Ref: 97-F-1207

06 AUG 1997

Mr. Felipe Gardyn
[redacted]

Dear Mr. Gardyn:

This responds to your June 9, 1997, Freedom of Information request. Your request was referred to this Directorate by the Department of the Army on July 7, 1997.

Your request was processed by the Defense Advanced Research Projects Agency (DARPA) which has provided the enclosed document to you as responsive.

There are no assessable fees for this response.

Sincerely,

SIGNED

A. H. Passarella
Director
Freedom of Information
and Security Review

Enclosure:
As stated

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This report presents the results of the preliminary analysis of the potential of a small, new, generic type of manned spaceplane as a military, manned research vehicle. A specific spaceplane research vehicle configuration, termed the Space Cruiser is presented. The Space Cruiser is designed for full-envelope cislunar (Earth-moon space), transatmospheric, and endoatmospheric flight research. Man-in-space, vehicular research and research on internal and external payloads would extend to manned space vehicles, the Space Shuttle, unmanned space vehicles, space station, space structures, transatmospheric and endoatmospheric vehicles. Results of a nation-wide preliminary survey for research and technology tasks for the Space Cruiser are reported. Initial planning for developmental and operational programs is presented.

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SPACEPLANE TECHNOLOGY AND RESEARCH (STAR)

Fred W. Redding, Jr.
DCS Corporation
1055 N. Fairfax Street
Alexandria, VA 22314

August 1984

Final Report for Period December 1983 - July 1984

Sponsored by

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PREFACE

This report extends the previous analyses of the generic high-performance spaceplane or "Space Cruiser" sponsored by DARPA under DARPA Orders 4097 and 4229, monitored respectively by the Defense Nuclear Agency and the Air Force Space Division (AFSD).

This current work was performed under DARPA Order 4913 and monitored by Colonel James N. Allburn, USAF, Special Assistant for Advanced Fighter Technology, Tactical Technology Office. Lieutenant Colonel Darryl W. Smith, Deputy for Space Systems, Directorate of New Concepts and Initiatives, Headquarters Air Force Systems Command was the Contracting Officer's Representative.

DCS wishes to express its sincere appreciation to those who contributed to this Spaceplane Technology and Research (STAR) analysis by responding to the survey concerning tasks for the Space Cruiser as a research vehicle.

The contributions of Mr. Stuart T. Meredith in his analysis of the STAR survey and of Mr. Fredric A. Dunbar in costing are gratefully acknowledged.

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1.0 INTRODUCTION

This report presents the results of the analysis of the research and technology potential of a generic type of manned spaceplane as a military research vehicle. A specific spaceplane configuration, termed the Space Cruiser, is configured herein to be capable in the near-term of full-envelope cislunar (Earth-moon space), transatmospheric, and endoatmospheric flight research. Figure 1 depicts the Space Cruiser in high orbit. The underlying question is: "Should the Space Cruiser be developed and used as a research vehicle?" The analysis addressed this fundamental question.

The study assumed the criterion that a space-capable research vehicle designed for an important but limited experimental scope, such as flight control and aerodynamics would not be justified. This criterion results in the requirement for the research vehicle to serve a broad range of beneficiaries and to perform, and to carry payloads that perform, over as broad a scope of research and technology as possible. Beneficiaries would include the Department of Defense, aerospace industry, national laboratories, commercial industry, insurers, and others. The scope of research and technology would include man-in-space, space operations, internal payloads, external payloads, vehicular subsystems, aerothermodynamics, materials and others. Further, sharing the cost of space system development and operations is rapidly becoming the economic and political standard. It is likely that if the Air Force were to sponsor such a research vehicle the cost-sharing would be far greater than existed during the predecessor X-15 manned research aircraft program. The primary emphasis during the configuration analysis portion of the study therefore was to configure the Space Cruiser, the overall system, and its operations to accomplish as many tasks or missions as possible. In this context the reader will find the term omnimission used throughout the report. To help identify and define such research and technology tasks and to evaluate the scope, utility and value of the Space Cruiser as a research vehicle a nationwide survey was conducted and is reported.

Tasks of a Spaceplane Technology and Research (STAR) flight program would apply to all future manned space vehicles, the Space Shuttle, unmanned space vehicles, space structures and transatmospheric and hypersonic vehicles. Small, responsive, versatile, high-performance, and permitting an operational risk level more appropriate to the military than to NASA, the research vehicle would both complement and greatly extend the Space Shuttle capabilities. Its small size and light weight assure that it need only

Figure 1 Space Cruiser Returning From High Orbit

occupy a small portion of the volume and weight-carrying capability of the Shuttle's Orbiter and that its cost-to-orbit as a manned vehicle will be minimized. Its configuration also enables it to be launched by expendable launch vehicles such as the three-stage MX booster stack.

In addition to the research and other technology questions pertinent to hardware and performance associated with space vehicles, there are other appropriate or vital questions whose answers are expected from the STAR research flight test program. Paramount among these is the national question of the value of military man in space. The "hands-on" experience and evaluation of man in space in the small, ubiquitous spaceplane should provide the answers required prior to major system acquisition of such manned space vehicles and complement the answers being obtained from the Shuttle program for the large, logistic, and space station type vehicles.

The Shuttle is now used as an operational system. Department of Defense space biotechnology R&D has become a relatively low priority within NASA. The Air Force's Aerospace Medical Division (AMD) has been tasked by several directives to explore military utility of man-in-space and exploit man's unique capabilities in enhancing military space systems. The resultant Military Space Biotechnology R&D program covers exploratory and advanced development areas. Though the Air Force has been careful to coordinate its program closely with the NASA Life Sciences program in order to avoid redundancy, tapping into the NASA system has been frought with problems of coordination, differences in priorities and the fact that NASA has its own R&D programs to consider. It is believed that the DoD needs a vehicle which will provide a manned orbital platform for exploring man's military utility in orbit. Unless the DoD is given the tools, the job will not be done. AMD personnel have stated (Appendix B) that the "Space Cruiser fills the bill."

The Defensive Technologies Study of the Strategic Defense Initiative (SDI) identified research programs for "a capability to service the space components and an ability to transfer items from one orbit to another." The Space Cruiser system is designed for the highest payload-velocity product that technology will allow in a manned vehicle. It may fulfill the SDI needs well.

The report begins in Section 2.0 with a summary in DARPA format of the work performed, its objectives, the problem addressed and the general methodology used in performing the effort. Technical results, findings, special comments and implications for further research complete the summary.

The main body of the report begins in Section 3.0 with a brief presentation of the background of the Space Cruiser. The generic spaceplane was generated as the solution to military problems. The problems and needs are delineated and the resultant high performance spaceplane or Space Cruiser is presented. This vehicle was used as the input configuration to the study.

Section 4.0 presents the results of the survey for research and technology tasks for the Space Cruiser. Example letter responses are contained in Appendix B. The analysis of the application of the Space Cruiser as a research vehicle begins in Section 5.0 with a discussion of the linkage of the configuration to the results of the survey and to other tasks considered during the study. The conceptual-design logic and the operational and design requirements that result are presented. The performance of the Space Cruiser as a vehicle and in the overall system configuration context with its launch vehicle options and external propulsion is presented quantitatively in Section 6.0. Section 7.0 examines the developmental and research planning options and makes recommendations. Space operations are presented from a functional viewpoint, including an overall functional system block diagram. Cost estimates are discussed in Section 8.0.

Conclusions and recommendations are presented in Section 9.0 and 10.0 respectively. References are provided in Appendix A. The survey letter with representative responses comprise Appendix B. An explanation of the principal changes to adapt the Titan III-34D rocket engine for use on an air-launched launch vehicle presented in Section 6.0 is given in Appendix C. Definitions of abbreviations and acronyms are listed in Appendix D.

2.0 SUMMARY

2.1 TASK OBJECTIVES

The overall task was to perform a research and technology planning effort that would produce a preliminary program plan for the development and use of the high-performance manned spaceplane or Space Cruiser as a military research aircraft. The Space Cruiser was to be configured for the research application as deemed necessary relative to its prior configurations. Configuration changes would as an objective retain and facilitate the option of its use as an operational military spaceplane.

2.2 TECHNICAL PROBLEM

There were two principal technical problems in the study. The first was to search for and evaluate potential research and technology tasks suitable for accomplishment by the Space Cruiser as a research vehicle. The second problem was to determine the overall system configuration and the performance of the Space Cruiser as a total system. The correlation of the two problems provided the best measure available of the justification of the research vehicle and formed the basis for research vehicle program planning.

2.3 GENERAL METHODOLOGY

A survey letter was prepared that explained the basis of the request for information, described the Space Cruiser, provided a representative performance specification for the vehicle system and provided an optional response format. The letter was sent to industry, the military, national laboratories, etc. The survey is discussed in Section 4.0. The survey letter and a cross-section of responses are provided in Appendix B.

The logic that results in the generic Space Cruiser configuration was developed. The principal motivation was to obtain the greatest degree of versatility and performance in as many tasks or missions as possible. The logic resulted in the operational and conceptual design requirements, which were then transformed into the specific configuration. Changes were made in the vehicle, relative to prior configurations, which improved its performance dramatically. Launch vehicle options were examined and overall system performance determined. The primary measure of performance for evaluation or figure of merit was determined to be the payload-velocity product. The logic and development of system performance are presented in Sections 5.0 and 6.0 respectively.

Options for flight testing the research vehicle were considered and recommendations made. Finally, vehicular costs were estimated based on historical data with emphasis on the highly successful X-15 manned research aircraft.

2.4 TECHNICAL RESULTS

Thirty-six responses were received to the survey letter with 60 distinct tasks or experiments. There was a surprising lack of duplication in the experiments recommended, which reflects the diversity of the needs of the respondents.

The STAR manned Space Cruiser is estimated to have a maximum velocity of 8,700 fps with internal propellants and no payload. The velocity with a 500 lbm payload is 8,075 fps. Use of the wide-body Centaur as a propulsion module with a single RL-10 Derivative-IIB engine will provide approximately 20,741 fps to the Space Cruiser loaded with sufficient propellant to add 8,700 fps after staging the Centaur. Options for external carry or push of payload with/without external propellant or a propulsion module such as the Centaur make the Cruiser a versatile, high payload-velocity vehicle. It is capable of landing autonomously at austere, helicopter-suitable sites.

2.5 IMPORTANT FINDINGS AND CONCLUSIONS

The Space Cruiser is a high payload-velocity performance spaceplane capable of research and military tasks throughout cislunar (Earth-moon) space. The survey brought forth a broad range of potential beneficiaries. The survey also showed the broad scope and depth of research and technology tasks of value to those surveyed. The high potential for a valuable, research program is clear. The Space Cruiser can go to any orbit, has endurance, carries internal payloads, carries unlimited payload externally, can maneuver synergistically and lands with a flying parachute or Parafoil.

The Aerospace Medical Division (AMD) has need of a space vehicle with the performance of the Space Cruiser for carrying out its military man-in-space responsibilities. The Space Cruiser will also meet Strategic Defense Initiative needs for on-orbit capability at all altitudes for ballistic missile defense system R&D and for subsequent operational tasks.

The cost estimate for the manned Space Cruiser R&D Program is best compared to the manned X-15 Program. Actual cost of 27 X-15 flights in 1964 was about $2M (1984$) for each flight. This cost seems conservative for the Space Cruiser less launch vehicle cost, considering all available data and assuming a comparable number of flights. An accurate costing will not be fully estimable until the STAR Program is initiated and the return on investment from internal and external R&D payloads, repair of satellites, a space rescue, and other space operations is calculated.

2.6 SPECIAL COMMENTS

The limits on available funding resources, the advances in technologies required, the major system acquisition process and political constraints create problems for procurement in the near-term of the relatively large trans-atmospheric vehicles. Therefore, in this special context it seems particularly appropriate to suggest that the Air Force consider the procurement and operation of the Space Cruiser as a research vehicle. Demonstrated military man-in-space capabilities in the Space Cruiser would earn support of and help pave the way for the transatmospheric vehicle.

2.7 IMPLICATIONS FOR FURTHER RESEARCH

1. It is recommended that a major system manufacturer be funded to refine the Space Cruiser design and to determine more detailed development and operational schedules and costs for its use as a research vehicle.
2. The small size and weight of the Space Cruiser and the advantages of aircraft launch suggest that the air-launch concept described in Section 6.0 be developed in a conceptual design study. The use of the final stage as an "infinitely reusable" space station, or stage-station, would provide distributed space stations at low cost and should be an integral part of the analysis.
3. The use of the Parafoil for aerodynamic plane-changing maneuvers at entry speeds has a dramatic potential performance payoff. It is recommended that the feasibility and implications of this new concept be examined.

3.0 SPACEPLANE BACKGROUND

3.1 MILITARY BASIS

The high-performance spaceplane concept was originated in 1979 as the solution to a problem stated by the Office of the Deputy Director, Defense Research and Engineering, Strategic and Space Systems (now Strategic and Theater Nuclear Forces). The problem was to review and critique Shuttle payload plans, options and alternatives from a military conceptual viewpoint with emphasis upon payloads with man in the loop or control. The purpose was to identify additional justifications for the military Shuttle.

The idea of the generic spaceplane was generated and approved. Two spaceplane-specific tasks were then stated in the Work Statement to (1) Prove the need and value of the high performance manned military spaceplane operating from the Space Shuttle and (2) Prove the need and value of the high performance manned military spaceplane operating independent of the Space Shuttle. The work was performed under contract DNA001-80-C-0217 and cosponsored by DARPA Order No. 4097.

The problems stated in the resulting analysis are summarized as follows:

The non-military characteristic and severely limited military capability of past, current, and proposed propelled spacecraft while the military need is substantial and increasing rapidly. Manned spacecraft programs and concepts have displayed predominantly non-military characteristics such as:

- Space maneuverability which is limited severely
- Payload-maneuverability in space which is limited severely
- Inability to perform synergistic and other maneuvers in and out of the atmosphere
- Substantially constrained mission profiles
- Weather dependency of launch and recovery
- Launch schedule inflexibility
- Vulnerability of the launch facilities and the global ground support to direct attack
- Dependence throughout their mission on extensive ground support monitoring, tracking, control and communications
- Little or no space rescue capability
- Dependence of orbital transfer vehicles on the Orbiter or future space station

These characteristics and capability limitations contrast sharply with the autonomy, flexibility, maneuverability, responsiveness, survivability and cost-effectiveness required of military aerospace operations as the result of experience and established in official Air Force aerospace doctrine. Further, the manned space vehicle programs and concepts have precipitated the commonly-held perception that the economics, technology and safety of man in space will force the continuation of these non-military characteristics into the future.

The National Command Authority and the Department of Defense rely heavily on unmanned satellites as vital elements in command, control, communications, intelligence, surveillance, and warning. Unmanned satellites have additional problems relative to manned vehicles, such as inherent vulnerability to anti-satellites, single-mission utility and inability to adapt or to think. The manned spaceplane could complement the unmanned satellites by providing a quick reaction capability for unforeseen contingincies and by servicing, protecting, supplementing or standing-in for satellites. Balance and mutual support must be achieved between the manned and unmanned military space systems.

The need was then stated and is summarized here:

The need is to provide the military man in space a highly cost-effective near-term vehicle system with the required military characteristics and capabilities that will 1) protect the United States resources from threats in and from space; 2) conduct needed aerospace offensive and defensive operations to use and protect the use of space by the United States and its allies; 3) enhance the land, sea and air forces; 4) serve as a practical utility vehicle in the support of space assets and in the exploitation of space; and 5) support as many aspects of U.S. national policy as possible, including arms control.

The specific vehicle need is for a truly military vehicle that integrates well with the Shuttle and other launch vehicles where required and that eliminates or minimizes the need for other vehicles or upper stages.

The solution presented was the high performance spaceplane concept, termed the Space Cruiser, which differs considerably from the other manned and unmanned space vehicles that have been studied or proposed.* It differs in configuration,

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* This conclusion resulted from a search for a vehicle concept that might meet the requirements. For example, NASA has no plans to develop such a vehicle. The statement remains valid.

cost, performance, ease and speed of development, in launch and recovery flexibility and in its capability to meet the characteristics and capabilities established by military doctrine.

The high performance spaceplane conceptual design was then studied and refined with industrial and laboratory support in the Spaceplane Examination study (Reference 1). The purpose of the Spaceplane Examination was stated as two-fold:

1. To define and evaluate a small man-rated space transportation vehicle for military space operations which is compatible with the Shuttle, expendable launch vehicles or air launching and is capable of earth return and parachute recovery.
2. To investigate configuration changes necessary to accomplish selected "off-design" missions.

3.2 PRE-STAR SPACEPLANE DESCRIPTION

The Statement of Work for this STAR study requires that the Space Cruiser be configured for application as a military research aircraft as deemed necessary and practical relative to its prior configurations. Consistent with this requirement, this Section begins with a description of the previous internal layout depicted in Figure 2, of the spaceplane resulting from the DARPA-sponsored Spaceplane Examination (Reference 1), Contract No. F04701-81-K-0001, completed 30 July 1982. The development of the design logic as completed in this STAR study is discussed in Section 5.0. Section 6.0 presents the configuration changes that resulted from the design logic and analysis of the application of the spaceplane as a research vehicle. Then it presents the resultant performance.

Figure 2 depicts the representative internal layout of the Space Cruiser based upon a conical reentry body shape. The geometrical shape of the airframe internal mold line is also conical, reflecting the conical shape of the reentry body. The conical reentry body shape studied and tested in a wind tunnel by Sandia National Laboratories for the spaceplane has small, extremely swept wings or "strakes" with elevons (not shown). The nose section, containing the forward payload bay, ballast and power batteries, can extend forward while in space to expose the forward reaction control nozzles for firing. No nozzles are located in the thermal protection structure (TPS) with this approach. The nose can be removed and replaced while in an extended position. After full extension, the nose folds aft alongside and is snubbed or secured near the nosetip. After the nose is folded, an elephant stand or similar light weight structure can be attached to the forward

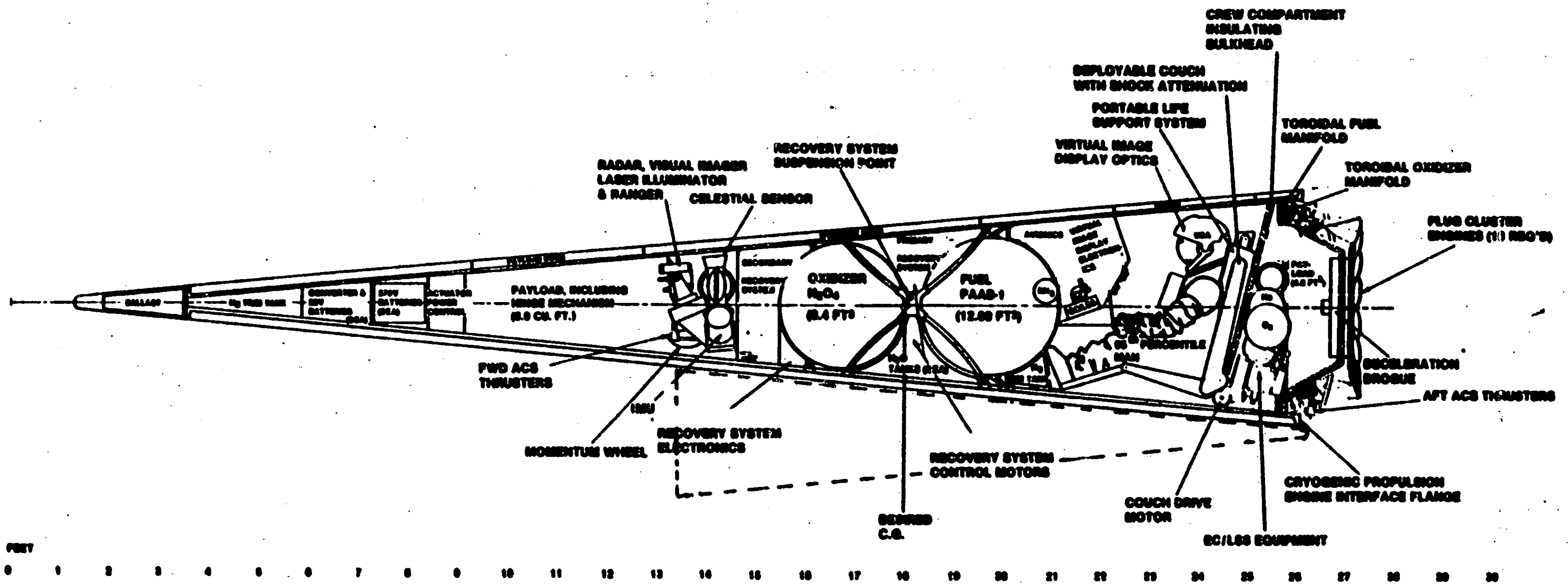

Figure 2 Representative Internal Layout

bulkhead or ring to attach external payloads. In this way the payload is pushed by the spaceplane and the maneuvering flight load force is the spaceplane thrust, independent of the weight of the payload. The pilot is seated at the aft end in a seat or couch which can be raised until the pilot's head is outboard, similar to an open-cockpit aircraft. In the raised position the pilot can view the external payload. Also, the pilot has unlimited visibility and can view the internal, forward payload bay contents when the top panel or door is open.

An example airframe construction is advanced non-catalytic thermal tile over a composite non-metallic substructure. Connections for refueling are located in the aft end with the plug-cluster engine (PCE), obviating penetration of the TPS. There are two payload bays, one in the nose section and the other in the aft end within the PCE thruster modules. This latter bay is called the "plug."

Landing is by controllable lifting parachute or "Parafoil" (References 2 and 3). After deployment of a deceleration drogue from the PCE plug volume prior to vehicle aerodynamic instability, close to the trans-sonic region, the reefed, Parafoil flying parachute is deployed from near the vehicle's center of gravity between the spherical propellant tanks. A redundant, identical Parafoil is located forward of the oxidizer tank. After deployment of the flying parachute, the spaceplane assumes a horizontal attitude for flight to the ground. A lifting aerobrake is located in the aft payload bay for aerobraking with otherwise excessive entry speed. The lifting aerobrake is reusable.

A 195 lb, six-foot one-inch pilot or 95th percentile man is assumed. An 8 psi Extravehicular Maneuvering Unit (EMU) or spacesuit, under development, is planned. This suit eliminates the requirement for prebreathing pure oxygen before flight. Its portable life support back pack is detachable before launch and at landing. Extravehicular Activity (EVA) does not require an umbilical. Fail operational/fail safe design criteria are used for environmental and life support (Reference 4). Pumped fluid coolants are used with coldplates for heat transfer from the heat source hardware such as avionics. A stacked evaporator is used for heat rejection. A helmet-mounted, internal virtual-image display is provided. Voice control of and through the computer is planned.

An autonomous optical navigator supplementing and with accuracy similar to the Global Positioning Satellite (GPS) is planned. Ring-laser gyro inertial platforms are used in the guidance and navigation system. Monopropellant-driven redundant auxiliary power units (APUs) are provided and integrated with the rechargeable power battery. The aircraft is all-electric. No hydraulics are permitted on board the spaceplane.

The PCE has 16 nozzles with independent on-off control for overall thrust vector and thrust magnitude control, eliminating nozzle actuators and flexible lines. The propellant tanks are spherical for light weight and are centered roughly about the vehicle's center of gravity. The propellants selected are nitrogen tetroxide as the oxidizer and an Aerojet proprietary amine blend for fuel. The fuel is also used as a monopropellant in the APUs. The PCE nozzles are film-cooled for long life. Elastomeric bladders are used in the pressurized propellant tanks. The attitude control system has nozzles mounted forward at the nose fold and aft with the PCE to provide six-degree-of-freedom attitude and translation control. Momentum wheels are provided for fine attitude control. A mercury trim control system is included for real-time center of gravity (CG) trim. CG control is important for endoatmospheric stability. It is planned that outboard propellant tanks and payloads will be saddle-mounted to protect the TPS.

4.0 RESEARCH SURVEY

4.1 PURPOSE

In order to define research and technology tasks as specified in Task I of the contract, DCS Corporation conducted a letter survey of appropriate aerospace industries and governmental organizations asking the letter recipients to identify specific research, technology and development tasks or experiments which they believed were suitable for accomplishment by the Space Cruiser in its role as a research vehicle. The industry recipients were selected to provide a broad cross section of industries ranging from component producers to major system manufacturers. The governmental recipients included research and technology organizations and laboratories in the Air Force, Navy, DoD and NASA. The purpose of the survey was to solicit suggestions for tasks or experiments from a diverse spectrum of perspectives in order to define research and technology tasks suitable for accomplishment by the STAR vehicle.

4.2 SURVEY METHODS AND RESPONSES

The letter soliciting suggestions for experiments was accompanied by attachments containing a description of the STAR vehicle and its specifications, and guidelines for the format of the responses. A copy of the letter with attachments is included in Appendix B of this report. A total of 126 requests were mailed. However, the number of agencies or corporations contacted was lower because in some cases more than one department or division within an agency or corporation was contacted.

DCS received a total of 36 separate responses to the letter request. Of these, 23 organizations did not offer specific experiments for consideration, even though most expressed an interest in the concept and a few indicated they may submit recommendations at some time in the future. The remaining 13 responses contained suggestions for a total of 60 distinct tasks or experiments. There was a surprising lack of duplication in the experiments recommended, which reflects the diversity of interests of the respondents.

Although the DCS request asked for research and technology tasks suited to accomplishment by the Space Cruiser, the responses proposed a broader range of tasks. Of the 60 tasks recommended, one fourth of them (15 tasks) were considered to be operational applications for the Space Cruiser rather than research and technology experiments. Additionally, of the 45 proposed tasks that were research and technology experiments, 35 tasks were experiments that could be accomplished by the Space Cruiser and the remaining 10 were experiments that should be carried out as part of the development of the Space Cruiser itself.

4.3 SURVEY RESULTS

This section consists of a synopsis of each of the tasks or experiments proposed in response to the DCS survey. For clarity they are grouped into the three basic categories: research tasks to be accomplished by the Space Cruiser; research tasks to be performed for the development of the Space Cruiser; and operational applications for the Space Cruiser. The tasks are also grouped within these three categories by the organization that submitted them.

4.3.1 Research Tasks to be Performed by the Space Cruiser

4.3.1.1 Tasks submitted by LTV Aerospace and Defense Company

Task: Component tests for exoatmospheric Electromagnetically-Launched (EML) guided projectile

Task Description: Determine accuracy of space launched EML guided projectile meeting packaging and EMP/g-load hardening design criteria.

Expected Results and Value: Validate EML guided projectile components designs for prototyping. This would be an extension of preliminary ground based demonstrator results. Will have applications to boost-phase and mid-course ballistic missile intercept.

Task: Ablative behavior of Carbon/Carbon (C/C) nosetips and projectiles.

Task Description: Fire reentry nosetips from orbit to simulate desired trajectory. Determine the ablative behavior and its effect on trajectory for various C/C composite materials.

Expected Results and Value: Will provide ability to select the optimum materials for various missiles ranging from ICBMs to railgun projectiles. Ablative behavior cannot be fully simulated from Earth; proof testing requires actual missile firings. Firing reentry bodies from the spaceplane would be less costly.

Task: Scramjet inlet and combustion phenomena.

Task Description: Use externally mounted scale propulsion unit to determine the effects of rarefied gasdynamics at hypersonic speed on inlet and combustion stability and performance of a supersonic combustion ramjet.

Expected Results and Value: Will increase understanding of supersonic combustion ramjet. Potential low weight propulsion for transatmospheric (TAV) type vehicles.

Task: Navigation system validation.

Task Description: Utilize special equipment to provide a brassboard demonstration of this Vought proprietary concept. Use multiple ground track velocity/position determination or GPS if available.

Expected Results and Value: Validation of the position and velocity determination of the vehicle. Potential for improved long range navigation.

4.3.1.2 Tasks submitted by United Technologies, Hamilton Standard

Tasks: Various tasks demonstrating EMU technology and EVA technology including satellite servicing.

Task Description:

EMU Technology Tasks:

1. Test quick reaction capability and subsequent effects on crewmember physiology.
2. Test radiation protection equipment by placing experiment on Long Duration Exposure Facility (LDEF) or free flyer which will be revisited every 90 days.
3. Test effects of EMU venting on sensors/optics and test effects of EMU suit contamination due to hydrazine, etc. Develop a method of cleaning suit while EVA.
4. Test crewman capability to react to quick contingency situations while suited in the EMU.
5. Conduct maintenance on the suit on-orbit.
6. Test suit puncture procedures on-orbit.
7. Conduct heads-up display experiments.
8. Conduct physiological tests were the EMU HAL system controls the life support system requirements as a function of crew metabolic load.
9. Conduct EMU range/rate device.

EVA Generic Technology Tasks:

1. Test crewman restraint interfaces with satellites, structures assembly, set-up/tear-down, etc.

2. Document crewman translational capability and evaluate translation aids.
3. Develop metholodology for module transfer.
4. Use Space Cruiser as an orbital maneuvering system to retrieve item to stationary crewmember, the Space Cruiser being controlled via HAL.
5. Conduct power-assisted end effector tests.

EVA Satellite Servicing Tasks:

1. Repair/replace modules. Determine module design and logistics.
2. Evaluate EVA as a secondary/complementary mode of operations and influence on satellite design.
3. On-orbit refueling of fluids causing safety problems within Shuttle (bi-props, cryogens)
4. Demonstrate satellite subsystem removal and repair (connectors, solar arrays, batteries, sensors).
5. Human factors engineering tests under varous environments, work envelope determination, task sequencing tests.
6. Determine optimal man/machine mix. Test task level and task complexity by interacting techniques which test the synergism of the man/machine system.
7. Perform service on transfer type vehicles, remove/repair engines, avionics, etc.
8. Test space berthing tasks such as berthing pin location/design, structural support, dynamics and interfaces.
9. Conduct Orbital Replacement Unit (ORU) replacement tests to determine MTBF and reliability, optimal locations for mounting and working on ORU.
10. Determine basic design considerations such as component and cable layout, mounting techniques, hazards identification, accessibility, crew work station, etc.
11. Deploy Space Cruiser from Shuttle payload bay via the RMS. Test maneuverability and logistics associated with payload by operations including Space Cruiser maintenance.
12. Conduct general satellite servicing from the Space Cruiser.

