GRUMMAN AEROSPACE CORPORATION
BETHPAGE, NEW YORK 11714

L. J. EVANS
president

27 March 1970

From: Grumman Aerospace Corporation
Bethpage, Long Island, New York 11714

To: National Aeronautics and Space Administration
Headquarters
Washington, D. C. 20546

Attention: Mr. Philip Sload, Code KD-5

Subject: Phase B Proposal for Space Shuttle Program Study

Enclosure: (1) Proposal to Accomplish Phase B Space Shuttle Program

Gentlemen:

1. The Grumman Aerospace Corporation and its Associates: General Electric, Northrop, Eastern Airlines, and Aerojet General, submit this proposal, which we believe to be fully responsive to all terms and conditions of NASA Request for Proposal No. 10-8423, with Amendments 1, 2, 3 and 4.

2. Grumman fully supports the Space Shuttle System as a program designed to give our Nation the ability to safely transport significant payloads of men and material to and from space with minimum expenditure of National resources. To this effect, you have identified the following system characteristics associated with achieving the stated objectives:

   a. An operational mode which will reduce costs an order of magnitude below present operating costs.

   b. A flexible capability to support a variety of payloads and missions.

   c. An airline-type operation for passengers and cargo transport.

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d. A reusable system with a high launch rate capability and short turnaround and reaction times compatible with rescue missions.

We are fully prepared and eager to support a development program and a vehicle preliminary design effort during the Phase B Space Shuttle Study which would analyze probable annual funding rates, minimize technical development risks, and provide the earliest possible flight date, by properly balancing development, acquisition, and operational costs.

3. To provide NASA with sound answers to questions posed by this Shuttle Program RFP, we are recommending a three-pronged Phase B Study effort evaluating two design approaches.

(i) Design 518

A detailed analysis, evaluation and design of a two-stage fully reusable Orbiter/Booster Space Shuttle utilizing LOX/LH_2 propellants and high pressure engines with both high and low cross-range in a single Orbiter, fully responsive to your Statement of Work.

(ii) Design 532

A detailed analysis, evaluation and design of a two-stage fully reusable Orbiter/Booster utilizing LOX/LH_2 propellants with high pressure engines in an Orbiter with both high and low aerodynamic cross-range in conjunction with a Booster utilizing proven Saturn LOX RP-1 propellants technology and F-1 engines compatible with KSC facilities with minimum modification. We have purposely structured this option to decouple the risks associated with the structure/heat protection system, large-scale reusable hydrogen cryogenics and advanced propulsion engines.

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(iii) A complete analysis will be made of the range of Space Shuttle Program alternatives utilizing the vehicle design alternatives developed in (i) and (ii). This will provide The Agency with the visibility required to make meaningful decisions for Phase C/D program initiation.

4. We believe we have assembled a team of extremely competent associates with the right space/aircraft background to fully qualify them to study all aspects of the proposed Phase B Program, and to design, develop and build the ultimate system. We have chosen our team not only for their technical talents, but also for their management and financial talent, as well as geographical location; all of which we believe will make more effective use of National aerospace resources. Our associates working with Grumman have a great deal to offer NASA (much of which is not easily defined in a page limited proposal) in properly assessing a low risk program, carried through with integrity and dedication within currently popular budget restraints.

5. Our team proposes to accomplish the study described in Enclosure (1) for a total fixed price of $8,006,287. This price will remain firm for a period of one hundred and twenty (120) days, as prescribed.

We are sure that you recognize that this price in no way represents the true value of the results to be obtained from the Study. Grumman and its Associates will continue to expend substantial sums for related effort in areas of high risk to ensure selection of the best possible options for Phase C/D decisions.

6. We would like to thank you for including Grumman on your bidders list. We would also like to call your attention to the fact that we would welcome an opportunity to draw on the combined knowledge and talents of other nations to work together as a united international team to meet the demands and challenges of the Shuttle System. We are ready, now, to send a team of our most qualified people to draw upon the existing technology and science of Europe, Asia and other areas that could bring vital expertise to this effort.

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7. Should you need any additional information, please contact Mr. Lawrence M. Mead, Vice President, Director, Space Shuttle Program (516) 575-2575 or 2969.

Very truly yours,

L. J. Evans

L. J. Evans
President

PROPOSAL TO ACCOMPLISH

PHASE B
SPACE SHUTTLE PROGRAM

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D. C. 20546

In Response to Request for Proposal No. 10-8423

by

GRUMMAN AEROSPACE CORPORATION
Bethpage, New York 11714

Lawrence M. Mead
Vice President
Director, Space Shuttle Program

Joseph G. Gavin, Jr.
Senior Vice President
Space Programs

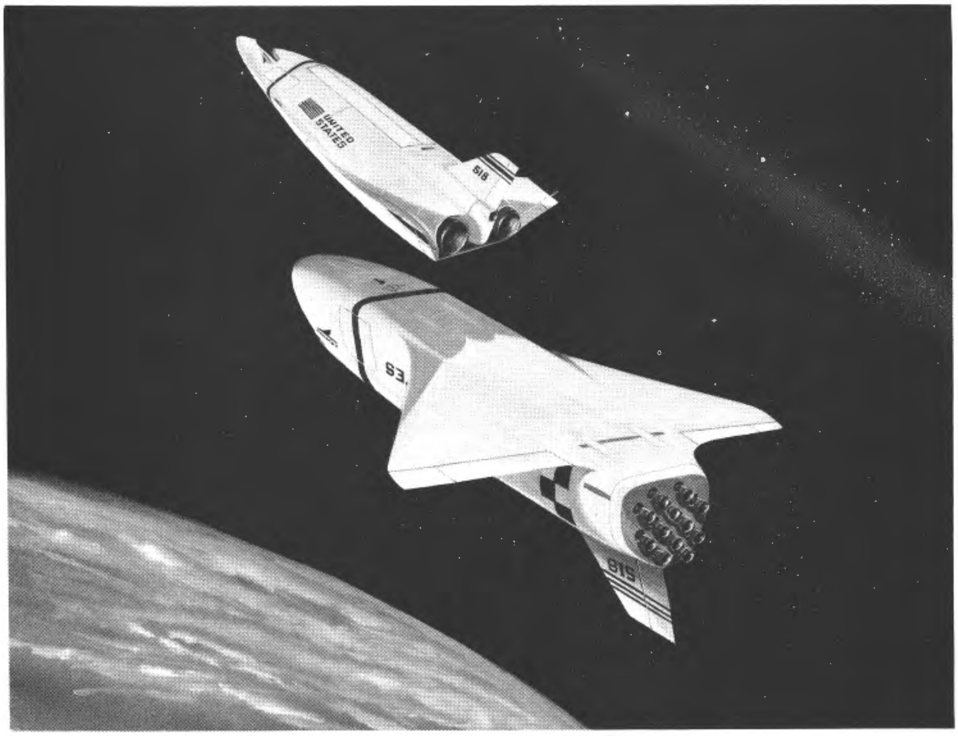
70-35NAS

30 March 1970

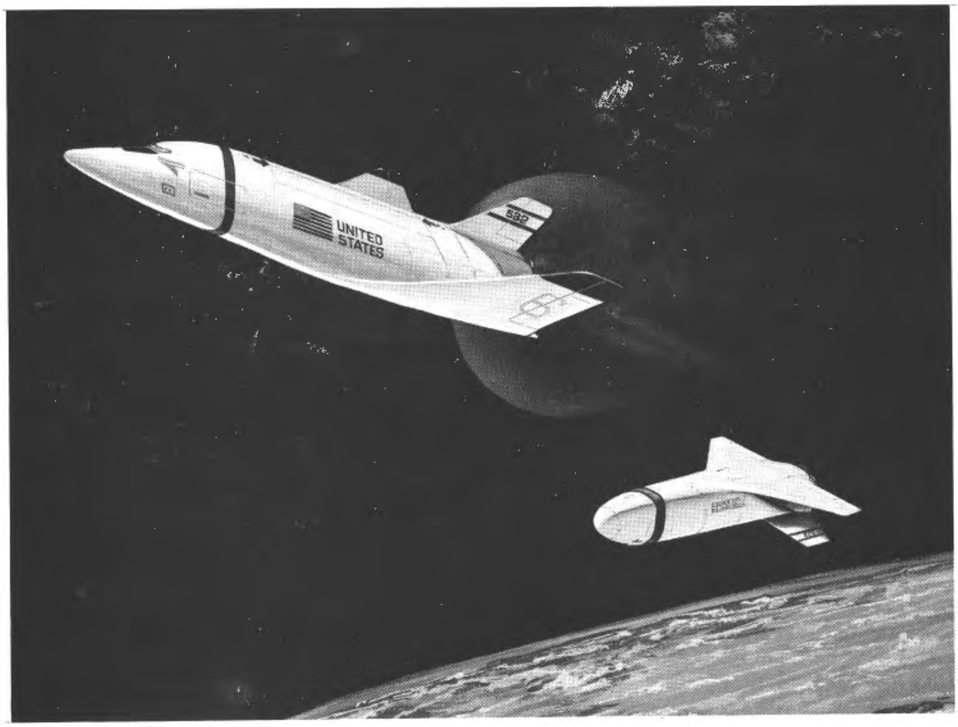
FOREWORD

This proposal has been prepared in response to National Aeronautics and Space Administration Request for Proposal No. 10-8423, dated February 20, 1970, and Amendments No. 1, 2, 3, & 4 thereto. It is firm for a period of not less than one hundred twenty (120) days from March 30, 1970. The executed certifications requested in Enclosures 5 and 6 of the Request for Proposal are appended at the end of this proposal. The negotiation team leaders and the persons authorized and available to negotiate, change proposals, and bind Grumman with respect to this requirement are:

Name	Position	Telephone
Lawrence Mead	*Vice-President and Director Space Shuttle Program*	*(516) 575-2575*
Peter Oram	*Director of Contracts*	*(516) 575-7460*
Rolf Larson	*Deputy Director of Contracts*	*(516) 575-1043*
Robert Benning	*Contract Manager*..............	*(516) 575-2081*



Design 518



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SUMMARY

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PROPOSAL TO ACCOMPLISH
PHASE B
SPACE SHUTTLE PROGRAM

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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In Response to Request for Proposal No. 10-8423

by

GRUMMAN AEROSPACE CORPORATION
Bethpage, New York 11714

GRUMMAN

Fig. S-1 Design 518. *Responsive to the Requirements of the Statement of Work*

SUMMARY

Grumman Aerospace Corporation, along with its associates -- the General Electric Company, Eastern Airlines, the Northrop Corporation, and the Aerojet-General Corporation -- are pleased to submit this proposal. This study must prove that technical challenges can be met at a cost commensurate with realistic national funding levels at an early date, (perferably prior to the late 1977 initial operating capability (IOC) indicated in the Statement of Work). We have assembled a team of extremely competent associates. Together, we are fully qualified to study all facets of the proposed Phase B study, and to develop and build the product. We believe we have already made a promising start toward defining the concept of the space shuttle system. Our goals in carrying out the study are to provide:

- A low cost, economic space transportation system
- System flexibility for a variety of payloads, cross range, and missions
- Airline-type operation for passengers and cargo
- An efficient reusable system (emphasizing simplicity), with high launch rate capability, and reaction times

It is essential that a practical and conservative detailed view be taken in studying this very imaginative system concept. Fundamentally, the proposed study effort must answer three questions:

- Can the nation build a cost effective shuttle system?
- Can the nation limit the program risks?
- Can the nation fit the program into the budget?

Our answer to these questions is a firm "yes".

We believe the answer to the first question can be provided by a comprehensive tradeoff study of our Designs 518 and 532 (518 is fully responsive; 532 is a promising alternative to limit program risk). The answer to the second question will be provided by our study of Design 532. The answer to the third question will be provided by a combination of our study of Design 532 and of additional alternatives which we believe will meet all known program objectives.

DESIGN 518

Design 518, Figure S-1, is a fully responsive and balanced reusable, two-stage design based on the prescribed 3.5 million lb gross lift-off weight (GLOW). The aerodynamic configuration of the orbiter was derived from an investigation of straight, swept delta, and lifting body configurations. The selected lifting body appears competitive in all respects (weight, flying qualities, elastic characteristics) and provides the potential for straightforward evolution to high cross-range reentry as thermal protection systems become qualified. Evaluation of a single aerodynamic configuration will provide a clear cut understanding of the weight, performance, and cost penalties associated with increased cross range. In the low cross-range mode, results to date show that the 3.5 million lb GLOW limits the fully internal payload to 32,200 lb.* The Design 518 orbiter represents a near optimum balance between size of vehicle, size of payload, and propulsion capability (ΔV) apportionment.

The Design 518 booster is a weight conscious, conservatively designed delta-wing configuration which includes the prescribed 400,000 lb thrust high-pressure rocket engines. A refinement which demands investigation is the application of larger, 1,000,000 lb thrust high-pressure engines. Preliminary design will be performed on Design 518, as described in Section 1 of this proposal. An acquisition plan will be created which will include the 400,000 lb thrust high-pressure engines and other characteristics decribed in the Statement of Work and its appendices. The program cost will be assessed for the IOC of late 1977. Grumman and its associates will pursue all of the objectives and requirements of the RFP for Design 518. In summary, Design 518 demonstrates that an attractive and promising responsive design can be achieved within the 3.5 million lb GLOW. With refinement, which can be expected during the Phase B study, we believe that improved payload capability can be obtained while continuing to observe the weight margin rules called for by the RFP.

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*All payloads are for the Design Reference Orbit – 270 n mi circular with 55° inclination, rounded off to nearest 100 lb.

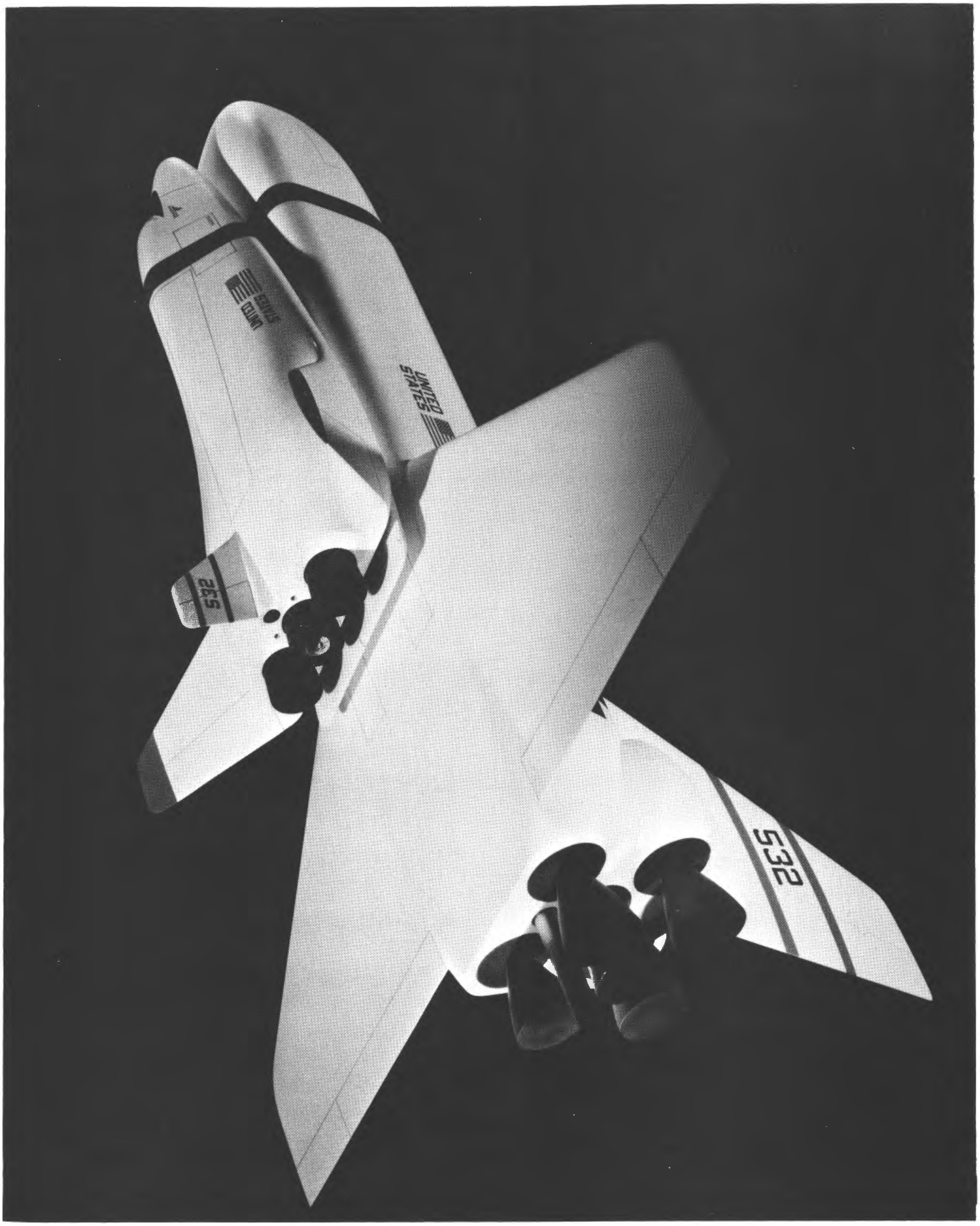


Fig. S-4 Design 532. *Offers Reduced Initial Cost and Reduced Technical Risk*

DESIGN 532

Design 532 is a quite different response which we believe holds promise for answering the question "Can we limit the program risk?" If Design 518 yields a program requiring a funding pattern as shown in Fig. S-2, we will face a situation which may permit neither the development of the space shuttle system nor the development of its payloads. This consideration as well as the NASA/MSC interest in a smaller, simpler, vehicle which could fly earlier, led to the development of Design 532.

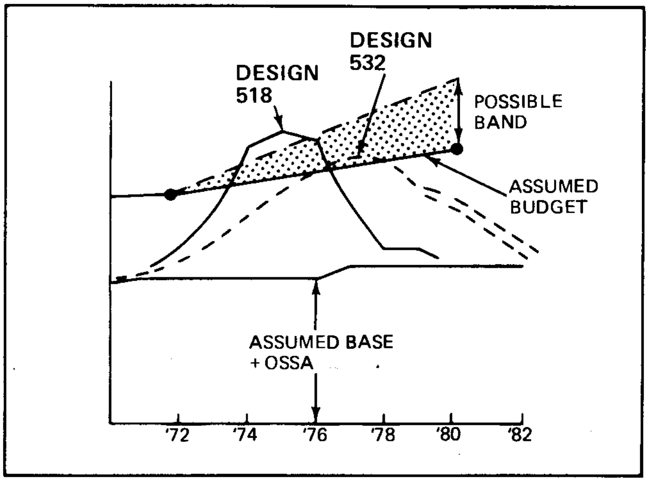


Fig. S-2 NASA Budget Forecasts a Potential Shuttle Funding Problem

Design 532 is a fully reusable, two-stage space shuttle with an initial low cross-range payload of 12,800 lb (Fig. S-4). Design 532 is also designed for the high aerodynamic cross-range potential and makes provisions for phased implementation of increased payload and performance capability as shown in Figure S-3. This approach permits a step-wise increase in capability and growth while decoupling the technical risk and reducing initial cost. Using engines and electronics derived from existing equipment should assure an earlier first flight. Additional performance becomes available with introduction of the high pressure orbiter engines with a payload of 22,600 lb (Fig. S-3).

The Design 532 booster is fully reusable with LOX/RP-1 propellants and five F1 engines. A deliberately conservative approach to the design of the booster minimizes technical risk and cost by avoiding development of large-scale hydrogen tankage. Development savings of several hundred million dollars per year appear possible for this orbiter-booster combination.

The Design 532 orbiter will, at first, use three J2S engines, operate at low cross range, and be fitted with first generation avionics. The baseline Design 532 orbiter is achieved by subsequent installation of the high I_{sp}, high-pressure 250,000 lb thrust engines. Improved thermal protection systems extend cross range, and second generation electronics improve operational efficiency. We believe that operational experience with the orbiter will show that for certain missions the air-breathing engines are not required. Therefore, the flying qualities have been tailored to accommodate both engine weight in and engine weight out cg positions. Removal of the air-breathing engines and reduction of on-orbit propellant will increase payload capacity to orbit to 52,700 lb. As a further step to make even heavier up-payloads possible, we have made provisions for a potential non-reusable kick stage. This would raise the payload limit to 76,500 lb. The options of Design 532 are shown in Fig. S-3. In conjunction with this attention to capacity for heavy payloads, the Design 532 cargo bay has been conceived as a "flat-bed" sized for a 10 ft. diameter payload carried internally, 15 ft. diameter carried semi-submerged, and for 22 ft. diameter carried externally (Fig. S-5).

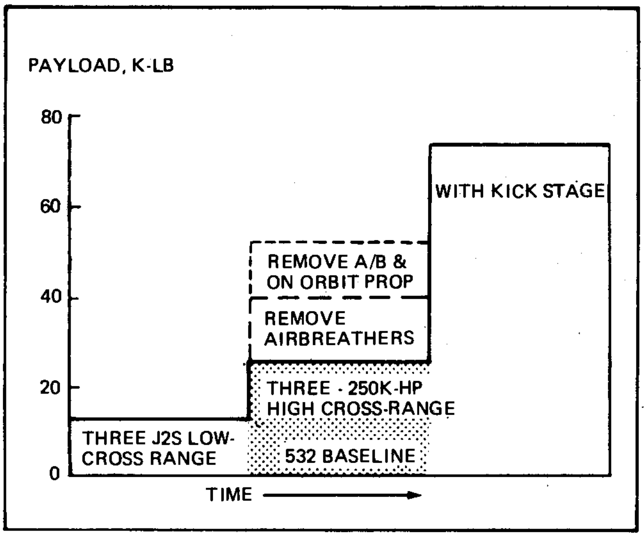


Fig. S-3 Payload Growth with Design 532

To summarize, Design 532 is based on the following considerations:

- Reduced initial funding requirements
- Payload flexibility and growth
- Early initial flight date and initial operational capability

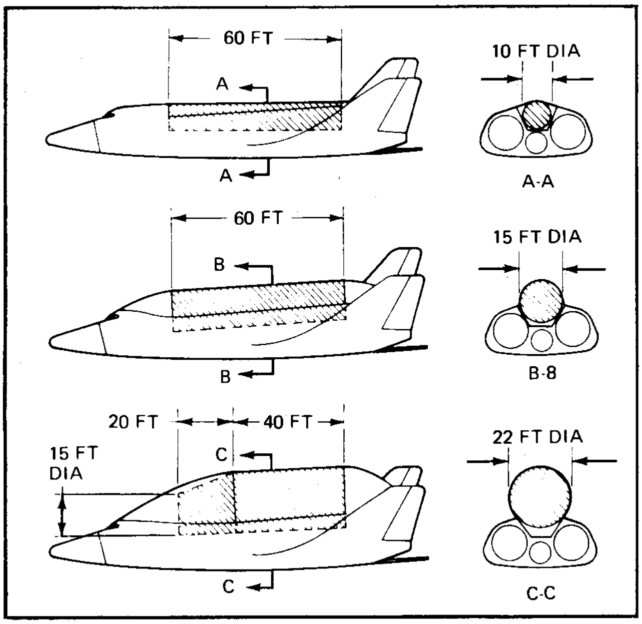


Fig. S-5 The "Flat Bed" Design 532 Offers Flexibility in Payload Size

- Phased introduction of advanced thermal protection system for high cross range
- Phased introduction of high-pressure engines
- Phased introduction of advanced avionics system
- Minimum facility modifications
- Maximum use of the Apollo investment; reduction of booster development risks
- Reduced total program cost.

Figure S-6 summarizes the weights, payload capabilities and options of Designs 518 and 532.

EVALUATION OF OPTIONS

We suggest that Designs 518 and 532 (as shown in Fig. S-9 through S-14) be used as starting points for the study after consultation with NASA and after NASA evaluation of our results. Tradeoff studies will be performed that will yield the final system concept. The selection of realistic options is essential in achieving viable funding requirements. Using the configuration baselines, we must evaluate options such as:

- Development of new high-pressure rocket engines tailored for the orbiter
- Use of modified S-IC booster for early orbiter flights. This must be viewed against the potential requirement for launching space station elements. Fig. S-7 shows one such possibility
- Development of new high-pressure rocket engines tailored for the booster. For example, if continued development of the J2S engine is determined to be adequate for the orbiter, an excellent argument can be made to develop a LO_2, LH_2 booster rather than the RP-1 fueled Design 532 booster. Fig. S-8 indicates a possible approach
- Delay full payload operations until space station logistics are required

DESIGN CHARACTERISTICS (All Wts to Nearest 100 lb)	518		532		532 PLUS KICK STAGE OUTSIZED PAYLOAD
	INITIAL LOW X-RANGE	FINAL HIGH X-RANGE	INITIAL LOW X-RANGE	FINAL HIGH X-RANGE	
CROSS RANGE, N MI	400	1,800	400	1,650	300
PAYLOAD, LB (i = 55 DEG, 270 N MI)	32,200	35,000	12,800	25,900	76,500
- REMOVE A/B & ΔV	–	62,900	–	52,700	100,000
ORBITER					
• ENGINES	2 x 400K-HP		3 x 206K J2S	3 x 250K-HP	
• PROPELLANT	LOX/LH_2		LOX/LH_2		
• DRY WEIGHT, LB	175,000		165,600		
• BOOST WEIGHT, LB	637,200		559,600	569,300	
• LENGTH, FT	146		131		
BOOSTER					
• ENGINES	12 x 400K-HP		5 x F-1		
• PROPELLANT	LOX/LH_2		LOX/RP_1		
• DRY WEIGHT, LB	439,600		593,800		
• BOOST WEIGHT, LB	2,862,700		6,353,400		
• LENGTH, FT	208		222		
BOOSTER & ORBITER					
• DRY WEIGHT, LB	614,600		759,400		
• GLOW, LB	3,500,000		6,912,900	6,922,700	7,200,000
• HEIGHT, FT	208		240		

Fig. S-6 Design 518 and 532 Weights, Payload Capabilities and Options

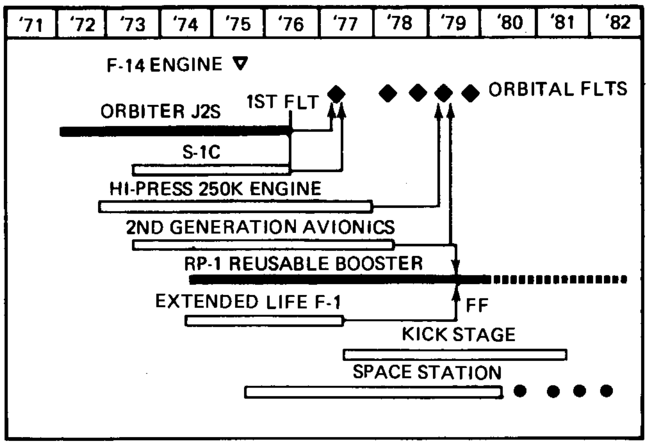


Fig. S-7 Use of J2S and S-1C Allows Early Orbiter Flights

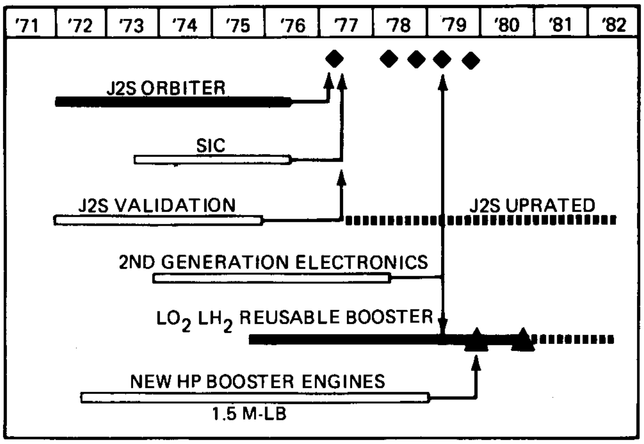


Fig. S-8 Uprating J2S Permits Development of Optimized LO_2 LH_2 Booster Engines

- Orbiters dedicated to selected missions
- The use for a oneway payload-kick-stage-booster combination

Facility availability and applicability throughout the United States will be analyzed to minimize facility costs. TEMPO, a division of General Electric, will do a study of the mission, traffic, and economic implications of the space shuttle program. This effort, along with the preceding items, will be included in our study approach, as discussed in Section 2, to answer the question "Can we fit the space shuttle into the budget?"

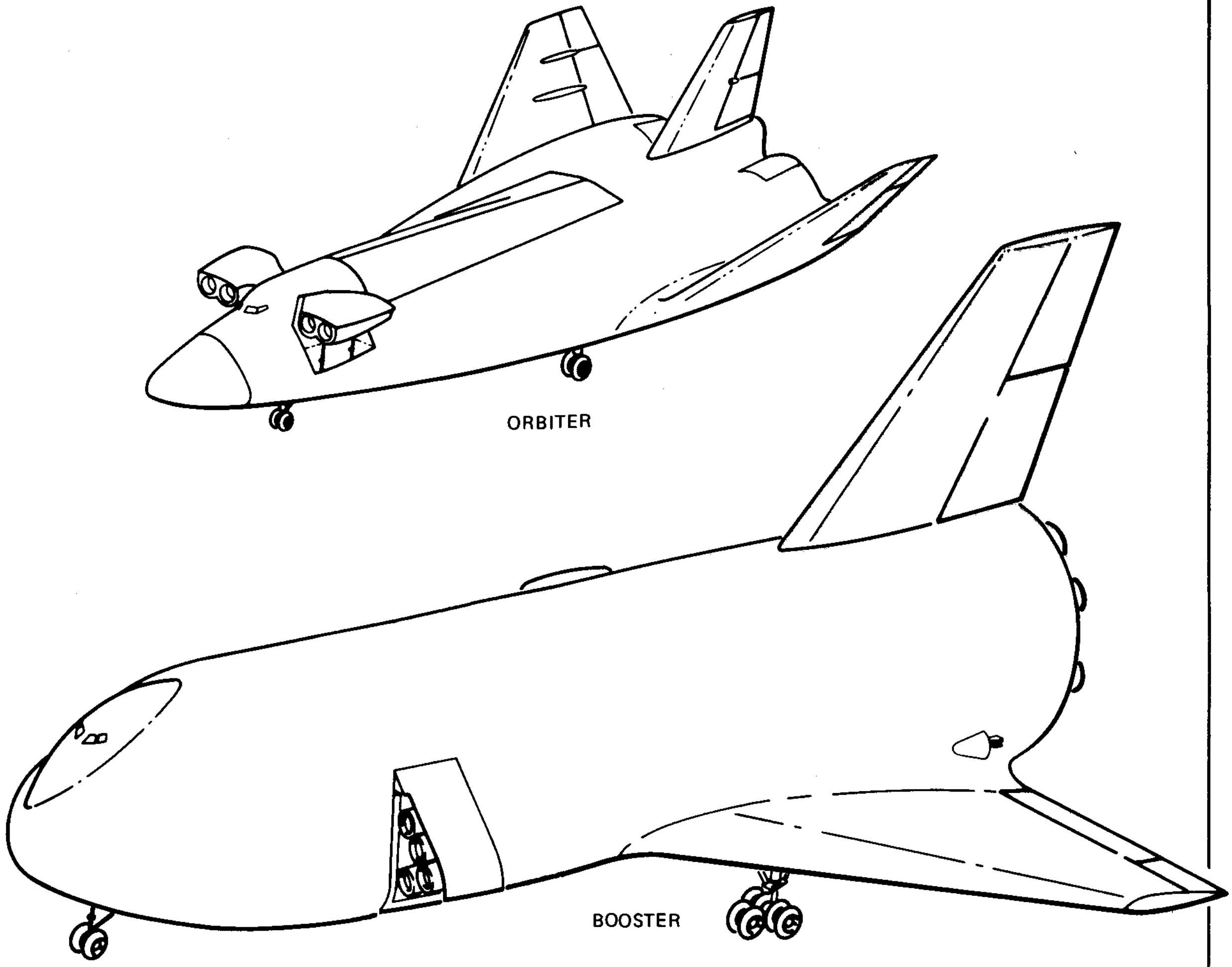
Our current space programs support the need for the shuttle. Our Apollo experience has provided a conviction that costs can be reduced by minimizing ground support equipment and providing reusable vehicles. The life of the NASA/Grumman Orbiting Astronomical Observatory, now in its 16th month, may be limited by the nitrogen supply for the attitude control system. Servicing by a shuttle could well extend the OAO life an additional year, a cost saving of $25 million.

We believe that it is important to fly early. An early flight program will provide early assessment of our technical approach. This will enhance the probability of meeting key system operational dates. We will identify and conduct supporting research and technology (SR&T) efforts required for success of this program. The details of the tradeoffs required to meet these goals and the SR&T plans are shown in Section 2.

STUDY APPROACH

The major considerations of our recommended study approach are:

- Technical Assurance – We must assure ourselves that the answers required to questions in aerothermodynamics, thermal protection, large cryogenic system design, vehicle autonomy, maintainability, engine development, and cross range, are soundly based in technical fact before we can proceed with minimum risk. Weight and payload are related in an extremely sensitive fashion. Misjudgement in the technical area can lead to an extremely costly program which will result in failure to attain low dollar per lb payload goals.
- Realistic Performance – The booster and the orbiter must be designed to ensure a payload of satisfactory magnitude. A flexible payload capability will permit launching a variety of satellites, expendables, personnel, experiment packages, and other vehicles into space
- Cost – The space shuttle system must demonstrate that development, acquisition and operational cost, when combined, will result in substantial savings over current operations, while maintaining versatility. This specifically includes the elimination of certain launch vehicles from our inventory and much greater flexibility in operation. Cost tradeoffs must also be attuned to national budget cycles and realistic development times. Costs must be credible for the ambitious tasks planned
- Operations – The ability to reuse a shuttle rapidly and economically is essential if the cost goal of low price payload to orbit are to be attained. Detailed investigations must be made of the entire cycle to include the landing of

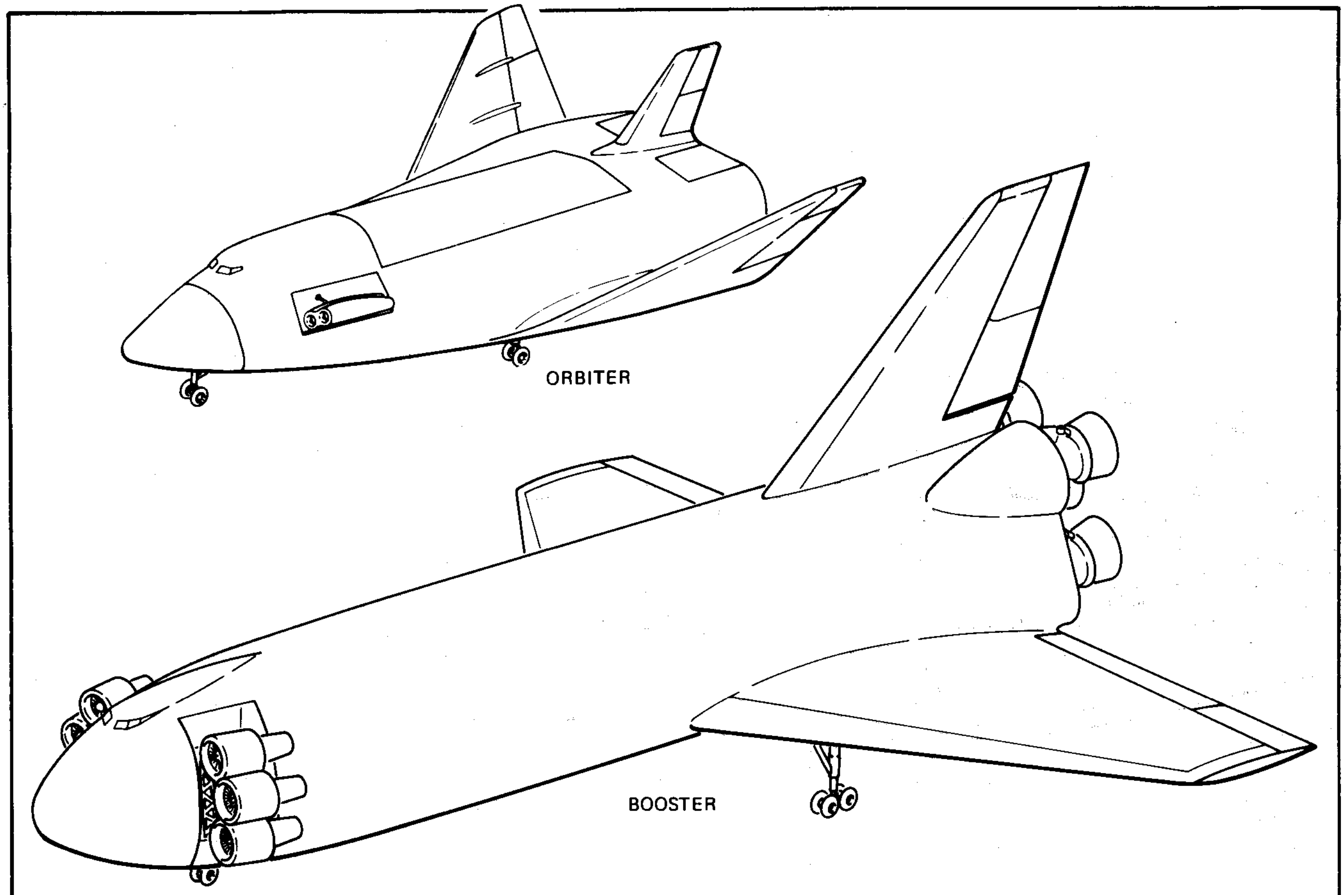


DESIGN 518 DATA

		ORBITER	BOOSTER
LAUNCH	GLOW	3,500,000	
	Height	208 ft 6 in.	
WEIGHT	Stage, lb	637,250	2,862,750
	Burnout, lb	245,850	491,311
	Re-entry, lb	211,000	477,146
	Landing, lb	209,170	443,589
	Empty, lb	174,920	439,653
SUBSONIC LOAD FACTOR		2.5g	2.5g
DIMENSIONS	Length	146 ft 6 in.	208 ft 6 in.
	Span	88 ft 6 in.	142 ft
	Height	48 ft	91 ft
	Plan Area	6100 sq ft	12,330 sq ft
	Ref Area	6100 sq ft	8,460 sq ft
PROPULSION	Main Rocket	(2) 400K	(12) 400K
	Fuel	LH_2	LH_2
	Air Breathers	(4) JTF-22	(8) JTF-22
	Fuel	LH_2	LH_2

	ORBITER	BOOSTER
HYPERSONIC PERFORMANCE		
L/D (at min design)	1.79/20 deg	–
L/D (at max design)	0.78/50 deg	0.76/50 deg
Max Cross Range	1800 n mi	–
SUBSONIC PERFORMANCE		
Return range	–	550 n mi
C_L max usable - (Ref area)	0.56	1.2
L/D_{max} Trimmed	5.1	6.4
Approach Speed	180 kt	152 kt
Approach Angle of Attack	10.7 deg	12.9 deg
Factored Landing Field Length (90°F SL)	9200 ft	7600 ft
Ferry Range	630 n mi	374 n mi
Balanced Field Length (90°F SL)	10,000 ft	8750 ft

Fig. S-9 Design 518 Characteristics



DESIGN 532 DATA

		ORBITER	BOOSTER
LAUNCH	GLOW, lb	6,992,744	
	Height	239 ft 7 in.	
WEIGHTS	Stage, lb	569,318	6,353,426
	Burn-Out, lb	225,318	753,426
	Re-entry, lb	192,103	708,771
	Landing, lb	190,203	610,271
	Empty, lb	165,590	593,765
SUBSONIC LOAD FACTOR		2.5g	2.5g
DIMENSIONS	Length	131 ft 3 in.	222 ft 11 in.
	Span	85 ft	167 ft
	Height	44 ft	91 ft 3 in.
	Plan Area	5500 sq ft	14,884 sq ft
	Ref Area	5500 sq ft	10,420 sq ft
PROPULSION	Main Rockets	(3) 250 kHP	(5) Uprated F1
	Fuel	LH_2	RP
	Air Breathers	(4) JTF22B-2	(6) RB211
	Fuel	LH_2	RP

	ORBITER	BOOSTER
HYPERSONIC PERFORMANCE		
L/D (at min design)	1.70/20 deg	–
L/D (at max design)	0.78/50 deg	0.64/50 deg
Max Cross Range	1650 n mi	–
SUBSONIC PERFORMANCE		
Return Range	–	560 n mi
C_L max usagle (ref area)	0.56	1.2
L/D_{max} Trimmed	4.9	6.4
Approach Speed	181 kt	162 kt
Approach Angle of Attack	11.6 deg	12.2 deg
Factored Landing Field Length (90°F SL)	9400 ft	8300 ft
Ferry Range	517 n mi	406 n mi
Balanced Field Length (90°F SL)	9250 ft	9600 ft

Fig. S-10 Design 532 Characteristics

DESIGN 518 ORBITER	
Lift Off Weight:	637,250 lb
Injection Weight:	245,850 lb
Entry Weight:	211,170 lb
Landing Weight:	209,170 lb
Dry Weight:	174,920 lb
PROPULSION SYSTEMS	
• Main Rocket: 400,000 lb High Pressure	(2)
• On-Orbit Rocket: RL-10 15,000 lb Thrust	(1)
• Air Breathing Engine: JTF-22 Turbofan	(4)
• Attitude Control Rocket: 1,000 lb Thrust	(26)
Trimmed (L/D) Hypersonic ($\alpha = 20^{o}$)	1.79
Trimmed L/D Hypersonic ($\alpha = 50^{o}$)	0.78
Trimmed L/D_{max} (Subsonic)	5.1
Subsonic Approach Velocity (90^{o}F, @ SL)	180 kt
REFERENCE PLAN AREA	6,100 sq ft
Wetted Areas	
• Body Net:	13,220 sq ft
• Base:	320 sq ft
• Tails:	3,000 sq ft
OUTBOARD FINS	
• Exposed Area (2):	1,160 sq ft
• Taper Ratio:	0.245
CENTER FIN	
• Exposed Area:	340 sq ft
• Taper Ratio:	0.493
CONTROL SURFACES	
• Outboard Elevon (2):	350 sq ft
• Rudder:	106 sq ft
• Hypersonic Flap:	700 sq ft
• Transonic Flap:	326 sq ft

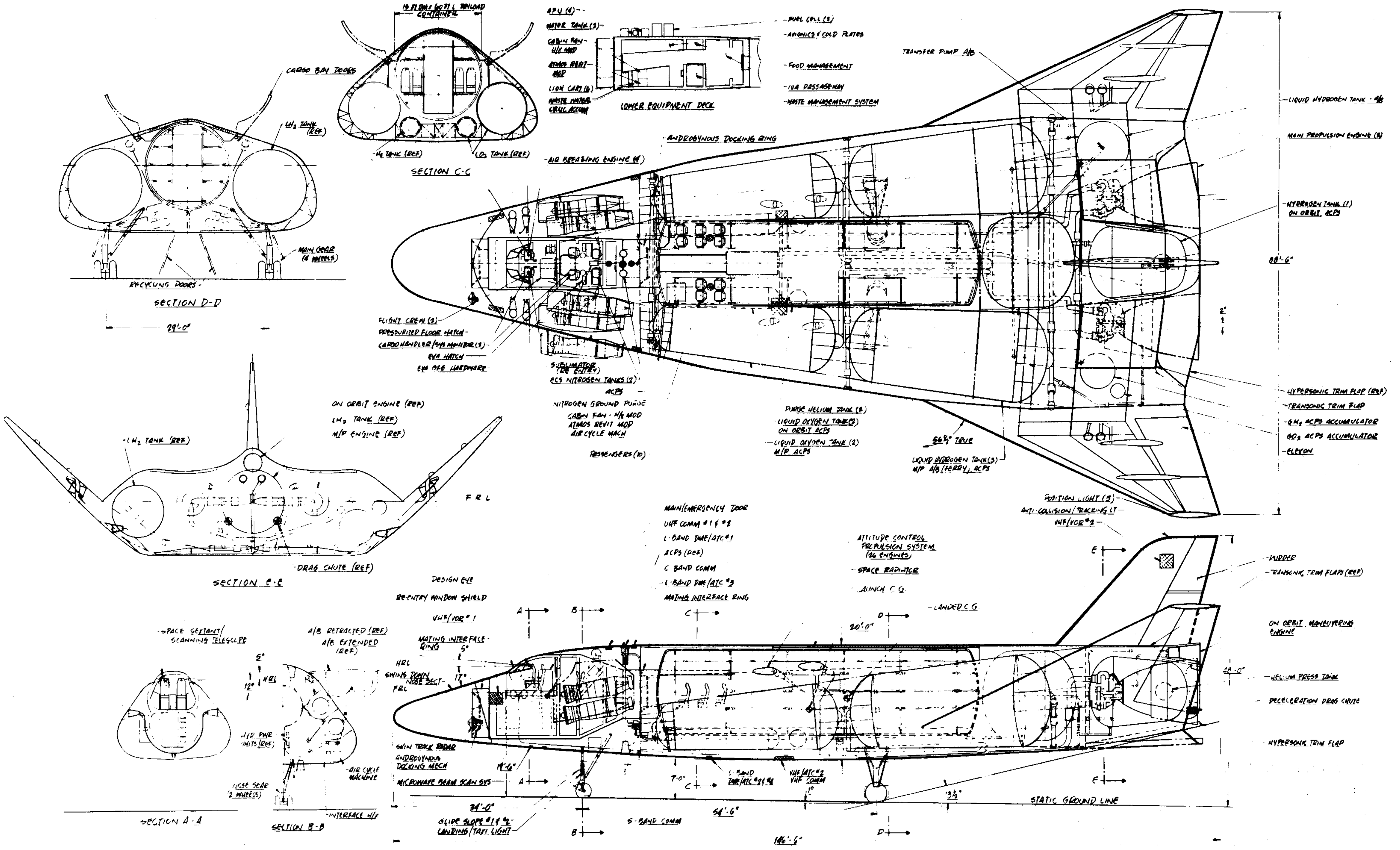


Fig. S-11 Design 518 Orbiter

DESIGN 518 BOOSTER	
Lift-Off Weight:	2,862,750 lb
Staging Weight:	491,311 lb
Landing Weight:	443,589 lb
Dry Weight:	439,653 lb
PROPULSION SYSTEMS	
• Main Rocket: 400,000 lb High Pressure	(12)
• Air Breathing Engine: JTF-22	(8)
• Attitude Control Rocket: 1,000 lb Thrust	(15)
$L/D/\alpha$ @ α_{max} Design (M = 20, 200K ft)	0.76/50 deg
Trimmed L/D_{max} (Subsonic)	6.4
Subsonic Approach Velocity (90°F, @ SL)	152 kt
PLAN AREA	12,330 sq ft
Wetted Area	
• Body:	23,430 sq ft
• Base:	833.3 sq ft
• Wing:	9,580 sq ft
• Tail:	3,050 sq ft
WING	
• Reference Area:	8,460 sq ft
• Exposed Area:	4,720 sq ft
• Taper Ratio:	0.2
• Aspect Ratio:	2.38
FIN	
• Exposed Area	1,500 sq ft
• Taper Ratio:	0.5
• Aspect Ratio:	1.07
CONTROL SURFACES:	
• Outboard Elevon (2):	278 sq ft
• Inboard Elevon (2):	586 sq ft
• Rudder:	520 sq ft

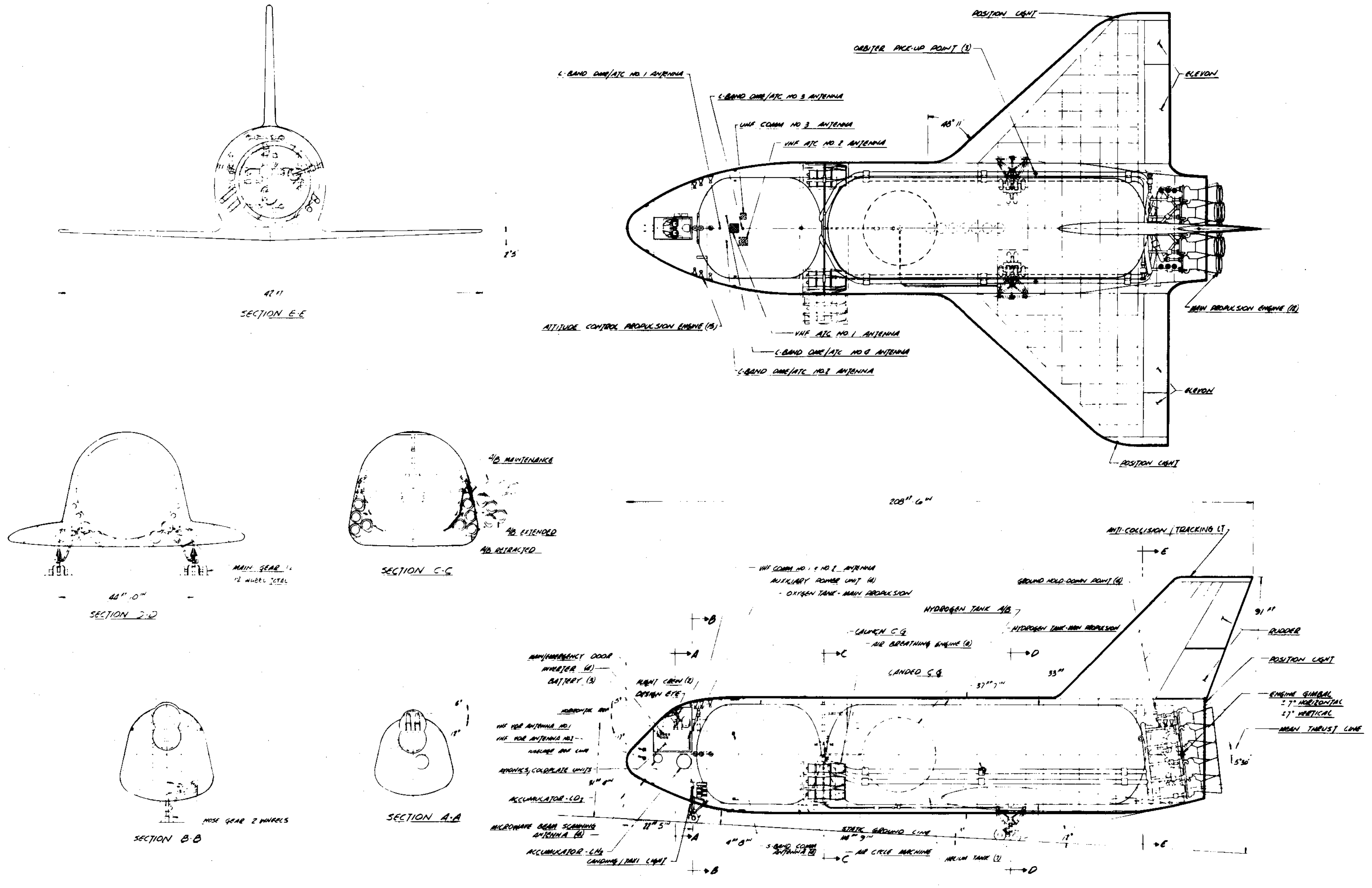


Fig. S-12 Design 518 Booster

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DESIGN 532 ORBITER	
Lift Off Weight:	569,318 lb
Injection Weight:	225,318 lb
Entry Weight:	192,103 lb
Landing Weight:	190,203 lb
Dry Weight:	165,590 lb
PROPULSION SYSTEMS	
● Main Rocket	(3)
● On-Orbit Rocket	(1)
● Air Breathing Engine	(4)
● Attitude Control Rocket	(20)
Trimmed (L/D) Hypersonic (α = 20°)	1.70
Trimmed L/D Hypersonic (α = 50°)	0.78
Trimmed L/D$_{max}$ (Subsonic)	4.9
Subxonic Approach Velocity (90°F, @ SL)	181 kt
REFERENCE PLAN AREA	5,500 sq ft
Wetted Areas	
● Body Net:	11,580 sq ft
● Base:	568 sq ft
● Tails:	3,340 sq ft
OUTBOARD FINS	
● Exposed Area (2):	1,444 sq ft
● Taper Ratio:	0.35
CENTER FIN	
● Exposed Area:	250 sq ft
● Taper Ratio:	0.52
CONTROL SURFACES	
● Outboard Elevon (2):	458 sq ft
● Rudder:	92 sq ft
● Hypersonic Flap:	683 sq ft
● Transonic Flap:	323 sq ft

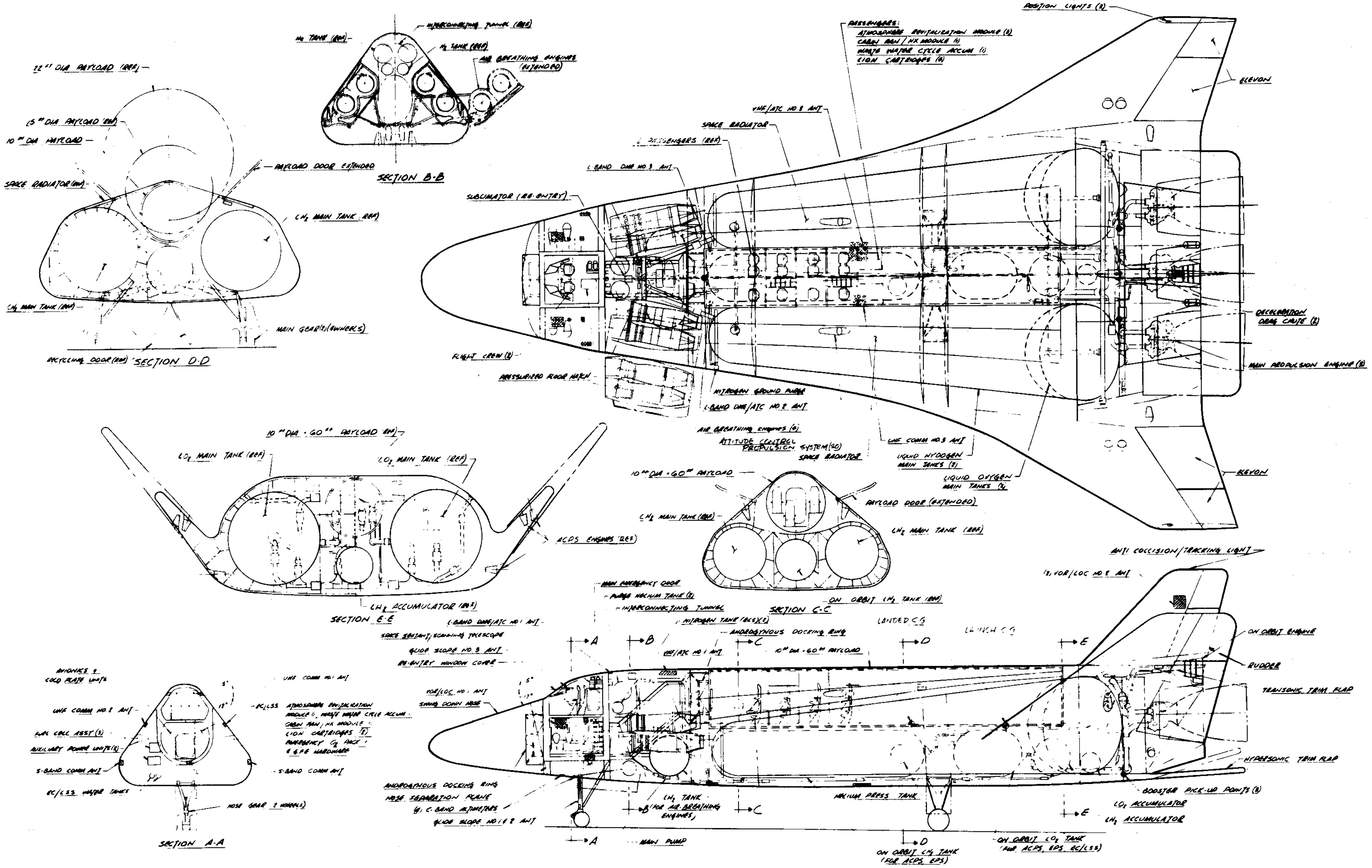


Fig. S-13 Design 532 Orbiter

DESIGN 532 BOOSTER

Lift Off Weight:	6,353,426 lb
Staging Weight:	753,426 lb
Landing Weight:	610,271 lb
Dry Weight:	593,765 lb
PROPULSION SYSTEMS	
• Main Rocket: Uprated F1 (1.8M lb Thrust)	(5)
• Air Breathing Engine: RB211	(6)
• Attitude Control Rocket: 1,000 lb Thrust	(20)
L/D/α @ α_{max} Design (M = 20, 200K ft)	0.64/50 deg
Trimmed L/D_{max} (Subsonic)	6.4
Subsonic Approach Velocity (90°F, @ SL)	162 kt
PLAN AREA	14,884 sq ft
Wetted Area	
• Body:	24,250 sq ft
• Base:	1,162 sq ft
• Wing:	14,500 sq ft
• Tail:	3,400 sq ft
WING	
• Reference Area:	10,420 sq ft
• Exposed Area:	7,000 sq ft
• Taper Ratio:	0.286
• Aspect Ratio:	2.66
FIN	
• Exposed Area:	1,670 sq ft
• Taper Ratio:	0.414
• Aspect Ratio:	1.05
CONTROL SURFACES:	
• Outboard Elevon (2):	374 sq ft
• Inboard Elevon (2):	737 sq ft
• Rudder:	493 sq ft

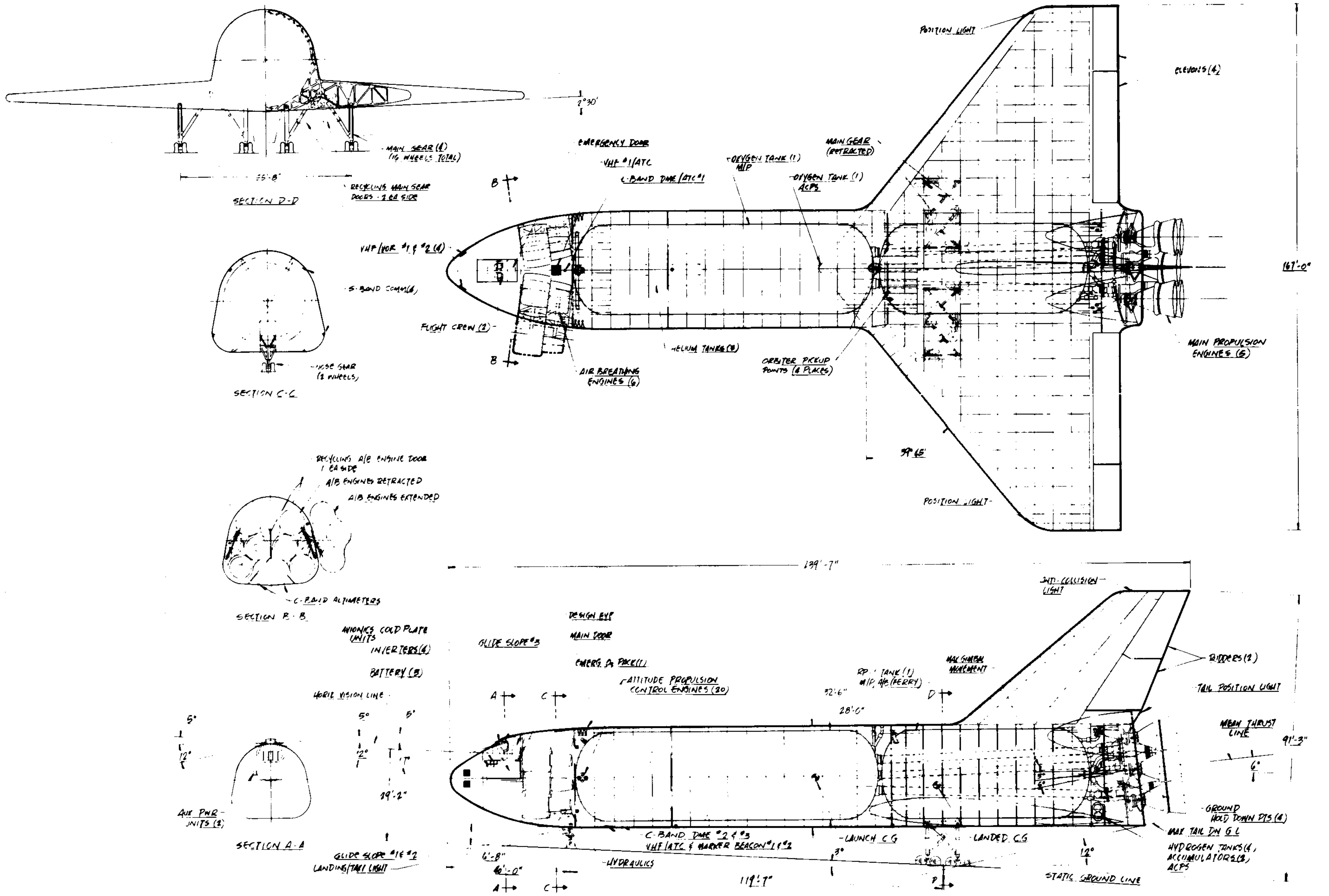


Fig. S-14 Design 532 Booster

GRUMMAN

both stages, ferrying, maintenance and preparation for the next flight. In depth studies must include: a detailed examination of the levels of quality control to be applied to the program, and improvement of manufacturing methods to increase product reliability and minimize checkout costs

- Integration – The design of a two-stage vehicle must ensure that both stages and the ground complex are, in fact, part of one system. The vehicle, in turn, must reflect a balanced solution of its operating requirements. The subsystems involved must be compatible in all modes
- Aircraft/Spacecraft Knowledge – The space shuttle requires the expertise of both aircraft and spacecraft, including reentry capability. The proper blending of these two elements; namely, the low cost of aircraft manufacture, flight operations, maintainability, and reusability, combined with the very high reliability required for space flight, will yield a practical program.

Our Study Approach is shown in Fig. S-15. The key features of our study approach, are briefly summarized below.

- Go-Ahead to Three Months – At go-ahead, we will have summarized results of all prior NASA and DOD efforts with our efforts and reflect them in two primary documents: the Phase B study plan required by the NASA RFP, and an in-house baseline requirements document. The objective of the first three months of study are to establish, with NASA approval, a requirements freeze for Designs 518 and 532 and all operational concepts

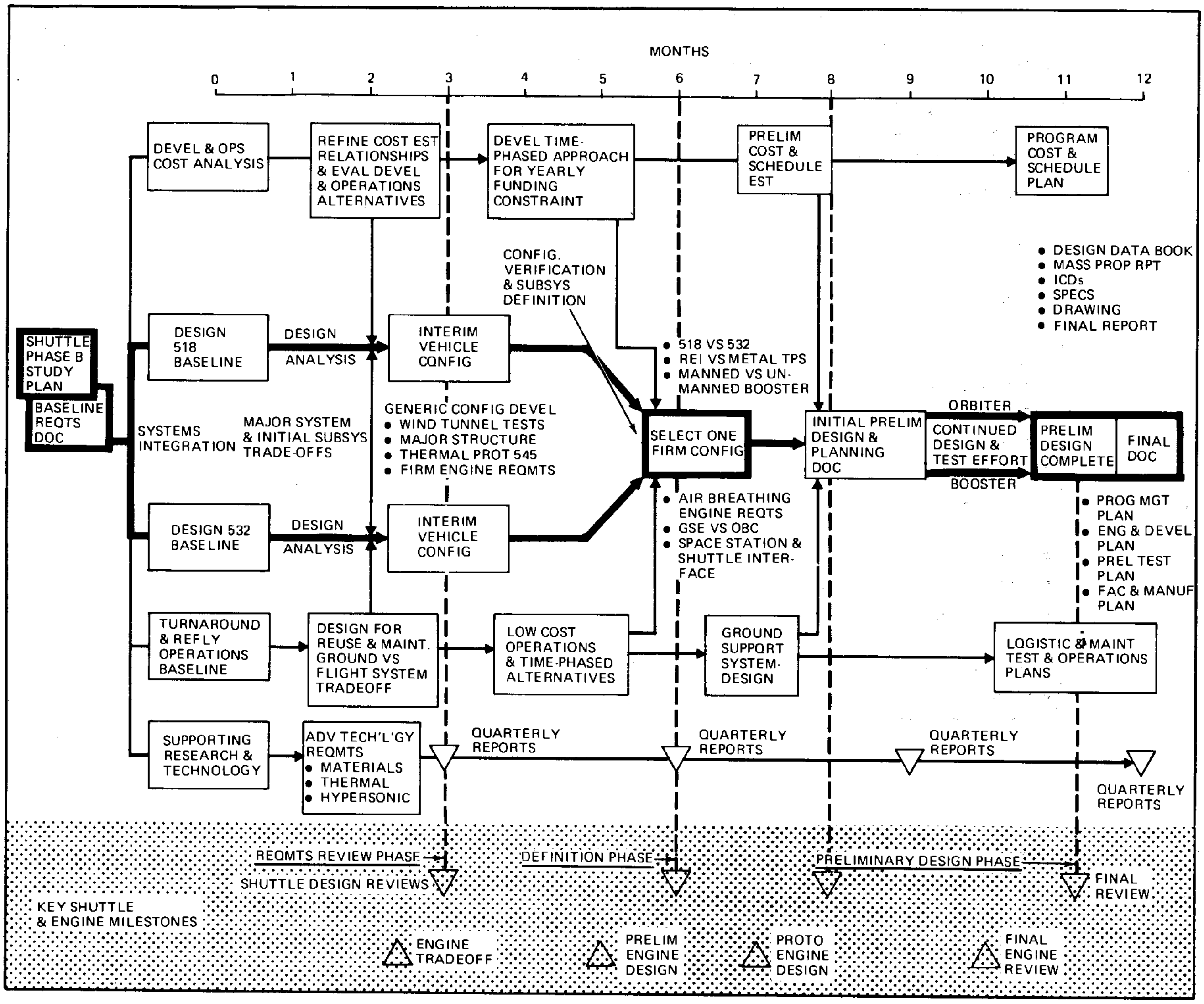


Fig. S-15 Phase B Study Approach and Schedule

- Three Months to Six Months – The objective at the end of this period of the study is to select, with your review and approval, either Design 518 or Design 532 or a cross-pollination of the best features of both designs and proceed with in-depth study. Decisions to examine or work with other alternatives including different development considerations will also be made at the six-month NASA Review
- Six Months to Eight Months – During this period, the majority of the study effort will be concentrated on an in-depth design definition of the single configuration approved at the six-month review. This will be supported by intensive wind tunnel and laboratory scale testing continued to verify design performance and weight and by a systems flight characteristics simulation program. The preliminary program planning material required by NASA at the eighth-month milestone will be developed during this period
- Eight Months to Twelve Months – The period from eight to eleven months will continue the in-depth design effort withconfiguration verification based on wind tunnel and development test and simulation. The preliminary design effort will be completed and reviewed by the end of the eleventh month. The twelfth month of the study is reserved for preparation of the final documentation. All final documentation will be delivered by the end of the twelfth month in accordance with the RFP

The thrust of our study plan is to develop a logically time-phased program which minimizes technical risks, reduces yearly expenditures, provides early operational capability, provides growth, and achieves the low operations cost objective. We will provide NASA operational analyses, design studies, test programs, program plans, mockups, and models, as requested. Additionally, large or full-scale representative sections of the primary structure and thermal protection systems will be proposed for fabrication and test.

STUDY MANAGEMENT

To assure success of this study, Grumman has assigned the management responsibility to proven, experienced senior leadership. Grumman has also assembled a team of outstanding, compatible associates. Grumman has been fortunate in securing associates who supplement Grumman's capabilities and, in particular, bring real competance to the key areas of a Phase B study, i.e., definition of a space shuttle system of low operational cost (Eastern Airlines); definition of a low weight, low cost, reliable thermal protection system, support in defining the avionics systems, and analysis of shuttle economic implications (General Electric); definition on an optimum cryogenic tankage system (Aerojet-General); and definition of an optimum aerodynamic configuration and design of large structures (Northrop).

We and our key associates will be located on the third floor of Plant 25, our Space Center on Long Island. We suggest that NASA appoint a Resident Shuttle Representative to serve with this group. The study effort will be led by Larry Mead, Grumman Vice President and Director, Space Shuttle Program, a leader in aircraft design and development for 29 years. His experience includes vehicles which have demonstrated advanced performance, such as the A-6 all-weather attack system. He led the team which did the conceptual design of the F-14 Mach 2+ air superiority fighter. We believe his most recent experience in creating new concepts of producibility for the F-14 Mach 2+ fighter to ensure low cost and schedule adherence is exactly what is needed in the shuttle program where the technical risk must be minimized to meet realistic levels of funding. Mr. Mead will report through Joe Gavin, Jr., Senior Vice President, Space Programs directly to Lew Evans, President of Grumman.

Mr. Mead will be ably supported by Deputy Director, Tom Kelly, who was the technical leader of the Lunar Module program from beginning to success, and by Assistand Director, Fred Raymes, who has had extensive aircraft/spacecraft experience from X-15/B-70 to Apollo CSM as well as on the space shuttle Phase A studies.

Our overview chart, Fig. S-16, shows the organization which will conduct a sound Phase B study. In specific response to your RFP, we have an Orbiter Team which will receive technical direction from Manned Spacecraft Center and a Booster Team which will receive technical direction from the Marshall Space Flight Center. Howard Wright, Orbiter Manager brings his background as LM Deputy Director; John Karanik, Booster Manager comes from an assignment as Program Manager of the C-2A logistics aircraft. Section 3 of our proposal lists each member of these teams.

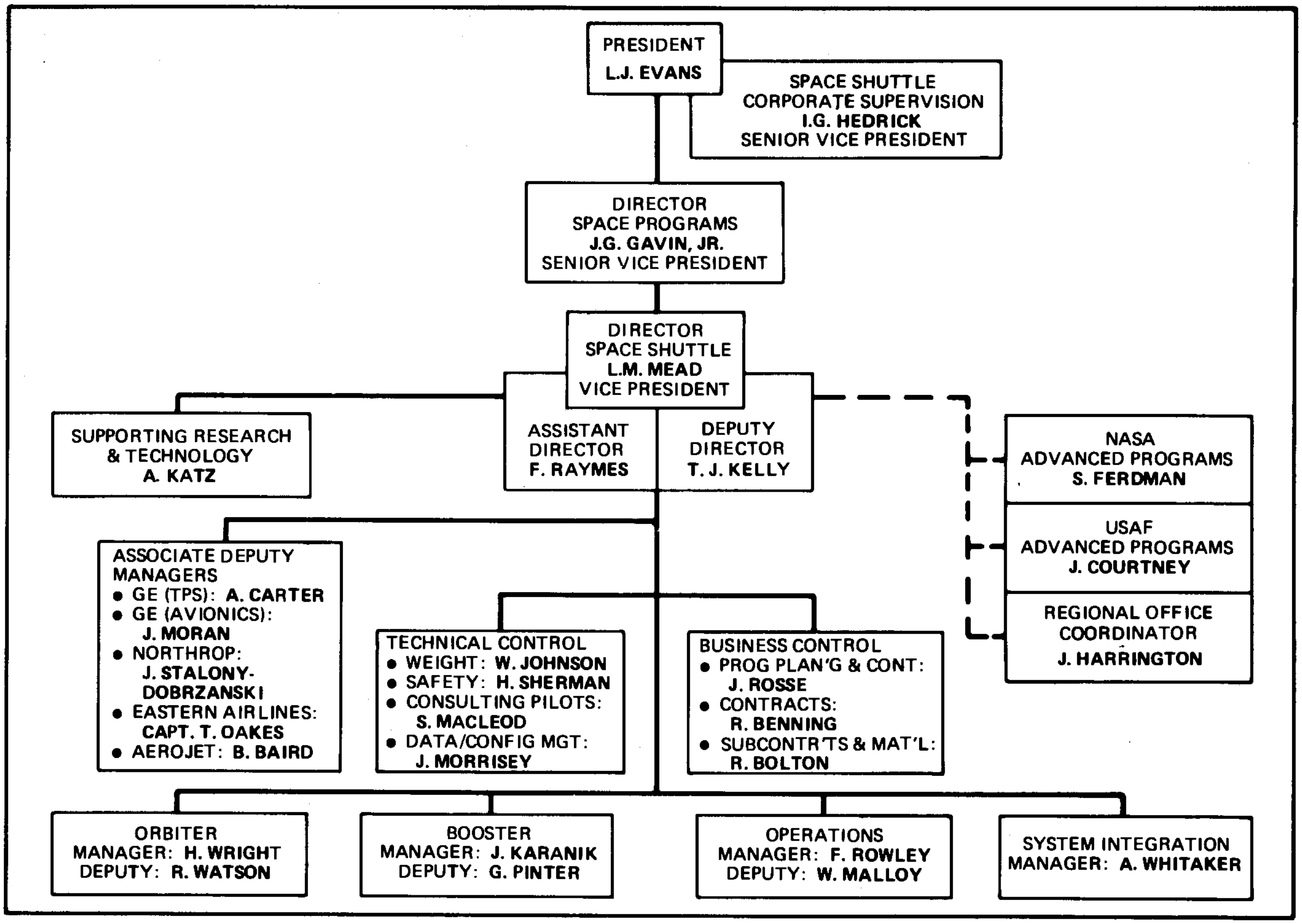


Fig. S-16 Phase B Study Organization Provides Experienced Management

The Operations group will be responsible for minimizing cost in ground turnaround, flight operations, payload handling, maintenance procedures and logistics operations. Fred Rowley, Operations Manager was Director of Flight Test prior to becoming Safety Director on LM. The Systems Integration Manager, Arnold Whitaker, will direct the tradeoff studies required in the "Study Approach," to ensure that the Orbiter, Booster, and Operations are in fact an integrated system. He was Systems Project Engineer for LM responsible for systems analysis and integration, system specifications, mission simulation and system test.

We are aware of the need to surface problems early and force solutions, in many cases applying techniques learned during the Apollo program. Specialists are assigned to the study director to help him do this, especially in Weight Control, Safety, Pilot compatibility, and Planning and Control. The control and discipline internally must be matched in the direction of our associates through clearly defined contractual and technical channels with complete visibility.

Our associates are providing highly qualified and responsible leaders. Dr. John Hutton GE's General Manager, Space Shuttle Programs with over 25 years of scientific leadership in avionics, and Curt Scoville, of General Electric, with a long Air Force career in X20/X24-A/PRIME development, have selected as full-time resident managers Andy Carter for TPS and Jim Moran for avionics. Andy Carter has many years of experience in reentry vehicle design and development; Jim Moran has been engaged for 15 years in computer and complex avionics systems. Jan Stalony-Dobranski of Northrop has a fine reputation gained in aerodynamic design of high performance aircraft and lifting body vehicles for over 20 years. Captain Thomas Oakes of Eastern Airlines, Director of Flight Operations, Advanced Projects, has had 35 years of flying and executive positions in development of new aircraft. His experience will be valuable in determining those areas of airline operations which must be evaluated to minimize shuttle costs in both dollars and time. Bruce Baird of Aerojet-General Corporation has 20 years of experience in the design and development of lightweight pressure vessels. He was program manager of the LM ascent and descent propellant tanks.

EXPERIENCE AND CAPABILITY

Table S-1 lists relevant programs performed by our associates. These are not only outstanding but in many cases unique:

Table S-2 extends the description of associate contractor technical capability into disciplines and operations.

Our Advanced Space Programs organizations are working on systems which will be contemporaries of the earth-to-orbit shuttle and will be its payloads:

- Space station
- Orbit-to-orbit shuttle
- Advanced lunar lander
- Weather satellites
- Military satellites
- Advanced Scientific Satellites
- Advanced Applicaions Satellites
- Manned Mars mission

Additionally, we will have active support from our Advanced Aircraft Systems organizations.

All of Grumman's airborne systems and other manned products have been designed for the user; namely, the pilot, the astronaut, and the operators. Table S-3 lists the programs and vehicles which we have built and key features applicable to the shuttle. These products have been characterized by their ease of operation, their durability, and their reliability. Many of these products have operated aboard Naval aircraft carriers which required rapid servicing and turnaround under very demanding conditions. We have provided specialized aircraft shops, checkout, support equipment and training to support our systems in every conceivable environment.

We have completed Phase B studies for the NASA on the Apollo Extension Systems and Apollo Applications Program in 1968 for MSC and for the Dual-Mode Lunar Roving Vehicle for MSFC in 1970. Additionally, Phase B definition studies have been completed on the F-14 fighter for DOD. Many of our previous programs have also been started with Phase B studies before the time when such formalized program definition activities were in existence.

Having summarized our approach, our plan for conducting the study, and our team, a few words con-

Table S-1 Our Associates' Shuttle Relevant Programs

Aerojet	Eastern Airlines	General Electric	Northrop
• M-1 LH_2 Engine • LM Tanks • Rocket Cases	• Originated Airline Shuttle Concept • Airline Operations	• MBRV - First Maneuverable Re-entry Vehicle • Discoverer Series • MK2 Mk12 Re-entry Vehicles • E-2 Avionics • Nimbus Satellites • Bios Satellites	• HL-10/M_2 F_2 Lifting Bodies • 747 Fuselage - Design & Manufacture • F-5 Fighter

Table S-2 Our Associates' Shuttle Relevant Technical Capability

Aerojet	Eastern Airlines	General Electric	Northrop
• Cryogenic Tankage • Propulsion • KSC Operations • Filament Wound Structures • Large Scale LH_2 Tests	• Flight Operations • Maintenance Operations • Design for Maintainability • Ground Operations • Cargo Handling • Crew & Shop Training	• Re-entry Technology • Thermal Protection Systems • Materials • Electconic Integration • Avionics • Data Management • Flight Control • Launch Operations • Economic Analysis	• Lifting Body Aerodynamics & Test • Large Structures • Proprietary Flight Control System

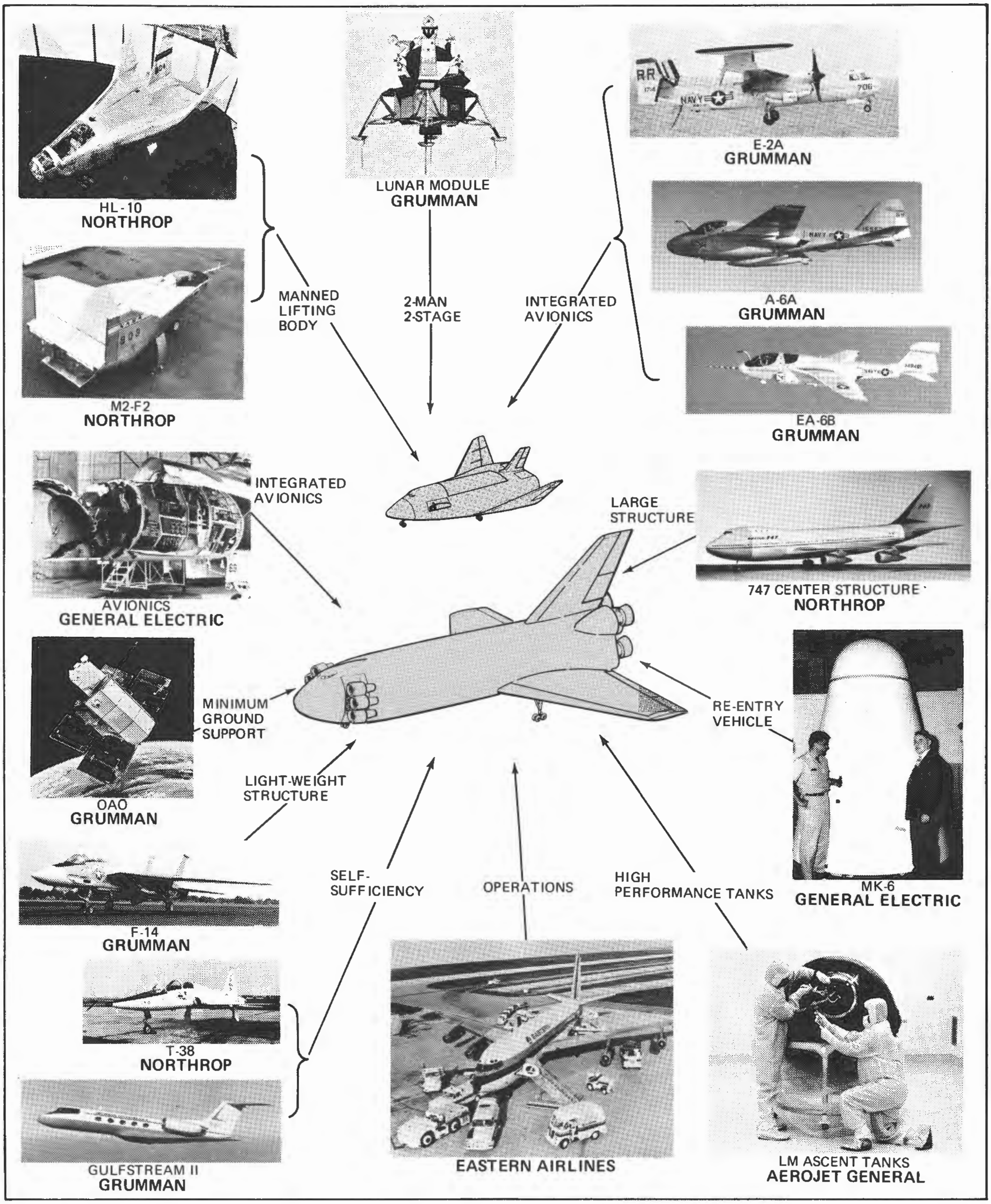


Fig. S-17 Our Products Provide Relevant Experience

Table S-3 Grumman's Recent Programs Apply to the Shuttle

Vehicle	Feature
Lunar Module (Apollo)	–Less than 8% weight growth in five years – Two-stage vehicle – Lunar launch with no ground equipment –8/10 propellant fraction – Conservative light-weight design
F-14 (Mach 2+ Air Superiority Fighter)	– Minimum ground support equipment – Maximum onboard checkout – Mission flexibility – Most advanced producibility – Extensive use of electron beam welding
Gulfstream I and II (Executive Propjet & Jet Transports)	– Self contained aircraft – No external equipment needed – Best corporate jet safety records
A-6A & EA-6B (All-Weather & Tactical Jamming Attack Systems)	– Safety - 45,000 accident free landings aboard Naval aircraft carriers – All weather operations

cerning corporate dedication are in order. The shuttle program is a major national requirement: it is the future of manned space flight. For Grumman, this is a total commitment led by the active involvement of our President, L. J. Evans. Conducting the phase B study and proceeding to carry out the development of a shuttle system are entirely consistent with our history of conservative yet imaginative involvement in the Lunar Module, the Ben Franklin submersible, our executive Gulfstreams, and our service proven military systems. We have a successful history of meeting the technical cost and operational challenges of novel transportation systems. Our associates bring equivalent dedication and proven capability to this enterprise. A composite of our products is shown in Figure S-17.

- We are ready technically
- We are capable financially
- We are convinced of the merit of the program
- We will obtain sound, practical answers
- We have no conflicting interests or demands
- We have proven our ability to work with both NASA and DOD

A brief review of the six sections in the proposal follows:

Section 1 – Configuration

Two baseline configurations are proposed for study. Design 518 is a fully responsive vehicle to the design parameters of the SOW with high and low cross range in a single orbiter. Design 532 is a two-stage fully reusable orbiter/booster combination again providing high and low cross range in a single orbiter. The orbiter has capability for growth in payload weight and volume. The booster uses LOX RP-1 propellants and F-1 engines. Design 532 is aimed at minimizing cost and development risk.

Major design features are discussed. Wherever feasible, booster subsystem components are identical to those used in the orbiter.

Section 2 – Study Approach

The rationale for accomplishing the specific tasks of Section 4 (SOW) are discussed within the framework of a balanced resolution between key technical design and program considerations that impact development, acquisition and operating costs:

- Cross range, high-pressure engine, thermal protection systems, large reusable cryogenic tankage
- Vehicle shape, vehicle size, controls, structural weight, maintainability, payload provisions
- Decoupling booster and orbiter development, advanced engine development, advanced avionics development, funding requirements

Design 518 will be used as the bench mark with which to compare Design 532. At the six month point, one design, possibly based on features from both baselines, will be selected as the basis for further definition to the end of Phase B.

Section 3 – Technical Experience/Capability & Personnel

This section presents the experience and capabilities of Grumman and its associates; General Electric, Northrop, Aerojet-General and Eastern Airlines. The capabilities of this team are described by program and technology disciplines. Major support is provided in the following areas:

- General Electric – reentry thermal protection systems, avionics, and cost analysis
- Northrop – large structures, lifting body aerodynamics
- Aerojet-General – cryogenic tankage large rocket propulsion systems
- Eastern Airlines – airline operations, maintenance and logistics

Resumes of key personnel are included.

Section 4 – Organization & Management
Vice President Larry Mead, Space Shuttle program director, leads an organization that consists of four major elements: orbiter, booster, operations, and systems integration. This closely linked team will perform the analysis and design required to yield a single concept that meets the objectives of performance and cost.

The shuttle system management methods are described and include the work breakdown structure, associated schedules, and other elements of the Phase B Study Plan.

Section 5 – Capability, Experience & Performance
The experience of Grumman as a prime contractor, associate and subcontractor on major space and aircraft programs is detailed in Section 5 in terms of cost, schedule and technical performance. Corporate interest and dedication in relation to space shuttle requirements is described along with our current business background and forecast of Grumman's role in the National space effort. The keys to our corporate health, namely personnel policy, government relationships, small business, and labor surplus area programs are enumerated.

Section 6 – Resources & Schedules
The cost of this Phase B study is detailed in this section. Labor, subcontracting, and material costs are presented along with other normal costing. The basis for our sound financial position to undertake this program is shown with recent sales and' income history. The methodology for the determination of the space shuttle system program cost and schedule is described. The facilities that Grumman and its associates will utilize are listed at the end of this section.

Table S-4 Cross Reference Index

SOW Para.	Subject	Configurations	Study Approach	Tech. Exp./Capab. And Personnel
4.1	System Analyses		2.1	3.1, 3.2, 3.3
	• Programmatic Analyses	1.1	2.1, 2.1.3	3.3.10
4.1.1	System Safety Analysis		2.1.1	3.2
4.1.2	Mission Analysis	1.2	2.1.2	3.3.9, 3.3.10
4.1.3	System Integration	1.2 – 1.8	2.1.3	3.3.10
4.1.4	Operations Analysis	1.3.1, 1.4.1	2.1.4	3.2.5
	• Test Analysis		2.1.4	3.2.5, 3.3.8
4.1.5	System Flight Characteristics	1.3, 1.4, 1.5	2.1.5	3.2.3, 3.3.1, 3.3.2, 3.3.9
	• Wind Tunnel Test Program	1.5	2.1.5	3.3.1
4.1.6	Payload Integration	1.1.2, 1.3.2, 1.4.2, 1.4.4, 1.4.5	2.1.6	3.1, 3.2.2
4.1.7	Aborts	1.2, 1.3.1	2.1.7	3.3.9, 3.3.10
4.1.8	Unmanned versus Manned Booster		2.1.8	3.3.5, 3.3.9, 3.3.10
4.1.9	Reliability & Quality		2.1.9	3.3.7
4.1.10	Maintainability	1.3.2, 1.7, 1.8	2.1.10	3.3.7
4.1.11	Self-Ferry & Ground Handling	1.3.2, 1.3.3, 1.4.2	2.1.11	3.2.2, 3.2.5, 3.3.1
4.1.12	Ground & Flight Systems Optimization		2.1.12	3.2.1, 3.2.2, (3.2.5) 3.3.5
4.1.13	Manufacturability	1.7	2.1.13	3.2.1, 3.2,2, 3.2.4
4.1.14	Operations Site Evaluation		2.1.14	3.2.5, 3.3.10
4.2	Design Analyses		2.2	3.3
	• Mass Properties	1.3, 1.4	2.2	3.2.1, 3.3.6
4.2.1	Structure	1.3.2, 1.3.3, 1.4.2 1.4.3, 1.7	2.2.1	3.3.3
4.2.2	Materials	1.7, 1.8	2.2.2, 2.2.3	3.2.2, 3.2.3
4.2.3	Thermal Protection System	1.5, 1.8	2.2.3.1, 2.2.1	3.2.3, 3.3.2
	• Vehicle Thermal Balance	1.7, 1.8	2.2.3.2	3.2.1, 3.3.2, 3.3.8

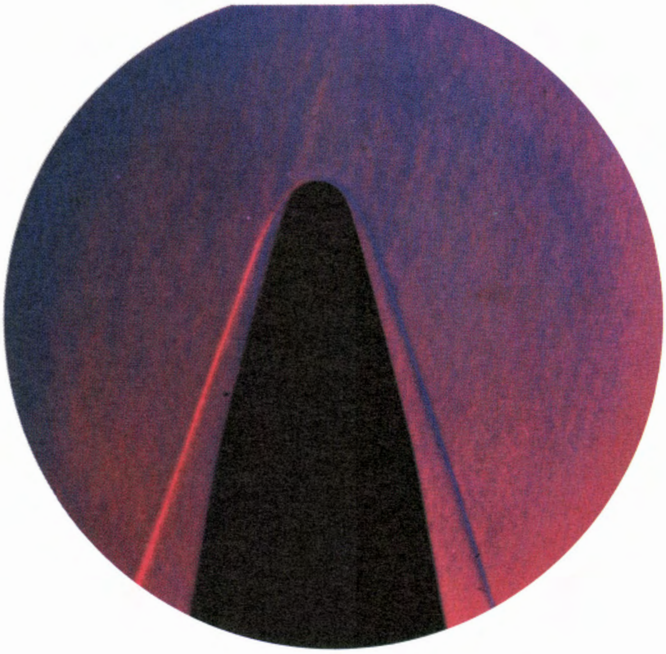
The above Cross Reference Index covers primarily the technical areas of this proposal (Sections 1, 2 and 3).

Table S-4 Cross Reference Index (Contd)

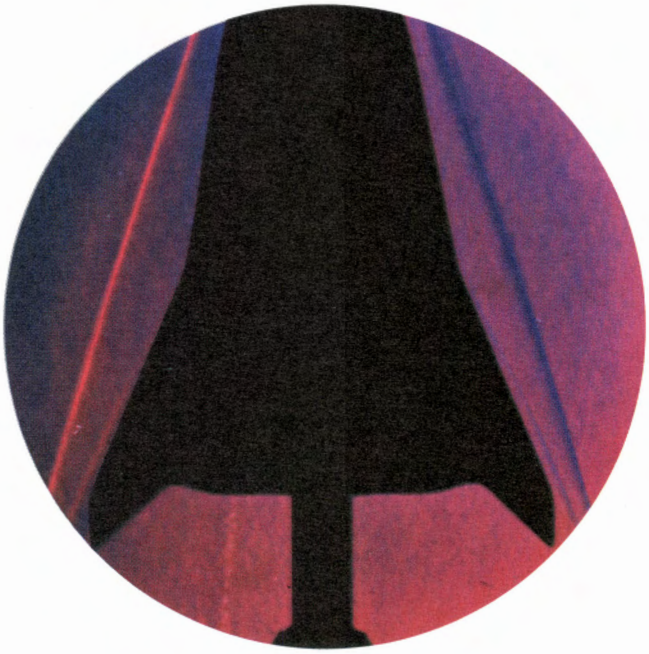
SOW PARA.	Subject	Configurations	Study Approach	Tech. Exp./Capab. And Personnel
4.3	Subsystem Definition	1.3.2, 1.3.3, 1.4.2, 1.4.3	2.3	3.2, 3.3
4.3.1	Propulsion Systems	1.3, 1.4, 1.6	2.3.1	3.2, 3.3.4
4.3.1.1	Main Propulsion System	1.3, 1.4, 1.6	2.3.1.1	3.2.4, 3.3.4
4.3.1.2	Attitude Control Propulsion System	1.3, 1.4, 1.6	2.3.1.2	3.3.4
4.3.1.3	Orbit Maneuvering System	1.3, 1.6, 1.7	2.3.1.3	3.2.4, 3.3.4
4.3.1.4	Air Breathing System	1.3, 1.4, 1.6	2.3.1.4	3.3.4
4.3.1.5	Cryogenic Tankage System	1.3, 1.4, 1.6, 1.7	2.3.1.5	3.2.4, 3.3.3
4.3.1.6	Engines/Vehicle Integration	1.3, 1.4, 1.6, 1.7	2.3.1.6	3.2, 3.3.4
4.3.2	Electro-Mechanical & Integrated Avionics	1.3.2, 1.4.2, 1.4.3, 1.4.5	2.3.2	3.2.1, 3.2.2, 3.3.5
4.3.3	Landing System	1.3.2, 1.3.3, 1.4.3	2.3.3	3.2.1, 3.2.2
4.3.4	Docking System	1.3.2, 1.7.1	2.3.4	3.2.1
4.3.5	Environmental Control & Life Support System		2.3.5	3.2.1, 3.2.2
4.3.6	Power System	1.3.2	2.3.2, 2.3.6	3.2.1, 3.2.2
4.3.7	Crew & Passenger Accomodations	1.3.2, 1.3.3, 1.4.2	2.3.7	3.2, 3.3.5
4.3.8	Launch System Interfaces	1.3.1, 1.4.1	2.3.8	3.2.1, 3.2.5
4.3.9	Flight Control System	1.3.2, 1.4.2, 1.5.1, 1.5.2	2.3.9	3.2, 3.3.5
4.4	Configuration Preliminary Design		2.4	3.1, 3.2
	• Design Drawings		2.4	3.1, 3.2
	• Part I CEI Specifications		2.4	3.1, 3.2
	• ICD's		2.4	3.1, 3.2
	• Mockups		2.4	
	• Scale Models		2.4	
	• Phase B Test Plan		2.4, (4.1.7)	3.1
4.5	Configuration Preliminary Verification		2.5	3.3.1
4.5.1	Structural Test Program		2.5.1	3.3.8
4.6	Supporting Research & Technology		2.6	3.3
4.7	Program Acquisition Plan		2.7	3.1
4.7.1	Program Management Plan		2.7.1	3.1
4.7.2	Engineering & Development Plan		2.7.2	3.1
4.7.3	Operations Plan		2.7.3	3.1
4.7.4	Facilities Utilization & Manufacturing Plan		2.7.4	3.1
4.7.5	Test Plan		2.1.4, 2.7.5	3.1
4.7.6	Logistics & Maintenance Plan		2.7.6	3.1
4.7.7	Program Cost & Schedule Estimates Plan		2.7.7	3.1

The above Cross Reference Index covers primarily the technical areas of this proposal (Sections 1, 2 and 3).

