ON THE FUTURE OF LUNAR DEVELOPMENT

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1.Introduction

Spaceflight can be considered as a natural, an essential and a logical step of the evolution of the human species. Exploring space, learning to live and work in space, and using its natural resources, will improve the quality of life on Earth and last-not-least enhance the survival chances of our civilization!

Automatic space vehicles are extremely useful in many applications; quite often they are essential. They have now been in operation for more than a decade in near Earth space as well as in interplanetary space; some have even left the solar system. There is no question that they will also be used heavily in the future. However, it must be realized that robots have advantages and limitations. In many cases they must be supplemented by human skills. For many decades in the past, astronauts and cosmonauts have demonstrated their usefulness in laboratories in orbits about the Earth and in exploring the Moon. However, the space activities we are privileged to witness during the present phase of human development, is just the beginning of mastering a new dimension. It must and will go on – the question to answer is only when and how. Options have to be defined, optimised and communicated to the decision makers in order to be ready for when the time comes to take new decisions 3,5,7,9,11,12,22,23.

2. Objectives and Ground rules

No later than after the expected completion of the International Space Station (ISS) the question will have to be answered: SHOULD WE STOP HUMAN EXPLORATION OF SPACE OR WHAT IS NEXT? It appears unlikely that the human exploration of space will be discontinued, because the evolution will not end 11, 12. A logical choice would be returning to the Moon and to establish an International Lunar Laboratory (ILL).

In so doing, the following objectives would be -at least partially – achieved 9, 16, 17:

1. Provide a science laboratory in the unique environment of the Moon for experiments that cannot be conducted on Earth.
2. Improve our knowledge of the Moon and its resources.
3. Improve the understanding of our own planet.
4. Improve our understanding of our solar system and the Universe.
5. Stimulate the development of advanced technology on Earth.
6. Establish the first extraterrestrial human settlement as an initial step for expanding human activities in our solar system beyond our home planet.

7. Produce marketable services and products on the Moon for extraterrestrial or terrestrial use.
8. Demonstrate the potential growth beyond the Earth.
9. Provide a survival shelter in case of global or cosmic catastrophes.
10. Provide reliable space transportation systems to the Moon.

An adequate sized lunar facility, also providing commercial opportunities and growth potential, seems to be an attractive and affordable option for the first half of the 21st century. A detailed model of such a lunar laboratory has the following main characteristics.

Ground rules and representative assumptions for lunar base studies:

1. - This initial lunar installation and the space transportation system supporting this lunar enterprise are government owned. They are financed by public funds through budget allocations of one or several national space agencies. This assumption excludes financing costs and a general profit. However, standard profits for the contractors delivering the hardware and services required, are included. - Leasing of some research facilities to commercial users during the later operational years are envisioned and will reduce the burden on the taxpayers accordingly.

2. - The fully reusable space transportation system serving the lunar installation is designed for growth. It could also be employed in other space projects requiring flights to the low Earth orbit, to the geostationary orbit or other extraterrestrial destinations. It is assumed that the lunar logistics activities require initially most of the available launch capacity and thus accepts the development burden. This is an assumption leading to conservative cost estimates! Additional uses of the space transportation system will lead to considerable savings to the lunar program. This, as always, is a choice of either a limited investment and high operation cost or vice versa, offering in addition growth potential.

3. - The first control variable for sizing these science oriented lunar facilities is the number of laboratory spaces to be provided for experimenters involved in public and commercial research and development activities on the lunar surface. - This parameter starts out with only few working places in the early years growing to about 45, equivalent to 45% of all persons on the Moon, in the 30th year of the life-cycle in the selected scenario.

4.- The second control variable of operating a lunar base is the length of the duty cycle per crew member. It impacts heavily the launch rate of the passenger vehicle serving the lunar facility and thus system cost. The average duty cycle for lunar crew members in this science oriented enterprise is planned to be about nine months. An average duty cycle of six months would increase the passenger transportation cost markedly, but is within the capabilities of the space transportation system proposed, if required.

5. - The third control variable for sizing lunar facilities is the mass of lunar products to be produced annually. - Typically, the production begins in the first year of the life-cycle processing lunar soil at a rate of about 20 metric tons per day growing to about 50 t per day in due course, producing lunar oxygen and some construction materials. The production activity becomes more effective during the life-cycle by increasing utilization rates of the lunar soil input, which grows in this model run from 1.5 percent initially to about 2.5 percent in the 30th year of the operational life-cycle.

6. - Facilities are sized allowing the production of nearly all the oxygen propellants for the lunar landing and launch vehicle (LUBUS) on the Moon. The return propellants of the HLLV payload stage will use Earth propellants to be onboard at launch for reasons for crew safety instead using lunar oxygen, but also in the interest of overall economy. Some liquid oxygen may also to be imported during the first years by tanker flights from the Earth to the lunar orbit service station (LUO-SOC), in case the production of lunar oxygen will not cover all of the requirements in the first two or three years. This assumption is a compromise, adopted with the intent to increase crew safety, not to overload the production facilities, to keep the operation as simple as possible and to keep the cost down.

7.- Hydrogen propellants are delivered from the Earth by the HLLV throughout the entire life-cycle to lunar orbit for refuelling the lunar launch- and landing vehicles(LUBUS) at the lunar orbit space operations centre(LUO-SOC). This is practical and cost-effective as has been found in the system analysis.

8. A space operations facility (LUO-SOC) is employed in lunar orbit for storage of propellants, transfer of cargo and passengers. This space based facility is a modified second stage of the heavy lift launch vehicle(HLLV). It is prepared for its mission in LEO, transferred to LUO by its own propulsion, and will be operational before the first lunar crew arrives at the lunar base site.

