SD 70-8

SPACE SHUTTLE TECHNOLOGY REQUIREMENTS

1 July 1970

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Prepared by

Space Shuttle Technology Staff

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Space Division
North American Rockwell

NASA CR 108530

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FOREWORD

This report identifies supporting research and development requirements for the Space Shuttle Program and is submitted by the Space Division of North American Rockwell Corporation, Downey, California, to the National Aeronautics and Space Administration, Manned Spacecraft Center, Houston, Texas. Quarterly updates of this report will be submitted during the Phase B performance period as a contract requirement.

The report is a cooperative effort by the Space Division of North American Rockwell Corporation and the Convair Division of General Dynamics, with important contributions made by Honeywell, Inc., and IBM. Inputs to the report are arranged to comply with the NASA shuttle technology panels.

ABSTRACT

One hundred and twenty-two areas have been identified where research and technology development is required in order to assure timely implementation of the Space Shuttle Program. Task descriptions and cost and schedule estimates have been prepared for all items and are submitted to the NASA for consideration and incorporation into their shuttle technology development program.

SUMMARY

Reduction of the cost to transport payloads to and from space by the proposed Space Shuttle is realized by adopting reusable booster and orbiter systems, combined with the economy of airline turnaround operations. This approach will keep the requirement for technology development to a minimum. Recognizing the importance of early identification of all shuttle related technology development areas for meeting the shuttle schedule and performance objectives, the NASA has made the Technology Requirements Report a Shuttle Phase B contractual requirement. This first issue of the report contains 122 items identified by members of the NR Space Shuttle Team where research and technology development is required to meet the shuttle goals. The items consisting of task descriptions and cost and schedule estimates have been combined into seven technology sections. The following table summarizes the number of task descriptions and the estimated total cost to perform the tasks for each of the technology areas.

Technology	Items	Total Estimated Cost (K$)
Aerothermodynamics/Configuration	15	3,470
Dynamics and Aeroelasticity	11	4,925
Propulsion	18	19,000
Structures and Thermal Protection System	40	48,245
Biotechnology	8	1,840
Integrated Electronics	17	8,005
Operations, Maintenance, and Safety	13	1,715
	122	87,200

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CONTENTS

INTRODUCTION

The primary objective of the Space Shuttle Program is a reduction of the cost for transporting payloads to and from earth orbit by an order of magnitude. The proposed concepts to accomplish this goal center around two-stage, fully reusable vehicles with moderate lift-to-drag capability. Initial investigations during the shuttle Phase A studies indicated that no major technology breakthroughs are required to develop a reusable space transportation system, but that technology development efforts in selected areas have to be conducted during Phase B and prior to and in support of the shuttle detail design and development phases. A continuous effort has been in progress during the Phase A study period to identify these areas. The NASA has recognized the need for continued and timely identification of areas where technology development is required to meet the shuttle objectives, and quarterly SRT reports are a Phase B contractual requirement. In order to provide the NASA with an early visibility of Supporting Research and Development tasks identified by the North American Rockwell Space Shuttle Team, this report is submitted at Phase B contract go-ahead. It provides 122 task descriptions, including cost and schedule estimates. The inputs have been assembled in seven sections to comply with the NASA shuttle technology panels. During performance of the Phase B study, identification of SRT items will be continued and reported on a quarterly basis.

SRT IDENTIFICATION

The following criteria were established for identification and selection of SRT items:

1. The state of the art is insufficient to meet established shuttle requirements.

2. Improvement of shuttle performance.

3. Reduction of shuttle cost.

4. Generation of design and development data required for Phase C/D performance not covered by Phase B.

The development areas compiled in this report were identified by the shuttle functional areas with support from the central engineering organizations of the North American Rockwell/General Dynamics Convair team. The shuttle configurations and subsystems presented in the Phase B Proposal were used as a baseline against which the requirements were established. After identification of the tasks, they were evaluated and screened by functional engineering management and the shuttle technology manager, and finally approved by the Space Shuttle Engineering Review Board. The development schedules were established to provide study results and data in time for the shuttle Phase C/D requirements. The majority of the tasks is scheduled to be completed at Phase D go-ahead.

Identification of SRT items during the Phase B study will be a continuous process. They will fall into two categories. Additional development items identified against the baseline configuration as the result of detailed studies will still be defined by the shuttle functional groups and approved by the technology office. SRT items required against changes to the baseline configuration or changes to shuttle requirements will be identified as part of the trade study process.

Technology development requirements against various trade concepts will be assessed and the requirements will be part of the evaluation criteria. The SRT requirements for the concept selected by the Engineering Review Board will be documented in the quarterly SRT report.

SRT DOCUMENTATION

A standard form has been prepared for each approved development item. In addition to subject identification, a statement of the study objectives, a description of the problem, and a recommended plan of action (statement of work) have been prepared, backed up by a study schedule and a cost estimate. The statements have been arranged as follows:

Aerothermodynamics/Configuration

Dynamics and Aeroelasticity

Propulsion

Structures/TPS and Materials

Biotechnology

Integrated Electronics

Operations, Maintenance, and Safety

These groups are in conformance with the NASA Shuttle Technology Panels to ensure rapid dissemination of the identified tasks to those NASA locations where action can most likely be expected. Each section is preceded by a summary, listing the task subjects, the estimated cost, and the estimated schedule shown against the Shuttle Master Schedule

AEROTHERMODYNAMICS/CONFIGURATION

AEROTHERMODYNAMICS/
CONFIGURATION

AEROTHERMODYNAMICS / CONFIGURATION

SHUTTLE MAJOR MILESTONES	1970	1971	1972	1973	1974	1975
PHASE B STUDY						
PHASE C STUDY						
PHASE D DEVELOPMENT						
PRELIMINARY DESIGN REVIEW						
CRITICAL DESIGN REVIEW						
BOOSTER AND ORBITER STRUCTURAL TEST ELEMENTS				MFG TEST		
FLIGHT TEST VEHICLE 1				MFG		
FLIGHT TEST VEHICLE 2				MFG		
BOOSTER AND ORBITER STRUCTURAL TEST ARTICLES				MFG	TEST	

	AEROTHERMODYNAMICS/CONFIGURATION	1970	1971	1972	1973	1974	EST COST (SK)
1-1	FLOW FIELD DETERMINATION						135
1-2	BOUNDARY LAYER TRANSITION CRITERIA TURBULENT HEATING CORRELATION, AND HEATING PREDICTION						200
1-3	SURFACE ROUGHNESS CRITERIA						180
1-4	INTERFERENCE HEATING						200
1-5	DEFINITION OF AEROHEATING DESIGN CRITERIA						85
1-6	AERODYNAMIC ENVIRONMENT DURING LAUNCH						315
1-7	SEPARATION AERODYNAMICS						285
1-8	ROCKET PLUME IMPINGEMENT EFFECTS						315
1-9	BASE HEATING						380
1-10	POSTSTAGING STABILITY AND CONTROL OPTIMIZATION						350
1-11	DEFINITION OF MINIMUM HEATING ENTRY TRAJECTORIES AND FLIGHT CONTROL APPROACH						265
1-12	EFFECT OF MACH NUMBER ON VEHICLE STABILITY AND CONTROL DURING PITCHDOWN MANEUVER						140
1-13	ROTARY AND STATIC DERIVATIVES AT HIGH ANGLES OF ATTACK						150
1-14	AIRBREATHING PROPULSION EFFECTS						210
1-15	VERIFICATION OF AEROHEATING ANALYTICAL METHODS						260
					TOTAL		3470

1-1 FLOW FIELD DETERMINATION

OBJECTIVE

Develop improved analytical procedures for predicting 3-D flow fields about the shuttle orbiter and/or booster to generate data for configuration optimization and refined aerodynamic and heat transfer evaluation.

PROBLEM

Accurate and rapid engineering methods are urgently needed for the analytical prediction of aerodynamic moments, forces, and surface flow property distributions. Such predictions will supplement wind tunnel testing, particularly where the test conditions do not match real gas effects.

TECHNICAL APPROACH

A computer program utilizing the time-dependent method will be developed and used in parametric studies of vertical control surface effectiveness and pitching moment characteristics of the shuttle vehicles at angle of attack.

Coupling of a 3-D surface streamline pattern program with a boundary layer program will provide heat transfer data with streamline divergence effects included.

A combination of the above programs will yield a capability for including boundary layer swallowing of the nose generated entropy layer in a 3-D flow.

The results from the calculations will be correlated with existing flight and wind tunnel test data.

Tasks	1970			1971												Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
Parametric 3-D Flow field studies																35
Rapid 3-D heating analysis program																20
Effect of entropy swallowing on heat transfer																45
Data correlation																35
														Total cost		135

GFY 1971: 80K

GFY 1971: 55 K

1-2 BOUNDARY LAYER TRANSITION CRITERIA, TURBULENT HEATING CORRELATION AND HEATING PREDICTION

OBJECTIVE

Develop exact and rapid methods for predicting aerodynamic heating around a 3-D body.

PROBLEM

Application of reusable reradiative thermal protection systems for the shuttle orbiter requires accurate and reliable heating prediction methods which are not available at present.

TECHNICAL APPROACH

Three major independent tasks are to be performed: (1) Development of a viscous flow program for 3-D body shapes to allow the detailed calculation of aerodynamic heating rates in the laminar, transition, and turbulent regime; (2) Definition of transition criteria to include the effect of 3-D bodies and angle of attack. The study will include the influence of the flight and body characteristics on the length of the transition region; (3) Include transition criteria into the generalized 3-D viscous flow program. Heating calculations in the transition region will be made by assuming that the eddy transport properties follow a smooth analytical law between the beginning and the end of the transition.

Comparison with experimental data will be made for the three tasks mentioned, and modifications to the proposed program will ensure the reliability of the final program output.

Tasks	1970			1971												Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
Generalized 3-D viscous flow program																40
Transition criteria																60
Introduction of transition criteria, heating predictions																30
Test data correlations																70
															Total cost	200

GFY 1970: 100 K

GFY 1971: 100 K

1-3 SURFACE ROUGHNESS CRITERIA

OBJECTIVE

Define surface roughness design criteria to assure laminar flow over orbiter during period of maximum heating.

PROBLEM

A better analysis of the influence of the surface roughness on the transition critiera is necessary in order to accurately predict the aerodynamic heating rates on critical 3-D vehicles with protuberances and cavities.

TECHNICAL APPROACH

Theoretical methods will be analyzed and compared with experimental data for a large range of flight and body geometry conditions. Statistical mathematical methods will be used to select and weigh the influence of the roughness geometry on the start of transition. Specific experimental studies will be conducted to confirm the results obtained through statistical methods. The method should be general enough to allow the analysis of the "periodic roughness case" (wavy surface) as well as that of the "random roughness case" (protuberance). The definition of a transition parameter will result in final analysis. Such a result should be made as simple as possible so it can be introduced into a more generalized transition criteria program.

Tasks	1970			1971												1972			Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	
Analysis of existing method																			5
Statistical analysis and criteria definition																			25
Specific experimental studies to confirm or improve criteria																			150
																		Total cost	180

GFY 1971: 80 K

GFY 1972: 100 K

1-4 INTERFERENCE HEATING

OBJECTIVE

Define interference heating factors for mated booster orbiter configurations and delta- and straight-wing orbiters.

PROBLEM

Increase in the heating rate coefficients of almost two orders of magnitude can be expected for given shuttle configurations because of flow interference effects. Definition of criteria and methods is necessary to extend analyses to actual size spacecraft and to mini-minimize the uncertainties in flux predictions.

TECHNICAL APPROACH

Increase of aerodynamic heating due to interference is always due to a shockwave network (one or several) interacting with a boundary layer. Two different cases are encountered in the interference heating problem: (1) the mated configuration where a complete family of shockwaves can decelerate the flow to low subsonic velocities. This analysis involves the introduction of a length of mixing to be compared to a critical distance between the mated configuration. The final result will define a criterion for stagnation flow-type heating, nozzle flow-type heating, or non-interaction-type heating; and (2) the interaction between vehicle components where a single shock impinges at a given location. This single shock interference heating can be analyzed theoretically by an extension of the present generalized viscous flow field program where pressure gradients inside the boundary layer will be included, as well as a coupling between the viscous and inviscid fluids. Both studies should be backed up with an intensive experimental program.

Tasks	1970	1971	1972	Est Cost ($K)
	O N D	J F M A M J J A S O N D	J F M A M J J A S	
Mated configurations (theory and experiment)				75
Vehicle components interaction (theory and experiment)				125
			Total cost	200

GFY 1971: 75 K

GFY 1972: 100 K

GFY 1973: 25 K

1-5 DEFINITION OF AEROHEATING DESIGN CRITERIA

OBJECTIVE

Establish design approach for controlling conservatism in heating rate estimates.

PROBLEM

SSV weight sensitivity and TPS design criticality preclude extensive conservatism in the definition of aeroheating rates.

TECHNICAL APPROACH

Uncertainty bands in skin temperature due to uncertainty in defining aerodynamic heating rates (flow field, turbulent heating method, boundary layer transition, separated flow, interference effects), will be defined in order to establish impact of uncertainty and the major contributors. Allowable uncertainty in heating predictions will be specified and compared with existing state-of-the-art. For those aspects where the uncertainty range is unacceptable, it is recommended that the theory or correlation be adopted which produces the minimum RMS deviation when compared with an acceptable amount of test data. This selected theory or correlation may not be adequate for design purposes. It is then recommended that a statistical factor be established which, when applied to the selected theory or correlation, will cover a predetermined percentage of the data (e.g., 3σ, 2σ).

Tasks	1970			1971									Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	
Define temperature uncertainty band													25
Define critical heating aspects													15
Define heating data requirements													20
Define method for establishing statistical safety factor													25

GFY 1971: 70 K

GFY 1972: 15 K

Total cost 85

1-6 AERODYNAMIC ENVIRONMENT DURING LAUNCH

OBJECTIVE

Establish pressure and acoustic loading on shuttle vehicle elements during launch.

PROBLEM

In the launch phase, acoustic environment, fluctuating pressures, venting, and local flow field data are required for structural design concepts, crew and passenger protection concepts, and panel flutter characteristics. A clustered launch system such as the space shuttle represents an unusual configuration posing a great deal of uncertainty as to the acoustic loading imposed on the crew compartment and structure. This loading is primarily due to shockwave-boundary layer interactions which, on this multiple body arrangement, occur in an extremely complex flow field. This program would define shock wave impingement patterns, separated regions, resulting acoustic load intensities, and venting requirements to establish design criteria affecting configuration concepts.

TECHNICAL APPROACH

A combined analytical and experimental program on related clustered-vehicle configurations will be conducted. Methods such as Van Dyke's second-order slender body theory at supersonic speeds and empirical techniques such as developed at USAF-FDL for hypersonic interference effects in the analytic interference study will be used. This phase is not expected to give quantitative results, but will identify critical flight regimes, allowing the experimental phase to be concentrated on those regimes. Implement venting analysis methods.

The wind tunnel test phase will consist of pretest planning, model design and fabrication testing, and data analysis and correlation. Wind tunnel models will be built as large as practicable since size of dynamic pressure transducers is directly related to boundary layer displacement thickness. Small models, with thin boundary layers, require very small transducers (which have low sensitivity) and instrumentation systems with very high frequency capability. For example, if frequencies up to 10 KHz for a full-size vehicle are of interest, use of a 1/100-scale model would require frequency capability of about 1000 KHz. Data to be collected during wind tunnel tests include (as a minimum) the following:

1. Shock location (using static pressure probes and Schlieren coverage).
2. Boundary layer and shock interaction pressures (using flush-mounted pressure transducers).
3. Boundary layer pressure cross-correlation data (using flush-mounted pressure transducers).

Tasks	1970					1971											Est Cost ($K)
	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	
Analyze acoustic load intensity and venting requirements																	40
Design and fabricate models																	75
Conduct wind tunnel test																	100
Analyze data and define design criteria																	100
																Total cost	315

GFY 1971: 215 K

GFY 1972: 100 K

1-7 SEPARATION AERODYNAMICS

OBJECTIVE

Verify satisfactory separation during staging or abort of the booster and orbiter elements.

PROBLEM

The complex staging associated with parallel stage space shuttle vehicles requires a complete knowledge of the forces, moments, and pressures on the individual components and the interaction of each on the other during normal separation and abort conditions. The separation must be "clean" in that there is no physical contact between the stages and it also must be such that the separating booster avoids the orbiter rocket plume and can recover satisfactorily from the separating maneuver and achieve a trim flight condition. The complexity of the shock-flow interactions dictates an experimental approach to the verification of satisfactory separation characteristics.

TECHNICAL APPROACH

Wind tunnel models of typical space shuttle launch configurations for obtaining aerodynamic stability of the elements will be designed and fabricated. Tests will be made to obtain static and dynamic load and flow conditions of the separating configurations. Orbiter rocket exhaust plume will be simulated using high-pressure cold gas. The models will be tested at nominal and abort separation conditions utilizing a facility having a captive trajectory system to simulate the resulting flight path. Time-dependent relative attitudes and displacements between elements must be simulated. Variations of release conditions and aerodynamic and/or reaction control input will be simulated. An analysis of the resulting data will verify the feasibility of the separation maneuver.

Tasks	1970			1971												Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
Plume analysis																40
Model, design and manufacturing																75
Wind tunnel test																100
Data analysis and staging verification																70
															Total cost	285

GFY 1971: 225 K

GFY 1972: 60 K

1-8 ROCKET PLUME IMPINGEMENT EFFECTS

OBJECTIVE

Evaluate the extent and severity of rocket exhaust plume impingement forces, pressures, and heating of vehicle elements.

PROBLEM

During the stage separation of boost and orbital vehicles, the rocket exhaust plume from the orbiter will impinge on the boost vehicle. The amount of impingement is a function of the engine characteristics, flight altitude and velocity, and separation sequence. Severe heating, as well as change in stability and local loading, can occur in areas of significant interaction between the vehicle and the plume. Plume impingement effects can also occur on the tail surfaces and base regions of the vehicles during boost, on vehicle surfaces during ACS firing, and rocket plumes can induce separation forward of the base on booster and orbiter at higher altitude.

TECHNICAL APPROACH

The exhaust plume properties as functions of time of flight will be defined. Using this data, the anticipated forces will be analyzed, moments and heat transfer to the affected vehicle surfaces for separation concepts being considered. The least-hazardous staging concepts will be selected for verification by experimental tests. Plume impingement tests will be conducted to confirm analytical studies.

Heat transfer to fin and base regions of the vehicles using defined plume properties will be analytically determined. Heating from ACS firing will be evaluated for use in determining local thermal protection requirements. These heat transfer predictions will be verified by model tests. Evaluate plume effects on flow separation and resulting pressure distributions forward of the base. Separation will be analyzed by means of correlations with data generated using control deflection, forward facing steps and cold gas plume configurations. Experiments will be conducted to verify analytic results.

	1970			1971												Est Cost
Tasks	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	($K)
Define plume properties																15
Predict vehicle forces, pressures, and heating																45
Predict flow separation effects																20
Prepare test plans																10
Design and fabricate models																80
Conduct test programs																120
Correlate test data																25
															Total cost	315

GFY 1971: 140 K

GFY 1972: 175 K

1-9 BASE HEATING

OBJECTIVE

Define the base heating during launch and entry phases to ensure adequate thermal protection in this area.

PROBLEM

The heat transfer rates to the base of the space shuttle booster and orbiter must be defined for both the launch and entry phases.

TECHNICAL APPROACH

Launch Phase

The engine plume geometry and properties will be defined using accepted calculation techniques. Use this information to develop analytical models of base recirculation. Radiation heat transfer to the base will be predicted using the plume geometry and properties. Analytical predictions with scale model hot rocket tests in an altitude chamber will be verified.

Entry Phase

The aerodynamic heating on the base region due to the backward-facing step will be studied, using experimental techniques (basically wind tunnel models). This data will be used in conjunction with the PRIME and ASSET base heating data to generate analytical models.

Tasks	1970			1971												1972						Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	
Develop base heating prediction methods																						50
Prepare test plan																						10
Design and fabricate models																						80
Conduct test program																						220
Correlate analytical test data																						30
Total cost																						380

GFY 1971: 250 K
GFY 1972: 130 K

1-10 POSTSTAGING STABILITY AND CONTROL OPTIMIZATION

OBJECTIVE

Develop aerodynamic control concepts which satisfy control requirements for the entry, transition, cruise and landing phases of the shuttle booster.

PROBLEM

The extremely large inertias of the shuttle element lead to very low airframe frequencies, which coupled with low damping, could lead to a system with diverging behavior or without adequate response to satisfactorily perform various flight maneuvers. The control power, reversal and coupling effects must be identified and aerodynamic control concepts established which will provide adequate vehicle control.

TECHNICAL APPROACH

The aerodynamic characteristics of the vehicle for entry, transition, cruise, and landing will be established based on wind tunnel tests for static derivatives and estimated rotary derivatives. Control configuration perturbations will be made to evaluate control effectiveness for various configurations. Wind tunnel tests will be performed of the entry configuration at hypersonic and supersonic speeds; the transition configuration at transonic speeds, and the cruise/landing configuration at subsonic speeds. Data will be analyzed to define control power, potential problems, and various regimes of control authorities; e.g., vertical surface controls for pitch and roll for the entry configuration and for pitch and yaw subsonically. Aerodynamic control concepts that provide satisfactory control throughout the entry phase will be defined.

Tasks	1970 O	N	D	1971 J	F	M	A	M	J	J	A	S	O	N	D	Est Cost ($K)
Entry configuration model																30
Hypersonic tests and data analysis																70
Transition configuration model																30
Transition tests and data analysis																90
Cruise/landing configuration model																30
Subsonic tests and data analysis																80
Rotary derivative analysis and control concept definition																20
															Total cost	350

GFY 1971: 250 K

GFY 1972: 100 K

1-11 DEFINITION OF MINIMUM HEATING ENTRY TRAJECTORIES AND FLIGHT CONTROL APPROACH

OBJECTIVE

Define a flight control approach and a system operational concept for providing minimum temperature entry trajectories.

PROBLEM

A flight control approach that provides minimum heating trajectories that is compatible with guidance and navigation requirements and is technically feasible, practical, and reliable has not yet been defined, but is urgently required to meet shuttle reusable heat shield requirements.

TECHNICAL APPROACH

A digital computer flight simulation program will be developed to provide a constant temperature flight maneuver capability by controlling bank angle and/or angle of attack as a function of body surface temperature rate.

Temperature (heating rate) calculation methods will be defined consistent with accuracy requirements and potential locations of temperature sensors will be established.

The bank and/or angle-of-attack histories required to maintain constant temperatures at various points on the body will be defined.

Control approach will be defined and hardware and software requirements will be evaluated.

Effects of vehicle, flight mode, and atmospheric variations on study results will be defined.

Tasks	1970			1971												1972									Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	
Develop program for constant temperature flight maneuver capability																									40
Constant temperature flight simulations																									50
Temperature sensor location selection																									50
Bank acceleration, temperature rate gain determination																									50
Hardware-software evaluation																									30
Guidance and navigation interface determination and integration																									50
Effects of variances on study results.																									25
																								Total cost	265

GFY 1971: 120 K

GFY 1972: 120 K

GFY 1973: 25 K

1-12 EFFECT OF MACH NUMBER ON VEHICLE STABILITY AND CONTROL DURING PITCHDOWN MANEUVER

OBJECTIVE

Determine the optimum mode of transition (i. e., subsonic or supersonic from high to low angle of attack).

PROBLEM

Establishment of a transition technique from high to low angle of attack that is aerodynamically stable, controllable, and consistent with guidance and automatic control requirements.

TECHNICAL APPROACH

The following will be accomplished: (1) Using a baseline orbiter, the potential problem areas associated with alternate modes of transition will be identified, (2) Configuration changes that offer solutions to problems identified in (1) will be determined; (3) Loads and structural changes that result from alternate transition modes will be defined; (4) Effect of transition at alternate mach numbers on vehicle (mission) performance will be determined; (5) The effect of alternate mach number transition on guidance and control requirements will be determined; and (6) Shuttle wind tunnel and free-flight test data will be correlated.

