LIFE SCIENCES AND THE US SPACE PROGRAM: AN ECONOMIC PERSPECTIVE.

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I. THE BASIC GOALS OF THE SPACE PROGRAM

Over the past three decades the US space program has come a long way in establishing a US presence in Space. The major accomplishments are the landing of man on the Moon and his safe return to Earth, the establishment of worldwide communications, and of increasingly frequent and accurate observations for security and civil uses. Other nations have sometimes led, and sometimes followed the US example. Without question, the conquest and dominance of Space is a central theme of the Soviet Space program. The communications and information related applications of Space are a key drive of the Space programs of many other nations. Yet, overriding as some of these accomplishments seem, and are, they miss the basic theme and rational of the drive into Space, the establishment of Earth independent human habitats - the colonization of Space.

(1) Project Earth Independence

One result of the Space effort, possibly the single most important achievement to-date, is the image of Earth suspended like a 'soap bubble' in the void of Space. Indeed it is this image more than anything else that has contributed so importantly to the worldwide awareness of mutual interdependence, vulnerability, and concerns.

Other images from Space have equally contributed to the evidence of the vulnerability of Earth and mankind: the cratered surfaces of the planets and the moons throughout the solar system. Obviously the 'space' around the solar system from time to time traverses `violent' neighborhoods.

In addition, as of late, manmade actions have the potential of bringing devastating world wide changes, either in the environment or through large scale nuclear war. The assured survival of civilization demands the establishment of Earth - independent communities, with the knowledge, know-how, and culture and historical awareness of man's origin and destination, an archive of man's achievements to-date, and the assurance of the continuation of this quest.

Civilizations of other times invested inordinately larger part of their wealth for less:

* the pyramids, for the assurance of the immortality of a single ruler or dynasty;

* the cathedrals of the Middle Ages for the celebration of the glory of Christianity mostly financed by local cities over many centuries (the cathedral of Cologne was built over 400 years);

* the Great Wall of China to provide for the defense of the first empire and simultaneously to rid the Chin dynasty of competing warlords and aspiring families;

* the libraries of Hammurabi (100,000 clay tablets), the library of Alexandria (burned to the ground, holding most of the

knowledge of the Old Ages), the libraries of the Middle Ages at the monasteries, the Library of Congress.

As a percentage of 'GNP' some of these efforts took anywhere from 15 to 25%, sometimes 50% and more of the total activities of those societies.

Can the United States do less, given the magnitude of the opportunity? Did generations in the past have more vision and drive than today's generation, for less encompassing goals?

(2) The Next 50 Years Of Manned Space Flight

The overall goals of the US space effort for the next 50 years have been set out in the Paine Commission report. The major milestones outlined in that report are shown in Figure 1. The goals include in addition to the Space Station a manned lunar outpost before 2005, a lunar Space port before 2015, a manned Mars outpost by 2015 and a full Mars base - permanently manned - before 2030.

II. POSITIVE ACHIEVEMENTS OF SPACE TO-DATE.

The achievements in Space enterprise to-date are several, very significant contributions to the well being of all of us. Among the contributions one can list

(1) The '<u>Global Awareness</u>' of today. Probably the single most important economic - and other - contribution Space has made is the image of the Earth rising above the moon. This has driven one message home: Earth is an extremely vulnerable "soap bubble" ready to "burst" at any moment. The fact that today indeed global discussions take place on the environment, the economies, on information, on military and national security issues, and in many other areas, can be attributed foremost to that one image taken on the moon by man. What to economists was but an abstract notion - the worldwide interdependence of economic systems in open world trade - is shown here in one simple picture. That one image may well justify the Space program and all the costs sunk into it to-date, and in years to come.

(2) The second major benefit of the Space program has been the <u>Stability</u> brought about in international strategic relations, thanks to information gathered independently from Space by the major powers. One should not rewrite or reinvent history. But the outbreak of wars, global wars, strategic wars in this century, can be attributed first and foremost to a lack of information, the uncertainty as to the intentions of the major adversaries, e.g. at the eve of World War I.

The likelihood of any large scale, major strategic conflict for the rest of this century may well be zero. The key reason for this changed state of affairs are the data provided from Space and the information this provides: independent, verifiable data. That has been, and will continue to be the second largest benefit of Space for the United States and for mankind.

