The High Frontier Vision: 1993 Status and Strategy

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Abstract

This paper reviews the vision for the human breakout into space as contained in O'Neill's classic work, The High Frontier. The status of key technologies and programs needed to open the High Frontier are examined. A suggested strategy for near-term action to attain our long-term goal is presented.

The High Frontier Vision

O'Neill's classic, The High Frontier, outlined a clear vision for human activity in the solar system. Although the basic elements of that vision are well-known to most of us, it is helpful to review the essential components of the vision in order to evaluate our progress towards attaining these goals.

At the time that this work was first published, most of the interest was in the first element of the vision, **human colonies in space**. The notion of large-scale, self-sufficient habitats in free space was a radical departure from the orthodox notion of planetary surface bases which represented, and to a large extent, still represent, mainstream space exploration thinking.

The second principal element of the vision is the concept of **clean energy supply from solar power satellites to the surface of the Earth**. Given the oil shocks of the mid-1970's this is an area that was topical when The High Frontier was published and which has become more important as our thinking about energy and the environment have progressed.

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A third area, and one that is often overlooked, was O'Neill's idea that we could not only prevent further damage to the Earth by using space creatively, but thatwe could **remediate the damage caused by industrialization** as we moved many of the heavy industrial processes required by civilization into space. O'Neill was, as usual, ahead of his time in realizing that civilization requires industry (although the myth of a pure service economy was strong in the 70's.) He showed that the processing of raw materials could take place outside the biosphere where both energy and materials are abundant and where there are no water or atmospheric agents to transport the byproducts to unwanted locales. Further, he suggested that as the Earth's industrial requirements were supported by space industry, that we could begin the process of returning industrial areas of our planet to their pre-industrial, natural state.

To my mind the most important summation of the High Frontier vision is that it offers **hope for the future through overcoming perceived limits to growth**. The essence of this vision is that there is a way out of the imagined 'bottle' of the Earth as a zero-sum game in terms of energy and other resources. In fact, the Earth never has been a closed system, rather it interacts with the space environment which surrounds it. The zero-sum perception still prevails, and it is our duty to dispel this myth.

The means by which we will inhabit space and apply its bounty to the needs of our home planet is through the use of the energy and material resources of space.

Status: Colonies in Space

Our thinking about the large space habitats that characterize The High Frontier has undergone a subtle change since 1977. During the mid-1980's[1] O'Neill began to think about how we could initiate space colonization with habitats much smaller than the Islands One, Two and Three of his articles and books. We had a number of discussions on the essential elements of true space colonies as opposed to space stations and concluded that there were three essential elements that characterize a true space colony. These are:

- Artificial Gravity such that normal human development can take place and one could return to Earth-normal gravity without danger;

- Sufficient radiation protection such that inhabitants could remain in the colony as long as they desired without concern about radiation dosage received;

- A closed cycle life support system providing for the air, water and food requirements of the colonists with only trace element resupply required, if any.

We do not yet have enough information on the gravity requirements of humans in space to address the first of these conditions for a space colony (other than specifying a one-gravity environment.) It may be the case that there is a threshold level of artificial gravity sufficient to meet our requirements which is much less than 1 G but the fact is that as of now, we have almost no data. Experiments to determine the necessary level will be essential to our future progress and we must encourage them.

In the area of radiation, it now appears that there is no safe threshold level under which exposure is not a challenge. The lowest practical level is the best level. In this regard, our space habitats may turn out to be models of the best way to travel within the solar system. One space physician has told me that the only good way to go to Mars safely is to hollow out a small asteroid and take it there! A habitat with shielding made from the by-products of lunar or asteroidal material processing looks like the best bet for long-term space habitation outside of the natural protection of our planet.