CONFIGURATIONS



Forward
Section
of
Model



Rear
Section
of
Model

Schlieren photographs of Design 518 orbiter at $M = 10.4$, $R_e = 10^6$, $\alpha = 20$ deg (Planform view). No bow shock impingement was observed on fins.

1 – CONFIGURATIONS

Grumman has established two baselines for study in Phase B. The first, Grumman Design 518, responds in all respects to explicit requirements in the Statement of Work. A fully reusable, 3.5-million lb GLOW, two-stage system, Design 518 features a lifting body orbiter with high cross-range potential, delta-wing booster, new high-pressure LH_2/LOX rocket engines in both, and integrated electronics.

The second baseline, Grumman Design 532, also responds to the Statement of Work but from a different point of view and is designed to explore other ways of achieving NASA's technical and program goals for the shuttle system. This baseline is a good starting point for study of programs that might be influenced by annual funding limitations. Design 532, also fully reusable, has a somewhat smaller lifting body orbiter with high cross-range potential with new high pressure LH_2/LOX engines, a booster designed around modified LOX/RP-1 burning F-1 engines, and first generation integrated electronics. It weighs 6.92 million lb at liftoff, but is similar in size and empty weight to Design 518. Reducing the number of technical development risks was a fundamental driver in the synthesis of Design 532. Two time-phasing possibilities have been specifically addressed in developing the 532 baseline – using an interim orbiter rocket engine and employing first generation electronics in a system that can grow to second generation hardware. Design 532's orbiter has been sized so that it can be flown using J2S engines for early operations, and first generation integrated electronics as cited above.

We expect to capitalize on comparisons that can be made between Designs 518 and 532 in developing results that will identify for NASA, design combinations and program options open for achieving their shuttle objectives. Grumman's study approach proposes to carry Designs 518 and 532 through the first 6 months of the study, at which point the best features of the two may be combined with programmatic alternatives of phased implementation into a single design/development concept and approach.

In the following paragraphs, we will explore in detail Designs 518 and 532. Highlights of our discussion will be: (Subsection number shown)

- Baseline Foundations – A short review of orbiter configuration rationale and of "baseline" programs used to select specific features of 518 and 532. (1.1)
- Baseline Characteristics Summary – Tabular comparisons of Designs 518 and 532 including some early configuration and growth possibilities (1.1.3)
- Mission Requirements and Sizing – A summary of mission and vehicle sizing (delta V allocations) for the baselines (1.2)
- Design 518 Description (1.3)
- Design 532 Description (1.4)
- Technical Discussions of Baseline Aerothermodynamics (1.5), Propulsion (1.6), Structure (1.7) and Thermal Protection (1.8)

1.1 BASELINE FOUNDATIONS

We believe that national interest requires a shuttle system ultimately capable of cross-ranging for distances of at least 1500 n mi. The shuttle system can be built around orbiter designs that are aerothermodynamically capable of 1500 n mi, even when early development is restricted to providing lesser distances. For both study baselines, Grumman has selected an orbiter configuration with inherent capability for attaining 1500 n mi cross range. As shown in Fig. 1-1, this configuration evolved from considerations of both low and high cross-range performance requirements.

A single orbiter configuration that encompasses both high and low cross range offers early development and performance growth in the same basic package. It lends itself to phased development of cross-range capability within a single system as materials technology and operating experience grow with time. Furthermore, both versions of the orbiter may be operated on a regular basis – one with high cross range, the other with greater payload at low cross range. Both versions can operate routinely with other elements of the shuttle system.

We have chosen to investigate the effects of high and low cross range in the same basic configuration, as indicated in the Statement of Work, so that we can isolate estimates of cost and risk differentials to a single cause (reentry). System operating concepts and designs for all other phases of the mission

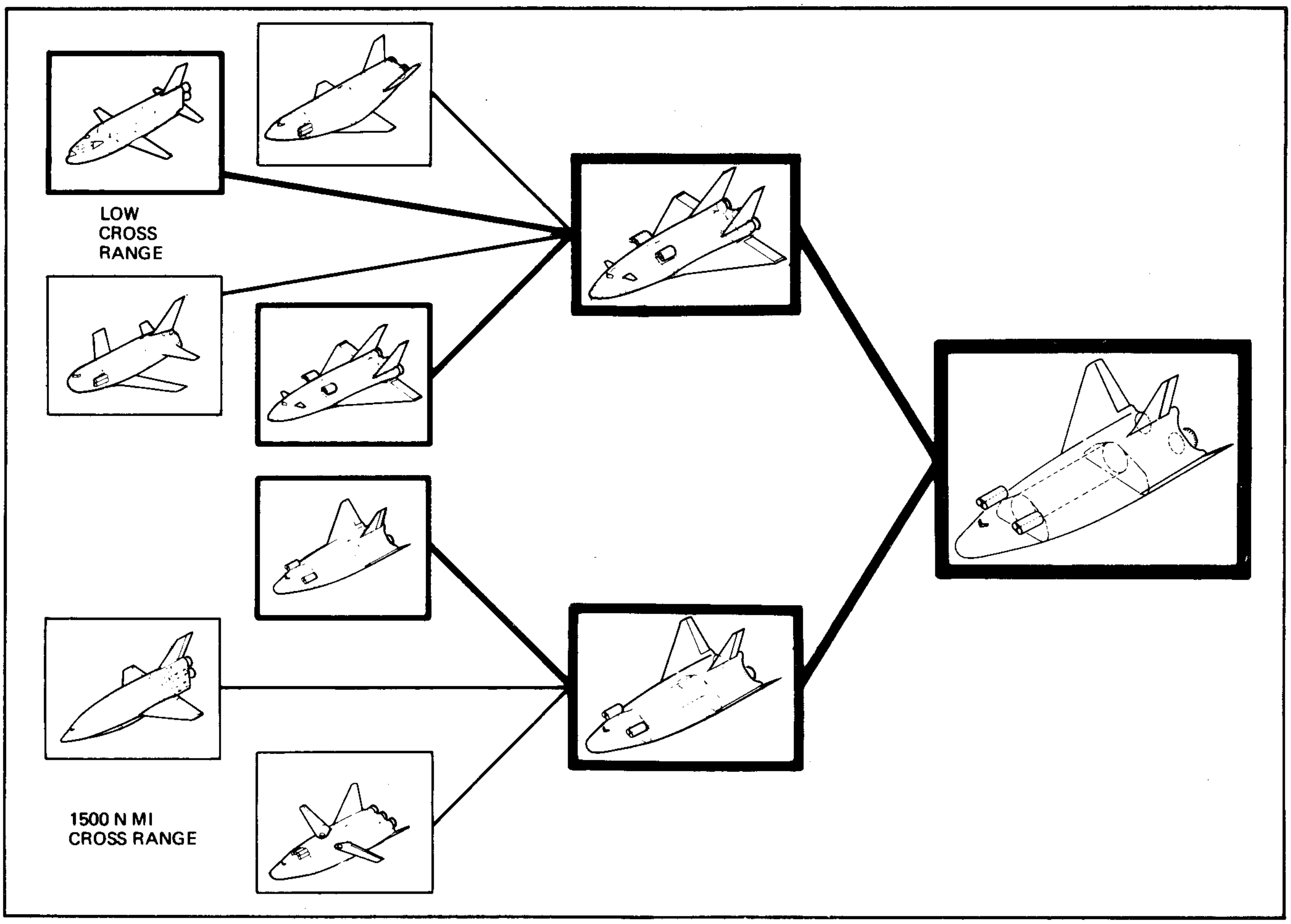


Fig. 1-1 Configuration Selection. *High and Low Cross-Range Orbiter Candidates Lead to Delta Wing and Lifting Body. Lifting Body Selected to Provide Low and 1500 n mi Cross-Range in One Basic Shape.*

will be identical unless a design change for cross-range forces a related change. Cost and risk differences can easily become blurred if operating concepts and design optimizations are different for other phases of the mission than those required for reentry.

1.1.1 Design 518 Program "Baseline"

Since we plan to study both design and program options, we must establish program "baselines" as well as design baselines. Design 518 has been developed to conform to NASA requirements in all areas of design and operations. The program for which Design 518 has been generated is strictly in accordance with NASA's schedule, and our study of this design will evaluate consequences on cost and schedule risk of concurrent developments of two major new airframe systems, orbiter and booster, with large reusable cryo tankage, new high-pressure rocket engines, and integrated avionics. Design 518's line of study is the reference against which the technical and program options being studied in Phase B for Design 532 can be judged for value. Design 532's three-step program is discussed next.

1.1.2 Design 532 Program "Baseline" – Low Annual Cost

Our second study line is based on a simple, but significantly different premise – What can be done to ensure a lower risk, lower annual cost, and earliest possible flight date? A high spending rate probably will be needed to carry on simultaneous development of an orbiter, a booster, and their new high-pressure engines and fully integrated electronics. Studies show that this can be reduced by:

- Undertaking fewer areas of technical risk at one time
- Spacing developments for the several new high-cost elements needed in a final system
- Making more use of proven Apollo technology, hardware and, particularly, ground facilities.

The baseline program for Design 532 is a three-step process beginning with: (A) low cross-range operational flights using J2S engines in the orbiter to achieve earlier IOC within annual cost ceilings; continuing to (B) a full-performance system in which the orbiter is re-engined with new high-pressure engines and maximum payload and cross-range capability is achieved for the two-stage system; and growing to (C) increased system utility and mission flexibility by adding capability for outsized payloads and for reaching higher and more inclined orbits with greater payload weight. This three-step process, described more fully in Section 2, is based on lowering annual funding through sequential development of costly and risky system elements, and by using existing facilities and proven hardware to accomplish interim steps.

Grumman's Design 532 baseline is a good starting point for studies of "low annual cost" programs because this design can achieve NASA's program objectives fully in its final configuration, and can attain important, useful, interim capabilities in its initial and intermediate configurations. Our Design 532 system has the performance elements to allow the study of early flight with interim engines, and development of the system through several steps of increasing performance to its ultimate capability.

In addition to baselining Design 532 so that consideration of phased development is convenient, we have included several interesting design concepts that can expand its utility and versatility in growth versions; for example, our "flatbed" payload concept with future capability for delivering payloads up to 22 ft in diameter, and our provisions for an expendable kick-stage that could eventually provide for payload weights of more than 70,000 lb and/or increased delta V for reaching more difficult orbits.

Some of these concepts are equally applicable for Design 518 but are not baselined as a starting point for that system so that meaningful comparisons can be made.

For both of our designs we will make comparisons of the technical risks and program costs for aquiring high cross-range capability in the early development, and will identify the differences in timing required for supporting technology as a consequence of an early or late high cross-range capability decision.

1.1.3 Baseline Characteristics Summary

Baseline system characteristics for Designs 518 and 532 are compared for easy reference in Table 1-1. Also shown for reference are interim and growth capabilities that might be provided for Design 532 using a typical phased development.

These designs are starting points. Each has features selected because they are fertile for studies of program risk and cost, and are not necessarily expected to be most efficient in a final system design. Our designs have been detailed where necessary to provide:

- A complete design – all requirements have been addressed
- Greater confidence in sizing and weight estimates
- More insight into detailed subsystem areas

Section 2 describes what we will do in the study to produce a shuttle system preliminary design.

1.2 MISSION REQUIREMENTS & SIZING

1.2.1 Design Reference Mission Flight Profiles

As specified, the logistics resupply of a space station with a total space shuttle self-sustaining lifetime of 7 days was used as a design reference mission (DRM) to ensure a balanced set of mission requirements for designing the vehicles. Flight profiles encompassing the mission phases from launch to landing are shown for both Design systems in Fig. 1-2.

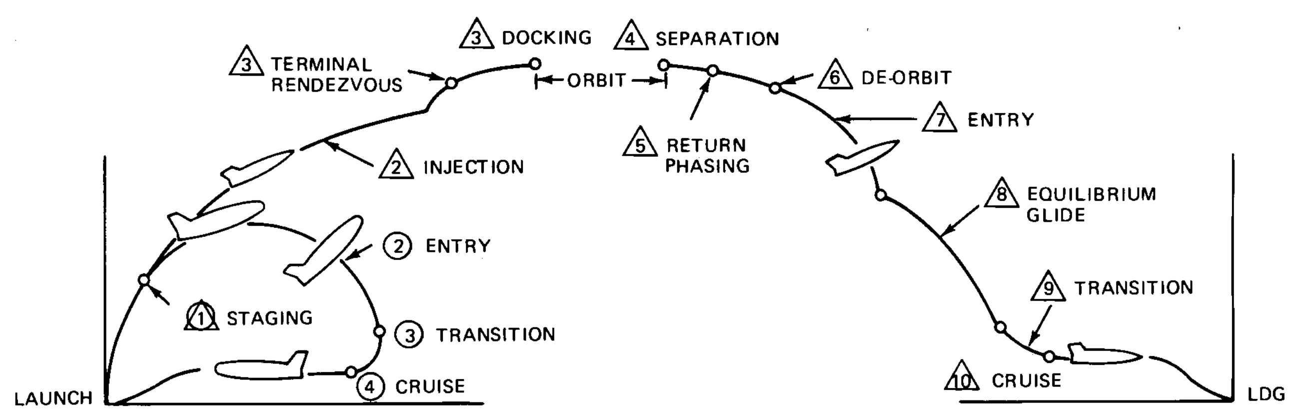
The space shuttle is launched vertically and booster/orbiter staging occurs at an altitude of about 280,000 ft for both Designs 518 and 532. After staging the booster rolls 40 deg, establishes a flight path angle of 0 deg and the initial angle of attack of 50 deg. Angle of attack modulation limits loading to 3g or less. The orbiter for both designs continues into a 50x100 n mi parking orbit-coplanar with the space station. It then performs a phasing maneuver and coelliptic rendezvous, orbits for 7 days, reenters, and lands as shown in Fig. 1-2.

1.2.2 Sizing

The Grumman vehicle sizing program from which Designs 518 and 532 were formulated is based on statistical weight/volume estimating methods, supplemented by analytical weight equations and coupled with the performance characteristics derived from trajectory studies. The program is used

Table 1-1 Baseline System Characteristics Summary

	Design 518 Baseline		Design 532 Low Annual Cost Devel	Design 532 Baseline		Design 532 Growth
ORBITER						
● Cross Range, n mi	Low	1500	Low	Low	1500	Same as Baseline
● Cargo: Payload Weight, lb Del'v'd/Returned	32K/32K	35K/35K	12.8K/12.8K	22.6K/22.6K	25.9K/25.9K	76.5K/25.9K
Payload Size and Carry (Max)	15D x 60 Internal	15D x 60 Internal	15D x 60 Flatbed	15D x 60 Flatbed	10D x 60 Internal	22D (Del'v'd) Flatbed/15D (Returned)
● Thermal Protection: Type	Metallic HS-188	REI	Metallic HS-188	Metallic HS-188	REI	
Weight	31,860 lb	29,280 lb	29,660 lb	29,660 lb	26,660 lb	Same as Baseline
● Main Rocket Engines: Type	2 x 400K (New High P_c)		3 x 206K (J2S)	3 x 250K (New High P_c)—		—●
Propellants	LH_2/LOX		LH_2/LOX	LH_2/LOX—		—●
● On-Orbit Engine: Type	RL 10 (15K)		●—	RL 10 (15K)—		—●
Propellants	LH_2/LOX		●—	LH_2/LOX—		—●
● Attitude Control Propulsion: Type	26 x 1000 lb (High P_c)		●—	20 x 1000 lb (High P_c)—		—●
Propellants	GH_2/GOX		●—	GH_2/GOX—		—●
Aux Equipt	High Pressure Turbopump		●—	High Pressure Turbopump—		—●
● Air Breathing Engines: Type	4 x JTF-22		●—	4 x JTF-22—		—●
Propellants	LH_2		●—	LH_2—		—●
● Avionics	Integrated (FO/FO/FS)		●—	First Generation (FO/FS)		2nd Gen (FO/FO/FS)
● Crew and Passenger Provisions	4 Crew in Cabin + 10 Pass.		●—	2 Crew + 12 Passengers—		—●
● Stage Weight, lb	637,250		559,468	569,318		620,000
BOOSTER						
● Main Rocket Engines: Type	12 x 400K (New High P_c)		●—	5 x 1800K F-1 (Upgraded)—		—●
Propellants	LH_2/LOX		●—	LOX/RP-1—		—●
● Attitude Control Propulsion: Type	15 x 1000 lb (High P_c)		●—	20 x 1000 lb (High P_c)—		—●
Propellants	GH_2/GOX		●—	GH_2/GOX—		—●
Aux Equipt	High Pressure Turbopump		●—	High Pressure Turbopump—		—●
● Air Breathing Engines: Type	8 x JTF-22		●—	6 x RB211—		—●
Propellant	LH_2		●—	RP-1—		—●
● Avionics	Second Generation (FO/FO/FS)		●—	First Generation (FO/FS)		2nd Gen (FO/FO/FS)
● Crew Provisions	2 Crew		●—	2 Crew—		—●
● Stage Weight, lb	2,862,750		●—	6,353,426		6,350,000
Oversized Payload Kick Stage						230,000 lb 3500 Ft/Sec ΔV
Gross Lift-Off Weight, million lb	3.5		6.91	6.92		7.2
Ground Handling Baseline	●—		Use of Apollo GSE—	—●—		—●



Design 518					Design 532				
Traj Pt	V, ft/sec	Alt, K-ft	Down Range Launch/Land, n mi		Traj Pt	Vel, fps	Alt, K-ft	Down Range Launch/Land, n mi	
Booster					Booster				
①	11,400*	280	165		①	11,600*	280	150	
②	11,400*	330	215		②	11,600*	330	215	
③	3,500*	100	510		③	3,500*	100	510	
④	500*	40	510		④	500*	40	510	
Orbiter					Orbiter				
△1	11,400*	280	165		△1	11,600*	280	150	
△2	25,835	310	770		△2	25,835	310	750	
△3	25,000	1,640	–		△3	25,000	1,640	–	
			CR = 200	CR = 1500				CR = 200	CR = 1500
△4	25,000	1,640	–	–	△4	25,000	1,640	–	–
△5	24,990	1,640	–	–	△5	24,990	1,640	–	–
△6	24,400	1,640	9,600	14,200	△6	24,400	1,640	9,600	14,200
△7	25,980	400	–	–	△7	25,980	400	–	–
△8	25,980	250	2,400	7,000	△8	25,980	250	2,400	7,000
△9	3,500*	100	50	50	△9	3,500*	100	50	50
△10	500*	40	10	10	△10	500*	40	10	10

*Relative V - All Others Inertial

Fig. 1-2 Flight Profiles. *Velocity, Altitude and Downrange Characteristics of all Mission Phases from Launch to Landing are Indicated.*

extensively in the early evaluation of design and mission interactions and reveals the effects they may have on the overall design approach. Design weights are used to improve the results as they become available. An outline of the vehicle sizing methodology is shown in Fig. 1-3.

Using this method of analysis, the total shuttle ideal incremental delta V was apportioned between the orbiter and the booster both with fixed sized engines. These results, shown in Fig. 1-4, represent the parametric families of Design 518 and 532. The orbiter velocity indicated includes gravity and drag losses. Although lower weights may be achieved by going to higher orbiter delta V, it would be at the expense of lower orbiter thrust-to-weight. Decreases in thrust-to-weight ratios were limited by acceptable levels of abort safety.

DESIGN 518 – The critical abort case for Design 518 sizing is the loss of one engine at orbiter ignition; the thrust-to-weight remaining must at least be sufficient to enable the vehicle to reach a low orbit and still have propellants remaining for deorbit. For Design 518 orbiter with two 400,000-lb engines, the one-engine-out case sizes the orbiter at

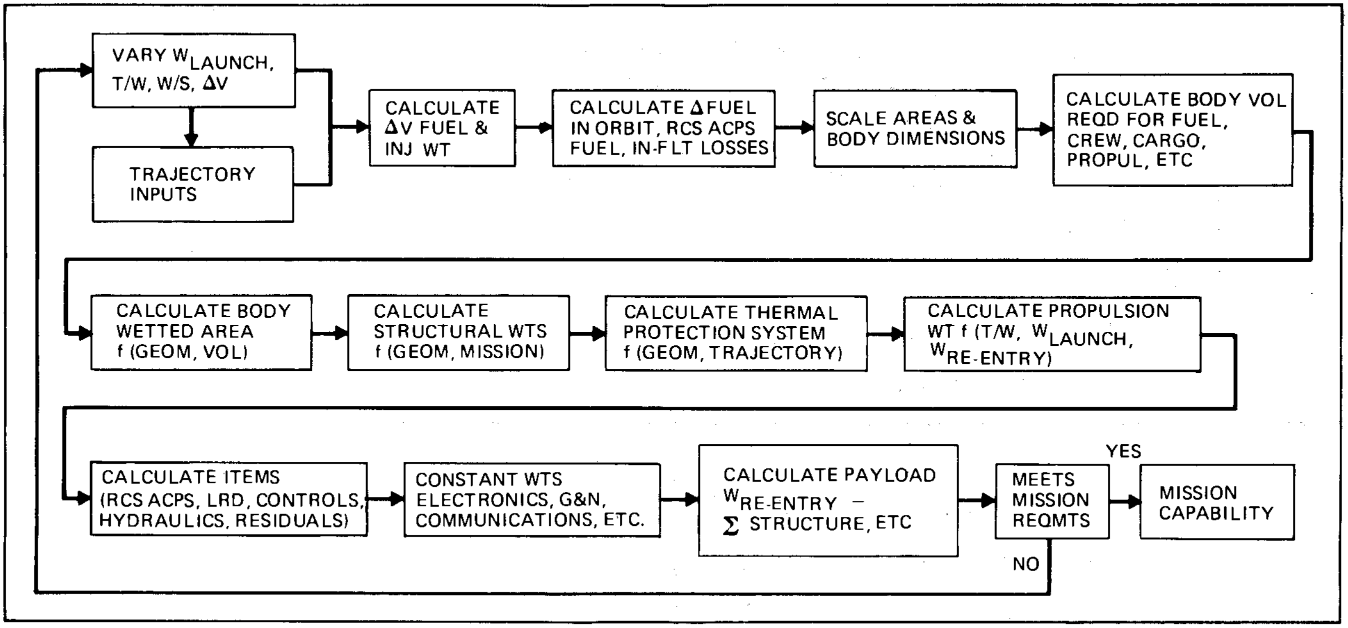


Fig. 1-3 Vehicle Sizing Methodology

637,000 lb with the resulting system weight shown. This orbiter size results in a stack GLOW of 3.5 million lb and a booster T/W of 1.37 with 12-400K thrust engines. In sizing, the boost acceleration limit was held to 3g. Further reduction in delta V losses could be achieved but at the expense of higher dynamic pressure and heating rates.

DESIGN 532 – A different condition is critical for Design 532 because of its three-engine installation —where two out of three remaining engines maintain a safe thrust-to-weight ratio. Abort at sea level is the critical case. In sizing the baseline Design 532, abort capabilities were considered for both the high-pressure (250K thrust) engine configuration and the J2S (206K thrust) engine configuration. Because of the lower thrust and I_{sp} of the J2S, its characteristics proved critical for sizing. To maintain a desired sea level thrust-to-weight margin of at least 1.2 with 15 percent emergency performance level, the orbiter gross weight is limited to 560,000 lb as shown by the cutoff limit line on Fig. 1-4. At this size with one engine out, the 532 orbiter has adequate propellant for injection and return to earth. As a result of these considerations the orbiter has 13,700 fps delta V, dictating a large booster and GLOW of 6.92M lb. The 532 booster with its uprated F-1 engines provides limited flexibility in the choice of engine numbers. Five engines provide a satisfactory T/W=1.3.

The resulting orbiter-booster combination serves as a suitable starting point for our Phase B baseline.

Rocketdyne, however, indicates that the J2S thrust could readily be increased to match the high-pressure 250K level. For this case a more optimum delta V balance could be achieved, with a corresponding reduction in GLOW. This will be investigated.

In the initial stages of design when absolute values are uncertain, partial derivatives or sensitivities, valid for the design points, are used to channel the design effort in directions promising the greatest gain. Sensitivities of pertinent parameters for both Designs 518 and 532 are shown in Table 1-2.

1.3 DESIGN 518 DESCRIPTION

1.3.1 Stacked Configuration

Prelaunch techniques and facilities currently used at KSC were used as operational baselines for developing the vehicle baselines. Personal safety during emergency pad conditions is provided by existing escape facilities and the rapid crew and passenger egress inherent in the configuration. The 212-ft high assembly is inclined 3 deg to the vertical at launch for proper alignment of thrust vector and liftoff c.g. as shown in Fig. 1-5. Weights are shown in Table 1-3. The mated configuration offers ready access to payload and crew compartments, and can be accommodated by a modified LC39 mobile launcher. The number of swing arms and GSE attachment points are reduced to the minimum necessary for safety and mandatory prelaunch servicing.

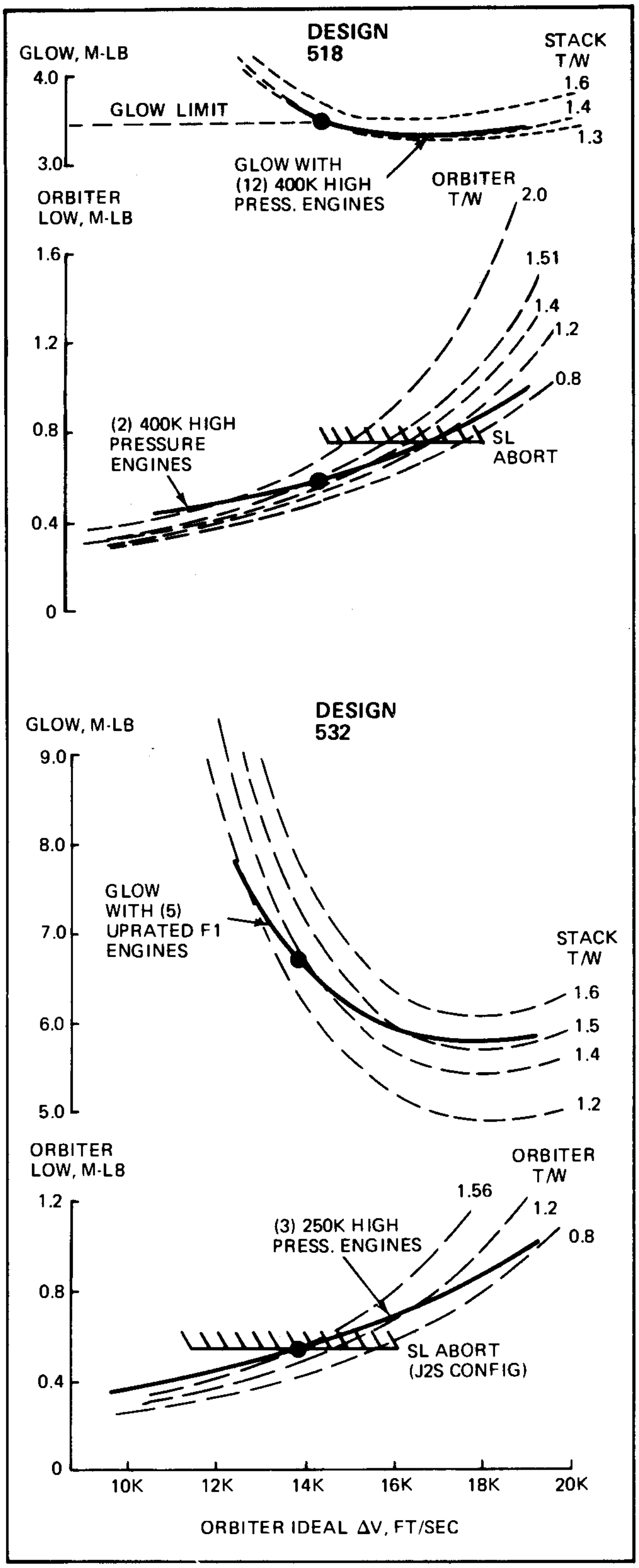


Fig. 1-4 Effects of Fixed Engines on Vehicle Size. *Fixed Engines Limit Vehicle Optimization.*

Table 1-2 Sensitivity Summary

Variable, unit	Δ Glow, lb/unit change Design 518	Design 532
● Payload, lb	45.5	120.8
● I_{SP} Orbiter, sec	-15,700	-37,600
● ΔV Orbiter, ft/sec	493	1141
● Cargo Volume, cu ft	75.3	229.5
● Contingency, Orbiter %	60,200	147,000
● Orbiter Wt, lb	5.55	12.7
● I_{SP} Booster, sec	-15,750	-94,350
● ΔV Booster, ft/sec	472.5	1729
● Booster Volume, cu ft	6.32	23.8
● Contingency, Booster %	39,200	141,350

The remaining launch pad interfaces provide crew and passenger ingress/egress, fueling, payload access, and vehicle hold down. The major modifications required to the launcher are: 1) elevation of the hold down arms so that vehicle-launcher clearance is improved; 2) relocation and modification of swing arms; 3) additional LH_2 line via the service mast. Fig. 1-5 lists the vehicle-ground interfaces which will be studied in detail in Phase B for cost effectiveness. The feasibility of restricting final countdown hardlines to LOX and LH_2 topping lines will be established. The standby status at launch minus 2 hrs assumes: 1) LH_2 tanks are thermally conditioned; 2) LH_2 and LOX are loaded simultaneously.

The two stages are mated in a belly-to-belly arrangement with the orbiter nose 166 in. aft of the booster nose. This was selected rather than a piggyback, tandem, back-to-back, or co-axial (split-body booster) configuration because:

- The heaviest structure in both vehicles is on their underside. In the orbiter, the interstage attachments are at the rear thrust structure and the forward cargo bay bulkhead. In the booster, the orbiter inertia load is introduced close to the main landing gear structure. Taking advantage of this inherent strength for mating minimizes the structural weight penalty for both vehicles
- This arrangement permits simple booster body, wing and tail shapes, minimizes the possibility of recontact during separation, and permits orbiter

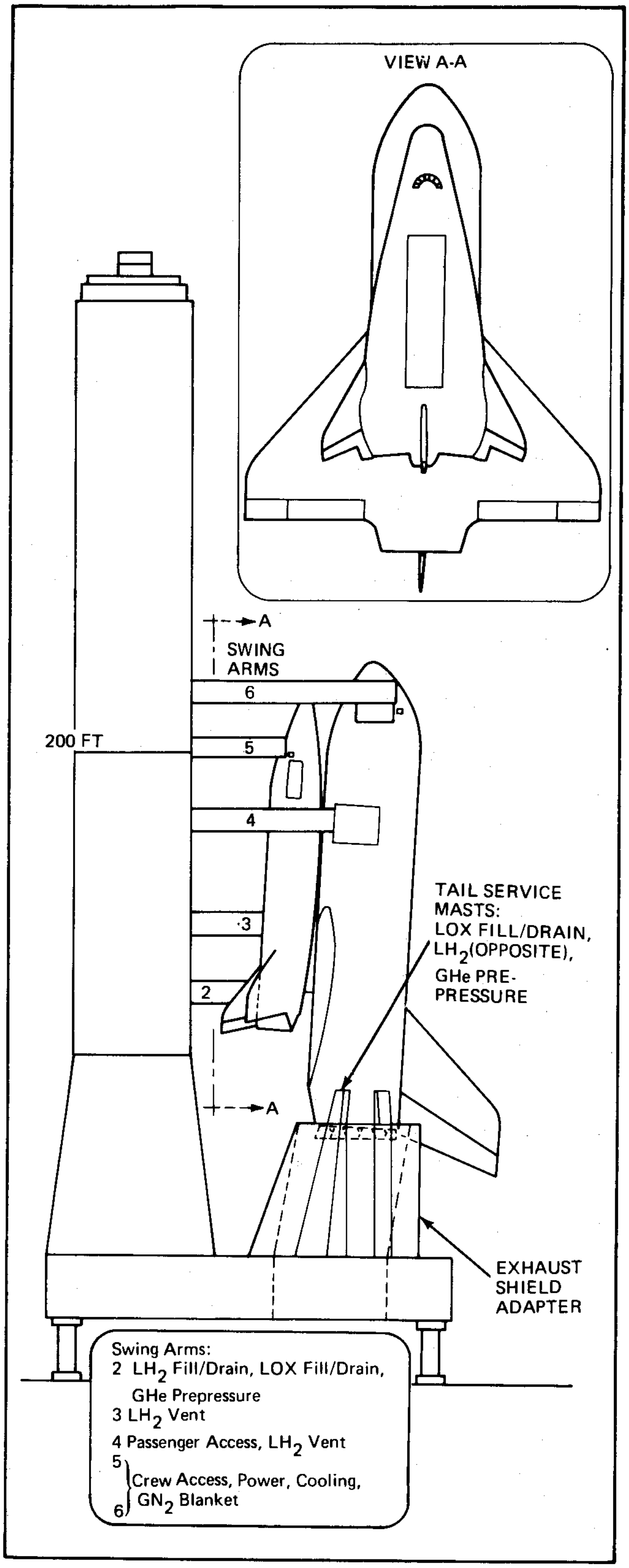


Fig. 1-5 Design 518 Stacked Configuration

Table 1-3 Design 518 Weight Summary

	Design 518		
Code	Subsystem	Orbiter	Booster
1.0	Aero Surfaces	11,610	73,190
2.0	Body Structure	56,375	151,375
3.0	Ind Envir Protect	31,860	41,360
4.0	Lnch, Recover, Dock	8,002	15,754
5.0	Main Propulsion	35,131	104,524
6.0	Orientation Cont	4,415	2,915
7.0	Prime Pwr Source	1,583	1,169
8.0	Pwr Conv & Distr	5,832	6,309
9.0	Guidance & Navig	1,081	1,018
10.0	Instrumentation	381	411
11.0	Communication	1,168	888
12.0	Envir Cont	871	222
14.0	Personnel Prov	597	442
15.0	Crew Sta Controls	110	110
	Contingency	15,904	39,966
	Dry Weight	174,920	439,653
17.0	Personnel	626	380
18.0	Cargo	32,160	
21.0	Resid Propellant	1,464	3,556
	Landed Weight	209,170	443,589
25.0	Fly Home Prop	2,000	33,557
	Max Cruise Wt	211,170	477,146
22.0	Reserv Propellant	8,959	13,215
25.0	On-orbit Prop (Man & Delta V)	25,721	
	Separation Devices		950
	Injection Wt	245,850	491,311
25.0	Injection Prop	391,400	2,371,439
	Liftoff Weight	637,250	2,862,750
	Gross Liftoff Wt	3,500,000	

engine ignition immediately if low-level abort separation is required, without endangering the booster, or the booster crew

- The combined bow shocks of the coupled vehicles will impinge on surfaces already designed for high temperatures

The position of the orbiter on the booster is satisfactory with respect to bow shock combination, stability and control, nozzle gimbal angles, booster rocket plume impingement on the orbiter during normal ascent and abort, relative attachment weight penalties, and abort feasibility.

There are no significant design penalties with this arrangement caused by vehicle cg travel and booster wing incidence in wind shear during ascent. By a combination of thrust structure cant angle and selective engine shutdown, the cg travel can be accommodated with ample allowance for control within the ±7 deg of gimbal angle available. Ascent studies show that wing lift forces can be canceled by a 15 deg up flap deflection.

INTERFACES – The three vehicle structural interfaces are shown in Fig. 1-6. Two aft fittings are located at the orbiter thrust structure and take load in all directions. The forward centerline fitting takes only lift and side loads. Although this arrangement results in some redundancy, it makes best use of the inherent strength of both vehicles.

There is no hardwire interface between stages. All signals are sent by rf link to simplify interstage design as well as the separation sequence. Receiver capture techniques are incorporated to preclude false commands from extraneous sources.

SEPARATION – The stage separation technique and associated hardware design considers both nominal and abort conditions. The design objectives are:

- Operational reliability
- No harmful impingement from the rockets of one vehicle on the other
- Positive assurance of no recontact under widely varying aerodynamics conditions
- Placing separation hardware penalty on the booster

The baseline separation approach, diagrammed in Fig. 1-7, uses stored energy devices fore and aft. The forward point also contains an extension device. For normal separation, and aborts above the atmosphere, the stored energy devices are operated simultaneously to separate the vehicles in a parallel orientation, achieving a 40 ft distance in 6 secs. The attitude control system on both vehicles will be activated to assist in stabilization during separation. For low level aborts, booster thrust is reduced by shut-down of engines nearest orbiter and throttling the remaining engines, simultaneously initiating orbiter engine start-up. As orbiter engine ignition is sensed, the forward extension device is actuated prior to actuation of the aft separation device. The delay permits the orbiter nose to start moving away from the booster and aerodynamic forces assist the separation maneuver. The abort conditions will be fully defined during the Phase B study as described in Subsection 2.1.7, and will consider the interrelationship of aerodynamics, plume fields, and vehicle dynamics.

1.3.2 Design 518 Orbiter

The Design 518 orbiter inboard profile and arrangement, and its major design characteristics are presented in Fig. 1-8.

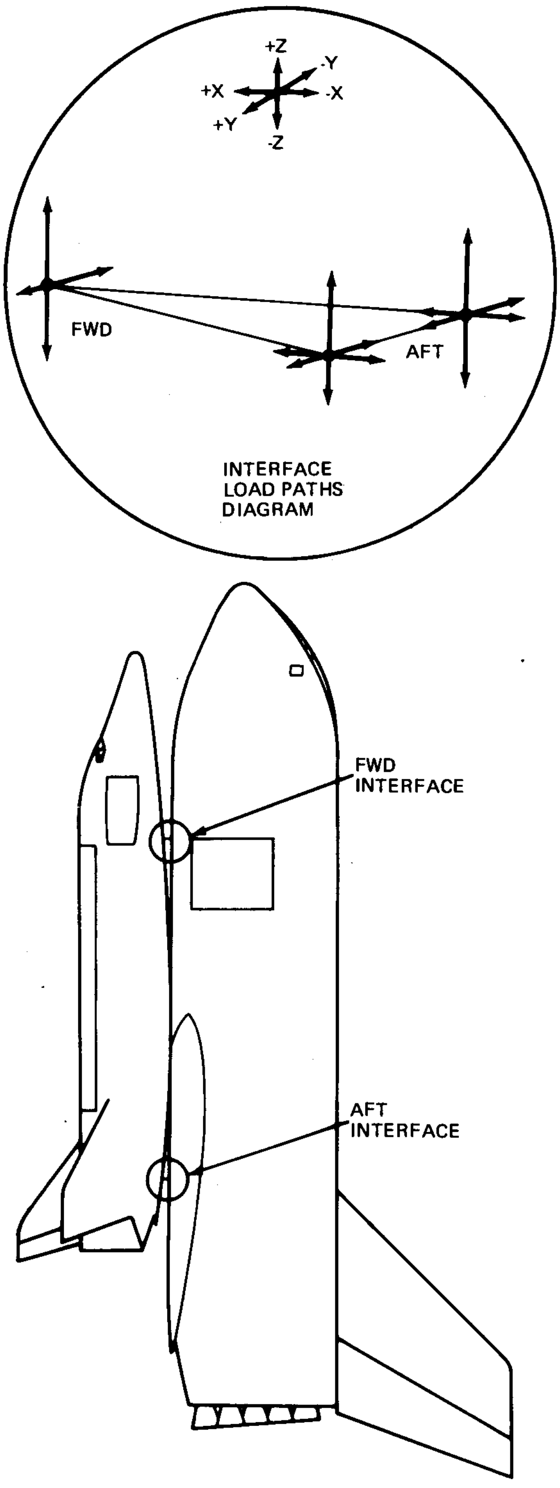


Fig. 1-6 Structural Interfaces. *Three Attachments, at Points of Inherent Strength in Each Vehicle.*

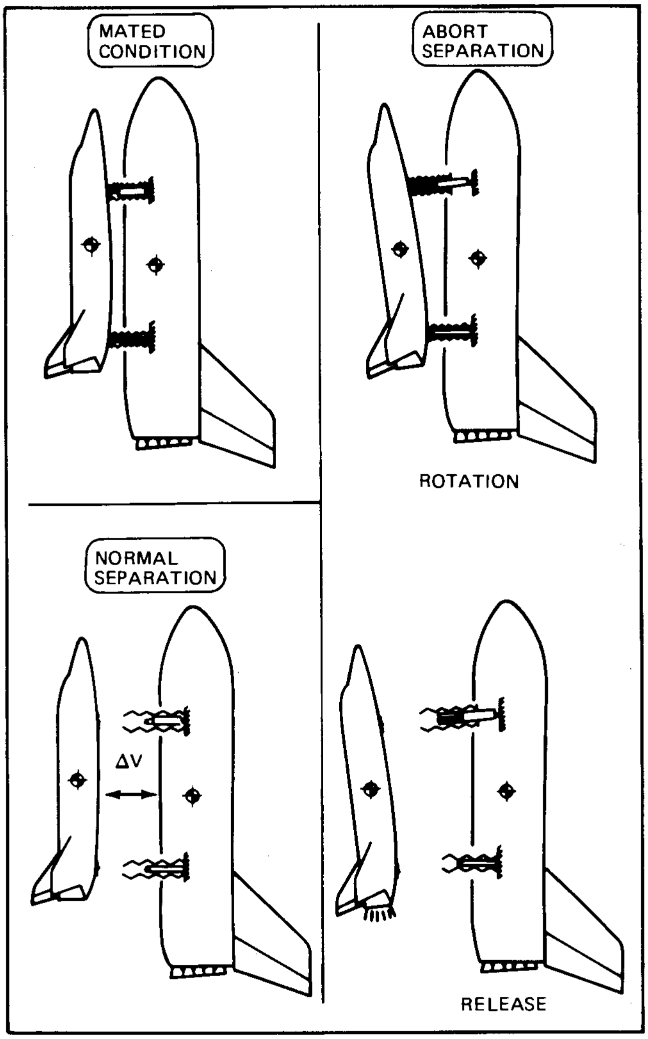


Fig. 1-7 Separation Concept. *Normal Separation Parallel; for Aborts at Significant g's, Orbiter Rotated First for Aero Assist.*

1.3.2.1 Aerodynamic Configuration

EXTERNAL SHAPE - The shape is a lifting body fully satisfying the aerothermodynamic requirements of hypersonic through subsonic flight. As configured, it operates satisfactorily over a hypersonic angle of attack range of 20 to 50 deg within manageable temperature limits and has satisfactory subsonic flying qualities. At a reentry angle of attack of 20 deg it achieves an aerodynamic cross range of more than 1500 n mi.

To achieve the hypersonic cross range within thermal constraints, the planform is gently tapered with the chine sweep angle varying from 76 deg to 82 deg. The underside camber is 2.9 percent on a 145-ft long body with a leading edge radius of 4 ft. This provides a positive hypersonic stability margin as shown in Fig. 1-9. The cp shift between angle of attack of 20 deg and 50 deg is restricted to 4.9 percent of body length. With control surfaces neutral, the cp coincides with the entry cg (full payload) at 28 deg angle of attack. Flap heating is minimized since a large flap deflection into the airflow is not required to trim at the critical thermal condition (angle of attack of 20 deg).

This basic body shape:

- Allows the tail surfaces to be kept entirely within the primary nose shock over the full angle of attack range thereby avoiding strong shock interaction. Shock tunnel results confirm that the design has avoided the interaction with a comfortable margin (Fig. 1-10)
- Reduces the windward surface area subjected to high temperature, and keeps the shape free from complex intersections and local hot spots
- Provides a low profile top surface, avoiding upper and side surface flow re-attachment and the consequent heating problems
- Provides packaging efficiencies equivalent to other candidate shapes. Fig. 1-11 shows body wetted area plotted against the volume of major installed systems for a variety of designs studied by Grumman

Satisfactory hypersonic directional stability is provided by the two outer tails with the additional stability needed subsonically contributed by the center tail. This arrangement makes possible a significant amount of control redundancy and reduces thermal protection weight since the center tail is positioned out of the high-temperature air flow.

SUBSONIC OPERATION – The orbiter's low speed handling qualities satisfy the requirements of the Military Standard Specification for transport type aircraft, as verified by wind tunnel testing. The vehicle is statically stable in pitch ($\partial C_n/\partial C_L \geq -0.01$) and yaw ($C_{n\beta} \geq +0.0009$) and trimmable through all flight and landing conditions. Longitudinal and lateral-directional dynamic characteristics exceed the specification requirements. The orbiter's approach speed is 180 kt with a design sink speed of 10 fps. The pilot has adequate one-engine-out control down to 160 kt. These basic characteristics are augmented by a three-axis stability augmentation system.

DESIGN 518 ORBITER

Lift Off Weight:	637,250 lb
Injection Weight:	245,850 lb
Entry Weight:	211,170 lb
Landing Weight:	209,170 lb
Dry Weight:	174,920 lb
PROPULSION SYSTEMS	
• Main Rocket: 400,000 lb High Pressure	(2)
• On-Orbit Rocket: RL-10 15,000 lb Thrust	(1)
• Air Breathing Engine: JTF-22 Turbofan	(4)
• Attitude Control Rocket: 1,000 lb Thrust	(26)
Trimmed (L/D) Hypersonic ($\alpha = 20^{\circ}$)	1.79
Trimmed L/D Hypersonic ($\alpha = 50^{\circ}$)	0.78
Trimmed L/D_{max} (Subsonic)	5.1
Subsonic Approach Velocity (90°F, @ SL)	180 kt
REFERENCE PLAN AREA	6,100 sq ft
Wetted Areas	
• Body Net:	13,220 sq ft
• Base:	320 sq ft
• Tails:	3,000 sq ft
OUTBOARD FINS	
• Exposed Area (2):	1,160 sq ft
• Taper Ratio:	0.245
CENTER FIN	
• Exposed Area:	340 sq ft
• Taper Ratio:	0.493
CONTROL SURFACES	
• Outboard Elevon (2):	350 sq ft
• Rudder:	106 sq ft
• Hypersonic Flap:	700 sq ft
• Transonic Flap:	326 sq ft

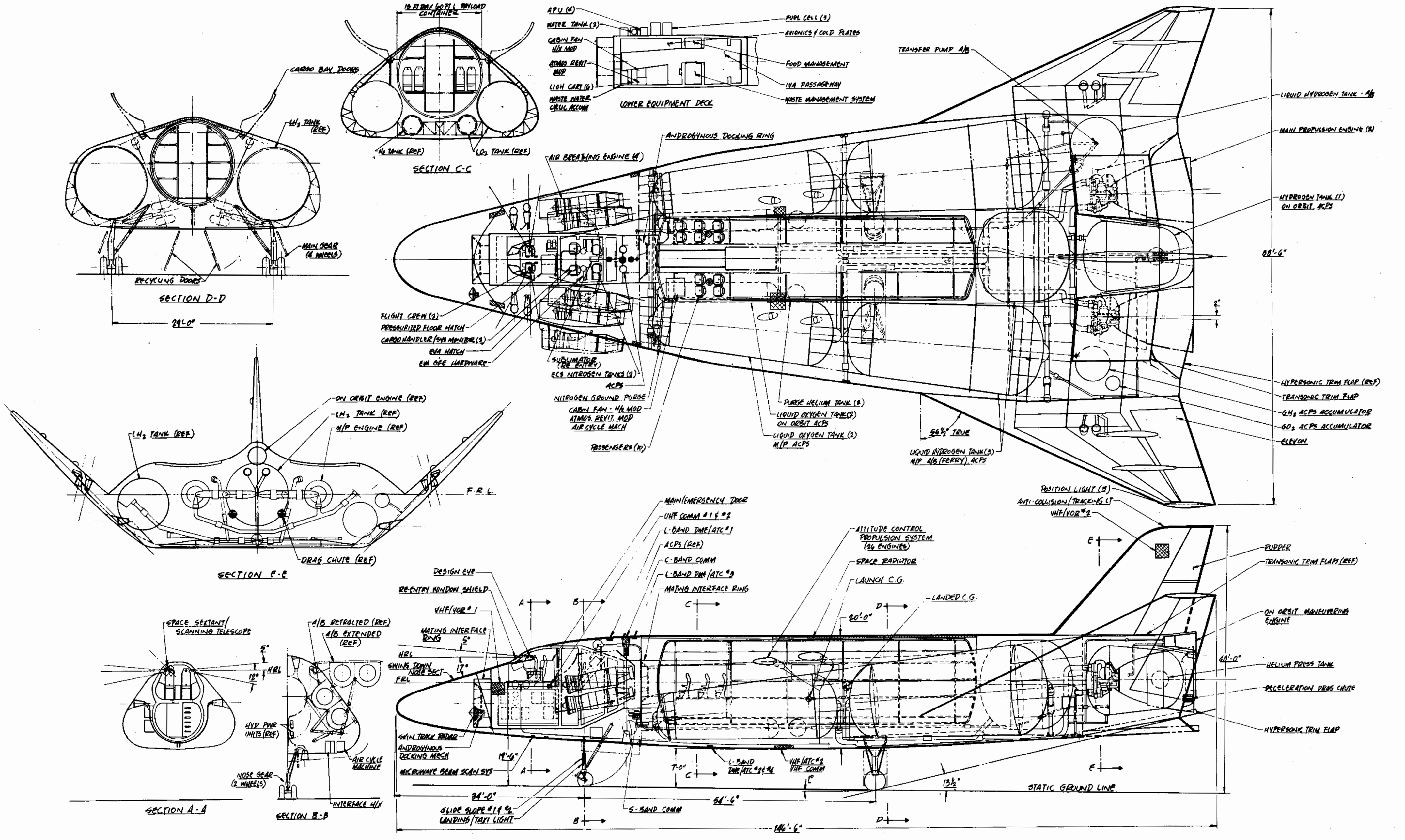


Fig. 1-8 Design 518 Orbiter General Arrangement and Inboard Profile

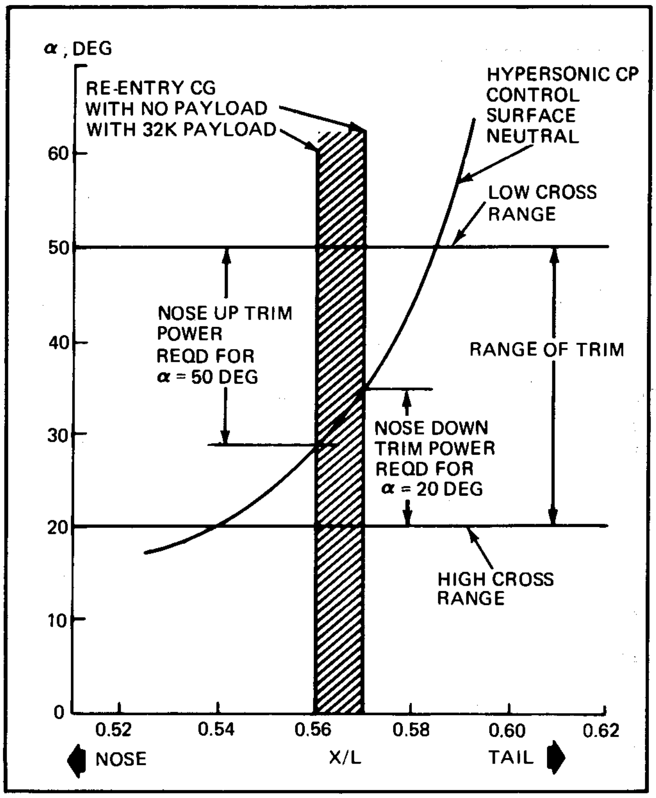


Fig. 1-9 Design 518 Orbiter Hypersonic Longitudinal Trim

The Design 518 orbiter has a self-ferry range of 630 n mi while meeting standard takeoff, cruise, and go-around requirements. This capability is based on zero payload and the addition of 34260 lb of LH_2 in a tank in the cargo bay.

1.3.2.2 Subsystems Installation & Features

Orbiter subsystem installation considerations are as follows:

- Provide a simple arrangement of each subsystem to minimize weight and development complexity
- Keep the orbiter entry cg forward without undue widening of the nose
- Limit orbiter entry cg variation with payload
- Keep the orbiter cg forward during main stage burning to limit the main rocket gimbal angles required in the one-engine-out condition

The following subsystems installation features will be discussed: structure and tanks, propulsion, crew and avionics, docking and cargo, and landing gear and braking. The inboard profile of Fig.1-8 shows the details.

STRUCTURE AND TANKS – The main propellant is carried in four integral tanks which carry both pressure loads and body loads to achieve a low body/tank structure weight and avoid the weight penalty of a separate bending structure. This design permits the body-wetted area to be shrunk to a practical minimum. The smaller on-orbit tanks are nonintegral because of their stringent insulation needs.

Prelaunch ice buildup in the main tanks is prevented by internal insulation of the hydrogen tanks and a dry, warm nitrogen blanket throughout the space between the tanks and the outer shell.

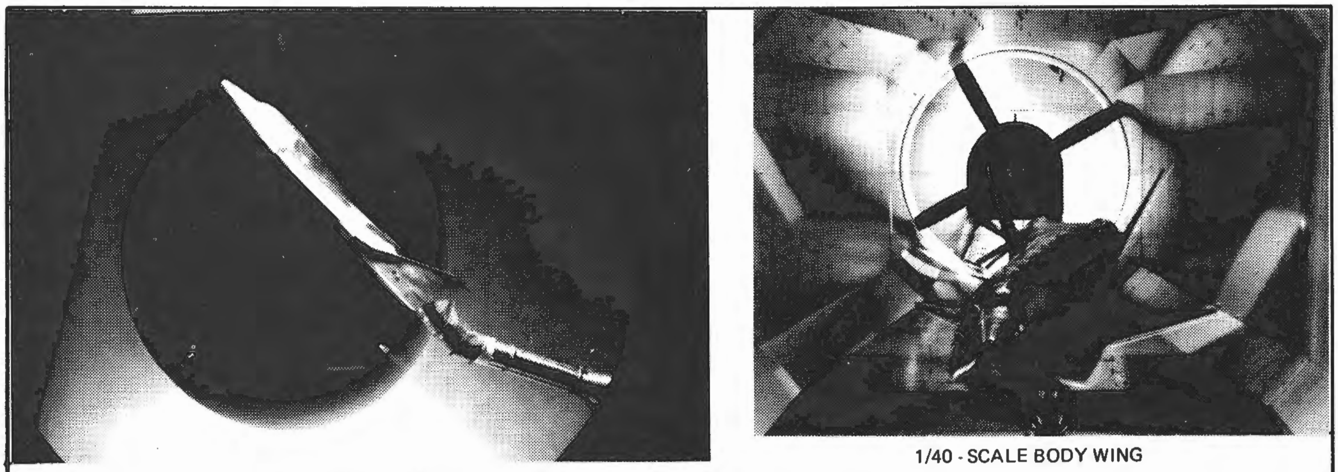
MAIN ROCKET ENGINES – Two 400,000 lb (S.L.) rocket engines, provided for boost and orbit injection, are positioned to thrust directly into the prime structure. They are toed out by 2 deg from the centerline. This keeps the specific impulse loss to 0.3 sec and allows for sufficient gimbal angle to control the one-engine-out flight path excursions. Separation of the engines allows for the afterbody to be boattailed to reduce base drag.

One RL10 15K lb vacuum rocket engine is installed for orbit changes and deorbiting. If the main engines were given multi-start capability, they could be used for on-orbit maneuvering and the RL10 eliminated. This approach, as well as the use of a new engine design specifically for on-orbit maneuvering, are under study.

AIR-BREATHING ENGINES – Subsonic propulsion is provided by four JTF-22 airbreathing engines (without afterburners), converted to run on LH_2. The JTF-22, under active development for the Grumman F-14B, has a thrust-to-weight ratio of 7.2, high efficiency, and low frontal area. The engines are stowed internally on pallets and deployed by rotating the pallets into the airstream.

Deployable air beathers provide a 15-20 percent performance improvement over buried installations and avoid their thermal and structural complications. Inspection and routine servicing are accomplished in the normal extended position; the pallet is swung to a higher position for extensive maintenance.

The removable air breathing engine package can be further exploited. In cases where the descent trajectory accuracy, landing field conditions, and flight crew experience permit removal of air breathing engines, the payload can be increased by the weight of the removed engine package and fuel (15,000 lb). The aft shift of the cg caused by removing the air-breathing engines can be accommodated by the hypersonic control surfaces as long as high angle of attack, low cross-range entry is planned.

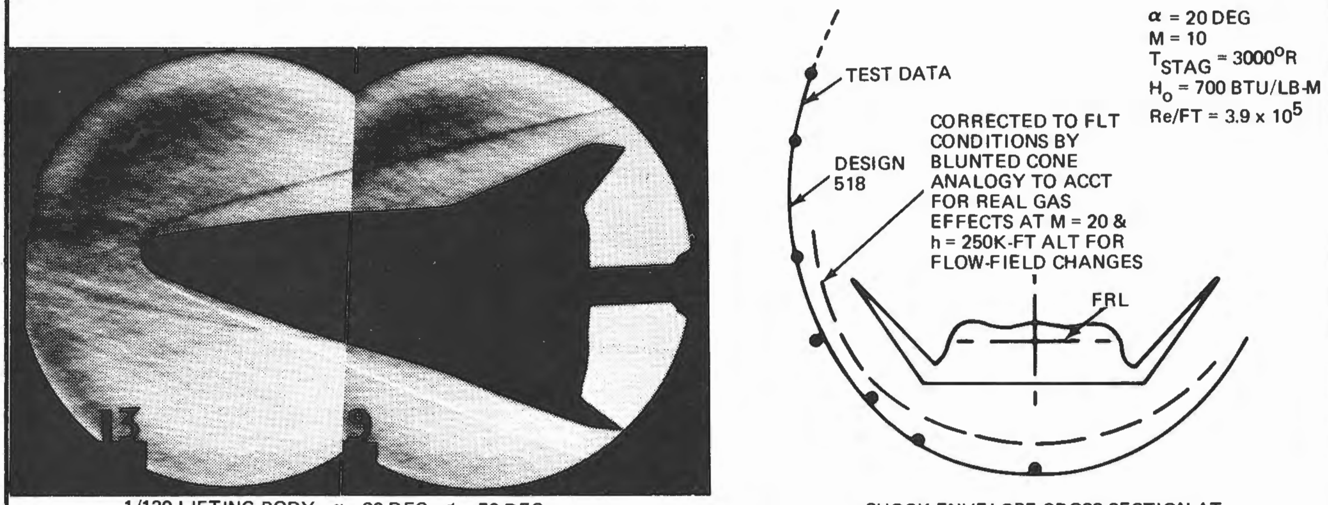


1/130 - SCALE LIFTING BODY

1/40 - SCALE BODY WING

HYPERSONIC AND SUBSONIC FORCE MODELS

Wind tunnel tests have been conducted on two classes of vehicles lifting body, & wing-body



1/130 LIFTING BODY, α = 20 DEG, φ = 70 DEG

SHOCK ENVELOPE CROSS-SECTION AT FIN TIP STATION

HYPERSONIC HEAT TRANSFER MODELS

Shock envelope established by Schlieren pictures & corrected to flight conditions, and phase change paint show no shock impingement on fins.

Fig. 1-10 Shock Tunnel Results

ATTITUDE CONTROL PROPULSION SYSTEM (ACPS) – Twenty-six 1000-lb thrust GOX and GH_2 reaction motors provide rotation and translation in all three axes. (See Fig. 1-40 in Subsection 1-6.) The arrangement allows mission completion in the event of on-orbit engine (RL10) failure. The aft positioning of the forward firing motors reduces impingement on the space station during docking maneuvers. Sufficient redundancy is provided to retain full maneuvering capability in the event of any one thruster failure. Nozzles on lower surfaces are shielded by rotating thermal protection covers during reentry (See Fig. 1-41 in Subsection 1.6.)

CREW PROVISIONS – The cabin arrangement provides the following features, shown in Fig. 1-12.

- Line-of sight 17 deg below FRL selected for landing visibility
- A flight deck with 6-ft headroom
- Accessible prelaunch, post-landing and emergency doors and an EVA air lock
- Galley and waste management areas in the crew quarters (lower level)
- IVA transfer of cargo and passengers without disturbing the flight crew

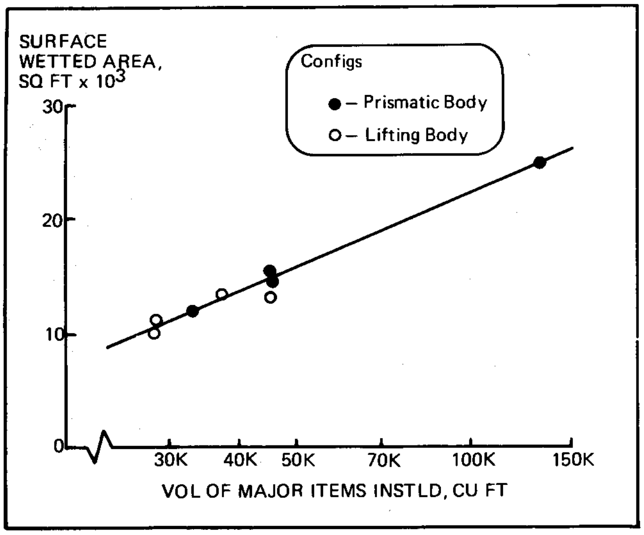


Fig. 1-11 Effect of Stowed Volume on Body Wetted Area

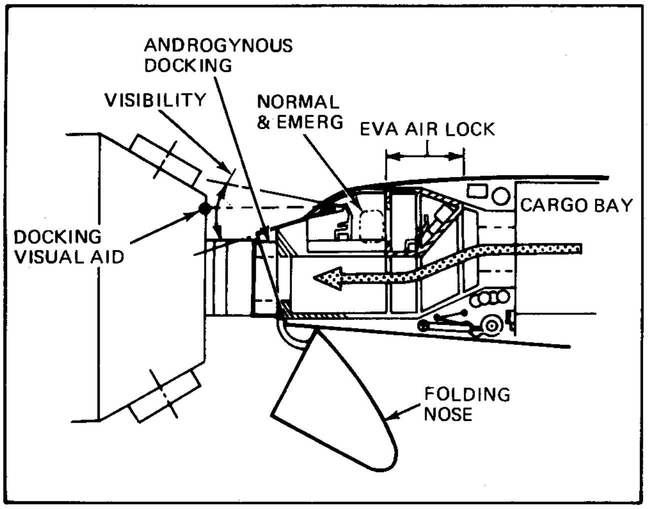


Fig. 1-12 Design 518 Crew Section Packaging. *Shirt Sleeve Cargo Transfer. Docking Approach Observed Through Pilots Window.*

AVIONICS – The 518 Avionics System meets a Fail-Ops, Fail-Ops, Fail-Safe criteria with on-board checkout capability to the LRU level. It features a centralized digital computer (500K ops/sec, 80K words, 32 bits/word) and a multiplexed data bus (1 mbs). Integrated displays and controls make use of four multi-function, computer-driven CRT's and solid-state keyboards and switch components. Inertial reference is obtained from a redundant nonorthogonal strapped down system (6 gyros, 6 accelerometers). Rendezvous with noncooperative targets (50 n mi, 10 sq meters) is by a skin-tracking radar (16 Ghz). Voice communication to ground is through a C-band RF link via a data relay satellite using a four-foot unfurlable parabolic antenna. Most of the 20-odd antennas are flush-mounted in the forward section using state-of-the-art concepts and are positioned on the sides and upper surface where possible.

The avionics are installed in the pressurized lower level of the crew quarters. Areas outside the pressure cabin are provided for the auxiliary power unit and fuel cells.

DOCKING – The orbiter uses a nose docking system which involves rotation of the nose section. The design provides ideal vision, cg, and ACPS alignment with minimum requirements for instrument aids. Docking loads aim through orbiter and space station cg's so that excessive moments and wrenching forces on the docking ring are avoided. Folding the nose allows for hard, universal androgynous nose docking, and virtually straight through IVA cargo transfer. The folding nose is powered by multiple redundant actuators to insure proper retraction and closure for entry. In the area where it passes through the TPS, the nose joint is thermally protected by an ablator strip, insulation and a multiple seal arrangement. This design is shown in Fig. 1-52 and discussed further in Subsection 2.3.4.

CARGO HANDLING – Cargo handling provisions consist of a pair of manipulator arms driven by electromechanical rotary and linear actuators as shown in Fig. 1-13. The cargo container is picked up close to its cg and can be deployed to and retrieved from any attitude required. Its attachment to the orbiter isolates it from body bending and differential thermal stresses. An alternate concept, shown in Fig. 1-14,involves docking the orbiter and rotating it through 90 deg. The cargo container is elevated by synchronized winch-driven cables and then driven 8 ft forward to engage the space station port. Both approaches are under study.

LANDING GEAR AND BRAKING – The tricycle landing system is a conventional approach, using well established current practices. The major features are:

- All legs have dual wheels with 46 in. x 16 in. mains and 32 in. x 8.8 in. nose
- The two 30-ft diameter parachutes augment the four main wheel brakes and are designed to meet roll out requirements with one chute failed

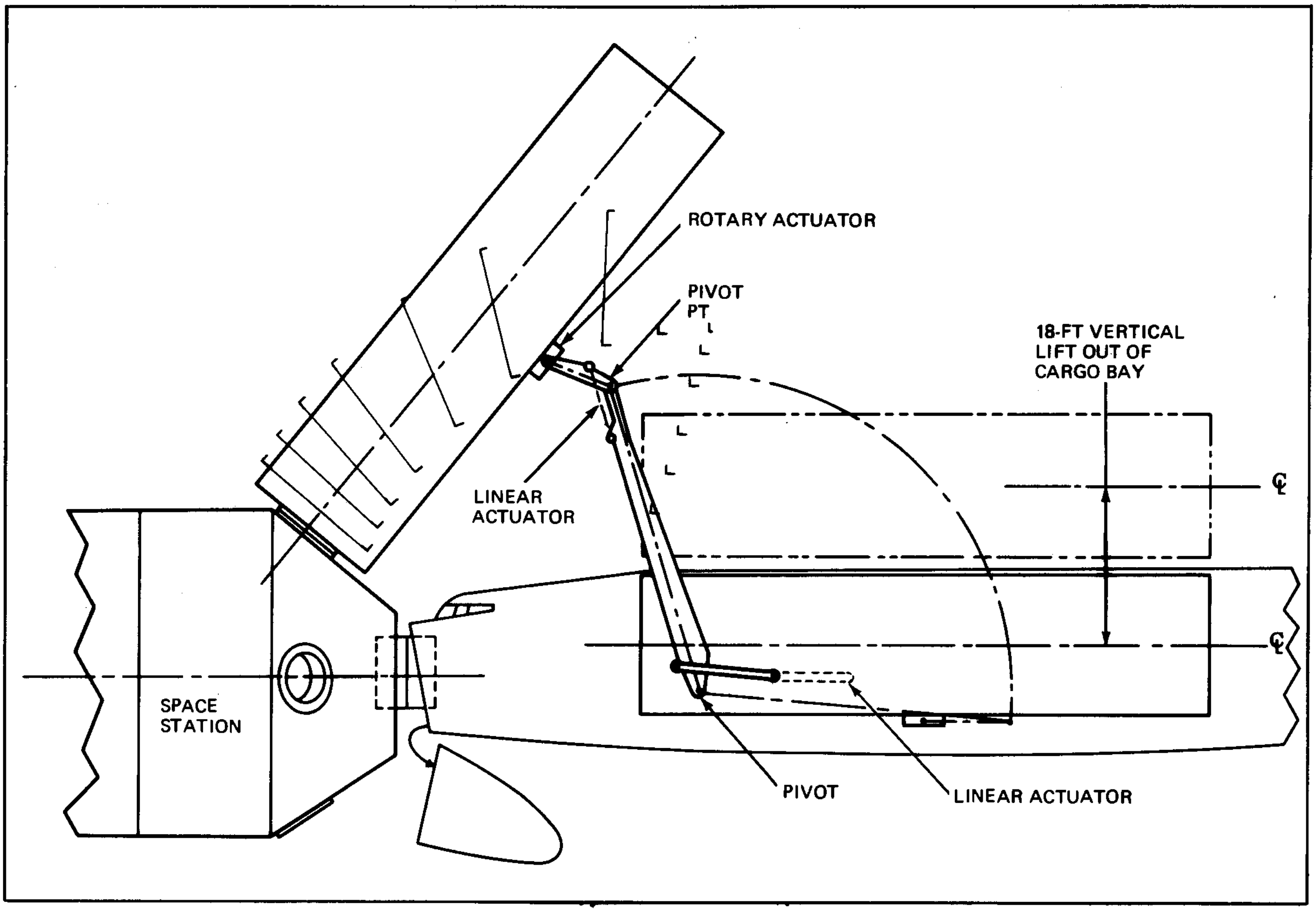


Fig. 1-13 Alternate 1 - Spatial Cherry Picker. *Manipulator Arms Exchange Payload Containers Between Shuttle and Station and Deploy/Retrieve Satellites.*

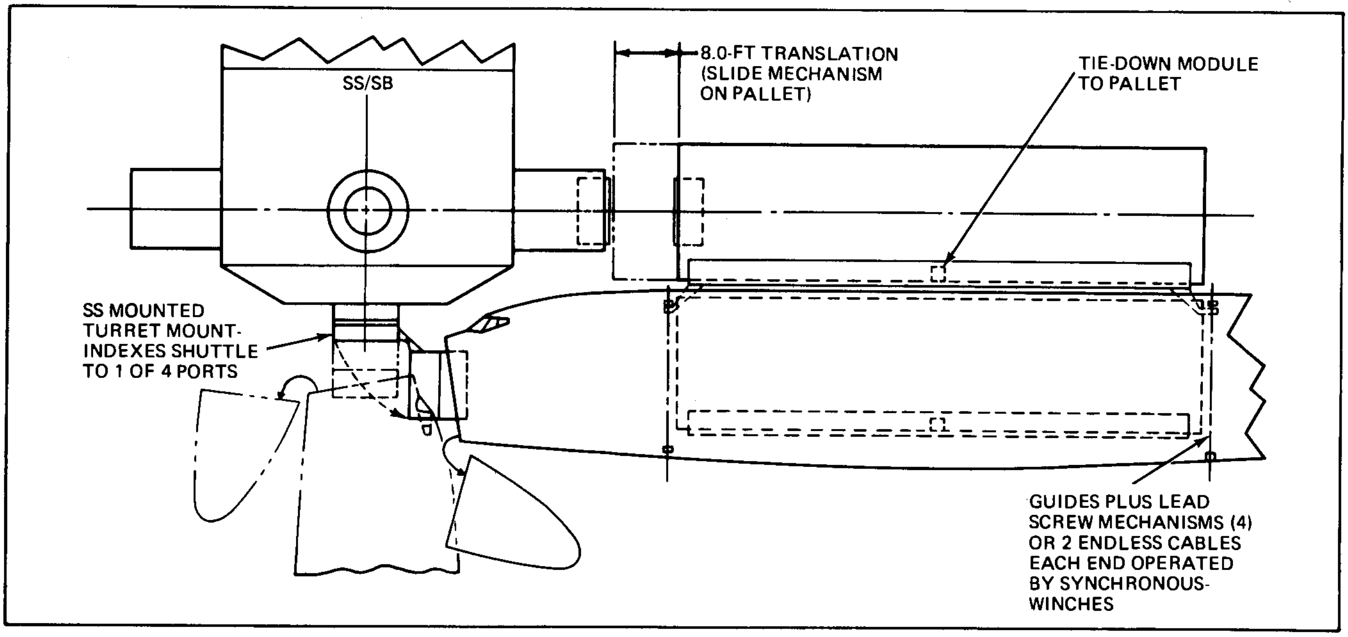


Fig. 1-14 Alternate 2 - Elevator Concept. *Elevator System Transfers Containers Between Shuttle and Station and Deploy/ Retrieve Satellites.*

- The antiskid braking system is insensitive to icy runways
- The 25-ft wide tread provides an overturn angle of 54 deg
- Nose wheel steering provides easy ground handling

1.3.3 Design 518 Booster

1.3.3.1 Aerodynamic Configuration

The booster general arrangement and inboard profile are shown in Fig. 1-15. Its mission and design requirements differ from the orbiter's in several major respects:

- Initial entry conditions are not as severe at staging velocities (about 11,500 fps)
- Cross ranging is not a factor
- Subsonic cruise back to launch site (approximately 550 n mi) is a significant part of the booster's mission

Wing-body configurations of a conventional airplane type are most efficient for subsonic cruise; we have selected a delta wing configuration because of its favorable characteristics as a booster (less tendency toward wing flutter and buffet, and favorable drag and shock interaction characteristics through the speed range) and acceptable characteristics as a reentry vehicle.

External contour along most of the body is defined by a full upper radius of 18 1/2 ft and a slightly vee-shaped bottom, connected by 6-ft corner radii. The last feature avoids the high local temperatures associated with sharp corners. This cross section is blended into a blunt nose shape, chosen for highest volumetric efficiency and low weight.

The booster has a self-ferry range of approximately 374 n mi with 20 percent reserve on internal fuel carried in the fly-home tank while meeting standard takeoff, cruise and go-around requirements. No strap-on components or landing gear strengthening is required for this range. (Refer to Subsection 1.5.1.3 for further discussion of booster aerodynanics.)

1.3.3.2 Subsystems Configuration

Wherever feasible booster subsystem components are identical to those used in the orbiter. Common components include the main engine power heads, the air-breather engines, and portions of the avionics, electrical power, and environmental control subsystems. In many cases, these subsystems are simpler for the booster because of its less complex role and shorter mission time.

The following features will be discussed: structures and tanks, propulsion, crew and landing system. Refer to Fig. 1-15 for inboard profile.

STRUCTURE AND TANKS – The body structure consists principally of the main propellant tanks. These are two 33-ft diameter aluminum cylinders with ellipsoidal domes. A common bulkhead between tanks was avoided to reduce cost and oxygen feed line problems. The uninsulated oxygen tank is placed forward to enhance controllability during ascent and to reduce thermal gradient problems in the region of the wing attachment and engine thrust structure. The booster thrust structure is tilted 5½ deg from a station plane so that engine thrust tracks the total cg travel of the mated vehicles without exceeding gimbal limits.

MAIN ROCKET ENGINES – The twelve 400,000 lb main rocket engines are arranged in four identical groups of three to simplify development testing. A maximum gimbal capability of ±7 deg in two axes is adequate for control under all conditions including abort. Control at burnout is possible because the thrust vector shifts 19 in. toward the orbiter when the three upper quadrant engines are shut down for g limitation.

ATTITUDE CONTROL PROPULSION SYSTEM – All specified requirements for booster attitude control during and after separation are provided by fifteen 1000-lb thrusters located on the fuselage. Their nozzle exit planes are slightly inside contour and, in areas affected by the aerothermal environment, are shielded as in the orbiter by rotating thermal protection covers during launch and reentry. (See Fig. 1-41 in Subsection 1.6.)

AIR BEATHING ENGINES – Thrust for cruise is supplied by eight hydrogen-fueled JTF-22 turbojets, identical to the cruise engines in the orbiter. They meet the one-engine-out performance criteria for go-around, with the least total propulsion system weight of all the hydrogen-fueled candidates assessed. The air breathers are deployed in groups of four by a 35 deg rotation from the sides of the fuselage. This location assures that thrust is applied near the vertical level of the cg, and that the engine intakes receive favorable airflow. The fore-and-aft location was chosen from considerations of cg, boundary layer thickness and re-entry skin temperatures.

DESIGN 518 BOOSTER	
Lift-Off Weight:	2,862,750 lb
Staging Weight:	491,311 lb
Landing Weight:	443,589 lb
Dry Weight:	439,653 lb
PROPULSION SYSTEMS	
• Main Rocket: 400,000 lb High Pressure	(12)
• Air Breathing Engine: JTF-22	(8)
• Attitude Control Rocket: 1,000 lb Thrust	(15)
L/D/α @ α_{max} Design (M = 20, 200K ft)	0.76/50 deg
Trimmed L/D$_{max}$ (Subsonic)	6.4
Subsonic Approach Velocity (90°F, @ SL)	152 kt
PLAN AREA	12,330 sq ft
Wetted Area	
• Body:	23,430 sq ft
• Base:	833.3 sq ft
• Wing:	9,580 sq ft
• Tail:	3,050 sq ft
WING	
• Reference Area:	8,460 sq ft
• Exposed Area:	4,720 sq ft
• Taper Ratio:	0.2
• Aspect Ratio:	2.38
FIN	
• Exposed Area	1,500 sq ft
• Taper Ratio:	0.5
• Aspect Ratio:	1.07
CONTROL SURFACES:	
• Outboard Elevon (2):	278 sq ft
• Inboard Elevon (2):	586 sq ft
• Rudder:	520 sq ft

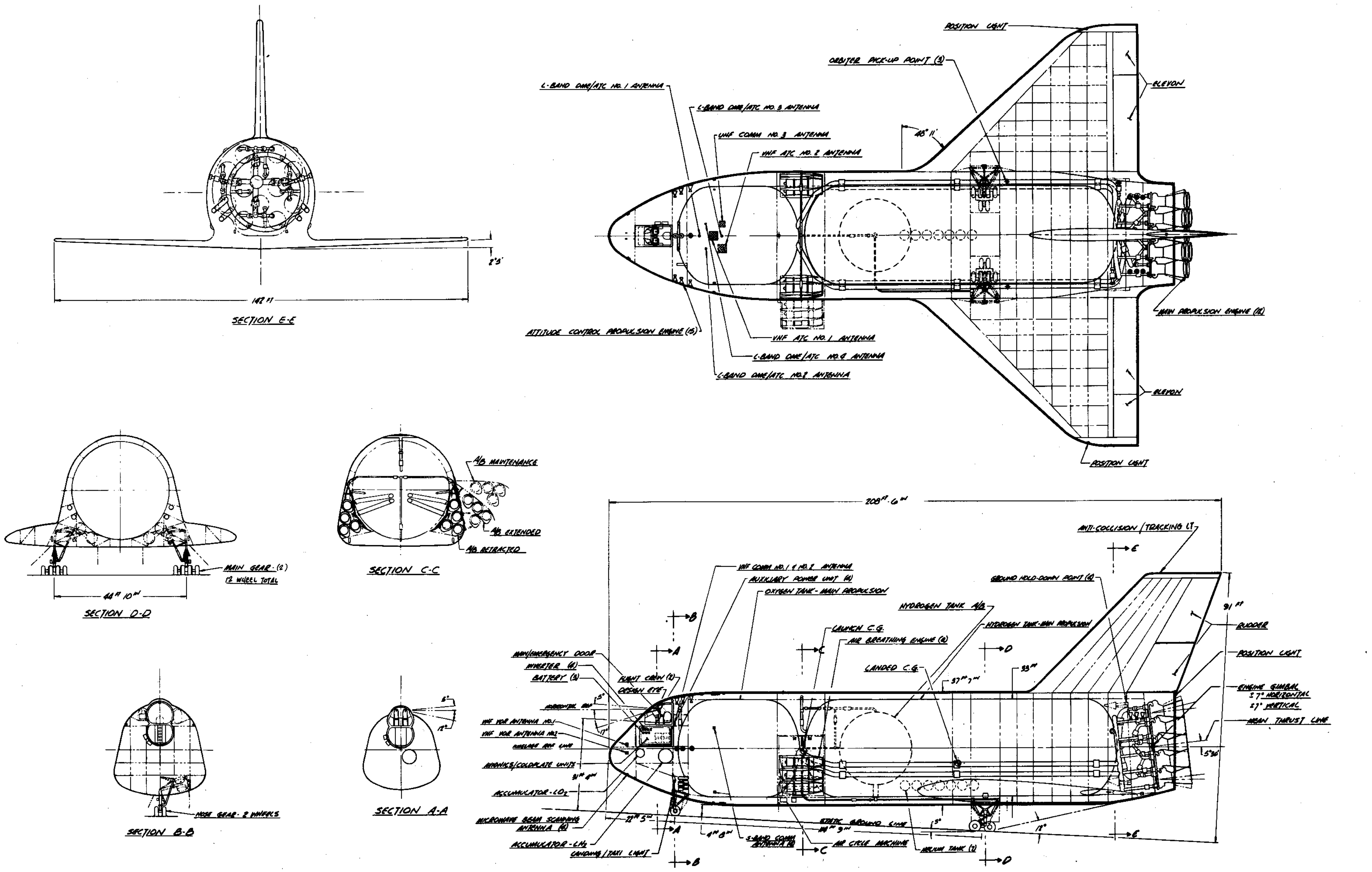


Fig. 1-15 Design 518 Booster General Arrangement

As shown, the engine package makes good use of tank dome structure and affords access to fly-home propellant plumbing.

CREW PROVISIONS – A noteworthy example of booster/orbiter commonality is in the crew compartment. The booster compartment (2 men) is the forward segment of an orbiter compartment (4 men). The forward and aft bulkheads are the same for both vehicles, except that docking ring and and hatches are eliminated from the booster. Commonality is achieved in areas such as window size, shape and framing, instrument panel and console support structure, cockpit floor, crew seats and primary and secondary controls. The volume below the flight deck is the same. The displays on the instrument panel are similar to the orbiter but reduced in quantity. Hatches are located behind both seats, providing passage to the fuselage skin through a short tunnel. These hatches provide egress on the pad, on the runaway and during all emergency conditions.

LANDING GEAR & BRAKING – The booster landing system for Design 518 employs a standard high heat treat steel aircraft landing gear for reliability, maintainability, and predictable weight and performance characteristics. All gears retract laterally. The nose gear has steerable dual wheels and the main gear consists of two main struts with six wheel bogies with tire sizes of 44 in. x 16 in. To simplify booster design and operation, the total runout stopping energy is supplied by the wheel brakes.

1.4 DESIGN 532 DESCRIPTION

1.4.1 Stacked Configuration

The Design 532 stacked configuration is shown in Fig. 1-16; weights are summarized in Table 1-4.

Because Design 532 uses essentially the same propellant quantities as Saturn V its impact on KSC facility utilization is minimized. Design 532 requires extension of the launch pad exhaust duct and hold downs, relocation of swing arms and other minor changes at launch complex 39, although the hold-down capacity for asymmetric load during the fill period has not been verified. Present propellant loading capacities are adequate. Standby status with two hours to launch assumes that the RP-1 is preload.

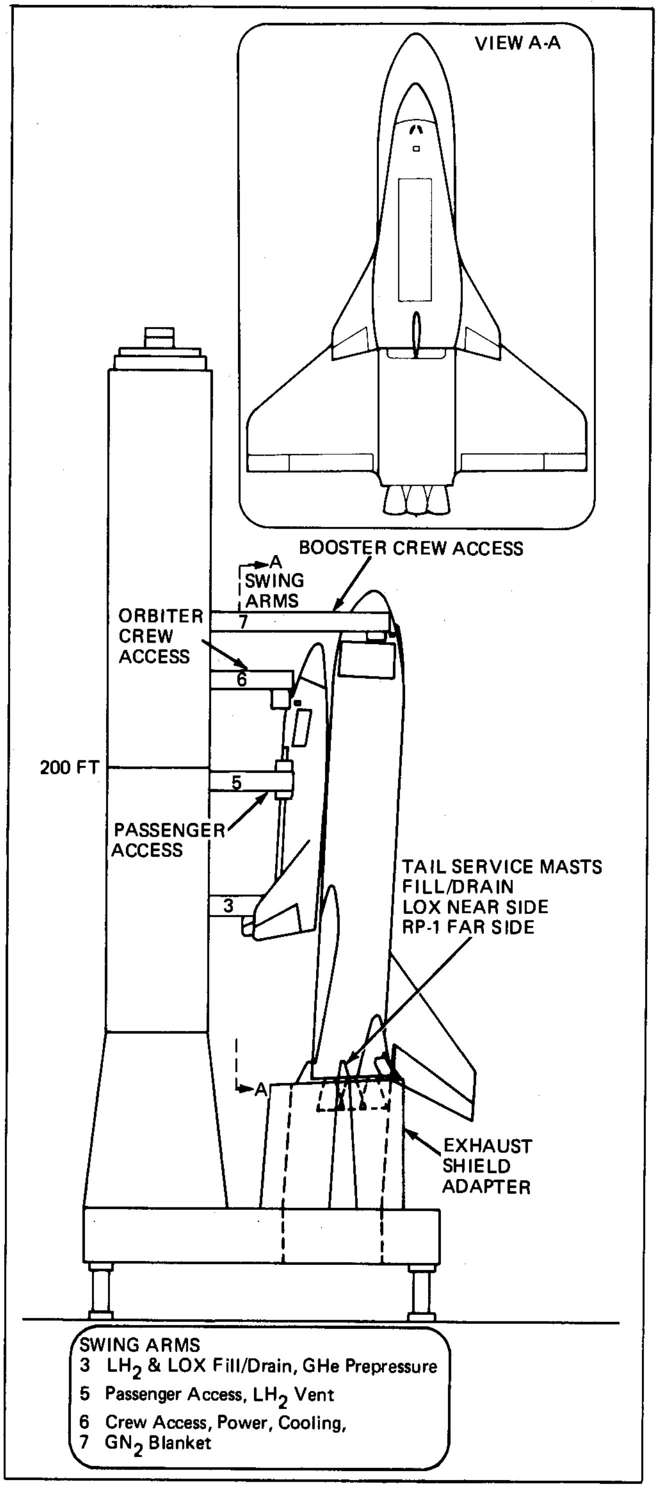


Fig. 1-16 Design 532 Stacked Configuration

As in Design 518, the stages are arranged belly-to-belly. The orbiter placement allows the future use of a kick stage behind the orbiter for very large payloads. (A description of this growth configura-

Table 1-4 Design 532 Weight Summary

		Design 532	
Code	Subsystem	Orbiter	Booster
1.0	Aero Surfaces	12,210	101,740
2.0	Body Structure	54,310	175,595
3.0	Ind Envir Protect	29,660	44,845
4.0	Lnch, Recover, Dock	7,309	23,777
5.0	Main Propulsion	32,674	180,675
6.0	Orientation Cont	4,180	3,575
7.0	Prime Pwr Source	1,583	853
8.0	Pwr Conv & Distr	4,620	5,890
9.0	Guidance & Navig	1,081	928
10.0	Instrumentation	386	374
11.0	Communication	1,168	761
12.0	Envir Cont	648	222
14.0	Personnel Prov	585	442
15.0	Crew Sta Controls	121	110
	Contingency	15,055	53,978
	Dry Weight	165,590	593,765
17.0	Personnel	626	380
18.0	Cargo	22,580	
21.0	Resid Propellant	1,407	16,126
	Landed Weight	190,203	610,271
25.0	Fly Home Prop	1,900	98,500
	Max Cruise Wt	192,103	708,771
22.0	Reserv Propellant	9,490	43,705
25.0	On-orbit Prop (Man. & Delta V)	23,725	
	Separation Devices		950
	Injection Weight	225,318	753,426
25.0	Injection Prop	344,000	5,600,000
	Liftoff Weight	569,318	6,353,426
	Gross Liftoff Wt	6,922,744	

tion is presented in Subsection 1.4.5). The stack assembly is inclined 2 deg to the vertical for launch.

The effects of cg travel and booster wing incidence are handled in the same way as for Design 518.

INTERFACES – The structural interfaces between the orbiter and booster are similar to those described for Design 518. The three points of attachment are chosen to match strong points in the orbiter. The aft points, which transmit thrust, lift and side loads, connect the orbiter thrust structure with the booster front wing beam attachment frame. The forward point, which transmits lift and side loads only, connects the forward cargo bay bulkhead in the orbiter to a point in the booster which is not a natural hard point. The resulting weight penalty on the booster is preferable to relocating this point forward which would penalize the orbiter. There is no wiring between stages. As in Design 518, all signals are sent by rf link.

SEPARATION – The approach to stage separation for normal and abort conditions is similar to that used in Design 518, with appropriate adjustments for the mass properties of the Design 532 vehicles.

1.4.2 Design 532 Orbiter

The orbiter is slightly smaller than Design 518 and was sized to optimize within the requirements discussed in Subsection 1.2.2; its aerodynamic shape is basically identical to that of Design 518 to permit a meaningful comparison during the Phase B study. Where configuration differences exist they derive from the following unique design objectives:

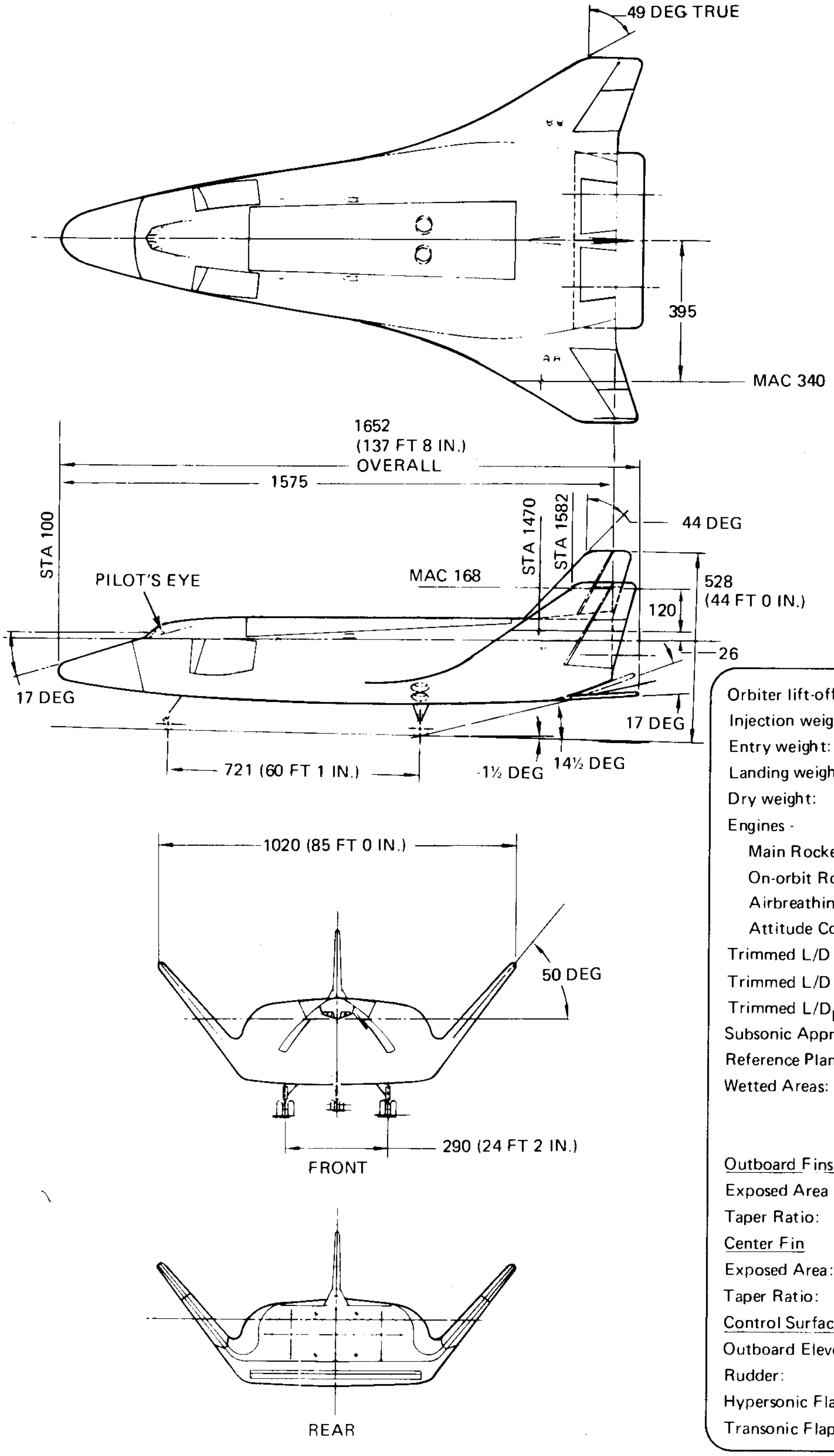
- Payload flexibility and growth utilizing a 10 ft by 60 ft internal cargo canister, and adaptable for exterior cargo containers of 15 ft by 60 ft and 22 ft by 40 ft
- Engine installation compatible with existing J2S engines and adaptable to the new high-pressure engines
- Use of first generation integrated avionics and less elaborate crew provisions, and simpler LOX/ LH_2 ACPS to minimize weight and cost

The Design 532 orbiter and its major design characteristics are shown in Fig. 1-17 and 1-18.

1.4.2.1 AERODYNAMIC CONFIGURATION/ CARGO SIZE INTERACTION

The design has the same aerodynamic base as Design 518, and an identical rationale was applied to the treatment of all perturbations resulting from the cargo bay and engine differences. Variations in body width, control surface areas, and base area treatment exist; however, there are no significant differences in aerodynamic performance and handling qualities.