Tasks	1970			1971												Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
Trajectory and aerodynamics analysis																40
Loads and structural analysis																30
Guidance and control interface																30
Test data correlation																40
															Total cost	140

GFY 1971: 100 K

GFY 1972: 40 K

1-13 ROTARY AND STATIC DERIVATIVES AT HIGH ANGLES OF ATTACK

OBJECTIVE

Determine appropriate analysis techniques at high angles of attack for estimating rotary and static derivatives.

PROBLEM

The lack of sufficient wind tunnel test data and estimation procedures at high angles of attack necessitates an investigation of possible theoretical and empirical solutions from subsonic through supersonic speeds.

TECHNICAL APPROACH

The following will be accomplished:

1. Theoretical and experimental data on potential theory solutions and cross flow data will be reviewed;
2. Analysis procedures that are available and their range of applicability (i. e., strip theory, Newtonian theory, etc.) will be determined;
3. Theoretical and empirical solutions will be developed in the Mach range where none are available;
4. A computer program of the results of (1) through (3) will be developed where needed.
5. Wind tunnel and free-flight test data will be correlated.

Tasks	1970			1971												Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
Determine applicability of existing solutions																10
Develop potential solutions																50
Develop necessary computer programs																40
Data correlation																40
															Total cost	150

GFY 1971: 90 K

GFY 1972: 60 K

1-14 AIRBREATHING PROPULSION EFFECTS

OBJECTIVE

Define the effects of jet engine operation on the subsonic aerodynamic characteristics of the shuttle configuration.

PROBLEM

The powered cruise, approach, and landing flight phases of the booster and/or orbiter require detailed analysis of jet engine effects on the vehicle drag, stability, and control characteristics. With forward-mounted jet engines on the body, the wake will affect most of the body and verticals as well as inboard wing sections. Effects of jet engine flow on the aerodynamic characteristics must be evaluated to establish potential problem areas in vehicle stability and control, particularly as the subsonic behavior influences vertical tail size and wing location, and potential base drag changes due to engine exhaust pumping which influences cruise L/D and resulting engine size and cruise fuel.

TECHNICAL APPROACH

A low-speed wind tunnel model including operating jet engines capable of simulating proper exhaust flow will be designed and fabricated. A matched inlet-exhaust flow simulation is not expected to add much more to engine effects than exhaust flow simulation since the engines are located so far forward. A subsonic wind tunnel test will be conducted on this configuration with and without jet engines operating, including the condition of assymmetric thrust due to an engine failure, and with engine position and configuration variations. Resulting data will be analyzed to determine effects of jet exhaust and configuration modifications required to minimize adverse effects.

Tasks	1970		1971												Est Cost ($K)
	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
Design and fabricate model															120
Conduct wind tunnel tests															60
Analyze data															30
														Total cost	210

GFY 1971: 190 K

GFY 1972: 20 K

1-15 VERIFICATION OF AEROHEATING ANALYTICAL METHODS

OBJECTIVE

Verify improved analytical methods for predicting the aerothermodynamic environment and structural temperature response of space shuttle vehicles.

PROBLEM

Space shuttle vehicles are being designed to achieve orbital velocities and altitudes, followed by maneuverable entry, cruise, and subsequent landing on conventional type runways. Shockwaves, generated by the body interact with boundary layers on adjacent body surfaces, cause locally high rates in aerodynamic heating. Similar effects can result, during the launch phase, from an intersection of nose-tip-generated shockwaves with adjacent vehicle surfaces, as would occur on any multibody-type configuration. The location and magnitude of peak heat transfer rates must be defined for each space shuttle design under consideration.

TECHNICAL APPROACH

A two-phase experimental approach should be pursued. These phases differ in the methods of obtaining data:

1. Temperature sensitive coatings/oil flow visualization
2. Pressure/heat transfer measurements.

Initially, temperature-sensitive coating (paint) and oil-flow visualization tests will be conducted, employing all variations of the basic configuration. Areas of high heating and flow separation will be located. Pressure and heat transfer measurements in these critical areas will be conducted.

Interchangeable sections near fin-body junctions on the pressure models will be incorporated. Schlieren and shadowgraph pictures will be obtained during the pressure tests to assist in defining the overall flow field.

The interchangeable-section concept in heat-transfer models will be incorporated. A thin-skinned model will be used in conjunction with the "transient temperature technique." Temperature sensors will be thermocouples mounted on the inside surface of the model skin.

Analytical models of the heat transfer with the test data will be correlated to improve the prediction of heat transfer in such areas. Extrapolation of prediction environments more severe than those provided by wind tunnels will require accurate analytical or semi-empirical methods based on a sound experimental program.

Tasks	1970			1971												1972						Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	
Evaluate prediction methods																						50
Wind tunnel test program																						160
Correlate test data																						50

Total cost	260

GFY 1971: 180 K

GFY 1972: 80 K

DYNAMICS AND AEROELASTICITY

DYNAMICS AND AEROELASTICITY

DYNAMICS AND AEROELASTICITY

SHUTTLE MAJOR MILESTONES	1970	1971	1972	1973	1974	1975
PHASE B STUDY						
PHASE C STUDY						
PHASE D DEVELOPMENT						
PRELIMINARY DESIGN REVIEW						
CRITICAL DESIGN REVIEW						
BOOSTER AND ORBITER STRUCTURAL TEST ELEMENTS				MFG TEST		
FLIGHT TEST VEHICLE 1					MFG	
FLIGHT TEST VEHICLE 2					MFG	
BOOSTER AND ORBITER STRUCTURAL TEST ARTICLES					MFG	TEST

DYNAMICS AND AEROELASTICITY	1970	1971	1972	1973	1974	EST COST (SK)
2-1 GROUND WIND LOADS						355
2-2 BUFFET AND GUST RESPONSE						820
2-3 FLUTTER MARGINS ANALYSES AND TEST						630
2-4 BOOST PHASE PROPELLANT SLOSH EFFECTS						170
2-5 SLOSH BAFFLE DEVELOPMENT						240
2-6 POGO ANALYSIS						790
2-7 LOAD RELIEF TECHNIQUES						250
2-8 ANALYTICAL PREDICTION OF AERO-ACOUSTIC NOISE DURING BOOST (MATED CONFIGURATION)						275
2-9 HIGH ANGLE OF ATTACK (STALL) FLUTTER						270
2-10 FLUTTER OF THERMAL PROTECTION PANELS						205
2-11 BOOST PHASE MODAL ANALYSIS VERIFICATION THROUGH MODEL TESTS						920
				TOTAL		4925

2-1 GROUND WIND LOADS

OBJECTIVE

Determine vortex shedding peculiarities associated with piggyback shuttle configurations.

PROBLEM

Vortices shed from cylindrical launch vehicles in groundwinds have resulted in significant vehicle response perpendicular to wind direction. Testing on past and present launch vehicles has shown response is very dependent on configuration including service tower, protrusions on the vehicle, and surface roughness. The piggyback shuttle could have additional unknown ground wind problems resulting in operational restrictions.

TECHNICAL APPROACH

A rigid-body model of the space shuttle with a variable flexible base support and interstage structure will be fabricated. Provision will be made for simulation of representative service towers. Wind tunnel testing measuring response at the base and at the interstage structure, will be performed. Recommendations for vehicle design and operation in specified environment will be provided.

Extensive testing of a detailed model with elastic lifting surfaces will be required to verify design loads or vortex shedding suppression devices once the basic shuttle configuration is selected.

Tasks	1970			1971												1972						Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	
Fabricate models	—	—	—	—																		50
Tunnel testing					—																	25
Design recommendations						—	—	—														30
Detailed model testing													—	—	—	—	—	—	—	—	—	250
																					Total cost	355

GFY 1971: 105 K

GFY 1972: 250 K

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2-2 BUFFET AND GUST RESPONSE

OBJECTIVE

Determine unsteady aerodynamic effects on structural response.

PROBLEM

Unsteady aerodynamic forces due to buffet and atmospheric turbulence during boost flight produce structural responses which add to the steady-state loads. These fluctuating loads may cause structural fatigue failures. The aerodynamic inputs are difficult to determine, and the vehicle transfer functions are complicated by the structural coupling due to the mounting arrangement.

TECHNICAL APPROACH

Wind tunnel tests will be conducted to determine fluctuating pressure distributions on booster, orbiter, and mated configurations in the mach number range from 0.6 to 1.4. The pressures will be recorded on magnetic tape for conversion to statistical form. Pressures will be converted to power spectral density (PSD) form as a function of frequency. The vehicle transfer functions relating desired response functions to forcing frequency will be determined analytically. Input PSD will be combined with vehicle transfer functions to determine output PSD. Using standard techniques, the fatigue damage is calculated from the output PSD and the amount of time the vehicle will encounter this environment in its lifetime.

For turbulence response, the input PSD is assumed to be specified in the design criteria for each altitude segment of flight. The input PSD is combined with the vehicle transfer functions as in the buffet analysis to determine fatigue damage.

Once the basic shuttle configuration is selected, the analytic procedure will be verified and calibrated with results from a detailed elastic buffet model.

Tasks	1970			1971												1972						Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	
Design and build wind tunnel models (booster orbiter, and booster + orbiter																						80
Conduct wind tunnel tests																						60
Reduce wind tunnel data																						50
Formulate analytical model and calculate transfer functions																						50
Perform buffet analysis																						40
Perform gust analysis																						40
Final configuration testing and analysis																						500
																Total cost						820

GFY 1971. 280 K

GFY 1972: 540 K

2-3 FLUTTER MARGINS ANALYSES AND TEST

OBJECTIVE

Determine flutter margins throughout the booster and orbiter subsonic and transonic flight regime.

PROBLEM

The critical flutter condition is expected to occur transonically during boost flight. The unsteady aerodynamic forces are extremely complex due to the aerodynamic and shock interference between the mated vehicles in the transonic speed regime. The structural weight required to alleviate a flutter condition could be significant. It is therefore necessary to detect potential flutter instabilities early in the design so that the lightest possible fix can be employed. Because current unsteady aerodynamic theories are inadequate, extensive wind tunnel flutter model testing is required.

TECHNICAL APPROACH

Transonic flutter models of the booster and orbiter will be constructed. They will be ground vibration tested and wind tunnel tested both individually and in the mated configuration. Mounting will be such as to simulate free flight. Control surface degrees of freedom will be included. Experimental results will be compared to theoretical calculations. Theoretical results will be obtained using kernel function, doublet-lattice, Mach box, and quasi-steady aerodynamic theories. Configuration parameters varied will include booster/orbiter attachment stiffness, aerodynamic control surface rotational stiffness, and booster propellant levels.

Tasks	1970			1971												1972						Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	
Design and construct flutter models	—	—	—	—	—	—	—															250
Ground vibration test							—	—														30
Wind tunnel test									—	—	—											50
Theoretical analysis using kernel function, doublet-lattice, Mach box, and quasi-steady flutter theories	—	—	—	—	—	—	—	—	—	—	—	—										50
Final configuration testing and analyses																—	—	—	—	—	—	250
																Total cost						630

GFY 1971: 330 K

GFY 1972: 300 K

2-4 BOOST PHASE PROPELLANT SLOSH EFFECTS

OBJECTIVE

Provide adequate assurance that the vehicle propellant sloshing modes are damped to a sufficient level to preclude large amplitude limit cycling of the engines.

PROBLEM

The space shuttle piggyback configuration will introduce coupling between roll and yaw motions and propellant sloshing. Also, the inclination of the tanks with respect to the thrust vector will require evaluation and refinements in sloshing models. Techniques to model the propellants are to be developed. Parametric evaluation of the propellant slosh models, rigid and elastic body modes, and baffle configurations are required to identify any significant differences from present day launch vehicles.

TECHNICAL APPROACH

Propellant slosh models for asymmetric vehicles will be developed. The sloshing parameters will be defined for each tank (both booster and orbiter) at selected liquid levels. These will include many booster levels and orbiter levels. Elastic-structure frequencies will be calculated for the booster-orbiter ascent configuration and for the orbiter only configuration. Preliminary rigid-body control frequency, propellant slosh frequencies, and elastic structure frequencies will be compared for possible overlaps where strong coupling could exist. Rigid-body plus sloshing root loci will be plotted at selected flight times for autopilot gain and compensation selection. Slosh baffling required for existing space shuttle tank designs will be defined. Baffle performance will be verified by digital simulation.

Tasks	1970			1971									Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	
Develop asymmetrical slosh models													70
Define slosh parameters and elastic structure frequencies													30
Plot root loci for rigid-body plus slosh													30
Parametric evaluation to define slosh baffling requirements													40
												Total Cost	170

2-5 SLOSH BAFFLE DEVELOPMENT

OBJECTIVE

Develop minimum-weight flexible baffle designs to provide slosh suppression in reusable space shuttle vehicles.

PROBLEM

Model studies, conducted in water, have indicated the excellent potential of flexible baffles for providing slosh damping for low unit weight. Analyses must be improved to include large deflection stress analysis and develop techniques to predict flow conditions due to deflected baffle. Design, material selection, and fabrication techniques accounting for cryogenics, compatibility, and stress concentrations must be developed and verified.

TECHNICAL APPROACH

Convair's Marker and Cell (MAC) method will be used as the basic engineering tool with which to solve the complete Navier-Stokes equations of fluid motion, including viscous and nonlinear terms, to determine pressure loads on submerged, deflected baffles. The structural finite element program will be extended to include stress distribution of annular rings under relatively large deformations. Design studies will be performed which deal simultaneously with material selection, fabrication techniques, installation, and pressure and thermal loading of the baffle system. The goal is to configure the many design alternatives and to recommend and justify selection of the most efficient baffle configuration in terms of weight.

The most promising baffle concepts for nearly full-scale testing in the flight environment will be fabricated to determine slosh suppression effectiveness and for comparison of flexible baffle loads with loads criteria. Test data will be compared with analytical results and a baffle design will be recommended for space shuttle application. Temperature and load fatigue tests will be run on selected designs with near full-scale specimen.

Tasks	1970 (O N D)	1971 (J F M A M J J A S O N D)	1972 (J F M A M J)	Est Cost ($K)
Determine flexible baffle pressure loading				20
Structural analysis of deflected baffles				15
Design candidate baffle systems				20
Fabricate selected baffles for testing				20
Near full-scale baffle testing				50
Comparison of analysis and test; recommend baffle concept				15
Fatigue tests on selected design				100
			Total cost	240

GFY 1971: 140 K

GFY 1972: 100 K

2-6 POGO ANALYSIS

OBJECTIVE

Establish sensitivity of unsymmetric shuttle configuration to POGO type instability and determine most effective decoupling mechanism.

PROBLEM

Longitudinal (POGO) instabilities resulting from coupling of engine, propellant, and pneumatic systems with vehicle longitudinal modes have been a problem for many liquid propellant launch vehicles.

The basic technology for POGO analysis is available but the shuttle configuration with its unsymmetric, piggyback body mated configuration and the unusual orbiter arrangement are so different from past experience that it is difficult to estimate the severity of the problem, its impact on the program, or appropriate fixes if a problem does exist. There will probably be significant coupling between lateral and longitudinal structural modes.

TECHNICAL APPROACH

Mathematical models of space shuttle structure, propellant tanks, and propellant feedlines will be prepared using modeling techniques developed for Saturn, Titan, and Atlas vehicles. Engine and pump models will be obtained from propulsion contractors. A stability analysis will be performed using the mathematical models to determine stability margins for various structural damping factors.

Possible passive fixes will be incorporated into the mathematical model, such as accumulators or increased feedline stiffness to determine most effective decoupling mechanism. Active suppression devices will be simulated such as control valve at pump inlet to ascertain effectiveness and problems associated with active techniques.

A detail closed-loop stability analysis will be performed to determine if nonlinear effects (such as compliance associated with pump inlet bubble formation) or higher modes (such as tank fluid-bulkhead modes) are properly stabilized.

Tasks	1970			1971												1972									Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	
Develop mathematical models of tank, structure and feedline (booster and orbiter, orbiter)																									50
Obtain engine models (preliminary and final)																									30
Perform stability analysis and variation of parameters																									30
Examine active and passive suppression effectiveness																									60
Recommendation for design																									20
Detailed POGO model and analysis																									200
Test verification of nonlinear and bulkhead math models																									400
																								Total cost	790

GFY 1971: 180 K

GFY 1972: 450 K

GFY 1973: 160 K

2-7 LOAD RELIEF TECHNIQUES

OBJECTIVE

Evaluate the potential payload gains due to utilization of load relief.

PROBLEM

The use of load relief techniques to lower the vehicle aerodynamic loads provides the potential to significantly reduce the structural weight of the booster and/or orbiter. However, a penalty is also accrued due to the vehicle departing from the reference trajectory. Fatigue damage can also be reduced utilizing the same sensors, actuators, etc., by increasing the effective damping of vehicle bending modes. The net payload gain (or loss) for each of the many techniques must be obtained to determine feasible systems.

TECHNICAL APPROACH

The steady-state wind and gust models will be selected to provide realistic forces on the space shuttle vehicle. The dynamic response models for the mated and unmated vehicles will be formulated to include the best estimates of aerodynamic, mass, and structural properties. The steady-state loads and fatigue spectra will be generated for typical flight regimes. The increase in weight to account for fatigue will be assessed. Load alleviation techniques utilizing various combinations of sensors (accelerometers, angle of attack sensors, etc.), and actuators (gimbaled engines, wing spoilers and/or ailerons, elevons/elevators), considering both central and local control will be considered and the effects on the vehicle loads evaluated. Control laws which tend to minimize the fatigue loading due to flexible body motion will be developed and the attendant weight savings evaluated. The penalties due to trajectory deviation will be determined and the net savings for each technique compiled. Finally, qualitative reliability and maintainability assessments will be made in an attempt to utilize this data in the final selection between techniques if appropriate.

If active mode stabilization gives attractive weight savings, a detailed stability analysis with statistical varying of parameters will be done to establish practical limits of its effectiveness.

Tasks	Est Cost ($K)
Formulate dynamic response models	20
Develop steady-state loads and fatigue spectra	50
Minimize steady-state loads through load relief	30
Minimize fatigue loads through load relief	30
Identify potential savings	20
Verification of practical load alleviation limits	100
Total cost	250

GFY 1971 150 K

GFY 1972: 100 K

2-8 ANALYTICAL PREDICTION OF AERO-ACOUSTIC NOISE DURING BOOST (MATED CONFIGURATION)

OBJECTIVE

Determine characteristics of the fluctuating pressure field adjacent to vehicles in order to calculate random vibration response.

PROBLEM

Present state-of-the-art methods are inadequate to permit prediction or calculation of this potentially important loading.

TECHNICAL APPROACH

A wind tunnel test program will be conducted to determine overall levels, spectra, and time-space cross correlation of the fluctuating pressure field. Models of adequate size and instrumentation of appropriate range will be used so that results can be scaled to the full-size vehicles. Pressure field parameters will be defined as a function of mach number, angle of attack and/or yaw, and location. Regions ahead and behind, ramps and steps, areas of shockwave-boundary layer intersections, and other separated flow regions will be investigated. The effect of wind tunnel noise will be assessed by conducting a flight test program and comparing results for a number of identical test conditions. The flight program will also evaluate Reynolds number effects.

Tasks	1971												1972												Est Cost ($K)
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
Model design and fabrication	—	—	—	—	—	—	—																		40
Instrument and checkout							—	—	—	—															60
Wind tunnel test program										—	—														50
Data evaluation												—													40
Flight test program												—	—	—	—	—	—	—	—	—	—				60
Comparison and/or correction of data and preparation of report																			—	—	—	—	—	—	25
																								Total Cost	275

GFY 1971: 100 K

GFY 1972: 150 K

GFY 1973: 25 K

2-9 HIGH ANGLE-OF-ATTACK (STALL) FLUTTER

OBJECTIVE

Determine orbiter flutter characteristics at very large angles of attack.

PROBLEM

There are indications that at angles of attack near stall, lifting surfaces may possess less flutter margin than they do at zero or small angles of attack.

TECHNICAL APPROACH

A wind tunnel flutter model program will be conducted to investigate this potential problem area. Models typical of straight- and swept/delta-wing orbiter configurations will be designed and constructed. Testing will be conducted at conditions simulating typical orbiter entry profile. Available theoretical approaches to stall flutter (rotor blades, propeller theory, etc) will be reviewed and flutter analyses will be conducted. Analytical results will be compared with test data.

Tasks	1971 J F M A M J J A S O N D	1972 J F M A M J J A S O N D	Est Cost ($K)
Design, fabricate, and ground test models			100
Conduct wind tunnel flutter tests			50
Reduce and evaluate test data			40
Conduct flutter analysis			50
Compare theory and test results			30
		Total cost	270

GFY 1971: 100 K

GFY 1972: 130 K

GFY 1973: 40 K

2-10 FLUTTER OF THERMAL PROTECTION PANELS

OBJECTIVE

Determine flutter tendencies of radiative-type thermal protection system panels.

PROBLEM

Panel flutter calculations are approximate at best. Current TPS radiative panel concepts with their high temperatures and flexible-mounting arrangements may be flutter prone. An experimental program is required to determine how critical the problem may be.

TECHNICAL APPROACH

Representative TPS panels will be tested in the wind tunnel, varying critical parameters such as edge conditions, mid-plane stress, temperature, etc. Panel flutter studies using current analytical/empirical approaches, such as AFFDL-TR-67-140, will be conducted. Analytical and test results will be compared and potential flutter tendencies of TPS panels will be evaluated.

Tasks	1971												1972						Est Cost ($K)
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	
Construct typical panels and ground vibration test																			70
Conduct wind tunnel tests																			40
Evaluate test data																			25
Perform panel flutter analysis																			40
Compare test and analytical results																			30
													Total cost						205

GFY 1971: 150 K

GFY 1972: 55 K

2-11 BOOST PHASE MODAL ANALYSIS VERIFICATION THROUGH MODEL TESTS

OBJECTIVE

Provide assurance that the elastic body dynamics of the complete boost phase shuttle vehicle can be accurately predicted analytically by vibration testing replica-type models and comparing with analysis.

PROBLEM

The prediction of the shuttle vibration modes must be quite accurate to prevent their coupling with other systems and causing such problems as POGO, control instability, and flutter. The shuttle is sufficiently complex to require verification of analytic techniques. The booster and orbiter can easily be tested separately (in the horizontal position without rocket propellants) in the manner of a conventional airplane ground vibration test. However, full-scale free vibration testing of the mated boost phase configuration will be very expensive.

TECHNICAL APPROACH

Models of both booster and orbiter will be a size which can be conveniently tested at existing facilities (1/10 to 1/5 scale). Structure important to overall vehicle modes will be built as a scaled replica of the actual vehicle wherever possible. Vibration mode tests in all axes will be conducted separately similar to aircraft ground vibration tests. The mated configuration will then be tested both empty and fueled. The best in finite element structural analysis techniques (probably NASTRAN) will be used to calculate all the model modes and compare with tests. It is expected that the tests will point up minor changes in the math modeling required to give good prediction of the vibration frequencies and mode shapes for all configurations. The calibrated analytic technique, when verified on the separate, empty, full-scale ground vibration tests of orbiter and booster, should then give satisfactory prediction of vibration modes for all flight conditions.