One area where there is good initial progress to report is in closed cycle life support. Here, our belief that such systems are possible, is now being proven out by actual hardware experiments. NASA operates some modest scale closed systems. The Russians began a vigorous closed cycle life support system research program in the early 1960's with the strong personal and public support of Korolev. This support began just after the flight of Yuri Gagarin[2] and culminated in the **Bios** facility at the Institute of Biophysics in Krasnoyarsk, Siberia which has maintained two humans for over six months in a state of complete closure in a volume similar to the auditorium which holds our conference. Dr. Gitelson showed films of life in the **Bios** facility at prior Princeton Conference meetings.

The most dramatic example of work in this area is, of course, the Biosphere 2 facility in the high desert, north of Tucson, Arizona. Despite all of the negative and positive hoopla in the press and even within scientific circles, the important fact is that the system *exists* and is working and producing information right now. Gitelson and others believe that the data produced is of critical importance and high scientific value. For example, the oxygen depletion problem, was unexpected and understanding the causative mechanism is of particular importance.

The fact that a group of humans has had to depend on a closed system for a significant amount of time, is psychologically important as well. Although they could always just open the hatch to import food or to abandon the experiment, the fact that they chose to tough out the low food production caused by the cloudiest two years in recorded weather history in the area, makes them true pioneers in my book. I know from electronic mail discussions with the Biospherians that their own thinking about the ramifications of long term habitation in space has changed as the result of their experience and look forward to learning more about their perspectives at the conclusion of the initial two-year closure period later this year.

So we have mixed results in the status of space colonies. We have almost no information on gravity requirements, but are making some progress on radiation and rather good progress on closed cycle life support.

Status: Energy for Earth

Providing clean and abundant energy for the Earth is the most likely economic driver for the human breakout into space. No doubt someday we will see space tourism, and eventually we will create new homelands in space, but the immediate driver is space power.

The idea of solar power satellites is not new. Why then, do we not have more progress in this regard? O'Neill asked a group of utility executives why they were not engaged in looking at solar power satellites despite their interest in his presentation on the subject. They said in effect, "We believe what you say, Professor O'Neill, but you must understand that in our industry, *the only technical risk that we are willing to take is the risk that tomorrow, water might not flow downhill.*"

Of course, the risk that a solar power satellite won't work is just about the same as the risk that gravity won't operate as normal. But there is a difference. The difference is in our experience. We've all experienced gravity and understand at the gut level, how it works. But wireless power transmission is the *one* part of the mix of technologies that we need to open the high frontier which is not part of everyday experience. This fact was driven home to me last year while working on space power with 100 graduate students at the International Space University session in Japan. The students had all seen videos of Bill Brown's historic work in microwave power transmission in the laboratory and at Goldstone. The students 'believed' it in their heads. However, the pivotal event for them was the chance to see and touch a small microwave power beaming demonstration which transmitted power across a small room. When they could touch and manipulate and examine the equipment first hand, then their attitudes changed in a dramatic way.

Our mission must be to removed the perceived risks of wireless power transmission. These perceptions are obstacles just as real as any technical barrier to our goals. Right now, the lack of first hand experience by decision-makers and the general public in wireless power transmission, is a barrier which we must overcome by demonstrations and other techniques.

International Developments

There are a number of positive international developments in the cause of space power. International cooperation is necessary for several reasons. Solar Power Satellites are intrinsically international as has been observed by Glaser, Dickinson[3] and others. A prime example is international frequency allocation for the power beams. Furthermore, by adding the support available around the world, we may achieve the critical mass necessary to advance these programs.

Glaser's paper at this conference refers to the Alaska-21 Project proposal for a ground-to-ground power transmission experiment and demonstration. France is contemplating demonstrations of this type at present. The first would beam perhaps 100 kW of power across a beautiful valley on Reunion Island in the Indian Ocean. This is the French equivalent of Hawaii, and the reasons for using wireless power transmission here would be about 50% esthetic and 50% to avoid a cable which would pose a hazard to aviation.

