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SPACEPORT OPERATIONS FOR DEEP SPACE MISSIONS

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Space Station Freedom is designed with the capability to cost-effectively evolve into a transportation node which can support manned lunar and Mars missions. To extend a permanent human presence to the outer planets (moon outposts) and to nearby star systems, additional orbiting space infrastructure and great advances in propulsion systems and other technology will be required. To identify primary operations and management requirements for these deep space missions, an interstellar design concept was developed and analyzed. The assembly, test, servicing, logistics resupply and increment management techniques anticipated for lunar and Mars missions appear to provide a pattern which can be extended in an analogous manner to deep space missions. A long range, space infrastructure development plan (encompassing deep space missions) coupled with energetic, breakthrough level propulsion research should be initiated now to assist us in making the best budget and schedule decisions.

INTRODUCTION

Sometime during the next 50 years, interplanetary flights between Space Station Freedom (Spaceport Earth) and Mars Outpost 1 will be established on a continuous and permanent basis. Manned exploration missions to the outer planets and moons will have been planned and initiated. Systems required for advanced space transportation and associated infrastructure will be researched, tested, checked out and serviced at or near Freedom. The implementation of the Space Exploration Initiative and associated U.S. space policy will require that a long range, propulsion R. & D. plan be initiated to provide assured interplanetary space transportation. Once we establish a permanent outpost or colony on Mars, our commitment to energetic, long-range technology R. & D. and the maintenance and improvement of orbiting space infrastructure will no longer be optional, it will be mandatory.

To make human transportation to the outer planets "practical" on a continual basis will require propulsion systems with the capability to reduce one way trip times to a couple years or less. Candidate propulsion systems include nuclear thermal and matter/anti-matter propulsion. To conduct manned interstellar missions which have meaning and value to an emerging space civilization (and which therefore can be economically justified) will require propulsion breakthroughs which "effectively" allow a spacecraft to exceed the speed of light. New and innovative research and development approaches are needed to develop interstellar transport capability or capabilities.

A conceptual design for a manned interstellar transport has been developed to assist in identifying spaceport infrastructure and operations requirements for the research and development, assembly and checkout, performance tests and trial runs of the manned interstellar transport. Advanced robotics, high temperature superconductor shielding and microengineered materials may play important roles in minimizing risks associated with the assembly and servicing of the propulsion systems. To enable routine, outer planet and interstellar transportation will likely require additional remote, orbiting space infrastructure elements and outer planet moon outposts with the capability to support orbital servicing. Increment management considerations for Space Station Freedom and the interstellar spacecraft assembly and test suggest the types of generic and specialized outfitting of space infrastructure which will be required (see Figure 1).

DEEP SPACE MISSION PROPULSION REQUIREMENTS

The propulsion requirements to explore and establish an outpost on Mars are well within the range of our current technology capabilities. To reduce trip times to Mars and to enhance the exploration of the Martian surface

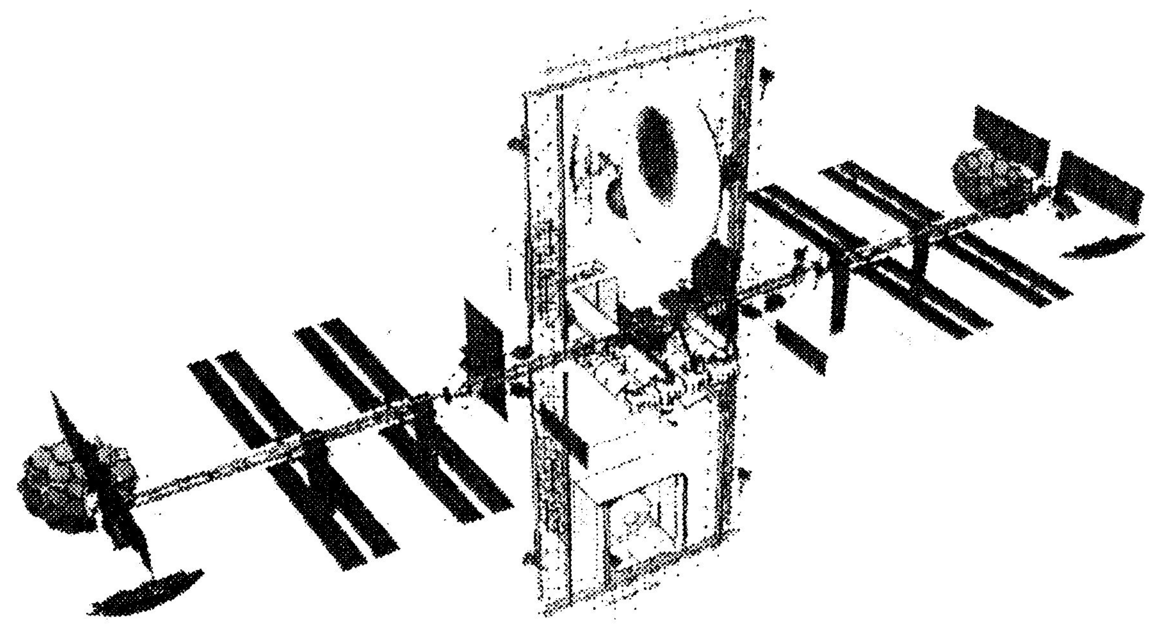

Figure 1. Space Station Freedom: Transportation Node Mars Vehicle Checkout

could require the development (or improvement) of nuclear thermal, nuclear electric and electromagnetic propulsion. These enhancements would also set the stage for the development of the advanced propulsion systems needed for manned exploration of the outer planets and moons.