Tasks	1971												1972									Est Cost ($K)
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	
Design and build replica models of booster and orbiter																						800
Define math models and calculate modes																						50
Perform vibration tests on Booster and Orbiter separately and mated																						50
Redefine model and calculated modes to match test																						20
																					Total cost	920

GFY 1971: 0

GFY 1972: 800 K

GFY 1973: 120 K

PROPULSION

PROPULSION

PROPULSION

SHUTTLE MAJOR MILESTONES	1970	1971	1972	1973	1974	1975
PHASE B STUDY						
PHASE C STUDY						
PHASE D DEVELOPMENT						
PRELIMINARY DESIGN REVIEW						
CRITICAL DESIGN REVIEW						
BOOSTER AND ORBITER STRUCTURAL TEST ELEMENTS				MFG	TEST	
FLIGHT TEST VEHICLE 1					MFG	
FLIGHT TEST VEHICLE 2					MFG	
BOOSTER AND ORBITER STRUCTURAL TEST ARTICLES					MFG	TEST

	PROPULSION	1970	1971	1972	1973	1974	EST COST (\$K)
3-1	AUXILIARY POWER UNIT DEVELOPMENT						1000
3-2	LO_2 TANK SUMP CONFIGURATION						210
3-3	MAIN PROPULSION LO_2 FEED SYSTEM						2500
3-4	MAIN PROPULSION LH_2 FEED SYSTEM						500
3-5	PROPELLANT FEED DUCTS						240
3-6	VEHICLE PURGE REQUIREMENTS						170
3-7	PROPELLANT BEHAVIOR FOLLOWING BECO DURING NORMAL MISSIONS AND IN ABORT SITUATIONS						650
3-8	REUSABLE CRYOGENIC PROPELLANT TANK INSULATION						4075
3-9	REUSABLE CRYOGENIC PROPELLANT DUCT INSULATION						1645
3-10	ORBIT MANEUVERING CRYOGENIC TANKAGE SYSTEM						1600
3-11	ATTITUDE CONTROL PROPULSION SYSTEM						600
3-12	AUXILIARY CRYOGENIC TANKS						950
3-13	GASEOUS H_2 AND O_2 ACCUMULATORS						950
3-14	FLUID SYSTEMS						2100
3-15	ORBIT MANEUVERING/ATTITUDE CONTROL PROPULSION SYSTEM INTEGRATION						75
3-16	AIRBREATHING ENGINE COMPATIBILITY STUDY						100
3-17	SATURATED HYDROGEN FEED SYSTEM						875
3-18	PROPULSION AND FLUID SYSTEMS COMPONENT REDUNDANCY REQUIREMENTS						760
	TOTAL						19,000

3-1 AUXILIARY POWER UNIT DEVELOPMENT

OBJECTIVE

Develop gas generator, turbine, and controls for a hydrogen/oxygen APU for space shuttle applications.

PROBLEM

A reliable APU with minimum weight and specific reactant consumption (SRC) is required to supply mechanical shaft power for a hydraulic pump and an ac. generator. The APU must be capable of providing the high peak requirements of the control surfaces and landing gear while maintaining a low SRC at the normal operating point (20 to 40 percent of rated power). Speed synchronization between several units (up to 4) will be required if ac generator outputs are to be paralleled. Life requirements for the booster application are approximately 500 hours.

TECHNICAL APPROACH

A parametric study will be conducted to determine optimum reactant inlet pressures, thermal conditioning for reactants, heat rejection for lube oil and hydraulic oil, and exit design pressure.

A simple and reliable two-stage turbine having an acceptable SRC considering two wheels, reentry wheel, pressure staging and velocity staging will be developed. Controls and system design, having minimum SRC at the normal operating point will be developed. A reliable ignition system and combustor will be developed.

Tasks	1970			1971												1972									Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	
Parametric study																									100
Hardware development																									900
																								Total cost	1000

GFY 1971: 150 K

GFY 1972: 750 K

GFY 1973: 100 K

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3-2 LO_2 TANK SUMP CONFIGURATION

OBJECTIVE

Develop a noncavitating sump that will flow saturated LO_2 to depletion at high velocities.

PROBLEM

Current technology requires a positive pressure above propellant vapor pressure to prevent premature cavitation of the tank outlet sump. Use of tank pressures above vapor pressures results in added system weight and complexity. The English Blue Streak missile is a classic example of this problem-flow of saturated LO_2 through the tank outlet resulted in early sump cavitation and shutdown of the engines 20 seconds prior to expected depletion.

TECHNICAL APPROACH

Gas pull-through analysis to size sump baffle will be performed. Cavitation analysis will be performed to predict rate of gas formation as sump approaches cavitation and to predict tank liquid level at time of cavitation.

Layout design of the two alternate sump configurations will be accomplished including tank bottom contour, sump, baffle, and outlet line.

Test program on scale model tanks will be performed, including tank bottom contour, sump, baffle, and outlet line. Tests will include two alternative sump configurations and line sizes. Tests will be performed utilizing LO_2 as no other liquid has a cavitation index (B_1) equal to LO_2.

Tasks	1970			1971				Est Cost ($K)
	O	N	D	J	F	M	A	
Analysis								16
Layout configurations								16
Manufacturing								50
Testing and Analysis								128
							Total Cost	210

GFY 1971: 210 K

3-3 MAIN PROPULSION LO_2 FEED SYSTEM

OBJECTIVE

Demonstrate propellant conditioning for main engine start.

PROBLEM

For proper engine start, the main propulsion LO_2 feed system must not geyser, must provide adequate engine NPSP, and must minimize water hammer effects. It is especially critical on the booster where the LO_2 ducting is exceptionally long with resulting high pressures.

TECHNICAL APPROACH

Thermodynamic analysis will be performed to determine heating rates to propellants in feed ducts. Recirculation analysis will be performed to size recirculation ducts to prevent geysering and attendant water hammer. Precondition bleed analysis will be performed to determine optimum method of preconditioning propellants to satisfy NPSP and prestart requirements at engine pump inlets; consideration shall be given to additional bleed through available engine bleed path, recirculation, subcooling, and prepressurization.

Layout design of the system test model and associated test hardware will be accomplished.

Tests will be performed to determine temperature rise and flowrate with recirculation and to verify no geysering and associated water hammer. Tests with recirculation system blocked (no recirculation) will be performed to determine if geysering and associated water hammer will occur. Tests with bleed flows including required bleed for engines will be performed to verify optimum technique to satisfy NPSP and prestart requirements at engine pump inlet. The test results will be evaluated to determine the adequacy of the analytical techniques.

Tasks	1970			1971													Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	
Analysis																	160
Design test hardware																	240
Manufacturing test hardware																	1140
Conduct tests																	960
																Total cost	2500

GFY 1971: 1500 K

GFY 1972: 1000 K

3-4 MAIN PROPULSION LH_2 FEED SYSTEM

OBJECTIVE

Demonstrate propellant conditioning for main engine start.

PROBLEM

The space shuttle booster LH_2 feed ducts are not provided with recirculation capability. During holds following tanking, the propellant may geyser into the tank. NPSP and geyser suppression can be provided in two manners: (1) by a constant-flow bleed at each engine pump inlet, and (2) by increasing tank pressure immediately prior to engine start.

TECHNICAL APPROACH

Thermodynamic analysis will be performed to determine heating rates to propellants in feed ducts. Precondition bleed analysis will be performed to determine the optimum method of preconditioning propellants to satisfy NPSP and prestart requirements at engine pump inlets and to suppress geysering; consideration will be given to additional bleed through available engine bleed path, subcooling, and prepressurization.

Layout design of system test and associated test hardware will be accomplished.

Tests will be performed with selected tank pressurization and bleed flows including required bleed for engines to verify optimum technique to satisfy NPSP and prestart requirements at engine pump inlet and to verify suppression of geysering. The tests will be evaluated to determine the adequacy of the analytical techniques.

Tasks	1970			1971											Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	
Analysis and design of test hardware															75
Manufacturing test hardware															225
Conduct tests															200
														Total cost	500

GFY 1971: 292 K

GFY 1972: 200 K

3-5 PROPELLANT FEED DUCTS

OBJECTIVE

Demonstrate 14 and 24 inch diameter ducts with LO_2 at 245 psi and LH_2 at 30-psi pressure for shuttle life requirements.

PROBLEM

The space shuttle booster LO_2 and LH_2 systems encounter significant thermal and structural deflection during operations. The relative motion between ducts and components must be accommodated within the system design. Further analysis and test of large bellows should be accomplished to determine their adequacy for shuttle requirements including pressure, long life, and reusability.

TECHNICAL APPROACH

Three basic types of flexible sections will be studied for use in absorbing LO_2 system deflections (i. e., gimbal ring restrained bellows, hinge restrained bellows, and externally supported bellows).

An analysis will be performed to determine the location, type, and displacement of each bellows in the ducting system and the expected life cycling history. The goal of this analysis is to arrive at the optimum number and design of flexible duct sections in order to reduce overall program cost.

A vendor search and detail design phase will produce the flexible duct sections required for the study.

The test specimen will then be subjected to a performance and life test program to include deflection cycling, pressure and temperature cycling, vibration, proof, and ultimate testing.

Tasks	1970			1971									Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	
Deflection analysis and flex section design													56
Test plan and fixture design													24
Specimen manufacture													96
Test and analysis													64
												Total cost	240

GFY 1971: 200 K

GFY 1972: 40 K

3-6 VEHICLE PURGE REQUIREMENTS

OBJECTIVE

Determine if purges are required to "safe" the booster and orbiter vehicles. Define purges that are needed, purge criteria, purge technique and procedure requirements, purge times, and quantity of gas consumed.

PROBLEM

Upon landing, after an operational or ferry type mission, the booster and orbiter vehicle propellant tanks will contain residual propellant gases and, in some cases, liquids that may represent a hazard to normal post- and preflight operations. The system hardware and safety requirements must be established and the purge procedure requirements established and verified.

TECHNICAL APPROACH

System hardware requirements will be determined, technical requirements will be defined for pressure and type of gas required to perform maintenance, checkout, and other ground operations.

Laboratory and large scale tests will be performed to determine allowable concentrations of GN_2 in the tanks for cryogenic loading and safe vehicle operation.

Safety requirements will be determined. Criteria for gaseous propellant concentration allowable for each booster and orbiter propellant system will be established. Criteria will encompass inflight requirements after completion of use of a propellant system and requirements associated with all ground operations.

Test criteria and methods for determining safety requirements will be defined. Tests will be performed to determine safe propellant concentration allowables for safe vehicle operation.

Purge requirements will be defined. Systems that require purge operations will be identified. Based on hardware and safety requirements, requirements will be defined sufficiently to identify when to purge and criteria to be used to ascertain adequacy of purge.

Vehicle purge techniques will be identified. Sufficient design analysis will be performed to determine purge technique and preliminary procedures. Purge and vent line connections and flow paths including liquid drain methods will be identified. Trade analysis of use of GN_2 versus GHe as purge media will be performed. Supporting equipment required to meet both booster and orbiter requirements, including measurements and/or sampling systems will be determined. Time required and gas consumption for booster and orbiter purge operations will be determined. Potential problem areas and hardware development requirements will be identified. Parametric data will be developed for gaseous propellant concentration and purge times for various purge gas consumption rates. Purge techniques with tests to determine gas quantities and purge times will be verified. Test results to vehicle configuration will be extrapolated.

Tasks	1970			1971												1972						Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	
Determine hardware and safety requirements																						15
GN_2 and concentration tests																						50
Identify vehicle purge techniques																						35
Test and evaluation of purge techniques																						70
																Total cost						170

GFY 1971: 120 K

GFY 1972: 50 K

3-7 PROPELLANT BEHAVIOR FOLLOWING BECO DURING NORMAL MISSIONS AND IN ABORT SITUATIONS

OBJECTIVE

Develop analytical tools to predict fluid orientation and propellant tank thermodynamics following BECO. Develop systems to control propellant orientation, dumping, and venting following BECO during normal reentry and abort conditions.

PROBLEM

Immediately following BECO, a significant amount of vehicle maneuvering can occur at fairly low thrust and drag levels. Accurate prediction of propellant orientation, sloshing, and tank thermodynamics under such conditions is not possible with present analytical tools. Such predictions are necessary in order to determine propellant control, vent, and tank pressure design requirements. It is also necessary to know the tank fluid conditions in order to evaluate the potential of using residual propellants for reaction control, auxiliary power and/or cooling of various subsystems.

TECHNICAL APPROACH

The recommended approach is to expand and modify existing numerical fluid analysis and propellant tank thermodynamic computer programs to handle the shuttle application and to develop systems for controlling liquid orientation following BECO.

It is proposed to use the Marker and Cell (MAC) numerical technique as a basis for the analytical development. In this program, the Navier Stokes and thermal-energy equations are cast in finite-difference form and solved explicitly as an initial value problem. Behavior of the liquid-vapor interface is calculated, and interface breakup is permitted. A motion picture depicting the motion of the fluid is furnished as a portion of the computer output. The program will be expanded to allow consideration of body force variance as a function of time and energy transfer at the liquid/vapor interface.

A tank thermodynamics program such as the Centaur pressurization and vent program will be modified to handle liquid/vapor surface conditions, for mass and energy transfer, as supplied by the MAC program.

Based on the analytical predictions, it is anticipated that special control systems in the form of baffles and/or surface tension containment devices will need to be developed in order to assure usable liquid and to control propellant dumping and venting following BECO, abort, and during reentry. Use of slosh control baffles will be the primary consideration in the case of the main tanks and surface tension or capillary screens for liquid supply the primary consideration for the auxiliary tanks.

Ground-based testing will consist of analytical model verification and control system demonstration testing. Tank sloshing and liquid-ullage spray testing will be accomplished on subscale systems.

Tasks	1970			1971												1972						Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	
Develop analytical models and run test cases																						150
Perform model verification testing and data correlation																						100
Develop optimum liquid control system for main tank																						175
Develop optimum liquid control system for auxiliary tanks																						225
																Total cost						650

GFY 1971: 200 K

GFY 1972: 450 K

3-8 REUSABLE CRYOGENIC PROPELLANT TANK INSULATION

OBJECTIVE

Develop cryogenic propellant tank insulation systems for a reusable launch vehicle

PROBLEM

Reusable launch vehicle propellant tanks require thermal insulation systems to minimize propellant losses and inert-gas purge systems to prevent cryopumping of air and oxygen, as well as moisture condensation during ground operations, launch, orbit, entry, and cruise.

Cryogenic insulation systems for expendable booster vehicles have been developed. However, systems that will withstand the severe cyclic environment experienced by a reusable vehicle are not presently available. A coordinated analysis, design, and subscale test program will be required to develop reliable cryogenic insulation systems for reusable shuttle vehicles.

TECHNICAL APPROACH

The main propellant tanks require thermal insulation to minimize propellant losses and eliminate cryopumping during ground operations and launch. Both internal and external insulation systems will be considered. Internal systems, including open-cell, gas-layer concepts and sealed 3D foam, have a warm adhesive bond line and are accessible without heat shield dismantlement. External systems such as helium-purged fiber blankets or nitrogen-purged, porous blankets are not subject to injestion into the fuel system and can serve as part of the overall high-temperature thermal protection system.

The required tasks are as follows:

1. Preliminary design and analysis

    a. Investigate the effects of integral and nonintegral tankage on insulation system design.

    b. Compare and evaluate internal and external insulation systems.

    c. Determine installation, inspection, and maintenance requirements associated with each system.

    d. Specify ground, launch, orbit, entry, and flyback environmental criteria (i.e., pressures, temperatures, etc.).

2. Material evaluation tests

    Empirically evaluate the more promising open-cell, foam, and fiber materials for thermal and structural performance.

3. Small-scale component tests and large-scale system tests

Perform tests to evaluate the following:

a. Thermal performance/efficiency

b. Environmental cycles

c. Thermal stress, launch loads, and vibration.

Tasks	1970			1971												1972						Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	
Perform predesign and analysis																						75
Conduct material evaluation tests																						215
Design test configuration article																						55
Conduct small-scale article tests																						520
Conduct centrifuge and load tests																						560
Select final insulation configurations (booster and orbiter)													▽									
Conduct large-scale article tests																						2,650
																					Total cost	4,075

GFY 1971: 1000 K

GFY 1972: 3075 K

3-9 REUSABLE CRYOGENIC PROPELLANT DUCT INSULATION

OBJECTIVE

Develop reusable lightweight duct insulation

PROBLEM

Cryogenic propellant lines including components such as prevalves and flanges require insulation to prevent cryopumping of air and to minimize heat leaks. The insulation should be reusable for up to 100 flights, requiring no purging for line sizes from 1.5 inches to 24 inches in diameter.

TECHNICAL APPROACH

The recommended approach is to conduct analysis on two types of promising, reusable insulation systems for propellant lines:

1. Rigid vacuum jacket propellant line with internal multilayered super-insulation

2. External bonded and sealed insulation

The analysis will include material, thermal, structural, weight, cost, and manufacturability considerations. Analyses will be compared, and the best concept selected for further consideration. The investigation will further include the analysis of components such as valves, joints, and supports.

Based on the analytical predictions, a development program for the associated propellant line and insulation components including insulation attachments and penetrations will be accomplished.

The final phase in the development of a reusable, lightweight, duct insulation is the design, fabrication, and test of full-scale components.

Tasks	1970			1971												1972						Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	
Conduct analysis and design	—	—	—	—	—	—																80
Conduct Materials evaluation					—	—	—	—	—													230
Develop components								—	—	—	—	—	—	—	—							465
Design, fabricate and test full-scale components										—	—	—	—	—	—	—	—	—	—	—	—	870
																Total cost						1,645

GFY 1971: 600 K
GFY 1972: 1045 K

3-10 ORBIT MANEUVERING CRYOGENIC TANKAGE SYSTEM

OBJECTIVE

Establish the feasibility of an orbit maneuvering, liquid hydrogen tankage system inclusive of its cryogenic thermal protection subsystem; insulation air isolation subsystem; thermodynamic venting subsystem; and cryogenic destratification subsystem to satisfy the reusability and long-term cryogenic storage requirements of the shuttle orbiter vehicle.

PROBLEM

Thermal performance predictions of cryogenic thermal protection systems have historically proven to be 200- to 500-percent lower than obtained in large-scale tankage system tests. The additional requirement for reusability and reentry environment endurance imposes even greater technological developments. Other new subsystem developments requiring proof of feasibility by large-scale tankage tests are (1) the isolating of insulation from air and moisture throughout the life cycle of the vehicle by maintaining the insulation within a vacuum-pressure environment of 10^{-5} mm Hg or lower; (2) tank venting under zero-g environments by means of a passive thermodynamic process; and (3) cryogenic thermal destratification.

TECHNICAL APPROACH

Phase I: Component Tests

Test components of the cryogenic tankage system will be designed and constructed to (1) demonstrate concept structural integrity, materials compatibility, and reusability performance, (2) establish feasibilities and concept selection data; and (3) formulate detail design information for the large-scale cryogenic tankage test article. Ascent-descent cryogenic hydrogen calorimetric tests will be performed on a small-scale tankage system (3 feet in diameter by 6 feet long) inclusive of insulation, air isolation subsystem, minimum heat leak tank supports, and plumbing, as well as combined centrifugal-vibration cryogenic hydrogen tests of insulation installation concepts in a vacuum environment.

Phase II: Cryogenic Tankage System Test

A large-scale orbit maneuvering cryogenic hydrogen tankage system will be designed and constructed. A test plan will be formulated. Ascent-descent thermal/pressure environmental profile tests and simulated space thermal/vacuum tests on the large-scale tankage system will be performed.

Tasks	1970 (O N D)	1971 (J F M A M J J A S O N D)	1972 (J F M A M J J A S)	Est Cost ($K)
Phase I: component tests				650
Phase II: cryogenic tankage system test				950
			Total cost	1600

GFY 1971: 400 K
GFY 1972: 1000 K
GFY 1973: 200 K

3-11 ATTITUDE CONTROL PROPULSION SYSTEM

OBJECTIVE

Develop an attitude control propulsion system that will provide three-axis attitude control and translational capability for the space shuttle vehicles. Establish design and test approach for a high-performance, reusable system that will require minimal refurbishment and maintenance.

PROBLEM

Components (pressure regulators, check valves, propellant conditioners, thrusters, etc.) for gaseous O_2/H_2 systems are not developed to a point where their performance, life time, or operational characteristics are compatible with space shuttle design goals. Approaches to design, development, and test verification of components and the ACPS must be initiated as soon as possible to provide needed design data and test criteria.

TECHNICAL APPROACH

Phase I

ACPS component design approaches, performance, operational characteristics for thruster, O_2/H_2 gas generators, valves, regulators, etc., will be developed.

Phase II

ACPS components and system test plans, methodology, and criteria will be developed. Test program will provide component and system performance, reliability, maintainability, and useful life data.

Phase III

Pilot test program to verify ACPS component and system performance, life, reliability, and maintenance goals.

Tasks	1970 (O N D)	1971 (J F M A M J J A S O)	Est Cost ($K)
Phase I: design approach thruster O_2/H_2 gas generator components			200
Phase II: test plans methodology criteria			100
Phase III: pilot test program		M'72	300
		Total cost	600

GFY 1971: 250 K

GFY 1972: 350 K

3-12 AUXILIARY CRYOGENIC TANKS

OBJECTIVE

Design, fabricate, and test LH_2/LO_2 storage and supply tankage applicable to space shuttle booster and orbiter attitude control propulsion system requirements.

PROBLEM

The ACPS propellant tankage for space shuttle booster and orbiter must store and supply LO_2 and LH_2 to meet attitude control engine pulsing and steady-state flow demands. The tankage will operate under conditions of low and zero-g for time periods ranging from 2 to 3 minutes for the booster to 7 days for the orbiter. Additionally, the tankage must supply propellants under varying vehicle attitudes and g levels up to 4 g during atmospheric entry. Entrainment of helium ullage gas (used for tank pressurization) in the propellant discharged from the tanks is to be prevented.

TECHNICAL APPROACH

Booster and orbiter ACPS requirements will be evaluated to define propellant storage and supply requirements including propellant quantities; prelaunch tanking and hold capability without topping; supply pressures; total propellant storage time and usage history; thermal environmental history; effect of g-levels and durations, including extended zero-g; and effect of vehicle maneuvering requirements.

Based on the established requirements, preliminary designs will be prepared for representative prototype ACPS LH_2 storage and supply tanks which meet major design and operational requirements and objectives for both booster and orbiter including: extended life requirements; minimum maintenance between flights; simplicity; flexibility; and minimum cost. Trade studies to select a configuration for detail design, including evaluation of candidate materials, fabrication techniques, and costs will be performed.

Detailed designs of the selected configuration will be prepared to enable fabrication of a prototype storage and supply tank including: thermal protection provisions; tankage, pressurization/vent, and outflow provisions; zero-g propellant retention device; and mounting provisions.

The prototype tanks will be fabricated. Fabrication techniques will be developed and proofed including forming methods for shell sections, weld schedules, insulation methods, propellant retention device fabrication and installation methods, inspection methods, etc.

Subsequent to fabrication, a test program will be conducted to evaluate performance of the tank under simulated operational conditions and capability to meet the design and operational requirements previously established will be verified. Testing will include: propellant outflow tests with various tank orientations for evaluation of propellant retention device performance; tank pressurization and outflow tests to evaluate helium pressurization gas requirements; and tank pressure and thermal cycling to evaluate capability to meet the design life requirements.

Tasks	1970		1971												1972					Est Cost ($K)
	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	
Preliminary design																				50
Detail design																				100
Fabrication																				500
Testing																				300
															Total cost					950

GFY 1971: 175 K

GFY 1972: 775 K

3-13 GASEOUS H_2 AND O_2 ACCUMULATORS

OBJECTIVE

Design, fabricate, and test high-pressure, gaseous H_2 and O_2 accumulators applicable to space shuttle booster and orbiter attitude control propulsion system requirements.

PROBLEM

ACPS configurations under consideration for the space shuttle booster and orbiter utilize high-pressure, gaseous accumulators to: provide a propellant reservoir for initial system startup and to allow for normal propellant conditioning system response lags; minimize system pressure surges; and minimize cyclic operation of conditioning system components. Accumulators will be required to operate in a cycling pressure mode, blowing down from 1000 psi to 400 psi up to 100 times per flight. The vessel will operate at temperatures ranging from 50 to 500 R. The design cyclic life requirement for the vessel will approach 20,000 cycles within design safety factors of 1.5 on yield and 2.0 on ultimate material strength. The capability to design, fabricate, and operate an accumulator to the above requirements must be demonstrated.

TECHNICAL APPROACH

Booster and orbiter ACPS requirements will be evaluated to establish accumulator operational requirements including maximum pressure level, maximum blowdown range, volume, cycles per mission, total cyclic life, and operating temperature ranges.