Our colleagues in Russia are now coming forward with information on their programs of research into space power. Although they had no single, coordinated solar power satellite program, many individual researchers and groups of researches performed valuable work in this area. There is now considerable interest in cooperative projects between the East and the West in this regard. One proposal, for example, involves using the Mir Space Station and the Progress robot freighter for a space to space power experiment. This idea was examined in some detail during the International Space Power Program of the ISU.[4]

Perhaps the greatest international interest in space power at present is in Japan. MITI is apparently committed to the idea of investigating solar power satellites. Just as interesting is a strong commitment to international cooperation in this endeavor. Japan has just succeeded in an important international space test of space power systems.

ISY-METS

ISY METS stands for International Space Year-Microwave Energy Transmission in Space. As a result of our International Space University project, an international invitation was given by ISAS, the Institute of Space and Astronautical Science (in Japan), to ISU and to Texas A&M University's Experimental Engineering Station to build and fly a rectenna in space.

A space-qualified rectenna was constructed in about 30 days for $30,000 US in what must be one of the smallest, cheapest and fastest space experiments in memory. The ISAS-launched mother ship transmitted 832 Watts of power to a daughter ship at an apogee of 220 km. The transmitter employed a solid state FET (Field Effect Transistor) phased array. The phased array design was tested on the ground by mounting it on the roof of a Nissan Pathfinder and beaming power to MILAX, a microwave-powered airplane which flew on August 29, 1992.

METS flew successfully on February 18, 1993 and marks a new era of cooperation in space power. Future joint experiments are now under discussion involving the SFU or Space Free-Flyer Unit which will be launched by the new Japanese H-2 rocket and recovered for re-use by the Space Shuttle. In the very near term, a series of ground to ground tests are planned which will hopefully include international cooperation. These may involve the use of a new microwave powered helicopter platform under development at the University of Alaska Fairbanks with the help of William C. Brown.

We are seeing some good progress recently in space power with the first space hardware experiments now underway.

Status: Space Resources

This is an area in which we have clearly won the battle. When this series of conferences first got underway, the idea of using materials in space for construction and operations was considered ahead of its time, to say the least. Now, however, the space community in the United States, Russia, Western Europe and Japan clearly subscribe to the concept of using nonterrestrial resources for most activities beyond low Earth orbit. In fact, this situation is the inverse of the perception problem of Wireless Power Transmission. In this instance the perception is better than the reality. That is, many people appear to believe that our knowledge of the chemistry of space resource processing is better than it actually is! In fact, great strides have been made in the number and quality of processes necessary for the conversion of lunar or asteroidal materials into the feedstocks for space construction and industry. At our early conferences speakers expressed the hope that we would find at least one technique for lunar material processing. We now find ourselves with an embarrassment of riches and the need to optimize our choices based on hardware experimentation.

Solar System Inventory

The one space resource area where we can obtain tremendous leverage and literally change the universe is in obtaining an inventory of Solar System Resources. Perhaps the single most important fact in our enterprise in 1993 is that our knowledge of the asteroids has changed markedly since 1977. In particular, the recent discovery that Asteroid 1979 VA is actually a 'lost' comet, rich in water, changes our thinking about space resources. The employment of Charge-Coupled Devices (CCD's) with quantum efficiencies better than photographic chemical emulsions is allowing discovery of Near-Earth Asteroids to proceed at an unprecedented rate with 5-10 new objects per month a normal figure.

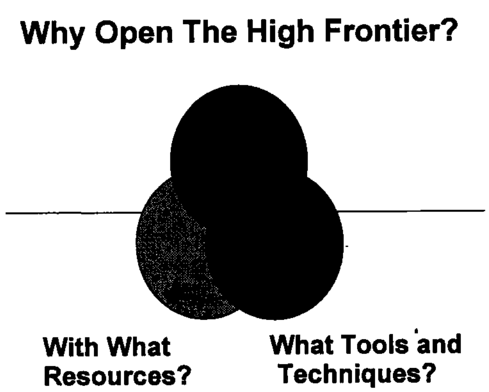
The significance of these discoveries is that we may be able to avoid any high-impulse maneuvers in our quest for space resources, possibly eliminating the need for lunar mass-drivers and the relative difficulty of processing lunar materials is we so choose.

