

SPACE STATION TECHNOLOGY TESTBED: 2010 DEEP SPACE TRANSPORT

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Abstract

A space station in a crew-tended or permanently crewed configuration will provide major R&D opportunities for innovative, technology and materials development and advanced space systems testing. A space station should be designed with the basic infrastructure elements required to grow into a major systems technology testbed. This space-based technology testbed can and should be used to support the development of technologies required to expand our utilization of near-Earth space, the Moon and the Earth-to-Jupiter region of the Solar System. Space station support of advanced technology and materials development will result in new techniques for high priority scientific research and the knowledge and R&D base needed for the development of major, new commercial product thrusts. To illustrate the technology testbed potential of a space station and to point the way to a bold, innovative approach to advanced space systems' development, a hypothetical deep space transport development and test plan is described. Key deep space transport R&D activities are described would lead to the readiness certification of an advanced, reusable interplanetary transport capable of supporting eight crewmembers or more. With the support of a focused and highly motivated, multi-agency ground R&D program, a deep space transport of this type could be assembled and tested by 2010. Key R&D activities on a space station would include: (1) Experimental research investigating the microgravity assisted, restructuring of micro-engineered, materials (to develop and verify the in-space and in-situ "tuning" of materials for use in debris and radiation shielding and other protective systems), (2) Exposure of microengineered materials to the space environment for passive and operational performance tests (to develop in-situ maintenance and repair techniques and to support the development, enhancement and implementation of protective systems, data and bio-processing systems and virtual reality and tele-presence/kinetic processes), (3) Subsystem tests of advanced nuclear power, nuclear propulsion and communication systems (using boom extensions, remote station-keeping platforms and mobile EVA crew and robots), (4) Logistics support (crew and equipment) and command and control of deep space transport assembly, maintenance, and refueling (using a station-keeping platform).

Introduction

In the exploration of all of humanity's great frontiers, there have always been frontier outposts which served as major hubs of activity in the pursuit of frontier resources and new living opportunities. Sometimes these outposts were established where a very obvious need existed and the benefits were very clear. At other times, they were not. In these cases, it was only after the outpost or fort had been in place for some time, did the real benefits become clear.

Depending on your perspective, the Space Station, our first permanent, international outpost in Earth orbit, can fall in one of these two categories. The obvious benefits may not turn out to be the most important, and as a result its overall importance in this stage of humanity's progress, may be greatly underestimated.

To help provide a broader framework and perspective of the potential value of a frontier outpost in Earth orbit, the potential role of a space station in developing the first reusable, interplanetary transport is described. Since it is hard to talk in generalities for something which lies beyond our normal experience, a specific design concept of a deep space transport has been developed. While it would be quite a coincidence if the first transport is similar to the design concept presented, it nevertheless encompasses the key elements which any future interplanetary transport must consider.

By focusing on a deep space transport which has capabilities which may not be used for another 20 to 50 years or more, it is easier to see the R&D path we might follow to develop equally valuable, interim technologies and materials. These interim technologies might greatly enhance lunar transport logistics, help jump-start the development of a Mars outpost and begin the human exploration of the outer planets.

2.0 Space Station Growth Technology Testbed

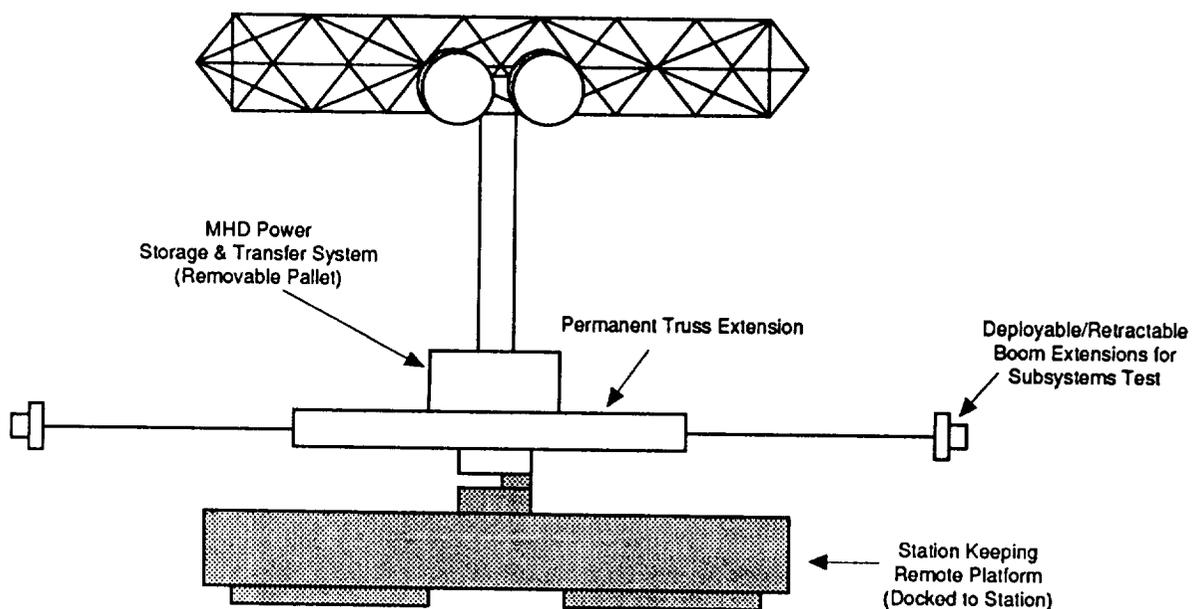
Several options exist for growth paths for a space station. There are, however, some key elements which are essential to a space station's technology test-bed potential (1-3).

Since some of the subsystems test and R&D activities involve the use of high strength electromagnetic fields and a station-keeping platform, a means must exist to separate the focal point of the external test activities from the pressurized modules and perhaps from the Shuttle docking envelope. For most space station configurations this separation could be fairly easily provided by extending a small truss down from a main horizontal truss or module (see Figure 1). The distance required would depend on the strength of the electromagnetic fields being used and the rendezvous and docking corridors for the Shuttle and the station-keeping platform.