(3) Ranked third in terms of significance of benefits from Space activities are <u>Global Communications</u>. The world today is so radically different from the world of the 1950s

because of instant, global Space communications: While other means of communications now exist, the fact that today we are a worldwide, instant information society is due largely to Space communications, and the commercial approach to Space communications at that. It is the only area where we chose the commercial route, with the creation of Comsat in 1962 and later Intelsat. Even the Soviet Union has now applied for membership in this most commercial of all international organizations.

The benefits of Space communications are "radical", widespread, and taken for granted today. But they are there nevertheless. To quantify these benefits would take some doing, but by any measure these benefits are enormous and pervasive.

III. CONSTRAINTS TO EXPANDED SPACE ACTIVITIES.

Yet, despite these vast benefits of Space today we are grounded, thanks to government failures and inactions. For some years in the 1980s the US could not launch; even with operational launch vehicles, one could not get insurance; one cannot pursue Space observations, because of the 1984 Landsat Remote Sensing 'Commercialization Act', which disallows private property rights to original Space data, even if privately funded (Title 4 of that act), makes such pursuits unprofitable.

And finally, if one were to reach the Moon again, or any other celestial body, one could not take possession of the resources there, so why go to the Moon and beyond under the UN Outer Space Treaty?

From this an entrepreneur reaching Space must conclude like Madame Sand upon reaching California: "There is no there there".

From this one must, reluctantly, conclude that serious constraints have been imposed on the commercial and beneficial uses of Space and private enterprise. These constraints have to be removed, if Space is to become a new frontier for enterprise.

In addition to the statutory and bureaucratic constraints, there are other, real economic constraints - i.e. costs - that hinder the full development of Space. These are:

(1) <u>Transportation Costs</u>. Space transportation costs are real, and they are high. The vision in the early 1970s of a fully reusable Space transportation system is still there to be fulfilled. Today we only have a partially reusable Space shuttle, once it is allowed to operate again. We never developed a reusable upper stage as recommended in 1972. We do not have a fully operational space transportation system. A Shuttle launch today still is an individually engineered, handcrafted event. We have to get from here to where we thought we would be getting in the early 1970s to achieve a low-cost, reusable space transportation capability.

Radical advances may be possible in Space transportation, indeed are needed in the decades ahead, possibly based on some of the technology breakthroughs and advances envisioned in kinetic and directed energy technologies envisioned by the Strategic Defense Initiative. Laser propulsion may at some time in the future allow ISPs of 2000 or more and thereby bring about radically lower Space transportation costs. In the meantime, gravity does exist and we can not wish it away. Transportation costs will put a severe limit on Space enterprise - and on how far we ever will go in Space for economic benefits on Earth.

(2) <u>Interest</u>. Just as physicists cannot do away with gravity, economists can not do away with the cost of time - interest. This cost of time - or the cost of the use of capital - is a truly universal cost inherent to any civilization, wherever that civilization may be.

While there may come the day of "anti-gravity" technologies speculated about in science fiction and advanced courses in theoretical physics, the cost of capital is an immutable fact - similar to the second law of thermodynamics. Any civilization has interest costs - there is a cost to time. The more innovative a civilization, theá higher this cost. Interest is the "economic gravity well" out of which there is no escape, and which will limit very far flung uses of resources even within our solar system, and certainly beyond that.

For example, going to Mars and back over a three year period in a $1 billion spacecraft with three astronauts will impose an interest cost of about $300 million, or $100 million per astronaut. This cost exists, whether it is explicitly paid for or whether it is born by taxpayers. One cannot do away with this cost, even if anti-gravity machines existed. As long as it takes time to go from here to there and back, interest costs exists and are a serious obstacle to the economic uses of resources that travel at less than the speed of light. (Two such commodities exist - information and solar energy
- and these are discussed below).

(3) <u>Demand</u>. Demand is a "constraint" to the uses of Space resources on Earth. What I mean by that is that the Earth is abundant in most mineral resources. If we had today, say, a huge asteroid of pure platinum to be landed at Edwards Air Force Base, it certainly is not likely to have paid for the costs of the mission to capture and recover such an asteroid: the first, and probably only, thing that would happen is that the prospect of a successful landing of such a massive asteroid would lead to a total collapse of the platinum prize on the Chicago Commodities Exchange, down to about zero.