At present, the Moon is easier to use than any known asteroid, but that could easily change if and when asteroids with more favorable orbital elements are discovered.

In short, we need to press for a complete survey of solar system resources including near-Earth asteroids and a complete geochemical map of the moon. This is the most critical task in the space resources area and the one most likely to produce a very large return on investment.

Strategic Questions

It is important for us to take stock as a community, of our basic mission. We need to examine our goals and our strategy for attaining these goals. The following figure shows the domains of three basic questions which we must answer in performing our mission of opening the High Frontier:



We have just examined the question of "what resources shall we use?" Knowing what resources are available is fundamental to our goal because the answer to that question changes the cost of the enterprise and determines what tools we will need to perform our physical work.

Most of SSI's efforts (with the notable exceptions of our Lunar Prospector work and our support for the Spacewatch Camera Telescope) have been in the domain of "What Tools and Techniques shall we use?" We have tended to concentrate in this area mainly because of who we are. As the old saying goes, when what you have is a hammer, problems tend to look like nails. We, as a group like to build things. Looking at the diagram, please notice the horizontal line through the center. The area above the line deals with the "Why do it" question.

This is where the *real* problem lies and hence where the bulk of our efforts should be concentrated. As Dr. O'Neill was fond of observing, the physical problems attendant to opening the High Frontier are not problems of physics but rather of engineering. And even in those areas where the engineering is not crystal clear, the means of getting the answers is generally is clear.

What we *must* do is work on the more difficult task of explaining why we must open the high frontier. This requires the discipline to put aside the easier and often more rewarding laboratory work and to take up the task of educating governments and individuals of the rationale for the High Frontier. This is necessary if we are to obtain the support that it will take to answer the 'What Resources' and 'What Tools' questions.

Changing the Models

How do we explain the rationale for opening the High Frontier? If people internalize the vision of the High Frontier, they will do it; it is sensible and in their best interest to do so. Fundamentally it is a question of changing the models that people carry around in their heads. Examples of changes which we must make to our culture's models about space include the following:

Space as Ocean vs. Space as a Desert

Our culture thinks of space as a void, a barren place. We view space as an ocean, rich in energy and materials resources which can be harvested for the benefit of humanity and our home planet.

Free Space vs. Planetary Surfaces

Isaac Asimov coined the term Planetary Chauvinism to describe the idea that the only useful 'destinations' in space are the surface of planets. Instead, we know that free space itself and the asteroids scattered on the plateau of free space are superior in many respects to planets at the bottom of deep gravity wells.

"The Prize" vs. Science

Many people believe that space exploration is about science. We believe that the resources of space and the benefits that those resources can bring to our people and our planet are the real prize (in the sense of Yergin's recent excellent book on the history and politics of oil entitled The Prize.)

New World vs. "Little America"

When most of the world dreams about human activity in space they picture a few elite astronauts inhabiting a space station or lunar base which operates in the style of Little America or one of the other Antarctic research stations. By contrast, we see space as the equivalent of America in its relationship to the Old World-a place of unlimited opportunity.

These modes are not merely semantics. Their parameters determine who gets the money that our society is willing to expend on space. Tom Rogers has conducted survey research which suggests that the absolute amount of money which the United States spends is unlikely to change by more than a few percent. That is, it is unlikely to be twice as large (or half as large) as it is today.

We must compete for an appropriate share of these resources and this competition is based, in large part upon the perceived utility of programs and ideas. We must face the fact that our ideas are not currently on the national or international agenda. Further we must have the discipline to understand that performing technological work alone is insufficient to further our cause since the real barrier is not technology but at present, ideology.

If we face these real issues, we will win the resources necessary to solve the technical problems which we enjoy tackling.

Lindbergh, Columbus and the Breakout List

We should be mindful that the talents of many in our community do lie primarily in the technical realm. What technical projects should be undertaken? Are there some which promise large changes in the way that people perceive space?