The station keeping platform's importance varies with the phase of test bed and research activities being conducted. In early phases, almost all of the testing could be conducted on the space station. Later, however, advanced propulsion and power systems with inherently higher risks may require the use of a platform which can move away from the station, conduct tests and then return to the station or its vicinity. Large scale assembly activities could use both the station and the platform as assembly "strongbacks" and as assembly and maintenance "depots".

Pressurized laboratories provide many options for the testing of advanced data and sensing subsystems. Truss structure and other exposed surfaces can provide opportunities for materials and shielding system tests. A thoughtfully designed space station has an inherent capability to grow in ways which can directly support humanity's continued drive to establish a permanent human presence on another planet and a greater understanding of the universe in which we live.

Figure 1. Growth/Technology Testbed Configuration.



3.0 Deep Space Transport Concept

3.1 Advanced/Innovative Systems

The deep space transport concept is designed to function as a logistics and personnel transport to Mars and as an outer planet exploration transport. This particular concept includes 13 major elements which could be launched by the Space Shuttle and Titan IVs. Many of the components (especially the modules) are similar in design to proposed space station elements (see Figures 2-4). The potential exists for substantial cost savings if many of the same components could be used and if a decision for keeping station manufacturing lines open could be made soon enough.

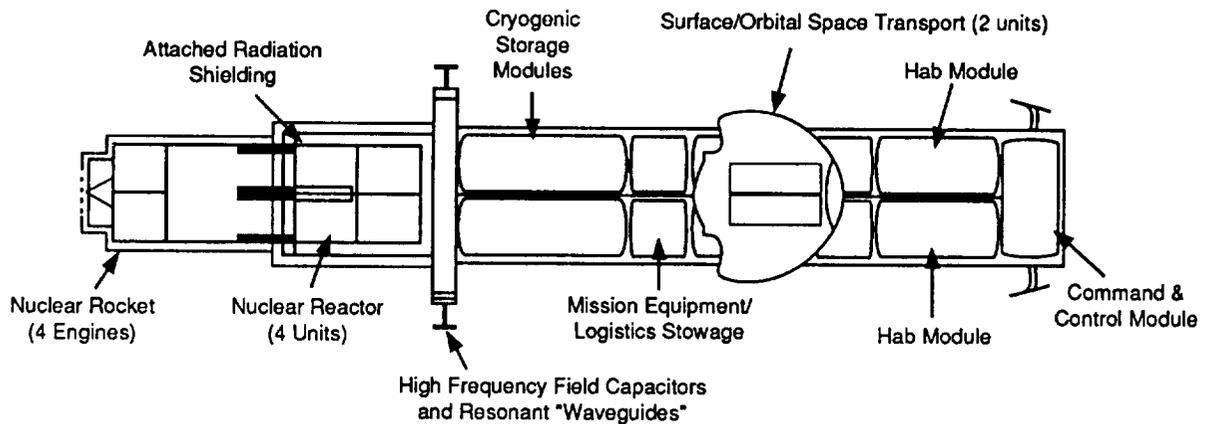
The deep space transport includes a nuclear energy generation system, a nuclear propulsion system, two cryogenics storage modules, two mission equipment/logistics storage modules, two habitability modules, a command and control module, an advanced MHD propulsion system and two surface/orbital transports. Advanced radiation and meteoroid/debris shields consisting primarily of micro-engineered materials are built into the outer surface of the elements. An additional layer is added after the transport element assembly is completed. Micro-engineered materials are also used for advanced data management, communication and environmental control systems. Structurally embedded maintenance diagnostics and in-situ repair techniques are also used.

Nuclear Power and MHD Energy Storage System

Nuclear power systems are absolutely essential to deep space exploration and are almost as critical for a space transport used exclusively for transport to and from Mars⁽⁴⁾. The availability of a compact high energy density storage system could reduce the reliance on nuclear fission or fusion systems. Compact solar arrays or chemical systems would serve as emergency backups.

There are several types of nuclear power systems which could be used^(5, 40, 50, 56, 59, 61). A fusion system is clearly advantageous if the weight and maintenance requirements are comparable. Reliability would remain a key factor, however. Therefore, four independent fusion reactors are used in this concept. To store and condition the high currents needed for the field interactive propulsion and protection system and for the charging of the Mars orbit-to-surface transport MHD system, MHD superconducting electrical energy storage systems are provided (see Figure 3)⁽⁶⁾.

Figure 2. Deep Space Transport.



- 13 Major Elements
 - 2 Nodes = 1 Major Element
 - Field Capacitors, Extension Booms, Energy Channels and Radiation Shielding = 2 Major Elements
- Each Major Element Requires a Space Shuttle or Titan 4 Launch

PROPULSION

- Impulse - RCS (H_2O_2)
 - Nuclear Pulse Rocket
- Field Transformer

POWER SYSTEMS

- Emergency Batteries - Fuel Cells
- MHD Storage/Transform System
- Nuclear Reactors (4)

MAJOR ELEMENTS

- Cryogenic Storage Modules (2)
- Logistics/Lab Modules (2)
- Habitability Modules (2)
- Command and Control Module

LANDING/ORBITAL CRAFT (2)

Figure 3. Mars Surface-To Orbit Nuclear Space Transport.