It can be argued that with the development of advanced radiation protection systems and a greater understanding of human space physiology, one way trip times of 5 to 10 years to the outer planets is feasible. However, to establish outposts on the moons of outer planets which can be justified economically and sociologically, substantial advances in propulsion technology are required. Propulsion technology with high specific impulses such as nuclear fusion thermal/electric and matter/anti-matter systems may be sufficient to meet this challenge. These outposts and the associated transportation logistics support activity will provide the experience and space infrastructure needed to initiate manned interstellar missions.

Some imaginative concepts (limited by the constraints of space-time, the speed of light) have been proposed for interstellar spacecraft which can be used to demonstrate that such missions are feasible with our current technical understanding. Unmanned interstellar probes should be studied with these concepts in mind. The trip times for manned exploration, however, represent a lifetime commitment even for the nearest stars. Even taking advantage of the time dilation factor of General Relativity, round trip times of 40 years or more would be required. It is difficult to see how support for such a mission could be generated.

If a means could be found to work around the constraints of space-time (to "effectively" exceed the speed of light), then the picture could change dramatically. The detection of planets around other star systems with the prospect for the existence of other lifeforms, including advanced intelligent lifeforms, would be additional compelling motivation for manned interstellar exploration. Even this motivation might not be sufficient, however, if the economic base is not exceptionally strong.

The economics of such endeavors can be dealt with if one of the following scenarios exists:

(1) Advanced, faster than light propulsion systems are developed which enable round trip times of less than 5 years.

- Economics associated with this trip are then no more formidable than those associated with outer planet exploration.

(2) Human civilization in the Solar System is threatened and options for new homes must be found.

- Economics are overridden by the motivation for survival.

(3) Economic justification is based on economic and technology development gains resulting from Solar System exploration and colonization and known potential for similar or greater gains in interstellar expeditions.

- Preliminary contact with other civilizations could also play into this scenario (SETI and other programs).

- Faster than light systems are likely still to be enabling in this scenario.

Thus in 2 out of the 3 scenarios, faster than light propulsion is enabling for a manned interstellar mission. Only the colony ship which is not concerned with maintaining contact with the civilization left behind would likely justify slower than light propulsion options.

Science fiction writers have for many years discussed faster than light propulsion systems. Realistic research and development approaches to develop such systems have been suggested from time to time. Based on the recent developments in technologies and materials such as high temperature superconductors, microengineered materials, compact superconducting magnets, free-electron lasers, high power, tunable microwave systems (masers), quasi-crystals, plasmoid generators, etc. and theoretical developments associated with the superstring multi-dimensional theory and other similar theories, we are poised to begin serious pursuit of faster than light propulsion systems.

Taking all these factors in account the design reference concept developed for the interstellar mission assumes the availability of faster than light propulsion systems. The hazards of such systems do not appear to be any more challenging than nuclear thermal propulsion systems. Faster than light propulsion systems could ultimately reduce space infrastructure needs, but the availability of such systems would not dramatically affect current and projected Solar System orbiting infrastructure requirements (which includes support for unmanned sub-light interstellar probes).

INTERSTELLAR TRANSPORT DESIGN CONCEPT

The interstellar transport concept developed for this analysis was based primarily on the following considerations:

- Modular design which can readily accommodate the removal and addition of elements during and after the design process.

- Adequate shielding of crews from nuclear power system and nuclear thermal, anti-matter/matter and space-time disengagement propulsion systems.

- Shielding and boundary constraints associated with radiation protection, micrometeoroid protection, and space-time disengagement system.

- Unique envelope configurations requirements associated with pulsed magnetic field vernier system and disengagement system.

These factors resulted in a compromise configuration which resulted in a reduction in the ease of module (and Orbital Replacement Unit) replacement. Multiple propulsion systems were selected for different mission phases and redundancy purposes.

Nuclear power sources are the highest density/unit mass power sources currently available and thus are at this point mandatory for mission success. Nuclear fusion has much cleaner products of reaction which would enable some hands-on maintenance activity.

A nuclear fusion thermal propulsion system was selected for interplanetary travel and as an option for intermittent use with the space-time disengagement system(ref 16). The system heats up hydrogen which is then expelled as a propellant through 8 thruster nozzles. The nuclear fusion propulsion systems requires 1.5 gigawatts of sustained reactor power and 2.5 gigawatts of peak power achieved utilizing MHD superconducting peak power modules. The 8 thrusters provide a variable thrust of 50,000 to 300,000 lbs (see Table 1).

Advanced Propulsion System Type	Translation Interaction	Effective Specific Impulse (Isp)	Thruster/ Propulsion Elements	Effective Thrust	Power Requirements (Avg/Peak Gigawatts)
VERNIER/Orbit Transfer					
(1a) Electro-plasma	High velocity ions – Action/reaction effect	5,000 - 10,000	12	0.5 - 40 lbs./thruster (up to 20 thrusters)	0.2/0.5
(1b) Pulsed Magnetic Field with pulsed plasmoid generators	Reaction against background magnetic field and plasma	1 x 10^{6}	4-Plasmoid 16-Pulsed * Field	Dependent on Background Field (Dual Redundant)	0.2/0.5
INTERPLANETARY					
(2a) Nuclear Fusion	Heated/Ionized gas – Action/reaction effect	1000 - 3500	8	50,000 - 300,000 lbs. (Quad Redundant)	1.5/2.5 (Reactor Power Level)
(2b) Matter/Anti-Matter	Heated/Ionized gas – Action/reaction effect	1000 - 5000	8	50,000 - 400,000 lbs.	0.2/0.5
INTERSTELLAR					
(3) Space-Time Field Disengagement (STFD) – with Field bias	Space-time bubble created – Relocated to space-time position which balances out bias field	1 x 10^{12}	16*	N/A	0.5/0.7

