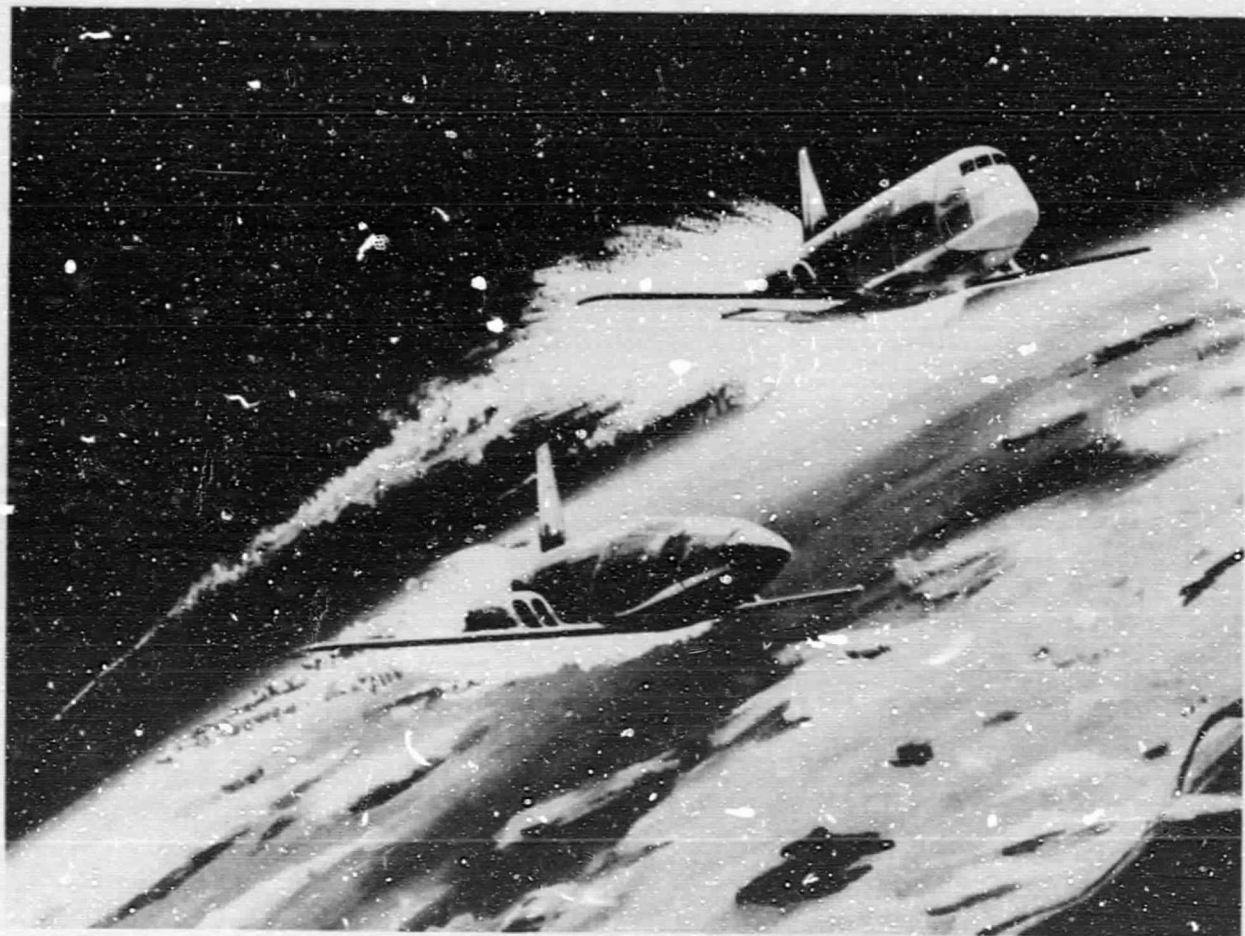


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MSC 00192



Study of Integral Launch and Reentry Vehicle System

FINAL REPORT

SD 69-573-2

Volume II • Technology Development Requirements

N70-31833

(ACCESSION NUMBER)

34

(PAGES)

CR-102106

(NASA CR OR TMX OR AD NUMBER)

(THRU)

1

(CODE)

31

(CATEGORY)



Space Division
North American Rockwell

SD 69-573-2

MSC 00192

FINAL REPORT

STUDY OF
INTEGRAL LAUNCH AND REENTRY VEHICLE SYSTEM

(Contract NAS 9-9205)

VOLUME II TECHNOLOGY DEVELOPMENT REQUIREMENTS

December 1969

APPROVED:


G.F. Fraser
Study Manager



Space Division
North American Rockwell

FOREWORD

This report is submitted to the NASA Manned Spacecraft Center, Houston, Texas, in accordance with Contract NAS9-9205 by the Space Division of North American Rockwell Corporation. It presents results of the Study of Integral Launch and Reentry Vehicle (ILRV) System. Acknowledgement is given to NASA MSC for the aerodynamic and aerothermodynamics test data provided in support of the study. The NASA MSC contracting officer's representative directing the study was R.H. Bradley.

This document is Volume II of a five-volume report. It defines technology necessary for development of the two-stage reusable logistic shuttle vehicle concept investigated during the second phase of the program. The volumes of the complete final report are as follows:

<u>Volume</u>	<u>Title</u>	<u>Report Number</u>
I	Summary Report	SD 69-573-1
II	Technology Development Requirements	SD 69-573-2
III	Technical Report - Second Phase: Environment and Performance	SD 69-573-3
IV	Technical Report - Second Phase: Design and Subsystems Analysis	SD 69-573-4
V	Technical Report - Second Phase: Operations and Resources	SD 69-573-5

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CONTENTS

Section		Page
1.0	INTRODUCTION	1
2.0	CONCEPT FUNDAMENTALS AND DESIGN DESCRIPTION	3
3.0	TECHNOLOGY DEVELOPMENT REQUIREMENTS	11
	3.1 Aerodynamics	11
	3.2 Aerothermodynamics	14
	3.3 Thermal-Protection and Insulation Materials	17
	3.4 Structure	21
	3.5 Propulsion	23
	3.6 Integrated Electronics and Guidance, Navigation, and Control	28

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ILLUSTRATIONS

Figure		Page
2-1	Configuration Definition - 50,000-Pound Payload, 15-Foot Diameter by 60-Foot-Length Cargo Bay . . .	4