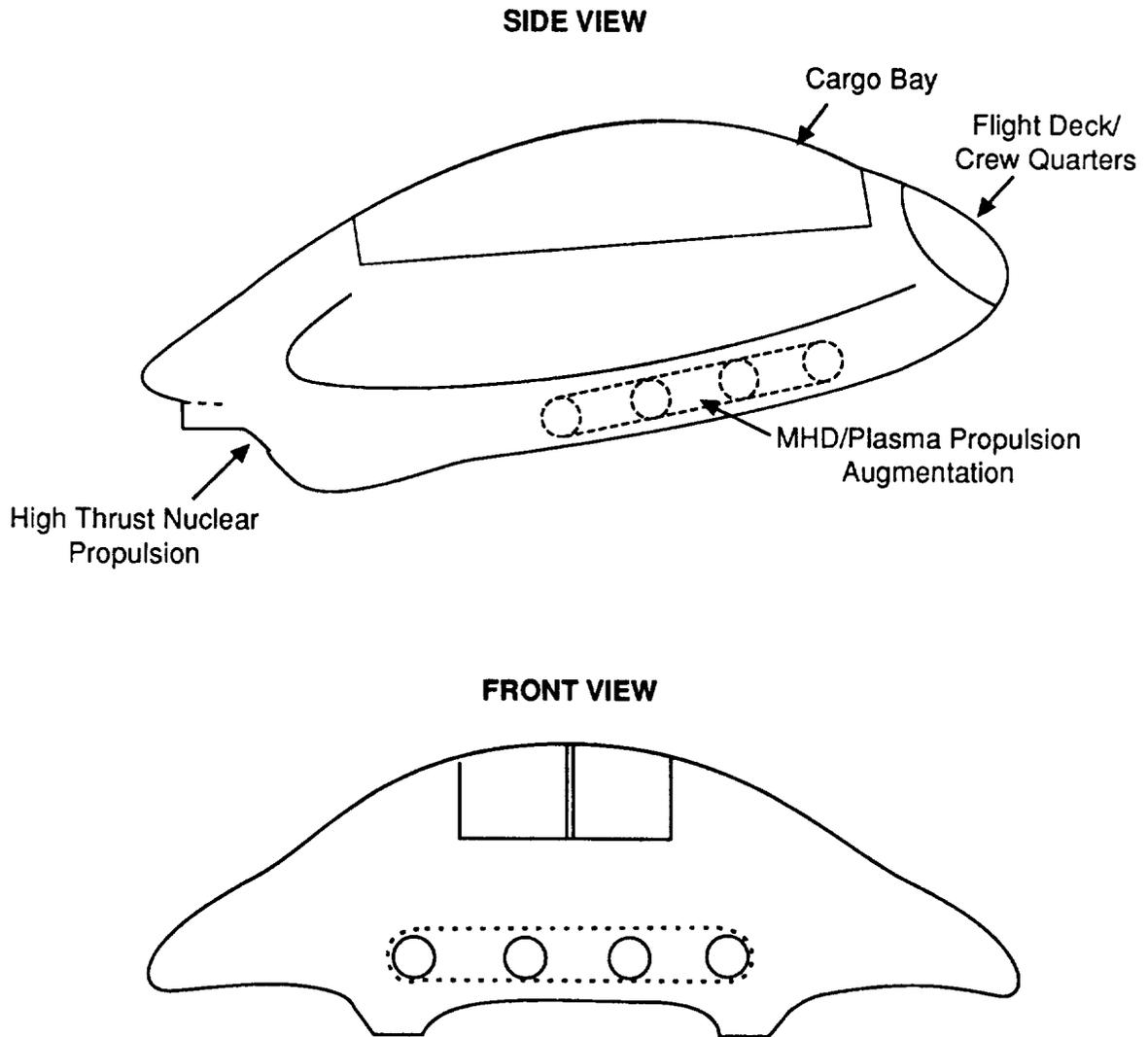
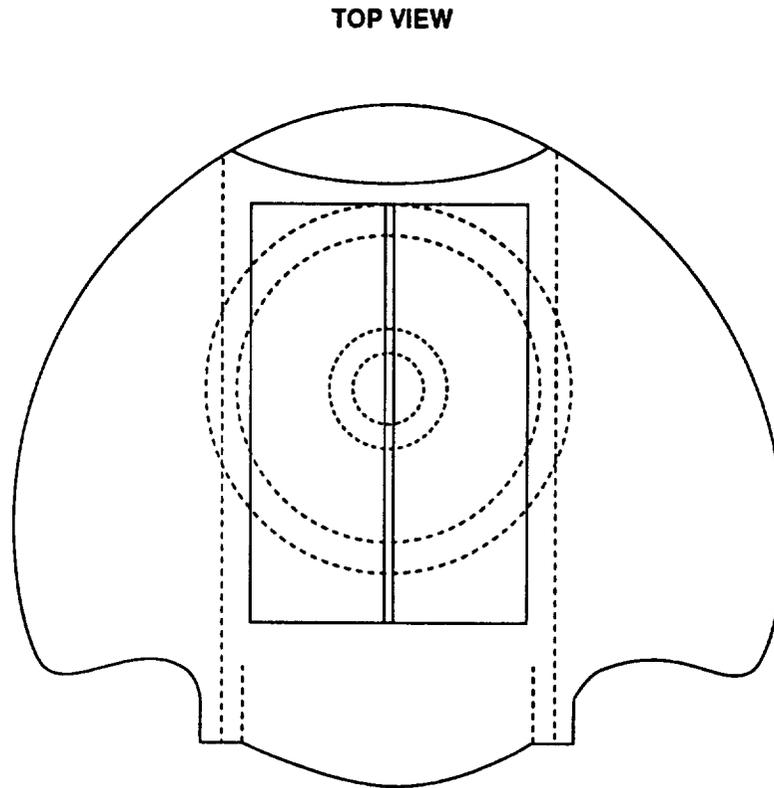


Figure 4. Mars Surface-To Orbit Nuclear Space Transport.



Nuclear and Field Interactive Propulsion Systems

Nuclear propulsion is clearly the next critical step in space propulsion. The term nuclear propulsion is used here in the broad sense and could cover particle and anti-particle energy conversion as well as advanced fission and fusion systems^(7-9,66). While nuclear fusion should be a viable candidate for a 2010 spacecraft, the nuclear propulsion system is not dependent on a fusion system being available. Nuclear propulsion, in the sense described, is still a big step behind the propulsion which will be needed to insure the viability of outposts and colonies in the Solar System and eventually to leave our star system.

Field interactive propulsion is a generic term covering a wide variety of electromagnetic, nuclear and gravitation field dependent propulsion types^(10,35,52,60,65). These could range from a nuclear fusion MHD propulsion system^(11-12,62,64) to exotic systems which screen or distort the gravitational field or jump across the space-time barrier^(13-12,34,38,45,49,63). Both MHD propulsion types are utilized in this concept. The deep space transport uses a field screening/distortion technique to augment the nuclear propulsion impulse. The orbit-to-surface Mars transport also uses nuclear and MHD propulsion.

Protective Shielding and Systems

New types of protective shielding and systems are needed to improve radiation protection^(53,55) and protection from micro-meteoroids and debris (in Earth orbit). The new shielding is expected to evolve from electromagnetically enhance composites or micro-engineered materials^(18,39). Some of the shielding required could be a by-product of the field interactive propulsion system⁽¹⁹⁾.