The Design 532 "flat bed" cargo carriage approach is based on (1) the desire to handle varying payload sizes and (2) the rationale that there is no requirement to return high bulk cargo from orbit with high cross range. The basic cargo bay encloses a 10 ft diameter by 60 ft long pod internally near the top of the body as shown in Fig. 1-19. Larger payloads, up to 22 ft in diameter by 60 ft, are carried nestled in this bay but extending above normal contour. The approach to cargo deployment and retrieval in orbit is identical to Design 518. During high cross-range reentry (at 20 deg angle of attack) the 10 ft diameter pod is protected from excessive thermal effects; for low cross range (50 deg angle of attack) the 15 ft diameter is returnable. Twenty-two foot diameter payloads can be delivered but not returned. The "flat bed" design concept provides a



Orbiter lift-off weight:	569,318
Injection weight:	225,318
Entry weight:	192,103
Landing weight:	190,203
Dry weight:	165,590
Engines -	
Main Rockets: 250,000 lb high pressure	(3)
On-orbit Rocket: RL-10, 15,000 lb thrust	(1)
Airbreathing: JTF-22 Turbofan	(4)
Attitude Control Rockets: 1000 lb Thrust	(20)
Trimmed L/D Hypersonic ($\alpha = 20^{o}$)	1.70
Trimmed L/D Hypersonic ($\alpha = 50^{o}$)	0.78
Trimmed L/D_{Max} (Subsonic):	4.9
Subsonic Approach Velocity (90^{o}F at SL):	181 kt
Reference Plan Area:	5,500 sq ft
Wetted Areas: Body Net:	11,580 sq ft
Base:	568 sq ft
Tails:	3,340 sq ft
Outboard Fins	
Exposed Area (2):	1,444 sq ft
Taper Ratio:	0.35
Center Fin	
Exposed Area:	250 sq ft
Taper Ratio:	0.52
Control Surfaces	
Outboard Elevons (2):	458 sq ft
Rudder:	92 sq ft
Hypersonic Flap:	683 sq ft
Transonic Flap (2):	323 sq ft

Fig. 1-17 Design 532 Orbiter General Arrangement

DESIGN 532 ORBITER	
Lift Off Weight:	569,318 lb
Injection Weight:	225,318 lb
Entry Weight:	192,103 lb
Landing Weight:	190,203 lb
Dry Weight:	165,590 lb
PROPULSION SYSTEMS	
● Main Rocket	(3)
● On-Orbit Rocket	(1)
● Air Breathing Engine	(4)
● Attitude Control Rocket	(20)
Trimmed (L/D) Hypersonic ($\alpha = 20^{\circ}$)	1.70
Trimmed L/D Hypersonic ($\alpha = 50^{\circ}$)	0.78
Trimmed L/D_{max} (Subsonic)	4.9
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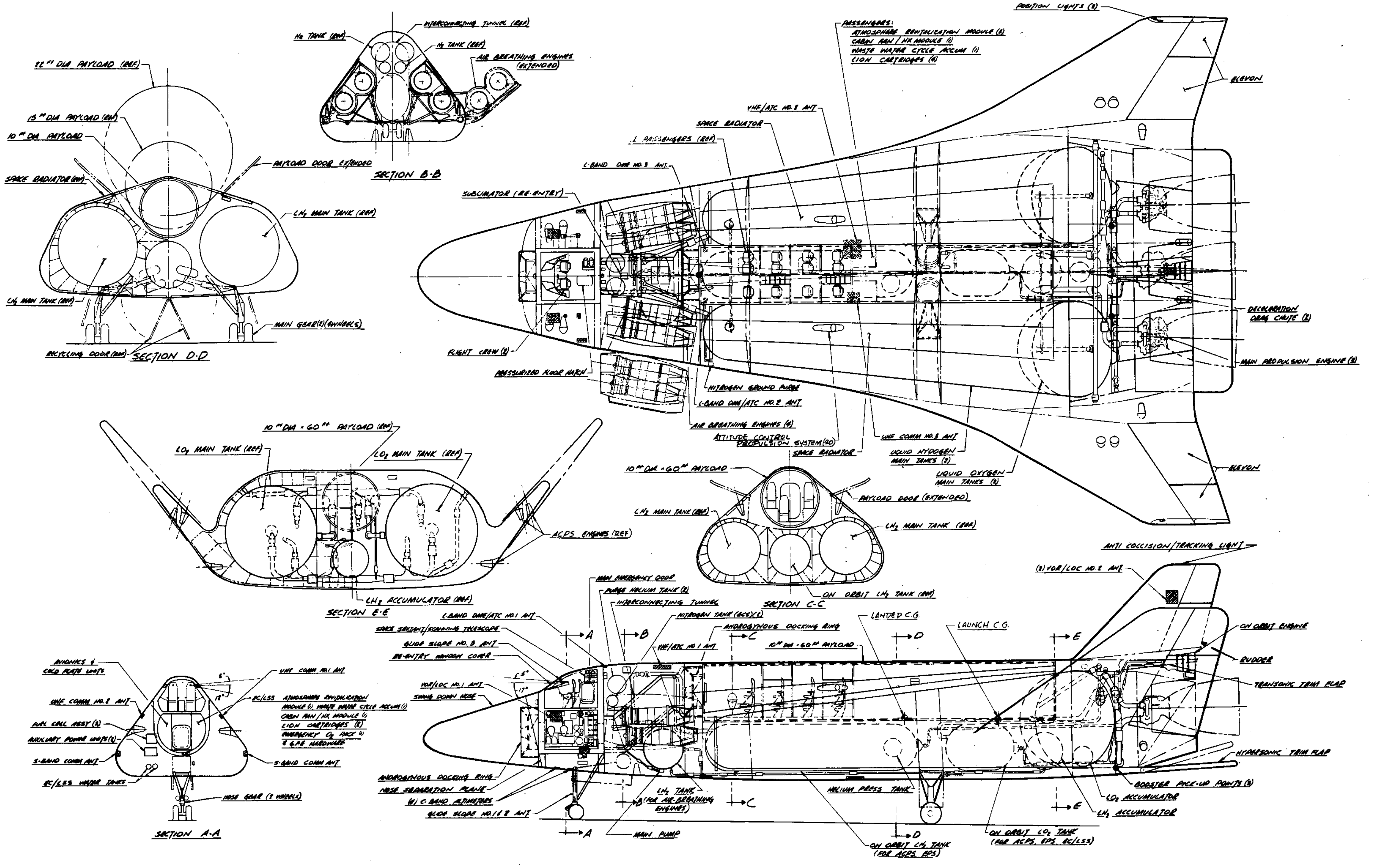


Fig. 1-18 Design 532 Orbiter General Arrangement and Inboard Profile

commodations in the cabin and the EVA airlock are deleted, and lighter and less elaborate food and waste management systems are provided.

AVIONICS – The 532 avionics system meets a Fail-Ops, Fail-Safe criteria with on-board checkout capability to the black box level. It retains much of the 518 system including the centralized digital computer (500K ops/sec, 64K words, 32 bits/word), multiplexed data bus (1mbs) and the integrated displays and controls. Voice communication to the ground is accomplished by an S-band system aboard the orbiter in conjunction with limited use of MSFN facilities. It has a cooperative target rendezvous capability (100 n mi) using VHF ranging and an optical telescope. Maximum use of the current hardware inventory, such as military developed four-gimballed inertial system (ASN-98 or LN-15), is intended to gain early availability and minimum development risk, while retaining the capability to evolve to the advanced 518 Avionics system.

1.4.3 Design 532 Booster

The Design 532 booster (Fig. 1-21) follows the same philosophy used in Design 518: optimization for the booster mission, and choice of approaches offering lowest technical risk. Using F-1 engines (uprated) for main propulsion is a significant step toward reducing program development risk and cost. The booster, therefore, has a higher weight at launch, but its empty weight is of the same order as Design 518 booster.

1.4.3.1 Aerodynamic Configuration

The body contour is similar in cross section to that of Design 518. The nose lines blend into the basic body through a transition section which houses the fly-home engines. The aft end of the body supports five F-1 engines, brought as close together as feasible. The center-to-center distance between the engines is 163 inches. Two fairings straddle the base of the vertical fin to protect the upper engine nozzles in a manner equivalent to the S-1C.

A delta wing was chosen for the reasons outlined for the Design 518 booster.

By loading about 103,000 lb of RP-1 (equal to fly-home plus reserves), a self-ferry range of 406 n mi is achieved with a 20 percent reserve. No strap-on components or landing gear augmentation is required, and all requirements for standard takeoff, cruise and go-around are met.

1.4.3.2 Subsystems Installation & Features

STRUCTURE AND TANKS – The main propellant tanks are of conventional Saturn IC technology and are 29 feet in diameter with conventional domes. They form the main body structure. The uninsulated oxygen tank is placed forward to enhance controllability during ascent, as well as to avoid thermal gradients in the engine thrust structure and wing attachment region. The aft tank contains the RP-1 fuel, as well as passageways for the oxygen feed lines.

MAIN PROPULSION – The entire main propulsion system makes use of S-1C designs wherever feasible. The five main rockets are F-1 engines, uprated to an already demonstrated 1.8 million-lb thrust. The combination of gimbal travel and selective engine shutdown gives the thrust vector sufficient range to maintain control over all extremes of cg travel, including operation with a kick stage.

AIR BREATHING PROPULSION – Cruise thrust is supplied by six RB211 turbofan engines developed for the L1011 Airbus. With RP-1 available in the vehicle, it is employed for cruise fuel as well. This led us to the selection of RB211's, whose low specific fuel consumption results in a lower total system weight than if ten JTF 22 orbiter engines were used. The selected engines are heavier, but the added weight near the nose is advantageous in achieving vehicle balance. The air breather installation is designed so that the engines can be deployed to a favorable location in the airstream, without excessive interruption of fuselage structural continuity, and without breaking through the TPS. As indicated in Fig. 1-21 each group of three engines is rotated 180 deg about a fore-and-aft axis. They pass through contour high on the fuselage sides through openings covered by double-hinged recycling doors. The fuel line accommodates engine deployment by a rotating joint on the hinge line. The deployed position provides good access for engine maintenance.

OTHER EQUIPMENT – Crew compartment commonality with the orbiter is achieved to the extent described for the Design 518 booster. Similarly, the avionics, electrical power and environmental control subsystems have common usage of booster and orbiter components wherever feasible.

As with Design 518, the landing system is a standard aircraft design. However, in this case the main

DESIGN 532 BOOSTER	
Lift Off Weight:	6,353,426 lb
Staging Weight:	753,426 lb
Landing Weight:	610,271 lb
Dry Weight:	593,765 lb
PROPULSION SYSTEMS	
• Main Rocket: Uprated F1 (1.8M lb Thrust)	(5)
• Air Breathing Engine: RB211	(6)
• Attitude Control Rocket: 1,000 lb Thrust	(20)
L/D/α @ α_{max} Design (M = 20, 200K ft)	0.64/50 deg
Trimmed L/D_{max} (Subsonic)	6.4
Subsonic Approach Velocity (90°F, @ SL)	162 kt
PLAN AREA	14,884 sq ft
Wetted Area	
• Body:	24,250 sq ft
• Base:	1,162 sq ft
• Wing:	14,500 sq ft
• Tail:	3,400 sq ft
WING	
• Reference Area:	10,420 sq ft
• Exposed Area:	7,000 sq ft
• Taper Ratio:	0.286
• Aspect Ratio:	2.66
FIN	
• Exposed Area:	1,670 sq ft
• Taper Ratio:	0.414
• Aspect Ratio:	1.05
CONTROL SURFACES:	
• Outboard Elevon (2):	374 sq ft
• Inboard Elevon (2):	737 sq ft
• Rudder:	493 sq ft

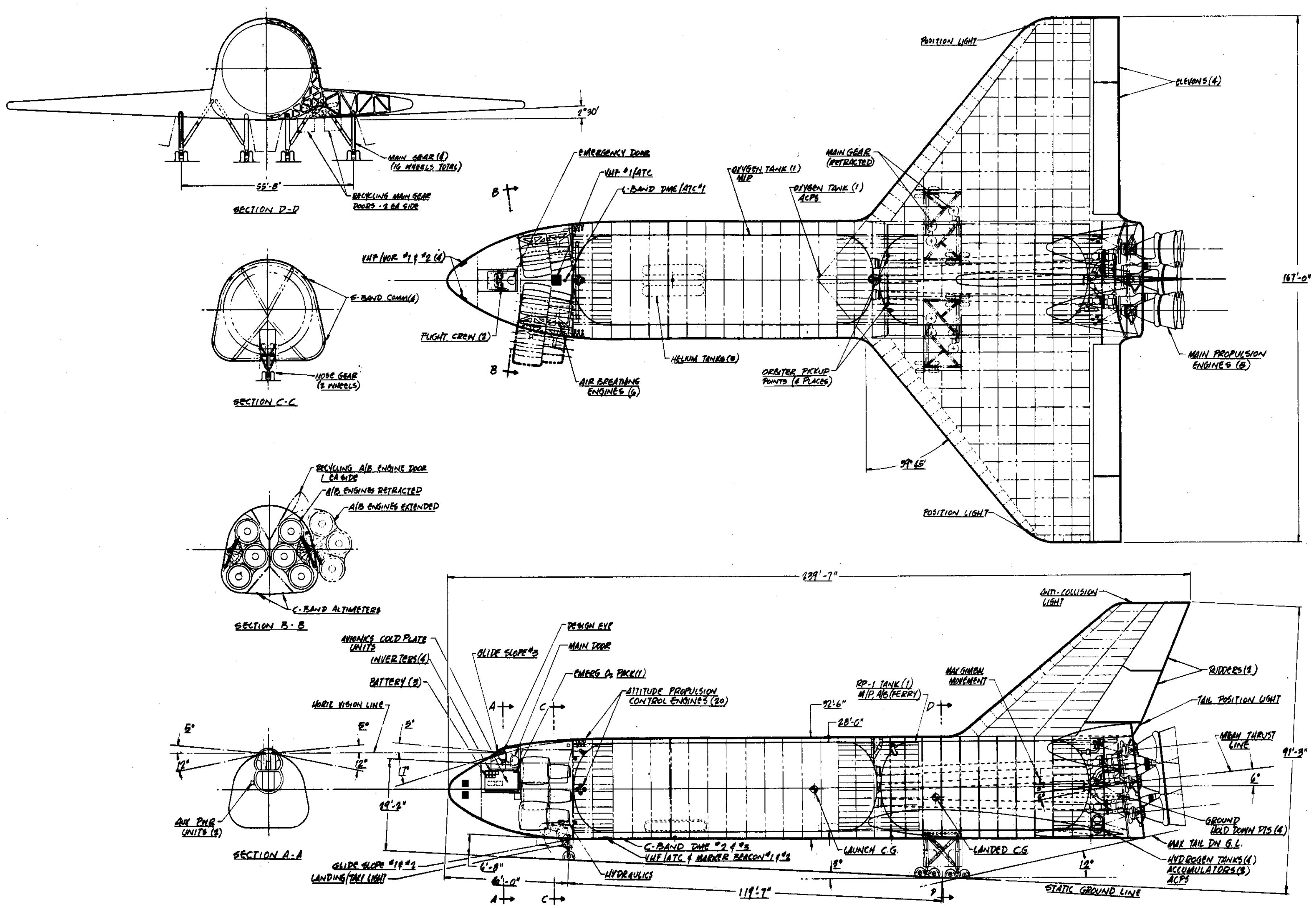


Fig. 1-21 Design 532 Booster General Arrangement

gear has four main legs with four-wheel bogies of 44 in. x 16 in. wheels.

1.4.4 Early Configurations

Toward our objective of achieving early useful capability within a low annual funding constraint, Design 532 has the performance to fly a 12,750 lb payload to a 270 n mi, 55 deg orbit by outfitting the orbiter with J2S engines (206K) in place of the baseline 250K high pressure engines. The J2S engines are 6 in. smaller at the maximum nozzle diameter and 10 in. shorter than manufacturer-estimated dimensions for the new engines. The three J2S engines are heavier (about 1000 lb) than the engines they replace, but the cg shift is within the allowable travel.

This early orbiter's configuration is indistinguishable from the Design 532 baseline orbiter shown earlier in Fig. 1-17 and 1-18.

Other system changes under consideration for early configurations are discussed in Section 2 in the study plans for electronics.

1.4.5 Growth Configurations

Grumman's baseline program for Design 532, described in the Summary, makes provisions for growth beyond the baseline system capabilities. These include a change to second generation avionics which will increase mission reliability by developing to the Fail Ops/Fail Ops/Fail Safe criteria through increased redundancy. (These changes can be limited to those systems which have shown troublesome behavior tendencies in operating experience.) Increased autonomy will also be achieved.

By far, the most significant capability increase will. be brought about in payload size and weight that can be delivered to orbit.

We are including Phase B studies of extra-large diameter payloads to 22 ft, and an expendable kick stage that will provide payload capabilities of more than 70,000 lb to space station orbits or 50,000 lb to more difficult orbits.

For use with heavy orbiter payloads, a kick stage is added behind the orbiter (Fig. 1-22). Low cost is the primary criterion in the design of this expendable component. Separate LH_2 and LO_2 tanks with ellipsoidal domes avoid the expense of a common bulkhead. These 19 ft diameter tanks are joined by a cylindrical section. At each end, a conical transition section transmits thrust. The forward transition attaches to four built-in thrust points around the center engine of the orbiter. The aft transition supports the four LH_2/LOX engines, their plumbing and actuators. Engine nozzles are shielded by a conical skirt. Gimballing is restricted to 7 deg radially outboard and ± 1 deg tangentially for roll control. This provides adequate control and reduces cost. Instrumentation and controls are reduced to a minimum. The overall length of the stage, before nozzle extension, is 65 ft.

Total weight of the kick stage is 230,000 lb at liftoff. The ideal delta V supplied to an orbiter carrying 76,500 lb of payload is 3500 fps.

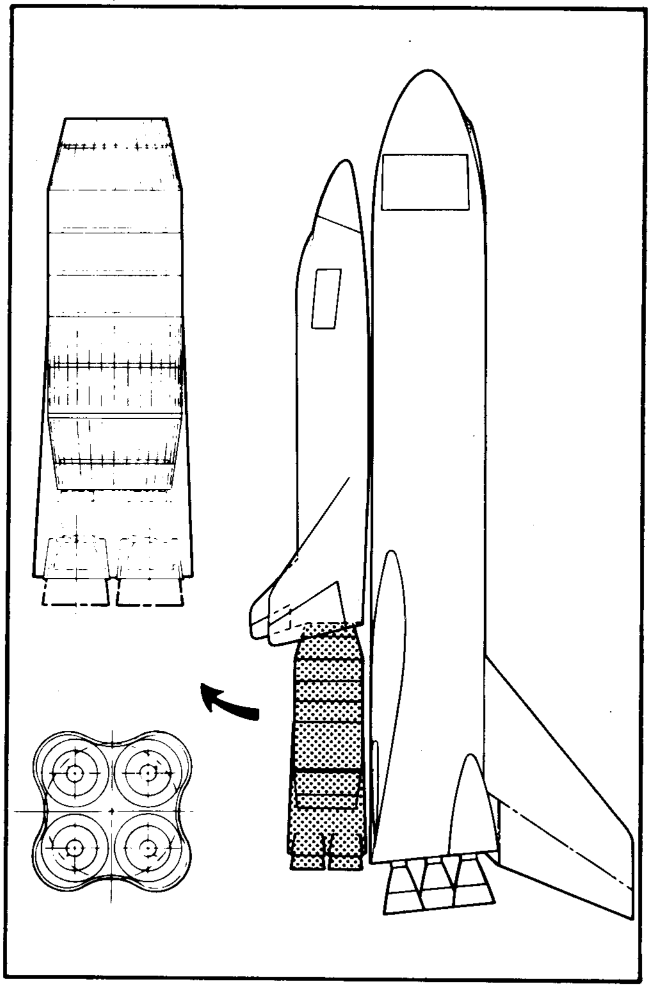


Fig. 1-22 Design 532 With Kick Stage

1.5 AERODYNAMICS

1.5.1 Aerothermo Configuration Development

The aerothermo characteristics of Grumman Designs 518 and 532 have been generated through a process of continuing design studies in conjunction with wind tunnel test programs.

1.5.1.1 Mated Configuration

The combined geometric shape of the mated vehicles during ascent generates a complex flow field produced by multishock interaction and shock reflection from local surfaces. The effectively streamlined shape of the mated Design 518 and 532, and the use of swept wing and tail surfaces reduce the impulsive loss due to drag during boost and minimize surface shock impingements with their consequent heat-transfer amplification. The "belly-to-belly" mating also minimizes thermal protection penalties during boost and the subsequent separation, since the bow shocks and rocket plumes will primarily intercept the protected windward vehicle surface areas. The resulting surface temperature patterns (Fig. 1-23) are based on the boost trajectories shown in (Fig. 1-24) The complex abort analysis described in Section 2 will yield the critical temperature design conditions for that environment.

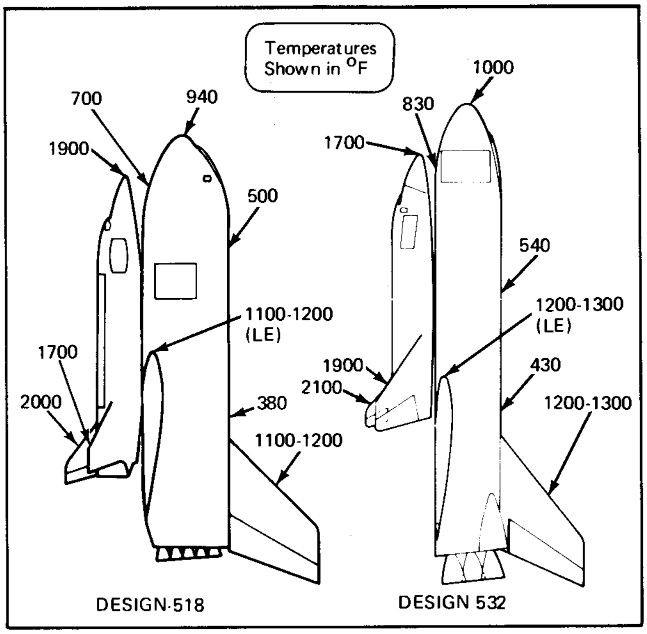


Fig. 1-23 Maximum Booster & Orbiter Boost Temperatures. *Orbiter maximums occur after separation*

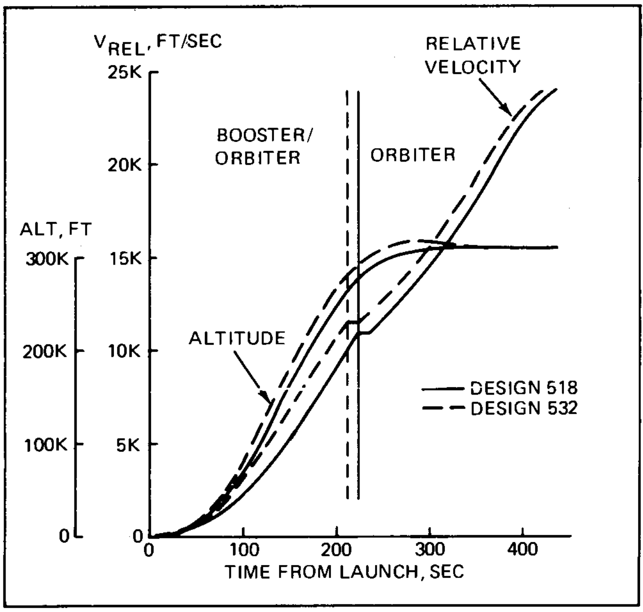


Fig. 1-24 Boost Altitude & Velocity vs Time for Designs 518 & 532

1.5.1.2 Orbiters

The aerothermodynamic design of both Design 518 and 532 orbiters provides the required lift to drag ratios (L/D) in the sub and hypersonic flight modes, with adequate hypersonic trim capability to accommodate diverse mission requirements (high and low-cross range).

HYPERSONICS - The hypersonic lift-to-drag ratios of 1.79 and 1.70 (Fig. 1-25) of Design 518 and 532 orbiters have been achieved by proportioning the planform, windward surface camber, forebody shape and general leading edge contours to provide low drag sections while maintaining desirable longitudinal and lateral-directional stability characteristics and sufficient margin to preclude critical thermodynamic problems. This provides the 1500 n mi aerodynamic cross-range potential.

Fin rollout is used to create stabilizing moments in roll and yaw, particularly at high angles of attack when the lee side pressures are negligible.

These characteristics have been accomplished by quantitative design studies employing Grumman's hypersonic aerodynamics prediction program. The ability of the program to handle a high degree of configuration detail is shown in the comparison of wind tunnel test and predicted results presented in Fig. 1-26.

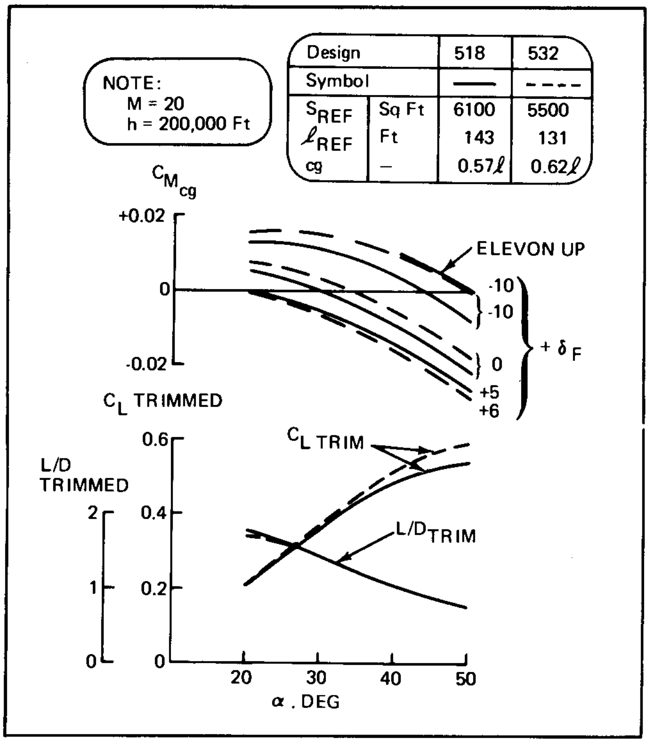


Fig. 1-25 Orbiter Hypersonic Aerodynamic Characteristics

Although the vehicle is primarily shaped for aerodynamic performance, significant attention has been paid to the configurational aspects of thermodynamics. For example:

- Large radii (50 in) and highly swept leading edges limit maximum temperatures to levels only 30 percent higher than centerline values
- The full upperbody cross sections embody gradual tumblehome in conjunction with large chine radii to prevent high heating reattachment zones seen on ASSET-type fuselages
- Reasonably high nose bluntness and body camber prolongs the zone of normal shock entropy, thus keeping centerline heating below attached shock values
- Smooth body lines and highly swept tails greatly reduce leading edge heating and avoid shock impingement effects on tails at low angles of attack (Fig. 1-10)

The thermodynamic impact associated with cross-ranging has also been carefully considered in the development of Designs 518 and 532. The trajectories shown in Fig. 1-27 were developed for 200 n mi and 1500 n mi cross range with minimum heat-

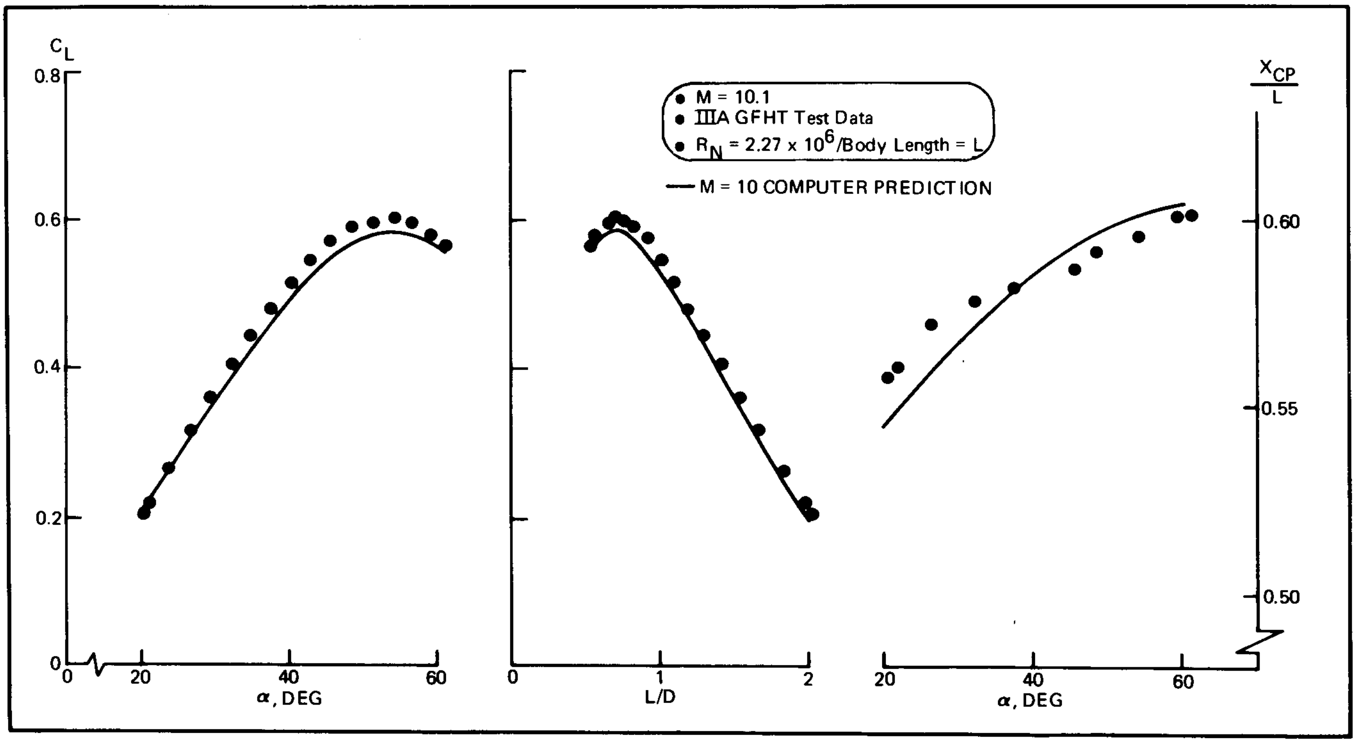


Fig. 1-26 Hypersonic Prediction Capability. *Excellent agreement between predictions & data is achieved with Grumman Hypersonic Prediction Program*

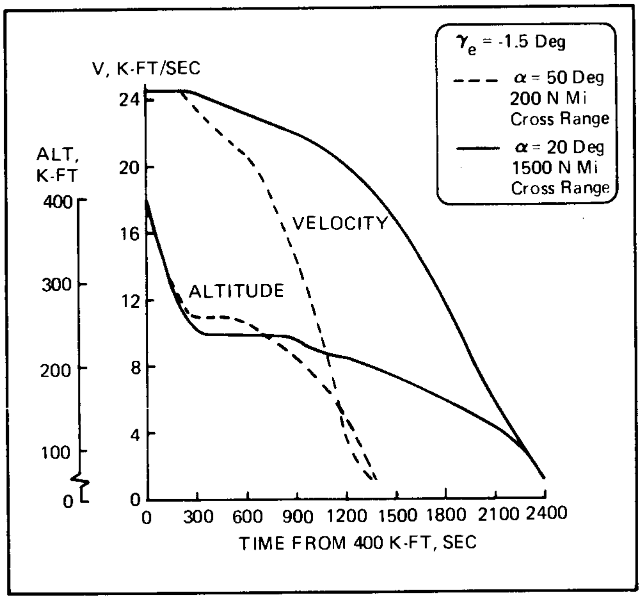


Fig. 1-27 Orbiter Reentry Trajectories for 200 & 1500 n mi Cross Range

transfer penalties. The primary impact is higher leading edge temperatures and greater total integrated heating, while underbody temperatures are only 300° higher as a result of more severe turbulent heating for the maximum cross-range mission.

These effects are shown in terms of vehicle maximum isotherms (Fig. 1-28) and the temperature time history (Fig. 1-29). Isotherms for both the high and low cross ranges were generated for the present designs using proven analytical techniques in conjunction with wind tunnel phase change paint model data.

TRANSONICS - The transonic speed regime for both shuttle stages is brief; however, safe and manageable flight characteristics in this regime are essential.

Transonic characteristics depend mostly on the overall slenderness ratio (volume/length^3), cross-section area distribution, and pitch angle. Past experience with compact lifting bodies (M2-F2/3, HL-10, X-24, etc.) shows that boattailing to reduce base area for better subsonic performance leads to early transonic flow separation. Separate split upper and lower control surfaces are one means to achieve satisfactory longitudinal and lateral stability as well as linear control characteristics.

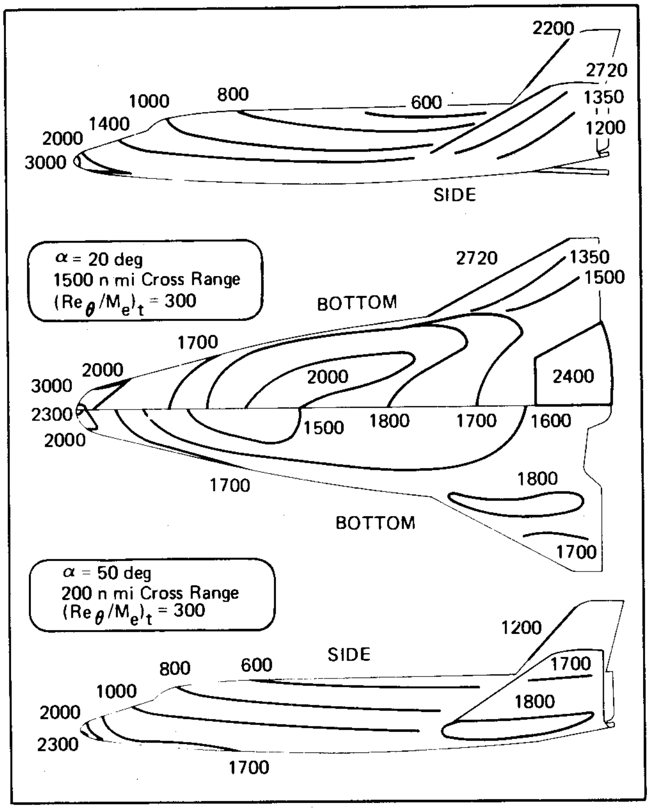


Fig. 1-28 Maximum Orbiter Reentry Isotherms Reflect Cross Range Temperature Penalties

Grumman-Northrop lifting body experience provides a base for the initial design. A thorough transonic model investigation will be conducted early in the study phase to acquire more quantitative information.

SUBSONICS - Throughout development of Design 518 and 532 orbiters, emphasis has been placed on low-speed aerodynamic characteristics. The excellent longitudinal and directional characteristics (see Fig. 1-30) have been achieved by paying careful attention to local flow problems in the wind tunnel and optimizing the interplay between such variables as local upper surface body lines, base area, and fin geometry while confining the external shape changes within the dictates of hypersonic requirements. Through the process of constant design evolution, Design 518 has been refined to achieve a subsonic trimmed lift-to-drag ratio of 5.1. Design 532 has a trimmed L/D of 4.9 due to trim penalties associated with its shorter tail arm. Stable lateral-directional and longitudinal characteristics are exhibited by both configurations.

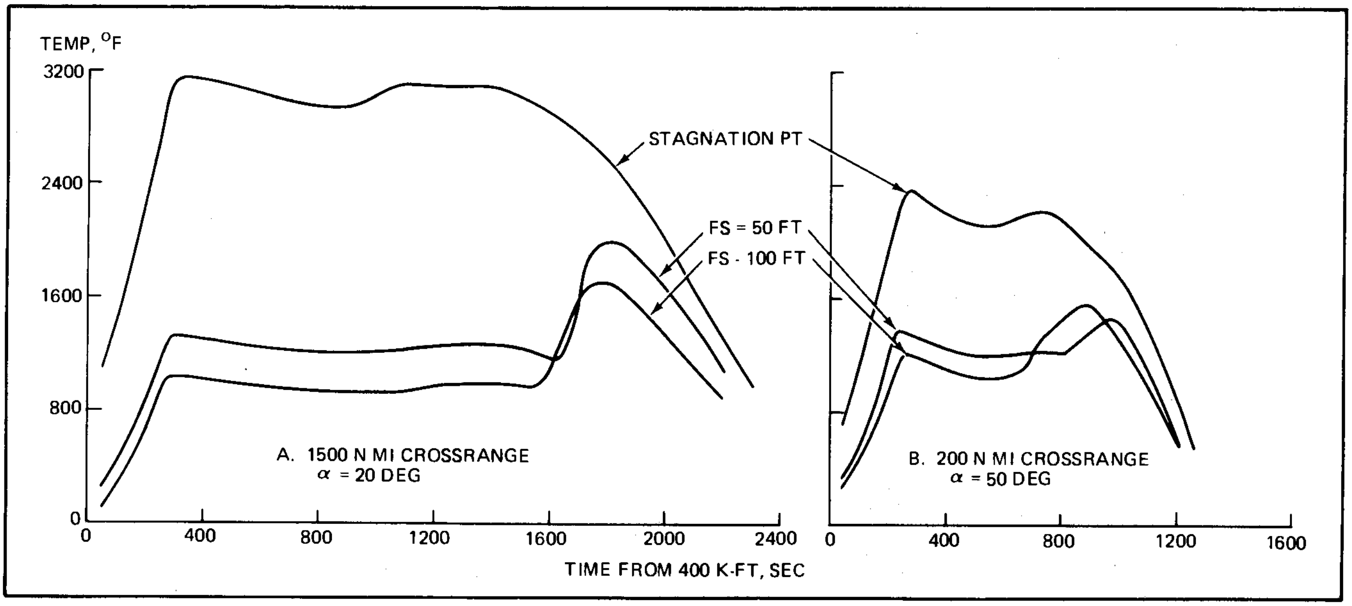
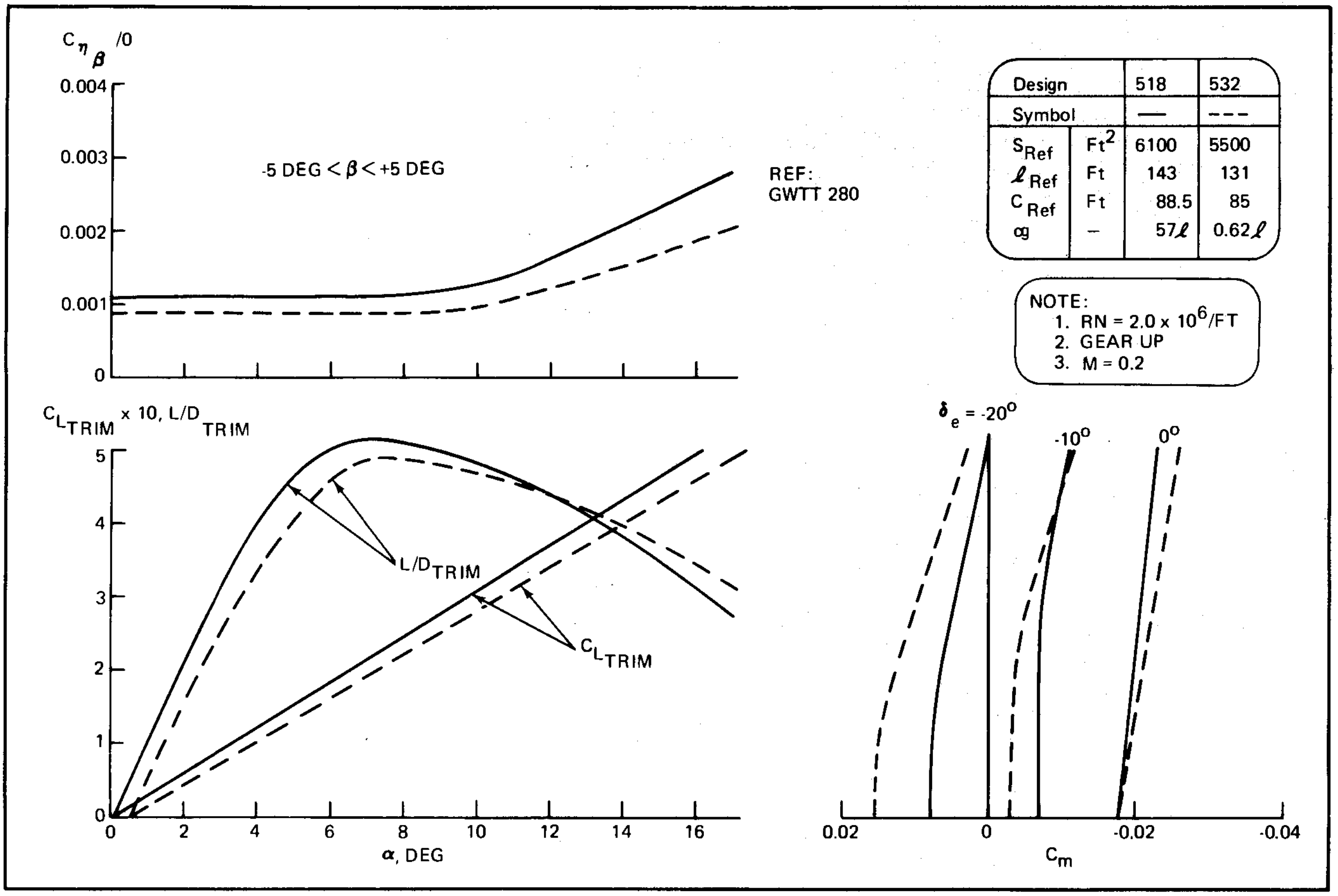


Fig. 1-29 Orbiter Reentry Temperatures vs Time at Windward Stations for 200 & 1500 n mi Cross Range



Design		518	532
Symbol		—	- - -
S_{Ref}	Ft^2	6100	5500
ℓ_{Ref}	Ft	143	131
C_{Ref}	Ft	88.5	85
cg	–	57ℓ	0.62ℓ

NOTE:
1. RN = 2.0 x 10^6/FT
2. GEAR UP
3. M = 0.2

Fig. 1-30 Orbiter Low Speed Aerodynamic Characteristics. *Careful Attention to Local Lines, Base Area & Fin Geometry Provide High L/D & Satisfactory Stability*

FLYING QUALITIES - The low-speed handling qualities of the orbiter and booster generally satisfy the requirements of MIL-F–8785B for transport type aircraft. The unaugmented low-speed characteristics of lifting body vehicles are generally poor with respect to roll/yaw coupling and roll damping. Considerable attention has been devoted to providing these vehicles with the best basic aerodynamic configuration from a stability and control standpoint without penalizing hypersonic reentry capability and subsonic performance. The basic capability is augmented by a 3-axis stability augmentation system.

Typical handling qualities for both the Design 518 and Design 532 orbiters, based on low-speed wind tunnel tests, are described below together with a comparison of these characteristics for the Lockheed C-5A and the Grumman A-6A (which has over 45,000 carrier landings without an accident).

- Lateral Directional Dynamics – The dutch roll frequency and damping compared in Table 1-5 and in Fig. 1-31 with the requirements of MIL-F-8785B, show that the basic lateral-directional dynamic stability of the orbiter is satisfactory. The control coupling induced by the rolled out fins is indicated by the ω_ϕ/ω_d factor. If further analysis indicates roll/yaw coupling is a problem, it will be eliminated via cross-feed to the center fin/rudder and/or by hinge line re-orientation to null out the aileron induced yawing moment
- Trim – The vehicle is statically stable both longitudinally and directionally and is capable of being trimmed throughout the angle of attack and sideslip range required for approach and landing

Table 1-5 Comparison of Dutch-Roll Frequency & Damping

Aircraft / Parameter*	Orbiter	A-6A	C-5A	MIL-F-8785B Reqmt
• Dutch roll freq, ω_d	1.42	1.23	0.50	>0.4
• Dutch roll damping, ζ_d	0.44	0.110	0.20	>0.08
• ω_ϕ/ω_d	0.575	0.87	–	0.8–1.1**

*All values shown are for unaugmented vehicles.
**Recommended; not a MIL-F-8785B reqmt.

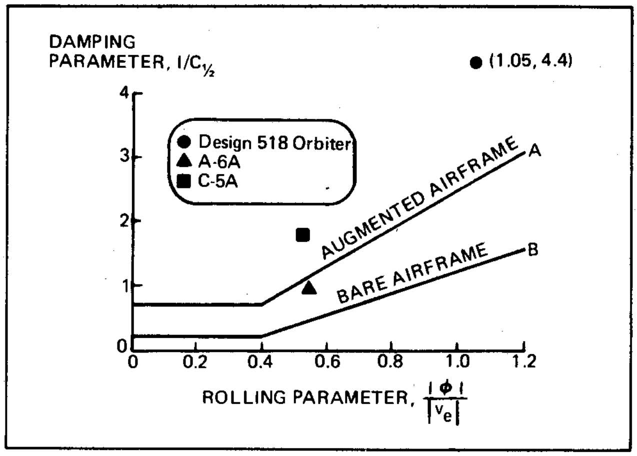
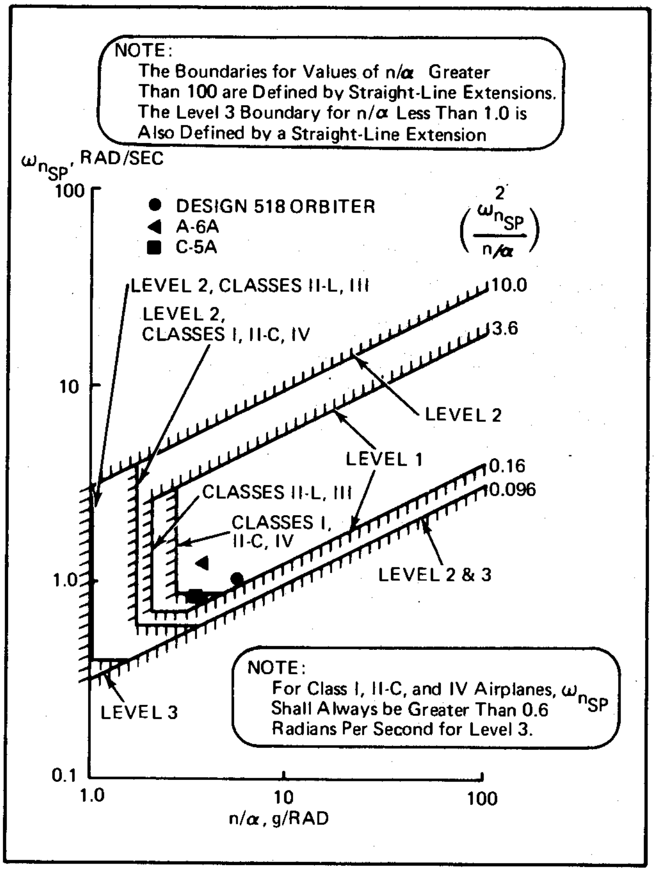


Fig. 1-31 Dutch-Roll Dynamic Characteristics. *The Unaugmented Orbiter Satisfies the Requirements of MIL-F-8785B in the Landing Configuration*


NOTE:
The Boundaries for Values of n/α Greater Than 100 are Defined by Straight-Line Extensions. The Level 3 Boundary for n/α Less Than 1.0 is Also Defined by a Straight-Line Extension

NOTE:
For Class I, II-C, and IV Airplanes, $\omega_{n_{SP}}$ Shall Always be Greater Than 0.6 Radians Per Second for Level 3.

Fig. 1-32 Longitudinal Short Period Dynamic Characteristics. *The Unaugmented Orbiter Satisfies Long Dynamics Requirements of MIL-F-8785B*

- Longitudinal Dynamic Stability – The longitudinal dynamics were evaluated using a 3 percent (body length) static margin. Results are shown in Fig. 1-32. This figure compares the aircraft short period response with requirements of MIL-F-8785B. The results show that the unaugmented vehicle is satisfactory. If the static margin is reduced to 1 percent necessary for subsonic performance the response is still adequate for landing with some increased workload on the pilot. Augmentation will be used to improve the response to an optimum level in either case

- Roll Performance – The low-speed roll performance for the orbiter is presented in Table 1-6 This table shows that the use of the elevons will provide sufficient roll control power. The roll computations assume plus or minus (±) 15 degrees of elevon deflection.

- One Engine Out Control – With the most critical engine failed at a landing weight of 194,000 lb, adequate control power from both the center fin and the elevon control surfaces is available to trim, down to 160 kt. This assumes the elevon is limited to ±15 deg from trim.

Table 1-6 Low-Speed Roll Performance

Roll Parameter \ Aircraft	Orbiter	A-6A	C-5A	MIL-F-8785B Reqmt
• Steady-state roll rate, deg/sec	35.4	60.0	–	–
• Roll time constant, sec	0.91	0.5	1.4	< 1.3
• Time to bank 30 deg*, sec	2.0	1.43	–	< 2.5

*Assumes 0.6-sec ramp input

1.5.1.3 Boosters

The design evolution of boosters for Design 518 and 532 emphasize development of good low-speed aerodynamics (Fig. 1-33) without impairing hypersonic flight characteristics.

HYPERSONICS – Hypersonically, the booster is configured to fly at high angles of attack ($\alpha = 50$ deg). This operational mode coupled with large wing leading edge radii and sweep angles keep underbody fuselage temperatures below 1300°F except in the leading edge and nose regions (See Fig. 1-34). The boosters are designed for hypersonic lateral-directional stability in high angle of attack flight through local windward aft body shaping. Operational and abort considerations may require hypersonic flight at low angles where these same designs do not have adequate directional stability.

Improved directional stability can be obtained by lessening the de-stabilizing forward body contribution and by increasing the effective vertical tail area through use of such geometric changes as shown and discussed in Subsection 2.1.5. The effects of such shape changes are reflected throughout the booster vehicle system design and are currently under study.

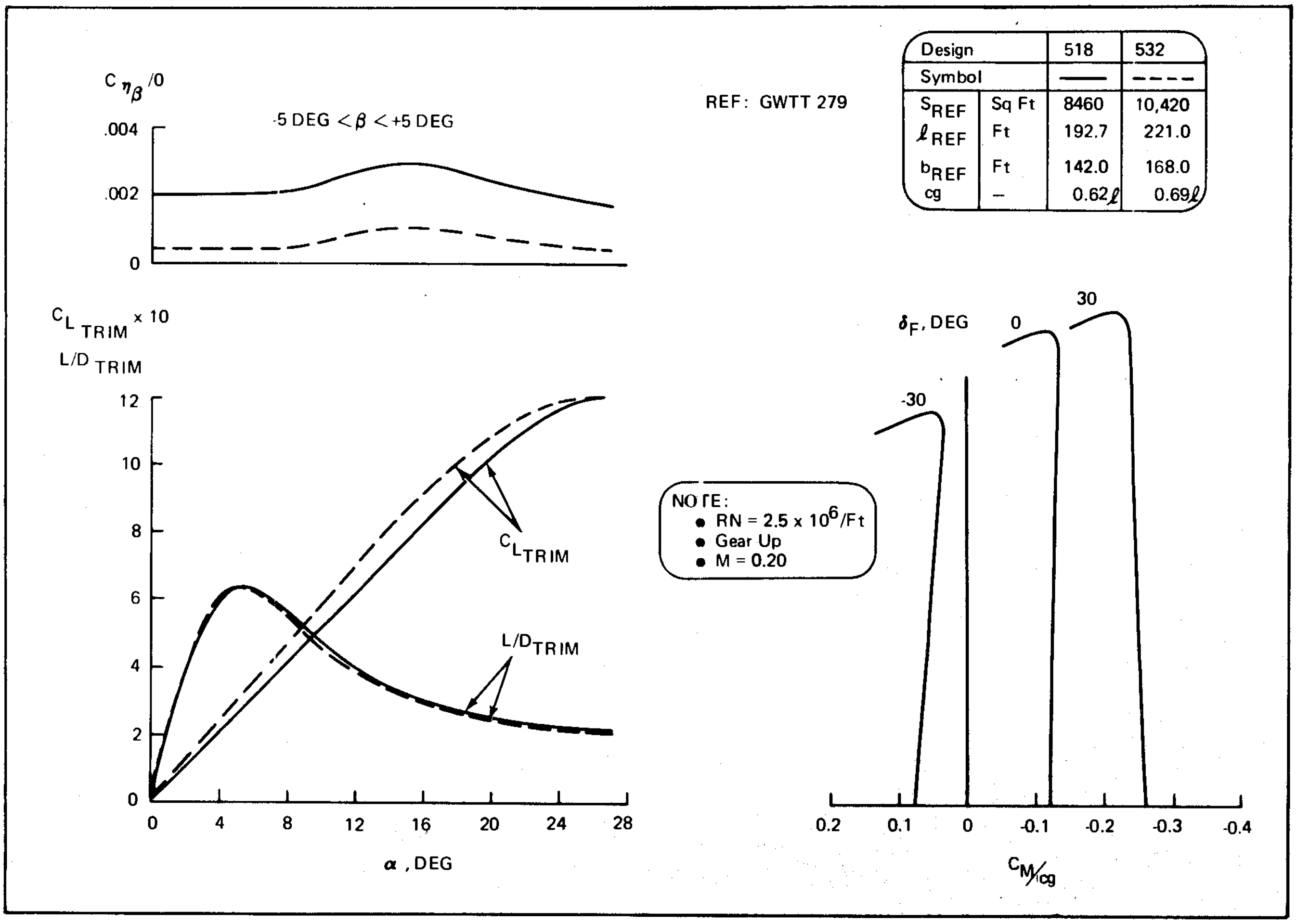
TRANSONICS – The transonic flow separation problem discussed previously for the orbiter applies to the booster as well. Because of the booster's basic shape, solutions developed for transonic aircraft are clearly applicable and will be verified by the wind tunnel investigation discussed in Subsection 2.1.5.4.

SUBSONICS – Preliminary results indicate that the use of a 10 percent thickness ratio delta wing arrangement provides the best combination of high aerodynamic efficiency for low weight, while minimizing buffet, flutter and aerodynamic heating problems of the various design approaches considered.

The use of moderate wing loadings (55 lb/ft^2) and large leading edge radii provide high lift capability (max. $C_L = 1.2$) and a subsonic lift-to-drag ratio of 6.4. Directional stability is provided through a top centerline positioned fin.

1.5.2 Performance

HYPERSONIC - DESIGNS 518 AND 532 – The hypersonic performance of both design 518 and 532 orbiters presented in Table 1-7 and the reentry footprint shown in Fig. 1-35 are based on the trimmed aerodynamic characteristics presented in Subsection 1.5.1.2. The orbiter's maximum cross-range potential is based on initial entry conditions at 400,000 ft altitude of 26,000 fps velocity and flight path angle of 1.4 deg. After the initial entry, a mild pull up-push over maneuver is followed by a near equilibrium bank lateral ranging glide which minimizes peak heating on exposed windward surfaces. The high cross



Design		518	532
Symbol		——	----
S_{REF}	Sq Ft	8460	10,420
ℓ_{REF}	Ft	192.7	221.0
b_{REF}	Ft	142.0	168.0
cg	–	0.62ℓ	0.69ℓ

Fig. 1-33 Low-Speed Aerodynamic Characteristics – Booster. *The 10% Thick Delta Wing Provides Good Low Speed Lift & Drag*

range potential is 1800 n mi for Design 518 and 1650 n mi for Design 532. The low cross range for both orbiters is 400 n mi.

SUBSONIC – Low-speed performance of both boosters and orbiters presented in Table 1-7 is based on the characteristics presented in Subsections 1.5.1.2 and 1.5.1.3.

- FAA factored field lengths have been calculated as shown in Fig. 1-36. Approach speeds are based on 130 percent of either power off stall speed or the speed associated with maximum usable C_L
- Approach climb gradients presented in Table 1-7 are for a sea level, 90° day operation in the approach configuration (gear up). The impact of this requirement for other nonstandard days and higher altitude is an item for future study

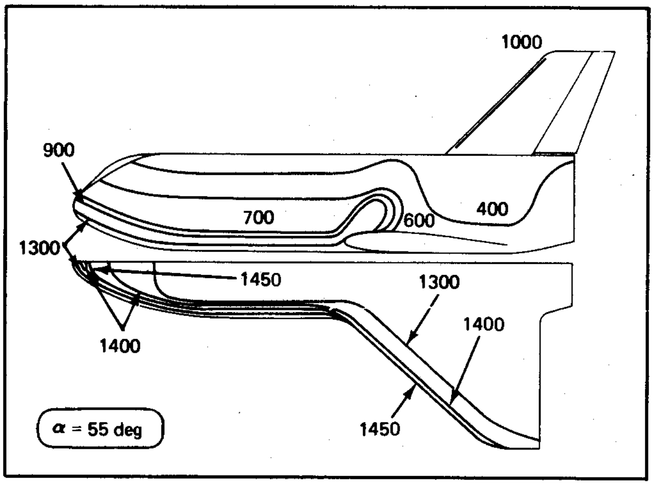


Fig. 1-34 Booster Reentry Temperatures

Table 1-7 Performance Summary

		Design 518		Design 532	
Hypersonic		Orbiter	Booster	Orbiter	Booster
L/D @ $\alpha = 20^\circ$ (M = 20, h = 200,000 ft)	–/deg	1.79/20	–	1.70/20	–
$C_{L\ Trim}$ @ $\alpha = 20^\circ$	–	0.203	–	0.204	–
L/D/α (@ $\alpha_{Max\ Design}$)	–/deg	0.78/50	0.76/50	0.78/50	0.64/50
$C_{L\ Max\ \alpha\ Design}$	–	0.54	0.82	0.59	0.78
Max Cross Range	n mi	1,800	–	1,650	–
Subsonic					
$C_{L\ Max\ Usable}$	–	0.56	1.2	0.56	1.2
$L/D_{Max\ Trimmed}$	–	5.1	6.4	4.9	6.4
Balanced Field Length (90°F, SL) (@ Max Cruise Wt)	ft	10,000	8,750	9,250	9,600
Ferry Range	n mi	630	374	517	406
Service Ceiling (@ Max Cruise Wt)	ft	13,000	15,500	14,300	14,700
Landing Approach Speed (90°F, SL)	kt	180	152	181	162
Approach α	deg	10.7	12.9	11.6	12.2
Factored Field Length (90°F, SL)	ft	9,200	7,600	9,400	8,300
Approach Climb Gradient (90°F, SL)	%	3.7	3.7	4.8	1.9

- Landing speeds up to 180 kt are characteristic of designs with high wing loadings that provide high performance throughout other portions of a mission. It is clear that ground facilities, flight and ground handling, crew size and visibility are significant among the many factors critical to reducing landing hazards and that proper consideration to these factors will provide safe landings at 180 kt
- Ferry range is based on a mission profile allowing 5 minutes for engine warm-up, taxi and take-off, a climb to and cruise at best cruise altitude, and 20 percent of initial fuel for reserves Fig. 1-37 shows payload range curves for both orbiters and boosters
- FAA balanced field lengths have been computed and are presented as a general curve in Fig. 1-38 In the case of the orbiters, deceleration for the refused takeoff is accomplished through use of parachutes and anti-skid brakes. For the boosters brakes only are used.

1.6 PROPULSION

The major features of the baseline propulsion subsystems are shown in Table 1-8.

1.6.1 Design 518

ORBITER 518 MAIN PROPULSION – Two 400K lb (nominal S.L.) high-pressure engines are provided for the main burn. Maximum gimbal angles are ±7 deg laterally and ±3 deg vertically. The engines require a single start, operate at a nominal mixture ratio of 6.0 and have extendable nozzles with an expansion ratio (200:1) to maximize performance. A throttling capability (to 50 percent thrust) is provided to limit vehicle accelerations. No deviations from the engine CEI specification have been identified as a result of our configuration study.

Main propellant is stored in three hydrogen and two oxygen tanks. The hydrogen tanks are interconnected; the engines are fed from a single tank,

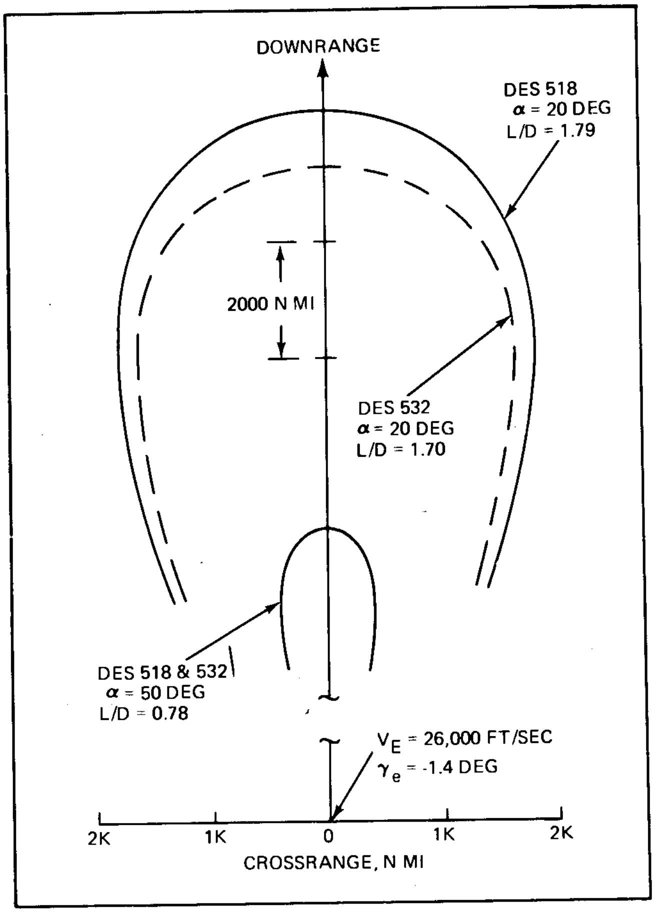


Fig. 1-35 Aerodynamic Cross-Range Capability. *Both Orbiters Provide Lateral Range Capability Beyond 1500 n mi to allow for Maneuvering & Thermal Relief*

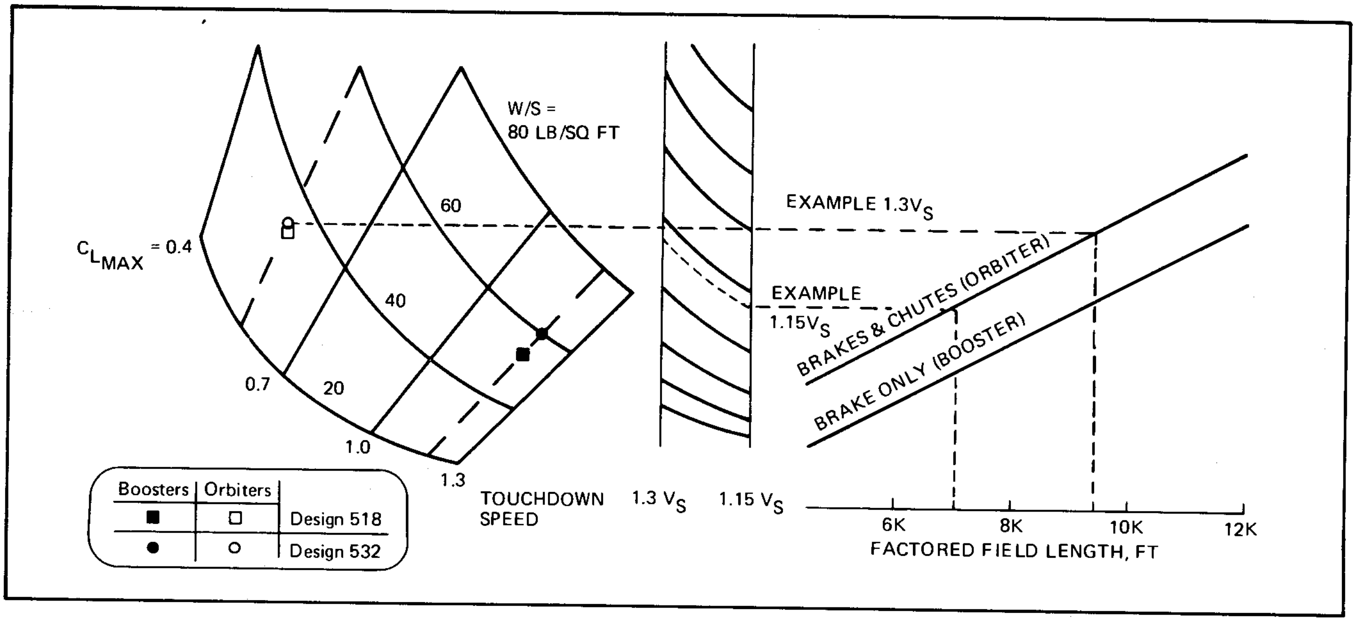


Fig. 1-36 FAA Landing Field Length. *Factored Field Lengths of Less Than 1000 Ft are Characteristic of Orbiters & Boosters*

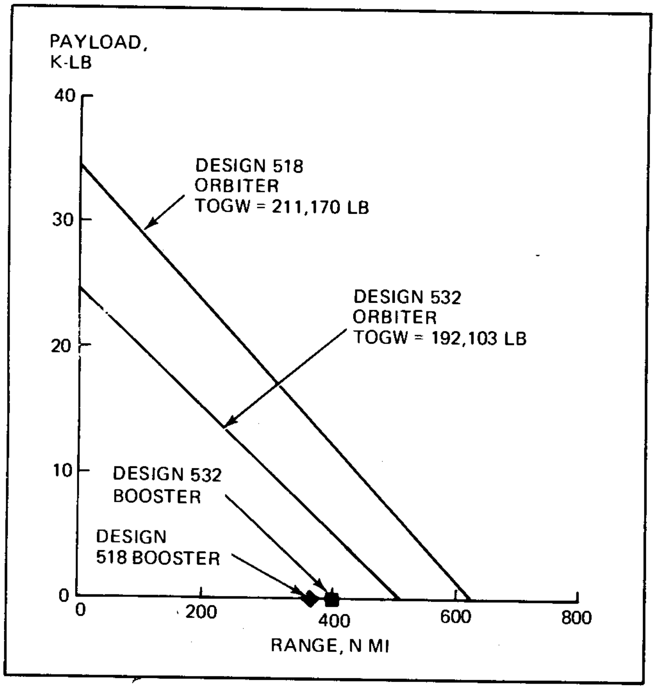


Fig. 1-37 Ferry Range. *Practical Ferry Capability is Achieved by Sustituting Fuel for Payload*

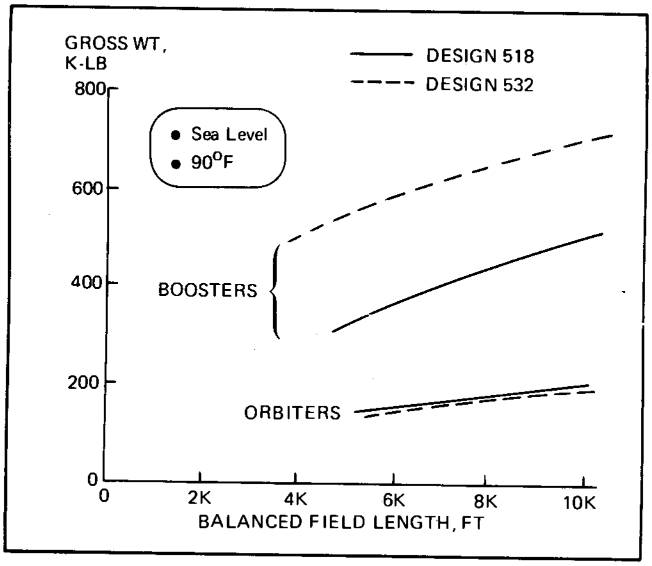


Fig. 1-38 Takeoff Field Length. *Balanced Field Lengths of Less Than 1000 Ft are Achieved Without Compromising Basic Mission Capability by Using "Strap-Ons"*

which acts as a sump. The O_2 tanks feed into a common line large enough to serve as a sump. The O_2 tanks are pressurized by helium, which is stored in bottles inside the H_2 tanks. To minimize the helium requirements the gas temperature is increased by an engine heat exchanger.

LH_2 tanks are internally insulated by evacuated honeycomb that limits structural temperature excursions and minimizes heat leaks. The LO_2 tanks are uninsulated internally.

There are no common tank bulkheads. Propellant feed lines are external to the tanks. Nonstructural tanks with added external multilayer superinsulation limit boiloff in on-orbit and air breathing propellant tanks. Dry external N_2 is maintained

Table 1-8 Salient Features of Propulsion Subsystems, Study Baseline Configurations

	Design 518		Design 532	
	Booster	Orbiter	Booster	Orbiter
Main Engines				
• Propell't; & O/F	H_2-O_2;6.0	H_2-O_2;6.0	LOX-RP;2.27	H_2-O_2;5.5
• No. & Thrust (S.L.)	12-400K	2-400K	5-1800K (F-1)	3-250K
• Expansion Ratio	55	90/200	16	90/200
Attitude Control				
• No. & Thrust	15-1000lb	26-1000lb	20-1000lb	20-1000lb
• Propellant	← GOX – GH_2 →			
• Aux Equipt	← High Pressure Turbo Pump Conditioning →			
Air-Breathing Deployable Instls	8-JTF22(H_2)	4-JTF22(H_2)	6-RB211-20(RP)	4-JTF-22(H_2)
Orbit Maneuv'g	———	H_2-O_2,1-15K(RL10)	———	H_2-O_2,1-15K(RL10)
Main Cryo Tanks	1-H_2 1-O_2	3-H_2 2-O_2	1-RP-1 1-O_2	2-H_2 2-O_2

within vehicle tank closures before launch to prevent accumulation of frost. Superinsulation closures are pressurized with helium after reentry for similar protection. Detailed discussion of propellant tank design is contained in Subsection 1.7.

The orbit maneuvering propulsion system consists of one RL 10 engine which is fed from the on-orbit tanks. Autogenous pressurization is used.

ORBITER 518 AIR BREATHERS – The baseline system consists of four JTF-22 deployable non-augmented hydrogen fueled turbofan engines, which are stowed in pressurized wells in the forward fuselage. Engines are started by windmilling, and fuel is pumped from the propellant tanks by the turbo-machinery of the attitude control propulsion system. The JTF-22 is currently under development at Pratt & Whitney for use in the Navy/Grumman F-14B.

ORBITER 518 ATTITUDE CONTROL – The baseline consists of a high-pressure turbo-pump system because of its versatility to handle fluid requirements for other subsystems, flexibility to accommodate changing orbiter mission duty cycles, and its high performance.

Attitude control system propellants are stored in bellows tanks within the on-orbit propellant tanks as shown in Fig. 1-39. The bellows tanks contain 2000 lb of H_2 and O_2 and are refilled once in space from the on-orbit tanks during a nominal mission. The helium pressurized tanks provide NPSH to the O_2 and H_2 turbopumps.

Separate low-temperature gas generators drive the turbines, which pump propellant through heat exchangers to high-pressure accumulators. There is enough ambient temperature gas in the accumulators to fire six 1K engines for 10 seconds. Since the turbo machinery will be required to start up about 30 times per flight, with a start up time of 1 to 2 seconds, vent gas is used to continuously chill the insulated pumps during active mission phases.

Twenty-six 1000 lb thrusters (Fig. 1-40) permit vehicle translation and rotation maneuvers in space. For reentry, doors are closed on the windward thrusters as shown in Fig. 1-41. The accumulators supply gaseous H_2 and O_2 for ECS, EPS, and APU. The turbopumps supply high-pressure liquid hydrogen to the cruise engines. The ACPS engines also serve as a backup to the OMS engine.

BOOSTER 518 MAIN PROPULSION – Twelve 400K high-pressure engines are used in the 3.5 million lb GLOW configuration. The initial thrust/weight of 1.37 is derived from consideration of

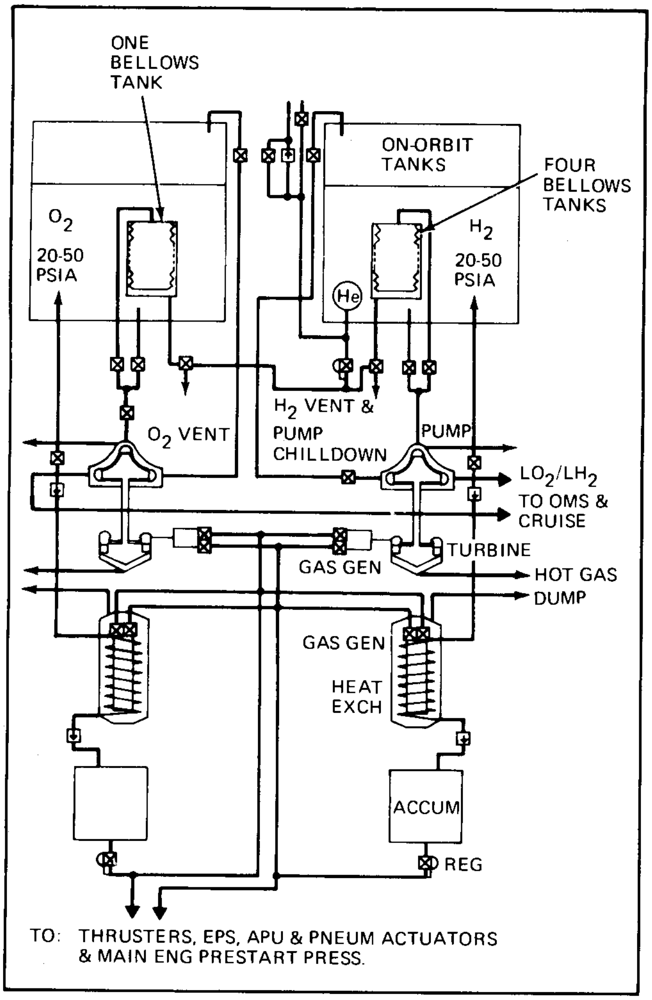


Fig. 1-39 **ACPS High-Pressure Turboprop Conditioning System**

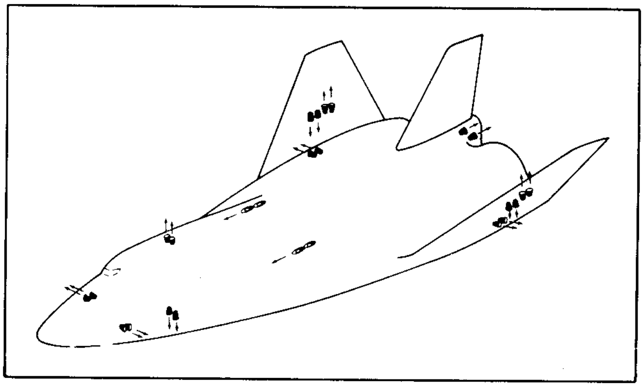


Fig. 1-40 **Design 518 Orbiter Attitude Control Thruster Locations**

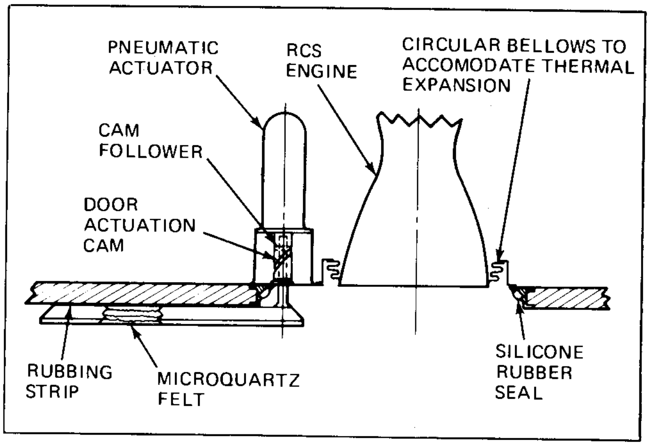


Fig. 1-41 **Conceptual Design of Reentry Closure for Windward Thrusters**

engine-out requirements, gravity loss penalties, booster base area, and aerodynamic loads encountered at maximum dynamic pressure. All engines are required to gimble ±7 deg to track the boost cg shift and to maintain control authority.

Configuration weight studies have indicated that an engine mixture ratio of 6.0 and engine expansion ratio of 55 result in minimum weight vehicles.

The Design 518 booster required no deviations from the engine CEI specification.

The engines are fed from one O_2 and one H_2 tank. The oxygen tank is pressurized with helium; autogenous pressurization is used for the hydrogen tank. Insulation techniques are the same as those used in the orbiter. A compartment within the main LH_2 tank supplies fly-home fuel.

BOOSTER 518 AIR BREATHERS – The configuration consists of eight JTF-22 engines mounted and deployed as in the orbiter. The selection of these engines for use on both orbiter and booster is based on installed weight comparison of various engines currently in development. A typical comparison is shown in Fig. 1-42 for a 400 n mi cruise back range. Absolute values and identifications are omitted because of security classification.

BOOSTER 518 ATTITUDE CONTROL – The booster ACS design consists of a high-pressure turbopump system that uses the same components as the orbiter. Ganged turbopumps and heat exchangers deliver propellants for the higher thruster demands. Fifteen 1K engines supply vehicle torque for post separation and reentry maneuvers. Nine engines are mounted forward for yaw and minus pitch, and six aft for roll and plus pitch. The thruster arrangement is redundant in all rotation axes and all engines are located on the upper side of the vehicle to minimize reentry heating effect.

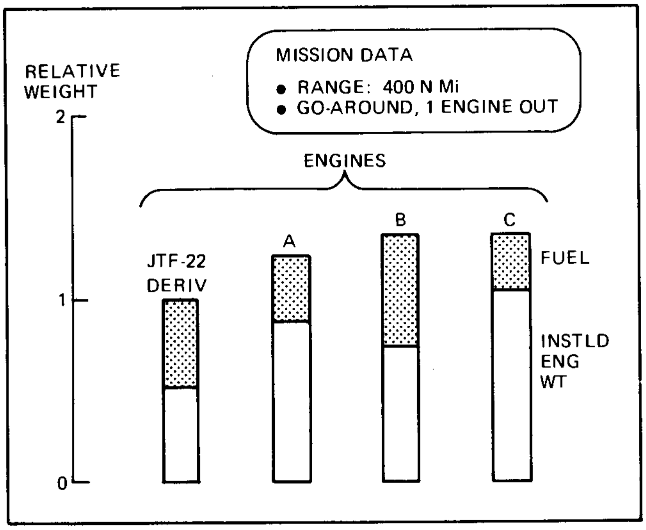


Fig. 1-42 Air Breathing Systems Relative Installed Weight Comparison

1.6.2 Design 532

ORBITER 532 MAIN PROPULSION – The base line design consists of three 250K, high-pressure, hydrogen/oxygen engines with two-position (90:1 and 200:1) expansion ratio bell nozzles. The gimbal angle is ±7 deg.

The 250K thrust level was selected as a point of departure for the following reasons:

- 250K is the lowest thrust level to be studied during Phase B engine studies
- At 250K thrust, the use of a J2S can be considered for early flights in the event a delay is encountered in the availability of the new high-pressure engine.

The main propellant tank concept is basically the same as that of Design 518 except that hydrogen is carried in two tanks instead of three.

The orbit maneuvering propulsion system consists of one RL10 engine which is fed from the on-orbit tanks. Autogenous pressurization is used for both propellant tanks.

ORBITER 532 AIR BREATHERS – The baseline system is the same as the Design 518 orbiter.

ORBITER 532 ATTITUDE CONTROL – The system is the same as Design 518 except that there are 20 thrusters instead of 26 as shown in Fig. 1-43. This configuration provides full control redundancy during reentry but does not provide pure couples for orbital maneuvers with a single-engine failure.

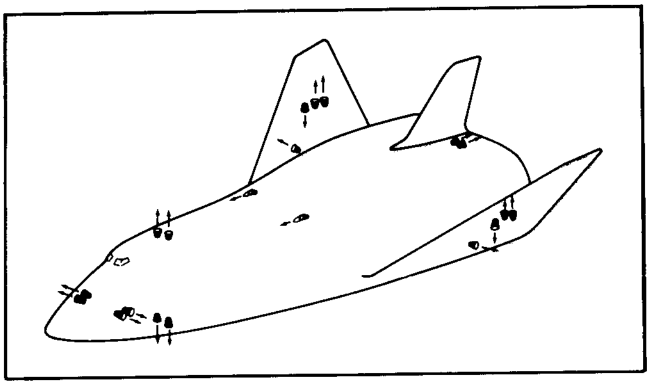


Fig. 1-43 Design 532 Orbiter Attitude Control Thruster Location

BOOSTER 532 MAIN PROPULSION – The Design 532 booster baseline uses five F-1 engines uprated to 1800K. These modifications have been demonstrated by Rocketdyne on two F1 engines under contract from MSFC. At a GLOW of 6.92 million lb, the initial thrust-to-weight ratio is 1.30. Engines are cut-off sequentially to limit accelerations to 3g and to limit the gimbal angle to ± 6 deg. The LOX-RP mixture ratio is 2.27; nozzle expansion ratio is 16.

The F-1 engine is uprated to 1800K by increasing the chamber pressure to 1135 psia, by incorporating a 30-in. turbine and by adding six additional partial impeller blades to the oxygen and fuel pumps. The sea level Isp has been increased to 271 seconds.

The tankage and feed system designs are based on the LOX-RP propellants technology used on the S-1C stage. The reasons for the selection of the F-1 booster system are discussed in Section 1.4.

BOOSTER 532 AIR BREATHERS – Six Rolls-Royce RB 211 Engines are used in the RP-1 fueled Design 532 booster. For the cruiseback range of 625 n mi the RP burning RB 211 engines save 19,000 lb in overall installed system weight over the JTF-22 engines.

BOOSTER DESIGN 532 ATTITUDE CONTROL – The system is the same as that used on the Design 518 booster except that separate insulated H_2 tanks, equipped with bellows for positive expulsion are provided, because RP not hydrogen is used as the main engine fuel. Twenty 1K thrusters are required because of the higher inertias of the vehicle.

1.7 STRUCTURE

1.7.1 Orbiter Designs 518 & 532

The orbiter structures for Designs 518 and 532 are very similar. The only significant difference is in the thrust structure which must accommodate two engines in the 518 and three engines in the 532. The engine thrust is carried into the tank through a skirt in Design 518 (Fig. 1-44), as is the outboard engine thrust in Design 532 (Fig. 1-45). The 532 center engine thrust is transferred outboard to the tank skirts through structural beams.

The cabin region is a pressurized double bubble with a docking mechanism support structure at its forward end and a "soft" (non-load carrying) connection to the cargo module at its aft end. It is supported by a bending structure which is connected to the forward end of the main propulsion tanks. The entire cabin region is thermally isolated from the external skin (TPS). The internal structure of 2219 aluminum alloy resembles the LM cabin in construction.

The center body is an integral primary load carrying tank design. The TPS is supported from the tank surface by struts and is thermally isolated here as in the cabin section. Details of this body section are discussed in 1.7.3.

Each of the three tail surfaces has a fixed forward section and a movable trailing edge. The submerged primary structure is made of titanium and is configured with trussed beams and ribs, and stiffened, buckle-free covers. An external thermal protection system maintains structural temperatures below 500°F. A shape-stable ablator is used for the leading edge.

1.7.2 Booster Designs 518 & 532

The booster designs, although similar, have one major difference because of the use of noninsulated RP-1 fuel tanks on Design 532 instead of insulated LH_2 tanks used on Design 518 (See Fig. 1-46). The booster delta wing has a stiffened titanium cover with a trussed multibeam and rib substructure. The upper cover is unshielded and the lower surface is thermally protected. Primary structural temperatures of each surface are maintained below 500°F. The wing is supported by nine machined aluminum fuselage bulkheads. Two of these bulkheads also support the main landing gears. Four elevons are attached to the aft wing structure.

1.7.3 General Structural Features

Structural features of the orbiter and booster designs proposed for the baseline vehicles are described in the following paragraphs.

When the booster and orbiter are mated, introduction of the drag loads to the aft end of the orbiter is the most efficient arrangement. Since this region is used for the orbiter engine thrust support structure, this heavy structure can also accommodate the drag load with a lower weight penalty than would be incurred if the drag load were introduced at the forward interconnection.

A major structural design objective is to introduce the engine thrust loads efficiently into the tank structure. This is most effectively accomplished by the attachment of the engine thrust structure directly to the aft tank skirt structure, which is made of 2219 aluminum alloy. This approach is logical since a major portion of the vehicle mass is contained in the tanks and the tank structure is designed to be the primary load-carrying structure.

We have shown integral primary load-carrying tanks as our baseline structure. We believe that it will prove to be lighter, less costly, and more reliable than a non-load carrying tank design. By making the tanks the backbone of this vehicle, the weight required for body bending goes into tank walls where ruggedness is desirable for other reasons, such as: ease of manufacture, less likelihood of accidental damage, and lower hoop stresses (therefore, more resistance to crack propogation). The integral tank also provides a solution to differential thermal expansions without requiring sliding of heavy load-carrying bearings. A detail design study is required for a conclusive answer to the question of integral vs nonintegral tanks and we propose this study as part of Phase B.

Thermal distortion requires special structural considerations. A major area of consideration is support of the free standing TPS on the body structure. The panels are restricted in size to about 18 in. by 18 in.– a size that requires minimum weight

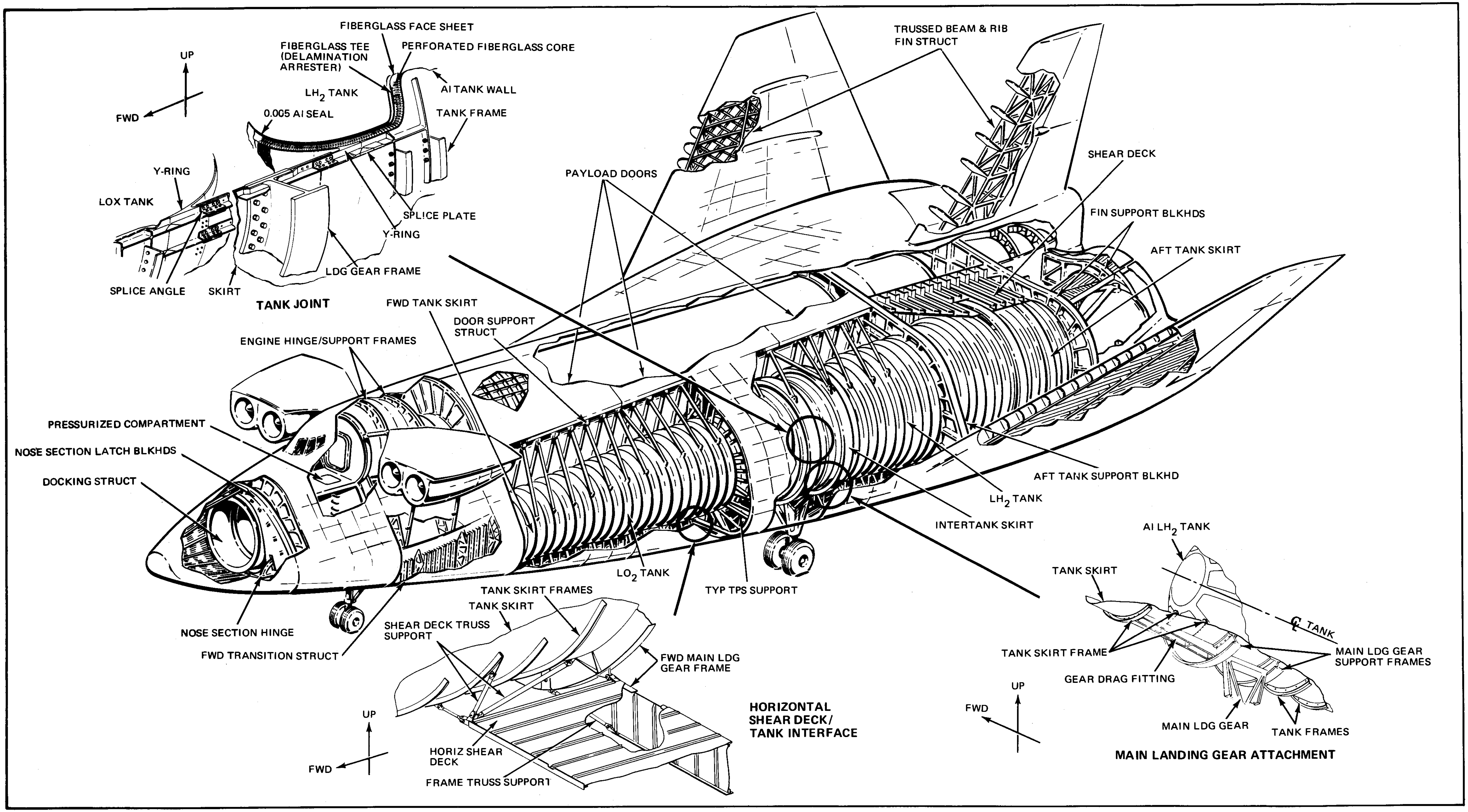


Fig. 1-44 Design 518 Orbiter Structural Arrangement

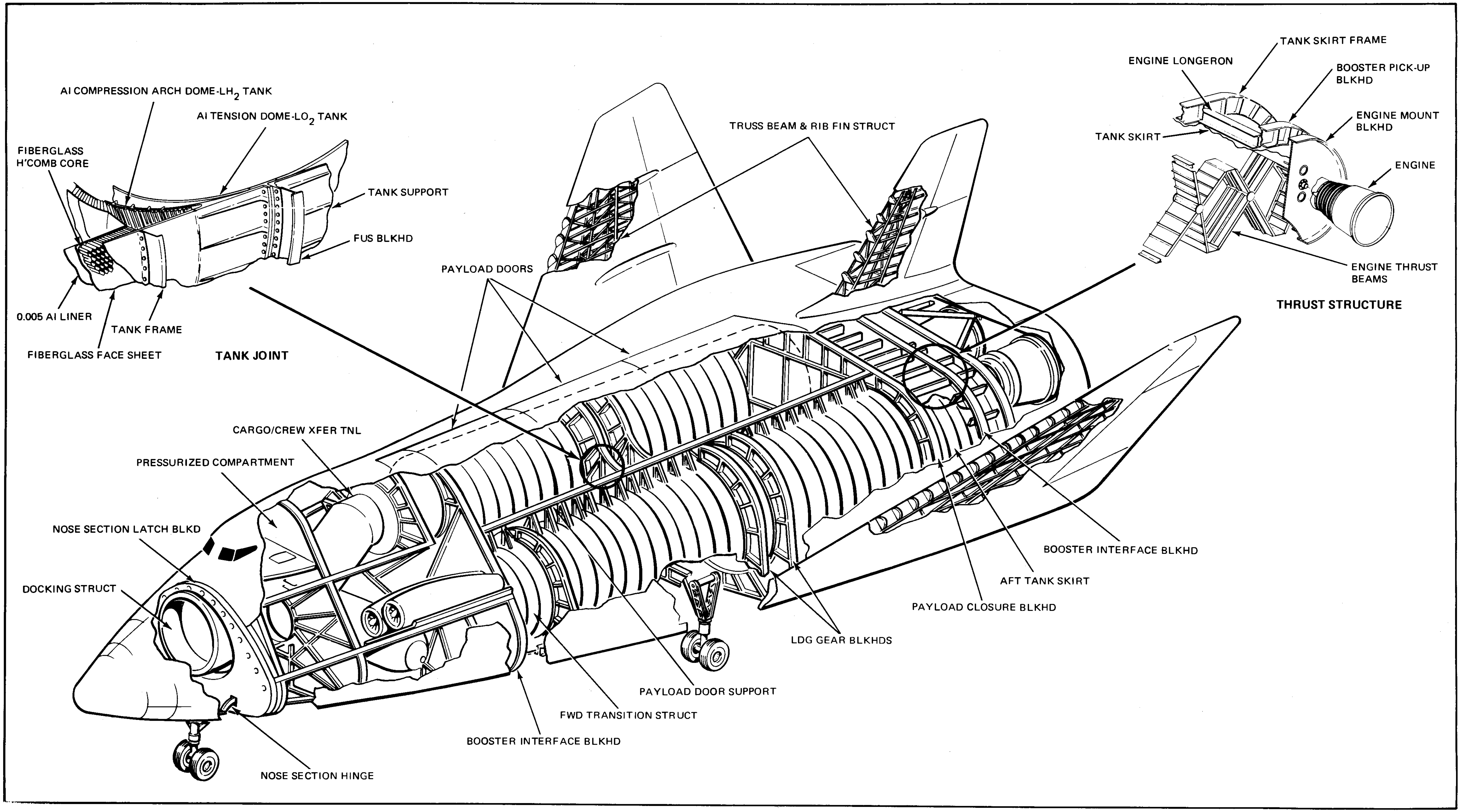


Fig. 1-45 Design 532 Orbiter Structural Arrangement

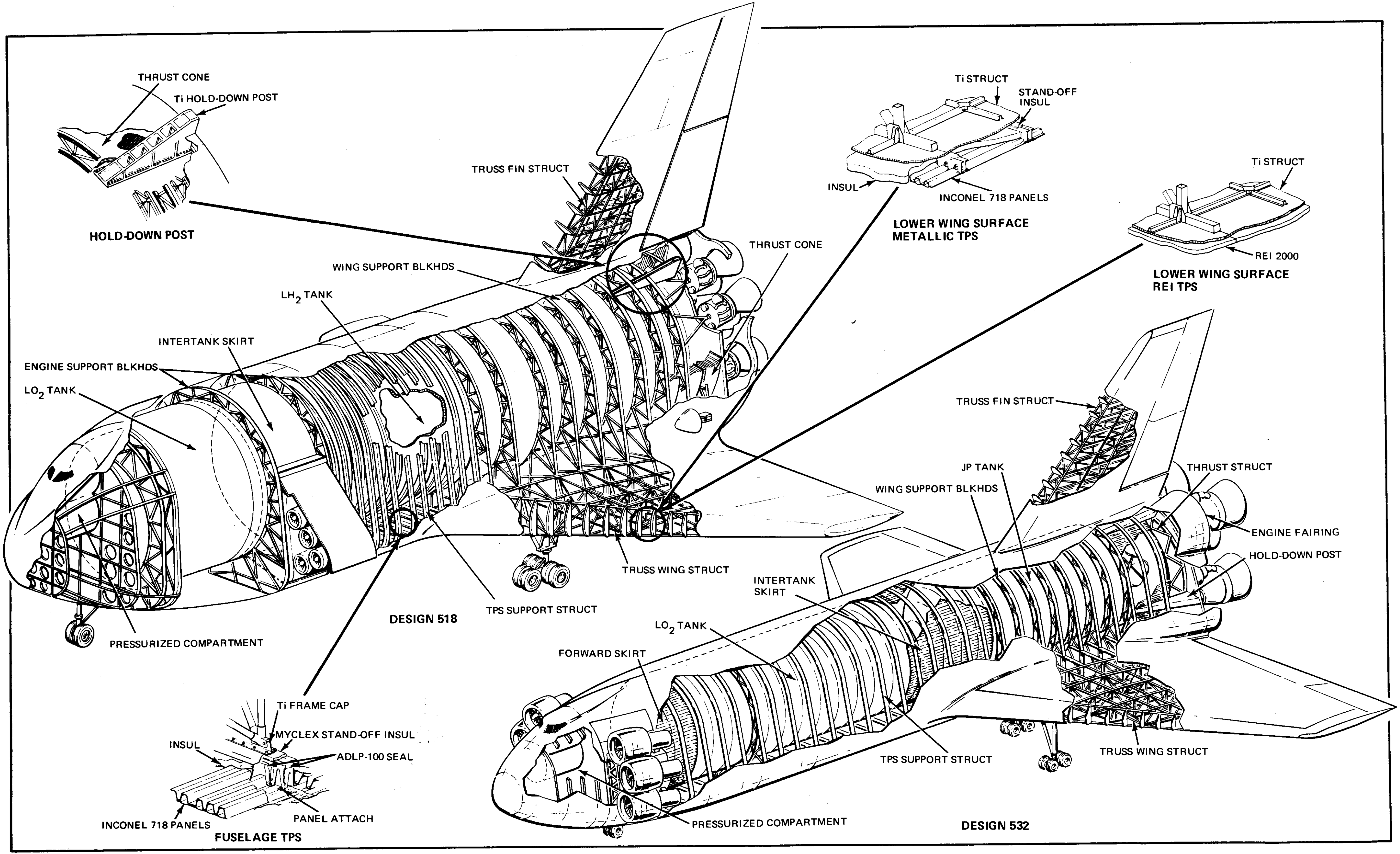


Fig. 1-46 Designs 518 & 532 Structural Arrangements

to support local air loads and does not require excessive gapping to accommodate the thermal strain. (See Fig. 1-53 in Subsection 1.8 for details.)