TABLES

Table		Page
2-1	Description of Final 50-000-Pound-Payload Vehicle . . .	5
3-1	Aerodynamics Technology Status Summary	12
3-2	Aerothermal Technology Status Summary	15
3-3	Thermal-Protection and Insulation Materials Technology Status Summary	18
3-4	Alternate External Insulation Concepts	19
3-5	Structure Technology Status Summary	22
3-6	Main-Rocket-Propulsion Technology Status Summary . . .	24
3-7	Reaction Control System (O ₂ H ₂) Technology Status Summary	25
3-8	Airbreathing Propulsion Technology Status Summary . . .	26
3-9	Integrated-Electronics and GN&C Technology Status Summary	30

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1.0 INTRODUCTION

Future space exploration will be constrained within a limited budget and will benefit from the development of an economical logistic system. NASA is therefore directing investigations of reusable logistic vehicles which offer potential for major operational cost reduction compared to current systems. A number of contracted design studies have been directed by NASA during 1969. This document is presented to the NASA Manned Spacecraft Center in accordance with Contract NAS9-9205. The document defines technology required for development of the advanced reusable space shuttle vehicle concept investigated during the second phase of this study.

The contract was negotiated on 31 January 1969, and activity began on 3 March 1969. The study schedule reflects an eight-month technical activity plus reporting period. The major objectives of the study were to define logistic systems which achieve an order of magnitude reduction in recurring costs and advance inherent safety. The program was divided into two phases. The first phase was two months in duration and encompassed comparison of logistic-vehicle concepts using expendable boosters. The second phase encompassed investigations of a two-stage reusable vehicle conceived by NASA MSC. This vehicle has similarly shaped booster and orbiter elements with fixed, low-sweep wings, and the main propulsion system uses LO_2/LH_2 propellant. In the study, vehicles were configured to deliver 10,000-, 25,000-, and 50,000-pound payloads to a 270-nautical-mile, 55-degree-inclination orbit.

A conceptual design definition was prepared for a selected vehicle, and the technology required to support development of the system was identified.

2.0 CONCEPT FUNDAMENTALS AND DESIGN DESCRIPTION

The vehicle studied during the second phase of the program was conceived by NASA MSC. The system, which is illustrated in Figure 2-1 has two reusable stages with similar aerodynamic shape and fixed, low-sweep wings. The main propulsion systems of both booster and orbiter use LO_2/LH_2 propellants with high-chamber-pressure bell or aerospike engines. The vehicle is configured for vertical takeoff with the orbiter mounted forward on the booster. This orbiter location is to provide a forward center of gravity during the ascent phase of the mission and thus achieve an aerodynamically stable configuration. This results in minimization of thrust vector control, angle of attack, and aerodynamic loads. A major requirement of the logistic vehicle is minimization of operational costs. It therefore becomes necessary to provide a reusable thermal protection system. This makes it desirable to limit temperatures experienced on the vehicle during reentry. The approach adopted is to design vehicles with large planform area and flat base and to enter at a high angle of attack to minimize the heating rate.

With the specified vehicle, the booster element must cruise back to a land-landing site after separation of the orbiter. For this purpose, therefore, turbojets are used for the cruise phase of the mission. Turbojets are also used on the orbiter for landing. A high subsonic lift-to-drag ratio is provided with booster and orbiter for efficient cruise capability and low landing speeds.

The selected vehicle is illustrated in Figure 2-1 and a summary description is presented in Table 2-1. The booster uses eleven 510,000-pound sea-level thrust bell engines with an expansion ratio of 35:1. The LO_2 and LH_2 tanks have a common bulkhead and provide the capability to carry prelaunch, launch, and reentry aerodynamic loads. LH_2 tank thermal control requirements are satisfied by polyurethane foam installed internally in the LH_2 tank. An aluminum truss and reinforced phenolic and polyimide honeycomb sandwich substructure is provided to maintain the desired flat base. This structure is also used to bond densified quartz external insulation to the booster bottom and side. The mild thermal environment on the top of the booster is within the capability of honeycomb-sandwich material. The booster wings are fabricated from titanium. The booster is 280 feet long and has a wing span of 244 feet and a liftoff weight of 3.62-million pounds.

The orbiter vehicle uses two engines with the same basic design as those used on the booster. These engines provide 590,000-pound vacuum-thrust

