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ENTRY TECHNOLOGY PANEL

Volume IX of XI

OAST Space Technology Workshop

ENTRY TECHNOLOGY PANEL

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SUMMARY

OAST SUMMER WORKSHOP ENTRY TEHCNOLOGY WORKING GROUP REPORT

The Entry Technology working group surveyed the available inputs such as the 1973 NASA Mission Model, the Outlook for Space document, and various user requirements, and based on these made recommendations for technology advancements through the use of the Space Transportation System.

Two major objectives have been identified that will insure that the technology requirements will be achieved. These objectives deal with the establishment of heatshield and aerothermodynamic technology for (a) an Advanced Space Transportation System Heavy Lift Orbiter and (b) Hypersonic Atmospheric Entry Missions.

Two minor objectives were also identified and are (c) the development of an emergency astronaut "life boat" and (d) basic research in boundary layer transition.

Specific payloads are identified in the report supporting the major and minor objectives cited above. The majority of the payloads are shuttle based, however, a planetary entry payload to Jupiter is also suggested. The shuttle is to be utilized in three specific ways: First, as a payload deployment base for deorbit, secondly, through the use of the TUG or IVS, and thirdly the orbiter itself will be instrumented.

Recurrent themes are (1) the unsuitability of ground based testing due to the inability to simulate proper test conditions and the resulting need for space testing, and (2) the need for better mathematical models describing accurately and realistically the flow fields around complex structures.

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I. SUMMARY

The Entry Technology Working Group of the OAST Technology Workshop has surveyed the 1973 NASA Payload Model, the OSS Statement of New Technology Requirements, the Outlook for Space, results of studies carried out by the Entry Technology Study Team of the OAST Space Shuttle Technology Payloads Office and numerous other user requirements in order to make recommendations for technology advancements through the use of the Space Transportation System. It was found that the required technology advancements could be achieved by carrying out research within the two major objectives of establishing heatshield and aerothermodynamic technology for an advanced space transportation system (STS) heavy lift orbiter and for hypervelocity atmospheric entry missions.

The need for an advanced heavy lift orbiter was repeatedly emphasized in the Outlook for Space where it was pointed out that several highly desirable missions such as the space solar power station and nuclear waste disposal are feasible (from a cost standpoint) only if launch costs are significantly reduced by developing such a heavy lift orbiter. Furthermore, it was pointed out that many missions (such as those involving the assembly of large structures in space) which are feasible with the present shuttle, would be significantly benefited by an improved shuttle, a second generation shuttle or an advanced heavy lift orbiter.

Advancement of hypervelocity atmospheric entry vehicle technology is needed to allow increased payload fractions (scientific instrumentation) and broadened entry corridors for atmospheric probe, lander, and sample return missions. This need is particularly great for missions to the giant planets (Saturn, Jupiter, Uranus) where presently designed heatshields account for 30 to 50 percent of the total entry vehicle mass. Advancements in this technology area are also required to assure earth reentry survival of a nuclear waste capsule following a launch vehicle abort during a nuclear waste disposal mission. The working group has also identified the need for individual emergency entry capsule development (which would be particularly valuable for use with a space station such as that recommended in the Outlook for Space) and identified an opportunity to investigate the phenomena of boundary layer transition with small entry vehicles, carried as "piggy back" payloads and launched from the space shuttle.

Regarding the establishment of heatshield and aerothermodynamic technology for the advanced STS orbiter, the working group has identified five technology requirements and nine payloads to satisfy these requirements. With regard to hypervelocity atmospheric entry, six technology requirements and five payloads were identified. One technology requirement and one corresponding payload were identified for the individual emergency entry capsule and opportunity driven boundary layer transition research respectively. These technology

requirements and payloads are listed in Tables I and II. The interaction of the technology requirements and payloads is illustrated in Figure 1 where an "X" indicates the technology requirement to which each payload contributes. It should be pointed out that in selecting payloads, the working group only considered technology problems that could not be solved in ground based test facilities. Hence, for the payloads and corresponding technology requirements considered in this report, the alternative of solving the problem in ground based test facilities does not exist.

The Entry Technology working group recommends that the entry payloads definition studies be continued and that the technology requirements and payloads described in the present report be pursued in a manner which will result in technology readiness at the appropriate mission or project initiation date. In some cases these technology readiness dates are now known, however, many dates will not be established for some time. Further work and planning is required to determine a priority ranking for the several payloads in light of available resources, both funding and manpower.

TABLE I. Entry Technology Requirements

Mission Driven

(1)	Advanced STS Orbiter	5
	Advanced STS Configuration Improved Thermal Protection Systems (TPS) Improved Mathematical Models for Complex Real Gas Flowfields and Ground-to-Flight Extrapolation Advanced Structures Boundary Layer Transition Criteria	
(2)	Hypervelocity Atmospheric Entry	7
	Planetary Entry Probe Heatshield and Configuration Nuclear Waste Disposal Package Radiative Flow Field Models Planetary Sample Return Heatshield and Configuration Manned Planetary Return Heatshield and Configuration Planetary Bouyant Station Deployment Flight Demonstration: RGT Heat Source Survival	
(3)	Individual Emergency Entry	1
	Astronaut Retrieval	
	TOTAL	13

Opportunity Driven

Basic Research	1
Prediction of Boundary Layer Transition	
TOTAL	1

TABLE II. Candidate Flight Payloads

(1)	Advanced STS Orbiter	9
	<u>Orbiter</u>	
	Air Data System	
	IR Camara-Lee/Windward Heating	
	Instrumented Test Panels	
	Catalytic Surface	
	Boundary Layer Transition Measurement System	
	Deployed Payloads	
	Advanced STS Configurations	
	Integral Tank Configurations	
	Advanced TPS Concepts	
	Advanced Hypersonic Cruise Vehicle Configurations	
(2)	Hypervelocity Atmospheric Entry	5
	Entry Probe	
	Nuclear Waste Disposal Package	
	Lifting Body Entry Vehicle	
	Bouyant Station	
	RTG Heat Source	
(3)	Individual Emergency Entry	1
	Astronaut Retrieval	
(4)	Basic Research	1
	Boundary Layer Transition	
	<u>TOTAL</u>	<u>16</u>

II. INTRODUCTION

The successful accomplishment of many future planned NASA missions is dependent on the ability to achieve safe atmospheric entry. The advanced space transportation system will be required to be an efficient light weight vehicle in order to reduce costs. The planetary exploration program incorporation of atmospheric entry probes requires safe entry of the carrier before any measurement of the atmosphere can be made.

Possible missions of the future have been elaborated in the 1973 NASA Mission Model, the Outlook for Space, the OSS Mission Model, and the users requirements. Some of these needs have previously been addressed by OAST.

The OAST Entry Technology 5 year plan activity is an annual "round robin" of all NASA centers participating in entry technology. The output of this coordinated activity is a document which outlines the current state of the art of available technology and indicates plans for the next 5 years. The working group compared the needs dictated by future missions with available technology in the OAST Entry Technology 5 year plan and identified technology requirements. These technology requirements were grouped into categories and two major objectives were formulated to focus future activity. The main objectives are to establish heatshield and aero-thermodynamic technology for (1) the Advanced STS Orbiter, (2) Hypervelocity Atmospheric Entry. Two additional minor objectives were identified and will be discussed in the main body of the report. The relation of the main objectives to the mission needs will be outlined below. However, before doing that it is significant to point out the previous output and activity of the entry working group.

Under the shuttle payloads office, experiment definition work has been conducted over the last two years by members of working groups. This work resulted in two studies: (1) an Advanced Shuttle Payload Sizing Study and (2) a Planetary/DOD Entry Technology Flight Experiments Study. The reasons for pointing out this previous activity are: (1) the working groups output will reflect many Phase C/D activities which are based on previous definition studies, and (2) the output will reflect the reaction to our activity by the RTAC (Space Vehicles)--namely, the RTAC endorsed the concept of utilizing the orbiter itself as a test bed.

The opportunity to develop entry technology in the space environment removes the most significant disadvantage of ground testing; that is, the inability to simulate the proper test conditions. To utilize space properly is a challenge. It is incumbent on the Entry Working Group to point out how the previously formulated objectives relate to future mission needs.

From the Outlook for Space, the OSS Mission Model, and the OAST Entry Technology 5 year plan, five technology requirements were identified relating to Hypervelocity Atmospheric Entry vehicle performance in severe radiative heating (the radiation arises from the shock layer in front of the entry probe). The development of the available technology has been hampered by the inability to simulate the radiative flow field in the laboratory about an ablating body of sufficient size and free stream velocity. Attainment, utilizing space of the objective of establishing heatshield and aerothermodynamic technology of hypervelocity atmospheric entry would establish a technology base to insure reliable atmospheric entry probe to carry out the desired missions.

The other major objective is establishing heatshield and aerothermodynamic technology for the Advanced STS Orbiter. This was formulated by identifying five technology requirements from the Outlook for Space and the OAST Entry Technology 5 year plan. The underlying technology driver for these five technology requirements is the need to model accurately and realistically the flow fields around a complex structure such as the shuttle where vortex roll-up, separation, and boundary transition are significant. The accurate modeling is needed to predict the aerodynamic behavior and heating distribution because of the inability to accurately extropolate to flight conditions the ground based data. There again, the opportunity to develop technology in space by verifying the modeling on the present orbiter eliminates the ground simulation problem. Attainment of the objective would establish a technology base to permit design of an efficient Advanced STS Orbiter, as well as optimize the present orbiter's performance.

This approach to accomplish the stated objectives utilizes the shuttle in three specific ways: First it a payload deployment for deorbit; second uses the IUS or TUG, for high energy entry; thirdly, the orbiter itself will be instrumented with possibly some instrument support equipment in the payload bay. This third way is consistent with the RTAC recommendation.

In this introduction the inputs and the source of the available technology were identified. The two major objectives encompassing the technology requirements were formulated and the relation of these objectives to the needs were outlined. Also, the previous activities of the members of the working group were mentioned.

III. TECHNOLOGY REQUIREMENTS

A. MISSION DRIVEN

1. ADVANCED SPACE TRANSPORTATION SYSTEM (STS) ORBITER

Throughout the Outlook for Space study, a recurrent theme appears--the need to develop a heavy lift orbiter capable of transporting larger payloads to low earth orbit at lower cost. There are some missions such as the space solar power station and nuclear waste disposal that are possible (from a cost standpoint) only if such an advanced orbiter is developed. Even some missions that are considered to be feasible with the present shuttle, would be significantly benefited by an improved shuttle, a second generation shuttle or an advanced heavy lift vehicle. One of the largest barriers to the design of more efficient (and hence lower cost) orbiters is our inability to adequately simulate entry flight conditions in ground based test facilities and the current uncertainties involved in extrapolating ground test results to flight conditions. As will be described in the discussions of proposed payloads presented in a subsequent section of this report, the use of the space shuttle to obtain entry flight data can contribute significantly to the removal of this barrier.

If systems capable of carrying larger payloads at lower cost per unit mass are to be realized, configurations of maximum efficiency must be defined and lower weight, less expensive, more reusable heatshields must be developed. Advanced structural concepts such as integral tanks and load carrying heatshields must be demonstrated under realistic entry flight conditions. The mathematical models used to calculate details of the heating and the real gas flow fields surrounding the orbiter, and to extrapolate wind tunnel data to flight conditions, must be validated by comparison with flight data so that less conservative designs having smaller margins of safety can be realized. Finally, the longstanding problem of accurately predicting boundary layer transition takes on increased importance because of the large size of several advanced orbiter concepts. These technology requirements are described in more detail below.

a. Advanced Space Transportation System (STS) Configurations

Numerous studies, such as that described in the Outlook for Space Forecast of Space Technology, have shown that launch costs ($/kg) can be significantly reduced by developing larger orbiters utilizing a variety of advanced concepts. There is, however, no unanimity of opinion regarding the most efficient configuration for these heavy lift orbiters. Both ballistic and airplane-like lifting configurations have been proposed. If the advanced heavy lift orbiter is to achieve the lowest possible launch costs, the most efficient configurations, consistent with mission constraints, must be determined. While much valuable information can be obtained from analytical and ground based experimental programs, there are significant uncertainties involved in predicting actual flight performance from the resulting data. What is required is to carry out entry flight tests, for a family of candidate configurations in order to define the one having maximum efficiency.

b. Improved Thermal Protection Systems (TPS) for Advanced STS and STS

Advanced heavy lift orbiters, capable of achieving significantly reduced launch costs require thermal protection systems that are genuinely reusable and that are lighter and less expensive than that used on the present shuttle orbiter. Actually, a number of attractive thermal protection system concepts have been developed as part of the shuttle technology program, but were not selected for the present shuttle because it was felt that they involved technological risks greater than those associated with the RSI tile/carbon-carbon system. What is required is flight test data that will demonstrate the capabilities of the various concepts in an actual entry environment and will allow the use of less conservatism in design and hence the achievement of lighter weight thermal protection systems.

c. Advanced Structures

It is estimated that the development and flight qualification of advanced structural concepts such as bead stiffened panels, integral tankage and integral thermal protection systems could lead to a structural weight reduction of up to 40% for an advanced heavy lift orbiter. The key requirement here is flight qualification. Many of these concepts cannot be adequately tested in ground based facilities because of incomplete simulation capability and size limitations. Furthermore, many of the most efficient of the new structural concepts will not be seriously considered for use on a manned vehicle until they have been demonstrated in an actual entry flight environment.

d. Improved Mathematical Models for Complex Real Gas Flowfields and Ground-to-Flight Extrapolation.

In the Outlook for Space, the need for improved mathematical modeling techniques was emphasized. Even the most complete and accurate collections of experimental data are much more meaningful when interpreted by means of an accurate mathematical model. There is a synergistic effect that causes the combination of a mathematical model and experimental data to be more valuable than either is alone. At present, several sophisticated flow field models have been developed for shuttle-like vehicles, but none of these are capable of accurately describing all the important details of these complex flowfields and their associated aerodynamic loads and heating distributions. The approach that appears to be most promising is to obtain entry flight data on the present shuttle orbiter, compare these data with predictions from the best available models, improve the models until they are capable of predicting the flight results and then use the improved models in designing advanced space transportation system orbiters.

e. Improved Boundary Layer Transition Criteria.

While boundary layer transition is a phenomena that may well be included in the flow field models mentioned above, it is of such importance in the design of advanced orbiters that it deserves mention as a separate Technology Requirement. While transition is a significant design consideration for the present shuttle orbiter, the percentage of the shuttle surface expected to experience turbulent flow is relatively small (from 0 to 30% depending on the transition used). Because of the large size of the advanced heavy lift orbiter, a much larger portion of the vehicle surface may experience turbulent heating. Accordingly, it is imperative that accurate boundary layer transition criteria be used in designing these vehicles. An uncertainty of an order of magnitude in boundary layer transition criteria (about the present state of the art) would not severely impact the present shuttle design but could concievably more than double the required heatshield weight for an advanced orbiter. Since boundary layer transition is really understood only in an empirical sense, transition criteria tend to be "configuration dependent." Hence, to be useful in designing an advanced orbiter, the transition criteria should be determined for vehicles having shapes, sizes and flight conditions as close as possible to those of the advanced vehicle. Of all the presently possible data sources, entry flight tests of the present shuttle orbiter (with special instrumentation) appear to be by far the best choice.

2. HYPERVELOCITY ATMOSPHERIC ENTRY

In order to establish heatshield and aerothermodynamic technology for Hypervelocity Atmospheric Entry, seven technology requirements have been identified. These technology requirements are:

(a) Planetary Entry Probe Heatshield and Configuration
(b) Nuclear Waste Disposal Package
(c) Radiative Flow Field Model
(d) Planetary Sample Return Heatshield and Configuration
(e) Manned Planetary Return Heatshield and Configuration
(f) Planetary Bouyant Station Deployment
(g) Flight Demonstration of RTG Heat Source Survival

All of these requirements have been addressed in past in-house and contractor studies within NASA. Since these requirements are related to past Earth entry practice within NASA and DOD, a state-of-the-art technology assessment would reveal these disciplines to be well advanced, however there is no experience at this time with entry into planets other than Earth, Past Earth entry experience is at speeds less than that proposed at the giant outer planets, or for planetary return missions. The underlying phenomenom of intense radiative excitation of gas molecules and atoms at the high entry velocities seem to tie all of these Technology Requirements together under one heading, Hypervelocity Atmospheric Entry. The exception in this grouping is the Planetary Bouyant Station Deployment requirement which is concerned with the aerodynamic, and structural response of a parachute/balloon system during high speed entry and deployment.

a. Planetary Entry Probe Heatshield and Configuration

A heatshield and configuration for an outer planet probe must be developed and tested within the next decade. Prior heatshield and configuration experience provides a starting point upon which to develop a new system capable of withstanding up to 75 kw/cm^2 of radiative heating upon entry to the planet Jupiter. There has been no experience with heatshields designed to accomodate radiative heating rates of this magnitude. A blative/reflective dialectric material heatshields offer superior potential to those of graphite or carbon phenolic materials; however, there has been no practical experience with these reflecting heatshields. Small samples of material may be tested in plasma-arc facilities, and heatshields may be constructed according to these results, however large test data uncertainties may result in excessive heatshield material requirements for the Jovian Entry Probe Mission. Space flight model tests in Earth's atmosphere will reduce these uncertainties and make design of mission hardware acceptable. Such tests can be conducted via full scale vehicles launched from the shuttle orbiter by the Interim Upper Stage or similar propulsion systems.

b. Nuclear Waste Disposal Package

An entry package to serve to protect Nuclear Waste in the event of an inadvertent entry must be developed and tested. A NASA study (TM-X-2911) had concluded that transporting radioactive waste (primarily long-lived isotopes) into space is feasible. Possibly more than 100 STS launches per year will be required for this purpose by the year 2000.

Currently radioactive therionic generators used on some spacecraft have been packaged for inadvertent entry, but these are very light systems compared to the 3000 kg nuclear waste package. **Direct solar system escape requires an 8.75 km/s** increment in velocity over Earth escape. With this amount of momentum available, an inadvertent Earth entry survival becomes a formidable problem. A packaging design concept has been evolved that appears on a qualitative basis to provide protection against the radioactive waste in accident environments. The concept however, does need a follow-up experimental program and safety assessment to establish a system design. The utilization of the shuttle to launch such test package is considered a cost effective test approach.

c. Radiative Flow Field Models

Improving the radiative transport predictions in non-equilibrium, non-adiabatic flow fields about ablating heatshields constitutes the substance of this Technology Requirement. At this time radiative transport may be accurately predicted for flow conditions which are in thermo-chemical equilibrium and have little or no ablation. Radiative flow field modeling technology is concerned with predicting the transport of mass, momentum and energy throughout a high temperature gas dynamic flow. The detail measurement and calculation of chemical species, density, temperature, velocity, radiative absorption coefficient, and relaxation rate is critical to arriving at a satisfactory numerical prediction model.

All of the past work can be brought to fruition only through formulation and verification of radiative transport predictions in non-equilibrium, non-adiabatic flow fields about a massively ablating Earth entry probe space flight test. Such an environment can be created utilizing vehicles launched from the shuttle by the IUS or similar propulsion systems.

d. Planetary Sample Return Heatshield & Configuration

Entering the Earth's atmosphere with Mars, Venus, Mercury, Titan, comet, or asteroid samples require an atmospheric entry probe configuration with a heatshield and structure capable of withstanding over 20 kw/cm^2 of radiative heating in addition to substantial convective heating. Configurations must be selected, analyzed and tested. Candidate materials must be selected and subjected to this entry environment in order to design the most efficient heatshield for these extraordinary missions. Ablative/ reflective dielectric heatshields may perform most efficiently for these applications.

Since these sample return probes are to be carried from Earth to another solar system body and return at great expenditure of energy per unit mass, it is imperative that the heatshield design be as efficient and of as low a mass fraction as practically possible so as to make these missions technically feasible. The technology required to design the Planetary Sample Return Heatshield is closely allied with that required to design the Planetary Entry Probe Heatshield and Configuration. This technology can be best developed through shuttle launched flight tests.

e. Manned Planetary Return Heatshield and Configuration

We must develop a heatshield and configuration to survive a manned Earth entry at speeds over 15 km/s. Manned return from the Moon at speeds to 11 km/s has been demonstrated. When returning from planets with men aboard, an entry vehicle must have means to control the angle of attack and trajectory in order not to exceed the acceleration limits of the crew. Flying at an angle of attack with a low-ballistic coefficient entry vehicle necessitates an investigation differing from unmanned applications. The heatshield design must be compromised by a configuration which allows the necessary flight conditions. Systems such as ablative/reflective heatshield materials or carbon phenolic materials in large arrays will have to be developed for this application.

A Manned Planetary Return Vehicle must be developed for the post 2000 time period to correspond with renewed manned exploration of the solar system. Since flights to other planets and asteroids are especially mass limited, means to combine the heatshield with the entry vehicle structure must be found. Considerable effort must be taken to find a configuration which satisfies the manned constraints and at the same time allows a low-mass heatshield structure.

Considerable uncertainty exists in predicting the magnitudes of radiative flux on the surface of such a large vehicle. Uncertainty in the boundary layer transition criteria must be reduced and a configuration which allows lift modulation without excessive heat flux must be found. The shuttle payload and launch capability provides the most cost effective test approach for obtaining the required technology.

f. Planetary Bouyant Station Deployment

In the terminal maneuver of a planetary entry probe carrying a planetary bouyant station, the science platform and communications station must be deployed with bouyant support. This technology requirement addresses the problem of developing a bouyant system capable of prompt deployment during a high speed free-fall. A system of retarding and erecting devices must be devised and experimentally evaluated.

The surface conditions of some planets are hostile for long term, or even short term survival, therefore a means to float within the atmosphere is necessary for long term planetary science measurements.

A great deal of difficulty is encountered in ground launching bouyant science platforms on earth even in the best weather conditions--a considerable advancement is required to launch a bouyant station from a high speed entry probe.

The only way such a bouyant station deployment system can be perfected is through a series of designs and tests culminating in space flight tests within the earth's atmosphere. The shuttle orbiter can provide the launch platform for such flight tests.

Bouyant station designs have been proposed and these designs should be investigated initially. Materials and structures may be subjected to environmental tests expected at the planets.

g. Radioisotope Thermoelectric Generator (RTG) Heat Source Survival

Whenever a spa~e vehicle carrying radioactive materials is launched into or beyond earth orbit, the possibility of exposing people to harmful radiation in the event of a entry following a launch vehicle malfunction becomes a serious consideration. The radioactive materials of concern are usually contained in the heat sources of the radioisotope thermoelectric generators (RTG) that provide electric power for the spacecraft. Whenever a spacecraft carrying an RTG is launched, an in-depth reentry safety analysis is carried out by an interagency (NASA, ERDA, DOD) nuclear safety review panel to dete~mine that the safety risks associated with the launch are acceptable. In every mission that has been studied in recent years (Pioneer, Viking, LES 8/9) it has been found that the uncertainties in the present state of the art are so large that survival of the RTG heat source during high velocity, steep (≈ 36,000 ft/sec,-30°) entries cannot be proved. Accordingly, heat source failure and release of the plutonium fuel to the atmosphere had to be assumed for all such entries. Fortunately, for all these missions, the probability of malfunctions leading to such high velocity entries was so low that the risks were deemed acceptable. It is, nonetheless, highly desirable to develop entry technology to the point that heat source survival can be definitely proven for all entries. The key technology issue is thermal stress failure of the heat source aeroshell which is usually made of graphite. What is required is an entry flight test that will expose an actual heat source with a fuel simulant to realistic entry conditions. Exhaustive studies and tests have shown conclusively that the required test conditions cannot be produced in ground test facilities and can only be obtained through a full scale flight test. Thus far, the high cost of such a flight test has prevented its being carried out. Initial studies have indicated that a suitable entry vehicle may be carried as a "piggy back" payload on a Shuttle/Spacelab flight and this may bring the cost down sufficiently to make such a test feasible.

3. INDIVIDUAL EMERGENCY ENTRY

Astronaut Retrieval

Numerous studies, including the Outlook for Space and OMSF Advanced Mission Concept Studies, have defined the practicality and desirability of manned earth orbiting space stations. Crew size range from 3-15 for near term stations. Additionally the present STS missions (of from 7 to 30 days) will have crews of up to seven persons. One of the primary objectives of each of these missions will be the safe return to earth of the personnel. Normal ferry service will be provided by the STS orbiter but provision must be made to provide safe return to earth in an emergency situation when the orbiter is not or cannot be made available.

The design and development of an astronaut "life boat" which can, in an emergency, return space station personnel to earth is within the state of the art. The STS provides a flight verification and qualification capability which heretofore has not existed. The development of a light weight, compact, stowable, man rated entry system can be accomplished utilizing STS flights to evaluate candidate system performance in an actual flight environment. These test flights could be conducted in a piggy back mode, thus minimizing one more confidence factor to one ability to safely return space personnel.

B. OPPORTUNITY DRIVEN

a. Boundary Layer Transition

The Entry Technology working group has identified an opportunity driven technology requirement to obtain fundamental boundary layer transition data which is free of ground facility effects.

The subject of boundary layer transition has long been recognized as one of the most important fundamental problems in aerothermodynamics, and much effort has been devoted to its study. In spite of this, present techniques for predicting transition for hypervelocity vehicles are only accurate to within an order of magnitude. Numerous recent investigations indicate that aerodynamic noise, present in most wind tunnels, greatly affects the flow conditions (Reynolds number, Mach number, etc.) under which transition occurs in those facilities. Hence, transition criteria defined in typical wind tunnels are dominated by "facility effects" and may bear little or no relation to flight. While transition data obtained from ballistic ranges appears to be largely free of facility effects, the small models used in such tests prohibit the study of many significant phenomena such as realistic surface roughness. New "quiet" tunnels are being developed, but data obtained from them needs to be validated by comparison with truly "facility-effect-free" data and such data can only be obtained from flight tests. While some flight transition data has been obtained, high costs have presented the collection of large bodies of flight data except for restricted classes of configurations (primarily cones) typical of DOD missions.