The interconnect horizontal shear decks between the main propulsion tanks on the orbiters are configured to eliminate the temperature distortion strain induced loads using determinate truss structure. This can be seen on Fig. 1-44.

The booster wing root chord lengthening relative to the cold main propulsion tanks (≈ 4 inches) can be accommodated without introduction of large internal structural loads by use of a determinate linkage from the wing root ribs at the body intersection to the tank sidewalls. The link is located near the chordwise center of the structural wing box. The tank frames supporting the wing forward and aft of this linkage system will not be constrained from warping and will, by warping, allow for the relative wing-to-fuselage motion.

MAIN TANKAGE – Most of the booster main propulsion tank shell is designed by pressure requirements. An efficiently designed composite tank with fiberglass wound on a metal shell is resistant to crack growth, has fail-safe features not obtained in a monolithic tank, and is considerably lighter. Cyclic load tests were recently conducted at Grumman on initially cracked aluminum alloy plates, similar to those described in NASA TN 5390, with and without fiberglass reinforcing. Although the bond between fiberglass and aluminum was much poorer than would be obtained in practice with a special adhesive, the reinforced plates showed much slower crack growth rates for the same cyclic stress range, than the bare plates, especially when the crack approached the "critical" size causing rapid fracture, and were able to sustain much larger cracks before failure. Still better crack resistance is to be expected in composite structures in which the metal wall is in initial compression as a result of winding tension in the fiberglass.

These crack-resistant features of composite tank construction can be obtained with considerable weight savings over monolithic tanks as shown in Fig. 1-47. With 20 percent of the tank wall weight in fiberglass, the weight reduction is 16 percent. At limit pressure the hoop stress in the aluminum walls of the composite tank is kept at the same value as in the monolithic tank. The fiberglass by itself provides a considerable increase in crack growth resistance, and has more than enough hoop strength to sustain the full relief valve pressure hoop load. With longitudinal stresses in the composite tank kept well below the hoop stresses in monolithic tanks, the composite tank is more resistant to crack growth in all directions than is the monolithic tank in the hoop direction.

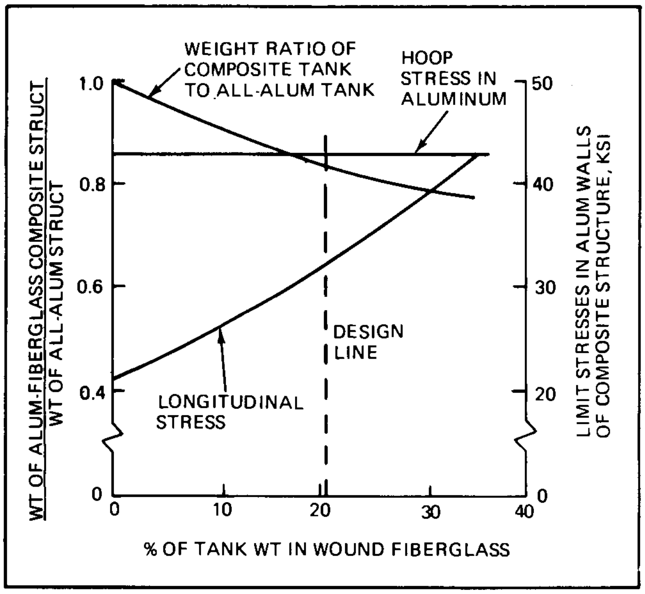


Fig. 1-47 Structural Efficiency of Cylindrical Pressure Tanks with Circumferentially Wound Fiberglass

A large portion of the main propulsion tanks on the orbiters is designed by external load conditions and minimum fabrication gages rather than pressure. These tanks, therefore, do not appear to be candidates for winding. The booster main propulsion tank, however, is sized in large measure by pressure and here filament winding would result in a tank with greater inherent strength and safety which would also be lighter.

Although tanks of this size have not been wound to our knowledge, Aerojet-General, our team member, has extensive tank winding experience and has wound many large tanks including one 260 in. in diameter and 54 ft long. The available winding equipment can be easily adapted to this tank.

The oxygen tanks use internal stiffeners and external rings. These tanks are not insulated since no LOX compatible insulating materials are now available. The stiffeners are mounted internally so that the tank can be filament wound in the same manner as the hydrogen tanks.

On Design 532 an inverted compression dome on the hydrogen tank, mated by a separating skirt to an elliptical tension domed oxygen tank, was found to be 60 in. shorter and 1100 lb lighter than a design using two tanks with elliptical tension domes. The compression dome design uses integrally machined stiffeners to maintain a high level of structural reliability.

Considerations other than tankage weight dictate the length of Design 518 orbiter. Therefore, conventional tension domes are used.

CRYO INSULATION – Structural studies indicate that evacuated honeycomb insulation efficiently stabilizes hydrogen tank walls. The internal insulation for integral LH_2 tanks employs evacuated honeycomb core sandwich construction. By a variation of the approach used on Saturn V stages, the core and inner face sheet can be designed to stabilize the tank wall for compressive loads, and to meet the thermal strain requirements. Significant weight (at least 10 percent) will be saved over competing integrally stiffened skin designs, even after fail-safe provisions are made for containing possible skin or core delaminations. The design employs fiberglass for the honeycomb core and face sheet. LH_2 permeation is prevented by bonding a thin seal layer of soft aluminum to the sandwich. Widely spaced integral longitudinal stiffeners penetrate into the core from the aluminum alloy tank wall, as do intermediate bonded fiberglass stiffeners from the fiberglass face sheet. (Refer to Fig. 1-44). The shear bond between stiffeners and honeycomb core effectively limits any core-skin bond delamination and thus provides fail-safe operation. Preliminary analysis and exploratory tests indicate that the loading requirements, including those imposed by thermal strains, can be met. Honeycomb beam specimens, simulating the tank wall structure, were fatigue cycled in bending while in a nitrogen cooled atmosphere with the simulated inner surface at -300°F and the tank wall at +15°F. The specimens can be seen in Fig. 1-48. The specimens were cycled through a strain range approximating the maximum strain range expected in the full scale tank. The specimen life exceeded 8000 cycles.

The aluminum alloy 2219 tank walls are constructed of machine welded planks which are machined in the flat and then formed. (See Fig. 2-17 in Subsection 2.1.13.)

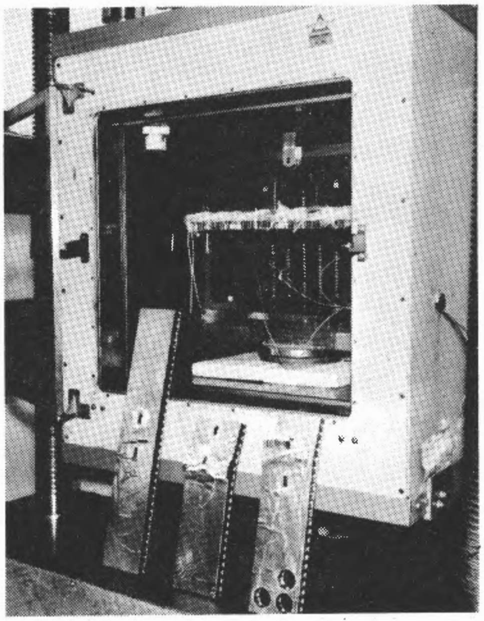


Fig. 1-48 Simulated LH_2 Tank Wall Test Specimens

Thermal studies indicate that evacuated honeycomb structures have minimum heat losses and easy inspection and maintenance. The combined insulation and structurally stiffened honeycomb wall of LH_2 tanks provides a highly efficient insulation system similar to that used on Saturn. The honeycomb has a large number of holes through the flutes and is purged by a low-pressure flow of gas (perhaps N_2) using a number of taps through the outer wall. This arrangement greatly reduces the manifolding requirements, relying primarily on cryopumping to evacuate the wall after filling. We are studying in our IR&D program the effectiveness of cryopumping traces of GH_2 at LH_2 temperatures using condensable gases at various initial pressures as the pumping vehicle (Subsection 4.2.3). The thermal effectiveness of the system is shown in Fig. 1-49.

A leak detection system similar to that on the Saturn stage is used employing a gas analyzer on the vacuum lines. The insulation can be compartmented as an aid in detecting the leak source.

A large port at one end of each main propulsion system tank provides access for inspection and repair. Collapsible work stands with large resilient foot pads to spread the load can rest directly on the rigid insulation in the LH_2 tank and on temporary flooring in the LOX tank.

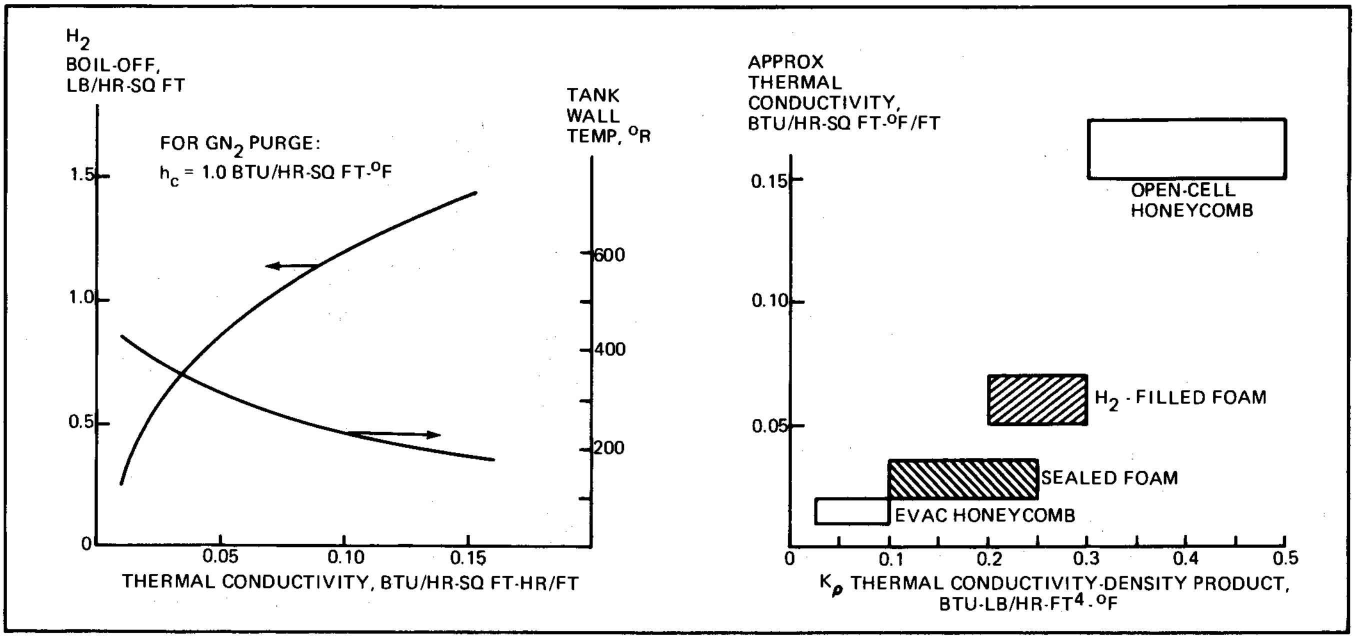


Fig. 1-49 LH_2 Cryogenic Tank Insulation Tradeoffs

Studies show tank baffle trees with flexible baffles as effective anti-slosh devices. This is a lightweight, economical way to prevent sloshing and is adaptable to almost any tank configuration. The baffle trees employ a series of longitudinal members around the periphery of the tank to which flexible baffles are attached. The trees are tied together and are self-supporting. Studies have indicated that flexible baffles are lighter than rigid baffles. The tree arrangement permits a major portion of the assembly work to be done outside of the tank and allows for easy installation and removal. Details of the design can be found in the report entitled "Proposal for Flexible Baffle Engineering Study," 70-22 NAS, 4 March 1970, submitted to NASA Langeley Research Center.

Low cost gaseous N_2 prevents internal ice formation during cryogenic fueling. GN_2 is used to purge the cryogenic fuel bay from fueling to launch to eliminate the danger of O_2 and H_2 combustion and to prevent ice and water formation inside the vehicle . Purge gas temperature is maintained above -65F so that MIL Specification parts may be used in electromechanical equipment mounted in the propellent bay.

ON-ORBIT TANKAGE – Low-pressure ground purge and high-performance external insulation provide a long-life on-orbit tank insulation system. Propellant from the on-orbit LH_2 tank is used by the orbiter's air-breathing engines at the end of the mission. Thus, a requirement for long-term (7-day) thermal isolation is added to safety and low cost for the LH_2 tank. Filament-wound, insulated, welded aluminum alloy tanks, supported by a minimum number of low-heat conduction supports , meet these basic requirements. The welded 2219 aluminum alloy structure provides a leak-tight structure compatible with the propellant. Filament-winding minimizes crack growth. Six fiberglass support struts minimize conductive heat transfer between the tank and the surrounding structure. The tank insulation system consists of a multilayer superinsulation blanket. The blanket is a composite of some 30 layers of perforated film separated by a double layer of net spacers. The outer five layers are 1/4 mil Kapton, gold-coated on each surface. The gold is used because it will not delaminate if exposed to moisture. The inner layers are 1/8 mil Mylar, aluminized on each surface. The insulation is supported on insulated standoffs bonded to the external tank surface. A lightweight shell resting on the tank surrounds the superinsulation blanket and provides a low pressure purge envelope, to prevent dirt and atmospheric moisture buildup on the tank wall or on the insulation layer while the orbiter is in the atmosphere.

In addition to the N_2 purge procedure used during fill and ground hold operations, dry gaseous H_e is used during reentry and flight to landing to prevent frost formation in the HPI insulation blanket.

Boiloff rates are minimized by allowing the LH2 pressure to rise from 20 to 50 psi while in orbit. Gang actuated slide valves are provided on the shell to seal the purge volume in the atmosphere and vent it during ascent and in-space operations.

An in-house test has been performed on a 16 in. diameter tank, using an insulation system consisting of 0.5 percent perforated 1/4 mil Mylar aluminized on both surfaces with a double layer of net spacers. Based on data from this test, it is anticipated that, with supports, the design heat leak of the on-orbit tank insulation will be approximately 1.0 btu/hr/ft^2.

WINDSHIELD—Windshield design contains reentry temperatures within known glass technology limits without heat shields. The windshield design is configured to reduce the reentry heating temperatures to within the strain point limits for fused silica (1815°F) and also provides adequate cockpit clearance and visibility. This eliminates the need for structural reliance on reentry temperature shields. The geometrical requirements for the orbiter windshield are shown in Fig. 1-50.

HEAT BALANCE —Vehicle heat balance presents no major difficulties. Large portions of the orbiter including the primary structure, insertion and on-orbit tankage, jet engines, landing gear and hydraulic lines, must be thermally controlled by passive means because of the prohibitive size and weight required for active controls. The baseline thermal approach is to locally insulate, and in some cases, locally heat equipments to accommodate short duration transients. This approach is satisfactory for prelaunch hold and reentry where bulk structure temperatures of -65°F and +275°F, respectively, may be realized.

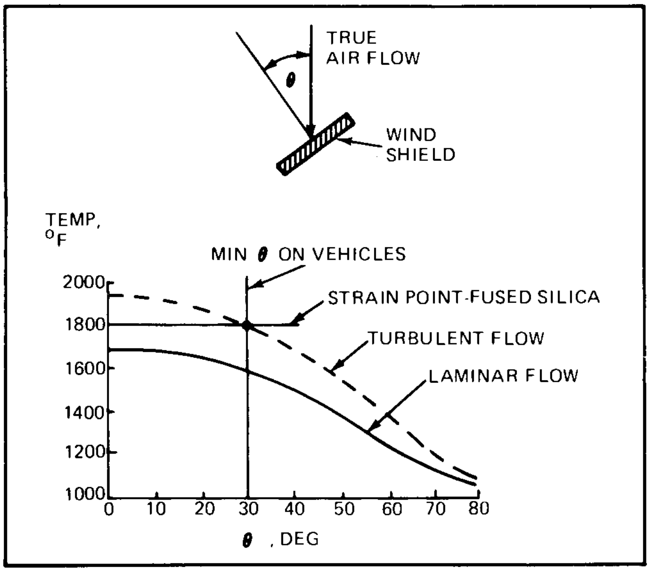


Fig. 1-50 Designs 518 & 532 Maximum Windshield Temperature, High Cross Range

Evaluating orbiter temperatures based on orbital average heat fluxes with no additional insulation above TPS requirements, and with inherent TPS high emittance ($\epsilon = 0.8$, $\alpha/\epsilon = 1.1$ to 1.2) yields bulk structural temperatures of between -60°F and 175°F for orbital extremes. More probable orientations would further narrow the already tolerable spread in temperature. This indicates that individual problems can be solved locally and that troublesome precisely selected (α/ϵ) coatings and delicate but heavy vehicle insulation approaches can be avoided.

1.8 BASELINE THERMAL PROTECTION FOR DESIGNS 518 & 532

For Grumman's study baseline Designs 518 and 532 have common aerodynamic and thermodynamic characteristics. We attach singular importance to the development requirements of a lightweight, safe and reusable thermal protection system. We have, therefore, elected to baseline two thermal protection system designs equally applicable to systems 518 and 532, consisting of metallic/radiative and the General Electric Reusable External Insulation (REI 2000) concepts because:

- The metallic/radiative system allows a reasonable payload for the low cross-range mission. The materials are todays technology and the problems are largely details of design. Therefore, we have proposed the metallic/radiative system for the low cross range baseline for both Design 518 and 532.
- A metallic/radiative system consistent with the high cross-range requirements would not allow reasonable payloads.
- We believe that a practical high cross-range vehicle is dependent on the development of low density REI. However low density REI is in an early state of development. Therefore, we have proposed the REI 2000 as baseline of both Design 518 and 532 for the high cross-range missions.

- The metallic/radiative and the REI 2000 systems fit the same sub-structure; ie.. a vehicle originally built with the metallic/radiative system can be retro-fitted with a REI 2000 system.

Both Design 518 and 532 have aerodynamic cross-range potential exceeding 1500 n mi. Either design is expected to be operated initially in the lower cross range, less severe thermodynamic environment. As a result, the two baseline designs 518 and 532 encompass baseline payload performance spread indicated in Table 1-9.

Table 1-9 Effect of TPS Material On Net Payload

System Design	Low Cross Range		High Cross Range	
	Metallic Radiator	REI-2000	Metallic Radiator	REI-2000
518 Orbiter (Hi-Press. Eng	32,160	38,710	20,410	35,000
532 Orbiter (Hi-Press. Eng	22,580	28,810	12,670	25,880

We propose an initial parallel design development of Designs 518 and 532 in conjunction with both the metallic/radiative and external insulation thermal protection systems. Six months after study initiation we will review with NASA the progress in development of REI-2000 to determine which TPS is appropriate for the final Phase B Design.

We believe this approach assures the selection of the lowest risk, maximum reuse potential for the thermal protection system will have been selected and given in-depth treatment.

1.8.1 Metallic/Radiative TPS

The metallic re-radiative TPS for the shuttle is derived from those metals and alloys with usable structural properties at temperatures above 600°F. Representative materials, their range of applicability, and comments concerning their use are shown in Table 1-10.

Table 1-10 Metallic TPS Materials Characteristics

Temp Range, °F	Material	Metallic Surface Panel Wt, lb/sq ft*	Comments
600-1200	INCO 718	0.96	Good oxidation resistance Good ductility and strength Good fabrication
1200-1500	Rene' 41	0.96	Poor fabricability Good oxidation resistance Good strength
1500-1800	Haynes 188	1.07	Good oxidation resistance High ductility
1800-2200	TD-Ni-Cr	1.25	Good oxidation resistance Poor ductility at temperature High cost
1800-2500	Cb 752	2.0	Coating problems Poor reliability High cost
2500-3000	TA-10W	3.72	Coating problems Poor reliability High cost

*Does not include insulation or attachments

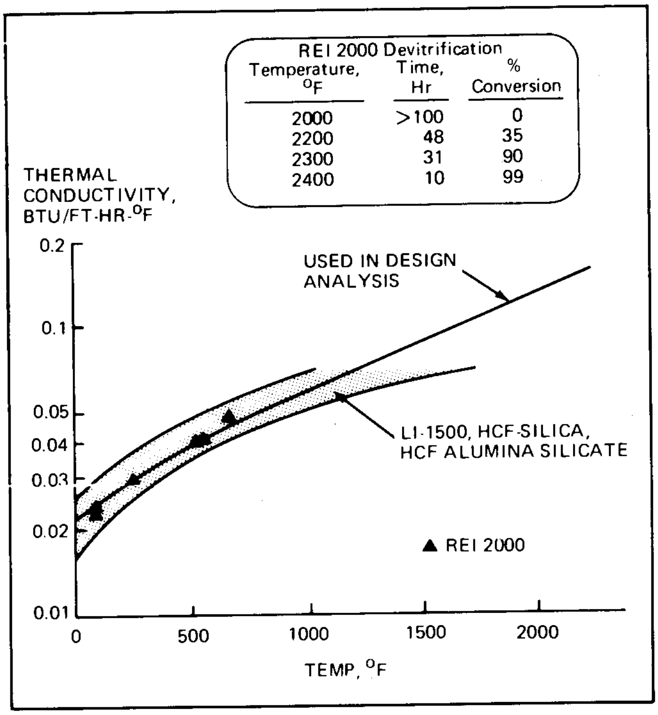
It is felt that metallic TPS can be considered for temperature applications up to 1800°F for reuse over 100 flights, with a one time over-temperature capability up to 2100°F utilizing Haynes 188 alloy. This capability is sufficient to meet the requirements of the low cross-range orbiters. Design concepts, while not completely optimized are shown in Fig. 1-52. A metallic TPS for temperatures above 1800°F, such as would be required for the high cross-range orbiters, would mean extensive use of coated Columbium alloys, and high-temperature internal insulation. This would result in an unacceptable weight as shown in Table 1-9. A detailed discussion of these problems is presented in Subsection 2.2.2. Both Grumman and General Electric are pursuing TPS metallic panel development programs with results anticipated in time for application to the Phase B study.

1.8.2 Reusable External Insulation (REI)

The nonmetallic, re-radiative TPS uses a family of proprietary materials systems developed by the General Electric Company and designated REI. Specific material systems are noted by the reuse temperature capability: REI-2000, REI-2300 and REI-2600. REI-2000 is based on a silicone resin impregnated quartz fiber mat sheathed in silica cloth and heat treated to convert the resin to a high silica, low density binder and rigidizing agent for the fibers. REI-2300 is a modified version of a commercially available, inorganically bound aluminum silicate fibrous blanket. REI-2600 is an alumina-silica-chromia fibrous mat bound and rigidized with an organic crystalline salt. The

REI materials obtain high emissivity for re-radiation through the introduction of carbon materials into the surface layer or by applying Hf O_2. The surface reinforcement is a thin dense layer of a proprietary resin and provides additonal desirable features such as impact and abrasion resistance.

Reusability has been demonstrated to be more than 100 hours at 2000°F by tests on the base material. Above 2000°F the REI 2000 material degrades at the surface due to devitrification and suffers a resultant reduction in insulative and mechanical properties. Refer to Fig. 1-51. The material is completely inert and upon experiencing a re-entry environment will not produce contaminants which will condense on other parts of the vehicle. In addition, it is stable in an orbital environment.



REI 2000 Devitrification

Temperature, °F	Time, Hr	% Conversion
2000	>100	0
2200	48	35
2300	31	90
2400	10	99

Fig. 1-51 Insulative Properties of REI

The REI offers a "forgiving" TPS when compared to other re-radiative systems. Non-nominal thermal environments can be accommodated. The 3000°F surface melt temperature represents four times the heating rate at the design temperature of 2000°F. While the number of reuse cycles is reduced, catastrophic results do not occur.

The application of REI-2000 as a TPS for the space shuttle is simpler and considerably lighter than coated columbium or other metallic panels. The REI can be bonded to a substrate panel in a conventional manner. Bonding has been proven on numerous reentry operational flights. The substrate does not experience high temperature (< 500°F for titanium) thereby minimizing the thermal expansion problem between the vehicle structure and the substrate and permitting the development of aerodynamic skin sealing in the low-temperature substrate. Thermal expansion differentials between the REI and the titanium substrate do not produce a problem due to the low modulus of the REI.

Basically, the REI represents a low-cost system ($ 100-$200/sq ft, compared to approximately $1000/sq ft for Columbium). It is composed of readily available materials and formulated in a well understood manner. The REI family of materials has been under development for almost two years. Structurally reinforced omniweave silica fiber matrix is being developed for flight testing on an Air Force program as an antenna window on the skirt of a high performance RV. The development of lower density REI versions was the result of the needs of the space shuttle program.

1.8.3 Booster and Orbiter Baseline Thermal Protection Systems

The baseline TPS for the 518 and 532 booster and orbiter is listed in Table 1-11.

518/532 LOW CROSS-RANGE ORBITERS – The salient design features of the 518 and 532 low cross-range orbiter metallic TPS approach are depicted and described in Fig. 1-52. State-of-the-art materials such as superalloys (HS188), silica based insulations, and shape stable ablators will be utilized throughout the TPS design to produce low program costs, minimum development, low risk, and reasonable performance.

The orbiter TPS design is also aimed toward upgrading performance to a completely reusable system and a high cross-range capability by developing the REI material. The ablative nose and fin leading edges are designed to be compatible with the more severe high cross-range environment. The thermal and structural interface between the metallic re-radiation panels and the attachment structure is such that REI panels can be efficiently substituted for the metallic TPS panels to upgrade the cross-range capability of the low cross-range orbiter when REI becomes operational.

Table 1-11 Baseline Thermal Protection Systems

			Fin			Body Panel			Booster Wing			
518/532 Orbiter	Nose	Body Chine	Leading Edge	Windward Side	Leeward Side	Upper	Lower	Control Surfaces	Upper	Lower	Total TPS Wt, lb	
Low Cross Range	Shape Stable Ablator	HS188	Shape Stable Ablator	HS188	HS188	INCO 718	HS188	HS188			518 532	31,860 29,660
High Cross Range	Shape Stable Ablator	REI	Shape Stable Ablator	REI	REI	REI	REI	REI			518 532	29,280 26,660
518/532 Booster	HS188	Rene' 41	HS188	INCO 718	INCO 718	Titanium	Rene' 41	HS188		Rene' 41	518 532	41,360 44,845

518/532 HIGH-CROSS RANGE ORBITERS – The salient design features of the 518 and 532 high cross-range orbiter REI TPS approach are depicted and described in Fig. 1-53. REI was selected as the baseline TPS for these vehicles since preliminary studies indicates that this is the only approach that offers the possibility of achieving a reasonable payload in the more severe high cross-range heating environment under the 3.5M GLOW limitation. Ablatives have been baselined as the nose and fin leading edge TPS because they are the only reliable system for the severe heating environment in these areas which are possibly subject to interference heating effects.

BOOSTERS (DESIGNS 518/532) – The thermal environment experienced by the booster is milder and of shorter duration, than that experienced by the orbiters. Consequently, the TPS will be designed using titanium alloys (6A1-4V or 4 A1-3Mo-IV) and superalloys (Inconel 718, Rene' 41 and HS-188) backed with Microquartz insulation. Refer to Table 1-11. These materials represent the basis for an efficient, low cost approach with minimum development risk. Details are discussed below and shown in Fig. 1-46.

The nose and fin leading edge areas experience the highest temperatures (1450°F) on the vehicle. For these areas, HS-188 alloy is utilized.

Fuselage – The fuselage uses corrugation stiffened face sheet panels backed by insulation to protect the integral tank primary structure. On the upper fuselage surface where temperatures do not exceed 800°F and air loads are low, these panels are constructed of titanium alloy. On the side of the vehicle, Inconel 718 panels are used for temperatures between 800°F and 1200°F. On the lower surfaces where air loads and temperatures are higher, Rene' 41 is used as the basic material. This panel concept has been fabricated and tested by Grumman.

Wing – The basic wing structure consists of titanium alloy. Only the lower surfaces are protected against heating since temperatures on the upper surface are within the 600°F capability of the titanium structure. The lower surfaces are protected with Rene 41 corrugation stiffened panels backed with microquartz insulation.

Fins – The fin construction is similar to that of the wing. The titanium primary structure is protected by corrugation stiffened surface panels fabricated of Inconel 718 to accommodate the 1200°F temperature environment.

1.9 OTHER SUBSYSTEMS

Those subsystems not covered in section 1 were not considered to be major configuration drivers. These are fully described in Section 2.

BASELINE TPS FOR LOW CROSS-RANGE ORBITER (518/532) Salient Features (See Sketch)

1. BODY PANEL CONFIGURATION AND ARRANGEMENT

Body panels are corrugation stiffened beaded face sheets 18-in. wide designed to attach to titanium rings of the support truss structure which are spaced at 18 in. A fiberous insulation layer separates the metal panel from the primary structure The panel is fastened to the support ring by rigid attachment at one end and by flexible standoffs at the other to allow for thermal differential expansion in the direction of the corrugations. Mica-phenolic insulation blocks reduce heat flow through the standoffs. The slip joints between panels allow relative movement between panels while maintaining a seal to prevent hot boundary layer leakage.

Thermal expansions normal to the corrugation are taken out by local deflection of the beads and corrugations, allowing panels to span considerable distances in the circumferential direction around the body without the need for slip joints. A similar configuration is used on the fin surfaces with the beads and corrugations running in the chord wise direction.

Materials are Haynes 188 and 3.5 lb/cu ft microquartz on the windward body and fin surfaces. Insulation is packaged in a nickel-foil envelope. On the upper body surfaces, Inconnel 718 material is used.

2. REMOVABLE NOSE ATTACHMENT DETAIL

Stagnation heating rates for the low cross-range orbiter do not permit use of superalloys, therefore a state-of-the-art shape stable ablator ECM 1004 AP, bonded to a titanium honeycomb substrate with RTV-360 is used. Attachment is designed for easy refurbishment after every flight. The nose ablator is designed to also permit its use on the high cross-range vehicle where heating rates are more severe. The 1800°F isotherm for the low cross range vehicle or the 2300°F isotherm for the high cross-range vehicle, whichever is more critical, determines the ablator-body panel interface. To upgrade reusability of the vehicle, the low cross-range nose could eventually be made of REI, which would only be replaced in case of inadvertent damage.

3. FIN REMOVABLE LEADING EDGE SECTION

The TPS for the fin leading edge is ESM-1004 AP shape stable ablator, bonded to a titanium honeycomb substrate and mechanically attached to the fin structure. Access hand holes with removeable cover plates are provided to permit removal and refurbishment. This ablator is also designed to permit its use on the high cross-range vehicle fin leading edge. Ablator-metal panel interface is configured as for the nose. To upgrade vehicle reuseability, the low cross-range leading edge could eventually be made of REI.

4. DOCKING NOSE AND LANDING GEAR DOOR SEALS

The baseline approach to the deployable nose body interface seal incorporates a replaceable triple redundant design. The primary seal is a glass-filled Teflon ring with the gaps sealed by elastomeric "O" rings. Both materials serve as ablators during re-entry; the glass-filled teflon ablator gives off a clean char. This primary seal is attached to a phenolic glass laminate ring which provides support from the structure, and is in itself an ablator should the primary seal fail. This complete seal system is mounted from a nose and fuselage coated Columbium frame cap providing a barrier seal should the ablation system fail.

The landing gear doors use a similar approach incorporating replaceable seals. The external surface employs a metal overlap labyrinth. The primary positive seal occurs at some depth below the surface and consists of an elastomeric compression "O" ring.

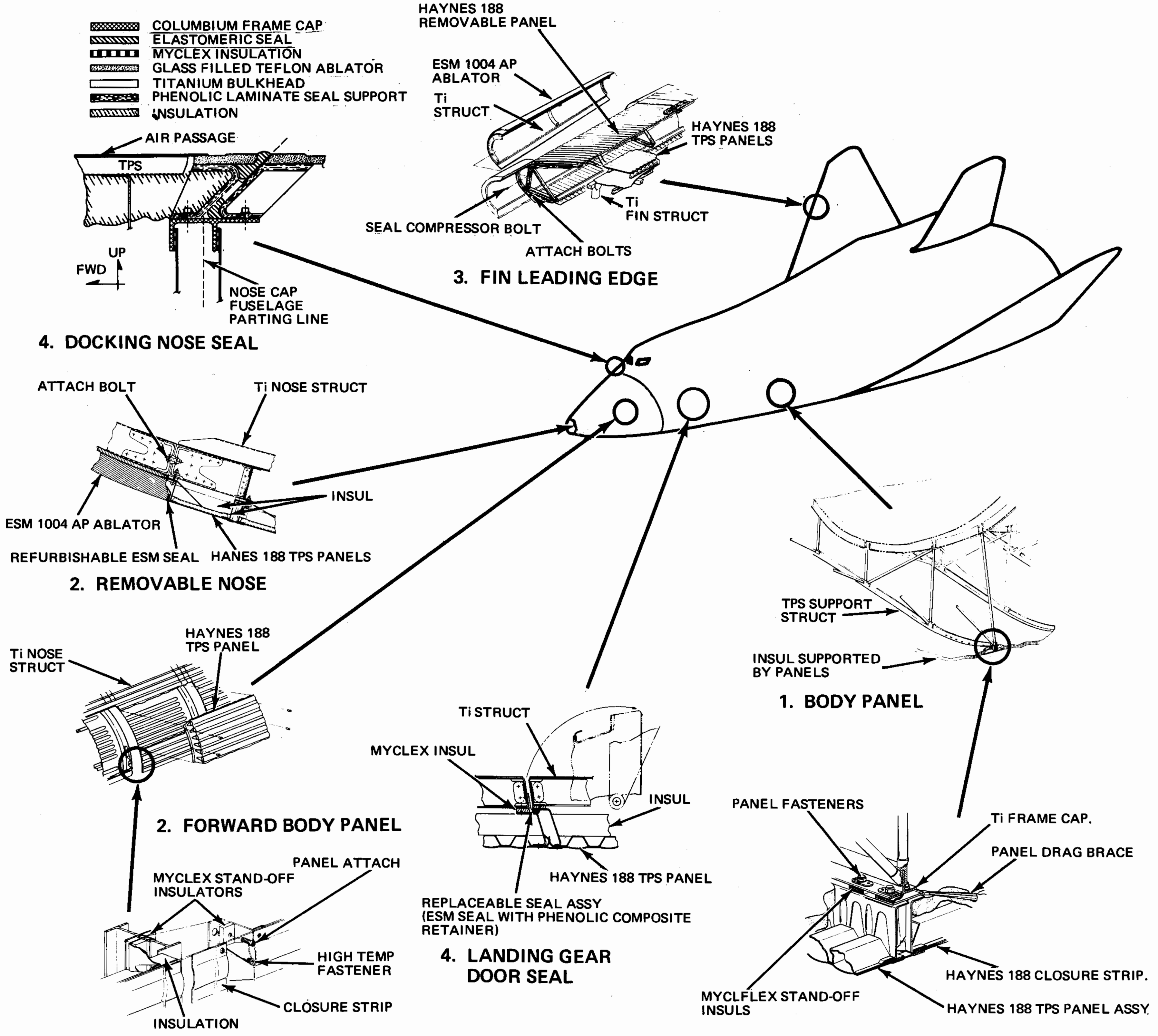


Fig. 1-52 Low Cross Range TPS Design Details

BASELINE TPS FOR HIGH CROSS RANGE ORBITER (518/532)

Salient Features (See Sketch)

1. BODY PANEL CONFIGURATION AND ARRANGEMENT

The body panels are 18 x 18 in., designed to attach to titanium rings of a spacing dictated by the support truss structure. The panels are made of REI-2000 bonded with a silicone adhesive (RTV-360) to a titanium honeycomb substrate and attached to the support ring by rigid attachment at one end. Flexible standoffs allow for thermal differential expansion and strain at the other end. The panels are primarily sized by the allowable joint size calculated for maximum allowable heating. Longitudinal edges of the panels are semi-scalloped and interlocked to adjacent panels to minimize joint heating due to edge alignment with aerodynamic flow.

2. BODY PANEL CORNER AND ATTACHMENT DETAIL

The aft end of the panels are supported on flexible standoffs designed to withstand air and inertia loads with minimum strain and yet permit longitudinal and transverse deflections required because of differential length changes between the cold cryogenic primary tank structure and the TPS. Longitudinal joints in the TPS external surface are sealed to aerodynamic flow by titanium expansion interlocks. Circumferential joints seal on the titanium ring.

3. LONGITUDINAL JOINT CROSS SECTION

The REI-2000 is sized to limit the titanium support structure temperature to 500°F maximum. REI thickness varies from point to point on the vehicle surface depending on the local environment. The panel is attached through the titanium honeycomb with titanium bolts, and the recessed hole is plugged with a fitted REI dowel bonded in place. This technique has been successfully demonstrated on operational ablative systems. The longitudinal semi-scalloped joint is designed with the REI scallopped and the honeycomb edge linear to provide maximum overlap for sealing.

4. FORWARD BODY PANEL CONFIGURATION

The forward body area uses a conventional frame structure with beaded skin panels for carrying primary loads. Attachment of the REI TPS panels is simplified due to the absence of cryotanks.

5. REMOVABLE NOSE ATTACHMENT DETAIL

The shape-stable ablative nose cap for the high cross-range orbiter is the same as for the low cross-range vehicle. This component would be replaced after every flight, since current technology does not permit reuse of ablators of optimum weight.

6. FIN REMOVABLE LEADING EDGE SECTION

The same shape-stable ablator used for the low cross-range vehicle is used here. The component would be replaced after every flight.

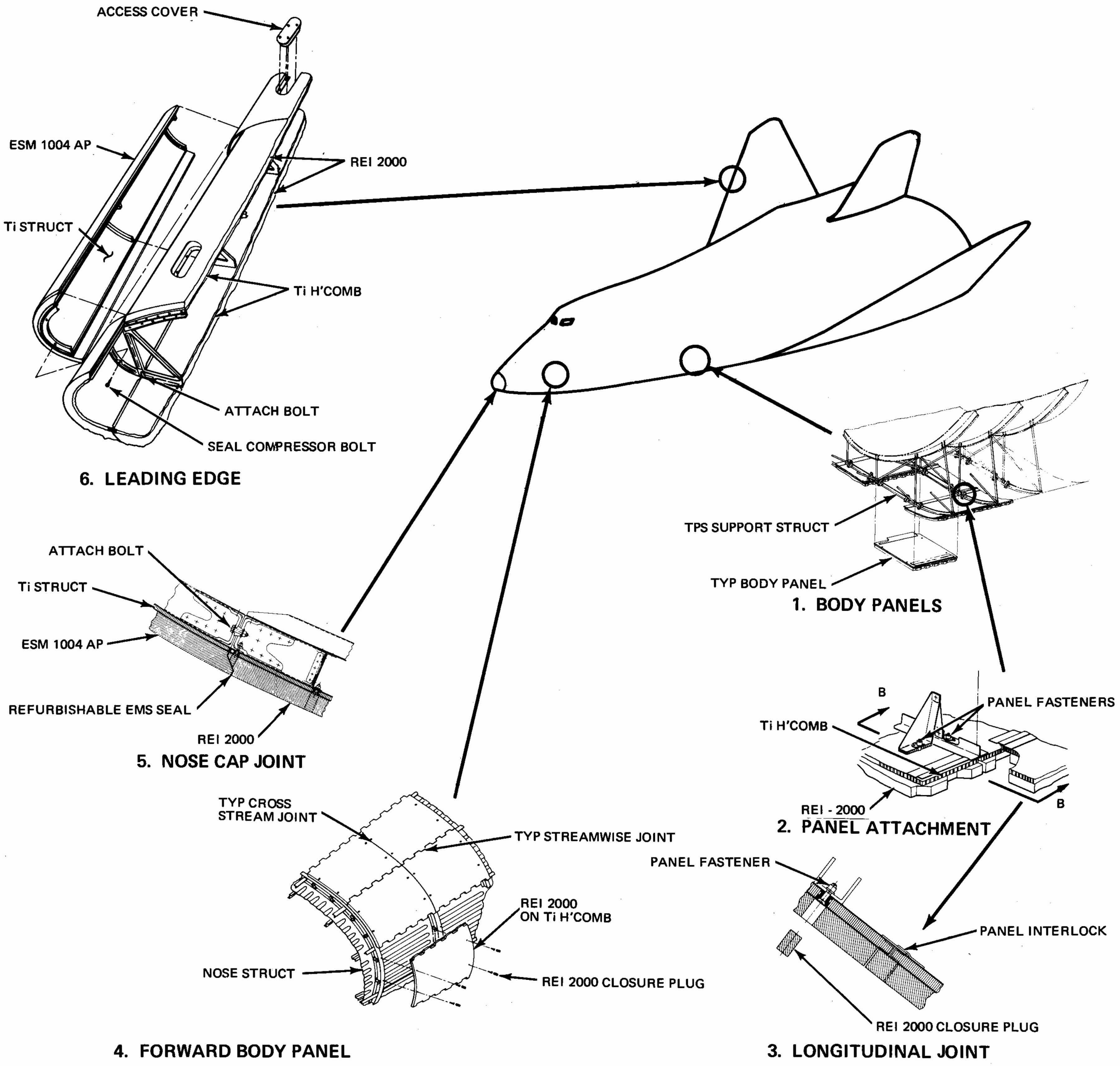


Fig. 1-53 High Cross Range TPS Design Details

STUDY APPROACH

2 – STUDY APPROACH

This section presents our approach and rationale for accomplishing each of the specific tasks called for in Section 4, Contractor Tasks of the NASA Statement of Work.

The Grumman team's study effort will define the shuttle system, accomplish preliminary designs with the orbiter optimized for low (200 n mi) and high (1500 n mi) cross range, determine the scope, schedule and cost of the shuttle system, and identify the supporting research and technology which must be accomplished. Through the in-depth study of the design, optimized for low and high aerodynamic cross range, we will explore the overall influence of this performance requirement on the acquisition of the shuttle system.

Our study approach was formulated to provide a balance of emphasis on technical and programmatic considerations which drive the development and operational costs. Key drivers which will receive emphasis include:

- Technical Issues – Those factors which affect development risk such as cross range, including particularly the reusable TPS, high pressure LOX/LH_2 engines, large reusable LH_2 tankage, low structural weight and maintainability.
- Programmatic Issues – Those factors which define the time-phasing of decisions for integration with other elements of the space program such as definition of and compatibility with the space station or to minimize shuttle program costs such as initiation of advanced engine and avionics developments and uncoupling of orbiter and booster development.

We believe the definition of the orbiter concept is a key "driver" in establishing a successful space shuttle system definition and, therefore, plan to place greater emphasis on it than on the booster.

As a result of our in-house space shuttle system studies, which include a careful evaluation of NASA's funded Phase A study reports, we have become convinced that consideration of realistic NASA yearly funding limitations are as significant as other shuttle technical development risks. Grumman's Design 518 is "one-prong" of a proposed "three-prong" study approach conceived to ensure that the NASA Phase B study results include a space shuttle system definition whose acquisition is achievable within potential NASA annual funding limits. The two additional "prongs" consist of:

- Design 532 which yields capabilities nearly comparable to Design 518 and with less program technical risk and reduced annual funding requirements
- Programmatic alternatives which consider more effective phased developments than are inherent in Design 532 baseline configuration

The relationship of principal features of the two baseline designs and the principal study points of interest are shown in Fig. 2-1. More detailed description of the baseline configurations is given in Section 1.

Des 518	Des 532	Legend: ■ In Baseline Definition ○ Study Point
ORBITER		CONSIDERATION
■	■	Low Cross Range
○	○	High Cross Range
	■	1st Generation Electronics
■	○	2nd Generation Electronics
■		400K HP LO_2 LH_2 Engine
	■	250K HP LO_2 LH_2 Engine
○	○	Reduced On-Orbit Propellant
■	■	Air Breather Engines
○	○	Glide Control Only (Remove Air Breathers for Certain Missions)
	○	SIC Booster Application
	○	Kick-Stage for Overweight Payloads
BOOSTER		
	■	F-1 Engine, Uprated
■		400K HP LO_2 LH_2 Engine
○	○	Large (1000K+) HP LO_2 LH_2 Engine

Fig. 2-1 Baseline Design Features and Study Points

An illustration of the significance of programmatic alternatives is presented in Fig. 2-2. Results of our current program cost studies indicate that the peak annual funding required for Design 518 may exceed the probable available funds. A program alternative based on Design 532 including phasing of major system elements produced an apparently more uniform distribution of funding required. Fig. 2-2 states the basic problem of making the program fit

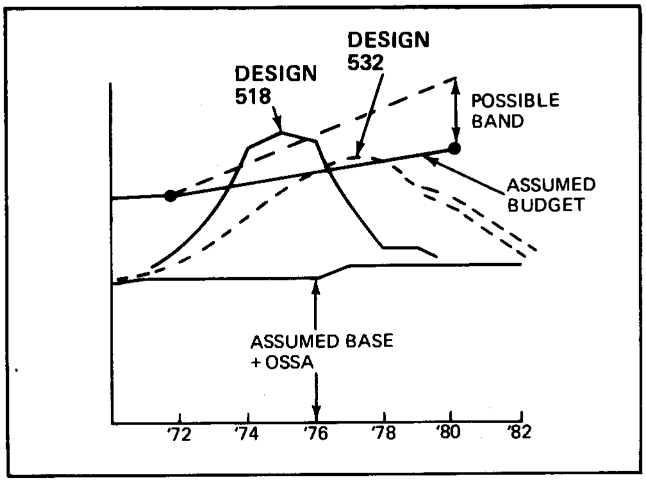


Fig. 2-2 NASA Budget Forecasts a Potential Shuttle Funding Problem

a reasonable budget; annual funding may well be more important than total funding.

In consideration of the annual funding limitation problem, the Design 532 study approach has been conceived to achieve its inherent performance through a three-step process consisting of:

- *Step A* – Development of the orbiter initially utilizing the demonstrated Rocketdyne J2S engine and first generation avionics. The fully reusable booster uses LOX/RP-1 tankage and Rocketdyne F-1 uprated engines in a similar 5-cluster engine arrangement to the Saturn S-1C stage. Use of KSC and other Saturn test facilities in connection with this booster represents major dollar savings in the proposed approach
- *Step B* – Improvement of the orbiter by substitution of the high pressure, higher Isp 250K thrust engine developed in parallel with Step A as well as upgrading to second generation avionics which improve ground turnaround time and reduce operational costs. In addition, the thermal protection system is qualified in Step B to enable full cross-range operation of the orbiter
- *Step C* – Design 532 makes provisions for introduction of a non-reusable kickstage. In addition, the orbiter employs a "flat-bed" design concept that accommodates a payload module up to 22 feet in diameter at launch. (Refer to Section 1.4.) Thus, Step C, by introducing a non-reusable kickstage provides increased payload capability for launching outsized payloads of up to an estimated 73,000 lb should such capability ultimately be desired or required

From the preceding, it can be seen that a major characteristic of Grumman's proposed Phase B study approach is that two major preliminary design efforts on similar, high cross-range potential, fully reusable configurations will be conducted in parallel with a third programmatic alternative investigation. Variations with respect to these baselines or between these two baselines provide the necessary background for selection of a suitable system. Fig. 2-46 on page 2-69 presents the study approach flow for this effort. This study approach is based on the conviction that the first six months of effort will provide sufficient information to enable NASA and Grumman to select a configuration with the best features of each of the two approaches for further in-depth preliminary design in the last five months of the study.

Grumman's study approach, shown in flow diagram form in the Summary and Fig. 2-46, has the following salient features:

First Three Months
At go-ahead, the results of all prior NASA and DOD effort as well as on-going in-house Grumman team efforts will be reflected in two primary documents, the Phase B Study Plan required by the NASA RFP and an in-house Baseline Requirements Document. The objective of the first three months of the study is to establish, with NASA approval, a requirements freeze for the designs and for the operational concepts. To achieve this objective, emphasis is placed on completing those operations, systems and design tradeoff studies which have a major impact on overall shuttle system cost and on the configuration size, weight and performance. After the three month NASA design review, the study plan and baseline requirements document will be updated to reflect the three month study departure point. In addition, it will be noted that the necessary interfaces with the engine development studies, supporting research and technology (SR&T) and on-going NASA and DOD funded and in-house studies are properly supported. The proposal for a major structural test program is provided in accordance with the NASA requirements.

Three to Six Months
The objective at the end of this period of the study is to select, with NASA review and approval, a con-

figuration for further in-depth design for the duration of the study. This includes making a choice between the metallic/radiative or the reusable external insulation thermal protection systems.

Decisions to implement any of the programmatic alternatives involving further phased development considerations will also be made at the six month NASA review. This requires emphasis on completion of the cost tradeoff studies in systems analysis, test, and operations as well as completion of all design tradeoff studies having a significant influence on cost, weight, performance and design confidence as it relates to program risk. To achieve the objective, emphasis is also placed on the continuation of the wind tunnel, materials, and structures testing initiated at or before go-ahead in support of the design and analyses. As in the previous period, the necessary interfaces with the engine development studies, and NASA and DOD studies are supported. After the six month NASA design review, the study plan and baseline requirements document will be updated to reflect the six month study departure point.

Six to Eight Months
During this period, the majority of the study effort will be concentrated on the further definition of the single configuration approved at the six month review, supported by verification of wind tunnel and laboratory testing to evaluate design performance and weight, and by the system flight characteristics simulation program. The preliminary program planning material required by NASA at the eighth month milestone is developed in this period. The main thrust of the design effort for the operations complex and support equipment area will be initiated during this period. The interfaces with the engine development study, SR&T, and NASA and DOD studies are continued as required during this period.

Eight to Twelve Months
While it is anticipated that some decisions will be made by NASA at the eighth month review that would tend to change some of the specific activity in this period, in general, the period from eight to eleven months is a continuation of the in-depth effort on the selected configuration with configuration verification based on wind tunnel and development test and simulation. As indicated in the study approach flow diagram of the Summary, the study approach is intended to complete the preliminary design effort by the end of the eleventh month. Booster and orbiter and ground system preliminary designs, reflected in drawings and specifications will be completed, as well as final program acquisition plans and other documentation required by the NASA RFP. The twelfth month of the study is reserved for preparation of the final documentation and is considered to be characterized primarily by the implementation of changes directed by NASA at the eleventh month review. All final documentation will be delivered by the end of the twelfth month in accordance with the NASA RFP.

Grumman believes that this study approach summary, when reviewed in context with the details of the study approach delineated in the remaining portions of this section, reflects complete compliance with the objectives, requirements and perhaps, more importantly, the intent of the NASA Phase B study as reflected in the RFP. We have attempted to treat the orbiter and booster and operations as an integral system during the first six months of the study due to the importance we attach to the fact that the total system defined must be capable of acquisition within potential annual NASA funding limitations. From the sixth to the twelfth month, the booster and the orbiter and support systems have been given individual attention and emphasis commensurate with the NASA requirement to issue separate RFP's for these vehicles for Phase C/D.

The remainder of Section 2 is organized in accordance with the task identification of Section 4 of the SOW. Subsections 2.1, Systems Analyses, 2.2, Design Analyses, etc., correspond to SOW Sections 4.1, 4.2, etc., and are identically titled and organized.

Task definitions and plans for accomplishing key milestones for the tasks are further clarified and amplified in the Phase B study plan presented in Section 4 of this proposal.

2.1 SYSTEMS ANALYSES

The system analyses required to identify and develop the most desirable approaches to the space shuttle system are discussed in this section as outlined in Section 4.1 of the NASA SOW. Each subsection contains our approach, the development issues and the tradeoffs to be performed as appropriate. In addition, we will give special emphasis in the study to the following three areas.

- Evaluation of costs for trade studies
- Programmatic analysis of cost and schedules for all configuration alternatives studied including budgetary considerations
- Evaluation of the total space shuttle economics by GE-TEMPO to evaluate its impact on DOD and NASA space activities and expenditures in 1977-1987 time period

Cost Trades

All elements of the shuttle system must be integrated and costed iteratively to define an optimum program within realistic developmental and operational budget constraints. As shown in Fig. 2-3, the Grumman study will relate the tradeoffs between vehicle design including subsystem alternatives, and ground, flight and support operations and costs, with proven cost models which have been adapted to the shuttle program. Prime cost driving factors such as the thermal protection system (TPS) and the test program will be addressed in the Phase B study in the context of the flow shown in Fig. 2.3. A description of the parametric design sizing may be found in Subsection 1.2, the operation analysis model in Subsection 2.1.4, and the cost estimating model in Subsection 6.4.

Reliable costing must be developed early in the study to ensure that the design concept meets the objectives of low acquisition cost, and economical operation. Phase A cost estimates appear optimistic when compared to several current subsonic and low supersonic aircraft (See Fig. 2-4). Short production runs of a high-performance manned spacecraft, which at best will be difficult to develop,

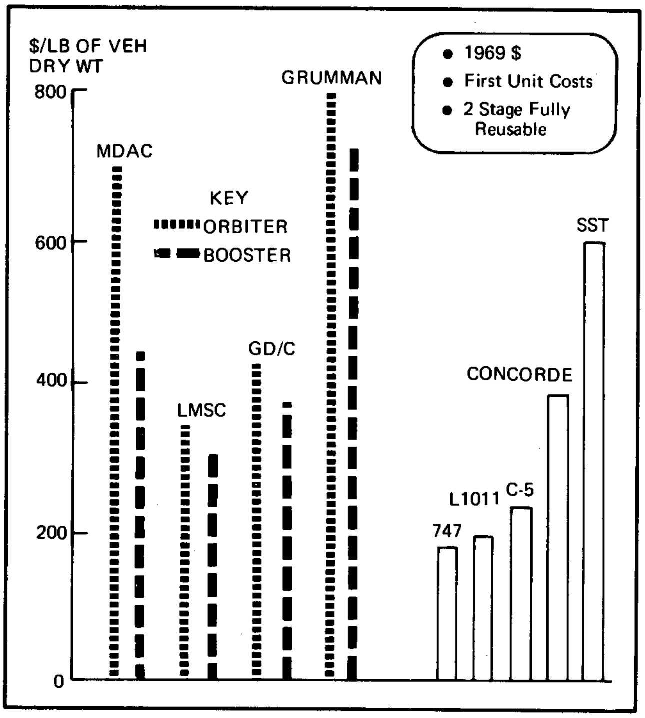


Fig. 2-4 Shuttle Acquisition Cost Comparisons. *Reliable Cost Estimation Through Comparative Analysis*

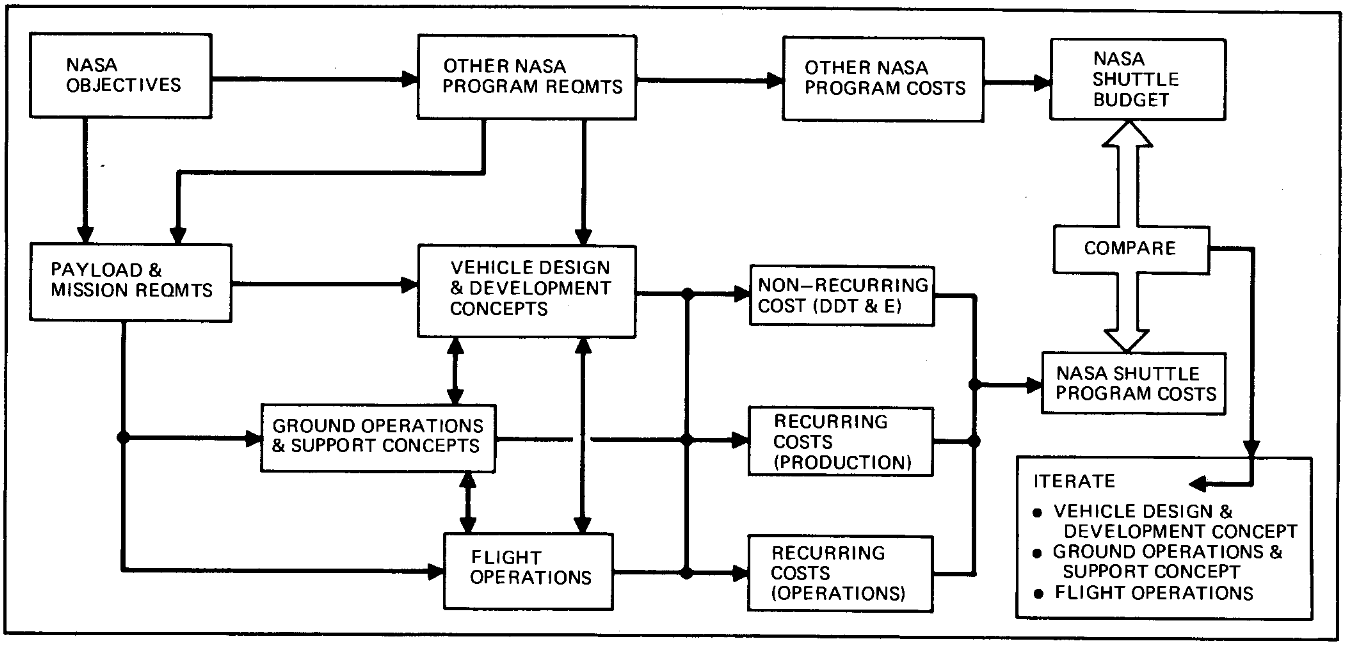


Fig. 2-3 Phase B Study Flow. *Definition of Realistic Low-Cost Shuttle Program Through Balanced Design/Cost/Performance*

will influence design and manufacturing concepts if costs are to be kept to a minimum.

Programmatic Analysis
A key element in our proposed study approach considers that further cost reductions may be realized by programmatic time-phased alternatives which may be applied to both Design 518 and 532. These programmatic factors address the reduction of annual cost possibly at the expense of a slight increase in total program cost. The need for reduced annual costs are evident when the time-phased distribution of the shuttle development costs are compared to present and projected future NASA budgets. Present indications of peak funding levels, though rather high, extend over only a limited number of years in the early development period. The Design 532 approach addresses this problem since, through use of present hardware, not only is development risk minimized but development costs are also reduced.

However, if further reductions in annual funding are required, several additional approaches may be used to further uncouple those high cost major program elements during the peak funding year requirements. One such approach investigated would uncouple the two major elements, namely the orbiter and booster, with initiation of orbiter development first. This approach preserves an early initial operating capability (IOC) for manned flight and recoverable payloads by utilizing S-1C boosters during test and initial low traffic launch schedules until full development of the booster.

Several other programs may be developed where annual funds are controlled by optimum initiation of other major element cost drivers such as the advanced high pressure engine, advanced avionics and thermal protection system for high cross range, operation without air-breathing engines and the use of kick stages for special high payload missions. In this way, proper balance can be realized between the technical and programmatic alternative tradeoffs to result in the development of a low cost transportation system in an era of budget austerity.

We intend to explore these alternatives in more depth during the first six months of our study to ensure the selection of a programmatic approach that will best fit NASA's needs.

Evaluation of Shuttle Economics
An evaluation will be performed by Grumman's team utilizing the resources of GE-TEMPO, to evaluate the capability of the space shuttle system to reduce future costs of the national space programs. The following activities will be undertaken:

- Analysis of potential national application of the space shuttle in terms of traffic rates, payload size, orbit inclination and altitude, payload density, and shape from 1977 to 1987
- Evaluation of present national launch vehicle inventory in terms of cost, including hardware, GSE, facilities, training, etc. Analyze degree of substitution of present launch vehicle inventory by space shuttle of several sizes. Estimate cost savings
- Utilizing payloads defined above, analysis of the merits of on-orbit maintenance, and/or return to ground for refurbishment. Estimate cost savings
- Integration of all three tasks into a total space shuttle economics analysis and evaluation of impact on DOD and NASA space activities and expenditure projections in 1977-1987 time period

2.1.1 System Safety Analysis

The excellent safety record of Grumman vehicles is known to both DOD and NASA. Grumman will use this aircraft/spacecraft experience to attack those problems unique to the shuttle which cross the ground operations, aircraft, orbiter, payload, booster and space station interfaces (see Table 2-1).

Several hazards unique to the shuttle have been identified. The following examples are typical:

- Fires due to fuel spills are a prime cause of serious injuries and deaths in aircraft accidents. In spite of this, the Phase A shuttle studies to date have not provided for fuel tank inerting before landing even though hydrogen fuel in the shuttle is more hazardous than JP or gasoline in aircraft. Furthermore, tank inerting would be difficult or impossible if Saturn IVB or membrane surface tension (MST) type insulation is used because hydrogen permeates such insulation material and is trapped. Design 518 and 532 tank construction and insulation, however, may not absorb hydrogen and can be inerted in flight by venting and introducing a non-flammable gas for the routine, abort or ferry missions

- The increased use of non-conducting materials on the shuttle makes the probability of serious lightning and static electricity discharge hazards much greater. New composite and laminated non-conductors will be monitored closely during Phase B. Simulated lightning tests such as those currently scheduled for the F-14 empennage (which uses new non-conducting boron materials) will be recommended, where necessary

- If an aborted launch occurs, propellant weight must be reduced quickly to a level safe for landing. It is desirable that propellant dump provisions be found which have little impact on shuttle weight, cost and complexity. Feasibility of dump systems will be examined along with possible alternate depletion methods such as burning propellant or utilizing the normal propulsion pumps and lines to dump raw propellant through the engine or tank vent outlets

These hazards, peculiar to the shuttle, will be included in the Grumman system safety analysis which:

- Will identify and classify all of the inherent shuttle/payload configurations and ground and mission operations hazards
- Will specify tradeoff studies concerning the systems safety aspects of the configuration
- Will analyze the safety or operations influencing the configuration and operational mode selection

Further, a gross hazards analysis will be performed using engineering, operational, and failure mode and effects analyses. These analyses will establish remedial measures such as self-help devices, escape and rescue provisions, and emergency techniques for damage control and isolation. These studies will be made within the guideline of NASA OMSF Safety Program Directive 1A. This approach, coupled with a judicious risk management philosophy, will yield a safe, cost effective shuttle program.

Table 2-1 Typical Safety Critical Interfaces. *System Interfaces Represent a Prime Source of Potential Safety Hazards*

INTERFACE AREA	HAZARD CRITICAL FUNCTIONS
Prepare for Launch or Post-Flight	
• Payload handling • Vehicle servicing • GSE/facility operation • Pyrotechnic handling	• Ground crew protection: cryogenics, fire, shock, radiation, heated surfaces. • GSE: stimuli, supplies, feedback for control, deservice/ safing tankage, compartment decontamination, payload removal, access to equipment, pyro instl/checkout/ safing.
Prelaunch	
• Booster/orbiter VAB erection • Vehicle - pad integration	• Erecting process - vehicle, GSE, facility interrelationships. • Lightning Protection. • Fuel disposal: joint LOX/LH_2 dump; fuel spills. • Launch releases: tiedowns, umbilical retract. • Hold/abort back-out procedures; egress operations.
Launch to Orbit	
• Range control & flight characteristics • Booster/orbiter separation • Payload control	• Aborts: fuel disposal, landing point control. • Plume impingement; separation control. • Payload: temperature/pressure/radiation level monitoring; CG constraint/restraint.
On Orbit	
• Docking • Unmanned docked orbiter • Payload handling • TPS operating environment	• Plume impingement, malfunction detection, visibility. • Malfunction detection/signal transmittal. • Satellite: deploy, retrieve, propulsion control • TPS collisions: meteoroids, debris, vehicle inspection/ checkout procedures.
Re-entry to Touchdown	
• Air traffic pattern • Runway - vehicle Reqmts	• Providing subsonic flight air space. • Runway: length, width, surface, lighting, landing aids, bearing strength. • Vehicle: landing gear, braking mechanism, rollout length.

2.1.2 Mission Analysis

Mission requirements drive system design. The mission analysis task includes identification of desired mission capabilities, and analyses of missions and vehicle parameters to define attainable requirements. The desired mission capabilities currently being studied are listed in Table 2-2. These typical mission requirements include those in the SOW plus several others recommended for the study. These are: rescue, a once-around polar mission, and delivery of a space station element. The orbit-to-orbit shuttle (OOS) is typical of a relatively heavy propulsive stage and imposes similar requirements on the shuttle as the delivery of propellants. None of the missions nominally require high cross range except for the once-around, and this mission may not require payload diameters exceeding 10 feet. This is the basis for the aerodynamic approach to Design 532. The requirements shown in this table will be reviewed and updated periodically with NASA.

These missions will be used during the study as a basis for analyzing total vehicle performance and operations requirements. To develop these requirements, the missions are further defined in terms of phase descriptions, event timelines and flight profiles. To provide a common basis for systems and mission analyses, these mission definitions are written into our design reference missions (DRM) document. The space station logistics resupply mission is being used as the principal source of performance requirements, and the alternate missions will be studied to identify potential additional requirements.

The gross mission requirements are also described in terms of operational logic flow diagrams that identify major flight/ground interactions. These will be generated for both the operational and test missions.

Mission profiles are analyzed in phases. Analyses will be conducted by flight profile mission phases considering critical factors such as those noted in Fig. 2-5. These profiles will reflect requirements of launch and entry loads, and heating for both nominal and abort situations. Sensitivity studies of performance capabilities to variations in key vehicle and mission parameters such as specific impulse, launch azimuth and guidance accuracy will be conducted. For example, Fig. 2-6 shows the baseline design payload-to-orbit capability sensitivity with respect to different inclinations and altitudes for Designs 518, 532, and 532 with a kick stage.

It should be noted that a combination of the Design 532 booster and a kick stage can place over 100,000 lb of discretionary payload into low altitude, low inclination orbits if the payload is located directly on the kick stage in place of the orbiter.

Both reference and critical design mission profiles will be used in the development of design concepts, and in the definition of equipment sizing and life requirements. Ground footprints (including tracking coverage) and daylight/darkness timelines will be provided to help define operational requirements and procedures. Logic flow, in conjunction with consumable usage timelines, will identify time critical mission periods. Mission capabilities for both operational and test missions will be determined.

Table 2-2 Typical Mission Requirements. *The Variety of Contemplated Missions Imposes a Wide Range of Requirements on the Shuttle System*

Characteristics Mission	Alt, n mi	Inclination, deg	Duration, days	Crew (Passengers)	Payload Max. Dia, ft	Payload Wt, lb	Cross Range
Space Station Logistics Resupply	270	55	7	2(12)	10-15	15K	Low
Satellite Placement & Retrieval	100-800	28-103	7	2(2)	15	1-34K	Low
Satellite Service	100-800	28-103	7-15	2(4)	15	TBD	Low
Orbital Operations	100-300	28-90	7-30	2(12)	15	25-50K	Low
Rescue	100-800	28-103	2	2(14)	10	10K	Med
OOS	100	28	3	2(1)	15	80K	Low
Once-Around	100	90	<1	2(0)	10	Low	1500 n mi
Space Station Element Delivery	270	55	7	2(2)	22	63K	Low

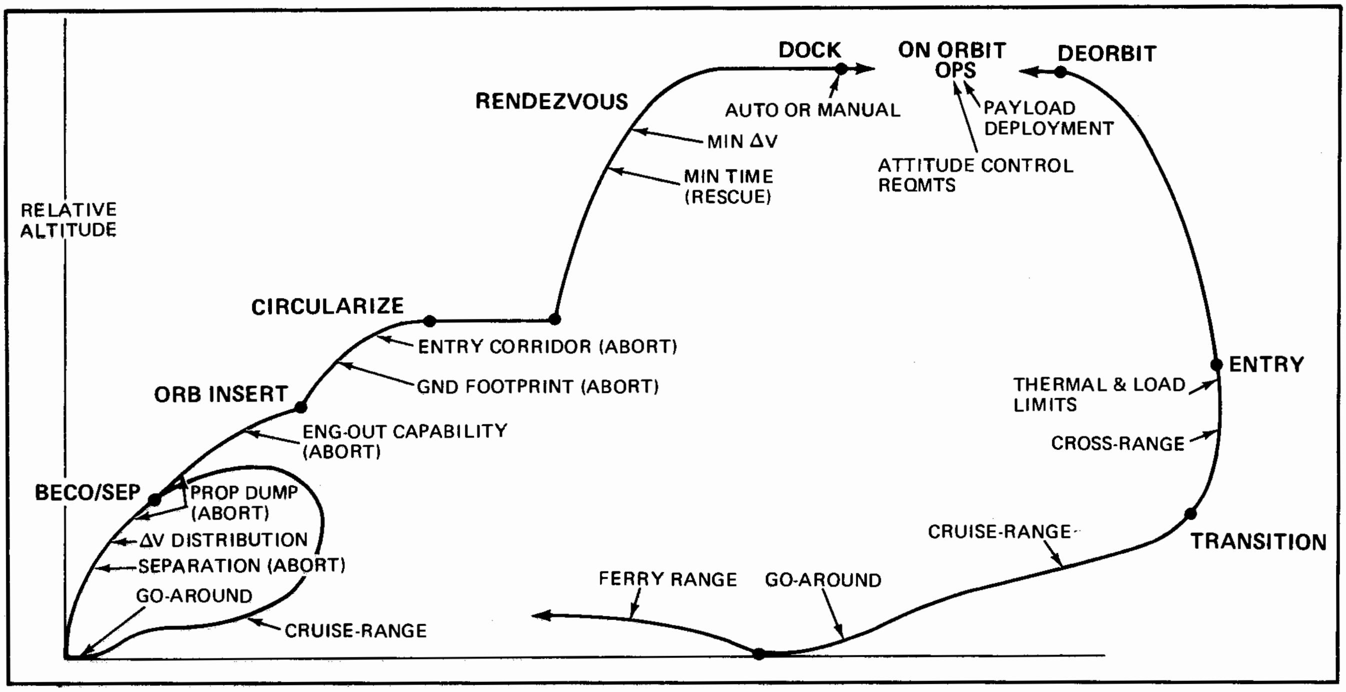


Fig. 2-5 Mission Phase Critical Considerations. *Critical Factors in Each Mission Phase Will Impact the Design*

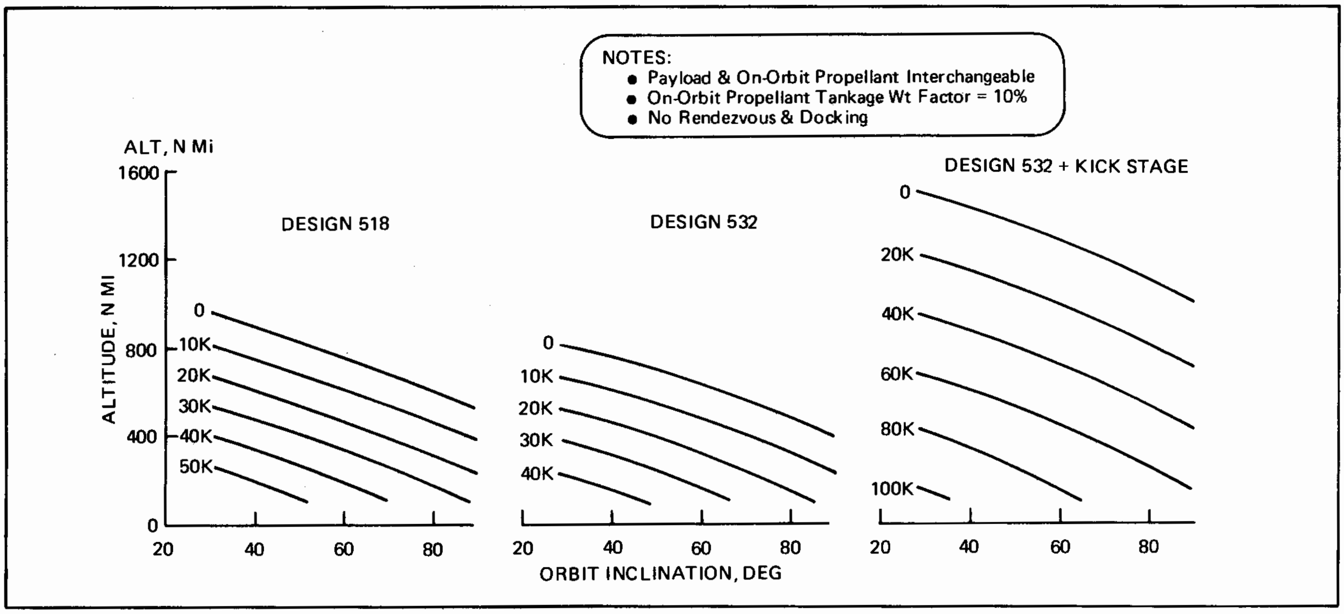


Fig. 2-6 Payload to Orbit Capabilities. *Baseline Designs Meet Mission Requirements*

The mission profiles, including key performance parameters and consumable usage data, will be organized in convenient blocks of operations so that a variety of missions may be evaluated without extensive analytic exercises for each.

Vehicle and equipment sizing, reliability analysis, and operations planning depend on the number and type of missions required of a single vehicle. An analysis of projected payload/mission frequency and schedule will be performed to define a best reference distribution of missions and cumulative flight time per vehicle.

Grumman experience with the Apollo Mission Planning Task Force indicates that the definition of mission requirements can be accomplished effectively through a similar NASA/Grumman relationship.

2.1.3 System Integration

System integration – a two level effort. System integration is being conducted at two levels. The first level is concerned with the relationships between the individual system elements (orbiter, booster, payloads, operations), and their relationship with the space station/space base. The second level is concerned with integration within an element, such as the airframe and subsystems within the orbiter, or booster. In this way, all physical and functional requirements will be identified and incorporated in the shuttle system design and operations plan. The study effort is structured so that, within both levels of integration, consideration is given to cost, schedule, and risk as well as design and performance factors. A typical first level task is the comparison of the proposed baseline program and the annual funding cost discussed in Section 2.1. An example of a second level task is the weight/cost tradeoff of integral vs non-integral cryogenic propellant tanks discussed in Subsection 2.2.1.

Requirements definition – establishing a baseline. System requirements will be identified through the study and defined by requirements documents, non-CEI specification, CEI specifications, and functional flow diagrams. Grumman has assembled requirements documents for the shuttle system, the orbiter, the booster, and the operations. They include requirements identified in the SOW plus others which we believe are appropriate. These documents are the single authoritative source of requirements for the study. They will be expanded as shown in Fig. 2-7 to become the specifications required at the end of Phase B.

The requirements documents also include interfaces with the space station and payloads. These interface requirements will be expanded to become the preliminary ICD's shown in Fig. 2-8. We intend to review our requirements documents with NASA for correctness at the orientation meeting, and at each review thereafter.

Requirements will be developed by a thorough analysis of the functional and physical interfaces between the shuttle elements, payloads, space station and ground systems by mission phase. A methodology for developing and tracking requirements is being used, similar to that used by General Electric in their space station studies.

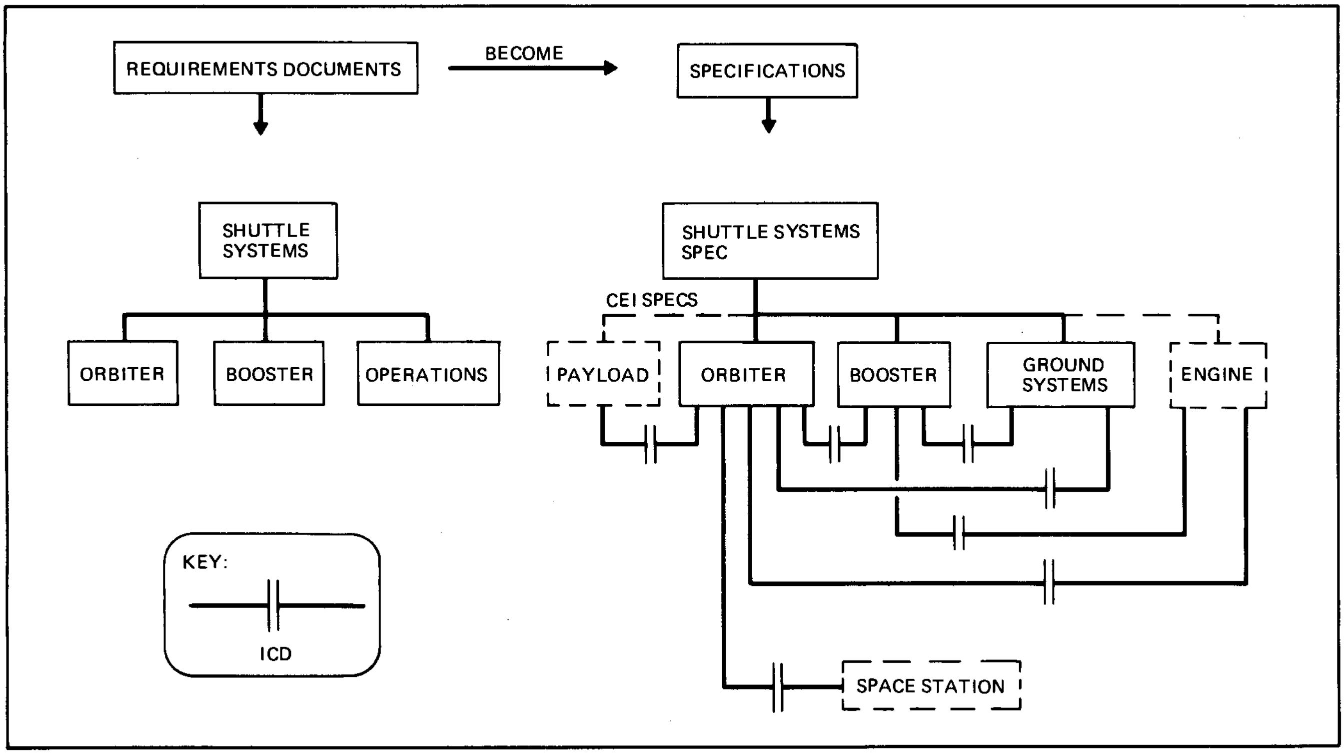


Fig. 2-7 Requirements Documentation. *Baselined at the Beginning of the Phase B Study, These Documents Will be Developed into Specifications*

This task also includes coordination of systems analyses or major trade studies required to firm up requirements. Emphasis will be placed on the following key decisions, which could have significant effects on the system definition:

- Degree of flight vehicle autonomy (including on-board checkout)
- Propulsion system options (i.e., go-around capabiligy, choice of fly back propellant)
- Choice of metal vs REI-type TPS
- Manned vs unmanned booster, considering abort implications
- Degree of crew participation in checkout
- Desired checkout test levels
- Display requirements
- Degree of centralization

This coordination involves:

- Structuring the study flow to feed key decision points indicated in the study plan
- Planning the major tradeoff studies to the proper depth of cut
- Monitoring study progress through reviews, and recommend remedial action
- Preparation of results and recommendations of system studies for program review
- Preparation of directives for implementation of program decisions

Coordination is also being provided through maintenance of the Design Data Book (DRL Item No. 10) Grumman has expanded this book to include current descriptions of the baseline booster orbiter designs as well as the design criteria and guidelines requested by the DRL SE004M. A Baseline Operations Data Book will also be maintained. These documents with the baseline requirements documents will provide a common basis for all tradeoff design studies.

Finally, assurance that the resulting subsystems preliminary designs meet their requirements will be provided through detailed functional flow diagramming. This technique was used successfully on the LM, OAO, and F-14 programs. These flow diagrams will identify degree of centralization, required information transfer, and fault detection capability. They will be baselined at the subsystem level and will be used for configuration and sequencing control, and test level determination.

2.1.4 Operations & Test Analysis

Grumman has closely related the analyses of operations and test to achieve substantially lower costs than in previous programs as required by Section 4.7.5 of the SOW. These analyses will be conducted in parallel and continuously interfaced with all other systems analyses described in this subsection.

Operations analysis – Bridging the design-to-operations gap. The combination of sequence and flow activity data and Grumman/Eastern Airlines simulation models for shuttle operations and maintainability, will provide rapid identification of efficient operational requirements. These requirements will become primary vehicle design considerations. The shuttle operational math models are an outgrowth of the Grumman computerized simulation model developed under contract to the Navy. The math model determined total logistics, equipment, facilities and manpower requirements of all aircraft avionic systems on all attack aircraft carriers through 1975. It examined 1400 assemblies in 350 subsystems for 9 different aircraft types. The Navy report stated "the model as it was developed and used in the study was an advancement in the state-of-the-art in simulation techniques." This technique will be employed during the Phase B study. The efficiencies for launch, mission, ground turnaround operations, and logistics and support concepts, for varying design approaches, can be simulated to derive the preferred requirements for the flight and ground regimes. Program requirements having severe impact on operations such as 2 hour launch from standby status will be highlighted for special attention. Study objectives providing operational efficiency such as flight autonomy will be stressed.

An analysis will be performed in conjunction with Subsections 2.1.3 and 2.1.12, to determine the impact of varying degrees of flight autonomy on operational cost, schedules and risks. As a final configuration is defined, the manpower for ground and flight operations will be defined by skill level and pay rate structure.

An operations management control system employing computer and graphic display methods to continuously provide change control, planning, scheduling and other operational information, will be specified. It will utilize new technology and practical airline experience to provide NASA visibility into operational functions. The nucleus of this effort will be the existing Eastern Airlines computerized system control center discussed in Subsection 3.2.5.

From experience in recent aircraft and spacecraft programs, and airline operations, the consulting pilots will ensure a practical evaluation of each design study and its potential effect on total launch-to-launch operations. Special emphasis will be placed on areas such as crew provisions, crew tasks, visibility, controls and displays, stability and control, and mission planning.

In satisfying a program objective for a low cost transportation system, we will place special emphasis in utilizing existing facilities and ground equipment. We will specify applicable units in NASA asset inventory wherever possible. Grumman is specially qualified in this area having just completed a study, culminating in a proposal to NASA Headquarters (PRD-ASU-69-07), to extend the useful life of NASA's ground assets.

Test analyses for economy at all test levels. Testing requirements at all levels, i.e., development, qualification and demonstration will be examined and a minimum practical test program will be defined which will ensure that testing will not become a major cost driver. As the system design evolves, specific configuration items that would result in high development test costs will be highlighted such that alternate design solutions can be evaluated. See Fig. 2-8.

Candidates for special attention in the study are:

- Landing gear design criteria vs horizontal take-off flight test endurance vs inflight refueling for the test vehicle
- Design criteria to allow test vehicle use for operational missions with minimum refurbishment

Test analysis is an effective integration and costing tool, which scrutinizes all test requirements for a candidate configuration. This technique was used on our AAP contracts with MSC and MSFC. Through integration, the analysis trades off various test approaches and eliminates redundancies, from development, through qualification, to vehicle acceptance. Interdisciplinary tradeoffs to be studied are:

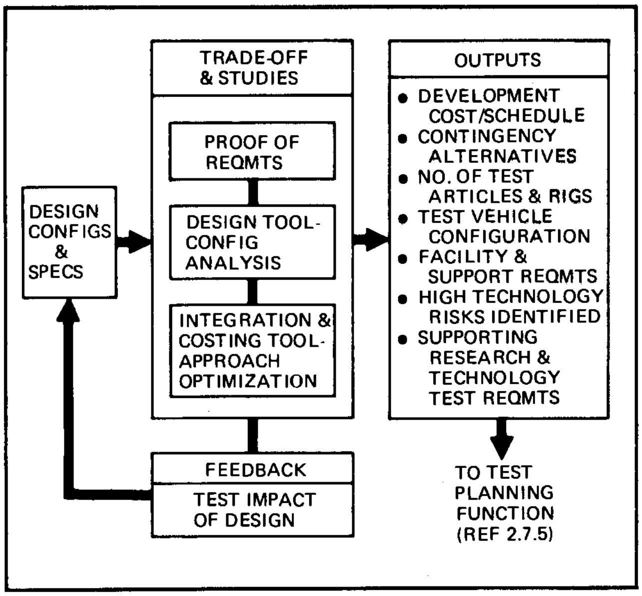


Fig. 2-8 Test Analysis. *Will Reduce Testing as a Major Program Cost Driver*

- Ground vs flight test
- Ground vs flight simulation
- Number of test articles vs time to complete
- System integration level vs number of integration phases
- Test program/IOC phasing strategy vs cost and schedule
- Manned vs unmanned testing
- Elimination or repetitious acceptance testing

Our Associates will lend their experience in this test analysis.

2.1.5 System Flight Characteristics

2.1.5.1 Analysis of System Flight Characteristics
The evaluation of vehicle flight characteristics will be performed for all mission phases. Particular emphasis will be given to:

- Development of steering laws to minimize Delta V losses, control policies for load relief and booster/orbiter separation (including aborts) during the boost phase
- Control policies for ranging and minimizing aerodynamic heating and loads; control blending and vehicle trim requirements during reentry and transition
- Handling qualities and cruise performance for subsonic and landing flight

Analytical techniques using existing computer programs developed for various aircraft and spacecraft programs (e.g., A-6A, F-14, and LM) will be supported by our program of wind tunnel testing and simulation described below. The integration of our analysis and testing efforts is shown in Fig. 2-9.

2.1.5.2 Guidance & Control System Requirements

Guidance and control system tradeoffs defining hardware, software and crew controls and display requirements will be performed.

Main engine thrust vector control (TVC) systems will be synthesized for both the booster and orbiter. The booster TVC will include lateral load relief techniques to reduce the effect of lateral gusts and wind shears either through guidance steering or acceleration feedback. The advantages of guidance steering to achieve the desired burnout state vector in the presence of a lateral disturbance will be compared to the simplicity offered by using lateral acceleration sensing as a simple control system feedback. Addition of an accelerometer feedback to a basic attitude/attitude rate scheme can provide the optimum combination of minimum loads and lateral drift. Both linear and non-linear control laws will be investigated. The effects of fuel slosh, engine throttling and body dynamics will be examined. Recommended control system gyro and accelerometer locations will be determined.

An attitude control propulsion system (ACPS) software control policy, using Grumman's Apollo digital autopilot experience will be developed for exo-atmospheric flight. Various booster and orbiter ACPS thruster configurations will be evaluated for vehicle handling qualities and propellant consumption with emphasis in selection given to simplicity and redundancy. Failure detection and jet isolation logic will be formulated using either inertial system sensing or thrust chamber measurements.

Reentry guidance techniques in Table 2-3 including that developed for Apollo will be investigated. The relative merits of each system will be established. Ability to control off-design reentry conditions within vehicle heating and loads constraints will be given prime consideration. The candidate systems will be evaluated in terms of computer complexity, interface requirements, crew monitoring potential and orbiter/booster commonality. Reentry guidance techniques can be separated into two classifications; predicted terminal point guidance, and differential guidance using a nominal reference trajectory. The former techniques use an analytic solution for terminal conditions based on an as-

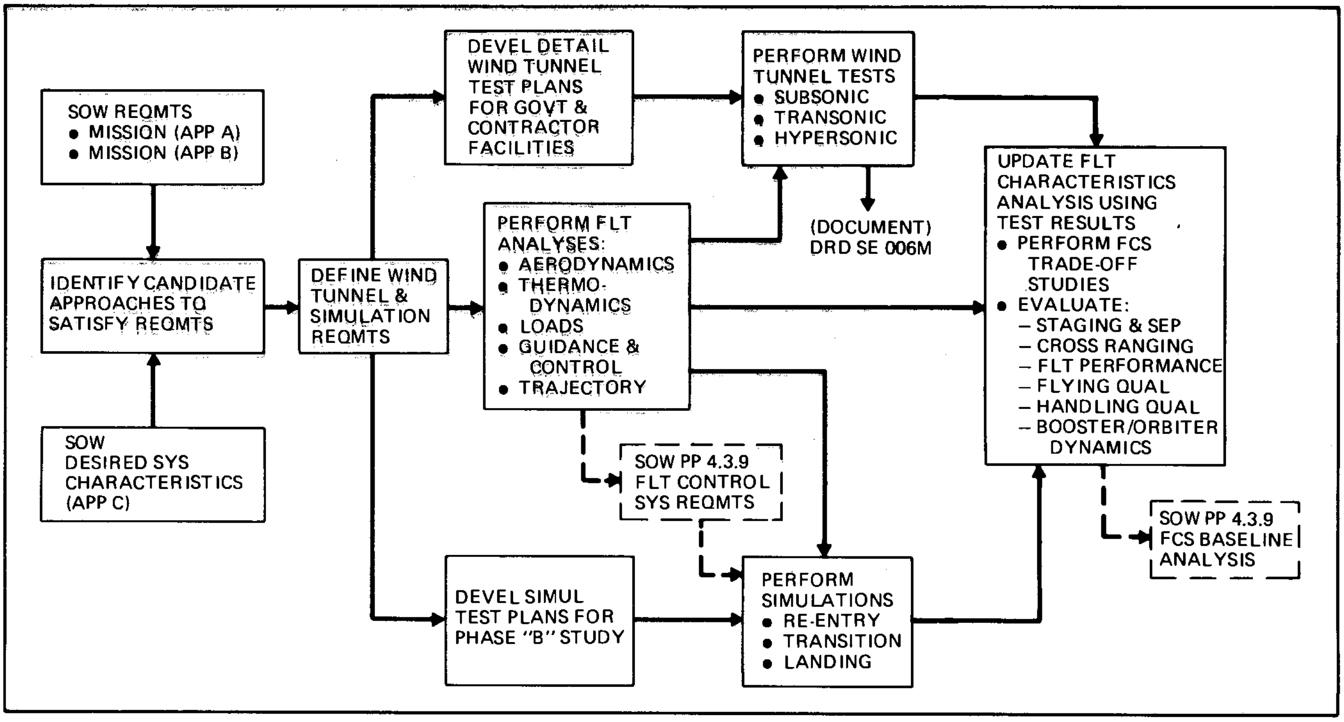


Fig. 2-9 Analysis of System Flight Characteristics. *Blending of analysis & test results provides confidence in design approach*

Table 2-3 Reentry Guidance Methods. *Evaluation of predictive & nominal trajectory reentry guidance methods will yield recommended reentry guidance technique*

	Guidance Using Predicted Capability		Guidance Using Reference Trajectory	
	Fast Time Prediction	Closed Form Prediction	Path Control	Terminal Control
Approach	• Desired control obtained in iterative manner by fast-time on-board integration of the equations of motion. • Desired control obtained from real-time on-board solution of re-entry optimization problem.	• Approx equations of motion & obtain closed form range prediction for types of controlled flt: - constant drag acceleration - constant altitude - constant flt path angle - equilibrium glide • Desired control obtained from difference between predicted & desired range.	• Store precomputed time or velocity-dependent state variables of a nominal trajectory & constant or variable feedback gains in computer. • Desired control obtained from deviation of actual state from nominal state and associated gain. • Northrop's TRFCS employs a stored nominal trajectory & constant gains for path control. Measurement of temp rate yields vehicle heating rates which never exceed the initial max value.	• Predict equilibrium glide range & add corrections to account for vehicle's non-equilibrium glide state. Influence coefficients relating non-equilibrium conditions to terminal range error obtained from linear perturbation theory. • Desired control obtained from difference between predicted & desired range. • Method used by Apollo CM for an L/D of 0.5.
Advantages	• Handles all flt conditions. • Flexibility provided by ability to predict range, acceleration and heating.	• Closed form prediction obtained with modest computer usage reqmt.	• Nominal trajectory & variable gains can be determined by prefit optimization techniques.	• Ref equilibrium glide trajectory & influence coefficients are available in analytic form on-board the vehicle.
Disadvantages	• May require significant computer useage reqmts. • Requires estimation of two vehicle aero parameters (i.e. L/D & W/C_DA).	• Missing state variables in prediction algorithm limits flexibility to handle off-design conditions. • Limited to analytically described trajectory.	• Various orbital inclinations & range reqmts at re-entry may require a number of stored nominal trajectories. • Constant gains lack flexibility to design vehicle response during re-entry.	• Limited to near-equilibrium glide re-entry trajectory.

sumed form of equilibrium glide or a faster than real-time integration of the trajectory. The Northrop temperature rate flight control system (TRFCS) is a good example of the differential guidance technique which provides a well damped trajectory with unique atmospheric adaptive and safety features by sensing vehicle nose and/or leading edge temperatures. In addition, this type of control provides an energy management technique which can produce uniform flight conditions at 100,000 feet over the entire footprint for the range of initial reentry conditions.

Subsonically, emphasis will be placed on defining the booster and orbiter handling qualities. Generally, the requirements of MIL-F-8785B for transport aircraft have been used as a standard, unless imposing these requirements results in an undue penalty. In this case, the impact on design to satisfy the requirement must be weighed against the relative importance associated with the particular handling quality to arrive at a design decision.

The airframe configuration has been designed to provide the best low speed aerodynamic configuration without undue thermal, load or performance penalties to the hypersonic reentry configuration. The desired level of stability, control and handling quality performance is achieved through the use of a three-axis stability augmentation system (quadruple redundant for Design 518 and triply redundant for Design 532). This approach, i.e., augmenting a basically good airframe configuration with SAS rather than depending entirely on SAS to overcome basic aerodynamic shortcomings has been used successfully by Grumman in designing a multitude of aircraft types from supersonic fighters (F-14), to subsonic attack A-6A, and AEW E-2 type aircraft. Less reliance is placed on the SAS and man-piloting capability is less critical in presence of SAS system failures.

For the shuttle vehicles, in the subsonic and low speed flight regime, particular emphasis will be given to the yaw/roll coupling problem associated with lifting bodies; potential control coupling because of the aerodynamic control surface arrangement; path control as affected by response to cruise engine thrust, wave-off and go-around capability. In addition, the more usual handling qualities and paramcters (i.e., longitudinal and lateral vehicle trim capability, directional stability, both static and dynamic, and aircraft response to control, particularly roll control because of the configuration's inherently poor roll damping) will be evaluated and configuration changes made to improve the unaugmented vehicle. The degree of required augmentation will depend upon the degree of success achievable aerodynamically.