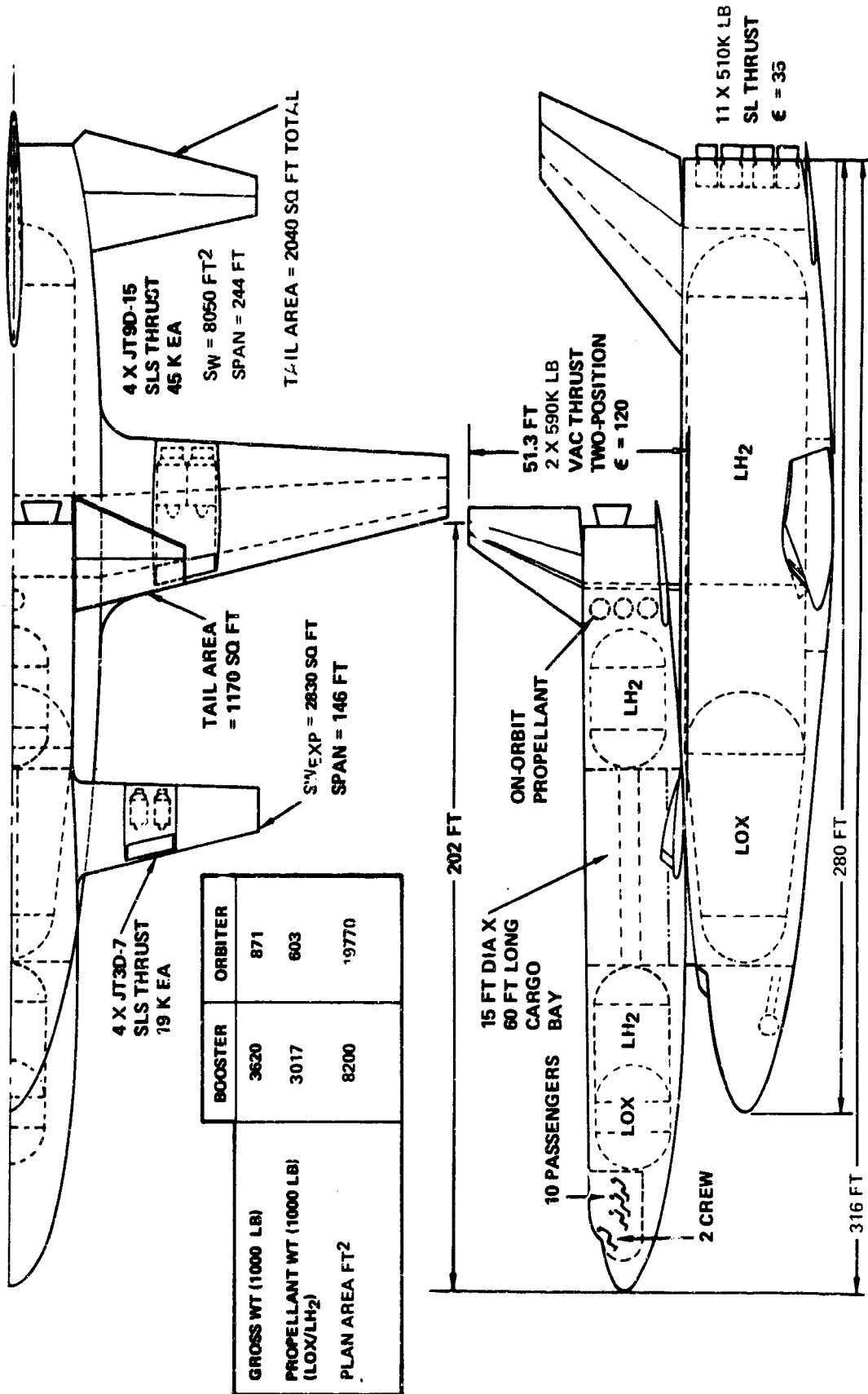


Figure 2-1. Configuration Definition—50,000-Pound Payload,
15-Foot-Diameter by 60-Foot-Length Cargo Bay

Table 2-1. Description of Final 50,000-Pound-Payload Vehicle

	Booster	Orbiter
Vehicle Weights		
Gross weight (lb)	3,619,872	870,977
Entry weight (lb)	587,522	256,515
Landing weight (lb)	532,002	254,807
Wing Geometry		
Span (ft)	244	146
Sweep (deg)	14	14
Taper ratio	0.319	0.333
Exposed area (sq ft)	6300	2010
MAC (ft)	37	21.4
Leading edge radius (in.)	7.1	4.05
Vehicle Dimensions		
Length (ft)	280	202
Planform area (ft ²)	19,770	8,200
Body wetted area (ft ²)	36,000	17,111
Wing wetted area (ft ²)	12,600	4,020
Horizontal-tail wetted area (ft ²)	4,080	2,340
Vertical-tail wetted area (ft ²)	3,180	1,170
Body mold-line volume (ft ³)	320,000	97,690
Volumetric efficiency ($V^{2/3}/A$)	0.13	0.124
Main Propulsion		
Propellant type	LO ₂ /LH ₂	LO ₂ /LH ₂
Mixture ratio	6:1	6:1
Engine thrust (1,000 lb)	510 (sl)	590 (vac)
Expansion ratio	35:1 (sl)	58:1 (sl)/120:1 (vac)
Number of engines	11	2
Firing sequence	1	2

Table 2-1. Description of Final 50,000-Pound-Payload Vehicle (Cont)

	Booster	Orbiter
Turbojet Propulsion		
Engine type	JT9D-15	JT3D-7
Number of engines	4	4
Engine-out capability	Yes	Yes
Engine thrust, SLS (1,000 lb)	45.5	19
SFC (lb/hr/lb)	0.364	0.55
Launch Data		
T/W (initial)	1.25	1.36
Engine-out capability	Yes	Yes
Maximum acceleration (g)	3	3
Burnout time, from lift-off (sec)	220	440
Burnout velocity (fps)	10,866	25,855
Burnout altitude (ft)	245,000	303,806
Burnout range (nm)	98	680
Burnout flight path angle (deg)	6.9	0
On-Orbit Data		
Inclination (deg)		55
Injection conditions (nm)		50 x 100
Station altitude (nm)		270
Maneuver ΔV (total) (fps)		2,000
Entry Data		
Reentry angle (deg)	6.5 (Staging)	-1.5
Reentry velocity (fps)		25,134
Lateral range, (nm) $\alpha = 60$	48	190
Longitudinal range (nm)	310 (Flyback)	2,545
Lateral range, T_{MAX} (nm)		1,240
Maximum acceleration (g)	4.0	2.08

Table 2-1. Description of Final 50,000-Pound-Payload Vehicle (Cont)

	Booster	Orbiter
Recovery Data		
Flyback range (nm)	310	0
Landing speed (knots)	113	128
Touch-down angle of attack (deg)	8	8
Aerodynamic Parameters		
Hypersonic (L/D) maximum (inviscid)	2.05	1.53
Hypersonic (L/D) design	0.69	0.53
Subsonic (L/D) maximum	8.40	7.30
Entry planform loading (psf)	30	31
Landing planform loading (psf)	27	31
Landing wing loading (psf)	67	88
Reserves		
RCS (lb)	460	950
ECS (lb)	0	50
Power (lb)	200	880
Turbojets, go-arounds (lb)	10,600	3,900
Orbit man system 500 fps (lb)	---	9,600
Primary propulsion, FPR (lb)	0	4,700
Safety Factors		
Crew compartment	2	2
Primary structure	1.5	1.5
Secondary structure	1.5	1.5
Pressure tanks (propellant)	1.5	1.5
(pneumatic)	2.0	2.0
Payload Definition		
Weight (lb)		50,000
Size, diameter x length (ft x ft)		15 x 60

Table 2-1. Description of Final 50,000-Pound-Payload Vehicle (Cont)

	Booster	Orbiter
Weight Factors		
Design stress allowable:		
Aluminum (2219-T87)	58.5 at 175 F	58.5 at 175 F
F_{tu} (ksi)	78.5 at -323 F	78.5 at -323 F
Titanium 6Al-4V STA,	129.5 at 400 F	129.5 at 400 F
F_{tu} (ksi)		
Safety Factors		
Crew compartment	2.0	2.0
Primary structure	1.5	1.5
Secondary structure	1.5	1.5
Pressure tanks (Propellant)	1.5	1.5
(Pneumatic)	2.0	2.0
Weight Margin		
Percent inert weight	10 percent and statistical data	10 percent and statistical data
How applied	Added at subsystem level	Added at subsystem level
Tank Sizing		
Ullage, percent LOX/H ₂	1.1 x Usable W _p	1.1 x Usable W _p
Tolerances, percent LOX/H ₂		
Residuals and Losses		
RCS, (lb)	100	200
ECS, (lb)	0	0
Power, (lb)	35	80
Turbojets, (lb)	200	100
One-man system, (lb)	-	330
Primary propulsion, (lb)	26,490	4,550