The economics of the uses of lunar or other celestial mineral resources is seriously limited, even at zero transportation cost: demand for most commodities is at most "unit elastic", meaning that one spends about the same budget on that commodity, irrespective of price. That is true for wheat, for food crops, and it is also true for mineral resources. The `Club of Rome` of the 1960s was wrong, the market was right.

The world today is overabundant in resources. Anybody who doubts that should call the Chicago Commodities Exchange and ask what happened to the prices of resources - wheat, barley, oil, energy since the

1970s. To add abundance to abundance makes little sense.

IV. ECONOMIC BENEFITS OF SPACE ACTIVITIES.

Given these serious constraints - and real costs - to Space enterprise, there are nevertheless also important, very basic benefits to such enterprise which amply justify our Space activities. Among the basic benefits I would list

(1) The Survival of Man: Extending Man's Presence beyond Earth. As mentioned earlier, the images of Earth from Space, and of the inner and outer solar system, have shown that the solar system is an extremely violent place. Sitting ion this "soap bubble" Earth, mankind has a duty to get off Earth and learn how to live and sustain itself outside this Earth. This is a true "Project Independence", or project survival. Mankind has to pursue manned Space flight. It is a historical, existentialist duty of our generation, and those to come.

This exploration will take place with or without the United States. If the US were not to pursue manned Space exploration the Russians will, and the Japanese, and the Chinese, and of course the Europeans. The US has no choice, even if the US wanted to. But the United States will go out there again, and the reason for that is survival, that of the United States and mankind's. Related to survival and the need to go into Space is another factor: today, for the first time the world is "closed", i.e. the known Earth is a closed world for the first time in history. Columbus set out for the unknown. Others set out for the unknown, some as recently as the early part of this century. Even in the 1950s the atlases of the world contained "white spots" of unknown, unexplored territories. These spots have disappeared today, there are no "white spots" of unknown territories left on Earth today. It is impossible for mankind to live in such a closed world for long - a zero sum world. Mankind needs open frontiers, the challenge of the unknown, which means man has to go into Space. These are not abstract notions; these are real, indeed the primary reasons for going into Space. The Space Station may not make much economic sense otherwise, but manned Space exploration is reason enough for this pursuit.

(2) The High Ground for National Security. For the past 25 years Space already has made significant contributions to the stability of strategic relations (see above). More importantly, we now do have the President's Strategic Defense Initiativeá (SDI), which holds the promise to liberate the United States and mankind from the unhealthy current situation of mutually assured destruction (MAD). MAD is a new, unhealthy condition of mankind. The moral equivalence it implies - in Europe and elsewhere - between the Soviet Union and the United States is obnoxious, to say the least. One has to get away from this confrontation, this nightmare, the currently very unstable "stability". SDI holds that promise. This indeed is a benefit of Space.

Now, beyond these basic benefits, possibly transcendental benefits to some, let me come to the more immediate, pecuniary, economic paybacks we may expect from

Space in the decades to come. Given the above real constraints - leaving the issues of principles aside, these are transportation costs and the cost of time - there will be two major benefit areas from Space activities: information and energy. Both commodities can be transmitted at low added cost and essentially at the speed of light. Both commodities meet the principle cost obstacles to the uses of Space just listed.

(3) The Information Economy. The payback from Space in the next decades will not be from Space processing or from natural resource uses of Space on Earth as envisioned by some. The high cost of transport of these massive commodities alone will prevent such large scale uses. The one immediate area that has and will 'pay back' in multiples is Space based information - communications, remote sensing, worldwide data bases and information management. Today's economies are information economies. In the United States, of the $4 trillion or so of GNP, about $2 trillion can be related to informational activities: the garnering of information, the creation of information, the storage and distribution of information, passing on information from one generation to the next.

Furthermore, and often overlooked, is the information content of products: an airplane today - in terms of manpower and materials expended on its design and construction - is mostly "information": CAD/CAM, avionics systems, fly by wire technologies, air traffic control systems, scheduling and operations of the aircraft etc. This is true for many other products as well.