Aerodynamic control surfaces are sized to provide the required control response for low speed flight. The baseline ACPS thrusters are sized for the exoatmospheric phases of flight. The manner in which these two control systems are blended and the degree of modification required for each will be established from an examination of the control moment requirements during the reentry and transition phases.

A hypersonic control flap is sized to provide trim capability from 20 to 50 degrees angle of attack. This provides the angle-of-attack modulation required to achieve the low and high cross-range capability.

2.1.5.3 Staging & Separation Analysis

The booster/orbiter separation problem is more complex than conventional "booster" staging because of the parallel mating arrangements under consideration. The problem is further complicated by the induced aerodynamic forces and moments resulting from mutual interference effects and the induced and direct pressure effects from rocket plumeimpingement (ACPS thruster and main engines).

Staging and separation studies will be performed to ensure safe separation for nominal and abort conditions. The baseline separation method currently preferred is based on lateral displacement of the two vehicles, with the relative booster/orbiter motion constrained by mechanical means. For nominal separation, the separation impulse is supplied mechanically by the booster followed by orbiter ignition. For aborts, the orbiter will be rotated relative to the booster mechanically (to permit aerodynamic augmentation of the separation), followed by booster throttling and orbiter ignition to effect the actual separation.

Dynamically, this problem is similar to the problem of store separation from aircraft, particularly missile firings, except for body sizes. Grumman's experience gained on the A-6A, F-111 and F-14 with separations of bombs and Sparrow and Phoenix missiles will form the basis for performing separation analyses. An existing computer program will be used to determine the relative motion of the two vehicles in six degrees-of-freedom. This program utilizes aerodynamic data obtained from wind tunnel tests of varying booster/orbiter relative locations.

Grumman experience with store separation also includes closed loop "quasi-dynamic" wind tunnel testing where the two vehicles are mounted on separate stings. The relative motion of one to the other is determined by measuring the forces (and moments) on one in the presence of the other and calculating its relative motion in a series of time steps. At each time step a computer coupled to the wind tunnel computes the relative position and repositions the model.

2.1.5.4 Configuration Tunnel Test Program

Our integrated wind tunnel test program (Fig. 2-10) provides phased experimental data for the related studies and subsequent development of the shuttle system. The experimental approach will be based on Grumman's aircraft and spacecraft test experience, in conjunction with Northrop's HL-10, M2-F2, and General Electric's maneuvering ballistic reentry vehicle know-how. Aerothermal wind tunnel test results will be submitted in accordance with DRL Item No. 5.

The combined wind tunnel test facilities of Grumman's team provides the capability to perform testing in virtually all critical regimes of interest in rapid succession. We have the following facilities:

- M≈20 shock tubes, 54 in.
- 5 megawatt arc
- Two hypersonic (30 in. and 36 in.) Mach 6 to 14 wind tunnels
- Two supersonic wind tunnels, 15 in. and 24 in.
- Two transonic 2x2 ft. tunnels
- Two 7x10 ft. subsonic tunnels

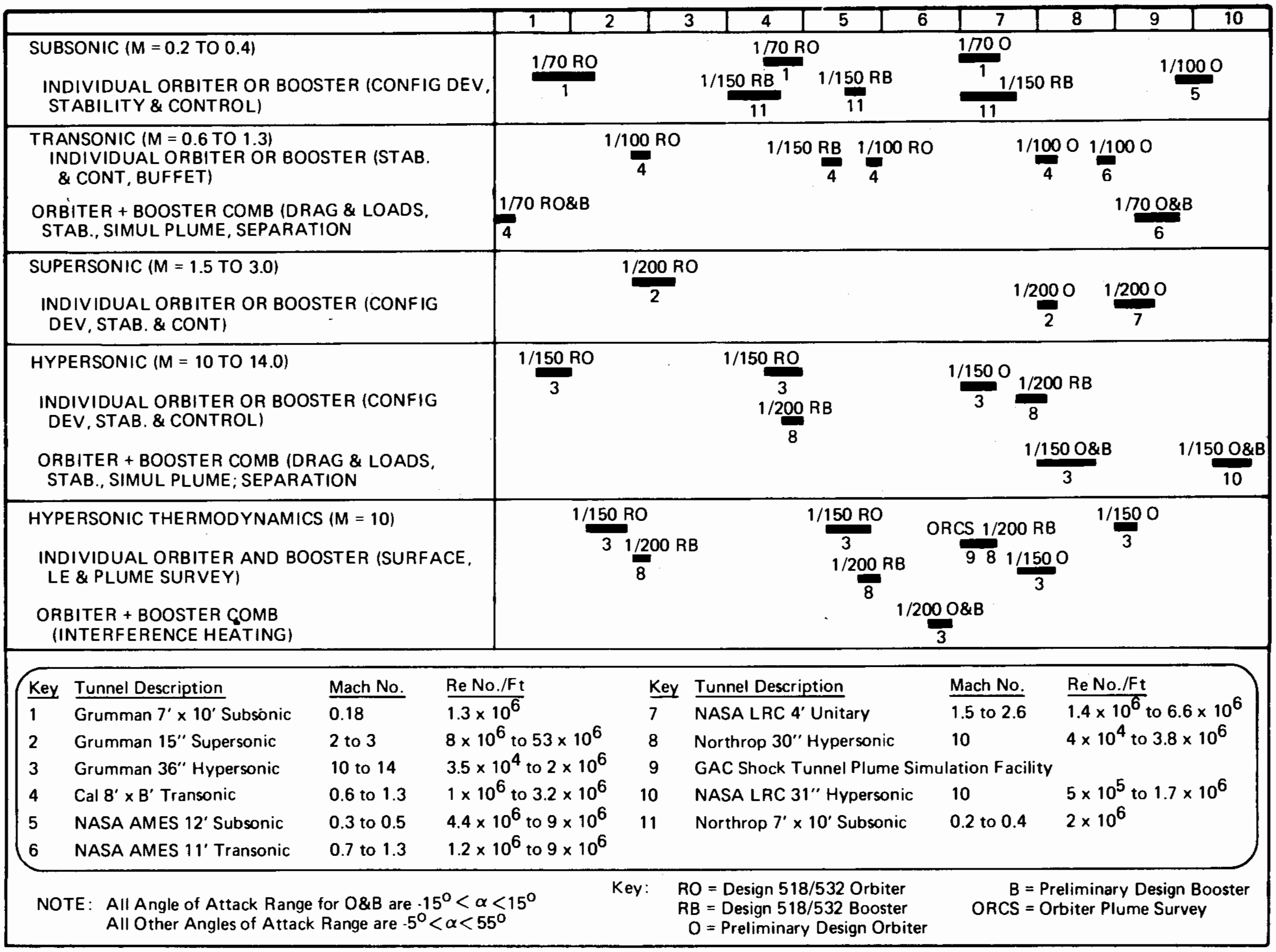
Testing will be performed to obtain aerodynamic, thermodynamic and loads data. Two boosters and two orbiter configurations will be tested. Typical shuttle configurations tested to date are shown in Fig. 2-10. The boosters for Designs 518 and 532 have similar geometric shape but vary in scale. The orbiters are of the same lifting body family with slight variations due to the packaging philosophy adopted, i.e., internal payload on the Design 518 versus external payload on Design 532.

The aerodynamic portion of the plan is keyed to drive Designs 518 and 532 toward one configuration within the first six months. The basic characteristics of each configuration will be established (e.g., sensitivity to geometric changes such as body camber, control power, buffet onset, mutual flow interference effects, ground effects, plume effects). An initial orbiter plus booster combination of our Design 518 baseline configuration will be tested transonically (M=0.6 to 1.3) in the early portion of Phase B to establish the relative drag and stability levels of the coupled system and to establish sensitivities when using the kickstage of Design 532. The aerodynamic forces and moments of the orbiter and booster during simulated separation will be determined during simulated separation.

The thermodynamic portion of the test program (Fig. 2-10) will define the hypersonic aerothermodynamic flight environment (M=10) of the shuttle system and the effects on adjacent vehicle surfaces of rocket plume impingement.

Aerodynamic heating tests will provide information in complex flow regions associated with shock impingement, boundary layer separation, reattachment and transition and will augment analytical predictions. Phase change paint, oil flow and Schlieren photography test techniques will be used for the early tests while thin skin thermocouples will be used for the final tests.

Rocket plume simulations in the Grumman shock tunnel will use techniques developed by Grumman during the LM program. Results of these tests at simulated space environment will be used to analyze the effects of plume impingement on surface heating.



Key	Tunnel Description	Mach No.	Re No./Ft
1	Grumman 7′ x 10′ Subsonic	0.18	1.3×10^6
2	Grumman 15″ Supersonic	2 to 3	8×10^6 to 53×10^6
3	Grumman 36″ Hypersonic	10 to 14	3.5×10^4 to 2×10^6
4	Cal 8′ x 8′ Transonic	0.6 to 1.3	1×10^6 to 3.2×10^6
5	NASA AMES 12′ Subsonic	0.3 to 0.5	4.4×10^6 to 9×10^6
6	NASA AMES 11′ Transonic	0.7 to 1.3	1.2×10^6 to 9×10^6
7	NASA LRC 4′ Unitary	1.5 to 2.6	1.4×10^6 to 6.6×10^6
8	Northrop 30″ Hypersonic	10	4×10^4 to 3.8×10^6
9	GAC Shock Tunnel Plume Simulation Facility		
10	NASA LRC 31″ Hypersonic	10	5×10^5 to 1.7×10^6
11	Northrop 7′ x 10′ Subsonic	0.2 to 0.4	2×10^6

NOTE: All Angle of Attack Range for O&B are $-15^\circ < \alpha < 15^\circ$
All Other Angles of Attack Range are $-5^\circ < \alpha < 55^\circ$

Key:
RO = Design 518/532 Orbiter
RB = Design 518/532 Booster
O = Preliminary Design Orbiter
B = Preliminary Design Booster
ORCS = Orbiter Plume Survey

Fig. 2-10 Aerothermal Wind Tunnel Test Program. *Will be used to supplement analysis*

2.1.5.5 Flight Control and Flying Qualities Simulation

Two part-task, six degree-of-freedom, flight crew shuttle simulators utilizing existing facilities in the simulation laboratories at Grumman and Northrop will be used for the analysis and evaluation of vehicle handling qualities and guidance techniques, and integration of the flight control system. A brief summary of anticipated simulation tasks is presented in Table 2-4.

The two major simulation activities are:

- A fixed base real-time hybrid simulator, with a mockup of the shuttle crew station and an external visual display system to present horizon and terrain cues, will be used at Grumman for the reentry, transition and landing studies. The computing and visual display equipment developed for the LM program for flight controls integration and software verification studies will be used.
- The Northrop fixed base real-time analog simulator will be used to develop and evaluate a temperature rate flight control system (TRFCS) design for reentry guidance. This simulator includes automatic and manual guidance capability from entry to 100,000 foot altitude.

Verification of the flight control function requirements will be performed by detailed simulation tests of the nominal and selected alternate missions.

Table 2-4 Part Task Piloted Simulators Evaluation. *Simulation test results will be used to supplement analysis*

SIMULATION	SIMULATION FLIGHT TASKS
Re-entry & Transition (400,000 - 40,000 ft) Fixed-Base Simulator	• Longitudinal dynamic stab. • Lateral-directional dynamic stab. • Yaw, pitch, & roll maneuvers • Flt control eval - ACPS/ aerodynamic control blending • TRFCS evaluation • Footprint evaluation • Trajectory control • Short term-stability • Transition maneuver • Influence of cg variations
Landing (40,000 - 0 ft) Fixed-Base Simulator	• Transients due to trim changes • Flt control evaluation • Longitudinal dynamic stability • Lateral-directional dynamic stability • Abort landing capability • Controller evaluation • Footprint evaluation • APC evaluation • Influence of cg variations • Window config • Handling qualities

Out-of-tolerance tests will be performed to estab- 3-sigma limits on equipment performance (simulated math models) and flight envelopes. These tests will be used to establish subsystem requirements and to identify parameters and displays for monitoring performance. Flight control displays and vehicle handling qualities will be evaluated by correlation of pilot opinion ratings with statistical engineering data.

Additional simulation activity is under consideration to supplement the program outlined above, including:

- A variable stability aircraft study will be considered to realistically simulate the booster and orbiter flying qualities as a supplement to our fixed base simulator studies
- A fixed-base rendezvous and docking simulation will be considered to provide evaluation of handling qualities, guidance techniques, docking aids, docking contact conditions, as well as propellant consumption

2.1.6 Payload Integration

This analysis includes the determination of the internal interfaces between payloads and the shuttle and the external interfaces between the shuttle and payloads with the space station, experiment modules, unmanned satellites and ground facilities. Installation, deployment, and retrieval provisions, for a variety of shuttle payloads, will be developed including:

- Space station logistics (passengers and expendables)
- Space base buildup elements and logistics
- Experiment modules
- Unmanned satellites
- Satellite maintenance/service
- Propulsion stages, e.g., OOS
- Propellants
- Rescue
- Passenger modules

General Electric TEMPO will assist in identifying the generic characteristics of candidate payloads in terms of size/weight, and special requirements such as spatial orientation data updating, and support requirements imposed on the shuttle.

These efforts will be supported by in-house study programs such as: space station, orbit-orbit shuttle, and experiment modules, and by NASA funded study contracts: mobility and restraint devices (NAS 9-10456), thermal control systems for space base (NAS 9-10436), control moment gyro applications to space base wobble damping and attitude control (NAS 9-10427). The latter study, for example, is developing space base control system/structural flexibility dynamic equations that will permit a realistic assessment of shuttle docking implications. A typical 14-man/30-day orbital mission module, developed by Grumman in-house studies, will be evaluated as one of the representative payloads. This module has an all-up weight of approximately 40,000 lb and a volume in excess of 1500 cu ft reserved for mission use.

Internal Interfaces

Representative payload/container interfaces will be developed using the study flow shown in Fig. 2-11. In this study a standard shuttle unpressurized payload bay interface will be defined for the preliminary phase of the study. For those payloads which are expected to be carried both up and down, the effect of vertical installation at launch and horizontal landing on return will be considered. Various installation mounting concepts such as single point with sway brace sup-

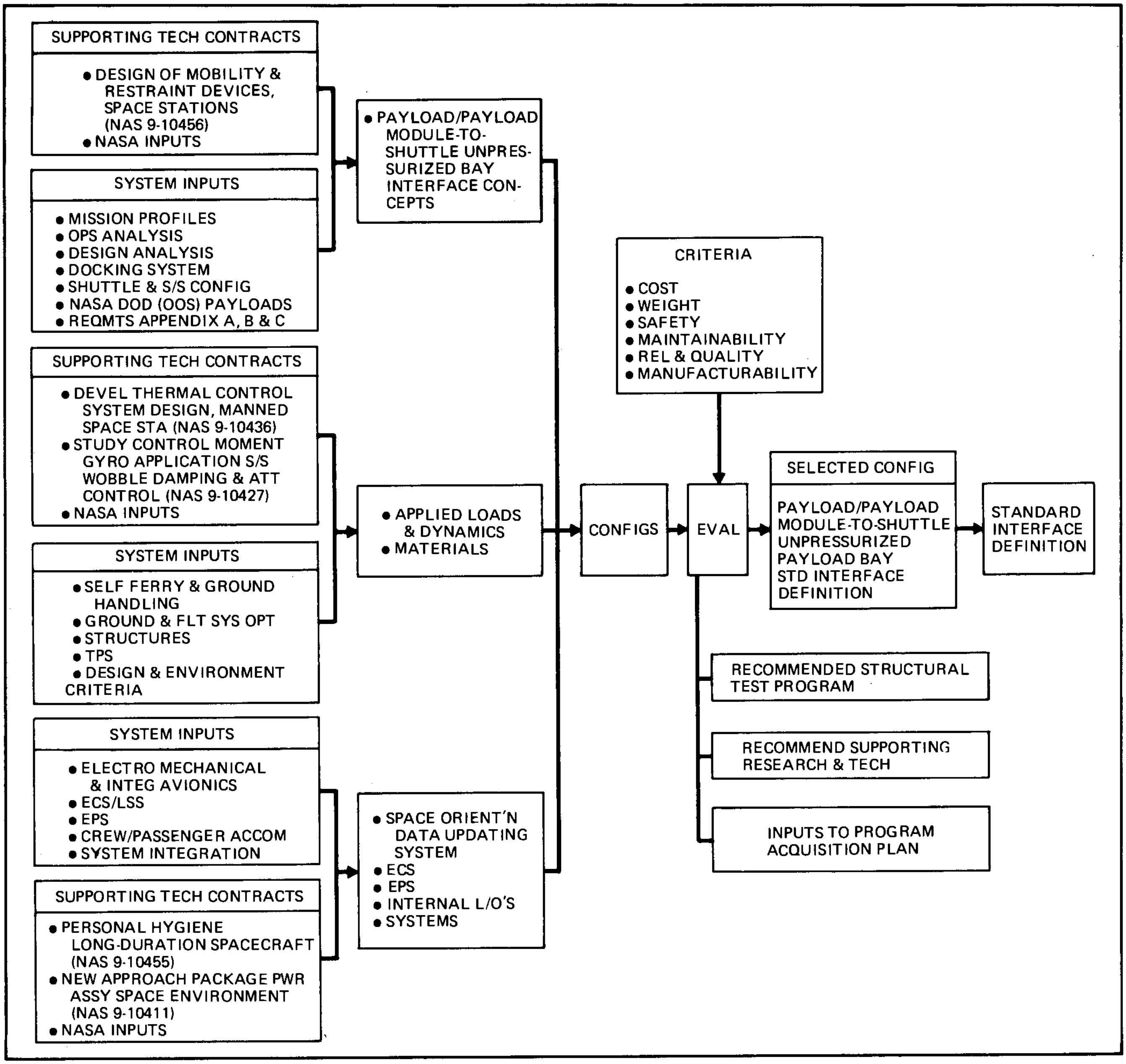


Fig. 2-11 Payload Integration Study Plan. *Analysis, integration & evaluation to define standard interface*

ports, three point engine type mount and clamped ball joint will be evaluated to determine the most desirable. Concepts for deployment and retrieval of payloads not associated with the space station/base will be evaluated as part of the internal payload installation interface. Shuttle support functions such as power and inertial orientation data for update of satellite stabilization system will also be defined.

External Interfaces
Major factors affecting the definition of external interfaces are:

- Docking Approaches – Impact vs non-impact, fixed vs hinged (articulated docking mechanism), rigid vs flexible retention, and nose vs overhead docking of the shuttle.
- In-Orbit Dynamics Implications – Stabilization/control and structural weight penalties imposed on the various orbital elements and the shuttle by virtue of their relative spatial positions and the manner in which the elements are docked. This includes consideration of various deployment/retrieval approaches. For example, shuttle active, space station/space base active or shared operations. Shuttle cost/weight penalties will be weighed against the number of rendezvous/docking operations anticipated with the various manned/unmanned orbital elements
- Ground Handling, Launch and Landing Dynamics Implications – Shuttle weight/cost penalties will be weighed against the weight/cost penalties imposed on candidate payloads (and their potential traffic volume), as a function of various shuttle installation concepts.

These studies will identify whether it is more economical to place the burden of accommodation on the payload, the shuttle, the orbital elements (manned or unmanned) or the ground support equipment.

2.1.7 Aborts

Investigation of abort regimes will examine the capability and constraints of intact abort for each mission phase. Studies to date have identified that the two most critical abort requirements affecting vehicle design are the methods of early separation within the atmosphere and propellant depletion. The baseline separation approach is described in Subsection 1.3.1.

Three approaches are illustrated for abort separation:

- Abort by thrusting to the normal injection condition (abort to orbit) which could be followed by de-orbiting back to the U.S.
- Abort by thrusting to increase velocity to an equilibrium glide return condition, which would result in long down ranges. Long down ranges may be advantageous for certain launch sites and azimuths. For example, recovery in the U.S. is possible for KSC launch towards 55°inclination orbit

- Abort without orbiter propulsion. Aborts from separation without thrust could result in exceeding "g" limits if propellant is not dumped. Ability to reach a landing site will depend on launch site and azimuth, and orbiter cruise-back capability

Key problem areas to be studied during Phase B are listed below and shown in Fig. 2-12.

- Abort Techniques and Procedures – Abort timelines will be generated to permit study of the provisions necessary to successfully recognize, respond and control the vehicle during a time-critical abort situation. The Phase B study will determine techniques and crew procedures required to execute a safe intact abort and continue the flight to a safe landing
- Prelaunch – Rapid crew evacuation in the event of a hazardous condition from cabin closeout to liftoff
- Liftoff Through Minimum Safe Altitude – Preliminary analysis indicates minimum safe aborts

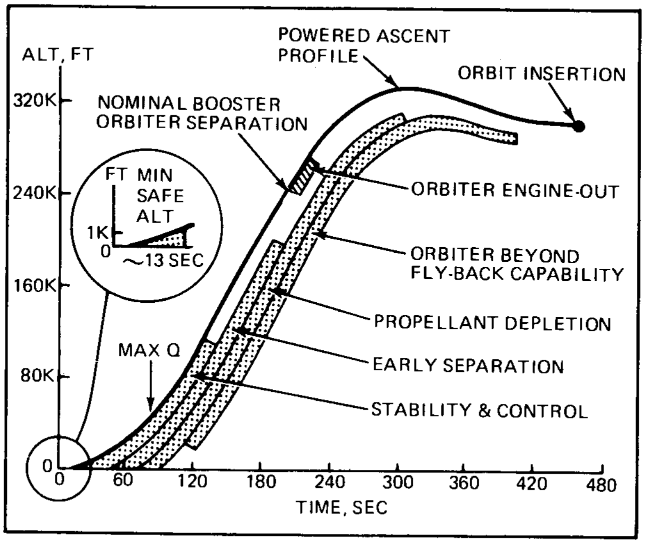


Fig. 2-12 **Powered Ascent Abort Regimes.** *Studies will determine their impact on vehicle design*

should be possible beyond approximately 13 seconds after launch

- From unsafe Separation Regimes to Nominal Separation
  - Alternate booster/orbiter separation methods at low altitude and in high dynamic pressure regions
  - Use of the ACPS jets or aerodynamic surfaces to maintain vehicle attitude control during separation sequence
  - Target the booster to nominal burnout conditions following early separation. Such maneuvers may require different guidance steering techniques than normal "gravity turn"
  - Post separation transitions of both vehicles to new trajectories to ensure that angle and angular rates are within acceptable limits
  - Methods for providing propellant dump capability. The propellant depletion problem is illustrated for the orbiter in Fig. 2-13. Two conditions are shown: abort two minutes after launch and abort at a point near normal separation. The abort shown at T + 120 seconds demonstrates the capability of the orbiter to return to the launch site by burning off propellant
  - Orbiter return within temperature and "g" limits, considering relationships between dumping, cross range, alternate site locations and ferry requirements
  - Availability and desirability of ground assistance in the form of backup navigation (i.e. state vector updates, targeting, weather information, etc.) and other ground aids
- Nominal Separation to Insertion – Utilization of on-orbit propulsion to achieve insertion with one engine out
- Orbital insertion through de-orbit – Capability of the ACPS system to de-orbit
- Effect of the larger payload diameter capability of Design 532 on entry and flyback capability during abort

Note that one of the attractive features of the GE external insulation (REI 2000) material is that it will tolerate the high temperature excursions that may occur during aborts. Although material replacement may be required, the characteristics of the material at overtemperature conditions provides a higher degree of inherent safety than metallic protection surfaces.

2.1.8 Unmanned versus Manned Booster

The issue of unmanned versus manned flight will be resolved in favor of the configuration which of-

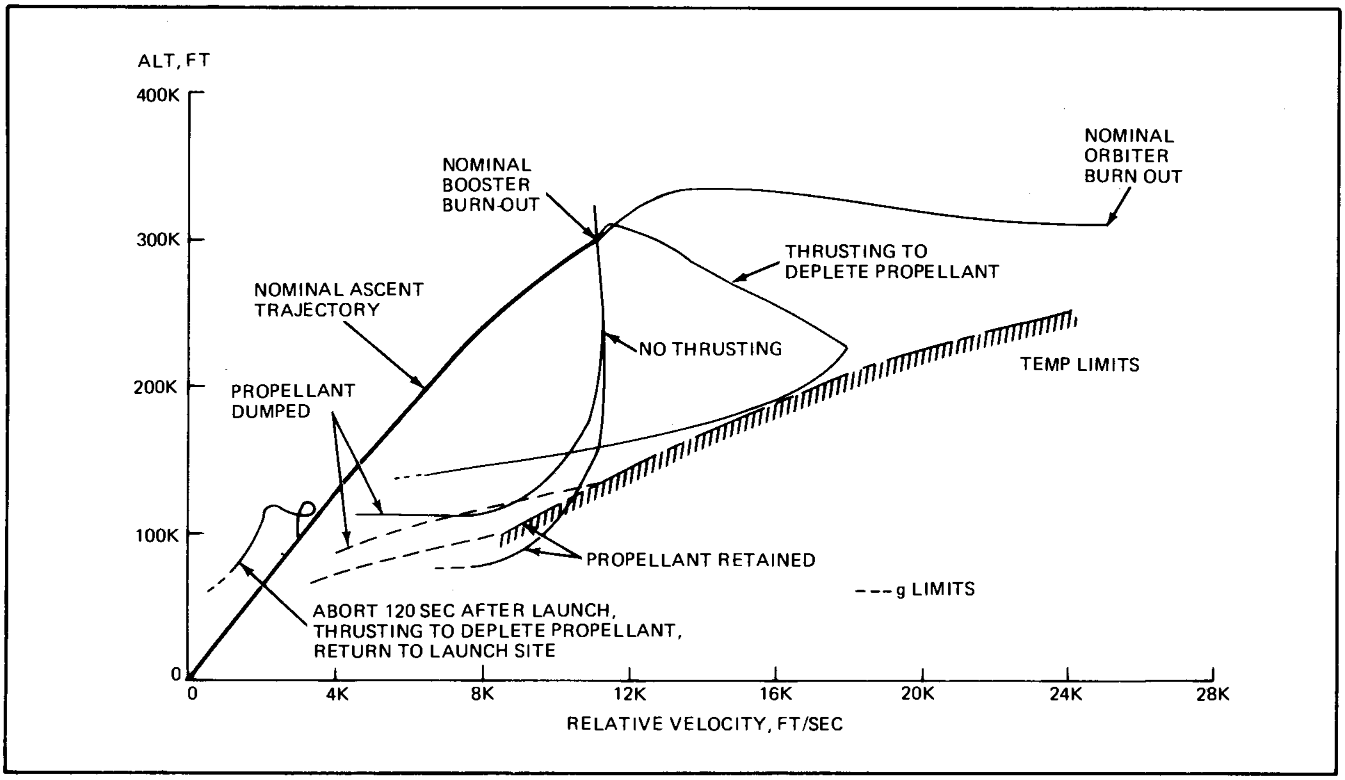


Fig. 2-13 Typical Abort Profiles. *Allowable abort profiles during the powered ascent are constrained by temperature and g limits*

fers the proper balance between development risks and cost, early IOC and operational risks and cost.

Manned baseline booster configurations have been selected for Designs 518/532. The system complexity imposed by booster life support, crew safety and crew operation functions will be determined with its effect on cost and on-orbit payload.

The operational gain afforded by manned systems is well known. A manned booster will allow tractable recovery operations following normal launch and permit normal aircraft/FAA coordination during self-ferry. Excluding ferry flights, the booster will normally return to the same restricted air traffic area shared by the launch site.

Unmanned booster recovery systems, require combined use of on-board (automatic) and ground-controlled systems. The basic approach will rely upon inertial guidance plus a multipath mission sequencer for accepting orbiter command during boost and mission ground command and control in other phases. During cruise, the booster could operate as a drone using either airborne or ground-based controllers to intercept and enter the landing approach corridor. Several automatic and ground-controlled landing systems already exist. The A-6A/SPN-42 carrier landing system for example, employs a ground-based tracking radar and guidance compution system to command the aircraft autopilot during automatic landings. However, direct application of SPN-42 to the booster would impose landing gear design penalties and a possible need for wider runways and ground arresting systems, since it lacks flareout, decrab, and rollout control.

An unmanned booster may be restricted to special sites and will require a different flight development test program than a manned system. The cost implications of such a program will be determined. Three booster configurations (manned, unmanned, and with manned ferry and flight test) will be examined to identify their implications affecting space shuttle system design, development and operation. Refer to Table 2-5. These factors will then be weighted against the reliability, complexity, crew safety and operations effectiveness associated with recovering an unmanned booster.

2.1.9 Reliability & Quality

Reliability and quality approach for space shuttle design. The approach to achieving high reliability and quality of the shuttle will be to emphasize redundancy and design margins beginning in the conceptual stages of the program. This traditional aircraft approach assures a high level of schedule integrity and mission success by designs that minimize, but yet accommodate, failures. This will permit the airline reliability approach through operations evaluation as described in the FAA "Handbook for Maintenance Control by Reliability Methods", FAA AC 120-17.

Reliability and quality engineers, working closely with system and subsystem design groups in all

Table 2-5 Booster Configuration Implications. *Manned configurations permit tractable ferry flights & related flight test operations*

	Always Manned	Always Unmanned	Manned Ferry & Flight Test
• Booster			
–Crew Sys	Complex-may need escape system	No need	Less complex
–Avionics	Least Complex	Most complex (G & N on-bd ckout, data mgmt, & r-f comd sys)	2nd Most complex
• Orbiter –Avionics	Monitor boost functions	Monitor & augment boost function control	Monitor & augment boost function control
• Ground Sys –Avionics	Monitor booster functions & activate remote recovy aids	Monitor & control booster functions & control recovy	Monitor & control booster functions & control recovy
• Devel Ops –Flt Test	Real-time pilot/ground coord shortens test sched (F-14)	More flights & longer sched	Horizontal flights similar to "Always Manned"
• Post-IOC			
–Shuttle Flt	Booster crew abort risk	Vehicle recovy abort risk & range safety	Vehicle recovy abort risk & range safety
–Ferry Flt	Normal ATC coordination	Special ATC coordination & flight safety precautions	Normal ATC coordination

phases of the program, will participate in the evaluation of alternatives, and the selection of optimum configurations. The basic tools for these evaluations are the failure modes and effects analysis (FMEA), the single point failure analysis, and informal design reviews. The early performance of these analyses, and the incorporation of the results into the design, will provide a sound basis for achieving desired reliability, maintainability and quality.

This technique of analysis and review, was employed on LM to select critical on-board instrumentation and to implement active redundancy for functions required during time critical phases of the mission. Preliminary mission oriented FMEA's have already been initiated on the shuttle baseline design to meet the desired fail-operational redundancy requirements. These analyses have yielded candidates for trade-offs in electrical power distribution, controls and displays, and on-orbit tankage subsystems. FMEA's also form a basis for such studies as: abort criteria and procedures, reliability, and maintainability, as well as redundancy techniques. The latter will be extended to the integrated avionics with particular emphasis given to the weight versus reliability in the implementation of active versus standby redundancy.

Grumman has applied its experience with NASA, DOD, and FAA requirements, such as NPC 200-2, MIL-Q-9858A and FAR 21 as well as the intent of NHB 5300.4 (1B) to identify the prime quality program "cost drivers" and minimize them without incurring additional risks, while maintaining established high reliability and quality standards.

All tradeoff studies will include consideration of inspectability, confidence level, process control requirements, manufacturing criteria, criticality, operational shelf-life limitation, failure rates, environmental applicability and potential reliability and quality problem areas. The effects on reliability and quality will be evaluated and documented.

Suitability studies of available equipment. Initial suitability studies of off-the-shelf man-rated equipment/parts for use on an early space shuttle system suggests the possibility of significant savings in development costs and time. Preliminary evaluation by Grumman and General Electric of available spacecraft and aircraft equipment, indicates that some are suitable as is, for use on the shuttle. Other equipment may require thermal vacuum or vibration testing and/or design modification before it can be considered suitable. The suitability criteria includes consideration of the equipment/part's test and failure history, comparison of designed-for versus anticipated environments including radiation, duty cycle, compatibility of materials and life characteristics. This data will be used as one basis for assessing selected equipment for Design 532.

Rapid maintenance inspection turnaround through nondestructive testing. A rapid maintenance inspection turnaround system will be developed for the structure, tankage and thermal protection systems to assure shuttle integrity and flightworthiness. Current and advanced nondestructive testing (NDT) techniques (Fig. 2-14) are being identified for application with emphasis on high speed data acquisition, interpretation, and decision criteria.

2.1.10 Maintainability

Grumman's experience in designing modern complex aircraft for short turnaround at minimum cost, coupled with our recent efforts in developing space techniques (including a NASA funded electronic packaging study contract) plus Eastern Airline's experience in maintaining large transport aircraft, assures the "know-how" to tackle the shuttle turnaround problem. Grumman's F-14, for instance, is guaranteed to come in at one-half hour turnaround, a factor of two MMH/FH improvement over any comparable aircraft.

Preliminary maintainability design is underway. Our designs 518 and 532 already include features to assure ease of refurbishment and maintenance. For example:

- Rapid visual nondestructive test inspection of TPS panels that are easily repaired or replaced
- Access to the interior of the integral tanks
- Modularized design of fluid/mechanical as well as electronic system
- An avionic equipment compartment with orthogonal decks for both horizontal and vertical mode access

Illustration of some of these details are shown on Fig. 2-15.

Maintainability analyses will continue throughout the study with special emphasis on access provisions, refurbishment requirements, rapid inspection techniques, the effects of the launch site environment, and elimination of ground support equipment.

MAJOR SHUTTLE CONSIDERATIONS INCLUDE:

- Thermal Protection System
- Structure
- Tankage

. . . Using Materials, Such As:

- Low & Medium Temp Alloys; e.g. Al, Ti
- High-Temp Superalloys & Refractory Metals
- Shape-Stable Ablatives
- Rigidized External Insulation

VARIATIONS IN DESIGN,MFG PROCESSES,& ENVIRONMENT AFFECT MATERIAL INTEGRITY THROUGH:

- Homogeneity of Materials
- Thermal (High/Low) Exposure
- Load (Vibration/Fatigue) History
- Chemical & Metallurgical Properties
- Physical Soundness of Members

. . . Causing Defects Such As:

- Cracks, Porosity, Creep & Leaks
- Delamination & Debonding
- Attachment Failures & Config Changes
- Damage from Unpredicted Overstresses

. . . & Degradation of Materials Such As:

- Decreasing Strength, Thickness & Oxidation Resistance
- Changing Emissivity, Thermal Conductivity & Dielectric Properties

BY UNDERSTANDING CAUSES & EFFECTS OF FAILURE MECHANISMS:

(1) An Effective, Systematic Approach Can be Defined For:

- Static & Fatigue Testing
- Manufacturing Process Control
- In-Flight Monitoring (With Active & Passive Equipment)
- Ground/Turnaround Operations - Maintenance Inspection, &

(2) Nondestructive Testing (NDT) Techniques Can Be Identified For Application Or Further Development:

Conventional Methods

- Radiography
- Ultrasonics
- Eddy Current
- Magnetics
- Thermal
- Dielectric
- Visual Aids
- Spectroscopy

Advanced or Emerging Techniques

- Neutron Radiography/ Activation
- Beta-ray Backscatter
- Infrared Imaging & Radiometry
- Thermochromic Mat'ls
- Acoustic Emission & Signature Analysis
- Infrared Interferential Spectroscopy
- Ultrasonic Imaging/ Spectrometry
- Visual Holography & Fourier Optics
- Thermoelectric Monitoring
- Strain Gage/Sensor Application
- Coupon Analysis

TECHNIQUES EMERGING FOR SHUTTLE APPLICATION MUST STRESS RAPID:

Data Acquisition and Interpretation

- High Speed Scanning
- Total Structure Signature
- High Stress Site Identification
- Random Access Mass Memory

- NDT Instrument-Computer Hook- Up
- Computer Analyses of Data
- Graphic Terminal/ Hard Copy Readout
- "Go-No Go" Decision Making

Fig. 2-14 Nondestructive Testing. *Techniques are being studied for rapid assessment of shuttle integrity & flight worthiness*

Built-in-test (BIT) and on-board checkout (OBC) will be used to minimize fault isolation time. The E-2A Hawkeye airborne early warning aircraft has been effectively utilizing built-in test equipment for eight years.

Modular designs will be used that minimize removal and replacement time. Particular emphasis will be placed on providing quick access to any equipment susceptible to unscheduled maintenance at the launch pad to assure schedule integrity and responsive "rescue mission" reaction time.

The analyses will identify logistic and support requirements, and will be guided by MM 7500.2, MIL STD 470, NPC 250-1 and other related documents. The results of these analyses and all tradeoffs will be documented to provide visibility of the degree that maintainability requirements are achieved.

2.1.11 Self-Ferry and Ground Handling

A study of the distribution of shuttle satisfactory air fields in the continental U.S. indicates that 360 n mi is the practical lower limit between such air fields. The Grumman baseline boosters have an inherent self-ferry range of nearly 400 n mi. The baseline orbiters will require ferry tanks in the payload bay to achieve this range. Longer ferry ranges will be studied to improve site requirements and minimize operational costs.

The baseline vehicle design will be studied in the areas of test, development and operation to identify the need for and the tradeoff implications of:

- Special and standard GSE both at the launch and recovery sites for launch, normal landing and emergency landing
- Vehicle and Payload GSE interfacing and hardpoints
- Safety standards and procedures

The potential impact on the orbiter and booster design of increasing ferry range will be studied. For the orbiters, the mounting hardpoint requirements will be identified for the addition of hydrogen tanks to the cargo bay. Thermal analyses will be conducted for the possibility of carrying ferry hydrogen in the main tanks without excessive icing or boiloff penalties. The requirements for increased thrust and landing gear capability will be included.

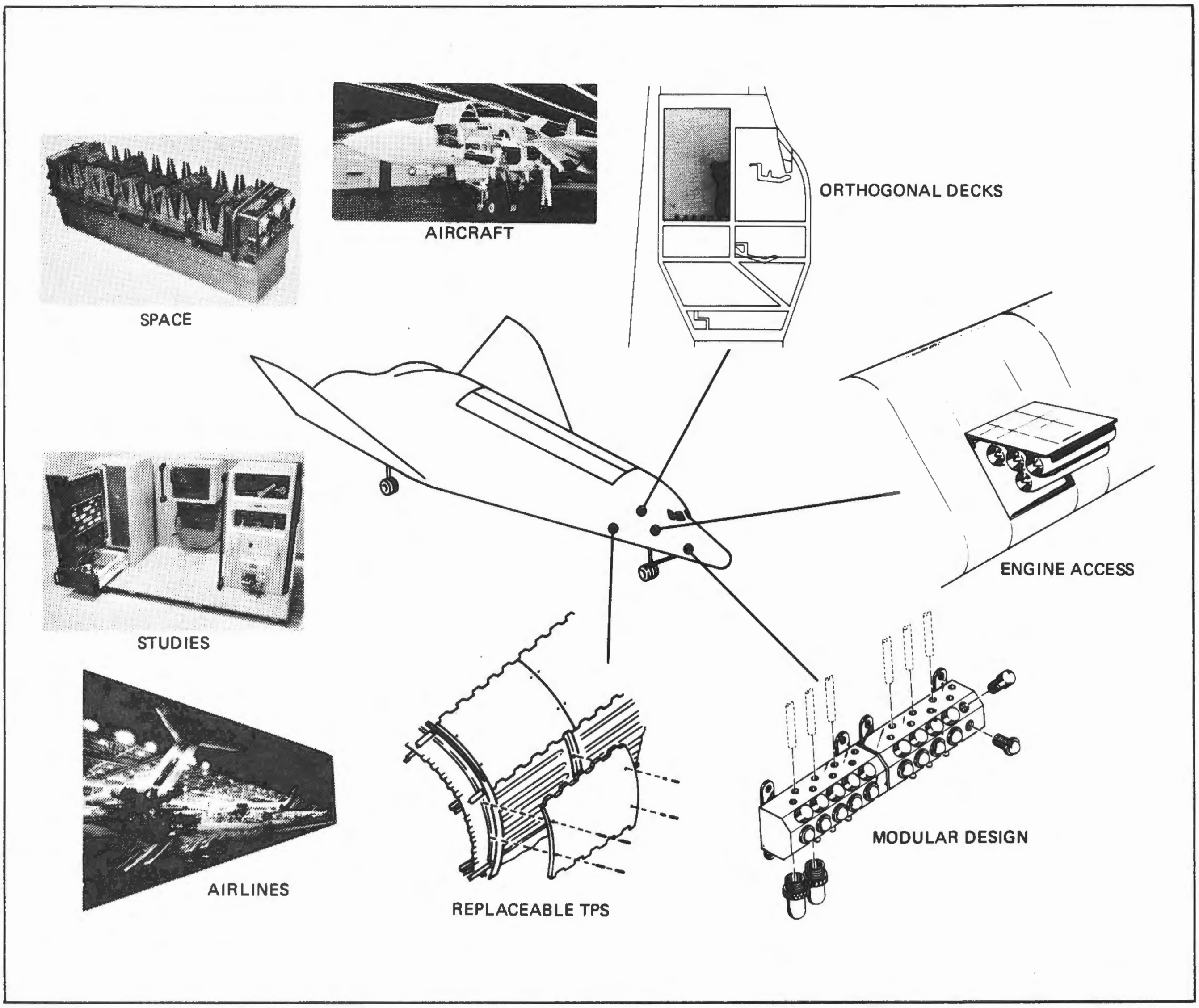


Fig. 2-15 Shuttle Design for Maintainability. *Experience with designing modern complex aircraft, coupled with our space maintainability studies & airline operation experience yields shuttle designs for maintainability*

Design approaches to ferry will also be studied for the cases of the orbiter with only powered approach capability and with no air-breathing propulsion. For each of the above variations, the impact on booster design with the corresponding impact on ground operations and site selection will be defined.

2.1.12 Flight/Ground Systems Optimization

The degree of on-board autonomy assigned to the space shuttle will be determined from the mission functional requirements imposed from the complete launch-to-launch cycle. All vehicle functions which impose a requirement on ground systems will be identified, and analyzed as to their optimum ground/flight apportionment during all vehicle operational and maintenance phases. The goal of the Phase B optimization studies will be to achieve the maximum practical level of autonomy within program constraints, particularly those concerned with the cost and operational analyses discussed in Subsections 2.1.3 and 2.1.4. The principal vehicle functions to be evaluated include: checkout, guidance navigation and control, communications and data management. The degree of on-board checkout in Designs 518 and 532 for example, will be determined by the extent to which desired levels of fault isolation, fault prediction, trend information and record keeping data must be relegated to the ground.

Command and control requirements to be investigated include: orbit determination, reentry control and atmospheric flight control. Other investigations will include such functions as mission management, maintenance, refurbishment and cargo handling.

The candidate flight/ground systems to be investigated include autonomous, ground dependent and hybrids. Vehicle/ground functions will be defined and the flight hardware equipment configuration and its corresponding support hardware identified.

Each candidate system will be evaluated in terms of: vehicle-ground independence versus the impact of on-board systems complexity, on development cost and risk, and crew operations. These factors will then be compared with the complexity and cost of associated ground operations to determine the optimum flight/ground system.

2.1.13 Manufacturability

The design will be examined thoroughly in Phase B to make sure it can be built simply. Manufacturability criteria will be established to define:

- Structural breakdowns that identify major assemblies, subassemblies and secondary structure interfaces with subsystems
- Minimal fixture, tool and equipment requirements which still provide optimum man-loading to reduce serial operations
- Manufacturing flow times early, to identify scheduling, crew loading and rate tooling fixtures
- Critical material lists which identify parts requiring materials, forgings, and castings of limited availability so that they may be reviewed for the potential use of more conventional materials

Special emphasis will be placed on the manufacturing of the cryogenic tanks, shown in Fig. 2-16, thermal protection system, and welding and machining of large bulkheads.

A manufacturability team working with the designers on the F-14 have held cost within 5 percent of target while weight has been held within 140 lb of target. The techniques used in this effort are being applied to the shuttle program. Preliminary indications are that large portions of the

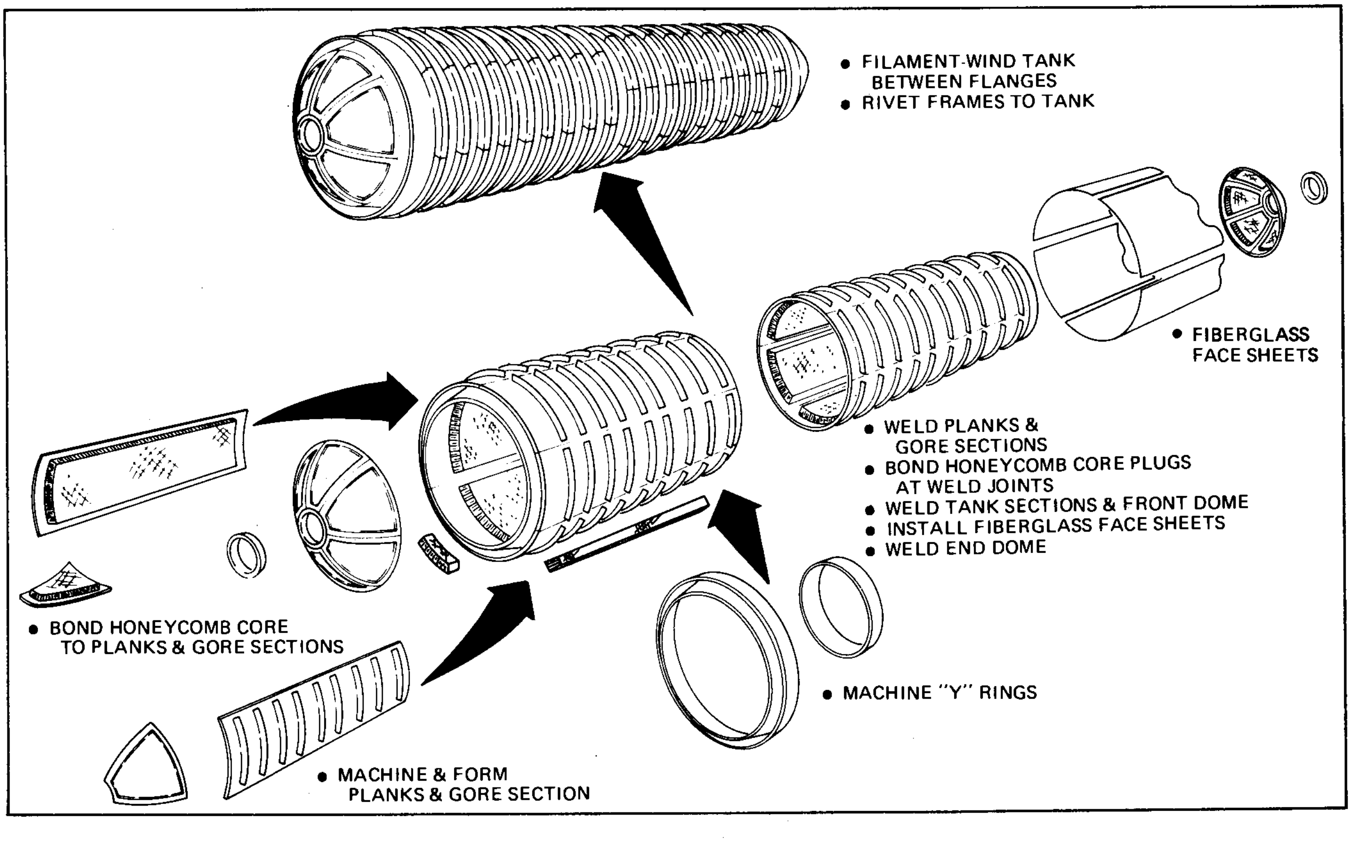


Fig. 2-16 Manufacturability Criteria. *LH_2 tank breakdown shows how typical criteria are established for design/manufacturability guidelines*

booster and orbiter structure will be adaptable to established aircraft and spacecraft manufacturing processes.

2.1.14 Operations Site Evaluation

Objectives and Methods of Evaluation
Grumman's analysis will identify the relative merits of various operations sites. The steps to be followed are shown in Fig. 2-17. The evaluation will be performed using the baseline vehicle configurations and operations models of 25 and 75 flights per year. Initial requirements for significant parameters will be established and evaluated against existing conditions at selected sites. The costs of satisfying these requirements will be estimated. Parameters which cannot be costed will be weighted and the sites will be numerically rated. Inland sites selected for comparison with KSC and WTR are Edwards AFB and Holloman AFB.

Parameters to be Analyzed
The analysis of operational constraints includes the effects of local environment on ground, flight operations, relative location of alternate landing sites, manufacturing facilities, and related ground test facilities. The safety of communities and public access areas will be considered with respect to launch, recovery, and suborbital overflight. Noise and propellant pollution, explosive overpressures, fragmentation, and the hazards associated with nuclear payloads will be considered. Sensitivity of the sites to surveillance or acts of interference will be considered.

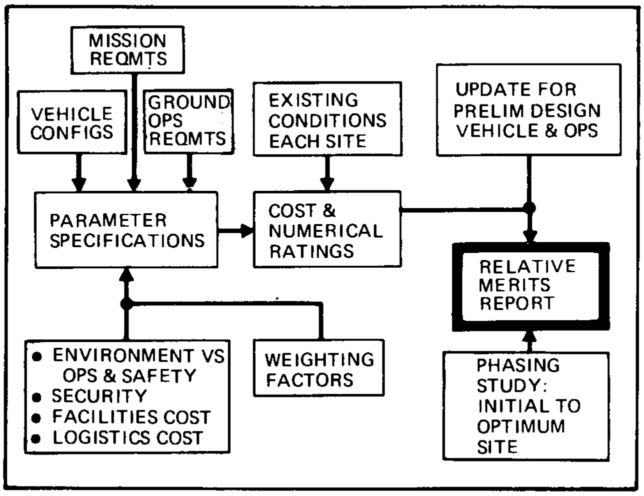


Fig. 2-17 Operations Site Evaluation Method. *A rigorous method produces credible results*

Weather, remoteness from large communities, related applicable facilities including range instrumentation, orientation towards R&D activities and closeness of large, natural, potential landing areas will be included as parameters.

Cost items will include direct operational and supporting facilities and logistics of vehicles, payload, and supplies including propellants. The effect of site location relative to LH_2 production source, manufacturing, engine test, and ground test sites will be evaluated.

Phased-Site Location
Phasing the operations site to match intermediate objectives may be economically advantageous. Test flights and early operations will be at a low rate so that decreased efficiency per operation may be offset by savings in facility cost at that time. The mission objectives of early operations may allow for less stringent initial site requirements. Grumman will include in this study, the use of existing facilities early in the program with construction of facilities at a site designed for the high operation rates. Such a study will be part of any phased shuttle system development and will be conducted for the final selected preliminary design configuration.

2.2 DESIGN ANALYSES

This subsection first presents weight estimation and control procedures applicable to the entire space shuttle system. It then covers analysis and design considerations for structures, materials and the thermal protection system (TPS) in Subsections 2.2.1, 2.2.2 and 2.2.3.

Accurate mass properties estimation and control provide confidence in weight/reliability/cost analyses and tradeoff studies. Grumman has long experience with NASA and DOD mass properties control techniques SP 6004 (NASA) and MIL-M-38310A. In addition, a comprehensive system of weight estimating methods developed at Grumman will be used during the study. These methods range from rapid estimating techniques and equations to computer programmed multistation analysis methods.

Space shuttle weight estimates completed to date are discussed in Subsections 1.3.1 and 1.4.1. These estimates will be checked via a set of independent, empirical, fixed-format equations in which the input parameters consist of factual data pertaining to performance, overall geometry, load levels, etc. The excellent correlation of the results of this procedure with production vehicle weights, and with our independently estimated orbiter and booster weights is shown in Fig. 2-18.

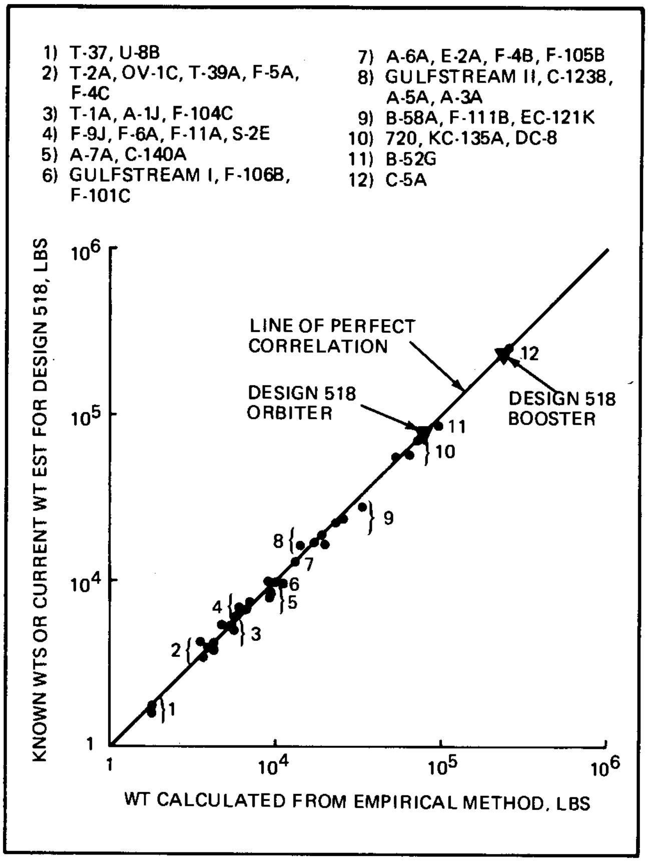


Fig. 2-18 Structural Weight Verification by Independent Empirical Method

As preliminary design progresses, the multistation analysis method will be employed. This method is an abbreviation of a full design procedure, starting with load distributions and proceeding through structural arrangement and establishment of cross-sectional areas, to obtain weight estimates. Continuous updating will provide improved confidence in estimates used as targets for weight control.

As design efforts proceed further, weight estimates will reflect information from preliminary design drawings. These weights will include established "non-optimum" factors based on experience gained from recent Grumman programs such as OAO, LM and F-14, and from recent Northrop experience on the 747. These "non-optimum" factors represent the differences between actual manufactured weights and theoretical weights due to minimum or stepped gages, fasteners, overlaps, etc.

Senior management reviews will assure that preliminary designs and associated weights are consistent with program goals in regard to payload, reliability, schedule, and subsequent development and manufacturing costs. Also, any weight problem will thus be quickly highlighted to enable early action on new or alternative design schemes directed toward weight savings. Because of mass control criticality, a weight control manager has been appointed who reports directly to the program director.

The excellent weight performance of recent Grumman programs has resulted from the special emphasis given to realistic procedures for accurate weight estimates and continuous activity directed toward weight control. The F-14 program, with 80 percent of design complete, and without any weight contingency in estimates at the beginning of the detail design phase, is within 1 percent of guaranteed weight.

2.2.1 Structure

Selection and design of the major structural assemblies/subassemblies will be governed by the interrelated requirements of environmental conditions, manufacturability and reliability. All of these requirements ultimately influence the cost and weight of the structure. In order to evaluate the results of Phase B tradeoff studies, incremental weights and costs will be judged on the basis of a criterion expressed in terms of allowable dollars per pound of weight saved.

This criterion will be determined via parametric studies by varying the weight of the overall structure and then re-sizing all affected vehicle parts and geometry to maintain the specified vehicle performance. This establishes a dollar increment in initial flyaway cost, and to this must be added the variation in operational costs. The total dollar increment divided by the initial structural weight increment provides the resultant tradeoff value in dollars per pound of weight saved. This can be graphically illustrated as shown in Fig. 2-19.

Integral versus non-integral fuselage/tank design is a basic consideration for optimum structure. The baseline configuration described in Subsec-

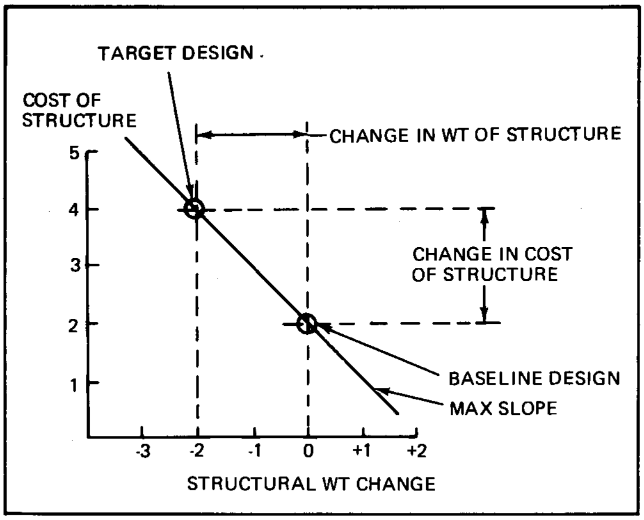


Fig. 2-19 Structural Weight/Cost Tradeoff Value

tion 1.7 uses tanks which are integral with the fuselage for both the booster and orbiter. In the case of the orbiter, however, additional detail design studies are required to explore the relative merits of integral and non-integral tanks. The non-integral design will consider semi-monocoque and/or truss type primary structure. The fuselage is intimately related to the TPS (refer to Subsection 2.2.3) and tank systems and therefore their design must be considered together. The concepts to be investigated include hot primary structure and an insulated warm structure for both the non-integral and the integral tank fuselage, as shown in Fig. 2-20. The results of structural studies for the cabin (Subsection 2.3.7), landing gear (Subsection 2.3.1). docking mechanism (Subsection 2.3.4), payload interface (Subsection 2.1.6), thrust structure (Subsection 2.3.1), TPS supports and booster/orbiter interface will be incorporated with the fuselage studies such that a total structure may be evaluated.

Cryogenic tank alternatives will be emphasized. Aerojet General experience will provide valuable support into the problems of cryogenic tank design.

For both integral and non-integral tanks, studies will be conducted to evaluate cryogenic tank structure considering monocoque stiffened shells with and without circumferential fiberglass overwrap. For the non-integral case, fiberglass filament wound tanks with thin metal liners will also be considered. This kind of tank, helix wound, will

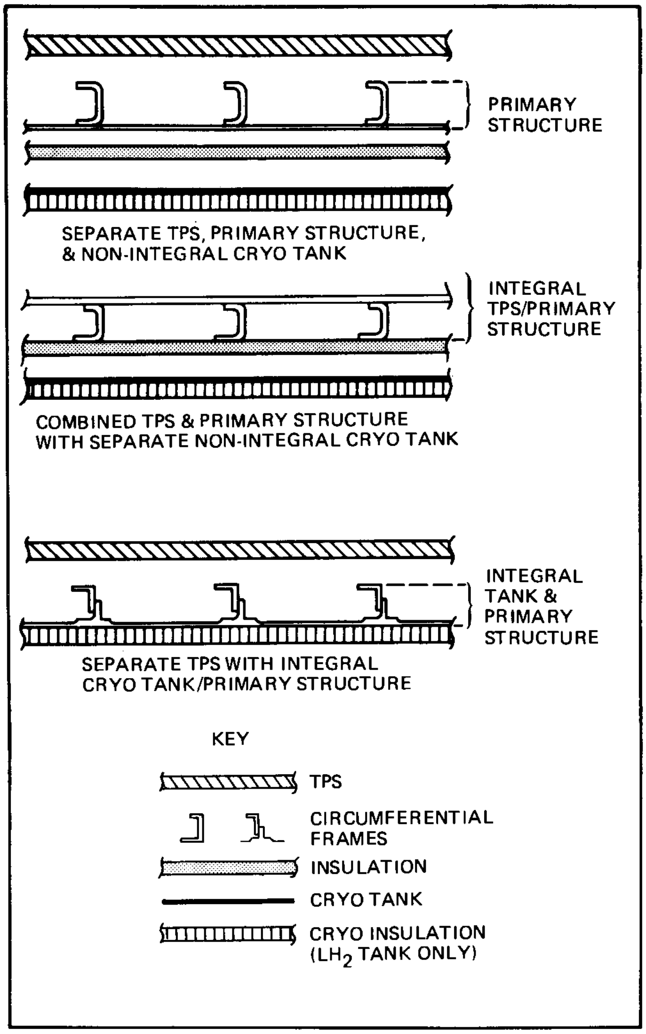


Fig. 2-20 Fuselage Cryogenic Tank Structural Concepts

provide the highest attainable strength/weight ratio for a pressure vessel. Inherent support difficulties, however, will force weight comparison with other designs before final tank construction is selected.

Parametric studies will optimize stiffened shell structure with respect to frame and stiffener or honeycomb-sandwich sizing and fuselage volume/area requirements.

Tank end closures, which will have a large impact on vehicle weight will be evaluated. End closures to be studied include spherical and elliptical common bulkheads, inverted domes, and pressure membranes. The shortest overall length and weight for the propulsion tanks (and hence the lightest vehicle weight) results from an inverted dome between the two tanks (refer to Subsection 1.7.3). The design challenge here will be to determine if this weight advantage can be realized by overcoming current construction cost and inspection disadvantages. Closures in major fuselage load redistribution regions, such as the landing gear bulkhead, could also be flat. Weight trade-offs of the tank closures will include the effect on overall vehicle length since a tank weight increase associated with decreased length may be more than offset if overall fuselage weight can be substantially reduced.

Tank access studies will include door configurations, sealing concepts, insulation continuity and shell reinforcement. Supports for on-orbit and non-integral main tanks will be developed, with special emphasis on low conductivity requirements for the on-orbit tanks. Studies for tank supports will examine use of conical ends, side mounts, and low conductivity struts (i.e., fiberglass, boron epoxy and titanium).

A number of tank insulation systems will be considered in arriving at the final design. They will include foams, gas layer, and evacuated honeycomb for the LH_2 tanks, and superinsulations for both LH_2 and LO_2 tanks. For the gas and foam layer insulation concepts, feasible arrangements are shown in the Grumman report "Proposal For Gas And Foam Layer Materials Composite For Use As Internal Insulation For LH_2 Tanks", 70-15 NAS, Feb 1970, submitted to MSFC. Test data and analysis will be used to determine thermal effectiveness, boiloff, purge requirements and weight. External superinsulation studies for the on-orbit tanks will include perforation size and spacing, spacers, number of layers, vapor shield design and moisture effects. Venting and purging provisions for all tanks will be determined.

Aerodynamic surface tradeoff studies include consideration of TPS panel interchangeability. Wings, fins and movable surfaces will have the same hot-structure and insulated warm-structure design alternatives as the fuselage, but without the complications of cryogenic tanks. In order to allow for replacement or interchangeability of metallic TPS panels with less rigid TPS material, stiffened surface skins are required. Several titanium skin stiffening designs will be evaluated including corrugations, Stresskin, and diffusion bonded and brazed honeycomb. Efficient edge attachment is the dominant factor in deriving significant advantage from the use of honeycomb sandwich. Various techniques will be developed and evaluated experimentally and will include the use of polyimide-fiberglass and polyimide syntactic foam as core edge filler.

The interaction between structural weight and aerodynamic performance for different surface thickness ratios will be considered in choosing cross-sectional shapes.

The design of wing carry-through structure is complicated by the presence of the propellant tanks in the fuselage. The baseline approach (refer to Subsection 1.7) utilizes truss-type fuselage bulkheads, but alternative approaches such as internal tank bulkheads will also be evaluated.

TPS support structure permits use of alternate TPS panel designs. The TPS support structure will be designed so that alternate TPS panels can be freely interchanged. It is anticipated that this approach will have a minimum weight impact; weight penalties if any will be determined. Support design will minimize deleterious effects of differential thermal expansion and thermal conductivity.

NASA criteria plus combined load/temperature envelopes and realistic design allowables lead to adequate strength, rigidity and safety. Early Phase B studies will utilize natural-environment criteria (NASA TM X-53973) and design criteria furnished by NASA at the initiation of the contract. However, it is likely that studies by all contractors of weight and/or performance sensitivity to criteria variations will lead to recommended revisions to these original documents. Grumman's representation on the NASA/industry planning committee for space shuttle design criteria will permit the direct use of our design-team experience in the periodic reformulation of the original documents, and will provide immediate feedback of committee thinking.

In relating criteria to structural adequacy, design envelopes will be constructed which combine static and dynamic external loadings, pressure loadings, thermal stresses, and manufacturing residuals. Load and temperature profiles will encompass all phases of a space-shuttle mission from launch through landing and ferry, as well as prelaunch conditions, such as assembly and transportation, and abort conditions. Strength allowables will realistically account for thermal cycling, environmental and stress corrosion, stress concentrations, crack propagation and fatigue, hydrogen embrittlement, brittle fracture, etc.

Comparison of strength allowables, stability and deflection criteria, and dynamic-response criteria with corresponding results from the analyses described in the following paragraphs will provide verification of minimum-weight structural designs with adequate strength, rigidity, and safety of personnel.

Integrated and managed analysis yields quick response evaluation of alternative structural arrangements. It will be necessary to evaluate a variety of structural configurations during Phase B, for various potentially critical design conditions. The analyses required must be performed quickly, and with an accuracy appropriate to the need.

For this work, Grumman will use its Integrated Design Analysis System (IDEAS), described in SAE Paper No. 680728, October 1968. This system has been successfully used to meet the tight schedule for the F-14A. It consists of a sequence of highly automated computer programs. The automation is not limited to each of the individual technical disciplines involved. More importantly, the analyses become modules in an integrated system that includes automated transfer of data at module interfaces.

While IDEAS modules provide all of the analysis capability that is required for final hardware design, they will be used here only to the depth required for Phase B preliminary design purposes.

The analysis flow begins with data from vehicle contour and structural arrangement drawings, control system characteristics, propulsion system characteristics, and mass properties. Math models, numerical idealizations of the vehicle, are then developed at an appropriate level of detail, and all subsequent analyses utilize applicable parts of this collection of data.

Four basic types of analyses will provide inputs to structural load calculations: shock and transient response loadings (e.g., engine ignition and shutdown, launch transients, stage separation, docking, and landing), wind and gust loads (both ground and inflight), control and maneuver loads, and thermal distributions. Air load distributions for these analyses will include aero and thermoelastic effects. Low frequency structural dynamic as well as rigid-body dynamic effects will be included in the dynamic loads analyses. Coupling with propellant slosh modes and control system modes will be included whenever these are significant. A by-product of the dynamic load analyses will be a set of responses for the evaluation of crew performance and safety.

After the various static and dynamic applied loads have been determined, internal structural loads and deflections will be calculated. These will be obtained by either: NASTRAN, the NASA structural analysis package; ASTRAL, an automated structural analysis package described in Grumman's IDEAS manual; or STARS, shell theory automated for rotational structures (refer to NASA CR-61299, -61300, -61301). For rapid interpretation and evaluation, the internal member loads and deflections from the ASTRAL program will be automatically presented in both graphical and tabular form.

In addition to the strength analyses, classical flutter (both primary and control surface) and divergence analyses are performed in other modules of the IDEAS sequence.

For the space shuttle, possible booster/orbiter divergence during boost as well as the common surface divergence will be considered. Possible instabilities involving control system dynamics will also be investigated, and POGO studies will include coupling between longitudinal and lateral oscillations.

Special problems require separate analyses and/or laboratory tests. The confident design and evaluation of structures involving unusual materials and fabrication techniques combined with extreme thermal environments will require supporting laboratory-scale component tests.

One such critical subassembly is the cryogenic tank structure. Crack propagation and fracture toughness tests will be run on specimens under representative loads and environments to establish maximum permissible initial flaws and to then determine appropriate pressures for either normal or cryogenic temperature proof tests.

Other tests will include a purge insulation demonstration, a compression dome-pressure test, and tests relating to temperature shock, thermal conductivity, and adhesive performance.

Most analyses of structural failure modes and effects will be performed directly using the IDEAS approach described above. Failure of certain critical items such as tanks or TPS panels, however, must necessarily be studied based on a different rationale involving probabilistic considerations.

High frequency vibration will be caused by pressure oscillations due to engine noise, boundary layer turbulence, and possible exhaust plume impingement. Vibration requirements for equipment, and design requirements for sonic fatigue, will be derived using existing semi-empirical methods in conjunction with available spacecraft and aircraft test data.

Dynamic aeroelastic phenomena for which reliable analytical representations are not yet available include panel flutter, stall flutter, "stop-sign" flutter, vortex shedding loads, buffet, and buzz. Design implications of these phenomena will be determined by empirical criteria.

One of the goals of the Phase B study will be the further identification and formulation of recommended NASA supporting research and technology programs in the structures area (refer to Subsection 2.6). Further major structural assemblies will be defined for assembly and manufacturing methods evaluation, and for the structural test program specifically required by NASA and described in Subsection 2.5.1.

2.2.2 Materials

Materials identification and evaluation will be accomplished in accordance with the requirements of the NASA SOW to arrive at the specification of materials for use on the space shuttle. Our study approach to this critical design analysis area is depicted by our approach to the technical issues discussed below.

Available technology will provide a firm base for identification and evaluation of candidate materials. Materials will be selected from those having an established record of successful use in aerospace applications and from an assessment of the advantages to be derived from advanced materials predicted to be within the scope of 1972 technology. Maximum use will be made of the results of NASA and DOD materials development and evaluation programs and of the combined materials talent of the Grumman, General Electric, Northrop and Aerojet-General team. The experience which this team will apply to the space shuttle materials area covers the complete aerospace spectrum from the creation of new materials through development, application, fabrication and manned flight demonstration. The team members have demonstrated competence in the materials area as applied to aircraft, reentry systems, jet engines, space nuclear power, manned spacecraft, orbital satellites, and satellite recovery vehicles.

External thermal insulations offer multimission use with compatibility to total thermo-structural environment. The reusable external insulation (REI - 2000 series) is a family of low density rigidized ceramic fiber materials developed by General Electric to provide a lightweight reusable TPS for major portions of the booster/orbiter surfaces. A detailed description of this material is contained in Subsection 1.8.2. The applicability of the REI material system is shown in Table 2-6. Confidence in this material will be established through a vigorous development program. This program is presently underway to evaluate the REI material system with respect to the environments presented in Table 2-6, to investigate other structural matrices, to evaluate the effects of devitrification inhibitors and to apply the resulting material system in a panel design.

High temperature internal insulation must be compatible with extreme environments. During the study, various candidate materials, rigid and non-rigid, such as fibrous silica, alumina-silica-chromia, zirconia, and other commercially available systems will be investigated as to applicability to design concepts and to the total environmental requirements.

In order to utilize the temperature capability of metallic surfaces, low density internal insulation must be employed to maintain internal temperatures within component and structural limits. Two basic considerations will be given to the selection of an internal insulation: 1) it must be low-density yet structurally adequate to withstand the total environment and life cycles, and

Table 2-6 REI TPS Characteristics

RAIN ENVIRONMENT AND MOIST AIR
- Each individual fiber coated with water repellent silicones
- Surface reinforcement porous to water vapor (in and out), repellent to water

FREEZING, WITH MOISTURE IN OPEN MATRIX
- Sufficient space to accommodate phase change of any entrapped condensate
- No freezing damage contemplated

STRENGTH
- Surface and edges reinforced with rigidized quartz fabric
- Interspersed fiber construction

RAIN AND DUST EROSION
- Reinforced surface with impregnated quartz fabric

SURFACE EMISSIVITY
- Smooth silica surface has low emissivity
- Roughening the surface or introduction of Hi ϵ mat. in surface layer

TEMPERATURE CYCLING (ORBITAL & ENTRY)
- REI/Bond system compatible with structure
- Silica system has multimission reuse capability - 2000°F

ACOUSTICAL & VIBRATIONAL LOADING
- No fiber abrasion, joints cemented

IMPACT DAMAGE
- Easily repairable

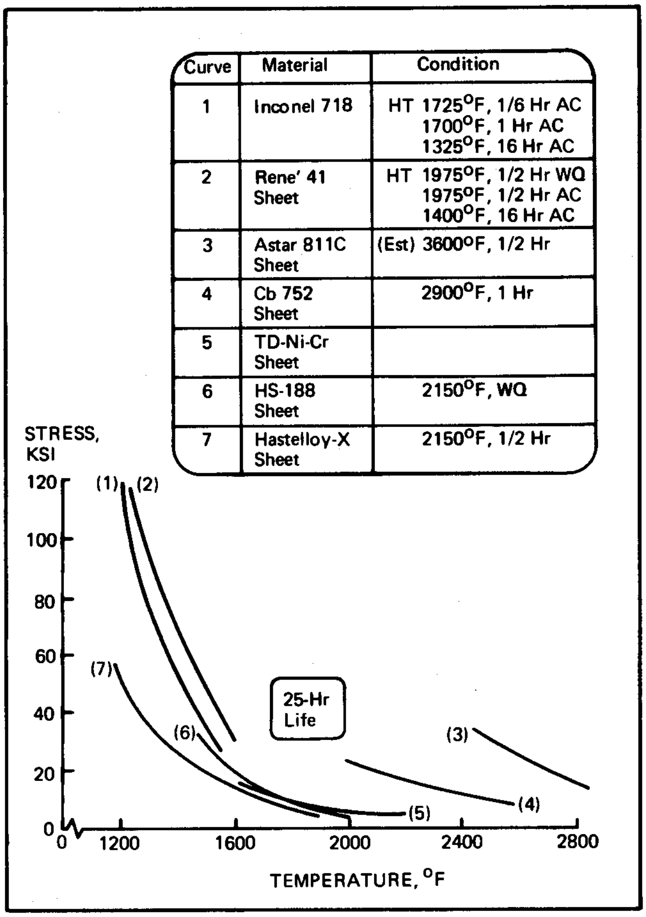
FUEL COMPATIBILITY
- Silica stable in fuel and oxidizing environment

2) it must have a demonstrated high reliability due to its application in non-inspectable locations.

Super alloys are acceptable TPS candidates for moderate heating environments. Many TPS materials requirements can be met with existing superalloys. The leading candidate materials in order of increasing temperature capability are Inconel 718 (to 1200° F), Rene 41 (to 1500° F), and Haynes 188 (1800°F). These and other candidate materials will be evaluated and material selections will be made for each TPS component based on the desired mechanical/physical properties, compatibility with the total environment, relative ease of fabrication and projected reliability for multimission capability.

Significant material properties which must be considered in the design of metallic TPS are creep deformation and creep rupture strength. Utilizing the material in efficient structural configurations requires determination of allowable stress levels which are usually governed by elevated temperature creep and creep rupture properties. Data for several candidate TPS materials are shown in Fig. 2-21. The ductility of these materials is also of significance because of the possibility of high local thermal strains.

In the selection of superalloys for use at temperatures to 1800° F, there are few alternatives to Haynes 188; it has similar strengths to the widely used Haynes 25 alloy but with superior oxidation resistance and thermal stability. Examples of other candidate materials that will be considered with specific tradeoffs are nickel base alloy U700 and TD-NiCr. TD-NiCr is the only non-refractory material with usable strength in the temperature range of 1800 to 2200° F. However, its poor hot ductility (approximately 0.5% at 2000°F), severe anisotropic mechanical properties and its inability to be welded without a severe loss of strength could inhibit its use. Process development studies underway by the primary producer to improve ductility and reduce anisotropic behavior will be closely reviewed.



Curve	Material	Condition
1	Inconel 718	HT 1725°F, 1/6 Hr AC 1700°F, 1 Hr AC 1325°F, 16 Hr AC
2	Rene' 41 Sheet	HT 1975°F, 1/2 Hr WQ 1975°F, 1/2 Hr AC 1400°F, 16 Hr AC
3	Astar 811C Sheet	(Est) 3600°F, 1/2 Hr
4	Cb 752 Sheet	2900°F, 1 Hr
5	TD-Ni-Cr Sheet	
6	HS-188 Sheet	2150°F, WQ
7	Hastelloy-X Sheet	2150°F, 1/2 Hr

Fig. 2-21 Creep Rupture Properties of Candidate Alloys

Refractory metals TPS usage is constrained by required coatings. The ability to utilize the excellent strengths of the refractory alloys at elevated temperatures depend on the integrity of coatings that must be applied to protect the alloys from oxidation, including metal recession and embrittlement due to oxygen penetration. Columbium alloy coating systems that have the necessary life capabilities to meet the reuse requirements of the space shuttle to 2500°F have been identified. The columbium alloys include Cb-752, FS-85, WC-129Y and WC-3015. Tantalum alloys potentially useful to 3000°F include ASTAR 811C, Ta-10W and T-111.

The coatings that have shown greatest potential of meeting the TPS requirements are the silicide types applied by the fused slurry techniques such as the Sylvania R512E or Vac Hyd 109 for columbium, or Sylvania R512C for tantalum.

Manufacturing and design considerations associated with the use of these coatings are:

- It is currently impractical to coat sheet material less than 0.006 in. thick due to diffusion effects and edge coverage difficulties
- All corners and edges must be rounded and smooth
- Spot or seam welding is undesirable because these fabrication procedures do not allow for coatings on faying surfaces
- Honeycomb sandwich construction is made very difficult because of the necessity to evacuate and permanently seal the sandwich interior, which, in turn, is necessary because interior surfaces cannot be precoated
- Thin surface sheet with mechanically attached corrugations require precoating of faying surfaces and coating after assembly for fastener protection. Further, to the greatest degree possible, practical designs should allow for arrangements wherein coated areas are not hidden from nondestructive testing inspection techniques.

The above considerations detract from refractory metals usage in the TPS. They will, however, be further investigated; they have not been proposed in Subsection 1.8.

The deterioration of a coated refractory alloy panel with a defect in the coating is not expected to be immediately catastrophic. Cyclic oxidation tests made by Sylvania on R512E coated columbium alloy specimens, through which 1/32 in. diameter holes were drilled, showed negligible metal loss and radial penetration of oxygen into the substrate. Approximately 0.080 in. oxygen penetration was detected after 10, one hour cycles to 2500°F peak temperature. During the aforementioned test series, defect-free specimens withstood more than 95 cycles from room temperature to 2500°F, with a one hour hold at peak temperature, before coating failure was detected. Tests and analysis of possible coating failure modes and their effect on the mechanical behavior of coated refractory alloy components will be made. Design details such as slip joints and attachments, will be considered. In addition, General Electric is developing a process for surface alloying with a silicide. This process, metalliding, shows great promise to meet the TPS requirements, particularly for complex shapes and for foil gage material. Potential uses of this process will be investigated during the study.

General Electric's ablative materials technology offers a low risk solution to special thermal protection areas. The application of these materials will be considered in areas of high heating rate such as the nose cap, leading edges and areas of interference heating where component replacement could be acceptable. The candidate ablative materials are shape stable over the range of heat fluxes predicted for the baseline orbiters and include chemical foam silicones, syntactic foam silicones, epoxy-silicones, phenolic-refrasil, and oxidation inhibited carbon/carbon. The most suitable ablative material will be recommended for each applicable component. The use of a passive transpiration system may offer a significant weight saving and will also be studied.

Assessment of structural materials will be refined. The basic structural materials requirements of the space shuttle can be fulfilled by current materials technology. Available aluminum alloys such as 2219-T81, 2219-T87, 2024-T8, and 7075-T73 are useful up to the 250° to 350°F range. Titanium alloys will be limited to a 550°F maximum temperature in primary structure, based on chloride stress corrosion threshold stress level limitations, and consideration of gaseous hydrogen embrittlement. The use of titanium alloys to 800°F will be considered in non-primary load-bearing structural applications where a possible stress corrosion failure would not affect mission safety. The good performance capabilities of nickel base alloys such as

Inconel 718, Inconel 750, and Rene 41 will permit their use as structural materials up to the 1200 to 1400°F range.

Design tradeoffs will consider the aluminum alloy 2219-T87 as the baseline material for cryogenic propellant tankage. The alloy 2021-T81 will be investigated as an alternate. The advantages of external filament winding overwrap will be explored to minimize tankage weight.

Less conventional material applications employing composites such as boron-epoxy, boron-polyimide, boron-aluminum, and boron-epoxy/aluminum will be assessed as a means for reducing structural airframe weight. The use of structural/thermal insulative composites will be considered for cryogenic propellant tankage. Refinement of the candidate materials selection will be made as various structural concepts are studied and evaluated.

Materials usage criteria and control system will consider compatibility and safety. A model materials control plan, supported by a materials usage guidance manual, will be prepared during the Phase B study. The NASA/COMAT data processing system, used by Grumman to confirm the safe use of materials in the Apollo LM crew compartment, will be extended. The proposed data system will encompass metallic and non-metallic materials usage throughout the booster and orbiter. Safety characteristics, including toxicity, outgassing, and flammability will be considered as well as compatibility with propellants and special fluids. A method of estimating crew compartment atmospheric contaminants will be included in the data processing system. The materials usage guidance manual will be maintained as a central source for all material design allowables used in the study. Other considerations pertinent to materials selection such as safety and compatibility characteristics, corrosion resistance, oxidation resistance, fracture toughness and stress corrosion thresholds will be included. This manual will be submitted periodically to NASA for concurrance.

Separate studies will provide materials selection for special purpose applications. The temperature extremes associated with the vehicle system taxes the present state-of-the-art of many materials used in special applications other than structural. A survey will be performed to assess, identify and define materials technological problems in such areas as lubricants, antennas, windshield and windows, bearings, seals and sealants, thermal control coatings and coolant fluids.

Experimental activities will define usage potential of candidate materials. Current General Electric and Grumman material programs are pertinent to the space shuttle thermal protection system and cryogenic propellant tankage. The results of these activities will strongly support the evaluation of candidate materials during the Phase B study and to the definition of requirements for technology programs. Details of these programs are noted in Subsection 4.2.

2.2.3 Thermal Protection System

Combined General Electric/Grumman experience spans thermal protection system requirements. General Electric and Grumman have extensive background in the analysis, design and fabrication of supersonic aircraft, spacecraft and reentry vehicles. This background provides valuable experience to realistically approach the TPS analysis and design problem.

We will perform an in-depth thermal analysis of metallic/radiative and reusable exterior insulation as a basis for the selection of the TPS as discussed in Subsection 1.8 which includes a comparative analysis of candidate TPS concepts, and performance criteria.

A logic network for the overall study of the problem is shown in Fig. 2-22. This comparative analysis begins with a comprehensive and detailed definition of the requirements and an assessment of their impact on the system's characteristics. Combining these with test results from a parallel component test program enables performance to be evaluated in terms of weight, cost, reliability and technological risk. Results will iterate into detailed design configurations for the major components of the thermal protection system. They will also define new problem areas for further technology development, and will contribute to the large scale demonstration program.

Aerothermodynamic heating investigations will utilize both test and analysis. Aerothermodynamic analytical methods and transition criteria, substantiated by NASA and Air Force flight tests of General Electric reentry vehicles, will influence the selection of the TPS design. Existing test data from

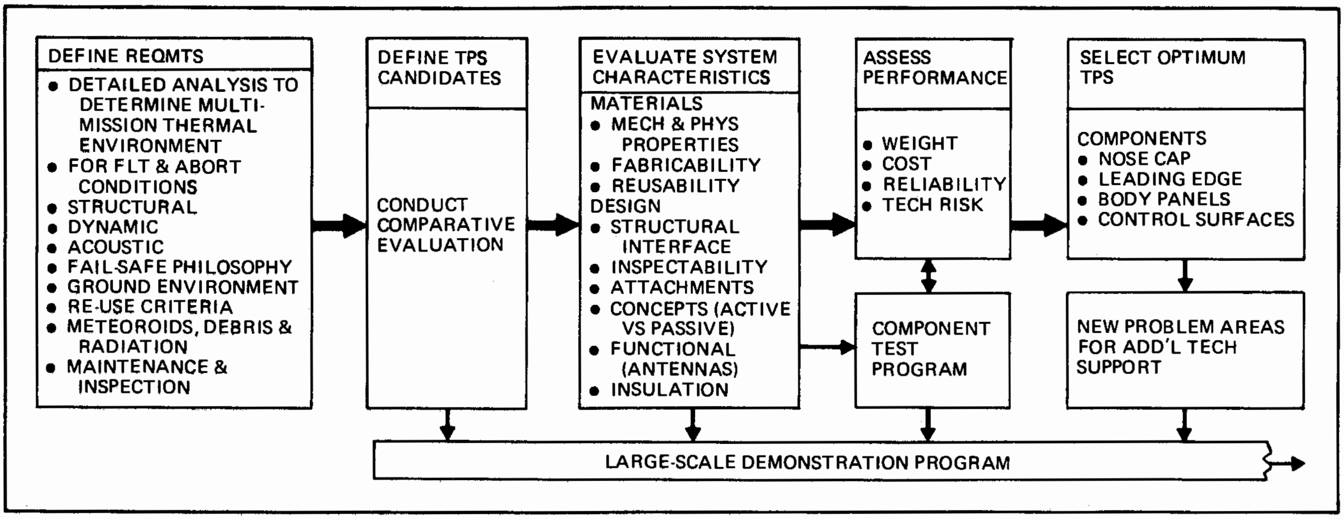


Fig. 2-22 TPS Logic Network

listing bodies such as HL-10, ASSET, PRIME, and the FDL configurations have generated confidence in the application of these methods to the complex shuttle configuration. Phase B wind tunnel test data, and other concurrent testing results, will further substantiate these methods and provide the primary source of information for heating in complex flow regions. These regions include those associated with shock interaction, interference, turbulent separation and reattachment.

Prediction of heat transfer in regions of stagnation points, stagnation lines, attached laminar and to some extent separation laminar flows, are well in hand. Heat transfer in these regions will be calculated using standard routines such as that of Fay and Riddell, swept cylinder theory, the integral streamline divergence method and cross flow theory. Surface anomalies such as gaps, proturberances and roughness which effect the TPS will be accounted for by using available data.

Flow fields are important for transition definition. Of particular relevance to the shuttle TPS design are the criteria establishing the onset of transition, the growth to fully turbulent flow and the appropriate turbulent heating methods. Correct application of any criteria or heating method must begin with a careful description of the local flow field. In this connection General Electric and Grumman have an extensive background of analytical methods to realistically evaluate flow fields. These include finite difference shock wave determination, streamline divergence description and mass entrainment calculation procedures. Use of these methods has indicated that the windward surface flow field for vehicles like Design 518 and Design 532, at angles of attack between 20 and 50 deg, is dominated by normal shock entropy. These flow fields are characterized by small axial pressure gradients, low edge Mach numbers (M_e) and little entropy layer/boundary layer interaction. Flow field effects such as boundary layer history, pressure gradients, three dimensionality and mass entrainment will be accounted for in the transition criteria described below through use of the momentum thickness Reynolds number (Re_θ).

Based on the flow field considerations described above, a quasi-flat plate model rather than a stagnation or entropy layer model best describes shuttle transition. Considerable data exists for this model which indicates that an Re_θ of 300 for transition, for $M_e<3$, is a prudent criterion (refer to Boundary Layer Transition Study Group BSD-TR-67-213). For $M_c \geqslant 3$, the extensive General Electric flight and ballistic range data, correlated under SAMSO contract with careful attention to edge properties, provides the criteria shown in Fig. 2-23 in terms of Re_θ, M_e and wall cooling ratio (h_w/h_{aw}). Surface roughness need not be reflected in the criteria since the roughness elements in the transition zone are well within the momentum thickness.

The length of the transition zone between laminar and turbulent regions increases as M_e increases, and decreases as edge Re increases. Since available data exhibits considerable scatter, the transition zone criteria will be based on a line through the

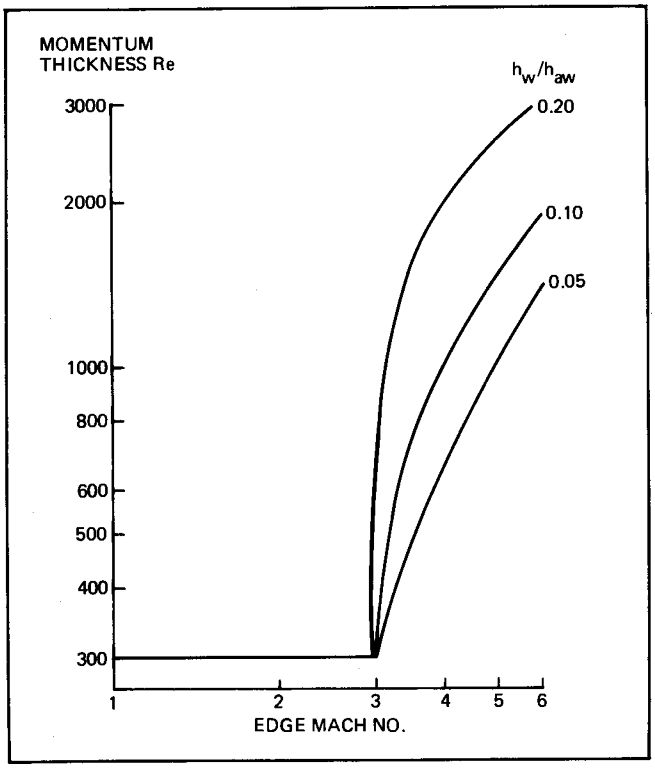


Fig. 2-23 Transition Reynolds Number Criterion

lowest data (refer to Fig. 2-24). The sensitivity of both peak temperatures and total integrated heating to transition and transition zone criteria is illustrated in Fig. 2-25 and 2-26. A sensitivity study will be performed to provide a full awareness of the weight penalties and technical risks involved in using the recommended criteria.

A test program will be conducted to lend further confidence in the transition criteria. For the case of most interest, M_e, h_w/h_{aw} and Re_θ will be simulated. In addition, tunnel noise and roughness uncertainties will be considered through acquisition of data that includes spectral distributions of disturbances in the test environment as well as on the model.

Turbulent heat transfer uses Eckert's reference enthalpy method. With regard to turbulent heat transfer, comparative analysis indicates some disparity between analysis methods such as Eckert, Spalding Chi, Rho Mu and Van Driest. Eckhert's reference Ethalpy method, which yields the highest values of heating, has been shown to be more accurate than other methods when compared to recent hypersonic flight data. Either Eckert's flat plate formulation, or an integral representation when boundary layer history is of importance, will be

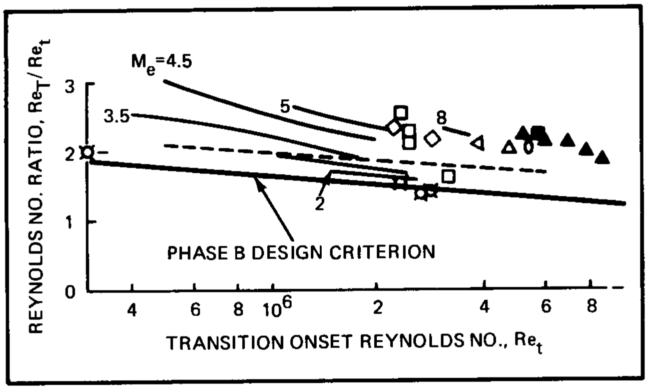


Fig. 2-24 Transition Zone Criterion

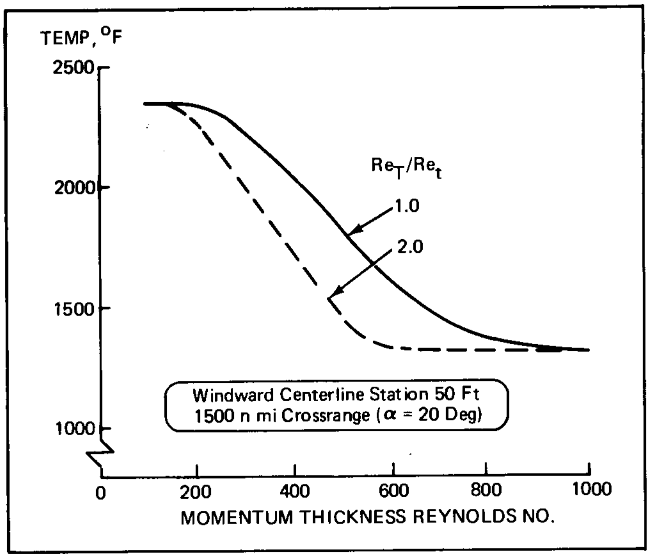


Fig. 2-25 Effect of Transition Reynolds Number on Maximum Surface Temperature

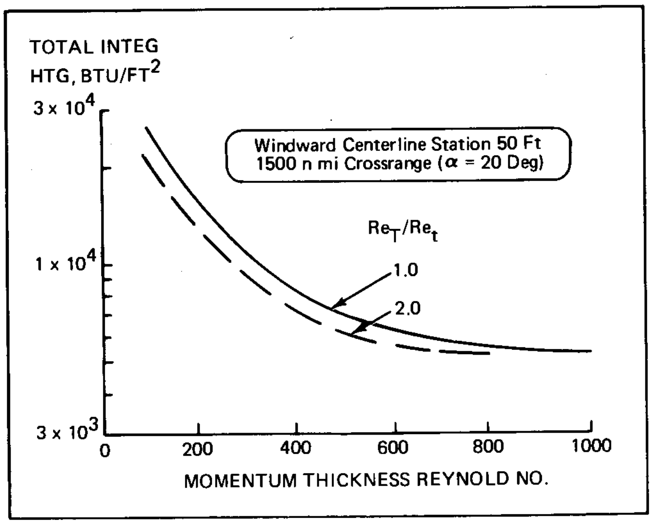


Fig. 2-26 Effect of Transition Reynolds Number on Maximum Total Integrated Heating Rate

used throughout the Phase B study. The services of Dr. C. DuPont Donaldson and Dr. R. Vaglio-Laurin will be available to consult in the areas of flow fields, transition and heating analyses.

Nose design requires special considerations. The nose of the vehicle experiences a severe environment; however, it is well within the TPS capabilities developed for orbital and strategic reentry vehicles. Experience by General Electric in this area will assure an appropriate design based upon operational vehicle results. High local heating and the possibility of damage caused by particulate matter (micrometeoroid, space debris, hail, etc.) impacting the nose indicate the desirability of a replaceable attachment concept. TPS concepts to be studied and compared are: shape stable ablators such as silicone foams, fabric reinforced phenolics and oxidation inhibited carbon composites; reusable external insulations (REI) such as rigidized refractory fiber felts; re-radiative metal systems utilizing coated refractory metals; and active or passive transpiration systems. Features of possible ablative and REI systems are illustrated in Figure 1-53.