The existence of the space shuttle and the large number of missions projected for the shuttle provide an unprecedented opportunity to obtain a large body of flight boundary layer transition data by carrying small "piggy back" entry vehicles on shuttle flights for which the prime payload does not use the full shuttle payload capacity. Such "piggy back" payloads could hopefully be carried out at relatively low cost and would provide flight transition data on a range of fundamental aerodynamic shapes (spheres, cylinders, flat plates, etc.). The resulting basic data would be of great value for basic fluid mechanics in general and hypersonic aerothermodynamics in particular.

TECHNOLOGY REQUIREMENTS → / PAYLOADS ↓	ADVANCED STS CONFIGURATION	IMPROVED THERMAL PROTECTION SYSTEMS	IMPROVED MATHEMATICAL MODEL EXTRAPOLATION PREDICTIONS	ADVANCED STRUCTURES	BOUNDARY LAYER TRANSITION CRITERIA
ORBITER (CARRIER)					
AIR DATA SYSTEM	X	X	X		X
IR CAMERA-LEE/WINDWARD HEATING	X	X	X		X
INSTRUMENTED TEST PANELS	X	X	X		
CATALYTIC SURFACE		X			
BOUNDARY LAYER TRANSITION MEASUREMENT SYSTEM	X	X	X		X
DEPLOYED PAYLOADS					
ADVANCED STS CONFIGURATION	X		X		
INTEGRAL TANK CONFIGURATIONS	X	X		X	
ADVANCED TPS CONCEPTS		X			
ADVANCED HYPERSONIC CRUISE VEHICLE CONFIGURATIONS	X		X		X

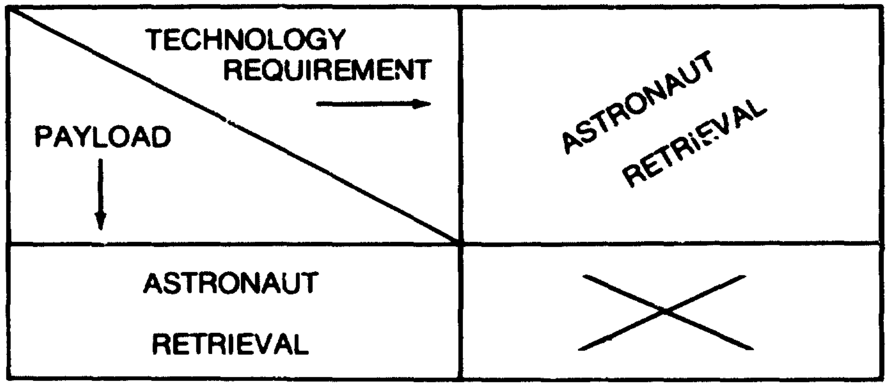
(a) Heatshield and aerothermodynamic technology for advanced STS orbiter

Fig. 1: RELATION OF ENTRY TECHNOLOGY PAYLOADS TO TECHNOLOGY REQUIREMENTS

TECHNOLOGY REQUIREMENTS → / PAYLOADS ↓	PLANETARY ENTRY PROBE HEATSHIELD AND CONFIGURATION	NUCLEAR WASTE DISPOSAL PACKAGE	RADIATIVE FLOW FIELD MODELS	PLANETARY SAMPLE RETURN HEATSHIELD AND CONFIGURATION	MANNED PLANETARY RETURN HEATSHIELD AND CONFIGURATION	PLANETARY BOUYANT STATION DEPLOYMENT
ENTRY PROBE	X	X	X	X	X	
NUCLEAR WASTE DISPOSAL PACKAGE	X	X	X	X	X	
LIFTING BODY ENTRY VEHICLES	X		X		X	
RTG HEAT SOURCE	X	X	X			
BOUYANT STATION						X

(b) Heatshield and aerothermodynamic technology for hypervelocity planetary atmospheric entry.

Fig. 1: RELATION OF ENTRY TECHNOLOGY PAYLOADS TO TECHNOLOGY REQUIREMENTS. (cont.)



(c) Heatshield and aerothermodynamic technology for individual emergency entry.

(d) Opportunity driven basic research

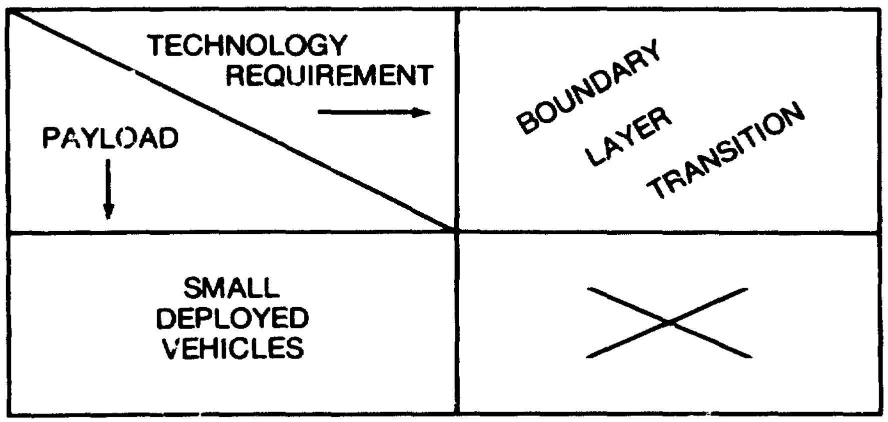


Fig. 1: RELATION OF ENTRY TECHNOLOGY PAYLOADS TO TECHNOLOGY REQUIREMENTS (cont.)

IV. PAYLOADS

A. FOR MISSION DRIVEN TECHNOLOGY REQUIREMENTS

1. ADVANCED STS ORBITER

a. Space Shuttle Orbiter Payloads

1. Air Data System (ADS)

The accuracy of any solution relative to a vehicle's aerodynamic and aerothermal performance is based on the accuracy of knowing vehicle altitude and free stress environment. Such information is required to define local flow field parameters such as pressure, temperature, heating rates, etc. as well as the aerodynamic performance of the vehicle. The required state data can and should be obtained on the STS orbiter to aide in the definition of problems associated with the Technology Requirements dealing with:

1. Advanced STS configurations
2. Models
3. Improved TPS, and
4. Boundary layer transition.

To obtain the necessary data an Air Data System should be installed on the orbiter to obtain stagnation region pressure and temperature levels and distribution. From this data freestream dynamic pressure can be obtained as well as α and β. The ADS data in conjunction with local measurements to be provided by Instrumented Panels (Payload #3) will provide data necessary to resolve many aerodynamic and aerothermal problems related to the Technology Requirement listed above.

A proposed ADS is depicted in Figures 2, 3, 4 which show the instrumented carbon-carbon nose cap concept. The ADS design is presently in the definition stage; with on-going studies relative to instrumentation techniques, carbon-carbon instrumentation compatibility, and accuracy of candidate data sensors. Continued studies, detail design analyses and ground tests of candidate instrumentation concepts are planned.

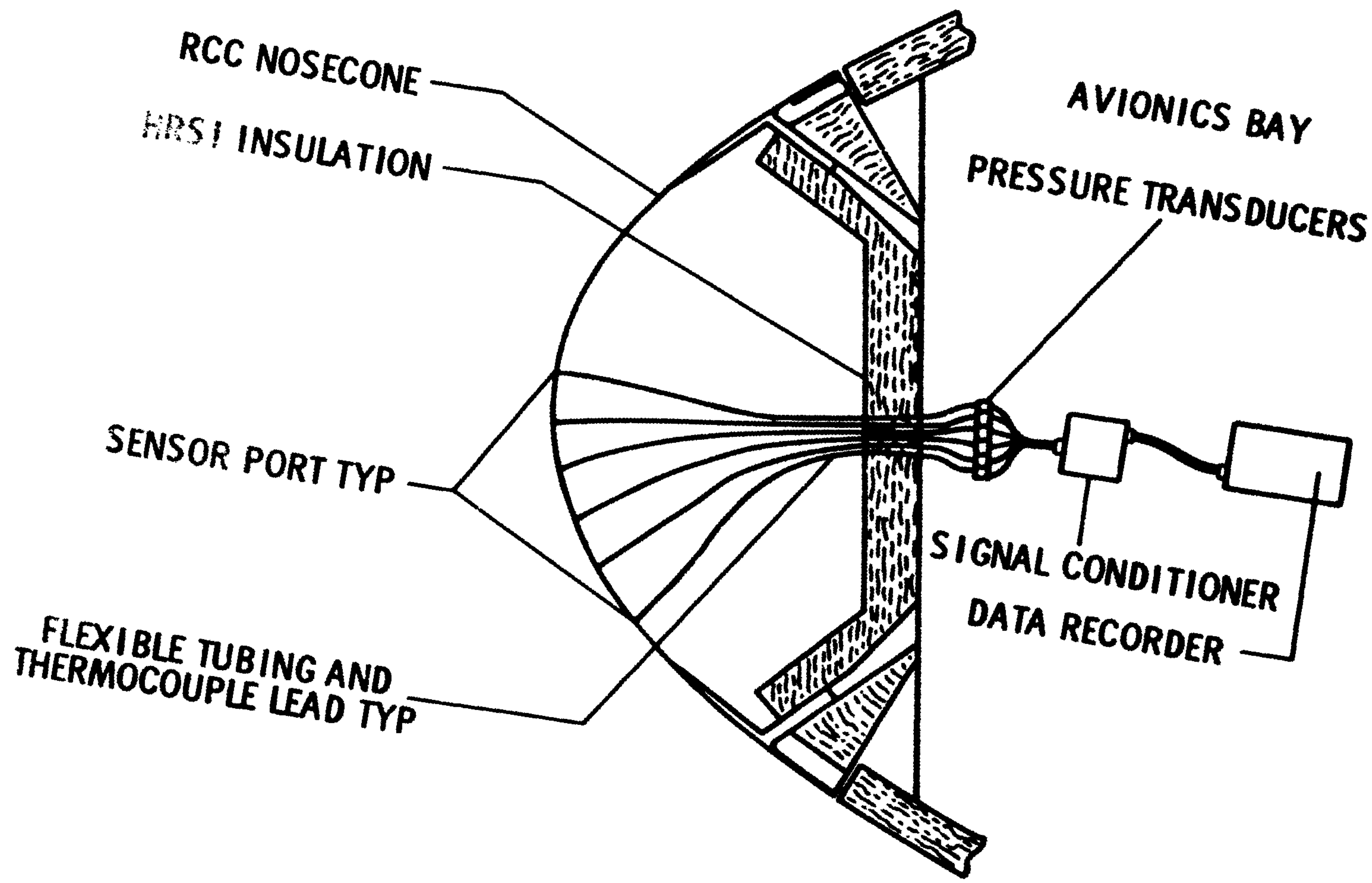


Fig. 2: CANDIDATE AIR DATA SYSTEM CONFIGURATION

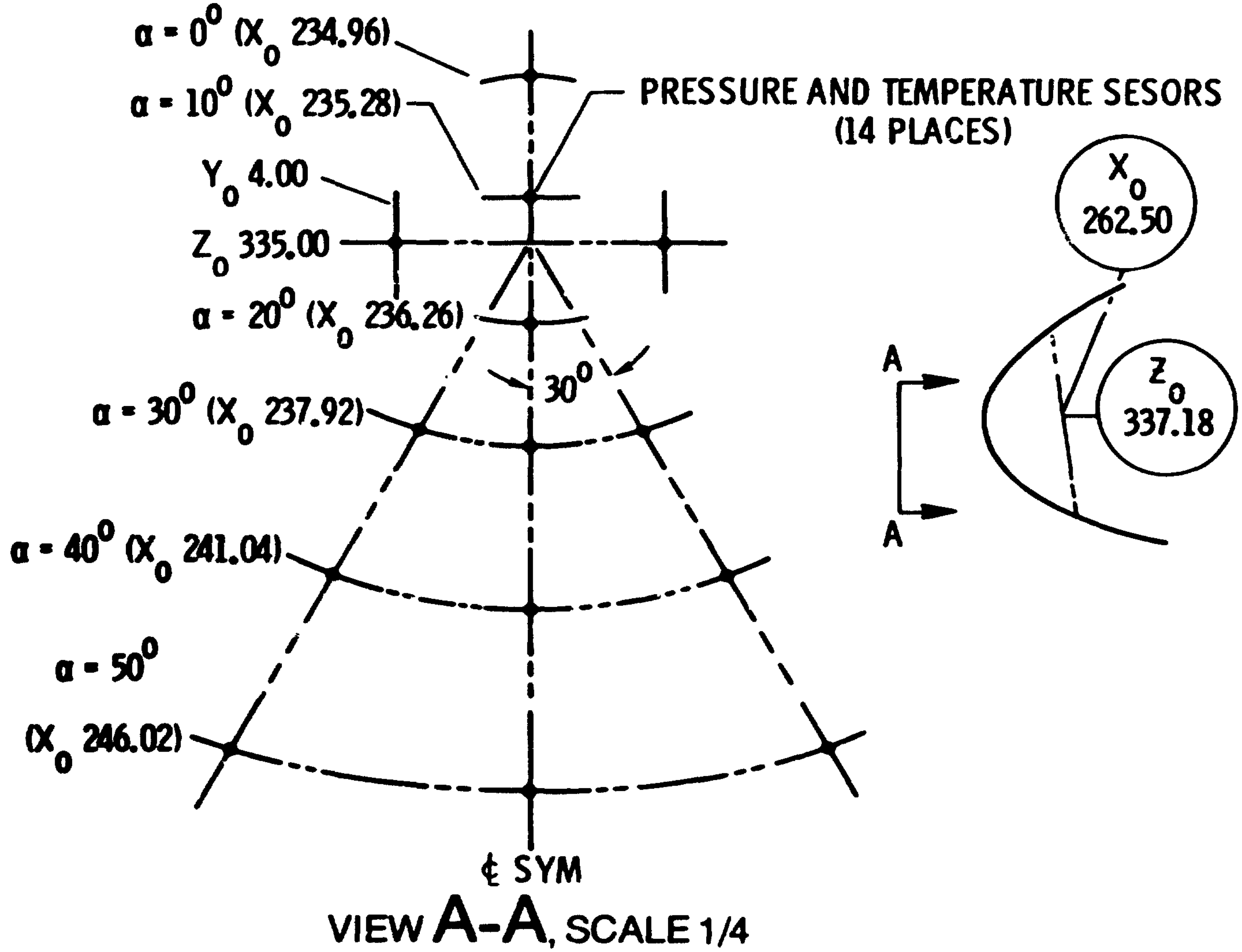


Fig. 3: CANDIDATE AIR DATA SYSTEM SE :SOR ARRAY

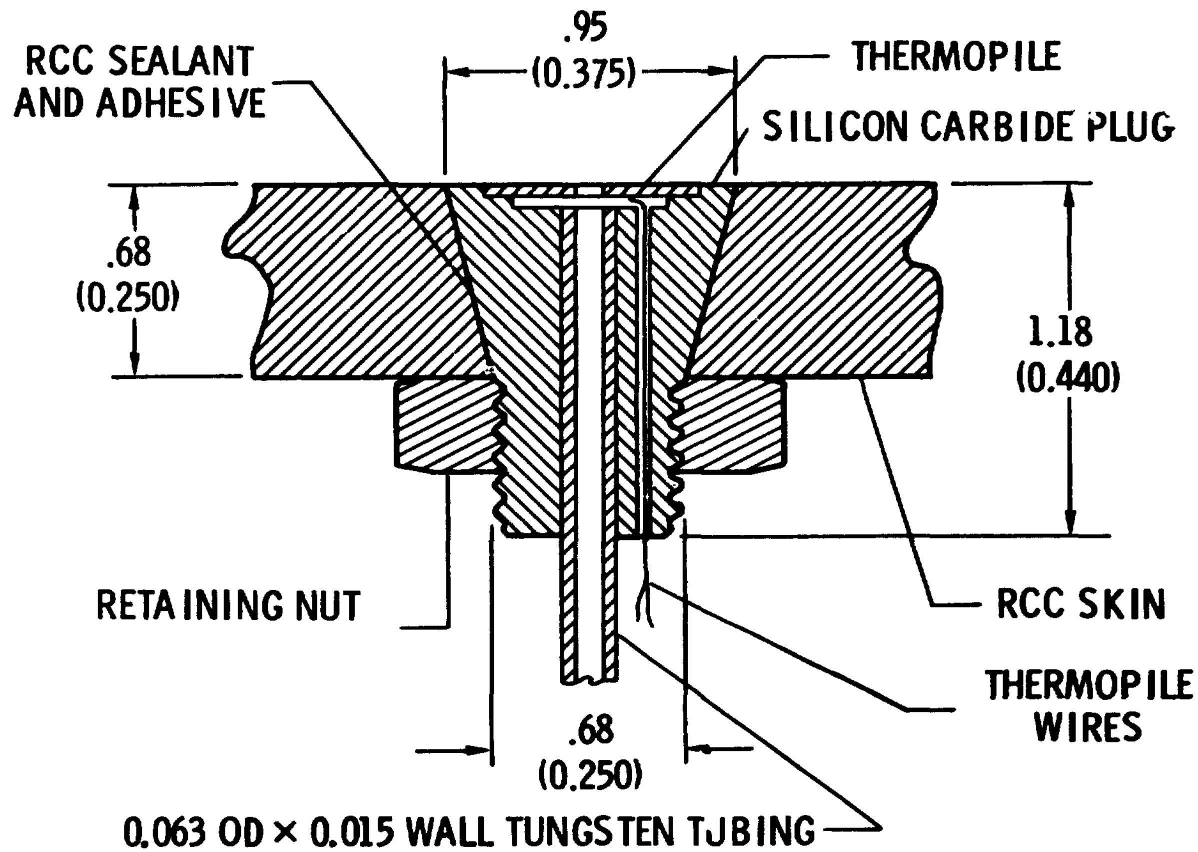


Fig. 4: CANDIDATE AIR DATA SYSTEM SENSOR

(2) IR Camera-Lee/Windward Heating

The definition of accurate heating levels and rates on the STS orbiter during entry is necessary to define preferred geometry and to reduce the weight and cost of the thermal protection systems on advanced STS configurations as well as the present orbiter. The purpose of this payload is to verify in a flight environment flow field ground test and modeling techniques, to establish highly accurate extrapolation parameters and provide data relative to boundary layer transition and the effects of geometric discontinuities. A technique capable of providing the data necessary to define leeside heating combines reference surface temperature measurements and a scanning Infra Red (IR) camera. The IR camera (Fig. 5) which would be mounted in the vertical tail (Fig. 6) while supporting systems (power supply, data recorder, etc) would be tail or payload bay mounted. This payload would provide the data required for a quick comprehensive (See Fig. 7 area coverage of side mount) assessment of the leeside heating on the orbiter to allow near term retro fit of a more appropriate TPS. In addition, this data would be used in the development of anayltical prediction technique which would allow for the optimized design of future systems.

To supplement the leeside data, an IR telescope mounted in a high altitude chase plane could provide qualitative data relative to the heating levels on the windward surfaces as well as identify transition and regions of separated flow requiring more detailed surface instrumented studies. The chase plane IR data would also provide an early comprehensive assessment of orbiter entry heating levels and identify any significant problem areas.

The incorporation of both of these payloads into early STS flights (development) is highly desirable to impart scheduled vehicle retro-fit schedules. The early input of such data into advanced system studies is also important to identify design options relative to geometry, weight and cost.

The orbiter mounted IR camera concept is in the definition design phase which must be continued to identify the most technically feasible concepts and cost.

