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Exploring and Using the Space Environment

A Different Approach

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Introduction

This paper describes some of the concerns that Space Frontier Operations, Inc. (SFO), has about space exploration and describes some of the initial results of studies being undertaken at SFO to further the exploration of space. These studies are preliminary and they are continuing.

Exploration and use of the space environment has been stymied for many reasons. Chief among these reasons are governments, large corporations and lack of political willpower. This state of affairs, coupled with a genuine lack of knowledge by most people, politicians included, has led to the idea that space exploration is complicated, expensive, very risky and therefore best left to governments. Space exploration can be complicated, it is expensive and sometimes risky, but it is not best left to governments!

To appreciate the reasons for this state of affairs we need to look at the origin of the space programs themselves. The two great pioneers, Goddard in the USA and before him, Tsiolkovsky in Russia, were experimenters whose work was largely ignored until the Germans managed to craft a weapon system using a rocket as the delivery mechanism. The birth of both the US and Russian space programs are therefore to be found in the weapons work of the Germans that led to the V-2 weapon used on the United Kingdom in the waning days of World War II.

Interestingly, since that time only two major launch vehicles have been built in the US that were not derived from ballistic missile weapon systems. These are the Apollo/Saturn V vehicle and the Space Shuttle. Of these two vehicles only the Apollo/Saturn V was optimized for its role. Even so, the Apollo/Saturn V vehicle was born out of fear of the Russians and their demonstrated space capability. Space Shuttle has its own problems, partly driven by design but also by lack of attention on the part of politicians.

In fact, the exploration of space cannot proceed because of the limitations placed on systems by the lack of investment generally and the lack of investment incentives from governments.

SFO recognizes this unsatisfactory state of affairs and is in the process of synthesizing a solution that will meet most requirements for space access.

Problem

The exploration of space can be achieved quite readily. We already have the analytical knowledge necessary to generate the capability to explore space. What we need is the will to pursue this exploration.

It may be argued that government's have little role in exploration. Exploration is not one of the major roles of government and we must not be surprised when they place little priority on such ventures. The US government is in the space exploration business primarily because most space launch vehicles grew out of weapon delivery systems – and the infra-structure developed to support those systems.

The Eisenhower administration recognized at least a part of this military heritage problem and this along with the Russian Sputnik success gave birth to NASA with a purely civilian but still governmental mandate. There is a role in space exploration for government but not as the primary exploration agency.

Another important reason for the lack of exploration by the corporate world comes from the fact that the major defence contractors often only have governments for customers. This means that their products are designed primarily to support their government customers and that any commercial use has to be bought at the same price as the government product and to the same specifications and requirements that governments deem necessary.

The vehicles designed by the major aerospace corporations reflect the needs of the government and secondarily the civilian communications market. They do not reflect any interest in exploration per se. Because technology has progressed so rapidly satellite size has either shrunk or more capability has been added to a given volume. The net result is that Launch Vehicles have not grown. The maximum payload capability is still around 50,000 lbs. EELV in its larger forms and Venture Star will have roughly this capacity.

The only place where capability of launch vehicles is being severely tested is the assembly of the International Space Station, (ISS). The size of ISS components is constrained to that which fits inside the dimensions of the shuttle payload bay and the lift capability of the shuttle to the desired orbit.

It may be said that we have reached a practical limit for the capability of current systems to support outward exploration missions.

Solution

Any exploration mission has several components and most of the exploration programs that are advanced for consideration today concentrate on what can happen once they are already in space. The problem of getting into and operating effectively in space is assumed to have been solved outside the constraints of the exploration task being advanced. As we know, this is far from being the case.

Casting our minds back to the Apollo/Saturn V program for a moment, it is interesting to note that this entire system of Launch Vehicle, Apollo Command Module, Service Module, Lunar Excursion Module and Lunar Rover were designed as an optimized set of components to perform one primary task – explore the moon and return. This extraordinary feat was accomplished precisely because all the system components worked seamlessly together. We have to design a similarly integrated system in order for exploration to proceed.

The solution to the problem of exploration is a little like climbing Mt. Everest, you start with a Base Camp and continually build new camps at successively higher altitudes until you can attempt the summit. Conquering space will need a similar approach.