* Share use of these elements

Table 1. Summary of Advanced Space Propulsion Systems

Coupled with the nuclear thermal system is a nuclear electric-plasma distributed thruster propulsion system which uses high energy electrical currents to heat the hydrogen gas with much higher Isp but lower thrust (ref. 2,3). The electric-plasma distributed thruster system requires an average of 0.5 gigawatts of electrical power. It generates thrusts from 2.0 to 40 lbs. with an Isp in the range 5000 to 10000.

As a backup system or higher performance special use system a matter/anti-matter propulsion capability has been included (ref 20). It would use many of the same components and the same thrusters used for the nuclear fusion propulsion system. The antimater pellets would be used as an alternative or backup to the nuclear power heat source for propulsion using auxillary magnetically confined storage and reaction chambers. The pellets could also be used as part of the fusion generation system itself (ref 16).

For vernier and orbit transfer propulsion the electro-plasma distributed thruster system or the pulsed magnetic field interaction system is used. Both systems have very high Isp's which is critical for an interstellar spacecraft. The pulsed magnetic field system requires 200 to 500 megawatt bursts of power to obtain a near-infinite Isp from its 4 primary (pulsed plasmoid mode, ref 5) and 16 secondary pulsed field sources (ref. 3). The maximum thrust for the pulsed magnetic field system varies depending on the background field and plasma densities. The system uses high temperature superconducting components.

For deep space propulsion, primarily for interstellar travel, a system which is capable of disconnecting or disengaging the spacecraft from the velocity constraints of space-time is used. This system is assumed to consist of two field generation systems. Each system has 16 field amplifiers or disengagers distributed along a critical boundary surface. These amplifiers have an operational mode which also allows them to be used in conjunction with the pulsed magnetic field system. The system can be viewed as forming a space-time bubble around the spacecraft. The bubble provides a natural and near perfect protection against radiation, micrometeoroids and any stray directed energy.

After the bubble has been formed, the spacecraft can be accelerated by biasing the bubble field or through a resonance interaction between the pulsed magnetic field and space-time fields. The disengagement system requires a sustained power of 0.5 gigawatts with 0.7 gigawatts of peak electrical power.

It is also possible to use the disengagement system in a sub-light mode alternating between nuclear or matter/antimatter propulsion and disengagement phases. This mode allows the protection capabilities to be used even when hyperlight velocities are not required or desired. This system also takes advantage of high temperature superconductors and materials sensitive to nuclear spin alignments and transitions.

Figure 2 depicts a conceptual layout of the interstellar spacecraft along with the multiple propulsion systems. The total mass of the vehicle is estimated to be 500,000 lbs. with a total internal usable volume of 5 million cu. ft. for habitability and mission elements. The length of the vehicle is 250 feet with a width of 200 feet. The habitable modules and storage provisions can accommodate a crew size of 24. The nuclear fusion power system is a quad redundant system with each system capable of generating 2.5 gigawatts of power. Peak power is normally limited to 3.5 gigawatts using superconducting MHD storage modules. Thermal rejection is accomplished through the use of coherent IR radiators and structurally integrated micro-radiators.

The primary structures of the spacecraft are aluminum-silicon and aluminum-lithium with integrated, microengineered sensors and data flow channels. A closed ECLSS system is complemented by a close-cycle greenhouse. Communications consist of multiple wavelength laser systems, a high power microwave system, and advanced experimental units which are designed to work during the disengagement phases. Extensive use is made of internal robotics systems and artificial intelligence (neural network) architectures. All systems as well as structures have pre-integrated or microengineered sensors. External robotics can be deployed with freeflying or "crawling" capabilities.

A wide variety of elements and functions will have to be supported by the interstellar spacecraft (ref 13). These elements are modular to the extent that the demands of propulsion and protection systems allow. They include: (1) four habitable modules (crew quarters), (2) two systems management modules, (3) proximity operations/training module (with cupolas/wall imagery), (4) three storage modules (oversized), (5) field induced simulated gravity system (?)-a by-product of disengagement system, (6) four excursion/landing vehicles (with integrated simulation capability), (7) two unmanned transport vehicles for surface logistics and outpost establishment, (8) vehicle servicing, maintenance and training facility, (9) vehicle refueling facility (hazardous processing facility), (10) external ORU maintenance and repair station (deployable), (11) deployable or built-in technology test and science experiment facilities, (12) multiple mini-labs/facilities – medical/life science lab, ORU maintenance/diagnostic facility, food production lab, data/comm center/library facility, materials repair, development and production facility, two bio-isolation labs, and data distribution center, (13) exercise and recreation module, and (14) two general purpose science and technology experiment labs.