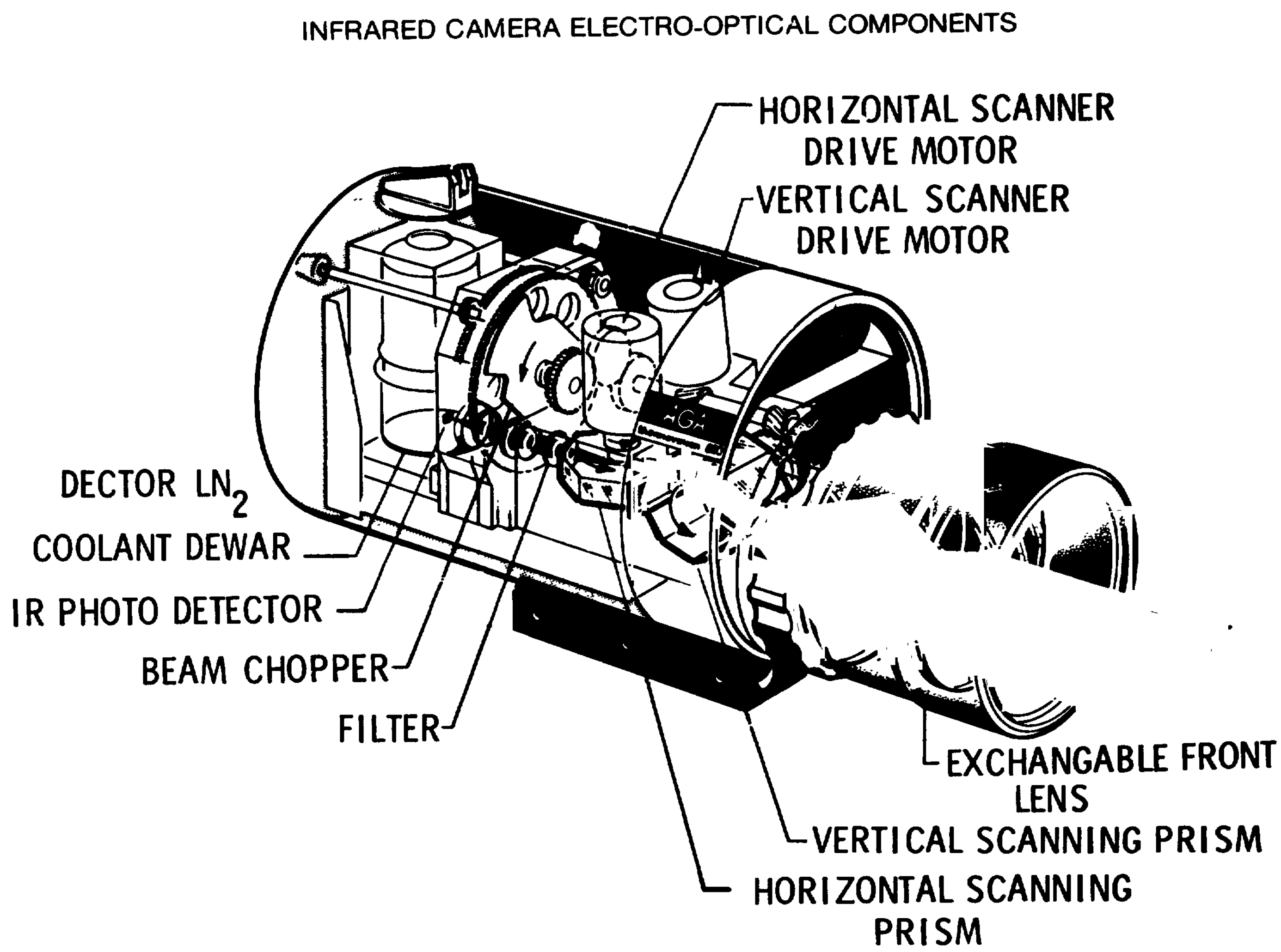


Fig. 5: CANDIDATE INFRARED CAMERA

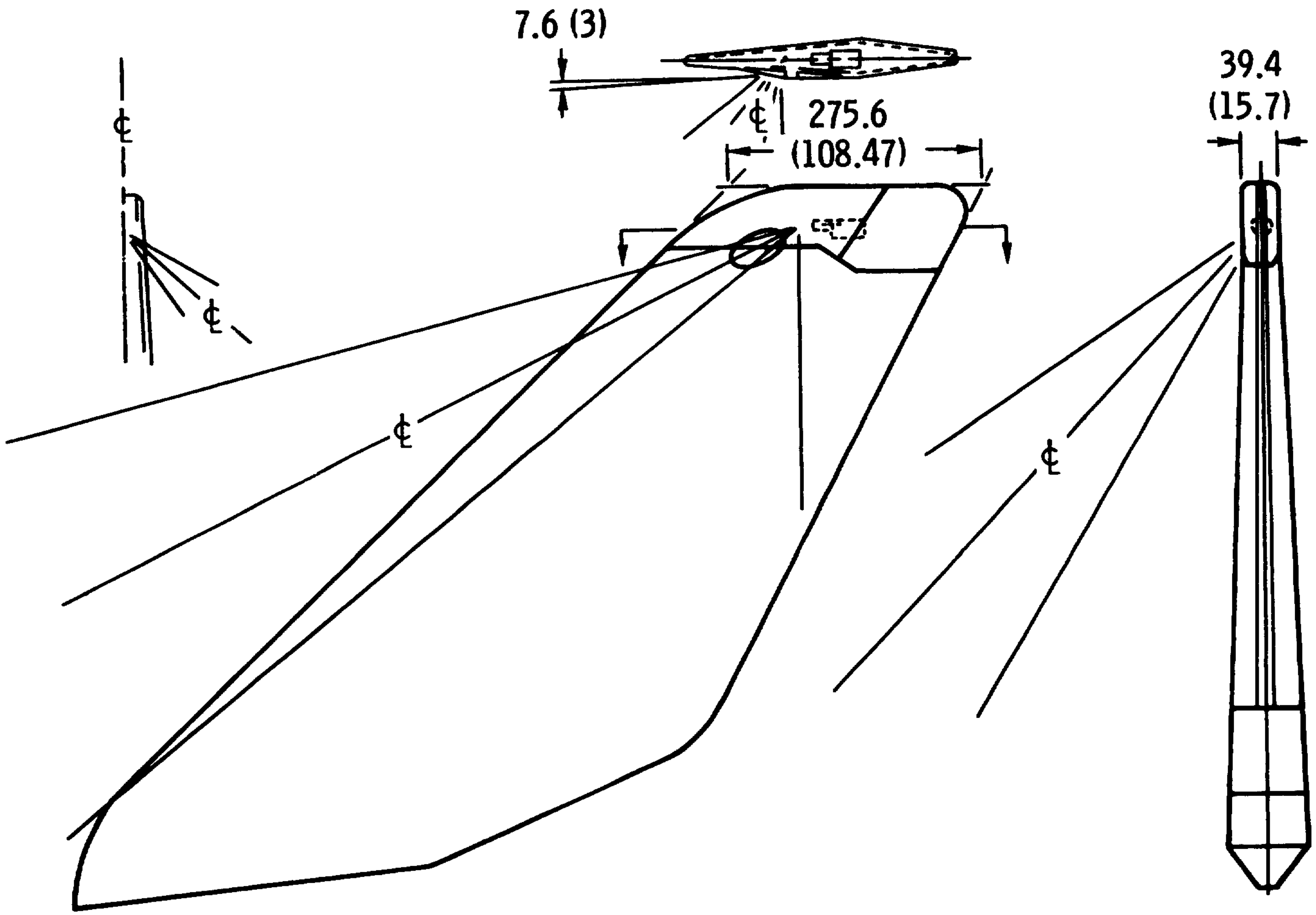


Fig. 6: INSTALLATION SIDE MOUNTED IR CAMERA

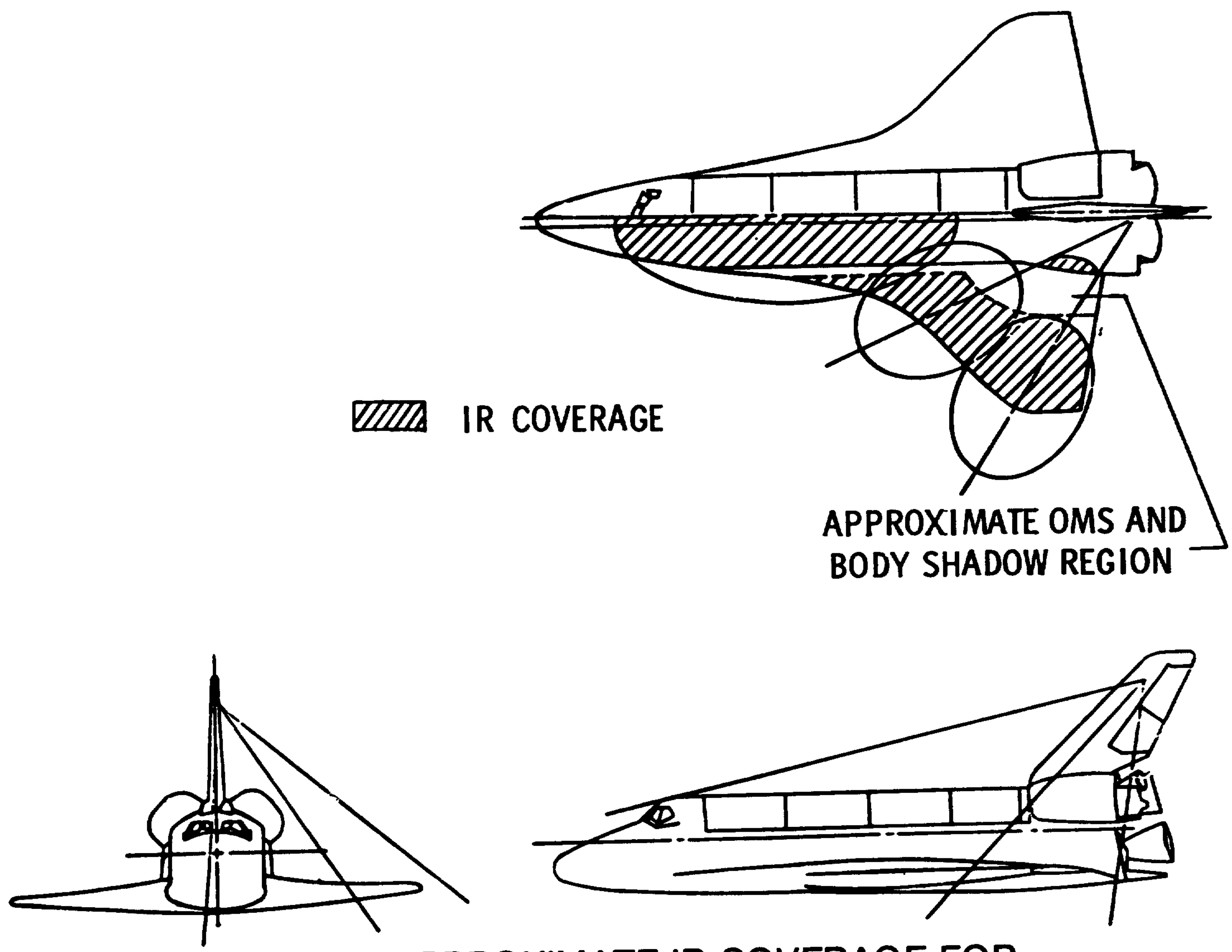


Fig. 7: APPROXIMATE IR COVERAGE FOR
SIDE TAIL MOUNTED CAMERA

(3) Instrumented Test Panels

The ability to determine the aerodynamic and aerothermal performance of any vehicle during entry is dependent on the appropriate utilization of instrumentation. The STS orbiter presents particular instrumentation problems in that the RSI tile are replaceable therefore operational instrumentation interfaces would have to be breakable. To eliminate this problem and to provide total flexibility in the type and location of instrumentation an instrumented tile or panel is proposed (Fig. 8).

The utilization of instrumented self-contained tiles each of which contain the required instruments, power source, and data recorder will allow the measurement of the parameters such as pressure, temperature, heat rate, skin friction, etc., which are required to resolve questions relative to gap heating, plume interaction, shock impingment, etc. Tile location would be based on data obtained from Development Flight Instrumentation (DFI) and the IR camera experiments. In addition to containing the instrumentation required to obtain data relative to flowfield modeling the tiles themselves could be made of TPS materials requiring flight qualification; such as metallic on coated silica.

In addition, instrumented panels larger than one RSI would be fabricated to provide flight qualification of advanced TPS concepts such as active cooling, lightweight hot structures, transpiration, heat pipes, etc.

Presently the definition of an instrumented tile is in the feasibility stage. The TPS panels concept on the other hand have been developed and limited testing of passive systems have been conducted in ground facilities.

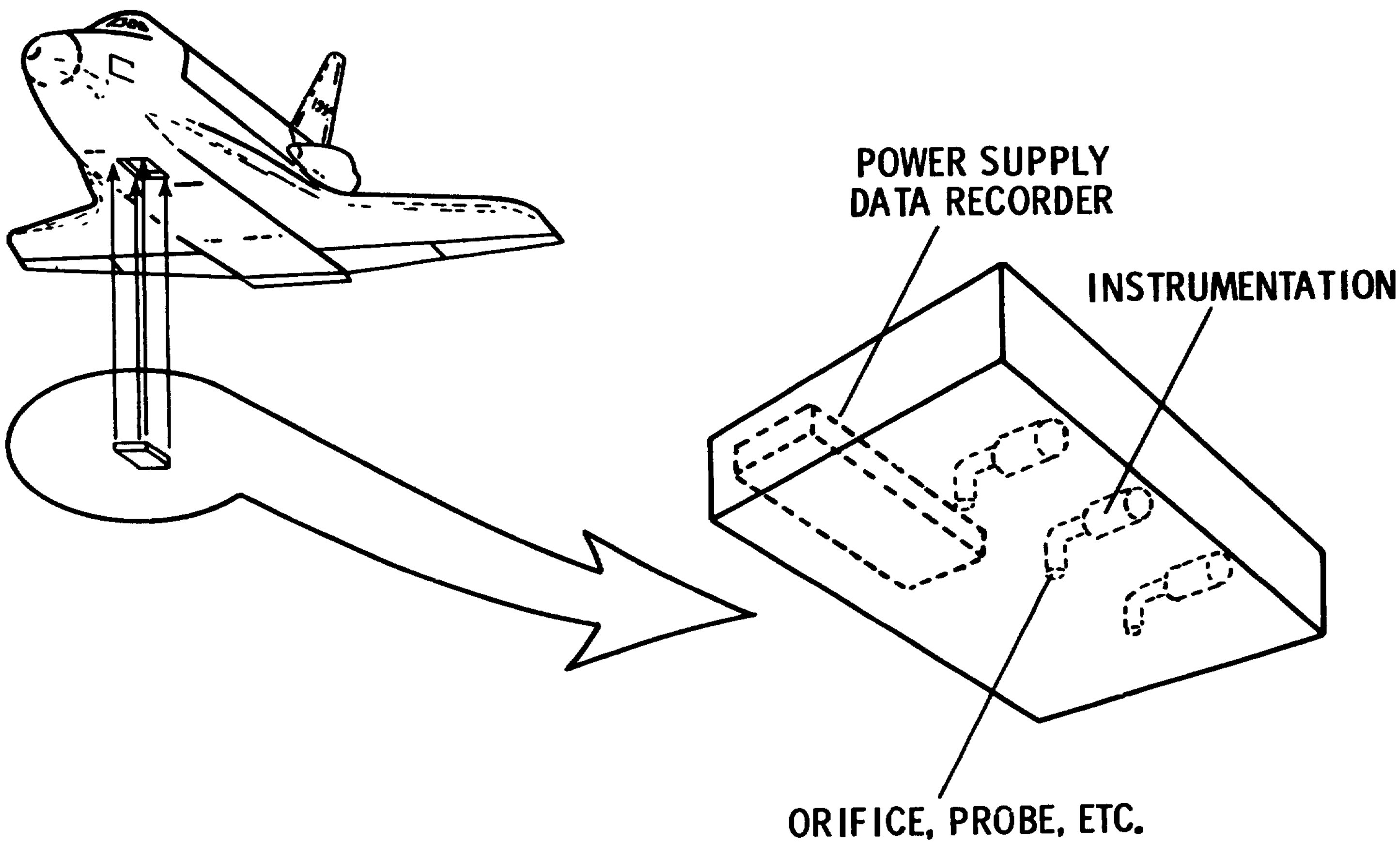


Fig. 8: TYPICAL INSTRUMENTAL PANEL-PRESSURE ORIFICE INSTRUMENTATION

(4) Catalytic Surface

The strong shock wave that encompasses the Shuttle during the entry manuever will severely compress and heat the air flowing through it and cause the molecules to dissociate, and react chemically with one another. Computations show that as the dissociated (atomic) oxygen approaches the cooler region of flow adjacent the wall it fails to recombine into molecular oxygen so that the very reactive oxygen atoms impinge on the Shuttle wall. If the wall is catalytic, the atoms recombine on the wall and give up their exothermic recombination energy. The present orbiter TPS baseline design, for example, assumes that all surfaces are catalytic. For a noncatalytic surface, no recombination takes place and the wall temperature is correspondingly lower--by as much as 230°F. Surface temperature reductions of this amount would correspond, for example, to a TPS weight reduction on the Shuttle orbiter of between about 3000 and 6000 lbs. depending on the extent of atom recombination on downstream surfaces. These non-equilibrium reaction-rate flows cannot be simulated properly in ground-based facilities unless they can test a full-scale model with perfect simulation of flight air chemistry; hence, it remains for in-flight measurements early in the entry maneuver--where non-equilibrium chemical effects are important because of low density flows, yet before the onset of turbulent flow-would be useful in understanding the chemical state of the boundary layer on lifting entry vehicles such as the Shuttle orbiter.

Implementation of the experiment as a payload requires obtaining the temperature distribution along the length of the orbiter. Installation of thermocouples to obtain temperature-time histories is one way to obtain the data. Another way would be to use either the leeward or windward IR camera. This data in conjunction with pre-flight predictions would ascertain the chemical state of the air adjacent to the RSI tile.

(5) Boundary Layer Transition Measurement Syster

The problem of boundary layer transition has implications relative to the aerodynamic and aerothermal performance of every flight vehicle. The present design criteria are unreliable at best because wind tunnel can not provide complete entry parameter simulation, and present mathematical models based on available data are not capable of treating complete configurations. The proper instrumentation of the STS orbiter would provide the data necessary to define areas of transition and provide data on complex vehicles from which transition design criteria and mathematical models could be established. These design criteria are required to design future STS vehicles and have application to optimizing the present STS TPS to provide greater payload weight, lower costs and extended flight envelopes.

The Boundary Layer Transition Payload will consist of an ADS (payload 2), the DFI, and instrumental tiles (payload 3).

b. Deployed Payloads

(1) Advanced STS Configurations

The requirements for an advanced STS having heavy lift capability and providing lower cost demands the development and flight testing of advanced configurations (structural and TPS) and advanced flight control systems. These advanced vehicles would be configured to minimize aerodynamic heating and to provide trade-offs between aerodynamic efficiency, aerodynamic heating and vehicle systems and mission constraints. Tests would be designed to verify aerodynamic and aerothermal systems designs relative to mission constraints and provide unmanned flight qualification of the vehicle utilizing the Remote Pilot Research Vehicle (RPRV) concept. The instrumented RPRV would be launched from the STS orbiter for entry. From telemetry, ground tracking and visual inspection of the recovered vehicle performance would be evaluated and compared to preflight predictions. The recovered vehicle would then be modified and reflown. Such flight tests will eliminate the need for design based on extrapolation criteria which evolve from the inability of ground facilities and present analysis techniques to treat flight environment and complex system geometeies.

(2) Integral Structures Configurations

Present flight vehicle design concepts incorporate an independent structure for flight surface and propellent tankage. The incorporation of these systems into an integral structure would result in system weight savings up to 40%. As with the advanced TPS payloads some integral structures can be tested utilizing the orbiter itself but more complex concepts will require vehicles launched from the orbiter to satisfy particular geometrical or performance requirements not attainable with the orbiter. The other factor is the cost effectiveness of modifying the orbiter or launching a scaled payload.

Integral structures, as well as advanced TPS payloads, would utilize advanced entry vehicle configurations launched from the orbiter to verify the performance of the concept in a flight environment. Present advanced concepts which have application are bead stiffened panels of the single sheet, circular and fluted tabular type utilizing aluminum and Rene' 41. These concepts have been ground tested and these along with concepts yet to be defined will require flight tests to establish the most cost effective utilization of each.

(3) Advanced TPS Concepts

The development of advanced Thermal Protection System concepts is imperative to the development of future flight systems. Present TPS concepts do not provide the low mass fraction and reusibility that will be required to provide cost effect future flight systems. While systems which are applicable to the Advanced STS can be flight tested on the present orbiter, vehicles whose operating envelope is beyond the capability of the orbiter will require testing on vehicles launched from the orbiter.

The testing of advanced TPS concepts on vehicles launched from the orbiter would utilize advanced configurations established from previous flight test or analyses based on flight established mathematical models and ground test. Typical TPS concepts presently considered for advanced configuration are: Metallic radiative, coated silica RSI, hot structures, active cooling, heat pipes, etc. These concepts are capable to withstand surface temperature up to 1600°K and leaning edge temperature greater than 1600°K. These concepts have for the most part been laboratory tested and require environmental flight test for qualification as part of a specific vehicle.

(4) Advanced Hypersonic Cruise Vehicle (AHCV) Configurations

Future configurations of advanced flight vehicles including STS and Hypersonic Cruise Vehicles will require flight test to verify advanced design concepts. Tests would be designed to verify the design of the aerodynamic and aerothermal systems of the AHCV as well as provide through an unmanned remote pilot concept (Remote Pilot Research Vehicle) the qualification of the vehicle for manned flight. The size of the actual AHCV will dictate the scale of the model to be launched from the orbiter for entry. The X-24C concept, for instance, could with stowable wing surface be launched full scale. The performance of the instrumented payload would be evaluated based on telemetry and ground track data and examination of the recovered vehicle. The recovered vehicle will be capable of modification and reflight.

The flight test vehicle would provide a test bed for the design optimization of such proposed AHCV system as canards, strakes, altitude control, TPS, etc., as well as provide verification of the modeling techniques and ground to flight extrapolation criteria utilized relative to real gas flow field and boundary layer transition. The utilization of the orbiter launched test vehicle for advanced deisgn concepts will result in lower cost, lower weight, and performance optimized systems and vehicles. Such vehicles could not evolve from ground facility tests alone due to the inability to simulate actual flight environments in the wind tunnel.

2. HYPERVELOCITY ATMOSPHERIC ENTRY

During the workshop five payloads were defined as required to establish heatshield and aerothermodynamic technology for Hypervelocity Atmospheric Entry. They are:

(a) Entry Probe
(b) Nuclear Waste Disposal Package
(c) Lifting Body Entry Vehicle
(d) Bouyant Station and the
(e) RTG Heat Source

Definition of the Entry Probe payload (Phase A) is now being accomplished with the aid of a contractor. The other future payloads have not been defined at this time, therefore, the working group recommends the early pursuit of Nuclear Waste Disposal Package and Bouyant Station payloads definition. Since manned return from Mars, Venus or the Outer Planets is not contemplated until after the year 2000, this payload does not seem to be in need of definition at this time. The payloads (a), (b), (c), and (e) will all contribute immensely to accurate radiative flow field modeling criteria, and in addition will satisfy a multiplicity of technology requirements.

By launching a probe into the Earth's atmosphere at speeds over 15 km/s, data may be obtained to develop and verify the technology of (a) planetary entry probe heatshield and configuration, (b) nuclear waste disposal package, (c) radiative flow field models, (d) planetary sample return heatshield and configuration, and (e) manned planetary return heatshield and configuration.

a. Entry Probe

An entry probe payload mission as seen in Fig. 9 will consist of deployment of the entry vehicle with an attached liquid propellent first stage and solid propellent second stage. The initial burn of the liquid stage from shuttle parking orbit lifts the entry probe payload into an elliptical orbit thus attaining a position from where it is possible to make a steep angle entry into the Earth's atmosphere. At the apogee of this elliptical orbit, the liquid propellent stage is again used to deorbit the entry probe payload thereby adjusting the entry angle to that required for the simulation. After separating the liquid stage engine and then coasting back to the edge of the atmosphere, the solid stage engine is ignited in order to attain the desired entry velocity. The entry velocity and agnle are chosen to correspond to the technology requirements, but generally the velocity varies from 14 km/s to 17 km/s with an entry angle of from 30^{o} to 60^{o}. Due to the high density of electrons about the entry probe during the braking maneuver, radio communication is blacked out. Dynamic and environmental data are stored on tape for later playback and/or recovery. During the terminal phase of flight a parachute is deployed making possible an airborne recovery of the entry probe vehicle by conventional aircraft.

b. Nuclear Waste Disposal Package

The need for nuclear waste disposal has been discussed as a technology requirement. The nuclear waste disposal payload, as seen in Fig. 10, will test a system capable of sending actinides with residual amounts of fission products into either high Earth orbits, solar orbits, or solar escape trajectories without the danger of Earth contamination should there be an inadvertent entry. Velocity increments above Earth orbital velocity to accomplish these missions range from 4.1 km/s to 8.75 km/s. The nuclear waste capsule must then be designed to withstand an entry velocity of from 14 km/s to 19 km/s, a subsequent impact on the surface at a speed of 0.3 km/s, and a survival of at least 5 days before vessel pressure burst on the surface.

The radioactive wastes are to be contained within a storage matrix enclosed within a stainless steel sphere. This sphere is to be carried within an aerodynamically stable entry body designed with a heatshield capable of surviving hypervelocity entry. A typical nuclear waste package will weigh over 3000 kg.

Possibly several payload missions may be required to develop this crucial environmental protection system. Methods used to test probable heatshields and aerodynamic configurations would require a rocket staging capability much more powerful than the planetary entry probe payload described above. From two to three shuttle launches will be required to assemble each nuclear waste capsule payload in Earth orbit if complete flight duplication is required.

c. Lifting Body Entry Vehicles

A manned planetary return mission differs so much in technology requirement from planetary sample return mission that a separate payload has been defined to satisfy the requirements. The manned planetary return mission requires a large-lifting-maneuverable-configuration with a heatshield capable of withstanding a long-time duration heat-pulse necessitated by the low acceleration entry. It is envisioned that the entry capsule system will be similiar to the current Apollo Command Module design in order to provide the same environment for the crew. Because the heating rates for a 15 km/s entry will be an order of magnitude greater than Apollo experience, advanced ablative/reflective heatshields will be considered.

It seems very likely that multiple lifting body entry vehicle payloads may be required to obtain the research and development knowledge required to design a manned planetary return capsule for future missions.

d. Bouyant Station

A bouyant station payload simulating the planetary bouyant station deployment mission may be space flight tested without the need for complete entry velocity duplication since the deployment phase of flight occurs at lower speeds. Because of this lower velocity requirement, space or atmospheric flight tests other than shuttle launched need to be considered.

The bouyant station payload will require only a propulsion system for deorbit maneuvering with no requirement for a velocity package as in the previously described payloads. On-board sensors and telemetry instrumentation can transmit data to a ground based observation station. Video or photographic equipment carried aboard the payload can record or transmit imagery central to the deployment problem. Recovery of the payload will be required in order to adequately survey the system performance.

e. <u>Radioisotope Thermoelectric Generation (RTG) Heat Source</u>

The key technology issue for the RTG heat source is thermal stress failure of the graphite aeroshell. The high ballistic coefficient of the heat source, together with supercircular entry velocities produce high levels of extremely transient aerodynamic heating, large temperature gradients and possible thermal stress failure. Numerous studies of the problem have shown that the required test conditions cannot be obtained in ground facilities and that a flight test of a full scale heat source is the only way of conclusively demonstrating heat source survival. A typical RTG heat source is a circular cylinder having a diameter of approximately 20 cm, a length of approximately 40 cm. and a weight of from 14 to 23 lbs. The required entry conditions are approximately 11 km/sec. and -30°. Hence, the shuttle payload would consist of the space craft (heat source) and a small solid lick stage such as the X-259. The resulting entry vehicle is small enough that it would fit over the tunnel of the spacelab (see Fig. 14) and hence might be a candidate for a "piggy back" payload on a space lab mission. The primary instrumentation on the entry vehicle will consist of thermocouples to measure temperature distributions in the graphite aeroshell and breakwires or films to detect aeroshell stress failure. Because of the high M/C_DA required for proper entry simulation, it would not appear feasible to package a recovery parachute. The most promising approach is to design for shallow water impact and underwater recovery aided by an onboard "pinger".

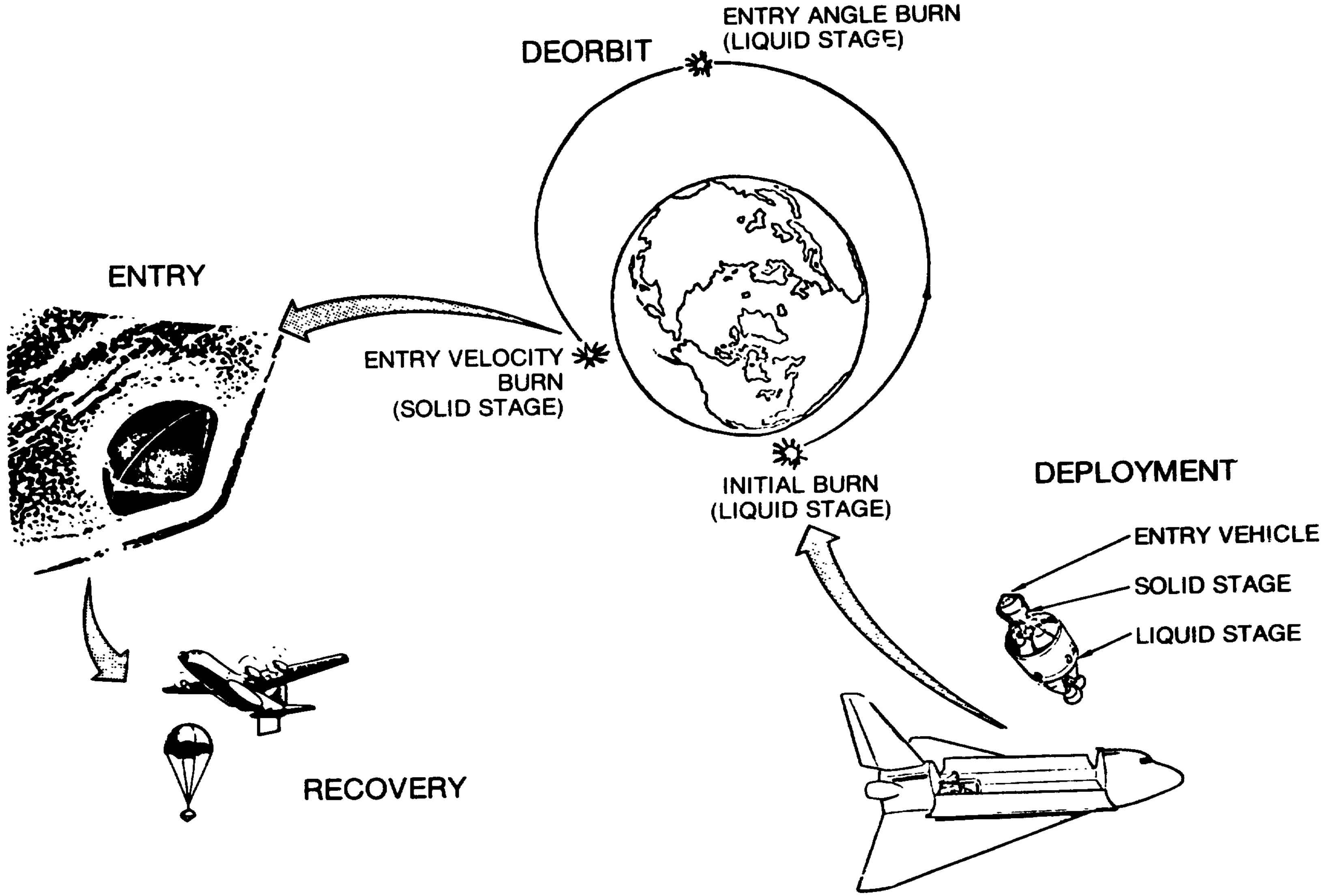
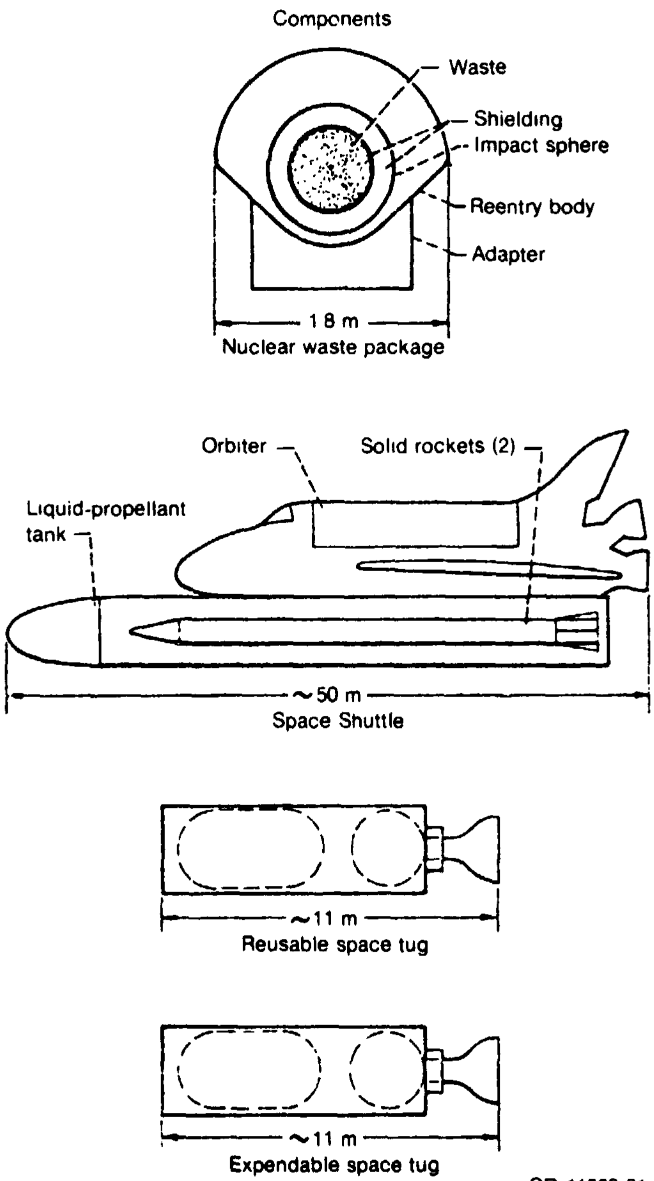


Fig. 9: PLANETARY ENTRY SIMULATION MISSION



CD-11569-31

Component	Weight, kg
Nuclear waste package:	
Waste (actinides plus 0 1 per cent fission products)	200
Shielding (LiH, W, matrix)	1 995
Impact sphere	640
Reentry body (heat shield)	410
Adapter	120
Space Shuttle:	
Orbiter (dry weight)	68 000
Liquid propellant and tank	737 000
Solid rockets	1 030 000
Reusable space tug:	
Propellant weight	23 900
Burnout weight	2 900
Expendable space tug:	
Propellant weight	22 000
Burnout weight	2 900

Fig. 10: COMPONENT WEIGHTS FOR NUCLEAR WASTE SPACE DISPOSAL MISSION.

