

Menzel, D'Aluisio, *Robosapiens.* 2000 The MIT Press

Metzger A. E., Haines E. L, and Etchegaray-Ramirez M. 1. (1979) Thorium concentrations in the lunar surface: III. Deconvolution of the Apenninus region. *Proc. Lunar Planet Sci. Conf 10th,* pp. 1701-1718.

Meyer C. Jr., McKay D. S., Anderson D. H., and Butler P. Jr. (1975) The source of sublimates on the Apollo 15 green and Apollo 17 orange glass samples. *Proc. Lunar Sci. Conf 6th,* 1673-1699.

Meyer, Rudolf X. *Elements of Space Technology.* 1999 Academic Press

Michael W. H., Jr. and Blacksheat W T, (1972) Recent results on the mass, gravitational field, and moments of inertia of the moon. *Moon, 3,* 388-402.

Michelson A. A. (1920) An interferometer for measuring stellar diameter. *Astrophys. J.,* 51, 257.

Miller H. H. (1983) *Passage to America.* Division of Archives and History, North Carolina University (Department of Cultural Resources), Raleigh, North Carolina. 84 pp.

Miller J. G. (1984) A living systems analysis of space habitats (abstract). In *Papers Presented to the Symposium on Lunar Bases and Space Activities of the 21st Century,* p. 36. NASA Johnson Space Center, Houston.

Miller, John and Tim Smith, Eds., Somnium (or, the Dream) and Other Trips to the Moon. Chronicle Books, 1995. ISBN: 0-811-81129-8

Miller. R. (1979) *Extraterrestrial-Materials Processing and Construction of Large Space Structures,* NASA Contract NAS 8-32935, NASA CR-161293, Space Systems Lab., MIT, 3 volumes.

Miller, Walter J., The Annotated Jules Verne From the Earth to the Moon. Gramercy Books, 1978. ISBN: 0-517-14833-1

Mindess S. and Young J. F (1981*) Concrete.* Prentice-Hall, New York 671 pp.

Minear J. W, Hubbard N., Johnson T V, and Clarke V C., Jr. (1977) *Mission Summary for Lunar Polar orbiter.* Jet Propulsion Laboratory Document 660-41, California institute of Technology, Pasadena, CA. 36 pp.

Ming, D. W., D. L. Henninger, *Lunar Base Agriculture: Soils for Plant Growth.* 1989 American Society of Agronomy

Minkin J. A., Chao E. C. 1, Christian R. P, Harris E. E., and Norton D. P- (1976) Three synthetic lunar glasses. *Meteoritics 11,* 167-171.

Mitchell J. K. and Houston W. N. (1970) Mechanics and stabilization of lunar soils. In *Lunar Surface Engineering Properties Experiment Definition,* Final Report: Vol. I of 4, Space Sciences Laboratory Series I 1, issue 10. University of California, Berkeley. 166 pp.

Mitsui A., Philips J. E., Kumazawa S., Reddy K. J., Ramachandran S., Matsunaga T, Haynes L, and Ikemoto,H. (1983) Progress in research toward outdoor biological hydrogen production, using solar energy, seawater and marine photosynthetic synthetic microorganisms. *Ann. N.Y Acad. Sci., 413,* 514-530.

Mizutani H., Spetzier H., Getting I., Martin F, J., and Soga N. (1977) The effect of outgassing upon the closure of cracks and the strength of lunar analogues. *Proc. Lunar Sci. Conf. 8th,* pp. 1235-1248.

Modell M., Gaudet G. G., Simon M., Houg G. T, and Biemann, K. (1982) Destruction of hazardous waste using supercritical water. *Solid Waste Manage., 55,* 202-212.

Moe J. M. (1962) Design of water-gas shift reactors. *Chem. Eng. Prog., 58,* 33-36.

Monfore G. E. and Lentz A. E. (1962) *Physical Properties of Concrete at Very Low Temperatures.* RD 145. Portland Cement Association, Skokie, IL 39 pp.

Moore A. D. (1973*) Electrostatics and Its Applications.* Wiley and Sons, New York. 481 pp.

Moore B., Wharton P- A. Jr., and MacElroy R. D. (1982) *Controlled Ecological Life Support System: First Principal Investigators Meeting.* NASA CP-2247. NASA, Ames Research Center, Moffett Field. 90 pp.

Moore H. J., Hodges C. A., and Scott D. H. (1974) Multiringed basins-illustrated by orientate and associated features. *Proc. Lunar Sci. Conf. 5th,* pp. 71 - 100.

Moore, Patrick, On the Moon. Cassell & Co., 2001. ISBN: 0-304-35469-4

Moore T. (2000, Spring), Renewed interest in space solar power, *EPRI Journal, pp.* 6-17.

Moran J. M. (1984) Masers in the nuclei of galaxies. *Nature, 310,* 270.

Moravec, Hans, "A Non-Synchronous Orbital Skyhook," *Journal qf Astronautical Sciences,* Vol. 25, No. 4, pp. 307-322, 1977.

Moravec, Hans *Robot - Mere Machine to Transcendent Mind.* 1999 Oxford University Press

Morgan J. W, Hertogen J., and Anders E. (1978) The moon: Composition determined by nebular processes. *Moon and Planets,* 18, 465-478.

Morris R. V. (1978) The surface exposure (maturity) of lunar soils: Some concepts and I,/FeO compilation. *Proc. Lunar Planet Sci. Conf 9th,* pp. 2287-2297.

Morris R. V. (1980) Origins and size distribution of metallic iron particles in the lunar regolith. *Proc. Lunar Planet. Sci. Conf. 11th,* 1697-1712.

Morris R. V. (1983) *Handbook of Lunar Soils.* NASA Planetary Materials Branch Public. 67. NASA, Johnson Space Center, Houston. 914 pp.

Morrison, L. V., "Analysis of lunar occultations in the years 1943-1974É," Astr. J., 1979**,** 75**,** 744

Morrison, L. V., and Appleby, G. M., "Analysis of lunar occultations - III. Systematic corrections to Watts' limb-profiles for the Moon," *MNRAS*, 1981, 196**,** 1013.

Morrow R., & Stutte, G. (2002). Biomass Production System (BPS) Photosynthesis Experiment and System Testing and Operations (PESTO). NASA: http://spaceresearch.nasa.gov/research_projects/ros/bpspesto.html

Muehlberger W P, Hörz F, Sevier J. R., and Ulrich G. E. (1980) Mission objectives for geological exploration of the Apollo 16 landing site. In *Proc. Lunar Highlands crust U. J.* Papike and R. B. Merrill, eds.), pp. I- 49. Pergamon Press, New York.

Mulch T. A. (1970*) Geology of the Moon,* Princeton University Press, Princeton, N. J. 391 pp.

Muller P. M. and Sjogren W. L. (1968) Mascons: Lunar mass concentrations. *Science, 161,* 680-684.

Mullin C.S. (1960) Some psychological aspects of isolated Antarctic living. *Amer. J. Psychiatry, 11* 7, 322-325.

Murase T. and McBirney A. P- (1970) Viscosity of lunar lavas. S*cience,* 167, 1491-1493

Murphy D. J. and Gido P. G. (1973) *Heat loss calculations for small diameter subterrene penetrator.* Los Alamos Scientific Laboratory Report LA-5207-MS, Los Alamos, New Mexico. 17 pp.

Murphy H. D., Neudecker J. W, Cort G. E., Turner W C., McFarland P, D., and Griggs J. E. (1976) *Development of coring consolidating subterrene penetrators.* Los Alamos Scientific Laboratory Report LA-6265-MS, Los Alamos, New Mexico. 39 pp.

Musgrove, Robert G., Ed., NASA SP-246 Lunar Photographs From Apollos 8, 10 and 11. U.S. Government Printing Office, 1971. Lib. Cong. 75-608546

Nakamura Y (1983) Seismic velocity structure of the lunar mantle. 1 *Geophys Res, 88,* 677-686.

Nakamura Y, Latham D., Lammlein D., Ewing M., Duennebier E, and Dorman J. (1974) Deep lunar interior inferred from recent seismic data. *Geophys Res. Lett.,* 1, 137-140.

Nakamura Y., Latham G. V, Dorman H. J., Ibrahim A. K., Koyama J., and Horvath P. (1979) Shallow moonquakes: Depth, distribution, and implications as to the present state of the lunar interior. *Proc. Lunar Planet. Sci. Conf. 10*th, pp. 2299-2309.

Nakamura Y., Latham G. V, and Dorman H. J. (1982) Apollo lunar seismic experiment-final summary. Proc. *Lunar Planet Sci. Conf 13th, in J. Geophys Res, 87,* A117-AI23.

Napier P. J., Thompson A. R., and Ekers R. D. (1983) The VLA: A large aperture synthesis interferometer. IEEE *Proc., 71,* 1295.

Nardini J. E., Herrmann P, S., and Rasmussen J. E. (1962) Navy psychiatric assessment in the Antarctic. *Amer. J. Psychiatry, 119,97-105.*

NASA GSFC Academy, Easy Low-Cost Lunar Explorer (ELLE). 1998.