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capability and have a two-position nozzle with maximum expansion ratio of 120:1. The orbiter element is configured with the 15-foot-diameter by 60-foot-length cargo bay located at the vehicle c. g. to provide a vehicle which can be trimmed on reentry and during cruise with or without payload. This cargo-bay location requires separation of propellant tanks. Small cargo modules can be transferred through a pressurized hatch in the main cargo doors. These main cargo-bay doors can also be opened for removal of large cargo containers. LO₂ and LH₂ tanks are located forward, with a common bulkhead separating the propellant and oxidizer. A second hydrogen tank is located aft of the cargo bay. These tanks are suspended and are not subjected to vehicle aerodynamic loads. A polyurethane insulation is used on the inside of the LH₂ tank. Separate tanks with superinsulation are used to contain propellant for orbiter maneuvers. The primary load-carrying structure is a skin-stiffened titanium shell. To withstand the entry thermal environment, the titanium structure is protected on the bottom and sides of the fuselage by an external densified-quartz insulation. Bare titanium is satisfactory on the top of the orbiter because of the mild thermal environment. A fiberglass insulation is used inside the titanium structure to limit the temperature of the tankage and insulation. The orbiter wings are fabricated from titanium. The orbiter is 202 feet in length, has a wing span of 146 feet, and weighs 856,000 pounds at liftoff.

3.0 TECHNOLOGY DEVELOPMENT REQUIREMENTS

The study has demonstrated the feasibility of the two-stage, reusable, fixed-wing concept. However, further design and development of the system and technology advancement are required in certain areas. Technology development areas which are critical to the success of the shuttle vehicle are:

1. Aerodynamics and aerothermodynamics
2. Thermal protection and structure system
3. Propulsion
4. Demonstration of reusability and low operating cost

The technology advancement requirements which have been identified in the study are described in subsequent paragraphs and summarized in Tables 3-1 through 3-9.

3.1 AERODYNAMICS

Operational flight of the shuttle vehicle encompasses two-stage boost, orbiter-booster separation, entry at a high angle of attack, flight at high angle of attack to subsonic velocities, transition from high to cruise angle of attack, and transport-airplane-type approach, landing, and ferry. The aerodynamic technology for the ILRV is well defined for the ascent phase of the mission and for cruise and landing. Aerodynamic technology for flight at high angle of attack from hypersonic to subsonic velocities, poststall flight, and transition from high to low angle of attack require advancement. Aerodynamic technology status is summarized in Table 3-1.

3.1.1 ILRV Aerodynamic Program Status

A series of aerodynamic stability and control wind tunnel tests has been conducted by NASA over the Mach range from 0.25 to 20. The longitudinal and lateral stability characteristics of the orbiter have been defined during tests at the Langley and Ames research centers. Using a two-percent scale model, tests have been conducted to define the control requirements for subsonic transition from high to low angle of attack. Transonic stability

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Table 3-1. Aerodynamics Technology Status Summary

Development Status	Related Development	Technology Advance Requirement	Risk in New Development	Evaluation
Preliminary tests on two-percent model to Mach 2	Apollo, Gemini, X-15, large transport airplanes, large rocket boosters, Navaho missile and booster (boost and staging)	Poststall aerodynamics (boundary layer, separation, flutter, vortex development and shedding Reynolds number, and Mach-number effects).	Feasibility demonstrated	Technology well defined for entry, cruise, and landing phases of flight
Range of angles of attack and yaw		Effect of variation in configuration geometry (body shaping, straight tail and wing aspect ratio)	Impact of shape and aerodynamic surfaces on vehicle weight and thermal environment is likely to require refinement	Technology less defined for poststall flight, transition from 60-degree angle of attack to cruise, and transonic flight
		Flight demonstration from supersonic to subsonic speeds and transition from high to cruise angle of attack		Flutter and buffet characteristics not established

characteristics were demonstrated in a test at the Ames Research Center. Additional tests have been conducted at ARC to evaluate Reynolds number effects on aerodynamic performance at high angles of attack. Landing characteristics of the orbiter have been investigated for NASA in the Texas A&M 7-foot by 10-foot wind tunnel. Hypersonic stability during entry has been investigated during LRC tests over the Mach range from 6.0 to 2.0.

3.1.2 Related Development

Launch, boost, and staging of a large, two-stage parallel-configured (piggyback) system was operationally demonstrated by the Navaho missile. Additionally, much applicable boost and separation experience has been gained through the Saturn V flights of tandem-mounted configurations. The aerodynamic technology for the boost and separation phases of the ILRV flight is therefore considered to be well defined.

Entry at high angle of attack has been performed by the Apollo command module. Stability and control concepts employed with the Apollo vehicle during entry are directly applicable to the ILRV configuration. Hence, it is believed that the aerodynamic technology during the entry phase of flight for the shuttle vehicles is also well defined. The cruise, approach, landing, takeoff, and ferry modes for the shuttle system are very similar to large transport-type airplanes, and the aerodynamic technology required for these phases of flight is readily available.

3.1.3 Technology Advancement Requirement

The aerodynamic technology for flight at a high angle of attack from hypersonic to subsonic velocities, poststall flight, and transition from a high to a low angle of attack requires additional technology development. Specifically, experimental and analytical studies of the following phenomena are required:

1. Vortex development and shedding and boundary layer separation associated with stall and poststall flight
2. Flutter transonically and in stalled flight
3. Reynolds number and Mach number effects at high angle of attack
4. The effect of configuration geometry (body shaping, wing and tail geometry, etc.)



3.1.4 Development Risk

Preliminary studies and test data indicate that the two-stage reusable vehicle with fixed, low-sweep wings will trim at high and low angle of attack; and, therefore, the concept of entering at a high angle of attack to minimize temperature and subsequently pitching down to a low angle of attack for glide is a feasible operating mode. It is considered that the concept can be developed, but flow-interference effects on the thermal environment may be a serious problem.

3.1.5 Evaluation

Technology is well defined for entry, cruise, and landing phases of flight. Technology is less defined for poststall flight, transition from 60-degree angle of attack to cruise, and transonic flight.