Preliminary designs for prototype accumulators representative of worst-case booster and orbiter requirements will be prepared based on the operational requirements. Material properties required and design safety factors will be established. Potential materials of construction to enable selection of the material providing a desirable balance between weight, fabrication cost, and technology risk will be evaluated. A configuration for detail design will be selected.

Detailed designs of the selected configuration will be prepared to enable fabrication of a prototype accumulator.

The prototype accumulator will be fabricated. Required materials forming techniques, weld schedules, and inspection methods will be developed and proofed.

A test program will be conducted to evaluate performance of the accumulator under the specified operating environment and criteria including pressure and temperature cycling over the range and total number of cycles anticipated. A burst test will be conducted at the completion of the cyclic life program.

Tasks	1970		1971												1972					Est Cost ($K)
	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	
Preliminary design																				50
Detail design																				100
Fabrication																				500
Testing																				300
															Total cost					950

GFY 1971: 175 K

GFY 1972: 775 K

3-14 FLUID SYSTEMS

OBJECTIVE

Develop design and analysis capability for fluid subsystems used for the storage, conditioning, location control, and transport of cryogenic and gaseous fluids on the shuttle orbit maneuvering and airbreather propulsion; ACPS; ECLSS; APU; and fuel cell systems.

PROBLEM

Cryogenic and gaseous fluid pressurization, venting, location control, line transport, and conditioning in a zero or near zero-g environment mandates the use of nondeveloped and untried concepts. Sustained zero-g fluid heat transfer and thermodynamic processes require correlations with test data most of which must be obtained in an orbital flight environment because sustained zero or near zero-g simulations exceed ground facility capabilities.

TECHNICAL APPROACH

Phase I: Concepts and Design Analysis

Concepts will be established and analysis tools will be developed for design of the following cryogenic and gaseous fluid subsystems and functional operations:

1. Pressurization
2. Thermal destratification
3. Thermodynamic venting/subcritical storage
4. Capillary retention/pump cryogen location control
5. In-orbit cryogen transfer and storage
6. LO_2 regenerative cooling/zero boiloff loss
7. Cryogen slosh and feedout thermohydrodynamics
8. Zero-g gauging
9. Vapor shield/supercritical storage

The analysis tools will incorporate capabilities to establish sizing, cyclic operational modes, transient responses, concept trades data, mission time line data, and subsystem operational interface effects. Laboratory tests will be conducted to establish emperical relationships in support of the analysis capability development.

Phase II: Orbital Flight Verification Tests

Subscale models of the cryogenic and gaseous fluid subsystems will be designed and constructed for orbital flight tests to be conducted as part of or in conjunction with the Skylab orbital test program. A test plan inclusive of instrumentation requirements will be formulated; flight test data will be correlated with predictions; and computer programs will be improved as necessary to develop analytical tools for shuttle hardware designs. Subsystems of the orbit maneuvering, airbreather, ACPS, ECLSS, APU, and fuel cell cryogenic tankage systems shall be included in three subscale test articles. Acquisition of subcritical and supercritical cryogen storage and scaling data and fluid transfer for tankage depletion and fill experimentation requires a minimum of three tankage system test articles. In addition to special experimental investigations of zero and low zero-g heat transfer and thermodynamic phenomena, simulations of the prelaunch, launch, and orbital phases of the shuttle orbiter mission shall be conducted.

Tasks	1970			1971												1972									Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	
Phase I: concepts and design analysis																									600
Phase II: orbital flight verification tests																									1500
																								Total cost	2100

GFY 1971: 300 K

GFY 1972: 1500 K

GFY 1973: 300 K

3-15 ORBIT MANEUVERING/ATTITUDE CONTROL PROPULSION SYSTEM INTEGRATION

OBJECTIVE

Define alternative design approaches, formulate design and analysis techniques, and evaluate promising concepts for integration of the OMS and ACPS propellant tankage, pumping, and conditioning subsystems.

PROBLEM

The OMS and ACPS both utilize high-pressure oxygen and hydrogen in liquid or gaseous form; therefore, the use of a common propellant supply may offer a major reduction in total propulsion system weight, complexity, and cost. The potential of this combined subsystem design approach and its attendant design options must be evaluated and its merits relative to existing concepts defined on a quantitive basis.

TECHNICAL APPROACH

Phase I

Candidate design options consisting of component and subsystem arrangement alternatives and operational utilization will be defined. Component and subsystem design, performance, cost, and schedule data from cognizant subcontractors will be solicited. Required analytical and comparative evaluation techniques will be formulated.

Phase II

Conceptual designs of each OMS/ACPS option and determined weight, performance, installation, and operational characteristics will be formulated. Relative cost and development requirements will be defined, and impact on overall space shuttle program will be determined.

Tasks	1970			1971			Est Cost ($K)
	O	N	D	J	F	M	
Phase I							35
Phase II							40
						Total cost	75

GFY 1971: 75 K

3-16 AIRBREATHING ENGINE COMPATIBILITY STUDY

OBJECTIVE

Determine interfacing air vehicle systems, materials and component hardware requirements, and configuration to support the application of H_2 fueled airbreathing engines to the space shuttle.

PROBLEM

The application of conventional jet engines to space vehicles subjects both the engines and conventional aircraft interfacing systems and materials to conditions foreign to their basic designs. To determine the modifications necessary to both engines and interfacing air vehicle systems, studies in depth by both the engine and vehicle manufacturers are required.

TECHNICAL APPROACH

The NASA has released two airbreathing engine RFP's in support of the shuttle program. These RFP's entail (1) design and development of hydrogen fuel pumping and control system, (2) definition of materials of construction or modification to engines for space environment and the use of hydrogen fuel, (3) definition of methods of providing lubrication of engine compatible with space and hydrogen fuel, and (4) determination of in flight engine start method. Parallel efforts required by air vehicle or supporting organizations are: (1) develop hydrogen fuel feed system, coordinate engine/vehicle interface operational and design requirements and develop dynamic line couplings and valves compatible with engine systems; (2) develop air vehicle engine control system concepts and simulation and/or breadboards for selected techniques. Form, fit, and functional interface requirements will be coordinated with engine manufacturers; (3) determine restraints or requirements for engine tolerance to space environment and develop engine installation system utilizing both active air vehicle control of engine environment and determine suitability of existing space vehicle hardware concepts for utilization; and (4) determine, with engine manufacturers, any requirement for support development of air start assist devices. If necessary, concepts and development requirements will be determined for space environment suitability of such existing devices or new concepts will be developed.

Tasks	1970			1971						Est Cost ($K)
	O	N	D	J	F	M	A	M	J	
Fuel Feed system	——	——	——	——	——	——	——	——	——	20
Engine control system	——	——	——	——	——	——	——	——	——	30
Engine installation-environmental control			——	——	——	——	——	——	——	25
Air start system			——	——	——	——	——	——	——	25
									Total cost	100

GFY 1971: 100 K

3-17 SATURATED HYDROGEN FEED SYSTEM

OBJECTIVE

Develop a feed system for transferring saturated liquid hydrogen from the flyback fuel tank to the airbreathing engines.

PROBLEM

The space shuttle's airbreathing engines are supplied with liquid hydrogen at pressures above the propellant vapor pressure to prevent cavitation in the engine pump. To accomplish this, a system is required to pump the saturated liquid hydrogen from the flyback fuel tank to the engine pump inlet at the necessary flow rates and net positive suction pressure (NPSP). This feed system must be simple, efficient, and capable of satisfactorily performing its function repeatedly over extended periods of time with no degradation in performance and with minimum initial cost, refurbishment and replacement.

TECHNICAL APPROACH

The specific design, functional, reliability and test requirements which the feed system is to meet, will be established; the basic systems will be analyzed and conceptual design layouts will be made of the various configured systems. Hardware for testing will be manufactured. Design evaluation tests (DET) will be performed to validate the analyses and design criteria, to verify the attainment of required performance, and to determine the optimum configuration.

The testing will include cryogenic flow tests at actual operating conditions to determine flow characteristics, efficiency, problems with cavitation, delivered NPSP, control of the system, installation requirements, and interface at the engine pump. Additional flow tests will be run using boiling propellant (saturated at high pressures) to evaluate the designs under worst-operating conditions. These DET tests will include life tests to ascertain the durability and reliability of the systems. Based on these analyses, designs, and tests, the final hydrogen feed system for the airbreathing engines will be selected.

Tasks	1970			1971												Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
Design, analyses, and conceptual drawings																155
Hardware manufacturing																300
Design evaluation testing* and analysis																420
*It is assumed that the LH_2 engine pumps (2) and boost pumps (3) are supplied as GFP.																
															Total cost	875

GFY 1971: 700 K
GFY 1972: 175 K

3-18 PROPULSION AND FLUID SYSTEMS COMPONENT REDUNDANCY REQUIREMENTS

OBJECTIVE

Determine the component redundancy and backup requirements for the booster and orbiter propulsion and fluid systems. Determine malfunction mode operating sequences of these components. Define and demonstrate techniques for detection of malfunctioning redundant or backup components.

PROBLEM

The reliability and safety requirements for space shuttle will necessitate use of redundancy and/or backup for critical components in the propulsion and fluid systems. The series/parallel arrangements of such components and the backup components necessary to meet these requirements need to be determined. The difficulty of detecting malfunctions in series/parallel operating redundant components and the maintenance techniques required must be evaluated in order to define detail configuration requirements.

TECHNICAL APPROACH

Reliability and Safety Requirements

The reliability and safety requirements for the booster and orbiter propulsion and fluid subsystems will be defined. The fail operational and fail safe criteria that is to apply for the operationally critical components will be identified.

Configuration Determination

Based on the reliability and safety requirements and the functional criteria of the components, the redundancy and backup configuration for subsystem critical components will be evaluated and established. The configuration evaluations will consider the component failure modes and their effects on system performance and the sequence of operations.

Checkout and Malfunction Detection Techniques

Methods will be defined to be used to detect component malfunctions occurring in series/parallel configurations of such propulsion components as feed valves, check valves, vent or relief valves, pumps, sensors, etc. Checkout methods to be used to determine status of redundant and backup components will be determined.

Evaluation of Checkout and Malfunction Detection Techniques

Evaluation tests will be performed on propulsion system redundant and backup component series/parallel configurations to verify the selected checkout methods and to determine the adequacy of the malfunction detection techniques. The instrumentation methods criteria and configurations to be used with the operational system components will be defined.

Tasks	1970 O	1970 N	1970 D	1971 J	1971 F	1971 M	1971 A	1971 M	1971 J	1971 J	1971 A	1971 S	1971 O	1971 N	1971 D	Est Cost ($K)
Reliability and safety requirements																60
Configuration determination																250
Checkout and malfunction detection techniques																100
Evaluation of techniques																350
															Total cost	760

GFY 1971: 400 K

GFY 1972: 360 K

STRUCTURES AND THERMAL PROTECTION SYSTEM

4-3 MATERIALS TECHNOLOGY OF SEALS, SEALANTS, LUBRICANTS, AND GREASES

OBJECTIVE

Demonstrate the functionality of the subject materials at the mission extremes of temperature, pressure, exposure time, and number of cycles.

PROBLEM

The ability of the seal, sealant, lubricant and grease materials to function under the Shuttle mission requirements for temperature, pressure, exposure time, and number of cycles has not been demonstrated.

TECHNICAL APPROACH

Material properties data will be obtained for the following disciplines: (1) high-temperature seals (i.e., door, flaps, ailerons, hinges, elevons, juncture seals etc), (2) fluid system seals (i.e., O-rings, gaskets, seals, bladders, diaphragms, etc)., (3) lubricants (i.e., wet, dry, solid, film, etc.), and (4) greases. A search for candidate materials will be conducted. Functionality with laboratory bench scale material specimens will be demonstrated. New high-temperature lubricating techniques (i.e., gas bearing, liquid metal, etc) will be developed. Functionality with system tests under simulated mission profile requirements will be demonstrated. Design allowables will be issued.

Tasks	1970			1971												1972												Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
Search for candidate materials	—	—	—	—	—	—																						35
Laboratory material testing				—	—	—	—	—	—	—	—																	200
Develop new lubricant techniques						—	—	—	—	—	—	—	—	—	—	—	—	—										350
Laboratory system testing and test evaluation											—	—	—	—	—	—	—	—	—	—	—	—	—	—				615
Develop and issue design allowables																		—	—	—	—	—	—	—				200
Total cost																												1400

GFY 1971: 500 K
GFY 1972: 700 K
GFY 1973: 200 K

4-4 FLAMMABILITY, TOXICITY, SMOKABILITY AND OUTGASSING

OBJECTIVE

Complete and issue a materials flammability and outgassing data file for shuttle material selection and design use.

PROBLEM

Shuttle performance and long-life requirements are more severe than those for previous aircraft and spacecraft programs. Materials that will not constitute flammability, outgassing, or toxicity hazards and are compatible with shuttle operational requirements have not been identified.

TECHNICAL APPROACH

Existing test data will be reviewed using the Apollo Program as a base for compatibility. Laboratory tests designed to furnish data identified as missing during the above review will be conducted. The limit life of marginal materials will be evaluated. A list of acceptable materials for design use will be issued.

Tasks	1970			1971												1972												Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
Data search																												30
Laboratory testing																												200
Limit life testing																												365
Issue and maintain design materials list																												75
																											Total cost	670

GFY 1971: 150 K
GFY 1972: 450 K
GFY 1973: 70 K

4-5 MATERIAL COMPATIBILITY

OBJECTIVE

Evaluate the compatibility of materials at cryogenic and elevated temperatures in oxidizing humid and hydrogenous atmospheres.

PROBLEM

Many shuttle materials will contact each other in possibly degrading environments.

TECHNICAL APPROACH

Potentially incompatible materials will be coupled in those environments considered deleterious and tested for degradation. Titanium in a hydrogen environment at low temperature and pressures will be examined for hydriding and embrittlement. Combinations of tantalum coated columbium, TD NiCr, Haynes 188, Rene' 41, Inconie 718, Zirconia, Dyna-Flex, LI-15, alumina graphite, and cabon/carbon composites will be tested under the thermal, pressure, and mass flow environments they will experience on entry.

Tasks	1970			1971												1972												Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
Titanium-H_2 at low pressure and low and room temperatures																												150
Combinations of Ta, Cb, Td NiCr, Zirconia, Dyna-Flex, Haynes 188 LI-15, Graphite, RPP, and Alumina																												300
Insulations and moisture																												50
Fluid systems																												75
																											Total cost	575

GFY 1971: 275 K
GFY 1972: 250 K
GFY 1973: 50 K

4-6 PHASE CHANGE MATERIALS APPLICATION

OBJECTIVE

Identify and/or develop materials that exhibit a reversible crystalline to amorphous phase-change where the enthalpy of transition is 60 Btu/lb or greater.

PROBLEM

Phase change materials offer potential weight and volume savings for reusable shuttle thermal protection systems, and in addition can be used for hot spot protection. Materials possessing a crystalline to amorphous reversible phase change with an enthalpy of transition of 60 Btu/lb or greater have not been identified and characterized. The methods of utilizing these phase change materials as part of a passive insulation system have not been developed.

TECHNICAL APPROACH

Temperature regions, thermal load requirements, vehicle locations that require a passive phase-change insulation, and individual material thermal characteristics will be analytically identified. Materials that exhibit required enthalpy and transition temperatures will be identified and laboratory will be verified. The phase-change thermal functionality and cyclic reversibility in system tests will be demonstrated. New materials will be developed or existing materials will be modified as required. Specific emphasis shall be directed toward maximizing the degree of crystallinity of the material. Develop/demonstrate the application/attachment of the phase-change insulation system. Engineering properties allowables will be developed and issued.

	1970			1971												1972												
Tasks	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	Est Cost ($K)
Analysis	—	—	—	—	—	—																						30
Laboratory evaluation				—	—	—	—	—	—	—	—	—																100
New materials development							—	—	—	—	—	—	—	—	—	—	—	—										140
System tests										—	—	—	—	—	—	—	—	—	—	—	—	—	—	—				120
Develop/demonstrate application/attachment																—	—	—	—	—	—	—	—	—				100
Develop and issue allowables.																			—	—	—	—	—	—				30
																											Total cost	520

GFY 1971: 200 K
GFY 1972: 270 K
GFY 1973: 50 K

4-7 EFFECT OF CORROSION ON REUSE AND LONG LIFE

OBJECTIVE

Establish screening of material degradation resulting from normal corrosion to be expected in service.

PROBLEM

The marine atmosphere of KSC coupled with boost and reentry environments may result in severe structural corrosion. Fluid system corrosion is also anticipated.

TECHNICAL APPROACH

Environmental exposure criteria utilizing both commercial and military aircraft experience will be developed. To minimize overall program cost, metals and fluids to which they will be exposed will be classified in generic classes and small specimen screening test method will be established appropriate to shuttle operational life.

Tasks	1970 (O N D)	1971 (J F M A M J J A S O N D)	1972 (J F M A M J J A S O N D)	Est Cost ($K)
Develop environmental exposure criteria				25
Classify in generic classes metals and fluids to which they will be exposed				25
Establish small specimen screening test method appropriate to shuttle operational life				50
Perform required testing				100
			Total cost	200

GFY 1970: 75 K
GFY 1971: 75 K
GFY 1972: 50 K

4-8 ATTACHMENTS FOR HIGH AND INTERMEDIATE TEMPERATURES

OBJECTIVE

Establish joining methods for the candidate TPS alloy for range of structural requirements and temperatures.

PROBLEM

Component size, new materials, and temperature environment indicate joining requirements beyond the current state of the art for efficient light weight structures.

TECHNICAL APPROACH

Installation techniques will be developed and producibility limits will be determined for thermal and mechanical joining of structural and non structural components by L&T and the manufacturing of typical assemblies.

Rivets

The relatively large size of components and the loads anticipated will require rivets of high-strength materials and sizes beyond those currently produced. This will require development of tooling and installation techniques. A development program with rivet suppliers will be necessary to achieve the desired types and sizes and the required installation tools. A further evaluation program will be required to fabricate typical components, establish installation techniques,and test.

Threaded Fasteners

Development and evaluation of minimum weight-threaded fasteners from high-strength, high-temperature materials will be required. Tests will be conducted to establish torque values and joint strength. In high-temperature areas where coatings may be required, application of the coatings will be developed and tests conducted to evaluate their effectiveness.

Welding

Effective welding methods, resistance, and fusion will be developed for the candidate weldable materials in the various anticipated thicknesses. Development of new, or modification of existing welding equipment will be required. Welding schedules will be established and extensive testing done to evaluate the metallurgical and mechanical properties of the welds.

Brazing

Brazed alloys will be developed and the metallurgical and mechanical properties of brazed joints evaluated. Tooling requirements for applicable sizes and shapes of typical components will be developed and established. Tests will be conducted to evaluate joint efficiency at various anticipated operating temperatures.

Diffusion Bonding

Columbium, steel, nickel and titanium alloys are all good candidates for diffusion bonding. The principal effort required to establish a diffusion bonding capability for typical components lies in tooling and techniques. Preliminary work will be required to establish the trade between time, temperature, and pressure. Development work will be required to establish technique in tooling and placement of filler materials, bagging, applying pressure, heating, and scale-up to full size components.

Tasks	1970 O N D	1971 J F M A M J J A S O N D	1972 J F M A M J J A S O N D	1973 J F M A M J	Est Cost ($K)
Mechanical fasteners	1-30				1500
Welding		1-30			1800
Brazing		1-30			500
Diffusion bonding		1-30			1500
				Total cost	5300

GFY 1971: 1800 K
GFY 1972: 3000 K
GFY 1973: 500 K

4-9 ATTACHMENTS FOR CRYOGENIC TANKS

OBJECTIVE

Determine bonding techniques for the various internal insulation systems being considered for the booster and orbiter, determine scale-up problems, and resolve closeout attachment problems.

PROBLEMS

The insulation must be structurally compatible with the propellant tank design and must be integrated into the structural environment including structural bending, flexing, buckling, and thermal stresses plus launch and vibration loads.

TECHNICAL APPROACH

Tank structural requirements will be determined. Potential adhesives will be evaluated for four candidate insulations (i.e., PPO foam, open cell honeycomb filled with open cell foam, open cell honeycomb filled with fibers and covered with a perforated liner, and 3D fiber reinforced foam with an internal liner). Processing parameters will be evaluated, and closeout techniques using balsa and/or high-density foam. Design properties on insulation and will be determined and structural analysis of insulated tank configurations will be conducted. Small and large-scale article tests will be conducted.

Tasks	1970 (O N D)	1971 (J F M A M J J A S O N D)	1972 (J F M A M J J A S O N D)	Est Cost ($K)
Determine design criteria				40
Conduct material evaluation tests				60
Conduct environmental tests on small-scale article				180
Select final insulation configuration and analyze		∇		
Conduct environmental test on large-scale component				820
			Total cost	1100

GFY 1971: 250 K
GFY 1972: 700 K
GFY 1973: 150 K

4-10 RAIN EROSION PROTECTION

OBJECTIVE

Evaluate the hazards of rain erosion on critical areas of the booster and orbiter, and develop suitable protective systems where they are required.

PROBLEM

At altitudes below 35,000 feet, the space shuttle booster and orbiter can encounter rain and be subjected to rain erosion on critical areas. The maximum velocity below 35,000 feet is M = 0.75. The original reentry profile determines the severity of heating on the booster and orbiter areas and dictates materials which may be critical for rain erosion, such as the wing and empennage leading edges and the nose of the vehicles. It is unlikely that there are additional protective coatings for these critical areas that can be effective in preventing rain erosion which will still survive the entry environment. The rain erosion problem then consists primarily of determining the damage potential that erosion has on the candidate materials for the vehicles. If the effects are too severe, it may be possible to modify critical areas with backup systems that are sufficient to prevent deterioration progressing to the point of endangering the vehicle.

TECHNICAL APPROACH

Critical areas of the baseline vehicles that are subject to rain erosion, such as the wing/empennage leading edges and the fuselage nose will be surveyed, including possible alternate materials under consideration for these areas in the survey.

Small preliminary test panels will be prepared for the nonmetallic materials with and without their coatings, and for the coated metallic materials from both the orbiter and booster critical areas.

Rain erosion tests will be run at 500 mph in facility at WPAFB after specimens have been subjected to the entry heating profile. Specimens will be evaluated and the criticality of the erosion due to testing will be determined.

A representative full scale section of wing leading edge incorporating the candidate materials for each vehicle will be prepared. This section will be retested in WPAFB 500 mph facility using a simulated flight profile and conservatively projected rain droplet size and frequency. The vehicle survival potential and backup requirements will be evaluated.

Tasks	1970			1971												1972						Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	
Survey critical areas and candidate systems																						40
Small samples test at WPAFB																						50
Screening tests at WPAFB																						200
																					Total cost	290

GFY 1972: 290 K

4-11 COMPATIBILITY OF METALLIC STRUCTURES WITH CARBON-CARBON COMPONENTS AND COATINGS

OBJECTIVE

Determine the effects of carbon particle impingement and coating on metallic radiative TPS cover panel performance.

PROBLEM

The use of carbonized composite heat shields upstream of coated metallic radiative heat shields may cause carbon particles to coat the metallic heat shields and degrade the performance of their disilicide coatings due to possible chemical reactions of the carbon and coatings.

TECHNICAL APPROACH

The compatibility of metallic heat shield coatings with carbon particles will be investigated by performing simulated entry environmental screening tests of subscale specimens. Subscale plasma arc specimens will be designed to allow carbon ablation products to impinge and coat metallic TPS specimens downstream of the carbon/carbon material. A detailed chemical analysis of metallic specimens both before and after plasma tests will be conducted to determine effects of carbon particles on metallic coatings. Cyclic life testing will be performed to determine long-term effects of carbon on selected disilicide coatings. NDT methods will be used to evaluate effects of carbon on metallic cover panels.

Tasks	1970			1971												1972						Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	
Design and fabricate specimens																						25
Conduct plasma arc tests																						15
Analyze specimens																						10
Conduct cyclic life tests																						25
Analyze and document test results																						25
																Total cost						100

GFY 1971: 50 K
GFY 1972: 50 K

4-12 SCREENING STUDY OF THERMAL CONTROL COATINGS FOR ON-ORBIT OPERATION

OBJECTIVE

Demonstrate adequacy of on-orbit thermal control coatings and develop any necessary refurbishment methods.