We are proposing to build a “Base Camp” in space, to support it with large crews and large Heavy Lift Vehicles as well as a Manned Vehicle capable of reaching the “Base Camp” and then being useful there. These three space segment components will need to be supported on the surface by an equally competent logistics and engineering organization. In a project of this size it is possible to use two or three stage rockets and dispose of some mass without significantly altering the economics of the whole project. There are also ways to mitigate the mass lost to the system and therefore improve the overall payload fraction. Since this “Base Camp” is going to require regular servicing and there will be additional construction projects to contend with, it becomes possible to see that there should be significant economy of scale to be found in the launch vehicle areas, both manned and unmanned.

SFO Program

SFO has been investigating the problems associated with the large-scale exploration of space for about four years now. Our approach is predicated on the thought that space exploration is a human endeavour for which technology is merely an enabling agent.

Consequently any system solution proposed by SFO is going to be “human sized”. That is to say that we are going to build systems that human beings can live in and with and that can be serviced by people trained to service such systems. This “human sized” “Base Camp” will be established in space and initially serviced from the surface of the Earth. SFO is firmly convinced that the only way to effectively explore the space environment is to get enough material into space to allow for a great deal of autonomy and ultimately to allow a self-sufficient colony to be established. Only then will we have an exploration capability equivalent to Earthly colonists of earlier years.

As with any “Base Camp” the majority of the people involved in the expedition will only go as far as the “Base Camp”, with each new camp beyond the Base Camp staffed with smaller and smaller numbers of people. In fact the majority of folk will not go much beyond the “Base Camp”. These are the people who will staff the “Base Camp” and enable further outward journeys to be undertaken. Appendix – 1, Crew Size Estimates, details the sizing argument. It is seen that we postulate a crew size of around 150 to support the anticipated size of the science and engineering tasks to be performed at the Camp. Crew size is expected to grow as the structure matures. This is not the final size of the Camp personnel capability, we have to be able to accommodate itinerant personnel from all sorts of projects that will require space to live and work. We are making an initial guess at this being an additional 150 people. Appendix – 2, Initial Estimate of Pressurized Volume of Base Camp, addresses the question of the size of the Camp. Table -1, Base Camp Design Criteria, shows the top-level design criteria for this “Base Camp”.

So, now we have a big, bold idea and we can service it from the surface. How do we achieve this goal? We cannot rely on the Space Shuttle – or any other developed launch vehicle; they are just not big enough to support this task.

The realization that a new launch vehicle with greater capability is required came with the realization that we were really being freed from really low Earth orbits. Shuttle can get to about 350 km or so, but with little duration at that altitude.

Consequently, SFO developed a Design Point Mission that included the following components:

A Heavy Lift Vehicle, (HLV) capable of raising 250 Tonnes to an 850 km circular orbit. This is undoubtedly a large vehicle but it is within our capability to construct such a large rocket. Further investigation has led to an optimum payload size between 150 and 175 Tonnes. Table -2, HLV Design Criteria, shows the top-level design criteria for this vehicle.

A Manned Vehicle, (MV) capable of transporting between 15 and 20 people to the “Base Camp”. This reusable vehicle will only carry people, baggage and any small, high value or urgently required items. Such a vehicle may be launched atop an Ariane V derivative vehicle. Several vehicles will be required to allow continuous operation if required. Table 3, MV Design Criteria, shows the top-level design criteria for this vehicle.

In addition, we have to consider the requirements of the Surface Support Infra-structure. We expect to have co-located manufacturing and launch, horizontal integration will be the norm and a Logistics activity to support the “Base Camp” will exist. Table 4, Launch Base Criteria, shows the top-level design criteria for this potion of the system.

It is expected that as the project matures the management of the “Base Camp” will transfer to the space segment. This will extend to all exploration effort as well as spacecraft engineering and “for profit” activities with other corporations using the system as customers. Table 5, Primary Components of SFO Design Point Mission, provides a brief overview of the primary characteristics of each component.

Preliminary requirements have been developed for all these systems and work is progressing to refine the mission and vehicle requirements.