3.2 AEROTHERMODYNAMICS

Flight modes of the shuttle vehicles encompass both high angles of attack (booster flyback and orbiter entry) and low angles of attack (booster and orbiter launch). Adequate aerodynamic-heating prediction methods are available for simple shapes where boundary layer conditions (laminar or turbulent) are known and the flow is uncomplicated by shocks or protuberances. Technology advancement is required to predict interference heating, to accurately define boundary layer transition effects, and to develop adequate scaling laws for application of small-scale test data to vehicle design. Aerothermodynamic technology status is summarized in Table 3-2.

3.2.1 ILRV Aerothermodynamic Program Status

Preliminary tests have been conducted by NASA to evaluate aerodynamic heating experienced by the orbiter during entry. Heat-sensitive paint tests of a small scale (0.5 percent) model have been conducted at LRC to obtain a qualitative assessment of overall heating distribution during entry and to evaluate wing-body-interference effects. These tests have indicated the existence of local hot spots on the wing leading edge and sides of the body due to flow interference.

Wing heating tests using a thin-skin two-dimensional 3.3-percent scale model of the wing alone have been conducted at LRC to obtain a quantitative evaluation of upper and lower surface heating. Leading edge heating tests have been conducted on a 13.3-percent-scale, two-dimensional model simulating the forward 40 percent of the wing. Additional heating rate distribution

Table 3-2. Aerothermal Technology Status Summary

Development Status	Related Development	Technology Advance Required	Risk in New Development	Evaluation
Qualitative tests confirm low heating rates during entry; potential interference areas indicated.	Apollo, Gemini, X-15, ASSET, BGRV, Mercury, Reentry F, Project Fire, MKII	High angle of attack heating distributions - both laminar and turbulent, boundary layer transition characteristics, entropy layer effect, interference heating effect during high angle of attack entry, during mated booster-orbiter phase, and at low angle of attack during orbiter terminal boost phase.	Analysis and data indicate two major areas of concern: shock wave interactions on orbiter and booster wings and horizontal tail, and shock wave and support structure interference during mated booster-orbiter phase. Extreme temperatures are expected without proper design. Risk can be minimized through extensive tests and subsequent modifications.	Basic technology fairly well defined; however, deficiencies remain, e.g., transition criteria, interference heating.



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data at low and high angles of attack have been obtained by MSC using small-scale models of the orbiter configuration tested in a 10-mw arc jet.

3.2.2 Related Development

High angle of attack entry has been performed by Apollo; however, the ablator heat shield masked out aeroheating details in regions comparable to the ILRV underbody during the flight tests. Use of ablator allowed conservatism to be built into the design for uncertainties and resulted in a small penalty in ablator thickness. That luxury cannot be afforded with a reusable TPS such as would be utilized on the shuttle vehicle.

Related programs incorporating re-radiative thermal protection systems and/or lifting entry which would provide some data on boundary layer transition and scale effects are the X-15, ASSET, and Ballistic Glide Reentry Vehicle (BGRV). However, these vehicles were flight tested at low angles of attack. No re-radiative structure vehicle has been flight tested at high angles of attack (the X-15 was ramped through moderate angles of attack).

3.2.3 Technology Advancement Requirement

Aerodynamic heating technology requires advancement in the following areas:

1. High-angle-of-attack heating distribution as affected by laminar and turbulent boundary layer
2. Boundary layer transition characteristics and entropy layer effects
3. Interference heating effects during launch phase, at low angles of attack after staging, and at high angles of attack during entry.

Interference heating and boundary layer transition probably represent the most difficult problems because of the many variables involved, lack of an analytical tool, and unknown scaling laws. Fuselage/wing shock interactions during launch and entry and fuselage/wing/support interactions during the mated phase of launch can cause extreme temperature levels without proper design. An extensive wind tunnel program will be required to synthesize an acceptable design, and considerable flight testing will be involved in verifying the design.

Of importance is top-side heating, not because of the high levels but because of the large area involved. Overestimating top-side heating will result in large increases in TPS weight. This region will require much

attention. Experimental data will have to be relied upon here also, and there will be difficulties in obtaining accurate ground test data because of low heating levels. Apollo experience showed that the wind tunnel simulation of separated (lee-side) heating was not very good and that flight data is required.

3.2.4 Development Risk

Based on Apollo experience with high angle of attack entry and the limited amount of ILRV data to date, the heating rates experienced in the undisturbed regions such as fuselage-underbody centerline are low. These results indicate that entry at high attack will minimize the severity of the thermal design environment. Of concern are local areas where shock-wave interactions and flow interference can cause high heating rates and high temperatures. Extensive testing will be required to minimize development risk.

3.2.5 Evaluation

The basic aeroheating technology is well defined for simple shapes where the boundary layer conditions are known and the flow is uncomplicated by shocks or protuberances. Deficiencies exist in transition criteria and interference heating. Trajectory analyses must be performed to identify trajectories with least stringent thermal environments.

3.3 THERMAL-PROTECTION AND INSULATION MATERIALS

The status of thermal protection system options is summarized in Table 3-3. The external thermal-protection material selected for a large area of the booster and orbiter vehicles is densified-quartz-fiber material (LI-15) currently being developed by Lockheed. Temperatures are less than 1500 F over 90 percent of the orbiter vehicle, and it is projected that the LI-15 would be acceptable for temperatures up to 2500 F. Alternate external insulation concepts are identified in Table 3-4.

Zirconium diboride base refractory ceramic has been selected for wing leading edges which are subjected to temperatures of 3000 F to 3800 F. Haynes 188, a cobalt-base alloy which is in commercial production, has been selected for leading edges of booster wings.

Intermediate insulation material between the propellant tanks and external structure is fiberglass (TG-15000). This will require development for reuse. Insulation selected for the inside of the LH₂ tank is polyurethane as used on the S-II stage of the Saturn V. Multilayer (metallized plastic film) superinsulation is proposed for thermal control of propellants used for orbital maneuvers.