Active protective systems, such as a free-electron laser system, would be included to better deal with all types of potential collision situations⁽²⁰⁾. Systems which incorporate directed energy soliton resonance effects are also assumed to be utilized^(21-22,57).

Regenerative Life Support

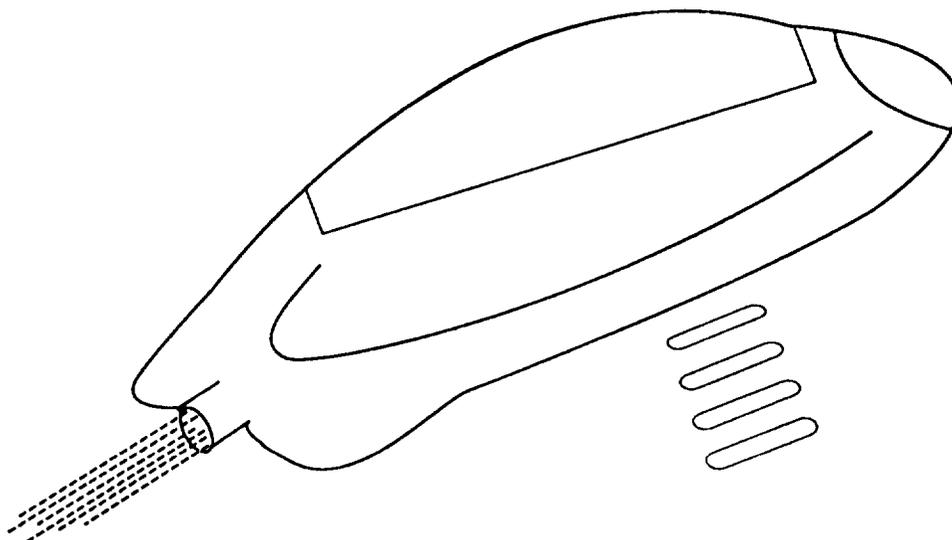
Great strides in regenerative life support should be achievable using structurally embedded micro-environment sensors and processors. Closed cycle systems are assumed to be available and reliable.

Mission Equipment

The mission equipment includes two Orbit-to-Surface transports which use nuclear and MHD propulsion (see Figure 5)^(23-25,37,43,44,58). The transports are capable of carrying cargoes which exceed those of the current Space Shuttle to and from a planetary surface. Other mission equipment would include key equipment for the start-up of an outpost (assumed to be initiated with the coordinated landing of an unmanned logistics transport).

Extensive orbital and surface diagnostic and sample gathering equipment would be included. Special equipment to interact with simple and more complex life forms would be available.

Figure 5. Nuclear Space Transport Take-Off/Landing Concept



3.2 Assembly and Test Scenario

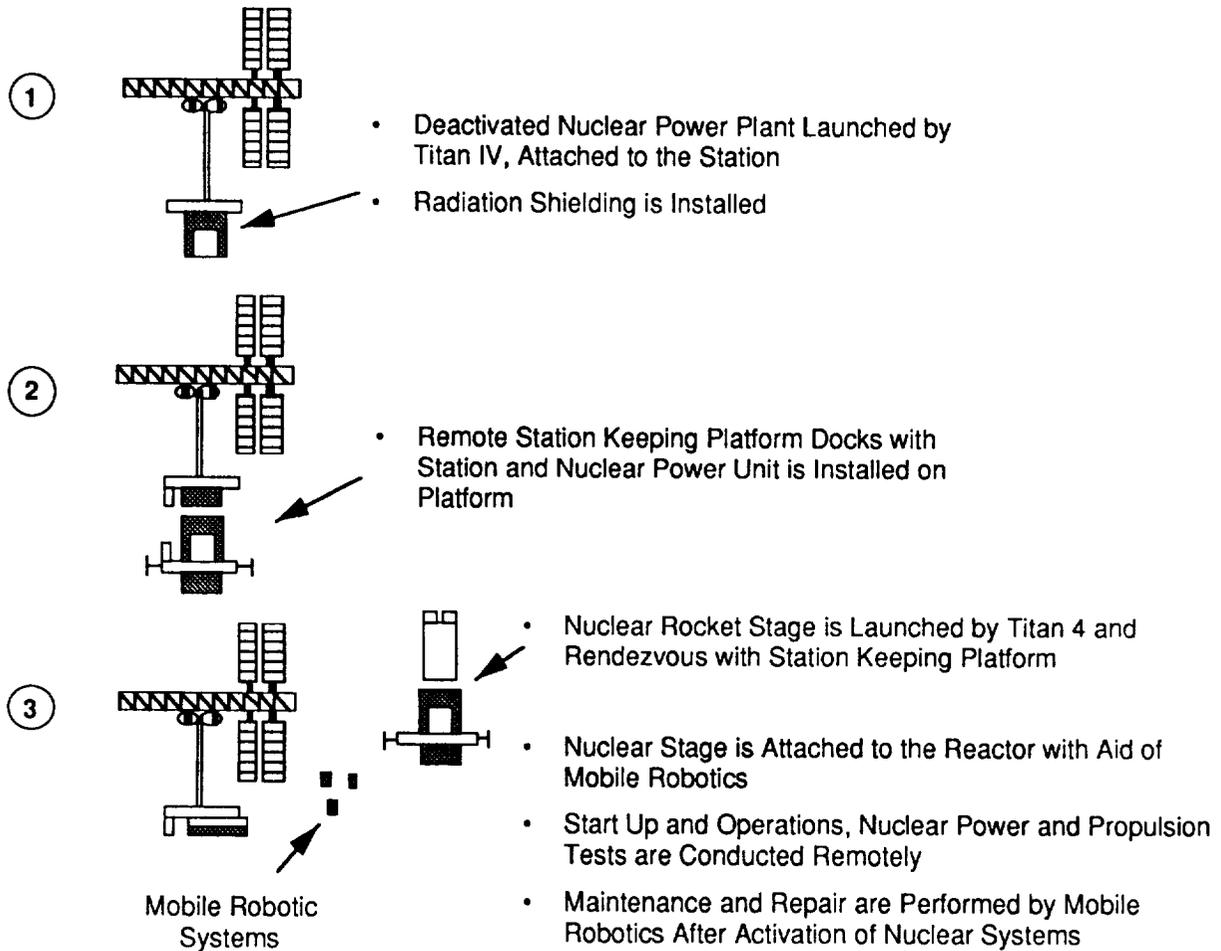
Several basic paths can be followed in the development and qualification of a deep space transport ⁽²⁶⁾. The easiest approach would be to build the entire transport on the ground and launch it into orbit in one effort. This might be possible with a super heavy lift launcher or with the utilization of a gravitational field screening technique. But neither approach is currently very viable in the absence of demonstrated capabilities in these areas.