Expected Results and Value: The Tasks as a whole would greatly expand knowledge of EMU technology and EVA technology and applications. The knowledge gained could lead to significantly enhanced capability in all phases of manned space operations.

4.3.1.3 Task submitted by the Air Force Office of Scientific Research

Task: Long term environmental durability of materials in space.

Task Description: Use the Space Cruiser as a launcher or flying test bed for samples of candidate spacecraft structural material and conduct periodic monitoring or recovery of samples.

Expected Results and Value: While this task could be done on the Shuttle, the long duration exposure facility on the Shuttle has had more than a ten year lead time. Using the Space Cruiser could expedite the acquisition of knowledge about durability of new materials in space.

4.3.1.4 Task submitted by the Charles Stark Draper Laboratory, Inc.

Task: Investigate the density phenomena of the atmosphere in the aerobraking altitude band (240,000-300,000 feet).

Task Description: Use the high lift space plane to traverse a path similar to that of an aerobraking Orbital Transfer Vehicle (OTV) in order to gather additional data on the consistency of the density of the atmosphere in the aerobraking band.

Expected Results and Value: Increased understanding of the density phenomena such as magnitude, spatial correlation distance, and gradient of density variations. This could reduce the possibility of overdesigning an aerobraking vehicle because of lack of understanding of the density phenomena, and aid in the development of a low performance operational aerobraking OTV using either drag modulation or a low L/D lifting brake.

4.3.1.5 Task submitted by United Technologies, Pratt & Whitney

Task: Testing of the Centaur RL10-IIB engine operation in a low gravity, vacuum environment.

Task Description: Use the Space Cruiser with an RL10-IIB powered Centaur to provide information on the effects of very low gravity on engine start, and to accurately determine the thrust produced at the engine's lowest thrust level (Tank-Head Idle).

Expected Results and Value: This task would provide data on the operation of the RL10-IIB in a low gravity vacuum environment which cannot be duplicated on Earth. While this is an experiment to be conducted by the Space Cruiser, it is also for the Space Cruiser in that it would allow expanded operations if successful.

4.3.1.6 Task submitted by Air Force Aerospace Medical Division

Task: Use of the Space Cruiser in support of a Military Space Biotechnology R&D program.

Task Description: The Aerospace Medical Division has been tasked to explore the military utility of man in space and exploit man's unique capabilities in enhancing military space systems. They have developed several human performance experiments which require an orbital platform, but have had difficulty in establishing priority in the Shuttle program. The Space Cruiser could be used as the orbital platform for the experiments.

Expected Results and Value: The several human performance experiments planned by the Aerospace Medical Division could be accomplished without interference with/from the Shuttle program. Accomplishment of the experiments could lead to an earlier understanding of man's utility in space.

4.3.1.7 Task submitted by Headquarters, 6510th Test Wing, Edwards AFB

Task: Use of Space Cruiser to examine one extreme of the reentry environment.

Task Description: There is need for further research in technology relating to hypersonic flight. Most of the areas of interest relate to entry configurations of low planform loading. Although the 6510th Test Wing did not suggest a specific task, they acknowledged reentries of the Space Cruiser could provide data for one extreme of the reentry environment.

Expected Results and Value: The Space Cruiser could provide data that will assist in Air Force hypersonic research at one extreme of the reentry environment.

4.3.2 Research Tasks to be Performed for the Development of the Space Cruiser

4.3.2.1 Task submitted by LTV Aerospace and Defense Company

Task: STAR Configuration Changes

Task Description: Validate the benefits of light weight strap-on wings for the Space Cruiser. Determine the altitude conditions for which extremely large strap-on wings are useful for maneuvers of the Space Cruiser.

Expected Results and Value: Obtain a better understanding of minimal energy maneuvers in rarefied atmosphere. There is the potential to expand the operational envelope of the Space Cruiser.

4.3.2.2 Tasks submitted by the Aerojet TechSystems Company

Task: Low cost guidance system evaluation for the Space Cruiser.

Task Description: Adapt the ultra-light weight low-cost Mark VI inertial reference system (developed by Aerojet TechSystems for NASA sounding rockets) to Space Cruiser guidance and control and untethered EVA. Applications could include space rescue.

Expected Results and Value: Potential for reduction in Space Cruiser guidance and control costs and weights by as much as 90% of the current state of the art values. Could make non-tethered EVA a practicality. Suitable for military applications, rescue missions and unmanned missions.

Task: Aerobraking Investigation

Task Description: Adapt structurally efficient clam shell shields to the conical shape of the Space Cruiser to evaluate the concept for aero-assisted reentry and synergistic plane and orbit altitude changes.

Expected Results and Value: Provides multi-purpose addition to Space Cruiser by functioning as a meteor shield, an aeromaneuvering surface and a heat shield during aeromaneuvering. Will provide an emergency de-orbit and orbit change capability, and broader mission envelope limits for the Space Cruiser.

Task: Plug cluster engine for primary Space Cruiser propulsion.

Task Description: The experiment involves (1) the application of scarfed nozzles on the sixteen 188 lbf rocket engines which are arrayed around the plug, and (2) on-line feed pump capability for two to four of the normally pressure fed 188 lbf engines from externally mounted, conformal propellant tanks.

Expected Results and Value: Will provide a flexible, short length, high-performance and low cost rocket engine for the Space Cruiser and a wide range of Air Force missions. Will also provide low flow rate pump technology for possible use in space platform, Space Shuttle, orbit thrusters, tactical missiles as well as the Space Cruiser.

4.3.2.3 Tasks submitted by AERO

Task: Spaceplane-Parafoil recovery demonstration

Task Description: A spaceplane-Parafoil would be constructed and dropped from an aircraft in the atmosphere to demonstrate gliding performance, controllability, low rate of sink, and a flare maneuver to a landing.

Expected Results and Value: Successful demonstration of the spaceplane Parafoil is essential to the viability of the Space Cruiser Parafoil-landing concept.

Task: Spaceplane-Parafoil space maneuvering and reentry analysis.
Task Description: This task consists of computer simulation and analysis of spaceplane maneuvering in space and during reentry utilizing the Parafoil.
Expected Results and Value: This task is necessary preparation for the actual testing of reentry and upper-atmosphere maneuvering with the Parafoil.

Task: Spaceplane-Parafoil wind tunnel tests.
Task Description: Wind tunnel tests of the spaceplane-Parafoil will be conducted at subsonic and supersonic speeds in order to optimize design and stability coefficients for space maneuvering, reentry, atmospheric gliding flight and flare landing.
Expected Results and Value: This task is also a necessary preparation for the actual testing of the Parafoil at entry speeds.

Task: Space Shuttle spaceplane-Parafoil flight tests.
Task Description: A model of the Space Cruiser will be launched from the Space Shuttle. The model will have an on-board guidance and control system to deploy the Parafoil in space, maneuver in space, reenter and fly in the atmosphere to a landing. Air-snatch of the spaceplane-Parafoil will also be demonstrated.
Expected Results and Value: This task could be used as the final test before actual deployment of either a manned or unmanned Space Cruiser.

4.3.2.4 Task submitted by the AVCO Corporation

Task: Develop material systems for structural and thermal protection of the Space Cruiser.
Task Description: Successful development of the Space Cruiser will require material system for thermal protection/structural use that are available, proven and affordable. AVCO proposes a detailed design study to define the limits of the Space Cruiser structural/thermal requirements and how current materials can be improved or new materials developed.
Expected Results and Value: This task is necessary for the growth development of the Space Cruiser. Materials developed for the Space Cruiser would also be likely to have applications for other space systems.

4.3.2.5 Task submitted by Morton Thiokol, Wasatch Division

Task: Evaluation of boosters for rapid launch of the Space Cruiser.

Task Description: The Morton Thiokol response suggested that the STAR effort include an evaluation of boosters for rapid launch of the Space Cruiser and also an evaluation of propulsion requirements for payloads or weapons which may be launched from the Space Cruiser.

Expected Results and Value: Evaluation of boosters for launch of the Space Cruiser is fundamental to its development. It is apparent in the following section of this report that describes operational applications for the Space Cruiser that a rapid launch capability and the ability launch to various orbits will greatly enhance the versatility of the Space Cruiser.

4.3.3 Operational Applications for the Space Cruiser

4.3.3.1 Tasks submitted by Emerson Electric Company.

Tasks: Various operational missions.

Task Description: Emerson submitted five tasks for operational missions that could be performed by the Space Cruiser:

1. Space junk collection.
2. Non-cooperating vehicle docking system.
3. Quick response, low orbit tactical reconnaissance system for real-time reporting of Photo Intelligence (PHOTINT), Electronic Intelligence (ELINT).
4. Ferry an automatic test system for interconnection with designated satellite systems for routine and emergency maintenance.
5. Use as a manned battle station to fly cover for high priority vehicles, destroying anti-satellite systems.

Expected Results and Value: These suggested operational applications illustrate the flexibility and utility offered by small, relatively simple, manned spaceplane system. An unmanned or very complex system could not offer similar quick reaction versatility.

4.3.3.2 Tasks Submitted by Ball, Aerospace System Division

Tasks: Various reconnaissance related missions.

Task Description: Ball Aerospace Division proposed four operational missions that relate to reconnaissance either directly or indirectly. The tasks proposed are:

1. Inspection of satellites for the presence of nuclear materials by thermal imaging.
2. Inspection of satellites for the presence of nuclear materials by x-ray and low energy gamma ray imaging.
3. Observations of bow shock radiative emissions.
4. In-orbit replenishment of inoperative satellites, specifically, superfluid helium cryogen replenishment of the Infrared Astronomical Satellite.

Expected Results and Value: These tasks or missions again illustrate the versatility of a manned system that is capable of being placed into any orbit(s). The first two could be used to verify treaties and agreements on utilization of space. The third task could provide valuable data for ballistic missile defense. The last task is one that could provide an inexpensive method of re-activating the Infrared Astronomical Satellite (IRAS) in order to conduct more survey work. The new scientific data that has already been obtained from the IRAS provides ample justification to continue that type of survey, but the same concept can be applied to replenish or re-activate a variety of satellites that have become inoperative for various reasons.

4.3.3.3 Tasks Submitted by California Microwave, Inc.

Tasks: Various reconnaissance of satellites tasks.

Task Description: California Microwave proposed six tasks which most of which relate to observations of satellites from close range to obtain various types of information. The specific tasks are:

1. Approach a satellite and monitor emissions for technical ELINT purposes.
2. Approach a satellite and monitor emissions for intelligence information.
3. Approach a satellite and obtain detailed photographs and spectrometer scans.
4. Monitor ground emissions for technical ELINT using maneuverability to access areas when not expected.
5. Utilize maneuverability to determine operational capabilities of space sensors and defense doctrine.
6. Maneuver about a satellite and make power, pattern and polarization measurements.

Expected Results and Value: These operational applications illustrate that even with a small payload capability a man-in-the-loop system has many possibilities, particularly in observation applications with various sensors. Maneuverability and the ability to be inserted into the orbits of various satellites enables the spaceplane to accomplish these types of missions.

4.4 CONCLUSIONS

The variety of tasks or experiments suggested by the survey respondents is indicative of the potential versatility of a Space Cruiser research vehicle. Although some of the proposed tasks could be conducted using the Space Shuttle, the Space Cruiser would appear to offer distinct advantages over the Space Shuttle because of probable lower costs and greater flexibility. Some of the proposed tasks cannot be accomplished using the Shuttle. The Space Cruiser offers a unique opportunity to conduct research and technology experiments that are not possible now. For these reasons, plus the fact that there will always be a heavy demand for Shuttle services for a variety of projects, the Space Cruiser should be considered as a valuable complementary system to the Shuttle.

It is apparent that though the basic concept of the Space Cruiser is that of a vehicle to conduct research and technology experiments, the Space Cruiser is also an experiment in itself and its development should enhance our knowledge of space and transatmospheric operations in general. The development and employment plan for the Space Cruiser should accord the highest priority to those R&D projects proposed for the specific development of the Space Cruiser. The plug cluster engine project proposed by Aerojet and the Parafoil projects proposed by AERO are obvious examples.

The number of proposed operational applications suggested by survey respondents suggests that there will be a natural evolution of the Space Cruiser from a research vehicle into an operational vehicle with numerous military applications. In fact, the distinction between some technology experiments and military applications may not be easily discernable.

The list of tasks or experiments contained in this section should not be considered exhaustive. Furthermore, it is likely that as knowledge is acquired of the Space Cruisers' capabilities during its development and initial operations, experiments will beget additional experiments. The tasks listed herein should be considered only as representative.

The survey letter and representative replies are contained with the letter in Appendix B.

5.0 STAR SYSTEM DESIGN LOGIC AND REQUIREMENTS

5.1 CONFIGURATION LINKAGE TO SURVEY RESULTS AND OTHER TASKS

The number and diversity of the tasks presented by the survey supports the need for the research vehicle. It was not possible to do a benefit or value analysis on a quantitative basis with the information received. However, it seems accurate to state that the criteria of serving a substantial number of beneficiaries and of performing research with numerous subjects and technologies would be met. In addition to those of the survey other tasks became evident. For example, the statements of critical technology, 5-10 year research programs, by the Strategic Defense Initiative Defensive Technology Study that are pertinent specifically to Space Cruiser capabilities are 1) the capability to service the space components and 2) an ability to transfer items from one orbit to another, including geosynchronous orbit (Reference 5).

Other examples of tasks beyond those listed separately in the survey are in the following compilation which summarizes the potential support which the STAR program could provide other type vehicles:

Space Shuttle:

- The Space Cruiser would extend the manned vehicular reach of the Orbiter throughout cislunar space and into the atmosphere for research and other tasks.
- Higher-risk tasks can be done
- Centaur-Cruiser-Orbiter cryogenic vehicle operations
- Military research can be done with the Cruiser launched and/or supported by the Orbiter
- Rescue research
- Orbiter/manned-vehicle integration/operations
- Multiple Space Cruiser operations

Future manned space vehicles

- Man-in-space for servicing, maintenance, repair, updating, inspecting, recovering and maneuvering of satellites
- Human factors/safety
- Vehicular subsystems such as Environmental Control and Life Support System (EC/LSS), propulsion, power, ...

- Operational research such as navigation, avionics, spacemanship, buddy operations,...
- Research on/with payloads, internal & external
- Environmental phenomena
- Controls/displays/voice control
- Software
- Endoatmospheric/transatmospheric flight and operations
- Rescue
- Aerobraking systems and related atmospheric environment phenomena
- Materials
- Radomes/antennas
- Recovery
- Space station operations

Future unmanned space vehicles

- Aerobraking
- Vehicular subsystems
- Software
- Recovery
- Phenomenology such as radiation hardness, propagation blackout,...
- Unmanned-vehicle spacemanship
- Remote control
- Robotics

Future transatmospheric vehicles

(See above for research areas for the Space Shuttle and the manned vehicles)

Hypersonic vehicles

- Vehicle subsystems
- Human factors
- Materials/structure

The potential tasks for the Space Cruiser as a research vehicle require full-envelope performance. That is, the vehicle must be capable of operating in the upper atmosphere as an endoatmospheric vehicle, as a transatmospheric vehicle, and as a cislunar vehicle. The spaceplane must go where the satellites are. This means it must be capable of research and technology tasks at least as high as the geosynchronous satellites. The EVA and EMU tasks of 4.3.1.2 and the SDI support tasks exemplify operation at up to geosynchronous altitude. While not discussed fully in this report, the Space Cruiser in combination with the Centaur(s) and launched by the Shuttle fulfill the growing interest for returning to the moon. Most satellites are located at low to medium altitudes, below 900 nmi and are reachable easily by the Space Cruiser.

The Space Cruiser example used as the input or reference vehicle in this study is limited to approximately 2650 fps with no payload and using only propellant from its internal spherical tanks. The addition of propellant to its two payload bays would increase its achievable delta velocity to approximately 3700 fps. These are modest velocity levels with respect to orbital maneuvering. For example, it takes approximately 1500 fps for a roundtrip from a 100 nmi orbit to a 300 nmi orbit. A return from geosynchronous orbit requires 4700 fps to 6000 fps, depending on whether a 28.5 deg plane change is accomplished. These examples demonstrate that there is a real need to improve the payload-velocity product of the Space Cruiser. To the extent possible, the required added propellant should be contained within the vehicle because the Cruiser cannot enter the atmosphere to perform a plane change or other maneuver while carrying appendages such as propellant tanks. The vehicle must be "clean" for entry. We shall now develop the design logic to both explain and to improve substantially the performance of the Space Cruiser while minimizing the resultant changes to the input configuration of Figure 2.

5.2 STAR CONCEPTUAL-DESIGN LOGIC

This section explains the design logic that results in the general configuration and conceptual design of the Space Cruiser for the research application. It is recognized that the development of the Space Cruiser by a major system manufacturer would result in numerous tradeoffs and refinements. However, as a consequence of the reasoning presented herein it is believed that the differences in configuration and performance between what is presented and the evolved aircraft will be more minor than major.

The general shape of the Space Cruiser is based on the slender right-circular or elliptical cone. The shape, length, weight and the performance of the vehicle derive logically from the constraints of: energy management, atmospheric entry, aerothermodynamics, F = ma, the strong gravitational field, rocket propulsion, launch vehicles, high cost-to-orbit and cislunar operation. While designing within these constraints there is ample room for ingenuity and for maximizing operational flexibility, responsiveness, safety, readiness and autonomy. This section is provided to clarify and substantiate the conceptual configuration and design approach of the Space Cruiser for STAR operations. The Space Cruiser will be used as a research spaceplane while retaining fully the option for its use as an operational military spaceplane.

The logic of the conceptual design derived from the need for omnimissionality: the capability to perform well in many roles, uses and functions. The word omnimissionality is used to distinguish between the Space Cruiser's mission capabilities and the term "multi-mission capability" normally used in reference to aircraft. The means for obtaining omnimission performance will be explained and in effect, be presented as a road map to this result. Following the discussion of omnimissionality the resulting overall operational requirements will be presented. The operational requirements are then focused to conceptual design requirements. The operational and design requirements are placed on a relative basis and then transformed into the resultant STAR Space Cruiser configuration example. Its performance is then quantified and presented in various ways as the basis for discussion of system development and operations, the topic of Section 7.0.

5.2.1 Omnimission Motivations

A principal motivation for incorporating the performance, flexibility and other characteristics which result in the capability to adapt well to a wide variety of uses or "missions" in space and the upper atmosphere is the uncertainty inherent in research future-missions prediction. The Space Cruiser's operational capabilities with a large payload-velocity product throughout cislunar space are predictable. It can go "where the action is", that is, where the satellites are or can be. It can operate manned and unmanned. Although many types of missions in space are generally predictable by analogy with our aircraft, naval, and space experience across the wide spectrum of research, military, scientific and commercial applications and operations, each category of the spectrum is expanding into space rapidly, perhaps exponentially. It is not possible to predict with confidence all the future research missions and uses.

The result is a strong motivation to design the spaceplane for the widest possible application. Indeed, it is anachronistic to build a research vehicle to provide data for a limited field, such as aerodynamics or flight control, at least in the context of spaceplane technology and research. The relatively high costs of space operations require that there be as many research beneficiaries as possible, to obtain the cost-effectiveness and benefits that will justify STAR clearly to the Congress, the Department of Defense, the scientific community and the public.

Correlated with the omni-mission requirement is the motivation to avoid a plethora of vehicle types. Every effort should be made to minimize the number of types of vehicles and to do so in such a way that the resulting vehicles can operate as synergistically as possible. For example, the upper stage(s) should double as propulsion modules for the Space Cruiser and the Cruiser should retrieve spent upper stages for reuse.

Space yields the unique opportunity to provide true multi-missionality in the Space Cruiser. We will expand this point. This is in contrast to the well-known difficulties facing multi-missionality of aircraft in the atmosphere.

5.2.2 Omnimission Means

Principal means or routes for obtaining omnimissionality include:

- Taking full advantage of the space environment
- Strong emphasis on energy management in design, configuration and operations
- Exploiting launch vehicle options
- Providing recovery options
- System modularity
- Minimizing costs as part of and as a result of the above omnimissionality means.

Let us expand this road map to omnimissionality by further consideration of each of the listed means.

5.2.2.1 Space Environment The most significant implication of space to omnimissionality is its being a vacuum. The resultant, drag-free operation allows great freedom in vehicular design and configuration. External carry of payloads, propellant, propulsion modules (i.e. with rocket motor), life-support consumables and equipment, and other support equipment and sidecars for passengers and equipment exemplifies modular configuration flexibility that results in adaptability to the missions in terms of configuration and performance. Configure for adaptabililty to what is needed when it is needed rather than penalize missions by specifically designing and configuring the vehicle for a single mission.

The zero drag environment combined with the absence of aerodynamic perturbation forces facilitate rendezvous, docking and caching. Rendezvous, docking and caching permit configuration changes while on orbit for efficiency, performance, and safety in accomplishing or changing missions. Zero drag also facilitates extravehicular activity throughout the space mission.

Each of the above zero drag implications contributes to what can be called buddy operations. Rendezvous and docking for refueling and transfer of payload, crew, or equipment between two Space Cruisers is a buddy operation. For example, two Cruisers could each inject into the same transfer orbit. One Cruiser carries the payload and therefore consumes more propellants. After the injection burn is complete, the Cruiser with the payload is refueled by the other in a buddy operation and will arrive at its apogee with full tanks. This procedure is analogous to upper-staging in terms of performance but no stage is used or expended and no space debris results.

Unlike airspeed, "spacespeed" is a function of the orbit, the destination and the time available to get there, rather than being a principal function of the shape, size and power of the vehicle. Space is the great leveler or normalizer. The large and the small perform the same velocity profile in the same orbit. The drag-free, free-fall space environment results in flight endurance, flight distances and low propellant consumption-per-mile totally beyond meaningful comparison with atmospheric vehicles. Omnimission vehicular capabilities derive from these time and distance free-variables.

A final observation in this discussion of the role of space environment in obtaining a high degree of omnimissionality in an appropriately configured Space Cruiser is the infinite line-of-sight distance available when not occluded by the Earth, moon or sun. The full benefits of line-of-sight and transparency are available to the small vehicle in its missions.

5.2.2.2 **Energy Management** What is needed is the smallest practicable manned vehicle so that it presents the minimum weight and volume to whatever the launch vehicle (LV) may be. Launch energy and costs are so large on a per-pound and per-dimension basis that the tradeoffs greatly favor smallness. The point could be made that there really is no tradeoff. Make the vehicle small and add modules and propellants as required.

Minimizing the weight and volume presented by the spaceplane to its LV equates to maximizing the payload capacity of the spaceplane, its achievable mass-ratio and payload-velocity product and the weight and volume available for other payloads on the LV. Up to perhaps four fully fueled or eight partially fueled Space Cruisers can be carried in the Shuttle Orbiter's cargo bay. The performance of modest size expendable launch vehicles (ELV) such as the MX booster is particularly sensitive to the minimization of the spaceplane. The advantages of ELV's in terms of responsiveness, readiness, availability and potentially, cost argue for any vehicle that exploits the use of the developing set of ELV's. The coordinated launch of one or more additional ELV's to place payload or propellant in place for pickup by the spaceplane can obviate the need for a larger LV from that which launches the spaceplane. Thus parallel or coordinated launch of two or more spaceplanes can be done with ELV's for flexibility and responsiveness.

A special case of ELV or partially reusable LV is the airborne launch vehicle (ALV). The performance benefits to the ALV-aircraft system from spaceplane smallness are even greater than those realized by the ground-launched LV. One principal result of spaceplane smallness is the enabling of existing aircraft such as the 747-200F to be used as the launch aircraft. Studies such as the Transatmospheric Vehicle (TAV) Concept Development and Evaluation, sponsored by the USAF Aeronautical Systems Division (ASD) have identified substantial operational advantages of aircraft launch for the military. Advantages include flexibility in basing, launch area and in launch azimuth. Additional advantages obtain for the research spaceplane. An aircraft-ALV-spaceplane system concept is presented in Section 6.3 that may prove to be the most cost-effective Space Cruiser operational launch method for the forseeable future.

Most of the TAV conceptual designs have sufficient cargo bay and weight lifting capability to carry a spaceplane designed for minimum weight and volume to even low polar orbit. The smaller the spaceplane the better the performance of the TAV-spaceplane system. The spaceplane complements the TAV in effectively extending its the reach into cislunar space. The TAV serves as a launch vehicle, a logistical support vehicle between the earth and the spaceplane on-orbit, and can join in buddy operations. For example the TAV could provide on-orbit command and control. The TAV could precede the spaceplane over a geographic area or space volume of interest and call in and vector the spaceplane (or vice versa).

Another energy management technique of great value is the use of aerobraking to decrease the spaceplane velocity and heating when traversing the upper atmosphere. The reusable aerobrake is especially valuable to the cislunar spaceplane with entry maneuvers from high orbits and from geosynchronous altitudes and beyond.

The high delta-velocity and propellant consumption required to perform a substantial plane change in low earth orbit can be reduced greatly by using aerodynamic lift in performing the plane change. This is the synergistic plane change. Propellant is only required to provide the retro velocity for entry, to make up the velocity loss due to drag and gravity and to inject and insert the spaceplane into the final orbit. Vehicles with lift-to-drag ratios of 1.5 or more can benefit substantially from the synergistic plane change as part of their energy management for obtaining omnimissionality.

5.2.2.3 **Launch Vehicle Options** The large differences in launch vehicles in use or available in the future are in part the results of differences in missions for which they were designed, differences in payloads, orbits, modularity, reusability, etc. The stable of LVs will continue to grow. Example LVs with sufficient capability for potential launch of the small spaceplane are:

Shuttle
Shuttle-derived launch vehicles
MX Peacekeeper ICBM booster stack
Future Transatmospheric Vehicles (TAVs)
Future Low-Earth-Orbit (LEO) logistics vehicles
Air-launched LVs
Commercial ground-launched LVs
Ariane

The key point is that one of the principal means for achieving omnimissionality with the small spaceplane is for it to be compatible with as many LVs as possible. The LV can then be selected to match the mission requirements, enabling the spaceplane to fulfill the mission needs in the best manner in terms of launch cost, payload, post-launch delta-velocity available, and so forth. The smaller and lighter the spaceplane the better, for mission flexibility with any LV.

5.2.2.4 **System Modularity** An important means of increasing the adaptability of the spaceplane to missions is to use system modularity. The following are configuration examples that represent the modular approach to increase the number of types of tasks and missions that can be accomplished with the small spaceplane.

External carry The carrying of equipment, payload and consumables externally as in contradistinction to the internal bay. In general, the larger the internal bay the heavier the vehicle. External carry increases system performance and versatility.

Internal layout Flexibility in the packaging and relocation of internal subsystems. For example, the option of removing internal propellant tanks while using external tanks would substantially increase the internal volume available for mission needs, including the option of carrying a second crew member.

Propulsion module(s) The addition of a propulsion module adapts the spaceplane to provide a large increase in the payload-velocity product. Man-rating available upper stages, lease-craft, Orbital Maneuvering Vehicle systems (OMV) etc. as propulsion modules for the spaceplane could increase mission flexibility. Deletion of avionics and attitude control equipment from the modules would result in lower cost and simplicity relative to the fully equipped propulsion system. The spaceplane's inherent capability in these subsystem areas may prove sufficient to include control of the module.

Buddy operation The previously discussed buddy type operations can be considered modular configurations, adapting the spaceplane to more missions and increasing performance without the development or purchase of new equipment, requiring a larger LV, etc.

Launch vehicle options The previously discussed LV options can be considered as modular configuration elements enhancing omnimissionality and performance - matching the mission and payload.

Stage stations The distributed stage station concept is designed to provide over a period of time as many small space stations as possible for the lowest cost. The stage stations would serve as sanctuaries, logistic stations, navigation light ships, rendezvous points, relaxation and repair centers, etc. The concept is to design the final stage of the LV to serve as a space station after its launch function is complete. Because the stage stations would be inserted and left in or near the orbits in which payloads and spaceplanes were inserted, they tend to be where the traffic is, where they would be within reach. Their on-orbit availability increases as their number increases. Launched on an otherwise expendable LV, they tend to make the ELV in a sense, reusable indefinitely. Their low cost results from the relatively small cost of the capability when designed into the stage from the outset. An ALV sketch with a stage station as the final stage is shown in Section 6.3 and discussed in the context of spaceplane operations in Section 7.0. A key feature of the stage stations concept is that they form a "distributed" space station with linkages such as communications and would be synergistic with the one or two large space stations planned currently. The ALV example of a stage station depicts a ten foot diameter final stage that has two rooms, one the empty hydrogen tank, and the other the empty liquid oxygen tank. Ten foot diameter looms large to the spaceplane pilot. Hundreds to thousands of pounds of supplies and equipment could be available on the stage station. Similar services could be achieved with the NASA space station. Spaceplane refueling at the large space station would be very cost effective. Changing crew, payloads, etc. would facilitate greatly the on-orbit accomplishment and changing of missions. Future TAV and logistics vehicles could provide support of the spaceplane and/or its payload and crew. In each case, the smaller the spaceplane the easier it becomes to support.

5.2.2.5 **Recovery Options** An important means toward omnimissionality is the provision for recovery options. The spaceplane should be inherently capable of truly autonomous self recovery. It should be capable of landing safely at austere sites, unprepared sites, "helicopter-compatible" sites. It should be capable of reaching and being stowed in as small a volume as possible in the Space Shuttle Orbiter for recovery or refurbishment. The Orbiter could recover the spaceplane's crew, payloads, propulsion module, sidecars, etc.