NASA Information Summaries, *Major NASA Launches*, PMS 031 (KSC), National Aeronautics and Space Administration, November 1985

NASA Information Summaries, PM 001 (KSC), National Aeronautics and Space Administration, November 1985

National Aeronautics and Space Administration Mission Report: Apollo 9 (MR-3)

National Aeronautics and Space Administration Mission Report: Apollo 10 (MR-4)

National Aeronautics and Space Administration Mission Report: Apollo 11 (MR-5)

National Aeronautics and Space Administration Mission Report: Apollo 12 (MR-8)

National Aeronautics and Space Administration Mission Report: Apollo 13 (MR-7)

National Aeronautics and Space Administration Mission Report: Apollo 14 (MR-9)

National Aeronautics and Space Administration Mission Report: Apollo 15 (MR-10)

National Aeronautics and Space Administration Mission Report: Apollo 16 (MR-11)

National Aeronautics and Space Administration Mission Report: Apollo 17 (MR-12)

National Research Council (Committee On the Biological Effects of Ionizing Radiations) (1980) *The Effects Populations of Exposure to Low Levels of Ionizing Radiation.* National Academy of Science, D.C. 523 pp.

Neudecker J. W. (1973*) Design description of melting-consolidating prototype subterrene penetrators,* Los Alamos Scientific Laboratory Report LA-5212-MS, Los Alamos, New Mexico. 17 pp.

Neudecker J. W. (1974) *Conceptual design of a coring subterrene geoprospector.* Los Alamos Scientific Laboratory Report LA-5517-MS, Los Alamos, New Mexico. 14 pp.

Neudecker J. W., Giger A. J., and Armstrong P. E. (1973) *Design and development of prototype universal extruding subterrene penetrators.* Los Alamos Scientific Laboratory Report LA-5205-MS, Los Alamos, New Mexico. 16 pp.

Neukum G. and Wise D. U. (1976) Mars: a standard crater curve and possible new time scale. *Science, 194,* 1381-1387.

Newsom H. E. (1984) The lunar core and the origin of the moon. *Eos, Trans AGU, 65,* 369-370.

Nicholson D. E. and Pariseau W G. (1971a) *Gravity Flow of Powder in a Lunar Environment. Part I. Testing of simulated Lunar-basalt Powder for Gravity Flow* RI 7543, Bureau of Mines, Washington. 34 pp.

Nicholson D. E. and Pariseau W G. (1971b) *Gravity Flow of Powder in a Lunar Environment Part II.- Analysis of Flow Initiation.* RI 7577, Bureau of Mines, Washington. 20 pp.

Nicogossian, Arnauld E., M.D., and James F. Parker, Jr., Ph.D., *Space Physiology and Medicine*, (SP-447), National Aeronautics and Space Administration, 1982

Nusse M. and Kramer J. (1984) Flow cytometric analysis of micronuclei found in cells after irradiation. *Cytometry,* 5,20-25.

Nuttall L J. (1980) Production and application of electrolytic hydrogen. in *Hydrogen: Production and Marketing* (W N. Smith and J. G. Santangelo, eds.), pp. 191-212. American Chemical Society, Washington.

O'Keefe J. D. and Ahrens T J. (1982) The interaction of the Cretaceous/Tertiary bolide with the atmosphere, ocean and the solid Earth. *Geol. Soc. Am. Spec. Pap. 190,103-120.*

O'Leary B. (1977) Mining the Apollo and Amor asteroids. *Science, 197,* 363.

O'Leary B. (1979) Asteroid prospecting and retrieval. in *Space Manufacturing Facilities 3,* pp. 17-24. Proceedings of the 4th Princeton/AIAA Conference, AIAA, New York

O'Leary B., Gaffey M. J., Ross D. G., and Salkeld P., (1979) Retrieval of asteroidal materials. In *Space Resources and Space Settlements U.* Billingham, W. Gilbreath, B. O'Leary, and B. Gosset, eds.), pp. 173-189. NASA SP428, NASA, Washington D.C.

O'Leary B. (1981) The Fertile Stars, pp. 38-4 1. Everest House, New York

O'Leary B. (1984) Phobos and Deimos as resource and exploration centers. In *The Case for Mars II,* Amer. Astronaut. Soc., Sci. Technol. Ser. Vol. 62, pp. 225-244.

O'Leary B. (1985) Phobos and Deimos (PhD): Concept for an early human mission for resources and science. Princeton, AIAA Conference on Space Manufacturing.

O'Neill G. K. (1977) *The High Frontier.* Wm. Morrow and Co., New York 288 pp.

Olhoeft G. P. (1979) Impulse radar studies of near-surface geological structures (abstract). In *Lunar and Planetary Science X,* pp. 943-945. Lunar and Planetary Institute, Houston.

Olhoeft G. R. (1984) Applications and limitations of ground penetrating radar (abstract). In *Society of Exploration Geophysicists Annual Meeting Expanded Technical Program Abstracts with Biographies,* pp. 147-148. Society of Exploration Geophysicists, Tulsa.

Olhoeft G. R. and Strangway D. W (1975) Dielectric properties of the first 100 meters of the moon. *Earth Planet. Sci. Lett., 24,* 394-404.

Orbital Technologies Corporation (2002). ORBITEC Biomass Production System: The next generation in orbital plant growth research. http://www.orbitec.com/orbitec/govern/bio.htm

Osbome B. A. and Garrett M. K. (1983) Quantum yields for C02 uptake in some diploid and tetraploid plant species. PlanC *Cell, Environ., 6,135-144.*

Overbeck V. R., (1975) The role of ballistic erosion and sedimentation in lunar stratigraphy. *Rev. Geophys. Space Phys, 13,* 337-362.

Paciesas W., Baker R., Bodet D., Brown S., Cline T, Costlow H., Durouchoux P., Ehrmann C., Gehrels N., Hameury J., Haymes P, Teegarden B., and Tueller J. (1983) A balloon-borne instrument for high-resolution astrophysical spectroscopy in the 20-8000 keV energy range. *Nucl. Instrum.. Methods, 215,* 261-276.

Paone J. and Schmidt P. L. (1968) Lunar drilling. In *Proceedings of the Sixth Annual Meeting of the Working Group on Exterrestrial Resources* NASA SP-177, pp. 107-117. NASA, Washington.

Pandit B. I. and Tozer D. C. (1970) Anomalous propagation of elastic energy within the Moon. *Nature, 226,* 335.

Papike J. J., Hodges F. N., Bence A. E., Cameron M., and Rhodes J. M (1976) Mare basalts: crystal chemistry, mineralogy and petrology. *Rev Geophys Space Phys, 14,* 475-540.
Papike J. J., Simon S. B., and Laul J. C. (1982) The lunar regolith: Chemistry, mineralogy and petrology. *Geophys. Space Phys., 20,* 761-82 6.

Papike J. J. (1984) Petrologic and chemical systematics of lunar soil size fractions: Basic data with implications for specific element extraction (abstract). In *Papers Presented to the Symposium on Lunar Bases and Space Activities of the 21st Century,* p. 122. NASA/Johnson Space Center, Houston.

Pariscau W G. and Nicholson D. E. (1972) Gravity flow bin design for lunar soil. Preprint, *2nd Symposium on Storage and Flow of Solids,* American Society of Mechanical Engineers, New York. 8 pp.

Pasachoff, J. M., and Nelson, B. O., "Timing of the 1984 Total Solar Eclipse and the Size of the Sun," *Solar Physics*, 1987, 108**,** 191-194

Peterson V. Z. (1983) Deep underwater muon and neutrino detection. In *Composition and Origin of Cosmic Rays* (M. M. Shapiro, ed.), pp. 251-268. Reidel, Dordrecht.

Pearson J., "The Orbital Tower: A Spacecraft Launcher Using the Earth's Rotational Energy," *Acta Astronautica,* Vol. 2, No. 9/10, pp. 785-799, September/October 1975.

Pearson J., "Using the Orbital Tower to Launch Earth-Escape Spacecraft Daily," IAF Congress Publication IAF-76-123, 27th International Astronautical Congress, Anaheim, CA, October 10-16, 1976.

Pearson, J., "Anchored Lunar Satellites for Cislunar Transportation and Communication," *Journal of Astronautical Sciences,* Vol. 26, No. 1, pp. 39-62, 1979.

Pearson J., "Achievable Space Elevators for Space Transportation and Starship Acceleration," *NASA Conference Publication 10059,* Vision-21: Space Travel for the Next Millennium, April 3-4, 1990.

Pearson J., "Konstantin Tsiolkovski and the Origin of the Space Elevator," IAF Congress Publication IAF-97IAA.2.1.09,48th International Astronautical Congress, Turin, Italy, October 6-10, 1997.

Pearson T. J. and Readhead A. C. S. (1984) Image formation by self-calibration in radio astronomy. *Ann. Rev. Astron. Astrophys., 22,* 97.