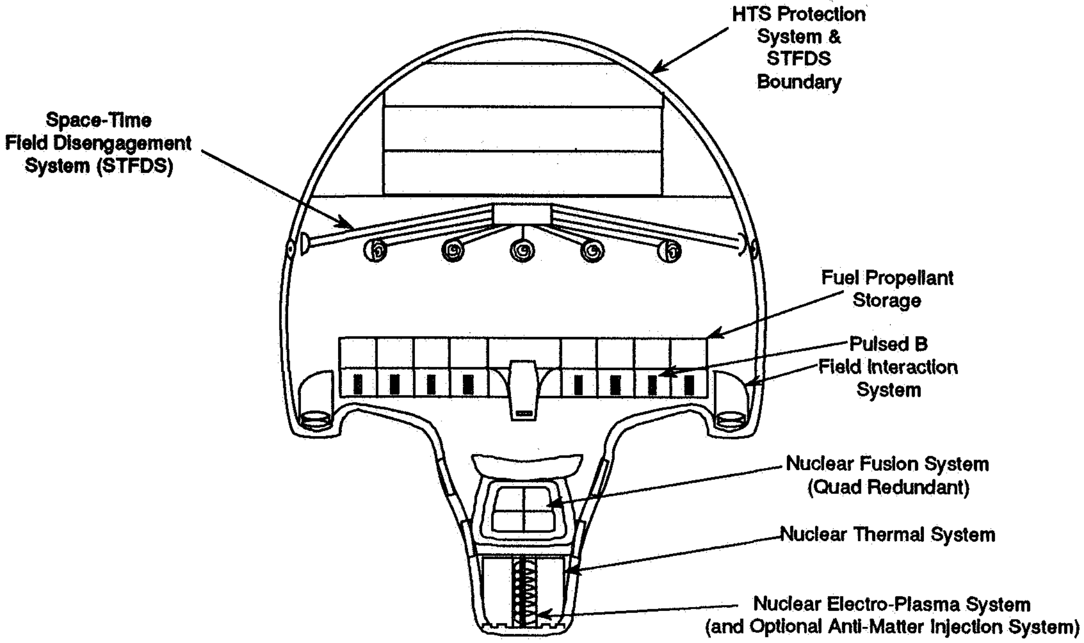

Figure 2. Conceptual Layout of Interstellar Transport Systems

Proximity operations capabilities include (ref. 4): (1) active and passive vehicle rendezvous and docking capabilities, (2) multiple vehicle, robotic systems and manned maneuvering unit, simultaneous tracking and guidance systems, (4) magnetic field/plasma "tractor" beam system, (5) remote power transfer capability – bi-directional,. maser and laser.

Protection systems include (ref. 5): (1) infrared and active meteoroid scanning, detection and tracking system, (2) magnetic field/superconducting surfaces for radiation, ion and micro-meteoroid protection (including microengineered composites), (3) high energy particle and cosmic ray scanning, tracking and identification system, (4) Stellar, planetary and interstellar cloud (dust and gas) imaging systems – multiple wavelengths, (5) magnetic and gravitational field anomaly detection systems, (6) laser/microwave dispersal systems. As indicated earlier while the disengagement system is in operation very effective protection against radiation and meteoroids is provided.

The 24 crewpersons conduct three shift, round-the-clock operations with the exception of two shift operations for two days every 5 days. This break in operations insures that each crewperson gets one day completely off each week and one day with limited duty. During the mission a substantial crew training capability will be utilized to get the crew trained to meet contingencies and upcoming mission phases. The onboard training will include (ref. 6): (1) in-orbit systems normal and malfunction operations, (2) excursion/landing vehicle systems and subsystems training and simulations, (3) outpost setup training, (4) experimental research preparation, (5) individual study.

INTERSTELLAR SPACECRAFT ASSEMBLY AND CHECKOUT REQUIREMENTS

The development, assembly and checkout of an interstellar transport can be divided into the following phases:

(1) Technology Research and Demonstrations (A)

(2) Transport Subsystems Tests (A)

(3) Transport Assembly and Interface Verification (A)/(B)

(4) Transport Final Subsystems and Low Power Performance Tests (B)/(C)

(5) Local and Distant Full Performance Test Runs (C)/(D)/(E)

(6) Crew and Cargo Transfer and Servicing (A)/(D)/(E)

The letters listed behind each phase refer to Figure 3 and the selected sites for the conduct or implementation of these phases. Space Station Freedom (Spaceport Earth) will still function as a major orbital technology/research and demonstration platform (ref. 7,8,17). Technology which requires the extended plasma environment and vacuum of space for testing can be mounted on the external truss network of this transportation node (See Figure 1). The availability of extensive robotics and crewpersons provides the capability to schedule technology tests when operational impacts are a minimum. Priorities can be shifted and environmental disturbances can be accommodated which might be prohibited or much more expensive and time-consuming to carry out on other unmanned or distant spaceports. Nevertheless, safety considerations will require that and some advanced propulsion tests, for example, would have to be conducted on unmanned co-orbiting platforms (see Table 2).