REQUIRED FOR MISSION: ONE SHUTTLE CARRYING REUSABLE SPACE TUG, AND ANOTHER SHUTTLE CARRYING EXPENDABLE SPACE TUG AND NUCLEAR WASTE PACKAGE.

3. INDIVIDUAL EMERGENCY ENTRY

Astronaut Retrieval

The advent of extended duration earth orbital space missions, and the associated objective of space personnel safe return create a demand for a system whereby personnel can be returned to earth in emergencies. The STS era will introduce long duration multi-manned (30-day mission--7 flight personnel) earth orbital missions. Advanced plans call for permanent space stations with even larger crews. The recovery, or rescue of such personnel in an emergency situation will be possible only via the STS oribter which may not be available in a true emergency situation. The development of an emergency earth return system for orbital personnel is therefore highly desirable. Such a system should provide the crew member aerodynamic stability, thermal protection, life support, and recovery systems. In addition, the system must be light, compact, and stowable because of weight and volume constraints which will exist in the orbital systems. A candidate system is shown in Fig. 11 while typical performance data are presented in Fig. 12 and 13. The payload would consist of the entry system, including capsule, deorbit propulsion, parachute, and a biomedical dummy and related life support systems. The deployment of such payloads from shuttle for flight verification is highly desirable. Such systems could be launched in a piggy-back mode and thereby provide for cost effective system qualification.

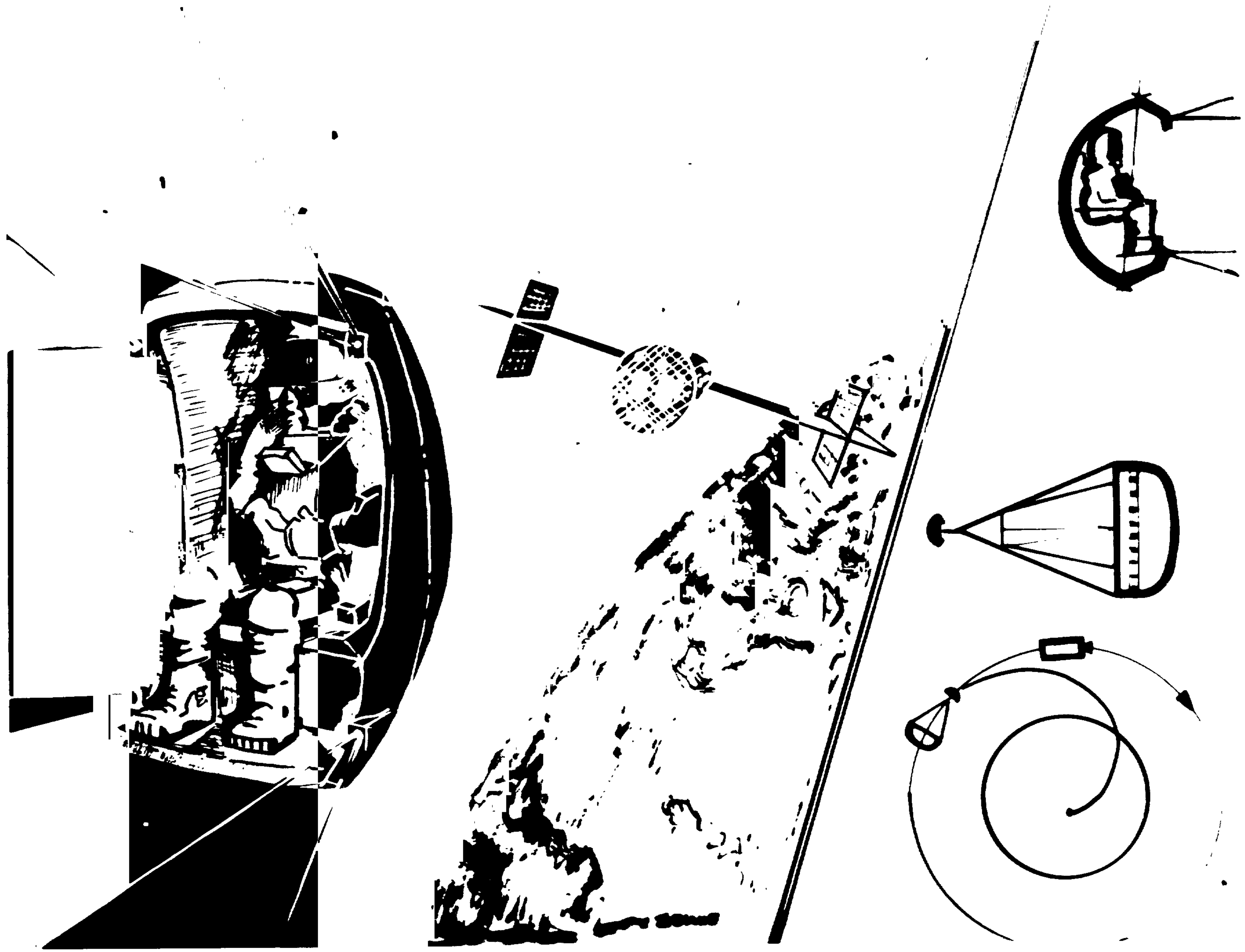


Fig. 11: CANDIDATE SPACEPERSON/PACKAGE RETRIEVAL SYSTEM

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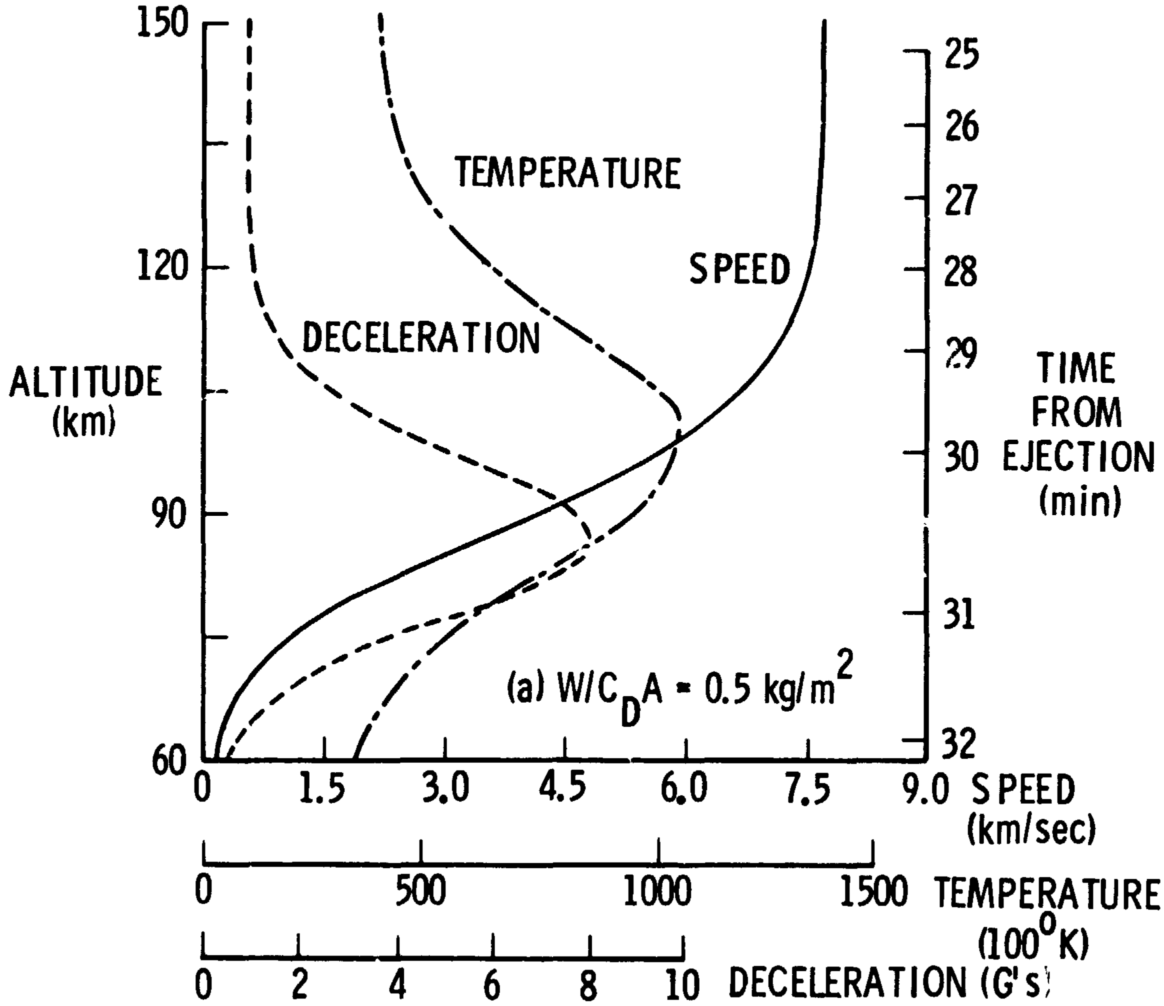

Fig. 12: TYPICAL PERFORMANCE
SPACEPERSON/PACKAGE RETRIEVAL SYSTEM

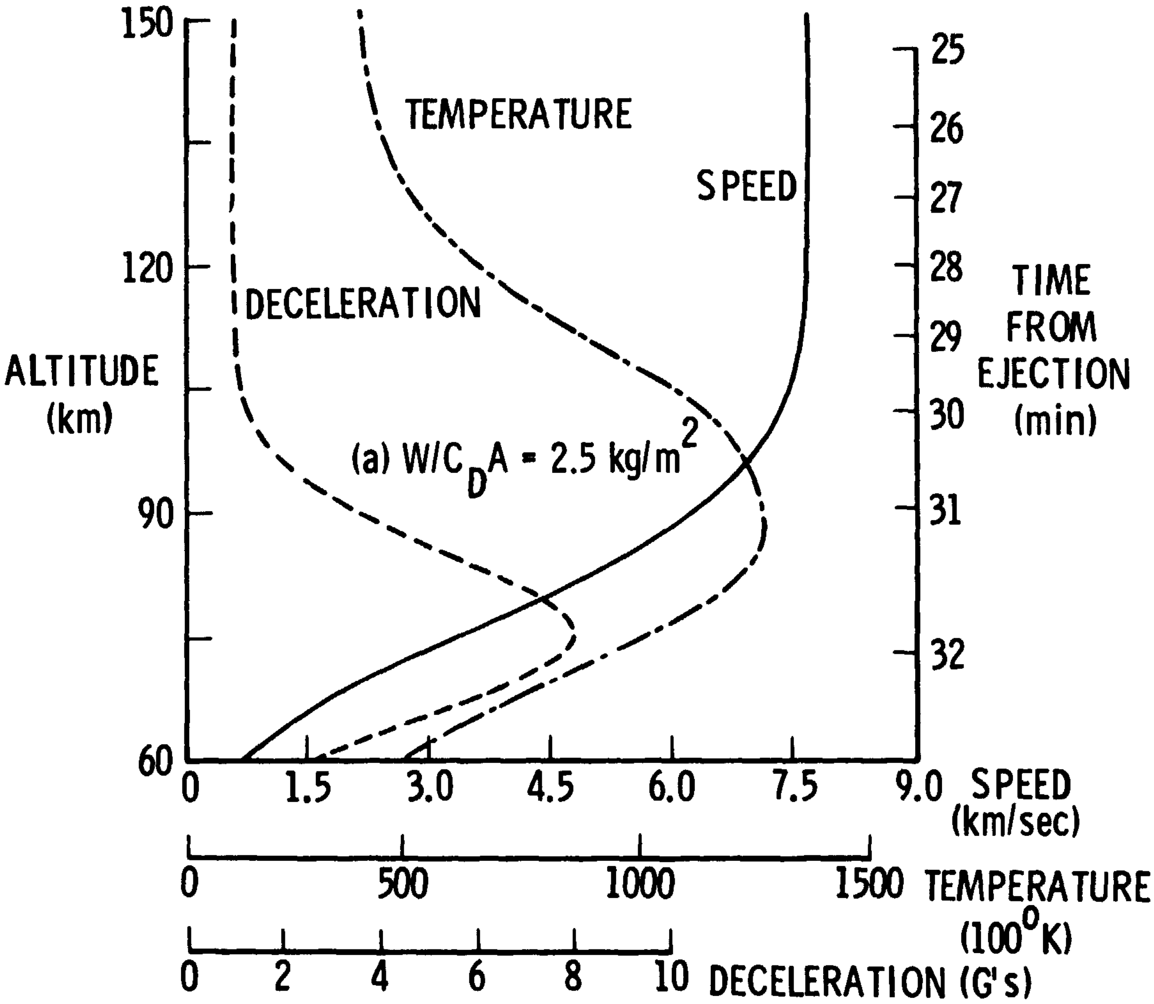

Fig. 13: TYPICAL PERFORMANCE
SPACEPERSON/PACKAGE RETRIEVAL SYSTEM

B. FOR OPPORTUNITY DRIVEN TECHNOLOGY REQUIREMENTS

Small Deployed Vehicles

One of the basic unsolved problems in fluid mechanics relative to hypersonic aerothermodynamics is boundary layer transition. Because of disturbances present in conventional wind tunnels these facilities cannot be used to conduct meaningful research on transition, even proposed "quiet" tunnels specifically designed to study transition will need to be validated by disturbance-free data that can only be obtained from ballistic ranges or from flight. Ballistic ranges can only test very small models and hence do not allow the investigation of all pertinent phenomena. High costs have so far prevented the collection of flight data except for restricted DOD missions. The existence of the STS mission provides an unprecedented opportunity to obtain a large data base relative to flight boundary layer transition. The STS can carry on a routine basis small deployable "piggy-back" entry probes in addition to its primary payload, i.e., Spacelab (Fig. 14). The total payload would consist of the probe and the required deorbit propulsion (TE364-4, X-259). The probes of various geometrics would be instrumented and equipped with telemetry and recording systems as well as being air or sea recoverable. The data would be free of ground facility effects and provide a means for establishing reliable boundary layer transition criteria and mathematical models. (Present criteria are only accurate to within an order of magnitude).

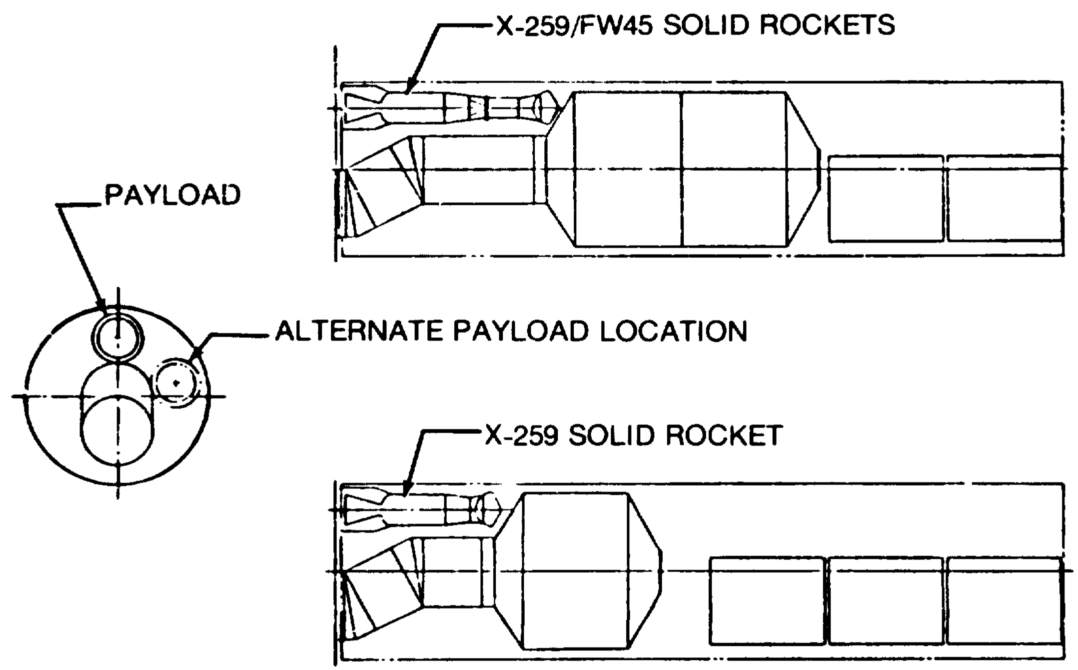

Fig. 14: TYPICAL PIGGY-BACK PAYLOAD INSTALLATION

APPENDIX 1.

TECHNOLOGY REQUIREMENTS FORMS

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 1

1. TECHNOLOGY REQUIREMENT (TITLE): Advanced STS Configuration PAGE 1 OF 2

2. TECHNOLOGY CATEGORY: Structural & Mechanical Entry -(9)

3. OBJECTIVE/ADVANCEMENT REQUIRED: To develop STS configurations having improved aerodynamic and aerothermal efficiency.

4. CURRENT STATE OF ART: Space Shuttle orbiter data base

HAS BEEN CARRIED TO LEVEL 5

5. DESCRIPTION OF TECHNOLOGY

Configurations of improved aerothermodynamic efficiency must be developed to provide STS vehicles with greater payload capacity, lower cost (resulting from reduced aerodynamic heating and hence more flights per heatshield) and an extended usable entry flight envelope. This will yield heavy lift vehicles capable of 2 to 3 times as many uses (between heat-shield refurbishment) as the present shuttle orbiter is capable of.

P/L REQUIREMENTS BASED ON: ☒ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Present shuttle orbiter is limited to 65,000 lbs. of payload and utilizes a TPS that is not truly reusable but must be continually refurbished in regions of severe heating. Advanced STS vehicles will provide increased payload capacity by factor of 2 to 3 and will be truly reusable.

b., e., c. Will benefit missions involving the placement of large structures in orbit, e.g. space power station, nuclear waste disposal.

d. This technology requirement will be satisfied by collecting aerothermodynamic data of subscale models launched from the shuttle and entering the earth's atmosphere.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 1

1. TECHNOLOGY REQUIREMENT(TITLE): Advanced STS Configuration PAGE 2 OF 2

7. TECHNOLOGY OPTIONS:

Vehicles can be configured to minimize aerodynamic heating and to provide optimum trade-offs between aerodynamic efficiency, aero heatloads and vehicle systems and mission constraints.

8. TECHNICAL PROBLEMS:

Wind tunnels do not provide complete simulation of entry conditions. Mathematical models are incapable of accurately testing complete configurations. Maximum configuration optimization can be obtained only through reentry flight tests.

9. POTENTIAL ALTERNATIVES:

Utilize present shuttle data base, wind tunnel tests of new configurations and best available numerical analysis techniques. Use necessary conservation in extrapolating to flight conditions. Accept less than optimum aerothermodynamic design.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Space Shuttle Development Support: LaRC and ARC (506-26-30)
Advanced Earth Orbital Spacecraft Design: LaRC and ARC (506-26-10)

EXPECTED UNPERTURBED LEVEL 5

11. RELATED TECHNOLOGY REQUIREMENTS:

1. Improved heatshields for advanced STS orbiters.
2. Boundary Layer Transition criteria for advanced STS orbiters
3. Improved mathematical modeling techniques for real gas flow fields and ground-to-flight data extrapolition.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 2

1. TECHNOLOGY REQUIREMENT (TITLE): Improved Thermal Protection Systems/for Advanced STS and STS PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Structures & Mechanical (9)-Entry

3. OBJECTIVE/ADVANCEMENT REQUIRED: Develop low mass fraction high efficiency, fully reusable heatshield materials

4. CURRENT STATE OF ART: Ranges from conceptual Design to testing in laboratory environment depending on specific concept.

HAS BEEN CARRIED TO LEVEL 3-5

5. DESCRIPTION OF TECHNOLOGY

The present STS TPS includes HRSI, LRSI, and C/C leading edges. These systems will not provide the low mass; high performance, nor reusibility required to maximize STS and Advanced STS payloads and reduce operational costs. The development of advanced TPS concepts: metallic radiative, coated (silica) RSI, lightweight hot structures, thick skin heat-sink structures, active cooling, transpiration, heatpipes, etc., is required to provide vehicle protection at surface temperatures from 900K to 1600K and leading edge temperature > 1600K as well as providing full reusibility.

P/L REQUIREMENTS BASED ON: ☒ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. TPS mass fraction decreases, performance increases and reusibility required to satisfy heavy lift, low cost space transportation requirements as well as STS.
b. The economic deployment of large multiple payloads, large lightweight structures, nuclear waste disposal, manned space stations, etc. described in OFS, A Forecsst of Space Technology Section II requires the development of a new heavy lift vehicle (2-11).
c. This technology is required to make a heavy lift low cost vehicle and associated missions a reality.
d. This technology requirement will be satisfied by the development of a flight system which has been fully tested in a full scale flight environment on board the STS Orbiter.

TO BE CARRIED TO LEVEL 8

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 2

1. TECHNOLOGY REQUIREMENT(TITLE): Improved Thermal-protection System for Advanced STS and STS. PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

Present TPS state-of-the-art (RSI, Ablative, etc.) does not provide an acceptable option. Utilization of existing systems would seriously limit lift and cost benefits. If such a system is to be a reality new TPS concepts must be flight qualified.

8. TECHNICAL PROBLEMS:

a. Validity of flow field prediction techniques, e.g., pressure, heat rates
b. Boundary Layer Transition Criteria
c. Materials
d. Structures

9. POTENTIAL ALTERNATIVES:

No light weight, heavylift, low cost advanced Space Transportation System

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Programs in metallic radiative, coated RSI have proceeded through laboratory test. No further activity planned.

EXPECTED UNPERTURBED LEVEL 5

11. RELATED TECHNOLOGY REQUIREMENTS:

Materials
Advanced STS Structures
Real Gas Flow Field Prediction Techniques
Boundary Layer Transition Criteria

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 2

1. TECHNOLOGY REQUIREMENT (TITLE): Improved TPS for Advanced STS PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Define Test req'ms																			
2. Devel. Test Hardware																			
3. Flight test Passive TPS																			
4. Flight Test Struct. TPS																			
5. Flight Test Active TPS																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																Active			
3. Operations					Passive			▽					Struct. ▽		▽				
4.																			

13. USAGE SCHEDULE:

																			TOTAL
TECHNOLOGY NEED DATE																			
NUMBER OF LAUNCHES																			

14. REFERENCES:

1. Shideler, John L.: Bohon, Hermal L. Evaluation of Bead Stiffened Metal Panels AIAA 75-815

2. Bohon, Hermal L.: Sawyer, J. Wayne; Hunt, L. Roane Performance of Full Size Metallic & RSI Thermal Protection Systems in a Mach 7 Environment

3. Outlook for Space - A Forecast of Space Technology NASA

4. NASA Mission Model - 1973

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 3

1. TECHNOLOGY REQUIREMENT (TITLE): Improved Mathematical Models for Real Gas Flowfields and Ground-to-Flight Data Extrapolation PAGE 1 OF 2

2. TECHNOLOGY CATEGORY: Structural and Mechanical; (9)-Entry

3. OBJECTIVE/ADVANCEMENT REQUIRED: Develop new mathematical models of demonstrated capability and accuracy to be used in designing advanced heavy-lift STS orbiters.

4. CURRENT STATE OF ART: Techniques developed to analyze current shuttle orbiter.

HAS BEEN CARRIED TO LEVEL 3

5. DESCRIPTION OF TECHNOLOGY

Mathematical modeling techniques of improved and demonstrated accuracy will be developed applying advanced numerical analysis methods and validating the resulting techniques by comparison with actual reetry flight data. These techniques are required for the design of optimized advanced STS orbiters.