5.2.2.6 **Minimum Cost** In addition to the capability to perform a multiplicity of missions with the spaceplane, the cost of performing the missions must be sufficiently low to warrant the spaceplane for their accomplishment. This is not to state that each must be done at less cost than by other possible means, but to make the point that on the average the cost must be less. A central point here is that the spaceplane may enable the obviation of the development and procurement of vehicles and propulsion systems capable of fewer uses and missions.

Each of the means toward omnimissionality which have been stated has its own implications for minimizing costs as well, by contributing to the number of options from which the mission configuration can be selected with criteria including individual option cost, relative costs and cost-effectiveness. A key point is that the flexible, high-performance spaceplane will result in cases where its payload-velocity and other performance will enable a combination of tasks or missions per flight, thereby reducing the cost per task by sharing.

Let us consider a brief summary of trends toward the high return-on-investment of omnimissionality. The intent is to clarify that the means also imply the reduction of mission cost. Selection of only the spaceplane "modules" required to accomplish the tasks and the avoidance thereby of costly capability-overkill for less than full-capability missions is a result. In partial summation:

- The smaller the spaceplane the larger its payload-velocity after launch by the LV; the less the launch cost; the less the resupply cost of spaceplanes and their support on orbit; and the more LV types are available.
- Autonomous recovery and capability of landing at unprepared sites should result in reduction of recovery cost by orders of magnitude. This could be vital to spaceplane use as a research vehicle for space operations.

- On-orbit cacheability offers cost reduction by minimizing the round-trips.
- The use throughout of current technology reduces development cost, increases the reliability of costing and reduces risk.

5.2.3 **Operational Requirements** Having considered the principal motivations and means toward achieving the omnimissionality potential of the small cislunar spaceplane we now consider their implication on operational requirements. We will then transform logically these overall operational requirements into the more specific design requirements.

The foremost operational requirement is for full-envelope operation. This requires that the spaceplane must be capable of cislunar, transatmospheric and endoatmospheric flight and operations. Further it is required that the spaceplane be capable of flight routinely among these three components of the full envelope. Thus, on a particular sortie the spaceplane could return from cislunar operations, perform synergistic plane changes followed by operations in low to medium altitude orbits, reenter, perform tasks in the atmosphere and then land at an unprepared site of the pilot's own choosing. Within this basic requirement, the spaceplane must have the following specific operational capabilities:

- Extravehicular activity operations must be routine. The spaceplane and the pilot's environment must facilitate EVA as often as desired during a flight.
- The spaceplane must be capable of autonomous landing safely at an austere site of opportunity and must permit final maneuvering for selecting the site and performing landing at zero speed.
- The spaceplane must inherently facilitate launch by launch vehicles currently available and available in the future.
- The spaceplane must be capable of both autonomous operations and coordinated operations with other space and Earth systems.

These requirements are in support of operational military doctrine and the minimization of the cost of support and flight operations whether military, research, commercial, or of other categories. By designing from the outset to meet the requirements of autonomous operation the probability of meeting the requirement is maximized. It is consistent with military flight operations and the need for a large reduction in the cost of operations. Expanding the requirement for cost reduction, the requirement exists for substantial reduction of costs across the board from an operational point of view. Thus the spaceplane and its operations are required to be low-cost on the average relative to other means of accomplishing missions for which it is suitable. Finally, all these requirements must result in the capability to perform as many tasks, uses, or in summary, missions as possible in an overall cost-effective manner.

5.2.4 **Conceptual Design Requirements** The design requirements for the spaceplane that result from the above discussion and operational requirements are:

- State-of-the-art systems and technology as the most advanced level but lower level technology may be preferred for practical reasons such as cost.
- Minimum weight and volume within practical reason.
- Maximum payload-velocity should be achieved in spaceplane design.
- Endoatmospheric energy management balance between the maximizing of the lift-to-drag ratio (L/D) and the minimization of drag. This must be done with the full consideration that the spaceplane is a cislunar vehicle, not a payload-to-ground, internal-payload-volume vehicle. For example the beneficial use of centripetal acceleration during chordal, trans-atmospheric passes must be included. The use of propellants for plane changes in an optimal trade among weight, velocity losses, aerodynamic shape, center-of-gravity control for stability and control, and control surface hinge-moments/energy requirements presents a design problem in which L/D is only one factor.
- A reusable restowable aerobrake is required. The aerobrake subsystem must be compatible with multiple operation per flight.
- The landing system must be based on the flying-parachute or Parafoil. Landing velocity should be centered on zero-velocity. Redundant Parafoils are required for safety.
- The cockpit shall be un-pressurized while in space.
- The spaceplane design will facilitate EVA as a normal routine operation. Safe control of the spaceplane shall be maintained by the pilot while on EVA. The spaceplane shall be designed to provide as much assistance as possible to the pilot or others who are performing EVA activity in the vicinity of the spaceplane.
- The overall spaceplane system configuration and designs will exploit modularity to provide the maximum omnimissionality and cost-effectiveness.

shows that all of the general design requirements discussed contribute to the omnimissionality of the spaceplane. This observation resulted from examining the outcome of the preparation of the chart and reflects omnimissionality as the principal criterion for defining the operational requirements. The bullets indicate strong, definiteness in correlation. The lb-delta v column represents payload-velocity. The 0 psi column represents the non-pressurized cockpit environment.

	DESIGN							
OPERATIONAL	**SOA**	**MIN W/VOL**	**lb-ΔV**	**L/D**	**AERO-BRAKE**	**PARA-FOIL**	**MODULAR**	**0 PSI**
FULL ENVELOPE	●	●	●	●	●		●	
EVA ROUTINELY	●						●	●
AUSTERE LANDING	●	●				●	●	
LAUNCH OPTIONS	●	●					●	
AUTONOMY	●		●	●	●	●	●	
UNMANNED	●					●		
LOW COST	●	●			●	●	●	●
OMNI-MISSION	●	●	●	●	●	●	●	●

Figure 3 Requirements Matrix

6.0 STAR SYSTEM CONFIGURATIONS AND PERFORMANCE

6.1 SPACE CRUISER CONFIGURATION FOR STAR RESEARCH

A key result from the analysis of the research vehicle application is that there is not a requirement to change the internal layout of the spaceplane from that of Figure 2. Also important is the corollary evidence that should internal changes result from development of the vehicle by a major system manufacturer it is unlikely that the performance of the vehicle as a research vehicle would be degraded as a result. The need for additional performance capability in the Space Cruiser was evident from the responses to the research survey. Numerous tasks were recommended that involved joining with satellites. While most satellites are in orbits below about 900 miles, it was determined that the Space Cruiser should have the capability to rendezvous with satellites at any altitude, including those in geosynchronous orbit. Although external propellant tankage or a propulsion module such as the Centaur could provide the required energy to carry experimental equipment or payloads to reach a higher satellite or satellites it has been a ground rule to retain sufficient internal propellant reserves to return safely without external propellant. Additional velocity would increase the capability for rescue operations as suggested in one survey response. The improvement includes the option to use added energy to reduce the orbital maneuvering time by enabling higher-energy but shorter duration transfer orbits. The input Cruiser configuration of Figure 2 is too limited in achieving velocity with internal propulsion.

There are important changes therefore that are recommended to result in the STAR spaceplane configuration. The overall entry body shape should be changed from the right-circular cone to the cone-ellipse. A number of significant advantages result. Before the advantages are presented it should be clarified how the internal layout is unconstrained by the reentry body change to an elliptical cross section.

The design concept is to design the outer airframe or reentry body to overlay the inner airframe or substructure which remains conical regardless of the final shape of the outer airframe. The outer airframe can be termed the aeroshell. The inner airframe is termed herein, the substructure. The volume between the aeroshell and the substructure is termed the auxiliary volume.

The principal advantages of the cone-ellipse are the increase in available volume internal to the thermal structure, the opportunity to eliminate wings or strakes, and an increase in L/D while retaining a low value of drag, perhaps decreasing drag. The elimination of wings or other appendages that aggravate the heating problem by creating shock interference and radiation against each other appears desirable from a thermal viewpoint. The top-and-bottom symmetry is retained sufficiently to permit the Space Cruiser to fly with top and bottom windward alternatively. This is not possible with the flat-bottomed, winged vehicles which cannot use this method to distribute the heat load or limit local heating.

Aerodynamic control would be accomplished by the conventional split windward flap method. As the alternative to four straked wings with elevons used in the Spaceplane Examination (Reference 1) the number of control surfaces and associated drive motors is reduced from four to two. This should reduce weight and volume at the aft end and reduce the cost of refurbishment. The elimination of the winged, cruciform configuration will impose greater demands on the autopilot in terms of stability control. However, the resultant increase in allowable entry velocity would be of great value.

The other principal, perhaps vital justification for the elliptical cross section is the availability of the auxiliary volume for propellant tankage. This volume would be substantially greater than that of the internal spherical tanks. As will be quantified, the Space Cruiser operates at the high-slope section of the logarithmic rocket equation curve. Therefore there is no way to have too much propellant or to reach the point of diminishing returns. High density-impulse propellants and as much propellant volume as possible are design requirements.

The design concept for auxiliary tankage is to use conformal, effectively non-pressurized tanks that fill the auxiliary volume efficiently. The fuel is located on one side of the aircraft and the oxidizer on the other side. This provides desirable separation. The propellants are pump-fed by small electric motor-driven pumps. Samarium or other modern magnetic material motors would be used. The pumps would be very small, with redundancy. Because there is no need to pump-feed all the plug-cluster engine nozzles at once, the motors can be optimized for packaging, reliability, etc. Once in orbit, the thrust level of the PCE is relatively unimportant because flight is at low flight path angles, resulting in very low gravitational velocity-losses. A small reduction in delivered specific impulse results from operating with fewer nozzles but the advantage of increased available energy makes this consideration moot.

Another reason for the cone-ellipse and the elimination of wings is the option to design the aeroshell and substructure as a system such that the aeroshell can be removed as a unit readily and replaced. This feature has several important uses. It provides for rapid replacement of the aeroshell when required, eliminating the impact of aeroshell refurbishment on Space Cruiser turn-around time. It provides the means for conducting research on/with the aeroshell without modification of the substructure and core vehicle. The internal subsystems can remain intact, inspected and untouched while a different aeroshell is attached. It is expected that aeroshell replacement would be a flight test hanger-compatible operation. Aeroshell research would include substantial shape changes, structural research and materials research.

The availability of auxiliary-volume propellant tankage provides the opportunity to remove the internal, spherical tanks, move the primary Parafoil forward toward the secondary Parafoil and install a second seat. The forward seat would be ideal for a payload or mission specialist. It would permit adjustments to be made on cargo or instrumentation from the second seat while the nose section is folded aft alongside. The location of the spherical tanks centered about the Cruiser's center of gravity allows the additional crew position with no significant change in CG location. The two-crew-member configuration can be used for example for astronaut rescue and recovery to earth. When the auxiliary tanks contain propellant the CG translates aft. This is unacceptable for entry. Therefore, the operational practice would be to use the auxiliary propellant first, permitting subsequent entry with full internal spherical tanks and possibly some propellants in the auxiliary tanks.

The resultant STAR configuration of the Space Cruiser is illustrated in Figure 4. The evident changes are the low-eccentricity elliptical cross section and the deletion of wings.

6.1.1 Centaur-SP

The performance and effectiveness of the Space Cruiser can be enhanced substantially by the addition of a propulsion module. The propulsion module is defined as an additional propulsion system with own rocket engine. The use of the wide body Centaur as an example propulsion module with the Cruiser is depicted in Figure 5.

It was analyzed for use with the Cruiser in the Spaceplane Examination. Figure 6 shows the Centaur-SP located in the Orbiter's cargo bay. The nose is shown attached normally, however it can be folded as indicated by the dotted lines (or removed) to provide an additional cargo bay space approximately 12 feet long.

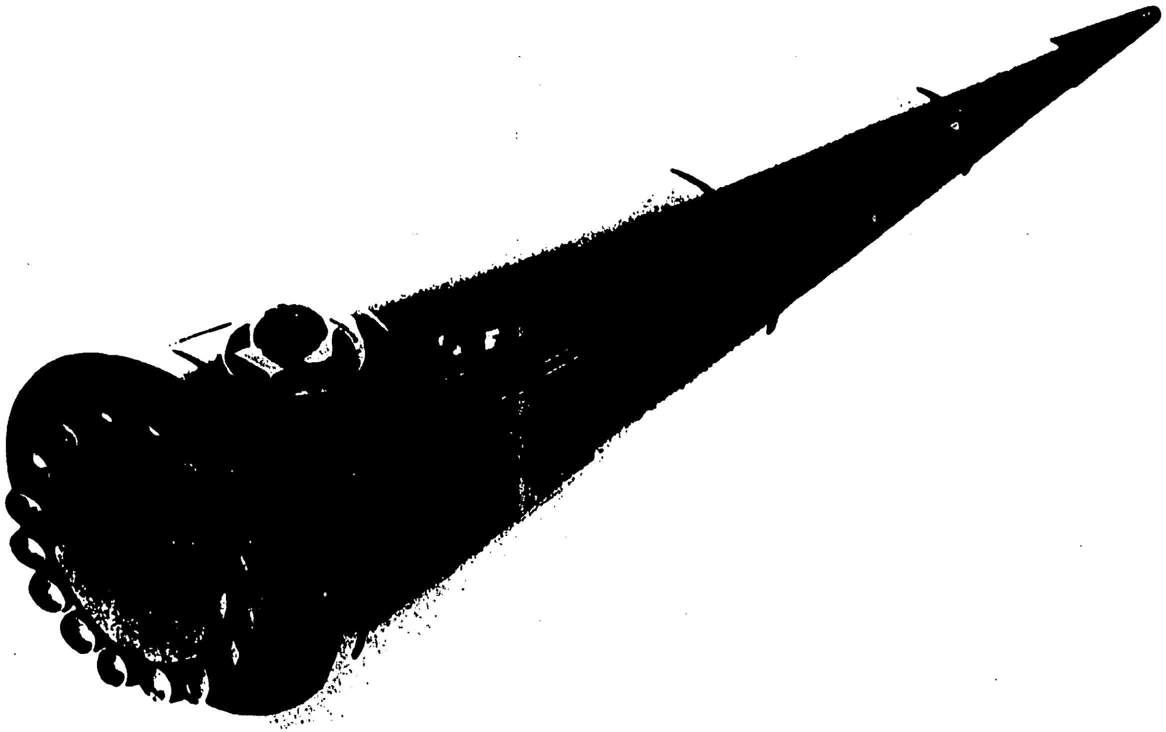

Figure 4 STAR Space Cruiser Configuration

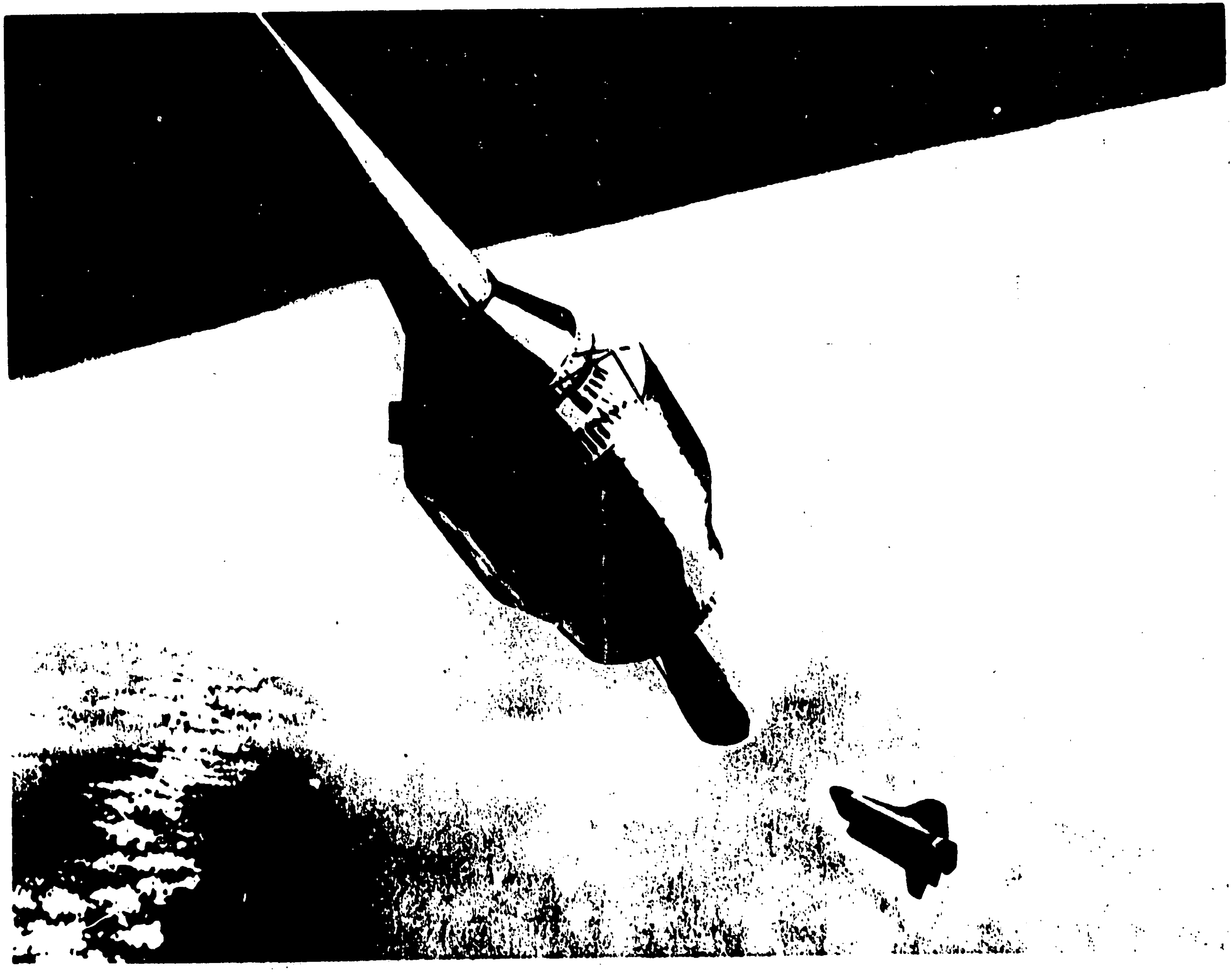

Figure 5 Centaur-SP

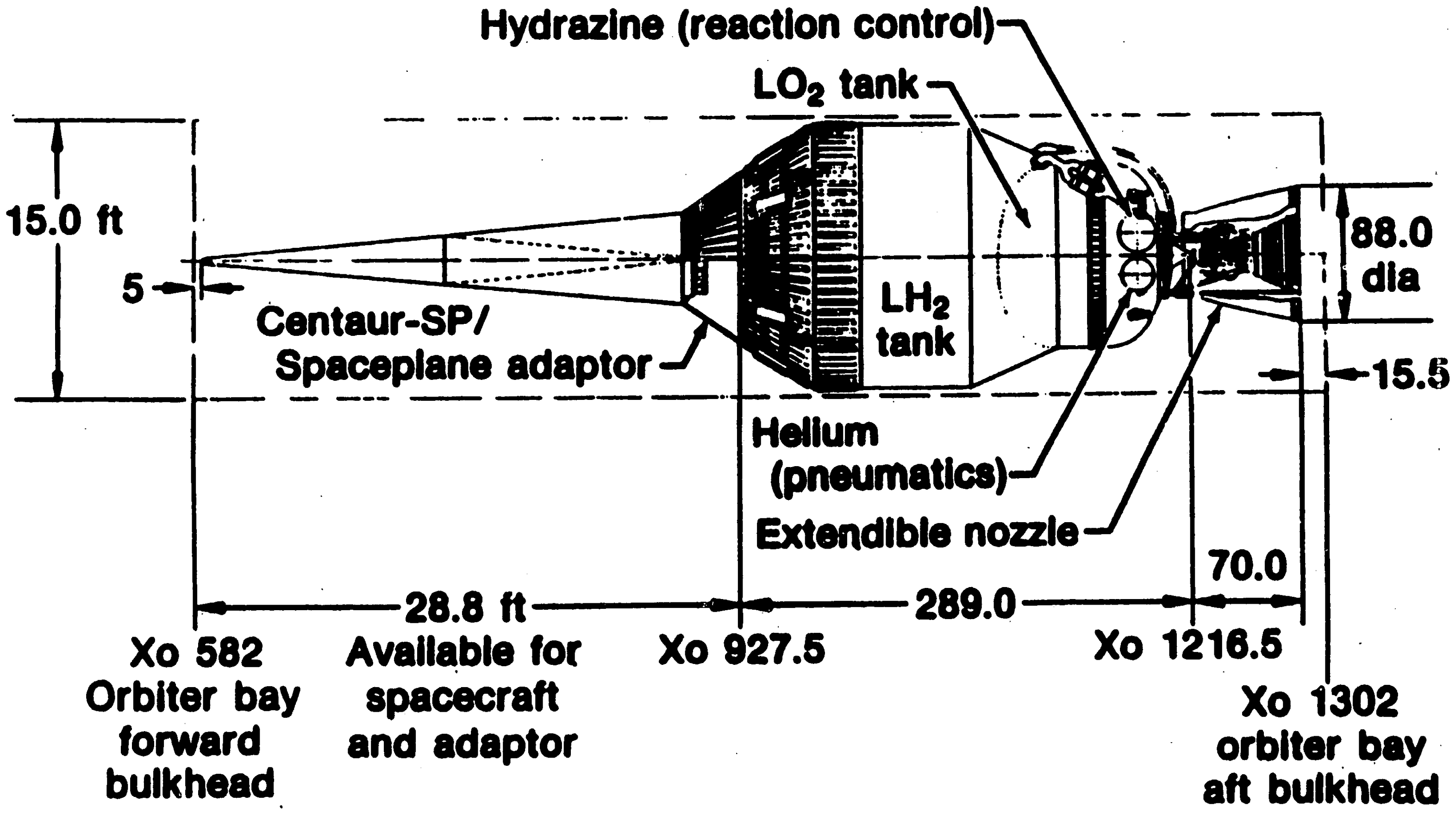

Figure 6 Centaur-SP in Orbiter Cargo Bay

The RL-10 Derivative IIB engine was recommended for the Centaur-SP. It uses an extendable exit cone and can operate at two reduced thrust levels when required. Pumped idle provides approximately 3700 lbf and tank-head idle provides approximately 150 lbf. The delivered specific impulse at full thrust of 15,000 lbf is 472 sec with a mixture ratio of 5.0.

6.1.2 Parafoil Performance (References 2 and 3)

The total recovery weight of the Space Cruiser is conservatively assumed at 5,000 lbm for sizing the Parafoil. The steady-state gliding performance with Parafoil deployed is given in Figure 7. The ability of the Parafoil to land with a velocity close to zero has been demonstrated many thousands of times [illegible] Parafoil sport jumpers and by various Department of Defense system demonstrations. The Parafoil is superior to the parachute by the L/D ratio. For an L/D = 6, the Parafoil has approximately one-sixth the rate of sink. The flare maneuver is quantified by Figure 8.

6.1.3 Payload-Maneuverability

The principle flight performance measures of the Space Cruiser are:

- Payload-velocity
- Zero-speed landing
- Plane change capability
- Atmosphere penetration

The basic result of payload-velocity is payload-maneuverability. Payload-velocity is the change in velocity, delta-V, that the spaceplane can give to a payload as a function of the payload weight and the spaceplane's configuration. It is the normalized measure of payload maneuverability in the sense that the velocity available with a given payload can be used in a wide spectrum of maneuvers. The choice of maneuver is optional and not the basic measure of vehicle performance. The transformation of velocity into typical maneuvers in space is for concept purposes a handbook matter. We can evaluate vehicular performance comprehensively in terms of payload-velocity without loss of generality. Several example maneuvers should then serve to present the transformation of payload-velocity to payload-maneuverability. Payload-velocity is an excellent and revealing measure for comparative evaluation of different space vehicles and among configurations of a particular space vehicle.

6.1.4 STAR Space Cruiser Performance The payload-velocity of the STAR Space Cruiser is given in Figure 9. The vacuum delivered specific impulse of the Aerojet plug-cluster engine with all nozzles operating is 316.85 sec. The individual nozzles or

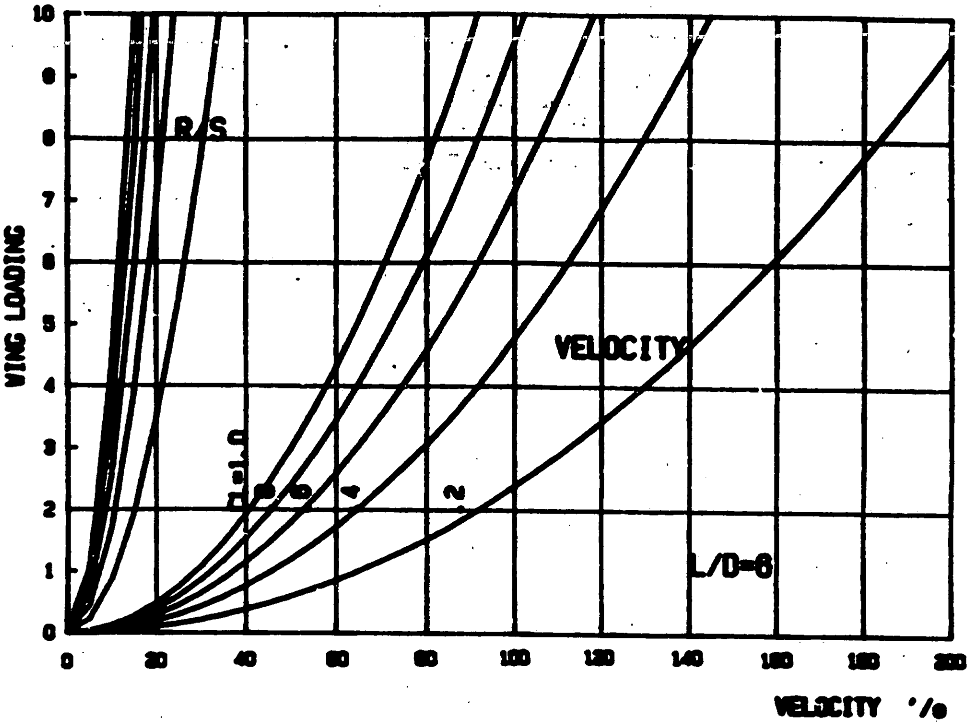

Figure 7 Steady State Gliding Performance

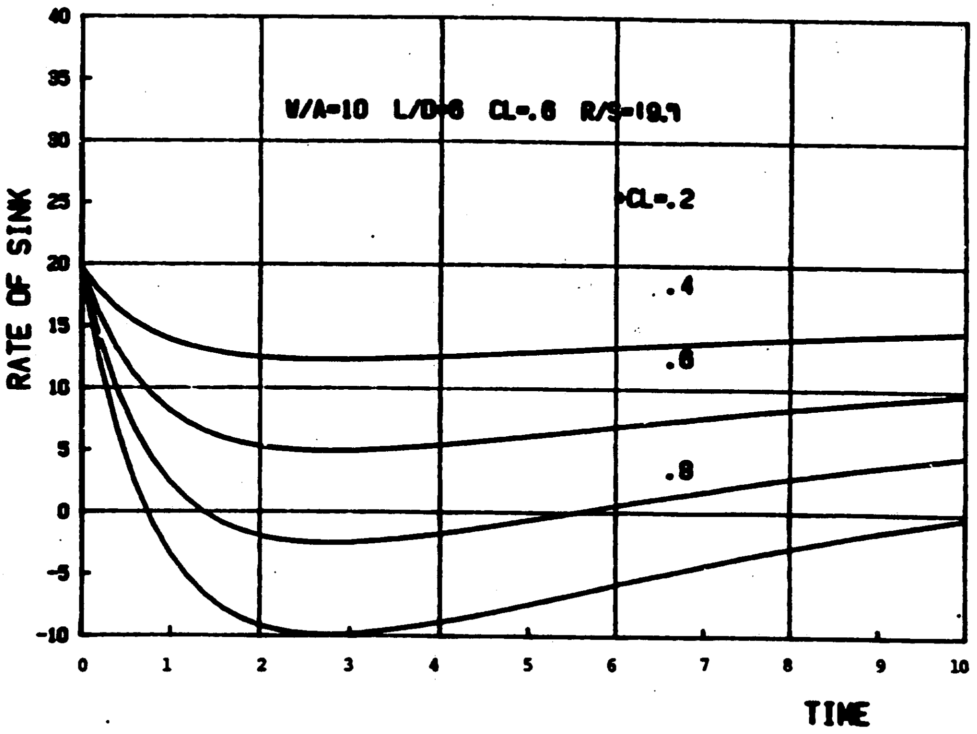

Figure 8 Steady State Gliding Performance/Flare Maneuver

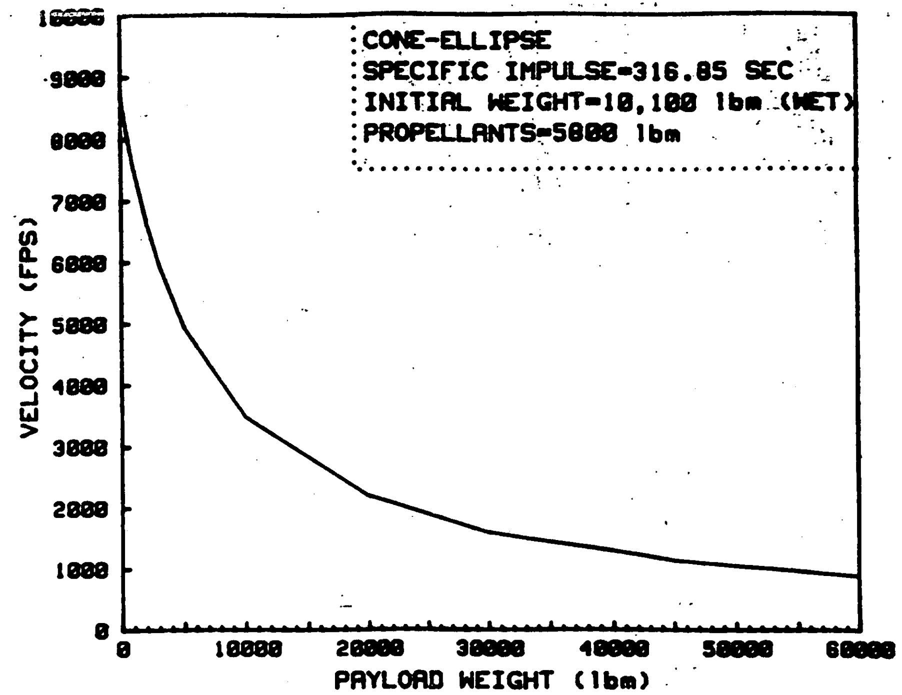

Figure 9 STAR Space Cruiser Payload-Velocity

modules have a specific impulse of 311.66 sec with chamber pressure = 188 psia. Fuel flow is 0.27 lbm/sec and oxidizer flow is 0.33 lbm/sec, for a total flow rate of 0.60 lbm/sec. The PCE diameter is 43.55 in. and its length is 13.88 inches. The module thrust is 188 lb and the PCE thrust is 3058.12 lb.