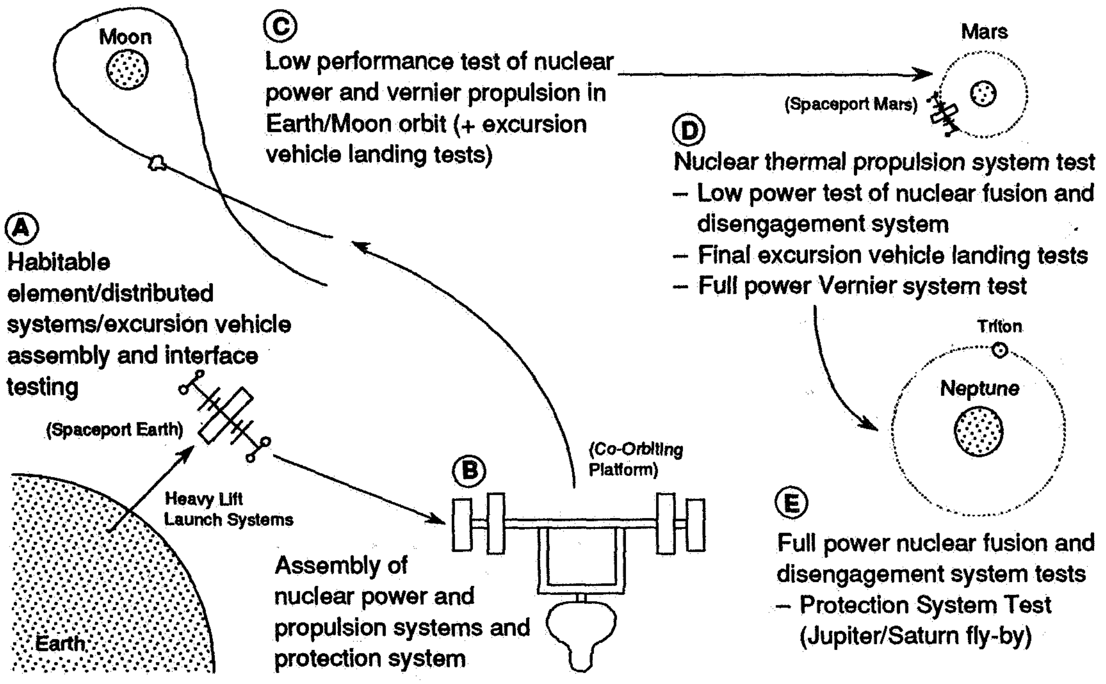

Figure 3. Assembly and Test Concept for Interstellar Spacecraft

Item	Assembly Location	Checkout/Interface Location	Performance Test Location	Robotics Telerobotic Mobile	Robotics Freeflying	Crew EVA	Crew IVA
Habitable Elements	SSF	SSF	SSF	X		X	X
ECLS, DMS & Utility Distribution Systems	SSF	SSF	SSF	X		X	X
Landing/Excursion Craft (Dry)	SSF	SSF	Moon/Mars	X	X	X	X
Storage - Crew, ECLSS	SSF	SSF	N/A	X		X	X
Propellant Storage	SSF	SSF	SSF/COP	X		X	X
Special Modules	SSF	SSF/COP	SSF/COP	X		X	X
Nuclear Fusion Power System	SSF/COP	COP/Moon	Moon/Mars	X	X		X
Propulsion Systems (Vernier)							
– Pulsed Ion Thruster (1a)	SSF	SSF	Moon/Mars	X		X	X
– Pulsed B Field Interaction System (1b)	SSF	SSF	COP/Moon	X		X	X
Propulsion Systems (Planetary)							
– Nuclear Fusion Thermal (2a)	SSF/COP	COP	Moon/Mars	X	X		X
– Matter/Anti-Matter (2b)	SSF/COP	COP/Moon	Moon/Mars	X	X		X
Propulsion Systems (Interstellar)							
– Space-Time Field Disengagement with 2a (3a)	SSF/COP	SSF/COP	Mars/Neptune	X		X	X
– STFD with 2b (3b)	SSF/COP	SSF/COP	Mars/Neptune	X	X	X	X
– STFD with STF Bias (3c)	SSF/COP	SSF/COP	Mars/Neptune	X		X	X

Table 2. Spacecraft Assembly and Checkout Requirements and Implementation Approaches

Some of the on-orbit interface testing can be accomplished at the subsystem level on Space Station Freedom (SSF)(ref. 18). Transport subsystems such as the data handling system, the environmental control life support system, communication subsystem and various module subsystems would be checked out and tested while attached to Space Station Freedom. The "active components" of the nuclear power system and matter/anti-matter propulsion system are hazardous and should be installed and checked out on a co-orbiting platform (ref. 1,15,19). Assembly of the major elements of the spacecraft would be easier to accomplish at the co-orbiting platform assuming that element subsystem in-orbit tests are accomplished on the station.

The interface testing for the overall spacecraft would be conducted at the co-orbiting platform (COP) which stays close enough to SSF to allow daily and extensive crew and robotics visits to the COP (ref 12). System power and data end-to-end checks would be conducted using the COP's power capabilities. Low power performance tests of portions of the nuclear and propulsion subsystems would also be conducted. The reactor would not be activated but the vernier and electro-plasma propulsion capabilities could be checked out using COP power input.

Once the reliability of the interstellar transport's propulsion capability is verified and a lunar transfer tug is available to escort the transport into a lunar/high Earth orbit, the transport can be decoupled from the COP. A final systems test will be conducted with a minimum checkout crew onboard. The transport's electro-plasma propulsion system will then be initiated to put the interstellar transport into a lunar transfer orbit or the transfer tug could be used to accomplish the orbit insertion. After the successful completion of this phase, the nuclear reactor will be started and checked in a low performance mode. Depending on checkout requirements and the number of problems which develop, one or more orbits of the moon will be required before the transport accepts the remainder of the crew.

At this point the transport will begin a lengthy duration test of all major systems to expose any system faults and gain confidence in the overall integrity of the vehicle. A lunar transfer tug will remain on standby during this period to handle any emergencies. In addition, two of the landing vehicles carried by the transport will be in a standby and fully checked out condition. All manned and unmanned vehicles will undergo test runs and landings on the Moon during this period. Any significant problems in these vehicles should be uncovered as a result of these tests. All of the performance tests for the landing craft will not be attempted on the Moon, however.