P/L REQUIREMENTS BASED ON: ☒ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Present techniques have not been validated by comparison with flight data and hence are of undemonstrated accuracy. Present techniques are estimated to involve uncertainties of from 10% to 50% depending on the phenomena being modeled. With flight data, these uncertainties can be significantly lowered allowing less conservation and thus saving heatshield weight and increasing payload capacity.

b. &

c. This technology is required for the design of advanced, heavy-lift STS orbiters needed for missions involving the placement the large structures in orbit, e.g. space power station, nuclear waste disposal, large antenna arrays for terrestrial monitoring.

d. This technology requirement will be satisfied by using the shuttle orbiter, equipped with special instrumentation to obtain flight data. This flight data will then be used to develop and validate the required techniques.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 3

1. TECHNOLOGY REQUIREMENT(TITLE): Improved Mathematical Models of Real Gas Flowfields and Ground-to-Flight Data Extrapolation PAGE 2 OF 2

7. TECHNOLOGY OPTIONS:

Mathematical models to be verified may range from numerical solutions to the complete Navier Stokes equations to empirical correlations of wind tunnel test data. The key requirement is validation of the techniques by comparison with flight results.

8. TECHNICAL PROBLEMS:

Present techniques have not been validated by comparison with flight data and hance are of undemonstrated accuracy. Present uncertainties are estimated to range from 10 to 50% depending on the phenomena being modeled.

9. POTENTIAL ALTERNATIVES:

Develop modeling techniques as well as possible with only wind tunnel tests for validation and accept the increased heatshield weights and smaller flight envelopes that result from the use of conservative design assumptions.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Ongoing analytical and ground based experimental investigations will yield some increased confidence in mathematical modeling techniques but without flight test validation large uncertainties wil. still exist.

EXPECTED UNPERTURBED LEVEL 7

11. RELATED TECHNOLOGY REQUIREMENTS:

(1) Improved Boundary Layer Transition Criteria.

(2) Improved Heatshields for Advanced STS.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 4

1. TECHNOLOGY REQUIREMENT (TITLE): Advanced Structures PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Structures & Mechanical (9)-Entry

3. OBJECTIVE/ADVANCEMENT REQUIRED: Develop Structural concepts that will provide low structural unit mass in an elevated temperature entry environment.

4. CURRENT STATE OF ART: Ranges from conceptual design to testing in laboratory environment depending on concept.

HAS BEEN CARRIED TO LEVEL 3-5

5. DESCRIPTION OF TECHNOLOGY

Present STS and air frame concepts such as conventional stringer stiffened panels do not provide the weight efficiency that will be required for a low weight, heavy-lift, low cost advanced STS. The development and flight tests of advanced concepts such as Bead-Stiffened Panels and integral structure/tankage can result in mass savings up to 40%.

P/L REQUIREMENTS BASED ON: ☒ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a.) Mass fraction decreases in vehicle structures to satisfy requirements for a low weight, heavy-lift, low cost advanced STS.

b.) The economic deployment of large multiple payloads, large light-weight structures, nuclear waste disposal, manned space stations, etc. described in OFS. A forecast of Space Technology Section II requires the development of a new heavy-lift vehicle (2-11).

c.) This technology is required to make a heavy-lift low cost vehicle and associated missions a reality.

d.) This technology requirement will be satisfied by the development of a flight system which has been fully tested in a full scale flight environment on-board the STS orbiter.

TO BE CARRIED TO LEVEL 8

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 4

1. TECHNOLOGY REQUIREMENT(TITLE): Advanced Structures PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

None

Present space vehicle structural concepts do not provide an acceptable option.

8. TECHNICAL PROBLEMS:

a. Materials
b. Validity of Flowfield prediction techniques
c. Boundary Layer Transition Criteria
d. Flight test.

9. POTENTIAL ALTERNATIVES:

None

No light-weight, heavy-lift, low-cost advanced STS.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Programs will carry technology to various stages of ground/laboratory tests.

EXPECTED UNPERTURBED LEVEL 5

11. RELATED TECHNOLOGY REQUIREMENTS:

See paragraph #8.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 4

1. TECHNOLOGY REQUIREMENT (TITLE): Advanced Structures PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1.																			
2.																			
3.																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

TECHNOLOGY NEED DATE																		TOTAL
NUMBER OF LAUNCHES																		

14. REFERENCES:

1. Shideler, John L.; Bohon, Hermal L. Evaluation of Bead Stiffened Metal Panels
2. OFS - A Forecast of Space Technology
3. NASA Mission Model - 1973

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 5

1. TECHNOLOGY REQUIREMENT (TITLE): Improved Boundary Layer Transition Criteria PAGE 1 OF 2

2. TECHNOLOGY CATEGORY: Structural & Mechanical; (9)-Entry

3. OBJECTIVE/ADVANCEMENT REQUIRED: Develop and validate techniques for more accurately predicting those regions of an advanced STS orbiter that will experience turbulent flow.

4. CURRENT STATE OF ART: Present transition criteria contain uncertainties of at least an order of magnitude. No experimental data is available for Advanced STS configuration.

HAS BEEN CARRIED TO LEVEL 6

5. DESCRIPTION OF TECHNOLOGY

Because of their large size, Advanced STS orbiters will have regions of turbulent flow much larger than those predicted for the present shuttle orbiter. Hence, turbulent heating will be a prime driver in the design of the Advanced STS, where as it has not been for the present shuttle. Studies have shown that transition data obtained in ground facilities is affected by noise and other "facility" effects and may bear little or no relation to the flight case. Because of their empirical nature, transition criteria are highly configuration dependent. Hence, criteria for the Advanced STS orbiter can be best obtained by using the present shuttle orbiter as a reentry test vehicle.

P/L REQUIREMENTS BASED ON: ☒ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Turbulent heating will design large regions of the thermal protection system for an Advanced STS orbiter. Use of conservative transition criteria could result in excessive heatshield weight. Design heatshield weights could be too large by a factor of two. This would significantly reduce payload capacity.
b. This technology is required for the design of an Advanced STS orbiter that is needed for missions involving the placement of large structures in orbit, e.g. space power station, nuclear waste disposal, large antenna arrays for terrestrial monitoring.
c. Better definition of the extent of turbulent heating experienced by an Advanced STS orbiter could increase payload capacity by up to 20 percent.
d. Transition criteria must be validated by comparison with flight test data obtained on a configuration and in a flight environment typical of that expected for the Advanced STS orbiter, i.e. data obtained on the present shuttle orbiter.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 5

1. TECHNOLOGY REQUIREMENT(TITLE): Improved Boundary Layer Transition Criteria

7. TECHNOLOGY OPTIONS:

The development of "quiet" wind tunnels is underway and these facilities may provide transition data that is more representative of flight that that produced in current tunnels. Even with these "quiet" tunnels, however, some facility effects are probably unavoidable. Also, these facilities will be capable of testing only small models and hence surface roughness effects, which may be very important for the Advanced STS orbiter, cannot be investigated.

8. TECHNICAL PROBLEMS:

Present boundary layer transition criteria are only accurate to within an order of magnitude. Many different transition criteria have been proposed, but because of the unreliability of wind tunnel data and a total lack of flight data on relevant configurations, no rational basis of judging the various proposed criteria is available.

9. POTENTIAL ALTERNATIVES:

Use conservative transition criteria in design of vehicle and accept reduced payload capability.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Ongoing studies (in NASA, DOD, industries, universities) on boundary layer transition. While the magnitude of the present program is relatively large, none of the present programs will provide the required flight data.

EXPECTED UNPERTURBED LEVEL ___

11. RELATED TECHNOLOGY REQUIREMENTS:

(1) Improved thermal protection systems for Advanced STS orbiter.
(2) Improved techniques for predicting air loads on Advanced STS orbiter.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 6

1. TECHNOLOGY REQUIREMENT (TITLE): Planetary Entry Probe Heatshield and Configuration PAGE 1 OF 2

2. TECHNOLOGY CATEGORY: Structural and Mechanical (9)-Entry

3. OBJECTIVE/ADVANCEMENT REQUIRED: To develop entry probe heatshield capable of planetary entry with larger ΔV environment.

4. CURRENT STATE OF ART: Apollo used heatshield, but will have a ΔV larger than existing probes on Apollo CM.

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

Entry Probe heatshield technology should be developed to withstand the entry heating environments of Saturn, Uranus and Jupiter which have peak rates of approximately 20, 7 and 75kW/cm^2. Low heatshield fractions are required in order to increase the size of the payload packages. A single entry probe for both Saturn and Uranus may prove economical, while a special one for Jupiter would be required. Ablative/reflecting dielectric heatshield concepts offer potential superior to those of conventional heatshield concepts.

P/L REQUIREMENTS BASED ON: ☒ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Heatshield mass fractions from .10 to .46 are required to satisfy the entry requirements. These fractions should be lowered to permit larger payloads.
b. The benefiting payloads are: PL-11-A "Pioneer Saturn/Uranus Flyby", PL-13-A "Pioneer Jupiter Probe", and PL-22-A "Pioneer Saturn Probe."
c. This technology is required to perfrom atmospheric measurements of Uranus, Saturn and Jupiter.
d. This technology requirement will be satisfied with an earth entry test.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 6

1. TECHNOLOGY REQUIREMENT(TITLE): Planetary Entry Probe Heatshield and Configuration PAGE 2 OF 2

7. TECHNOLOGY OPTIONS:

Alternate ablative materials such as opaque subliners (e.g., carbon-phenolic, graphite can be used although with decreased performance. Radiative heatshield concepts may offer some possibilities particularly if minimum foreign material is desired in the region of probe measurements.

8. TECHNICAL PROBLEMS:

a. Validity of ablative analysis at high heating rates
b. Sensitivity of analysis to atmospheric composition, radiation blockade and sublimation chemistry. Heatshield configurations that reduce the possibility of turbulent flow.
c. Scaling of time for testing purposes.
d. Reliability of components in radiation environment.

9. POTENTIAL ALTERNATIVES:

Radiative heatshields plus insulation protective layer are a possibility although there may be interference with measurements.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

a. W74-70253 (502-21-20), Advanced Materials for Space, Lewis Research Center, W. D. Klopp, (216) 433-6676.
b. W74-70331 (502-07-01), Gas Dynamics Research, Langley Research Center, Eugene S. Love, (703) 827-2893.
c. Martin Contract with NASA ARC.
d. McDAC Contract with NASA ARC.

EXPECTED UNPERTURBED LEVEL 4

11. RELATED TECHNOLOGY REQUIREMENTS:

a. Insulation between heatshield and probe instruments.
b. Radiative Flowfield Modeling
c. Entry Probe Configuration

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 7

1. TECHNOLOGY REQUIREMENT (TITLE): Nuclear Waste Disposal Package PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Structural & Mechanical (9)-Entry

3. OBJECTIVE/ADVANCEMENT REQUIRED: To develop safe disposal packages to withstand abort re-entry impact.

4. CURRENT STATE OF ART: Relatively light weight RTG's. No massive weight experience

HAS BEEN CARRIED TO LEVEL 4

5. DESCRIPTION OF TECHNOLOGY

Heatshield, impact, and shielding technology should be developed to withstand abort entry heating environments and subsequent impact. That package requires radioactive shielding to provide safe handling. Entry heating levels are several orders to magnitude greater than state of the art.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Large heatshield mass fractions required. These fractions should be lowered to permit larger payloads. Benefiting users:

b. 1. Outlook for Space: Theme Objectives 024, 043
   2. 1973 Mission Model: All Spacecraft employing RTG's
   3. OSS Mission Model: All Spacecraft employing RTG's

c. This technology is required to remove toxic and nuclear waste from the biosphere

d. Technology requirement will be satisfied by testing in space environment

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 7

1. TECHNOLOGY REQUIREMENT(TITLE): Nuclear Waste Disposal Package PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

Package size must be optimized by radiation shielding requirements. Large massive packages will lead to high ballistic coefficients and subsequent extreme heating. All abort trajectories are possible and a two layer heatshield silica over graphite will be optimized to handle the steep intense entry and the slow orbital decay entry.

8. TECHNICAL PROBLEMS:

a. Validity of radiative flowfield modeling
b. Light-weight shielding development
c. Impact resistant structures
d. Heavy payloads or operation system.

9. POTENTIAL ALTERNATIVES:

Alternate means of waste disposal is to store it on earth. Time scale is on the order of a 1000 years. And few sites on earth are totally safe from erosion, geological upheaval or sabatoge.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

EXPECTED UNPERTURBED LEVEL __

11. RELATED TECHNOLOGY REQUIREMENTS:

a. Nuclear radiation shielding

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. 7

1. TECHNOLOGY REQUIREMENT (TITLE): Nuclear Waste Disposal Package — PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1.																			
2.																			
3.																			
4.																			
5.																			
APPLICATION																			
1. Design (Ph. C)																			
2. Devl/Fab (Ph. D)																			
3. Operations																			
4.																			

13. USAGE SCHEDULE:

TECHNOLOGY NEED DATE																	TOTAL
NUMBER OF LAUNCHES																	

14. REFERENCES:

Feasibility of Space Disposal of Radioactive Nuclear Waste

I. Executive Summary NASA TMS-2911
II. Technical Summary NASA TMX-2912

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 8

1. TECHNOLOGY REQUIREMENT (TITLE): Radiative Flow-field Models PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: Structures and Mechanical (9)-Entry

3. OBJECTIVE/ADVANCEMENT REQUIRED: To improve the radiative transport predictions in non-equilibrium, non-adiabatic flow-fields about ablating heatshields.

4. CURRENT STATE OF ART: Radiative transport may be accurately predicted within thermochemically equilibrium flowfields about low-ablating heatshields. HAS BEEN CARRIED TO LEVEL 5

5. DESCRIPTION OF TECHNOLOGY

Radiative Flowfield Modeling Technology is concerned with predicting the transport of mass, momentum and energy throughout a high temperature gas-dynamic flow.
In this technology the detail measurement and calculation of chemical species density, temperature, velocity, radiative absorption coefficient, and relaxation rate is critical to arriving at a satisfactory prediction model.
The thermochemical properties known of most gas mixtures are computed from quantum mechanical models derived from spectroscopic measurements. Chemical relaxation rates and absorption coefficients must be obtained from experimental measurements--usually a shock tube experiment.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a.) All of this past work can be brought to fruition through formulation and verification of radiative transport predictions in non-equilibrium, non-adiabatic flowfields about a massively ablating earth re-entry probe space flight test.
b.) Radiative Flux to an earth re-entry heatshield can equal that of Jovian entry at about one-third of the entry speed at Jupiter (50 km/s) due to the difference in the molecular weight of the atmospheric gases.
c.) This space flight test will be conducted after all suitable laboratory tests are completed.
d.) This technology is required to perform atmospheric measurements of Jupiter, and to design planetary return heatshields.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 8

1. TECHNOLOGY REQUIREMENT(TITLE): Radiative Flowfield Models PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

The risk of not performing an accurate radiative transport prediction capability for Jovian atmospheric entry may very well result in a large penalty in heatshield weight due to uncertainty.

8. TECHNICAL PROBLEMS:

There will be significant technical problems in making meaningful measurements, transmitting and interpreting these measurements from space flight test.

9. POTENTIAL ALTERNATIVES:

None

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

The Planetary Probe Design Specific Objective Addresses the technology requirement. Plans are to advance the state-of-the-art through laboratory test supported flowfield analysis.

EXPECTED UNPERTURBED LEVEL 5

11. RELATED TECHNOLOGY REQUIREMENTS:

A.) Entry Probe Hea shield
B.) Entry Probe Configuration
C.) Planetary Sample Return Heatshield
D.) Manned Planetary Return Heatshield

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. 8

1. TECHNOLOGY REQUIREMENT (TITLE): Radiative Flowfield Models PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. Radiative gasdynamic measurements	—	—	—	—	—														
2. Computer Code Advancements	—	—	—	—	—	—	—	—	—	—	—	—	—						
3. Shuttle-ARC Tests					—	—	—	—	—										
4. GPF-ARC Tests			—	—	—	—			—	—	—								
5.																			
APPLICATION																			
1. Design (Ph. C)				—	—														
2. Devl/Fab (Ph. D)					—	—													
3. Operations						—	—	—	—	—	—	—	—						
4.																			

13. USAGE SCHEDULE:

	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	TOTAL
TECHNOLOGY NEED DATE								J		R_1				R_2				
NUMBER OF LAUNCHES								1		1				1				3

14. REFERENCES:

J = Jupiter
R_1 = Planetary Sample Return
R_2 = Manned Planetary Return

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

DEFINITION OF TECHNOLOGY REQUIREMENT | NO. 9

1. TECHNOLOGY REQUIREMENT (TITLE): Planetary Sample Return Heatshield and Configuration | PAGE 1 OF 2

2. TECHNOLOGY CATEGORY: Structural and Mechanical (9)-Entry

3. OBJECTIVE/ADVANCEMENT REQUIRED: Develop a heatshield for planetary sample return probe capable of earth entry speeds to 15-20 km/s and study effect of configuration on heating and stability

4. CURRENT STATE OF ART: Missile heatshield capability to speeds of 7/ms/s at large M/CDA, and Apollo entry to 11 km/s now exists.

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

Entering the Earth's atmosphere with Mars, Venus, Titan, comet or asteroid samples require a probe with a heatshield capable of withstanding over 20 kw/cm^2 of radiative heating combined with substantial convective heating. Candidate materials must be selected and subjected to this entry environment in order to design the most efficient heatshield for these extraordinary missions. Ablative/reflective dielectric heatshields may perform most efficiently for these applications.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Since these sample return probes are to be carried from Earth to another solar system body, and then returned at great expenditure of energy, it is imperative that the heat ield design be as efficient of mass utilization as practi y possible so as to make these missions technically feas le.

b. The technology required to design the Planetary Sample Return Heatshield is closely allied with that required to design the planetary entry probe heatshield.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 9

1. TECHNOLOGY REQUIREMENT(TITLE): Planetary Sample Return Heatshield and Configuration PAGE 2 OF 2

7. TECHNOLOGY OPTIONS:

Ablative/reflective heatshields are thought to offer the most promise for entry conditions where radiative heating is the dominant form of energy transfer to the probe surface, however, carbon-phenoelic, grapite and other opaque materials may perform adequately under these circumstances.

8. TECHNICAL PROBLEMS:

a. Validity of ablative analysis at high heating rates
b. Lack of previous experience in high radiative heating environment
c. Uncertainty in boundary layer transition criteria
d. Uncertainty in spallation process encountered at high temperature.

9. POTENTIAL ALTERNATIVES:

Combined heatshields and probe structure should be actively pursued for these mass critical missions.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

EXPECTED UNPERTURBED LEVEL ___

11. RELATED TECHNOLOGY REQUIREMENTS:

a. Outer planets entry probe heatshield
b. Radiative flowfield modeling

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 10

1. TECHNOLOGY REQUIREMENT (TITLE): Manned Planetary Return Heatshield and Configuration PAGE 1 OF 2

2. TECHNOLOGY CATEGORY: Structural & Mechanical (9)-Entry

3. OBJECTIVE/ADVANCEMENT REQUIRED: To develop a heatshield and configuration to survive a manned earth re-entry at speeds to 11 km/s

4. CURRENT STATE OF ART: Man return from moon at speeds to 11 km/s

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

When returning from planets with men aboard, an entry vehicle must have means to control the angle of attack and trajectory in order not to exceed the acceleration limits of the crew. Flying at an angle of attack with a low-ballistic coefficient entry vehicle necessitates an investigation differing from unmanned applications. The heatshield design must be compromised by a configuration which allows the necessary flight conditions. Ablative/reflective heatshield materials or carbon phenolic materials in large arrays will have to be developed for this application.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a.) A manned planetary return vehicle must be developed for the post 2000 time period to correspond with re-newed manned exploration of the solar system.

b.) Since flights to other planets and asteriods are especially mass limited, means to combine the heatshield with the entry vehicle structure must be found.

c.) Considerable effort must be taken to find a configuration which satisfies the manned constraints and at the same time allow a low-mass heatshield/structure.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 10

1. TECHNOLOGY REQUIREMENT(TITLE): Manned Planetary Return Heatshield and Configuration

7. TECHNOLOGY OPTIONS:

Combined ablative/reflective heatshield with structure would seem to be the necessary approach, however, more conventional opaque heatshield materials with a separate structure could be used where launch mass allowances are sufficient.

8. TECHNICAL PROBLEMS:

a. Considerable uncertainty exists in predicting the magnitudes of radiative flux on the surface of such a large vehicle.
b. Uncertainty in the boundary layer transition criteria.
c. A configuration which allows lift modulation without excessive heat flux must be found.

9. POTENTIAL ALTERNATIVES:

a. An Apollo Command Module with pre-entry retro-propulsion

b. Transfer of crew to earth orbit by retro-propulsion, then return by STS.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

None

EXPECTED UNPERTURBED LEVEL ___

11. RELATED TECHNOLOGY REQUIREMENTS:

a. Outer Planets Entry Probe Heatshield and Configuration
b. Radiative Flowfield Modeling

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 11

1. TECHNOLOGY REQUIREMENT (TITLE): Planetary Bouyant Station Deployment PAGE 1 OF 2

2. TECHNOLOGY CATEGORY: Structural/Mechanical (9)-Entry

3. OBJECTIVE/ADVANCEMENT REQUIRED: To enter and deploy successfully a bouyant station within a planetary atmosphere.

4. CURRENT STATE OF ART: Ground launched bouyant science platforms have been successfully built and flown in the earth's atmosphere.

HAS BEEN CARRIED TO LEVEL __

5. DESCRIPTION OF TECHNOLOGY

In the terminal maneuver of a planetary entry probe carrying a planetary bouyant station, the science platform and communications station must be deployed with bouyant support. This technology requirement addresses the problem of developing a bouyant system capable of prompt deployment during high speed free-fall. A system of retarding and erecting devices must be devised and experimentally evaluated.

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a) The surface conditions of some planets are too hostile for long term or even short term survival, therefore, a means to float within the atmosphere is necessary for long term planetary science measurements.

b) A great deal of difficulty is encountered in ground launching bouyant science platforms on earth even in the best weather conditions--a considerable advancement is required to launch a bouyant station from a high speed entry probe.

c) The only way such a bouyant station deployment system can be perfected is through a series of designs and tests culminating in space flight tests within the earth's atmosphere.

TO BE CARRIED TO LEVEL __

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 11

1. TECHNOLOGY REQUIREMENT(TITLE): Planetary Bouyant Station Deployment PAGE 2 OF 2

7. TECHNOLOGY OPTIONS:

Bouyant station designs have been proposed and these designs should be investigated initially. Materials and structures may be subjected to environmental tests expected at the planets.

8. TECHNICAL PROBLEMS:

a) Minimizing structural/materials weight and still maintain a system strong enough to withstand launching forces and atmospheric turbulence

9. POTENTIAL ALTERNATIVES:

a) Use free-fall capsule for atmospheric measurements

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

EXPECTED UNPERTURBED LEVEL ___

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 12

1. TECHNOLOGY REQUIREMENT (TITLE): Radioisotope Thermoelectric Generator (RTG) Heat Source Survival PAGE 1 OF 2

2. TECHNOLOGY CATEGORY: Structural/Mechanical (9)-Entry

3. OBJECTIVE/ADVANCEMENT REQUIRED: Flight demonstration of RTG heat source survival during supercircular entries.

4. CURRENT STATE OF ART: Ground facilities do not produce the test conditions necessary to validate analyses or to ensure reentry survival.

HAS BEEN CARRIED TO LEVEL 3

5. DESCRIPTION OF TECHNOLOGY

Full scale RTG heat source must be flown on an entry trajectory typical of that resulting from a launch vehicle upper stage malfunction leading to a supercircular entry.

P/L REQUIREMENTS BASED ON: ☒ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. Ground test facilities cannot produce the test conditions required to demonstrate survival of RTG heat sources during high speed (supercircular) entries.

b. Benefiting missions: All those employing RTG's.

c. This technology is required to accurately assess the risk involved in launching spacecraft employing RTG's.

d. This technology requirement will be satisfied by an earth entry flight test.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 12

1. TECHNOLOGY REQUIREMENT(TITLE): Radioisotope Thermoelectric Heat Source Survival PAGE 2 OF 2

7. TECHNOLOGY OPTIONS:

Present RTG heat source designs are typically cylindrical graphite shells, containing the plutonium fuel and having ballistic coefficients on the order of 100. Present configurations are dictated by RTG efficiency considerations. Reentry design is a secondary consideration. Should flight tests show heat source thermal stress failure, some redesign to enhance reentry performance is possible and would probably be carried out.

8. TECHNICAL PROBLEMS:

a. Aerodynamic heating to typical aerodynamic shapes

b. Thermal stress failure analysis for graphite materials

9. POTENTIAL ALTERNATIVES:

Employ conservative assumptions in reentry nuclear safety analyses and concentrate of reducing launch vehicle failure probabilities that the risk of nuclear fuel release is acceptable.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

No comparable programs are planned. More sophisticated numerical analyses are being carried out but require validation.

EXPECTED UNPERTURBED LEVEL 3

11. RELATED TECHNOLOGY REQUIREMENTS:

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 13

1. TECHNOLOGY REQUIREMENT (TITLE): Astronaut Retrieval PAGE 1 OF 2

2. TECHNOLOGY CATEGORY: Structures/Mechanical (9)-Entry

3. OBJECTIVE/ADVANCEMENT REQUIRED: Develop heatshield and aerothermodynamics for emergency recovery of earth orbital space station/vehicle personnel and/or equipment.

4. CURRENT STATE OF ART: Unknown - some components, materials may exist but presently undefined.

HAS BEEN CARRIED TO LEVEL 2

5. DESCRIPTION OF TECHNOLOGY

A minimum weight, compact, easily storable entry package should be developed to provide safe entry for space station personnel who because of emergency must abandon their station and return to earth.

P/L REQUIREMENTS BASED ON: ☒ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

a. The advent of permanent space stations will demand the development of an emergency earth return system which is light, compact and storable because of weight and volume constraints within the station.

b. Extended shuttle missions; Space Stations.

c. The primary emphasis of any manned space mission is the safe return of personnel. Such an emergency system would provide that capability.

d. The development of the heatshield and aerothermodynamics must be manrated through level 8.