Leading edge design considerations must reflect strain compatibility with leading edge structure. The thermal protection for leading edges must withstand high heating rates and particulate impact damage and also be capable of maintaining strain compatibility with the primary leading edge substructure. These requirements suggest a spanwise segmented design to alleviate overall expansion and bending incompatibility and to allow individual segment replacement. Similar problems have been encountered in nose cone RV design and satisfactorily solved. Operational vehicles have been designed with circumferential gaps in the heat shield to relieve strain due to differential thermal expansion and externally imposed shear loads. The materials considered for the leading edge are the same as those for the nose. Fig. 2-27 shows typical graphite composite and metallic leading edge segments. Figure 1-53 shows typical elastomeric ablative and REI segments.

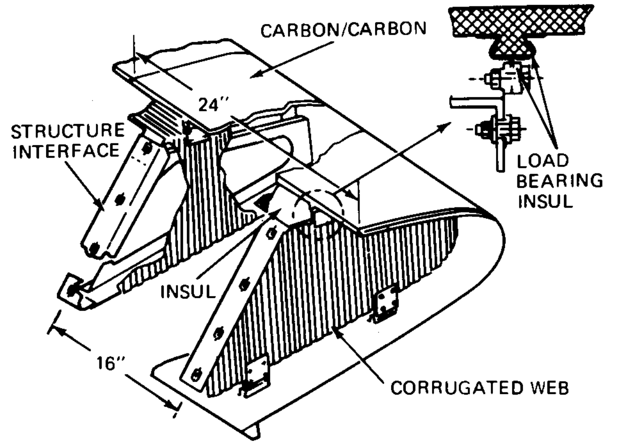
TPS for the orbiter control surfaces must consider severe cyclic heating environment. The movement of control surfaces causes cyclic heating of these surfaces and results in large transient temperature gradients through the depth of the TPS and the possibility of thermal distortions which could affect control response. Sealing techniques will be defined, if required, to prevent flow through control surface gaps which would otherwise cause increased local heating and loss of control effectiveness. The control surfaces on MBRV, a manuevering vehicle developed and flight tested by GE for the Air Force, were designed for a close fit at the buried hinge line, but with a gap. Analytical predictions, verified by MBRV flight tests, indicated satisfactory performance. Protection for bearing and lubrication systems will also be defined. The TPS materials which are considered candidates for the control surfaces are essentially the same as for the nose and leading edge.

Body panel design integration with structure minimizes total system weight. The fuselage TPS accounts for most of the vehicle TPS weight and an optimum weight design is therefore very important. This TPS must, in addition to providing an acceptable temperature environment for the major portion of the internal primary structure, carry the local air loads and form a reasonably smooth external aerodynamic shape. Panel stiffness must be adequate to prevent flutter. TPS materials considered applicable for the body surfaces are REI, replaceable low density elastomeric ablators, and re-radiative metallic panels backed with insulation. Comparative data for these systems are illustrated in Fig. 2-27. Design concepts are illustrated in Fig. 2-27. The surface panel design and supporting structure are interrelated. Consideration will be given to panel joint design to accommodate differential expansion between hot panels and the cooler vehicle structure. Fig. 2-27 gives relative panel motions for titanium supported REI panels and reradiative metallic panels when used in conjunction with an integral cryogenic tank structure. Panel joint designs will be provided to seal against aerodynamic flow. Provision for internal vehicle purging and venting will be made. Individually removable panels, to facilitate replacement and inspection, will be a design objective. Openings in the TPS such as landing gear doors, RCS doors and access hatches will be designed to allow proper sealing and insulative integrity.

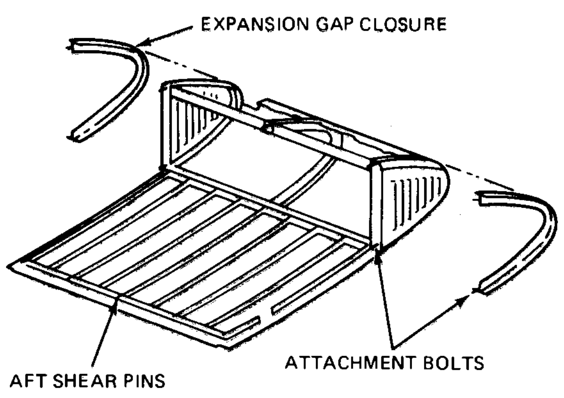
In the case of metallic panels, proper packaging of the internal insulation blanket will be investigated to avoid moisture absorption and vibration damage. Materials for use as insulation blankets above 2000°F for repeated cycles will be evaluated. Fig. 2-27 shows the relationship between density and insulation efficiency.

LEADING EDGES

- REMOVABILITY REQMT
- IMPACT & EROSION
- HIGH TEMPERATURE AREA
- HIGH NORMAL PRESSURE
- SURFACE SMOOTHNESS
- CURVATURE
- BODY INTERSECTION



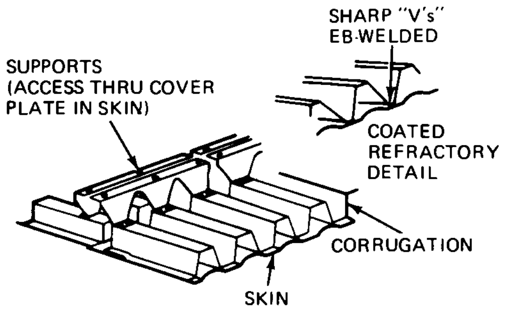
CARBON/CARBON LEADING EDGE CONCEPT



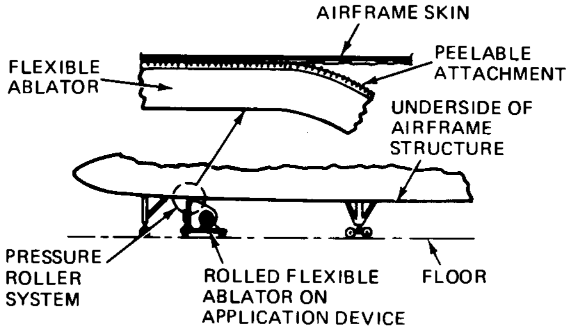
RERADIATIVE METALLIC LEADING EDGE CONCEPT

BODY PANELS

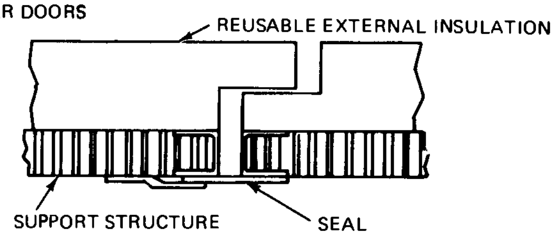
- CRITICAL WEIGHT & COST
- FLUTTER
- RETRACTABLE DOORS
- LANDING GEAR DOORS



RERADIATIVE METALLIC THERMAL PROTECTION CONCEPT

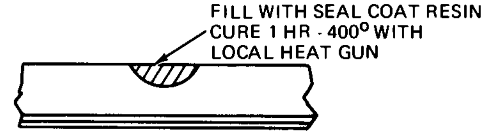


REFURBISHABLE ABLATIVE THERMAL PROTECTION CONCEPT



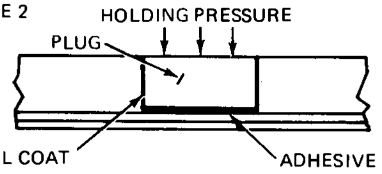
REI LONGITUDINAL SEAL

TYPE 1



SMALL SURFACE DEFECTS - NON AERODYNAMIC CRITICAL SURFACES

TYPE 2



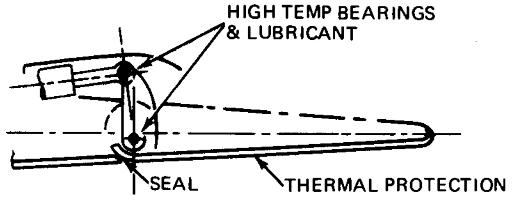
DAMAGE CONFINED TO 8-IN. DIA CIRCLE - CRITICAL AERODYNAMIC SURFACES

REPAIR STEPS
1. Core Out Damaged Area
2. Bond Standard Size Plug Cure 4-6 Hr Room Temp
3. Fill Gap Around Plug Seal Coat Resin Cure 1 Hr - 400° Local Heat Gun

REI REPAIR TECHNIQUES

CONTROL SURFACES

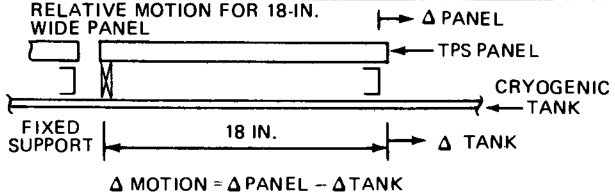
- MOVABLE JOINT & SEAL
- CYCLIC HEATING & LOAD
- HIGH-TEMP BEARINGS & LUBRICANTS
- PROTRUSIONS



CONTROL SURFACE DETAILS

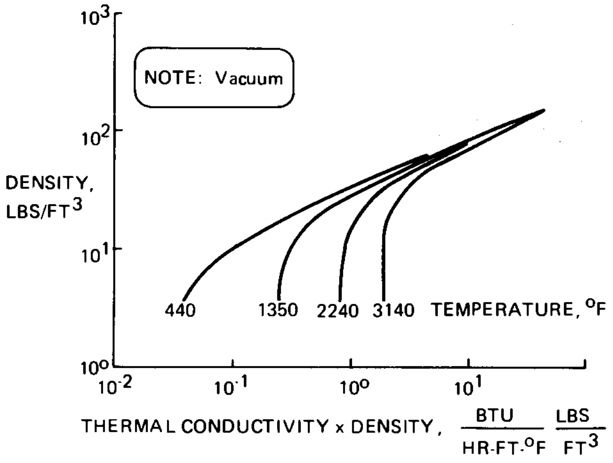
TPS DESIGN CONSIDERATIONS:
- Design Adequacy
- Cost
- Reusability
- Fabrication
- Inspection
- Radiation
- Weight
- Technology Status
- Reliability
- Maintenance
- Refurbishment

BASIC TRADE DATA

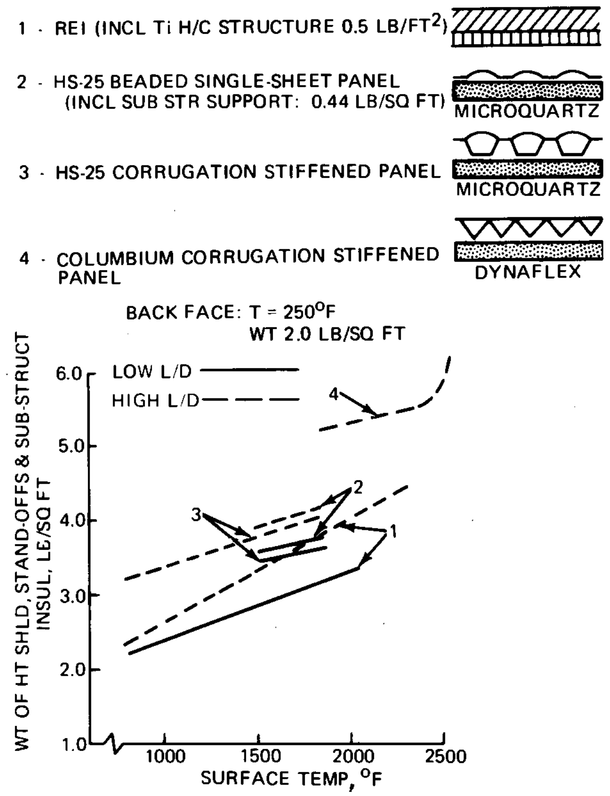


Envmt \ Panel	Delta Motion, In.			
	REI with Ti Support	Coated Cb	Haynes 188	INCO 718
Assy On Primary Struct (Cryo Tank @ 70°F)	0	0	0	0
Abort Condition Tank @ -300°F Panel @ +100°F Tank Bending ϵ = -0.3%	+0.142	+0.142	+0.144	+0.136
Re-entry Tank @ -300°F Panel as Noted	+100°F +0.088	2000°F +0.241	1500°F +0.313	700°F +0.174
After Re-entry Tank @ +250°F Panel as Noted	+500°F -0.006	+100°F -0.039	+100°F -0.038	+100°F -0.039

* Note: Temps are for metallic panel



INSULATION WT EFFICIENCY OF REFRACTORY FIBRE FELTS



TPS WEIGHT TRADE CONSIDERATIONS

	Ablative	Carbon/ Carbon	REI	Coated Cb	Haynes 188
Nose	25-40	450-600	150-200	800-1200	80-120
Chine	20-35	400-550	125-175	500-1000	50-100
Leading Edge	20-35	400-550	125-175	500-1000	50-100
Flat Body Panels	10-15	–	100-150	400-800	40-80
All Costs Estimated On Volume Production & Initial Installation.					

TPS COST COMPARISON, $/SQ FT

Fig. 2-27 TPS Design Considerations

Nondestructive test methods and design for inspection are essential. Nondestructive test methods have been developed for evaluating the candidate materials and inspecting the manufactured components. Such tests as ultrasonic pulse-echo and velocity, radiometric gaging, microwave and low frequency dielectrics will be specified for composites, ceramics and non-metallics. Thermoelectrics, backscatter radiography, eddy current and sonic resonance techniques will be evaluated for assuring the quality and predicting residual useful life of coated metallic parts. In addition, the use of onboard sensors such as thermocouples, accelerometers, strain gages and thermochromic materials will be evaluated for detecting and monitoring overstress conditions and temperature excursions which may cause excessive damage or unpredicted degradation. The possibility of designing components to allow for the inspection of critical areas such as bonds, faying surfaces, fasteners, joints, etc. in the initial as-manufactured stage and as part of the integrated space shuttle structure will be assessed.

Test program will assure resolution of important unknowns. Component tests will be used to verify design and fabrication concepts and to support TPS weight estimates. The components considered for these tests will be the fuselage body panels. Two REI panels will be fabricated and supported with representative attachments. One will be tested in either the AFFDL 50 megawatt facility or in the 5 megawatt General Electric facility. The other will be tested through 100 representative cycles at the General Electric high temperature facility using radiant lamps. In addition, two metallic panels, one of columbium CB 752 coated with R512E oxidation protective coating, and one of HS-188 superalloy will be fabricated and tested with sufficient insulation to keep the substructure temperature to 500°F. They will be subjected to representative time-temperature profiles with peaks of 2400°F and 1800°F, respectively.

Thermal mathematical model is needed to obtain vehicle heat balance. Thermal system integration, including the salient problem associated with man in the loop, has been successfully performed on LM and OAO by Grumman, and on numerous reentry vehicles and satellites by General Electric. The interfaces unique to a craft docked to a space station were extensively studied during the AAP/LM-A contract. This type of design synthesis will begin in Phase B.

A thermal mathematical model specifically for the shuttle, including the active environmental control system loop, will be generated to assure that thermal control approaches on the subsystems level are compatible and coordinated on a vehicle basis. The model will also serve as a focal point for the collection and control of subsystems and interface requirements and mission thermal penalties and constraints. Consistent with minimum refurbishment and weight goals, precise absorption/emittance ratio (a/ϵ) control coatings and gross insulation schemes shall be avoided in favor of integrated local solutions.

2.3 SUBSYSTEM DEFINTION

This section of the proposal comprises the definitions and descriptions of the major subsystems of the booster and orbiter configurations proposed by Grumman for the Phase B study. Section 1 described those subsystems that constituted design baseline drivers.

This definition study will include descriptions of the major subsystem characteristics, namely: performance/reliability/safety, size/weight/power, interface/integration/logistics, and installation recommendations. Specific design tasks are identified in those areas in which the baseline design is not defined, and recommended approaches to the design tasks are proposed.

These studies are aimed at subsystem optimization with respect to vehicle performance, mission capability, and support minimization.

2.3.1 Propulsion Systems

Propulsion requirements are so extensive in the Statement of Work, that a comprehensive study plan covering each area of work cannot be accomplished within existing page limitations. We will comply with all of the study requirements and high priority will be placed on timely completion of the design studies required to be submitted to NASA in accordance with item #6 of the data requirements list.

An interrelationship exists among studies conducted under five propulsion subsystems: main propulsion, attitude control propulsion, orbit maneuvering, air breathing and cryogenic tankage and under engines/vehicle integration. An example is the influence of main rocket expansion ratio and gimbal angle studies on vehicle base drag which, in turn, impacts air breathing, fuel tankage and engines/vehicle integration studies. Another example is interaction of booster and orbiter studies where common usage of propulsion components and engines is a high-priority cost reduction goal factored into each subsystem study. With these interrelationships, all propulsion studies will be accomplished by a single propulsion group with emphasis placed on maintaining technical continuity among all studies. To achieve this goal, we will rely on experienced Grumman LM propulsion personnel, supported by Aerojet-General, utilizing analytical computer programs developed during the Apollo program.

Experience gained on the LM program indicates a number of problem areas and suggests possible solutions common to all propulsion subsystems. Studies will be made to identify components, seals, bearings, materials, penetration joints, and line joints, etc., that can be used in all propulsion subsystems.

2.3.1.1 Main Propulsion System

Tradeoff and design studies will be made to define orbiter and booster main propulsion systems including desired engine operating parameters and characteristics. Studies will place emphasis on systems which are consistent with high mass fraction, reusability and operational requirements of the program. The main propulsion systems for Designs 518 and 532 are described in Subsection 1.6.

Techniques to increase propellant density will be traded off against penalties of added GSE. Propellant feed system design criteria for POGO suppression will be established by analysis of coupling action between dynamic characteristics of vehicle and propulsion system. Lateral vehicle modes as well as longitudinal will be examined due to unsymmetrical launch configuration.

Tradeoff studies to evaluate propellant jettisoning schemes will consider burning the propellant through the main engines, jettisoning through overboard vents using tank pressure or pumps, and dumping through the engines. A combined concept, which is to operate the engines at minimum thrust while dumping only oxidizer through an overboard vent, will also be studied as a means to allow for retention of sufficient hydrogen to meet longer cruise range associated with abort cases.

To minimize facility requirements and booster engine/vehicle system development test costs, design studies will be conducted to provide for identical feed lines to symmetrical engine groups; the objective is to minimize number of engines required to be fired simultaneously in feed system/engine compatibility tests. A study will be made of line runs and engine installation changes required to accommodate installation of either three J-2S engines or two or three high-pressure engines in Design 532 orbiter.

Studies will be conducted on Design 518 to determine desirable engine operating parameters and characteristics while using a common engine in both stages. All mission phases including normal and emergency, e.g., engine-out, operations will be considered. Items to be included in this study are shown in the logic network in Fig. 2-28; iteration loops have been omitted for purposes of clarity. In conjunction with Design 532, similar studies will be conducted on uprated J-2S and F-1 engines where emphasis will be placed on definition of thrust level, throttling, mixture ratio control, combustion stability, and increased service life. Rocketdyne has offered to freely support us in these activities. Design modification and requalification costs will be traded against costs of periodic overhauls to meet multimission requirements. Studies will be conducted on both designs to define engine-support methods, clearances, and thermal and vibration environments.

Active propellant utilization (PU) systems are selected as baseline on both orbiter designs; passive PU is selected on both boosters. Passive propellant management (PM) is selected as the baseline on orbiters. Although Grumman experience on LM descent stage has indicated passive PM is practical on a system with multiple tanks, detailed analysis will be conducted to determine the best approach for each orbiter design. Advantages and disadvantages of sumps, balance lines between like tanks and individual calibration (orificing) of parallel feed system legs will be studied. Factors that will be considered include vehicle accelerations and attitude, temperature, pressure, and hydraulic resistance differences in parallel legs. Tradeoffs will be conducted to determine relative merits of passive vs active PM and PU, as well as to establish tank/feed system design criteria and quantity gaging system requirements. These studies will be conducted with the aid of an existing computer program. In the Design 532 orbiter, the possible use of J-2S engines, requires a study to make PU and PM systems and vehicle tankage compatible with different operating mixture ratio ranges of the J-2S (4.5 – 5.5) and high-pressure engine (5.0 – 7.0). A study will be made to establish propellant loading procedures aimed at minimizing residuals while being consistent with the unique mission and operational requirements of the shuttle.

2.3.1.2 Attitude Control Propulsion System (ACPS)

The baseline ACPS conditioning system for Design 518 and Design 532 vehicles incorporates high-pressure turbopumps and bellows tanks. It was selected because it represents a balance between weight, performance sensitivities, growth potential, auxiliary capabilities and overall systems cost. If the development time of the turbopump system is not compatible with the 532 vehicle schedule the thermopressurized conditioning system offers an excellent cost-saving alternative.

Four basic conditioning systems (turbopump, thermopressurized, turbo compressor and low pressure) will be studied, and a detailed description of design and operating characteristics of these systems is contained in Grumman's proposal in response to MSFC's RFP, "Space Shuttle Auxiliary Propulsion System Definition," DCN 1-0-50-09579 and MSC-JC421-M68-0-101-P.

TURBOPUMP SYSTEM – With the turbopump system, propellant orientation and acquisition is a problem for study since subcooled liquids are required at the pump interface. Accumulator size and weight affect system optimization and larger accumulators reduce startup cycles and system transient losses. As turbomachinery life and reliability increase, the weight and size of the accumulators can be decreased and, by adding redundant turbopumps and heat exchangers, it is possible to achieve greater overall system (ACPS and auxiliary) reliability and lower development costs in the integrated system concept.

THERMOPRESSURIZED SYSTEM – The thermopressurized system is characterized by short development time, low development cost, and minimum interface problems with the vehicle main propulsion. This system does not require high-response rotating machinery. Separate high-pressure cryogenic propellant storage tanks are required as well as accumulators to minimize gas generator/heat exchanger startups and reduce engine control requirements.

LOW-PRESSURE SYSTEM – The low-pressure system uses main propellant tanks as accumulators and requires studies to tradeoff complexity against performance, weight, and interface problems. The

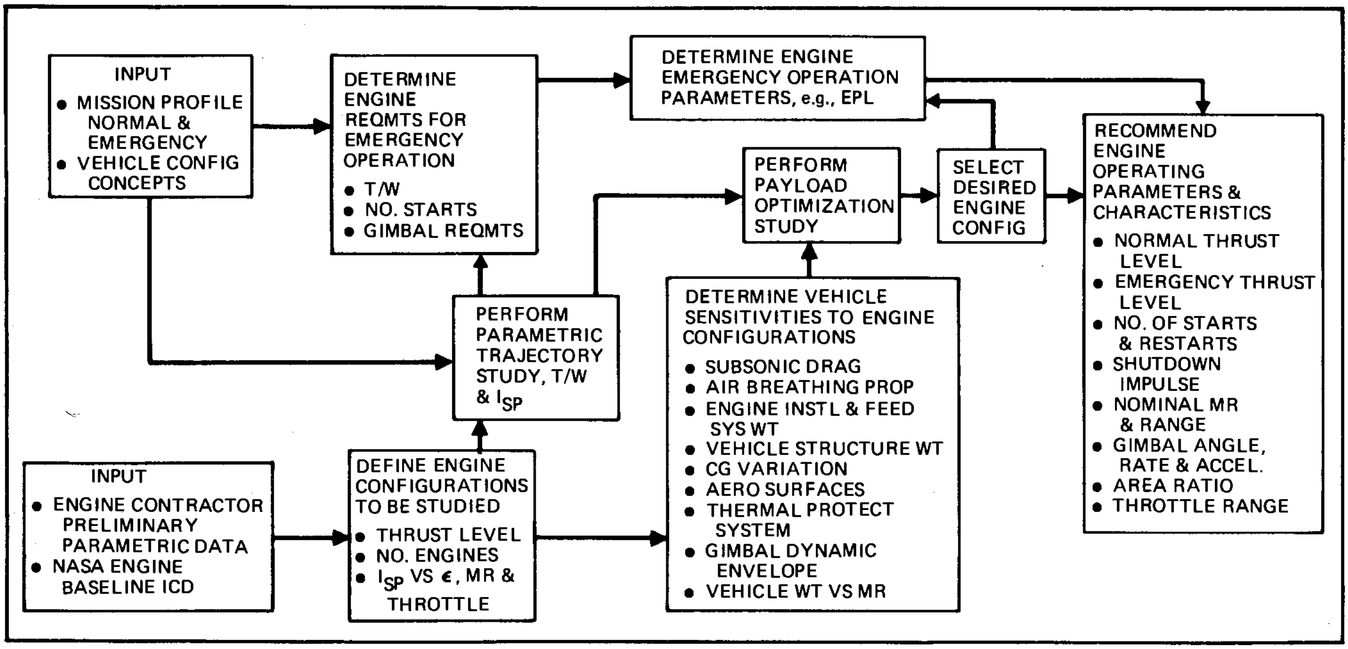


Fig. 2-28 Engine/Vehicle System Study

simplest system, which does not involve gas-generator-fed heat exchangers or rotating machinery, could be penalized by high vent losses, post reentry residuals, high main tank weight, and wide variations in engine interface propellant conditions. Adding heat exchangers, rotating machinery, and more sensitive control systems, can minimize these penalties. The primary goal therefore, is to establish the proper balance between simplicity and performance.

TURBOCOMPRESSOR SYSTEM – The primary problem of the turbocompressor system is the heat exchanger control to minimize vapor superheat into the compressor with a low heat exchanger pressure drop. Compressor power and system performance losses become unreasonably high if this propellant superheat is not minimized. This system does not require a propellant orientation and acquisition system since liquids or vapors can be accepted at the system interface.

The study logic network for generating a detailed ACPS design is shown in Fig. 2-29. Studies will establish the vehicle control requirements. These will be factored into tradeoffs between the four conditioning system concepts and a complete detailed design of the selected system will be made.

Tradeoff studies will be conducted on engine location, orthogonal, and nonorthogonal orientation, heat shield penetration, nozzle closures, redundancy, and common thrust level engines for both booster and orbiter. Nonorthogonal engine orientation can greatly increase engine redundancy for a given number of engines; however, this feature is offset by three disadvantages: increased propellant consumption, increased number of pulses per engine and lower specific impulse.

A six-degree-of-freedom trajectory digital program with both guidance law and flight control systems incorporated, will be utilized to evaluate control power requirements during reentry.

2.3.1.3 Orbit Maneuvering System (OMS)

As a baseline, orbit maneuvers are performed by a single RL-10 engine and the attitude control

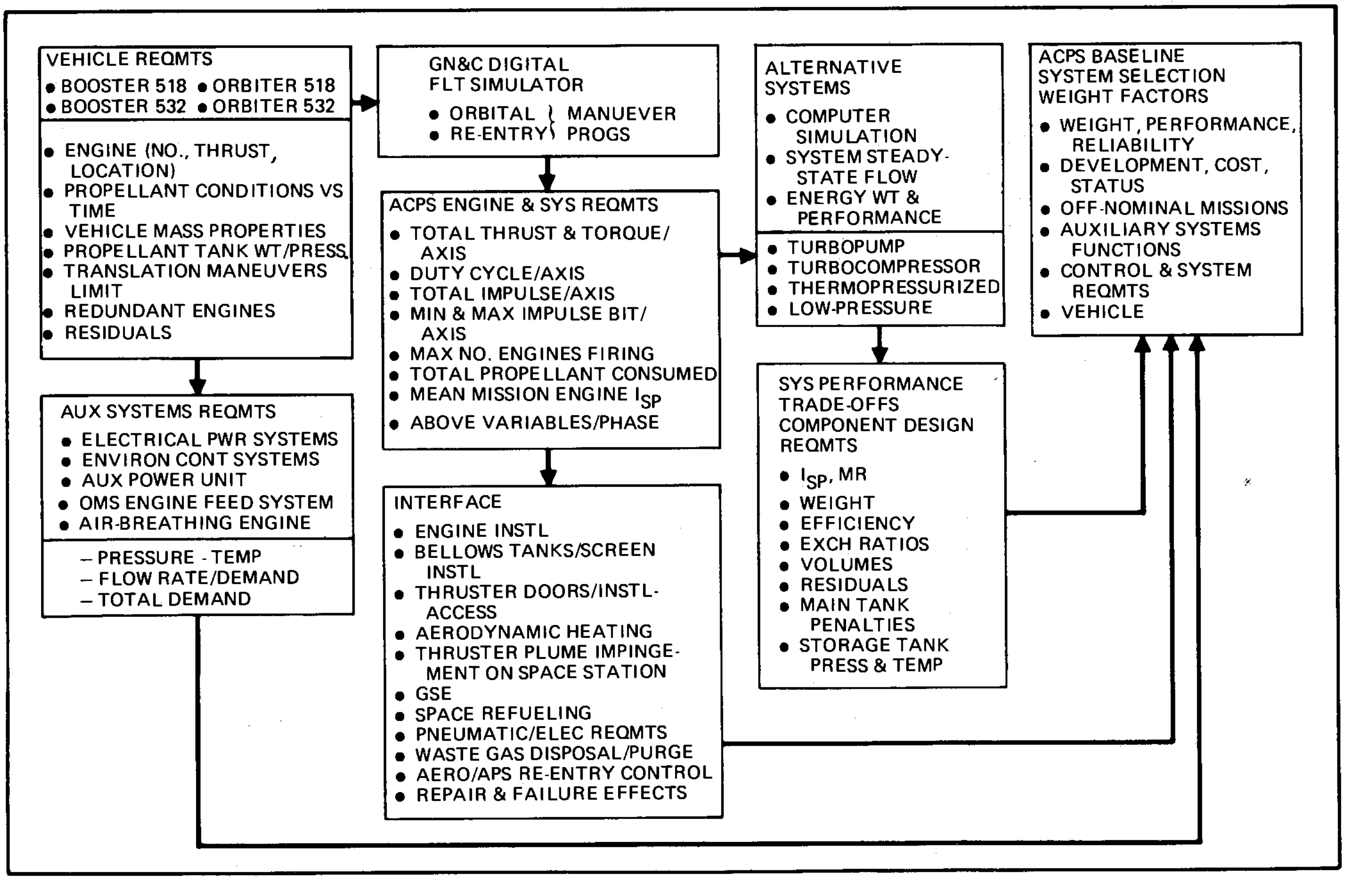


Fig. 2-29 ACPS Study Logic Network

propulsion system (ACPS) engines with a delta V split of 1300 fps and 200 fps, respectively. Propellant is stored in tanks insulated for long-term orbital storage. Autogenous pressurization is used.

OMS requirements will be determined for the specific designs, including thrust level, total impulse, number of starts and duty cycle and tradeoff studies to select the optimum OMS will be conducted. The use of throttled main engines, ACPS engines and dedicated engines will be considered. Selection criteria will include weight, safety, operational flexibility, and ease of providing redundancy. Modification and requalification of the RL-10 to provide idle mode operation and increased lifetime will be studied; this will be traded against the performance, weight, durability and cost of a new engine designed specifically for the shuttle application.

A detailed description of the selected system including performance specifications, interface requirements, weights, and volumes will be provided as a study output.

2.3.1.4 Airbreathing Systems

Turbofan engines equipped with simple inlets and exhausts and deployed from forward fuselage stowage wells is the baseline configuration. Common orbiter/booster engines of Design 518 and of the Design 532 orbiter are hydrogen-fueled versions of the JTF22 engine under development for the Navy/Grumman F-14B. JP-fueled RB211-22 engines power the 532 booster. See the inboard profile drawings in Subsections 1.3.2 and 1.4.2.

The impact of engine type is shown in Table 2-7.

Table 2-7 Relative Installed Engine Plus Fuel Weight

Vehicles	Candidate Air-Breathing Engines			
	JTF-22	RB-211-56	Pegasus-11	RB-211-22
Design 518 Booster	1.0	1.29	1.32	1.26
Design 518 Orbiter	1.0	2.34	1.38	1.88
Design 532 Booster	1.0	0.90	1.08	0.90
Design 532 Orbiter	1.0	2.36	1.39	1.89

A complete study of candidate engines including lift fans and subsonic cruise type turbofans will be made and a recommended air-breathing system, completely defined for each vehicle.

CONFIGURATION STUDIES – Submerged and podded engine installations will be evaluated against baseline configurations to optimize the installation. The deployed concept is a strong contender because of less thermal protection, lower weight inlets and exhausts, plus better installed performance.

Present turbofan capabilities exceed shuttle load factor for space stowage and minor modifications will be defined and traded against pressurization weight penalty. In orbit, a stowage pressure of 1 mm of Hg may preclude bearing oil out-gassing; booster stay in space appears too short to cause problems. Delivery of hydrogen to the turbofans, tankage allocation and feed system interfaces, will be studied in detail, approaches evaluated and compared.

OPERATIONAL STUDIES – Orbiter short-cruise offers JP vs H_2 tradeoff with respect to complexity, logistics and safety; dual fuel systems, H_2 for cruise and JP for landing and ferry, will also be evaluated. The use of standard fuel, JP and/or RP-1 will be evaluated against H_2 for Design 532 booster.

Windmill start at about 25,000 ft Mach 0.4, consistent with present engine capability and expected to improve with hydrogen, is baselined. The study will establish automatic sequence (yaw control) requirement and trade off the baseline against starter/APU assist modes. Ground start is by GSE air.

Orbiter landing modes with assist engines and also with no air-breathing propulsion will be traded against the baseline go-around requirements to determine impact on payload and on booster requirements. Landing of the orbiter without air breathing propulsion depends on descent trajectory accuracy, crew experience, and landing field conditions; resulting higher touchdown speeds may require additional braking capability and increase in landing gear weight; another source of cabin air, and added APU hydraulic and electrical power must be provided. Orbiter configuration for each landing mode and required strap-on ferry power system will be traded against baseline configuration.

2.3.1.5 Cryogenic Tank Systems

Booster/orbiter tank designs are described in Subsections 1.4.4, 1.5, and 2.2.

Preliminary definition of vehicle/tank configurations will initiate effort within the thermal, structural, and propulsion areas, to achieve a closely coordinated program. Feedback of propulsion design studies data for pressurization, vent, fluid dynamics and propellant control provide inputs to iterate vehicle configuration and tank geometry and size. The supporting activities of mass properties, manufacturing and maintainability/reliability will be factored into the study effort leading to selection of the final design. Fig. 2-30 describes study logic and tradeoffs required to define a maximum payload, cost-effective vehicle. Major propulsion studies include tank pressure level and system optimization; vent systems, tank inerting and vehicle purging; anti-slosh and anti-vortex baffle concepts; inflight dumping; and propellant loading, quantity gaging, and handling of residuals.

Pressurization & Purging – The pressurization evaluation includes integration of structural and propulsion requirements to define optimum vehicle tank pressures, the effects of insulation and ullage upon transient and steady-state gas flows, and autogeneous vs helium pressurization. A modification of a LM quasi-steady state/thermal model will be applied.

Vent systems include propellant loading requirements, tank pressure determination vs time and use of two-phase expansion valves with heat exchanger or ACPS propellant settling for zero g venting. The need for passivation of the tank system will be established and penalties associated with use of an all-He pressurization system, He refilling or purging, filtered air, inerting agents, and external ram air purging will be assessed. Use of an external dry He gas blanket after liftoff to prevent frost accumulation, air liquefication, and multilayer insulation degradation will be studied.

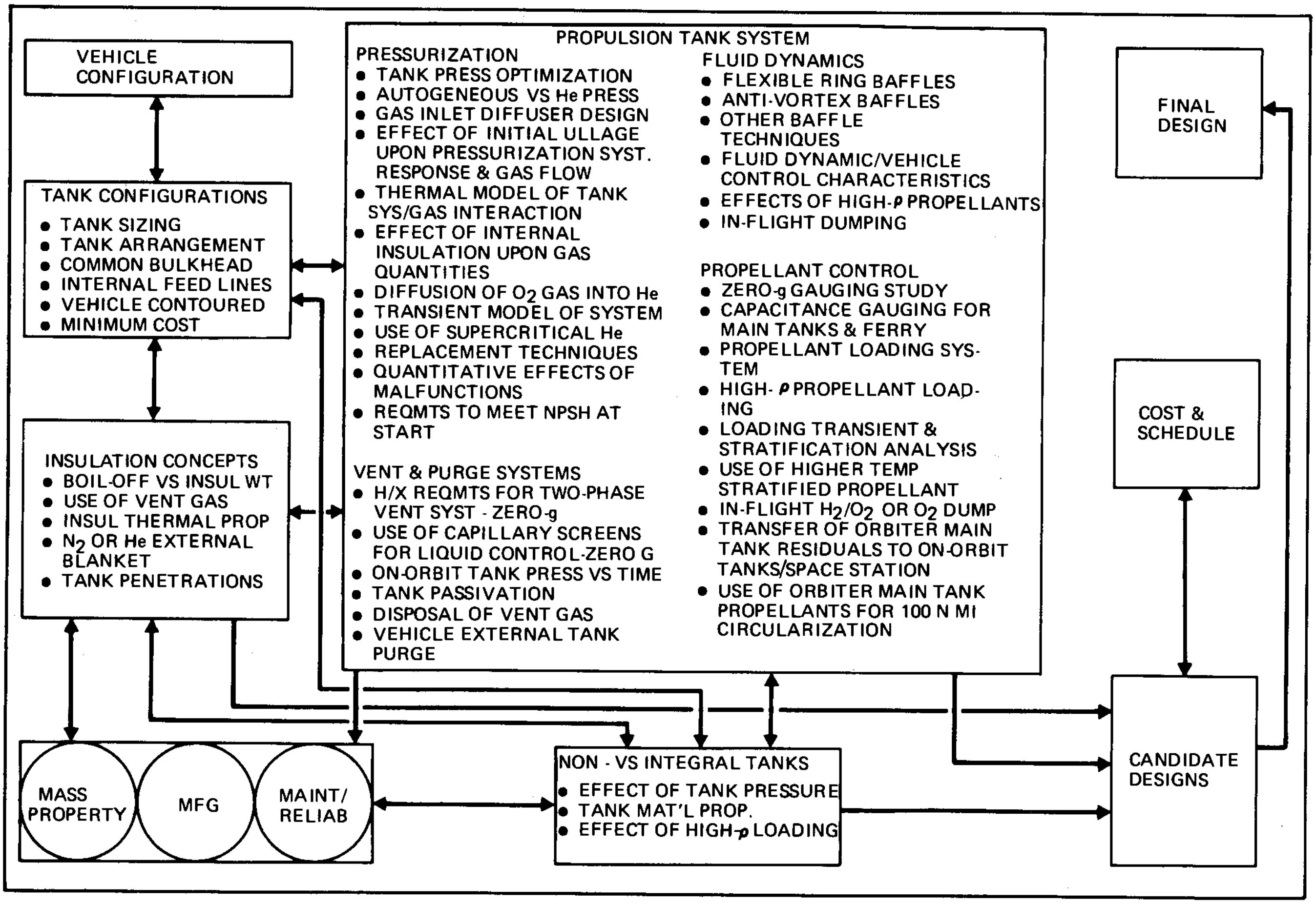


Fig. 2-30 Cryogenic Tank Systems Study Logic

Tank Internal Features – The use of flexible ring baffles for propellant dynamic control will be compared to conventional concepts. The flexible concept is described in our 70-22NAS "Flexible Baffle Engineering Study", 4 March 1970. Anti-vortex and anti-slosh studies will employ a modified LM program to determine fluid dynamic/vehicle control characteristics. Air breathing fuel anti-slosh control will include evaluation of a single feed compartment. Common storage of air breathing fuel in main or on-orbit tanks will be evaluated for weight and volume advantage. Added weight and complexity of tanks with internal compartments and lines and increased residuals will be traded off against weight of a separate tank and increase in total 3σ fuel dispersions. Gauging systems capable of horizontal and vertical quantity measurement will be investigated. Flight dumping techniques will be evaluated in conjunction with main propulsion for defined abort modes.

Tank top capacitance sensors with a computerized loading system and booster/orbiter main tank bottom, (10 percent) capacitance systems for P.U. will be studied. Reduction of overall propellants by root-sum-squaring of booster/orbiter 3σ dispersions will be evaluated. Analytical procedures developed for the LM program to minimize dispersions and residuals will be employed.

2.3.1.6 Engine/Vehicle Integration

The interrelationship of the main rocket engines with vehicle configuration requires timely vehicle inputs, regarding desired engine parameters, factored into the engine Phase B studies. Evaluation of results of the engine contractors parametric analyses will be conducted with the constraint of using common engine powerheads on orbiter and booster. Engine parameters as described in paragraph 4.1.4.1 of space shuttle main engine Statement of Work will be evaluated and reported in accordance with Appendix F of the space shuttle system Statement of Work. Studies dealing with the definition of primary propulsion parameters on a vehicle with two interrelated stages are not new to Grumman; a similar task was performed on the LM ascent and descent stages. This unique experience, provides a strong base for conducting this study.

2.3.2 Electromechanical & Integrated Avionics System

THE BASELINES – Two alternate baselines will be studied. The baseline for Design 518 is highly autonomous consistent with the goal of minimizing operational costs. It employs advanced hardware technology with extensive built-in-test capability and meets the Fail Operational-Fail Operational-Fail Safe (FO/FO/FS) criteria. The baseline for Design 532 is designed to meet early essential mission requirements. It makes maximum use of existing qualified hardware (Refer to Subsection 2.1.9). On-board checkout to the black box level of critical functions and a Fail Operational-Fail Safe (FO/FS) capability is provided. These baselines are functionally identical, permitting an orderly growth-oriented transition from the baseline for Design 532 (hereafter called first generation) to an advanced configuration baselined for Design 518 (hereafter called second generation). Functional elements of the booster and orbiter for both generation configurations are shown in Fig. 2-31. Basic requirements, major implementation characteristics and functional studies are given in Table 2-8.

Computer – Both configurations use a centralized computer subsystem that communicates with, controls, and integrates all other components and subsystems over a multiplexed data bus through standard interface units (SIU's). The SIU modular family is based on current developments at GE/ Houston under MSC auspices (NAS 9-10230). The choice of a centralized computer with a multiplexed data bus over a federated computer has the advantages of lower cost, lower weight, easier accommodation of changes, and flexibility for transition from first- to second-generation configurations. The added complexity in software/programming is minimized by using a modular approach to software design and by providing sufficient margin or growth capability in memory size. Recognizing that the selection of the data management approach is fundamental to the integrated avionic systems, this study will be expanded and results verified during Phase B with appropriate NASA inputs and guidance.

Displays & Controls – The display and controls for both generations are virtually identical, differing only in the use of minor dedicated displays and controls required for existing hardware or early testing. This avoids major cockpit redesign and crew retraining in the first- to second-generation transition. Multi-purpose CRT displays, computer aided data entry keyboards, side-arm rotation and engine/translation controls, and pedals, are integrated D&C subsystem features designed for two men but operable by one. These D&C

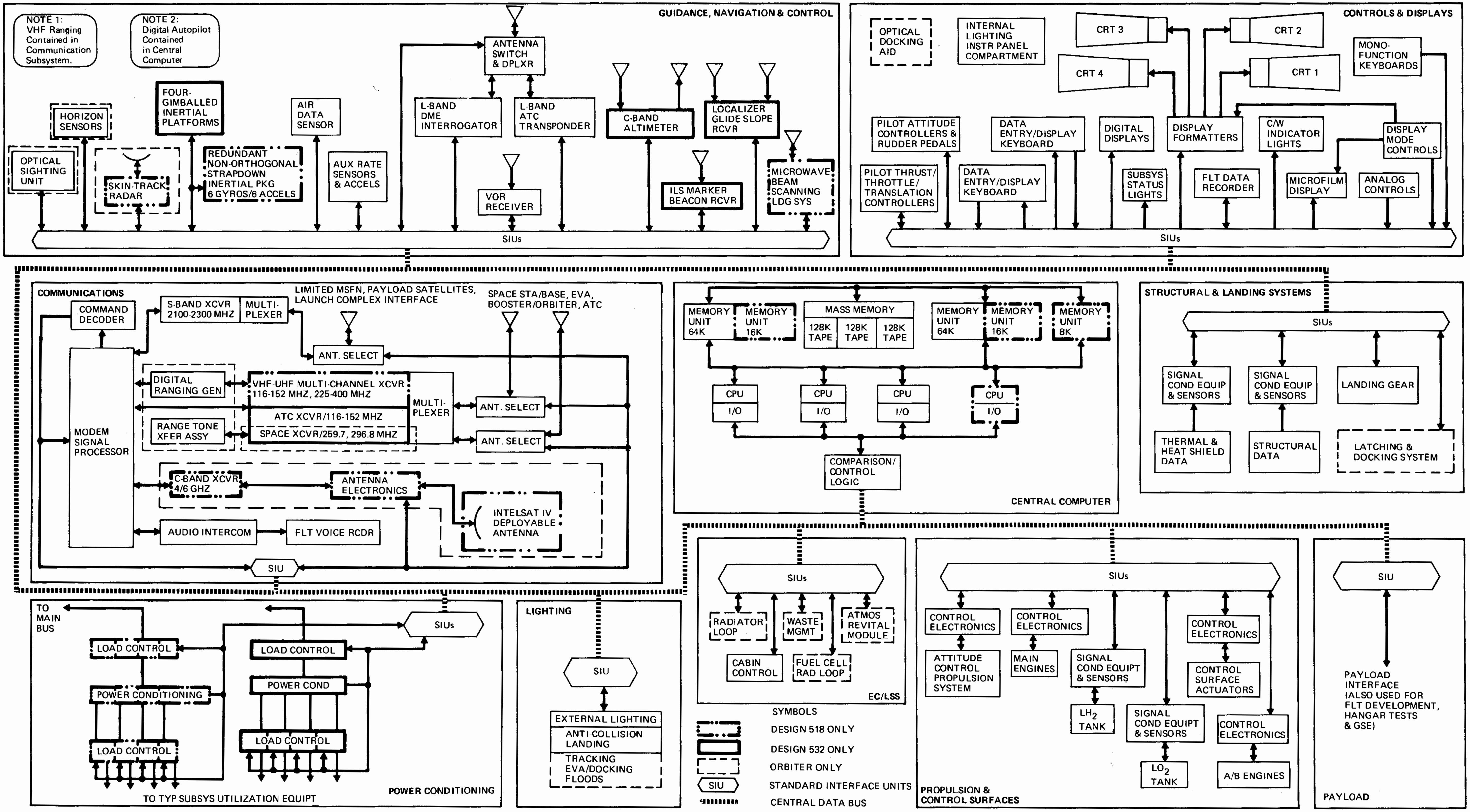


Fig. 2-31 Electromechanical & Integrated Avionics System Functional Block Diagram

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Table 2-8 Subsystem Functional Descriptions & Studies (Sheet 1 of 2)

FUNCTION: BASIC REQUIREMENTS	1ST GENERATION BASELINE IMPLEMENTATION	1ST GENERATION BASELINE RATIONALE	2ND GENERATION BASELINE	MAJOR FUNCTIONAL STUDY TASKS
Nav during re-entry: nav sys update after end of comm blackout reqd for limited cruise range orbiters & unpowered ldgs; 10 n mi (3σ) error at 60,000 ft. GUIDANCE NAVIGATION & CONTROL	Inertial nav sensor sys (three 4-gimballed platforms) with updates from air data sensor (baro alt) & RF nav aids: nav computations perf in centralized computer.	MIL/commercially devel inertial sensor sys (ASN-90, LN-15, LN-30, etc.) – high alt pressure sensor, VOR/DME.	Use redundant non-orthogonal strapdown inertial sensor sys; reduces gyro/accel components; increases reliability; enhances maintainability; anticipated commonality with Space Station.	● Trade-off redundant non-orthogonal strapdown sensor sys vs. multiple 4-gimballed platforms vs. multiple orthogonal strapdown sys. ● Evaluate VOR/DME & TACAN station characteristics vs. alt for each ldg site (ρ - ρ vs ρ - θ) ● Trade-off nav accuracy vs. glide capabilities & alt of update.
Guidance & control thru re-entry: re-entry energy mgmt reqd for controlling surf temp & extending cross range; maintain orbiter within entry corridor of -0.8 to -2.8 deg; control V_V to 10 ft/sec at 400 K-ft to assure ldg at footprint edge.	Inertial nav sensor sys with centralized computer solving energy mgmt control laws.	Use of inertial guid techniques for re-entry guid & control	Use redundant non-orthogonal strapdown inertial sensor sys.	● Trade-off conventional inertial implementation techniques vs. temp rate flt cont sys vs. mixed/hybrid sys. ● Determine if absolute temp measmts reqd. ● Study control xfer from RCS to control surfaces.
Terminal guidance, approach & ldg: auto approach & ldg with pilot-control capability; acquire glide path at 8 n mi range (2500-ft alt).	Commercial ILS & C-band altimeter; improved sys capabilities thru INS smoothing of ILS data (on-board auto system).	GE/707 flight test program over 90 successful auto ldgs performed; off-the-shelf hdwe.	Microwave beam scanning sys replaces conventional ILS + C-Band altimeter; advantages: selectable glideslope angles, long-range capture, proven techniques/FAA supported.	● Study extension of ILS & microwave beam scanning systems for automatic unmanned landings. ● Evaluate candidate sys max range/az-elev angle data.
Flt control system – aerodynamic & orbital mission phases: stab aug & control; orb attitude comd & cont; aerodynamic cruise outer autopilot loops (alt hold/Mach hold, structural mode relief, etc.); auto modes of operation (guidance steering, etc.).	Fly-by-wire digital cont sys-control laws/filters/computations (stab aug, autopilot, etc.) implemented in centralized computer for both orb & aerodynamic mission phases; INS sensors plus aux rate sensors & accels (as reqd).	Digital autopilot in LM-CSM performance demonstrated; extension of dig autopilot concept for aerodynamic cruise & ldg control next logical step; software implementation of inner control loops must be verified.	Digital autopilot techniques, also apply to 2nd generation: add'l computational redundancy for increased reliability.	● Trade-off conventional aircraft analog vs. digital stability augmentation system.
Direct full duplex voice channel bet shuttle & ground, EVA, space/airborne vehicles; direct data-link & full duplex voice channel bet booster & orbiter; direct data link bet shuttle & ground, space sta/base, payload satellites; data link & full duplex voice channel bet shuttle & ground via satellite relay (2nd generation only); shuttle voice intercom & flt voice & data recording. COMMUNICATIONS	Two VHF sys for space-space, air-ground ATC, orbiter-booster link; Unified S-band for launch sys interface, MSFN, SGLS & expmt modules when in LOS; VHF coop ranging with Space Station; modem sig processor–PCM, PM, FM, AM; auto select & switch of antennas for optimum coverage (S-band & VHF – spherical, VHF/ATC – omni in azimuth); dual redundancy for xcvrs.	Equipt sources: LM comm VHF & S-band xcvrs, sig proc assy, digital uplink assy, range tone xfer assy; CSM digital ranging generator; std military/commercial aircraft CNI with built-in test; antenna concepts state-of-art (spirals, annular slots, flush half loops).	Additions: – C-Band xcvr interface to Intelsat IV; steered deployable high gain C-band ant; advanced VHF-UHF xcvr compatible with ATC/ Space/Mil comm; Modifications: modem sig processor to accommodate C-band svs & add'l automation of functions; incorp extensive built-in test. Retention of S-band depends on phasing out MSFN, space sta, expmt satellite payload, & AF reqmts & NASA dedicated TDRS	● Generate configs for accomplishing all RF functions with min redundancy, wt, cost impact, & increased reliability. ● Identify & assess RF blackout during re-entry. ● Determine shuttle—comm satellite interface to minimize complexity & satisfy mission objectives. ● Perform trade-offs & prelim des emphasizing: optimum des & location of antennas; built-in test sequence; RF technology (multichnl xcvrs, low noise rcvrs, high-power amps, high/low-gain antennas, etc.); commonality of functions; failure modes & auto reconfig; reliability.
Performance monitoring; operational testing; selective trending; fault isolation; verify onboard checkout function; control, display, record; self-test of DMS; caution & warning. ON-BOARD CHECKOUT (OBC)	Selective applic of NASA MSC-devel OCS concept (measmt & stimuli functions); interpretive software to simplify operator control; checkout functions initiated onboard, commanded from modified existing ground checkout equipt, or mission cont ctr; built-in sys safeguards.	Available space-qual hdwe has negligible built-in test & reqs ext'l computer-controlled checkout & stimulus; applic of NASA-sponsored OCS modules, software as required; min hdwe & software devel risk & cost; expandable test capability.	OBC as a function uses: std interface unit – data acquis, stimuli control & generation, limited processing, data bus interface; multiplexed data bus; computer complex; controls, displays & recorders incl local indicators on built-in test equipt boxes; critical monitor & alarm sys; built-in test & self-test. Adaptable to config changes.	● Devel subsys checkout data & equipt reqmts. ● Establish unified test philosophy. ● Integrate OBC functions with data mgmt sys functions. ● Define checkout reqmts based on availability of GSE. ● Define use of OBC during devel testing.
Changing & controlling total sys state in prescribed fashion according to mission phase & failure condition; level of pilot participation depends on reaction times reqd, pilot loading, criticality of operation, equipt status. CONFIG & SEQUENCING CONTROL	Semi-auto; manual safing upon docking & ldg; semi-auto redundant & alt mode control except for time-critical functions; astronaut-reqd intervention in turning equipt on & off, initiation of checks, data requests & comds; implemented by data mgmt, displays & control subsys.	Present aircraft/spacecraft employ these techniques. For example, operational readiness check in F-14A, engine sequencing on LM.	Auto checklist; auto safing; auto redundant & alt mode control; astronaut intervention limited to higher level decisons & override.	● Definition of sequencing & control reqmts according to mission phase & failure condition. ● Estab philosophy for crew participation. ● Size software & computational reqmts. ● Eval impact on DMS data bus, SIUs, OBC function. ● Eval reqd complexity in disp & cont.

Table 2-8 Subsystem Functional Descriptions & Studies (Sheet 2 of 2)

FUNCTION: BASIC REQUIREMENTS	1ST GENERATION BASELINE IMPLEMENTATION	1ST GENERATION BASELINE RATIONALE	2ND GENERATION BASELINE	MAJOR FUNCTIONAL STUDY TASKS
Two-man crew console operable by one; auto &/or manual flt cont; provide all necessary info for all mission phases; crew alerted to anomalies; rapid access to data file; minimize conventional gages, switches & electro-mech devices. DISPLAYS & CONTROLS	4-CRT multipurpose disp set; auto prog & manual call-up of prime flt data, subsys data, OBC data, ext sensor data, comm & TV; meets FO/FO/FS critieria; two-computer data disp keybds; microfilm data disp; C & W annunciators & subsys status lights (LM); subsys mono & multi-function keybds for rapid manual select/funct'l override: side-arm flt controls (thrust, pitch, & roll); pedals (yaw, steering & brakes).	CRT implementation uses proven disp technology devel on A-6, F-111B, F-14A, & E-2 Progs; limited use of Apollo dedicated instr to suppt early subsys implem where necessary; solid-state disp to use light-emitting diodes.	Fully-integ disp & cont: solid-state keybds & switch components; improved microfilm disp implementation.	● Adapt aircraft disp formats & symbols ● Conduct simulations to determine design optimization for all mission phases ● Eval TV aids for ldg & docking. ● Eval head-up (outside) projection disp based on crew/mission utility & vehicle geometry constraints.
The basic functions include: Guidance Navigation and Control (GN&C) Processing; Display & Command (D&C) Processing; On Board Checkout (OBC); Configuration and Sequencing Control (C&SC); Alternate and Redundant Mode Control; Mission, Operations and Payload Support; Internal Information Transfer. Peak loading is estimated at 300,000 operations per second. Half of this is equally distributed between GN&C and C&SC. The other half is distributed among the other functions with D&C, OBC and the computer executive taking up the major portion. Approximately 32,000 words (32 bits/word) of active storage are required for GN&C and 16,000 words for the other functions. Major considerations include a balance between main and mass memory program storage; minimization of executive program overhead; full implementation of autopilot operation; flexibility to take on varied display updating, formatting and possibly refresh requirements; control of up and down link telemetry; operation on a priority interrupt basis; special attention to program integrity and preservation. DATA MANAGEMENT	COMPUTER COMPLEX. Modular, centralized uniprocessing 500K ops/sec, 64K, 32 bit words of prog storage, 128K bulk storage; FO/FS complex with redundant memory, triply redundant CPU's and I/Os, reconfig for fail safe mode. DATA BUS. Master data bus – intramemory module & mass memory xfer, triply redundant with error correction; 8K, work block xfer 10MS; central data bus – DMS to all other subsys, triply redundant, separate comd & response lines, comd-resp-comd op, directly addressable SIU's. Max rate 1 MHz, coding for error control, split phase, bipolar mod coding. STANDARD INTERFACE UNIT'S (SIUs). Family of 3 SIU modules – no processing in simplest, limit testing in next level, mini processor capability in high level; mini processor has 2K hdwe memory, 128-word scratch pad, simple arith & logic; selective redundancy to meet FO/FS; ext to subsys.	COMPUTER COMPLEX. 1971 Technology – CDC α, Kearfott FOCUS, potential sources with min devel for I/O & FO/FS reqmt; uniprocessor yields 24% less hdwe (4 CPUs, 4 I/Os, 1MU), approx 15% less prog length but more complex in software implem compared to 2-computer approach. DATA BUS Master data bus – coax bus used on E-2C; central data bus – balanced twisted shielded pair meets reqmts with optimal wt shielding; dedicated runs as reqd; FO/FO/FS Config. STD INTERFACE UNITS (SIUs) Family of 3 reduces wt with 1971 technology; ext config minimizes mods to available equipt; compatible with built-in test or ext checkout philosophy, SIUs under devel at GE & Grumman; use of NASA/MSC-devel OCS modules & software as reqd.	COMPUTER COMPLEX. 1st-generation complex extended to meet FO/FO/FS; quad CPUs & I/Os; 80K word memory (propul plant trending, extensive config, mode & sequencing cont); multiprocessor software if reqd. DATA BUS Same as 1st gen. SIUs. Single SIU – most functionally complex from 1st gen; full use of large scale integ arrays (LSI); packaged as integ part of subsys.	● Study of software difficulties & risks in centralized complex vs. those in complex with dedicated GN & C computer. ● Consider software difficulties involved in extending sys to multiprocessor. ● Consider alternate SIU concepts, e.g. a set of std interfacing & processing submodules interconnected to meet a particular subsys SIU reqmt. ● Consider dedicated hardwire for everything except long lines to control surface actuators, propul sys. ● Spec tolerable error rates & sys design of appropriate on-line error rate control. ● Consider alt concepts for meeting FO/FS & FO/FO/FS reqmts. (Failure-tolerant techniques). ● Interrupt capability on bus.
Rendez with coop tgts – 100 n mi, uncoop tgts – 50 n mi (2nd-gen only); station keeping; nav update; docking. TARGET TRACKING & SENSORS	Rendez with coop tgt via VHF ranging & optical sextant/telescope with beacon on tgt vehicle; manual station keeping; manual docking; on-board nav updating using sextant/telescope & horizon sensors.	APOLLO CSM VHF ranging sys & optical telescope & sextant; simplicity; manual docking experience on Apollo.	Advanced radar: auto acquire & track coop/uncoop tgt, high detection probability, integ 2-gimbal ant/xmtr/rcvr, Full BIT; nav updating with auto optical sighting unit.	● Optimize sensor mix (radar, laser, passive optical & IR) to meet basic reqmts for each mission phase. ● Trade-off astronaut-in-loop nav updating/att align vs. on-board autonomy. ● Determine necessity & reqmts for auto docking & station keeping.
Condition & control power to equipt; protect against overloads & shorts; detect & isolate faults; standardize source & load interfaces; provide load isolation; provide power mgmt capability. POWER CONDITIONING	Existing hdwe &/or scaled designs; load dedicated equipt with parallel redundancy; decreases common mode effects, minimizes fault interruptions.	Minimize cost/devel time by max use of existing technology and booster/orbiter equipment commonality.	Std function modules – advanced components/circuits; minimizes logistics, minimizes maintenance time/training.	● Determine fault detect/isolation philosophy ● Define insulation criteria. ● Identify protection reqmts.

concepts have been endorsed by the Grumman/EAL consulting pilot team and will be systematically evaluated in mockups and simulation studies.

Guidance, Navigation & Control – First generation GN & C equipments reflect a blending of traditional aircraft concepts with present space technology to assure minimum development costs and associated risks, e.g. an all-attitude, four-gimballed inertial platform. The second generation system is a redundant nonorthogonal strapdown inertial sensor system with increased redundancy capability with minimum size, weight and an increased computational load. For the first generation, rendezvous with a space station is accomplished using Apollo equipments for ranging (VHF) and angle information (Apollo sextant). The second generation will include equipments for tracking and rendezvous with noncooperative targets.

Communications – For the first generation communications subsystem, a maximum of space (VHF and S-Band) and military/commercial (ATC and RF Navigation Aids) equipments are used. For the second-generation, advanced multi-functional equipments with higher redundancy and increased built in test capability will be used. Additions include a C-band transceiver interface to Intelsat IV with a steered, deployable, unfurlable, high-gain antenna and an advanced VHF-UHF transceiver compatible with ATC, space, and military communications. The modem signal processor will be modified to accommodate C-band an and additional automation of functions. S-band retention depends on status of MSFN, space station, TDRS and other interface requirements.

Redundancy – The use of available equipment and the need to provide maximum payload weight has resulted in a tradeoff in redundancy implementation for the first generation avionics. Thus, this configuration meets a FO/FS condition for all critical functions. While this may result in an occasional launch hold, it still permit an in-flight failure without loss of mission success. Apollo, for example, has successfully flown six manned missions with most of the critical functions containing only sufficient redundancy to assure a FS operation. As the technology advances and additional redundancy can be included, the second-generation avionics will attain the FO/FO/FS requirements with minimum weight penalty. Based on the first generation avionics, the "minimum equipment dispatch" list may include all the critical components. Second generation avionics will contain more that the minimum launch equipment, permitting an airline type operation that allows dispatch with selected equipments inoperative.

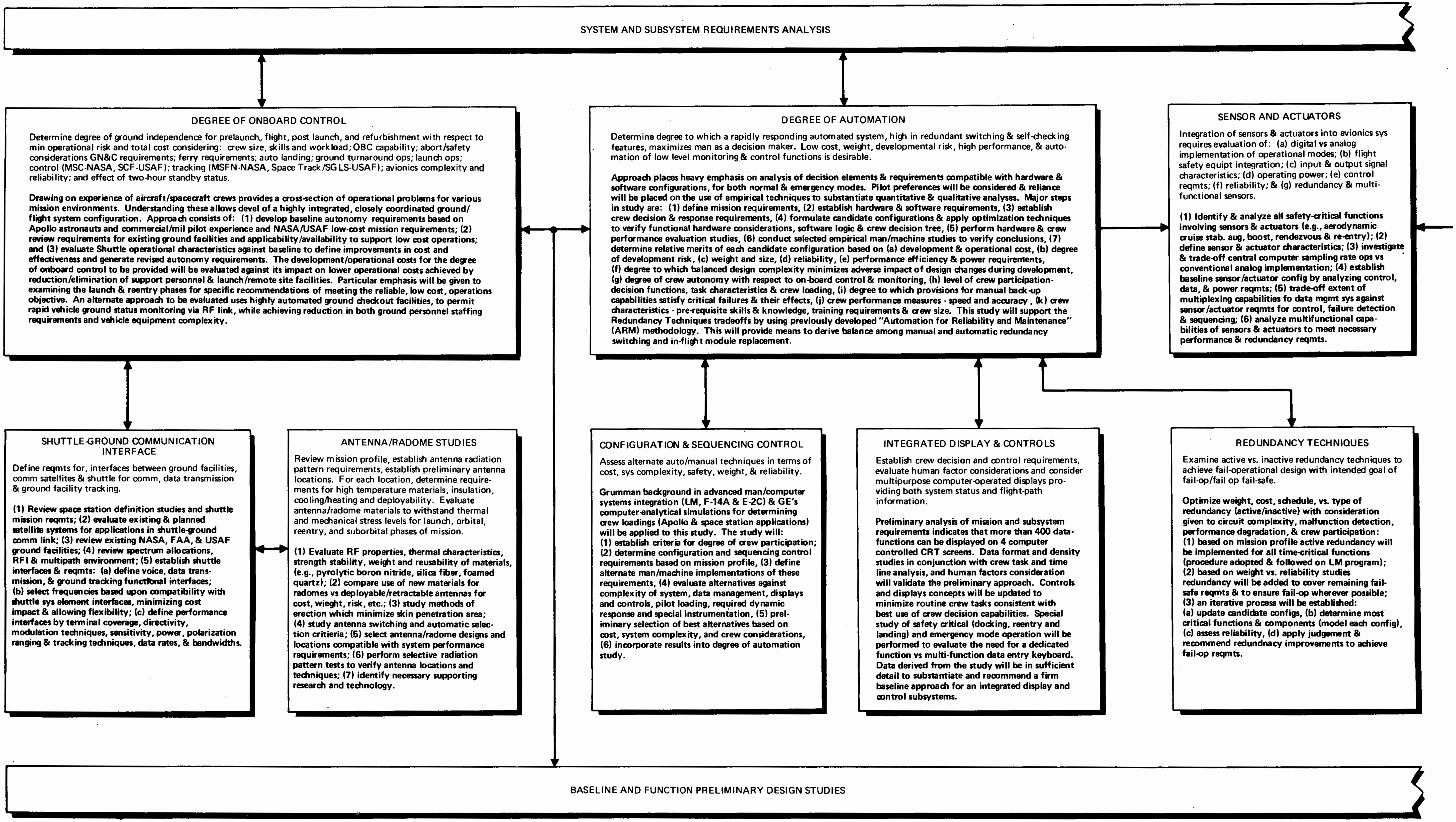
THE APPROACH – The Grumman/GE baselines, documented in the design data book, serve as a point of departure for all studies. A systematic traceable requirements analysis technique developed and applied by GE on the space station and MOL studies has been applied to the definition of these baselines and its use will be continued in Phase B. Concurrently, the results of functional subsystem studies (Table 2-8) and special tradeoff studies (Fig. 2-32) with cost/risk/weight as the predominant factors will be used to refine the baselines.

THE TRADEOFFS – The definitions and descriptions of the major system tradeoff studies and their interrelationships are shown in Fig. 2-32. The four main areas of study, and those that have the greatest influence on the ultimate system design are: degree of on-board control, degree of automation, centralization of functions and on-board checkout. The degree of on-board control, or vehicle autonomy, is the single greatest factor in determining the operating costs of the shuttle system. The on-board checkout capability is an integral part of the degree of autonomy. The degree of automation is greatly dependant on the degree of autonomy since the magnitude of the control function in a highly autonomous vehicle may exceed the reasonable limits of multiple crew capability. The degree of centralization is also affected since higher information processing and equipment control requirements demand the system efficiency that is inherent in a centralized design.

The tradeoff studies performed in these critical areas, as well as the other subsidiary areas will have as their goal, the optimization of the overall avionic system with respect to cost, and weight.

2.3.3 Landing System

BASIC DESIGN STUDIES – The landing gear tradeoff studies proposed for Phase B are shown in Table 2-9. In conducting these studies, dynamic analyses will be employed to determine landing-system energy-absorption characteristics, maximum gear loads, and vehicle-landing dynamic response for Items 1, 2, 3 and 4. For Item 2, runway roughness, we will use surface conditions defined by methods acceptable to NASA.



SYSTEM AND SUBSYSTEM REQUIREMENTS ANALYSIS

DEGREE OF ONBOARD CONTROL

Determine degree of ground independence for prelaunch,, flight, post launch, and refurbishment with respect to min operational risk and total cost considering: crew size, skills and workload; OBC capability; abort/safety considerations GN&C requirements; ferry requirements; auto landing; ground turnaround ops; launch ops; control (MSC-NASA, SCF-USAF); tracking (MSFN-NASA, Space Track/SGLS-USAF); avionics complexity and reliability; and effect of two-hour standby status.

Drawing on experience of aircraft/spacecraft crews provides a cross-section of operational problems for various mission environments. Understanding these allows devel of a highly integrated, closely coordinated ground/flight system configuration. Approach consists of: (1) develop baseline autonomy requirements based on Apollo astronauts and commercial/mil pilot experience and NASA/USAF low-cost mission requirements; (2) review requirements for existing ground facilities and applicability/availability to support low cost operations; and (3) evaluate Shuttle operational characteristics against baseline to define improvements in cost and effectiveness and generate revised autonomy requirements. The development/operational costs for the degree of onboard control to be provided will be evaluated against its impact on lower operational costs achieved by reduction/elimination of support personnel & launch/remote site facilities. Particular emphasis will be given to examining the launch & reentry phases for specific recommendations of meeting the reliable, low cost, operations objective. An alternate approach to be evaluated uses highly automated ground checkout facilities, to permit rapid vehicle ground status monitoring via RF link, while achieving reduction in both ground personnel staffing requirements and vehicle equipment complexity.

DEGREE OF AUTOMATION

Determine degree to which a rapidly responding automated system, high in redundant switching & self-checking features, maximizes man as a decision maker. Low cost, weight, developmental risk, high performance, & automation of low level monitoring & control functions is desirable.

Approach places heavy emphasis on analysis of decision elements & requirements compatible with hardware & software configurations, for both normal & emergency modes. Pilot preferences will be considered & reliance will be placed on the use of empirical techniques to substantiate quantitative & qualitative analyses. Major steps in study are: (1) define mission requirements, (2) establish hardware & software requirements, (3) establish crew decision & response requirements, (4) formulate candidate configurations & apply optimization techniques to verify functional hardware considerations, software logic & crew decision tree, (5) perform hardware & crew performance evaluation studies, (6) conduct selected empirical man/machine studies to verify conclusions, (7) determine relative merits of each candidate configuration based on (a) development & operational cost, (b) degree of development risk, (c) weight and size, (d) reliability, (e) performance efficiency & power requirements, (f) degree to which balanced design complexity minimizes adverse impact of design changes during development, (g) degree of crew autonomy with respect to on-board control & monitoring, (h) level of crew participation-decision functions, task characteristics & crew loading, (i) degree to which provisions for manual back-up capabilities satisfy critical failures & their effects, (j) crew performance measures - speed and accuracy , (k) crew characteristics - pre-requisite skills & knowledge, training requirements & crew size. This study will support the Redundancy Techniques tradeoffs by using previously developed "Automation for Reliability and Maintenance" (ARM) methodology. This will provide means to derive balance among manual and automatic redundancy switching and in-flight module replacement.

SENSOR AND ACTUATORS

Integration of sensors & actuators into avionics sys requires evaluation of: (a) digital vs analog implementation of operational modes; (b) flight safety equipt integration; (c) input & output signal characteristics; (d) operating power; (e) control reqmts; (f) reliability; & (g) redundancy & multi-functional sensors.

(1) Identify & analyze all safety-critical functions involving sensors & actuators (e.g., aerodynamic cruise stab. aug, boost, rendezvous & re-entry); (2) define sensor & actuator characteristics; (3) investigate & trade-off central computer sampling rate ops vs conventional analog implementation; (4) establish baseline sensor/actuator config by analyzing control, data, & power reqmts; (5) trade-off extent of multiplexing capabilities fo data mgmt sys against sensor/actuator reqmts for control, failure detection & sequencing; (6) analyze multifunctional capabilities of sensors & actuators to meet necessary performance & redundancy reqmts.

SHUTTLE-GROUND COMMUNICATION INTERFACE

Define reqmts for, interfaces between ground facilities, comm satellites & shuttle for comm, data transmission & ground facility tracking.

(1) Review space station definition studies and shuttle mission reqmts; (2) evaluate existing & planned satellite systems for applications in shuttle-ground comm link; (3) review existing NASA, FAA, & USAF ground facilities; (4) review spectrum allocations, RFI & multipath environment; (5) establish shuttle interfaces & reqmts: (a) define voice, data transmission, & ground tracking functional interfaces; (b) select frequencies based upon compatibility with shuttle sys element interfaces, minimizing cost impact & allowing flexibility; (c) define performance interfaces by terminal coverage, directivity, modulation techniques, sensitivity, power, polarization ranging & tracking techniques, data rates, & bandwidths.

ANTENNA/RADOME STUDIES

Review mission profile, establish antenna radiation pattern requirements, establish preliminary antenna locations. For each location, determine requirements for high temperature materials, insulation, cooling/heating and deployability. Evaluate antenna/radome materials to withstand thermal and mechanical stress levels for launch, orbital, reentry, and suborbital phases of mission.

(1) Evaluate RF properties, thermal characteristics, strength stability, weight and reusability of materials, (e.g., pyrolytic boron nitride, silica fiber, foamed quartz); (2) compare use of new materials for radomes vs deployable/retractable antennas for cost, wieght, risk, etc.; (3) study methods of erection which minimize skin penetration area; (4) study antenna switching and automatic selection critieria; (5) select antenna/radome designs and locations compatible with system performance requirements; (6) perform selective radiation pattern tests to verify antenna locations and techniques; (7) identify necessary supporting research and technology.

CONFIGURATION & SEQUENCING CONTROL

Assess alternate auto/manual techniques in terms of cost, sys complexity, safety, weight, & reliability.

Grumman background in advanced man/computer systems integration (LM, F-14A & E-2C) & GE's computer-analytical simulations for determining crew loadings (Apollo & space station applications) will be applied to this study. The study will:
(1) establish criteria for degree of crew participation;
(2) determine configuration and sequencing control requirements based on mission profile, (3) define alternate man/machine implementations of these requirements, (4) evaluate alternatives against complexity of system, data management, displays and controls, pilot loading, required dynamic response and special instrumentation, (5) preliminary selection of best alternatives based on cost, system complexity, and crew considerations, (6) incorporate results into degree of automation study.

INTEGRATED DISPLAY & CONTROLS

Establish crew decision and control requirements, evaluate human factor considerations and consider multipurpose computer-operated displays providing both system status and flight-path information.

Preliminary analysis of mission and subsystem requirements indicates that more than 400 data-functions can be displayed on 4 computer controlled CRT screens. Data format and density studies in conjunction with crew task and time line analysis, and human factors consideration will validate the preliminary approach. Controls and displays concepts will be updated to minimize routine crew tasks consistent with best use of crew decision capabilities. Special study of safety critical (docking, reentry and landing) and emergency mode operation will be performed to evaluate the need for a dedicated function vs multi-function data entry keyboard. Data derived from the study will be in sufficient detail to substantiate and recommend a firm baseline approach for an integrated display and control subsystems.

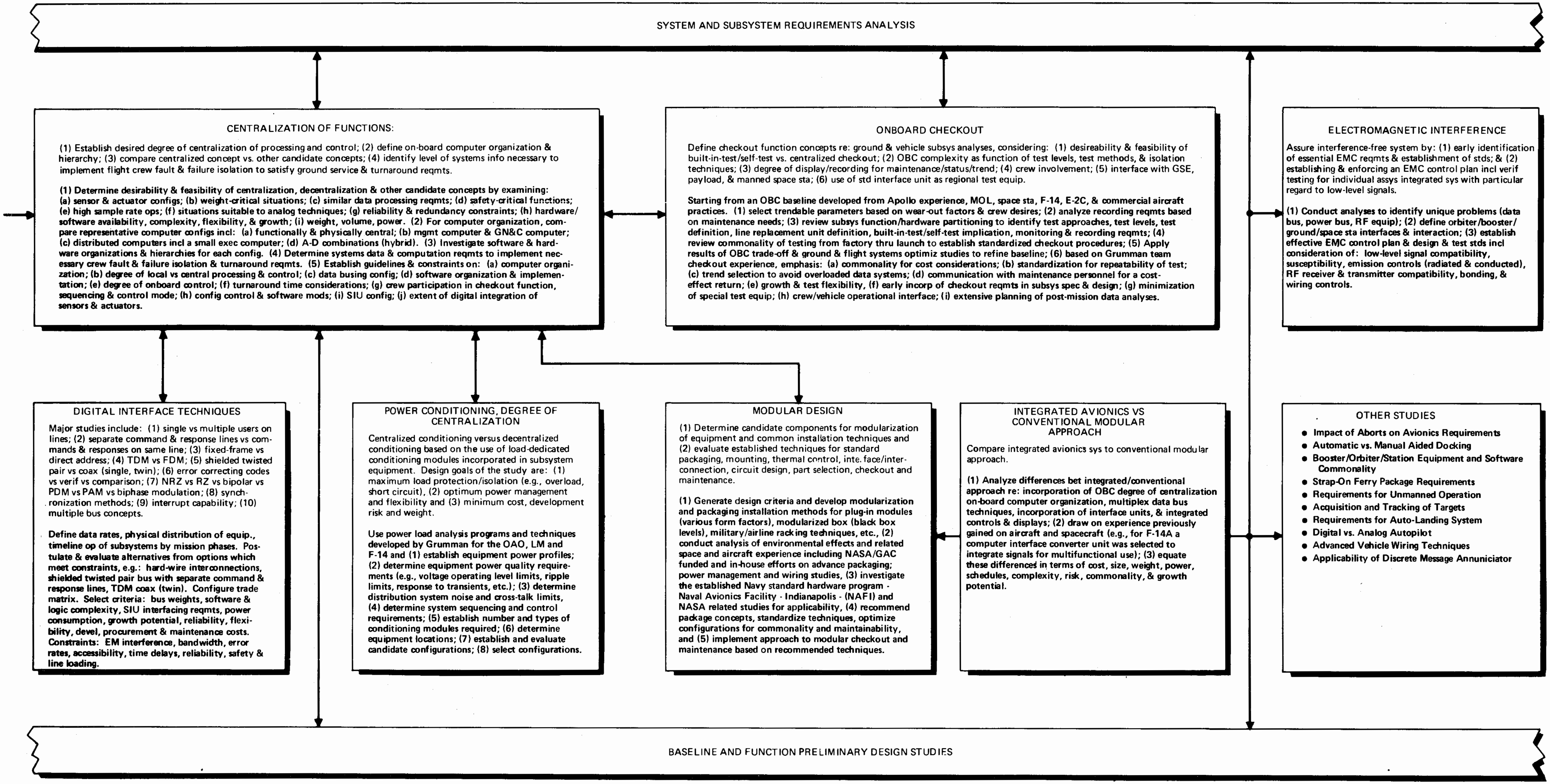
REDUNDANCY TECHNIQUES

Examine active vs. inactive redundancy techniques to achieve fail-operational design with intended goal of fail-op/fail op fail-safe.

Optimize weight, cost, schedule, vs. type of redundancy (active/inactive) with consideration given to circuit complexity, malfunction detection, performance degradation, & crew participation:
(1) based on mission profile active redundancy will be implemented for all time-critical functions (procedure adopted & followed on LM program);
(2) based on weight vs. reliability studies redundancy will be added to cover remaining fail-safe reqmts & to ensure fail-op wherever possible;
(3) an iterative process will be established:
(a) update candidate configs, (b) determine most critical functions & components (model each config), (c) assess reliability, (d) apply judgement & recommend redundnacy improvements to achieve fail-op reqmts.

BASELINE AND FUNCTION PRELIMINARY DESIGN STUDIES

Fig. 2-32 Approach to Avionic Tradeoff Studies (Sheet 1 of 2)



SYSTEM AND SUBSYSTEM REQUIREMENTS ANALYSIS

CENTRALIZATION OF FUNCTIONS:

(1) Establish desired degree of centralization of processing and control; (2) define on-board computer organization & hierarchy; (3) compare centralized concept vs. other candidate concepts; (4) identify level of systems info necessary to implement flight crew fault & failure isolation to satisfy ground service & turnaround reqmts.

(1) Determine desirability & feasibility of centralization, decentralization & other candidate concepts by examining: (a) sensor & actuator configs; (b) weight-critical situations; (c) similar data processing reqmts; (d) safety-critical functions; (e) high sample rate ops; (f) situations suitable to analog techniques; (g) reliability & redundancy constraints; (h) hardware/software availability, complexity, flexibility, & growth; (i) weight, volume, power. (2) For computer organization, compare representative computer configs incl: (a) functionally & physically central; (b) mgmt computer & GN&C computer; (c) distributed computers incl a small exec computer; (d) A-D combinations (hybrid). (3) Investigate software & hardware organizations & hierarchies for each config. (4) Determine systems data & computation reqmts to implement necessary crew fault & failure isolation & turnaround reqmts. (5) Establish guidelines & constraints on: (a) computer organization; (b) degree of local vs central processing & control; (c) data busing config; (d) software organization & implementation; (e) degree of onboard control; (f) turnaround time considerations; (g) crew participation in checkout function, sequencing & control mode; (h) config control & software mods; (i) SIU config; (j) extent of digital integration of sensors & actuators.

ONBOARD CHECKOUT

Define checkout function concepts re: ground & vehicle subsys analyses, considering: (1) desireability & feasibility of built-in-test/self-test vs. centralized checkout; (2) OBC complexity as function of test levels, test methods, & isolation techniques; (3) degree of display/recording for maintenance/status/trend; (4) crew involvement; (5) interface with GSE, payload, & manned space sta; (6) use of std interface unit as regional test equip.

Starting from an OBC baseline developed from Apollo experience, MOL, space sta, F-14, E-2C, & commercial aircraft practices. (1) select trendable parameters based on wear-out factors & crew desires; (2) analyze recording reqmts based on maintenance needs; (3) review subsys function/hardware partitioning to identify test approaches, test levels, test definition, line replacement unit definition, built-in-test/self-test implication, monitoring & recording reqmts; (4) review commonality of testing from factory thru launch to establish standardized checkout procedures; (5) Apply results of OBC trade-off & ground & flight systems optimiz studies to refine baseline; (6) based on Grumman team checkout experience, emphasis: (a) commonality for cost considerations; (b) standardization for repeatability of test; (c) trend selection to avoid overloaded data systems; (d) communication with maintenance personnel for a cost-effect return; (e) growth & test flexibility, (f) early incorp of checkout reqmts in subsys spec & design; (g) minimization of special test equip; (h) crew/vehicle operational interface; (i) extensive planning of post-mission data analyses.

ELECTROMAGNETIC INTERFERENCE

Assure interference-free system by: (1) early identification of essential EMC reqmts & establishment of stds; & (2) establishing & enforcing an EMC control plan incl verif testing for individual assys integrated sys with particular regard to low-level signals.

(1) Conduct analyses to identify unique problems (data bus, power bus, RF equip); (2) define orbiter/booster/ground/space sta interfaces & interaction; (3) establish effective EMC control plan & design & test stds incl consideration of: low-level signal compatibility, susceptibility, emission controls (radiated & conducted), RF receiver & transmitter compatibility, bonding, & wiring controls.

DIGITAL INTERFACE TECHNIQUES

Major studies include: (1) single vs multiple users on lines; (2) separate command & response lines vs commands & responses on same line; (3) fixed-frame vs direct address; (4) TDM vs FDM; (5) shielded twisted pair vs coax (single, twin); (6) error correcting codes vs verif vs comparison; (7) NRZ vs RZ vs bipolar vs PDM vs PAM vs biphase modulation; (8) synchronization methods; (9) interrupt capability; (10) multiple bus concepts.

Define data rates, physical distribution of equip., timeline op of subsystems by mission phases. Postulate & evaluate alternatives from options which meet constraints, e.g.: hard-wire interconnections, shielded twisted pair bus with separate command & response lines, TDM coax (twin). Configure trade matrix. Select criteria: bus weights, software & logic complexity, SIU interfacing reqmts, power consumption, growth potential, reliability, flexibility, devel, procurement & maintenance costs. Constraints: EM interference, bandwidth, error rates, accessibility, time delays, reliability, safety & line loading.

POWER CONDITIONING, DEGREE OF CENTRALIZATION

Centralized conditioning versus decentralized conditioning based on the use of load-dedicated conditioning modules incorporated in subsystem equipment. Design goals of the study are: (1) maximum load protection/isolation (e.g., overload, short circuit), (2) optimum power management and flexibility and (3) minimum cost, development risk and weight.

Use power load analysis programs and techniques developed by Grumman for the OAO, LM and F-14 and (1) establish equipment power profiles; (2) determine equipment power quality requirements (e.g., voltage operating level limits, ripple limits, response to transients, etc.); (3) determine distribution system noise and cross-talk limits, (4) determine system sequencing and control requirements; (5) establish number and types of conditioning modules required; (6) determine equipment locations; (7) establish and evaluate candidate configurations; (8) select configurations.

MODULAR DESIGN

(1) Determine candidate components for modularization of equipment and common installation techniques and (2) evaluate established techniques for standard packaging, mounting, thermal control, interface/interconnection, circuit design, part selection, checkout and maintenance.

(1) Generate design criteria and develop modularization and packaging installation methods for plug-in modules (various form factors), modularized box (black box levels), military/airline racking techniques, etc., (2) conduct analysis of environmental effects and related space and aircraft experience including NASA/GAC funded and in-house efforts on advance packaging; power management and wiring studies, (3) investigate the established Navy standard hardware program - Naval Avionics Facility - Indianapolis - (NAFI) and NASA related studies for applicability, (4) recommend package concepts, standardize techniques, optimize configurations for commonality and maintainability, and (5) implement approach to modular checkout and maintenance based on recommended techniques.

INTEGRATED AVIONICS VS CONVENTIONAL MODULAR APPROACH

Compare integrated avionics sys to conventional modular approach.

(1) Analyze differences bet integrated/conventional approach re: incorporation of OBC degree of centralization on-board computer organization, multiplex data bus techniques, incorporation of interface units, & integrated controls & displays; (2) draw on experience previously gained on aircraft and spacecraft (e.g., for F-14A a computer interface converter unit was selected to integrate signals for multifunctional use); (3) equate these differences in terms of cost, size, weight, power, schedules, complexity, risk, commonality, & growth potential.

OTHER STUDIES

- **Impact of Aborts on Avionics Requirements**
- **Automatic vs. Manual Aided Docking**
- **Booster/Orbiter/Station Equipment and Software Commonality**
- **Strap-On Ferry Package Requirements**
- **Requirements for Unmanned Operation**
- **Acquisition and Tracking of Targets**
- **Requirements for Auto-Landing System**
- **Digital vs. Analog Autopilot**
- **Advanced Vehicle Wiring Techniques**
- **Applicability of Discrete Message Annuniciator**

BASELINE AND FUNCTION PRELIMINARY DESIGN STUDIES

Fig. 2-32 Approach to Avionic Tradeoff Studies
(Sheet 2 of 2)

Stress analysis of components will lead to accurate weight estimates. We will consider: a) isolated gear assemblies with essential features of bogie or trail arm mechanisms for wheel spin-up, gear motion, spring-back loads and gear element loads; and b) the total vehicle aspects of landing using Grumman's three-dimensional landing and taxi (run-out) analysis to cover all phenomena important to landing, including effects of decelerating devices. Results from these analyses will refine energy-absorption requirements and establish support structure loads and time histories for overall vehicle response calculations. Emergency landing on land and water will also be investigated. Vehicle ground lines and critical turn-over and tip-back angles will be under continual review.

Table 2-9 Landing Gear Tradeoff Studies

Trade-off Studies	Expected Result
1. Compare a wheel/tire combination to other landing contact devices (skid, brushes, etc.).	Establish feasibility & merits of using other contact devices considering: • Ground handling • Development • Weight • Volume
2. Trade-off min acceptable surface touchdown conditions with various ldg sys designs by using dynamic & structural analysis.	Optimized ldg sys design considering: • Weight • Volume • Cost
3. Fully actuated ldg gear sys (extend and retract) compared to "extend only" (gravity drop) sys.	Establish degree of safety & reliability considering: • Ditching • Weight • Cost
4. Decel devices (drag chute, arresting hook, etc.) to augment wheel braking as compared to full braking capability in wheel brakes.	Establish degree of safety considering: • Reliability • Runway conditions • Maintenance • Weight • Volume
5. Environmental temp & vacuum effects on aircraft tires & substantiate by test (supported by IR & D).	• Establish need for, or degree of environmental control reqd.
6. Bearings, seals, lubes, coatings, & finishes for compatability with space, atmospheric, & ground handling reqmts.	Define areas of risk & establish a criteria for detail design

Sealing systems, methods of seal inspection, and door closure linkage mechanisms to assure proper seal pressure will be extensively studied. Alternative arrangements of hinge locations, door panel arrangements and landing gear folding geometry will be traded off for optimum sealing considerations.

2.3.4 Docking Systems

The Grumman baseline docking system is based on Apollo technology and pilot-controlled docking procedures. It includes a reusable docking mechanism, which permits any two space modules to dock, and a hard-docked interface that facilitates crew and payload transfer. Nose docking provides good visibility and minimizes cg offsets, but requires deployment of the nose cone. There are problems associated with the nose deployment concept but we are confident that with careful design of mechanisms, consideration for redundancy, and proper selection of materials, a reliable, safe system can be designed. The redundancy techniques employed will be similar to those used in primary flight controls. Moreover two alternate port locations, one on the vehicle and the other on the payload will be studied. Feasible docking means will also be considered. These will be traded off against the baseline and the docking requirements.

Fig. 2-33 shows the baseline docking configuration and the present approach to the hinge, deployment, multiple perimeter locks, and sealing mechanisms. Consideration will be given to the thermal distortion effects on the nose/body interface contours and methods to achieve and confirm correct interface sealing will be extensively studied. Parallel studies will be made on systems that do not require nose deployment.

Future mission studies indicate that the shuttle may be required to dock to passive spacecraft or to modules with large cg offsets. An automatic approach and docking system may prove the key to more flexible operations by providing consistently accurate guidance and post contact stabilization. Our study will examine the relationship of the automatic flight control system, the docking mechanisms, and the dynamic and stabilization requirements of the orbiter docked to other space modules. Payload handling studies will provide focus

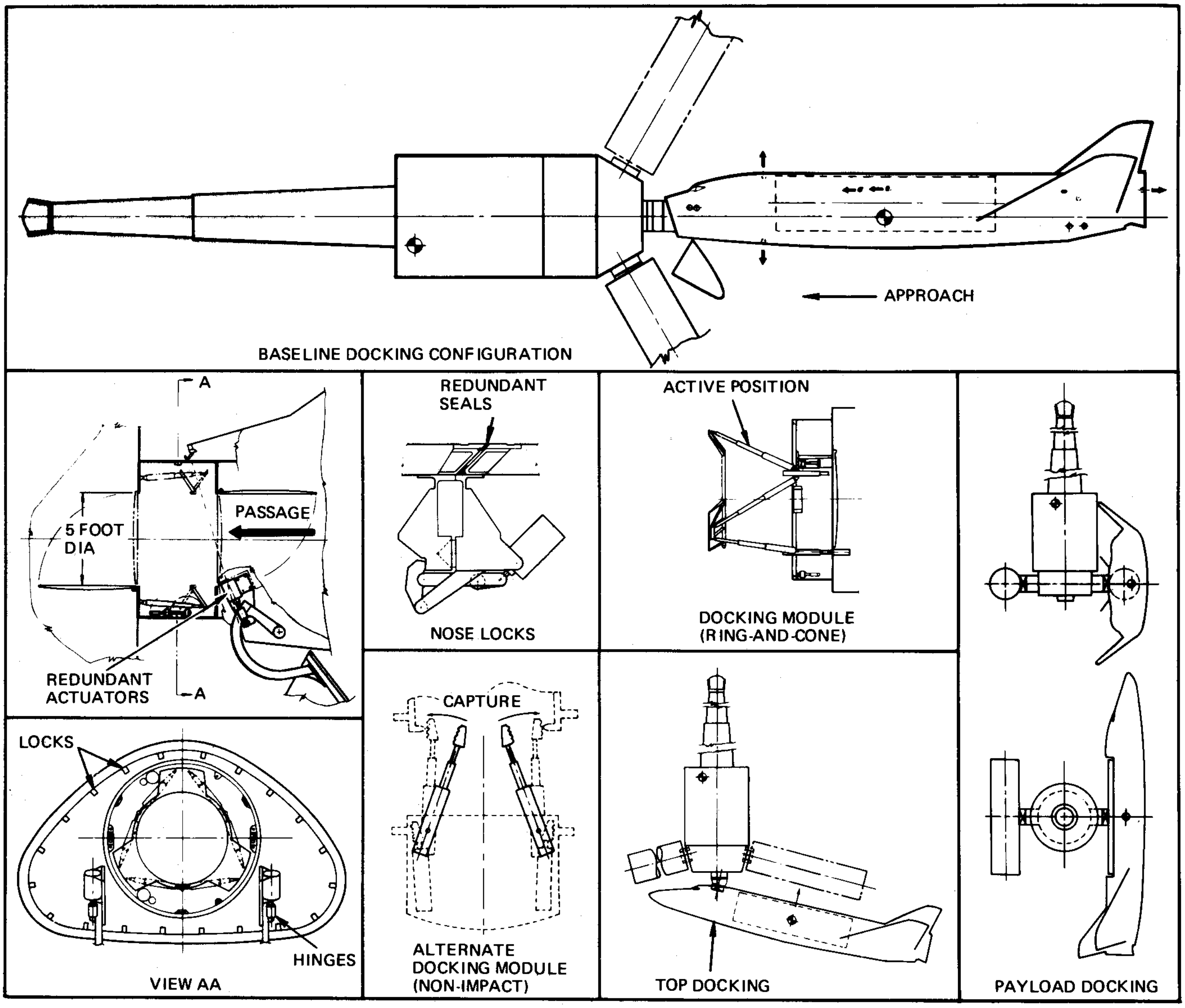


Fig. 2-33 Baseline Docking System

for the study and a basis for judging the desired docked position for crew and payload interchange, supplemented by studies to establish pilot display and control requirements. The study outline, Fig. 2-34, shows the system interactions and tradeoff studies that will be made. We will define an approach guidance system, together with docking mechanisms and a stabilization system that will control the spacecraft during docking shock transients and for longer term docked periods. The docked interface will be optimized considering the loads and stabilization of the configuration.

Initial docking contact conditions, plus contingency limits, will determine docking loads and spacecraft reactions. These conditions will be defined for both automatic and pilot controlled approaches using manned simulation data and digital computer analyses, respectively. Loads and reactions will be computed using impulse-momentum and energy balance principles for early studies. A digital computer program will define transient spacecraft motion and mechanism energy absorption requirements. The study being performed by Grumman for NASA (Contract NAS 9-10247), will be useful in analysis of space base docking transients and control system interactions.