The total weight of the PCE is 85 lbm. The useable propellant from the spherical tanks is 1,300 lbm. The conformal auxiliary tanks provide an additional 4,500 lbm of propellant for the STAR configuration presented herein with an elliptical cross-section with an eccentricity of approximately 0.707. Because the auxiliary volume is directly proportional to the semi-major axis of the elliptical cross-section and L/D increases with an increase in eccentricity, the auxiliary propellant volume is believed to be conservatively estimated. A nose ballast weight of 492 lbm was included, corresponding to no payload in the payload bays. This value decreases if a payload is located in the forward bay and remains approximately the same if payloads are located in both bays.

The maximum delta-V achievable by the Space Cruiser with zero payload is 8,700 fps. A velocity of 8,075 fps is provided to a payload of 500 lbm. This corresponds to an internal payload density in the forward bay of approximately 60 pounds/cubic foot. Of course, the large payloads would be carried externally.

6.1.5 Centaur-SP Performance The payload-velocity performance of the combined Centaur-Space Cruiser is given by Figure 10. The wide body Centaur would be modified by replacing the two RL-10 engines with a single RL-10 Derivative IIB engine. For overspeed entry of the Centaur a lifting aerobrake would be attached to the aft end. The lower curve represents the Centaur as a propulsion module with the full, wet Space Cruiser as a payload of 10,100 lbm. The zero-payload velocity is 20,741 fps. This corresponds to a plane change at 100 nmi altitude of more than 45 degrees. A velocity of 14,000 fps corresponds to payload delivery from an inclination of 28.5 deg to geosynchronous orbit. It is interesting to observe that the Centaur-SP could push the entire Orbiter to a velocity of 3,600 fps. This corresponds to a maneuver in which the Orbiter is pushed from a 100 nmi circular orbit to a 300 nmi circular orbit and back down again to a 100 nmi circular orbit, twice, the Orbiter is then deorbited, the Centaur propulsion module is left in low orbit and the Spaceplane is then free to maneuver fully with up to 8,700 fps and to return to land "on the wing of the Orbiter." The Orbital Maneuvering System (OMS) engines of the Orbiter were not used.

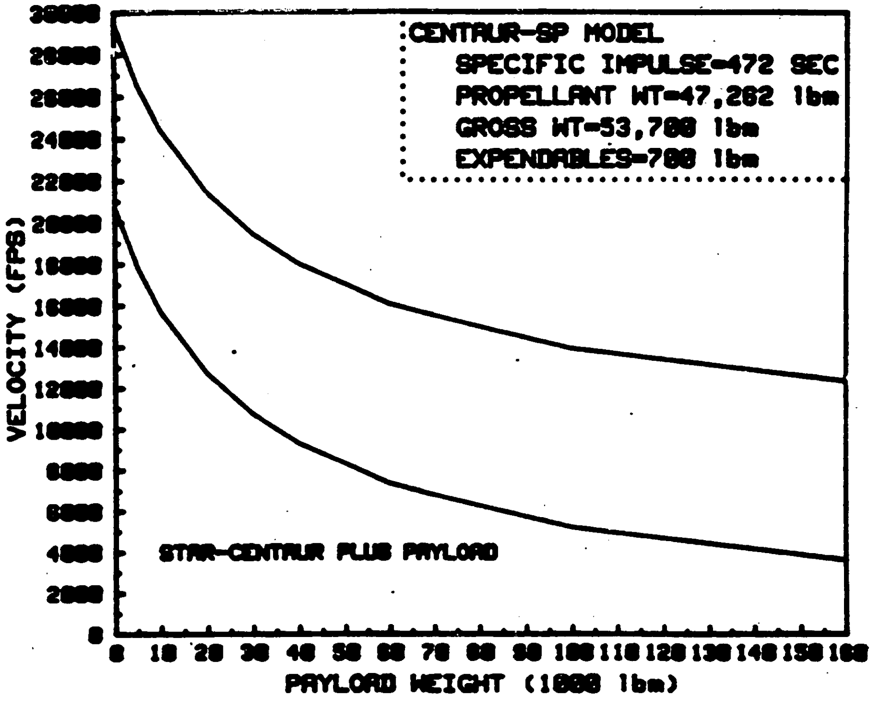

Figure 10 Centaur-SP Payload-Velocity

The upper curve shows the 8700 fps velocity achievable by the Space Cruiser after staging from the Centaur and the external payload. As a point of comparison the Apollo 15 used 28,832 fps to land on the moon and return. It should be noted that the addition of another Centaur stage would add approximately 7,000 fps and permit substantial payload delivery to the moon's surface followed by spaceplane return to Earth. Return to the atmosphere from geosynchronous orbit requires approximately 4,700 fps to 6,000 fps depending on whether the 28.5 degree plane change is done. Landing site flexibility suggests the 4,700 fps value for maximum payload to geosynchronous orbit.

Figure 11 combines the three payload-velocity curves, forming a composite performance representation. Not shown, but calculated, is the case where the Cruiser alone pushes the Orbiter. A velocity of 348 fps is achieved with an empty Orbiter. This value is insensitive to Orbiter payload and indicates the Orbiter rescue capability of the Cruiser.

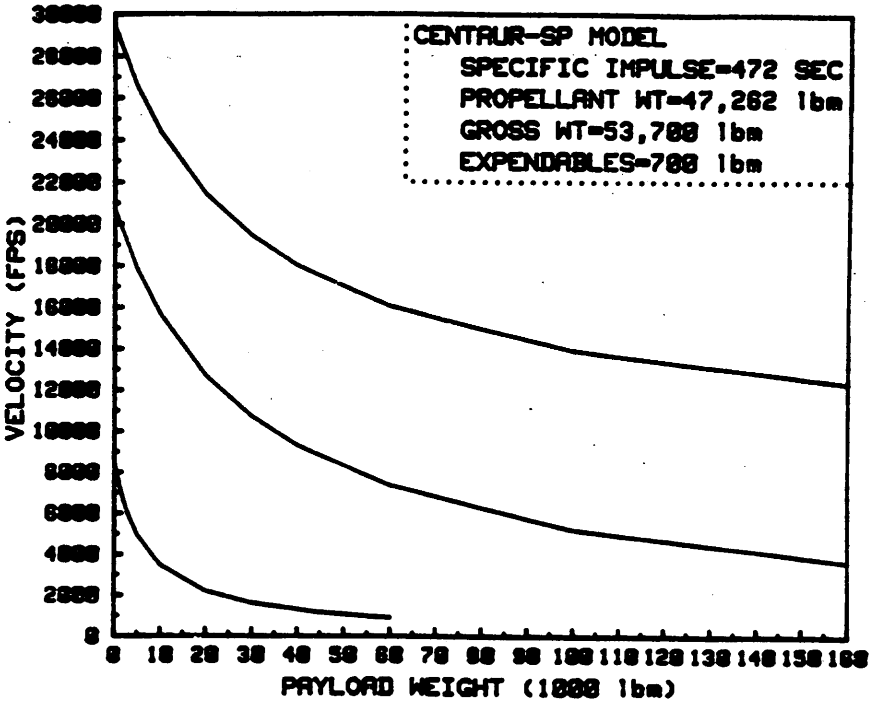

Figure 11 Payload-Velocity Map

6.1.6 Cruiser Maneuverability There are several points that can be made appropriately at this juncture about Space Cruiser maneuverability. The literature abounds with analyses of optimal maneuvers and charts of standard maneuvers under conditions of optimality. Optimality makes sense because delta-V is "hard to come by" in space. The Solar Max repair mission showed the very limited maneuverability of the Orbiter in terms of velocity and of its attitude control system. We also saw that it was the man-in-space that maneuvered the Orbiter, that operated the remote manipulator arm, that retrieved the satellite, that secured the satellite, that repaired the satellite, that operated the arm again, that controlled the Orbiter, etc. Man-in-space is often irreplaceable, just as on Earth and in the air.

In this context one of the principal goals of the STAR research program and of the Space Cruiser as the research vehicle is to obtain flexibility, as much freedom as possible from the constraints of limited hardware performance and designed-in limitations on the astronaut. Another is to explore non-energy optimal, but practical nevertheless, maneuvers.

As an example, consider transfer from a 100 nmi circular orbit to a 300 nmi circular orbit. In real-life, optimal transfer may mean performing the transfer in substantially less time. Rescue may be involved. The requirement may be to rendezvous with an object as soon as possible.

Figure 12 presents quantitatively the dynamics of the problem. The independent variable chosen is the terminal crossing angle (TCA) where the 300 nmi orbit is intersected. This angle is the angle between the local horizontal at the point of intersection and the Space Cruiser's velocity vector at the intersection. The values of the injection velocity beginning the transfer and the insertion velocity required at the intersection of the 300 nmi orbit are plotted as a function of TCA. These velocities are summed in the curve labeled Total Delta-V. The time duration required to perform the transfer is also plotted as a function of TCA.

The origin values correspond to the two-impulse Hohmann transfer in which an insertion velocity of 349 fps is applied horizontally, followed by an insertion burn of 344 fps at intersection, for a total of 693 fps. The delta-time is 45.85 minutes. If a TCA of 2 deg is used, the time is reduced by 15.7 min. The added total velocity is 681 fps, for a total of 1,374 fps. A TCA of 5 deg results in a transfer time of 15.9 min or approximately 35 % of the Hohmann transfer time. The total delta-V required to transfer is then 3,527 fps. This value is well less than half of the maximum velocity of the Cruiser. The Cruiser could therefore return in the same time as well, and have ample propellant for deorbiting and reentry. In this

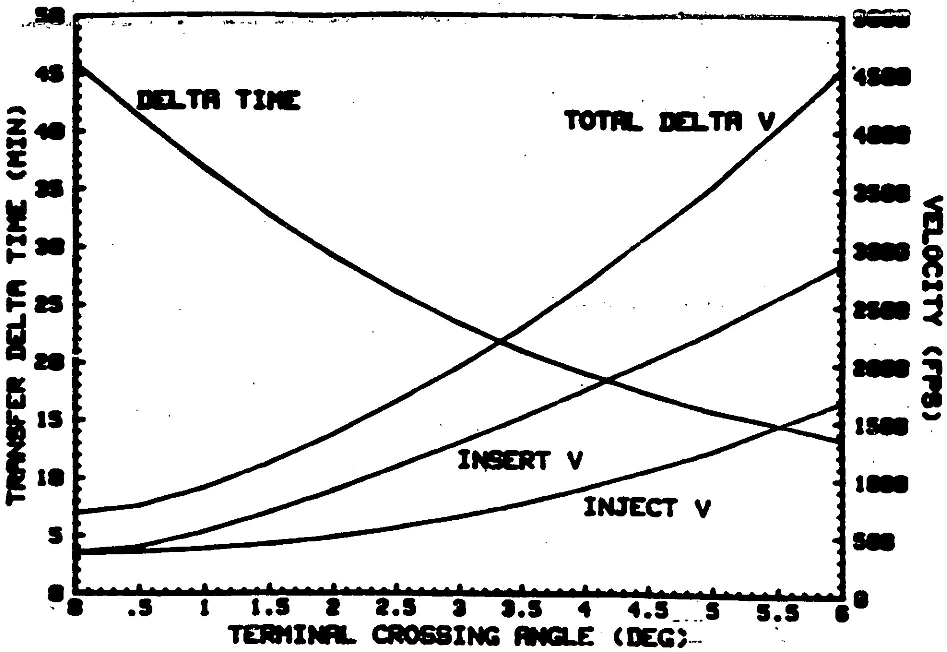

Figure 12 100nmi-300nmi Transfer-Dynamics

case the total time used in the double transfer is 32 min. which is approximately 1/3 of one complete orbit. This example of a non-optimal maneuver is intended to remind us how important it is to design the manned spaceplane for the maximum possible delta-V and at the least weight so that the LV can permit the largest possible propellant load and/or payload weight.

6.2 PEACEKEEPER - SP PERFORMANCE

The performance of the three-stage MX Peacekeeper booster as an LV for the Space Cruiser is indicated in Figure 13. This graph plots the terminal velocity of the LV as a function of throw weight. The trajectories run as the source for this graph were terminated at an altitude of 60 nmi. A non-rotating earth was assumed. This corresponds approximately to polar launch. A velocity of approximately 1,350 fps should be added to the terminal velocities of Figure 12 for the case of east launch from a latitude of 28.5 deg. The coast period between the second and third stages was allowed as a free variable in achieving final flight path angle. The coast times shown are associated with a burnout flight path angle of zero degrees. Results were also obtained for a burnout flight path angle of two

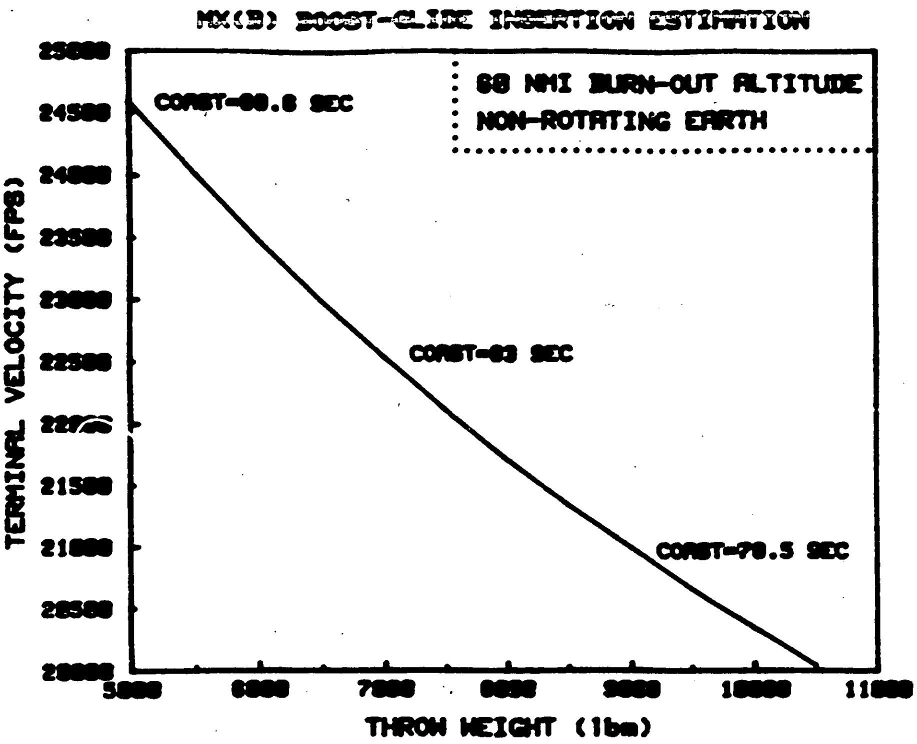

Figure 13 Peacekeeper-SP Performance

degrees. The velocity versus throw-weight curve remained essentially the same. However, the coast times differed substantially. The transformation is 78.5:56.7, 83:59 and 88.6:62.6 seconds.

The Peacekeeper, without its post-boost vehicle, is capable of boosting the Space Cruiser to sufficient trajectory conditions that the Cruiser can be staged and reach orbit with propellant remaining. This is evident regardless of propellant loading in the auxiliary tanks.

With no auxiliary propellant, the wet, manned vehicle weighs approximately 5,600 lbm and the LV provides a staging velocity of 24,000 fps plus the component of the Earth's rotational velocity at the latitude involved. The 5,600 lbm Space Cruiser has then a maximum delta-velocity available of approximately 2,650 fps. If propellant were added to the two payload bays, the vehicle would weigh 6,290 lbm and would be capable of 3,700 fps after staging. If the spherical tanks and the auxiliary tanks are full the vehicle would weigh 10,100 lbm and be capable of 8,700 fps.

A total velocity of 24,000 fps plus 2,650 fps, or 26,500 fps is available (plus the Earth's rotational component) at a LV throw weight of 5,600 lbm. Similarly, a total velocity of 20,300 fps plus 8,700 fps, or 29,000 fps is available with the spherical and auxiliary tanks full. Clearly the staging ratio is sufficiently far from optimal that the Space Cruiser does not reach the point of diminishing returns in terms of increasing the fuel load.

Human tolerance and performance under the specific conditions for launch by the Peacekeeper as an LV have been studied during exposures to multiple, sequential + GX acceleration pulses peaking at 5, 8, and 9 GX in support of the continuing examination of the Space Cruiser concept. The experiments were performed by the Air Force Aerospace Medical Research Laboratory, Aerospace Medical Division, Wright-Patterson Air Force Base. The main findings showed the profile to be well-tolerated physiologically. The complete findings are reported in AFAMRL-TR-84-012, dated February 1984 (Reference 6).

6.3 AIRBORNE LAUNCH VEHICLE

As introduced in Section 5.2.2.2, the launch of the Space Cruiser from a Boeing 747-200F appears feasible and operationally attractive. The 200F model is configured and structured to be a freighter with significantly greater payload weight capability than the passenger models. It is feasible to lift well over 300,000 lbm with a 200F. Fuel is offloaded to enable the maximum payload lift capability. It is assumed that the USAF's operational in-flight refueling system would be added to increase range, duration and payload.

The ALV with its spaceplane(s) payload is attached to the 747-200F underneath the aircraft, between the main landing gear and the nose wheel. The landing gear must be extended vertically approximately 4 feet to accommodate the ALV. The extension concept is to attach a streamlined pylon assembly to each wheel well and attach the standard landing gear to the pylon. It will probably be unnecessary to raise the gear. Fixed gear would be the simplest. Thus, the aircraft would be raised approximately 4 feet and the ALV and the Space Cruiser would be very accessible from the ground. The launch aircraft also serves as the carrier aircraft in transporting the ALV and its ground and airborne support equipment. Indeed the concept is that the aircraft would be the complete servicing, transportation, launch and control facility. The crew, office, flight test instrumentation, computers, etc., would be contained in the aircraft. For launch, ground support equipment, ground crew, etc., are offloaded to minimize take-off weight.

The ALV concept is indicated in Figure 14 and supporting data is presented in Table 1. The ALV is shown with RP-1 fuel; however, improved performance and logistics would result from the use of propane (Reference 7). The dimensions are given in feet.

Each strap-on booster would be recoverable with a Parafoil and the final stage would be designed to be a stage-station, discussed in Section 5.2.2.4 as a modularity option. When the payload weight prevents insertion of the stage, engine restart could be used after Cruiser deployment to provide the velocity maneuver to the final orbit. In this regard, operation of the RL-10 at pumped-idle conditions with a thrust level of approximately 3,700 lbf might be best from an attitude control aspect.

The Space Cruiser serves as its own final stage and could provide the guidance, navigation and autopilot functions during launch. The use of the basically production engines on the ALV would decrease development time and cost greatly. The conversion of the Titan first stage engines to the liquid oxygen and propane propellants is discussed in Appendix C.

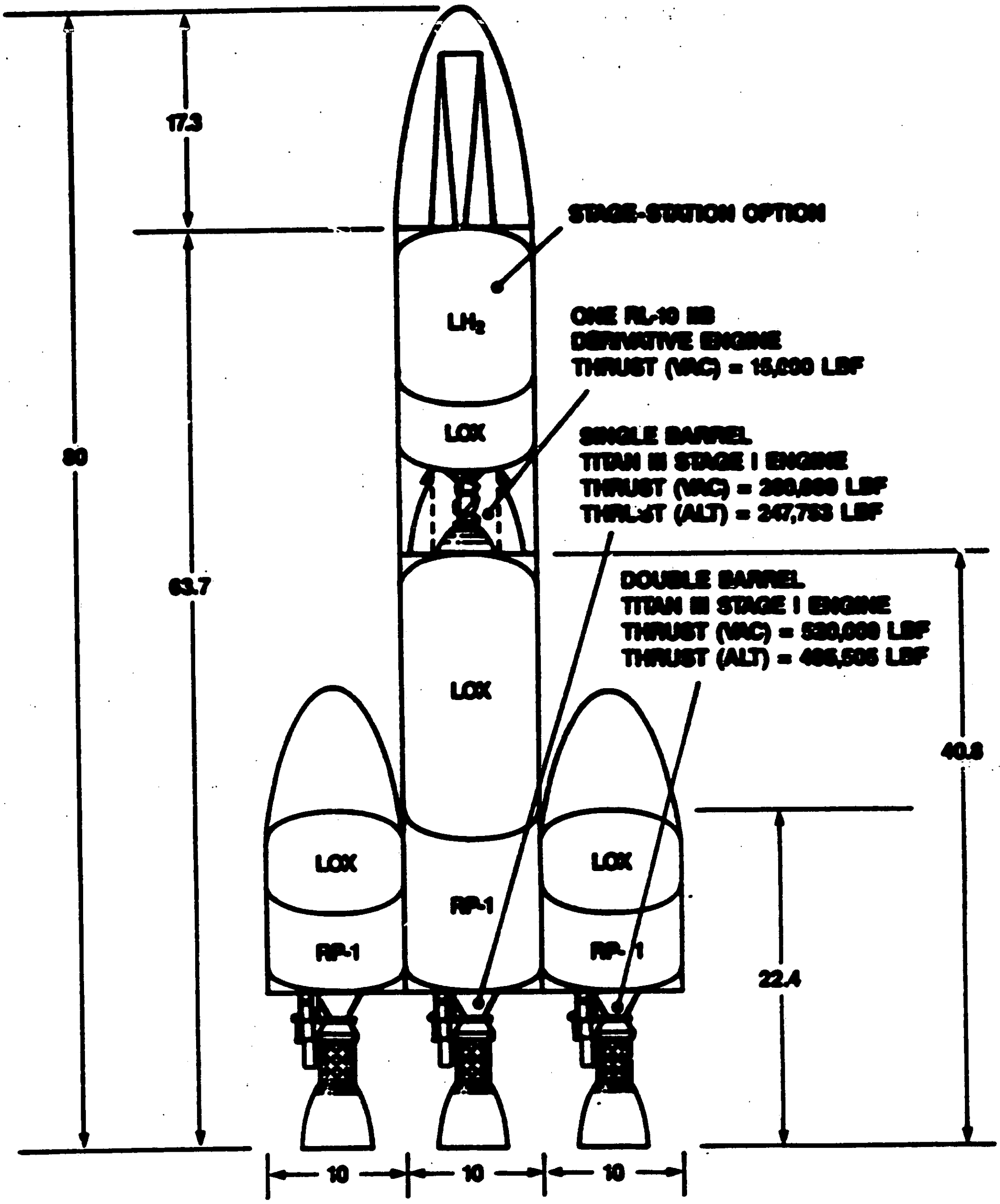

Figure 14 Airborne Launch Vehicle Sketch

TABLE I
AIRBORNE LAUNCH VEHICLE DATA

Gross lift off weight, lbm	322,117.
STRAP ON STAGE (Two barrels)	
Gross wt, lbm	116,374.
Prop wt, lbm	100,000.
Prop Mass Fraction	.859
Ave Isp, sec	302.7
Total Burn Time, sec	57.8
STAGE I	
Gross wt, lbm	163,580.
Prop wt, lbm	141,321.
Prop Mass Fraction	.864
Ave Isp, sec	302.7
Total Burn Time, sec	163.4
STAGE II	
Gross wt, lbm	27,163.
Prop wt, lbm	22,703.
Prop Mass Fraction	.834
Ave Isp, sec	472.
Total Burn Time, sec	693.0
PAYLOAD	15,000.*

* Total Payload Delta-V = 25,607 ft/sec
airlaunch at h=30 kft, flight path angle = 0 deg

ADDITIONAL STAGE DATA

STRAP ON STAGE

- f/wt @ ignition = 3.85
- f/wt @ shutdown = 6.01
- Parallel burn with Stage I
- Isp altitude = 295 sec
- Isp vacuum = 310 sec
- MR = 2.25 (LOX/RP-1)

STAGE I

- f/wt @ ignition = 3.85
- f/wt @ shutdown = 3.79
- Parallel burn with strap-on stages
- Isp altitude = 295 sec
- Isp vacuum = 310 sec
- f/wt @ strap-on separation = 1.32
- MR = 2.25 (LOX/RP-1)

STAGE II

- f/wt @ ignition = 3.56
- f/wt @ shutdown = .745
- MR = 5.0 (Lox/LH$_2$)

7.0 STAR DEVELOPMENT AND RESEARCH PROGRAM PLAN

7.1 DEVELOPMENT PHASE

The principal results required in the consideration of the development phase of the STAR program were the estimated overall scheduling and costs. The approach used was to coordinate with the contractors which had supported the Spaceplane Examination study (Reference 1). Each contractor knew the Space Cruiser conceptual design well and especially the subsystem for which the contractor was responsible. Each was asked to provide an estimate of the time required from work start to delivery of the first system(s) for installation in the Space Cruiser. Costs and delivery are discussed in Section 8.0. A total of six shipsets were planned.

The subsystems were the Environmental Control and Life Support System, the propulsion system including the propulsion components for the attitude control system, and the complete avionics system. The ground rules included the assumption of a research type development program procedure similar to commercial development, ROM quality estimation and being reasonably conservative. Each contractor estimated first delivery in approximately two years. This period was also considered reasonable for the soft-tooled aeroshell and the substructure which would be soft-tooled if non-metallic or prototype tooled if metallic. It was further estimated by each contractor that a flight test program of approximately one year would be required after initial delivery. The flight tests were focused on launch from the NASA Orbiter and Orbiter availability was assumed. The small size of the Space Cruiser and the capabililty to remove its nose section was used as the basis for assumption of the availability of the Orbiter. The priorities and cost waiver rights of NASA for research payloads are potential advantages for the STAR research vehicle as an Orbiter payload.

The Space Cruiser does not fly in a range of speeds from slightly over transonic to the speed of an ultralight aircraft. After the deceleration drogue is deployed and until the Parafoil is disreefed the Cruiser is stabilized and decelerated by parachute. Therefore, flight tests concerning flight and subsystem performance over this speed range are not required or possible. Further, there will be no landing gear tests because there is no landing gear. The small size of the Cruiser suggests that an inexpensive boiler-plate version be used for landing tests and training. Training can also be done with available flying parachute configurations. It would be undesirable to land on a paved runway. There is no apparent requirement for expensive special tracking and control facilities near or at a landing site.

One of the most important flight test objectives is to verify the degree of autonomy that can be permitted the Space Cruiser with respect to ground support and control. Autonomy will reduce the cost of operations. On the other hand, it is necessary to obtain sufficient data and other results from the flight test operations. Therefore, a higher degree of autonomy is expected in operations subsequent to completion of the Space Cruiser developmental flight tests.

The wide spectrum of research and technology tasks identified during this study suggests the Space Cruiser system configuration be versatile, modular and responsive to various internal and external payloads and test needs. It seems appropriate therefore to begin the discussion of the development and research program plan with the presentation of the overall functional configuration of system operations from which specific recommendations can be derived and the available alternatives clarified.

7.1.1 System Operations Plan

The functional operation of the Space Cruiser in a total-system sense has been developed during the study. In striving for the goal of great versatility, or omnimissionality, the manned vehicle must be as small as is practical, have as large a payload-velocity product as is practical with modern technology, and use modularity to adapt to the needs or missions as cost-effectively as possible. The question then arises of what constitutes the total system. How does it all fit and work together? What is the system configuration as a function of research mission? What is the system configuration as a function of development and need priorities?

Consideration of such questions of the development, use, interactions, missions, etc., from the overall operations system viewpoint can be aided with the block diagram of Figure 15. The starting points are the ELV Launch-Boost block and the STS Launch-Boost block. The usual finish point for the Space Cruiser is the Cruiser Facilities/Payloads block at the lower left. The primary focus of the diagram is on the Missions block. This block is double-boxed for emphasis. A secondary focus is made on the Stage-Station Operations block which is also double-boxed.

Observe that from the Missions block the Cruiser can return to the surface, return to the Orbiter, be cached on orbit or rendezvous with a stage station.