Penzo, P.A., "Tethers for Mars Space Operations," *AAS Science & Technical Series, The Case for Mars II,* Vol. 62, pp. 445465, July 1984.

Penzo, P.A.: "Earth Orbit Tether Transportation System," AAS Paper 87-436, AAS/AIAA Astrodynamics Conference, Kalispell, MT, August 10- 1 3, 1987

Penzo, P..A., "Lunar Orbit Tether Station Concept," Calspace Study, *NASA Report CR-1 72084,* June 1988.

Perry P, H. and Chilton C. H. (editors) (1973*) Chemical Engineers Handbook.* McGraw-Hill, New York. 106 pp.

Peterson E. (1983) New results from the Soudan I detector. In *Fourth Workshop on Grand Unification* (H. A. Weldon, P. Langacker, and P. J. Steinhardt, eds.), pp. 35-46. Birkhauser, Boston.

Petschek Albert G., Neutrino Measurements on the Moon, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 345 – 348

Pettit Donald P, Fractional Distillation in a Lunar Environment, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 507 – 518

Philip's Moon Map. George Philip Ltd., 2000. ISBN: 0-540-01208-4

Phillips P., (editor) (1974) *Moonstruck. An Anthology of Lunar Poetry.* Vanguard, New York 181 pp.

Phinney W. C., Criswell D. R., Drexler E., and Garmirian J. (I1977) Lunar resources and their utilization. In *Space Based Manufacturing for Nonterrestrial Materials* (G. K. O'Neill, ed.), p. 97-123. *Prog. Astronaut. Aeronaut,* 57, American institute of Aeronautics and Astronautics, New York

Pieters C. M., McCord T. B., Zisk S., and Adams J. B. (1973) Lunar black spots and nature of the Apollo 17 landing area. *J. Geophys. Re&, 78,* 5867-5875.

Pieters C., McCord T. B., Charette, M. P., and Adams J. B. (1974) Lunar surface: identification of the dark mantling material in the Apollo 17 soil samples. Science, 183,1191-1193.

Pieters C. M. (1978) Mare basalt types on the front side of the Moon: A summary of spectral reflectance data. *Proc. Lunar Sci. Conf. 9th,* pp. 2825-2849.

Pieters C. M. (1982) Copernicus crater central peak: Lunar mountain of unique composition. *Science, 215,* 59- 61.

Pillinger C. T (1979) Solar wind exposure effects in the lunar soil. *Rep. Prog. Phys, 42,* 897-961.

Pieters, C.M., Gaffey, M., McFadden L., Possible Source Regions for ALHA 81005 on the Moon, EOS, 64, No. 18, 253, 1983.

Podnieks E. P. and Chamberlain P. G. (1970) Method for rock property determination in ultrahigh vacuum. *Proc. 5th Space Simulation Conference, Special Publication 336,* pp. 209-223. National Bureau of Standards, Washington.

Podnieks E. P,, Chamberlain P. G. and Thill P. E. (1972) Environmental effects on rock properties. *Proc 10th Symposium on Rock Mechanics Basic and Applied Rock Mechanics,* pp. 215-24 1. Society of Mining Engineers of AIME, Denver.

Podnieks E.P. and W. W. Roepke Mining for Lunar Base Support, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 445 – 452

Project Apollo: Manned Exploration of the Moon, Educational Data Sheet #306, NASA Ames Research Center, Moffett Field, California, Revised May, 1974

Puttkamer von J., (1976) Developing space occupancy: perspectives on NASA future space programme development. J*. Interplanet. Soc., 29,* 147-173.

Quattrone P. D. (1984) Extended mission life support systems. *Advances in the Astronautical Sciences,* Sci. Technol. Ser., 57,131-162.

Ramaty R. and Lingenfelter R. E. (1982) Gamma-ray astronomy. *Annu. Rev. Nucl. Part. Sci.,* 32,235-269.

Rampino M. R and Stothers R B. (1984a) Terrestrial mass extinction, cometary impacts and the Sun's motion perpendicular to the galactic plane. *Nature, 308,* 709-712.

Rampino M. R and Stothers R B. (1984b) Geological rhythms and cometary impacts. *Science, 226,* 142 7-143 1.

Randolph J. E. (1984) *Planetary Observer Planning FY 1984 Final Report.* jet Propulsion Laboratory Document D- 1 846, California institute of Technology, Pasadena. 313 pp.

Rao D. B., Choudary U. V., Erstfield T. E., Williams R. J., and Chang Y. A. (1979) Extraction processes for the production of aluminium, titanium, iron, magnesium, and oxygen from nonterrestrial sources. In *Space Resources and Space Settlements* U.

Billingham, W Gilbreath, B. O'Leary, and B. Gosset, eds.), pp. 257-274, NASA SP- 428, NASA, Washington.

Raup D. M. (1984) Evolutionary radiations and extinctions. in *Patterns of Change in Earth Evolution* (H. D. Holland and A. E Trendall, eds.), pp. 5- 15. Springer Verlag, Berlin

Raup D. M. and Sepkoski J. J., Jr. (1984) Periodicity of extinctions in the geologic past. *Proc. Natl. Acad. Sci.* US.A., 81, 801-805.

Rawson H. M. (1970) Spikelet number, its control and relation to yield per ear in wheat. AUSL *J. Biol. Sci., 23,1-15.*

Readhead A. C. S. and Wilkinson P N. (1978) Phase closure in VLBI. *Astrophys J.,* 223,25.

Reedy R. C. and Arnold J. R. (1972) Interaction of solar and galactic cosmic ray particles with the Moon. J. *Geophys Res.,* 77, 537-555.

Reedy R. C. (1978) Planetary gamma ray spectroscopy. in *Gamma Ray Spectroscopy in Astrophys.* (T. L. Cline and P, Ramaty, eds.), pp. 98-148. NASA TM-79619, NASA, Washington, D.C.

Reid M. J. (1984) H2 0 masers and distance measurements: The impact of QUASAT. In *QUASAT-A VLBI Observatory in Space,* p. 181. ESA Scientific Publication, The Netherlands.

Reines F (1965), as reported in Shapiro M. M. (1965) Galactic cosmic rays. In *NASA 1965 Summer Conference on Lunar Exploration and Science,* pp. 31 7-330, NASA SP-88. NASA, Washington.

Report of Apollo 13 Review Board, National Aeronautics and Space Administration, June 15, 1970

Reynolds, David W., Apollo: The Epic Journey to the Moon. Harcourt, 2002. ISBN: 0-151-00964-3

Rickett B. J. A. (1977) Interstellar scattering and scintillation of radio sources. *Ann. Rev. Astron. Astrophys.,* 15, 479.

Ringwood A. E. and Essene E. (1970) Petrogenesis of Apollo 11 basalts, internal constitution and origin of the moon. *Proc. Apollo 11 Lunar Sci. Conf ,* pp. 7 69- 799.

Robinson J. A. and Tiedje J. M. (1984) Competition between sulfate-reducing and methanogenic bacteria for H2 under resting and growing conditions. *Arch. Microbiol., 137,* 26-32.

Roedder E. (1980) Use of lunar materials in space construction. in *Lunar Materials Processing,* (D. Criswell, ed.), pp. 213-230. NSR09-051-001, (No. 24), Lunar and Planetary Institute, Houston.

Roepke W. W. (1969) Friction tests in simulated lunar vacuum. In *Proceedings of the Seventh Annual Meeting of the Working Group on Exterrestrial Resources* NASA SP-29, pp. 107-111. NASA, Washington.

Roepke W. W. (1975) *Experimental System for Drilling Simulated Lunar Rock in Ultrahigh Vacuum.* NASA CR146419. NASA, Washington. 13 pp.

Roepke W. W. and Peng S. S. (1975) *Surface Friction of Rock in Terrestrial and Simulated Lunar Environments.* NASA CR- 146359. NASA, Washington. 34 pp.

Roepke W. W. and Schultz C. W. (1967) Mass spectrometer studies of outgassing from simulated lunar materials in UHV *Proc. 14th Nat. Vacuum Symp. of the Amer. Vacuum Soc.,* pp. 165-166. American Vacuum Society, New York.

Rogers A. E. E. (1976) The two-element interferometer. *Methods of Experimental Physics, Vol. 12C.- Astrophysics, Radio Observations* (M. L. Meed, ed.), p. 139.

Rosenberg S. D. (1984) A lunar-based propulsion system (abstract). In *Papers Presented to the Symposium on Lunar Bases and Space Activities of the 21st Century,* p. 29. NASA/Johnson Space Center, Houston

Rosenberg S. D., Guter G. A., and Miller E E. (1965) The utilization of lunar resources for propellant manufacture. *Adv. Astronaut Sci., 20,* 665.

Rosenberg Sanders D., A Lunar-Based Propulsion System, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 169 – 176

Rowley J. C. and Neudecker J. W (1984) *In situ* rock melting applied to lunar base construction and for exploration drilling and coring on the Moon (abstract). In *Papers Presented to the Symposium on Lunar Bases and Space Activities of the 21st Century,* p. 77. NASA/Johnson Space Center, Houston.