The Phase B study will generate cost and technical data permitting the selection of the optimum ways to dock the shuttle, including the selection and preliminary design of controls and mechanisms for the

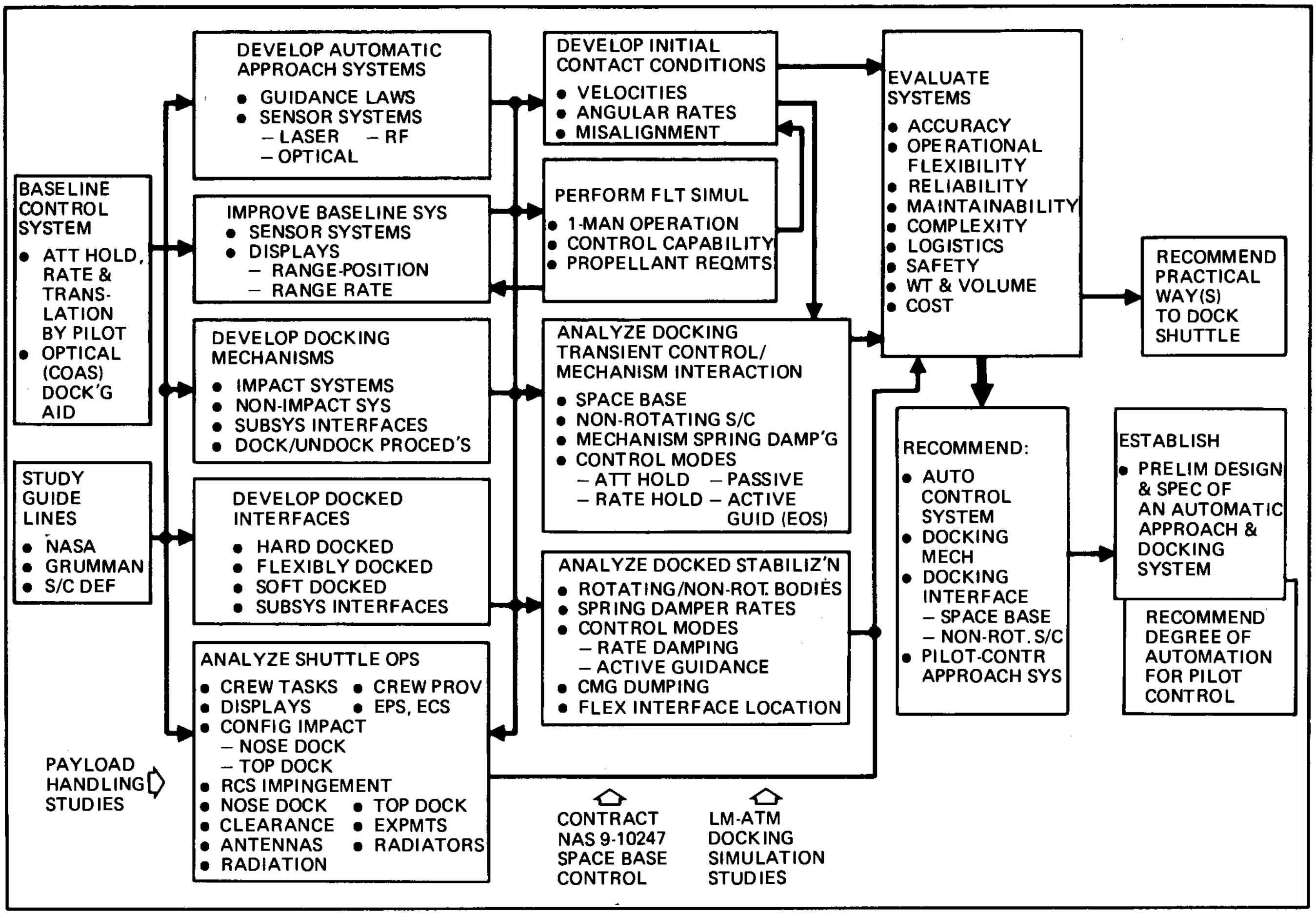


Fig. 2-34 Docking System Study Outline

docking system. It will also assess the desirable degree of automation in a less complex pilot controlled system to assure one-man operation.

2.3.5 Environmental Control & Life Support Subsystems

Grumman's study approach provides subsystem growth with minimum impact on hardware cost. Specifically, modularization will be extended to subsystem elements whenever practicable. This approach can be effected with today's technology, and maximum use of Grumman's space and aircraft experience will be made.

The following sections briefly describe the baseline system and indicate major areas to be studied within each section. Fig. 2-35 illustrates the interrelationship between sections.

ATMOSPHERE REVITALIZATION SECTION (ARS) – The function of the ARS is to remove CO_2, trace gas contaminants, and excess humidity from the cabin atmosphere. Because of the large possible variations in crew/passenger size with each mission, the design lends itself to modularization of a complete package. Baseline module is a four man, seven day system with replaceable LiOH cartridges for CO_2 removal. Identical plug-in units are added to the payload compartment as required to handle up to 14 men missions. Major studies required in this section are: (a) optimization of module size (number of men per module) for low cost and weight, (b) for CO_2 removal system, trade-off individual expendables (LiOH) in each module vs. integrated regenerative (molecular sieve) system, (c) evaluate alternative methods (inertial, static, desiccant) to remove excess humidity, (d) trade-off incorporating emergency functions into each module (suit circuit) vs. a central purge system.

THERMAL CONTROL SECTION – This section consists of a heat rejection loop and an internal heat transport loop connected by an interface heat exchanger. The internal loop, using inhibited water

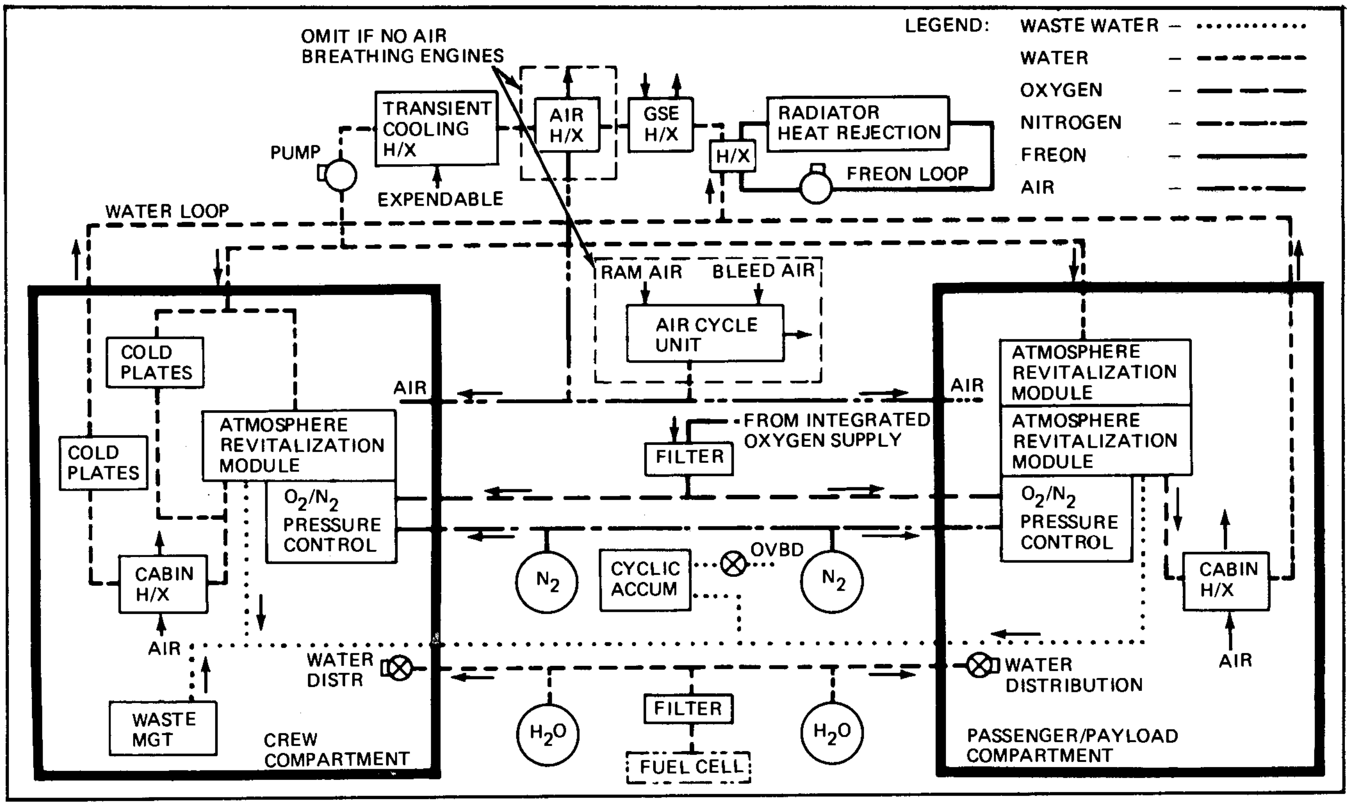


Fig. 2-35 Orbiter EC/LSS Baseline Schematic

as the coolant fluid, is functionally complete in each compartment. Shirt-sleeve temperature control is maintained by modular cabin fan/heat exchanger combinations which are added to the internal loop in the payload compartment as required for different passenger loads. This concept will be evaluated in conjunction with an alternate approach of active control of cabin wall temperature.

On-orbit heat rejection is provided by radiators integrated into payload doors or on upper fuselage surface and sized for maximum load mission. A valve stagnation control system is used to provide maximum turndown ratio. Studies will be conducted to trade-off this system with a regenerative control. Grumman will study the problem of radiator coating degradation due to reentry heating and will concentrate on either utilizing a replaceable material such as silvered teflon or locating the radiators on the inside of the cargo doors for reentry protection. Tradeoffs will be conducted to determine the frequency of coating repair as a function of radiator size and coating degradation.

Baseline thermal control for transient and atmospheric phases will utilize thermal inertia on ascent, expendable cooling during reentry, and an air cycle during the high heat soakback subsonic cruise phase. If air breathing engines are omitted from the orbiter, the air cycle will be replaced by expendable cooling. The trade-off study will consider expendable cooling, fuel heat sink, air cycle and thermal inertia for each of the non-orbit phases.

Ground cooling after engine shutdown is accomplished by attaching a GSE cooling cart to a heat exchanger in the internal water loop. Studies will evaluate on-board cooling systems (such as a gas turbine compressor feeding the air cycle system) to eliminate GSE dependancy.

The Booster heat rejection system uses thermal inertia followed by air cycle operation for cruise.

CONSUMABLE STORAGE & SUPPLY SECTION – Oxygen requirements for baseline configuration are provided from integrated subsystems tankage (EPS/ACPS/OMS/PROPULSION) to minimize contingencies and residuals and provide flexibility to meet variations in usage. Although nitrogen is provided from high pressure tanks in the baseline, cryogenic storage will be studied for increased requirements resulting from longer missions, added cabin repress cycles, and possible wheel well and/or engine bay pressurization. Detailed analyses will be done to define the atmospheric pressurization, composition control and monitoring design.

WATER MANAGEMENT SECTION – Water Management Section collects, stores, and delivers water for metabolic consumption and auxiliary heat rejection. Least weight is obtained by recovering only fuel cell water with no reclamation of metabolic condensate. Experience gained on LM and Grumman's in-house Biotechnology AD efforts will be applied to define a design ensuring adequate potability and sterility. Tradeoffs of regeneration systems to provide additional water for crew hygiene for the longer duration orbital mission will also be evaluated.

WASTE MANAGEMENT SECTION – The baseline configuration incorporates an active system providing: a) collection and disposition of urine, b) collection, drying, and storage of solid waste with microbial control. In defining design details of this system, emphasis will be placed on both technical objectives of performance and acceptability to crew members.

2.3.6 Power System

The integrated power systems for the booster and orbiter, shown in Fig. 2-36, provide electric and hydraulic power for both vehicles, with common equipment, based on existing hardware. The power system for Design 518 is based on Fail-Ops/Fail-Ops/Fail-Safe criteria for the electronic equipment such as converters and inverters, and Fail-Ops/Fail-Safe criteria for the nonelectronic equipment such as fuel cells, batteries, APU's, generators, and pumps. The fuel cells supply electrical power dur-

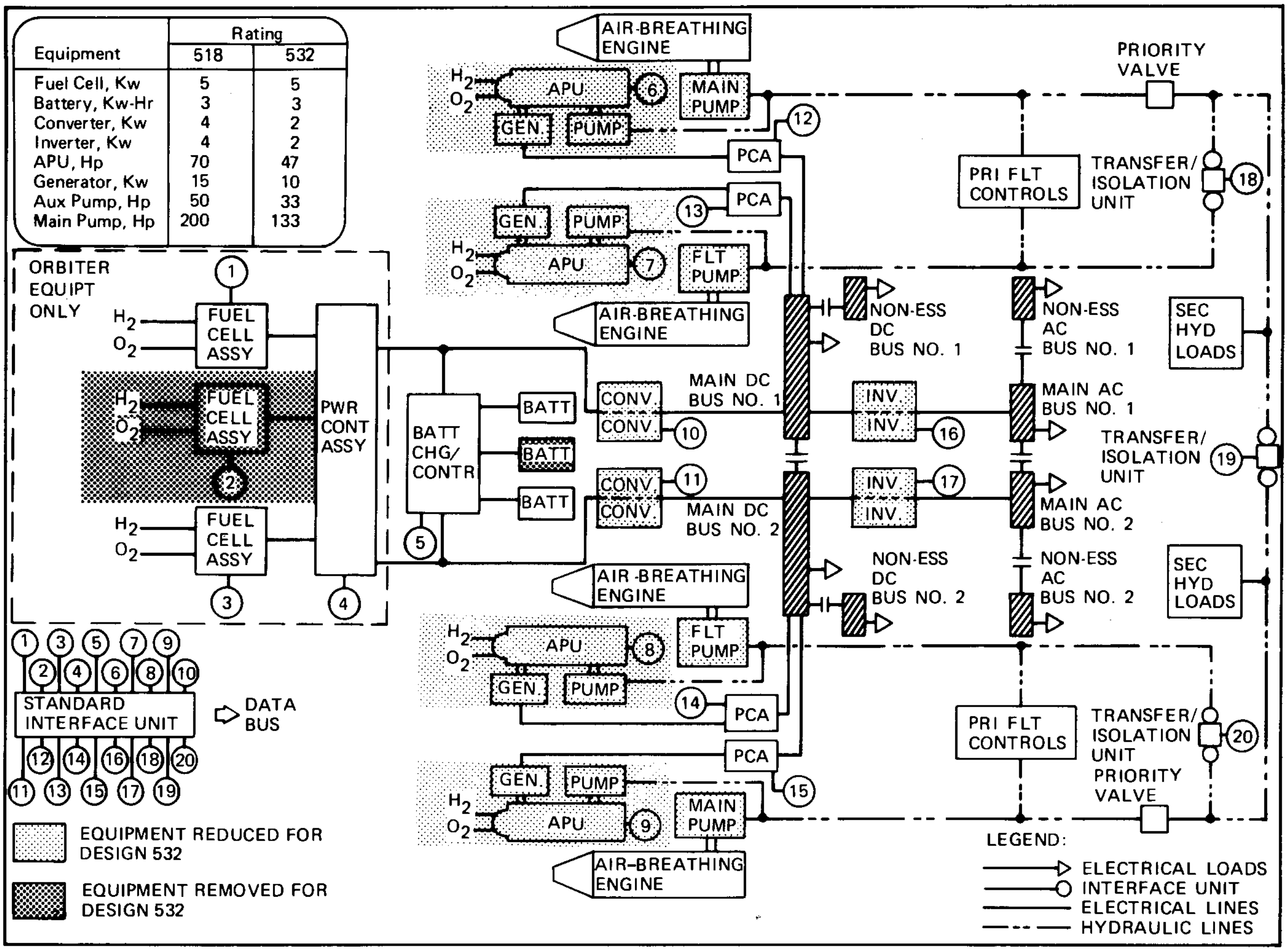


Fig. 2-36 Integrated Power System

ing the orbital phase of the orbiter mission, the APU's and engine-mounted pumps supply electric and hydraulic power during all transitional phases of both the orbiter and booster missions, and the batteries provide peak and auxiliary power during all phases for both vehicles. Ground power is supplied either by the APU's or by GSE through electric and hydraulic interfaces. The H_2 and O_2 reactants used by the fuel cells, APU's, and ACPS are stored in common tanks.

The fuel cell design is based on the low-temperature, capillary matrix type developed for the MOL and AAP; the APU design is based on the cryogenic-fueled, turbine-driven unit developed for the Dynasoar; the brushless dc generator is similar to the F-14 emergency generator; the pumps are of conventional design. Electric power distribution is based on aluminum feeders and solid-state control equipment, and hydraulic power distribution is based on welded/brazed transmission lines and encapsulated control equipment.

The power system for Design 532 is based on Fail-Ops/Fail-Safe criteria for the electronic equipment and Fail-Safe criteria for the nonelectronic equipment. The system is designed to use modified existing hardware of the same type as that used in Design 518, for minimum cost and development risk. The system weight is lower because of the smaller number and/or ratings of the equipment consistent with the lower reliability criteria and power requirements established for the design. The operation of the system is exactly the same as that for Design 518 including the on-board and GSE interfaces.

During the Phase B study, power profiles will be established for the integrated electric/hydraulic loads for both the booster and orbiter missions. These will be used as a basis for system optimization. Table 2-10 summarizes the system and equipment tradeoff studies planned for Phase B.

2.3.7 Crew & Passenger Accommodations

Grumman has applied its extensive aircraft/spacecraft crew integration experience, supplemented by Eastern Airlines' commercial operations, to establish a baseline configuration that meets multimission requirements. The design goal is to provide a safe, efficient, versatile environment for 2 crew members, 12 passengers and those services and devices required to achieve a self-sustaining, 7-day mission.

Design 518 (see Fig. 2-37) meets these design goals with a single pressure vessel divided into three compartments, each capable of maintaining pressure during emergency or EVA operations. Highlight features are:

- Forward compartment containing two man shirtsleeve flight station, (See Fig. 2-38) complete with fully integrated computerized displays and controls, powered seat/couches, external door, internal hatches and windows providing excellent vision during rendezvous/docking and landing
- Aft compartment containing two cargo handling passengers/system monitors, external hatch, GFE hardware and donning/doffing station. This volume can be depressurized during EVA without disturbing flight crew or IVA operations

Table 2-10 Power System Tradeoff Studies

Study	Description and Approaches	Impact
Electric distribution voltage	Optimize elec distr voltage for conductor/control ratings within 80 to 300 VDC range	Minimum system weight
Hydraulic distribution pressure	Optimize hydr distr pressure for line/actuator ratings within 3000 to 6000 psi range	Minimum system weight
Long-life vs. conv fuel cell	Reduce electrolyte loss by optimum membrane design & contaminant level by chemical scrubbers	Reduce costs (refurbishment)
Adiabatic APU vs. isothermal APU	Optimize operating temp, no. of turbine stages & reactant consumption for specific mission profile	Reduce APU wt & increase life
Sec batt vs. APU for peak loads	Eliminate batteries & chargers by extending APU utilization	Reduce system weight
DC vs. DC/AC vs. AC elec generators	Use F-14 high-flux magnetics & oil-spray cooled generator design with integral rectifiers	Reduce weight & developmt risk
Dual flow/press vs. conv pump	Reduce stress on hydraulic pumps & system by using combined high/low or variable pressure pumps	Increase pump & system life

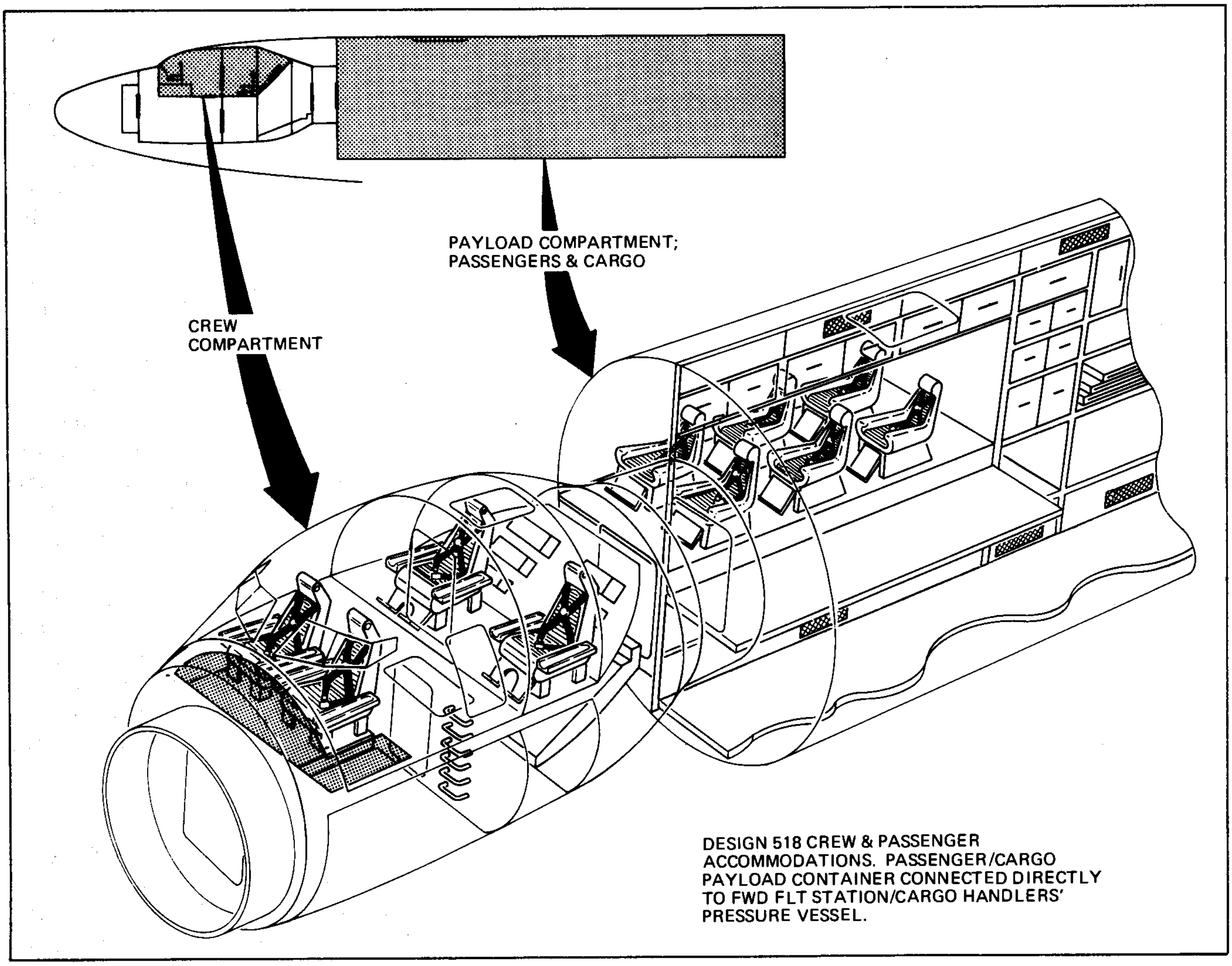


Fig. 2-37 Design 518 Crew & Passenger Accommodations

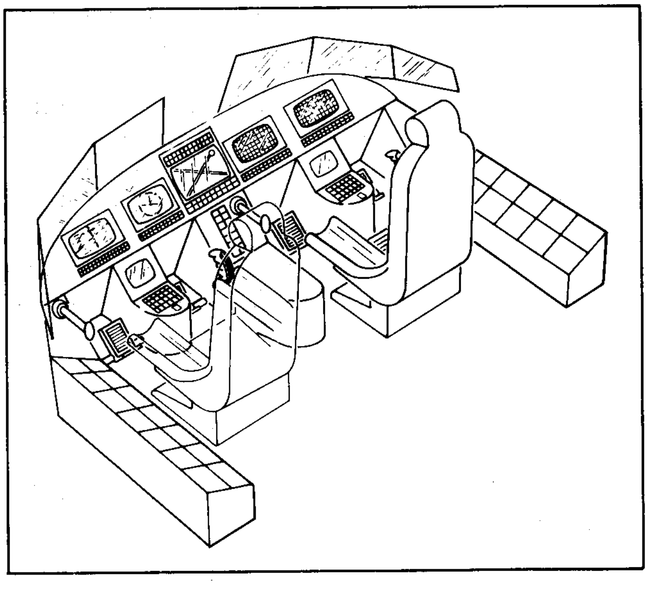


Fig. 2-38 Typical Booster & Orbiter Flight Station

- Lower compartment containing avionics, ECS, food, and waste management and direct passageway for IVA transfer of passengers and limited cargo
- The payload container, configured to accommodate 10 passengers and varied cargo sizes and arrangements, is connected directly to the forward tri-compartmented pressure vessel, thus deleting need for an interconnecting tunnel

Design 532 is similar to Design 518 with the following exceptions:

- Minimum sized pressure vessel for two crew men only
- Two compartments, upper flight deck and lower IVA transfer deck
- EVA, donning/doffing performed at flight station

The booster pressure vessel is similar to Design 532 orbiter except that there is no requirement for EVA, docking interface, food and waste management.

ACCOMMODATION TRADES – Designs resulting from system, subsystem, mission analysis, human factors, and safety engineering requirements will be exercised through extensive tradeoff studies, and incorporated into soft mock-ups for review and evaluation. These design iterations and undesirable features are uncovered early in the development program, corrected or modified at low cost.

Tradeoff studies will include variations in:

- Flight crew placement, position and orientation
- Normal vs tilted flight station
- Total visibility envelope requirements as constrained by glass size and weight, thermoaerodynamic loads and external protective shields
- Panel geometry, size, arrangement, and display techniques
- Type, location, and actuation of primary and secondary controls: side arm vs center-mounted attitude controller, 2-axis vs 3-axis attitude controller and integrated vs dedicated controls
- Crew and passenger seat/couch configuration, adjustment and motion
- Permanent cabin seating vs "palletized" accommodations in the payload container
- Provisions and location for two cargo handlers/ systems monitors
- Location and installation of avionics, ECS and GFE hardware
- Types and preparation of food and waste management systems
- Location, size, operation of normal and emergency ingress/egress hatches and tunnels
- Interface and operation procedure for PAD ingress/egress
- Requirements and provisions for EVA interface
- Compartmentalization for damage control and isolation
- Traffic pattern for IVA transfer of passengers and limited cargo
- Mobility aids and self help devices
- Internal/external illumination systems
- Payload container configuration for passengers and cargo

2.3.8 Launch System Interfaces
Ground and flight system functional interface definition and identification of physical connections will be established for all prelaunch and launch operations consistent with the objectives to: a) ensure the safety of pilot, crew, and passengers; b) minimize launch pad service lines and pad checkout requirements; c) launch from a standby status within 2 hours; d) liftoff within a 60-second launch window, and e) minimize vehicle/systems sensitivity to weather conditions during checkout and launch.

The definition of interface requirements will be coordinated with the ground and flight system optimization studies described in paragraph 2.1.12. Interface identification will include all physical connections for structural support and stabilization, propellants, fluids and gases, power, communications, control, and checkout. The combined experience of team members (Grumman, General Electric and Aerojet) and their knowledge of total launch complex interfaces (successfully demonstrated in prior on-time site activation and successful launch operations from KSC) will be applied to this study. The propellant loading requirements for Design 532 makes maximum use of existing facilities, GSE and technology available at KSC. The defined launch system interfaces for the candidate configuration will be documented in preliminary interface control documents (ICD's).

2.3.9 Flight Control System (FCS)
Grumman's current LM and extensive aircraft experience (particularly advanced aircraft like F-14 and A-6) combined with General Electric's aircraft autopilot/Polaris, Poseidon booster guidance experience and Northrop's HL-10, M2-F2 lifting body experience, provides the key needs for space shuttle flight control system development. We will determine the FCS requirements, subsystems and interfaces by conducting the analysis requested.

The baseline FCS (see Fig. 2-39) which is the point of departure for the Phase B study, is functionally the same for Designs 518/532 booster and orbiter configurations. It provides aerodynamic control through functionally redundant, split control surfaces. Each surface is driven by dual-tandem hydraulic actuators. Each actuator receives power from two (of four) independent hydraulic supplies and is controlled by four electrohydraulic servo valves. Power transfer units provide rapid switchover in the event of engine/pump failures in any of the four hydraulic systems. Aerodynamic control surfaces are positioned by the central computer which provides stability/command augmentation using passive adaptive filter techniques. ACPS control

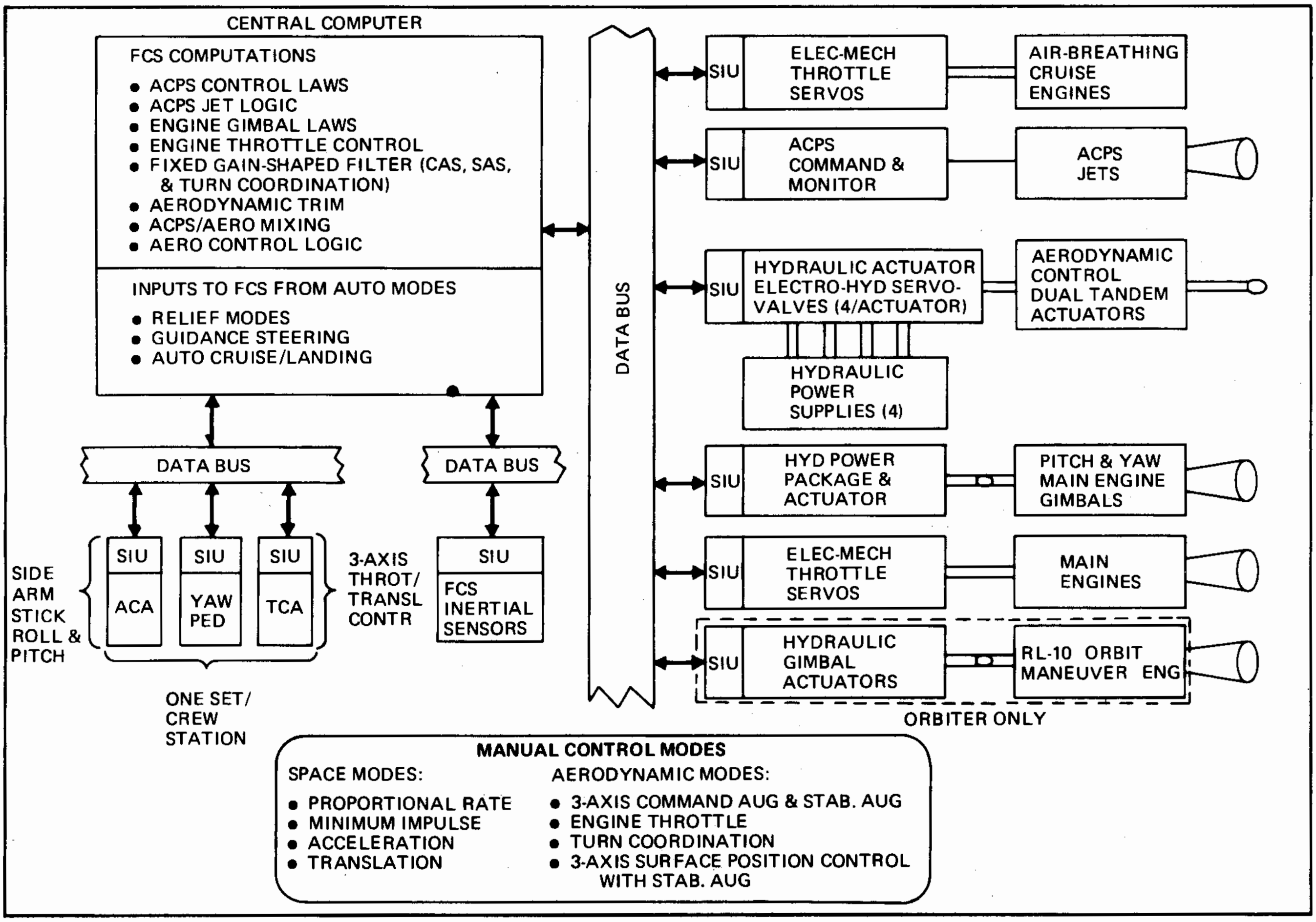


Fig. 2-39 Baseline Flight Control System

uses Apollo digital autopilot techniques. Engine gimbal/throttle control is provided by high rate, linear control laws. CG tracking on launch is accomplished by simultaneous gimballing of all engines. Roll control is achieved through differential engine deflections. Integrated pilot controls are provided for aerodynamic and space control. A two-axis sidearm controller provides pitch and roll control with pedals used for yaw. A three-axis controller is used for ACPS translation and cruise engine throttling. All manual controls are redundant, fly-by-wire type. The Grumman FCS baseline includes the best features derived from aircraft/spacecraft experience. Conservative, accepted and proven techniques are used for vehicle control throughout the mission.

FCS study tasks are directed at evaluation of baseline system and trades with promising alternate approaches having potential for performance, reliability and cost benefits. Flight control system performance analyses (e.g., stability, duty cycle, etc.) are discussed in Subsection 2.1.5. Major tradeoff studies are:

- Entry control – baseline inertial vs Temperature Rate FCS and mixed systems. Aero/ACPS blending for best power/propellant economy and performance within vehicle thermal/structural constraints.
- Pilot controls – evaluation of baseline vs alternate pilot controls (e.g., separate 3-axis ACPS controller and stick for aerodynamic control) for best handling qualities, safety, and reliability
- Alternate mechanizations of electrohydraulic actuation/control surfaces/ACPS and engine gimbal/throttle arrangements (e.g., multiple parallel surface actuators, orthogonal/nonorthogonal ACPS engine geometry)
- Computational trades to minimize data bus rates and computation time associated with high frequency FCS computations.

Tradeoff study results and preliminary FCS design will be evaluated and verified on FCS part task reentry fixed base simulator as discussed in Subsection 2.1.5. FCS study tasks provide evaluation of baseline configuration and promising alternates to obtain a firm and thoroughly verified preliminary FCS design.

2.4 CONFIGURATION PRELIMINARY DESIGN

At Phase B go-ahead, our teams for Designs 518 and 532 will begin configuration development studies leading to a single design selection with NASA at the end of six months. The selected design will then be subjected to an indepth design activity for the remaining five month period. The configuration drawings and layouts provide a focal point for the supporting engineering, producibility, reliability/quality, maintainability, safety and operations groups. To attain meaningful cost, weight and performance data plus the necessary design confidence related to program risk, the design team will use wind tunnel and laboratory scale tests, soft mockups, various engineering aids, and the proposed major structural test program to support their studies. The major structural test program is a key element in achieving the design confidence necessary to start Phase C/D.

All the drawings required to support the analytical studies previously covered in Section 2 will be developed.

The following subsections describe the principal activities related to Phase B space shuttle configuration development and definition.

2.4.1 Configuration Development

During the first three months, the design activity will be focused on design sensitivity studies of the orbiter/booster system which have a major impact on configuration size, weight, performance, and cost.

At go-ahead, Designs 518 and 532, together with their baseline requirements and additional NASA furnished requirements, will be studied with respect to the technical drivers affecting vehicle payload and performance growth capabilities. Delta V apportionment between orbiter and booster plus orbiter return cruise capabilities, for example, affect vehicle mass fractions, deliverable payload and program costs. The scar weight imposed by orbiter air breathers will be examined relative to the operational gain versus the penalty for self-ferry strap-on engines. Configuration penalties associated with propulsion Isp, and orbiter cross range will also be determined as it affects tank design, engine installations, thermal protection systems and low speed handling qualities. At the end of the third month, these studies, together with the other systems and designs analysis tradeoffs, will have been completed in sufficient depth to establish, with NASA, a requirements freeze for the operational concepts applicable to Designs 518 and 532.

The second three months will be focused toward developing Design 518 and Design 532 to the point where a single design selection can be made with NASA to confidently proceed with further definition.

Using the updated requirements, both designs will undergo configuration development tradeoffs, as an integral orbiter/booster system, to establish baseline design concepts for vehicle structure, thermal protection, thermal control and internal arrangement of all subsystems. The results of wind tunnel testing, laboratory materials and structures testing, and flight characteristics simulation program and window configuration mockup studies will be applied as data becomes available. Both designs will be progressively refined as the remaining sizing studies are completed. Vehicle weight estimates will also become more accurate throughout the refinement process. By the end of the sixth month, both designs will be defined to the same depth to allow selection of the best features of Design 518 & 532 for the final design activity. The required preliminary interface control drawings will be prepared for both designs. Thus, the proper requirements will be available immediately after the single design selection is made with NASA.

2.4.2 Configuration Definition

At midpoint, a single space shuttle design will be selected and intensive in-depth design activity will continue, focused on the selected orbiter and booster, their operational capabilities, limitations, supporting ground systems, major ground facilities and equipments. At the end of Phase B, complete CEI specifications (Part I) will be available and all flight hardware and ground equipment will have been defined to levels 6 and 5 (assemblies and subsystems) respectively. Accordingly, greater emphasis will be placed on ground equipment design than during the first six months. In addition, new hardware and software will be identified as well as any modifications or additions to existing flight hardware, ground facilities and ground equipments.

During this period, extensive wind tunnel, flight control simulation, and laboratory scale test data will become available to confirm weight and design performance analysis. Results from the major structural test program will also become available, together with results of the forward pressure vessel mockup study.

Grumman F-14 experience has shown that highly confident weight estimates can be attained from appropriate in-depth loads and stress analysis reinforced with related test data.

The supporting preliminary design analysis will describe: vehicle performance, stability and control, and flight mechanics for all mission phases; vehicle structure, thermal protection, thermal control and all other orbiter and booster subsystems; supporting ground systems, facilities and equipments needed for ground operations and flight operations; logistics support; system safety and simplicity; orbiter/booster producibility, reliability and quality assurance; and orbiter/booster growth potential.

Orbiter and booster design drawings will include: three-view drawings defining major external dimensions, contours, primary systems and features; layouts defining structural arrangements, major structural assemblies/subassemblies/components, major joints, typical details and critical attachments; inboard profiles defining subsystem installations and clearances, crew station arrangement and provisions, passageways, hatches, windows and orbiter/payload interfaces; layouts defining size, actuation limits, and features of major mechanical systems, mechanisms, actuators, and devices; and layouts and drawings defining features of major sites, major facilities/facility subsystems, and major ground equipment/equipment subsystems.

As in the first six months, we will continue to exchange required data with the engine development studies. As interim preliminary design will be presented to NASA at the eight-month review together with the preliminary CEI specifications (Part I), required plans, and preliminary draft of the final Phase B report (Part II). Subsequent recommendations plus newly available test data will be included during the final design activity leading to the eleventh month presentation.

2.4.3 Design Reviews

At Grumman, design reviews occur nearly every day. The project engineer performs these reviews on a continuous basis, often with both study director and upper management participation. Mr. I. Grant Hedrick, Senior Vice President for Technical Operations, is a frequent participant in these sessions. We expect him and our other senior officers to continue this practice in Phase B. However, in order to monitor control package costs, schedules and technical effort, we will hold control package reviews a minimum of once every two weeks, In addition to these in-house reviews, we will also meet with NASA for the required informal and formal design reviews.

2.4.4 Configuration Development Testing

A comprehensive Phase B test program will establish the confidence needed to initiate Phase C/D. Our program will meet that goal by providing supplemental data in those areas where in-depth analysis is insufficient to establish technical feasibility and where existing data are not applicable. As previously described in the noted subsections, the Phase B testing will include: wind tunnel tests and flight control simulations, structural tests, thermal protection system tests , and the proposed major structural test program (Subsections 2.1.5, 2.2.1, 2.2.3 and 2.5.1, respectively). It is anticipated that additional data will be available from related Grumman SR&T programs described in Subsection 4.2.3. This subsection also describes Grumman's related current Government funded hardware programs which will provide information and data of value to the space shuttle, as well as similarly related company R&D and government funded hardware programs at General Electric, Northrop, and Aerojet-General. As noted in Subsection 2.1.4, Eastern Airlines operations/maintenance data will also be available for the study.

2.4.5 Mockups & Models

Full scale soft mockup and engineering aid models provide a very effective tool for respectively evaluating and depicting critical areas of the space shuttle configuration.

Full scale soft mockups, supporting the effort of Subsection 2.3.7, will be used to validate man-machine interfaces for the orbiter and booster crew compartments. Since both vehicles have similar crew compartment designs, only one set of mockups are required. Two mockups will be constructed: the first to study cockpit window configuration visibility; and the second to study forward pressure vessel internal arrangements (Fig. 2-40). The forward pressure vessel will also be designed to allow human factors and safety studies in normal launch and post landing attitudes.

At the end of Phase B, Grumman will provide to NASA, a 1/96 scale engineering aid display model of the orbiter and booster featuring: major external aerodynamic lines, flight control system geometry, landing gear, engines, payload modules, normal launch arrangement, major ground launch facility and support equipment.

2.5 CONFIGURATION PRELIMINARY VERIFICATION

Eleven months after the start of Phase B, Grumman will deliver to NASA the wind tunnel models used for the testing described in Subsection 2.1.5,

2.5.1 Structural Test Program

Tests of large or full-scale structures will be proposed by the third month in the critical design areas such as cryotank shells, tank thrust and drag structures, radiative heat shield and substructure assemblies. The types of test articles which might be proposed for these tests are illustrated in Fig. 2-41 and the test objectives would be as follows:

- Filament-Wound Cryotank – Early testing of a large-scale tank fabricated using pre-production techniques will verify the weight, producibility, and fail-safe characteristics of this concept and will permit the design of dependent structure to proceed with maximum weight effectiveness
- Tank Thrust and Drag Structure – The complex load paths between the tank skirts, the engines and the interstage attachments should be verified by combined load and temperature tests. The conditions to be evaluated will range from the cryotank equilibrium state at booster ignition to the base heat soakback case at orbiter engine cutoff
- Orbiter Body Heat Shield and Cryotank – The leading edge region of the orbiter body contains sharp thermal gradients and heat shield transitions combined with radiative and conductive cryotank coupling. The tests will evaluate the effects of reentry heating with cold tanks after abort and with warm tanks after the full orbital mission. This test may also provide a comparison of the performance of rigidized insulation and metallic heat shields in the critical areas of producibility, weight and thermal performance
- Orbiter Nose Cap – The nose is the most desirable position for forward looking antennas and sensors and will fold to uncover the docking adapter. Tests will be proposed for the nose cap and its supporting structure for combined load and heating profiles throughout the range of stagnation point locations. These tests will evaluate the structure and heat shield performance and the effects of deformation on antenna and sensor accuracy.
- Large-Scale Fin Section – A tapering cantilever structure is characteristic of surfaces combining the different TPS elements used for leading edges and upper and lower surfaces. Testing of a large-scale section for repeated heating, bending and torsion conditions will provide data on cumulative damage and will verify producibility and weight.

Test capabilities exist for spectrum fatigue loading combined with radiant heating up to 2 megawatts at GE, Philadelphia, and to 1 megawatt at Grumman, Bethpage. Both facilities can store and transfer LOX and LN_2 and the Grumman Calverton site has LH_2 handling capability.

The large-scale structural test programs will be proposed for supplemental funding in priority order with separate test definitions and costs for ease of evaluation in accordance with DRL Item No. 7.

2.6 SUPPORTING RESEARCH & TECHNOLOGY

Success of the space shuttle system will be enhanced by technology improvement. Technology improvement is needed to gain the confidence necessary to proceed to Phase C and D, and to reduce the development and operational costs of the final system. We have an ongoing shuttle Supporting Research and Technology (SR&T) Office, which is an integral part of the shuttle organization. Its main function is to bring together the talent and the information to identify and define technology improvement that is necessary to the success of the shuttle system. One of the key sources for this information will be the problems uncovered by the shuttle technical personnel during performance of

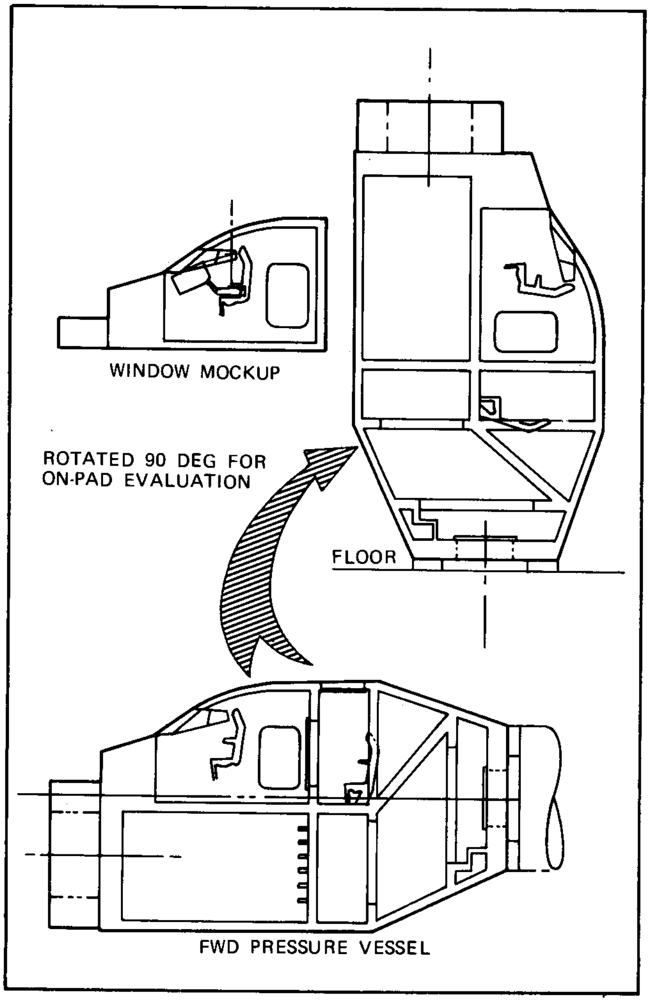


Fig. 2-40 Forward Pressure Vessel Internal Arrangement

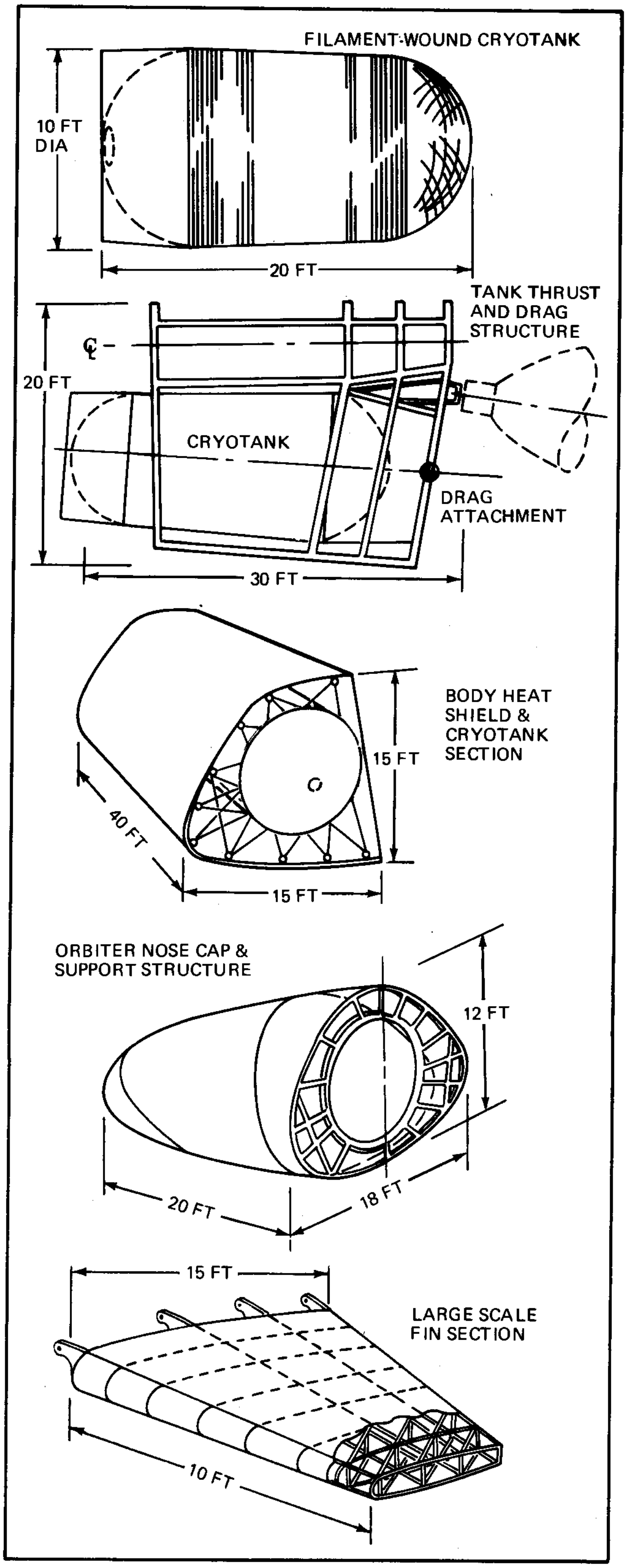


Fig. 2-41 Structural Test Articles

the Phase B study. The technological data required in our shuttle effort will be transmitted in quarterly reports to the NASA shuttle office, giving specific types and range for the required data. We will also regularly contact the space shuttle technology working group.

In addition, our SR&T office will act as a catalyst for technology development within the team of Grumman and its associates, bringing new technology back from NASA and other outside sources, stimulating better alignment of company IR&D programs with shuttle needs, and infusing new development into the shuttle program. General Electric, Northrop and Aerojet-General will each have representatives in the SR&T office who will play an important role in all its activities. Subsection 4.2 contains a more explicit description of the function and organization of the SR&T program.

Risks must be exposed in time to keep from stalling the program. Risk factors which could prevent the shuttle system from attaining its fundamental goals, center about meeting weight allocations, engine performance, operational practicality, and virtually complete reusability. Within the framework of these major risk categories, we have already identified these typical areas; the SR&T will act on them:

- Large cryotanks
  - Degradation of insulation
  - Fatigue from thermal cycling
  - Temperature – dependent properties affecting buckling criteria, etc
- Impact of uncertainty in boundary layer transition in flight have a large impact on TPS weight and reliability
- Characteristics of new materials or design concepts for TPS and tanks
  - Failure modes
  - Environmental effects
- Upper and side surface flow reattachment impact on TPS weight
- Weight growth, new composites
- H_2 safety hazards for flight and ground operations

Investigation of potential technology improvements will lead to substantial dollar savings. The SR&T office in concert with the NASA space shuttle technology group will search for ways to improve the shuttle technology base.

Examples of technology improvements needed are:

- Better analysis methods that would result in weight savings in large complex structures, particularly axial loading of asymmetric shells (finite element theory, thin shock layer theory to improve pressure distributions)
- Better materials that are lighter, stronger, more durable at extreme temperatures (zirconia fabrics, high temperature composites)
- Special problems that limit the use of better design concepts (e.g., H_2 diffusion limits use of cryopumped vacuum tank wall)
- New manufacturing methods that would reduce cost and increase life and reliability (EB welding, shock wave riveting, cryoquenching)

The Grumman team has active shuttle-related R&D programs. Subsection 4.2 contains a listing of 1970 IR&D programs in progress at this time. A number of these are mentioned below because they relate to areas of significant program risk.

Current Grumman research programs include: investigations of hypersonic interactions with reaction control jets; flow separation and its effect on controls; 3-D nonlinear method of characteristics; thin shock layer theory to treat expansion around a chine; rocket plumes in space and aerothermodynamic impulse testing and analysis.

Others include structural analysis by finite-element methods; quantative system synthesis methods; evaluation of high temperature metallic and nonmetallic materials properties; and boost and entry trajectory optimization.

Major advanced development programs of shuttle significance are: hypersonic aerothermodynamic wind tunnel testing and analysis; thermal protection system development; flutter analysis methods; high temperature materials and material processing; cryogenic tank insulation development; structural weight optimization; optimal aircraft control; and flexible vehicle gust response analysis. In many cases, the joint efforts of Grumman's research and advanced development departments are applied to a single program because of the unique talents each can bring to bear on the problem.

Northop's IR&D programs are concentrating on shuttle support in the areas of redundant structures analysis, composite materials evaluation for high temperature use, trajectory optimization, and flow field calculations in subsonic, transonic and supersonic flow regimes.

General Electric has an extensive company-sponsored program covering development of light weight external insulation (REI-2000), and other thermal protection system design, fabrication and testing. In addition, their Utica Division is conducting programs in long-life electronics development, LSI computer component and circuit development, to mention a few.

Aerojet-General has recently completed the development of a cryogenic tank for long term storage of cryogens. Structural design factors of safety are the basis of a 5-sigma statistical study. A computer program for two dimensional finite element analyses has been completed. Aerojet-General is thereby able to determine stresses in areas of hi-discontinuity surfaces with combined loads. Manufacturing has been studying advanced techniques in diffusion bonding and electron beam welding.

Eastern Airlines is conducting research and development projects that support the Shuttle effort: self-checking airborne systems, packaging and handling of cargo with environmental constraints, new instrument landing systems, runway requirements and ground handling of large aircraft, and efficient methods for repair and refurbishment of large aircraft.

The SR&T effort is an important part of the overall Grumman study and will provide significant support to the shuttle program.

2.7 PROGRAM ACQUISITION PLAN

Grumman will use the results of the Phase B study to develop a Phase C/D Program Acquisition Plan which meets NASA requirements specified in Appendix D to the statement of work, with particular emphasis on minimizing areas of technological risk and major cost drivers, such as testing. We will draw on our past space, military and commercial experience and that of our associates to find candidate solutions to these problems. These solutions will be evaluated for the program approach selected for the design phase of the study. We will incorporate the appropriate solutions into the Program Acquisition Plan.

2.7.1 Program Management Plan Conforming With DRD No. MA017M

The program management plan will define the management system required for development and operation of the shuttle system. Grumman's program management system, used currently on the F-14 Program, benefited by the experience derived from the LM program management approach, which was worked out with the cooperation of NASA. The shuttle Program Management Plan will incorporate the basic structures and related experience from this system as it has matured on the F-14. The F-14 system incorporates the most recent practices in management systems and satisfies DOD 7000.2. (It has been reviewed by the Navy: Department of Navy Ltr. PMA241-4: DMK/MAT 023:RCG dated 12 December 1969). Detailed operation of the system is described in Subsection 4.1.3 of this proposal.

We will examine F-14 operating experience for changes which are appropriate to the technical challenge of the shuttle program. An additional part of the study will involve a review of our Gulfstream II commercial aircraft program and Northrop production of the 747 fuselage for cost reduction ideas applicable to the shuttle program.

The probable magnitude of subcontracting on the shuttle requires well-conceived procurement planning under which the subcontractor can ultimately be properly selected and managed to achieve all program objectives. Recognizing that a major portion of the shuttle system will be subcontracted to widely dispersed corporations, Grumman will combine the management organization, practices and personnel of the LM and F-14 programs to achieve the strong subcontract management which will be needed.

Upon completion of the Phase B subsystem hardware definition matrix, Grumman will list those sections of the vehicles and associated equipment which could be subcontracted in total or in part. In parallel with this make-or-buy planning, Grumman's subcontract management organization will coordinate the generation of preliminary in-house estimates of subsystem costs based on specific mission requirements. Other companies, including our associates, will be consulted for estimates in specialized areas as required.

Major attention will be given to reduction of documentation requirements. Grumman has significant experience in reducing program data costs which can be applied during the shuttle study. The Grumman proposal for fiscal year 1970 funding for the EA-6B included a $3 million reduction in data costs. We were selected as the Navy contractor to assist Harbridge House with their study to reduce DOD data requirements. On the E-2C aircraft program, we are working with the Assistant Secretary of Navy for R&D to reduce data requirements. Reduced data costs were also included in our FY 1970 F-14B proposal. On AAP/LM-A, we worked successfully with NASA/MSFC to minimize data requirements. The result was then subsequently applied to the Dual-Mode Lunar Roving Vehicle and Lunar Roving Vehicle (LRV) proposals.

2.7.2 Engineering & Development Plan Conforming with DRD No. SE001M

The engineering and development plan will establish a time-phased approach to the design and development of vehicle and ground support equipment. High-risk areas will be identified early in the program and will be given special attention to ensure their timely resolution.

Special emphasis will be placed on minimizing tests to reduce program costs. This will be accomplished by establishment of a verification program which will identify only those issues that must have tests in addition to analysis to obtain necessary confidence in the design and/or manufacturing process. Where a test is necessary, test requirements and criteria will be issued to control the test. Accordingly, test requirements will specify the environment in which the test should be accomplished, and the number of times the test must be conducted. The test criteria will specify the parameters to be measured together with allowable tolerances.

As a further approach to low program costs, booster and orbiter subsystem and support equipment requirements will be reviewed to determine items where a single design will satisfy both vehicles.

2.7.3 Operations Plan Conforming With DRD No. MP010M

In-depth analyses of ground flow and flight sequence date, performed in parallel with systems and mission analyses, will be used to develop the operations plan. Experience gained in leading the Apollo Mission Planning Task Force and LM operational site activation activities will be applied. The plan will be divided into sections identifying and describing mission, flight, and ground operations. Mission operations will include overall planning considerations such as mission sequence, length, payload, time lines (daylight vs darkness) and trajectories. Interfaces with experiments, alternate mission, and emergency operation plans for abort modes, alternate landing sites, possible impact areas and rescue operations, will be included. Flight operations will include communications, procedures relative to tracking and data acquisitions environmental influences and crew functions for all flight modes. Emphasis on navigation and use of the data relay satellites will be provided. Ground operations will reflect Eastern Airlines experience in maintenance and ground systems routines. This plan will cover turnaround operations including landing and safeing, maintenance and refurbishment, loading and checkout, servicing and launch with emphasis on major ground stations, facilities, logistics and GSE requirements. An operational data system which builds on relevent data generated in successive stages of program experience. This plan will identify implementation requirements for Phase C and D. (See Fig. 2-42)

2.7.4 Facility Utilization & Manufacturing Plan Conforming with DRD No. TM001M

Grumman will evaluate use of existing DOD & NASA facilities. We recognize that facilities cost must be minimized and that requirements for facilities acquisition or major modification must be thoroughly justified. Facility and equipment requirements will be derived. The resulting plan will describe the major elements of the facilities, special test equipment, and GSE, and will identify long lead procurement.

Early identification and evaluation of potential manufacturing problems is essential to the development of a producible shuttle system. Experienced space and aircraft manufacturability engineers are teamed with design engineers to evaluate the impact of all design features on manufacturing and operational costs. Areas which will be investigated for potential fabrication, tooling, process, assembly, installation, inspection, and maintenance problems include:

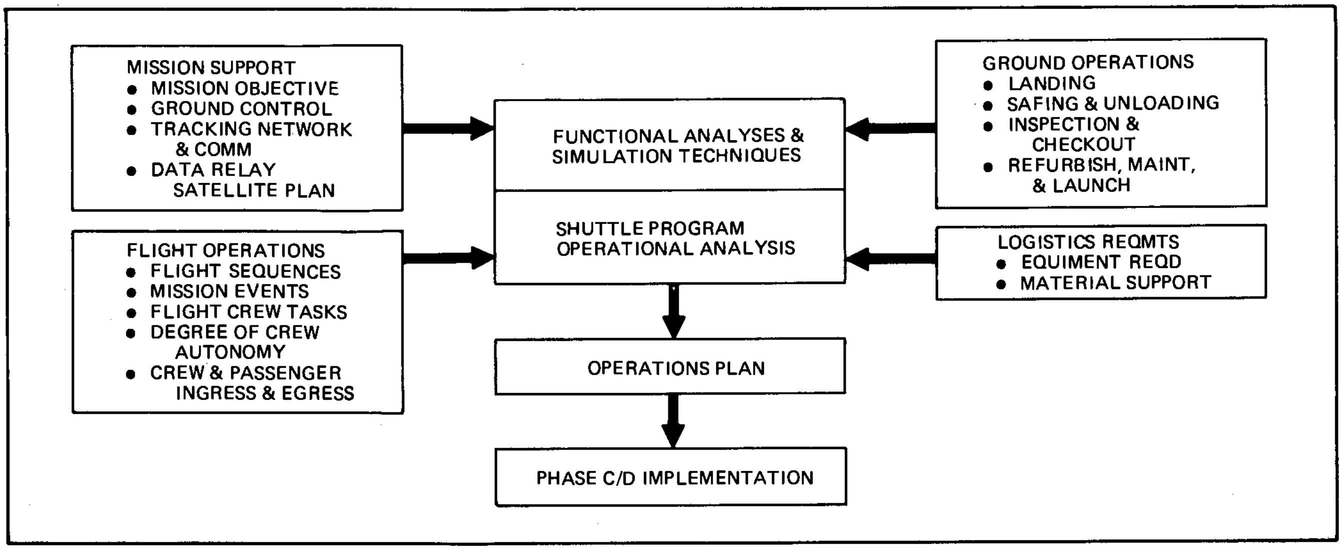


Fig. 2-42 The Operations Plan. *Definitive ground & flight activities are identified*

- Advanced Materials – Superalloys and composites
- Thermal Protection System – Metallic and nonmetallic radiative insulative systems (REI), high-temperature fasteners and oxide protection coatings
- Cryogenic Tanks – Integral versus nonintegral, filament winding, insulation (foam, gas layer) and overall size/weight
- Assembly Methods – Work station accessibility structural breakdown, subsystem insulation, handling systems and equipment installation

Tradeoff studies will be conducted on alternate design/fabrication approaches to demonstrate feasibility, prove fabrication methods, and substantiate manufacturing cost and flow time projections. The results of these studies, coupled with information obtained from related in-house and industry programs, will provide the basis for recommending solutions to the identified programs. (See Fig. 2-43)

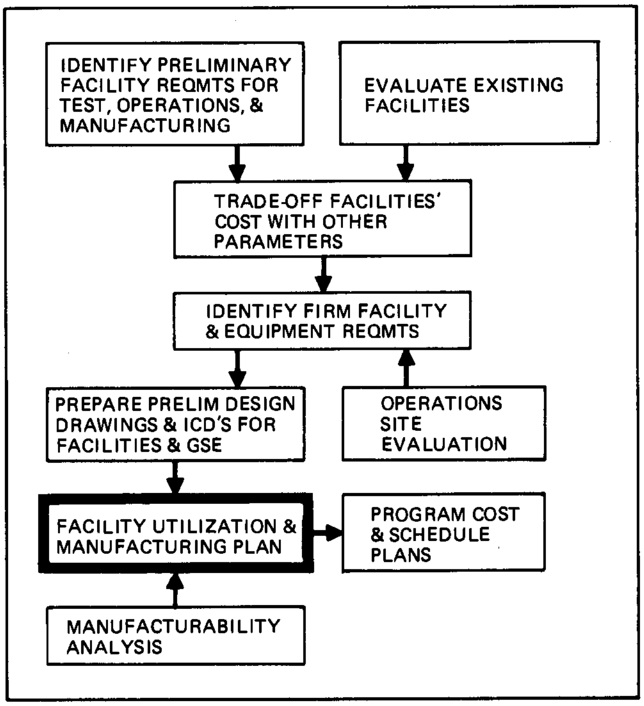


Fig. 2-43 Facilities & Manufacturing Plan. *The plan is based on fully justified requirements*

2.7.5 Test Plan Conforming With DRD No. TM 002M

Our test plan will describe the overall test program to achieve substantially lower costs and provide the information requested in NASA's SOW. The integrated test plan will reflect a balance of aircraft and spacecraft test technology. Grumman's recent experience will be applied to the shuttle program so that the best "dollar-value" program will result. The F-14 flight development program plan was reduced from an estimated 34-month test program to a 17-month test program. LM assembly and acceptance time was reduced from 52 weeks to 30 weeks. Stepped buildup and early identification of potential "program stoppers" will insure a smooth, predictable development program. The system integration test station (SITS) utilized on the EA-6B development program permitted decoupling the aircraft and electronic development programs, resulting in early identification and solution of electronic integration problems without delays to the aircraft development.

Our previous test experience and the results of the test analysis described in Subsection 2.1.4 will be applied to define a low-cost program using aircraft/spacecraft technology. Some of the goals of this plan are:

- Commonality in test and measurement techniques
- Minimization of special test equipment
- Buildup approach in ground and flight testing
- Stepped qualification
- Elimination of test redundancy

LM program experience indicates that test planning, which eliminates redundant or low value testing, throughout the vendor, pre-installation, system buildup and integral vehicle test programs, removes one test cost "driver."

LM Assembly and Checkout Demonstrated Integrated Planning and Control. This was achieved through centralized test management, supported by an information system for visibility into all test activities. The plan will be definitive in scope, test logic, test definition, organizational participation, facility, data acquisition, and logistics requirements. The rationale and justification for Phase C/D unique test features to achieve a low-cost, high-confidence test program will be presented. (See Fig. 2-44)

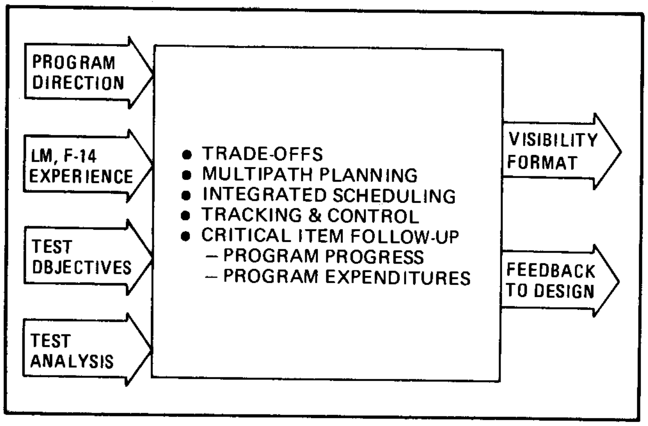


Fig. 2-44 Centralized Test Planning & Control. *The key to a low cost test program is centralized planning & control*

2.7.6 Logistics & Maintenance Plan Conforming With DRD No. LS001M

This plan will address the program development, test and operational requirements for logistics and maintenance to assure feasibility and low cost. These requirements will be generated from interfacing systems, operations and maintainability analysis. Experience previously gained through Grumman's successful support of multiple naval squadrons, as well as Eastern Airlines hour-to-hour support of their operating fleets, will be applied. Grumman's recognition as the industry leader for integrated logistics support (ILS) was most recently high-lighted by the Air Force's F-15 and Minuteman systems program offices reviews of the outstanding F-14 ILS presentation. The Assistant Secretary of Defense for Installation and Logistics was equally impressed, as was General F.J. Chesarek, Commanding General, U.S. Army Material Command, who quoted, "One of the better examples of the application of integrated logistics support in the Navy is the contract with Grumman for the F-14 aircraft." The logistics and maintenance plan will be structured to become the "what to be done" document. By adding the specification for a logistics program plan, there will also be a "how to do it" document. The MSFC MM 7500.2 logistics requirement manual dated 4 December 1969 will be used as a guide when developing the plan. (See Fig. 2-45)

2.7.7 Program Cost & Schedule Estimates Plan Conforming With DRD MF003M

Grumman will provide cost and schedule estimate for Phase C/D as defined in MF003M. We are currently performing to NASA's requirements on the LM Cost/Schedule/Technical Characteristics Study under CCA 2680 to NAS 9-1100. Virtually all the requirements of MF003M are contained in the LM historical study. In addition, we have already submitted a cost and resource plan (in accordance with MF002M, similar to MF003M) for the DLRV Phase B final report under Contract NAS 8-24529. Furthermore, Grumman has provided life cycle cost estimates (covering development, acquisition and 10-year operational phases) for the F-14 weapons system. Grumman has contracted for eight years of development and production on the basis of those estimates. *Our resources will be augmented by Northrop 747 Fuselage structural cost experience factors.*

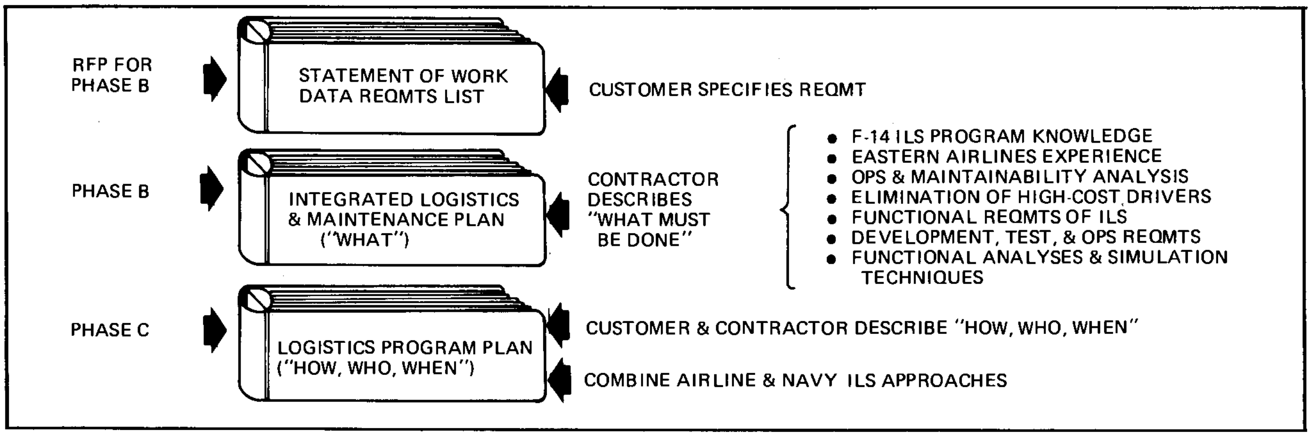


Fig. 2-45 Logistics & Maintenance Plan. *Will define the program development, test & operational requirements for logistics & maintenance*

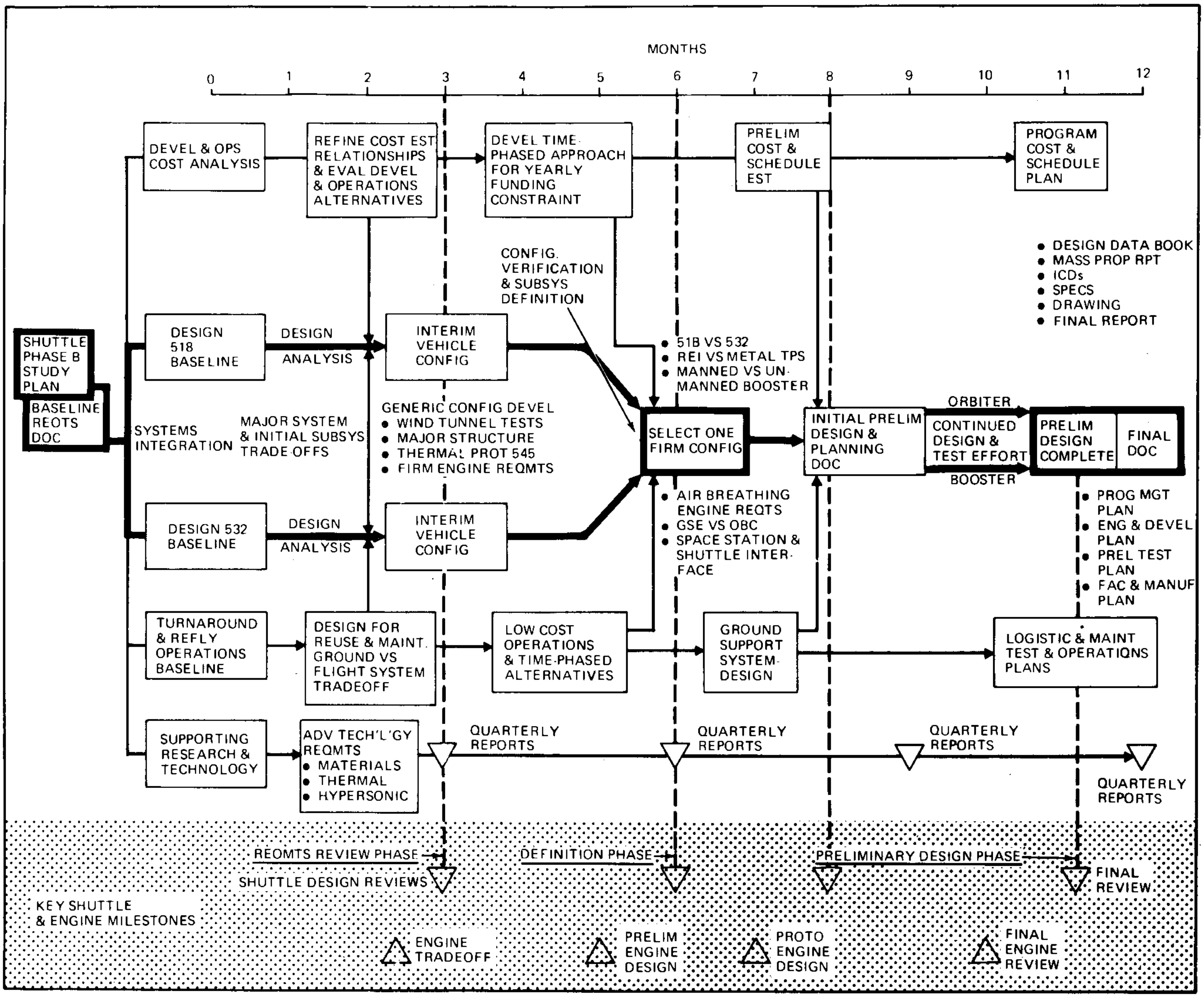


Fig. 2-46 Phase B Study Approach and Schedule

Providing the Phase B data requirement of MF003M to the extent required by the study is a straightforward problem in compilation of data. Grumman has mechanized the interrelationship of cost and schedule data in a computer program capable of calculating T_d, T_s, and the general spread functions at each work breakdown structure (WBS) level. Similarly, the interdependence of technical characteristics to cost and schedule factors is fully understood by Grumman as a result of our LM cost study.

In accordance with paragraph D of MF003M, the work breakdown structure, elements of cost and subdivisions of work will be developed jointly by NASA and Grumman subsequent to contract award and will be finalized 30 to 60 days after contract award.

Grumman's approach and our ability to generate realistic cost and schedule estimates, which will provide the input data for this report, are discussed in detail in Subsection 6.4.

TECHNICAL EXPERIENCE/CAPABILITY & PERSONNEL

3 – TECHNICAL EXPERIENCE/CAPABILITY & PERSONNEL

The Grumman Team brings a wealth of relevant technical experience and capability to the Space Shuttle System Phase B Study. Personnel have been selected for positions of responsibility who have had personal involvement in the Corporate Team's relevant technical experience and have the stature in their respective companies to bring this Corporate capability to bear on the technological challenges of Space Shuttle System definition. Grumman, as the team leader, brings the essential dual capability of relevant spacecraft and aircraft experience, (Apollo LM, F-14, EA6-B, E-2A Gulstream II, etc.), singularly embodied within a non-divisionalized operating structure that will ensure unity of action as well as purpose, in the leadership role. Our Associates in the team bring complementary technical experience, capability, and similarly select personnel to fully cover the scope of the Space Shuttle technological challenge. Associate corporate participation is provided through their key and supporting personnel functional and physical integration into the proposed Phase B Study organization at Grumman's Bethpage location.

Associate participation encompasses:

- General Electric – Reentry Technology (Reentry & Environmental Systems Div.)
  - – Operations Analysis (TEMPO Div.)
  - – Avionics (Aircraft Equipment Div.)
- Northrop – Aerothermodynamics and large structures
- Aerojet General – Large Rocket Propulsion Systems
- Eastern Airlines – Operations and Logistics Systems

The space shuttle contractor will need to have competence in phased program definition, to be experienced in major spacecraft and aircraft programs, to possess strength in key technologies, and to have available a group of outstanding individuals to work on the study. The material is organized to correspond to these requirements as follows:

- Phase B study experience
- Major program experience
- Technology capability
- Resumes

3.1 PHASE B STUDIES

Grumman and its team of associates have performed many Phase B studies on a variety of spacecraft, aircraft and reentry vehicle projects. The following are some major examples:

GRUMMAN

- *VFX Weapons System (N00019-69-C-0053)* – Advanced fighter definition study (F-14)
- *Apollo Extension Systems (NAS 9-4983)* – Investigated application of LM for a wide variety of NASA and DOD earth orbital and lunar missions. An addendum to the contract covered definition studies of payload integration for these missions (July 1965 to February 1966)
- *Dual Mode Lunar Roving Vehicle (NAS 8-24529)* – Conducted DLRV design definition study for manned/remote controlled lunar roving vehicle
- *Utilization of LM for Apollo Applications Program (NAS 8-6608) and (NAS 9-25000)* –Phase B study of the modification of LM ascent stage for use with the NASA/MSFC Apollo Telescope Mount in a long duration earth orbital mission. Contract period, May 1966 to October 1968. Phase B work completed with a Preliminary Requirement Review (PRR) in April of 1968. (Phase C performed between April and October 1968)

GENERAL ELECTRIC

- *Convair Model 21 VSX Project (S-3A) (N00019-69-C-0055)* – S-3A/VSC design definition study for total avionics integration including data bus
- *Space Station Design Definition Study* (North American Subcontract M9M8XDZ-680066D) – Phase B study for experiment integration information management system and orbital operations
- *Integrated Medical and Behavioral Laboratory Measurement System* (IMBLMS) (NASW-1630 MOD 1 through MOD 3) Phase B-1 through Phase B-3 – design definition of data management system, controls and displays plus manned measurements
- *Voyager Capsule Preliminary Design – Phase B (MAC/DAC) Cont. 270044)* – Preliminary design of cannister/biobarrier, heat shield and RTG,integration

- *Mars Hard-Lander Capsule Study (NAS 1-8098)* – Parametric data and range of point designs to show feasibility of hard lander

NORTHROP

- *Feasibility of Minimum Manned Lifting Entry System (NAS 4-840)* Advanced M2 plus Gemini Lander Vehicle
- *AX Specialized Close Air Support Weapon System* (USAF Contract F33657-67-C-1500)
- *V/STOL Jet Operating Research Aircraft Design Study* – (NASA Contract NAS 1-6777)
- *Condor Missile Design Definition Study* – Navy Contract NOW65-0457f)

3.2 PROGRAM EXPERIENCE

The programs cited here constitute relevant technical experience with major aspects of the space shuttle system: spacecraft, aircraft, reentry and lifting body, large rocket propulsion systems, and operations/ground support. In each area we identify key personnel responsible for significant aspects of these accomplishments, who will apply their experience and capabilities to the shuttle program.

3.2.1 Spacecraft Programs

Grumman participated in the conceptual studies (equivalent to present Phase A) which led to choosing lunar-orbit rendezvous for Apollo. When the contract was awarded to Grumman, the LM program began with a definition study (equivalent of Phase B). We not only completed that study, as we have many others, but now have the invaluable perspective of looking back on Phase B after completing the hardware contract based on it.

During the LM Phase B in 1963, Grumman coordinated the skills of system analysis, performance tradeoffs, cost and schedule analysis, vehicle design, and subsystem analysis and succeeded in defining a vehicle whose basic design changed very little in subsequent years as it was refined until ready for the lunar landing. The approach defined in 1963 (lunar landing achieved in 1969) may well be considered the ultimate in low mass-fraction design to date.

Supporting this vehicle design were outstanding engineering efforts on such key areas as propulsion systems, high-reliability lightweight electronics, navigation and control, thermal protection, and life support. The two men most responsible for Grumman's contribution to the LM success, Joe Gavin and Tom Kelly, will be active on the shuttle and ensure continuation of corporate management's functioning interface with NASA management.

OAO is NASA's largest and most complex unmanned scientific satellite. On this program, Grumman demonstrated its ability to define, develop and produce such a spacecraft, starting with the equivalent of Phase B. The fact that the OAO recently recorded its 16th month of continuous operation, characterized by a consistently high scientific yield, bears testimony to our spacecraft capabilities. Like the LM, the program required a major electronics integration job. With respect to weight and mass balance control, key shuttle challenges, OAO achieved the precise mass balance control required for its ±0.1 arc second pointing capability. The 4436-pound spacecraft (OAO A2) was 64 pounds below its weight limit (E. Stern, chief systems engineer on the OAO is on our shuttle team).

General Electric designed and built the Nimbus, the U.S. Weather Bureau's standard weather satellite, capable of handling 12 different payload experiments and the Biosatellite, a successful, integrated reentry spacecraft. General Electric was also responsible for mission integration and operational systems on the MOL program which, until its recent cancellation, was the primary manned military spacecraft program. (Key General Electric personnel bringing this background to the shuttle are H. Bloom, R. Smevog, and J. Lovell.)

3.2.2 Aircraft Experience

Grumman has successfully developed a large number of different aircraft in the last 10 years, bringing them from design analysis through final production, operations and support with excellent cost and schedule performance through effective management systems. These aircraft have been widely recognized as having exceptional flying characteristics (with minimum reliance on stability augmentation) and with integrated systems that provide self-sufficiency and flexibility of operation.

The Navy/Grumman F-14, currently well into development is expected to fly on schedule in January 1971–is this nation's most advanced fighter featuring integrated aircraft/engine design and computerized weapon and information management. As part of the entire program, Grumman has invested some $40 million in advanced testing and production facilities and equipment, many of which, such as titanium hot forming presses and electron-beam welders, never existed before. In the materials and structures area, the F-14 program sets new standards for modular lightweight design. The extreme importance of low weight to the success of this high performance fighter justified the pursuit of every weight saving possibility offered by the latest material developments. For example, electron-beam welded titanium is used for the wing box beam. Boron fiber reinforced composite is used for the cover skins of the horizontal stabilizer. Despite its many design challenges, schedule and cost are all on target in preparation for the F-14's first flight.

The F-14A, with two Pratt & Whitney TF-30-P-412 turbofan engines, will become operational in early 1973. The F-14B with advanced technology engines will succeed the F-14A at a later date. These engines will be 40 percent more powerful and 25 percent lighter and are candidates for the shuttle air-breathing engines. Advanced avionics, developed concurrently, will be incorporated when ready into an F-14C growth version. Many key shuttle personnel played important roles on the F-14 in its early design definition phases, including L. Mead, A. Whitaker, H. Moss and M. Mohr who are now on our Shuttle team.

The Navy/Grumman A-6A, of which some 430 have been built to date, is the nation's only all-weather, carrier-based attack aircraft. Its' unusual self-sufficiency, based on the DIANE computer navigation system, is repeatedly demonstrated on long-range missions in zero visibility conditions. The A-6 is known by pilots as a rugged, dependable flying machine: it continues to set safety records in combat environments with over 45,000 carrier landings and takeoffs without accident to date. (L. Mead directed development of the A-6.)

On A-6, Grumman pioneered one of our first fully integrated avionics system. Today, an added A-6 "family" of specialized mission growth versions exists: KA-6D tanker; A-6C TRIM (Trails Roads Interdiction Multi-Sensor) aircraft; A-6B special purpose missileer; EA-6A tactical countermeasures aircraft; and EA-6B, a new four-man stretched airframe, incorporating the first complete airborne electronic warfare system ever developed.

The E-2A airborne tactical data system, a flying command and control center, performs early warning and intercept control missions. Long duration, large size, a crew of five (pilot, co-pilot, and three computer operators), and a 24-foot diameter rotodome radar antenna mounted above the fuselage are the distinguishing features of this carrier-based aircraft. With its large-capacity general-purpose computer, a single E-2A is able to monitor the equivalent of all the commercial air traffic between Boston and Washington, D.C. Like the A-6, the E-2 design concept has evolved into growth versions: E-2B, which incorporates a more advanced, higher capacity computer; and E-2C, with a completely updated early warning and control system geared to fleet operations throughout the next decade. (H. Wright, manager of the orbiter, was assistant program director, avionics, on the E-2 program.)

The Navy/Grumman C-2A is a carrier-on-board-delivery aircraft structurally related to the E-2A Hawkeye. Deployed with the fleet since 1967, the long range C-2A has reliably performed its prime logistic mission of airlifting personnel and heavy high-priority cargo (15,000-pound payload) between shore points and the aircraft carrier deck. (J. Karanik, booster manager, was program manager on C-2A, and also on EA-6A).

Northrop also has major aircraft program experience, including the F-5, T-38, and the major fuselage section of the Boeing 747 jumbo jet, which approximates the shuttle's structural dimensions. (A. Arslan brings this experience to the shuttle program.)

3.2.3 Lifting Body/Reentry Vehicle

Our team's background in lifting bodies includes major related efforts on HL-10, M2-F3, Grumman 359 Series, and Project ASSET. In addition, General Electric and Northrop have extensive experience in lifting body thermal protection, structures and materials. Program experience is briefly summarized as follows:

- HL-10 and M2-F3 – Northrop's HL-10 and M2-F-3, designed and manufactured in conjunction with NASA/FRC represents advanced manned lifting body aero/propulsion technology. Aluminum airframe and rocket propulsion system were integrated to attain Mach 2. Both vehicles have flown a total of 50 flights during a four-year flight test program. Extensive flight performance data was obtained on stability and control problems of lifting bodies with lift-to-drag ratios of 3-4.
- Project ASSET – Northrop also made major contributions to reentry energy management with Temperature Rate Flight Control System

(TRFCS) flight tested on Project ASSET. (J. Stalony-Dobrzanski brings the Northrop background to the Shuttle program.)

- M2-F2 – General Electric analyzed TPS requirements and performed tradeoff studies of ablative and radiative systems for NASA. The study also involved trajectory analysis, heat flux investigations, and error analysis
- Grumman Series 359 – Grumman has conducted an analytical/experimental program in Lifting Body aerodynamics for over 10 years. We have investigated numerous government-proposed designs (Mercury, Apollo, HL-10, AF-1) and conducted detailed studies of a series of Grumman configurations. In particular, extensive tunnel tests were run on Design 359D, a medium L/D cylindrical body, and Design 359E, a high L/D straight conical body design. (F. Blomback brings this background to the Shuttle team.

The team's background in reentry vehicles includes over 30 reentry/recovery projects by General Electric RESD over the past 14 years:

- Ballistic Reentry Vehicle (RV) Series (Mk 2, 3, 6, 12) – MK 2 was the first heat-sink type RV; Mk 3 the first operational ablative RV. The special research vehicle Mk 3/CTP made the first flight of an ablative RV using graphite fins for control surfaces. Mk 6 is the largest AF operational high-performance reentry vehicle and the Mk 12 is the latest major ICBM weapon system
- Discoverer Series – first orbital recoverable spacecraft which has served as the U.S.'s workhorse satellite for many years. With the Discoverer series, General Electric pioneered development of ablative composite heat shield structure incorporating a thermal control coating for sustained vehicle operation in near-earth orbits (R. Smevog brings this background to the shuttle program).
- Reentry-F Research Vehicle – General Electric developed flight test vehicle for NASA/LRC to investigate boundary layer transition and turbulent heating for a smooth, sharp cone
- MBRV (Maneuverable Ballistic Reentry Vehicle) – first hypersonic reentry system capable of maneuvering outside a ballistic path. General Electric developed and incorporated an ablative thermal protection system (TPS) using an ablative thermal control surface

3.2.4 Large Rocket Propulsion Systems

Aerojet-General contributes to the team its experience in large rocket propulsion systems and related specific projects. They designed, developed, fabricated, tested, and qualified the main propulsion system for the Titan I, II, and III (B, C, D, M). Their responsibilities included integration of the propulsion system into the missile. The entire program including development, production and support had a magnitude of approximately $1 billion.

Aerojet-General builds the entire propulsion system for the second stage of the Delta booster. This includes engine, tanks, flight controls, attitude controls, and pressurization system.

They have done major development work on the M-1 engine, a 1.5-million-pound thrust liquid oxygen/liquid hydrogen engine. This program was cancelled in 1967. Other programs include ARES (classified) and NERVA. (B.L. Baird brings the Aerojet-General background to the Shuttle program.)

General Electric designed, manufactured and integrated the radio inertial guidance system for the ICBM-range Atlas, and the inertial guidance system for Polaris/Poseidon. (R.E. Scanlan and L.J. Degan bring this background to the shuttle program.)

3.2.5 Operations/Ground Support

Both Grumman and Eastern Airlines have had major experience in planning and managing operations and support programs with challenging requirements, which establish a point of departure for the shuttle study. Grumman, of course, has concentrated on meeting the requirements of the military, including aircraft carrier environment, while Eastern has worked on efficient commercial operations, including such innovative operational ventures as the first passenger air shuttle.

Grumman has been in the forefront of the development of integrated logistic support (ILS), starting with the A-6 and E-2 aircraft systems. The E-2C command/control aircraft incorporates SCRAM (Signal Readout and Alarm Module), a single GO/NO GO status with 80 percent probability of detecting and isolating faults. The system is designed to provide 30-minute aircraft turn-around. We are now implementing the latest and most comprehensive ILS program in the industry for the F-14. In the F-14, Grumman provides 418 sq ft of maintenance access area. Our design establishes capability for an engine change in three hours. This aircraft, more than any other previous Navy carrier-based vehicle, is integrated with the support environment (maintenance and servicing facilities) on the carrier.

Grumman also performed a Navy operations study on aircraft turnaround and logistics support for aircraft carriers. We developed a simulation model considered by the Navy "an advancement in the state-of-the-art." The model utilized data on skill levels, support equipment, and spares to support various mixes of nine aircraft types on three types of carriers. This simulation experience will be utilized in the Phase B study. The study also provided implementation plans and schedules which, according to the Navy review team, "would result in the effective implementation of the program." The management plan was "found to be complete, comprehensive and attainable through employment of existing Navy organizations." (N. Reinertsen and H. Peck bring this experience to the Shuttle program.)

Grumman team experience in automatic checkout has application to on-board checkout tradeoffs and maintenance requirements. Grumman developed semi-automatic checkout equipment (SACE), the largest integrated automatic checkout system in use by the military today. It made maximum use of existing Navy assets and was the first to have integrated usage between programs. A digital test station is being developed by Grumman for the EA-6B. It is a computer-controlled test station for the latest high-speed digital computers and related digital equipment. ACE, designed by GE and used on the Apollo and Skylab programs, is an example of an adaptable automatic checkout system used for factory and prelaunch checkout. It was updated for the MOL program to reduce operating personnel and increase capability.

In the commercial aircraft field, Eastern is a leader in constantly improving the maintainability of its fleet. Failure trend data on 245 company-owned aircraft has been used to initiate modifications which have reduced the maintenance manhours per flight hour from 13.2 to 11.9. In 1969, Eastern was ranked number one by the CAB for on-schedule departures: 75.2 percent of 504,000 scheduled departures were on time or within three minutes of set time. In addition, 90.1 percent of 1100 scheduled routine maintenance checks were completed on time and of the 218.7 million miles scheduled, only 0.44 percent were canceled due to mechanical problems. Eastern has the most experience in operating a single maintenance center (Miami) through which all their aircraft pass every 3-4 days, thus reducing maintenance cost and delays. It is the only airline to use a centralized, real-time operations control system.

EAL has provided the commercial aircraft industry with a number of improvements towards reducing ground support. They pioneered the use of auxiliary power units in commercial aircraft to eliminate the need for ground power, pneumatic air start and ground air conditioning units. They developed and applied a three-dimensional airborne navigation system, resulting in reduced requirements for ground controller assistance.

In addition to ground support, Eastern also provides depths in commercial aircraft operations. Their current facility tradeoff studies for incorporation of the L-1011 into their fleet are particularly applicable to the shuttle operations study. Changes in Eastern's current facilities and the impact on aircraft design changes are being studied on cost-reduction bases. (P.F. Donnelly and J.C. Mize bring this experience to the Shuttle program.)

3.3 TECHNOLOGY CAPABILITIES

This subsection discusses the technology capabilities necessary to perform the shuttle studies and our team's specific experience in these relevant areas. Aerodynamics, thermodynamics, structures, propulsion, electronics, weight control, and reliability/maintainability are covered. In addition, because of their importance to the Phase B study, we also include environmental testing, flight dynamics and systems and operations analysis and integration.

3.3.1 Aerodynamics

The Grumman team brings a long history of aerodynamics capability to the shuttle study. Our experience covers the field from aerodynamics research programs aimed at understanding basic flow phenomena, to design, development, test and production of complex aircraft such as the A-6A, Gulfstream II, F-14, MR-6, MR-12, and Reentry F. The F-14, currently in development, incorporates the latest ideas in modern high speed aerodynamics. Northrop and General Electric bring specific experience to the shuttle effort in sophisticated aerodynamic analysis and design techniques of reentry vehicles.

3.3.1.1 Capability/Experience

Grumman's aerodynamics research includes investigation of characteristic flow phenomena ranging from Mach 0 through Mach 20. Particular attention was given to hypersonic flow fields about bodies and wing-body combinations, including shock layer structure; blunt body flow; real gas phenomena; influence of viscous phenomena on control and configuration characteristics including separation, skin friction, aerodynamic heating, and viscous interaction. Other areas include three dimensional supersonic flows with embedded shock waves by the "method of near characteristics;" theoretical calculations of transonic flows over airfoils; low speed viscous airfoil theory including prediction of CL_{max} flap effectiveness, and other airfoil characteristics associated with high lift.

Examples of our team's relevant research achievements are:

- Grumman's Hypersonic Aerodynamics Research Programs – Initiated in 1959 under Air Force Contract (AF33(616)-6400), this work developed theoretical techniques for predicting hypersonic pressure distribution for configurations with attached leading edge shocks. Grumman's theoretical and experimental research on flows past transverse jets showed that force augmentation due to jet/flow field interaction makes this an effective control mechanism, and it will be considered for roll control on the shuttle
- Investigation of Various Types of Control Devices on a Lifting Body at Supersonic and Hypersonic Speeds – In this classified program, Northrop tested representative control devices on a hypersonic lifting vehicle resembling the shuttle reentry vehicle. The program determined control effectiveness, heating effects, hinge moments, control cross-coupling, and the effects of control operation on vehicle performance. It was conducted in Mach 3, 10, and 20 tunnels at AEDC and in the Mach 10 hypersonic tunnel at Northrop
- Supersonic Air Induction Systems – In this program, Northrop developed steady-state and transient analytical/empirical tools for design of efficient air induction systems for highly maneuverable vehicles with supersonic capabilities. Achievements relevant to shuttle include formulation of a dynamic mathematical model of transient phenomena predicting effects of nonuniform approaching flow field, and predicting shock position and shape, compression ramp profiles
- Thrust Augmented Maneuvering (TAM) was used by Northrop in an in-depth comparison of the M-2 and FDL-5 for a large cross-range requirement in which the TAM/M-2 was found more cost effective. Northrop developed, temperature rate flight control system (TRFCS) capability includes flight path control, energy management, guidance, and stability augmentation functions. TRFCS feasibility was demonstrated by an open loop test on the ASSET AEV-2.
- Reentry Aerotechnology – General Electric has conducted complete aerodynamic analyses on numerous major vehicle systems, mostly ballistic and orbital reentry (Subsection 3.2.3). Company-sponsored studies on lifting vehicles such as the Orbital Maneuvering Reentry Vehicle and Slamast have been continuing since 1962.