Communications satellites of today are just the beginning. One has today the capability to commit the US to putting all the information contained in the Library of Congress "into orbit" and make this information accessible to all mankind worldwide through small, portable terminals, without any intervening controls or groundbased network 'interfaces'. This would require two or three large platforms in geo-synchronous orbit. The Library of Congress comprises about 80 trillion bits of data in all the books and documents stored there.

Such "Information Platforms" will be the end of the control of information, the control of societies, where governments often deny access to information to their own people. Such "Information Platforms" are in my mind among the most revolutionary, new frontiers, that still remain to be conquered. Such "Information Platforms would also go a long way to assure the "survival" of man's knowledge, should indeed a major nuclear war ever destroy the main repositories of man's knowledge today, which are few indeed.

Instead of pursuing such ideas and technologies, the US has cut back - indeed eliminated - any such NASA communications R&D.

(4) Energy. The other major payback from Space - not in the next decade, but certainly in the next century - will be the collection of solar energy in Space and its transmission to Earth to provide for mankind's energy needs. The reason for

this, once more, is that energy once garnered can be transmitted at low additional cost and essentially at the speed of light, the two necessary attributes for any large scale economic uses of Space. And again the US has managed to terminate all R&D into this potential in the United States: A National Research Council committee concluded in the late 1970s that the US should not even do research on the Solar Power Satellite (SPS). Some dissented, but that did not change the conclusion of that illustrious committee.

The potential for solar energy collected in Space is vast: the incidence of solar energy at Earth orbit is 1.3 KW per square meter! The "disk" described by the Earth in Space has incident solar energy at one AU and over ten days equivalent to the total known and speculated about fossil fuel resources accumulated on Earth over millions and millions of years. All fossil energy resources are equivalent to but ten days of solar energy that passes through a circle with about 5,000 miles in diameter.

If one were to put such a disk closer to the Sun, say at the distance of Mercury, that energy equivalent disk would "shrink" to 3,200 miles, roughly the distance from Bar Harbor, Maine, to San Diego, California, with a total area equivalent to that of the Soviet Union. In one day more energy passes through that disk than the energy needed by all mankind to put it on the same per capita energy availability as that enjoyed by Europe.

Instead today one has an insurmountable contradiction: we say that we want all mankind to have "our" standard of living, i.e. 5 billion people. At the average European energy consumption, i.e. much less than in the United States, that would mean 40 billion tons of coal equivalent energy consumption per year. Nobody can do that on Earth, even if the fossil resources were available, which of course they are not. And even if they were available, the environment would not allow such use.

V. LIFE SCIENCES AND THE FUTURE OF THE US SPACE PROGRAM.

The achievement of these goals is not a foregone conclusion. The funding of the necessary technical development programs aside, serious bottlenecks, possibly even showstoppers, exist to extended manned Space flight. The key areas of concern must include:

effect of micro-gravity on the human body

the cardiovascular system

the muscle and bone structure

the metabolism

psychological and psychiatric effects

mental functions and effectiveness

the effect of radiation:

solar flares

heavy particle radiation

general background radiation

the effect of isolation

psychological

psychiatric

mental and physical effectiveness

The establishment of an Earth independent habitat is possible on free flying Space stations, on the Moon, and to establish the ability of man to expand throughout the solar system, a habitat on Mars.

The ability to reach the Moon and to return has been proven by Apollo. The 'transit time' is a few days, and the effects of heavy particle radiation have been sustained by the astronauts without apparent long lasting damage (outside the Van Allen belt).

The ability to sustain extended manned flight in low Earth orbit has been established by the Russians up to 9 months, with apparent recovery of its astronauts from the effects of such extended stays.

Beyond these accomplishments to-date the following three key questions for extended manned Space flight need to be answered:

how long can man live in micro-gravity beyond the 9 months proven to-date?

how long can man sustain flight in the radiation environment beyond the Van Allen belt, i.e. heavy particle radiation and solar flares?

what are the means and costs of achieving these extended flight capabilities, if they can be achieved at all?