A smaller number of launches with the use of a heavy lift vehicle might be reasonable, but with no new starts in this area underway there would be readiness risks even for a 2010 space transport development. Therefore, the assembly and test scenario used assumed that a series of Space Shuttle and Titan IV launches would be required to bring up components to be assembled in space. While some of these components could be assembled automatically or with minimal support from the Space Shuttle, many of the components require other assembly support to avoid driving costs up needlessly. Therefore, it is assumed that the space transport would be assembled with the support of a space station and a station-keeping platform.

The station-keeping platform allows hazardous elements to be tested at a safe distance from the station (such as nuclear power and propulsion systems). The platform can also serve as a "strongback" for the assembly process and can assist in assembly operations support. The scenario selected is one of many which could utilize a space station and a station-keeping platform. The scenario illustrates the need for a space crane and mobile robotics capabilities.

Figures 6-8 depict the assembly and test scenario steps. In step 1 (see Figure 6) an inactive nuclear power plant is launched by a Titan IV and attached to the extended boom below the space station. Additional radiation shielding is then installed around the power plant. In step 2, a previously launched, station-keeping platform docks with the station and the nuclear power unit is transferred to the platform using station and platform robotics.

Figure 6. Assembly and Test Scenario



In step 3, a nuclear rocket stage is launched by a Titan IV and rendezvous with the station-keeping platform (the platform can be the active agent). The nuclear stage (and small cryogenic fuel tank) is attached to the reactor with aid of mobile robotics (and EVA crewpersons if necessary) from the station nearby⁽²⁷⁻²⁸⁾. The platform then moves away from the station and the nuclear reactor is powered up. Following a checkout period, the nuclear rocket stage is fired and its performance is assessed. Subsequent maintenance and repair tasks on the nuclear systems are performance by mobile robotics⁽²⁹⁾.

Space Shuttle and Titan IV launches bring other components of the space transport to the station in step 4 (Figure 7) cryogenic tanks, logistics/mission equipment modules, habitable modules, connecting nodes and a command module are assembled and checked out at the station. During this timeframe, field interactive propulsion components are launched by a Titan IV (or Space Shuttle) and attached to the nuclear power module on the platform using fixed robotics on the platform (or mobile robotics from the Shuttle).

In step 5, the station-keeping platform is maneuvered to the station and is attached to the assembled modules using the platform manipulator. The nuclear energy and propulsion stages are detached from the platform and added to the module assembly. Additional radiation and micro-meteoroid and debris shielding are added as well as field capacitor channels and antenna for the MHD propulsion system. The entire assembly is detached and eased away from the station with the help of the platform. Once the assembly is at a safe distance, nuclear systems are re-activated and integrated performance and integrity tests are conducted in the station's vicinity.

Following any maintenance and repair required after integrated checkouts near the station, medium performance runs are conducted in low Earth orbit (step 6, Figure 8). These are followed by full up system tests (no crew) during a lunar flyby with a return to a high Earth orbit. Following a "cool down" period, the transport is brought down to the station's altitude by the platform or a space tug. At a TBD distance from the station maintenance, repair and crew habitability activation and final environmental integrity checks are conducted.

In step 7, the two Landing/Orbital Maneuvering craft are launched and attached to the station for some initial checks with the crew. They are then transported over to the deep space transport and installed in their stowage locations.

Figure 7. Assembly and Test Scenario (Continued)

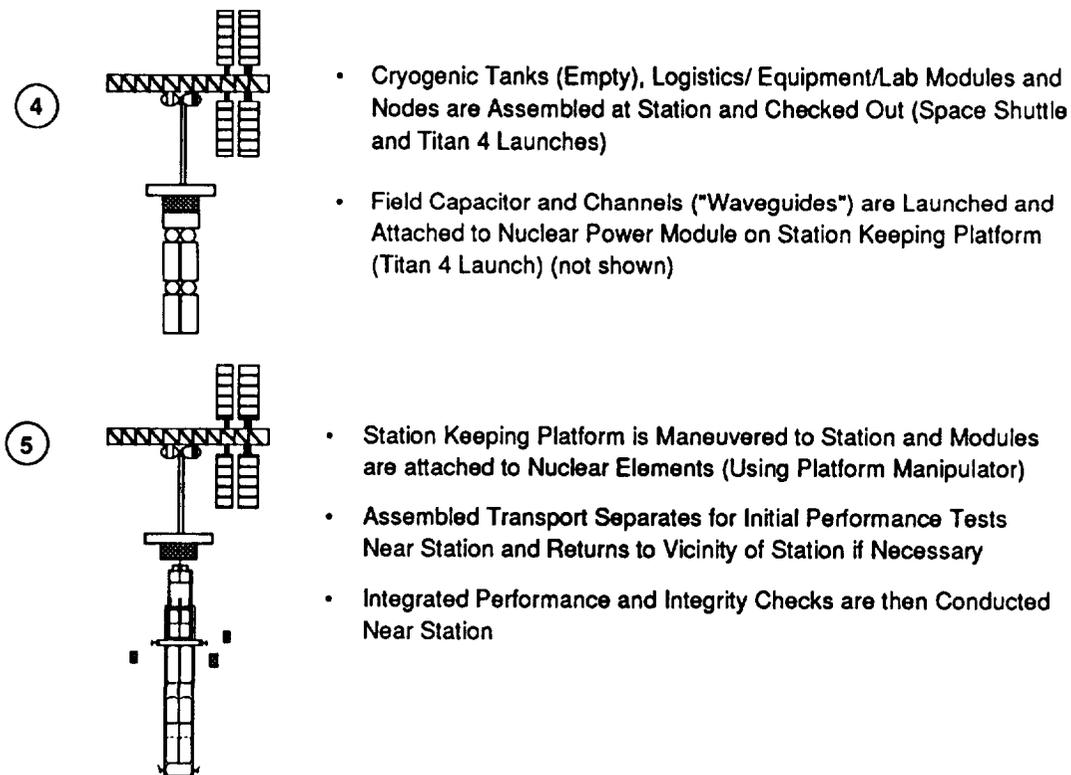
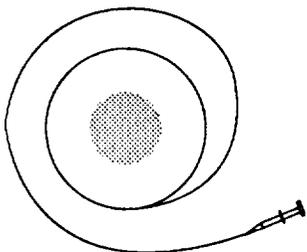