Rukl, Antonin (translated into French by Martine Richebe), *Atlas de la Lune*. Grund, 1993. ISBN: 2-700-01554-1

Runcom S. K (1983) Lunar magnetism, polar displacements and primeval satellites in the earth-moon system. *Nature, 304,* 589-596.

Russell D. A. (1979) The enigma of the extinction of dinosaurs. *Annu Rev. Earth Planet Sci., 7,* 163-182.

Russell C. T, Coleman P J., Jr., and Goldstein B. E. (1981) Measurements of the lunar induced magnetic moment in the geomagnetic tail: Evidence for a lunar core. *Proc. Lunar Planet Sci. 12B,* pp. 831-836.

Ruzic, N.P., the case for going to the Moon. G.P. Putnam's Sons, 1965. Lib. Cong. 65-22124

Ryder G. and Norman M. D. (1980) *Catalog of Apollo 16 Rocks.* NASA Curatorial Branch Public. 52. NASA/ Johnson Space Center, Houston. II 44 pp.

Ryder G. (1982) Why lunar sample studies are not finished. EOS, *7)rans AGU, 63,* 785-787.

Ryle M. and Hewish A. (1960) The synthesis of a large radio telescope. *MNRAS,* 120,220-230.

Salisbury, F. B., & Bugbee, B. (1985). Wheat farming in a lunar base. In M. B. Duke & W. W. Mendell (Eds.), *Lunar bases and space activities of the 21st century.* Houston: Lunar and Planetary Institute.

Samorski M. and Stamm W (1983) Detection of 2 x *10 exp*15-2 x 10 exp 16 eV gamma-rays from Cygnus X-3. *Astrophys, J.Lett, 268,* LI 7.

Sachs, M., The Moon. Abbeville Press, 1998. ISBN: 0-789-20341-3

Salisbury F. B. (1984) Achieving maximum plant yield in a weightless, bioregenerative system for a space craft. *Physiologist 27,* S-31-34.

Salisbury F. B. and Ross C. W. (1969) *Plant Physiology,* pp. 492-493. Wadsworth, Belmont, CA.

Salisbury F. B. and Ross C. W. (1985) *Plant Physiology.* Third edition, pp. 195-228. Wadsworth, Belmont, CA.

Salkeld R. J. (1966) Economic implications of extracting propellants from the Moon. *J. Spacecraft and Rocket4* 3, 254-260.

Sarmont E., Web site for image and technical information on a LEO space elevator concept, http:// www.affordablespaceflight.com Accessed June 1999.

Sastri S. (1984) Role of iron in space (abstract). in *Papers Presented to the Symposium on Lunar Bases and Space Activities of the 21st Century,* p. 125. NASA, Johnson Space Center, Houston.

Sauer R. L. and Rapp R. M. (1983) *Shuttle OFT Medical Report.* NASA TM-58252. NASA Johnson Space Center, Houston. 102 pp.

Sauer R. L., Metabolic Support for a Lunar Base, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 647 – 652

Saturn AS-205/CSM-101 Postflight Trajectory, Chrysler Corporation Space Division (TN-AP-68-369) (NASA CR-98345) (NTIS N92-70426)

Saturn IB Flight Evaluation Working Group, Results of the Fifth Saturn IB Launch Vehicle Test Flight AS-205 (Apollo 7 Mission), NASA George C. Marshall Space Flight Center, Alabama, January 25, 1969 (MPR-SAT-FE-68-4)

Saturn V Flight Evaluation Working Group, Saturn V Launch Vehicle Flight Evaluation Report AS-503: Apollo 8 Mission, NASA George C. Marshall Space Flight Center, Alabama, February 20, 1969 (MPR-SAT-FE-69-1)

Saturn V Launch Vehicle Flight Evaluation Report AS-504: Apollo 9 Mission, NASA George C. Marshall Space Flight Center, Alabama, (MPR-SAT-FE-69-4/NASA-TM-X-62545) (NTIS 69X-77591)

Saturn V Launch Vehicle Flight Evaluation Report AS-505: Apollo 10 Mission, NASA George C. Marshall Space Flight Center, Alabama, (MPR-SAT-FE-69-7/NASA-TM-X-62548) (NTIS 69X-77668)

Saturn V Launch Vehicle Flight Evaluation Report AS-506: Apollo 11 Mission, NASA George C. Marshall Space Flight Center, Alabama, (MPR-SAT-FE-69-9/NASA-TM-X-62558) (NTIS 90N-70431/70X-10801)

Saturn V Launch Vehicle Flight Evaluation Report AS-507: Apollo 12 Mission, NASA George C. Marshall Space Flight Center, Alabama, (MPR-SAT-FE-70-1/NASA-TM-X-62644) (NTIS 70X-12182)

Saturn V Launch Vehicle Flight Evaluation Report AS-508: Apollo 13 Mission, NASA George C. Marshall Space Flight Center, Alabama, (MPR-SAT-FE-70-2/NASA-TM-X-64422) (NTIS 90N-70432/70X-16774)

Saturn V Launch Vehicle Flight Evaluation Report AS-509: Apollo 14 Mission, NASA George C. Marshall Space Flight Center, Alabama, (MPR-SAT-FE-71-1/NASA-TM-X-69536) (NTIS N73-33824)

Saturn V Launch Vehicle Flight Evaluation Report AS-510: Apollo 15 Mission, NASA George C. Marshall Space Flight Center, Alabama, (MPR-SAT-FE-71-2/NASA-TM-X-69539) (NTIS N73-33819)

Saturn V Launch Vehicle Flight Evaluation Report AS-511: Apollo 16 Mission, NASA George C. Marshall Space Flight Center, Alabama, (MPR-SAT-FE-72-1/NASA-TM-X-69535) (NTIS N73-33823)

Saturn V Launch Vehicle Flight Evaluation Report AS-512: Apollo 17 Mission, NASA George C. Marshall Space Flight Center, Alabama, (MPR-SAT-FE-73-1/NASA-TM-X-69534) (NTIS N73-33822)

Sax N.. (1965*) Dangerous Properties of Industrial Materials* Reinhold, New York 1343 pp.

Science Applications International Corp. (SAIC) (1984a) *A Manned Lunar Science Base. An Alternative to Space Station Science?* Report No. SAIC-84/1502, SAIC, Los Alamos. 31 pp.

Schaber G. G. (1973) Lava flows in Mare Imbrium: Geologic evidence from Apollo orbital photography. Proc. *Lunar Sci. Conf. 4th,* pp. 73-92.

Scherzer B. M. U., Ehrenberg J., and Behrisch F., (I 983) High fluence He implantation in Ni: Trapping, re-emission and surface modification *Radiat Eff., 78,* 417-426.

Schrunk D., Sharpe, B., Cooper, B. and Thangavelu, M. (1999) The Moon: Resources, Future Development and Colonization, 432pp., Wiley.

Schilizzi P. T. Burke B. E, Booth R S., Preston R. A., Wilkinson P, N., Jordan J. E, Preuss E., and Roberts D. (1984) The QUASAT project. In *VLBI and Compact Radio Sources* (R. Fanti, K. Kellerman, and G. Setti, eds.), p.407. D. Reidel, Boston

Schlegel H.G. and Schneider K. (1978) Distribution and physiological role of hydrogenases in micro-organisms. *In Hydrogenases.. Their Catalytic Activity, Structure and Function* (H. G. Schlegel and K. Schneider, eds.) E. Goetze K. G., Göttingen.

Schlegel H. G. (1984) *Allgemeine Mikrobiologie.* G. Thieme-Heriag, Stuttgart. 571 pp.

Schmidt P. L. (1969) Developing a lunar drill: A 1969 status report. in *Proceedings of the Seventh Annual Meeting of the Working Group on a terrestrial Resources* NASA SP-229. NASA, Washington. 148 pp.

Schmidt P. L. (1970) Diamond flunk test on lunar hammer-drill. *Drilling* 32,34-35, 64

Schneider K. and Schlegel H. G. (I 9 7 7) Localization and stability of hydrogenases in aerobic hydrogen bacteria. *Arch. Microbiol., 122,229-238.*

Scholz C. H. (1972) Static fatigue of quartz. *J. Geophys. Res., 77,* 2104-2114.

Schrunk, David et al, The Moon: Resources, Future Development and Colonization. Praxis Publishing, 1999. ISBN: 0-471-97635-0

Schubert G., Cassen P., and Young R. E. (1979) Subsolidus convective cooling histories of terrestrial planets. *Icarus, 38,192-211*.

Schubert E. H., Wynveen P. A., and Quattrone P D. (1984) Advanced regenerative environmental control and life support systems: Air and water regeneration In *Advances in Space Research: Life Sciences and Space Research* = (2) (H. Oser, J. Oro, R. D. MacElroy, H. P. Klein, D. L. De Vincenzi, and R. S. Young, eds.), pp. 279-289. Pergamon, Oxford.