During this period the changeout of crews will be accomplished by regular space plane flights to SSF and subsequent transfer to the interstellar transport via lunar transfer tug. At the completion of this phase, low to moderate power tests of the nuclear power system and low power tests of the pulsed magnetic field, and nuclear electroplasma propulsion systems will be conducted. Subsystems of the nuclear fusion thermal and matter/anti-matter systems will also be tested out using low quantities of tracer particles instead of fusion and anti-matter propulsion "pellets."

The next phase of performance testing will involve a flights to Mars, electromagnetic braking into Mars orbit and return to a high Earth orbit. During this phase low power tests of the nuclear fusion thermal propulsion system and matter/anti-matter system will be conducted. The transport will initially be injected into a free return trajectory around Mars to provide crew safety options in case of any major contingencies. Spaceport Mars will be used for station-keeping servicing and repair operations, when needed. It will be outfitted with extensive robotics for hazardous systems servicing and checkout. If the transport's propulsion systems are functioning normally, including several starts and stops, then an electromagnetic braking and transfer into a Mars orbit co-planer with Spaceport Mars will be initiated (ref. 10).

While in Martian orbit, the manned and unmanned landing vehicles will be put through all remaining performance and endurance tests. The pulsed magnetic field interaction system will be tested at full power after shifting to a higher orbit around Mars. Once these tests have been completed, the transport will return to Earth. Lunar or GEO transfer tugs will changeout the crew and resupply the transport. Any significant repairs will be done with a small servicing platform brought up to the higher orbit. Should major repairs be required, for any reason, the COP's orbit can be raised and the transport brought down to it. However, this would be considered a contingency mode since major hazardous repairs are planned for Spaceport Mars.

The final phase of performance testing of the interstellar transport is conducted on a free return trajectory around the Neptune/Triton outpost. During this trip full power, nuclear thermal and matter/anti-matter propulsion system tests are conducted. In addition, space-time disengagement system tests are conducted for short periods. If everything proceeds smoothly on the outgoing leg, the transport will enter a Neptune orbit co-planar with the orbit of Triton. While the crew has received routine examinations during the other test phases, a special exam is scheduled on Triton to monitor any irregularities associated with the disengagement tests. Backup crewmembers are available on Triton if any of the crewmembers need to be replaced.

The unmanned and manned vehicles are deployed for test runs to verify that the disengagement process has not affected any of their systems. If the disengagement tests have been successful on the way out, a flyby of Jupiter or Saturn would be conducted upon the return to further test the protection systems of the transport. In particular, to test the capabilities of the disengagement induced protection system. The full performance trip to Neptune can be repeated as often as necessary to gain confidence in the durability and reliability of the transport and its systems.

The first manned interstellar flight would also be setup on a free return trajectory around a nearby star such as Alpha Centauri A. The mission would start from a high Earth orbit with a rendezvous at Triton for a final mission readiness review prior to committing to an interstellar mission. The crew would have the option, with some guidance from mission control center on Triton, to proceed with a trip to the primary destination of Epsilon Bootes should transport performance meet pre-determined criteria. Epsilon Bootes may have a planetary system with a star similar to that of the Sun. The crew has the authority to explore the planet or planets most likely to harbor life and if advisable, establish an outpost prior to returning. Of course, many alternate scenarios have been developed to deal with any indigenous intelligent life forms.

Table 2 summarizes the various subsystems and elements of the interstellar transport and associated checkout requirements and implementation approaches. Locations of tests and the need for robotics and crew are also indicated.

SPACEPORT OPERATIONS AND INCREMENT MANAGEMENT

Increment Management Options and Considerations

In the context of the various test, checkout and performance test phases which have been presented, an increment refers to any segment of the activities which has a clear start and stop associated with the interaction with other space infrastructure and spacecraft (ref 11). What will be described in this section is not comprehensive, but represents some initial considerations.

In general, it is expected even with the availability of Nova class launch systems, that the interstellar spacecraft will have to be assembled in low Earth orbit at Space Station Freedom or Spaceport Earth. If many launch packages are involved, SSF would probably be the best site for the initial, non-hazardous integration activities. The large number of crewpersons, robotic systems and servicing capabilities would favor SSF over the Co-orbiting Platform (COP). If, on the other hand, a few very large packages were put into orbit with Nova class launchers, then one of two options could be pursued. The packages could be assembled at the COP or at a separate site much like SSF was originally (but with many less flights).

A combination of these options could also be considered. The interstellar transport could be assembled initially to serve as a mobile spaceport and evolve into use as a deep space transport. The practicality of this approach for interstellar spacecraft is doubtful because of the need for faster than light propulsion technology and the associated configuration considerations. It could, however, prove more than adequate for outer planet exploration and moon outpost support.

Nuclear system components and other potentially hazardous components or components with other kinds of public sensitivity, should be considered for launch from a relatively isolated Pacific spaceport. Alternatively, the components could be developed at a lunar outpost and transferred to a high Earth orbit for installation and assembly. Unless nuclear elements are mined and processed on the lunar surface, however, the launch of nuclear components from Earth can not be avoided. In addition, economics may not allow the lunar outpost to specialize in certain kinds of activity. For example, the collection and storage of anti-matter may require a lot of expensive and highly specialized equipment.

The servicing and maintenance of nuclear powered systems and other hazardous operations are best accomplished at co-orbiting platform sites in high Earth, lunar or Mars orbits. The platforms have to have the capability to fly to the deep space vehicle or guide a vehicle into a soft or hard docking.