PROBLEM

Long-duration earth orbital exposure may degrade thermal control coating performance. Coatings exposed to high temperature during entry may require refurbishment between flights.

TECHNICAL APPROACH

The following will be accomplished: (1) Literature search for candidate materials and properties; (2) optical property measurements (in situ) during and following exposure to orbital environment; (3) effect of total mission environment on optical properties; and (4) rapid refurbishment techniques for correction of entry degradation.

Tasks	1970	1971	1972	Est Cost ($K)
	O N D	J F M A M J J A S O N D	J F M A M J J A S O N D	
Literature search	1-3			10
On-orbit degradation measurement		3-12		100
Effect of total mission		10-18		50
Refurbishment technique		16-24		50
			Total cost	210

GFY 1971: 120 K
GFY 1972: 90 K

4-13 STRUCTURAL DESIGN CRITERIA

OBJECTIVE

Develop structural design criteria for shuttle vehicles.

PROBLEM

The space shuttle has the combined mission profile of aircraft, launch vehicles, and entry vehicles. A single criterion applicable to this range of conditions or environments does not exist. Aircraft generally have longer life than the space shuttle, and launch vehicles/entry vehicles have shorter life than the space shuttle. A criterion encompassing the service conditions and life requirements of the shuttle is required for design and also as a beginning for developing a vehicle specification.

TECHNICAL APPROACH

The existing committee work by NASA and industry on shuttle criteria will be used to establish the basic requirements. It will be modified, however, to meet individual vehicle peculiarities and requirements by using a combination of DOD and FAA aircraft regulations, and a combination of NASA and DOD space and missile system specifications. Areas will be identified where current technology is insufficient to establish a useable criteria.

In establishing the criteria, all service conditions that have to be accounted for will be identified. Margins and factors necessary for structural adequacy will be established. Combinations of loads and environments will be identified, as will the testing and analytical data that is necessary to verify structural adequacy. Life criteria in terms of the numbers of reuses of the vehicle will be established based on the degree of reusability that is required at the end of a set number of flights.

Tasks	1971 J	F	M	A	M	J	J	A	S	O	N	D	Est Cost ($K)
Establish factors related to loads and environment identification													25
Establish factors related to structural strength and rigidity by major components													25
Establish structural verification test requirements as to environment and structure simulation													30
Establish systems and component life criteria for space shuttle mission profiles (loads and temperature)													120
												Total cost	200

GFY 1971: 150 K
GFY 1972: 50 K

4-14 EFFECTS OF VARIATION OF DESIGN CRITERIA ON VEHICLE STRUCTURAL WEIGHT

OBJECTIVE

To determine the sensitivity of structural weight of various components to changes in design criteria.

PROBLEM

Critical weight requirements of the shuttle vehicle requires examination of the weight/ payload sensitivity to structural criteria in order to achieve an optimum design.

TECHNICAL APPROACH

Establish nominal design criteria for a current space shuttle vehicle configuration and break it down into specific design criteria for each major structural component such as wing, body, tanks, payload bay area, thrust structure, fin and TPS. Determine critical design condition(s) for each component. Perturbate those criteria that affect the critical design conditions and determine the associated weight changes for each component. Investigate potential perturbations in design criteria such as ground wind intensities, T/W ratio at liftoff, maximum αq values, maximum axial acceleration during boost, noise and vibration environments, abort trajectories, shock overpressures, dispersions in exit and entry trajectories, wind shear profiles, subsonic gust velocities, propellant tank proof and maximum pressures, factors of safety, flutter margins, design life, design temperatures, material allowables and fracture toughness sensitivity, reliability goals for orbiter and booster structures, fail safe philosophy, landing sink speed, manufacturing technology, fabrication control and tolerances. Define structure and component weight changes as function of changes in design criteria. Identify effect on lift off and payload change. Recommend design criteria modifications.

Tasks	1971												Est Cost ($K)
	J	F	M	A	M	J	J	A	S	O	N	D	
Determine critical design conditions													30
Perturbate nominal design criteria													30
Determine component weight changes													50
Determine vehicle weight sensitivities													20
Determine effects on liftoff weight, payload, etc.													20
												Total cost	150

GFY 1971: 120 K
GFY 1972: 30 K

4-15 DESIGN, FABRICATION, AND TEST OF LARGE LOAD-CARRYING TANKS

OBJECTIVE

Establish an optimum design of a cryogenic tank that performs as a primary load-carrying structure.

PROBLEM

Large reusable cryogenic tanks have not been produced before. The production of a weight/cost effective article requires an efficient integration of complex design considerations. The impact on booster structure weight and costs is substantial.

TECHNICAL APPROACH

All pertinent factors of design, manufacture, and proof of suitability can best be identified and procedures or criteria established, by a program to design, build, and test typical tanks. This approach would provide actual experience and material evidence of structural feasibility. The study would:

1. Develop realistic design criteria based on failure analysis and statistical history. Fracture mechanics technology for prevention of flaw growth, manufacturing requirements and capabilities, and service maintenance will be defined.

2. Develop failure mode analyses for space shuttle environment and loads. Typical limit and ultimate ullage and hydrostatic pressures, shear and vehicle bending requirements will be used in space shuttle mission profile environment.

   Material allowables and configuration constraints will be defined in consideration of deformation, crack propagation limit, fatigue (mechanical, thermal, and sonic) and useful life.

3. Design concepts will be studied to refine fail-safe and safe-life capabilities.

4. Manufacturing capability will be established with regard to material stock size available, manufacturing sequences of machining, welding, and tolerance maintenance for weight control.

5. Define the test specimen size for manufacture, considering the reliability of scale factors for simulation of thermal effects and process development.

6. Determine NDT requirements and evaluate capabilities to define flaws in both the basic material and the weld joints.

7. Fabricate and test a representative reduced scale segment of the tank approximately 10 feet in diameter and 30 feet long. Evaluate results.

Tasks	1970			1971												1972						Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	
Design and analysis of test specimen																						130
Establish inspection and test procedures to evaluate tanks with or without wall insulation																						40
Evaluate manufacturing tasks in tank development. Fabricate tank																						1840
Test and evaluate tank specimen																						240
																					Total cost	2150

GFY 1971: 1150 K
GFY 1972: 1000 K

4-16 NONLINEAR TANK ANALYSIS

OBJECTIVE

Develop practical means for the structural analysis of nonlinear problems associated with space shuttle tankage.

PROBLEM

To properly analyze the structural behavior of pressurized tankage, it will be necessary to consider (1) nonlinear pressure coupling in the skin, stringers, and rings, (2) the nonlinearity of material stress-strain response (tankage material departs from a straight line well below 0.2 percent offset yield), and (3) structural stability of pressurized, stiffened cylinders subjected to overall bending and axial compression. The stability considerations must account for prebuckling deformation due to pressure. In view of the complexity of these three items, practical computer programs should be developed.

TECHNICAL APPROACH

A digital computer program will be developed for the nonlinear analysis of stresses and deformations in pressurized stiffened cylinders by building upon a Convair production program originally developed for monocoque shells. This task has already been partially accomplished. An incremental approach appears best to incorporate the effects from nonlinearity of the stress-strain material response.

A digital computer program will be developed to determine critical loading for the buckling of stiffened pressurized cylinders using the governing equations established by the Langley Research Center. The influences from prebuckling deformations and stiffener eccentricities would be included.

Tasks	1970			1971									Est Cost ($K)
	O	N	D	J	F	M	A	M	J	A	S		
Develop and program analysis of nonlinear response of pressurized stiffened cylinders													100
Develop program for analysis of stability for stiffened cylinders having prebuckling deformations													80
												Total cost	180

GFY 1971: 180 K

4-17 FRACTURE MECHANICS IMPACT ON SHUTTLE DESIGN

OBJECTIVE

Establish the fracture mechanics design data, structural analysis methodology, and test procedures for shuttle pressurized and unpressurized structure.

PROBLEM

Premature structural failures in pressure vessels and unpressurized structures have occurred due to uninhibited propagation of undetected flaws.

TECHNICAL APPROACH

Coupon materials testing will be performed to determine fracture toughness, sustained loading threshold, and crack growth rates for candidate materials in operational environment.

Fracture mechanics structural analysis methodology that incorporates loading history, proof test flaw screening, flaw growth prediction, and selection of operating stress level will be developed.

Structural development test articles will be designed and fabricated for candidate materials and construction based on the developed methodology.

Articles will be tested for expected cyclic load and operational temperature to verify structural analyses methodology.

Task	1970 (O N D)	1971 (J F M A M J J A S O N D)	1972 (J F M A M J J A S O N D)	1973 (J F M A M J J A S O N D)	Est Cost ($K)
Coupon testing for fracture mechanics properties data					500
Develop fracture mechanics structural analysis methodology					100
Design and fabricate test articles					250
Test panels to verify and update methodology					150
				Total cost	1000

GFY 1971: 700 K
GFY 1972: 300 K

4-18 HIGH-TEMPERATURE WINDSHIELD DESIGN

OBJECTIVE

Develop a fail-safe prototype windshield design and conduct laboratory tests under simulated thermal conditions.

PROBLEM

Shuttle windshields will see environments more stringent than Apollo and X-15 windshields. The thermal, mechanical, and optical properties of the windshield must be compatible with the high temperatures during entry. Retaining structure and material must be designed to withstand internal pressure and not induce failure stresses on the windshield resulting from structural deflections due to thermal gradients. High-temperature sealing techniques are required.

TECHNICAL APPROACH

Thermal analysis will be conducted to determine environmental design criteria. Windshield configuration conceptual designs will be developed including number of panes, cooling paths, heat dissipation method, and thermal radiation shielding. Survey to select transparency and seal materials will be conducted. Retaining structure design will be developed, materials will be selected, and thermal gradient, stress, and deflection analysis will be conducted. Laboratory tests of a prototype configuration, subjecting the structure/windshield specimen to the temperature profiles encountered during entry, will be conducted.

Tasks	1971										1972			Est Cost ($K)
	M	A	M	J	J	A	S	O	N	D	J	F	M	
Criteria, concepts, material evaluation														50
Design, fabricate, and test														120
											Total cost			170

GFY 1971: 70 K
GFY 1972: 100 K

4-19 ADVANCED COMPOSITES APPLICATIONS TO SPACE SHUTTLE STRUCTURE

OBJECTIVE

Develop design data and design allowables for advanced composites in the operational environment of the space shuttle. Demonstrate structural performance by developing the necessary manufacturing, tooling, and test techniques necessary to fabricate full-scale vehicle test components from both resin and metal matrix composites.

PROBLEM

The predicted benefits of composite material utilization for the solution of potential vehicle structural weight and balance problems require confirmation. Detail design allowables are not available and the necessary development for full scale demonstration components has not been accomplished.

TECHNICAL APPROACH

A number of significant tasks need to be accomplished in order to qualify advanced composites for space shuttle structural applications. These include the following:

1. Development of structural analysis methods for structure peculiar to the shuttle. Criteria, sizing routines, and specialized analytical techniques need to be developed.

2. Material and design configuration studies have to be accomplished and design allowables developed, including fatigue/residual strength data and joints. System tradeoff studies are required.

3. Tooling and fabrication concepts and methods for both resin and metal matrix structures which consider the actual sizes and loads must be established.

4. Subscale (1/8 - 1/2) element fabrication and test for process, quality assurance, and performance review are necessary prior to full-scale element/component tests. Specimens will parallel those noted in (5) below.

5. Full-scale elements need to be fabricated and tested under simulated operating conditions to establish full assurance of the composite material's suitability for use on the shuttle vehicle. These elements include selected portions of the booster thrust structure and fuselage frames, and the orbiter thrust structure and fuselage shell. Other components may need to be added as development proceeds.

Tasks	1970 (O N D)	1971 (J F M A M J J A S O N D)	1972 (J F M A M J J A S O N D)	Est Cost ($K)
Analytical methods development				150
Material and design configuration studies				125
Design allowables				350
Tradeoff studies				100
Tooling and fabrication methods development				75
Subscale elements fabrication and test				1250
Large-scale fabrication and test				3950
			Total cost	6000

GFY 1971: 1500 K
GFY 1972: 4000 K
GFY 1973: 450 K

4-20 HOT STRUCTURE DESIGN AND EVALUATION

OBJECTIVE

Develop reliable hot structure designs

PROBLEM

In order to take advantage of the low-weight, hot structure concept for shuttle, applicable temperature regimes and design allowables have to be defined. This requires identification of candidate design concepts, areas of critical stress concentration, thermal gradients and distributions, and methods for stress relief.

TECHNICAL APPROACH

Short-time. and long-time loading allowables at applicable temperatures for candidate materials will be determined. Design concepts that minimize thermal stresses will be established and evaluated. Environmental and functional tests on critical elements will be conducted. Full-scale components will be designed, analyzed, and fabricated and subject to functional, environmental, and life cycle tests. Test data will be analyzed and the results documented.

	1970			1971												1972									
Tasks	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	Est Cost ($K)
Design criteria and concept evaluation																									50
Design components																									75
Fabricate components																									225
Test																									150
Evaluate results																									50
																Total cost									550

GFY 1971: 180 K
GFY 1972: 320 K
GFY 1973: 50 K

4-21 DESIGN CONSIDERATIONS OF HIGH-TEMPERATURE CONTROL SURFACES

OBJECTIVE

Validate the design concept developed for each identifiable critical areas of high-temperature control surfaces. Such areas are the leading edge, transition between the hot leading edge and cooler windward and leeward surfaces, hot load carrying structure, adjacent trailing edge, hinges, seals between fixed and movable surfaces, actuating system, and damping systems for the non-aerodynamically balanced movable surfaces.

PROBLEM

High temperatures and heating rates are developed in localized areas of control surfaces. Realistic testing must be done to verify flow theory associated with leading edge gaps and leeward surface flow separation. Environmental conditions exceed current seal capability in terms of temperatures, reuse and gap magnitude at temperature. Without seals, internal components will require excessive insulation and the structure will be heavier. Actuating devices should be investigated and tested to determine the resistance to high temperatures and fatigue.

TECHNICAL APPROACH

A basic approach integrating the structure, insulation system, and actuation system for the high-temperature control surfaces will be defined and selected. Analyses will be performed and designs generated for each of the problem areas with attention to the interfaces with adjacent problem areas. Selection will be made from candidate designs considering reliability, life, weight, and cost. Selected concepts will be validated by environmental and functional tests. A large-scale component will be fabricated and subjected to a simulated hypersonic entry environment in a selected test facility. A 12-foot by 12-foot section of the elevator structure could be used.

Tasks	1970: O N D / 1971: J F M A M J J A S O N D / 1972: J F M A M J J A S O N D	Est Cost ($K)
Establish design criteria		25
Design and analyze components		60
Order materials		60
Fabricate specimens		360
Conduct environmental tests		180
Reduce and correlate data		75
	Total cost	760

GFY 1971: 300 K
GFY 1972: 460 K

Tasks	1970			1971												Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
Characteristics of representative electromechanical system																50
Detection, identification, and isolation technique development																50
Techniques effectiveness analysis																25
Laboratory breadboard tests and test evaluation																50
												Total cost				175

GFY 1971: 150 K

GFY 1972: 25 K

6-2 DETECTION, IDENTIFICATION AND ISOLATION OF FAILURES OF ELECTROMECHANICAL SYSTEMS

OBJECTIVE

Develop the technologies required for detection, identification, and isolation of electromechanical systems failures as applicable to the space shuttle vehicle.

PROBLEM

The electromechanical systems, subsystems, and components in present aerospace vehicles and supporting equipment do not possess the capabilities to (1) assess ability of system to perform its intended function, (2) assess real-time performance of system and (3) detect, identify, and isolate failures which are required to satisfy the repeated flight, long-duration mission, and short-turnaround refurbishment requirements.

TECHNICAL APPROACH

Vehicle electromechanical systems will be analyzed (control surface actuation systems, air-breathing engine retraction systems, landing gear, fuel cells, hydraulic systems, etc.) to define the degree of applicability of readiness assessment, status monitoring, and fault detection and isolation concepts to a particular system. Systems will be selected for study that are representative of a wide range of mechanical systems.

Selected systems will be analyzed to define pertinent characteristic useable in performance assessment and fault detection, such as measurability of the system's intended functions and parameters, susceptibility to and effects of failures, adaptability to automatic detection identification and isolation techniques, ability to accept stimuli, etc.

Develop fail-obvious monitoring techniques for automatic fault detection and isolation using state-of-the-art instrumentation approaches as a baseline.

The application of these techniques to each system will be evaluated to judge the effectiveness of the techniques. Development of techniques will be assisted by laboratory breadboard fabrication and test to determine and evaluate characteristics such as monitoring levels, nuisance fault rates, etc.

Techniques will be applied to particular systems to evaluate impact on implementation adequacy of monitoring to assure required level of fault detection and effect on overall system reliability.

6-1 APPLICATION OF ONBOARD CHECKOUT TO SPACE SHUTTLE SUBSYSTEMS

OBJECTIVE

Develop subsystem sensor criteria and evaluation algorithms necessary to perform the processes of fault detection and fault isolation onboard the shuttle vehicles.

PROBLEM

The key problem in the development of an onboard checkout system is defining the measurement/analysis combination that is appropriate for autonomy and economical operation. Historically, ground checkout used measurement parameters not designed into subsystems, but added into systems as measurement requirements were determined. These previous methods are not practical on the shuttle. They result in excess weight, excess costs, and reduced system reliability.

TECHNICAL APPROACH

Decisions and supporting information requirements through failure mode and effect analysis will be identified using a baseline configuration. Measurement requirements will be identified and characterized to yield the needed information. Methods will be determined and requirements and procedures designed that would be used to implement the information requirements, including consideration of using functional and special measurements, determining adequate sensing methods, sensor locations, data processing requirements, degree of crew participation, and resulting data dissemination (display, recording) requirements for preflight, inflight, and postflight checkout, monitoring and evaluation requirements.

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Task	1970			1971									Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	
Identify decisions													20
Identify information requirements													40
Identify proper operation and failure modes													90
Identify checkout measurements and characteristics													120
Identify sensing requirements													140
Identify processing requirements													130
Identify crew participation and display requirements													40
												Total cost	580

GFY 1971: 450 K

GFY 1972: 130 K

4-22 DESIGN, ANALYSIS, FABRICATION, AND TEST OF LARGE-SCALE COMPONENTS OF THE SPACE SHUTTLE BOOSTER

OBJECTIVE

Establish the size, type, and test procedures for major structural components of the space shuttle vehicle system that are necessary to verify its strength and integrity.

PROBLEM

The space shuttle vehicles represent the largest aircraft-type of cryogenically fueled structures planned to date. In the course of their development, large segments of the control surfaces, wings and fuselage have to be realistically tested to prove out the structural concept. The cost of the specimens, the facilities required for their test and the cost of environmentally similar test conditions are formidable problems in vehicle development, and need to be studied.

TECHNICAL APPROACH

The major component/subcomponent test specimens that are necessary for vehicle development will be defined. In order to provide the necessary design, fabrication and test techniques prior to full-scale vehicle development testing, one typical component will be selected for static load tests in its predicted critical environment. Because of its location on the vehicle, the empennage presents a major structural problem. It is located in a high heating area and is subjected to a severe acoustic environment in addition to its normal static loadings and excitations. Therefore, an inboard segment of one fin and its root attachments that is at least 1-1/2 chord lengths long will be selected as a typical component for study and test. The fin segment will be designed and fabricated in as close to its final configuration as possible. It will be installed in a static test facility that has the capability to program both loads and temperatures. Its suitability for strength, creep, and thermal cycling will be established. In addition, typical cover panel segments will be fabricated and tested in acoustic fatigue.

Tasks	1970 (O N D)	1971 (J F M A M J J A S O N D)	1972 (J F M A M J J A S O N D)	Est Cost ($K)
Define specimen, test conditions, and test plan				50
Analyze and design specimen				240
Design and prepare tooling				750
Fabricate and instrument specimen				1960
Prepare test jigs and heating facility				150
Conduct and evaluate static thermal cycling and fatigue tests				410
			Total cost	3560

GFY 1971: 1000 K
GFY 1972: 2200 K
GFY 1973: 360 K

4-23 DESIGN, FABRICATION AND TEST OF LARGE SCALE COMPONENTS OF THE SPACE SHUTTLE ORBITER

OBJECTIVE

Verify the weight credibility of the Shuttle orbiter fuselage complete with tankage, insulation, purge system, body load carrying structure, and TPS.

PROBLEM

The combined weight and suitability of the cryogenic tankage, TPS, insulation, and purge system can only be verified by fabrication and testing to design conditions.

TECHNICAL APPROACH

1. Loads, heat inputs, structural temperatures, tank pressures, etc., will be defined for the baseline delta-wing forebody consisting of the LH_2 tank, and attachment to outer load carrying shell with insulation and TPS.

2. Flight weight test article structures and components will be designed to satisfy environmental requirements.

3. A test article will be fabricated to minimum weight criteria.

4. Test article and fixture will be designed to allow checkout and verification of several critical components and assemblies (i.e., wheel wells, cargo doors, booster/orbiter attach points, body/wing junction) fueling, pressurization, loading, heating, and tests will be performed.

Tasks	1970			1971												1972												1973			Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	
Define test article environmental requirements																															100
Design test article to satisfy environmental requirements																															500
Fabricate test article and fixture																															3000
Perform tests on test article																															1500
																										Total cost					5600

GFY 1971. 300 K
GFY 1972: 4000 K
GFY 1973· 1300 K

4-24 ACCEPTABLE FAILURE MODES AND FAIL SAFE CONSIDERATIONS FOR THE VEHICLE STRUCTURAL SYSTEM

OBJECTIVE

Establish reasonable solutions for the booster and orbiter structural arrangements that will provide non-catastrophic failure modes by applying fail-safe or safe life principles developed for aircraft.

PROBLEM

Orbiter and booster structures combine cryogenic tanks, heat shields, and primary structure in an aircraft configuration. Both are subjected to cyclic loadings due to air and inertia loads, temperatures, and sonic excitation. No research has been accomplished on fail-safe or safe-life approaches to the primary structure under these circumstances.

TECHNICAL APPROACH

The approach will be to examine all space shuttle structural systems to determine their potential failure modes in response to environment and loads. These modes will be assessed in terms of their effect on the integrity of the entire vehicle. Studies of design concepts and materials combinations will be made to evaluate perturbations of fracture toughness, crack arrest techniques, mechanical properties, and fabricability. Parametric studies of failure modes as a function of weight, crack propagation rates, degree of damage, detection, and ease of repair will be made.

A development test program will be defined, and a criterion for components of the vehicle system will be recommended.

	1970			1971									
Tasks	O	N	D	J	F	M	A	M	J	J	A	S	Est Cost ($K)
Study plan													10
Investigate and identify critical failure modes													20
Evaluate criticality of failures in terms of life support, structural, and temperature control requirements													40
Evaluate materials and design concepts													20
Development test program to test representative structural elements													20
Summarize and recommend criteria													30
												Total cost	140

GFY 1971: 100 K
GFY 1972: 40 K

4-25 ACTIVE TPS COOLING FOR THE ORBITER

OBJECTIVE

Establish the thermal requirements (performance, limitations, uncertainties, and weight) of candidate active TPS cooling concepts for the orbiter.

PROBLEM

A reliable, reusable, low-weight, effective thermal protection system is critical to the design of lifting entry vehicles. Metallic radiators and rigid insulators meet these requirements for large, relatively flat surfaces. Some active cooling augmentation may be required for leading edges, interference heating areas, etc.

TECHNICAL APPROACH

Candidate active TPS cooling concepts (e.g., transpiration cooling, an internal closed-coolant-loop/water boiler system, a heat pipe/water boiler system) will be selected. The thermal environment will be established. The thermal model for the TPS concepts will be developed. Parametric weight, dimensional, and thermal performance data for the candidate cooling system will be developed. The limitations of the candidate systems will be established, and demonstration tests of selected concepts will be performed.