Schultz P. H. (1976a) *Moon Morphology,* University of Texas Press, Austin, TX. 626 pp.

Schultz P. H. and Gault D. E. (1975a) Seismic effects from major basin formations on the Moon and Mercury. *Moon, 12,* 159-177.

Schultz P. H. and Gault D. E. (1975b) Seismically induced modification of lunar surface features. *Proc. Lunar Sci. Conf 6th,* 2845-2862.

Schultz P. H. and Spudis P. D. (1979) Evidence for ancient mare volcanism. *proc. Lunar Planet Sci. Conf. 10th,* pp.2899-2918.

Schultz P. H. and Spudis P D. (1983) Beginning and end of lunar mare volcanism. *Nature,* 302,233-236.

Schwartz R. D. and James P. B. (1984) Periodic mass extinctions and the Sun's oscillation about the galactic plane. *Nature, 308,712-713.*

Sedej M. Meyer, Implementing Supercritical Water Oxidation Technology in a Lunar Base Environmental Control-Life Support System, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 653 – 662

Sellers, Jerry Jon *Understanding Space - An Introduction to Astronautics.* 2000 McGraw-Hill

Shao M., Colavita M., Staelin D., and Johnston K. (1984) The technology requirements for a small space-based astrometric interferometer. *Bull. Am. Astron. Soc., 16,* 750.

Shapiro M. M. and Silberberg P- (1970) Heavy cosmic ray nuclei. *Ann. Rev. Nucl. Sci.,* 20,323.

Shapiro M. M. and Silberberg R. (1979) Neutrinos from young supernova remnants. In *Proc. 16th Intl. Cosmic Ray Conf, Vol. 10*, pp. 363-366. Univ. Tokyo, Kyoto

Shapiro M. M. and Silberberg R. (1983) Gamma rays and neutrinos as complementary probes in astrophysics. *Space Sci. Rev&, 36,* 51-56.

Shea, J.H.: "Sky-hook," Reply by Isaacs et al., *Science, Vol.* 152,p.800,1966.

Sheridan, Thomas B. *Humans and Automation: System Design and Research Issues.* 2002 John Wiley & Sons

Shoemaker E. M. and Hackman P, J. (1962) Stratigraphic basis for a lunar time scale. in *The Moon* (Z. Kopal and Z. K. Mikhailov, eds.), pp. 289-300. Academic Press, London.

Shoemaker E. M. (1983) Asteroid and comet bombardment of the Earth. *Annu. Rev. Earth Planet Sci., 11,* 15-41.

Silver L. T. and Schultz P. H. (editors) (1982) Geological implications of impacts of large asteroids and comets on Earth. *Geol. Soc. Am. Spec. Pap.* 190, 528 pp.

Silberberg P. and Tsao C. H. (1973) Partial cross sections in high-energy nuclear reactions, and astrophysical applications. Ap. *J. Suppl., 25,* 315-333.

Silberberg P, and Shapiro M. M. (1979) Neutrinos as a probe for the nature of and process in active galactic neutrinos. in *Proc 16th Intl. Cosmic Ray Conf., Vol. 10,* pp. 357-362. Univ. Tokyo, Kyoto.

Silberberg R. and Shapiro M. M. (1983) Sources of extragalactic cosmic rays: Photons and neutrinos as probes. *in Composition and Origin of Cosmic Rays* (M. M. Shapiro, ed.) pp. 231-244. Reidel, Dordrecht.

Silberberg R., Tsao C. H., Adams J. H. Jr., and Letaw J. R. (1984) Radiation doses and LET distributions of cosmic rays. *Rad. Res,* 98,209-226.

Silberberg R., Tsao C. H., Adams J. H. Jr., Hulburt E. O., and Letaw J. P, (1985) Radiation transport of cosmic ray nuclei in lunar material and radiation doses (abstract). This volume.

Simon Michael C., A Parametric Analysis of Lunar Oxygen Production, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 531 – 542

Simpson J. A. (1983) Elemental and isotopic compositions of the galactic cosmic rays. *Ann. Rev. Nucl. Part. Sci., 33,* 323-381.

Singer S. F. (1984) The Ph-D proposal: A manned mission to Phobos and Deimos. In *The Case for Mars,* Am. Astronaut. Soc. Sci. Technot. Ser. Vol. 57, pp. 39-65.

Sjostedt, Ulf, Hasselblad: First Man on the Moon, July 20, 1969. Hasselblad/Typografia, 1969.

Smith D. D. (1980) The Moon Treaty and private enterprise. *Astronaut. and Aeronaut, 18,* 62-63.

Smith D. D., Paptkieviez S., and Rothblatt M. (1983) Legal implications of a permanent manned presence in space. W. *Va. L. Rev.,* 85,857-872.

Smith R. E. and West G. S. (Compilers) (I 983) *Space and Planetary Environment criteria Guidelines for Use in Space Vehicle Development Vol.* 1. NASA TM-82478 NASA, Washington, D.C. 246 pp.

Smith, W.H., Haskin, L., Arvidson, R., McKinnon, W., Korotev, R., Baines, K.H., Delamere, A., and McFadden, L., "LUMIS: Lunar Ultraviolet-Infrared Mapping Interferometric Spectrometer." B.A.A.S. 22, 1049, 1990.

Smka L J., Hoyt J. L, Harvey J. V. S., and McCoy J. E. (1979) A study of the Rima Sirsalis lunar magnetic anomaly. *Phys. Earth Planet Int.,* 20, 281-290.

Smolders A. B. and van Haarlem, M. P. (editors) (2001 September 4) Perspectives on radio astronomy technologies for large antenna arrays, Netherlands Fndt. Res. in Astronomy,

Soderblom L A. (1977) Historical variations in the density and distribution of impacting debris in the inner solar system: evidence from planetary imaging. In *Impact and Explosion Cratering (D.* J. Roddy, R. 0. Pepin, and R. B. Merrill, eds.), pp. 629-633. Pergamon, New York

Solomon S. C. (1978) The nature of isostasy on the moon: How big a Pratt-fall for Airy models? *Proc. Lunar Planet Sci. Conf. 9th,* pp. 3499-351 1.

Solomon S. C. and Head J. W (1980) Lunar mascon basins: Lava filling, tectonics, and evolution of the lithosphere. *Rev. Geophys Space Phys,* 18,107-14 1.

Sonett C. P. (1982) Electromagnetic induction in the moon. *Rev. Geophys Space Phys., 20,* 411-455.

Sonett C. P., Smith B. F., Colbum D. S., Schubert G., and Schwartz K. (1972) The induced magnetic field of the moon: Conductivity profiles and inferred temperature. *Proc. Lunar Planet Sci. Conf. 3rd,* pp. 2309-2336.

Space Physiology and Medicine. NASA SP-447, 1982 U.S. Government Printing Office

Space Settlements - A Design Study. NASA SP-413, 1977 U.S. Government Printing Office (033-000-00669)

Space Resources and Space Settlements. NASA SP-428, 1979 U. S. Government Printing Office (0--293-364)

Space Studies Board, A Review of Space Research, Planetary Sciences Reports, 1961

Space Studies Board, 1960 Science in Space, Chapter 4, "The Moon", Planetary Sciences Reports, National Academy of Sciences, Washington, D.C. 1960

Space Studies Board, Space Research: Directions for the Future, Part I, Planetary Sciences Reports, National Academy of Sciences, Washington, D.C. 1965

Space Studies Board, Space Research: Directions for the Future, Planetary Sciences Reports, National Academy of Sciences, Washington, D.C. 1966

Space Studies Board, Lunar Exploration: Strategy for Research 1969-1975, Planetary Sciences Reports, National Academy of Sciences, Washington, D.C. 1969

Space Studies Board, Report on Space Science, Planetary Sciences Reports, National Academy of Sciences, Washington, D.C. 1975

Space Studies Board, *Origin and Evolution of Life-Implications for the Planets: A Scientific Strategy for the 1980s*,* Committee on Planetary Biology and Chemical Evolution, National Academy Press, Washington, D.C,1981

Space Studies Board, Letter report regarding science planning for the CRAF mission, from the Committee on Planetary and Lunar Exploration to Geoffrey A. Briggs (NASA), National Academy Press, Washington, D.C, May 31 1985

Space Studies Board, *A Strategy for Exploration of the Outer Planets: 1986-1996*, Committee on Planetary and Lunar Exploration, National Academy Press, Washington, D.C, 1986

Space Studies Board, Letter report regarding review of the planned scientific content of the CRAF mission, from the Committee on Planetary and Lunar Exploration to Geoffrey A. Briggs (NASA), May 27, 1987

Space Studies Board, *United States and Western Europe Cooperation in Planetary Exploration*, Joint Working Group on Cooperation in Planetary Exploration, National Academy Press, Washington, D.C, 1986

Space Studies Board, Space Science in the Twenty-First Century: Planetary and Lunar Exploration, Task Group on Planetary and Lunar Exploration Letter report [3] regarding an assessment of the impact on integrated science return from the 1992 Mars Observer mission to Geoffrey A. Briggs (NASA), July 12, Planetary Sciences Reports, National Academy Press, Washington, D.C, 1988.