It is important to keep in mind the difference between extended stay-times below the Van Allen belt, important for manned Space flight operations around Earth, and the ability of man for extended Space flight in the 'dirty' radiation environment beyond the Van Allen belt.

The thresholds for lunar flights have been demonstrated by the Apollo program; the thresholds for geostationary platforms, short and long excursion flights to Mars remain to be ádemonstrated, indeed are the key outstanding questions of the US Space program - and that of any other nation to be answered in the next decade, and the next 50 years. The answers to these questions derived from an aggressive life sciences program importantly bear on the basic feasibility of some of the contemplated missions, the enabling of such missions in some cases, and the possible requirement of totally different systems technologies in case very rapid transition times are required.

The answers to the questions raised are neither intuitive, nor obvious, nor really based on any substantive, factual knowledge to support the generally held believe or assumption, that the mere technical means of going to Mars and to return will suffice - with manned survival or effectiveness subsumed rather than proven.

In fact, until proven otherwise, one has to assume - based on the available evidence - that manned flight to Mars is not possible, either with chemical propulsion systems or high ISP systems such as nuclear or laser systems.

Hence a Life Sciences program build around these key questions and concerns is the core program of NASA, without which the agency can not proceed beyond the next decade - and low Earth orbit or the Moon.

(3) THE INTERMEDIATE STEPS:

Space Shuttle Stay Time
1 week, 2 weeks, 4 weeks

Space Station Stay Times
1 month, 3 months, 9 months, 24 months

Manned Orbital Maneuvering Vehicle
To Geosynchronous Orbits
To Lunar Orbits
Excursion Times: Days, Weeks, Months

Manned Geosynchronous Platforms: Beyond The Van Allen Belt

Permanently Manned Lunar Base
Above Ground, Underground

Missions To Mars

Flybys
18 months to 24 months: low ISP 12 months or less: high ISP

Lander Missions

excursions: 18 months to 3 years
permanent bases: with crew rotation
self-supporting colony

Cycling Spaceships

A Possible Answer To Heavy Particle Radiation

Life Support

(4) Methodology.

(4.1) Define Baseline Missions

1.1 Space Shuttle

1.2 Space Station

1.3 Lunar Base

1.4 Mars Base
1.4.1 Mars Flyby
1.4.2 Mars Sprint Mission
1.4.3 Mars Manned Base

Given the outlook given in the introduction, and the express goals of the Space Commission, the OVERALL BASELINE must be considered to be the establishment of a permanently manned Mars Base within the next 50 Years.

The requirements on the worst possible assumption basis can be reasonably speculated about, including:

* extensive shielding against solar storms

* extensive shielding against heavy particle radiation - in part enabling research may be required, such as very powerful electromagnetic shields equivalent to the protection provided by the Van Allen belt;

* extensive gravity generation for long duration Space missions;

* minimal uses of man in Space flight missions, essentially limited to survival in transition; severe psychological, psychiatric, cardiovascular, other bio-medical limitations;

* chemical propulsion only;

* one time use of flight crews only;

* mitigated by unlimited stay time on Mars.

Crude, rudimentary, baseline system requirements can be developed and derived from the above most unfavorable assumptions. It may also result that without enabling R&D breakthroughs, Mars missions of the type contemplated by the Space Commission and by NASA are not possible. E.g. heavy particle radiation shielding by conventional means may not be feasible, making in some cases the problem worse than the heavy particle radiation to begin with ("Billiard Ball effects").

The shielding through powerful electro-magnetic fields, an area in which the Soviets reportedly show considerable interest, may first require breakthroughs in material sciences such as superconducting materials, energy storage, transmission, etc. not yet within known state of the art.

The physiological effects of long duration Space flight may be such as to require continuous artificial gravity of close to 1g, which in turn may cause other bio-medical effects, e.g. through coriolis force effects.

Questions of psychological stability, composition and number of crews, skills of crews as to self-supporting "autark" support services capabilities - including rudimentary medical and surgical skills are unanswerable to-day.

(4.2) Enabling, Trade-off and Optimization Studies.

Once the Baseline Mission and requirements have been defined, a whole host of analysis tools can be used to investigate the relative effectiveness, scale and 'paybacks' of the life sciences R&D program and its constituent components.