Launch Site Location

Given the size of the HLV, it is virtually certain that no US launch site could handle this vehicle. There is no longer any possibility of having Heavy Lift Pads built north of Complex 39 at KSC. There is also no possibility of obtaining manned and unmanned launches in the quantity needed to support this venture.

We are left, therefore, with Kourou in French Guiana and Alcantara in Brazil as potential sites with the Australian Cape York site as a possible contender. These sites are generally for equatorial launches. We have to consider the possibility of Polar launches but there is no candidate site identified. Operationally, polar orbits have some environmental advantages over equatorial orbits. Trade studies are in progress to see if it is worth attempting a polar placement.

Launch Frequency

For any exploration concept to work it has to be accomplished in a reasonable amount of time. This project will have a long lead-time of between 8 to 10 years. At he end of that time we will have in position all the systems we need to start the exploration proper. Initial Operational Capability, IOC will be achieved with 21 launches of the HLV. This will be a period of time between 21 and 30 weeks. Sometime about four weeks later, the “Base Camp” will be declared “operational” and should be capable of earning revenue. Construction will continue until a permanent, self-sustaining system has been created.

Space Operation

Initial placement of segments will occur with two launches of essentially inert segments. Rendezvous and Docking of these two segments will be automated. Following docking an activation crew will arrive within twenty four hours and dock with one segment. A period of seven to ten days is available to activate and configure the Base. The next HLV launch should lift to orbit a structural node with six docking adapter rings and hatches. This node will eventually form the center of the Base and become the center of rotation. The fourth and fifth launches will connect to the outboard docking adapter of the structural node.

Program Issues

Several issues make themselves felt quite early in a project like this. They are generally connected with one or more of the following items:

1. Money
2. Time
3. Engineering
4. Marketing

A singular characteristic of space missions is the "up-front" cost; it's usually very high and often coupled with significant program risk concerning the ultimate outcome of the mission. Predicting return on an investment of this magnitude and risk is about as difficult and as speculative as it gets. Many programs of this complexity that are pushing the envelope of capability have very little cost data on which to base arguments. Programs of this nature typically rely on Parametric Cost Modeling at this stage of development. However, the limitations of the technique can be found quickly. Each of the models we have used has not provided adequate cost data and as a result, we are developing a new model. Parametric models are limited by the necessity to use historical data; changes in technology or a change in the "mix" of technologies within a model component that are not factored into the model all conspire to produce estimates that are insufficiently accurate for contract work.

So, money becomes a real issue, but in similar highly speculative adventures there have been successes. The Space Industry today is no worse off than the Shipping Industry, the Airline Industry and the Oil Industry were before demonstrated markets were identified and proven. Therefore, precedent does exist even in this era of highly sophisticated money management.

The question always asked is; "Where is the market?" The answer right now is that it does not exist. It will have to be built little by little, as the Base comes "on-line". One good feature of the Base as described is that it will be big enough to accommodate science, servicing and exploration missions separately. Therefore, if we can keep the operating costs under control it should be possible to produce a revenue stream very early on.

This Base is designed with a lifetime of 100 years and construction to a usable but expandable state will take no more than nine months. Amortization of construction costs should be seen as a 20 to 25 year objective that not only allows the mortgage to be paid but also surplus revenue for re-investment. The Launch Base will be able to earn revenue from both support and growth of the Base Camp and from third party launches. With this thinking, two distinct profit centers begin to stand out as having real possibilities; the Base and the Launch System. Perhaps a Marketing Plan and therefore, a Business Plan is not as far out as it seems, we just need to get the thing built and we can market it!

In the early days, selling this program and keeping it sold are going to be major problems. We are going to have to demonstrate progress on a regular basis in order to keep moving and keep people interested.

Conclusion

SFO has shown that development of a very large space structure can probably be accomplished quite quickly by developing the entire system of structure and service vehicles as an optimized system.

Much work remains to be done to bring this program to a start position. Within the next year each major component is going to be much better defined and hopefully we will also have a good cost model. We expect to report much progress in the next year. SFO is bringing a European R&D facility "on-line" in February/March 2000 to consider many of the problems associated with the system level design.