Table 3-3. Thermal-Protection and Insulation Materials Technology Status Summary

Configuration Area or Subsystem Concept	Development Status	Related Development	Technology Advancement Requirement	Risk in New Development	Evaluation
Diboride ceramics (zirconium diboride selected)	Developmental; 50-percent developed (available from Man Labs)	Unknown	Size scale-up, uniformity, quality control, attachment techniques	Moderate to meet schedule	Capability of manufacturing usable sizes with uniform properties has not been demonstrated, and installation may be serious problem.
Haynes 188 alloy (selected)	Commercial production	Used in gas-turbine applications, similar to L605	Negligible	Low	No major problems foreseen
Rene 41	Commercial production	Wide usage	Negligible	Low	No major problems foreseen
Inconel 718	Commercial production	Wide usage	Negligible	Low	No major problems foreseen
Ti-6AL-4V (selected)	Commercial production	Wide usage	Negligible	Low	No major problems foreseen
Proposed aluminum alloys (2219, 7075, etc.) (selected)	Commercial production	Wide usage	Negligible	Low	No major problems foreseen
LI-15 (selected)	In development with Lockheed	Alternate external insulation concepts being investigated	Complete development program	High at 15 lb/ft ² ; moderate at 30 lb/ft ² ; low if ablator with refurbishment is considered as alternative	Excellent concept, detailed execution technique unknown
Zirconia fiber	Pilot-plant production	Other zirconia	Full scale	Low risk, but efforts will stop if commercial market fails to develop as anticipated	Only available insulation for areas over 2800 F
Dynaflex/dynaquartz	Developed	Current space vehicles	Requires demonstration of reuse capability	Established reuse criteria may not satisfy program requirements	Best material in this class
TG-15000 (selected)	Developed	Other forms of glass-bat insulation	Reuse capability must be demonstrated	Established reuse criteria may not satisfy program requirements	Widely used in aircraft for long durations at lower temperatures
Multilayer super-insulation (selected)	Basic materials developed; detail design and application 75-percent	Numerous NASA and AF contracts on concept	Demonstrate reuse capability and purge techniques	Low, unless unrealistically low conductivities are required	Required for ILRV missions
Cryogenic insulation (selected)	S-II foam development complete	S-II tank insulation	Demonstrate reuse and application technique	Low, except that reuse criteria may not satisfy program reqmts	Temperature constraint results in vehicle-weight penalty
	Material for reuse at 350 F in early laboratory stage		Total program	High	Weight-saving potential high
Columbium alloys	Approximately 75-percent developed	Apollo SPS engine skirt, ASSET, ASCEP, other Air Force programs	Oxidation-resistant coating process integration onto manufacturing sequences; specific alloys require further coating development	Moderate	Assembly of coated details may present problem
TD nickel chromium	Developmental; 65-percent developed	Air Force HASP contract, dispersion-strengthened metal structural development contract	Minimization of anisotropy, improvement of elevated-temperature ductility	Moderate to medium	This material is sole-source
Phase-change material	Solid-to-liquid material development, 50-percent; packaging concepts 10-percent complete		Efficient packaging, reuse criteria	Low risk if low weight efficiency is tolerable	Preliminary development phase
	Solid-to-solid 5 percent complete		Total program	High-risk concept, may not be feasible	
Advanced composites	Boron epoxy material 100-percent developed; graphite epoxy material 75-percent developed	Many AF programs	Fabrication and test of production-sized items; increased temperature capability	Low	Excellent weight-reduction potential

Table 3-4. Alternate External Insulation Concepts

Description	Source	Detail Configuration
Wycor foam	Corning	2-in., 10-lb-per-cu-ft density, 0.20 full density skin 1-in., 20-lb-per-cu-ft density, 0.020-in. full-density skin 0.67-in., 30-lb-per-cu-ft density, 0.020 full-density skin
Zirconia textiles	Union Carbide Research	2-psf blanket, ZYW-30 fabric bag containing 14-lb-per-cu-ft ZYF-100 felt 2-psf blanket, 2-ply ZYW-15 fabric (laminated with zirconia) pan containing ZYF-100 felt
Boron-nitride textiles	Carborundum R&D	2-psf blanket boron-nitride fabric (~1.5 lb-per-sq yd) bag containing 4 to 6-lb-per-cu-ft boron-nitride fibers 2-psf blanket, 1-ply boron-nitride fabric (as above) laminated with boron nitride pan containing 4 to 6-lb-per-cu-ft boron-nitride fibers
Quartz fabric (no binder)	AVCO	2-psf blanket, quartz-fabric bag containing quartz felt 2-psf blanket, quartz-fabric bag containing low-density three-dimensional quartz weave
Silica fabric (with binder)	General Electric	2-psf slab of "converted" silicone resin reinforced with random fibers 2-psf slab of "converted" silicone resin reinforced with quartz fiber "Omni-weave"

The technology status of the previously described insulation materials and alternate insulations and metallic thermal control systems are summarized in Table 3-3.

For alternate metallic heat shields, coated columbium alloys can be operated to approximately 2500 F but are creep- and coating-limited to 2400 F. TD nickel chromium may be operated to 2000 F in multiple reuses,

but problems associated with creep and loss of chromium may be experienced. Rene 41, a nickel-base alloy, is available but is difficult to fabricate and may be used where its strength at 1300 F to 1700 F is required. Inconel may be used and has good ductility at temperatures up to 1300 F.

As alternate intermediate insulation, Dyna-Flex and Dyna Quartz may be considered in place of TG-15000; it is available from Johns Manville in densities from 4.5 to 12 lb/ft³.

3.3.1 Thermal Protection and Insulation-Material Status

The development of densified quartz fiber material (LI-15) which is proposed for surfaces of the ILRV that are subjected to temperatures of less than 2000 F is in its infancy. The material is subject to water absorption and possibly erosion under operating conditions, and it will be necessary to provide an external coating. This material is a critical development item for the ILRV.

Zirconium diboride is available from Man Labs, but production of special sizes and shapes and installation provisions may be a problem. TG-15000 has been successful on the Apollo. Polyurethane-foam in-place material has been successful on the S-II but has not been developed for multiple reuse. Superinsulation is currently in development.

3.3.2 Related Development

As indicated above, the TG-15000 and polyurethane are currently in use on the Apollo and Saturn S-II.

3.3.3 Technology Advancement Requirement

The TG-15000 polyurethane and superinsulation insulation will require test programs to demonstrate their reuse capability. Zirconium diboride will require development in production techniques for the sizes and shapes required for the ILRV. Methods of providing a satisfactory installation for the wing-flexing and vibration environment of the ILRV will also be necessary. LI-15 will require an extensive test program to develop satisfactory coatings to prevent water absorption and to increase durability of material. Sizes of panel, methods of attachments, and sealing must also be established.

3.3.4 Development Risk

The risk associated with the TG-15000, polyurethane, and super-insulation is associated with the reuse capability, and vehicle refurbishment



requirements may be greater than desirable to repair the insulation. The use of zirconium diboride could create installation difficulties and result in schedule slippage.