A comprehensive PERT type planning scenario tracing the various interconnections and dependencies between the projects, programs and interim milestones can be sketched out and updated.

4.2.1 Definition of Baselines.

Cost analyses, risk analyses, estimates of possible timing requirements, choices of alternative systems technologies, and interconnections between projects on the Space Shuttle, the Space Station, and Lunar Bases with and to the Mars mission can be established. However, to apply the various analytic techniques, it is important to establish a reasonable Baseline (1) Overall for the basic goal of NASA with regard to Mars missions and their timing and (2) for each of the major programmatic milestones - the Space Shuttle, the Space Station, Manned OMVs, Manned Geostations, Lunar Bases, Mars "Sprint Missions" and Mars Permanent Settlements.

The Baseline in each case should reflect the most conservative assumptions based on existing technology and knowledge, with the missions carried out in the most rudimentary and "state of the art" worst case scenarios. The defined Baselines should be well within the Space Commission Study Goals, and more recent specific goals set by NASA.

4.2.2 The four Dimensions of the Life Sciences R&D Program.

The basic manned systems considered have certain "clusters" of requirements, all revolving around "staytime" of the crew. The critical "dimensions" pushed by the life sciences program include:

* micro-gravity effects

* radiation effects

* autonomy/degree of regeneration/self-sufficiency/robustness

* habitability/psychological/sociological issues

In combination these dimensions determine the maximum duration of manned Space flight and the productivity (research, work) of the crew.

A qualitative difference exists between manned activities below and above the Van Allen Belt (see South Atlantic Anomaly for starters);

The "clusters" are the duration of the missions: up to three months proven by Skylab, sufficient for near Earth excursion missions and lunar travel; up to 12 months for lunar oráSpace Station basing; and 2 - 3 years for chemically propelled Mars excursion missions.

A sample effectiveness impact analysis of different crew stay-time capabilities is shown in the enclosed figures. Each of the critical life-sciences parameters can be examined, alone or in combination with other factors, to weigh the relative importance of added capabilities of crew stay-time and effectiveness.

Two basic "times" are involved:

(1) physical stay-time

(2) productive time.

The health and safety of crew requirements of long duration Space flight outside the Van Allen belt will have dramatic cost effects on missions, their risks, and their accomplishments.

Significant feedbacks to basic technology requirements will result from such an inspired life sciences analysis program, including Space Transportation systems requirements. In the most rudimentary sense, further experience and bio-medical research may show that manned Space flight can safely be extended only to say 12 months. In this case clearly high ISP Space transportation technology is required.

Similarly, if protection against heavy particle radiation can not be provided other than through powerful electro-magnetic shielding, then an intensive enabling research program in materials and a host of other technologies is required NOW, if the schedules and goals outlined for the US are to be attained at all.

On the positive side, intensive life sciences research may show that with further advances in bio-medical sciences and the better understanding of the human body and mind, long duration Space flight may be just as routine and exciting as car and rail travel.

Let us not forget, that the most dire predictions were made as to the health and mental effects of "high speed" rail travel of, say, 25 miles an hour.

To-day we simply do not know. It is the central purpose of the life sciences program to provide and advance answers in this field - with important bearing on the overall cost and economic feasibility of the BASELINE mission to Mars over the next 50 years. The stakes for the United States - and the Western World are enormous.

(4.3) A Possible Showstopper: HZE.

Micro-gravity, solar flares, psychological problems all seem to be amenable - within limits - to countermeasures. The effect of galactic cosmic radiation has been somewhat neglected - possibly for two reasons:

* the doses received to-date in 14 day or shorter missions beyond the Van Allen belt are relatively minor;

* there is little one can do to shield against such radiation.

Heavy particle radiation destroys existing cells of the central nervous system. On lunar missions impacts of such heavy particle radiation on the optical nerves of astronauts led to `light flashes' in astronauts' brains and to different degrees of irritation. Each of these `hits' took with it a few thousand neurons. Over longer duration Space flights these destructive effects can lead to a subtle but progressive loss of judgment, memory, coordination, and ultimately leading to dementia. William M. DeCampli, "The limits of Manned Space Flight", 1986).

(4.4) Questions of Effectiveness.