TO BE CARRIED TO LEVEL 8

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 13

1. TECHNOLOGY REQUIREMENT(TITLE): Astronaut Retrieval PAGE 2 OF 2

7. TECHNOLOGY OPTIONS:

Presently no options exist other than STS launch for recovery. Emergency situation may not allow for such.

8. TECHNICAL PROBLEMS:

a. Validity of flowfield prediction techniques
b. TPS Development
   - lightweight
   - high performance
   - storable

c. Flight Tests

9. POTENTIAL ALTERNATIVES:

STS rescue if applicable

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

None

EXPECTED UNPERTURBED LEVEL 2

11. RELATED TECHNOLOGY REQUIREMENTS:

Decelerator - high temperature
Space Suit

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 14

1. TECHNOLOGY REQUIREMENT (TITLE): Boundary Layer Transition PAGE 1 OF 2

2. TECHNOLOGY CATEGORY: Structural/Mechanical (9)-Entry

3. OBJECTIVE/ADVANCEMENT REQUIRED: Obtain fundamental transition data, free of ground facility effects, on various basic aerodynamic shapes.

4. CURRENT STATE OF ART: Present transition criteria contain uncertainties of at least an order of magnitude.

HAS BEEN CARRIED TO LEVEL 6

5. DESCRIPTION OF TECHNOLOGY

Because of disturbances (primarily noise) present in conventional wind tunnels, it now appears that these facilities cannot be used to conduct meaningful research on boundary layer transition. New "quiet" tunnels are being developed, but data obtained from them needs to be validated by disturbance-free data that can only be obtained from ballistic ranges or from flight. Ballistic ranges can only test very small models and hence do not allow the investigation of all pertinent phenomena: High costs have so far prevented the collection of large bodies of flight data except for restricted types of DOD missions.

P/L REQUIREMENTS BASED ON: ☒ PRE-A, ☐ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS

This is an opportunity driven technology requirement and hence it does not relate to specific payloads or missions. The existence of the space shuttle and the large number of projected missions for the shuttle provide an unprecedented opportunity to obtain a large body of flight boundary layer transition data by carrying small "piggy-back" entry probes on shuttle flights for which the prime payload does not use the full shuttle payload capacity. The resulting basic data would be of great value for basic fluid mechanics in general and hypersonic aerothermodynamics in particular.

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 14

1. TECHNOLOGY REQUIREMENT(TITLE): Boundary Layer Transition PAGE 2 OF 2

7. TECHNOLOGY OPTIONS:

None

8. TECHNICAL PROBLEMS:

Present boundary layer transition criteria are only accurate to within an order of magnitude. Many different transition criteria have been proposed but because of the unreliability of wind tunnel data and a total lack of flight test data on relevant configurations and flight conditions, no rational basis of judging the various proposed criteria is available.

9. POTENTIAL ALTERNATIVES:

None

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

No presently planned programs would provide the type of flight data that is required.

EXPECTED UNPERTURBED LEVEL 6

11. RELATED TECHNOLOGY REQUIREMENTS:

1. Boundary layer transition criteria for advanced STS orbiter.
2. Improved mathematical modeling techniques for real gas flow fields and ground-to-flight extrapolation.
3. Improved aerodynamic configurations for Advanced STS orbiters.

APPENDIX 2.

PAYLOAD FORMS

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. E-1
PAGE 1

1. REF. NO. ______ PREP DATE ______ REV DATE ______ LTR ______
CATEGORY Entry (9)

2. TITLE AIR DATA SYSTEM

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

Provides accurate measurements of stagnation conditions and vehicle attitude (α, β) from which free-stream conditions (e.g.q.) can be calculated and used to verify aerodynamics and aerothermal characteristics of the orbiter across the speed range. Provides flight data base for validation of real gas flow models and boundary layer transition and separation criteria. Data necessary for defining data required to define flow conditions for TPS testing.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1979
PAYLOAD DEVELOPMENT LEAD TIME 2 YEARS. TECHNOLOGY NEED DATE 1977

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______

TECHNICAL BENEFITS Improvements in aerodynamic and aerothermal efficiency benefit STS vehicles by providing greater payload, lower costs for TPS's, and extended flight envelopes. These improvements can be made possible through improved transition criteria available only from flight data, and through the utilization of advanced TPS concepts again made possible by flight data and experience.

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS 1. Wind tunnels cannot completely simulate entry conditions. 2. Mathematical models are incapable of treating complete configurations. 3. Order of magnitude errors in boundary layer transition criteria. 4. Validity of real gas flowfield prediction techniques.

REQUIRED SUPPORTING TECHNOLOGIES 1. Boundary layer transition criteria 2. Improved mathematical modeling and ground-to-flight extrapolation techniques. 3. Advanced in materials and structures providing improved TPS's. 4. Improved techniques for predicting air loads on Advanced STS orbiter.

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TDR-1) 7/75

TITLE AIR DATA SYSTEM

NO. E-1

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: STS orbiter, air data system and related instrumentation

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

BENEFIT OF SPACE TEST: Provides flight test data across speed range to verify ground base tests and analyses

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: None

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE High

9. GROUND TEST OPTION TEST ARTICLE: N/A

TEST DESCRIPTION/REQUIREMENTS: N/A

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ____

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

F1 (TDR-2) 7/75

FUTURE PAYLOAD TECHNOLOGY NO. E-2

TESTING AND DEVELOPMENT REQUIREMENT PAGE 1

1. REF. NO. ______ PREP DATE ______ REV DATE ______ LTR ______

CATEGORY Entry (9)

2. TITLE IR Camera-L-e/Windward Heating

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

Provides flight verification of the flow over Lee/Windward surfaces. This in turn provides verification of heating rate predictions, Reynold's and Mach number effects; establishes ground-to-flight extrapolation techniques; establishes guidelines for lee side vortex alleviation requirements. Provides needed flight data on boundary layer transition and separation to verify real gas flow field and boundary layer modeling technique.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1979

PAYLOAD DEVELOPMENT LEAD TIME 2 YEARS. TECHNOLOGY NEED DATE 1977

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______

TECHNICAL BENEFITS Improvements in boundary layer transition criteria, and validation of real gas flow field models can be made by comparison with actual orbiter flight data free from wind tunnel effects. Benefits advanced TPS concepts through actual flight experience and provides weight reduction and cost reduction of TPS of future space vehicles and retrofitted orbiters.

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS
1. Validity of flow field prediction techniques.
2. Boundary layer transition criteria
3. Materials
4. Structures

Related ~~REQUIRED SUPPORTING~~ TECHNOLOGIES 1. Improved techniques for predicting air loads on STS orbiter and real gas flowfields, 2. Improved boundary layer transition criteria, 3. Improved thermal protection system for STS orbiter, 4. Materials, 5. Advanced STS structures

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TDR-1) 7/75

TITLE IR Camera-Lee/Windward Heating NO. E-2

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: STS Orbital

IR Cameras-Vertical tail mounted/Chase plane

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

BENEFIT OF SPACE TEST: Provide flight verification of ground test and modeling data

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE High

9. GROUND TEST OPTION TEST ARTICLE: Payload provides ground test verification

TEST DESCRIPTION/REQUIREMENTS: N/A

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: N/A

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

FT (1DR-2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. E-3
PAGE 1

1. REF. NO. ______ PREP DATE ______ REV DATE ______ LTR ______
CATEGORY Entry (9)

2. TITLE Instrumented Test Panels

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
3-5	5	8

The definition of Advanced STS configurations, improved thermal protection systems, flowfield modeling techniques and extrapolation criteria and boundary layer transition require accurate flight data. This data (pressure, temperature, heat rate, etc.) can be best obtained on the STS orbiter via deplaceable instrumented RSI tile and/or panels of TPS systems.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1980
PAYLOAD DEVELOPMENT LEAD TIME 3 YEARS. TECHNOLOGY NEED DATE 1977

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______

TECHNICAL BENEFITS Acquisition of data required to define aerothermodynamics for Advanced STS configurations, TPS, and flowfield models free of ground facility effects. Will result in weight and cost savings relative to future flight systems.

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS
1. Validity of flowfield models.
2. TPS
3. Advanced configuration concepts

Related TPS, Materials, Structures, Real gas flowfields, boundary layer transition

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TDR-1) 7/75

TITLE Instrumented Test Panels NO. E-3

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: STS Orbiter - Instrumented with tiles and panels to measure pressure, temperature, heat flux, etc.

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

Instrumented RSI tiles and/or TPS panels

BENEFIT OF SPACE TEST: STS Orbiter entry will provide flight test environment

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: none

EXISTING: YES [X] NO [ ]

TEST CONFIDENCE High

9. GROUND TEST OPTION TEST ARTICLE: None

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES [ ] NO [ ]

GROUND TEST LIMITATIONS: ____

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

FT (TDR-2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. E-4
PAGE 1

1. REF. NO. ______ PREP DATE ______ REV DATE ______ LTR ______
CATEGORY Entry (9)

2. TITLE Catalytic Surface

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

To develop improved heatshields for the Advanced STS. The current state-of-the-art is the RSI tile. The base line design assumes full catalytic recombination at the wall. The state of the chemistry at the surface of the tile for flight conditions is unknown.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1981
PAYLOAD DEVELOPMENT LEAD TIME 3 YEARS. TECHNOLOGY NEED DATE 1978

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______

TECHNICAL BENEFITS A non catalytic surface would experience a much lower temperature. Reduced temperatures could lead to a reduction in TPS weight of thousands of pounds.

POTENTIAL COST BENEFITS The cost savings are related to refurbishment and avoidance of replacement.

ESTIMATED COST SAVINGS $ Medium

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS 1. Modeling non-equilibrium chemistry-unknown reaction rates. 2. Simulation of flight conditions is difficult in ground based air jets.

~~REQUIRED SUPPORTING~~ Related TECHNOLOGIES ______

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TD-1) 7/75

TITLE Catalytic Surface NO. E-4
PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: STS Orbiter with instrumented tiles/panels

TEST DESCRIPTION: ALT. (max/min) ____/____ km, INCL. ____ deg, TIME ____ hr

BENEFIT OF SPACE TEST: STS Orbiter provides flight environment

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW
POINTING ____ STABILITY ____ DATA ____
ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____/____
SPECIAL GROUND FACILITIES: ____
EXISTING: YES ☐ NO ☐
TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: None

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____
EXISTING: YES ☐ NO ☐
GROUND TEST LIMITATIONS: ____
TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS 2. DESIGN 3. MFG & C/O 4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

FT (TDR-2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. E-5
PAGE 1

1. REF. NO. ______ PREP DATE ______ REV DATE ______ LTR ______
CATEGORY Entry (9)

2. TITLE Boundary Layer Transition/Measurement System

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
4	5	8

Provides flight boundary layer transition data on large-size STS type configurations (via, the shuttle orbiter) unobtainable in wind tunnels or on small models. This transition data defines regions of turbulent flow which is of primary importance in the design of the advanced STS. Measurements from the design of the air data system (ADS) instrumented tiles and/or imbedded thermocouples define the transition areas.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1988
PAYLOAD DEVELOPMENT LEAD TIME 3 YEARS. TECHNOLOGY NEED DATE 1977

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______

TECHNICAL BENEFITS Improved aerodynamic and aerothermal efficiency in the design of the advanced STS. Greater payloads, lower costs, and an extended usable flight envelope result from these improvements. Provides flight data base to evaluate and refine advanced STS concepts and to validate mathematical models of complete configurations.

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS 1. Wind tunnels do not provide complete simulation of entry conditions 2. Mathematical models are incapable of accurately treating complete configurations 3. Boundary layer transition criteria are only accurate to within an order of magnitude.

~~REQUIRED SUPPORTING~~ Related TECHNOLOGIES 1. Improved real gas flowfields, air loads and boundary layer transition predictions on complete configurations 2. Improved thermal protection systems for advanced STS.

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TDR-1) 7/75

TITLE Boundary Layer Transition Measurement System NO. E-5
PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: STS Orbiter and instrumented tiles

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

BENEFIT OF SPACE TEST: STS Orbiter will provide flight environment

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: None

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ____

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

F1 (TDR 2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. E-6
PAGE 1

1. REF. NO. ______ PREP DATE ______ REV DATE ______ LTR ______
CATEGORY Entry (9)

2. TITLE Advanced STS Configurations

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
3-5	5	8

Develop structural concepts that will provide low structural unit mass in an elevated temperature entry environment and develop mathematical modeling techniques of demonstrated capability and accuracy to be used in designing advanced heavy lift STS orbiters.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1984
PAYLOAD DEVELOPMENT LEAD TIME 5 YEARS. TECHNOLOGY NEED DATE 1979

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______

TECHNICAL BENEFITS The development of advanced concepts such as bead-stiffened panels and integral structure/tankage can result in mass savings up to 40%. Validation of mathematical modeling techniques is needed in the design of optimized advanced STS orbiters.

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS 1. Materials, 2. Validity of flowfiel prediction techniques, 3. Boundary layer transition criteria, 4. Flight test, 5. Current mathematical models have not been validated with flight data and are of undemonstrated accuracy.

~~REQUIRED SUPPORTING~~ Related TECHNOLOGIES 1. Those related to the above problem areas, 2. Improved boundary layer transition criteria, 3. Improved heatshields for Advanced STS.

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TDR-1) 7/75

TITLE Advanced STS Configurations NO. E-6
PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Scale model of Advanced configurations

TEST DESCRIPTION: ALT. (max/min) ____/____ km, INCL. ____ deg, TIME ____ hr

Launch RPV from orbiter for entry to simulate flight environment

BENEFIT OF SPACE TEST: Provide flight environment to verify design techniques

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____/____

SPECIAL GROUND FACILITIES: Tracking, recovery

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: None

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ____

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

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FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

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PAGE 1

1. REF. NO. ________ PREP DATE ________ REV DATE ________ LTR ____
CATEGORY Entry (9)

2. TITLE Integral Structures Configurations

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
3-5	5	8

The development of structural concepts that will provide low structural unit mass. A different entry environment than that of the shuttle can be achieved using deplayed vehicles.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1983
PAYLOAD DEVELOPMENT LEAD TIME 5 YEARS. TECHNOLOGY NEED DATE 1978

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ________

TECHNICAL BENEFITS Present airframe concepts such as conventional stringer stiffened panels do not provide the weight efficiency required for a low weight vehicle. Development and flight tests of integral structure/tankage, can result in mass savings of up to 40%.

POTENTIAL COST BENEFITS ________

ESTIMATED COST SAVINGS $ ________

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS
a. Materials
b. Validity of flowfield prediction techniques
c. Boundary layer transition criteria
d. Flight test

~~REQUIRED SUPPORTING~~ Related TECHNOLOGIES Related technologies are the same as these problem areas listed above.

7. REFERENCE DOCUMENTS/COMMENTS ________

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TITLE Integral Structures-Configurations NO. E-7

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Shuttle launched payload incorporating Integral Structures Concept

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

BENEFIT OF SPACE TEST: Provide flight verification and qualification of design concept and system respectively.

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: Recovery System, Tracking

EXISTING: YES [X] NO [ ]

TEST CONFIDENCE High

9. GROUND TEST OPTION TEST ARTICLE: None

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES [ ] NO [ ]

GROUND TEST LIMITATIONS: ____

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

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FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. E-8
PAGE 1

1. REF. NO. ______ PREP DATE ______ REV DATE ______ LTR ______
CATEGORY Entry (9)

2. TITLE Advanced TPS Concepts

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
3-5	5	8

Development of low mass fraction, high efficiency, fully re-usable heat-shield materials. A different entry environment from that of the shuttle can be achieved using deployed vehicles.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1983
PAYLOAD DEVELOPMENT LEAD TIME 5 YEARS. TECHNOLOGY NEED DATE 1978

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______

TECHNICAL BENEFITS The development of advanced TPS concepts: metallic radiative, coated (silica) RSI, lightweight hot structures, thick skin heat-sink structures, active cooling, transpiration, heatpipes, etc. is required to provide vehicle protection at surface temperatures from 900K to 1600K and leading edge temperature > 1600 K as well as providing full re-usability.

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS
a. Validity of flowfield prediction techniques, e.g. pressure, heat rates.
b. Boundary layer transition criteria
c. Materials
d. Structures

~~REQUIRED SUPPORTING~~ Related TECHNOLOGIES
1. Materials
2. Advanced STS Structures
3. Real gas flowfield prediction techniques
4. Boundary layer transition criteria

7. REFERENCE DOCUMENTS/COMMENTS ______

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TITLE Advanced TPS Concepts NO. E-8
PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: STS launched payload incorporating TPS concept

TEST DESCRIPTION: ALT. (max/min) ____/____ km, INCL. ____ deg, TIME ____ hr

BENEFIT OF SPACE TEST: Provide flight validation and qualification of TPS concepts.

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____/____

SPECIAL GROUND FACILITIES: Ground recovery system, Tracking

EXISTING: YES [X] NO [ ]

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: None

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES [ ] NO [ ]

GROUND TEST LIMITATIONS: ____

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	Space Test Option						COST ($)	Ground Test Option						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

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FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

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PAGE 1

1. REF. NO. ______ PREP DATE ______ REV DATE ______ LTR ______
CATEGORY Entry (9)

2. TITLE Advanced Hypersonic Cruise Vehicle (AHCV) Configurations

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
3-5	5	7-8

Verification in flight environment of (AHCV) geometric configurations, flight control systems, TPS, and flowfield and aerodynamic modeling techniques as well as ground test and extrapolation techniques. Scale models of AHCV would be orbiter launched.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1984
PAYLOAD DEVELOPMENT LEAD TIME 4 YEARS. TECHNOLOGY NEED DATE 1980

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______

TECHNICAL BENEFITS Allows for the establishment and verification of aerodynamic and thermodynamic modeling techniques and ground test extrapolation techniques. Also provides for flight demonstration and qualification of advanced flight systems and design concepts.

POTENTIAL COST BENEFITS By decreasing design uncertainties and optimizing systems design through developed design techniques increased scientific of logistic payloads will evolve.

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS 1. Validity of flowfield prediction techniques. 2. Boundary layer transition criteria. 3. Materials 4. Structures 5. Existing flowfield models have not been validated. Uncertainties of up to 50% exist in aero and thermo design criteria.

REQUIRED SUPPORTING TECHNOLOGIES Improved boundary layer transition criteria 2. Improved TPS 3. Materials 4. Structures 5. Real gas flowfield prediction techniques.

7. REFERENCE DOCUMENTS/COMMENTS ______

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TITLE Advanced Hypersonic Cruise Vehicle (AHCV) Configurations

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PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Large to full scale advanced hypersonic cruise vehicle-unmanned RPV

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

BENEFIT OF SPACE TEST: Provide flight test environment required to verify analyses and systems.

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: Ground track and recovery systems

EXISTING: YES [X] NO [ ]

TEST CONFIDENCE High

9. GROUND TEST OPTION TEST ARTICLE: None - continue system overdesign based on ground facility test

TEST DESCRIPTION/REQUIREMENTS: --

SPECIAL GROUND FACILITIES: --

EXISTING: YES [ ] NO [ ]

GROUND TEST LIMITATIONS: Accuracy of performance and system designs resulting from ground up to 50% in error.

TEST CONFIDENCE --

10. SCHEDULE & COST

TASK	CY (Space Test Option)						COST ($)	CY (Ground Test Option)						COST ($)
1. ANALYSIS														
2. DESIGN														
3. MFG & C/O														
4. TEST & EVAL														
TECH NEED DATE														
GRAND TOTAL								GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

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FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

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PAGE 1

1. REF. NO. ____ PREP DATE ____ REV DATE ____ LTR ____
CATEGORY Structural/Spacecraft Mechanical (9)

2. TITLE Entry Probe

3. TECHNOLOGY ADVANCEMENT REQUIRED

To develop entry probe heatshield capable of planetary entry with large ΔV environment.

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
4	4	7

The current state of the art is the Apollo heatshield but some planetary missions will have a ΔV larger than the capability of the existing thermal shield used on the Apollo Command Module.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1980
PAYLOAD DEVELOPMENT LEAD TIME 2 YEARS. TECHNOLOGY NEED DATE 1978

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS 2

TECHNICAL BENEFITS The large ΔV entry probe heatshield technology is required to enable passage through the measurements of the atmospheres of Uranus, Saturn, and Jupiter.

POTENTIAL COST BENEFITS The cost savings are related to the effectiveness of the mission and avoidance of excessive repetition.

ESTIMATED COST SAVINGS $ Low

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS 1. Validity of ablative analyses at high heating rates; 2. Sensitivity of analysis to atmospheric composition, radiation blockade, and subliming chemistry; 3. Scaling validity; 4. Effect of high radiation on components; 5. Radio transmission blackout possibilities at some angles.

REQUIRED SUPPORTING TECHNOLOGIES 1. Insulation between heatshield and probe instruments.

7. REFERENCE DOCUMENTS/COMMENTS a. FPTRS Rpt No. CASD-NAS-75-004, June 75; b. Atmospheric Entry Probes for Outer Planet. Exploration - A Technical Review and Summary by Dynatrend, Inc., August 1974.

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TITLE Entry Probe NO. E-10

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Scaled down experimental entry probe heatshield plus instruments and radio relay link launched from a planetary payload such as PL 11-A or PL-13-A.

TEST DESCRIPTION: ALT. (max/min) (1) / (1) km, INCL. (1) deg, TIME 6 hr

Enter scaled down probe with experimental heatshield into atmosphere of Jupiter from a high velocity trajectory; relay heatshield measurements to mother spacecraft via radio.

BENEFIT OF SPACE TEST: Provide a representative high velocity trajectory into a high density atmosphere.

EQUIPMENT: WEIGHT 100 kg, SIZE X 0.5mD X 0.5 m, POWER 0.1 kW

POINTING 1^o STABILITY 1^o DATA 100 bps

ORIENTATION Shield toward planet CREW: NO. 0 OPERATIONS/DURATION 1 / 6 hrs.

SPECIAL GROUND FACILITIES: Tests in hyper velocity tunnels at ARC or Tullahoma, Tenn. EXISTING: YES [X] NO [ ]

TEST CONFIDENCE 0.7

9. GROUND TEST OPTION TEST ARTICLE: Scaled down entry probe heatshield plus sensors and instrumentation.

TEST DESCRIPTION/REQUIREMENTS: Test experimental heatshield in a hyper velocity or plasma tunnel.

SPECIAL GROUND FACILITIES: Hyper velocity tunnel with velocities beyond 20,000 m/s and progressively increasing densities up to Jupiter atmosphere values. EXISTING: YES [ ] NO [X]

GROUND TEST LIMITATIONS: No adequate high velocity tunnel exists at present; it may be difficult to simulate by using a high acceleration rocket to ram the test model into the ~~atmosphere of earth.~~ TEST CONFIDENCE 0.1

10. SCHEDULE & COST

TASK	SPACE TEST OPTION	COST ($)	GROUND TEST OPTION	COST ($)
1. ANALYSIS				
2. DESIGN				
3. MFG & C/O				
4. TEST & EVAL				
TECH NEED DATE				
GRAND TOTAL		15M(2)		15M

11. VALUE OF SPACE TEST $ 312M (SUM OF PROGRAM COSTS $ 520M)

12. DOMINANT RISK/TECH PROBLEM

DOMINANT RISK/TECH PROBLEM	COST IMPACT	PROBABILITY
(1) Heatshield Materials	2M	0.5

COST RISK $ 1M

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(1) Scaled Model probe to enter Jupiter atmosphere.
(2) Costs shared with scientific mission on a planetary payload.

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. E-11
PAGE 1

1. REF. NO. ______ PREP DATE ______ REV DATE ______ LTR ______
CATEGORY Entry (9)

2. TITLE Nuclear Waste Disposal Package

3. TECHNOLOGY ADVANCEMENT REQUIRED

To develop safe disposal packages to withstand abort Re-entry and Impact

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
4	4	7

The current state of the art is heatshield and impact shells for the relatively light weight RTG's. There is no massive weight experience.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1985
PAYLOAD DEVELOPMENT LEAD TIME 5 YEARS. TECHNOLOGY NEED DATE 1980

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______

TECHNICAL BENEFITS The technology is required to provide the option of space disposal of nuclear waste.

POTENTIAL COST BENEFITS Elimination of the waste disposal problem would permit widespread nuclear power generation thereby allowing the U.S. to be independent of outside sources for energy.

ESTIMATED COST SAVINGS $ High

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS
a. Validity of radiative flowfield modeling
b. Light weight shielding development
c. Impact resistant structures
d. Heavy payloads

REQUIRED SUPPORTING TECHNOLOGIES Nuclear radiation shielding

7. REFERENCE DOCUMENTS/COMMENTS Feasibility of Space Disposal of Radioactive Nuclear Waste I. Executive Summary NASA TMX2911 II Technical Summary NASA TMX-2912

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TITLE Nuclear Waste Disposal Package

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PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Nuclear Waste Disposal Package

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

Launch capsule and propulsion system from orbiter for entry.

BENEFIT OF SPACE TEST: Simulate full-scale flight environment

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: Tracking, Recovery

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: None

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ____

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

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FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

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PAGE 1

1. REF. NO. ______ PREP DATE ______ REV DATE ______ LTR ______
CATEGORY ______

2. TITLE Lifting Body Entry Vehicles

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
3	4	7

The development of a heatshield and configuration to survive on earth re-entry at speeds over 15 km/sec. The heatshield and entry vehicle structure are to be combined for mass saving. Ablative/reflective or carbon phenolic materials are needed to satisfy manned flight constraints.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1988
PAYLOAD DEVELOPMENT LEAD TIME 5 YEARS. TECHNOLOGY NEED DATE 1983

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______

TECHNICAL BENEFITS A heatshield design based on flying at an angle of attack with a low ballistic coefficient entry vehicle as dictated by the necessity of controlling angle of attack and trajectory. These constraints are necessary so that the acceleration limits of the crew are not exceeded.

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS a. Considerable uncertainty exists in predicting the magnitudes of radiative flux on the surface of large vehicles. b. uncertainty in boundary layer transition criteria. c. a configuration which allows lift modulation without excessive heat flux must be found.