LI-15 if it does not live up to expectations could be replaced by a low-density material, which would increase ILRV refurbishment requirements. If the ILRV design requires modification to incorporate a different thermal control system, this would result in schedule slippage.

3.3.5 Evaluation

The selected thermal-control materials offer merit for a safe low-weight space shuttle vehicle with low operational cost, but further studies and testing will be necessary before the vehicle design is finalized.

3.4 STRUCTURE

The status of selected ILRV structure design concepts is summarized in Table 3-5.

The orbiter body outer shell is made up of hat-stiffened skins and frames. The structure will be 6Al-4V STA titanium alloy. The design, analysis, and fabrication of this type of structure are fully developed as illustrated by the F-100 aft fuselage and the B-70 forward fuselage experience. A negligible amount of technology advancement will be required in the handling and joining of the hat-stiffened skin panels which go down to .020-inch thicknesses.

The wing and tail structures are made of 6Al-4V STA titanium alloy. They will be highly efficient, straight, Y-tee stiffened skin panels. The design, analysis, and fabrication of these types of structures have been fully developed as shown by the B-70 canard. The risks and need for technology advancement are negligible.

The booster tankage will be made of 2219 T-87 aluminum. Here the tank carries the body bending and shear loads and is very similar to the S-II stage of the Saturn V vehicle. A small amount of development is needed because the frames and stiffeners are on the outside of the shell. The risks are negligible. The inaccessibility of the tank surface creates a problem for inspection to determine if corrosion exists. Titanium and Inco 718 are backup candidates which would practically eliminate the corrosion problem. The orbiter tanks are suspended; they are produced from aluminum.



Table 3-5. Structure Technology Status Summary

Configuration or Subsystem Concept	Status of Development	Related Development	Technology Advancement Requirement	Risk in New Development	Evaluation Comments
Orbiter outer shell (structure titanium)	Fully developed	B-70 fwd fuselage, F-100 aft fuselage	Negligible	Negligible	Most of structure will be very thin gauges
Structures on aerodynamic surfaces, titanium	Fully developed	B-70 canard	Negligible	Negligible	Acceptable if temperature limited; some surfaces unprotected - i.e. insulation
Propellant tanks, aluminum	Integral tanks fully developed; some development on tanks designed by press. load	S-II and Apollo	Negligible	Some	Corrosion of buried and inaccessible tanks may lead to use of titanium and Inco 718 materials
Landing gears, titanium	Limited number of uses	SR-71 and 747 gears	High strength properties of thick laminated fittings; needs development	Some	Higher costs justifiable on orbiter, possibly also on booster to minimize weight
Potential weight savings from high-modulus composites	Much development needed; 15 to 20 percent developed	F-100 boron epoxy wing contract	Design fabrication and test of joints	Considerable	Desirable for weight-sensitive orbiter
Hot structure backup for insulated titanium structure	20 percent developed (see Material Requirements)	X-15, B-70	Technology all available; some demonstration tests needed	Moderate risks	Will be needed if LI-15 insulation concept is not feasible



Titanium landing gears offer potential for weight minimization on the ILRV. Obtaining high-strength properties in thick sections or laminating sheet or plate material requires some development. Related titanium landing gear development has been achieved by Lockheed on the SR-71 landing gears and Boeing on the 747 landing gears. Higher landing gear costs can be justified on the orbiter and possibly also on the booster to minimize vehicle weight and overall costs.

The potential weight saving of high-modulus composites is about 20 percent. Much development is needed, especially in joining. Design fabrication, and tests are needed of panels, joints, and components. The NR Los Angeles Division is developing an F-100 boron-epoxy wing-skin program for the Air Force. Considerable risks are involved in this development. These composites are very desirable for the weight-sensitive orbiter.

Any problem in the development and use of the LI-15 insulation on the outer surface of the titanium structures could introduce the hot structure as a backup structure. Much experience has been developed on the X-15 and the B-70 programs using hot structures. The materials and structural concepts for the ILRV will require structural tests of components. Only moderate risks are present because all the needed technology is available.

3.5 PROPULSION

The shuttle vehicle uses LO_2/LH_2 main rocket propulsion for ascent and on-orbit maneuvers, GO_2/GH_2 reaction control system propulsion for vehicle exoatmospheric control and translation, and airbreathing propulsion for cruise back to landing site, go-around landing, and ferry operations. The propulsion system technology assessment is shown in Tables 3-6, 3-7, and 3-8.

3.5.1 Development Status

Engine component tests have been conducted for both high chamber pressure bell nozzle engine and aerospike engine concepts. These tests have included large-scale thrust chambers, two-position bell nozzles, higher pressure discharge LO_2 and LH_2 pumps, preburner combustors, and various cooling techniques. A significant program is currently in progress at AFRPL on the high chamber pressure bell nozzle engine. This advanced program development (APD) is currently in the component-development phase. A demonstrator engine of flight-weight component design is scheduled to be tested by mid 1972.



Table 3-6. Main-Rocket-Propulsion Technology Status Summary

Development Status	Related Development	Technology Advancement Requirement	Risk in New Development	Evaluation
Component tests completed a) Thrust chamber with two-position nozzle b) High-pressure discharge pumps c) Preburner d) Cooling APD in work to test complete demonstrator engine	Large booster engines have been developed and are operational	Complete APD to demonstrate a) Successful integration of component technology into operating engine b) High predicted performance c) Low predicted weight Extend APD and other programs to: a) Demonstrate reusability b) Between-flight checkout c) Engine start on mixed phase propellant d) Throttle to 10 percent e) Accelerate demonstration f) Evaluate engine-vehicle interface	Moderate to meet schedule	Basic component technology available. High performance, high P, low weight, reusability critical to shuttle concept. Should accelerate and expand complete engine demonstration to minimize schedule risk since engine development has historically been long lead item. Need vehicle-engine integration study to establish interfaces.