Issues of overall mission feasibility aside, a vigorous life sciences program will shed important light on the effectiveness of manned operations in Earth orbit, lunar missions and long duration Space flights to Mars.

Key questions that can be answered by the Space Station and by long duration Space Shuttle flights are issues related to the endurance and effectiveness of manual labor, judgment and improvisation in Space flight and Space construction.

Clearly the ability to assemble large structures in LEO or GEO has important bearing on the technology and even basic capabilities in Space, e.g. the assembly of large structures for use in LEO or GEO. A host of exciting and potentially large-scale capabilities with tremendous economic paybacks may be enabled by efficient manned assembly operations, maintenance, recovery, and updating of Space based assets. However, today we do not know the degree to which man can be used to perform such functions reliably and efficiently.

(5) A First Order Sketch of Interdependence of Programmatic Milestones, Life Science Issues and Program Costs and Risks.

(5.1) Space Flight Mission Times:

5.1.1 Space Shuttle: 1 week, 2 weeks, 4 weeks;

5.1.2 Space Station: 3 months, 9 months, 12 months, 36 months;

5.1.3 OMVs: 1 week, 4 weeks, 3 months;

5.1.4 Space Flight "beyond the Van Allen Belt": 1 month, 12 months, 36 months;

(5.2) Autark Systems for above Periods:

5.2.1 Life Support

5.2.2 Energy

5.2.3 Ecological (environmental)

5.2.4 Agriculture/Regenerative Systems

5.2.5 Mechanical Redundancies and Recuperative Capabilities

(5.3) Physiological

5.3.1 Cardiovascular issues

5.3.2 Bone Structure/Strength

5.3.3 Muscle & other Organs

5.3.4 Brain Functions

(5.4) Psychiatric & Sociological

5.4.1 Long Term Isolation effects

5.4.2 Small Space/Confinement effects

5.4.3 Minimum Group Size for long term stability

5.4.4 Telepresence, Gaming, Information

(5.5) Radiation Issues

5.5.1 Solar Flares

5.5.2 General Background Radiation

5.5.3 Heavy Particle Radiation

(5.6) Countermeasures/ by Issue

5.6.1 Electro-magnetic Shielding

5.6.2 High ISP/Short Trip Times

5.6.3 Exercise Programs

5.6.4 Drug Therapy

5.6.5 Sleep/Suspended Animation

5.6.6 Operational Efficiency Issues

6.0 The MILESTONE Scenarios

6.1 Space Shuttle based

6.2 Space Station based

6.3 ISF based

6.4 Bio-Platforms

6.5 Lunar Base

6.6 Mars Fly-by

6.7 Mars Base

7.0 The Lunar Imperative.

* for same overall funding as for Space station US can operate Moonbase with 8 people;

* number of HLV flights per year about six (vs. 5 to six Shuttle flights for Space Station ops);

* many of the technology elements of Space Station can be used for Lunar Base;

* Lunar Base can be grown beyond initial 8 people at

substantially lower incremental costs;

* Moon has 1/6 g environment, much better than zero g;

* lunar resources of use in increasing autonomy of Space operations, as well as support functions for missions beyond cis-lunar space;

* take possession of key lunar resources for US use;
# water, if any, or hydrogen;
# caves for living and storage space;
# polar regions for solar energy plant locations;
# back side of moon for key scientific bases, and defense;
* transportation node;

* control of access to Space;

* the "rock of Gibraltar" to the sea of space.

* for asteroidal and other celestial resource accumulation - rather than Earth (1/6 g);

* energy sector, agricultural sector, health sector, lox plant(s), H-storage, telepresence and robotics test bed;

* large scale interferometry;

* control and servicing of geosynchronous Space;

Von Thuenen Space economics!! Information and energy!!

CELLS:

(1) The Benefits of establishing "Earth Independent" Civilizations (Assurance of Survival)

(2) The Benefits to the Space Program (See above)

(3) The Benefits of "Cells" Technology to Earth!!!

* Understanding Earth's Environmental Balance

* Minimization of Resource Uses: An Answer to the Population Concerns

* The Impact of self-regulating, sustaining and self repairing, highly reliable, Remote Control or Self-Control Technologies.