3. Typical Lunar Laboratory performance

A typical lunar laboratory based on the ground rules listed above that is to be established in the first half of the 21st century may have the following attributes and/or performance characteristics:

Duration of development period 10 years
Duration of operational life cycle 30 years
Average crew duty cycle 0.75 years
Number of lunar crew members 20 to 100
Accumulative number of lunar labour-years 2,000

Mass of lunar facilities & equipment at end of LC 1,000 t
Average annual imports 88 t
Average annual output mass of lunar products 450 t

The cost of such an enterprise supported by public funds is summarized in the next table. The total program costs add up to 74 billion (1999) U.S. dollar in a 40 year period, less than 2 B $ p.a., and is broken down in table below!

Cost summary of a Lunar Laboratory with a 10 year development phase and a 30 year operational life-cycle - (million 1999 $ at 0.2 million $ per man-year) :

Development & test of lunar facilities-10 year: 9,340
Dev.& test of space transportation system-10year: 18,923
Subtotal development & test - 10 year: 28,263
Sustained engineering STS - 30 year: 4,146
Production of space transportation system(STS): 9,911
Operation of space transportation system(STS): 6,620
Operation lunar facilities: 24,690
Subtotal operations - 30 years operational LC: 45,377
Total Lunar Laboratory System - 40 year life-cycle: 73,630
Specific cost per lunar labour year 38

It is important to notice that these investments for a first lunar laboratory would not be required in the next few years! They would have to be budgeted beginning about ten years from now, with the peak after year 2010. By then, the military expenditures are expected to come down by more than these amounts. This assumption is based on the presently expected geopolitical trends in the foreseeable future.

While there will be an unavoidable peak during the development phase, there is a major decline of annual cost after initial beneficial occupancy of the lunar laboratory. This public financial burden can be further reduced by leasing laboratory spaces on the Moon to interested commercial enterprises and also by selling lunar products at the amount of about 100 tons p.a. to the interested companies or persons. This commercial potential could amount to several hundred million dollars per annum.

In case the lunar space transportation system or elements of it are also employed in other space missions, e.g. planetary exploration, the development burden of the lunar space transportation system for the lunar base will be reduced by 1/3 to 1/2.

4. Conclusions based on results of recent lunar base studies

In the process of analysing and evaluating alternative plans for the next phase of lunar development, several options have been investigated by means of detailed simulation models. These have resulted in annual estimates of the most important system parameters and the system behaviour as a whole. The governing consideration in this analysis can be formulated as follows:

"The primary objective in the process of the evolution of the human species is to develop the access to extraterrestrial resources, beginning with the Moon, to learn to live and work in space, use the resources available and last not least, to establish the first extraterrestrial human settlement."

A representative lunar laboratory development, modestly extending the present state-of-the-art, has been analysed in some detail to obtain a general overview of the costs and benefits involved. A typical scenario would be a go-ahead in the year 2005, a development phase from 2006 to 2015 and beneficial occupancy in 2016 with a 30-year operational life-cycle. A science and technical development oriented lunar base would start out with a crew of less than 20 people. The lunar population would reach a level of about 50 after ten and 100 after 30 years. Various services are offered to users on Earth and pilot plants would experiment with the manufacturing of lunar products. It could be downsized at any time in the operational phase if the expected benefits are not achieved, or upgraded if new developments require such action.

The development and operation of a modest lunar base could be realized in a 40-year period for less than 80 billion (1999) US dollars, if planned carefully and managed by a competent organization. The peak demands of public funds would reach about seven billion dollars annually at the end of the development phase, an amount that is less than one percent of current global military expenditures. The average annual cost over the 40-year life-cycle would be less than two billion dollar, which is merely one percent of the present annual military expenditures of the United States. Form this viewpoint it appears economically feasible even on a national scale, at least for the United States of America.

SUMMARY AND RECOMMENDATIONS:

1. There is no quick and dirty or cheap solution to return to the Moon soon and to accomplish a meaningful activity of lunar exploration to achieve the defined objectives. Establishing a small lunar outpost with a few people and for a limited time does not appear to be an attractive proposition due to its poor cost-effectiveness (> 1 B $ per lunar labour-year) and the high risks involved. Even for the smallest outpost, total expenditures cannot be held below 50 Billion dollars and moreover, most investments would have to go into an infrastructure that is poorly used.

2. Based on present insights and extending modestly the present state-of-the-art, it is possible to develop technically feasible and attractive concepts of returning to the Moon in order to establish semi-permanent or permanent lunar facilities. This would allow the continuation of lunar exploration early in the 21st century at affordable expenditures and an acceptable risk.

3. The required investments appear feasible and affordable if seen in perspective. The big hurdle of a decision to enter a new phase of lunar development is the sizable up-front investment requiring an average of about $ 4 billion (1999) and peaks of up to $ 7 billion for a ten-year period. This investment can not come from private sources, it would probably require the efforts of a group of national governments interested in the exploration and utilization of extraterrestrial resources for the benefit of the present and future generations.

4. It appears quite possible that - after an initial phase - the annual burden to the public for maintaining the operation of this type of a lunar base can - by partially commercialising lunar activities - be held to about one billion dollar which makes this option a very attractive proposition. It would open the door to a development leading to space based solar and/or nuclear energy delivered to the users on Earth and in space.

5. Thus, it is recommended to re-open the discussion of returning to the Moon at the time the International Space Station (ISS) is nearly completed, or even before. After a few years of discussion at the international level an agreement among the participating nations should be possible by the year 2005. Development could begin by 2006 and beneficial occupancy of an initial lunar base should then be possible by the year 2016. This planning effort should include the option to continue this line of exploring and utilizing extraterrestrial resources by expeditions to the planet Mars involving human crews.

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