The number and location of Orbital Replacement Units (ORU) is a challenge which will always be with us. With the use of built-in and microengineered sensors, our ability to predict and detect failures should greatly improve. The use of active microengineered elements such as heating elements, electrical and magnetic field effect variation devices, and built-in optical data paths can help compensate for and in some cases prevent ORU failures. As we continue to test new systems, especially propulsion systems, critical spares will still be required. The pattern of testing described earlier in this paper will allow many critical spares to be located on orbiting space infrastructure and at outposts rather than all on the transport itself. As we proceed in our space exploration and colonization activities, the improvement of component reliability and failure prediction should be one of the major design engineering efforts. At the same time logistics systems must plan and implement greater capabilities than will ever be needed to cover unforeseen contingencies.

While much has already been said about phases of systems and performance testing, it is worthwhile pointing out that contingency modes of environmental and crew systems should also be tested while attached to Space Station Freedom or while in low Earth orbit. Outer planet or interstellar spacecraft crews should not proceed on any mission without demonstrated viability of all planned contingency modes.

Operations and Life Cycle Costs

Operations and life cycle costs for outer planet and interstellar missions will have the benefit of earlier lunar and Mars activities. As technology and materials improve, we expect the life cycle costs to continue to decline. Operations costs should also decline with increased reliance on automation and artificial intelligence systems. Most of the operations costs will be shared with other space operations activities. If commercial space infrastructure and self-reliant colonies and outposts have made sufficient progress, the operations costs could be quite reasonable in comparison to the costs likely to be associated with government ownership and operation.

In general, space infrastructure elements (spaceports, servicing platforms, outposts, colonies, etc.) should be multifunctional with a lead capability in one or more assembly, servicing, test and/or refueling functions. Each space infrastructure element will likely have some natural advantage which allows it to more cost-effectively perform certain functions. For example, a dedicated orbiting facility to conduct hazardous servicing operations or safe and recover from contingency situations might be an area of emphasis. While Earth orbiting platforms in this area are essential, the Mars Spaceport might specialize in major cleanup jobs involving nuclear radiation and matter/anti-matter systems.

To develop multifunctional facilities with special areas of emphasis, commercial involvement to add space infrastructure capabilities should be greatly encouraged and supported. In addition, the primary logistics routes between Earth, Spaceport Earth and the Lunar Outpost should eventually be a commercially bidded and operated activity. Multiple companies and vehicles should be simultaneously involved. Logistics between Earth, Spaceport Mars and the Mars colony/outposts could be supported by a combination of commercial and government funded efforts (ref 14). Logistics to the outer planets including Neptune and the Triton outpost will probably remain government funded until very advanced transport vehicles are more commonly available.

While it may or may not reduce operations costs, command and control, crew training and degrees of payload integration should be distributed among space infrastructure elements. Operations efficiency and safety are great benefactors of a planned distributed approach.

RESEARCH AND DEVELOPMENT OPPORTUNITIES AND SUGGESTIONS

The author has argued that support for manned interstellar missions will be dependent on the development of technology which will "effectively" enable a spacecraft to travel faster than the speed of light. Without faster than light capability even the nearest stars (Alpha Centauri A is 4.35 light years away) requires a 40 year round trip time. The more interesting planetary systems are likely to be found around more distant stars such as Epsilon Bootes which is 114.1 light years away. Epsilon Bootes is a single star with a size much like that of our star, the Sun.

Recent theoretical studies, such as those associated with Superstring Theory, twistors, and other theories, point to the potential existence of higher dimensional physics. If the Superconducting SuperCollider does allow us to detect a Higgs boson, which may have linked the primary forces in the early universe, then the motivation for finding a means for interacting with the remnant hyperfield physics will be greatly increased. Even with the absence of such evidence there are R. & D. approaches which the author believes are worthwhile pursuing today to attempt to uncover "shortcuts" through space-time or to eliminate the speed of light restrictions which space-time imposes.

While specific attempts at resonant interactions with hyperfield physics are needed, a review of past and future experimental tests in other areas might also be useful. Experimental activity (ref. 5) associated with (1) plasmoid generation and anomalous magnetic flux replenishment (Los Alamos National Laboratory), (2) macro spin physics (Japan), (3) NASA gravity wave interferometer detector, (5) microfield anomalies in high temperature superconductors, quasi-crystals and other microengineered materials and (6) electromagnetic pulse tests should be examined.

New technology and research tools are available to assist in specific research. The tools include: (1) high temperature superconductors, (2) compact superconducting magnets with very high magnetic fields, (3) free-electron lasers, (4) high power, tunable microwave systems, (5) quasicrystals, (6) Superstring Theory, (7) microengineered materials

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with optical and magnetic "tailoring," (8) plasmoid generators and (9) supercomputers. These tools coupled with fundamental insight into the physics of the universe can lead to some startling technology systems.

The following suggestions for research into space-time disengagement or faster than light systems have not, to the author's knowledge, been pursued to any significant degree. Perhaps when these suggestions and others are pursued seriously the spark of insight which these suggestions represent will result in the igniting of a brilliant flame. Think of the enthusiasm which could be generated in students who are asked to examine these and similar ideas — who are encouraged "to go where no students have gone before."

Since there is no effective way of explaining these suggestions in a comprehensive way in this paper, these suggestions are best viewed as stimulation for the generation of your own ideas.