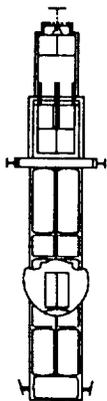
Figure 8. Assembly and Test Scenario (Continued)

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- Following Checkout Run Near Space Station, Full up Systems Test (no crew) is Conducted on Lunar Flyby; Return is to High Earth Orbit
- Transport Returns to Station Keeping Platform which Maneuvers it TBD Distance from Station to Conduct Maintenance, Repair and Crew Habitability Activation and Integrity Check (30 day stay)

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- Landing/Orbital Maneuvering Craft (2) are Launched, Assembled and Checked Out at the Space Station and then Transferred to and Attached to the Deep Space Transport

4.0 Advanced Space Transport R&D and Tests

In this section, specific examples of R. & D. and test activities are described which could be accomplished on or near a space station which has a growth capability. All of these R. & D. activities would be preceded by or would be conducted in parallel with extensive ground development and testing. For some of these activities, an extensive ground testing program followed by operational checkouts in space and subsequent refinements could be sufficient. For others the use of very fast, advanced computers, could greatly minimize space R. & D. requirements. All of the R&D activities, however, will benefit from developmental and test opportunities on the space station. For a few activities, the in-space R&D opportunity appears to be critical to success.

4.1 Micro-Engineered Materials R&D

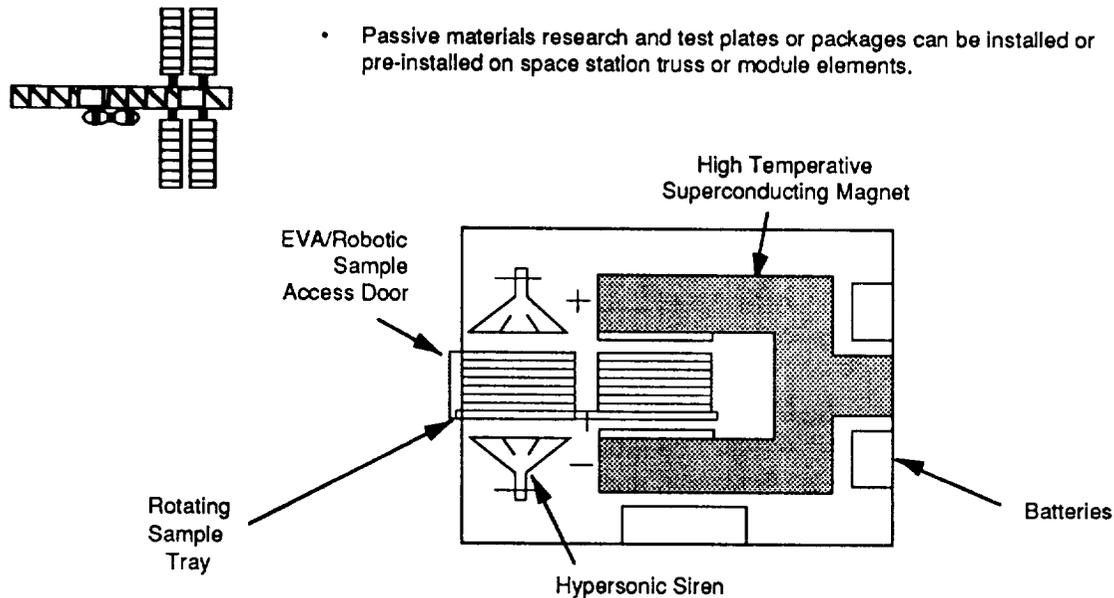
Extensive research is currently being conducted to develop and investigate new types of materials and atomic and molecular interactions: fullerenes, atomic clusters, high temperature superconductors, conducting plastics, etc.⁽¹⁸⁾⁽³⁰⁾. The use of micro-engineering materials for sensors and actuators which are embedded in structural surfaces continues to increase in aerospace and non-aerospace applications. New forms of micro-engineered materials are beginning to take shape which have a great potential for reducing space infrastructure construction costs, while greatly increasing performance.

During the Space Shuttle/Spacelab flights and on the MIR space station, extensive research has already been carried out on the effects of a microgravity environment on the formation of materials. Much higher quality crystals, metal welds and a better understanding of fluid and other molecular processes have resulted. The research summarized in Figure 9 represents a specific approach to altering layered/micro-engineered materials by combining the effects of microgravity with high strength magnetic and acoustic fields. The objective of this research is to develop materials with enhanced and new properties. In particular, materials which can respond in new non-linear ways to these kinds of fields.

The microgravity environment allows the atoms to be rearranged in ways which would not occur in an one-G environment or which would occur only with greatly difficulty or by chance. As with many materials research approaches, one of the objectives would be to find a way to duplicate beneficial results on the ground⁽⁴²⁾. But we also have to be prepared to acknowledge that it may not be possible to get the same results on the ground, until we find ways of neutralizing the gravitational force effects on the ground.

The payload described in Figure 9 is a payload which could be attached to a truss segment or module surface of a space station. It would be initially designed to be independent from station services (power, data, etc.). High energy density batteries, solar cells and a superconducting storage medium could be used to conduct small scale tests on samples. The samples could be installed and removed by the Canadian robotic arm or by an EVA crew member during the conduct of other tasks.

Figure 9. Microgravity Restructuring of Microengineering Materials (Example Only).



- Passive materials research and test plates or packages can be installed or pre-installed on space station truss or module elements.