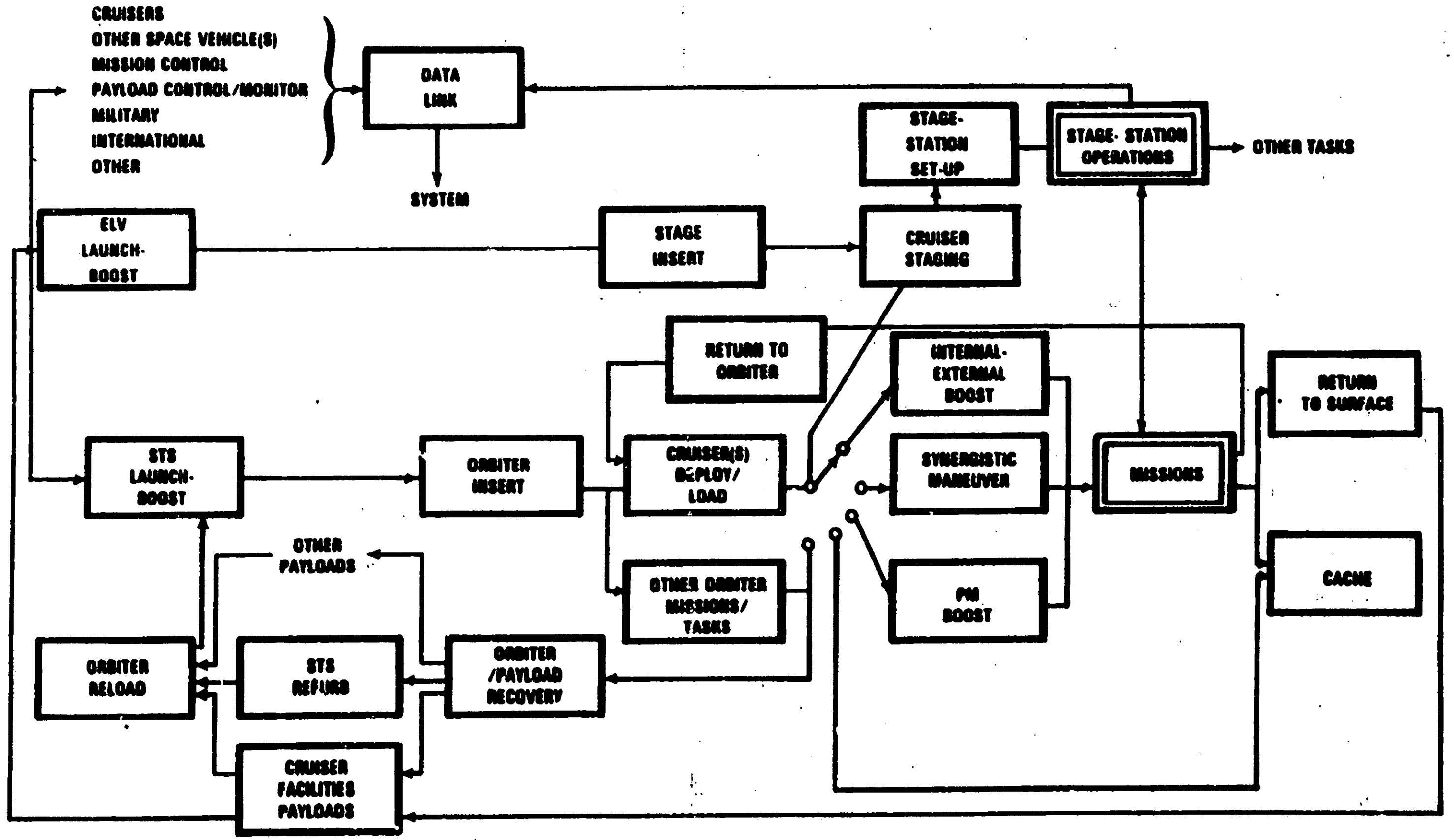

Figure 15 Overall Operations Block Diagram

Observe also that the Cruiser could enter the mission with internal propellant, external propellant, or a propulsion module boost whether launched by the Orbiter or by an ELV. For simplicity the ELV term is intended to include the ALV, with which it is planned that only one stage is expendable. Missions can be entered while in space or following a synergistic maneuver with a clean configuration. It is important to observe that the Orbiter is typically free to perform other missions/tasks independent of the Cruiser. The block parallel to the Cruiser(s) Deploy/Load block represents this capability.

The Cruiser(s) Deploy/Load block represents that up to an estimated 8 Cruisers could be carried in the Orbiter's cargo bay and that Cruisers can be deployed and recovered or loaded in space (as the Solar Max Satellite). The parallel paths for vehicle recovery and handling of payloads are indicated in the lower left portion of the diagram.

The Data Link shown at the top of the diagram connects the Space Cruiser operational system with a selection of participants. Clearly, the autonomous performance capability or mode is only one mode of operation.

Once on-orbit, the stage stations can be operated as satellites independent of Space Cruiser operations and may pay their own way. Stage stations add a new dimension to the debate between expendable and reusable launch vehicles, namely the indefinitely reusable final stage. For completeness, it is recognized that stage stations without their propulsion systems other than attitude control could be deployed by the Orbiters. They may also be used as an interface between the Space Cruisers and the future NASA space station.

7.1.2 Flight Test Configuration

The Space Shuttle is recommended and explained herein as the initial launch vehicle for the Space Cruiser flight tests. The Orbiter can provide the types of built-in support and control in Space Cruiser operations analogous to those U.S. Navy aircraft carriers provide for the Fleet Air Wings. The proven reliability of the man-rated Shuttle, its unique capability for on-orbit support and if required, recovery of the Cruiser result in the lowest risk factor and the maximum flexibility in achieving the flight test objectives.

Analysis of the 1984 Outside Users Payload Model report (Reference 8) and discussions with NASA and Battelle's Columbus Laboratories revealed that the Shuttle is available for Space Cruiser flight tests during 1987, 1988 and 1989. There are several payload openings on scheduled flights. There are also several payloads with a sufficiently low probability of flight that it is reasonable to expect additional availability during the above time period. It is recognized that if actual Shuttle flight rates are significantly less than planned, consolidation of flight payloads may delay the Space Cruiser flight test operations. On the other hand there are reserve capacity opportunities in the form of currently unscheduled flights as well as the less-than-full cargo flights. The opportunity to obtain space tends to decrease as the flight date approaches. The option's tend to close 36 to 24 months prior to flight as progress payments for payload space are received, payload integration becomes well under way, etc.

Following the developmental and verification flight testing of the Space Cruiser itself would be further developmental flights from time to time for the purpose of expanding its capabilities and configuration. For example, the introduction of the MX booster as an expendable LV would require flight testing with the Cruiser as its payload prior to its use as a STAR program LV. The integration of any propulsion module, such as the Centaur-SP discussed in Section 6.1.1, would also require flight testing before operational STAR use with the Cruiser. The current Centaur family of upper stages represents an available propulsion module source for the Cruiser. The NASA Centaur G' (G-Prime) is a wide-body upper stage with 46,000 lbm of propellant. It has two RL-10 engines and is planned to fly twice in May 1986. Two Orbiters will be used to meet launch window constraints. The Centaur G differs primarily from the G' in propellant load. It carries approximately 30,000 lbm of propellant. It will be launched in a DoD shuttle in 1987. The development of an ALV and the potential stage station are additional examples of configuration changes to the STAR system that will in themselves require flight testing with the Cruiser prior to operational use. A key conclusion or point to be made is that the developmental effort would rise and fall as the configuration and performance expand. Concurrent development and STAR operations would result after the flight test verification of the basic Space Cruiser is complete. Extrapolations through the lifetime of the Space Cruiser are beyond the scope of this brief study. In this context the report emphasizes the flight test of the Cruiser itself to the point when it can first be flown on operational flights in the STAR program.

7.1.3 Flight Tests

Subsequent to validation and verification of the Space Cruiser systems and subsystems and integration tests, the following tests would provide the basis for certifying the Cruiser for STAR. For context with the eventual overall operations the development tests are presented with implicit reference to the overall operations plan of Figure 15. Here the mission is to flight test the Cruiser.

The Space Cruiser is loaded into the Orbiter's cargo bay where it is held with a cradle. The nose will be detached but mounted in a position similar to the folded position with normal connections between the nose and the aft or main body. Cruiser check-out is enabled using the Cruiser's on-board power while the nose section is connected but detached. Nose detachment reduces the cost of launch, simplifies the structural dynamics problem during the Shuttle launch environment and provides experience with handling of nose sections in the cargo bay.

When on-orbit the pilot or payload specialist attaches the nose to the aft section. Options should be provided to attach the nose while the Space Cruiser is held in its cradle support structure as transported to orbit and also after the Cruiser is rotated to the deployment angle at or close to perpendicular to the Orbiter's longitudinal axis.

When deployed, the Cruiser will undergo final system checkout while in the vicinity of the Orbiter. The relative location will be selected to enable the orbiter to recover the Space Cruiser should the need arise.

After checkout the Cruiser is deorbited to pass through the upper atmosphere in a chordlike-arc. After atmospheric exit the Cruiser is maneuvered back to the vicinity of the Orbiter for inspection, data reduction and rendezvous experience.

If required, the Cruiser is returned to its cradle for servicing or return to Earth after the Orbiter's other tasks are completed. If its systems are normal the Cruiser reenters the atmosphere for further aerothermodynamic and control system tests. It then either returns to the Orbiter as before or completes the recovery flight path to a landing. A key point is that the Orbiter provides the capabililty for on-orbit inspection, checkout, repair and if required, recovery of the Space Cruiser.

The Orbiter performed its complete flight profile from launch through landing during its first space flight. The Cruiser should be capable of performing launch through landing on its first flight also. However, support by the Orbiter could increase the number of tests and objectives met per flight and increase flight safety. The Orbiter may be able to provide computer and communication support and backup. Its location at a higher altitude and in the vicinity of the Cruiser offers a unique opportunity for support on the global basis of the flight test program. The flight tests of the Cruiser as a free flyer could be accomplished over a period of days to allow time for intermediate evaluation of system and test data and for corrective action or adjustment.

Determination of the number of flights required to confirm full operational status depends upon the specific design of the Space Cruiser, the modular or other changes planned to the Cruiser system, the measure of maturity and the portion of the performance envelope in which operational status is required. It is planned that research and technology tasks will be accomplished concurrently on a relatively lower level of priority during the pre-operational flight program.

Should the need arise for accelerating the schedule, a substantial improvement would result from deploying two or more Space Cruisers from one Orbiter. The multi-day normal operating flight duration of the Orbiter would facilitate this type of test operation. It is possible that after several Orbiter flights with one Space Cruiser per flight it would be cost-effective to dedicate one or more Orbiter flights to carrying two or more Space Cruisers.

It is clear that the Space Shuttle is capable of excellent, unique support to the Space Cruiser flight test program and subsequently to the STAR operational program.

7.2 STAR RESEARCH PROGRAM

7.2.1 Plan Composition

Stated succinctly, the STAR program plan is to acquire and operate a limited number of Space Cruisers with an evolutionary, modular configuration to perform a wide variety of research and technology tasks for a wide range of beneficiaries that includes the military, the aerospace industry, government agencies and national laboratories.

This report has presented the configuration, performance, system operations and other information that constitute much of the STAR program plan. In this context, the planned STAR vehicle conceptual design complies with the design and operations logic plan developed in Section 5.0 and is based strongly on the input configuration resulting from previous studies as presented in Section 3.0, the Spaceplane Background. Modification of this input configuration improves its performance for the STAR program dramatically. The planned modifications are presented with the resulting performance estimates in Section 6.0. The balance of the overall modular system, which includes for example launch vehicles and additional propulsion, is presented in Sections 5.0 and 6.0. The planned full-system operation configuration is block diagrammed and discussed in Section 7.1. Many potential STAR research and technology tasks considered important by members of the aerospace industry, the Air Force, etc. are presented in Section 4.0. The linkage between the research tasks and the STAR Space Cruiser configuration is presented principally in Section 5.1. The operational procedures for use in flight testing the STAR research vehicle are presented in Section 7.1 These operational procedures and the associated configuration with the Space Shuttle as the launch vehicle are planned to continue during and to define the first phase of the STAR program. The second phase of operations includes the MX booster as a launch vehicle. The third phase is centered on the incorporation of the Centaur family of upper stages as propulsion modules for the Space Cruiser to extend its performance at all altitudes through the geosynchronous orbit and if required, to lunar missions. The fourth phase of the program plan is defined by the use of an airborne launch vehicle as presented in Section 6.3. The fourth phase also includes the use of the stage stations which are presented in Sections 5.2.2, and 6.3 and 7.1.1.

7.2.2 STAR Program Phases

The principal phases of the STAR program are as follows:

Phase I - Low to medium altitude orbital and transatmospheric STAR operations with the Space Shuttle as the launch vehicle

Phase II - Introduction and use of the MX booster as a complementary launch vehicle

Phase III - Introduction and use of the Centaur upper stage as a propulsion module for all orbital altitudes in cislunar space

Phase IV - Introduction and use of the airborne launch vehicle system and associated stage stations

It is estimated that as a research program:
Phase I STAR flights could begin as early as 3 years after initiation of Space Cruiser development. Phase II flights could begin as early as 4 years from initiation of Space Cruiser development. Phase III flights could begin as early as 5 years from initiation of Space Cruiser development. Phase IV flights could begin as early as 5 years from initiation of Space Cruiser development.

8.0 DEVELOPMENT AND OPERATIONS COST ESTIMATION

8.1 INTRODUCTION

To obtain a Rough Order of Magnitude (ROM) estimate of costs for the Space Cruiser, several aerospace corporations familiar with the spaceplane and government agencies were surveyed. Cost estimates were received for propulsion, avionics, and Environmental Control/Life Support System (EC/LSS) subsystems. R&D and Life Cycle Costs (LCC) of several programs were evaluated. Several pertinent type studies were reviewed for program cost estimates. Cost estimation in these various reports varied widely, primarily in view of the different methods of calculation in each program's cost estimate.

To determine cost estimates for the Space Cruiser, various factors were considered. Maximum use of off-of-the-shelf or modified GFE hardware was used which provided as realistic cost estimates as possible. The design of the Space Cruiser in itself permits certain cost-savings to the R&D Program. Specific examples are:

- Shape simplicity (Cone-Ellipse)
- Recoverable and reusable
- Small size and weight
- Launch vehicle/platform available
- Subsystems not required in Space Cruiser:
  - Landing gear system
  - Ejection seat system
  - Wings and associated control surfaces
  - Vertical and horizontal stabilizer
  - Hydraulic system
  - Autopilot below approximately Mach 1.2

The Space Cruiser is to be developed and constructed as an experimental vehicle without NASA-type programmatic constraints.

Although the above subsystems will not be required, the Space Cruiser, as an operable vehicle, will be an integration of the following subsystems and equipment:

- Thermal protective system (TPS)
- Lift control surfaces or flaps

- EC/LSS
- Substructure amd aeroshell
- Ballast
- Electric power
- Avionics and communications
- Controls and displays
- Recovery system
- Propulsion/attitude control
- Pilot/couch

Improved cost estimates for these subsystems can be definitized after the Space Cruiser configuration is known in greater detail. The cost estimates received in this survey, which were of value in establishing the estimated costs for the Space Cruiser R&D Program, are reported below.

8.2 COST SURVEY RESULTS

8.2.1 Avionic Cost Estimates

Cost estimates were provided for the baseline avionics subsystem except for the RF portion of the telemetry/command system and the auxiliary power system (including the batteries). The scope of the costing figures includes all non-recurring engineering, all hardware, software, flight equipment and data suitable for conducting an avionics flight test program with the Space Cruiser. Total program costs, with progress payments, were estimated at $130M. Conversely, total program costs, with payment on delivery was estimated at $160M.

8.2.2 Environmental Control and Life Support System (EC/LSS) Cost Estimates

Non-recurring costs associated with the EC/LSS, pilot's couch, cockpit controls, the 8 PSI EMU to be worn by the pilot, and ground support equipment for recharging vehicle fluid systems were estimated at $10-15 million through qualification. The cost estimate for each shipset, in low quantities, was $6-10 million. These are ROM costing figures.

8.2.3 Propulsion Cost Estimates

Cost estimates for each Space Cruiser included:

1. 18 PCE module units rated at 188 lbs of thrust each
2. 14 ACS module units rated at 15 lbs of thrust each

3. One fuel tank
4. One oxidizer tank
5. Fuel lines and manifolds
6. The cost of vacuum testing of a water-cooled test plug,
7. For integration purposes, the cost of a propulsion system mockup

The first shipset was estimated to cost $5 million (1983$) and $20 million (1983$) for five additional shipsets. The cost estimates include assembly and preparing shipment to Tullahoma, Tennessee for operation under vacuum conditions. Delivery of the first shipset would occur 28 months after program initiation, the second shipset a year after acceptance of the first shipset, and additional shipsets at three month intervals after the second shipset is delivered. The mock-up would be available 18 months after program initiation.

8.2.4 Launch Vehicle Cost Estimates

There are many financial considerations in using the STS to transport payloads to orbit. For each launch, or as in the Space Cruiser research vehicle program, a series of launches, a number of combinations of services (launch alternatives) are available. Combinations of standard services, optional flight systems, optional payload related services, special fees, and reimbursement schedules can result in a different price and cash flow. Further, because the Space Cruiser could support NASA in payload deployment, servicing, repair, inspection and retrieval it is logical to expect that NASA or the non-NASA payload organization would reimburse the STAR program for such services and support. The STS reimbursement procedures stated in the Space Transportation System Reimbursement Guide (Reference 9) applies to all non-U.S. Government and civil U.S. Government users. It does not apply to Department of Defense users. Though the transportation price is charged, there is no added "use fee" charged to U.S. Government users. A shared-flight user will pay a percentage of the dedicated-flight price, based on either payload weight or payload length, whichever results in the larger payment. Folding or removing the nose of the Space Cruiser would therefore result in a substantial cost saving. The launch reimbursement is a function of the required orbital inclination as well. It would not be necessary to require additional Orbiter altitude or velocity in transporting the Space Cruiser. Charges for such Orbiter performance changes would therefore be avoided. Another consideration that would be subject to negotiation would be occasions of recovery, i.e. transportation of the Space Cruiser and its payloads back to the Orbiter's landing site.

An estimate of the charge factor can be made based upon the Guide as follows. The payload length is estimated as the Space Cruiser length with nose removed plus two feet, or approximately 16 ft. The load factor is thus 16/60 = 0.27 and the charge factor is 0.27/0.75 = 0.335 for launch with an inclination of 28.5 deg. If the charge factor is based on payload weight then the load factor is 10,100/65,000 = 0.1554 and the charge factor is 0.1554/0.75 = 0.207. Comparison of the length derived and weight derived charge factors indicates the large cost reduction that would result from designing the Space Cruiser to be installed in the cargo bay in a vertical or nearly vertical position. The cost savings would be as large as 0.355-0.207 = 14.8% of the full 100% dedicated price of launch. Equivalently, an increase in price of 71.5% occurs if the price is changed from the weight criterion to the length criterion and the length used is 16 ft.

Special consideration is given to users having an experimental, new use of space or having a first-time use of space that has great potential public value. This is called an exceptional determination. An STS exceptional program selection process is used to determine which payloads qualify. In all cases, the NASA Administrator has final authority in the decision.

The non-DoD dedicated users price is $71 million in 1982 dollars in the period of fiscal years 1986 through 1988. The DoD dedicated users price is $57.8 million in 1983 dollars. This price is expected to rise to a value between 60 and 100 million for years past 1988. The launch cost for the Space Cruiser is estimated to be between $12 million and $24 million depending on whether the length or the weight criteria are used and whether the non-DoD or the DoD rates apply. As we have indicated there are other factors which cannot be determined at this time. These may raise or lower the cost. Note that if two or three Space Cruisers are transported in the same length of bay then the cost per Space Cruiser is reduced substantially, at least from the length criterion to that of the weight criterion.

The purchase price of a MX booster as a LV is expected to be between $3.5 million and $12 million in current dollars depending upon production quantity. The lower figure corresponds to a very large production quantity and must be considered very unlikely. Perhaps the only case in which such a large buy would obtain would be one where the SDI were to use the MX booster as a LV for orbiting a large network of low altitude satellites.

Advantages of the Orbiter as a LV include its capacity for: carrying an additional pilot for the Cruiser, carrying large amounts of additional propellant in

Cruiser external type tanks and in carrying payloads for the Cruiser. The potential launch cost savings and the on-demand and inclination flexibilities are advantages of the MX booster. Coordinated launch of two boosters, one with the Cruiser as a payload and the other with Cruiser payload or propellant may preserve launch flexibility while increasing mission flexibility through additional payload or propellant. Rendezvous and docking would be required. Clearly there are numerous options possible for use of the MX booster in individual and multiple launches and in combination with the Shuttle. At this point it seems evident that the MX booster stack is a viable cost-effective candidate as a LV in the Space Cruiser system. Many questions arise with respect to the adaptation and cost of the MX booster system as a LV for the Space Cruiser. For example: Should strap-on motors be used to increase its payload capability to orbit? What are the implications of man-rating the LV? How much weight is required to attach the Cruiser to the LV? Can the high-cost ICBM guidance system be replaced with a simple, low-cost system? Can the Space Cruiser's guidance system substitute for the LV guidance system? What are the costs and sharing of the launch operations, facilities and equipment? Discussions with industry during the study indicated that the MX booster should be considered.

Launch services, but not Orbiter launch costs were considered in the costing information of a Centaur launch vehicle. The Centaur "G" was estimated to cost $32M (1984$) and the Centaur-SP, with a single RL-10 engine, was estimated to cost $27M (1984$). In some cases the Centaur would be recovered.

8.2.5 Parafoil Costing Estimates

Atmospheric drops of a "boiler-plate" Space Cruiser by helicopter would cost approximately $250K (1984$) for five drops at the Pasa Robles test range in California. To conduct the tests at a military test range would cost as much as $500K (1984$).

8.3 REFERENCE COSTS

8.3.1 X-15 Program Costs (References 10 and 11)

Although the X-15 Program occurred 20 years ago, the similarity of that program to the proposed Space Cruiser R&D program makes it more directly comparable than any other program. Both are manned vehicles with redundant/emergency systems and are relatively small airframes. A total of 27 X-15 flights were flown in 1964 at an average cost of $602K (1964$). This is equivalent to

$1,906,874 in 1984 dollars. Table II reflects the initial X-15 Program costs that have been inflated from 1964 to 1984 dollars. As noted earlier in this costing discussion, several of the X-15 subsystems are not applicable to the design of the Space Cruiser. Table III projects a cost per pound (kilogram) of selected X-15 systems. Note that the Space Cruiser is approximately one half the length of the X-15 and has a dry weight of approximately one-third the dry weight of the X-15.

8.3.2 Shuttle-Launched Research Vehicle (SLRV) Program Costs

A cost-benefits analysis of the SLRV concept technology development planning was conducted by NASA using two classes of vehicle. The primary difference between the two programs depicted in TABLE IV is the Navigation, Guidance and Control Subsystems of the SLRV. The SLRV's are smaller than the Space Cruiser and are unmanned (Reference 12).

8.3.3 Maneuvering Reentry Research Vehicle (MRRV) Program Costs

Preliminary MRRV lifting-body research vehicle cost estimates were developed for acquisition and five years of operational costs. Historical data from the X-15 and HiMAT programs were the basis for the engineering labor costs shown in TABLE V. Manufacturing hours were based on hours per pound for each type of construction. The MRRV is comparable to the Space Cruiser in length and weight but is unmanned and has a substantially more complicated, flat-bottomed winged lifting body shape (Reference 13).

8.3.4 Transatmospheric Vehicle (TAV) Program Costs

Life Cycle Cost (LCC) estimate for the TAV were generated by vehicle contractors based on the following scenario:

- 1995 Initial Operating Capability (IOC)
- 50 vehicle fleet
- 1995-2115 (20 year) operational period
- 100 flights per year
- 10 bases
- 1983 dollars

The TAV is a large lifting-body reentry vehicle and is launched with its own launch vehicle. The TAV's require technology advances, are very large in comparison with the Space Cruiser and are manned. Due to the large uncertainties of the vehicle concept definition, at this early stage in the program the cost estimates of the program (excluding payloads) varied greatly as follows:

	83$	84$
DDT&E	$5-15B	$5.1-15.2B
Vehicle Production & Facilities	$25-40B	$25.4-40.7B
Operations	$10-30B	$10.2-30.5B
(Cost per flight =	$5-15M	5.1-15.2B)
Total LCC	$40-80B	$40.7-81.3B

These data were provided from Reference 14.

8.4 COST SUMMARY

Cost avoidance can be realized relative to other vehicle concepts in the Space Cruiser R&D program because subsystems normally used with vehicles are not required and because off-of-the-shelf subsystems and components can be used. The cost estimates reviewed in the survey and study evaluations are quite different due to the size of programs evaluated and costing methodology used. The TAV study concluded that a uniform cost analysis must be established for determining the cost of the TAV's because there were so many uncertainties in cost data generated by the contractors at this early stage of TAV definition. Vehicle and concept data were shown to be needed in conjunction with historical costs of spaceplane programs in generating a uniform comparison of TAV concepts and configuration types. It would seem appropriate to attempt to cost out the Space Cruiser with the resultant uniform procedure for a relative measure of cost with the TAV.

Because the X-15 was the last comparable manned vehicle program, more credence has been given to the historical development and operational costs of that program. The cost per flight of 27 X-15 flights cost was $602K (1964$) which is $1,907K in 1984 dollars. Considering the X-15 subsystems that are not required and the off-of-the-shelf subsystems and equipment that can be used in the Space Cruiser, the figure of $2M per Space Cruiser flight plus launch vehicle costs obtains. Unlike the X-15 program the Space Cruiser would carry payloads internally and externally, has endurance, goes to orbit and can provide on-orbit services to satellites and its payloads. Therefore, the benefits, cost-sharing and reimbursements should be included when available in determining the net cost as the true cost of acquisition and operations.

TABLE II - INITIAL X-15 PROGRAM COSTS

(Reference 10)

	Cost, millions of dollars		Percentage of total
	64 $	84 $	
Airframe -			
Development and flight tests	49.90	158.06	
3 airframes	23.51	74.47	
Subtotal	73.41	232.53	45
Engine -			
Development	43.79	138.71	
10 rocket engines	10.04	31.80	
Subtotal	53.83	170.51	33
Aircraft systems -			
Auxiliary power units	2.70	8.55	
Inertial flight data systems	3.40	10.77	
Adaptive control systems	2.30	7.29	
Flow-direction sensor (ball nose)	.60	1.90	
Pressure suits	.15	.48	
Subtotal	9.15	28.98	6
Aerospace ground equipment (AGE) and peripheral equipment -			
Launch platform (modify two B-52 airplanes)	3.26	10.33	
Airframe AGE and spares	6.70	21.22	
Engine AGE and spares	4.06	12.86	
Systems spares	.10	.32	
Propulsion system test stand	.41	1.30	
Monitoring station construction	5.81	18.40	
Mission control	6.07	19.22	
Subtotal	26.41	83.66	16
Total	162.80	515.68	100

TABLE III

UNIT COSTS PER POUND (KILOGRAM) OF SELECTED X-15 SYSTEMS

(Initial procurement)

(Reference 10)	Total cost, millions		No. of units	Unit empty weight, pounds (kilograms)	Cost per pound (kilogram), dollars	
	64$	84$			64$	84$
X-15 airframe	73.41	232.53	3	12,650 (5,740)	1,930 (4,260)	6,113 (13,494)
Engine	53.83	170.51	10	915 (415)	5,900 (12,970)	18,689 (41,083)
Stability augmentation system	1.40	4.35	4	65 (29)	5,400 (12,069)	17,105 (38,229)
Inertial flight data system	3.40	10.77	6	120 (54)	4,700 (10,500)	14,888 (33,259)
Auxiliary power unit	2.70	8.55	16	45 (20)	3,750 (8,438)	11,878 (26,728)
Flow-direction sensor	.60	1.90	6	78 (35)	1,300 (2,857)	4118 (9,050)
B-52 airplane	62.02	196.45	2	177,500 (80,500)	170 (385)	538 (1,220)

TABLE IV

TYPICAL SLRV DEVELOPMENT PROGRAM COSTS AND WORK BREAKDOWN DISTRIBUTIONS

Tasks	SLRV Ballistic Test Vehicle	SLRV Maneuvering Test Vehicle
Program Management	8%	9%
System Engineering	10%	13%
Subsystem Development		
- Shield/Structure S/S	24%	12%
- Separation S/S	3%	1%
- Recovery S/S	6%	3%
- NG&S S/S	7%	26%
- EP&D I&C S/S	15%	11%
- Specialty S/S Elements	7%	4%
- Assembly and Integration	9%	7%
System Test Programs	7%	9%
AGE/TSE	4%	5%
Total Cost: 1980 $	$20 - 24M	$46 - 55M
1984 $	$25 - 30M	$57 - 69M

(Reference 12)

Acronyms:

S/S - Sub-System
NG&C - Navigation, Guidance & Control Subsystem
EP&D - Electrical Power & Distribution Subsystem
I&C - Instrumentation & Communication Subsystem

TABLE V

MRRV PROGRAM COST ESTIMATES

Category	Cost in Dollars	
	79 $	84 $
Engineering	21,599,000	29,730,213
Tooling labor	8,532,000	11,743,978
Manufacturing labor	10,556,000	14,529,938
Material (cost in dollars):	5,242,000	7,215,416
Manufacturing	1,284,600	1,768,204
Tooling	1,493,500	2,055,747
Subsystems	1,690,000	2,326,222
Engineering	779,200	1,072,540
Propulsion system	347,000	447,632
Subtotal acquisition [a]	46,276,000	63,697,178
Operational and support cost (5 years)	35,612,000	49,018,582
Total program cost (two vehicles)	$ 81,888,000	$ 112,715,760

[a] Acquisition cost based on X-15 and HIMAT data

(Reference 13)

9.0 CONCLUSIONS

This section summarizes the major conclusions resulting from the study:

1. Given the high cost of space vehicles and operations and the limitations on funding, a prospective research vehicle must serve a broad range of beneficiaries and perform cost-effectively over a wide scope of research and technologies.