Table 3-7. Reaction Control System (O₂H₂) Technology Status Summary

Development Status	Related Development	Technology Advancement Requirement	Risk in New Development	Evaluation
New technology, limited thruster and system feasibility programs completed and in progress. 10 and 100 psi P _c thrust chamber programs conducted to evaluate performance, ignition, and response	Storable RCS technology	Develop thruster technology a) Cooling b) Ignition c) Response d) P _c e) Thrust Develop propellant storage and conditioning a) Pumps b) Compressors c) Vaporizers d) Accumulator e) Control valves Develop reusable system	Moderate to meet schedule, assuming significant technology started soon Storable system technology well developed and is backup	Very limited technology. Large effort required to a) develop basic component technology b) develop system technology c) compare O ₂ /H ₂ system options d) compare to storable systems



Table 3-8. Airbreathing-Propulsion Technology Status Summary

Development Status	Related Development	Technology Advancement Requirement	Risk in New Development	Evaluation
Commercial turbojets operational Limited programs to define modifications for space environment Turbojets have been modified and tested with H ₂ fuel High T/W technology being developed	Commercial and military turbojets	Modifications for space environment Effect on non-rotation during boost to orbit Modifications to H ₂ fuel Lighter-weight designs	Low - commercial turbojets can be made to perform mission but they are a significant penalty	Basic technology and systems available H ₂ fuel in booster has significant benefit High T/W ($\approx 15:1$) has significant benefit



The O₂/H₂ RCS is a new technology item on which rather limited work has been conducted in the past. These programs and ones currently in progress have shown feasibility.

Of course, commercial transport and military turbojet engines are operational. Limited work has been done to assess the modification required for the space environment. Development tests have been conducted which show the feasibility of modifying a JP turbojet engine to use hydrogen fuel. Development work is in progress to establish the technology base for high T/W lift fan engines with relatively short operating duration. Advanced turbojet designs also show significant improvement in engine T/W.

3.5.2 Related Development

The related technology which has been obtained in the development of the J-2 and F-1 engines is applicable, also the technology gains made on the M-1 engine.

The technology developed for storable propellant systems provides the insight into many of the unique problems of developing small, fast-response thrusters.

The technology developed for commercial and military aircraft is directly applicable.

3.5.3 Technology Advancement Requirement

The shuttle system concept depends on main rocket engines with high performance, compact size, low weight, and reusability. To demonstrate these qualities the current APD is required to verify (1) successful integration of current component technology into a complete engine, (2) the high predicted performance, (3) the low predicted weight. An extension of the APD or other programs is required for (1) demonstrating reusability, (2) between-flight checkout requirements, (3) engine start on mixed phase propellant, (4) throttle capability to 10 percent, (5) accelerating total-engine demonstration, and (6) evaluating and identifying engine-vehicle interface.

New programs are required to develop O₂/H₂ thruster technology with emphasis on cooling, ignition technique, ignition response, effect of chamber pressure, and effect of thrust level. The current study identified chamber pressure of 300 psia and thrust levels of 800 pounds and 1800 pounds. New programs are required to develop O₂/H₂ storage and conditioning systems and components. Development is required to demonstrate reusability.



Technology is required to identify modification to existing turbojet systems for operation in the space environment and effect of boost vibration and accoustics while the turbo machinery is not operating. Development of lighter engines also needs to be pursued.

3.5.4 Risk in New Development

See Tables 3-6, 3-7, and 3-8.

3.5.5 Evaluation

Main Rocket Propulsion

The basic component technology is available. The high performance, compact envelope, low weight, and reusability are critical to the shuttle vehicle performance and operational cost. Technology should be accelerated to demonstrate these features in a complete demonstrator engine. Also, vehicle-engine integration studies need to be conducted to guide further engine technology programs.

Reaction Control System

Very limited technology exists for the O_2/H_2 RCS. A large technology effort is required so that the various system options can be adequately evaluated and also so the O_2/H_2 systems can be compared to other propellant options. The development of O_2/H_2 systems is not vital for vehicle performance since storable technology is well in hand. However, from the point of reuse at minimum operational cost, the O_2/H_2 system seems very attractive.

Airbreathing Propulsion

The basic system technology is available, and current turbojets can be used with modification for the space environment. However, the use of hydrogen fuel in the booster and high T/W engines in the orbiter provide significant payload gains for potential system growth.

3.6 INTEGRATED ELECTRONICS AND GUIDANCE, NAVIGATION, AND CONTROL

Electronics technology generally is available, but selection of the best subsystem concept to minimize weight requires further investigations and design integration studies (see Table 3-9). Technologies are available in the following areas and concepts currently in use or developed: nonvolatile mass-memory system, magnetic core, magnetic drum/disk, plated wire,



LSI, hologram film, magnetic thin film, displays and controls, F-111, F-14, F-15, C-5A, 747, multiplex. System tradeoff studies are necessary to select low-cost, low-weight, reliable, integrated system. The system can be developed but a major expenditure is necessary to develop and produce the system.

Critical GN&C system development items for the ILRV are the automatic rendezvous-and-docking and automatic-landing systems. A technology status summary of these systems is presented in Table 3-9.



Table 3-9. Integrated Electronics and GN&C
Technology Status Summary

Configuration Area or Subsystem Concept	Development Status	Related Development	Technology Advancement Required	Risk in New Development	Evaluation
Electronics/GN&C systems	Technology generally available but selection of best subsystem concept to minimize weight requires further investigations and design integration studies.	Technologies available in following areas and concepts currently in use or developed: Nonvolatile mass-memory system Magnetic core Magnetic drum/disk Plated wire LSI Hologram film Magnetic thin film Displays and controls F-111, F-14, F-15, C-5A, 747, Multiplex	System tradeoff studies necessary to select low-cost, low-weight, reliable, integrated system.	Minimal	System can be developed but major expenditure necessary to develop and produce system.
Automatic landing SPN 42 STATE AILS (Requires ground signals and vehicle control implementation)	SPN 42 Navy-sponsored for carrier use STATE Near-operational Prototype developed and being tested by Army AILS Tested by FAA at Atlantic City	SPN 42 In-flight tests on carriers In-flight tests by NASA STATE Tactical use in Vietnam AILS Currently being tested by French Sweden AF is testing for use on STOL fighter Integrate with vehicle	SPN 42 No major advancement required Not compatible with FAA Requires ground-based equipment STATE Can be made compatible with FAA AILS No major advancements required Vehicle system integration	SPN 42 Rollout problem Decrab problem STATE Rollout problem Decrab problem AILS Rollout problem Decrab problem	SPN 42 Minimum air weight penalty Near operational Does not provide flare capability Does not treat decrab problem STATE Good potential for shuttle use AILS One of top candidates for shuttle
Automatic docking (laser radar and space station reflectors proposed)	No prototypes available ITT research using laser techniques	No system but laser development related	Develop system to provide accurate range, range rate, and angular measurements	May not achieve desired state-of-art in time for shuttle Adds complexity C&C system	No significant evaluation has been made of the ITT concept. Will require manual vs. automatic trades since manual docking is a well-proven concept.