- Passive package uses batteries, solar cells and superconducting magnet to generate, store and transfer power
- One-half of test package has solar cells and other half exposes a variety samples to space environment for analyses

4.2 Debris and Radiation Shielding

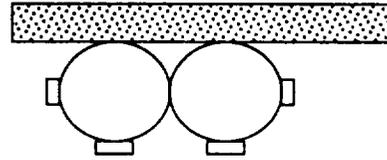
Advanced shielding techniques and materials using microengineered materials have already been proposed⁽¹⁸⁾. The new composite materials would be initially tested on the ground, and when feasible in space environment simulators. The availability of extended, external surface areas on a space station would provide many opportunities for testing the effects of the space environment on these new shielding materials. In addition, the new materials could be overlaid over the top of existing shielding materials providing some augmentation and increased safety margins while their space environment feasibility is being evaluated.

Some of these materials will utilize the effects of electromagnetic fields to alter or enhance the shielding properties (see Figure 10). This is particularly true for the type of shielding materials assumed for the deep space transport. In fact, the shielding materials or layers will serve several purposes. The deep space transport protection system will provide radiation and micro-meteoroid/debris shielding, provide sensing and transmitting functions (reacting to physical disturbances and field effects) and will play a key part in the implementation of the field interactive propulsion system.

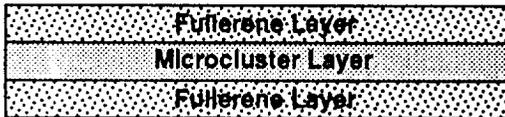
Figure 10. Debris and Radiation Shielding Tests.



- Shield units tested on external truss and returned for analysis



- Shielding units attached to external part of module debris shielding
 - Measurement of radiation penetration made inside module under "cone" of shielding material



Example of Advanced Debris/ Radiation Shielding Approach

4.3 Micro-Engineered Data and Bio-Processing Systems

The virtual explosion of new materials with new properties in the past few years promises some major advances in data and bio-processing systems and techniques^(31-33, 41, 46, 54). With the exception of those materials requiring a microgravity environment for development, most of the materials will be developed and tested on the ground. However, because these micro-systems would be dispersed throughout module structures and surfaces (i.e., they do not have a traditional macro systems' hardware and software configuration or maintenance approach), their operational effectiveness and usefulness will need to be tested in operational space environment.

The primary goal of this R&D effort would be the development of micro-engineering techniques which would allow the dispersal of atomic clusters, polymers, etc. throughout external and internal surfaces to essentially achieve built-in, multiple, redundant data and power transfer systems (See Figure 11). Fiber optics and electrical cables may be installed, but they would be used as backup systems in an advanced vehicle.

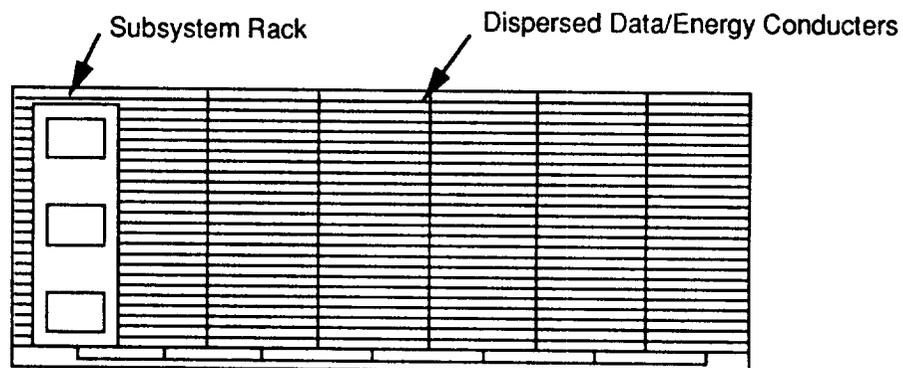
Crew members must gain some familiarity with the difference in operational interfaces for these micro-systems to help determine how best to phase in these capabilities in new vehicles and to determine where the benefits outweigh other operational considerations. For example, hand held lasers could be used to obtain access to data (i.e., create a screen) anywhere over a large surface. This capability may be quite useful in some activities or areas of the station or transport, but could constitute an "overkill" in others.

In addition to nominal operational considerations, techniques for surface and sub-surface maintenance and repair will have to be developed and evaluated. The design approach would try to make the dispersed system immune to minor surface damage or localized failures or sufficiently redundant to avoid having to make repairs until the density of failures exceeded a certain level. In-situ repair techniques using advanced microengineered materials (sensors and actuators) would be implemented and tested. Techniques for replacing sections would be developed and tested.

While much ground work would go into perfecting and evaluating these techniques, on-orbit operational tests have a way of identifying practicality considerations which are sometimes difficult to highlight in any other way. Confidence in the capability of a new approach is also very important. Crew members and managers should have the opportunity to evaluate the operational effectiveness of these types of systems in space, before committing them to use as the primary design approach in a new vehicle or for certain vehicle components.

Figure 11. Micro-Engineered Data and Bio-Processing.

- Goal would be to develop micro-engineering techniques which would allow the dispersal of atomic clusters, polymers, etc. throughout external and internal surfaces to essentially achieve built-in multiple, redundant data and power transfer systems
- Fiber optics and electrical cables may be installed, but would be used as backup systems in advanced vehicle
- Feasibility of approach is dependent on developing in-situ techniques for surface maintenance and repair



- Access to dispersed data network is initially accomplished via induced "nexus", generated by hand held laser. Power network could be accessed in a similar manner.