Tasks	1971 J F M A M J J A S O N D	1972 J F M A M J	Est Cost ($K)
Establish thermal environment			18
Select candidate system			12
Develop thermal models			72
Develop parametric data			180
Establish limitations			18
Perform demonstration tests			300
		Total cost	600

GFY 1971: 150 K
GFY 1972: 450 K

4-26 ACCELERATED LIFE TESTING

OBJECTIVE

Develop accelerated life testing methods for orbiter materials and material systems.

PROBLEM

Real-time testing of orbiter materials and material systems for the shuttle is prohibitive from a time and cost standpoint. Accelerated life-test methods and their correlation with real-time test methods to support shuttle total mission environments do not exist.

TECHNICAL APPROACH

The following will be accomplished:

1. Survey for existing accelerated life-test methods and their adaptability to shuttle orbiter requirements.
2. Establish an orbiter materials and material systems criticality list for life testing.
3. Develop material accelerated life-test methods.
4. Develop material system accelerated life-test methods.
5. Publish a life expectancy of material properties handbook for materials and materials systems.
6. Items 3 and 4 above shall be correlated with real-time test methods.

Tasks	1970			1971												1972												Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
Survey for existing methods																												20
Establish criticality list and maintain same																												20
Develop material test methods																												200
Develop material system test methods																												350
Publish life expectancy handbook																												10
																											Total cost	600

GFY 1971: 150 K
GFY 1972: 400 K
GFY 1973: 50 K

4-27 ADVANCED METALLIC TPS

OBJECTIVE

Extend the state of the art and improve the design of reusable, metallic heat shield thermal protection systems.

PROBLEM

Presently conceived reusable, metallic, heat shield designs are pressing the state of the art in material development and use at elevated temperatures. Specialized heat shield design problems which require further attention are: panel arrangements and attachments, sealing heat shield surface, and improving surface contour control (mismatch, steps, wavness, roughness).

TECHNICAL APPROACH

Advanced metallic thermal protection systems will be developed through combined efforts of thermal analysis, structural analysis, and design functions. The approach to be followed will be concept development, preliminary design and analysis, selection of promising arrangements, detail design and analysis (including attachments), and experimental verification of the final designs. Special design problems, which will be attacked, center on the problem of providing a smooth, air-tight aerodynamic surface.

Tasks	1971 (J F M A M J J A S O N D)	1972 (J F M A M J J A S O N D)	Est Cost ($K)
Concept and criteria development			270
Preliminary design			240
Thermal analysis			480
Structural analysis			480
Concept selection			60
Detail design			180
Model fabrication			540
Test			360
Analysis of test results and documentation			180
		Total cost	2790

GFY 1971: 750 K
GFY 1972: 1500 K
GFY 1973: 540 K

4-28 TPS SINGULARITIES

OBJECTIVE

Develop analysis and design methods to treat locally discontinuous areas or penetrations of the TPS.

PROBLEM

The practical design of a shuttle vehicle will result in many anomalies to the basic TPS, such as doors, windows, hatches, ACPS nozzles, antennas, attachments, etc. Combined thermal/structural/design methods and approaches must be developed to support the Phase C program.

TECHNICAL APPROACH

The singularity problem may be resolved into general classes or types of heat shield penetrations. Analytical models of each class of penetrations will be formulated. Parametric studies will be performed to guide penetration design. Design methods will be developed for each class of singularity. The analytical models will be used to predict internal heat transfer and temperature profiles in the region of the penetration and to predict the effect of the singularity on the surrounding TPS. Methods will be developed for locally protecting sensitive components and penetrations. Verification tests will be performed for selected configurations.

Tasks	1970 O N D	1971 J F M A M J J A S O N D	1972 J F M A M J J A S	Est Cost ($K)
Definition of penetration classes				30
Formulation of Analytical models				90
Development of methodology				120
Parametric studies				90
Develop design methods				90
Verification tests				600
			Total cost	1020

GFY 1971: 200 K
GFY 1972: 700 K
GFY 1973: 120 K

4-29 FAIL-SAFE TPS CONCEPTS

OBJECTIVE

Develop heat shield concepts which are redundant and fail in a predictable manner.

PROBLEM

A number of the current TPS designs probably would not protect the shuttle vehicle through the entry phase if an external heat shield panel was severely damaged or lost during entry, or if the design environments were significantly exceeded.

TECHNICAL APPROACH

Fail-safe heat shield concepts will be investigated for both integral and nonintegral tank designs for reradiative TPS concepts. The most effective method of providing a backup system will be determined by concept development, analysis, design, and ground test. Initially, the design philosophy and design criteria will be established. A failure criteria will be defined and failure mode analysis will be performed. Attractive concepts will be pursued through the analysis and preliminary design phase. Further screening will be performed and selected concepts will be chosen for detail design and test.

Tasks	1970			1971												1972						Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	
Concept definition establish criteria																						120
Perform thermal/ structural analysis																						200
Design																						120
Model fabrication and test																						180
Test analysis and evaluation and documentation																						80
																Total cost						700

GFY 1971: 120 K
GFY 1972: 580 K

4-30 RIGIDIZED EXTERNAL INSULATION

OBJECTIVE

Develop rigidized external insulation reusable for 100 missions without refurbishment.

PROBLEM

External insulation capable of withstanding shuttle environment for total vehicle life has not been demonstrated.

TECHNICAL APPROACH

Applicable design environment for representative locations and requirements for candidate system elements (insulation, coating, attachments) will be defined. Candidate materials will be screened to the requirements of candidate system elements. Subscale specimens of complete insulation systems will be fabricated and tested to individual environmental limits. Subscale specimens will be fabricated and tested for 100-mission cycle capability. Full-scale specimens representative of actual vehicle hardware will be designed and fabricated.

	1970			1971												1972									Est Cost
Tasks	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	($K)
Define requirements and screen materials																									375
Subscale development and test																									800
Full-scale specimen fabrication																									900
Test full-scale specimen																									625
															Total cost										2700

GFY 1971: 500 K
GFY 1972: 1790 K
GFY 1973: 400 K

4-31 CARBON-CARBON HEAT SHIELD ELEMENTS

OBJECTIVE

Develop carbon-carbon/carbon-graphite heat shield systems adequate for 100 missions without refurbishment, publish design allowables, and demonstrate full-scale hardware performance.

PROBLEM

No pyrolized system has shown sufficient oxidation resistance for 100 - mission use. Detail allowables are not available.

TECHNICAL APPROACH

Small specimen tests will be performed to evaluate various categories of oxidation protective systems (coating, in-depth, etc.) and materials (silicon, borides, etc.) Preliminary mechanized properties of leading candidates in each category will be determined. Subscale elements (leading edge, heat shield panel, etc.) for leading candidate materials will be designed, fabricated, and tested. Applicability of high modulus fibers to pyrolized systems will be investigated by testing small specimens. Design allowables for finally selected systems will be determined and full-scale components representative of vehicle structure will be designed, fabricated, and tested.

	1970			1971												1972									
Tasks	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	Est Cost ($K)
Coating verification																									300
Mechanical properties																									100
Subscale testing																									400
Design allowables																									200
Full-scale test																									300
																Total cost									1300

GFY 1971: 500 K
GFY 1972: 600 K
GFY 1973: 200 K

4-32 IMPROVEMENT OF CARBON-CARBON BY INCLUSION OF GRAPHITE FILAMENTS

OBJECTIVE

Determine if structural strength of carbon-carbon composites can be increased by inclusion of high modulus graphite filaments.

PROBLEM

Although strength characteristics of carbon-carbon composites are suitable for many structural applications, an increase in strength makes carbon-carbon composites suitable for use in areas where they are now marginal, unsatisfactory, or cannot compete with metallic materials.

TECHNICAL APPROACH

The selective use of high modulus graphite filaments to improve the strength of standard carbon-carbon composites for use in areas requiring higher low carrying capability will be investigated. Determination will be made if the incorporation of the fabrication processes of carbon-carbon components will degrade the characteristics of high modulus filament. The relative advantage of filaments usage will be evaluated by comparative testing. Preliminary material allowables for the most promising filament system will be determined.

Tasks	1970			1971												1972			Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	
Define and develop fabrication processes																			60
Determine material allowables																			40
Design fabrication, and test of small-scale test specimens																			60
Reduce and correlate data																			40
																Total cost			200

GFY 1971: 120k

GFY 1972: 80k

4-33 MATERIALS TECHNOLOGY OF BULK INSULATION

OBJECTIVE

Develop techniques for the packaging and support of bulk insulation systems in the TPS and for purging them with inert gas. Determine the thermal efficiency of insulation systems before and after cycling. Determine the life of the concepts by mission simulation cycles. Validate selected concepts for application to the Space Shuttle.

PROBLEM

Moisture absorption from humidity or rain would have a deleterious effect on the performance of fiberous insulations (bulk) materials. Moist insulation could densify (i.e., compress), thereby altering the thermal and physical characteristics of the system. Certain entry TPS concepts provide for inert gas purging. Normal blankets must be supported and segregated from the heat shields and/or primary structure to provide for free flow of the purge gas. The high-temperature material compatibility must be established.

TECHNICAL APPROACH

Candidate materials will be selected on the basis of high-temperature capability, low product of thermal conductivity and density, compatibility with adjacent materials, dimensional stability, chemical stability, and general vibration environments. Where data are not available for the above selection criteria, provide same in the laboratory. Packaging and/or purge requirements will be established for the TPS bulk insulation. Packaging designs and processes that will meet shuttle requirements and purge designs and processes that will meet shuttle requirements will be developed. Novel materials and/or system concepts (i.e., quartz fiber cloth with high-temperature capabilities, water repellant characteristics, and "breathing" capability) will be developed and evaluated. System tests of the TPS bulk insulation under simulated shuttle mission profiles (including temperature, pressure, vibration, time of exposure, recycle, and water absorption) will be conducted. Design allowables will be issued.

Tasks	1970			1971												1972												Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
Select materials and concepts																												250
Establish requirements																												50
Packaging development																												200
Purge development																												200
Develop novel materials/systems																												860
System tests																												600
																											Total cost	2160

GFY 1971: 900 K

GFY 1972: 960 K

GFY 1973: 300 K

4-35 COMPOSITE REINFORCEMENT OF CONVENTIONAL METAL STRUCTURES

OBJECTIVE

Determine the fabrication procedures for producing and attaching curved cap sections to metal substrates and for producing large tubular truss members from Al-B composite.

PROBLEM

Very large (30 feet long by 10 inches wide by 1 inch thick) curved sections that are typical of the space shuttle booster frames have not been developed to date in Al-boron. The methods for attaching these large, high-strength sections to a substrate, or of splicing such a section have not been studied. Similarly, large Al-boron tubular truss members 4 inches in diameter and 5 feet long and their attachments have not been developed.

TECHNICAL APPROACH

Test segment of frame section will be designed so that it can be fabricated and tested in order to demonstrate capping, splice, and attachment procedures. Cap consolidation may be by braze bonding of tape layers or by diffusion bonding to shape. Methods of attaching reinforcement to frame including adhesives, brazing, mechanical fasteners, welding and diffusion bonding will be evaluated. Splice and doubler procedures for connecting cap segments will be determined. Thick composite sections will be drilled and machined for installation of fasteners. Inspection and NDT procedures will be determined. Repair methods on caps relative to attachment to frames and damage to composite will be evaluated. Static and structural dynamic testing program on typical specimens including tension compression, shear and fatigue will be conducted. Fabrication of tubular truss members by high pressure diffusion bonding will be investigated. Filament orientation requirements and tape composition will be determined. Fitting configuration, overlap, and material selection will be investigated. Tube fitting attachment by methods including adhesive bonding, brazing, and mechanical fastening will be studied. Joints by metallography and NDT will be inspected, and single tubes and fittings in tension, short- and long-column compression, and fatigue will be tested. A representative truss frame section will be designed and fabricated and structurally tested under typical load.

4-34 ADVANCED SPACE THERMAL CONTROL CONCEPTS

OBJECTIVE

Define and evaluate advanced space thermal control concepts which could be employed in an efficient, long-life thermal management system.

PROBLEM

The orbiter is required to perform ascent, orbital (for extended periods), and reentry phases of a mission. Therefore, the thermal control systems must be compatible with the TPS system designed for entry and ascent. In addition, the vehicle is extremely large having a complex shape (dictated by aerodynamic considerations) and with limited power available for temperature control. These characteristics will require advanced passive techniques for minimizing active thermal control requirements.

TECHNICAL APPROACH

Advanced passive thermal control concepts (i.e., heat pipes, phase changes materials (PCM) louvers, thermal switches, etc.) which are currently in use or being developed for unmanned spacecraft will be evaluated for application to space shuttle. Space shuttle thermal control concepts will be developed employing these devices singly or in combination for subsystem thermal control. Parametric thermal performance analyses will be performed for each of these concepts applied to the temperature control of selected subsystems. Optimum thermal management systems will be selected.

Tasks	1970			1971												Cost Est ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
Evaluate concepts																20
Develop thermal control concepts																120
Parametric data																160
Define optimum system																50
															Total cost	350

GFY 1971: 300 K

GFY 1972: 50 K

Tasks	1970			1971												1972			Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	
Design of test specimens																			70
Fabrication development of caps																			200
Cap strip to frame attach																			150
Splice and machining methods																			70
Repair and inspection procedures																			40
Tubular Truss and joint development																			100
Coupon and structural testing																			150
																		Total cost	780

GFY 1971: 400 K

GFY 1972: 380 K

4-36 LIGHTWEIGHT FLUID SYSTEMS

OBJECTIVE

Establish methods of forming and joining lightweight fluid systems.

PROBLEM

Forming and joining of high-strength tubing to achieve minimum weight will require techniques beyond the current state of the art.

TECHNICAL APPROACH

Forming and heat treat techniques will be developed for minimum bend and maximum strength tubing. Mechanical and thermal joining processes will be developed.

1. Minimum Bends. Establish minimum design bend data for tubular material in the alloys, diameters, and wall thickness to be used. Develop bending techniques and evaluate the effect on metallurgical and mechanical properties.

2. Mechanical Joints. Develop and test mechanical joining methods and joint hardware for both removal and permanent assemblies with emphasis on minimum weight and maximum reliability.

3. Heat Treat Cycle. Develop heat treat cycle and sequence of forming, joining, and heat treating. Conduct feasibility tests and establish heat treat response in terms of mechanical and metallurgical properties.

4. Metallurgical Joints. Develop effective welding and brazing methods for the candidate materials in the various anticipated sizes. Develop new, or modify existing welding equipment. Establish welding schedules and test extensively to evaluate the mechanical and metallurgical properties of the joint. Brazed joints will require development of joint design, fittings, braze alloy, and heating methods.

Tasks	1970	1971	1972	Est Cost ($K)
	O N D	J F M A M J J A S O N D	J F M A M J J A S	
Minimum bends	1 — 6			145
Mechanical joints		1 — 24		300
Removal and permanent				
Develop heat treat cycle				45
Develop metallurgical joint				300
			Total cost	790

GFY 1971: 400 K

GFY 1972: 390 K

4-37 TANK FABRICATION TECHNIQUES

OBJECTIVE

Develop optimum tank fabrication techniques for producing the required quality reproducibly at minimum cost.

PROBLEM

Correlated machining, tooling and welding methods, and techniques for tank fabrication that are competitively practical and reproducible for the required component configurations and quality must be selected.

TECHNICAL APPROACH

Optimum conditions will be determined for welding tank plate stock (1/4-inch 2219 aluminum) by various advanced welding methods (TIG/MIG/EB and Plasma). Variables will include welding position (flat, vertical, overhead), tooling concepts, protective gases, and joint preparation. Welds will be evaluated by nondestructive and tensile tests.

Optimum fabrication techniques will be determined for producing integrally reinforced and contoured tank panels and contoured tee rings from 2-inch thick plate. Development will include optimizing machining and forming techniques; also weld tooling concepts and techniques for one or two methods selected from Phase I. Welding work will include mismatch and distortion control and effects of weld position. Welded panels and rings will be evaluated for distortion, for integrity (nondestructive testing), and for mechanical properties (element tensile and fracture toughness).

A simulated tank section will be fabricated by machining and forming and welding techniques selected in Phase 2. Two panels will be produced, one for mechanical testing. Evaluation will include distortion, joint integrity (nondestructive testing) and mechanical tests (tensile and fracture toughness).

Tasks	1970						1971						Est Cost ($K)
	J	A	S	O	N	D	J	F	M	A	M	J	
Welding tests													30
Fabrication tests													35
Sample tank fabrication													35
												Total cost	100

GFY 1971. 100 K

4-38 COMPOSITE REINFORCED METAL STRUCTURE MANUFACTURING METHODS

OBJECTIVE

Establish manufacturing methods for reinforcing conventional structure with metallic and nonmetallic composites.

PROBLEM

Experience in joining metallic and nonmetallic composites to conventional metal structure is limited to laboratory conditions and small test parts. "Hands-on" experience under shop conditions is necessary to identify specific difficulties to establish a manufacturing capability at minimum costs.

TECHNICAL APPROACH

Portable drilling techniques for laminated structure utilizing ultrasonic, diamond tools, and abrasive methods will be developed. Surface finishes, interference tolerances, and sizing methods will be evaluated.

Test panels of sandwich assemblies will be fabricated using adhesives, brazing, and fasteners for evaluation.

Sandwich assemblies will be evaluated by nondestructive testing methods such as X-ray, ultrasonics, visual inspection for filament crushing, and delamination. Section for coining, head gap, and shank void effects.

A simulated space shuttle part, as determined by design, will be produced and evaluated nondestructively using the above data.

Tasks	1970						1971						Est Cost ($K)
	J	A	S	O	N	D	J	F	M	A	M	J	
Drilling techniques													20
Panel fabrication													30
Evaluation of panels													20
Fabricate sample													30
GFY 1971: 100 K												Total cost	100

4-39 WELDING METHODS FOR THERMAL PROTECTION SYSTEM

OBJECTIVE

Develop economical fusion and resistance welding techniques for hot aerodynamic and structural members in the space shuttle configuration.

PROBLEM

High-temperature metals tend to be crack sensitive in welding. This problem can be adequately controlled only by special welding techniques. Further, effective mill-scale (oxidation and processing contamination) removal in weld preparation is an associated problem.

TECHNICAL APPROACH

Various simulated structural members will be fusion welded. (1) sinusoidal ring to thruster, (2) U, T, and I beam members and (3) honeycomb panel edge closure. The welding conditions relative to welding methods (TIG, EB, Plasma) tooling concepts, gas protection, etc. will be optimized. The weldments will be evaluated by non-destructive and mechanical tests (element tensile, fracture toughness). Materials will include Ti6 Al 4V and Inconel 718.

Simulated leading edge members, outboard and inboard, will be fusion welded. Materials will be Rene' 41 (outboard) and HS 188 and refractory alloys (Tantalum 222 and Columbium 129Y) for inboard. All welding conditions (weld process - TIG, EB, plasma tooling concepts, gas protection, etc.) will be optimized. The weldments will be evaluated by nondestructive and mechanical tests (element tensile and fracture toughness).

Simulated heat shield structure in Ti 6Al 4V and Inconel 718 will be resistance welded. Evaluate by nondestructive and mechanical tests (element tensile and fracture toughness).

Simulated heat shield panels in Ti 6 Al 4V and Inconel 718 will be resistance diffusion bonded. Evaluate by nondestructive metallographic and mechanical tests (element tensile and fracture toughness).

Tasks	1970						1971						Est Cost ($K)
	J	A	S	O	N	D	J	F	M	A	M	J	
Structural members													20
Leading edge members													20
Heat shield bond													20
Heat shield weld													20
Report													
												Total cost	80

GFY 1971: 100 K

4-40 NONMETALLIC COMPOSITE STRUCTURAL DEVELOPMENT

OBJECTIVE

Develop manufacturing and tooling concepts for fabrication of nonmetallic composite structures.

PROBLEM

Tooling concepts must be developed that overcome thermal expansion differentials, and adequate fiber orientation tolerances must be determined and maintained.

TECHNICAL APPROACH

Tooling concepts will be developed.

Tasks	1970			1971												Est Cost ($K)
	O	N	D	J	F	M	J	J	A	S	O	N	D			
Develop tooling concepts																75
														Total cost		75

GFY 1971: 75 K

BIOTECHNOLOGY

BIOTECHNOLOGY

BIOTECHNOLOGY

SHUTTLE MAJOR MILESTONES	1970	1971	1972	1973	1974	1975
PHASE B STUDY						
PHASE C STUDY						
PHASE D DEVELOPMENT						
PRELIMINARY DESIGN REVIEW						
CRITICAL DESIGN REVIEW						
BOOSTER AND ORBITER STRUCTURAL TEST ELEMENTS				MFG	TEST	
FLIGHT TEST VEHICLE 1				MFG		
FLIGHT TEST VEHICLE 2					MFG	
BOOSTER AND ORBITER STRUCTURAL TEST ARTICLES					MFG	TEST

	BIOTECHNOLOGY	1970	1971	1972	1973	1974	EST COST ($K)
5-1	INGRESS/EGRESS TECHNIQUES						70
5-2	CREW AND PASSENGER SEATING REQUIREMENTS						125
5-3	VISIBILITY REQUIREMENTS						100
5-4	EVA REQUIREMENTS						100
5-5	DECOMPRESSION HAZARDS						80
5-6	CREW CARGO HANDLING TECHNIQUES AT SPACE STATION						125
5-7	SHUTTLE WASTE MANAGEMENT SYSTEMS						470
5-8	CRYOGENIC HYDROGEN BOILER SYSTEM						770
						TOTAL	1840

5-1 INGRESS AND EGRESS TECHNIQUES

OBJECTIVE

Determine optimum methods of accomplishing flight crew and passenger ingress and egress within the SSV orbiter and booster during normal and emergency modes of operational and development test vehicles.

PROBLEM

The SSV orbiter and booster require specialized techniques to support operationally effective and safe ingress and egress functions to satisfy manned mission acceptability. This is evident in the horizontal and vertical prelaunch checkout and maintenance operations, prelaunch flight crew and passenger normal and emergency ingress and egress, and mission traffic flows including EVA, and postlanding normal and emergency egress functions.

TECHNICAL APPROACH

All crew and passenger ingress and egress requirements will be identified for selected mission phases and contingencies. Analyses of anthropometric and mobility ranges of crew/passenger population samples will be performed and compared with internal structure and equipment configuration concepts. Trade studies of traffic flows, hatch locations, timelined functions, and support equipment and aids (internal and external) required for safe, expeditions, and effective movement will be performed.

Criteria and candidate conceptual systems and techniques of ingress and egress will be developed. Survivability criteria for emergency egress will be defined.

Tasks	1970			1971									Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	
Perform analyses of ingress and egress requirement and define operations													10
Develop crew/ passenger population samples of size and movement relationships													20
Study internal structure and equipment configuration factors. Indicate influences constraining safe and effective ingress and egress													20
Perform trade studies to determine optimum systems and techniques													20
GFY 1971: 70 K												Total cost	70

5-2 CREW AND PASSENGER SEATING REQUIREMENTS

OBJECTIVE

Develop and define specialized human containment requirements for passengers and flight crew, including seating geometry and restraint characteristics.

PROBLEM

Flight crew and passenger complements will require specialized couch, seating, and restraint characteristics constituting total containment, yet facilitating ease of access. The energy environment of vibration, sustained linear acceleration, and the potential of rotational and/or impact acceleration during mission contingencies dictate definition of a total seating system for crew and passengers that employs operational efficiency.

TECHNICAL APPROACH

An analysis of mission/crew operations will indicate energy environment envelopes and crew containment needs. A population model will then be developed to represent flight crew and passenger anthropometric ranges and age/physical condition criteria. An analysis of couch, seating, and restraint systems will be conducted, employing tradeoff techniques and parametric data development. Candidate configurations will be evolved and evaluated.

Configuration criteria and concepts will be defined with supporting rationale describing evaluation criteria, human factors and comfort criteria, and safety characteristics described in the defined systems.