~~REQUIRED SUPPORTING~~ Related TECHNOLOGIES a. Outer Planets Entry Probe Heatshield and Configuration b. Radiative Flowfield Modeling

7. REFERENCE DOCUMENTS/COMMENTS ______

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TITLE Lifting Body Entry Vehicles NO. E-12

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Scaled Lifting Body Entry Vehicle

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

Launch vehicle and propulsion from orbiter for entry

BENEFIT OF SPACE TEST: Simulate flight environment

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: Tracking, recovery

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: None

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ____

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	SPACE TEST OPTION							GROUND TEST OPTION						
CY							COST ($)							COST ($)
1. ANALYSIS														
2. DESIGN														
3. MFG & C/O														
4. TEST & EVAL														
TECH NEED DATE														
	GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

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FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. E-13
PAGE 1

1. REF. NO. ______ PREP DATE ______ REV DATE ______ LTR ______
CATEGORY Entry (9)

2. TITLE Buoyant Station

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED
3	4	7

The successful entry and deployment of a buoyant station in the earth's atmosphere provides flight data and experience to be utilized in the perfection of a planetary buoyant station deployment system.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1983
PAYLOAD DEVELOPMENT LEAD TIME 3 YEARS. TECHNOLOGY NEED DATE 1980

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______

TECHNICAL BENEFITS Experimental evaluation of retarding and erecting devices that are a part of the deployment system for a planetary buoyant station. The science platform and communications station of planetary entry probes to some planets require buoyant support from a system capable of prompt deployment during a high-speed free-fall.

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS 1. Minimizing structural/materials weight and still maintain a system strong enough to withstand launching forces and atmospheric turbulence. 2. Providing a realistic test environment. 3. The ground launch of buoyant stations present considerable difficulties.

~~REQUIRED SUPPORTING TECHNOLOGIES~~ Related Technologies None

7. REFERENCE DOCUMENTS/COMMENTS ______

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TITLE Bouyant Station

NO. E-13
PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Buoyant Station

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

Launch Bouyant station from orbiter for entry and system operation verification.

BENEFIT OF SPACE TEST: Simulate full-scale environment for system tests.

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: Tracking, recovery

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: None

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ____

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

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FUTURE PAYLOAD TECHNOLOGY **NO.** E-14

TESTING AND DEVELOPMENT REQUIREMENT **PAGE** 1

1. REF. NO. ____ **PREP DATE** ____ **REV DATE** ____ **LTR** ____

CATEGORY Entry (9)

2. TITLE Radioisotope Thermoelectric Generator

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

Full scale RTG heat source must be flown on an entry trajectory typical of that resulting from a launch vehicle upper stage malfunction leading to a supercircular entry.

4. SCHEDULE REQUIREMENTS **FIRST PAYLOAD FLIGHT DATE** 1980

PAYLOAD DEVELOPMENT LEAD TIME 2 **YEARS. TECHNOLOGY NEED DATE** 1978

5. BENEFIT OF ADVANCEMENT **NUMBER OF PAYLOADS** ____

TECHNICAL BENEFITS Validates thermal stress analyses and demonstrates re-entry survival of RTG heat sources so that the risks (exposure to nuclear material) associated with launching spacecraft employing RTG's can be accurately assessed.

POTENTIAL COST BENEFITS Could reduce the magnitude of the interagency safety review process required for each RTG-carrying mission.

ESTIMATED COST SAVINGS $?

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS
a. Aerodynamic heating to typical aerodynamic shapes.
b. Thermal stress analyses for graphite materials.

REQUIRED SUPPORTING TECHNOLOGIES
a. Re-entry aerodynamic heating
b. Re-entry ablation analyses

7. REFERENCE DOCUMENTS/COMMENTS

FT (TDR-1) 7/75

TITLE Radioisotope Thermoelectric Generator Heat Source NO. E-14
PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: RTG Heat Source (simulated)

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

Launch RTG heat source (simulated) from orbiter for entry survival verification.

BENEFIT OF SPACE TEST: Provide flight verification environment.

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: Tracking, recovery

EXISTING: YES ☐ NO ☐

TEST CONFIDENCE ____

9. GROUND TEST OPTION TEST ARTICLE: ____

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____

EXISTING: ·S ☐ NO ☐

GROUND TEST LIMITATIONS: ____

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

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FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. E-15
PAGE 1

1. REF. NO. ______ PREP DATE ______ REV DATE ______ LTR ______
CATEGORY Entry (9)

2. TITLE Astronaut Retrieval

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

Develop heatshield and aerothermo-dynamics for emergency recovery of earth orbital space station/vehicle personnel and/or equipment. The current state of the art is unknown. Some components and materials may exist but are presently undefined.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1981
PAYLOAD DEVELOPMENT LEAD TIME 3 YEARS. TECHNOLOGY NEED DATE 1978

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______

TECHNICAL BENEFITS A minimum weight, compact, easily storable entry package that provides safe entry for space station personnel who-because of emergency, must abondon their station and return to earth. Lives saved!

POTENTIAL COST BENEFITS Human Life! Cost of replacing trained personnel

ESTIMATED COST SAVINGS $ 00

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS
a. Validity of flowfield prediction techniques
b. TPS Development: light weight, high performance, storable
c. Flight tests

REQUIRED SUPPORTING TECHNOLOGIES Space Suit
High temperature decelerator

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TDR-1) 7/75

TITLE Astronaut Retrieval NO. E-15

PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION TEST ARTICLE: Recovery system, Biomedical dummy

TEST DESCRIPTION: ALT. (max/min) ____ / ____ km, INCL. ____ deg, TIME ____ hr

Not important

BENEFIT OF SPACE TEST: Verify design concepts - qualify system

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW

POINTING ____ STABILITY ____ DATA ____

ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____ / ____

SPECIAL GROUND FACILITIES: Recovery, tracking

EXISTING: YES [X] NO [ ]

TEST CONFIDENCE High

9. GROUND TEST OPTION TEST ARTICLE: ____

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____

EXISTING: YES [ ] NO [ ]

GROUND TEST LIMITATIONS: ____

TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	SPACE TEST OPTION: CY						COST ($)	GROUND TEST OPTION: CY						COST ($)
1. ANALYSIS														
2. DESIGN														
3. MFG & C/O														
4. TEST & EVAL														
TECH NEED DATE														
GRAND TOTAL														

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM COST IMPACT PROBABILITY

COST RISK $ ____

FT (TDR-2) 7/75

FUTURE PAYLOAD TECHNOLOGY
TESTING AND DEVELOPMENT REQUIREMENT

NO. E-16
PAGE 1

1. REF. NO. ______ PREP DATE ______ REV DATE ______ LTR ______
CATEGORY Entry (9)

2. TITLE Small Deployed Vehicles

3. TECHNOLOGY ADVANCEMENT REQUIRED

LEVEL OF STATE OF ART		
CURRENT	UNPERTURBED	REQUIRED

Obtain fundamental transition data fr-e from ground facility effects on various basic aerodynamic shapes. Development and validation of techniques for more accurately predicting regions on these shapes that will experience turbulent flow. Present transition criteria contain uncertainties of at least an order of magnitude.

4. SCHEDULE REQUIREMENTS FIRST PAYLOAD FLIGHT DATE 1980
PAYLOAD DEVELOPMENT LEAD TIME 3 YEARS. TECHNOLOGY NEED DATE 1977

5. BENEFIT OF ADVANCEMENT NUMBER OF PAYLOADS ______

TECHNICAL BENEFITS Flight test transition data on larger models than can be tested in ballistic ranges. Boundary layer transition data not contaminated by aerodynamic noise and "facility effects" that would be present in conventional wind tunnels.

POTENTIAL COST BENEFITS ______

ESTIMATED COST SAVINGS $ ______

6. RISK IN TECHNOLOGY ADVANCEMENT

TECHNICAL PROBLEMS No rational basis for judging the various transition criteria is available due to 1. the fact that the criteria are only accurate within an order of magnitude. 2. the unreliability of wind tunnel data. 3. the total lack of flight data.

~~REQUIRED SUPPORTING~~ Related TECHNOLOGIES 1. Improved mathematical modeling techniques for real gas flowfields and ground/flight extrapolation.

7. REFERENCE DOCUMENTS/COMMENTS ______

FT (TDR-1) 7/75

TITLE Small Deployed Vehicles — NO. E-16
PAGE 2

COMPARISON OF SPACE & GROUND TEST OPTIONS

8. SPACE TEST OPTION — TEST ARTICLE: Deployed payloads - Piggy - back, small with propulsion

TEST DESCRIPTION: ALT. (max/min) ____/____ km, INCL. ____ deg, TIME ____ hr
Launch small payloads with required propulsion

BENEFIT OF SPACE TEST: Provide free - flight environment

EQUIPMENT: WEIGHT ____ kg, SIZE ____ X ____ X ____ m, POWER ____ kW
POINTING ____ STABILITY ____ DATA ____
ORIENTATION ____ CREW: NO. ____ OPERATIONS/DURATION ____/____
SPECIAL GROUND FACILITIES: Tracking, recovery
EXISTING: YES ☐ NO ☐
TEST CONFIDENCE ____

9. GROUND TEST OPTION — TEST ARTICLE: None

TEST DESCRIPTION/REQUIREMENTS: ____

SPECIAL GROUND FACILITIES: ____
EXISTING: YES ☐ NO ☐

GROUND TEST LIMITATIONS: ____
TEST CONFIDENCE ____

10. SCHEDULE & COST

TASK	CY	SPACE TEST OPTION						COST ($)	GROUND TEST OPTION						COST ($)
1. ANALYSIS															
2. DESIGN															
3. MFG & C/O															
4. TEST & EVAL															
TECH NEED DATE															
		GRAND TOTAL							GRAND TOTAL						

11. VALUE OF SPACE TEST $ ____ (SUM OF PROGRAM COSTS $ ____)

12. DOMINANT RISK/TECH PROBLEM — COST IMPACT — PROBABILITY

COST RISK $ ____

FT (TDR-2) 7/75

APPENDIX 3.

FRC INPUT

SPACE RESEARCH AND TECHNOLOGY OPPORTUNITY

I. TITLE

Space Shuttle Parameter Estimation

II. OBJECTIVE AND SCOPE

Aerodynamic data for reentry flight conditions are virtually nonexistent. The objective of the parameter estimation program, therefore, is to extend the applicability of currently available mathematical tools for determination of stability and control, performance, structural and atmospheric turbulence characteristics in the reentry environment. It is expected that the flight studies will yield the vehicle structural mode characteristics, structural mode coupling and turbulence response as well as the aerodynamic modes. In addition to providing final verification of the predicted aerodynamic characteristics, the results will serve directly as a medium for expanding the vehicle flight envelope, improving the overall system performance, and assessing compliance with design specifications. Estimates of these characteristics as they become available will also be useful for upgrading fixed-base simulators and projecting future mission profiles.

III. CURRENT STATE OF THE ART

During the past decade, stability and control characteristics have been derived from flight tests by means of a modified maximum likelihood method* developed at the NASA Flight Research Center. Over 2000 maneuvers have been successfully analyzed with this method for twenty different aircraft tested at the Center as well as many other aircraft tested by various aircraft companies and other government agencies. These aircraft range from lifting bodies to several large transports, including a large supersonic bomber. The Shuttle is expected to differ from the earlier applications principally in the type of maneuvering required during entry, the influence of control augmented damping, the transient nature of the flight test conditions, and the degree of coupling between the structural and aerodynamic modes. It is anticipated that the additional complexities introduced in the reentry environment can be adequately handled by a more generalized version of the existing method currently under development. In particular, allowances are made for rapid variations of velocity and dynamic pressure during maneuvers and for structural/aerodynamic mode coupling. The generalized method has been partially verified on the basis of simulated data and is about to enter a

*Practical Aspects of Using a Maximum Likelihood Estimator, by Kenneth W. Iliff and Richard E. Maine, NASA Flight Research Center.

III. Current State of the Art (continued)

test phase on several aircraft, including the B-1. The possible lack of precise air data measurements at hypersonic speeds may present some difficulty in reducing the flight data to dimensionless wind tunnel tests and analytic studies.

IV. PROPOSED RESEARCH PROGRAM

A. Technical Approach

The approach to be used in extracting aerodynamic characteristics during the reentry phase will be essentially the same as those employed in earlier flight test programs. Maneuvers will be requested for a grid of flight conditions within the Shuttle's operational envelope. These maneuvers will include longitudinal and lateral-directional excitations in and out of turbulence for periods from 5 to 30 seconds in duration. Standard stability and control studies including various types of control inputs (i.e., pilot, computer generated, and perhaps optimal inputs). Performance maneuvers will consist of rapid pushovers, pull-ups, and wind up turns. Obtaining performance data from dynamic maneuvers is particularly advantageous where the flight conditions are rapidly changing.

B. Resource Requirements

The funding required for adaptation of existing parameter estimation methods can be obtained from in-house sources already designated for developing new analytical techniques. Manpower and facilities also would be drawn from existing sources.

V. PREPARED BY

Kenneth W. Iliff
Flight Research Center

SPACE RESEARCH AND TECHNOLOGY OPPORTUNITY

I. TITLE

Determination of Lift and Drag in the Hypersonic Speed Region in Flight

II. OBJECTIVE AND SCOPE

The objective of the proposed experiment is to obtain a data base of aerodynamic information on the Shuttle Orbiter Vehicle in the hypersonic flight region which can be correlated with analytical and model test predictions. In order to accomplish this task, a spherical shaped body incorporating flush static ports for measuring pressures is recommended to be installed on the Orbiter vehicle at the nose location. This nose installation will permit the measuring of air data quantities which are necessary in order to determine the aerodynamic information which is needed for correlation.

The scope of the investigation is to design, fabricate and install on the nose of the Shuttle Orbiter Vehicle this spherical shaped body. Wind tunnel tests of the system will have to be accomplished before any full-scale testing in flight. From flight data, during reentry, lift and drag data will be obtained, analyzed and correlated with model test and analytical predictions. The data obtained will be used to extend air data technology beyond current limits and also to provide design data for advanced vehicles and air data systems.

III. CURRENT STATE OF THE ART

Air data measurements of the Shuttle Orbiter Vehicle in the hypersonic speed region are currently being obtained from inertial measurements. These measurements are deemed inadequate for determining aerodynamic phenomena, such as lift and drag, due to the fact that atmospheric winds do occur in that altitide region where the hypersonic speed regime of interest will occur. Also, the inertial system senses altitude by using a model which conforms to a standard atmosphere. The density variations from a standard atmosphere due to location, season and weather cause large uncertainties in altitude, thereby making correlation with model tests and theory almost impossible. The state of the art limits have been set by investigations which were performed while using the X-15 research aircraft, with it's maximum speed and altitude being approximately M=6.0 and H=350,000 feet, respectively.

IV. PROPOSED RESEARCH PROGRAM

A. Technical Approach

Full-scale lift and drag data will be obtained at various flight conditions. Measurements will include pressures on the nose of the vehicle from which angle of attack, angle of sideslip and stagnation pressure will be determined. These measurements will be obtained over the hypersonic Mach number and altitude range during a nominal mission. The speed range of interest is from M=4.0 to M=10.0. This data will be correlated with results from model tests and theoretical predictions.

B. Funding and Manpower

Additional funding will be required to provide for the fabrication of the nose cone with the needed pressure ports. Environmental control of the sensors which will be used will also require additional funding.

Manpower requirements to accomplish this technology research have not been accomplished.

V. PREPARED BY

Harold P. Washington
Flight Research Center

SPACE RESEARCH AND TECHNOLOGY OPPORTUNITY

I. TITLE

Reaction Control Interactions

II. OBJECTIVE

The aerodynamic interactions between reaction control jets and adjacent vehicle surfaces at high Mach numbers produce control moments that are sensitive to viscous (scale) effects and thus are difficult to predict from small-scale wing tunnel studies. The goal of this experiment is to measure full-scale reaction control effectiveness and, in turn, assess the accuracy of design estimates.

III. CURRENT STATE OF THE ART

Entry attitude control of the Shuttle will be provided by reaction control thrusters (RCS) mounted in pods on each side of the rear of the fuselage. Each pod contains four up thrusters, four down thrusters, and four side thrusters which can be operated in various combinations to provide pitch, roll, and yaw control (figure 1). During initial reentry, a combination of aerodynamic and reaction controls will be used for maneuvering.

For dynamic pressures up to 5 psf, only the RCS is used for attitude control. From 5 to 20 psf, a combination of aerodynamic and reaction control is used. Wind tunnel studies have shown that where sensible aerodynamic forces and moments are present in sufficient magnitude to affect the motions of the vehicle, the reaction controls - depending on the thrusters used and mode of control applied - interact with aerodynamic flow. This interaction under certain conditions may result in a decrease in jet-control effectiveness. The mechanism for this effect is not yet fully understood, particularly in relation to shock wave and boundary-layer phenomena at high Mach numbers.

IV. PROPOSED RESEARCH PROGRAM

A. Technical Approach

Full-scale data will be obtained involving various combinations of thrusters for each mode of control to obtain net control effectiveness and extent of jet interference with the surrounding flow. Measurements will include vehicle response, derivative characteristics, and static-pressures on the wing, fuselage, and vertical tail. Also, if feasible, provisions will be made for tuft studies of flow to reveal any flow separation due to the jet thrusters.

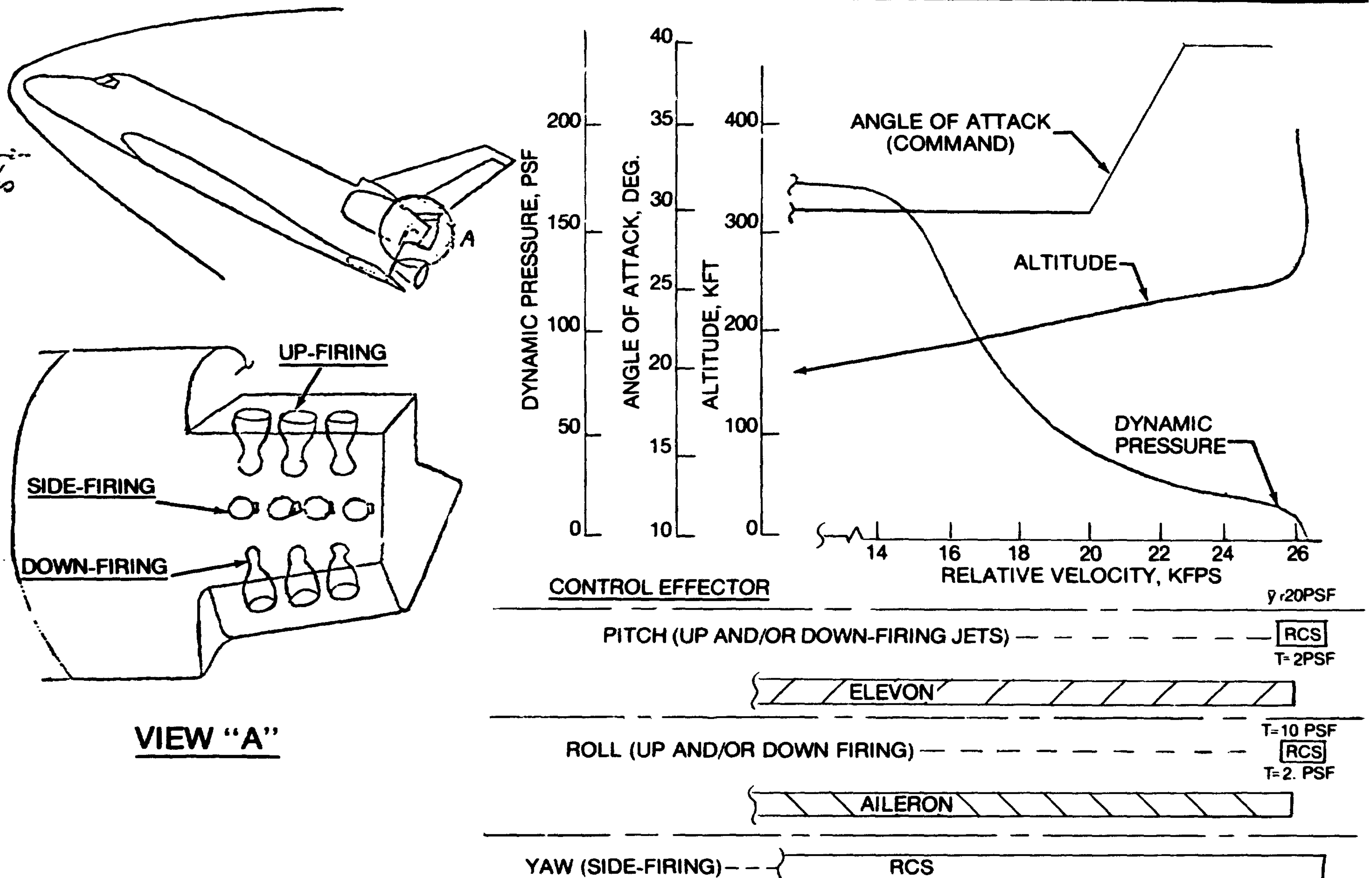
B. Funding and Manpower

Additional funding may be required to provide a sufficient number of static-pressure orifices to show the changes due to jet interference. Also, a camera will be required for photographing tuft patterns.

Flight Research Center manpower requirements include primarily a research engineer (full time), an instrumentation engineer (half time), an instrumentation technician (full time), for a period of two or more years.

V. PREPARED BY

Chester H. Wolowicz
Flight Research Center



North American Space Operations — Space Division, Rockwell International

5-11

RCS REQUIREMENT FOR ENTRY (HIGH & TRAJECTORY)

SPACE RESEARCH AND TECHNOLOGY OPPORTUNITY

I. TITLE

The Real Environment Hypersonic Boundary-Layer

II. OBJECTIVE

The objective will be to measure and define important boundary-layer parameters in a real flight environment and compare the results with semi-empirical predictions and ground facility data.

III. PROPOSED RESEARCH

The proposed research would utilize the orbiter as a carrier vehicle similar to the way the X-15 research airplane was used to expose specialized instrumentation to real flight generated boundary-layers. Examples of why this kind of data is needed and how these data would be obtained follows.

It may be helpful to recall that in order to predict skin friction or heat transfer at high Mach numbers, and for non-adiabatic conditions, empirical and semi-empirical methods must be used, i.e., the best "theory", if you could decide which one that was, must rely on experimentally determined constants. Furthermore, these constants have been obtained over a wide range of conditions which are difficult to control, and this has contributed to a confusing picture. An example is given in figure 1 where it can be seen that as the various prediction methods depart from an adiabatic wall temperature, a large divergence occurs. Another example is given in figure 2 where values of the Reynolds analogy factor from several experiments and curves representing experimentally derived expressions are given for hypersonic Mach numbers. The scatter in the data show that much more work must be done before accurate predictions can be expected. This work will be expedited if special instrumented complexes are installed on the Orbiter vehicle.

Examples of such a complex are shown in figures 3(a) and 3(b). Though the bottom surface of the Orbiter would be the most ideal location from the standpoint of the experiment itself, it is assumed that the special instrumentation must be located so as to avoid the lower surface thermal protection system. Therefore, it is proposed that the instrumented complexes be located at one or more of the locations shown in figure 4. Such a complex would define: boundary-layer thickness and shape, local skin friction coefficient, surface static pressure, wall temperature, and heat transfer coefficients. Baseline data of this type should be obtained for plain surfaces which are flush with the vehicle mold line. In addition, it of interest to get heat transfer data for surfaces which deviate from the mold line, such as cavities, waves, corrugations, and some elementary protuberance shapes.

Two examples of such panels are shown in figures 5 and 6 which were tested on the X-15. For this type of work, the vehicle should have mirror-image twin instrumented complex locations so that baseline heat transfer data for the flush surface can be obtained at the same time. It should be emphasized that aside from the task of turning the data on and off, this type of experiment should be entirely piggy-back and should not affect the pilot task.