Space Studies Board, The Search for Life's Origins: Progress and Future Directions in Planetary Biology and Chemical Evolution, Planetary Sciences Reports, National Academy Press, Washington, D.C. 1990

Space Studies Board, Assessment of Solar System Exploration Programs, Planetary Sciences Reports, National Academy Press, Washington, D.C, 1991

Space Studies Board, "Scientific Assessment of Proposed Robotic Lunar Missions of NASA's Office of Exploration," letter report 3 to Michael D. Griffin (NASA), August 21, National Academy Press, Washington, D.C. 1992

Space Studies Board, "Scientific Assessment of the Strategic Defense Initiative Organization's Integrated Sensor Experiment (CLEMENTINE)," letter report from the Committee on Planetary and Lunar Exploration to Simon P. Worden (SDIO) and Wesley T. Huntress, Jr. (NASA), August 21

Space Studies Board, An Integrated Strategy for the Planetary Sciences: 1995-2010, Planetary Sciences Reports, National Academy Press, Washington, D.C. 1994

Spitale, J. N. (2002 April 5) Asteroid hazard mitigation using the Yarkovsky Effect, *Science, 296,* #5565, 77. Spudis P. D. (1978) Composition and origin of the Apennine Bench formation. *Proc. Lunar Planet. Sci. Conf 9th,* pp. 3379-3394.

Spudis, P.D., The Once and Future Moon. Smithsonian Institution, 1996. ISBN: 1-560-98634-4

Stachnik P, V, Ashlin K., and Hamilton S. (1984) Space station SAMSI: A spacecraft array for Michelson spatial interferometry. *Bull. Am. Astron. Soc., 16,* 818.

Stadler C. R., Bourland C. T, Rapp P. M., and Sauer P. L. (1982) Food system for Space Shuttle Columbia. *J. Am. Diet. Assoc.,* 80, 108-114.

Staehle P., (1983) Finding "Paydirt" on the Moon and asteroids. *Astronaut Aeronaut, 21,* 44.

Stecker F. W. (1979) Diffuse fluxes of cosmic high-energy neutrinos. *Astrophys J.,* 228, 919-927.

Steinkamp J. A. and Crissman H. A. (1974) Automated analysis of deoxyribonucleic acid, protein, and nuclear to cytoplasmic relationships in tumor cells and gynecological specimens. *J. Histochem. Cytochem., 22,* 616621.

Steinkamp J. A. (1984) Flow cytometry. *Rev. Sci. Instrum., 55,1375-1400.*

Steinkamp J. A., Wilson J. S., Saunders G. C., and Stewart C. C. (I 982) Phagocytosis: Flow cytometric quantitation with fluorescent microspheres. *Science, 215,* 64-66.

Stenger V. J. (1984) The production of very high energy photons and neutrinos from cosmic proton sources. *Astrophys J, 284,* 810-816.

Steurer W. H. (1982) *Extraterrestrial Materials Processing.* NASA CR- 1 69268, NASA, Washington. 147 pp.

Steurer W. H. (1984) Use of lunar materials in the construction and operation of a lunar base (abstract). In *Papers Presented to the Symposium on Lunar Bases and Space Activities of the 21st Century,* p. 77. NASA/ Johnson Space Center, Houston.

Strain P. L. and El-Baz F. (1980) The geology and morphology of Ina. *Proc. Lunar Planet. Sci. Conf 11*th, pp 2437-2446.

Strangway D. W., Chapman W B., Olhoeft G. R., and Carues J. (1972) Electrical properties of lunar soil: Dependence on frequency, temperature, and moisture. *Earth. Planet. Sci. Lett., 16,* 275-281.

Strangway D. W. (1976) Future geophysical techniques for probing beneath the regolith - prospecting objectives (abstract). In *Lunar Science VII, Special Session Abstracts,* pp. 132-136. Lunar Science Institute, Houston.

Strangway D. W and Olhoeft G. P, (1977) Electrical properties of planetary surfaces. *Philos 7rans. Roy. Soc.London, Ser.* A 285,441-450.

Strangway D. W., Rylaarsdam J. C., and Annan A. P. (1975) Magnetic anomalies near Van de Graaf Crater. *Proc. Lunar Sci. Conf 5th,* pp. 2975-2984.

Strangway D. W., Pearce G. W, and Olhoeft G. R. (1977) Magnetic and dielectric properties of lunar samples. *In The Soviet American Conference on Cosmochemistry of the Moon and Planets U.* H. Pomeroy and N. J. Hubbard, eds.), Part 1, pp. 417-43 1. NASA SP-370, NASA Washington, D.C.

Strangway D. W., Geophysics and Lunar Resources, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 265 - 270

Stuart-Alexander D. E. and Howard K. A. (1970) Lunar maria and circular basins- A review. *Icarus, 12,* 440- 456.

Sugiura N., Wu Y. M., Strangway D. W, Pearce G. W, and Taylor L A. (1979) A new magnetic paleointensity value for a young lunar glass. *Proc. Lunar Planet. Sci. Conf 10th,* pp. 2189-2198.

Sullivan T. A. and McKay, D. S. (1991)*, Using Space Resources, pp.* 11-1 2, NASA, Johnson Space Center, 27 pp.

Sunshine, J.M., McFadden, L.A., Pieters, C.M., "Reflectance Spectra of the Elephant Moraine A79001 Meteorite: Implications for Remote Sensing of Planetary Bodies," Icarus, 105, 79-91, 1994.

Takashima S. and Amano F (1960) Some studies on lower calcium silicates in portland cement. *Reviews of 74th General Meeting of Cement Association of Japan.* Yogyo Cement Co., Osaka. 44 pp.

Talwani M., Thompson G., Dent B., Kahle H. G., and Buck S. (1973) Traverse gravimeter experiment, Apollo 17. In *Apollo 17 Preliminary Science Report* 13-1 to 13-13. NASA SP-330, NASA, Washington, D.C.

Taylor G. J., The Need for a Lunar Base: Answering Basic Questions about Planetary Science, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 189 – 198

Taylor L. A., Nyquist L. E., and Laul J. C. (1983) Mare-basalt volcanism in the lunar highlands. Earth *Planet Sci. Lett., 66,* 33-47.

Taylor L. A. (1984) Layered intrusives on the Moon: A source of chromite deposits? (abstract). In *Papers Presented to the symposium on Lunar Bases and Space Activities of the 21st Century,* p. 15. NASA/Johnson Space Center, Houston.

Taylor H. (editor) (1974) *Poetry: Points of Departure.* Winthrop, Cambridge. 345 pp.

Taylor S. P., (1975) *Lunar Science. A Post-Apollo View.* Pergamon, New York- 372 pp.

Taylor S. P., (1982) *Planetary Science. A Lunar Perspective.* Lunar and Planetary Institute, Houston 481 pp.

Taylor S. P., (1982) *Planetary Science. A Lunar Perspective.* Lunar and Planetary institute, Houston. 481 pp.

Taylor S. P. (1984) Tests of the lunar fission hypothesis (abstract). In *Papers Presented to the Conference on the origin of the Moon,* p. 25. Lunar and Planetary Institute, Houston.

Telford W. M., Geldard L. P., Sheriff R E., and Keys D. A. (1976) *Applied Geophysics,* Cambridge University Press. 860 pp.

Thirumalai K. and Demou S. G. (1970) Effect of reduced pressure on thermal-expansion behavior of rocks and its significance to thermal fragmentation. J. *Appl. Phys., 41,* 5147-5151.

Thorton W. E. and Ord J. (1977) Physiological mass measurements in Skylab. In *Biomedical Results from Skylab,* pp. 175-181, NASA SP-377. NASA, Johnson Space Center Houston.

Tiesenhausen, von G., "Tethers in Space: Birth and Growth of a New Avenue to Space Utilization," *NASA TM-82571,* Marshall Space Flight Center, 1984Tinga W P., *(1969) Multiphase Dielectric Theory-Applied to Cellulose Mixtures,* pp. 62-65. Ph.D. Thesis, University of Alberta.

Tinga W. P., (1970) Interactions of microwaves with materials. *Proc. IMPI,* pp. 19-29.

Tinga W. R. and Edwards E. M. (I 968) Dielectric measurement using swept frequency techniques. J *Microwave Power,* 3,144-175.

Tinga W P, and Nelson S. 0. (1973) Dielectric properties of materials for microwave processing-tabulated. *J. Microwave Power,* 8,23-66.

Tinga W. P., and Voss W A. G. (1968) Materials evaluation and measurement technique. In *Microwave Power Engineering* (E. Okress, ed.), pp. 1 89-194. Academic, New York

Toksöz M. N., Dainty A. M., Solomon S. C., and Anderson K. R (1974) Structure of the moon. *Rev. Geophys. Space Phys., 12,* 539-567.