Tasks	1970			1971									Cost Est ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	
Analyze mission/crew operations and define energy and seating.													15
Develop representative population model.													15
Analyze couch/seating restraint systems. Perform trades.													25
Evolve and develop candidate systems.													35
Define requirements and concepts.													35
												Total cost	125

GFY 1971: 90 K
GFY 1972: 35 K

5-3 VISIBILITY REQUIREMENTS

OBJECTIVE

Develop total mission external visibility and internal veiwing requirements for orbiter and booster flight crews.

PROBLEM

The varied and complex mission objectives of the orbiter and booster vehicle systems require examination of the crew visibility requirements for manual control of mission operations. The variations in the vehicle attitudes and attitude rates coupled with complex mission requirements of rendezvous/docking, visual confirmations, inspection, landmark recognition, possible abort control, and approach/landing phases require external visibility envelope/illumination environment studies.*

TECHNICAL APPROACH

After a thorough study of crew visual observation and sighting requirements, crew visual functions and accuracy standards will be defined. Identification of the external/internal visual environment will include illumination level ranges, vehicle dynamics (attitude and acceleration effects), window geometry, crew station layout, and crewman eye positions. Visual envelopes with alternative visual field options for mission phases will be developed. Illumination criteria will be specified for external/internal viewing. Visual operational standards will be developed and specified, including requirements for visual aids and devices. The study would culminate in concepts and soft mockups of visual systems selections.

*Additionally, a concomitant study requirement exists to develop crew internal viewing and observation requirements for total visual operations continuity. Hardware impact areas requiring early resolution are vehicle structure, window glass, thermal protective system interfaces, and visual aids.

Tasks	1970			1971									Cost Est ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	
Study visual observation modes and sighting requirements													8
Identify crew visual functions and accuracy standards for crew control and observation													14
Specify the external/internal visual environment													11
Develop and specify visual envelopes with alternatives and illumination criteria													21
Define visual standards aids requirements													18
Develop concepts and mockups													28
												Total cost	100

GFY 1971: 75 K

GFY 1972: 25 K

5-4 EVA REQUIREMENTS

OBJECTIVE

Determine the need for EVA operations and systems support by the orbiter and indicate possible impact to design areas within the vehicle.

PROBLEM

The present baseline design concept for the orbiter does not provide a pressure suit capability. Some question exists as to whether the personnel and cargo areas will be completely separated pressure vessels. If pressure suits were provided for EVA, both checkout and maintenance capabilities will be needed in company with some form of airlock transfer device. EVA restraints, lighting, and locomotion provisions would also be needed.

TECHNICAL APPROACH

Both the baseline 7-day mission with up to 14 occupants and the contingency 30-day missions will be examined to determine potential requirements for EVA. Elements, such as in-flight maintenance and repair and cargo handling, would be considered for the 7-day mission with such things as satellite deployment and repair or experiment deployment from the orbiter contemplated during the 30-day mission evaluation. The identification of candidate EVA requirements would then lead to supporting systems definition for both EC/LSS and orbiter ingress and egress. Ancillary equipment, which include EVA work stations, locomotion requirements, and lighting, would also be identified. The existing potential inventory of EVA pressure suits would be reviewed and the requirements for the support of specific EMU's identified. Finally, the cost of EVA activities will be compared to IVA or shirtsleeve alternatives.

Tasks	1970 O	1970 N	1970 D	1971 J	1971 F	1971 M	1971 A	1971 M	1971 J	1971 J	1971 A	1971 S	Est Cost ($K)
Evaluate the 7-day mission for potential EVA requirements													10
Evaluate the 30-day mission for potential EVA requirements													15
Define the vehicle and subsystem requirements necessary to support the identified EVA activity													25
Conduct a comparative analysis of the overall systems cost between EVA and possible a alternative of IVA and shirtsleeve operation													25
Identify, define, and recommend EVA operational mission objectives to support mainline missions													25
											Total cost		100

GFY 1971: 75 K

GFY 1972: 25 K

5-5 DECOMPRESSION HAZARDS

OBJECTIVE

Define the potential crew hazards from accidental cabin decompression and analyze the possible alternatives which may be employed to alleviate these hazards.

PROBLEM

Although both the orbiter and booster will operate in a pressure regimen that requires counter-pressure for survival, the extent of exposure will be significantly longer in the orbiter. The orbiter will be exposed to the micrometeoroid environment; will carry passengers as well as crew; will remain in a vacuum environment for up to 30 days; and must depend upon more complex systems for environmental control of a shirtsleeve atmosphere.

TECHNICAL APPROACH

Initial efforts must define the environmental elements and systems failures that could result in accidental decompression in context with the period of exposure to these potential hazards. The resulting criteria will then be utilized in the examination of candidate personnal protective sub-system methods and equipments in terms of weight, engineering complexity mission flexibility and crew utility. Separate studies will be required for the orbiter and booster due to the differences in personnel complements and flight time above 35,000 feet. The resulting trade studies will indicate the relative cost of optimum crew/passenger protection and lead to subsystems selection for the two vehicles. Final efforts will define the research and development leading to operational hardware in context with known methodology that may be adapted for SSV usage.

Tasks	1970			1971									Cost Est ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	
Define decompression hazards for the orbiter													15
Define decompression hazards for the booster													10
Conduct analysis and trade studies of candidate systems for the orbiter													15
Conduct analysis and trade studies of candidate systems for the booster. Define major differences for orbiter over booster needs													15
Define R&D needed to acquire operational hardware to provide pressure protection in the orbiter and booster vehicles.													25
GFY 1971: 80 K												Total cost	80

5-6 CREW CARGO HANDLING TECHNIQUES AT SPACE STATION

OBJECTIVE

Develop and define optimum crew cargo handling, transfer, and total management techniques resulting in safe and effective transfer operations.

PROBLEM

Utilization of man in the zero-g environment to control the transfer of orbiter cargo establishes the requirement to define methods and assist/support systems. Human mass management of cargo constituents requires investigation, and selected techniques with assists could radically influence vehicle configuration and space station interface factors.

TECHNICAL APPROACH

A summary identification of cargo modules and cargo constituents would be made. Analysis of potential cargo containment, mobility, transfer, and mass control functions will be made. Simultaneously, SSV-SS/B vehicular interface alternatives will be studied to identify potential arrangement/junction characteristics.

Trade factors will be established and tradeoffs conducted, considering the above and human control and work performance. Criteria will be developed for crew control and mass management to apply to the modules. Human engineering data will be developed for systems configurations and translational/rotational characteristics. Crew assists, such as hand-holds, translational/stability devices, and module/hose restraint criteria will be identified and described. Human mobility, mass management performance, and control criteria will be specified. Finally, operational procedures will be developed as further supporting criteria, and neutral buoyancy and tractionless environment simulation techniques will be designed and a series of pilot evaluations conducted to validate criteria and performance variables.

Tasks	1970			1971									Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	
Identify cargo/hardware concepts													15
Analyze potential cargo containment and transfer functions and interfaces													10
Develop trade factors and perform tradeoffs													15
Define crew performance and control criteria													25
Specify human engineering data													15
Develop crew assist and support system criteria													15
Develop procedures and simulation techniques. Perform evaluations													30
												Total cost	125

GFY 1971: 70 K

GFY 1972: 55 K

5-7 SHUTTLE WASTE MANAGEMENT SYSTEMS

OBJECTIVE

Identify the waste propagation, by type and quantity for personnel complements of 2, 4, and 14 and for mission durations of 7 and 30 days. Indicate subsystem requirements necessary for health and crew acceptance.

PROBLEM

The flexibility of the orbiter mission presents a varying waste management requirement which must be reflected in a versatile subsystems design. Hardware developments post-Apollo have improved the capability in this area significantly. All candidate subsystem components should be evaluated both in terms of crew habitability requirements and overall cost to vehicle development and approach.

TECHNICAL APPROACH

Preliminary parametric studies have indicated that the waste management provisions utilized on Apollo can be updated without excess vehicle cost and should be pursued to verify the requirements and penalties of increased sophistication. Fecal elimination and personal hygiene provisions on Apollo were not well accepted by the crew and would receive even greater rejection by the proposed scientific passenger complement. Space station subsystems are only designed for the actual station complement, and orbiter systems must continue to be used in the docked condition, as well as during independent missions of up to 30 days. Candidate waste management components would be examined in detail so that all interfaces can be identified and the optimum system chosen.

Tasks	1970			1971												Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
Define the nature and quantity of wastes to be generated relative to crew size and mission duration																14
Define health and habitability criteria for orbiter waste management																21
Analyze candidate vendor hardware for compliance with these requirements.																
Identify crew interface and loading requirements for the system																15
Select, build, and test a total waste management system on the basis of crew and vehicle requirements including housekeeping functional wastes																400
															Total cost	470

GFY 1971: 100 K

GFY 1972: 370 K

5-8 CRYOGENIC HYDROGEN BOILER SYSTEM

OBJECTIVE

Develop a hydrogen heat exchanger/evaporator for an all mission phase heat sink.

PROBLEM

Presently, each mission phase requires a different heat sink (i. e., water evaporator-boost, ground support prelaunch, etc). Development of a heat sink utilizing hydrogen could allow independent prelaunch operation and one heat sink for all mission phases.

TECHNICAL APPROACH

The Dynasoar used a hydrogen heat exchanger concept. However, the system was not developed to the present state of the art of existing space and ground heat sinks. It also was for gaseous hydrogen and not liquid. Predicated on the Dynasoar system concept, a specification will be prepared for a prototype system providing heat loads, heat load ratios, and other performance data. The system would then be fabricated. Development testing would complete the development cycle. Qualification testing then could be done concurrent with other shuttle systems.

Tasks	1970 (O N D)	1971 (J F M A M J J A S O N D)	1972 (J F M A M J J A S O N D)	Est Cost ($K)
Define orbiter and booster load range and heat sink operation requirements for each mission and mission phase				32
Prepare specification for prototype system				18
Build and development test prototype system				120
Build flight system				200
Test and evaluate flight system				400
			Total cost	770

GFY 1971: 50 K
GFY 1972: 400 K
GFY 1973: 320 K

INTEGRATED ELECTRONICS

INTEGRATED ELECTRONICS

INTEGRATED ELECTRONICS

SHUTTLE MAJOR MILESTONES	1970	1971	1972	1973	1974	1975
PHASE B STUDY						
PHASE C STUDY						
PHASE D DEVELOPMENT						
PRELIMINARY DESIGN REVIEW						
CRITICAL DESIGN REVIEW						
BOOSTER AND ORBITER STRUCTURAL TEST ELEMENTS				MFG	TEST	
FLIGHT TEST VEHICLE 1					MFG	
FLIGHT TEST VEHICLE 2					MFG	
BOOSTER AND ORBITER STRUCTURAL TEST ARTICLES					MFG	TEST

	INTEGRATED ELECTRONICS	1970	1971	1972	1973	1974	EST COST ($K)
6-1	APPLICATION OF ONBOARD CHECKOUT TO SPACE SHUTTLE SUBSYSTEMS						580
6-2	DETECTION IDENTIFICATION AND ISOLATION OF FAILURES OF ELECTROMECHANICAL SYSTEMS						175
6-3	REDUNDANCY REQUIREMENTS AND IMPLEMENTATION FOR SPACE SHUTTLE AVIONICS						300
6-4	SOFTWARE LANGUAGE						245
6-5	STAR MAPPER FOR NAVIGATION SYSTEM ALIGNMENT OR NAVIGATION AID						
6-6	SYNTHESIS OF ANALOG BACKUP FLIGHT CONTROL SYSTEM						485
6-7	AUTOMATIC LANDING SYSTEM						160
6-8	HIGH-TEMPERATURE ANTENNAS AND ANTENNA WINDOWS						410
6-9	OPTIMIZATION OF ELECTRONIC PACKAGING AND INTERCONNECTION TECHNIQUES						130
6-10	ADVANCED CREW CONTROL AND DISPLAY SYSTEMS						740
6-11	IMPROVED POWER CONTROLLER						100
6-12	ELECTROMAGNETIC COMPATIBILITY TECHNIQUES						260
6-13	FUEL CELL IMPROVEMENTS						3600
6-14	BATTERY STATE-OF-CHANGE INDICATOR						85
6-15	STANDARD DATA-BUS INTERFACE UNIT						260
6-16	DIGITAL PREPROCESSOR-APPLICATION FOR SHUTTLE						250
6-17	SPACE SHUTTLE DIGITAL SYSTEM ONBOARD CHECKOUT HARDWARE STUDIES						225
					TOTAL		8005

6-3 REDUNDANCY REQUIREMENTS AND IMPLEMENTATION FOR SPACE SHUTTLE AVIONICS

OBJECTIVE

Determine design approaches, performance, prediction, and evaluation for application and selection of redundancy techniques for the space shuttle avionics.

PROBLEM

The principles of redundancy techniques and their level of implementation need to be established. A variety of techniques exists, such as parallel, triple modular, standby, spare, signal (coding), self-repair, error-correcting, etc., and their applicability or adaptability to representative shuttle avionics systems or subsystems should be determined. Where representative types of subsystems are nonadaptable to current techniques and verification, new methods or approaches should be investigated.

TECHNICAL APPROACH

Phase I

Methods of performance evaluation, allocation, and design approaches in the selection of redundancy techniques will be determined, as well as means of providing nondisruptive verification, based on mathematical analysis and preliminary design. Criteria will be defined for selection and application to representative types of avionics systems or subsystems, including optimum levels, degree of protection criticality, and alternatives. Literature search will be performed. Where some representative types are nonadaptable to current techniques of redundancy and verification, new approaches and technology will be investigated and analyzed. Baseline configurations of selected redundancy and verification techniques suitable for computer simulation and/or breadboard will be provided.

Phase II

Simulation and/or breadboard selected redundancy and verification techniques will be performed. Validity of techniques by applying faults, failures, systematic and random errors will be verified. Simulation and/or breadboard will be correlated with theoretical analysis.

Phase III

Subsystem, and network specifications will be developed for design and mechanization redundancy of major avionic systems.

Tasks	1970			1971												72	Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	
Investigate, evaluate, and select redundancy techniques																	130
Perform simulation and/or breadboarding of selected redundancy approaches																	140
Develop specification for design and mechanization of redundancy																	30
																Total cost	300

GFY 1971: 200 K

GFY 1972: 100 K

6-4 SOFTWARE LANGUAGE

OBJECTIVE

Early development of single, machine-independent, high-level language that can be used uniformly in factory and subcontractor checkout systems integration checkout operational programs, flight test programs, and trainers.

PROBLEM

No existing high-level language contains features that satisfy all requirements for computer program generation and maintenance for all phases of the space shuttle program. Several existing languages would have to be used.

TECHNICAL APPROACH

The use of high level languages is required in order to reduce the programming cost during design, test, and operation of the space shuttle system. A single, high-level language to satisfy most or all of the programming requirements will further reduce cost because of commonality of training, documentation, interchangeability of computer programs, and easier program maintenance.

The language derived should include the applicable capabilities of the Space Programming Language (SPL) and the related Compiler Language for Aeronautics and Space Programming (CLASP) being developed for NASA/ERC, together with a checkout and test language like Automatic Test Operations Launch Language (ATOLL). Features should also be included to allow the language to be used efficiently for simulation, data management, configuration and sequencing control, onboard checkout, mission planning, and other space shuttle-unique types of computer programs.

Tasks	1970 O	N	D	1971 J	F	M	A	M	J	J	A	S	Est Cost ($K)
Investigate SPL, ATOLL													20
Detail math, logic, etc.													25
Derive high-level language													200
												Total cost	245

GFY 1971: 200 K

GFY 1972: 45 K

6-5 STAR MAPPER FOR NAVIGATION SYSTEM ALIGNMENT OR NAVIGATION AID

OBJECTIVE

Evaluate the use of a star mapper for alternate inertial navigation system alignment or navigation aid, as compared to baseline manual optics or optional horizon sensor techniques.

PROBLEM

Additional accuracy will be provided, and as system development advances, the cost advantages will be more favorable.

TECHNICAL APPROACH

Star mappers versus manual optics versus horizon sensors will be evaluated to determine advantages available from the star mapper system. Results will be expressed in terms of program cost savings resulting from increased accuracy, such as fuel saved, more pounds in orbit, and less auxiliary equipment.

Tasks	1970			1971								Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	
Perform evaluation	———	———	———	———	———	———	———	———	———	———	———	75
											Total cost	75

GFY 1971: 75 K

6-7 AUTOMATIC LANDING SYSTEM

OBJECTIVE

Improve the performance of Autoland System to provide: (1) an accurate and smooth touchdown under adverse environmental conditions; and (2) minimum nuisance system disconnect.

PROBLEM

ILS system marginal performance, radio altimeter error due to terrain roughness, large aircraft ground effect, slow aircraft response, effect of high gust, etc., constitute problem areas of the Autoland System operation. In addition, the frequency of nuisance disconnect of the Autoland System must be minimized.

TECHNICAL APPROACH

ILS characteristics will be reviewed and data utilization optimized for Autoland System.

Means will be investigated to: (1) augment ILS capability through the use of on-board INS, special radar, AFCS sensors, special inertial sensors, etc.; (2) trade-off augmentation approaches for simplicity, reliability, cost, etc.; and (3) compare digital Kalman filtering with analog mixing of control signals.

Major sources of characteristics, nuisance disconnects, and mode of propagation will be determined.

Approaches to minimize nuisance disconnects will be developed, such as combining data as required from ILS, ILS augmentation inputs, and AFCS to provide verification and inhibition of component level nuisance disconnects.

The gust environments will be simulated into the space shuttle selected Autoland Systems to verify the adequacy of their performances. Also, nuisance disconnect signals to check the effectiveness of the verification and inhibition approach will be simulated concurrently.

6-6 SYNTHESIS OF ANALOG BACKUP FLIGHT CONTROL SYSTEM

OBJECTIVE

Develop a functional model of an analog flight control system to serve as backup for the baseline shuttle digital system.

PROBLEM

A working laboratory system may be required to fully evaulate a shuttle backup analog flight control system. Present plans call for trade study of analog versus digital backup system, but no testing is planned.

TECHNICAL APPROACH

Laboratory capability will be developed to duplicate closed-loop flight control system performance, including pilot controls, hexad sensors, air data simulations, flight control computer simulations, and control surface and vehicle handling simulations.

Tasks	1971									1972			Est Cost ($K)
	A	M	J	J	A	S	O	N	D	J	F	M	
Develop requirements based on Phase B study													10
Develop laboratory capability													400
Perform flight control system evaluations													75
										Total cost			485

CFY 1971: 100 K

CFY 1972: 385 K

Tasks	1970			1971												72	Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	
ILS data utilization optimization																	13
Augmenting ILS capability																	30
Develop approach to minimize nuisance disconnects																	38
Analyze performance of selected Autoland Systems through simulation																	60
Analyze performance of selected Autoland Systems through simulation, adding nuisance disconnect signal to verify inhibition effectiveness																	19
																Total cost	160

GFY 1971: 100 K

GFY 1972: 60 K

6-8 HIGH-TEMPERATURE ANTENNAS AND ANTENNA WINDOWS

OBJECTIVE

Develop high-temperature antennas and evaluate antenna window materials for use on shuttle during entry.

PROBLEM

The high temperatures experienced during entry require special development of reusable antennas and rf windows on underside of shuttle. The adequate performance of antenna window materials has not been demonstrated.

TECHNICAL APPROACH

Planned antennas, window materials, and installation designs will be evaluated. Window material laboratory tests to define and validate high-temperature properties will be performed.

Tests performed on engineering model designs of flush-mounted antennas in high-temperature areas, simulating shuttle vehicle installation and environment. RF transparency, distortion, and signal degradation, physical design, heat transfer, and reusability feature will be evaluated.

	1970			1971												1972									
Tasks	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	Est Cost ($K)
Summarize antenna types, locations, design options, and materials																									10
Material testing																									100
Fabricate test facility																									100
System testing																									200
																								Total cost	410

GFY 1971: 200 K

GFY 1972: 210 K

6-9 OPTIMIZATION OF ELECTRONIC PACKAGING AND INTERCONNECTION TECHNIQUES

OBJECTIVE

Improve the quality of small size, lightweight avionic equipment by promoting the use of common hardware designs and fabrication processes among equipment suppliers.

PROBLEM

Every vendor of avionics systems has his own unique way of making hardware. This variety creates the need for a wide assortment of processes, control requirements, and specifications. The reliability of the resulting equipment is very difficult and expensive to determine and control due to the relatively limited application experience accumulated on any one packaging method. Lack of internal electronic module hardware commonality among avionic equipment manufacturers also aggravates subsystem maintenance and logistic support problems.

TECHNICAL APPROACH

Candidate electronic packaging approaches proposed by potential shuttle/orbiter avionic equipment suppliers will be analyzed for simplicity of fabrication processes, predicted reliability, and cost. The two best methods with the broadest possible application flexibility consistent with minimum space and weight will be selected. A means to adapt the selected configurations to other subsystems with minimum impact on each proposed configuration will be determined.

Tasks	1970			1971												Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
Study avionics packaging proposals																15
Perform hardware analysis and tradeoff																30
Develop adaptation approaches																60
Generate revised configuration																25
															Total cost	130

GFY 1971: 100 K

GFY 1972: 30 K

6-10 ADVANCED CREW CONTROL AND DISPLAY SYSTEMS

OBJECTIVE

Design and develop a crew control and display simulation capability with hardware for technology evaluation.

PROBLEM

The integration and implementation of the SSV control and display system will be a unique man/machine combination, considering the number of functions to be performed, the new hardware to be employed, and the extensive use of the computers in the avionics systems. Development, checkout, and design verification of the system requires a ground simulation facility not yet in existence.

TECHNICAL APPROACH

A simulation capability will be designed and developed that will permit development of maximum system performance and best man/machine integration. The nature and number of controls/displays for information flow will be evaluated. Designs under simulated lighting conditions and crew work loads will be evaluated. Simulation capability would be used on a continuing basis as program progressed.

Tasks	1970			1971												Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	
Develop simulation requirements																20
SSV functions																
D&C hardware system																
Computer system																
Crew facilities																
Develop facility																600
Perform simulations																120
															Total cost	740

CFY 1971: 620 K

CFY 1972: 120 K

6-11 IMPROVED POWER CONTROLLER

OBJECTIVE

Develop improved solid-state power controllers that provide circuit protection features that will limit amount of energy following fault thus minimizing fire hazard.

PROBLEM

Current controllers in use and under development do not sense fault conditions and isolate faulty circuits rapidly enough to limit amount of energy to the level below that required for ignition.

TECHNICAL APPROACH

Improved controllers will be developed that sense both load voltage and current and that can thus control power to an established limit. Short-circuit detection would indicate maximum power and immediate shutoff of controller. Provisions will be made for transient conditions to avoid unnecessary shutoff. Also, current solid-state controllers are not being designed for vacuum or cold plate operation, but for aircraft usage. Emphasis is needed on space applications.

	1970			1971									
Tasks	O	N	D	J	F	M	A	M	J	J	A	S	Est Cost ($K)
Develop requirements Power rating Ignition levels Transient isolation													10
Evaluate existing and planned designs													10
Develop circuits for protection, breadboard													40
Develop, or modify, solid-state controller													40
												Total cost	100

CFY 1971: 70 K

CFY 1972: 30 K

6-12 ELECTROMAGNETIC COMPATIBILITY TECHNIQUES

OBJECTIVE

Develop computer programs to predict compatibility of systems. Develop methodology for electromagnetic criteria for equipment and system specifications, interconnecting wiring, and new structural materials.

PROBLEMS

Electromagnetic noise is a fundamental limitation on the performance of electronic systems in space boosters and systems. Due to the large number of electromagnetic interrelationships in space systems, a manual analysis used for predicting electromagnetic incompatibilities would be very time consuming and would not be readily useful in evaluating anticipated changes. Utilization of new technology and technical products or their development must be considered for EMC ramifications.