Criterion No.	Description
1	Design Lifetime 100 yrs. Minimum.
2	Initial launches will be of “outfitted segments” especially early in the sequence.
3	Each orbital segment will be autonomous until connected to the main structure.
4	Each segment will contain common Control, Communications and Computer capability. This will provide significant redundancy at the system level in the early stages of construction. It may be possible to remove equipment for re-use once the system is mature.
5	Routing of all system inter-connects will be internal. This applies to fluids as well as electrical connections. Accessibility will be designed into the system.
6	Main power will be generated from either Fuel Cells, Solar PV, Solar thermo-dynamic or Nuclear Generators or some combination of these techniques. The power generation technique will change as the system matures and the power requirements rise.
7	Ring circuits will be used for power and data distribution.
8	Each segment will be equipped with batteries for emergency electrical power. Emergency power distribution will be separate from the main power distribution system.
9	Segment atmosphere will be air at one atmosphere. (14.7 psi)
10	Storage of potable water and liquid air will be at remote locations on the habitable volume.
11	Bulk propellants will be stored in a location away from the main structure. Only station keeping propellant will be stored in tanks on the main structure.
12	Target size for each segment is 40ft.x70ft.
13	Mature system will spin “end over end” for gravity simulation.

Table – 1, Base Camp Design Criteria

Criterion No.	Description
1	Payload 150 to 175 Tonnes
2	All Control, Computing and Communications Equipment will be located just below the Payload and will separate with the Payload for recovery.
3	All Control, Computing and Communications Equipment will be recovered and re-used.
4	Design in the capability to carry third and possibly second stages to orbit for later recovery and use.
5	Third and possibly second stage engines can then be recovered for re-use.
6	Tanks so recovered can be used for bulk fluid storage at “Base Camp”
7	HLV will be integrated horizontally and erected at the Pad.
8	A variety of Payload Carriers will be required.
9	Study the need to jettison the Payload Fairing.
10	35 to 50 day maximum preparation time for launch.
11	Payload can be changed as late as 5 days before launch.
12	Target time at Launch Pad is 2 days
13	Late Access requirement for the storage of perishable items prior to launch

Table – 2, HLV Design Criteria

Criterion No.	Description
1	Reliable re-usable vehicle capable of transporting 15 to 20 people to and from orbit.
2	Flight Crew of 2.
3	All Control, computing and Communications equipment are common with those of the “Base Camp” and the HLV.
4	All Life Support systems will be common with those of the “Base Camp” where possible. This may be a size driven issue for some items.
5	Free space duration of 7 days (landing, docking or servicing mission).
6	Ariane V derived Launch Vehicle seems best option at this point.
7	A special third stage may be needed. If so, it will be recovered for re-use.
8	As in an airliner, some seats must be removable and cargo stowage capacity made available on an “as required" basis. This will allow the timely launch or return of re-usable items.
9	MV and third stage will be mated horizontally.
10	Personnel pressurized accommodations will be integral with the flight deck.
11	Anticipated preparation time for launch is 7 days or less.
12	MV will be equipped to land at any airport with commercial capability.
13	Design study to consider the feasibility of adding Jet Engine(s) to enhance manouvering capability in atmospheric flight.

Table 3 – MV design Criteria

Criterion No.	Description
1	Has to support the manufacture, integration and launch of the HLV and the MV. This may entail new construction.
2	Has to have available land area for the construction of heavy lift launch pads.
3	Requires easy access by land, sea and air for personnel and equipment.
4	Both the HLV and the MV will be integrated horizontally.
5	Current estimate is for 5 new launch pads for HLV. MV capability is understood as a modified Ariane 5 pad. This may be an existing or new pad. If new then we need at least two to support operations.
6	Access to bulk storage of both cryogenic and storable propellants is required.
7	Access to liquid air and potable water supply is required.
8	Access to fresh foods will be required in the early phase of the construction.