Charles Lindbergh provides an example of a person who dramatically changed the way people thought about aviation with a small-scale effort. Lindbergh knew that aviation engine technology had progressed to the point where an attempt at the Ortieg prize for a New York to Paris non-stop flight was feasible. Unlike his competition, he believed that a smaller, faster cheaper approach (i.e. a single engine-single pilot airplane) was appropriate to the task.

Columbus, on a slightly larger scale, found government funding for what became in essence a mapping mission. He did not prove that the world was round. Every educated person of his era knew that already. What he did do was to begin to survey the resources of the New World. Even though he was wildly inaccurate, the fact that he took his first small steps generated the impetus which led to the colonization of the New World.

In 1991, discouraged by the lack of activity in space exploration, I made a list of potential projects which could help us break out of our malaise and perhaps hasten the human breakout into space. I discussed the list with Dr. O'Neill and it appears below with a few comments, in the original order as written. It is submitted for its suggestions for near-term action. As you can see, some progress has been made in a number of these projects.

Breakout List- August, 1991

- Find little asteroids close to the Earth in terms of energy and distance.

The discovery that 1979 VA is a dormant comet core and other recent Near-Earth

Objects provides some real success in this area.

- Find water and other frozen volatiles at the poles of the moon.

The demise of the NASA Office of Exploration will slow the development of a NASA equivalent of SSI's Lunar Prospector but strong interest remains in this type of small, fast lunar mission, which we must continue to sustain.

The flight of the first Clementine Mission by the Ballistic Missile Defense Organization (formerly SDIO) in 1994 will hopefully orbit the Moon and then fly-by the asteroid Geographos. In honor of SSI's founder, the mission has been named O'Neill I.

- Demonstrate space power beaming between spacecraft

The flight of ISY METS in early 1993 has accomplished this objective on a small scale!

- Fly a solar thermal propulsion system

- Build a megawatt scale power platform for use as a demonstrator and a utility core

- Save a space shuttle external tank in orbit.

- Fly a solar sail

The recent flight of the Banner prototype solar sail by the Russians is an important step in this direction.

- Design and build ion or solar thermal microspacecraft for lunar or translunar exploration.

- Look for asteroids at the Earth-Sun L4 and L5 positions.

- Demonstrate partially self-replicating machine systems.

See Steven Levy's interesting and provocative book Artificial Life. *(Pantheon, 1992, New York.)*

- Fly a private spacecraft anywhere.

- Build lunar microrobot explorers

See David Miller and Rodney Brook's work at JPL and MIT as examples of this new approach to robotics.

- Build a working tabletop lunar material processing system.

Conclusions

We should play to *win*, which means working the *real* problems, rather than the ones which we find entertaining to work on at present. We need to analyze how to achieve a win, rather than playing the game for the sake of playing.

We *have* succeeded in convincing the relevant aerospace communities of the benefits of using space resources for space projects.

A Solar System Inventory is the most pressing *resource* issue facing us at present.

Proving the technology and safety of Wireless Power Transmission is the most critical *tools* issue at present.

Changing the popular models about space is the real mission of our community. If we succeed here, we will win the resources and attention we need to open the High Frontier.

References

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1. O'Neill documented his thoughts on 'small' space colonies in a set of handwritten notes dated June 3, 1985. Two pages of notes, entitled Early Space Colony Sizes & Rotation Rates summarized his thoughts on the minimum size required for a space colony.

2. Personal Communication by Dr. Josef Gitelson to Gregg Maryniak and James Harford

3. Dickinson, Richard M., *Challenges of International Programs in Commercial Wireless Power Transmission,* in Brown, A. editor, Wireless Power Transmission Conference (WPT'93) Center for Space Power, College Station, Texas, 1993.

4. *Space Solar Power Program Final Report,* International Space University, Cambridge, Massachusetts and Kitakyushu, Japan, 1993. See especially pages 301-321.