2. The national survey evidenced a broad range of beneficiaries which could benefit from use of the research vehicle. It also evidenced the broad scope and depth of research and technology tasks of interest to those surveyed. The key question remaining is the cost effectiveness to the researcher of performing the tasks.

3. The number of proposed operational applications suggested by survey respondents suggests that there will be an evolution of the Space Cruiser from a research vehicle into an operational vehicle with numerous military applications.

4. Smallness of size and weight coupled with the optimalization of energy management are the overall design specifications for the Space Cruiser concept. L/D must be traded-off with low vehicular weight, mass ratio, launch performance, low drag for minimization of velocity loss during low-lift flight phases, etc. The Space Cruiser configuration is responsive to this system performance evaluation approach. It is capable of full-envelope cislunar, transatmospheric and endoatmospheric flight with the maximum payload-velocity map.

5. The STAR program would provide research and technology support to the Shuttle, future manned space vehicles, future unmanned space vehicles, future transatmospheric vehicles and hypersonic vehicles.

6. The development of a man-rated launch vehicle from the MX booster stack would provide significant operational advantages in terms of responsiveness and autonomy.

7. The near-term air-launched LV concept based on the use of Titan and RL-10 engines and dropping from the 747-200F would potentially be the most flexible and cost-effective launch system. The associated use of stage-stations appears especially cost-effective and may provide a source of income.

8. The Air Force Aerospace Medical Division has stated a need for a Space Cruiser type vehicle for carrying out its military man-in-space responsibilities.

9. The Space Cruiser system will meet needs of the Strategic Defense Initiative in terms of on-orbit utility and research support.

10. A test concept is suggested for evaluation in which the Cruiser would perform one or more endoatmospheric passes from the Orbiter, with return to the Orbiter for inspection before full reentry and landing.

11. The potential exists for using the standard or a special-purpose Parafoil instead of the vehicular body for plane changing. If feasible, the energy management gains would be dramatic and the Space Cruiser could be used to perform the Parafoil plane-changing research.

12. Cost-sharing space system development and operations is becoming the economic and political standard. Therefore, the potential exists for dramatic reduction in Air Force funding required for acquisition and use of the research spaceplane. Commercial application of the Space Cruiser raises the possibility of low or no-cost development in terms of funding of contractors.

13. NASA has no plans to build a Space Cruiser type vehicle.

10.0 RECOMMENDATIONS

As a result of the STAR study the following recommendations are made:

1. It is recommended that the Air Force consider the need for the STAR research vehicle thoroughly. This consideration should include the evaluation of the potential for dramatic reduction in Air Force funding required for acquisition and use of the Space Cruiser as a result of cost-sharing.

2. It is recommended that a balanced, technical joint DARPA/Air Force/Industry working group be organized by the Air Force to specify the key technical questions of and the key needs for the research vehicle.

3. It is recommended that the Strategic Air Command and the Space Command examine the operations capabilities of the full-envelope STAR Space Cruiser and its enabling of operational requirements.

4. From a technical development point of view there are several concepts introduced by the study that appear to warrant further work. Recommended are:

   (a) The air launched launch vehicle concept for launch from under the 747-200F.
   (b) The distributed, stage-station concept.
   (c) The use of the Parafoil type deployable surface for maneuvering in the upper atmosphere at entry speeds. This work should include analysis of flying to the ground with the Parafoil.

5. Examination of man-rating and adapting the MX booster as a launch vehicle is recommended. Launch sites, support and cost should be included.

6. It is recommended that funding for the Space Cruiser and STAR concept development be continued until the consideration of the STAR research program has resulted in a decision to move ahead or end the project. It is recommended further that one or more major system manufacturers be funded to detail the Space Cruiser and STAR program work to provide development and operational schedules and costs.

APPENDIX A
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APPENDIX B

SURVEY LETTER AND SAMPLE REPLIES

This Appendix contains the DCS Corporation survey letter with attachments and copies of suggested tasks submitted by four different corporations in response to the survey letter.

The responses included herein were selected on the basis of being more complete and detailed and also on the basis of presenting the most realistic and promising of the tasks. Responses suggesting tasks for each of the three broad categories of tasks were selected: The Air Force Aerospace Medical Division and LTV Aerospace and Defense Company recommended tasks that could be accomplished by the Space Cruiser; the Aerojet TechSystems Company suggested projects that should be accomplished for the development of the Space Cruiser; and the Emerson Electric Company and Ball Aerospace Systems Division recommended operational applications of the Space Cruiser. These letter responses and their suggested tasks are also included in this appendix.

DCS CORPORATION 1055 N. Fairfax Street * Alexandria, Virginia 22314 * (703) 683-8

February 24, 1984

Mr. G. L. Sayre
Ball Aerospace Systems Division
Box 1062
Industrial Park
Boulder, CO 80306

Dear Mr. Sayre:

Our Spaceplane Technology and Research (STAR) planning contract, sponsored by the Defense Advanced Research Projects Agency (DARPA), requires DCS Corporation to search for potential research and technology tasks suited to accomplishment by a new generic type of manned aircraft (spaceplane) termed the "Space Cruiser." Please interpret this letter as a request for information, at no cost, helpful to the Government in determining the scope, utility and value of the Space Cruiser as a research aircraft.

The Space Cruiser system is configured for efficient manned and unmanned endoatmospheric, transatmospheric, earth orbit and cislunar operations. The small size and low weight of the clean aircraft assure that it need only occupy a small portion of the volume and weight-carrying capability of the Shuttle's Orbiter and that its cost-to-orbit will be the minimum. It can also be launched by expendable launch vehicles such as the MX booster stack. Addition of external propellant tanks or a propulsion module such as the wide-body Centaur (less avionics) results in payload-velocity envelopes compatible with geosynchronous and cislunar operations or substantial orbital altitude changes of large external payloads.

Research, development and technology tasks can be done in vehicular systems and subsystems; hypersonic flight up through entry speeds, aerobraking; atmospheric and space environmental phenomena; space operations, management and control; etc. The Space Cruiser can carry modest size internal payloads and essentially unlimited external payloads. Research on payloads and payload synergistics with the manned vehicle and extra-vehicular activity may turn out to be the most enduring and beneficial category of tasks for the STAR program. Further, "hands-on" experience and evaluation of military man-in-space in the small, omni-mission spaceplane should provide the answers required prior to major system acquisition of military space vehicles and complement the answers being obtained from the Shuttle program for the larger, logistic and space-station type vehicles.

In short, we are requesting specific research, development and technology task descriptions that you believe to be of value and suited to the Space Cruiser and/or its payloads.

The enclosure is provided as additional information that may be immediately helpful in determining your response and of assistance to those preparing the information. Please note that the period for preparation and incorporation of the research, technology and development task descriptions is quite short. The representative at DARPA is Lt. Col. James N. Allburn (DARPA/TTO) and at the Headquarters Air Force Systems Command Lt. Col. Darryl W. Smith (HqAFSC/XRB). Should your organization have any questions regarding this request for information, please call me at: (703) 683-8430 office or (703)525-3335 residence.

It is our hope that you will find the prospect of the Space Cruiser as a research vehicle an exciting one and that your suggestions for its use will add to its value in the national interest.

Very truly yours,

FW Redding, Jr.

Fred W. Redding, Jr.
STAR Project Manager

Assistant to the President for
Concept Development

Enclosure

cc: Lt. Col. James N. Allburn
Lt. Col. Darryl W. Smith (COR)

ATTACHMENT

Spaceplane Technology and Research (STAR) request for information	**1 page**
Response Guideline	**2 pages**
Space Cruiser Description	**2 pages**
STAR Vehicle Representative Specifications	**1 page**

Spaceplane Technology and Research (STAR) request for information

Requesting: Specific research, technology or development tasks/experiments for the Space Cruiser as a research aircraft.

Request recipients: Cross-section of aerospace industry, from component to major system manufacturers; private and Government laboratories; military services; department of Defense Agencies; NASA; commercial.

Requestor: DCS Corporation, 1055 N. Fairfax Street, Alexandria, Virginia 22314 Attention: F. W. Redding, Jr., Phone: (703) 683-8430; contract MDA903-84-C-0087.

Response date: Mail two weeks from receiving this request. If additional time needed, please notify the requestor.

Response format: Informal. No proprietary information at this time. Unclassified response preferred. Classification through SECRET can be arranged. Backup or reference material will be appreciated.

Response Guideline: (Attached)

RESPONSE GUIDELINE

This following guideline is offered for your use to assist in the preparation of specific STAR task information and to expedite our understanding and use of the resulting information. Please add whatever you believe may be helpful.

The term "task" is used herein for its brevity. It signifies any experiment, project, operation, etc. to be accomplished in, with, or by the STAR research vehicle.

To maximize the cost-effectiveness of STAR operations it will be important to combine or integrate tasks and to perform as many tasks per flight as practicable. There is room for and we are looking for the smaller tasks as well as the larger ones.

Name of experiment:

ITEM

1. Organization:
   (Company, Laboratory, Agency, etc.)
2. Principal Investigator:
3. Liaison office or person: (If different from Principal Investigator)
4. Beneficiary categories: (Please identify those to benefit the most)

_____ Industry
_____ Commercial
_____ Laboratory
_____ Military
_____ Government
_____ International
_____ Insurers/Investors
_____ Other ...

_____ Science
_____ Technology
_____ Aircraft
_____ Spaceplanes
_____ Satellites
_____ Space Station
_____ Other vehicles

5. Brief task description:
(Then please include complete description as Item 13)

6. Key results desired:

7. Potential value/benefits:

8. Schedule estimate:
(Start/completion/Key phases/Number of flights/Schedule sensitivity/etc.)

9. Task-subject categories:
(Please identify those relevant and clarify where helpful)

______ Man-in space
______ Internal payloads
______ External payloads
______ Vehicular system/subsystem/components
______ Controls/displays
______ Life support
______ Aerothermodynamics
______ Materials
______ Structures
______ Space operations
______ Flight support
______ Flight control/command
______ Launch
______ Recovery
______ Phenomenology
______ Other ...

10. Flight profile or parameters <u>during</u> the experiment:

11. Any critical or unusual handling/support requirements:

12. Comments relative to doing task <u>without</u> the STAR research vehicle: (i.e. by other means)

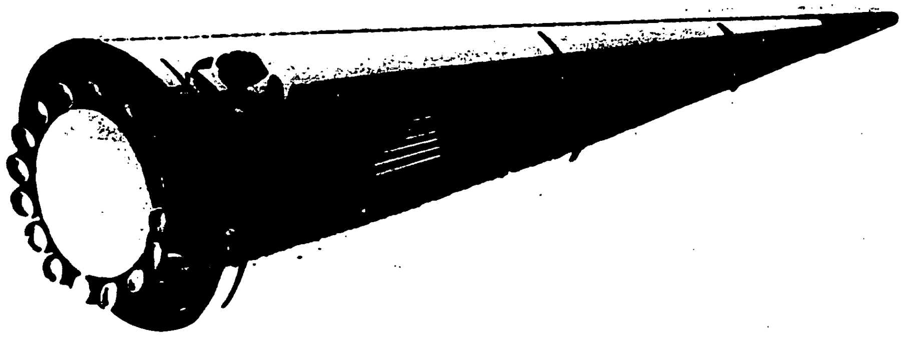
13. Task Description:

- Informal
- Recipient's format
- Attached or separate
- Where helpful, note what is firm, potential, estimated, guessed, etc.
- What, why, how, where, when

SPACE CRUISER DESCRIPTION

GENERAL DESIGN GOALS

- Minimum weight and volume... Optimizes the research vehicle's payload and velocity to orbit during the launch phase. Maximizes the available payload-velocity and permits reduction in transit time during maneuvers.
- Modular system... External carry of payload, propellant, stages, life support consumables, support equipment and sidecars. Ground and on-orbit replacement of the nose section with its internal power supply and the primary payload bay.
- Synergistic-maneuverable... The high velocity required for a substantial plane change in low earth orbit results in high pay-off for lifting-turn plane change followed by propelled return to orbital flight.
- Launch options... Shuttle; air and ground launched expendable launch vehicles, future reusable launch vehicles.
- Austere-site landing... Capability to land at unprepared sites, helicopter-suitable areas, etc.
- Unmanned mode... Rescue, high-risk flights, cache on-orbit and high-g endoatmospheric flights.
- State-of-the-Art... Accomplish the above within the state-of-the-art and where practical, using developed or under development hardware.
- Minimize cost... Small vehicle, reusable, rapid turn-around, maximum payload per flight, maximum maneuverability, minimum launch cost, austere control and recovery support, state-of-the art.
- Launch and forget/listen... Autonomous option with respect to ground operations.
- Cislunar operations... Go where the satellites are or can go. In velocity space orbital altitudes comparable to the lunar distance result from velocities close to those for attaining synchronous altitude. This capability would be phased with the Centaur upper stage program.



DESCRIPTION COMMENTS

The following comments may be helpful in understanding the Space Cruiser. The nose section containing the forward payload bay, ballast and power batteries extends in space to expose the forward reaction control nozzles for firing. No nozzles are located in the thermal protection structure (TPS) with this approach. The nose can be removed and replaced while in its extended position. After full extension the nose can fold aft alongside and is snubbed near the nosetip while in the folded position. After the nose is folded, an elephant stand or similar light weight structure can be attached to the forward bulkhead or ring to attach the external payloads.

The pilot is seated at the aft end in a seat or couch which can be raised until the pilot's head is outboard, similar to an open-cockpit aircraft. In the raised position the pilot can view the external payload. Also, the pilot can view the forward payload bay contents when the top panel or door is open. There are two payload bays, one in the nose section and the other in the aft end within the plug-cluster-engine (PCE) nozzles.

Landing is by controllable lifting parachute or "Parafoil". The parafoil is deployed from near the vehicle's center of gravity after deployment of a deceleration drogue from the PCE plug volume. After deployment and disreefing of the lifting parachute the Cruiser assumes a horizontal attitude for flight to the ground.

A lifting aerobrake can be located in the aft payload bay for atmospheric entry and aerobraking with otherwise excessive entry speeds. The lifting aerobrake is reusable.

An 8 psi EMU or spacesuit, under development, is planned. This suit eliminates the requirement for prebreathing before flight. The portable life support back pack is detachable before launch and after landing. EVA does not include an umbilical. Fail operational/fail-safe design criteria are used for environmental control and life support. Pumped fluid coolants are used with coldplates for heat transfer from the heat source to hardware such as avionics. A helmet mounted, internal virtual-image display is provided. Voice control of and through the computer is planned. An autonomous optical navigator with accuracy similar to the GPS is planned. Ring laser gyro inertial platforms are used in the guidance and navigation system. Monopropellant-driven auxiliary power units (APU's) are provided and integrated with the rechargeable power battery. The aircraft is all-electric, with no hydraulics.

The PCE has 16 nozzles with independent on-off control for thrust vector and thrust magnitude control, eliminating actuators.

The propellants are nitrogen tetroxide as the oxidizer and a proprietary amine blend for fuel. The fuel is also used as the monopropellant in the APU's. The PCE nozzles are film-cooled. The attitude control system has nozzles mounted at the nose fold and with the PCE to provide six-degree-of-freedom attitude and translation control. Momentum wheels are provided for fine attitude control. A mercury trim control system is included for real-time, on-orbit CG trim. Trim is important for reentry stability. It is expected that outboard propellant tanks will be saddle-mounted to protect the TPS.

The Centaur upper stage is used as the external cryogenic propulsion module or stage. The wide-body Centaur could be modified by replacing the two RL-10 engines with a single RL-10 Derivative IIB engine. For overspeed reentry with the Centaur a lifting aerobrake would be attached to the aft end of the Centaur.

STAR VEHICLE REPRESENTATIVE SPECIFICATIONS

	Conical*	Cone-Ellipse* (Where Different)
Velocity with internal propellants	4000 fps	8000 fps
Velocity with cryogenic propulsion	25000 fps	
Total velocity (stages) without payload	29000 fps	
Payload to geosynchronous orbit	10000-12000 lbm	
Velocity to payload of 160,000 lbm (with Centaur propulsion module)	3700 fps	
Endurance with internal consumables	24 hr	
Endurance with external consumables	days to weeks	
Number of aircraft per Orbiter bay		
with internal propellant	8 max.	
with Centaur cryogenic propulsion module	1	
Launch options		
Shuttle		
MX booster		
Aircraft launch		
Others possible		
Recovery		
Parafoil flying parachute		
Unprepared site		
Helicopter-compatible site		
Turnaround time	Similar to High Performance Aircraft	
Crew		
Pilot		Pilot + 1 crew (option with propellant off-load)
Multiple-passenger sidecars in space		
Weight		
Dry	4000 lbm	
Wet	5600 lbm	
Wet with auxiliary fuel in bays	6300 lbm	10000 lbm
Payload bay volumes		
Nose bay 22dia x 15.2dia x 41.5 length	6 cubic ft.	Adds appx. 20 cubic ft. option about the CG
AFT bay	4 cubic ft.	
Vehicle length	26 ft.	

*Refers to the general configuration of the STAR vehicle selection to be made later. <u>Ellipse</u> re to the cross-section shape of the vehicle.

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AEROSPACE MEDICAL DIVISION (AFSC)
BROOKS AIR FORCE BASE, TEXAS 78235

2 MAY 1984

Mr Fred W. Redding, Jr
STAR Project Manager
DCS Corporation
1055 N. Fairfax Street
Alexandria, Virginia 22314

Dear Mr Redding

Thank you for the information you forwarded to me concerning the Space Cruiser as a research vehicle. My initial response is - let's get it flying! The one missing link we now have in the space R&D area is a vehicle specifically designed to do R&D. The Shuttle is being marketed as an operational system, and rightly so. As such, however, any R&D, at least in biotechnology areas, is given a secondary priority. Department of Defense Space biotechnology R&D becomes even a lower priority subset of the system.

The Aerospace Medical Division (AMD) has been tasked by several directives to explore the military utility of man-in-space and exploit man's unique capabilities in enhancing military space systems. We have consequently developed a Military Space Biotechnology R&D program which covers exploratory and advanced development areas. We have been careful to keep our program closely coordinated with the NASA Life Sciences R&D program in order to avoid redundancy in areas of common interest. We have developed several human performance experiments which require an orbital platform and have therefore attempted to tap into the NASA system for Shuttle flights. This has been frought with problems of coordination, differences in priorities and the fact that NASA has its own R&D programs to consider. The DOD has need of a vehicle which will provide a manned orbital platform for exploring mans' military utility in orbit. Unless we (the DoD) are given the tools, we won't be able to do our job. In order to do R&D for man in space, we need to be able to have free R&D access to space.

In my estimation, the Space Cruiser fills the bill. We have direction to do space R&D, but as yet, we have been deprived of the necessary tool to do so. I am attaching a brief description of our program which clearly justifies the existence of the cruiser.

Please keep in touch and apprise us of any progress in the Space Cruiser development.

Sincerely

RALPH J. LUCIANI, MAJ, USAF, MC, FS
Director, Aerospace Medicine R&D
Research, Development and Acquisition

1 Atch
Space Biotech Program

MILITARY SPACE BIOTECHNOLOGY PROGRAM

AEROSPACE MEDICAL DIVISION (AFSC)

The products of this program can be grouped into four major categories or thrusts: Performance Effects and Performance Enhancement which are man-machine integration functional concerns, and Biotechnical Countermeasures, which are crew protection functional concerns.

With respect to man-machine integration, the objective is to enhance man's integration into military space systems, whether he be ground based or space based. The consideration of man in the system must be incorporated in the initial design stages of the system for optimum utility of the entire system. Human Engineering concepts must be employed to optimize the performance of the integrated man-machine system. This factor becomes extremely critical for military systems in which conflict management may be an objective, and national security the goal.

The investigation of Performance Effects will produce a quantifiable data base of the environmental effects on man as a control system. Predictable compromises in his output functions as a controller, information processor and decision maker must be quantified to evaluate their impact on the military mission. Man's performance requirements and shortcomings must be known before adequate and optimal enhancing techniques can be developed to ensure the timely, efficient completion of the mission.

The thrust addressing Performance Enhancement will produce human engineering answers to any quantified performance shortcomings which might compromise the mission. Engineering techniques using controls, displays, artificial intelligence and other performance extenders (e.g. teleoperators) will be produced as extrinsic enhancers. Human factors and cybernetic techniques and systems will be produced to enhance man's internal control systems (e.g. neuromuscular input enhancers).

In the crew protection function, the objective is to ensure crew protection and survivability in the military space based environment. As previously stated, the space environment is biologically hostile to man, but the problems of additional stressors associated specifically with the military system (e.g. accelerations, information displays, etc) must also be addressed. The assessment of relevant Biomedical Effects will not be addressed by Advanced Technology Development (6.3).

A thrust to investigate Biomedical Effects will rely solely on exploratory development to produce a quantifiable data base of physiological degradations due to the military space environment itself. Biologic compromises due to weightlessness, radiation and vacuum, have been and continue to be explored by NASA. However, these changes must be assessed in the light of specific military mission requirements. This data base is essential in order to develop countermeasures and to prioritize that development for the best cost/benefit ratio.

The applications of the Biotechnical Countermeasures thrust are obvious. The countermeasures developed will be designed to eliminate the environmental effects quantified in the first thrust area. The products will be techniques and/or hardware designed to prevent potential military mission compromise caused by environmental biomedical effects, and thereby augment man's effectiveness in the weapon system.

LTV Aerospace and Defense Company

VICE PRESIDENT -
ADVANCED PROGRAMS AND TECHNOLOGY

10 April 1984

Mr. Fred W. Redding, Jr.
Star Project Manager
Assistant to the President for
  Concept Development
DCS Corporation
1055 N. Fairfax Street
Alexandria, Virginia 22314

Dear Mr. Redding:

Reference is made to your letter to Mr. Robert L. Kirk dated 14 February 1984, pertaining to the subject of potential research and technology tasks suited for accomplishment by the Space Cruiser. In response to your request we have surveyed our organization and are forwarding the results to you in accordance with the suggested format.

I trust you will find these submissions useful and responsive to your needs. A copy of your final report, when available, would be greatly appreciated.

Sincerely,

FW Fenter

F. W. Fenter

Attachments

LTV AEROSPACE AND DEFENSE COMPANY VOUGHT MISSILES AND ADVANCED PROGRAMS DIVISION • POST OFFICE BOX 225907 • DALLAS, TEXAS 75265
TELEPHONE (214) 266-7566

STAR TASK DESCRIPTION SUMMARY

Task Title: Component Tests for Exoatmospheric Electromagnetically-Launched (EML) Guided Projectile

Vought Missiles and Advanced Programs Division
Post Office Box 225907
Dallas, Texas 75265

Principal Investigator: Dr. M. M. Tower

Focal Point: Dr. C. H. Haight

Beneficiary Categories: (Please rank top five)

____ Industry
____ Commercial
____ Laboratory
__X__ Military
____ Government
____ International
____ Insurers/Investors
____ Other

____ Science
__X__ Technology
____ Aircraft
____ Spaceplanes
____ Satellites
____ Space Station
____ Other Vehicles

Brief Task Description: (please include complete description on last page)

Determine accuracy of space-range EML guided projectile meeting packaging and EMP/g-load hardening design criteria.

Key Results Desired:

Validate EML guided projectile component designs for prototyping.

Potential Value/Benefits:

Extension of preliminary ground-located demonstrator results, limited by endoatmospheric environment, to full scale validation. Applicable to boost-phase and mid-course BMD intercept.

STAR TASK DESCRIPTION SUMMARY (CONT'D)

Schedule Estimate:
(Start/Completion/Key Phases/Number of Flights/Schedule Sensitivity/etc.)

Start 1987/complete 1989

Phase I: Launch Simulation - Projectile Accuracy

Phase II: EM Launch-Projectile Accuracy

Four Flight Minimum/SDI Schedule Sensitivity

Task Subject Categories: (Please identify those relevant and clarify where helpful)

_____ Man in space
X Internal payloads
X External Payloads
_____ Vehicular system/subsystem/components
_____ Controls/displays
_____ Life Support
_____ Aerothermodynamics
_____ Materials
_____ Structures
_____ Space operations
_____ Flight support
_____ Flight control/command
_____ Launch
_____ Recovery
_____ Phenomenology
SDI Other

Category elaborated in Space Defense Initiatives (SDI) Program.

Flight Profile or Parameters During the Experiments:

To be determined

Any Critical or Unusual Handling/Support Requirements:

Phase I - Projectile Launch Velocity capabilities

Phase II - EMP effect on Space Cruiser Components

Comments Relative to Doing Task Without the STAR Research Vehicle:

High Cost for Shuttle or alternates for validation tests.

STAR TASK DESCRIPTION SUMMARY (CONT'D)

TASK DESCRIPTION: (Please include a problem statement, objective(s) and a recommended approach)

Phase 1: Launch Simulation - Projectile Accuracy.

Impart velocity of 6-8 Km/sec to projectile using spacecraft or auxiliary propulsion and utilize command and homing Space Cruiser module to guide projectile to simulated battle space (up to 1000 Km range).

Phase II: EM Launch - Projectile Accuracy

Utilize railgun external payload with re-loadable single-shot capability and re-usable power supply to launch projectile; subject to EML. EMP and g-loading and ascertain accuracy for Phase I conditions.

STAR TASK DESCRIPTION SUMMARY

Task Title: Ablative behavior of C/C (Carbon/Carbon) nosetips and projectiles

Vought Missiles and Advanced Programs Division
Post Office Box 225907
Dallas, Texas 75265

Principal Investigator: Herbert F. Volk (materials) and

Focal Point: To be determined for re-entry

Beneficiary Categories: (Please rank top five)

____ Industry
____ Commercial
____ Laboratory
x Military
____ Government
____ International
____ Insurers/Investors
____ Other

____ Science
x Technology
____ Aircraft
____ Spaceplanes
____ Satellites
____ Space Station
Missiles Other Vehicles

Brief Task Description: (please include complete description on last page)
Determine the ablative behavior and its effect on trajectory for various carbon/carbon composite materials.

Key Results Desired: Ability to select the optimum materials for various missiles, ranging from ICBMs to railgun projectiles.

Potential Value/Benefits: Ablative behavior cannot be fully simulated on earth, proof testing requires actual missile firings. Shooting re-entry bodies from a space vehicle would be less costly.

STAR TASK DESCRIPTION SUMMARY (CONT'D)

Schedule Estimate:
(Start/Completion/Key Phases/Number of Flights/Schedule Sensitivity/etc.)

To be determined, depends on number of re-entry bodies to be investigated.

Task Subject Categories: (Please identify those relevant and clarify where helpful)

____ Man in space
____ Internal payloads
____ External Payloads
____ Vehicular system/subsystem/components
____ Controls/displays
____ Life Support
__x__ Aerothermodynamics
__x__ Materials

____ Structures
____ Space operations
____ Flight support
____ Flight control/command
____ Launch
____ Recovery
____ Phenomenology
____ Other

Flight Profile or Parameters During the Experiments:

To be determined

Any Critical or Unusual Handling/Support Requirements:

No

Comments Relative to Doing Task Without the STAR Research Vehicle:

Could be done directly from shuttle orbiter

STAR TASK DESCRIPTION SUMMARY (CONT'D)

TASK DESCRIPTION: (Please include a problem statement, objective(s) and a recommended approach)

Problem: The ablative behavior of missile nose tips affects the trajectory and accuracy. This behavior cannot be fully evaluated on earth and requires expensive proof-testing through missile firings. Evaluation and optimization of materials is thus very expensive.

Objective: Evaluate the ablative behavior and it's effect on trajectory for various carbon/carbon re-entry materials in an inexpensive manner.

Approach: Fire re-entry nose tips from orbit to simulate desired trajectory. Select firing position so that impact is on an easily observed land area.

STAR TASK DESCRIPTION SUMMARY

Task Title: Scramjet Inlet and Combustion Phenomena

Vought Missiles and Advanced Programs Division
Post Office Box 225907
Dallas, Texas 75265

Principal Investigator: TBD

Focal Point: Dr. C. S. Wells/Dr. J. L. Porter

Beneficiary Categories: (Please rank top five)

	Industry	1	Science
	Commercial	2	Technology
	Laboratory	3	Aircraft
1	Military	4	Spaceplanes
2	Government		Satellites
	International		Space Station
	Insurers/Investors	5	Other Vehicles
	Other		

Brief Task Description: (please include complete description on last page)

Determine limits of scramjet operation in rarefied atmospheres.

Key Results Desired: Verification of scramjet capabilities at suborbital altitudes.

Potential Value/Benefits: Low weight propulsion for STAR/TAV-type vehicles.

STAR TASK DESCRIPTION SUMMARY (CONT'D)

Schedule Estimate:
(Start/Completion/Key Phases/Number of Flights/Schedule Sensitivity/etc.)

TBD

Task Subject Categories: (Please identify those relevant and clarify where helpful)

☐ Man in space
☐ Internal payloads
☐ External Payloads
☒ Vehicular system/subsystem/components
☐ Controls/displays
☐ Life Support
☒ Aerothermodynamics
☐ Materials
☐ Structures
☐ Space operations
☐ Flight support
☒ Flight control/command
☐ Launch
☐ Recovery
☐ Phenomenology
☐ Other

Flight Profile or Parameters During the Experiments: Altitude, Mach and fuel flow rate.

Any Critical or Unusual Handling/Support Requirements: Thrust balancing for external propulsion system. In-flight instrumentation.

Comments Relative to Doing Task Without the STAR Research Vehicle: Existing propulsion test facilities cannot achieve required conditions.

STAR TASK DESCRIPTION SUMMARY (CONT'D)

TASK DESCRIPTION: (Please include a problem statement, objective(s) and a recommended approach)

Prob: Effects of rarefied gasdynamics at hypersonic speeds on inlet and combustion stability and performance of a supersonic combustion "ramjet" are not well known or understood.