Table 4, Launch Base Design Criteria

ITEM	HLV	MLV	BASE	GROUND
Payload to orbit	150 – 175 Tonnes	5 Tonnes	N/A	N/A
Personnel Passengers Flight Crew	 None None	 20 2	 Up to 150 Approx. 150	TBD
Power	Batteries	Batteries/Fuel Cells	Batteries Fuel Cells Solar Dynamic Solar PV Nuclear	N/A
Stages	3	3	N/A	N/A
Special requirements	Capability to orbit 2nd. and 3rd. stages Control Electronics will be housed in the Payload Bay beneath the payload support structures and recovered from orbit for re-use.	Potential study to attach Jet Engine(s) to the MV for expanding the atmospheric flight capability	"End over end" rotation to simulate gravity.	5 new HLV Launch Pads. Specialized infra-structure. LOX/LH2 Liquid Air production. Gases
Interfaces	HLV Data to GND HLV to P/L 1st. and 2nd. Stages to have common engines.	MV to/from GND Comm. MV to/from GND Data	Mechanical Electrical Power Data Fluids Communications	Air Sea Land
Launch Frequency	Every 7 to 10 Days	As required 36 Hour notice	N/A	N/A
Launch Site Equatorial Orbits Polar Orbits	 Kourou Alcantara? TBD	 Kourou Alcantara? TBD	N/A	N/A
Orbit Equatorial Polar	 Under Consideration Under Consideration	 Under Consideration Under Consideration	 Under Consideration Under Consideration	N/A
Altitude			1) 850 km min. 2) Between 1000 and 2000km Max.	N/A

Table – 5, Primary Components of SFO Design Point Mission.

Appendix 1, Crew Size Estimates

Estimates of crew size are based on the following assumptions:

- Three Shift, Seven day week for many crewmen.
- Trades will be represented at the technician level.
- One Engineer to two technicians.
- Technicians and craftsmen will work for the appropriate Engineering discipline

Job Assignment	Professionals	Craftsmen/Technicians
Management		
Manager	1	
Deputy Manager	1	
Assistant Manager	2	
Engineering		
Chief Engineer	1	
Communications	2	4
Computers	2	4
Electronics	1	2
Sensors & Guidance	2	4
Environmental	2	4
Propulsion	3	6
Mechanical	1	2
Civil	1	2
Electrical	1	2
Medical		
Senior Dr.	1	
Doctors	1	
Nurses	2	
Medical Techs.		3
Food Service		
Senior Chef	1	
Chefs	3	
Kitchen Help		4
Maintenance		
Manager	1	
Janitors		4
Science	TBD	TBD
Exploration	TBD	TBD

Totals by category	**29**	**41**

Total Crew Size		**70**

It may also be assumed that many personnel will elect to bring spouses along. Potentially, this could double the size of the crew from 70 to 140. Such spouses will also be trained in some aspect of Base operations.

Appendix 2, Initial Estimate of Pressurized Volume of Base Camp.

Volume of space required for each individual is calculated based upon the following assumptions:

- Modern Hotel Room is about 20X10 ft.
- Bathroom is about 8x8 ft.
- Assume an 8ft. ceiling height.

Crew Space	Volume Item (Cu. Ft.)	
Per Capita accommodation (20x10x8 and 8x8x8)	2,240	
Total crew accommodation for 150	336,000	
Itinerant User crew volume up to 150 people	336,600	
Total Accommodation Volume		**672,000**
Common Area Facilities, (Mess-halls etc) at 25 % of total	168,000	
Work Space (shops etc. not including Itinerant areas)	13,440	
Total Workspace and Common areas		**181,440**
Storage Areas Equipment - small	8960	
- large	8960	
- refrigerated	2240	
NOTE: Does NOT include Propellant or Fluid storage		
Total Storage Areas		**20160**
Base Systems, Power, HVAC, etc. estimate	20,000	
Computers, Communications, GN&C	10,000	
Control Center	4,480	
Air Locks and EVA storage	64,000	
Environmental; air etc	4480	
Total Base Systems		**92,960**
Itinerant Operations Facilities at IOC		
Test and Validation shops - electrical	2240	
- mechanical	2240	
Re-work shop	2240	
Machine Shop	4480	
Assembly Facility	4480	
Fueling Facility – on base	4480	
Office Space	2240	
Total Itinerant Operations Facilities		**22,400**
Science Lab. Space at IOC	8960	**8,960**
Total Pressurized Volume Estimate at IOC (Cubic Feet)		**997,920**