Toksöz M. N., Goins N. P., and Cheng C. H. (1977) Moonquakes: Mechanisms and relation to tidal stresses *Science,* 196,979-981.

Toksöz M. N., Hsui A. T, and Johnston D. H. (1978) Thermal evolutions of the terrestrial planets. *Moon and Planets,* 18,281-320.

Toon 0. B. (1984) Sudden changes in atmospheric composition and climate. In *Patterns of Change in Earth Evolution* (H. D. Holland and A. F. Trendall, eds.), pp. 41-61. Springer Verlag Berlin.

Torbett M. V and Smoluchowski B. (1984) Orbital stability of the unseen solar companion linked to periodic extinction events. *Nature, 311,* 641-642.

Traub W A. and Carleton N. P. (1984) COSMIC: A high-resolution large collecting area telescope. *Bull Am Astron. Soc., 16,* 810.

Tsao C. H., Silberberg R., Adams J. H. Jr., and Letaw J. R. (1984) Cosmic Ray Effects on Microelectronics, Part III: Propagation of Cosmic Rays in the Atmosphere. NRL Memorandum Report 5402, Naval Research Laboratory, Washington, D.C. 87 pp.

Tucker D. S., D. T Vaniman, J. L. Anderson, F W Clinard Jr., P, C. Feber Jr., H. M. Frost, T. T. Meek, and T C. Wallace Hydrogen Recovery From Extraterrestrial Materials Using Microwave Energy, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 583 – 590

Ulrich, Hodges, Muehlberger, *Geology of the Apollo 16 Area, Central Lunar Highlands* U.S. Geological Survey Professional Paper 1048

Ungenfelter P. E., Canfield E. H., and Hampet V. E. (1972) The lunar neutron flux revisited. *Earth Planet Sci. Lett,* 16, 355-369.

U.S. Congress, Senate Committee on Commerce, Science, and Transportation (1980) *Agreement Governing the Activities of States on the Moon and Other Celestial Bodies,* Committee Print, 96th Congress, 2nd session.

U.S. Scientific Laboratory (1950) *The Effects of atomic Weapons.* Combat Forces Press, Washington. 730 pp.

U.S. News & World Report, U.S. on the Moon: What it means to us. Books by U.S. News & World Report, 1969. Lib. Cong. 78-88664

van den Bergh G., Periodicity and Variation of Solar (and Lunar) Eclipses, Tjeenk Willink, Haarlem, Netherlands, 1955

Vas Dias R. (editor) (1970) *Inside Outer Space.* Doubleday Anchor, New York. 398 pp.

Veverka J. and Bums J. A. (1980) The moons of mars. *Annu. Rev. Earth Planet Sci., 8,* 527-558.

Vilas F., Jensen, E.A., Domingue, D.L., McFadden, L.A., Coombs, C.R., "An Unusual Photometric Signature Detected on Lunar Complex Crater Rims at the South Pole," Lunar and Planetary Sci. Conf. XXIX, 1998.

Vishnapuu A., Marek B. C., and Jensen J. W (1973) Conversion of ilmenite to rutile by a carbonyl process. U *S. Bureau ofmines Rept 7719.* U. S. Bureau of Mines, Washington 20 pp.

Von Hippel A. R. (1954a) *Dielectrics and Waves* Wiley and Sons, New York 284 pp.

Von Hippel A. R. (1954b) *Dielectric Materials and Applications.* Wiley, New York. 438 pp.

Waldron R.D. and Criswell D. P, (1982) Materials processing in space. in *Space Industrialization* (B. O'Leary, ed.) p. 97-130. CRC Press, Boca Raton, FL

Waldron R. D. (1984) Diversity and purity. Keys to industrial growth with refined lunar materials (abstract). *in Papers Printed to the Symposium on Lunar Bases and Space Activities of the 21st Century,* p. 123. NASA/Johnson Space Center, Houston

Waldron R. W (1985) Total separation and refinement of lunar soils by the HF acid leach process. In *Proc. 7th Princeton Space Manufacturing Conf,* pp. 132-149. AIAA, New York

Waldron, R. D. and Criswell, D. R. (1995), Overview of Lunar Industrial Operations, *Proc. of the 12th Symposium on Space Nuclear Power and Propulsion: The Conference on Alternative Power from Space,* AIP Conf. Proc. 324, Part Two: 965-971.

Waldron, R. D. and Criswell, D. R,. (1998)*, Costs of space power and rectennas onEarth,* IAF-98-R.4.03: 5, Melbourne, Australia, (2 October).

Wallace-Crabbe C. (editor) (1980) *The Golden Apples of the Sun: Twentieth Century Australian Poetry.* Melbourne University Press, Melbourne. 243 pp.

Warren P. H., and Rasmussen K. L. (1984) Megaregolith thickness, heat flow, and the bulk composition of the moon (abstract). In *Papers Presented to the Conference on the origin of the Moon,* p. 18. Lunar and Planetary Institute, Houston.

Warren P. H. and Wasson J. T (1979) The origin of KREEP. *Rev. Geophys. Space Phys., 17,* 73-88.

Watson A. A. (1975) Energy spectrum and mass composition of cosmic ray nuclei from 1012 to 1020 eV In *Origin of Cosmic Rays (J.* L Osborne and A. W. Wolfendale, eds.), pp. 61-96. Reidel, Dordrecht.

Watson K., Murray B.C. and Brown H., (1961) The behavior of volatiles on the lunar surface. *J. Geophys Rev, 66,* 3033-3045.

Watts, C. B., "The Marginal Zone of the Moon," Astron. Papers Amer. Ephem., 1963, 17**,** 1-951

Weingartner, S. and Blumenberg, J. (1995), Solar power satellite-life-cycle energy recovery considerations, *Acta Astronautica,* 35, No. 9-11: 591-599.

Weissmann P. P, (1982) Terrestrial impact rates for long and short-period comets. *Geol. Soc. Am. Spec. Pap.* 190,15-24.

Wemer M., Gold, and Hanvit G. (1967) On the detection of water on the Moon. *Planet. Space Sci., 15,* 771774.Wetherill G. W (1975) Late heavy bombardment of the moon and the terrestrial planets. *Proc. Lunar Sci. conf. 6th,* pp. 1539-1561.

Wetherill G. W and Shoemaker E. M. (1982) Collision of astronomically observable bodies with the Earth. Geol. S*oc. Am. Spec. Pap. 190,1*l- 14.

Whitaker E. A. (1972) Lunar color boundaries and their relationship to topographic features. *Moon, 4,* 348- 355.

Whitaker, Ewen A., Mapping and Naming the Moon: A History of Lunar Cartography and Nomenclature. Cambridge University Press, 1999. ISBN: 0-521-62248-4

White David C. and Peter Hirsch, Microbial Extraction of Hydrogen from Lunar Dust, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 591 - 602

Whitford-Stark J. L. and Head J. W. (1977) The Procellarum volcanic complexes: Contrasting styles of volcanism. *Proc. Lunar Sci. Conf. 8th,* pp. 2705-2724.

Whitmire D. P. and Jackson A. A. (1984) Are periodic mass extinctions driven by distant solar companion? *Nature, 308,* 713-715.

Wilhelms D. E. (1968) Geologic map of the Mare Vaporum quadrangle of the Moon. *U. S. Geol. Survey Misc. Geol. Inv. Map I-54&*

Wilhelms D. E. and McCauley J. E (1971) Geologic map of the nearside of the Moon. U *S. Geol. Survey Misc. Inv. Map I-703.*

Wilhelms D. E. (1984) Moon. in *The Geology of the Terrestrial Planets* (M. H. Carr, ed.), pp. 107-205. NASA SP-469. NASA, Washington, D.C.

Wilhelms D. E., Unmanned Spaceflights Needed as Scientific Preparation for a Manned Lunar Base, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 245 – 252

Wilhelms D. E. (1985) The geologic history of the Moon. U *S. Geol. Survey Prof. Paper 134*.

Wilhelms, Don E. *To A Rocky Moon: A Geologist's History of the Moon*, University of Arizona Press, 1993

Willard P, J. and Hjelmstad K. E. (1971) Effect of moisture and temperature on the fracture morphology of dacite. *Internat. Rock Mech. Min. Sci., 8,* 529-539.

Williams R. J. and Erstfeld T. E. (1979) High Temperature Electrolyte Recovery of oxygen from Gaseous Effluents from the Carbo-chlorination of lunar Anorthite and the Hydrogenation of ilmenite. A Theoretical Study NASA TM-58214, NASA, Washington. 51 pp.

Williams R. J. and Jadwick J. J. (1980*) Handbook of Lunar Material,* NASA Ref Public. 1057, NASA, Washington, 120 pp.

Williams R. J., McKay D. S., Giles D., and Bunch T. E. (1979) Mining and beneficiation of lunar ores. In *Space Resources and Space Settlements* U. Billingham, W Gilbreath, B. O'Leary, and B. Gosset, eds.), pp 275-288. NASA SP-428, NASA, Washington.