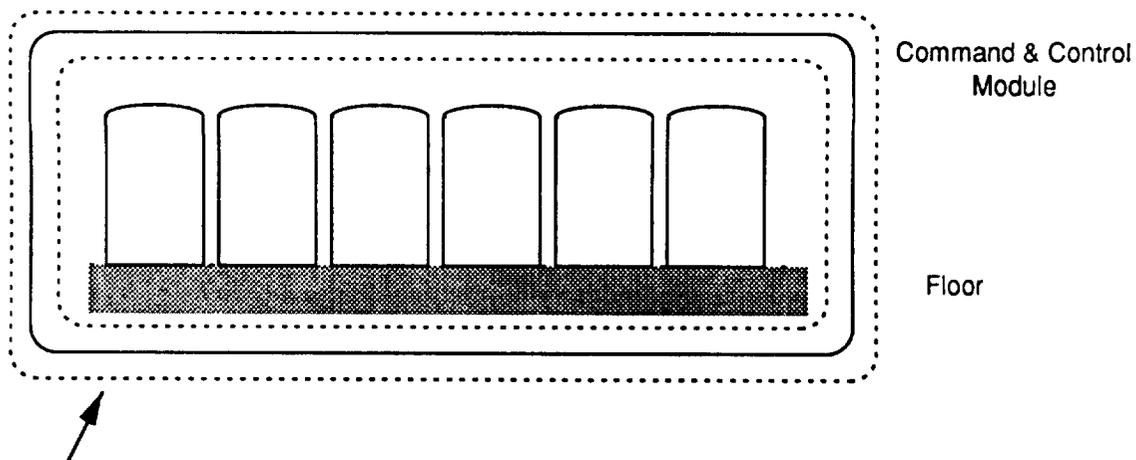
4.4 Dispersed Virtual Reality and Telepresence/Kinetics

Robotic capabilities and applications will continue to expand in space activities, especially where the benefits clearly exceed the capabilities of an EVA or IVA crewmember. This criteria is dependent on the ability of robots to duplicate as much as possible the sensory data which a crew member normally has access to and to exceed that capability in critical areas. The dispersal of micro-sensors and transmitters throughout external and internal structural materials (in a cost-effective manner) would greatly contribute to the usefulness of robotic systems.

Figure 12 depicts a command and control module which has external and internal structural or shielding layers through which micro-sensors and transmitters have been dispersed. This capability could be used to provide a window to the outside where no physical window exists in a direct mode. For example, embedded fiber optics or atomic channels in the material could directly amplify and route photons impinging on the outer surface to any inner surface, including a crew member's IVA or EVA virtual reality helmet.

Similar micro-sensors/transmitters dispersed in external equipment surfaces could be used to direct the activities of a robot in much the same way that a crew member would direct the activities of his own body. Much progress has already been made in these kinds of telepresence and telekinetic approaches.

Figure 12. Dispersed Virtual Reality/Telepresence/Kinetic Enablers.



- External layer absorbs or deflects photons and records data or routes photons to inner surfaces
- Laser pattern activates stored data and replays it on internal module wall or inside virtual reality IVA or EVA crew helmet
- Telepresence and kinetics of IVA or EVA robots can be accomplished via laser link from micro-sensored robot to Station command and control module.

4.5 Nuclear/Field Interactive Propulsion Subsystem Tests

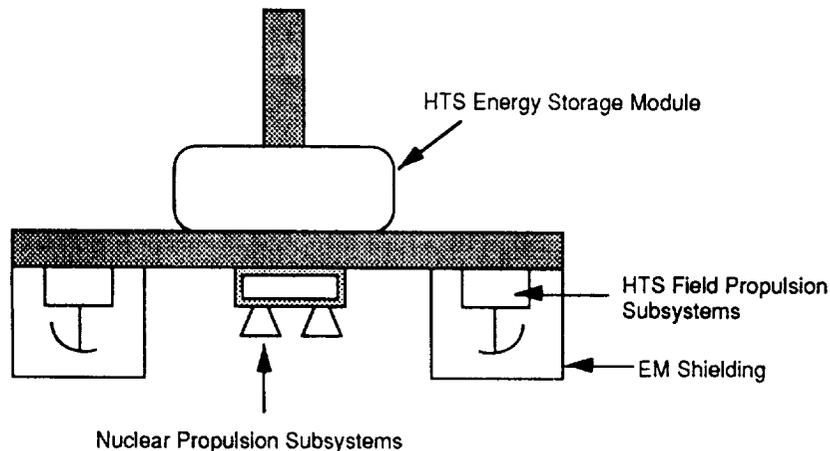
Tests of nuclear propulsion and interactive field propulsion systems can be conducted at the subsystem level on a technology test-bed boom extending below a space station (See Figure 13). The tests would not involve active nuclear energy systems, but would require the use of high current power. This power could be supplied using MHD superconducting storage devices and a plasma generator.

High field tests of field interactive propulsion subsystems are also candidates for testing on the boom⁽⁴⁷⁾. The field emitters can be shielded to minimize electromagnetic exposure to other parts of the station. While ground tests will be crucial for exotic propulsion systems, the verification of ground studies in the space environment will be required. These in-space studies could lead to different configurations, applications and enhancements of subsystem or overall system performance.

Tests at the station offer the advantage of direct crew member involvement and an array of supporting services, including robotics for adjustments and repairs. In addition, the capability to relatively easily and quickly remove and return components to Earth for improvements is a major advantage. When field strengths or other risks appear to become too great the tendency would be to rule out R&D testing of these exotic systems at the station. The danger is that these decisions could be made without really understanding the true risks as compared to other inherent risks associated with a space station. A space station should have as a major objective and focus the support of technology test-bed activities, including some moderate risk technology R&D activities.

Figure 13. Nuclear/Field Propulsion Subsystem Tests.

- Nuclear propulsion subsystems can be tested on technology test-bed boom on a growth station using MHD stored power and a plasma generator rather than power from a nuclear reactor
 - Station re-orientation may be required during test to beneficially use impulse generated
- High field strength propulsion, sub-system tests can be conducted on the boom also, prior to higher power tests on the station keeping platform



Summary

A space station should have the growth capability to support the technology development and test and materials R&D which will be required to expand and maintain the human presence in the Solar System (to Mars and beyond). While its too early to know what the redesign station's growth (or replacement potential) will be, many of the key R&D capabilities described in this paper will survive. Options could include the later addition of a station-keeping platform to support future programs. Although some truss or module structure for an extended boom connection is highly desirable, access to a station-keeping platform which can easily rendezvous and dock with the station could accommodate a large percentage of the boom R&D requirements.

By focusing on the space technology and operations needs of the future, the role and potential of the space station and other space infrastructure can be more clearly identified^(36, 48). One of the primary objectives and challenges of permanent space infrastructure should be the enablement of future space utilization and exploration and future transportation technology.

In the process of examining in greater depth the means for accommodating the development and test of the advanced technology and materials proposed for a deep space transport, interim technologies and materials will be identified. These interim technologies and materials can be used to reduce the cost of space utilization and would lead to new frontier technologies and new economic benefits.

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