Def: Determine the limits of M_0-Alt performance.

Appr: Externally mounted scale propulsion unit with manual controls.

STAR TASK DESCRIPTION SUMMARY

Task Title: Navigation System Validation

Vought Missiles and Advanced Programs Division
Post Office Box 225907
Dallas, Texas 75265

Principal Investigator: TBD

Focal Point: Dr. C. S. Wells/Dr. J. L. Porter

Beneficiary Categories: (Please rank top five)

____ Industry
5 Commercial
____ Laboratory
1 Military
4 Government
____ International
____ Insurers/Investors
____ Other

____ Science
____ Technology
____ Aircraft
2 Spaceplanes
____ Satellites
____ Space Station
3 Other Vehicles

Brief Task Description: (please include complete description on last page)
Utilize special equipment to provide a brassboard demonstration of this Vought-proprietary concept.

Key Results Desired: Validation of the position and velocity determination of the vehicle.

Potential Value/Benefits: Improved long-range navigation.

STAR TASK DESCRIPTION SUMMARY (CONT'D)

Schedule Estimate:
(Start/Completion/Key Phases/Number of Flights/Schedule Sensitivity/etc.)

TBD

Task Subject Categories: (Please identify those relevant and clarify where helpful)

- ___ Man in space
- ___ Internal payloads
- ___ External Payloads
- X Vehicular system/subsystem/components
- X Controls/displays
- ___ Life Support
- ___ Aerothermodynamics
- ___ Materials
- ___ Structures
- ___ Space operations
- ___ Flight support
- X Flight control/command
- ___ Launch
- ___ Recovery
- ___ Phenomenology
- ___ Other

Flight Profile or Parameters During the Experiments: TBD

Any Critical or Unusual Handling/Support Requirements: None

Comments Relative to Doing Task Without the STAR Research Vehicle:

Probably 10 times more costly for this particular experiment to do it without pilot and environmentally controlled station.

STAR TASK DESCRIPTION SUMMARY (CONT'D)

TASK DESCRIPTION: (Please include a problem statement, objective(s) and a recommended approach)

Approach: Provide validation of brassboard system thru multiple ground-track velocity-position determination. Alt: Use GPS if available.

EMERSON

ELECTRONICS & SPACE DIVISION
EMERSON ELECTRIC CO.

14 March 1984

Mr. Fred W. Redding, Jr.
DCS Corporation
1055 N. Fairfax St.
Alexandria, VA 22314

Dear Mr. Redding:

In response to your request for information on potential uses of the Space Cruiser, Emerson Electric has outlined five tasks which we believe to be suitable for the vehicle you describe.

If you have questions on any of the enclosed tasks please contact me at 314-553-4521.

Sincerely,

Charles C. Cromer

Charles C. Cromer
Manager, Research & Development

CCC:jhc
Enclosures (5)

EMERSON ELECTRIC CO.
8100 W FLORISSANT
ST. LOUIS, MISSOURI 63136
Mailing Station 4521
Telephone: (314) 553-4521

SPACE JUNK COLLECTION

ITEM

1. Organization: EMERSON ELECTRIC CO., 8100 W. Florissant
St. Louis, Missouri 63136

2. Principal Investigator: R. D. WELLING

3. Liaison office or person: N/A

4. Beneficiary categories:

Commercial
Military
International
Insurers/Investors
Space Station

5. Brief task description: Space Junk Collection

6. Key results desired:

- Collection and transfer to non-interfering orbits of non-operational orbiting vehicles, debris.

7. Potential value/benefits:

- o Gain experience with emergency rendezvous, docking with disabled vehicles
- o Clear high-value orbital planes, altitudes
- o Remove low-orbit vehicles in hazardous deteriorating orbits (especially those with nuclear fuel sources)
- o Collect "junk" in assigned regions for future industrial recovery, processing.

8. Schedule estimate:

- o Time line unknown
- o Flights would surge at front end of program, move to routine orbital maintenance schedule (continuous)

9. Task-subject categories: Space operations

10. Flight profile or parameters <u>during</u> the experiment: Among all orbital levels

ITEM

11. Critical/unusual handling/support requirements:

    Docking with non-cooperating vehicle

12. Comments relative to doing task without the STAR research vehicle:

    STAR can perform this task concurrently with other unrelated tasks, experiments. It is doubtful a larger or dedicated vehicle would be committed exclusively for such a task.

13. Task Description:

    - Collect non-operational orbiting vehicles, debris
    - Condense collected material within limited neighborhood for
      - Processing
      - Temporary parking
    - Transfer to parking orbit
      - By direct towing
      - Attached boosters
    - Temporary parking point may include external tank for later mission to transfer collection to final location.

NON-COOPERATING VEHICLE DOCKING SYSTEM

ITEM

1. Organization: EMERSON ELECTRIC CO., 8100 W. Florissant
St. Louis, Missouri 63136

2. Principal Investigator: R. D. WELLING

3. Liaison office or person: N/A

4. Beneficiary categories:

   Military
   Technology

5. Brief task description:

   Non-cooperating vehicle docking system

6. Key results desired:

   - Dock with non-cooperative targets
   - Perform reconaissance, inspection

7. Potential value/benefits:

   Strategic intelligence value

8. Schedule estimate: Unknown

9. Task-subject categories: Space operations

10. Flight profile or parameters during the experiment: Unknown

11. Critical/unusual handling/support requirements:

    - Establish physical, non-destructive, non-interfering, non-detectable physical connection with non-cooperating vehicle
    - Establish rigid link once physical connection completed

12. Comments relative to doing task without the STAR research vehicle:

    - STAR overt mission could screen reconnaissance
    - Multiple STARS make detection monitoring more difficult
    - Dedicated vehicle more conspicuous, expensive

ITEM

13\. Task Description:

- Rendezvous with vehicle of interest
- Extend contact/adhesion device
- Establish rigid link
- PerformEVA, reconnaissance
- Return to STAR
- Sever link

TACTICAL THEATER MULTISENSOR SURVEILLANCE SYSTEM

ITEM

1. Organization: EMERSON ELECTRIC CO., 8100 W. Florissant
St. Louis, Missouri 63136

2. Principal Investigator: R. D. WELLING

3. Liaison office or person: N/A

4. Beneficiary categories: Military

5. Brief task description:

A quick-response, low-orbit tactical reconnaissance system for real-time reporting of PHOTINT, ELINT.

6. Key results desired:

Provide theater and subordinate commanders with on-call (less than 2 hours) information on enemy dispositions, movement, location of high-threat systems.

7. Potential value/benefits:

- Fills gap in battlefield surveillance between TR-1 aircraft and strategic reconnaissance satellites
- Greater survivability than TR-1, greater resolution than satellites
- Detection of lower powered emitters possible, with high viewing angles providing increased dwell time over targets

8. Schedule estimate: Unknown

9. Task-subject categories: Unknown

10. Flight profile or parameters during the experiment: transatmospheric

11. Critical/unusual handling/support requirements:

- Coordinating target locations, time-over target
- Real-time communication of surveillance data

ITEM

12. Comments relative to doing task without the STAR research vehicle:

    No similar on-call system exists

13. Task Description:

    - STAR payload is multisensor package
    - STAR in stand-by launch or parking orbit configuration
    - Reconnaissance request from theater commander received and sets launch or new orbital parameters
    - STAR conducts single or multiple-pass sensings of battlefield, down links data to commander for real-time processing.

ORBITAL VEHICLE TEST/DIAGNOSTIC SYSTEM

ITEM

1. Organization: EMERSON ELECTRIC CO., 8100 W. Florissant
St. Louis, Missouri 63136

2. Principal Investigator: R. D. WELLING

3. Liaison Office or person: N/A

4. Beneficiary categories:

Commercial
Insurers/Investors
Satellites

5. Brief task description:

Ferry an automatic test system for interconnection with designated satellite systems for routine and emergency maintenance.

6. Key results desired:

Make it possible to obtain functional data on unmanned and perhaps dormant satellites for assessment on feasibility of repair/replacement.

7. Potential value/benefits:

   o Provide accurate information on disposition of malfunctioning high-cost satellites.

   o Repair rather than abandon/replace malfunctioning systems

8. Schedule estimate: Unknown

9. Task-subject categories:

Vehicular system/subsystem/components

10. Flight profile or parameters during the experiment:

Low to high orbit

11. Critical/unusual handling/support requirements:

   o Interface specifications critical

   o Standardization of diagnostic/test procedures required

<u>ITEM</u>

12. Comments relative to doing task <u>without</u> the STAR research vehicle:

    Without STAR, presumably no such test system would be transportable in the near term.

13. Task Description:

    - STAR payload is automatic test/diagnosis system
    - STAR rendezvous docks with satellite, mates test system with satellite
    - Test sequence results either stored on-board, down-linked or both
    - Decision made as to feasibility of repair/replacement

MAN-IN-LOOP DEFENSIVE BATTLE STATION

Name of Task:

ITEM

1. Organization: EMERSON ELECTRIC CO., 8100 W. Florissant
   St. Louis, Missouri 63136

2. Principal Investigator: R. D. WELLING

3. Liaison office or person: N/A

4. Beneficiary categories: Military

5. Brief task description:

   STAR vehicle as a manned battle station to "fly cover" for high-priority vehicles, destroying anti-sattelite systems.

6. Key results desired:

   Provide close-in defense of high-priority space vehicles

7. Potential value/benefits:

   - Provide semi-autonomous battle stations during high ionization periods
   - Operate on-call, activating dormant anti-anti-satellite systems
   - Provide stop-gap to near-term image understanding capabilities
   - Promote near-term deployment of space-based defense

8. Schedule estimate: Unknown

9. Task-subject categories:

Man-in-space	
Space operations	Launch
Flight control/command	Recovery

10. Flight profile or parameters <u>during</u> the experiment: Unknown

11. Critical/unusual handling/support requirements:

   - Rendezvous, docking with passive, low radar cross-section vehicl
   - Low-probability of intercept (LPI) communications with remote sensors, weapon platforms, ground.

ITEM

12. Comments relative to doing task without the STAR research vehicle:

    - Completely automated system (reliability problems) or ground link (ionization problems) required.
    - Deficiencies in artificial intelligence developments (image understanding, sensor fusion) require man-in-loop and permanent, semi-permanent manned stations.

13. Task Description:

    - Stand-by launch to rendezvous with dormant, low radar cross-section battle station
    - Provide passive surveillance with IR, RF, radar (from multistatic emitters) sensors
    - Attack threat vehicles under all conditions, including isolation of ground control because of nuclear-induced ionization

AEROJET

COMPANY

ROGER I. RAMSEIER
PRESIDENT

P.O. Box 13222 • Sacramento California 95813 • (916) 355 3633

21 March 1984

Mr. Fred W. Redding, Jr.
STAR Project Manager
DCS Corporation
1055 N. Fairfax Street
Alexandria, Virginia 22314

Dear Mr. Redding:

Your letter of February 14, 1984 requesting information on potential research and technology tasks for the Space Cruiser has been received. My technical staff has reviewed requirements and suggests three experiment areas for the STAR Program. These are:

1. Low cost Guidance System Evaluation for Space Cruiser and Untethered EVA.
2. Aerobraking Investigation.
3. Plug Cluster Engine for Primary Space Cruiser Propulsion.

I believe they meet your objectives for the Space Cruiser and its broad mission capabilities. While the two non-propulsion experiments are not prime product lines at Aerojet TechSystems, components of them have either been studied or are in development here and elsewhere. The unit thruster for the Plug Cluster Engine is an element of a major product line at TechSystems, Space and Satellite Propulsion. With funding tailored to the relative technology level achieved in the three areas, each could be made available to the flight test program and make contributions to the technology as well as future space operations. The attachments provide additional detail on the experiments. Should you have any further questions, please contact Clayton W. Williams, (916) 355-3634.

The Space Cruiser is an interesting and unique concept. We at Aerojet TechSystems wish you success in carrying it into development and flight test phases. We will continue to help in any way we can.

Sincerely,

Enclosure: Experiments (3)

Attachment 1.
Page 1 of 3

Name of Experiment: Low Cost Guidance System Evaluation for Space Cruiser and Untethered-EVA

1. Organization: Aerojet TechSystems Company

2. Principal Investigator:
James P. Taylor
Manager, Mission Analysis
Advanced Systems Division

3. Liaison Office or Person:
Clayton W. Williams
Director, Propulsion Technology
Advanced Systems Division

4. Beneficiary Categories:

2 Industry
____ Commercial
____ Laboratory
1 Military
1 Government
____ International
____ Insurers/Investors
1 Other -- Rescue

____ Science
2 Technology
____ Aircraft
1 Spaceplanes
1 Satellites
____ Space Station
____ Other Vehicles

Legend:

1. Direct Beneficiary

2. Indirect Beneficiary

5. Brief Task Description

Adapt the ultra-light weight, low cost Mark VI inertial reference system, developed by Aerojet TechSystems for NASA sounding rockets, to Space Cruiser guidance and control and to untethered EVA. Other applications could include space rescue, free flying platform guidance systems such as would be required by the NASA Spartan and the USAF Shuttle Disposable payloads (DSP), and space station EVA. This series of experiments accommodates the following STAR objective categories:

a. Vehicle systems and subsystems
b. Research on payloads and payload synergistics with the manned vehicle and extra vehicular activity
c. Evaluation of military man in space.

6. Key Results derived:

a. System accuracy as a function of weight and mission duration
b. Suitability for military applications
c. Suitability for rescue missions
d. Suitability for unmanned missions
e. Man-machine and man-environment synergism and interaction data

7. Potential Value/Benefits:

a. Reduction in guidance and control costs by an order of magnitude
b. Inertially guided EVA (i.e., rescue, satellite rendezvous, et al)
c. Advancement in the technology of light weight guidance and control systems

8. Schedule Estimate:

Start	1984 or later
Completion	60 months ATP
Key Phases	
a. Study definition	6 months
b. System development	24 months
c. System production	12 months
d. Flight test operations	18 months
Number of flights	6
Schedule sensitivity	None, the Mark VI system is already being produced for the NASA Sounding Rocket Program.

9. Task-subject categories:

*	Man-in-space
	Internal payloads
*	External payloads
*	Vehicular system/subsystem/components
*	Controls/displays
	Life support
	Aerothermodynamics
	Materials
	Structures
*	Space operations
	Flight support
*	Flight control/command
*	Launch
*	Recovery
	Phenomenology
*	Other... Deployment of free flyers for military surveillance, force reconstitution, beacons, et al

10. Flight Profile or Parameter <u>During</u> the Experiment:

a. Programmed for stable LEO with controlled attitude during entire mission
b. From shuttle or ELV deployment through controlled or flown-by-wire re-entry from LEO
c. Synergistic plane and orbit altitude changes
d. Pilot EVA with "return to Space Cruiser" fail safe mode

11. Any Critical or Unusual Handling/Support Requirements:

None. The Mark VI is designed to survive space shuttle launch environments.

12. Comments relative to doing task without the STAR research vehicle:

Space rescue, synergetic plane changes, and controlled reentries can only be accomplished with the STAR research or other equivalent vehicle. This research could be accomplished most economically with STAR since any other free flying platform would have to return to the shuttle for return to earth.

13. Task Description:

The proposed experiments using the Mark VI navigation system would investigate the adaptability and reliability of a low cost, light weight navigation system in trans-atmospheric, low earth orbit, and reentry environments. A kit of gyro and computer modules and programmed software would be supplied with each experimental system to permit parametric evaluation of the mission variables: weight, and accuracy as a function of system weight, mission duration, and mission profile. It is estimated that costs and guidance system weights for the brief missions of the Space Cruiser could result in savings of as much as 90% of the current state-of-the-art values in each category, weight and acquisition cost. It is believed that a low cost, light weight inertial navigation system, coupled with a suitable propulsion system (also to be furnished with the modified Mark VI), could make non-tethered EVA a practicality.

Name of Experiment: Aerobraking Investigation

1. **Organization:** Aerojet TechSystems Company

2. **Principal Investigator:**
James P. Taylor
Manager, Mission Analysis
Advanced Systems Division

3. **Liaison Office or Person:**
Clayton W. Williams
Director, Propulsion Technology
Advanced Systems Division

4. **Beneficiary Categories:**

Industry
2 Commercial
___ Laboratory
2 Military
2 Government
___ International
___ Insurers/Investors
2 Other ... Rescue

Science
1 Technology
___ Aircraft
1 Spaceplanes
___ Satellites
2 Space Station
2 Other vehicles (OTV)

Legend:
1. Direct Beneficiary
2. Indirect Beneficiary

5. **Brief Task Description:**

Adapt structurally efficient clamshell shields to the conical shape of the STAR research vehicle to evaluate this unique concept for aero-assisted re-entry and synergistic plane and orbit altitude changes.

6. **Key Results Derived:**

   a. Suitability for military applications
   b. Emergency de-orbit and plane change and orbit altitude change
   c. Structural weight advantages compared to conventional re-entry modes
   d. Possible re-entry corridors
   e. Weight as a function of materials technology

7. **Potential Value/Benefits:**

   a. Broader mission envelope limits
   b. Emergency de-orbit and orbit change capability
   c. Multiple purpose - the Aeroshield serves as a meteoroid shield, an aeromaneuvering surface, and a heat shield during aero-maneuvering.

d. Positive control - surface aréa modulation, angle of attack changes, and impulsive firings enable trajectory control and may also allow plane changes.
e. Simplicity - the concept requires no new technology. It is simple from such standpoints as aerodynamic analysis, structural design, thermal control, mechanical systems, etc.
f. Reusability - the Aeroshield is fully reusable without servicing or maintenance.
g. Basing - the Aeroshield is suited to either earth-basing or space-basing; it provides a large brake area even within the volume constraints imposed by the Shuttle payload bay during transit to low earth orbit.
h. Light Weight - there is no significant weight penalty associated with the multi-purpose capabilities of the Aeroshield.
i. Cost - concept simplicity leads to easier development, light weight to increased payload capability, and reusability to low operational costs. The overall result is lowest life cycle cost.
j. Most strongly supports early introduction of the Space Cruiser into higher energy orbits (GEO and Cis-Lunar) by providing a promise of major cost reductions.

8. Schedule Estimate:

Start	1984 or later
Completion	60 months ATP
Key Phases	
a. Study Definition	12 months
b. System Development	24 months
c. System Production	12 months
d. Flight Test Operation	12 months
Number of Flights	6
Schedule Sensitivity	The design and manufacture should be done in conjunction with Space Cruiser design and manufacture because of the high degree of integration.

9. Task-subject Categories:

★	Man-in-space
★	Internal payloads
★	External payloads - provides re-entry capability
★	Vehicular system/subsystem/components
	Controls/displays
	Life support
★	Aerothermodynamics

*	Materials
*	Structures
*	Space operations
	Flight support
	Flight control/command
	Launch
*	Recovery
	Phenomenology
	Other ...

10. Flight Profile or Parameter <u>During</u> the Experiment (Reference Table I)

    a. Normal re-entry from LEO
    b. Normal re-entry from GEO or Cis-Lunar
    c. Synergistic plane changes
    d. Aero-braked return to LEO from higher energy orbit
    e. Emergency de-orbit

11. Any Critical or Unusual Handling/Support Requirements:

    The Aero-Shell must be totally integrated with the Space Cruiser structure for maximum effectiveness.

12. Comments relative to doing task without the STAR research vehicle:

    The experiment could be performed with the proposed NASA Orbital Transfer Vehicle (OTV) but at considerably greater expense and in a highly uncertain time frame.

13. Task Description:

    a. Concept Description - the Aero-Shield allows multiple use of basic structure for both aeromaneuvering and for meteroid protection. It consists of two semi-conical surfaces hinged along one edge. When closed, the surfaces form a tight cone that serves as the meteroid shield for the Space Cruiser and payload within. When open, the surfaces form a variable area, low L/D, lifting brake for aeromaneuvering while passing through the earth's atmosphere.

       During aeromaneuvering the vehicle is aligned normal to the velocity vector in a vertical attitude while passing through the earth's atmosphere. Trajectory control is obtained by modulating the surface area, changing the angle of attack, and/or by engine firings at reduced thrust. Thus the drag coefficient, lift coefficient, and frontal area can be changed in accordance with control requirements (acceleration feedback) and operating constraints (heating, pressure loads, acceleration, etc.).

       With increasing airframe-wing-heatshield functional integration, the conical space cruiser re-entry shape could go forward to high L/D re-entry platform and broader mission capability.

b. Proposed Study Definition Phase Program - the proposed program is intended to evaluate the Aeroshield concept more rigorously than was possible in the 1983 Aerojet TechSystems-funded effort. It consists of three major tasks:

Conceptual Design Evaluation - Conceptual Aero-shield designs will be generated for a representative vehicle and mission to be selected with DCS/DARPA approval. The baseline concepts will be evaluated for the selected mission, using a computer program developed during an Aerojet TechSystems Company IR&D program, to determine thermal and pressure loads. The structural design of the Aero-shield and its deployment mechanism will be addressed. The thermjal design will also be considered, with primary emphasis on passivbe systems such as the Space Shuttle Thermal Protection System (TPS). Active cooling will be considered if necessary. Guidance, Navigation, and Control (GN&C) requirements will be examined for compatibility with the configuration/operational concepts generated.

System Tradeoffs - this task will study the effects of vehicle trajectory, drag modulation, and atmospheric variations on the Aero-shield configuration, TPS, GN&C, and propulsion requirements, expressing these effects in terms of weight impacts to the baseline design. Other aspects of the concept to be considered are summarized in Table I.

Technology Requirements Definition - technologyh gaps uncovered in the preceding tasks will be identified. 1 A technology acquisition plan will be prepared to define the scope of programs necessary to generate the missing technology.

c. Following completion of the study phase, the remainder of tha 60 month experimental program (as summarized under 8.) would be defined in detail.

TABLE I

CONSIDERATIONS IN AEROSHIELD CONCEPT DESIGNS

A. FLOW FIELD AND AEROTHERMODYNAMIC CONSIDERATIONS

- UPPER ATMOSPHERIC UNCERTAINTIES AND VARIATIONS
- WAKE FLOW INTERACTIONS
- THRUST PLUME INTERACTIONS
- NONEQUILIBRIUM AEROTHERMODYNAMIC EFFECTS
- RADIATION EXCITATION AND DEEXITATION IN UPPER ATMOSPHERE
- REAL GAS COMPUTER CODES
- VISCOUS INTERACTION BOUNDARY LAYER CONTROL

B. POTENTIAL THERMAL PROTECTION SYSTEMS

- REUSABLE SEMIRIGID SYSTEMS FOR UP TO 3,000°F - NONABLATIVE
- RIGID TPS - 4,000°F
- USE OF COMPOSITES AND NEW MATERIALS - SIC, FRI, ETC.
- ACTIVE COOLING

C. GUIDANCE, NAVIGATION & CONTROL (GN&C) EFFECTS

- AUTONOMOUS ADAPTIVE CONTROL IN CONTINUALLY VARYING ENVIRONMENT
- METHODS OF CONTROL EFFECTIVENESS
- CONTROL SENSITIVITIES
- APPROACH NAVIGATION

D. STRUCTURAL CONSIDERATIONS

- STRUCTURAL WEIGHT
- VOLUME EFFICIENCY
- DESIGN SIMPLICITY

E. PROPULSIVE INTERACTIONS

- ISP
- THRUST/WEIGHT RATIO
- MULTIPLE ENGINE CONCEPTS

Name of Experiment: Plug Cluster Engine (hereinafter referred to as PCE) for Primary Space Cruiser Propulsion for a Wide Range of Propellant Loads and Back Pressures From Sea Level to Hard Vacuum.

1. Organization: Aerojet TechSystems Company

2. Principal Investigator:
Donald W. Culver
Manager, Propulsion Systems
Advanced Systems Division

3. Liaison Office or Person:
Clayton W. Williams
Director, Propulsion Technology
Advanced Systems Division

4. Beneficiary Categories:

Industry
____ Commercial
____ Laboratory
2 Military
2 Government
____ International
____ Insurers/Investors
____ Other ...

Science
1 Technology
____ Aircraft
1 Spaceplanes
____ Satellites
2 Space Station
2 Other Vehicles

Legend:

1. Direct Beneficiary

2. Indirect Beneficiary

5. Brief Task Description: The experiment involves (1) the application of scarfed nozzles on the sixteen 188 lbF rocket engines which are arrayed around the plug and (2) on-line pump feed capability for two to four of the normally pressure fed 188 lbF engines from externally mounted, conformal propellant tanks

6. Key Results Derived:

   a. Optimum area ratio and scarfing angle for the 188 lbF engine for sea level, high-endo, and exoatmospheric Space Cruiser operation.
   b. Reliability, performance, and operating life for the equivalent 376 lbF to 752 lbF thrust pumps for feeding propellants from external, conformal propellant tanks to the 188 lbF rocket engines.
   c. Design data for ultra light weight, conformal propellant tanks.

7. Potential Value/Benefits:

   a. Flexible, short, high performance, and low cost rocket engine developed for a wide range of Air Force missions.

b. Low flow rate pump technology for possible use in space platform, Space Shuttle, orbit thruster, tactical missiles, as well as Space Cruiser.

8. Schedule Estimate:

Start	1984 or later
Completion	60 months ATP
Key Phases	
a. Study Definition	6 months
b. System Development	24 months
c. System Production	12 months (1)
d. Flight Test Operations	18 months
Number of Flights	6
Schedule Sensitivity	None. The basic thruster and turbopump technology is on-going at Aerojet TechSystems.

9. Task-subject Categories:
(Please identify those relevant and clarify where helpful)

___ Man-in-space
___ Internal payloads
_*_ External payloads
_*_ Vehicular system/subsystem/components
___ Controls/displays
___ Life support
_*_ Aerothermodynamics
_*_ Materials
___ Structures
_*_ Space operations
___ Flight support
___ Flight control/command
___ Launch
___ Recovery
_*_ Phenomenology
_*_ Other ... Endo-atmospheric operation; synergistic aero-maneuvering

---

(1) This phase overlaps development and flight test operation for effective 24 month production period.

10. Flight Profile or Parameter <u>During</u> the Experiment:

a. Synergistic plane and orbit altitude changes
b. Sea level and high endo-atmospheric operation

11. Any Critical or Unusual Handling/Support Requirements:

None. The PCE will be designed to survive Space Shuttle and ELV launch environments.

12. Comments relative to doing task without the STAR research vehicle:

Synergistic plane changes and controlled re-entries can only be accomplished with the STAR research or other equivalent vehicle. the research could be accomplished most economically with STAR since any other free flying platform would have to return to the Shuttle for return to earth.

13. Task Description:

a. Plug Cluster Engine (PCE) Module Scarfed Nozzles

The existing bell nozzles on each of the 188 lbF PCE modules were designed for vacuum operation of the Spaceplane. For near optimum operation at various altitudes and ambient pressures, these nozzles will be replaced with scarfed nozzles. At 100 psia chamber pressure, the nozzles will be scarfed from an area ratio of approximately 3.5 to the exit plane.

The resulting PCE will operate at all altitudes without unstable nozzle flow separation which could structurally damage or destroy the modules and PCE. Additionally the use of unscarfed nozzles would result in performance penalties during any non-optimum altitude operation. At sea level the nozzles will provide optimum flow expansion resulting in maximum PCE thrust. At higher altitudes flow expansion will also occur on the plug lateral surface, formed by the scarfed nozzles, providing additional thrust. At a sufficiently high altitude, recirculation of module exhaust gases on the plug base will provide additional thrust. Total PCE thrust at mid and high altitudes can be further increased, at a slight sea level thrust penalty, by tilting the modules towards the vehicle centerline.

The scarfed nozzles will be structurally supported by the module thrust chamber, of which the nozzle is an integral part, and the plug.

b. Pump Fed Operation With External Tanks

Low thrust operation with high total impulse requires a pump fed propulsion system. A pressure fed system would require unacceptably heavy propellant tanks. This requirement can be met on the Spaceplane by the use of externally attached conformal propellant tanks with integral electric motor driven propellant pumps. The Spaceplane vehicle would provide the electrical power and/or electrical on-off signal to operate the pump motors. The pumps, motors and electrical power supply if included in the tank assembly, would provide propellant flowrates adequate for operation of 2 to 4 of the PCE modules. The development of low flowrate, low head rise pumps is currently underway at Aerojet TechSystems Company.

The use of these externally attached tank/motor/pump assemblies will require structural, fluid (propellant) and electrical interfaces with the Spaceplane.

A surface tension type propellant acquisition device can be used in the external tanks since only low G operation will be experienced during propellant expulsion from these tanks.

The difference between the internal and external tank pressures will enable propellant transfer from the internal to the external tanks. The reverse transfer can be done with the external tank pumps.

Aerospace Systems Division
P.O. Box 1062, Boulder, Colorado 80306-1062 (303) 441-4000 TWX 910-940-3241 Telex 45-605 Cable BAREC

13 March 1984
B6800-84.059

DCS Corporation
1055 N. Fairfax Street
Alexandria, VA 22314

Dear F.W. Redding, Jr.:

Ball Aerospace Systems Division is pleased to participate in your search for research and technology tasks suited to the Space Cruiser. Enclosed please find descriptions of our recommended programs. Two of the write-ups present methods of detecting nuclear materials on foreign spacecraft (Space Treaty verification). Another describes some phenomenology measurements of interest to the BMD community and the last describes an application to satellite repair - in particular, the replenishment of cryogenic fluids. This last is of obvious interest to the IRAS program but also should be of interest to potential military programs.

Our reading of your request is that you are looking for relatively near-term applications that benefit U.S. research and technology programs. For this reason, we have attempted to keep our imaginations from running too wild. (As I am sure you must have determined for yourself, the STAR vehicle inspires some fairly fantastic ideas.) We feel that all of our suggested tasks are near-term and practical.