Williams R. J. and Hubbard N. (1981) *Report of Wbrkshop on Methodology for Evaluating Potential Lunar Resource Site* NASA TM-58235. NASA, Washington 120 pp.

Williams R. J. and Mullins 0. (1983) Enhanced production of water from ilmenite: An experimental test o a concept for producing lunar oxygen (abstract). In *Lunar and Planetary Science* XIV pp. 34-35. Lunar and Planetary Institute, Houston.

Williams Richard J., Oxygen Extraction from Lunar Materials: An Experimental Test of an Ilmenite Reduction Process, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 551 – 558

Woo W. G., Bensko J., Lindelof L, and Paone J. (I 967) A lunar drill concept. In *The Industrial Diamond Revolution,* pp. 257-274. Ind. Diamond Assn. of America, Chicago.

Wolfe, Bailey, Lucchitta, Muehlberger, Scott, Sutton, and Wilshire, *Geologic Investigation of the Taurus-Littrow Valley: Apollo 17 Landing Site* U.S. Geological Survey Professional Paper 1080

Wolff, Richard, The Moon. Tyndale House Publishers, 1969. Lib. Cong. 71-86226

Wood J. A. (1975) Lunar petrogenesis in a well-stirred magma ocean. *Proc. Lunar Sci. Conf. 6th,* pp. 1087- 1102.

Wood J. A. (1975) The Moon. *Sci. Amer., 233,* 93-102.

Wood, L., Ishikawa, M., and Hyde, R. (1998), Global warming and nuclear power, UCRL-JSC 1 31306 (preprint), Workshop on Innovative Energy Systems and C02 stabilization, Aspen, (July 14-24), 20 pp.

Woodcock Gordon P., Mission and Operations Modes for Lunar Basing in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 111 – 124

Woolum D. S. and Bumett D. S. (1974) In-situ measurement of the rate of 235-U fission induced by lunar neutrons. *Earth Planet Sci. Lett., 21,* 153-163.

Wong L., Buechler G., Downs W, Sjogren W L, Miller P M., and Gottlieb P. (1971) A surface layer representation of the lunar gravity field, *J. Geophys. Re&, 76,* 6220-6236.

Wright, Hamilton et al, to the Moon: A Distillation of the Great Writings From Ancient Legend to Space Exploration. Meredith Press, 1968. Lib. Cong. 68-10622

Wunsch, C. (2000), Moon, tides and climate, *Nature,* 405: 743-744, (15 June).

Yasaka, T., Hanada., T., and Matsuoka, T. (1996), Model of the geosynchronous debris environment, *47th Cong. Intern. Astron. Fed.,* IAF-96-IAA.6.3.08, 9 pp.

Yakobson B.I., and Smalley, R.E.: "Fullerene Nanotubes: C1.000.000 and Beyond," *American Scientist 85,* pp. 324-337, July/August 1997.

Yamamoto Y (1984) Diffusion analysis on the thermal release of tritium from a neutron absorbing material. J. *Nucl. Mat., 120,161-165.*

Yoder C. E. (1981) The free librations of a dissipative moon. *Philos. Trans Roy London, Ser. A, 303,* 327.

Young J. Francis, Concrete and Other Cement-Based Composites for Lunar Base Construction, in: Mendell, W.W., Ed., Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, 1985. ISBN: 0-942-86202-3 pp. 391 – 397

Zubrin, Robert *Entering Space - Creating a Spacefaring Civilization.* 1999 Tarcher / Putnam

WWW Links and Bibliography
(by Apollo Lunar Surface Journal)
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In addition to the web sites and books mentioned here, readers may want to consult a list of NASA History publications, several of which are now available on the World Wide Web. See, also, NASA Histories On-line

Sources of Apollo photos and videos are discussed in the Photos and Video chapter.

Web Sites of Interest

The Apollo Flight Journal will detail all aspects of the Apollo missions not covered in the ALSJ. Editors David Woods and Frank O'Brien Have completed Apollo 15 and are currently working on Apollo 8. Highly recommended.

Kipp Teague's Apollo Archives contains excellent high-resolution images, film clips, and other marvelous material.

The Alan Bean Online Gallery contains scans of all of Alan's artwork.

For those in need of ready arguments to refute claims that the Apollo Landings never happened (the so-called Moon Hoax), the following sites are recommended: Moon Base Clavius, Jim Scotti's Apollo Page, Neil Atkinson's site, and Phill Plait's Bad Astronomy/Apollo Hoax page. All these sites have links to other sources of information.

Ron Monsen has an on-line 3D LM Simulator which is currently undergoing "major systems tests". Windows only, unfortunately. Check out the movie!

Rob Godwin's Mission Reports are important sources of background material and high quality multimedia concerning Apollo and related programs.

Sam Russell was a member of the TV Support Team at NASA's Manned Spacecraft Center (Houston) during Apollo 15 and his website contains some lovely detail.

Karl Dodenhoff's Little Space Museum contains a great deal of marvelous material including equipment drawings and photos and info about space models.

The Lunar and Planetary Institutes webpage Exploring the Moon contains a wealth of information not only on Apollo but on lunar programs before and since.

The Astromaterials Curationwebsite contains a wealth of information about the lunar sample collection.

Dan Durda has created a fascinating site with views of the Apollo landing sites from Earth and then with ever better precision down to the best pan camera frames.

Accurate co-ordinates for the six landing sites are available at the National Space Science Data Center website. I am told that Clementine data is being used to update our knowledge of the shape of the Moon and the co-ordinates of the landing sites will soon change again. Note, also, that the co-ordinates at the NSSDC site do not necessarily agree with those which were determined at in immediate post-mission analysis because of changes in the global lunar grid in the intervening years.

Chuck Maddox has created a detailed site concering Watches worn on or near the moon.

Phill Parker calls our attention to Boeing's webpage for the 30th anniversary of Apollo 11 and, in particular, a collection of Apollo memories written by Boeing employees.

Journal Contributor and Commercial Pilot Gary Neff calls attention to Peter Yost's article NASA's Vomit Comet: Hitchin' a Ride on a Buckin' KC-135

A browser for the Clementine Baseline Mosaic provides access to 100m/pixel maps of the entire Moon.

The Lunar Orbiter Photographic Atlas of the Moon is now available in digital format. The Lunar Orbiter Photographic Atlas of the Moon by Bowker and Hughes (NASA SP-206) is considered the definitive reference manual to the global photographic coverage of the Moon. The images contained within the atlas are excellent for studying lunar morphology because they were obtained at low to moderate Sun angles. This digital archive consists of the complete set of 675 plates contained in Bowker and Hughes. Images in the archive have been enhanced to display the best photo quality possible. For accuracy and usability surface feature information has been improved and updated, and multiple search capabilities added to the database.

A discussion of the role played by NASA's Honeysuckle Creek Receiving Station during Apollo has been compiled by former Deputy Director Mike Dinn; and a detailed account of the role played by the Parkes Radio Observatory, Australia, in the reception of the Apollo 11 TV signal has been compiled by John Sarkissian. Both are recommended. See, also, the October 2000 Australian film "The Dish", which deals with the same material, albeit in a highly fictionalized form. The film takes considerable liberties in characterization, with events at Parkes, and completely ignores the central role of Honeysuckle Creek; but is both funny and moving. Di and I highly recommend it.

The complete collection of paintings by Apollo 12 LMP Alan Bean is now available at the Alan Bean Gallery

Gert-Jan Bartelds calls our attention to John Duncan's Saturn V Reference Page, which contains a great deal of useful information and photographs.

A collection of Apollo Press Kits is now available on-line. **Readers are warned that these are very large pdf files.**

Various technical diagrams and drawings for the Mercury, Gemini, and Apollo Programs are available at a new site at the NASA HQ History Office. Scanning was done by Journal Contributor Kipp Teague.

The Lunar and Planetary Institute's Stereo Atlas of the Solar System includes a number of Apollo stereopairs and other wonderful material. Ordering info for the CD-ROM version is available on the Website.

The Lunar and Planetary Institute's site also contains mission summaries and a superb collection of landing site images.

Mark Wade's Encyclopedia Astronautica contains a detailed description of the Soviet Lunar Programs, among many other things.

David Woods, editor of the Apollo Flight Journal, calls our attention to Eugene Dorr's excellent site dealing with mission patches for Gemini, Apollo, Skylab, and ASTP.

Ulli Lotzmann calls our attention to the USS Hornet Museum, which provides fascinating details about the prime recovery vessel for both Apollo 11 and Apollo 12.

David Sander is building a replica A7LB EMU (Extravehicular Mobility Unit). His site includes photos and links to related sites.

Ry Alford calls our attention to Frank Pullo's Lunar Module Space/Craft Assembly & Test webpage, which contains photos and other useful information about the LM.

Journal Contributor Ken Glover points us to:

A Field Guide to American Spacecraft

NASA Watch

Justin Wigg's Links

Apollo QuickTime VR

Jim Oberg's Page Other space resources can be accessed through the NASA Human Spaceflight webpage.