- Microwave/pulsed B field interactions with or without topologically, microengineered structures.
  - Could create microscopic discontinuities in space-time leading to macro-boundary discontinuities.
- Magneto-optical interactions for topological bending of light fields.
  - Could stimulate gravitational field interactions and space-time disturbances.
- Laser/plasma boundary generation – "light fluid."
  - Could create photon lattice-like structure enhancing and enlarging quantum field fluctuations.
- Topological patterned ferrofluid boundary – EM wave excitation.
  - Could create resonance with remnant hyperfields, generating artificial "space-time bubble"

SUMMARY

Mankind has a great future in space awaiting it if we allow our innate frontier spirit to carry us forward. We can not afford to shy away from the challenges which we face in the development of cost-effective orbiting space infrastructure and associated operations. By looking ahead we can acquire a perspective which will help us make the right decisions in our near-term space development activities, such as Space Station Freedom evolution, lunar utilization and outpost and Mars exploration and outpost development.

The same approach which is used to assembly and test a manned Mars transfer vehicle will likely be applicable to manned outer planet and interstellar missions. Earth, Mars and Neptune/Triton spaceports and outposts will provide a very effective performance testing "safety net." Standardized, verified and consistently improved procedures and approaches for assembling and testing hazardous elements and systems should be primary goals of all exploration/colonization missions.

Manned interstellar propulsion will require faster than light propulsion to be economically justifiable. Even if mankind's survival were at stake so that the economics of sub-light propulsion were acceptable, we should still be challenging the speed of light constraint. Focused research and development activities by our national laboratories addressing these and other challenges of deep space missions should be started now (not a 100 years from now). These activities will help maintain our leadership in new technology and encourage new levels of student motivation and interest in science and math, both of which are critical to our nation's and mankind's future.

REFERENCES

1. "Pioneering the Space Frontier, Our Next 50 Years in Space," National Commission on Space, 1986.

2. Connolly, D. J. and J. Lazar, "Aerospace Applications of High Temperature Superconductivity, Power and Propulsion," AIAA/Hampton Roads Section, Invited Lecture Series, April 13-15, 1988.

3. Stone, J. R. "Recent Advances in Low-Thrust Propulsion Technology," NASA Lewis Research Center, AIAA/ASME/ASEE 24th Joint Propulsion Conference, AIAA-88-3283, July 11-13, 1988.

4. Holt, A. C. "Space Station Support of Manned Mars Missions," NASA Study Report, Manned Mars Mission, 1986.

5. Protective Force Field Feasibility Study, Final Report, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, OH and NASA, A. C. Holt, August 1988.

6. Holt, A. C., "Automation and Robotics and In-Flight Training for Manned Mars Mission," NASA Study Report, Manned Mars Mission, 1986.

7. Holt, A. C. "Space Station Freedom: Accommodations for Technology R. & D.," AIAA/ASME/SAE/ASEE 25th Joint Propulsion Conference, Monterey, CA, July 10-12, 1989.

8. Holt, A. C. "Space Station Freedom: Technology R. & D. and Test Facility for the 21st Century," Proceedings of the Third Pacific Basin International Symposium on Advances in Space Science Technology and Its Applications (PISSTA), Los Angeles, CA, March 6-8, 1989.

9. A Radiological Assessment of Nuclear Power and Propulsion Operations Near Space Station Freedom, NASA Lewis Research Center Contractor Report 185185, W. E. Bolch, J. R. Thomas, K. L. Peddicord, P. Nelson, D. T. Marshall and D. M. Busche, Texas A&M University, College Station, Texas.

10. Holt, A. C. "Electromagnetic Braking Techniques for Mars Spacecraft," AIAA Joint Propulsion Conference, Huntsville, Alabama, June 17, 1986.

11. Space Station Operations Task Force Summary Report, NASA Space Station Freedom Program Office, October, 1987.

12. Holt, A.C., "Mobile Robotics and Artificial Intelligence for Large Payload Assembly and Maintenance", AIAA Eleventh Annual Technical Symposium, NASA Johnson Space Center, June 4, 1986.

13. Manned Mars Missions Working Group Papers, Volume I and II, NASA M002, June, 1986.

14. Holt, A.C., "Space Station to Mars Supply Depot", Tenth Annual Technical Symposium, NASA Johnson Space Center, May 10, 1985.

15. Comstock, D.A. and J. Maloney, "STV Accommodations at Transportation Node", Presentation to Space Station Transition Working Session (NASA Langley Research Center), General Dynamics Space Systems Division, May 1, 1989.

16. Fusion Propulsion Study, Astronautics Laboratory, Air Force Space Technology Center, Edwards AFB, AL-TR-89-005, V.E. Haloulakos (McDonnell-Douglas Space Systems) and R.F. Bourque (General Atomics), July, 1989.

17. OAST Technology for the Future, Executive Summary, NASA In-Space Technology Experiments Workshops, NASA Office of Aeronautics and Space Technology, NASA Headquarters, December, 1988.

18. On-orbit Assembly/Servicing Task Definition Study, GFY 1989 Summary Report, Kennedy Space Center, NAS 10-11400, R. Vargo, F. Mitchell, K. Flemming, M. Willis, McDonnel-Douglas Space Systems, November, 1989.

19. Evolutionary Space Station Fluids Management Strategics, Contract Final Report, NASA Lewis Research Center, GDSS-CRAD-89-002, General Dynamics Systems Division, San Diego, August, 1989.

20. R.L. Forward and J. Davis, Mirror Matter, John Wiley & Sons, Inc., New York, 1988.