The existing general EMC specifications (MIL-STD-461 and MIL-E-6051D) are not specifically oriented for space vehicles, nor are they in sufficient detail to influence the needed EMC design and performance. Areas usually not detailed in such specifications include wiring practices and new structural materials. The limitations and capabilities of digital circuits must be thoroughly understood to improve wiring practices. Similarly, new structural materials have many characteristics which can significantly affect shielding effectiveness, power returns, and bonding practices. The use of titanium and composite structures alter the airframe as a circuit return, shield, and sink for currents induced by lightning. Hence, the effects of new structural materials must be studied and EMC criteria must be established. System anomalies caused by design deficiencies can generally be traced to insufficient design criteria.

TECHNICAL APPROACH

Existing EMC specifications, space shuttle mission requirements, and the space shuttle's operational environment will be analyzed, including environmental effects of electrostatic potential generated by space vehicle rockets.

All emitters, receptors, and other entities which could affect EMC will be identified. Significant characteristics (i.e., rise times, frequencies, sensitivities, emitter amplitudes, wiring requirements, structural materials, return current diffusion, shielding efficiencies, etc.) will be isolated.

A simulation model will be built to simulate the space shuttle system relative to EMC, and the model will be validated.

A computer program for EMC analysis will be developed.

The computer program will be used to generate system compatibility requirements and specific criteria for equipment and subsystems. The computer program will also be used to analyze the effects of changes suggested by desired tradeoffs. EMC specification limits (component and system), specifically for space shuttle, will be generated. Design criteria for equipment, power distribution, wiring practices, structural materials, bonding practices, and shielding practices to adequately assure EMC will be generated.

Tasks	1970			1971									Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	
Analyze existing data	—	—											10
Identify EMC characteristics		—	—										10
Isolate significant characteristics		—	—										10
Build simulation model and validate			—	—	—								40
Develop computer program			—	—	—	—	—	—	—	—			60
Define system EMC requirements						—	—	—	—	—			50
Analyze space shuttle tradeoffs							—	—	—	—	—		50
Generate EMC specifications								—	—	—	—	—	20
Generate design criteria								—	—	—	—	—	10
												Total cost	260

GFY 1971: 150 K

GFY 1972: 110 K

6-13 FUEL CELL IMPROVEMENTS

OBJECTIVE

Develop fuel cell powerplant compatible with space shuttle and space station usage.

PROBLEM

Current alkaline fuel cells exhibit a small degradation rate using hydrogen and oxygen containing 1 ppm carbon dioxide. The accumulated degradation over 5,000 to 10,000 hours operating life becomes significant. Accessories such as coolant pumps require development to increase life and/or to permit replaceability.

TECHNICAL APPROACH

Current status of fuel cell development will be determined. Methods to reduce sensitivity to carbon dioxide and/or methods to reduce carbon dioxide content of reactants will be evaluated. Methods to improve life of accessory equipment (i. e., material compatibility, bearings, lubrication, replacement of rotating equipment with static or pulsating equipment, etc.) will be evaluated. Methods to improve maintainability, such as, separate replaceable pump packages will be developed.

Tasks	1970			1971												1972												1973			Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	
Status definition and design study																															600
Advanced development and concept verification																															3000
																														Total cost	3600

GFY 1971: 500 K

GFY 1972: 2,100 K

GFY 1973: 1,000 K

6-14 BATTERY STATE-OF-CHARGE INDICATOR

OBJECTIVE

Develop conclusive method to indicate state-of-charge for silver-zinc secondary battery.

PROBLEM

State-of-charge devices are needed to indicate 100-percent charge for a charge termination signal and the percent of full charge remaining for operational purposes. Present charge termination methods use a current cutoff with modified constant potential charging. Present percent of full charge indicators use a resettable unilateral or bilateral ampere-hour meter. Direct measurement devices are desirable for more accurate determination of state-of-charge.

TECHNICAL APPROACH

Possible methods for state-of-charge indication, such as, third electrodes and capacitance measurements will be experimentally evaluated. Promising methods through advanced development state will be developed.

Tasks	1970			1971						Est Cost ($K)
	O	N	D	J	F	M	A	M	J	
Experimental evaluation of state-of-charge methods										35
Develop and characterize parametrically										50
GFY 1971: 85 K								Total cost		85

6-15 STANDARD DATA BUS INTERFACE UNIT

OBJECTIVE

Define and develop critical circuits for a standard interface unit.

PROBLEM

In developing a multiplexed data bus concept, emphasis must be given to ascertaining what functions can best be performed at a standard interface unit (SIU). In order to develop a high degree of confidence in the proposed SIU, circuits critical to the SIU must be identified and breadboarded.

TECHNICAL APPROACH

An analysis of commonality of measurements and control requirements for the EM/IAS subsystem will be made. This will result in identifying those measurements and controls which might be placed in an SIU. A comparison (cost, weight, etc.) between locating these functions in an SIU or central interface will then be made and recommended SIU functions evolved. As a result, critical SIU circuitry will be designed, breadboarded, and tested.

Tasks	1970			1971									Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	
Commonality and trade studies	—	—	—										35
Functional analysis and predesign		—	—	—									25
Circuit design and breadboard test					—	—	—	—	—	—	—	—	200
												Total cost	260

GFY 1971: 200 K

GFY 1972: 60 K

6-16 DIGITAL PREPROCESSOR APPLICATION FOR SHUTTLE

OBJECTIVE

Define and characterize a preprocessor design approach that will meet most or all subsystem processing requirements.

PROBLEM

Preliminary definition studies of the shuttle electronics system have identified requirements for subsystem data processing. Definition of a standard processor meeting most or all requirements can reduce development, procurement, software, and logistics costs through commonality.

TECHNICAL APPROACH

The initial task of the project will define the division of the data processing problem between a central processor and several subsystem processors. This task will establish the requirements for subsystem processors.

After establishment of requirements, the remainder of the project will be directed toward characterization of the subsystem processor. Such characteristics as architecture and organization technology, storage medium, packaging, redundancy and software will be identified and defined.

The product of the project will be a functional specification for the subsystem processor.

Tasks	1970			1971									Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	
Requirements and concept definition													30
Technology and packaging trade studies													150
Software, redundancy, and control definition													70
												Total cost	250

GFY 1971: 200 K

GFY 1971: 50 K

6-17 SPACE SHUTTLE DIGITAL SYSTEM ONBOARD CHECKOUT HARDWARE STUDIES

OBJECTIVE

Examine onboard checkout functional responsibilities and problems at the subsystem level.

PROBLEM

Detailed studies should be performed applying the space shuttle checkout philosophy to representative equipments. Special checkout problems exist within various hardware classes, particularly fault detection and isolation within digital systems. Additional study areas include transient suppression in redundancy switching and commonality of test functions for minimizing onboard hardware.

TECHNICAL APPROACH

This study will be divided into four major task areas — baseline system definition, fault detection and isolation techniques, redundancy switching techniques, and test function commonality for minimizing onboard hardware. Each major task will be divided into subtasks for classifying equipments, defining various approaches and evaluating methods for each class, performing relative comparisons of approaches, and extracting design guidelines. Recommendations and generalized guidelines for determining preferred approaches versus equipment classes will be made. Specific guidelines for equipment classes regarding the incorporation of checkout and the control of redundancy also will be documented.

Tasks	1970			1971									Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	
Baseline system definition													10
Fault detection and isolation techniques													90
Control of redundancy													50
Test hardware commonality													75
												Total cost	225

GFY 1971: 175 K

GFY 1972: 50 K

OPERATIONS, MAINTENANCE, AND SAFETY

OPERATIONS, MAINTENANCE, AND SAFETY

OPERATIONS, MAINTENANCE, AND SAFETY

SHUTTLE MAJOR MILESTONES	1970	1971	1972	1973	1974	1975
PHASE B STUDY						
PHASE C STUDY						
PHASE D DEVELOPMENT						
PRELIMINARY DESIGN REVIEW						
CRITICAL DESIGN REVIEW						
BOOSTER AND ORBITER STRUCTURAL TEST ELEMENTS				MFG	TEST	
FLIGHT TEST VEHICLE 1					MFG	
FLIGHT TEST VEHICLE 2					MFG	
BOOSTER AND ORBITER STRUCTURAL TEST ARTICLES					MFG	TEST

OPERATIONS, MAINTENANCE, AND SAFETY	1970	1971	1972	1973	1974	EST COST (SK)
7-1 GROUND OPERATIONS INTEGRATION						50
7-2 FAILURE MODES & EFFECTS ANAL OF REDUNDANT HDWE & SOFTWARE						110
7-3 RELIABILITY/QUALITY DATA PROCESSING						50
7-4 PROPELLANT AND GAS HANDLING						90
7-5 COMMONALITY OF SHUTTLE, SKYLAB, SPACE STATION, & GRD EQUIP.						65
7-6 NONDESTRUCTIVE TESTING TECHNIQUES FOR FL READINESS VERIF						500
7-7 DEVELOPMENT TEST PLANNING COST MODEL						105
7-8 MAINTAINABILITY						70
7-9 ERECTOR CONCEPTS						90
7-10 RISE-OFF DISCONNECT PANELS						130
7-11 LEAK DETERMINATION AND DETECTION TECHNIQUES						80
7-12 PERSONNEL ESCAPE TECHNIQUES						80
7-13 GROUND SYSTEMS MISSION PLANNING AND MODELING						295
				TOTAL		1715

7-1 GROUND OPERATIONS INTEGRATION

OBJECTIVE

Integrate all ground operations contract activities of KSC, MSFC, and MSC.

PROBLEM

Numerous contracts were let by centers; therefore, some overlap exists, requiring a need to integrate effort.

TECHNICAL APPROACH

Functional flows of shuttle ground operations to third level will be generated. Studies and trades required to establish baseline for ground operations will be defined.

Studies and trades not covered by present contact efforts will be assessed and determined. Studies to be undertaken will be recommended.

Statement of works for selected studies will be generated.

Tasks	1970					1971				Est Cost ($K)
	A	S	O	N	D	J	F	M	A	
Functional flows										40
Study definition										10
Recommend studies										20
							Total cost			70

GFY 1971: 70K

7.2 FAILURE MODES AND EFFECTS ANALYSES OF REDUNDANT HARDWARE AND SOFTWARE

OBJECTIVE

Provide an automated technique for verification of designs that have fail operational/fail operational/fail safe capability.

PROBLEM

The required technology for the identification of single point failures for both mechanical and electronic equipment is well in hand. The capability of performing design analyses has not, however, been developed that will allow systematic and comprehensive evaluations of the effects of dual and triple failures. It is necessary that a technique be developed to perform failure modes analyses to verify that no credible hardware or software failure modes exist that would preclude fail operational/fail operational/fail safe capability of the design.

TECHNICAL APPROACH

Several automated techniques have been developed that provide for the identification of potential failure mechanisms in complex avionics equipments. The process involved in conducting these analyses requires the capability of analyzing multiple fault mechanisms, any combination of which can result in false system status indications. This process thus has properties that are very similar to the properties required for the detection of combinations of failure modes that can preclude fail operational/fail operational/fail safe capability of the design. It is therefore proposed that a technology study be conducted that will result in an application of these techniques to failure modes and effects analyses of redundant space shuttle equipment.

Tasks	1970			1971					Est Cost ($K)
	O	N	D	J	F	M	A	M	
Evaluate automated systems that have potential application to FMEA									25
Select systems that have greatest applicability to FMEA Coordinate with NASA									20
Modify system for FMEA									45
Select representative space shuttle systems to test technique									20

GFY 1971: 110K

Total cost	$110

7-3 RELIABILITY/QUALITY DATA PROCESSING

OBJECTIVE

Develop the method for collection, processing and display of component, subsystem, and system historical operating data.

PROBLEM

The certification before flight of critical components will require maximum visibility of historical data. The number of components is compounded by the need for accelerated review to meet turnaround schedules. The magnitude of the data review points up the need for a method currently not developed.

TECHNICAL APPROACH

A trail program of automated data management will be established for use in the area of component historical characteristics. The conditions to be encountered, the parameters to be recorded, collection methods, display and analysis techniques, and schedule constraints will be defined. After completion of program definition, a trial run demonstration of the cycle life of two selected typical components will be conducted, including manufacture, test acceptance, systems test, flight, maintenance, repair, and reuse.

Tasks	1970			1971				Est Cost ($K)
	O	N	D	J	F	M	A	
Review requirements for data	▭	▭						15
Establish program elements			▭	▭				15
Plan trail program run					▭			10
Conduct trail						▭		10
Review and document results							▭	10
GFY 1970: 60K						Total cost		60

7-4 PROPELLANT AND GAS HANDLING

OBJECTIVE

To define Space Shuttle requirements in the areas of (1) cryogenic loading, (2) reduced helium useage, (3) LO_2 geysering, and (4) improved propellant level sensors.

PROBLEM

Credible cost and schedule impact estimates in these four areas are required to assure proper contractor and NASA management decisions.

TECHNICAL APPROACH

1. Cryogenic loading. Define requirements and solutions so that estimates can be made to incorporate the following alternatives: (1) minimum modification to Complex 39B; (2) 39B mods necessary for rapid load; and (3) a new complex.

2. Reduce helium usage. Define methods for postflight purging of the vehicle LH_2 tanks to reduce the amount of helium used when compared to Saturn V.

3. LO_2 geysering. Select the best of several alternatives for preventing vehicle LO_2 duct geysering. Conduct proofing tests.

4. Improved propellant level sensors. Conduct survey and recommend best system approach. Conduct development lab tests of modified Centaur PU system.

Tasks	1970			1971									Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	
Define Cx 39 PLS minimum modifications													15
Define Cx 39 rapid-load modifications													15
Study helium reduction													15
Study LO_2 geysering													10
Conduct tests													25
Study LO_2/LH_2 level sensors													15
Laboratory tests													25
Cost and schedule estimates													20
												Total cost	140

GFY 1971: 110 K
GFY 1972: 30 K

7-5 COMMONALITY OF SHUTTLE, SKYLAB, SPACE STATION, AND GROUND EQUIPMENT

OBJECTIVE

Establish plan to ensure commonality of equipment to reduce shuttle program cost.

PROBLEM

Previous programs have used unique equipment with no commonality to other programs.

TECHNICAL APPROACH

Commonality list will be defined and updated.

A plan will be established to ensure commonality in the following:

1. Development and qualification test
2. Checkout testing
3. Fabrication
4. Maintenance and repair

Tasks	1970					1971						Est Cost ($K)
	A	S	O	N	D	J	F	M	A	M	J	
Commonality list	1st list Avail	Baseline List				▽	Update List ▽				▽	25
Plan establishment						Outline Plan ▽			Nasa Rev ▽		Final Plan ▽	40
											Total cost	65

7-6 DEVELOPMENT OF NONDESTRUCTIVE TESTING METHODS FOR SPACE SHUTTLE STRUCTURES

OBJECTIVE

Develop high-speed nondestructive test equipment for space shuttle vehicle.

PROBLEM

There is lack of nondestructive test equipment systems which can verify structural flight readiness within a two-week turnaround period after numerous previous missions.

TECHNICAL APPROACH

A search will be made for developmental approaches which can solve the problem. Experiments will be designed to verify the feasibility of promising methods. Those techniques which can satisfy shuttle turnaround requirement will be selected. In conjunction with major suppliers of nondestructive test hardware, on-board systems and high-speed support equipment to meet the shuttle requirement will be designed and constructed. The prototype hardware will be evaluated, and the best means to implement shuttle operation will be recommended.

Tasks	1970			1971												1972									Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	
Applications definition																									20
Feasibility verification																									80
Methods selection																									20
Prototype development																									250
Prototype evaluation																									50
Design implementation																									30
Source establishment																									50
																								Total cost	500

GFY 1971: 200K

GFY 1972: 250K

GFY 1973: 50K

7-7 DEVELOPMENT TEST PLANNING COST MODEL

OBJECTIVE

Develop and define a method to estimate the costs of major ground and flight test requirements, with emphasis on test hardware and manhours through definition of test activity planning factors that are related to such factors as system and subsystem performance requirements and physical characteristics vis-a-vis the state-of-the-art advance.

PROBLEM

DDT&E of a new system program represents a large portion of the total cost and is required during a relatively short period of time. It has been recognized that test hardware and test-operations costs are a significant portion of the DDT&E costs. Therefore, the major test plan parameters need to be identified and quantified in terms of their influence on cost

TECHNICAL APPROACH

Major test categories and type of test hardware to be considered in the test program cost model will be identified.

System/subsystem physical characteristics and performance parameters to be related to test hardware and activity parameters used in relationships developed by this study will be identified.

A method for quantifying or ranking advances in the state-of-the-art (SOA-A) for system/subsystem hardware will be eatablished.

Available aircraft and launch vehicle historical program data applicable to all or portions of a surface-to-orbit type system will be researched.

Estimating relationships (using researched data) will be established for test activity parameters and hardware quantities from system physical or performance parameters and/or known test parameters, taking into consideration some measure of advances in the state-of-the-art.

The model structure will be developed for determining test resource requirements (manhours, hardware and expendables) from established test parameters and system characteristics; and for applying the necessary cost factors (established from new or updated CERs) to these resource requirements in order to identify specific aspects of DDT&E test costs.

Model will be checked and validated with available historical program data.

Tasks	1970			1971									Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	
Identify test categories and hardware													5
Identify system/subsystem physical/performance parameter													5
Devise determination of SOA-A													10
Research historical data													35
Establish estimating relationships													35
Finalize test plan model													10
Check and validate model													5
GFY 1971: 105 K												Total cost	105

7-8 MAINTAINABILITY

OBJECTIVE

Provide a means for acquiring maintenance information during development and test phase and translating such information into design constraints and/or guidelines to be reflected in the final design configuration.

PROBLEM

No effective method now exists as an integral process for applying practical maintenance experience gained during early stages of a development program to the design process so that the mature hardware system will exhibit maintainability characteristics tailored to its actual needs.

TECHNICAL APPROACH

Development of the means to accomplish the stated objective will require attention in three distinct areas — data collection, data processing, and corrective action.

Data Collection

1. Review existing forms and procedures to determine adequacy and completeness of data collected with respect to the stated objective.

2. Modify existing forms and/or prepare new forms as necessary to provide the capability for collection of all required maintenance information on a standardized basis.

3. Modify existing procedures and/or prepare new procedures as required to cover collection of the required data in standard format and context

Data Processing

1. Develop procedures for extracting and assessing the validity of maintenance task data from the collection forms, and for inserting relevant data and instructions into the IS&R program. These procedures must be usable in conjunction with and compatible to the existing System Requirements Analysis process.

2. Develop a computer program subroutine and related data processing techniques as necessary to be an adjunct to the System Requirements Analysis IS&R computer program. This subroutine must readily accept new information in random quantities and at random times, provide a capability for normalizing the information in accordance with a set of alterable instructions, and act upon stored information without losing identity of the new information source and content.

Corrective Action

1. Develop computer programming to perform computations required, make comparisons between computed values and preset upper limit values, select prestored descriptive phrases, and provide a printout format that can be delivered directly to the design function as a requirements document. This programming to be in conjunction with the existing system requirements analysis IS&R printout of a maintainability interface report.

Tasks	1970			1971						Est Cost ($K)
	O	N	D	J	F	M	A	M	J.	
Data collection	—	—	—	—	—	—				25
Data processing				—	—	—	—	—		25
Corrective action				—	—	—	—	—	—	20
GFY 1971: 70 K									Total cost	70

7-9 ERECTOR CONCEPTS

OBJECTIVE

Research and development of new concepts for lifting devices and/or erectors to raise space shuttle from a horizontal position to a vertical position on the launch pad. System to be fail-safe with low or no maintenance.

PROBLEM

Rapid turnaround of space shuttle and concept for horizontal movement to pad generates needs for a lifting capability to erect space shuttle for launch.

TECHNICAL APPROACH

Erector requirements will be defined based on a horizontal space shuttle. New concepts will be determined for lifting devices such as telescoping cylinders, fixed cranes, and hydromechanical systems. Predesign erector configurations will be prepared. Tradeoff studies between various candidate configurations will be performed and the best approaches established.

A development plan will be prepared.

Tasks	1970			1971							Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	
Concept definition and predesign											25
Tradeoff studies and development plan											65
								Total cost			90

GFY 1971: 90K

7-10 RISE-OFF DISCONNECT PANELS

OBJECTIVE

Development of rise-off disconnect panels, which will permit rapid interconnect and disconnect of fuel lines, testing lines, communication lines and required facilities to prepare and checkout space shuttle for launch. Establish design and configurations for a high-performance, reusable system which will require minimal refurbishment and maintenance.

PROBLEM

Rise-off disconnect panels to provide leak-free positive interconnect and disconnect are not developed. Design effort has not been expended to provide operational panels necessary for rapid failure, free-rise compatible with space shuttle design goals.

TECHNICAL APPROACH

Facility needs will be defined which the panel must provide to the booster for quick-turnaround. Fuel flow requirements and line sizes will be determined. Materials, fittings, transfer functions, and valves meeting space shuttle specifications will be analyzed. Methods and means for positive quick-connect, leakproof connections, and openings will be determined.

Heat protection requirements will be evaluated to assure rapid reuse of panels.

Tasks	1970			1971							Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	
Requirements definition											20
Prepare predesign panel configurations											25
Perform tradeoffs											60
Prepare development plan											25
GFY 1971: 130 K										Total cost	130

4

7-11 LEAK DETERMINATION AND DETECTION TECHNIQUES

OBJECTIVE

Develop techniques, procedures, and instrumentation to detect leaks in the booster, refueling system, and storage areas.

PROBLEM

The certification of the flight prior to launch to assure mission success is dependent upon the ability to detect weak leaks in the system and to design fixes prior to production. Hazardous conditions caused by leaks could result in mission abort or space shuttle destruction.

TECHNICAL APPROACH

A system to determine possible leak locations will be analyzed. Findings will be evaluated to determine design corrections. Leak detection instrumentation systems available will be analyzed. Concepts and techniques for leak detection systems and instrumentation will be developed. Development programs will be established.

Tasks	1970			1971							Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	
Systems analysis											25
Instrumentation analysis											20
Concepts development and evaluation											35
									Total cost		80

GFY 1971: 80 K

7-12 PERSONNEL ESCAPE TECHNIQUES

OBJECTIVE

Development of techniques and facilities to provide rapid, positive egress of personnel from tower supporting space shuttle under emergency conditions.

PROBLEM

TECHNICAL APPROACH

Probable emergency conditions which would cause personnel to exit space shuttle and tower will be determined. Methods, techniques, and escape systems for exiting the tower will be established. Exiting systems will be predesigned. Tradeoff studies to determine best approaches will be performed. Development plan will be established.

Tasks	1970			1971							Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	
Establish methods and techniques		———	———								20
Predesign best approaches				———	———	———	———				20
Perform tradeoffs					———	———	———	———			20
Development plan									———	———	20
								Total cost			80

7-13 GROUND SYSTEMS MISSION PLANNING AND MODELING

OBJECTIVE

Specification and initial development of planning tools through the use of ground systems models supporting the space shuttle.

PROBLEM

The space shuttle and space station projects will require use of evolutions of current ground systems. In order to determine the nature of the required systems, and to determine the possible joint usage of facilities by these projects, a program of specification of mission planning requirements, and the initial development of ground systems data processing models will be required.

TECHNICAL APPROACH

Detailed flow diagrams and systems engineering analysis will be developed for the ground mission planning and ground systems flows. A general purpose systems simulation model (GPSS) will be developed for the entire mission planning and ground support process for the space shuttle. This model will be used to evaluate various flows of systems, software and hardware. On the basis of the modeling activity, two specific subtasks will be implemented:

1. Evaluation of the combined space station/space shuttle mission profile related to ground systems, resulting in recommendations about common uses of facilities.

2. Specification and initial implementation of flexible guidance software systems (FGSS) or similar tools for use in planning the shuttle missions. The product of this phase would be detailed systems specifications for these elements.

Tasks	1970			1971									Est Cost ($K)
	O	N	D	J	F	M	A	M	J	J	A	S	
Ground systems analysis	—	—	—	—									50
Planning system specification			—	—	—	—							65
Model development			—	—	—	—	—	—	—				125
Model analysis of ground systems							—	—	—	—	—	—	55
												Total cost	295

GFY 1971: 250 K

GFY 1972: 45 K