IV. PREPARED BY

Edwin J. Saltzman
Flight Research Center

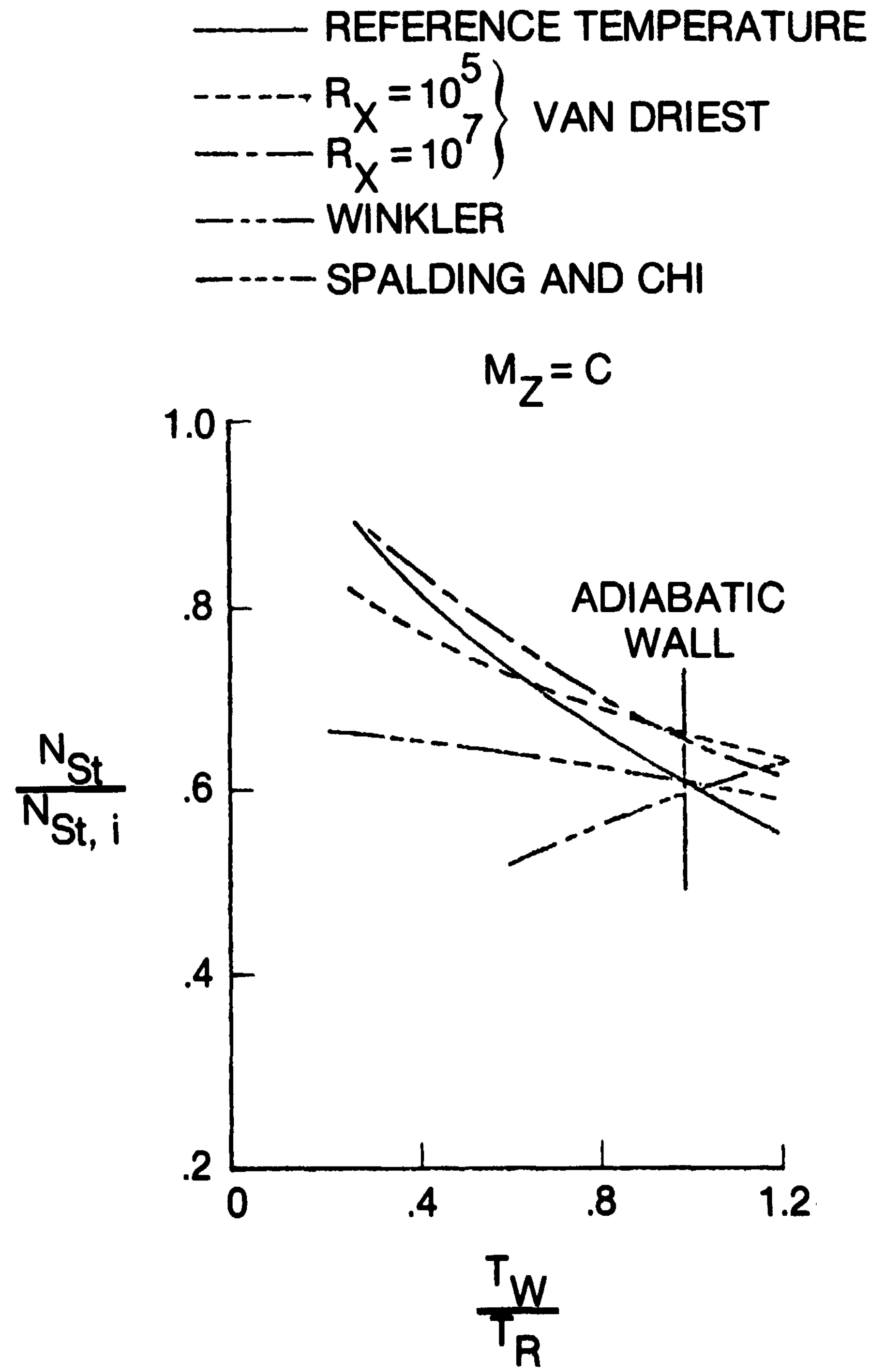


Fig. 1: TURBULENT HEAT-TRANSFER METHODS

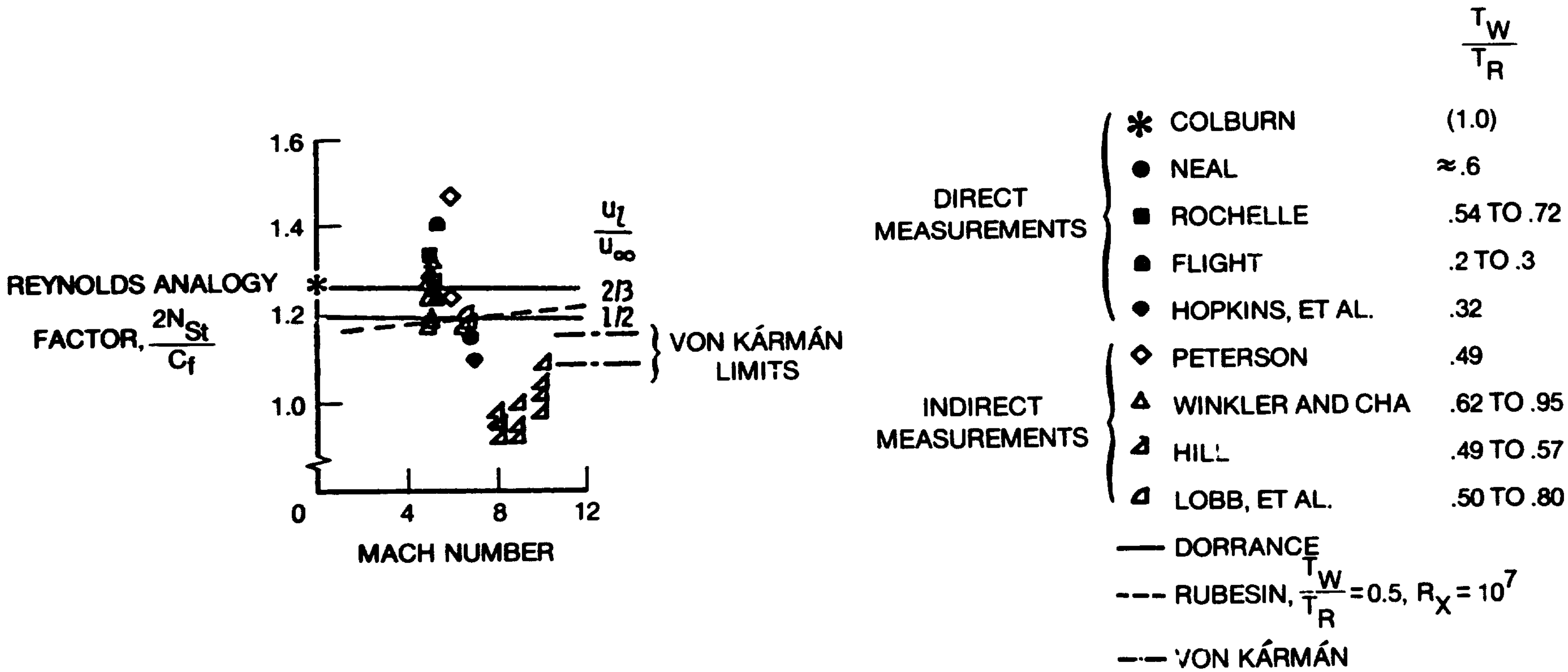


Fig. 2: VARIATION OF REYNOLDS ANALOGY FACTOR WITH MACH NUMBER
(NOTE: WIDE RANGE IN FACTOR AT GIVEN MACH FOR MEASURED VALUES)

NASA
E-19726

Fig. 3(a): BOUNDARY - LAYER COMPLEX, XB-70.

(B.L. RAKE, FRICTION BALANCE, PRESTON PROBE, WALL TEMPERATURE.)

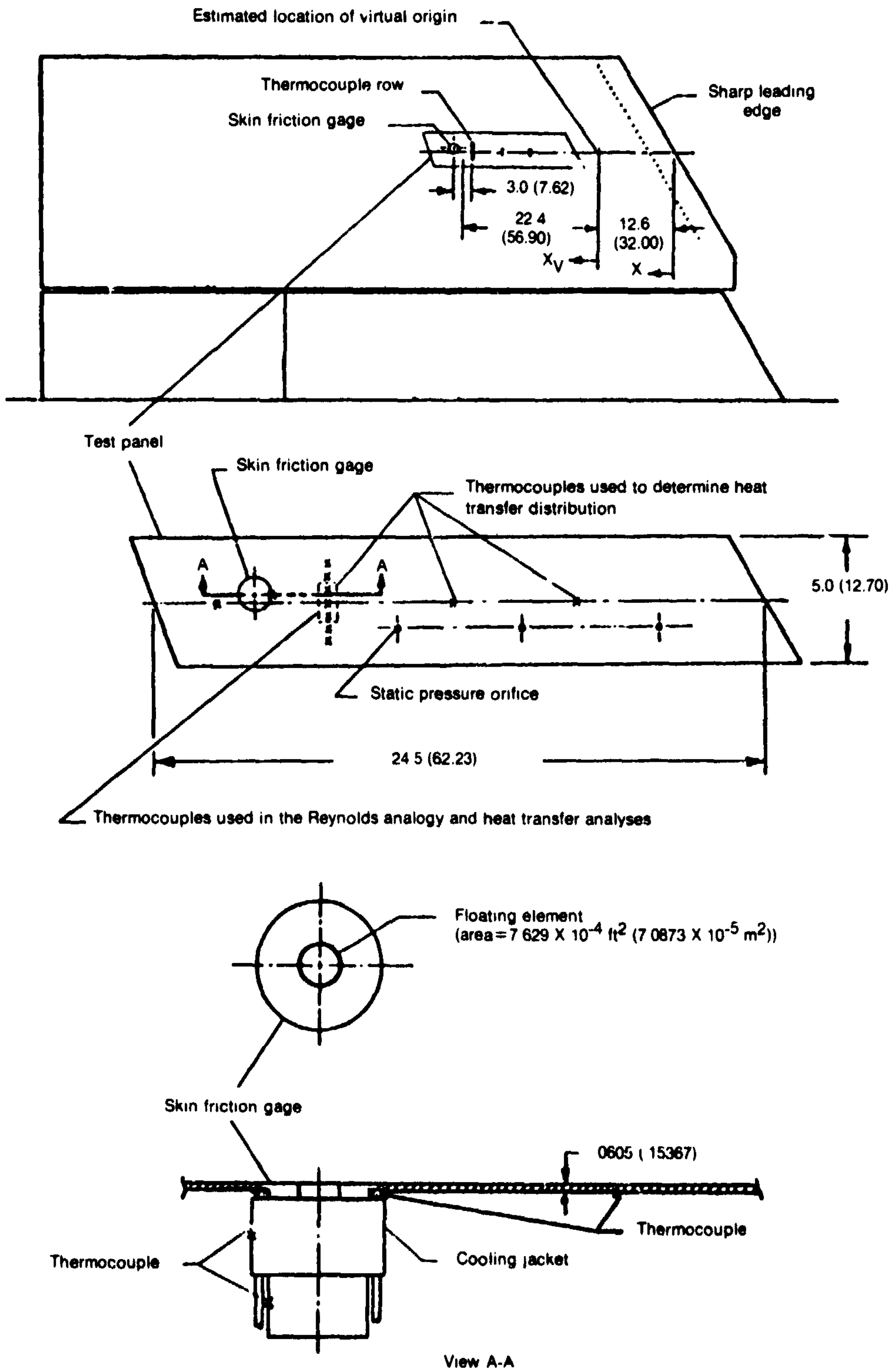


Fig. 3(b): LOCATIONS OF INSTRUMENTATION. ALL DIMENSIONS ARE IN INCHES (centimeters) UNLESS OTHERWISE NOTED.

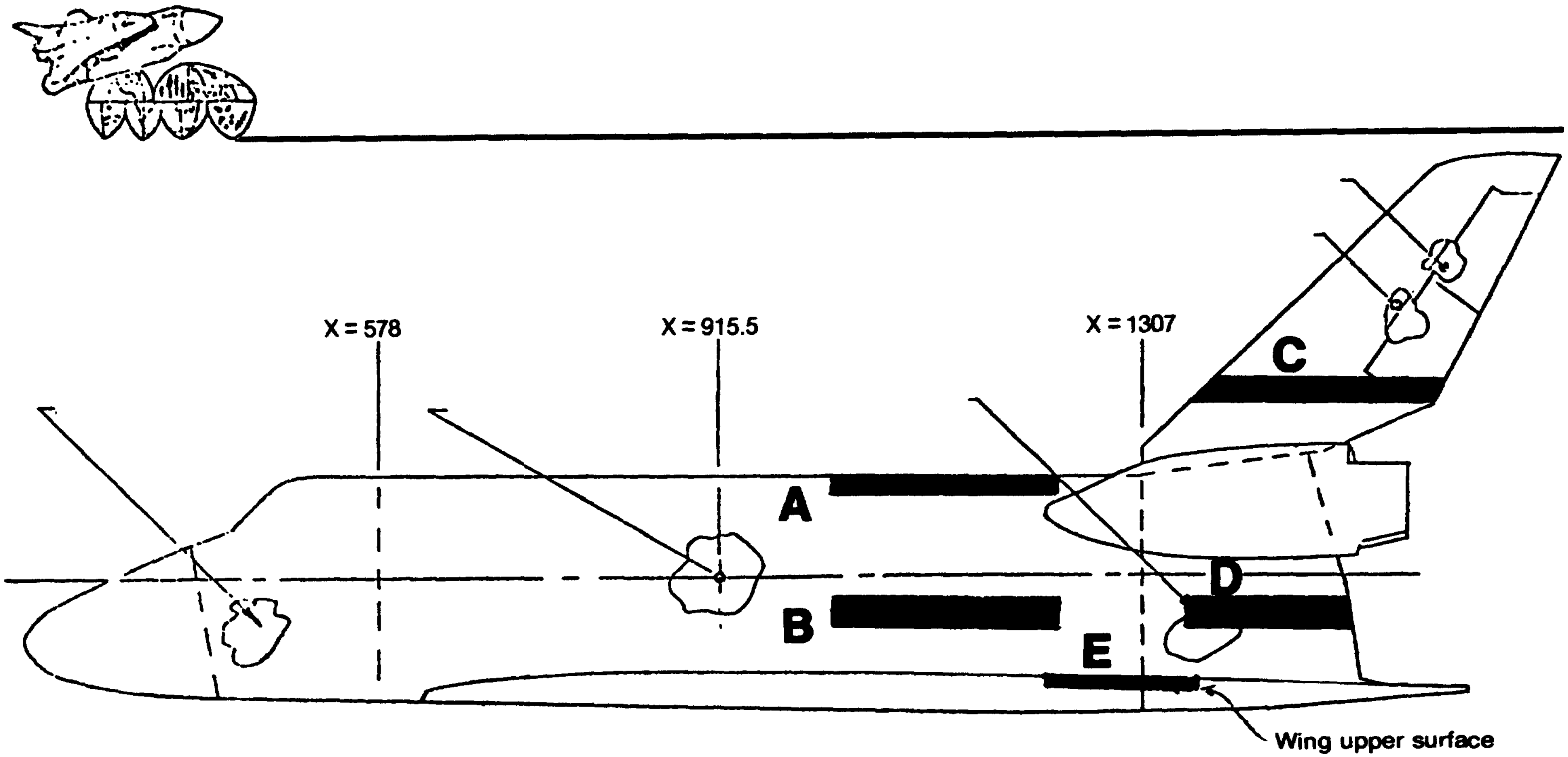


Fig 4: CANDIDATE LOCATIONS FOR HEAT TRANSFER - BOUNDARY LAYER PROTUBERANCE - SURFACE DISCONTINUITY EXPERIMENT COMPLEX

(EACH OF THESE LOCATIONS MAY BE BEST UTILIZED IF IT HAD A MIRROR - IMAGE TWIN LOCATION ON OPPOSITE SIDE OF VEHICLE.)

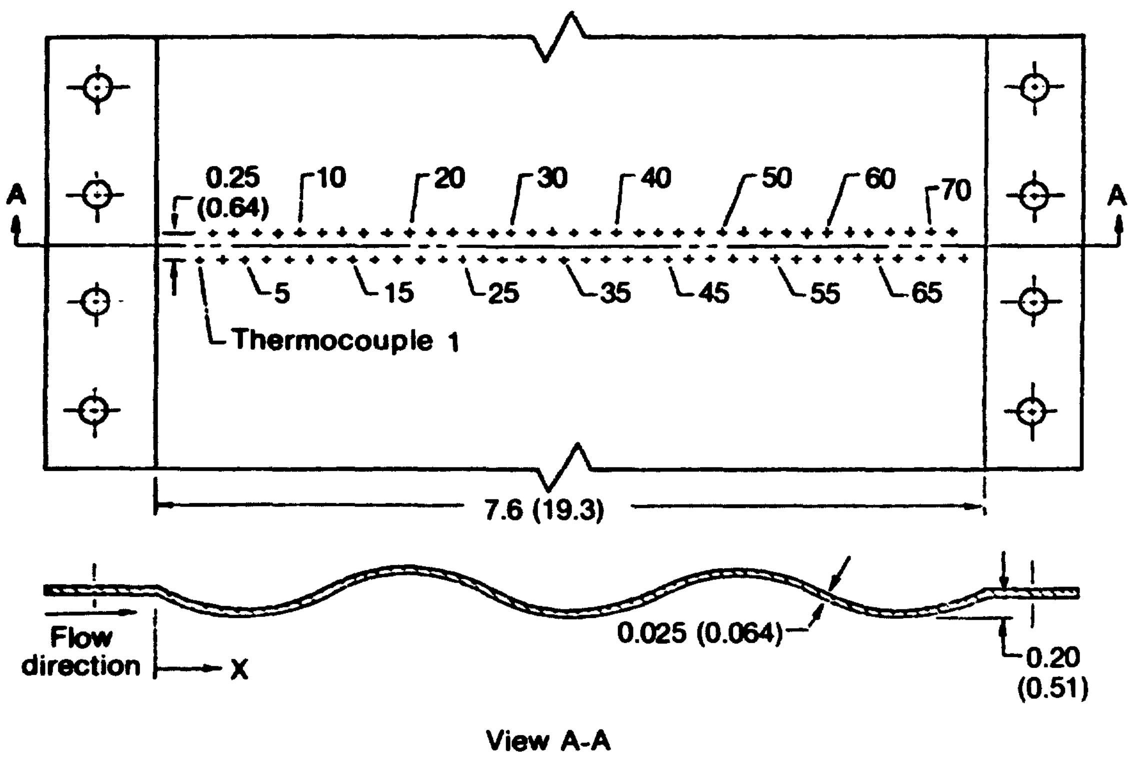
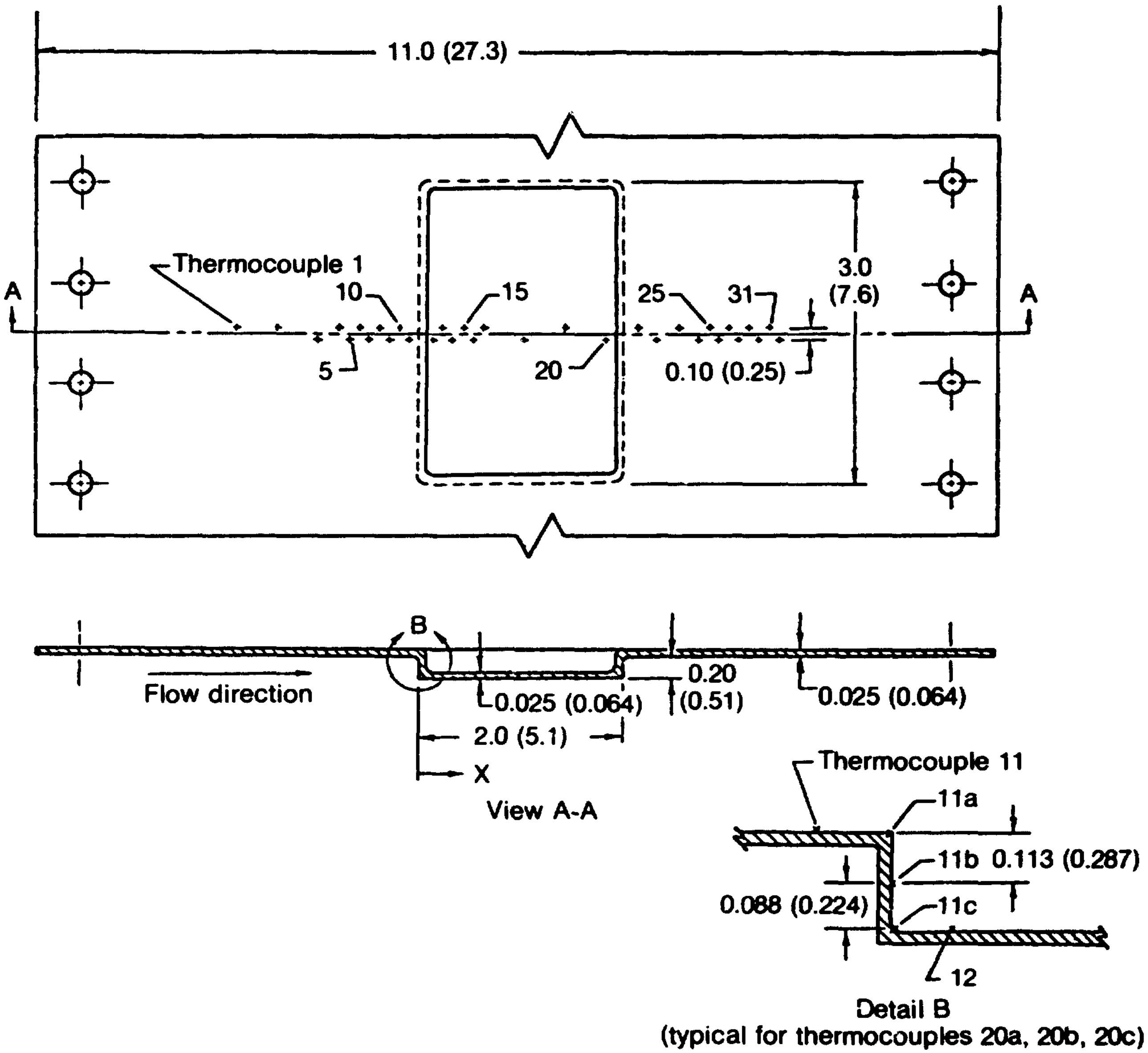


Fig. 5: SINE-WAVE CONFIGURATION.
ALL DIMENSIONS IN INCHES
(centimeters)

Thermo-couple	X	
	in	cm
1	0 3	0 8
2	4	1 0
3	5	1 3
4	6	1 6
5	7	1 8
6	8	2.0
7	9	2 3
8	1 0	2 6
9	1 1	2 8
10	1 2	3 0
11	1 3	3 3
12	1 4	3 6
13	1 5	3 8
14	1 6	4 1
15	1 7	4 3
16	1 8	4 6
17	1 9	4 8
18	2 0	5 1
19	2 1	5 3
20	2 2	5 6
21	2 3	5 8
22	2 4	6 1
23	2 5	6 4
24	2 6	6 6
25	2 7	6 9
26	2 8	7 1
27	2 9	7 4
28	3 0	7 6
29	3 1	7 9
30	3 2	8 1
31	3 3	8 4
32	3 4	8 6
33	3 5	8 9
34	3 6	9 1
35	3 7	9 4
36	3 8	9 6
37	3 9	9 9
38	4 0	10 2
39	4 1	10 4
40	4 2	10 7
41	4 3	10 9
42	4 4	11 2
43	4 5	11 4
44	4 6	11 7
45	4 7	11 9
46	4 8	12 2
47	4 9	12 4
48	5 0	12 7
49	5 1	12 9
50	5 2	13 2
51	5 3	13 5
52	5 4	13 7
53	5 5	14 0
54	5 6	14 2
55	5 7	14 5
56	5 8	14 7
57	5 9	15 0
58	6 0	15 2
59	6 1	15 5
60	6 2	15 7
61	6 3	16 0
62	6 4	16 3
63	6 5	16 5
64	6 6	16 8
65	6 7	17 0
66	6 8	17 3
67	6 9	17 5
68	7 0	17 8
69	7 1	18 0
70	7 2	18 3
71	7 3	18 5
72	7 4	18 8
73	7 5	19 1



Thermo-couple	X	
	in.	cm.
1	-1.8	-4.6
2	-1.4	-3.5
3	-1.0	-2.5
4	-0.8	-2.0
5	-.7	-1.8
6	-.6	-1.5
7	-.5	-1.3
8	-.4	-1.0
9	-.3	-.8
10	-.2	-.5
11	-.1	-.3
11a	0	0
11b	0	0
11c	0	0
12	.1	.3
13	.2	.5
14	.3	.8
15	.4	1.0
16	.5	1.3
17	.6	1.5
18	1.0	2.5
19	1.4	3.6
20	1.8	4.6
20a	2.0	5.1
20b	2.0	5.1
20c	2.0	5.1
21	2.1	5.3
22	2.3	5.8
23	2.5	6.4
24	2.7	6.9
25	2.8	7.1
26	2.9	7.4
27	3.0	7.6
28	3.1	7.9
29	3.2	8.1
30	3.3	8.4
31	3.4	8.6
32	3.5	8.9

Fig. 6: STEP CONFIGURATION. ALL DIMENSIONS IN INCHES. (centimeters)

SPACE RESEARCH AND TECHNOLOGY OPPORTUNITY

I. TITLE

Orbiter Airloads Research

II. OBJECTIVE

Both measurement and prediction of airloads on a delta wing-body shape in the transonic range and in the influence of aerodynamic heating and dissociated gases at hypersonic speeds need considerable further development for future applications. Data generated from the Orbiter flight test would supply much of the experimental data needed to advance these disciplines.

III. PROPOSED RESEARCH PROGRAM

A. Technical Approach

The current development program provides instrumentation to measure airloads on the wing and vertical tail using calibrated strain gages, one chordwise row of pressures orifices at the mid span of the wing and three rows on the vertical tail. Hinge moments on all control surfaces also will be measured. It is proposed as a minimum that a detailed comparison be made between the flight measurements from the sources and wind tunnel and theoretical predictions to assess generally the state of the art in this area. It is highly desirable, however, that additional rows of orifices and thermocouples be provided on the wing to enable a more comprehensive evaluation of the techniques used in the Shuttle structural design. Specific tasks would include:

1) Reduction of flight data for selected flight conditions.

2) Integration of wind tunnel results to obtain comparative airload predictions.

3) Setting up of an aero-thermo-elastic computer program for transformation of the wind tunnel results to predictions for the full-scale vehicle at the selected flight conditions.

B. Resource Requirements

Additional funding would be required if an expanded loads measurement system were allowed in the course of the flight program.

B. Resource Requirements (continued)

Flight Research Center manpower allocations for a two year period would include two research engineers (full time), one instrumentation engineer (half time), and an instrumentation technician (full time). A computer programmer would be required part time for the aero-thermo-elastic computations.

IV. PREPARED BY

Alan L. Carter
Flight Research Center

ABBREVIATED OUTLINE

SPACE RESEARCH AND TECHNOLOGY OPPORTUNITY

I TITLE - Energy Management

II OBJECTIVES AND SCOPE - To assess all aspects of energy management from orbital retrofire to touchdown during Vertical Flight Test and Operational Flights to improve the Orbiter navigational footprint.

III PROPOSED RESEARCH PROGRAM -

A. Technical Approach:

Within limitations of orbiter constraints, determine energy management techniques to obtain target navigational footprint. Required analysis and study would entail.

- Alternate targeting concepts, e.g. high key aim point.
- New methods for obtairing meterological data along entry trajectory.
- Use of air data from orbit to landing (not currently baselined).
- Use of ground and/or satelite navigation aids.

B. Funding, NASA manpower, facilities:

	CALENDAR YEAR						
	1975	1976	1977	1978	1979	1980	1981
Civil Service Manyears	1/2	1	1	2	2	3	2
Funding -$1000	0	0	10	100	100	100	100

C. Need for space flight experiments

1.) Space Shuttle Orbiter - Current orbiter footprint severly limited by thermal constraints, atmospheric properties uncertainties, lack of air data system in supersonic regime,etc.

New techniques based on operational data should considerably enlarge the orbiter navigational footprint.

2.) Advanced vechicles - Experimental results will provide information for design of navigation and guidance systems for future vehicles.

IV PREPARED BY

Richard E. Day