We hope that these tasks help you in your efforts. Please feel free to contact us if you have any questions.

Yours truly,

George E. [illegible], Deputy Director

for Gerald D. Godden, Director
Defense Systems

P.S. If you have any promotional materials on the Space Cruiser such as artist's conceptions, we would appreciate receiving some. It would be useful in keeping the Cruiser in our minds and in stimulating thought on future projects.

GDG/ER/chb

1.Organization: Ball Aerospace Systems Division
P.O. Box 1062
Boulder, Colorado 80306

2.Principal Investigator: Eric Ramberg

3.Liason: Dr. Gerry Godden

4.Beneficiary Categories: Military, Government

5.Brief Task Description: Inspection of satellites for the presence of nuclear materials by thermal imaging.

6.Key Results Desired: Knowledge of the amount, distribution and potential use of nuclear materials onboard a foreign spacecraft.

7.Potential Value: This provides a method of verifying the 1967 Outer Space Treaty that banned the presence of nuclear weapons in space. From the strict military viewpoint, this is a method of gathering military intelligence for selecting ASAT high priority targets. In addition, this sensor will allow determination of whether a spaceborne reactor is operating or dormant.

8.Schedule Estimate: A feasibility program could be accomplished in about three years. The infrared imager could be configured similar to current military FLIR imagers. The signal processing and focal plane would be the major design drivers.

9.Task-subject categories: man in space, internal payloads, space operations flight control/command, phenomenology and intelligence.

10.Flight Profile: The space cruiser would have to maneuver quite close to the target satellite. A range of less than one kilometer would be desireable. Relative motion would have to be kept to a minimum while the target was observed.

11.Critical Handling/support requirements: None

12.Comments on doing task without STAR: Although this mission could, in principle, be performed by an independent satellite, the maneuverability and man-in-the-loop operation make the use of the space cruiser an overwhelming advantage. The rendezvous with the target satellite will be quite difficult. The reaction time of the pilot can allow very close approach. In addition, the pilot can make decisions about the quality of the image. If he determines that a different view would bring in more information, then he will be able to maneuver to a different look angle.

13.Task Description:

A Soviet nuclear weapon armed orbiting platform would be a grave threat to the security of the United States. Only if such platforms were known to exist and their locations tracked carefully, would it be possible to have an early warning. For this reason the United States must acquire and demonstrate the ability to detect and identify such platforms. Even though such platforms are outlawed by the 1967 Outer Space Treaty, treaties and agreements are useless if no means of verification are available.

Upon detection of the launch of a satellite that would be capable of concealing targetable nuclear weapons, standard intelligence techniques would be employed in an effort to determine the satellite mission. If these techniques failed to determine the purpose of the satellite and indicated that it could be an orbiting nuclear arms platform, then a specific mission using the STAR vehicle could be launched in order to investigate this possibility.

The approach explained in this letter uses a thermal imaging system to view the spatial structure of a "heat print-through image". The method of operation would be that the cruiser would maneuver close to the target satellite. The payload bay cover would then open and the infrared telescope would view the target. The IR picture would be taken and observed in near real-time by the pilot. If necessary, the pilot could remaneuver for improved imagery.

Active nuclear reactors and nuclear warheads are significant sources of heat (10's to 1000's of watts). Because a satellite is something of a closed system, this heat must be dissipated. The most practical method is radiative cooling in the neighborhood of the heat source. (This could be avoided by employing a stored cryogen, but it would significantly restrict the vehicle lifetime). This radiated heat produces a significant change in the infrared signature of the satellite which is detectable by an IR sensor.

The thermal imaging system required is within the state-of-the-art. In order to see the "print through" phenomena, the temperature sensitivity of the sensor would have to be on the order of .05 K. Because the target would have a temperature range of 250K-400K, the standard thermal infrared band (7-14 microns) would be appropriate. In order to get adequate resolution of the satellite at a kilometer standoff range, the aperture would have to be on the order of half a meter in diameter. With good IR detectors, this aperture would provide sufficient collecting area to provide adequate signal to noise ratio.

A major consideration in the design of this sensor would be the dynamic range required. Because the temperature could vary over a factor of two and a resolution of .05 degrees is desired, the dynamic range would have to be between one thousand and ten thousand. This might provide a challenge for CCD detectors. Discrete detectors may be necessary. This detector array would not, however, be pushing the technology. The other area that would be affected is that of image/signal processing. This dynamic range is well beyond that useable by an operator. Computer processing would be required to uncover the information desired by the operator. This would not particularly push the state of the art.

1.Organization: Ball Aerospace Systems Division
P.O. Box 1062
Boulder, Colorado 80306

2.Principal Investigator: Dr. James M. Picwaty

3.Liason: Dr. Gerry Godden

4.Beneficiary Categories: Military,Government

5.Brief Task Description: Inspection of satellites for the presence of nuclear materials by x-ray and low energy gamma ray imaging.

6.Key Results Desired: Knowledge of the amount, distribution and potential use of nuclear materials onboard a foreign spacecraft.

7.Potential Value: This provides a method of verifying the 1967 Outer Space Treaty that banned the presence of nuclear weapons in space. From the strict military viewpoint, this is also a method of gathering military intelligence for selecting ASAT high priority targets.

8.Schedule Estimate: A feasibility program could be accomplished in about three years. The x-ray imager could be configured similar to the Hadamard camera scheduled to be flown on AXAF by LANL as an off focal plane instrument.

9.Task-subject categories: man in space, internal payloads, space operations flight control/command, phenomenology and intelligence.

10.Flight Profile: The space cruiser would have to maneuver quite close to the target satellite. Relative motion would have to be kept to a minimum while the target was observed.

11.Critical Handling/support requirements: Because the cruiser would have to station keep for periods on the order of minutes, an internal radar would probably be necessary. One of the critical performance parameters would be how accurately the cruiser could maintain its position.

12.Comments on doing task without STAR: Although this mission could, in principle, be performed by an independent satellite, the maneuverability and man-in-the-loop operation make the use of the space cruiser an overwhelming advantage. The rendezvous with the target satellite will be quite difficult. The reaction time of the pilot can allow very close approach. In addition, the pilot can make decisions about the quality of the image. If he determines that a different view would bring in more information, then he will be able to maneuver to a different look angle.

13.Task Description:

A Soviet nuclear weapon armed orbiting platform would be a grave threat to the security of the United States. Only if such platforms were known to exist and their locations tracked carefully, would it be possible to have an early warning. For this reason the United States must acquire and demonstrate the ability to detect and identify such platforms. Even though such platforms are outlawed by the 1967 Outer Space Treaty, treaties and agreements are useless if no means of verification are available.

Upon detection of the launch of a satellite that would be capable of concealing targetable nuclear weapons, standard intelligence techniques would be employed in an effort to determine the satellite mission. If these techniques failed to determine the purpose of the satellite and indicated that it could be an orbiting nuclear arms platform, then a specific mission using the STAR vehicle could be launched in order to investigate this possibility.

The approach described in this letter uses x-ray and low gamma ray imaging to produce information about the type, quantity and distribution of fissionable materials on board the target satellite.

Active nuclear reactors and nuclear warheads are significant sources of x and gamma ray emissions. Because of weight limitations, it is impractical to completely shield such devices. Thus the emissions are available for analysis. The energy spectrum indicates what fissionable material is on board. The distribution of the material will determine whether the device is a reactor or multiple warheads.

The feasibility of a large x-ray imaging telescope has recently been demonstrated and the Hadamard camera shows the most promise in this application due to its light weight and robustness. A Xenon gas imaging proportional counter could act as the active focal plane detector. (X-ray film might also have some advantages).

Preliminary calculations indicate that, for adequate signal to noise, the experiment would have to integrate over time periods on the order of minutes if the standoff range was one kilometer. The technical driver of this system would be the spatial resolution achievable by a large area proportional counter.

There are other nuclear detection methods that might be used. One could envision ejecting a radioactive material that produces well characterized gamma rays from the cruiser before flying by the target satellite. The source would pass on one side of the target and the cruiser, equipped with an array of gamma detectors, would pass on the other. A gamma absorption image could then be built up. The distribution of high Z materials could then be derived. This is a concept that we have named GRIDS (Gamma Ray Image Display System). It has been explained in detail for a ground based application in an internal company proprietary report number DPD-WP-81.011.

One extension of this idea is that, if the satellite were spinning, the image could be built up similar to a computerized axial tomography (CAT) scan. This could, in principle, produce a full 3 dimensional image of the internal structure of the satellite.

One final technique that we have considered is to use neutron activation to generate unique high energy gamma ray signatures. In this concept, a small quantity of Cf-252 is deposited on the target vehicle in the vicinity of the suspected warhead. This material produces continuous activation of the radioactive material. The resulting gamma emission would have distinct spectra depending on what the fissionable material was. This would be especially useful in discerning warheads from simulators.

1.Organization: Ball Aerospace Systems Division
P.O. Box 1062
Boulder, Colorado 80306

2.Principal Investigator: Dr. Charles M. Bradford

3.Liason: Dr. Gerry Godden

4.Beneficiary Categories:
MILITARY

5.Brief Task Description: OBSERVATIONS OF BOW SHOCK RADIATIVE EMISSIONS

6.Key Results Desired: SPECTRAL AND SPATIAL SIGNATURES OF BOW SHOCK EMISSIONS DURING RE-ENTRY OF SPACEPLANE

7.Potential Value: Measurements of this type could be of very high value to the national defense and the BMD community.

8.Schedule Estimate: TBD

9.Task-subject categories:
Aerothermodynamics
Phenomenology
BMD Discrimination

10.Flight Profile: EARLY RE-ENTRY

11.Critical Handling/support requirements. NONE

12.Comments on doing task without STAR:
Such measurements could be done by techniques other than the use of the STAR vehicle, but would require a dedicated mission to do so. By using the STAR vechicle, the desired observations can be made during the dead time between other missions and be of lower cost.

13.Task Description:

OBSERVATIONS OF BOW SHOCK RADIATIVE EMISSIONS

A continuing requirement exists within the national ballistic missile defense community for improved and more effective discrimination capabilities in identifying and targeting ballistic warhead reentry vehicles. As better decoys and penetration aids are developed, requirements for discrimination become more stringent.

Most currently observed reentry optical signatures are derived from thermal sources. The radiation emitted is due to the bulk temperature of the emitting material, whether it is the RV body or the hot gases in the boundary and wake of the RV.

However, the recently observed shuttle glow phenomenon indicates that optical signatures from near earth orbit bodies can be generated by non-thermal mechanisms. Typically, non-thermal emissions occur at specific wavelengths which make it possible to design sensors with narrow spectral responses without loss of signal.

Both the thermal and non-thermal emissions from the bow shock of orbiting and suborbital bodies have an unexamined potential for BMD discrimination. The STAR research vehicle (STAR-RV) is an excellent means to examine bow shock emissions. It can be used both as an observation platform and as a target. The STAR-RV itself has the shape of a modern nuclear warhead reentry vehicle. It could be used as a target to be observed by shuttle-borne sensors, by sensors aboard a companion STAR-RV or even by sensors being self-carried.

Both spatially and spectrally resolved measurements are recommended, covering the spectral region from about 100 nm to the short wave infrared. For the measurements recommended here, initial emphasis should be on the visible and UV spectral regions because these regions have a high potential to produce non-thermal signals that could be discriminatory. Spatial resolution should be a few centimeters; spectral resolution initially should be a few Angstroms.

Selected observations of portions of the bow shock radiation, including spectral signatures, can be made by sensors on board the target vehicle itself, without disturbing the boundary layer flow patterns. These measurements would be made by looking through forward-looking low-profile windows. Direct observation of the stagnation region in the front of the vehicle will necessarily require sensors on other vehicles, such as a companion STAR-RV. Both types of experiments are needed and recommended.

Measurements of this type are best made with an imaging spectrometer, which uses a 2-dimensional detector array to collect spectral and spatial data simultaneously. BASD is currently pioneering imaging spectrometer design for military applications and should be involved in all aspects of a program of this type, from mission planning to data analysis.

ORGANIZATION: BALL AEROSPACE SYSTEMS DIVISION
P.O.BOX 1062
BOULDER, CO 80306

PRINCIPAL INVESTIGATOR: DR. DONALD W. STRECKER

LIASON: DR. G. D. GODDEN

BENEFICIARY CATEGORIES: MILITARY, GOVERNMENT, INTERNATIONAL, SCIENCE, TECHNOLOGY

BRIEF TASK DESCRIPTION: On-orbit refurbishment of inoperative satellites, specifically, superfluid helium cryogen replenishment of the Infrared Astronomical Satellite

KEY RESULTS DESIRED: Extended operational lifetime of the LWIR/FIR survey instrument

POTENTIAL VALUE/BENEFITS: Another IRAS will not be launched, a cryogen replenishment will allow IRAS to operate again, perform more survey work, take spectra of interesting objects, and provide time variability information.

SCHEDULE ESTIMATES: The cryogen replenishment effort could start any time; it would require one flight, it is reasonably schedule insensitive; but it would require a near polar orbit.

TASK-SUBJECT CATEGORIES: Man-in space, external payloads, space operations.

FLIGHT PROFILE: The Space Cruiser orbit would have to match the IRAS 900 km altitude, 99 degree inclination, near polar orbit to achieve cryogen transfer.

HANDLING/SUPPORT REQUIREMENTS: External superfluid helium cryogen tanks and associated transfer lines are required.

COMMENTS ON TASK WITHOUT STAR: This on-orbit transfer of liquid helium cryogen to IRAS is probably impractical by any other means. IRAS' polar orbit is difficult, if not impossible, for STS to achieve and the cryogen replenishment requires a man and an EVA to complete.

ON ORBIT SATELLITE REFURBISHMENT

PROBLEM:

Several types of recent earth orbiting artificial satellites have become inoperative for a variety of reasons such as: electrical failures (Solar Maximum Mission); Payload Assist Motor failures; and cryogen depletion (Infrared Astronomical Satellite). Many of these satellites were not designed for repair on orbit, or for return to the Shuttle for repair, or for return to earth for repair. They may be spin stabilized craft with no provision for de-spinning or they may not have attach points available at all or compatible with STS equipment. The problem is how to get these instruments back into operation, economically.

SOLUTION:

The "Space Cruiser" could be used to repair or refurbish specific spacecraft or instruments either by visiting the spacecraft and servicing it on the spacecraft orbit or by attaching to the spacecraft and returning it to the STS. After servicing by the STS, the spacecraft can then be returned to its original orbit or placed into another orbit by the space cruiser. The space cruiser could achieve orbits not available to the Shuttle. Also, the pilot of the spaceplane could perform the complex orbital matching and attachment maneuvers in real time with instant feedback. The pilot is also available for extra-vehicular activity, as required, for servicing the damaged or inoperative spacecraft.

A specific example of this satellite refurbishment concept would be to use the space cruiser to replenish the depleted liquid helium cryogen supply on the Infrared Astronomical Satellite (IRAS). IRAS was a survey instrument in the Long Wave Infrared (LWIR) to Far Infrared (FIR) with options for LWIR spectroscopy and extended pointed observations. It performed admirably for 10 months before its superfluid helium cryogen supply at about 1.8K ran out and the system warmed up to near ambient temperatures and became inoperative.

The liquid helium cryogen replenishment would re-vitalize the IRAS instrument and would benefit the world's astronomical community. The next American astronomical infrared orbiting instrument with sensitivity greater than IRAS will be the Shuttle Infrared Telescope Facility (SIRTF) but that system will not fly until the mid 1990's at the earliest, if at all. The original mission lifetime for IRAS was about 12 months and it lasted only 10 months before its cryogen supply was exhausted. It would be advantageous to re-observe many newly discovered IRAS sources after most of the survey data analysis has been done. A second look for re-confirmation and expanded study in a more relaxed time frame could be very productive. The resurrected IRAS could perform a more complete sky survey, perform more spectroscopic observations of selected objects, perform many more increased sensitivity pointed observations or mini-surveys and, particularly, obtain information on variability of the new sources discovered by IRAS with a time base of several years rather than with a base of minutes, hours, or a few months. IRAS could also perform some of the mission goals of SIRTF. IRAS originally was an international effort among the United States, the Netherlands, and the United Kingdom, so the resurrection of IRAS would probably be an international effort also.

APPROACH:

The approach which we prefer at this time, uses the Space Cruiser itself to replenish IRAS' cryogen supply. In this scenario, the Space Cruiser is launched via STS, picks up the strap on liquid helium cryogen tanks from the Shuttle bay along with the required liquid helium transfer lines and electronic interface connector and then changes orbits to match the 99 degree inclination IRAS 900 km orbit and performs a rendezvous with IRAS. The manned aspect of the Space Cruiser is definitely an asset in this approach and it is certainly possible that the IRAS cryogen refurbishment could not be performed by a remotely controlled unmanned vehicle. After rendezvous, the pilot performs an EVA where he removes a readily accessible cover which then allows easy access to IRAS' helium fill and vent line beyonet connectors and the electrical connector which controls the cryogenic valve operation. He attaches the electronic control panel and liquid helium fill and vent lines and the executes the procedure to begin transferring liquid helium from the Space Cruiser tanks into the IRAS main cryogen tank. We estimate, from previous ground based and in-orbit experience, to cool the IRAS' optics, detectors, and main cryogen tank from its orbital ambient temperature (about 130K) to superfluid helium (SfHe) temperature (about 2K) using cold helium blowoff gas and liquid helium would require 30 to 40 hours. We would also prefer to fill IRAS with superfluid helium rather than with normal liquid helium so we can take advantage of the increased cooling capacity of a full tank of SfHe for an increased operational lifetime. If IRAS' tanks were filled with normal helium which was then vented to cool to the superfulid state, we estimate a 7 month operational lifetime would be achievable whereas a superfluid fill would result in an estimated 10 month operational lifetime.

After cryogen replenishment, the pilot returns the cryogenic manifold and valves to the operational configuration, disconnects the fill and vent bayonet connections, and returns to the Space Cruiser. He then changes orbits to return to earth and along the way he ejects the strap on tanks and external equipment.

The equipment required to be carried by the Space Cruiser from STS to IRAS would fill an estimated 1000 cubic foot volume of about 10 ft. by 10 ft. by 10 ft. in external strap on payload and would consist of fill and vent connection lines, electronic control panel and connectors, and about 2000 liters of liquid helium.

SUMMARY:

We have presented a concept for on orbit repair and refurbishment of inoperative satellites by the Space Cruiser. As a specific example, we believe that on-orbit replenishment of the depleted Infrared Astronomical Satellite (IRAS) liquid helium cryogen by the Space Cruiser with strap on payloads and EVA by the pilot is feasible and desirable. This refurbishment is of general astrophysical interest and LWIR to FIR astronomical interest for this international program. The Space Cruiser appears uniquely suited to this effort due to the high altitude, high inclination IRAS orbit not achievable by the Shuttle and the requirement for an EVA to perform the mate, liquid helium transfer and control, and demate of the Space Cruiser to IRAS.

STAR TASK DESCRIPTION SUMMARY

Task Title: STAR Configuration Changes

Vought Missiles and Advanced Programs Division
Post Office Box 225907
Dallas, Texas 75265

Principal Investigator: TBD

Focal Point: Dr. C. S. Wells/Dr. J. L. Porter

Beneficiary Categories: (Please rank top five)

- Industry
- X Commercial
- Laboratory
- X Military
- Government
- International
- Insurers/Investors
- Other

- Science
- X Technology
- X Aircraft
- X Spaceplanes
- Satellites
- Space Station
- Other Vehicles

Brief Task Description: (please include complete description on last page)
Determination of the altitude conditions for which extremely large "strap-on" wings are useful for maneuvers.

Key Results Desired: Validate the benefits of lightweight "strap-on" wings for the STAR vehicle. Determine the min/max altitudes for a "Space Glider".

Potential Value/Benefits: Minimal energy maneuvers in rarefied atmosphere.

STAR TASK DESCRIPTION SUMMARY (CONT'D)

Schedule Estimate:
(Start/Completion/Key Phases/Number of Flights/Schedule Sensitivity/etc.)

TBD

Task Subject Categories: (Please identify those relevant and clarify where helpful)

X Man in space
____ Internal payloads
X External Payloads
X Vehicular system/subsystem/components
X Controls/displays
____ Life Support
X Aerothermodynamics
____ Materials

____ Structures
____ Space operations
____ Flight support
X Flight control/command
____ Launch
____ Recovery
____ Phenomenology
____ Other

Flight Profile or Parameters During the Experiments: Altitude, Reynold's Number, Wing Area/Shape, Effect of Heating and Focusing of sun through wing.

Any Critical or Unusual Handling/Support Requirements: EVA required for assembly.

Comments Relative to Doing Task Without the STAR Research Vehicle: Not possible - i.e. task is specific to a STAR-type vehicle.

APPENDIX C

TITAN TURBOPUMP CONVERSION

The following discussion reviews the apparent functional and environmental considerations of converting Titan III T-34D turbopumps from ambient temperature propellants to the cryogenic propellants liquid oxygen and liquid propane. Design operating conditions (see Table C-1) are used as operating conditions where factors concerning performance or stress are concerned. This discussion is derived from Aerojet Tech Systems Memo No. 9735: 057, 9 July 1981

OIL COOLER

Current oil lubricated turbopump gearboxes employ Aerozine 50 tapped from the pump discharge housing as a coolant. Heat transfer takes place in a multipass shell and tube heat exchanger that is directly flanged to the oil reservoir. The use of propane (-42°F) would result in unacceptably high viscosities if not freezing of the MIL-L-7808 oil. If this fuel were to be considered as a coolant, it would have to be warmed elsewhere in the engine or have its flow regulated as a function of sensing oil exit temperature in order to avoid high viscosity or freezing.

AUTOGENOUS PRESSURIZATION SYSTEM

Fuel and oxidizer propellant tanks are pressurized by cooled turbine gas and vaporized oxidizer respectively. A change to propane and oxygen would probably necessitate the redesign of the hot gas (fuel rich) cooler and oxidizer vaporizer. The basic system is believed to be chemically compatible with cryogenic propellants but may require some bleed-in changes to account for the potential shift from gas to liquid phase during start-up.

GENERAL TEMPERATURE CONSIDERATIONS

A change from ambient temperature propellants to cryogenic will necessitate a review of part fits and running clearances. The problem will probably require a slight change to be made where parts of significantly different coefficients of expansion exist adjacent to one another. Examples of this are the aluminum impeller to gearbox shaft fit, stainless steel liners in aluminum parts and impeller clearance.

TABLE C-1

ASSUMED TITAN III TURBOMACHINERY OPERATING CONDITIONS

PROPELLANTS	NITROGEN TETRAOXIDE/ AEROZINE-50		OXYGEN/ PROPANE	
	Nominal Engine Balance Conditions			
TYPE	FUEL (3)	OX (3)	FUEL	OX
Chamber Pressure psia			870	
Propellant Temperature °F	60	60	-42	-297
Pump Speed rpm	9,637	8,497	10,716	9,756
Flow Rate gpm	2,481	2,892	2,510	3,445
Head Rise ft	3,275	1,758	4,877	2,337
Suction Pressure psia	34(3) 36(1)	86(3) 119(1)	40(2)	64(2)
Vapor Pressure psia	1.85	10.2	15.	15.
Power hp	2,730	2,506	2,629	3,149
(Q/N) gpm/rpm	0.257	0.34	0.234	0.345
NPSH ft	81	116	99	99
Fluid Density lb/ft^3	56.62	90.84	36.3	71.3
Discharge Pressure psia	1,354	1,189	1,269	1,221
Percent $(Q/N)_{neb}$	100	100	91	104

(1) Maximum flight values

(2) Minimum required to meet assumed operating conditions at a maximum turbine speed of 28,000 rpm

(3) Nominal engine balance conditions

Use of cryogenic propellants will necessitate a review of propellant bleed-in schedule and heat transfer phenomena. A portion of fluid passage wall heat will be given up to the cryogenic propellant as it is initially bled in, changing it from a subcooled liquid to a gas. The two phase mixture resulting will limit weight flow rate to values less than neat liquid and thus will require longer bleed-in times. Lower density of the vapor raises mixture velocities creating greater fluid friction losses. If the pressure ratio in the line is sufficient, sonic choking of the two phase mixture can occur due to the sonic velocity of a mixture being lower than either the liquid or gas sonic velocities alone.

An additional phenomena is the time to stabilize the turbo machinery temperatures to the degree that unsymmetrical parts bind, rub or otherwise cause deviant performance. Most sensitive would be close clearance parts such as bearings, seals and thrust balancers.

VENTING

Vessels with cryogenic fluids must by definition be vented to the atmosphere to keep them from overpressurizing the container. A vessel with a number of small passages will tend to generate vapor due to heat conducted from the warmer outside wall. These small passages may then collect vapor in pockets where perhaps none is desired. Such pockets must then be individually vented in addition to the main propellant tank.

One method to avoid pocket venting is to circulate the cryogenic fluid by a separate pump. This may be the main pump, boost pump or a specifically dedicated circulation pump.

OFF-DESIGN PERFORMANCE

Use of Titan III pumps to meet the pressure flow requirements of an oxygen/propane fueled engine will require one or more of the pumps and/or turbine to be operated off-design. Pressures and flow rates other than the original values will cause the rotors of these components to sustain larger radial and/or axial thrusts or pressures than they were designed for. To obtain a feel for the magnitude of the performance shift Table C-1 compares operating conditions of an oxygen/propane flow parameters to the Titan First Stage XLR-87-AJ-5 turbopump. A maximum turbine speed of 28,000 rpm was assumed to assess the upper speed capability of the current design. A speed of 27,500 rpm has been demonstrated as possible without cataclysmic failure although some parts were in distress as reported in Aerojet Report 0095-P025-1, 31 July 1971. The major areas of concern are noted briefly in the following paragraphs.

SPECIFIC SPEED

The potential for mechanical changes may quickly be assessed by determining the percent deviation from the "nominal engine balance" (NEB) flow rate to speed ratio conditions. Operation beyond ± 25% of the NEB flow rate to speed ratio can be considered to almost guarantee that some redesign will be required for structural or mechanical reasons in order to obtain the same degree of life and/or reliability from the turbopump. The pumps for oxygen/propane are less than 10 percent of NEB flow rate to speed ratios.

The 40 psia suction pressure required for the propane pump is slightly greater than the maximum experienced in the original Titan II flight service. Should this raise a stress problem it can be easily rectified by increasing the suction barrel wall thickness.

The discharge pressure of the oxidizer pump of the oxygen/propane engine is a few percent over the nominal NEB pressure but would probably not cause a stress problem by itself. The sub-ambient propellant temperatures could cause the aluminum pump housings to be deficient in elongation. However, this problem might be rectified by a change in material, design, heat treatment procedures or a combination of the three.

In summary, the pumps will probably require some changes, however, they are not considered major redesign.

GEARBOX

The gearbox might require some modification to accomodate the 26 percent additional power required of the oxygen pump of the oxygen/propane case. We know the gear set can take the power short term, but life would have to be confirmed by test for a much longer duration than the demonstrated, 193 seconds (1).

The gearbox will definitely require some sort of thermal isolation from the cryogenic propellants. For short durations isolation by low conductivity material can help reduce the heat loss to the colder pumps. Titan I practice employed the use of electric resistance heaters as a heat source for long holding durations.

TURBINE

The turbine power required for the oxygen/propane is 110 percent of design. This power results in turbine inlet pressures of 600 psia for an inlet temperature of 2000°R. Because this temperature is 110°F less than the original, there is believed to be little problem in converting the Titan III turbine. The original Titan III turbine inlet design pressure is 500 psia.

APPENDIX D

ABBREVIATIONS AND ACRYONYMS

ACE - Attitude Control System
AGE - Aerospace Ground Equipment
ALV - Airborne Launch Vehicle
AMD - Headquarters Aerospace Medical Division (AFSC)
AMST - Advanced Military Space Technology
AOTV - Aerobraking OTV
ASD - Aeronautical Systems Division
APU - Auxiliary Power Unit
C/C - Carbon-Carbon
CG - Center of Gravity
COTV - Cargo OTV
DARPA - Defense Advanced Research Projects Agency
DDT&E - Design, Development, Test and Engineering
DNA - Defense Nuclear Agency
DoD - Department of Defense
ELINT - Electronic-Intelligence
EC/LSS - Environmental Control and Life Support System
ELV - Expendable Launch Vehicle
EML - Electromagnetically Launched
EMP - Electromagnetic Pulse
EMU - Extravehicular Maneuverability Unit
EVA - Extravehicular Activity
GFE - Government Furnished Equipment
GPs - Global Positioning Satellite
GX - Acceleration in the x direction
HAL - Combined system of heads-up display, voice recognition and synthesis, Audio-visual and Logistics
IRAS - Infrared Astronomical Satellite
lbf - pounds force

lbm - pounds mass
LCC - Life cycle costs
L/D - Lift-to-Drag Ratio
LDEF - Long Duration Exposure Facility
LEO - Low earth orbit
LV - Launch Vehicle
MOTV - Manned OTV
MRRV - Maneuvering Reentry Research Vehicle
MTBF - Mean-time-between-failure
NEB - Nominal Engine Balance
OMS - Orbital Maneuvering System
ORU - Orbital Replacement Unit
OTV - Orbital Transfer Vehicle
PCE - Plug-Cluster-Engine
PHOTINT - Photo-Intelligence
psi - pounds per square inch
R&D - Research and Development
RMS - Remote Manipulator System
ROM - Rough Order of Magnitude
SDI - Strategic Defense Initiative
SFO - Space Flight Operations
SLRV - Shuttle Launched Research Vehicle
SP - Spaceplane
STAR - Spaceplane Technology and Research
STS - Space Transportation System
TCA - Terminal Crossing Angle
TPS - Thermal Protective System
TSE - Testing Support Equipment
TAV - Transatmospheric Vehicle