3.3.1.2 Design Tools/Data

The following computer programs and techniques are among those related to the Shuttle that are used at Grumman for aerodynamic analysis:

- Real Gas Blunt Nose Method of Characteristics Program – This program for axisymmetric and two-dimensional flow fields containing imbedded shocks can be used to determine blast wave pressure carry over, leading edge pressure distributions, entropy layer thickness and corresponding degradation of trailing edge control flap effectiveness as well as leading edge contribution to fin-type surface effectiveness at small side slip
- Computer Program for Predicting the Aerodynamic Characteristics of Arbitrary Hypersonic Configurations – This program's capabilities have been thoroughly substantiated by extensive comparison with NASA HL-10, M2 and MSC winged shuttle configuration pressure and force test data. In the latter case, the results of this program completely duplicated NASA/MSC in-house predictions. Further, this program automatically accounts for component/component aerodynamic shielding in addition to providing detailed local surface flow skin friction estimates. The program provides a highly developed computer/graphics data presentation. All longitudinal/lateral/directional static and dynamic derivatives are computed
- Reentry Trajectory Programs
  - Generalized three degree-of-freedom program with a wide variety of operational parametric inputs
  - Rigorous three degree-of-freedom reentry trajectory optimization program
  - Approximate engineering three degree-of-freedom reentry trajectory optimization program – allows rapid assessment of trajectory ranging/heating tradeoffs. The results of this program compare favorably with rigorous three degree-of-freedom modulated bank/angle of attack/flight path determinations

3.3.1.3 Facilities

The Phase B study will have available Grumman's hypersonic wind tunnel facility and hypersonic shock tunnel. The wind tunnel facility contains three blow-down tunnels which simulate a Mach range of 0.3 to 14. The shock tunnel can simulate Mach 5 to 25, with realistic Reynolds numbers and moderate enthalpy.

In the Grumman hypersonic tunnel, Mach 8, 10 and 14 can be simulated in the 36-inch diameter test section with a large range of Reynolds number per foot extending from 30 thousand to 4.5 million. A pebble bed heater heats the air (to a maximum of 3500°R) which is then expanded through an axisymmetric contoured nozzle and exhausted through a diffuser and after cooler to a 65,500 cu ft vacuum sphere. The closed jet test section incorporates a water cooled sting-balance sector rig which features a model injection system. The transonic tunnel is a 26-inch octognal slotted tunnel with a Mach range of 0.3 to 1.3 and a Reynolds number per foot range of 5 to 30 million. In the past, this tunnel has been used for aerodynamic, inlet and flutter testing. The 15 x 15 inch supersonic tunnel has been used primarily for aerodynamic and inlet testing. Mach numbers from 1.5 to 4.0 and Reynolds number per foot from 8 to 65 million can be developed in the test section by interchanging the various nozzle blocks. Grumman's subsonic tunnel is a 7 x 10 foot open circuit continuous tunnel. Full aircraft and reflection plane scale models have been tested for subsonic flight, takeoff and landing characteristics, as well as flutter and powered model tests.

General Electric's 6/54-inch parallel flow shock tunnel with a test core of 28 inches at Mach 20, and 35 inches at Mach 10 is also available. Using a 40-channel tape recorder for the Schlieren photography, it has been used to measure model pressure and heat transfer, aerodynamic force and pitching moments, density and temperature points, and for flow density structure visualization.

The Northrop Norair 30-inch hypersonic wind tunnel is capable of speeds from Mach 6 to 14, with 30-inch diameter free and closed jet test sections using interchangeable axisymmetric nozzles.

The Northrop high-speed test facility has trisonic and hypersonic circuits. In the 2 by 2 foot trisonic test section, Mach 0.2 to 3 are attainable. The 30-inch diameter hypersonic test section can produce Mach 6, 10 and 14.

3.3.2 Thermodynamics

The shuttle presents a wide spectrum of thermodynamics problems such as cryogenic management, hypersonic entry and rocket plume protection, passive control of the entire vehicle and active control for men and equipment. The Grumman team has successfully provided thermodynamic solutions in every temperature and flight regime pertinent to the shuttle. In the course of developing major systems such as LM, OAO, Discoverer, Biosatellite, Nimbus, Mark II, III, VI, XII, Reentry F, the RVX Series, etc., an extensive collection of thermodynamic data, mechanized analytical tools and test facilities, directly applicable to shuttle technology, has been assembled.

3.3.2.1 Analysis

For evaluation of the shuttle's aerothermodynamic environment, the extensive collection of flight-proven flow field and aerodynamic heating programs will be used. The various aeroheating routines programmed include Eckert's reference enthalpy, Spalding Chi, Van Driest, ρ_r/μ_r and the Vaglio Laurin streamline divergence methods. Careful attention will be given to definition of local properties through use of finite difference shock shape, streamline tracking, and streamline divergence methods.

A major area of concern is definition of boundary layer transition criteria. In this connection, GE has not only explored the fundamental aspects of the problem but has developed correlations based on ballistic range data and flight data obtained from the NASA/GE Reentry F and the AF/GE vehicles flown in the AF Transition Performance Program.

Correlated aeroheating data will be used to substantiate analytical methods and provide information in regions not amenable to analysis. As an example, data from GE flight test programs such as NASA/Wallops finned vehicle, the Mark VIP, and MBRV will aid in design of control flap surfaces and fins.

Description of the interaction between rocket plumes and vehicles will make use of analytical methods developed on the LM program to predict heat transfer in continuous and non-continuous flows from RCS, descent and ascent engine plumes.

Full scale testing of RCS plume impingement in hard vacuum ($< 10^{-4}$ Torr) and subsequent flight data corroborated the analytical model.

Prediction of ablation and graphitic material thermodynamic response to the hypersonic environment will make use of the GE reaction kinetics ablation program which solves the transient heat conduction equation, accounting for chemical reaction at the surface as well as in the material, char formation and removal and surface regression. This analysis has been flight proven on full-scale recoverable materials test vehicles such as the RVX series and MBRV.

Analytical methods for vehicle thermal balance include nodal networks with subroutines to include the active ECS contribution, orbital heat flux routine which accounts for blocking action and Script F programs. LM and OAO flight data has established the validity of these programs and the associated analytical modeling techniques.

3.3.2.2 Testing Facilities

Aerothermodynamic analysis will be complemented by the data generated in the hypersonic facilities of GE, Grumman, and Northrop. These include the GE parallel flow shock tunnel (39-inch test section at Mach 10, 28 inches at Mach 20), the Grumman Mach 10 shock tunnel, the Grumman Mach 10, 36-inch pebble bed blowdown wind tunnel and the Northrop Mach 6, 10 and 14, 30-inch pebble bed blowdown wind tunnel. Heat transfer surveys will be conducted in the wind tunnels using paint techniques. The shock tunnels will be used for verification and shock shape definition. Plume impingement will be studied in the Grumman plume simulator detonation shock tunnel.

Evaluation of ablators, composite materials,and coatings will be conducted in GE's arc jet, rocket exhaust and electrically heated facilities. These include the tandem-gerdian hyperthermal 5 megawatt arc which can operate as a tunnel, free jet, channel flow or shroud; the Malta rocket exhaust test facility with 5-inch and 15-inch nozzle exit diameters; and the electron bombardment,induction, and laser heating facility.

Thermal properties of materials may be measured in the Grumman thermal laboratory. Capability exists for measuring thermal conductivity of materials and composites from -300°F to +2000°F and emissivity/absorptivity from -300°F to +3000°F in vacuum or at atmospheric pressure.

3.3.2.3 Advanced Research/Technology

General Electric has a unique and outstanding record in the development, characterization, fabrication and application of thermal protection material systems which have been flown on over 30 major vehicle systems. This experience is further enhanced by the development of long-life, superalloy and refractory metal systems, such as the Rene series, for jet engines, nuclear space power and reradiative thermal protection systems. A few pertinent examples follow:

- Developed the technology base for refractory metals and superalloys for the ASSET vehicle, the first operational heat sink (Mk 2) and metallics for WAC and Reentry F vehicles
- Developed the first foamed silicone ablator designed for the lifting entry environment, flight tested on Mk 12, MBRV, Mk 3, MA-8 and X-15 and was the only aerospace organization providing low cost materials for AF minimum cost booster study program. Leader in the development of graphite, carbon-carbon, inorganic reradiative and antenna window materials; graphites flown on AJC nose, Mk 3/CTP fins, TVX, WAC frustum and nose and RVTO 911
- Designed and developed a successful thermal protection for the control/body surface interaction heating environment for the MBRV.

3.3.3 Structures

The Grumman team's background of experience in the design of aerospace structures spans the entire range of shuttle requirements. Grumman has expertise in lightweight spacecraft as well as aircraft structural design, Northrop has large airframe structure experience, Aerojet-General is a leading designer of large aerospace tank structure, and General Electric has an extensive entry vehicle and high temperature metallic applications background.

3.3.3.1 Advanced Research/Technology

Grumman has conducted a number of advanced development programs in which the focus is upon advanced structural concepts. Examples of these programs are:

- Full-scale coated tantalum/tungsten alloy hypersonic rudder, successfully loaded and heated to a 3000°F peak temperature at WPAFB
- High-temperature heat shield panels. Designed in HS-25 alloy and successfully loaded and heated to 1800°F at Grumman. These are insulated load bearing heat shields capable of withstanding repeated hypersonic entry cycles
- Titanium electron beam welded box beam. Currently being employed in the design and construction of the F-14 wing carry-through box

- Full-scale boron composite box beam, successfully completed fatigue and ultimate load testing at 260°F at WPAFB. Currently being employed in the design and construction of the F-14 stabilizer

At Grumman, materials investigations are underway on high-temperature oxidation, thermal protection systems and materials, glass and glass ceramics and stress corrosion. In our work on high-temperature fibrous insulation, we have emphasized design and fabrication of insulator configurations compatible with heat shield configurations. We have studied fibrous textile zirconia in tapes, cloth, and felted forms for rigidization into insulation blocks and blankets, and their thermomechanical and erosion properties have been evaluated.

A major NASA-supported research effort at Grumman is developing finite-element methods for analysis (plastic and large-deflection) of complex, built-up structures. Emphasis has been placed on structural response to cyclic and reversed loading into the plastic range, involving membrane and bending effects in structural elements and combinations of the two. The effects of finite deflections in both elastically and plastically deforming structures have also been treated.

General Electric has conducted extensive investigations of structures and materials in association with its entry vehicle programs. Some of these programs have been identified in Subsection 3.3.2.3. The work has required supporting efforts in such areas as shell analysis, vehicle optimization studies, penetration load analysis, refractory anisotropic analysis, heat protection system analysis, shock, vibration and acoustic environments, behavior of orthotropic structures, experimental structural mechanics and static and dynamic structural analysis.

Northrop is currently producing the entire 153-foot long fuselage section of the 747 jetliner. Each ship set comprises 27 panels with eight doors and other assorted assemblies. The largest of the panels, 17 x 40 feet, is constructed of aluminum skin with bonded doublers and triplers with stringers and frames.

3.3.3.2 Analysis Techniques/Methods

- Grumman, Integrated Design Analysis System (IDEAS) - Most of the analysis capabilities required for the shuttle are contained in this system. It is a systematic integrated program for deriving all critical internal loads from the basic requirements of the external conditions. Structural evaluation of candidate shuttle configurations using this technique will include calculations of external applied loads, flutter characteristics, thermo and aeroelastic effects on air load distribution, divergence, shock response, and internal structural loads and deflections including thermal effects (Refer also to Subsection 2.2.1)
- Grumman, STARS II Shell Analysis Program - This program is a numerical integration analysis for axisymmetric shells of revolution, developed for NASA under Contract No. NAS 8-2113. This program covers problems associated with asymmetric loading, temperature effects and nonlinearities
- Grumman, Structural Design for Optimum Weight - This program is being developed for the Air Force (under Contract No. F33615-69-C-1278) for use in optimizing large-scale structures subjected to both stress and deflection limiting constraints
- Grumman Contour Development Programs - Apply to rapid construction and curve fittings of all shapes for full-scale model tests
- General Electric Safe and Orthosafe - Stress analysis by a finite elements computer program. The basic element is a convex quadrilateral in which no interior vertex angle can be greater than 180 deg; system of computer routines for the general thermostructural analysis of multi-material, orthotropic, elastic bodies

3.3.3.3 Aerojet-General Experience in Large Tank Design and Fabrication

Aerojet-General is a leader in the field of composite material and filament-wound tank development. Among its accomplishments in analysis, design, fabrication and test are the following:

- Development and production of Polaris A-3 and Minuteman filament-wound rocket motor cases
- Development and fabrication of the Titan I, II and III rocket chamber reinforced plastic skirt extension
- Design of filament winding machinery and equipment, including a machine capable of winding pressure vessels 260 in. in diameter by 54 in. long
- Design and development of segmented aluminum and steel mandrels for Polaris and 260 in. diameter filament-wound vessels
- Design and development of techniques for the curing of large diameter parts for Polaris filament-wound cases
- Development of impregnation processes and equipment

- Development of structural analysis techniques for many specific types of composite structures

3.3.4 Propulsion

Grumman and Aerojet-General represent noteworthy experience in rocket and air-breathing propulsion system technology. The LM, F-14, Minuteman, Apollo SPS, Polaris and many other major programs have all contributed to the capability of this team. Grumman and Aerojet-General bring a long history of accomplishment in engine design, development, and integration as well as propulsion system tankage and component development system performance analysis and system integration to the shuttle program.

3.3.4.1 Analysis/Testing

AIR-BREATHING PROPULSION SYSTEM – Grumman has designed the engine air inlets, secondary air system, engine exhaust nozzles and integrated the engine with the airframe on such aircraft as the A-6A, F-11F, F-111, F-14 and Gulfstream II. This experience includes work with normal shock inlets as well as fixed and variable-geometry inlets and high-speed inlets. We have extensive background in the design of exhaust nozzles and in the methods for determining minimum-drag nozzle-fuselage interactions.

At Grumman, aircraft propulsion system performance covers basic installed internal thrust, as well as the changes in external forces that vary with power level, such as forebody drag as a function of inlet mass flow ratio, and aft-fuselage drag as a function of nozzle pressure ratio and nozzle area.

Computers are utilized to establish an accurate evaluation of installed engine and system component performance and total aircraft performance. These techniques will be extremely important to the success of the shuttle study since the cruise air-breathing propulsion system performance is a critical factor in sizing both the booster and oribter payloads.

ROCKET PROPULSION – The Lunar Module program has provided experience in the analysis, design and development of rocket propulsion systems including rocket engines, propellant feed systems, cryogenic and stored gas pressurization systems as well as establishing the criteria for and conducting vehicle level propulsion system hot firing tests to man-rate rocket propulsion systems.

The background acquired from the LM descent and ascent propulsion systems will be applied to the main propulsion system on the shuttle. Grumman is the only company to have mated a rocket engine to its propellant feed system in flight vehicles without preflight firings. This approach will be explored for shuttle application.

Various Aerojet facilities have been engaged since 1945 in studies related to storage and delivery of cryogenic fluid. More than one billion pounds of fluid, i.e., liquid hydrogen (500,000 lb), liquid nitrogen, liquid oxygen and liquid fluorine have been used in this work under NASA and DOD contract.

Under U.S.Air Force Contract AF 04 (611) - 5170 (Project Hydra), Aerojet conducted analytical and experimental studies of LOX/LF_2 with ablative thrust chambers, analytical and experimental studies of pressurization systems, and mission studies including stage sizing studies using existing boosters.

The pressurization studies were of liquid hydrogen expulsion with gaseous hydrogen as the pressurization fluid. As part of this investigation, tests were conducted to determine the effects of sloshing the liquid during expulsion and the effects of storing the pressurization gas in auxiliary tankage inside the main propellant tank.

Other significant pressurization studies provided by Aerojet include the following:

- Study of pressurization systems for liquid propellant rocket engine (NAS 5-1108)
- Investigation and development of propellant feed systems for space vehicles (NAS 7-169)

REACTION CONTROL SYSTEM – The LM and the OAO provide experience in reaction control systems which covers bi-propellant and cold gas systems. Computer programs developed for the LM and OAO to predict dynamic and steady-state performance of the total reaction control system have been expanded to the space shuttle problem. Computer programs are being used to evaluate both high- and low-pressure LOX/LH_2 stems. Mathematical models are available to evaluate turbo-pump, turbo-compressor, thermally pressurized, and low-pressure auxiliary propulsion systems.

3.3.4.2 Design Tools/Data

Grumman's rocket propulsion analytical methods include the following:

- Computer program for the simulation of liquid systems for a multipropellant tank fuel system
- Computer program that simulates gas pressurization systems and is capable of predicting system performance
- Propellant thermochemistry computer programs

A theoretical thermochemical program which will calculate concentrations of thermally ionized species in the combustion products, as well as the more customary performance parameters has been developed:

- To calculate the theoretical transport properties of multicomponent reacting gas mixtures
- To calculate the theoretical properties of any arbitrary gas mixture, such as combusted jet fuel/air or rocket engine exhaust gases

3.3.5 Integrated Avionics

Grumman and GE combine the strong capabilities of each company in the critical shuttle avionics technology areas. Of particular importance is the team's experience in data management systems; guidance, navigation and controls systems; flight controls technology and control and display systems.

3.3.5.1 Data Management Systems

The Grumman team has extensive experience in DMS component design, development and integration. The main components of these systems -- the computer, the standard interface unit, and the data multiplexing components -- are discussed below.

In computer design, Grumman's experience includes the integration and software development of the L304 multiprocessor for the E-2C aircraft and the integration of the primary and abort guidance computers on the LM. More recent experience has been gained in the synthesis and integration of the weapons system central computer on the F-14. General Electric's integrated medical and behavioral laboratory measurement system (IMBLMS) performs trend analysis, pattern recognition, data compression and reduction and sequencing and control.

In addition, GE is currently defining the information management system, including the checkout function, for the NASA Phase B space station/space base study.

Experience in multiplexing data systems includes the aircraft integrated data system (AIDS), a GE system of party-line data buses servicing remote multiplexers, and Grumman's multiplex data bus system on the VSX, capable of handling 200 Kbps of aircraft data. In addition, Grumman is developing a coaxial multiplex on-board checkout system for the E-2C aircraft.

Experience in the development of standard interface units (SIU) includes GE's data acquisition remote terminal (DART), and adaptive controller processor (ACP), a preprocessor for large distributive data systems using built-in limit checking. Grumman's SIU experience includes SCRAM (signal command readout and alarm module) which combines the checkout and interface functions on the E-2C, and CICU (computer integrated control unit) developed in-house for the F-14A.

On-board checkout systems experience includes development and integration of OBC systems for E-2A, B, C; A-6A, E; F-14A; EA-6B; OAO and LM. A current Navy study is underway to develop an advanced OBC system for the F-14C. This experience includes:

- F-14A OBC system uses AWG-9 computer
- E-2C OBC system uses L304 computer and six identical Grumman designed computer terminals
- Advanced on-board checkout program to monitor F-14A engine inflight status, health, and performance

3.3.5.2 Guidance, Navigation and Control Systems

Grumman's experience most directly related to the space shuttle system includes design, development, and integration responsibilities for the Apollo LM primary (GFE) and abort guidance, navigation and control systems (GN&C). In addition, Grumman has had prime contractor responsibilities for design, development and integration of the aircraft GN&C systems for advanced aircraft including the F-14, EA-6A/B, A-6A, E-2A, and C-2A aircraft. All of this experience includes GN&C system/pilot interfacing. The Apollo LM experience includes:

- Lunar ascent and descent GN&C
- Rendezvous and docking GN&C
- On-board GN&C autonomy with provisions for ground updating
- On-board inertial reference subsystem alignment via on-board optical alignment equipment

The aircraft GN&C system experience includes all on-board systems operational interfacing with ground navigation aid systems with which the shuttle system on-board GN&C will be required to interface for cruise back, ferry flight, etc., operations.

3.3.5.3 Flight Control and Automatic Landing Systems

Grumman experience includes responsibility for the design, development and integration of FCS's for the A-6A, EA-6A/B, F-14, etc.

GE's experience in FCS development includes:

- Fly-by-wire systems - Major participant in the 681J design competition for a high-performance, integrated FCS for future supersonic Air Force aircraft systems. An active quadrax redundant system engineering model, developed by GE for the SST, satisfies the FO/FO/FS criteria

- Self-adaptive systems - A leader in this area, GE designed and built the active, triple redundant autopilot for the F-111. GE also developed, for reentry vehicles, a discretely adaptive flight control system that adjusts compensation parameters at discrete points in the flight regime

GE designed and developed an automatic landing system for the Boeing 707-80 aircraft using a fail-operational, triplex, incremental digital computer which controls all three axes and dampers. Incorporating triplex sensors and actuators, this system brings the aircraft down through flare and touchdown. In addition, Grumman integrated an automatic all-weather carrier landing system (AWCLS), operational on A-6, E-2A and C-2A aircraft. In addition, Grumman developed and tested an automatic throttle control system for the A-6 airplane.

3.3.5.4 Controls and Displays

In the area of controls and displays, Grumman flew one of the first heads-up displays in the F-111B. The F-14A also uses an advanced heads-up display. In addition, we designed and integrated several multipurpose CRT display systems; examples are:

- A-6, F-14 - Horizontal displays for display of radar, navigation, ECM and E-O sensor data
- F-14 - Vertical display for display of combined TV and vertical situation. This display utilizes self-generated symbology in all modes. Grumman flew the first integrated multipurpose vertical situation display in the A-6A aircraft which is now operational in all A-6A's.
- Combined command and control display used in E-2A, B and C, interfaces directly with computer-generated data, and processed and raw radar data

3.3.6 Weight Control

Weight control and accurate weight estimating is an essential part of the shuttle definition study.

3.3.6.1 Advanced Technology

This is concerned with application of the Grumman developed comprehensive system of weight estimating methods. Estimating equations and charts used in the early stages permit rapid configuration weight checks. These Grumman developed methods, based on an abbreviation of the normal design procedure (load distribution, arrangement, geometry, member sizing weight determination), have been formalized, programmed for IBM and evaluated statistically for estimating reliability. They permit estimation of even non-conventional configurations with high confidence. Multistation analysis methods for the structure are brought to bear for final analysis.

3.3.6.2 Weight Optimization

The application of weight estimation technology is handled by the weight optimization group. This group works directly with the designers and analysts to assure constant attention to weight control. The F-14 program, utilizing the above techniques is within 140 lbs. of its original target weight of 53,500 lbs, with over 70 percent of the drawings released to manufacturing.

3.3.7 Reliability/Maintainability

Grumman's approach to reliability/maintainability is tailored to strike an effective balance between vehicle weight, performance, reliability, maintenance requirements, and overall mission success. Underlying these are program considerations of cost and schedule during the development phases and on into the operations phase.

3.3.7.1 Reliability

Among the techniques in use at Grumman to assess vehicle and component reliability are the following:

- Failure Mode and Effects Analyses (FMEA) - This technique and Single Point Failure Analysis (SPFA) were pioneered at Grumman and have been extensively developed and applied to identify potential failures having an impact on crew safety, mission success, and equipment performance

- Overstress Test Techniques - Grumman is a leader in developing overstress test techniques and in using them for equipment development, reliability improvement programs, and as a means of multiple source product selection

3.3.7.2 Maintainability

Various techniques have been developed which are used to build in maintainability at Grumman. Among these are:

- Single Path Logic Diagram Analysis (SPLDA) - By identifying all maintenance tasks and arranging them in their proper sequence, based on the most probable frequency of occurrence, the SPLDA provides a systematic and logical approach to maintainability analysis, and furnishes a means to update predictions of M parameters. Any impact on M caused by design change may be assessed with this technique
- Optimization of Equipment Location for Maintenance - Techniques, procedures, policies, data, and criteria have been built up using mockups to assist the location of equipment to minimize maintenance time and provide access, working space, test points, and visibility
- A data bank, incorporating both in-house and field collections of malfunction, repair, maintenance, operating time, and operational data, is computerized for providing background material for such analyses as system costs, maintainability parameters, system and equipment failure rates, mission reliability, availability, and life cycle costing. These data enable early determination of alternative system designs through trade-off studies based on facts

Nondestructive Testing - The nondestructive test facilities at GE include radiography, ultrasonics, eddy current, thickness and dielectric measurements microwaves, radiometric testing, precision gaging and infrared test equipment

3.3.8 Combined Environments Testing

Environments that are critical to the design of flight vehicle components include: static loads, vibration, shock, temperature, vacuum and acoustic loads. We will be testing candidate structural components under various combinations of these. Representative experience of this type follows.

3.3.8.1 Thermal-Vacuum-Vibration

LM descent stage base heat shield: this article was tested in high vacuum (less than 10^{-4} torr). Temperature and vibration were applied respectively by quartz lamps and a shaker, both mounted inside a large vacuum chamber. Structural and thermal performance was measured from 0° to 2200°F and random vibration was applied over a spectrum having a g rms of 3.6.

3.3.8.2 Temperature and Structural Load

Tantalum control surface for reentry vehicle: a combination of temperature and pressure was applied to this structure by use of quartz lamps and hydraulic loading cylinders respectively. The test was performed by Grumman at WADC. Temperature range was up to 3000°F.

3.3.8.3 Combined Temperature and Acoustic Loading

F-111 aft centerbody: this article was tested at WADC with combined temperature and acoustic loadings. Temperatures up to 1200°F were obtained with quartz lamps, and acoustic levels up to 164 db were provided by the Aero-Acoustic Lab facility.

3.3.9 Flight Dynamics

Grumman's flight dynamics experience includes many aircraft as well as current Apollo, OAO and F-14 programs.

3.3.9.1 Design Tools/Data

Grumman-developed computer programs that are applicable to the space shuttle include the following : automatic and manual rendezvous; automatic stationkeeping and docking; orbit prediction; ascent and booster performance evaluation; re-entry design; trajectory optimization; aircraft navigation system performance; generalized linear error analysis (100 error state Kalman filter programs); deterministic inertial navigation (Kalman filter program); and multi-satellite and ground station tracking orbit determination program.

Techniques used for flight dynamics analysis include: statistical analyses for linear systems; Monte Carlo nonlinear system analysis; recursive estimation Kalman and maximum likelihood filtering; trajectory optimization and classical/modern linear and nonlinear control system analysis and sampled-data analysis.

Our NASA-and Air Force-supported research and aerospace flight trajectory optimization techniques have been applied to such diverse trajectory optimization problems as SST takeoff with engine Mach

No./temperature limitations and constraints on sonic boom overpressure, 3D orbital rendezvous optimization, and interplanetary trajectory studies.

3.3.9.2 Facilities/Testing

Grumman simulation experience includes many aircraft programs as well as current Apollo, OAO, A-6, and F-14 programs. F-14 simulators related to the shuttle include a landing simulator design and study on the motion simulator and a dedicated F-14 fixed base simulator for both high speed and low speed flying qualities studies. Space shuttle related LM experience includes rendezvous and docking simulation, guidance/control software verification, and mission crew verification.

Grumman's systems simulation laboratory has the following capabilities: visual display generation; physical environment simulation; crew station and display, both fixed and moving base; and systems hardware integration.

The LM full mission engineering simulator/flight control integration (FMES/FCI) simulation facility is a real-time hybrid computer, piloted simulator using both fixed and moving base crew stations. Six degree-of-freedom motion equations are used in the simulator to describe its motion.

Northrop's lifting reentry vehicle laboratory contains a six-degree-of-freedom analog entry simulation in which the vehicle rigid body equations of motion are simulated with all important inertia and aerodynamic coupling. The forces acting on the vehicle are applied to trajectory equations over a rotating spherical earth. The control system components are represented by appropriate transfer functions, and control surface deflections and deflection rates can be limited. Reaction control with threshold networks are simulated. This simulation operates continuously from entry into the effective atmosphere (usually taken at 60 nautical miles) to an altitude of 100,000 feet, and can be rescaled for high dynamic pressures and operated to an altitude of 15,000 feet for abort cases. The simulation includes fully automatic and manual guidance.

3.3.10 Systems & Operations Analysis & Integration

The primary objectives of our systems analysis and integration activities are:

- Definition of missions and system-level requirements
- Planning of flight missions for both nominal and contingency operations
- Analysis of system performance capabilities
- Assurance of system and element-level functional and operational compatibility

3.3.10.1 Mission & System Analyses

Grumman was the prime mover in developing the concept of critical design missions and the design reference mission for the Apollo program. This concept results in a powerful mechanism for analyzing and formulating the spacecraft system requirements.

A plan for collecting, organizing and maintaining analytical and operational data was developed during the LM and AAP/LM-A programs. The data is published as a "Spacecraft Operational Data Book" (SODB) which serves as a single official source book for all operational constraints and hardware performance parameters.

The "Timeline and Consumable Usage" computer program (T-CUP) is utilized for rapid construction and alteration of detailed mission and mission block timelines with accurate presentation of consumable usage.

To verify the level of performance prior to availability of hardware, complete system math model simulation of all flight hardware was developed for the LM which formed the basis for the present LM Full Mission Engineering Simulator (FMES).

Missions and system analysis technology is directly applicable to the space shuttle program for generation of critical design and reference missions, maintenance of a design data book, and verification of system performance capability.

3.3.10.2 Operations Analysis

TEMPO will support Grumman in performing an economic evaluation of the impact of the Space Shuttle on NASA and DOD space activities in the decade of 1970/80. Since its inception in 1956, TEMPO has been engaged in over 700 long-range studies for governmental agencies-domestic and foreign-and industry with a technical staff of over 200 scientists, engineers, economists, mathematicians, physicists, etc. Space programs have been a particularly strong interest as follows:

- TEMPO conducted a study for RESD two years ago on future NASA requirements for reentry vehicles twenty years hence. An assessment of the future economic outlook and the international environment was made and related to future U.S. space programs. Specific applications such as space ferry, space rescue, multi-purpose spacecraft were examined.

- TEMPO developed for MSVD, Valley Forge, a methodology for a cost evaluation on a military orbital development system (MODS). This consists of manned space station in a near earth orbit with crew rotation and re-supply provided by Gemini or Apollo type ferry vehicles with Titan III or Saturn C-1B boosters.
- TEMPO just completed a 1969 study for NASA on management alternatives in regard to the Mississippi Test Facility. Support of the Space Shuttle program was one facet that was analyzed
- TEMPO conducted a study on Satellite Maintenance and Repair Techniques. This is on the economic feasibility of using man in space for the repair of orbiting mission satellites.
- TEMPO is preeminent in the areas of economic analysis and cost-effectiveness. One early in-house project is entitled Economic Analysis in the Selection of Space Systems.

3.3.10.2 Systems Integration

The major function of systems integration is to assure that all physical and functional requirements for the system and its elements have been identified and satisfied in the most logical and economical manner. System and subsystem level functional diagrams and descriptions are generated which serve as the baseline for system design and also serve to identify all interfaces, both internal and external to the system.

3.4 PEOPLE BRING EXPERIENCE TO THIS STUDY

Lawrence M. Mead - Vice President and Program Director

Prior to his currect assignment, Mr. Mead directed FX/VFAX advanced fighter studies and directed the conceptual evaluation of the F-14 air superiority fighter. Subsequent to the award of the RDT&E contract, Mr. Mead was appointed Vice President and Director of F-14 Product Operations. In this capacity he was responsible for the gearing-up and organization of the Manufacturing Engineering, Tooling, Material, Production, Machining Operations, Quality Control and Planning Departments for the manufacture of the first test and flight articles. Concurrently, he was Chairman of the Corporate Titanium and Boron Composite Committees.

Mr. Mead's many accomplishments of 29 years in the aerospace industry include structural design responsibilities on fighter aircraft from F6F to F9F, the design and development of the XF10F-1 variable sweep fighter, and F11F fighter aircrafts. He has also directed the Preliminary Design and Advanced Systems Department. He directed the design development of the A-6A from inception to Navy acceptance trials.

Mr. Mead has BSE and CE degrees from Princeton University, and has graduated from the Harvard Business School's Advanced Management Program. He is an Associate Fellow and a member of the Technical Committee on Management of the AIAA.

Thomas J. Kelly - Deputy Program Director

Mr. Kelly, as the LM Assistant Program Director was responsible for all engineering activities on the spacecraft. Since the inception of the Program at Grumman, he has served as Project Engineer, Engineering Manager and Vehicle Test Manager. Dubbed "Mr. LM" at Grumman, he has been involved in the spacecraft engineering effort from its feasibility study stage to its latest operational success. Prior to the Apollo Program, he directed numerous company-sponsored studies; he was propulsion engineer on the Rigel Missile and F-11F aircraft programs.

Mr. Kelly holds a Masters of Science in Mechanical Engineering from Columbia University and is a member of the AIAA Technical Committee for Space Systems.

Mr. Kelly, a Sloan Fellow, is presently attending the Alfred P. Sloan School of Management at M.I.T. enrolled in the Fellows Program in Executive Development. At the same time, he has been closely following the Shuttle Study activity and will resume full-time duties in early June 1970

Frederick Raymes - Assistant Program Director

Mr. Raymes has 18 years of spacecraft, launch vehicle, and high-speed aircraft experience. In his most recent position as Manager, Shuttle Technology and USAF Programs at North American Rockwell, Space Division, he directed Shuttle Phase A studies, related company-sponsored R&D projects, and NASA Space Shuttle Space Task Group supporting activities. Prior to that he was responsible for all manned Logistics study activities covering the spectrum of Apollo derivatives to new systems for Space Station resupply. He will bring to the Space Shuttle Study, experience blending the development of high-speed aircraft (X-15/B-70), spacecraft (Apollo), and lifting entry systems (Prime/X24A), in various management/technical positions at North American Rockwell, Aerospace Corporation, and Redstone Arsenal ABMA.

He is a member of AIAA Technical Committee for Space Systems, and holds BSME and MSBA degrees from California State College at Los Angeles.

Table 3-1 Associate Management & Personnel Resumes

HUTTON, JOHN G., DR. Manager, G E Space Shuttle System, (G E) General Mgr Light Military Electronic Department. Introduced microelectronic computer, cryogencies, thermoplastic recording & silicon controlled rectifier circuits and power supplies. Developed first aircraft A.C. electrical system.

SCOVILLE, CURTIS L., Manager, Thermal Protection Programs, (G E). Program Mgr, G.E. RESD Space Transportation Programs. Chief of the Missile Systems Division - Development Directorate of DCS/R&D, Hq. USAF. Air Force representative on DDR&E Re-entry Programs Review Group, member Strategic Panel of the Air Staff Board. Director of START (Spacecraft Technology & Advanced Re-entry Tests) Program for SAMSO. Directed development & flight testing of first maneuvering re-entry vehicle.

SCANLAN, R.A., Manager Avionics Programs, (G E). 24 yr exp. Mgr, Advanced System Engineering. Engineering Mgr for Special Information Products. Program Mgr of VS(X) during Phase B. Engineering Mgr, Atlas Missile Radio Guidance System. Experienced all aspects of design of guidance control & instrumentation systems (NASA & AF).

CARTER, ANDREW G., Jr., Associate Deputy Manager, (GE, TPS). 9 yr exp. Chief Engineer, Advanced RV Systems, directed studies for space transportation, space escape, erectable RV systems, and nuclear recovery vehicles. Program Mgr - Research, advanced tactical weapon delivery system, and earth impact & penetration project; design & development nuclear warhead.

MORAN, J.F., Associate Deputy Manager, (GE Avionics). 15 years exp., Manager, Computer System Engineering. Experience in real-time Computer Systems and complex avionics systems.

BAIRD, BRUCE L., Associate Deputy Manager, (Aerojet). 20 years exp., Manager LM Ascent and Descent Propellant Tank Program. Extensive background in high-strength, light weight pressure vessels.

STALONY-DOBRZANSKI, J., Associate Deputy Manager, (Northrop). Mgr, Advanced Systems Study Projects Northrop Norair. Aerodynamicist for NASA Minimum Manned Lifting Body Entry Vehicle Feasibility Study. Project Mgr. Hughes Space Ferry. Asst Chief Aerodynamicist, AVRO.

OAKES, THOMAS, CAPT., Associate Deputy Manager, (Eastern Airlines). Director of Flight Operations, Advanced Projects for Eastern. His 35 yrs of flying & executive positions cover flight crew reqmts, development of area nav. equip. STOL A/C demonstrations. Member of industry and Government committees for development of new A/C & traffic control systems; member of the DOT Advisory Group to Secretary of Transportation

BLOOM, H.A., (G.E.). 22 yr exp. Mgr, Manned System Engineering activities; Technical Director, Space Station concept studies (including experiments and released data); Systems Engineer, Advanced Concepts of satellites and space rescue system; feasibility studies for Manned Space activities; aerodynamicist, developed nose cone configuration.

ETTUS, M.J., (G.E.) 20 yr exp. Program Mgr, Apollo Systems Organization - Planning and directing technical activities for on-board data management, ground checkout & avionics systems engineering. Manager, Simulation & Support Systems - Apollo Program. Subsystem Program Manager, Mercury, Centaur Vega, and X-15.

MULTHOPP, HANS (GE). 35 yrs. exp. Consulting Engineer-Mechanical Systems. Created widely-used methods of wing theory, body aerodynamics, and flow interaction. Adv. Design Chief at Focke Wulf (Germany) and Martin-Baltimore, responsible for development of many aircraft, missiles, and spacecraft. Most experience in lifting reentry vehicles: Martin-Bell Dynasoar/SV-5/PRIME/X-24A/GEM-4...

FLORENCE, D., (G.E.) 12 yr exp. Supervising Engineering, Thermodynamics Lab., GE-RESD. Directed Advanced Reentry Systems Thermal Analysis unit, design of thermal protection systems selection & sizing of the Slamast & G.D. S5 heat shield, definition of aerothermo environment for Venus entry mission and Mars Voyager. Analyzed reentry heating & ablation data for silicone elastomer & phenolic reinforced refractory material.

SMEVOG, R.A., (G.E.). 21 yr exp. Mgr, Research and Engineering, Reentry and Environmental Systems Division. Mgr Biosatellite Vehicle, Engineering Mgr of Satellite Vehicle Engineering design, develop & qual. of recoverable satellite vehicles, Manager of A45, K10, K11, H30, Biosatellite, TE and TT feasibility studies. Mgr vehicle shielding subsystem for all reentry/recovery vehicles.

Howard T. Wright, Manager Orbiter
Mr. Wright was responsible for the electronic system design and subsequent operation for both the LM program and the U.S. Navy airborne early warning aircraft, which he developed. His organizational ability was demonstrated by his participation in establishing the LM spacecraft assembly and test organization and directing the efforts of both Grumman and Grumman subcontractors in support of lunar missions at the Houston Mission Control Center. Prior to LM, he was Manager of Avionics Engineering.

Mr. Wright has a degree in Electrical Engineering from Cooper Union with graduate work in computer engineering and advanced mathematics. He is presently enrolled at Harvard University, until June 1970, in the Advanced Program Management Development curriculum. Concurrently, he has been keeping abreast of the Shuttle Program activity and will return to his post in June 1970.

Table 3-2 Orbiter Team

WATSON, ROBERT M., Deputy Manager Orbiter. 17 yr exp. Technical Director, Advanced Space Programs, directing studies for space station and other space vehicles. Assistant Program Manager, AAP, LM-A development involving the AAP workshop; Engineering Manager, design & development of Apollo CSM stabilization control system.

DONALDSON, COLEMAN du P., DR., Consultant (President of Aeronautical Research Associates of Princeton, Inc.) Consultant in aerodynamic heating, general aerodynamic boundary layer stability and general fluid mechanics General Editor of Princeton Series on High Speed Aerodynamics & Jet Propulsion. Head of Aero-Physics Section, NACS, Langley.

HOUBOLT, JOHN, C., DR., Consultant, (Vice President and Senior Consultant of Aeronautical Research Associates of Princeton, Inc.). Authority in field of aeroelasticity Associated with NACA/NASA 1942 through 1963 serving as Chief of the Theoretical Mechanism Division. Developed lunar orbital rendezvous concept; taught graduate courses in elastic stability, vibrations, A/C flutter & calculus of variations.

KELLEY, HENRY J., DR., Consultant, Developed variational methods and numerical techniques for trajectory optimization and optimal guidance approximations, researched accelerated gradient methods for parameter optimization, solution of ordinary minimum problems, featuring constraints & approximate solution of variational problems in terms of asymptotic expansions to A/C flight performance & mission shaping.

VAGLIO-LAURIN, ROBERTO, DR., Consultant. Specialist in high-speed aerodynamics, transition criteria, aerodynamic heating & system design. Consultant to the Institute for Defense Analysis, General Applied Science Laboratory, Inc., Advanced Technology Laboratories, & is on the AIAA Technical Committee on Fluid Dynamics.

KLINE, RICHARD L., Project Engineer, Orbiter. 15 yr exp., Assistant to V.P. of Engineering responsible for technical & administrative assignment in A/C and S/C projects. LM, LTA-8 technical chief. LM Thermal Shield Program Manager. Asst Chief of Corporate Thermodynamics Section.

MESSINA, FRANK J., Manager, Producibility & Manufacturing, Orbiter. 33 yr exp. Director, Product Manufacturing, Space Programs, responsible for Manufacturing Engineering, Tooling, Production, Machine Operations, & Planning & Control functions. Has wide background in all phases of development manufacturing.

KINGFIELD, JOSEPH, T.P., Manager, Quality Control, Orbiter. 28 yr exp. Director Quality Control, Space Programs; Corporate Deputy Director of Quality Control. LM Quality Control Manager (WSTF, MSC and KSC) background in Statistical Quality Control of development programs. Knowledgeable of NASA quality & technical requirements.

GOODWIN, CHARLES, J., Vehicle Design, Orbiter. 27 yr exp. Specializes in A/C configuration design. Program Director of Blue Streak (IRBM). Intimate knowledge of vehicle dynamics, major structural element design, manufacturing & test problems associated with advance concepts & designs. F-14 Project Engineer for design & Asst Eng'g Mgr of Associates.

BARNES, THOMAS G., Manager, Systems, Orbiter. 23 yr exp. Preliminary design studies for advanced manned spacecraft. Engineering Manager for LM modifications - Telescope Mount Mission; directed NASA contracted engineering studies of AES; Chairman of Apollo Mission Planning Task Force; Project Eng for NASA study for lunar logistic systems.

Table 3-2 Orbiter Team (Contd)

WOOD, FRED, E., Manager, Flight Mechanics, Orbiter. 16 yr exp. Systems Manager for Space Station Studies; performed feasibility studies of Grand Tour Interplanetary Mission using planet orbiters, probes & landers. Developed large hybrid simulation facility. Deputy Manager of LM Mission Support Engineering. Experience in A/C aero configuration developement.

MOHR, MICHAEL, T., Manager, Electronics, Orbiter. 17 yr exp. Mgr, Electronic Equipment Engineering. Board technical and managerial background in field of aircraft and space avionics.. Directed design & development of all electronic equipment used in GAC's products for past few years. Participated in the design of electronics for F-14.

THOMPSON, ROBERT, L., Manager, Fluid Systems & Propulsion, Orbiter. 19 yr exp. Active in the early design stages of LM propulsion & reaction control systems. Assistant Head of LM Propulsion Section, primary responsibility for ascent propulsion system. At KSC was responsible for mechanical, structural and fluid systems.

John Karanik, Manager Booster
Mr. Karanik was appointed Program Manager for the C-2A carrier logistic aircraft in 1962 and served in that capacity for four years. More recently, he was Program Director of the EA-6A tactical countermeasures aircraft.

He has extensive background in production engineering, preliminary design and power plant engineering. He supervised developmental engine installation for the F-5F, F-6F, F-7F, F9F, and F11F, served as Chief of Power Plant and then Chief of Systems Design.

Mr. Karanik has a B.S. from New York University, is a licensed Professional Engineer and attended the Cornell School of Management.

Table 3-3 Booster Team

PINTER, GEORGE, R., Deputy Manager, Booster. 31 yr exp. Staff Engineer to Director, Product Engineering Space Programs. Management of design and development efforts including LM Descent Engine supercritical helium pressurization systems & directed studies for Voyager.

WALDT, RICHARD, E., Manager Project Engineering, Booster, 20 yr exp. Project Engineer, advanced aircraft design and development, USAF and USN. As project engineer for EA-6A and EA-6B, directed vehicle design, development and test from inception to production hardware.

RUDES, FRANK, Manager, Producibility & Manfuacturing, Booster. 11 yr exp. Manufacturing Mgr, LM G.S.E. responsible for all manufacturing functions. Structural/environmental test engineer, developed a system to measure LM's ability to land on lunar surface.

LANGEVIN, ROGER, G., Manager, Quality Control, Booster. 10 yr exp. Q.A. Mgr for Advanced Space Programs. Background in manufacturing, product design, reliability and test in aerospace & electronic industries. Started quality system study implementing advanced methods of control of quality. Authored Corporate Calibration System Manual.

PAULSRUD, LEONARD, Manager, Vehicle Design, Booster. 30 yr exp. Configuration Leader, Advanced Space Programs — development of preliminary Orbiter & Booster configurations; LM Ass't Project Engineer — study & design of increased lunar staytime LM vehicle design & Integration Subsystem Mgr.

MC CAFFREY, RONALD, W., Manager, Systems, Booster. 18 yr exp. Project Engineer on advanced space systems (manned and unmanned). Missions & Operations Project Engineer for GAC phase B space Voyager capsule. Participated in AES Phase B Addendum Study.

HUBERT, JOSEPH, J., Manager, Flight Mechanics, Booster. 37 yr exp. Staff Asst to V.P. of Engineering involved in special assignment in Advanced Systems for four (4) yrs. Chief of Aerodynamics involved in missile & aircraft projects since 1947. Chief aerodynamicist for special projects at Messerschmitt Co., Germany.

STEIN, DONALD, B., Manager, Electronics, Booster. 21 yr exp. Electronics Project Engineer for Advanced Space Programs directed the electronic system design study for the space station program & Voyager programs.

PIRY, MARCEL, Manager, Fluid Systems & Propulsion, Booster. 20 yr exp. Authority in Space Power Systems & Space Propulsion Systems. Cognizant engineer of LM ascent engine. Group leader of overall ascent stage propulsion. Was instructor of Internal Combustion Engines at University of Minnesota. Was Mgr, Republic Aviation Space Lab.

Table 3-3 Booster Team (Contd)

ARSLAN, A.E., (Northrop). Structural Design, Booster. Mgr of Airframe Design, Advanced Aircraft Systems; Directed structural design & analysis of the X-21A. Design specialist in Wing & Empennage Branch; Proposal work on Boeing 747; studies of advanced structural materials. Patent on flap design.

CHEN, W.S., (Northrop). 17 yr exp. Aerodynamics and therodynamics of entry vehicles, missiles, A/C, Responsible for all aero-thermal analysis & design efforts. TPS Staff Engineer at AC Spark Plug, in support of TRFCS Programs, concentrating on hypersonic aerodynamics, heat & mass transfer to lifting & nonlifting reentry vehicles.

KALVISTE, J., (Northrop). 10 yr exp. Control system stability analysis, aerodynamic & control system simulation development and analysis of TRFCS at WPAFB (CTSF) (hybrid simulation of X-20 with actual hardware in the system). Control & stability analysis & simulations on the minimum Manned Lifting Entry Vehicle Feasibility Study Program.

Frederick Rowley, Manager, Operations

Mr. Rowley has spent 13 of his 26 years of aerospace experience directing Grumman's Flight Test Operations Department in the testing and certification of aircraft and space vehicles. He has participated in and supervised the development, test and evaluation of 17 military/commercial aircraft types and 3 NASA space projects. He piloted the first flight aircraft of the Mallard, Albatross, F-9F6, S-2F, E-1B and Gulfstream I.

Until his present appointment, he was Director of Safety, Space Programs, having been responsible for the safety program on the Apollo project.

Mr. Rowley has 20 years experience as engineering test pilot. He holds a degree in Mechanical Engineering from Drexel Institute of Technology.

Table 3-4 Operations Team

MALLOY, WILLIAM, T., Deputy Manager, Operations. 13 yr exp. Director of Support — Responsible for Ground Support Engineering, Training, Publications, Supply Operations & Field Service for all space programs. LM Asst Prog, Director.

CROSSFIELD, SCOTT, A., Consultant, Operations (Eastern Airlines Division V.P. — Flight Research and Development). Pilot of D-588-II & X-15 (included 130 air launch rocket flights). Division director of test & quality assurance for North American A/C and S/C.

PEARCE, JAMES, L., Consultant, Operations. Director of Apollo CSM Operations for North American Rockwell at KSC. Director of Apollo CSM test & checkout operations at Downey, Los Cruces, White Sands Missile Range and MSC. Previously was experimental test pilot.

WILSON, ROBERT, B., Consultant, Operations (Eastern Airlines Staff V.P. — Management services). Responsible for financial analysis, industrial engineering, 30 years experience in engineering, maintenance planning, facilities and cost control.

BEAUREGARD, ALBERT, J., Manager, Test, Operations. 29 yr exp. Spacecraft Director LM-7. Spacecraft Director LM-5, first on the moon. Responsible for vehicle design, assembly, test, checkout, launch, mission support & analysis. Test Mgr on E-2A, E-2B, C-2A. 11 yrs in Flight Test. Asst Chief Engineer at Lockheed (1947 to 1950).

PECK, HOWARD, Manager, Support, Operations. 23 yr exp. Deputy Support Program Mgr on LM, directed the planning & implementation of G.S.E., trainers, training program, spares & technical publications. Directed major test equipment design for LM & A/C programs.

YEZEK, ROBERT, W., Manager, Facilities; 14 yr exp. — Section Chief, Facilities Dept.; Overall management of facilities project efforts. F-14 Facilities Project Engineer. Corp Facilities Plan for VSX and VFX proposals.

REINERTSEN, NORMAN, Manager, Operations System Integration, Operations. 17 yr exp. Chief Engineer Product Support Dept responsible for managing & directing the design & development of all G.S.E., Factory Test Equipment, Training Devices, Development Test Equipment. LM Deputy Mgr for S/C Assy & Test.

DONNELLY, PETER, F., (Eastern Airlines). 10 yr exp. Mgr Special Project, Passenger Service — development of improved systems for passenger & cargo processing & handling. Coordinates planning for intro of 747 and L-1011. Eastern's development engineering representative for PAX & Cargo requirements. Senior Engineer, American Airlines, Power Plants. Development engineer for ITEK Corp.

MIZE, JAMES, C., (Eastern Airlines). 23 yr exp. Mgr, Material Logistics — Logistic support for maintenance & overhaul material requirements. Mgr, Material Control, Airframes & Structures — Initial provisioning & inventory control. Developed computerized system for inventory control.

Arnold B. Whitaker - Manager, Systems Integration
Mr. Whitaker has 24 years of major systems experience in the aerospace industry. He was Assistant Director of the Systems Technology Department until selected for his Shuttle assignment. As Systems Project Engineer for the LM program, he directed all systems engineering functions and was responsible for defining all system specifications, simulating the LM mission, developing reliability and system test programs and performing structural, thermal and dynamic analysis. He also conducted the Mission Analysis for F-14.

Previously, as Chief of Preliminary Design for Missiles, he directed systems studies and the technical proposal on the Navy's TFX missile system. Mr. Whitaker has an Aeronautical Engineering degree from M.I.T. and a Master of Science in Applied Mathematics.

Table 3-5 Systems Integration Team

RYAN, JOSEPH, M., Manager, Corporate Estimating. 13 yr exp. Manager, Central Pricing, responsible for all pricing & related cost analysis activities. Intimately involved in F-14 cost analysis. Background in costing, industrial engineering, tool engineering & production.

STERN, ERICK, Manager, Systems Analysis. 21 yr exp. Deputy Manager, Advanced Concepts Group, Advanced Space Dept. Directed technical development effort for Space Station proposal as Engineering Manager; Deputy Engineering Manager on LM. Directed OAO stabilization & control analysis, design, development, procurement & manufacture.

MOSS, HAROLD, M., Manager, Parametric Resource Analysis. 20 yr exp. Manager, Systems Technology in Operations Analysis, responsible for prediction of advanced technologies & application to alternative system requirements through parametric analysis. Director of Parametrics, vehicle design studies F-14.

Table 3-6 Staff

FERDMAN, SAUL, Manager, NASA, Advanced Programs. 22 yr exp. Director of Advanced Space Programs directing all phases of space studies. Director of Lunar Exploration & AAP, Director of Space Vehicle Development. Authority on flight test development.

COURTNEY, JOHN, J., Manager, USAF, Advanced Programs. 27 yr exp. Mgr Military Space Systems. Directs concept formulation, contract definition and studies related to new programs. Experience in Military Space product development, Defense and aerospace Systems Analysis, Weapon Systems Operational Analysis, Weapon Systems Management. Planning & Operational Model Design & Intelligence Systems Management.

HARRINGTON, JAMES, Regional Coordinator. 7 yr exp. S/C Director LM-6, (Apollo 12,) responsible for all aspects of operations from initial structural buildup through Final Assembly and checkout pre-launch, preparation for launch mission support. Was the LM-1 (Apollo 5) S/C Manager & Test Director for LM LTA-1, completely familiar with operations at KSC.

KATZ, ARTHUR, J., Manager, Supporting Research and Technology. 22 yr exp. Deputy Technology Director, Advanced Space Programs has technical and development responsibility for selection of areas of study, provides NASA and AF interfaces. Head of LM Thermal Protection System, authority on thermal control analysis, ablation & radiation heat transfer analysis.

JOHNSON, WESLEY, Manager of Weights. 18 years experience; responsible for weight activities on AAP leading to LM-A/LMMP awards. Project weight engineer on OAO. Proposal efforts on Project FIRE, AOSO, MOLAB, MORL and Apollo Command Module. Republic Aviation engineering F84F, XF103, F105 aircraft.

SHERMAN, HOWARD, Manager, Safety. 20 yr exp. Deputy Director, Safety, Space Programs, responsible for establishment and maintenance of safety (crew safety, flight safety, industrial safety and pad safety). LM Safety Director. Head of Crew Systems, responsible for establishing & integrating crew requirements.

MACLEOD, SCOTT, R., Chief Consulting Pilot. 24 yr exp. Director, Flight Crew Integration and Chief Consulting Pilot – establishes flight crew requirements for all manned spacecraft; tests & evaluates spacecraft. Aeronautical Research Scientist at NACA, Langley, LM Consulting Pilot – experienced in all pertinent S/C simulators (Mercury through Apollo).

ORGANIZATION & MANAGEMENT

4.1 Study Plan

4.2 Application of Related Effort

Section 4

4 – ORGANIZATION & MANAGEMENT

We have attempted to carefully tailor the shuttle program organization to maximize returns for the Phase B study. Every person assigned to the program has been carefully selected to fill a very specific requirement. We have devoted much thought to the assignment of outstanding men to each major study area. We have also worked to create a cohesive group that will make the most efficient use of this talent.

Larry Mead, a Vice President of the corporation, has been selected to lead our shuttle study. He brings to the program extensive experience in the design of modern, complex, high-performance aircraft and the management of such major projects as the A-6 and F-14. As program director, he is completely responsible for all aspects of the study. He will report through Joe Gavin, Senior Vice President – Space Programs, directly to Lew Evans, President of the Corporation. Because shuttle technology poses such an extreme challenge, Mr. Evans has appointed Grant Hedrick, Senior Vice President – Technical Operations, who directs all of the technical resources of the company, to act as his assistant and monitor progress of the program for the president.

In our opinion, the shuttle will combine the best features of a spacecraft and an aircraft in one vehicle. It is important to note that Grumman has extensive experience in both areas and combines all aerospace skills in a nondivisionalized company organization. Our most effective talent can be quickly brought to bear on any problem area. Our personnel work together extraordinarily well as a team because of their long association within this single organization. To provide maximum depth in key technology areas, we have augmented our team with talent from four other highly qualified and competent companies with relevant current and past experience:

- General Electric – Reentry thermal protection systems, electronics and shuttle economic analysis
- Northrop – Aero/thermodynamics and large structures
- Aerojet – Cryogenics and large rocket propulsion
- Eastern Airlines – Operations

The shuttle organization consists of four major study groups, each closely linked to the other: orbiter, booster, operations, and systems integration. A very senior and competent manager has been selected to lead each group.

All key personnel (including those from associate companies) will be located on one floor of Plant 25,our Space Center at Bethpage, during the entire study phase. The personnel of our associates will be integrated into Grumman's functional units. This will establish the face-to-face, instantaneous communications that are essential for meaningful results in such a study. It will also provide NASA with complete single-point contact and visibility.

Grumman has shown its capability to manage a wide spectrum of high-technology transportation systems for a wide variety of customers as evidenced by the following related programs:

- Spacecraft – Apollo Lunar Module, Orbiting Astronomical Observatory, LM-A (Apollo Applications), Dual-Mode Lunar Roving Vehicle
- Aircraft – F-14 (Mach 2+ air superiority fighter), EA-6B (electronics countermeasures), Gulfstream II (executive jet transport), A-6 (all-weather attack), E-2 (airborne early warning), C-2 (carrier on-board delivery), OV-1 (tactical observation)
- Watercraft – Hydrofoil Boat, PX-15 Long-Duration Research Submarine
- Train – 300 mph Tracked Air Cushion Rail Vehicle for Department of Transportation

On most of these programs, Grumman directed and integrated the efforts of several large company associates in achieving program goals.

Grumman's nondivisionalized structure will permit the experience and management techniques developed in these programs to be applied directly to the shuttle program. A detailed description of this management system and organization is presented in the following pages in the format of the required study plan. Following that is an explanation of the process that provides up-to-date information on supporting research and technology to the study, and a description of the Grumman team's specific company-sponsored programs.

4.1 STUDY PLAN

4.1.1 Introduction

We believe that Grumman's study plan will provide the framework for development of a successful economical space transportation system that minimizes developmental and operational costs while retaining the capability to support a variety of payloads and missions.

The thrust of our study plan is to develop a logically time-phased program that decouples and minimizes technical risks, requires minimum yearly expenditures, provides early operational capability, provides growth, and achieves the low operations cost objective. This is described in our study approach (Fig. 4-1). The details of our proposed study approach are specifically delineated in Section 2; the details of our study plan are provided herein.

Grumman Phase B studies demonstrate a successful management approach. Grumman has performed Phase B study programs for NASA and DOD and has demonstrated the ability to provide the right combination of scientific know-how and complementary management systems to do the job. Our NASA studies include the Apollo Extension System (AES), Apollo Applications Program (AAP/LM-A) and the Dual Mode Lunar Roving Vehicle (DLRV). Our Phase B work for DOD includes sophisticated weapon systems in air superiority fighters (F-14), integrated airborne command and control (E-2C) and electronic countermeasures (EA-6B).

The best of our aeronautics and astronautics technology experience directly relates to the space shuttle program. Our approach (Fig. 4-2) simply stated is:

- Understand and plan the job in depth
- Staff the program with top quality people
- Provide proven management to "make it happen"
- Control and direct the program with a credible management system

Recognizing that NASA and industry are now embarking on a space shuttle program to be produced during the next decade, we have structured our management and all of our planning to consider as overriding criteria, the ability to change and to evolve in response to the changing program needs and NASA direction. We are prepared to respond in a rapid, disciplined fashion. This is described in detail herein. We have structured the balance of this section to respond to RFP requirements, the referenced data requirement description (MA080A) and a complete study plan that provides NASA with a meaningful program control document. The specific benefits of our proposed organization and management system, along with our space shuttle work breakdown structure (WBS), logic networks, schedules, and manpower requirements are described. The data has been prepared to be immediately adaptable for use at an orientation meeting, as described on the data requirement list.

4.1.2 Organization

Grumman recognizes that the space shuttle study represents the next step in what must be a major portion of our business for years to come. We have assigned our best people and provided top management attention in depth to make certain that corporate resources are made available when needed. This corporate commitment to a space shuttle presents to us the opportunity to continue our participation in an integrated space program that will permit the nation to fully utilize this great new territory at reasonable cost.

Our space shuttle program provides short lines to top management. Our Space Shuttle Program reports to the President, L. J. Evans through Senior Vice President J. G. Gavin, Director of Space Programs at Grumman (Fig. 4-3). Mr. Gavin led our Lunar Module program from its inception. Grant Hedrick, Senior Vice President, has been appointed to assist the President on shuttle technical policy. He is a nationally accredited authority in the field of aircraft and spacecraft structural design. Mr. Hedrick is Director of Technical Operations and as such commands the entire technical resources of the company. This corporate relationship is described in Subsection 5.3. Special appointments such as this have been made in the past on major programs with outstanding results. Senior Vice President Richard Hutton provides executive level policy and guidance on the F-14 program.

Outstanding study program direction is assured. The selection of Vice President L. M. Mead as the Space Shuttle Program Director is further acknowledgement of the importance of this program. He fully understands the scope, timing, and cost implications of a new space transportation system. His broad experience in both development and operational program phases will provide the balance needed during the study phase. Experience such as this will assure technical, schedule, and financial realism of the study output.

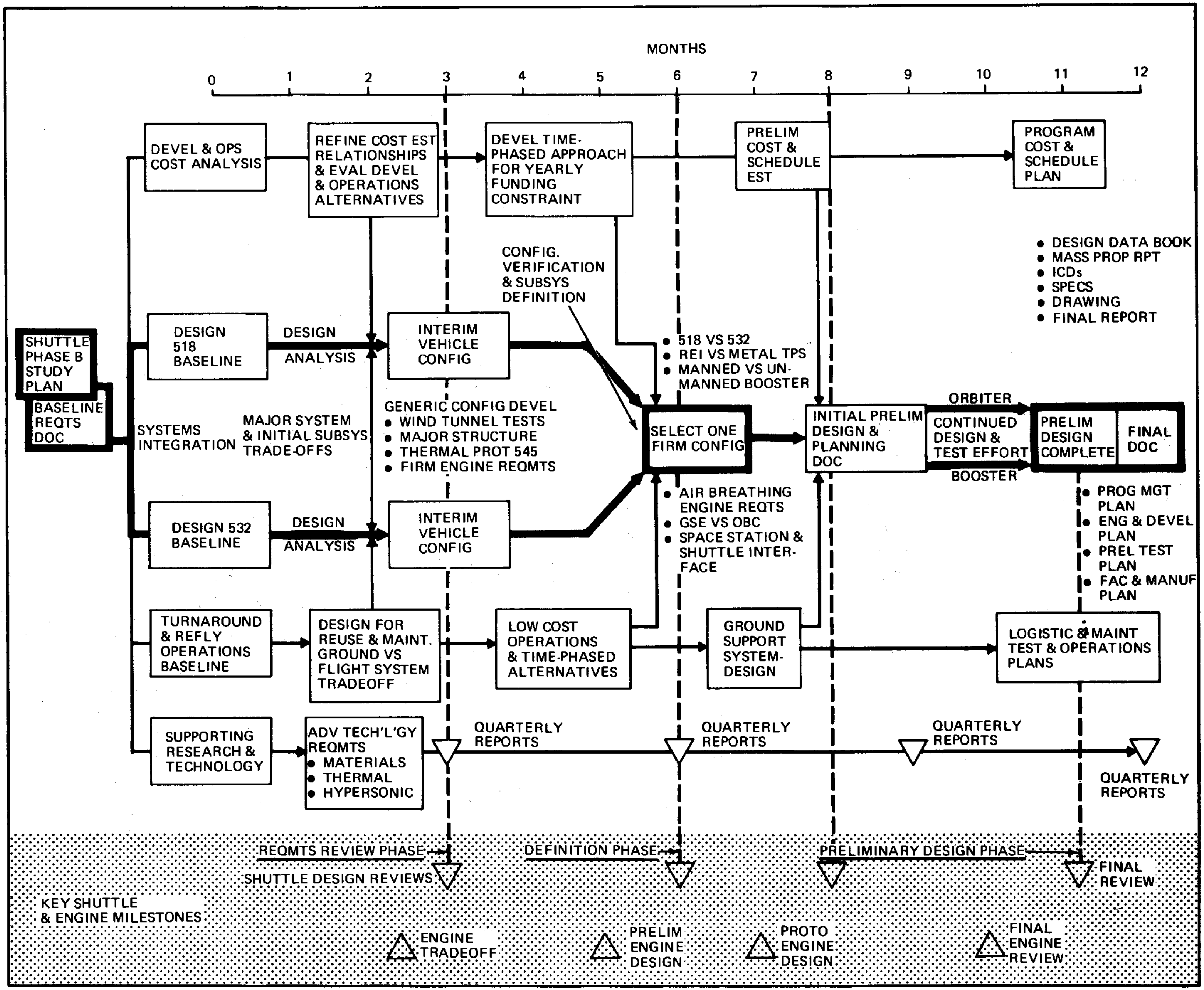


Fig. 4-1 Study Approach

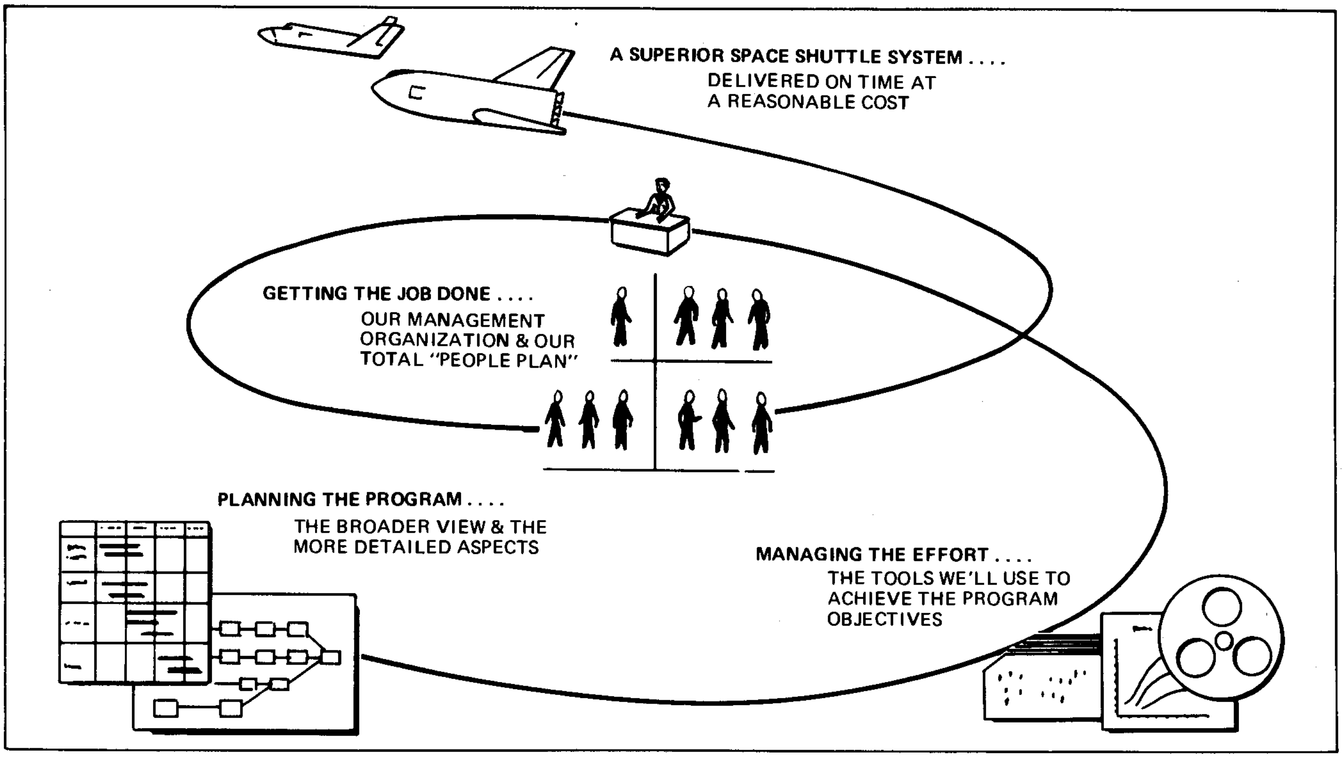


Fig. 4-2 Grumman Management Approach. *The best products are produced by top people working with a credible management system.*

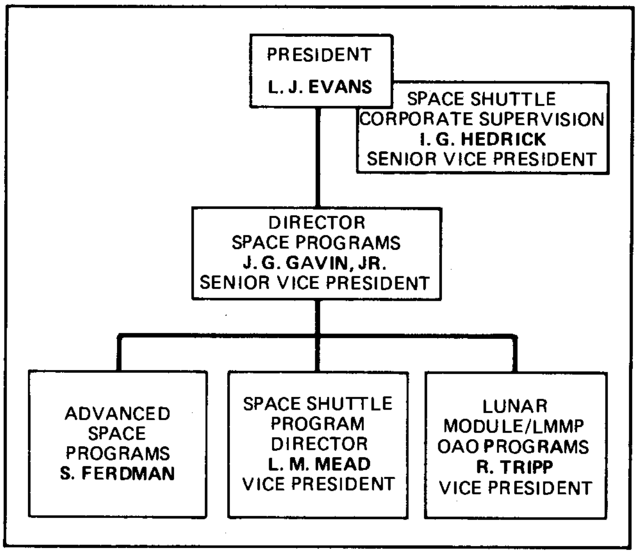


Fig. 4-3 Space Shuttle Corporate Relationship. *Direct line to the top provides proper emphasis and control and assures resource availability.*

Mr. Mead was responsible for the development of the A-6 Intruder aircraft, directed studies to improve the F-111B, and subsequently led the entire conceptual effort toward developing the F-14 weapon system. His experience with the successful development of difficult systems has earned him the high respect he commands from all his associates. He has directed the effort that led to this proposal and he has full authority for the overall management direction of the study and the accomplishment of all program objectives. Mr. Mead serves as the senior interface with NASA management for this program. He is responsible for all major program decisions that can affect schedule, performance, or cost compliance. As full-time study program director, he implements the contract and any changes or redirections, approves all program control documents, reviews status, and redirects efforts as required. Appointment or reassignment of all key personnel will require program director approval and NASA concurrence.

Strong, full-time assistance supports the study director. Full-time assistance roles (Fig. 4-4) are filled by two men with the capabilities essential to a superior study; Tom Kelly as Deputy Director and Fred Raymes as Assistant Director. Mr. Kelly brings his broad Lunar Module engineering development and test experience to the program. Mr. Raymes will infuse his extensive lifting entry, manned logistic spacecraft and Phase A shuttle study background into our Phase B effort.

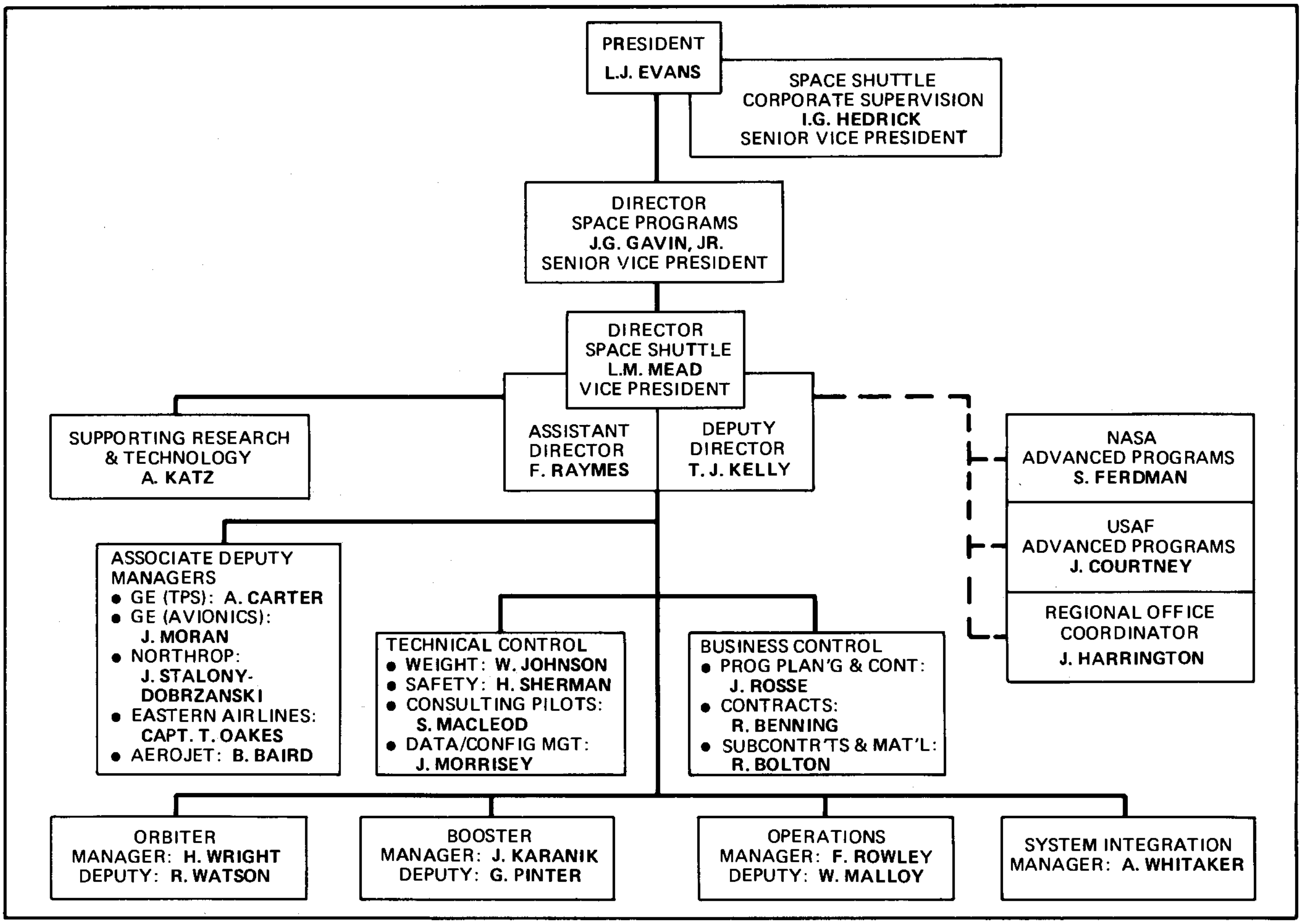


Fig. 4-4 Space Shuttle Phase B Organization. *Single point management of each major study element.*

Realism and credibility of study output are assured. Tom Kelly, dubbed "Mr. LM" at Grumman, was responsible for all spacecraft engineering activities from preliminary design through all phases of development and test. He is currently enrolled in the Alfred P. Sloan Fellows Program in Executive Development at MIT. He has maintained contact with our space shuttle activities and will return as a full-time participant in June. In addition to his role as full-time deputy to the study director, Mr. Kelly will assure rapid responsiveness and integrate shuttle inputs from NASA and the Grumman Offices at MSC, MSFC and KSC.

A strong manned logistics/shuttle background is incorporated. Mr. Raymes is well known in NASA and DOD for his program responsibilities on advanced manned logistics spacecraft studies, ranging from lifting entry spacecraft to Apollo derivatives. Mr. Raymes joined Grumman after completing the direction of the Phase A shuttle and technology activities at North American Rockwell. He brings the Phase A results and technology to our effort, and his broad background in spacecraft and aircraft design. In addition to his role as full time assistant director, he will oversee the application of shuttle related technology activity.

The program director's full-time staff provides complete control. A complete staff in key technical and business areas assists the study program directorate in controlling all aspects of the program. In the technical control area we have placed special emphasis on three vital areas: safety, weight control and pilot compatibility during the design process. Safety is emphasized to assure that safe and routine transportation is fundamental to our design. Weight control is essential because of the extreme sensitivity of the payload fraction. Grumman recognized the importance of the pilot in the loop early in the design and development of spacecraft and aircraft, and pioneered in the development of the consulting pilot discipline on both the LM and F-14 programs. These pilots act as the primary interface between Grumman and NASA astronauts. The shuttle-assigned pilots include those trained and experienced in aircraft and spacecraft engineering flight test programs. Grumman has assigned the consulting pilots the responsibility of assuring that the crew member's point of view is reflected in all facets of design.

In the business areas we have provided effective control in contracts, subcontracts and material, and program planning and control disciplines. We have centralized the planning and control functions. This provides an efficient operation, with independent and objective insight into all study program operations.

The associate deputy managers (General Electric, Northrop, Eastern Airlines and Aerojet) specifically augment our capability in key system and technology areas. They are responsible to the program director's office for supervision of their on-site personnel, and for providing the necessary interface with and resources of their respective corporations to support the overall study program. They work within well-defined work task areas within negotiated manpower levels. (Refer to Subsection 4.1.7 for the subcontract management plan and procedures). These managers have direct access to all resources in their own corporation and to their corporate in-house studies that would benefit this program.

The on-site associate managers' relationship to their parent organizations is shown in Fig. 4-5. It should be noted that General Electric Managers J. Moran and A. Carter report through R. Scanlan and C. Scoville, respectively, to Dr. J. Hutton, GE General Manager for Space Shuttle Programs.

Clearly identifiable managers streamline the interfaces. Our organization provides single point management for each of the vehicle elements to establish precise interfaces with the cognizant NASA centers. The organization is structured so that the Orbiter Manager, H. Wright, interfaces directly with his counterpart at MSC, and the Booster Manager, J. Karanik, interfaces directly with his counterpart at MSFC. The System Integration Manager, A. Whitaker, interfaces with the integration team at OMSF as well as the individual integration groups at each center. Recognizing the need to minimize the large costs involved in the turn-around/ground operations, we have established a group concerned primarily with the operations aspects of the study under the Operations Manager, F. Rowley, who will interface with KSC, MSC, and MSFC.

The clear delineation between orbiter, booster, operations and system integration provides the visibility required by the various responsible NASA agencies. The co-location of these four managers with the program director makes possible rapid decisions and coordination.

Key organizational elements emphasize responsibility and authority. Each space shuttle study program organizational element has its own manager, who has well defined responsibilities and authority for the successful completion of his assignment. The manager assigned on a full-time basis to the program will remain on the program throughout Phase B and into Phase C if we are the successful bidder. He controls all personnel in his organization; no one can be reassigned without his concurrence. The discussion that follows provides a full definition of the areas of responsibility for each of the major elements of the program. Specific study tasks are described in detail, man-loaded, and scheduled in Subsection 4.1.6.

Orbiter and booster groups organized for performance. The orbiter and booster study organizations, Fig. 4-6 and 4-7, are structured in a similar manner. The responsibilities and authority descriptions that follow are applicable to either vehicle. The manager is responsible for the daily operations of the study within the guidelines established by the program director. He has control of the committed resources and together with his deputies. translates the policies for the Shuttle Program into action items. Specifically, he:

- Acts as an interface with his counterpart at NASA
- Directs the preparation and implementation of detailed planning
- Participates in and approves all applicable technical decisions that can affect performance, cost, and schedule
- Approves technical reports and documents submitted to NASA

The deputy manager in both the orbiter and booster areas assists the manager in all of his duties; he is the manager's direct representative, assuming all authority and responsibility in his absence.

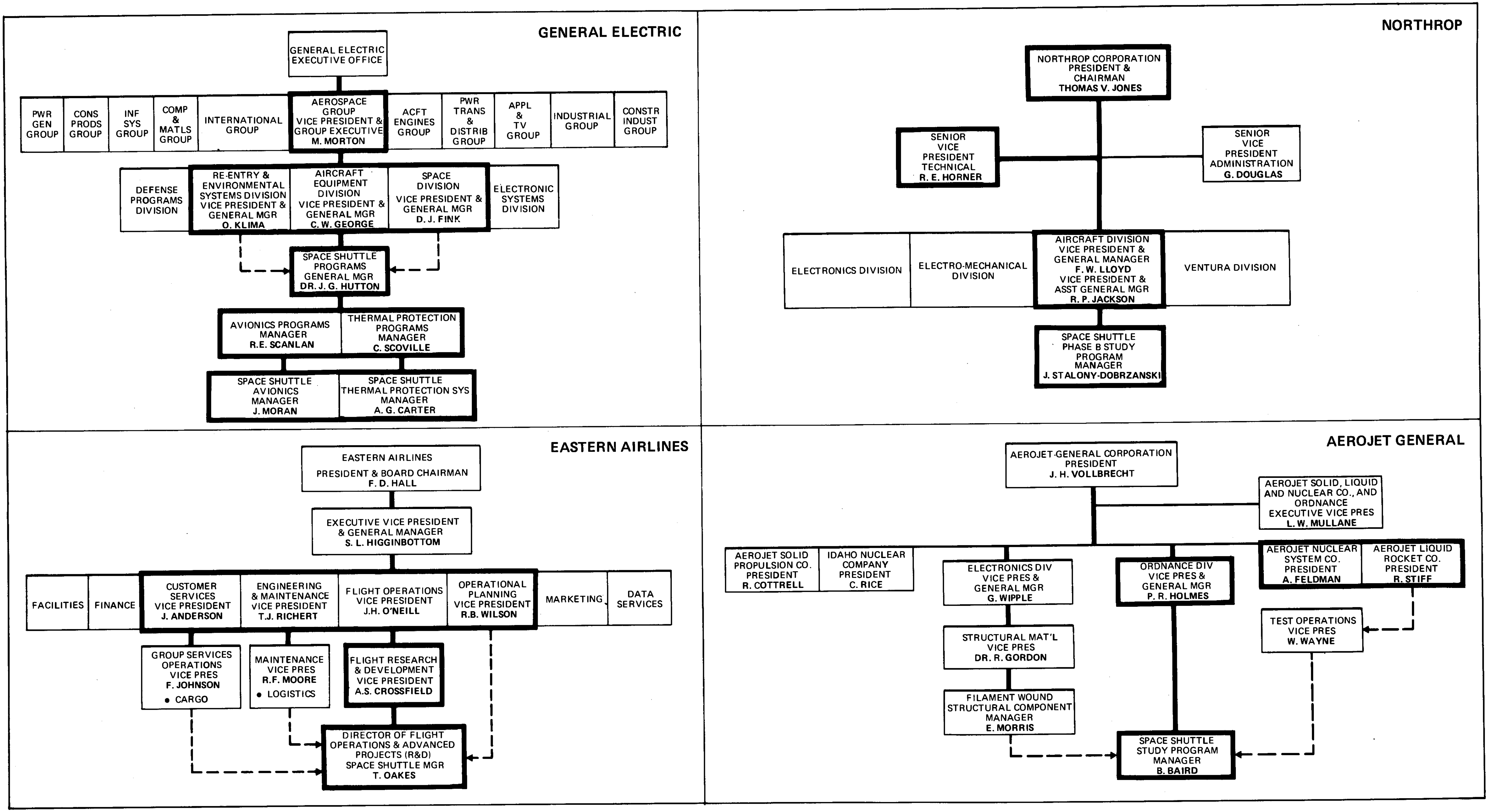


Fig. 4-5 Associate Contractors' Organizations. *Integrated at Bethpage and highly placed at each associate's corporation.*

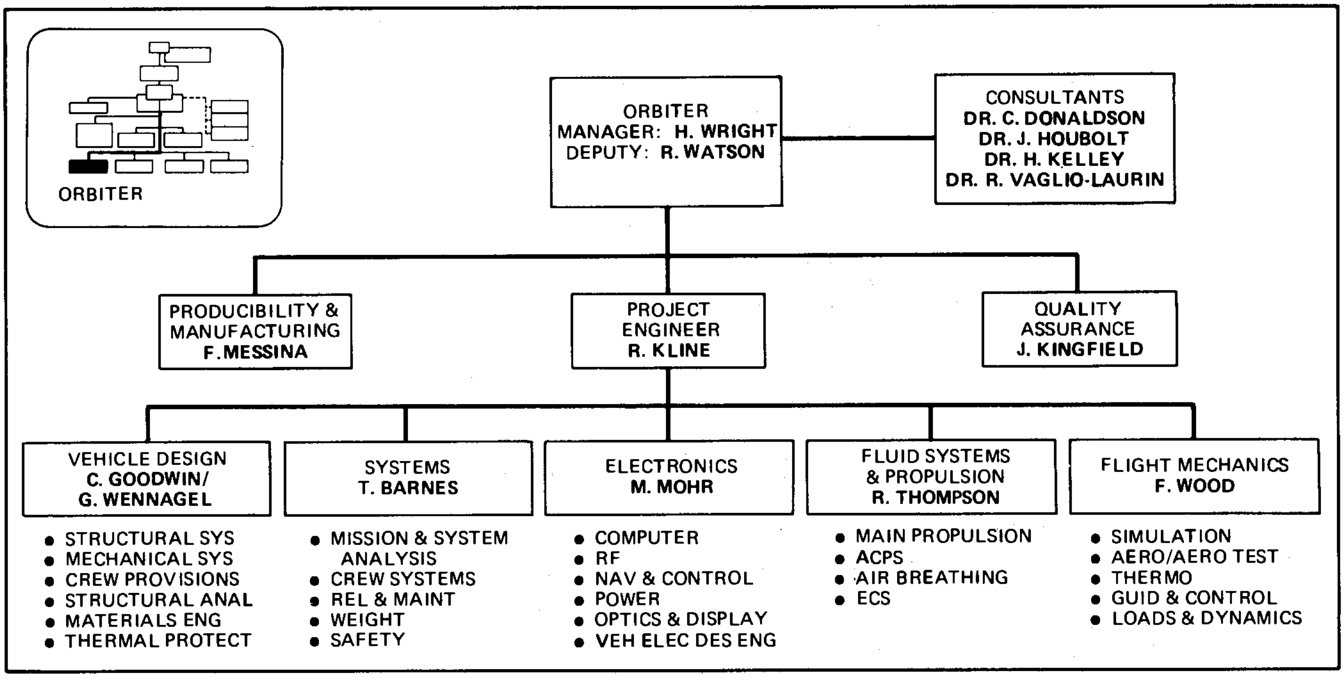


Fig. 4-6 Orbiter Study Organization

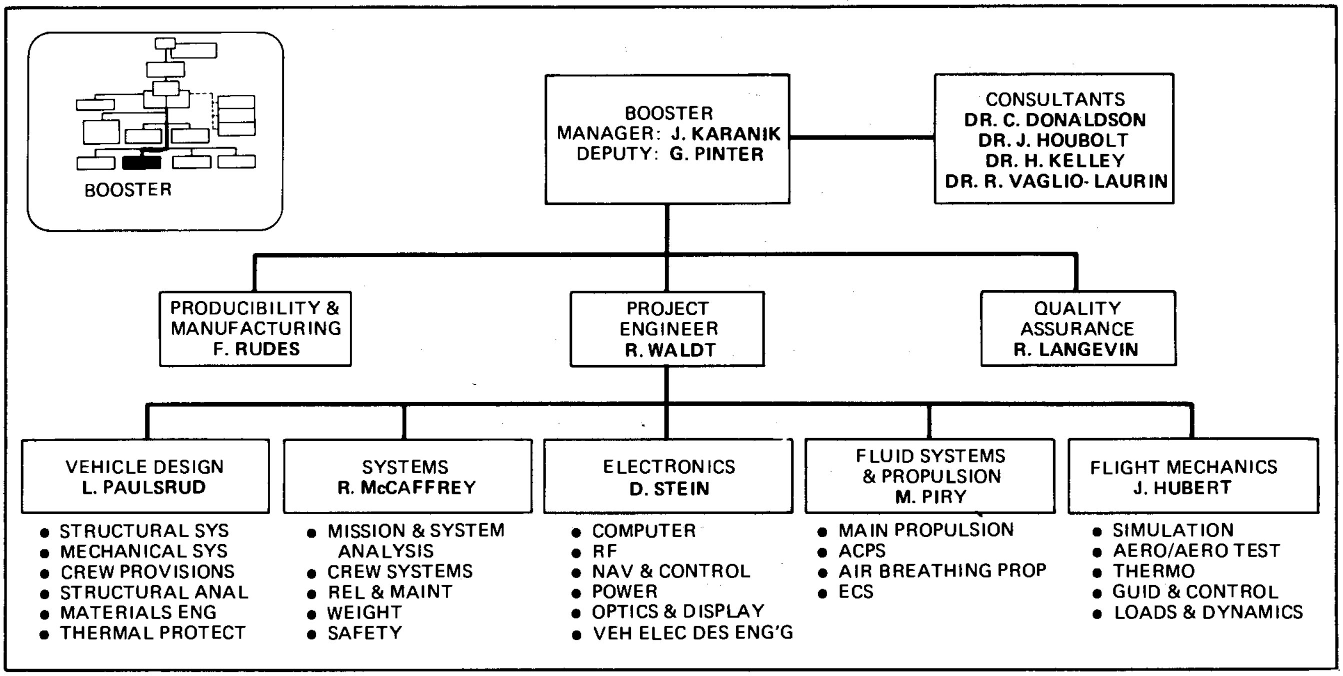


Fig. 4-7 Booster Study Organization

A staff of consultants will be working closely with the orbiter and booster managers providing specialized support in their related areas.

- Dr. Coleman du P. Donaldson: Heat transfer and viscous effects
- Dr. John C. Houbolt: Space flight problems
- Dr. Henry J. Kelley: Boost and reentry phases
- Dr. Roberto Vaglio-Laurin: High-speed aerodynamics

Key functional areas provide full support. The project engineer is a key individual charged with the overall design and development of the orbiter and booster (as appropriate). He is responsible for all design and analysis activities, and cost tradeoffs. He:

- Directs the tradeoff studies and design of hardware including preparation and approval of specifications and test requirements for components and subsystems
- Maintains direct contact with his counterpart of the other vehicle to assure maximum commonalty of the concept, approach and implementation, and most efficient use of technical disciplines
- Directs technical activities for design reviews
- Provides all technical reports and documents for NASA
- Directs the efforts of Grumman and associate contractors' personnel in vehicle design, systems. engineering, electronics design, fluid systems and propulsion design, and flight mechanics groups in fulfilling the requirements of the study

The producibility and manufacturing manager is responsible for bringing the fabrication and assembly planning inputs to the design study. He:

- Establishes manufacturing criteria as design requirements and insures their use in design/manufacturability/cost tradeoff studies
- Defines all manufacturing activities for subsequent phases
- Establishes a detailed tooling, fabrication, and assembly plan consistent with approved configurations and schedules
- Conducts and documents studies of manufacturing cost and schedules

The quality assurance manager is responsible for providing a sound base for achieving the required quality characteristics for the space shuttle. He:

- Assures maximum integration and consistency between orbiter/booster and Grumman quality assurance procedures
- Monitors the design from a quality assurance standpoint
- Evaluates effect on quality of cost tradeoffs

The operations organization emphasizes low costs. The operations manager and his deputies (Fig. 4-8) are responsible for developing the concept, definition and preliminary design of the operational system. Specifically, he:

- Directs the analysis and integration of all launch, mission and turnaround operations
- Directs the development of requirements and preparation of the logistics, maintenance, facility, and equipment and operations plans
- Directs the analysis and preparation of a comprehensive test plan

These functions have been combined into one organizational element to provide maximum influence on primary design in order to evolve a substantially lower cost operational system.

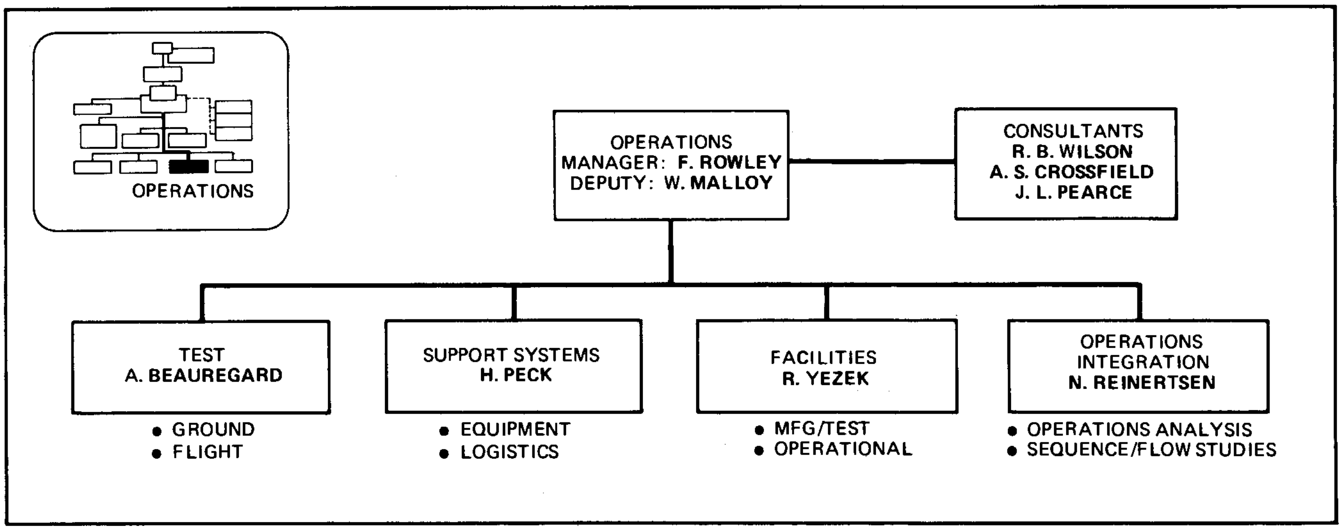


Fig. 4-8 Operations Study Organization

A staff of consultants will work closely with the operations manager:

- R. B. Wilson, Vice President, Staff Management Services, Eastern Airlines
- A. S. Crossfield, Vice President, Research and Development, Eastern Airlines
- J. L. Pearce, President, J. L. Pearce and Associates

System integration balances the total program needs. The system integration manager (Fig. 4-9) is responsible for the studies, analyses and evaluations of the overall system from the viewpoint of physical and functional requirements for both intra- and inter-vehiclular relationships. System integration provides special attention to cost/funding implications and provides the focal point for technical control of the total system. The system integration manager, coordinating the areas of cost estimating, systems analysis, and parametric resources analysis, is responsible for:

- Performing overall system level tradeoffs and analyses necessary to establish and evaluate the requirements on which the vehicle and operations study effort will proceed
- Identifying all physical functional and performance requirements, and assuring that they satisfy the recommended shuttle system design and operations plan
- Evaluating the design solutions, including tradeoff studies performed at the vehicle design, subsystems, and operations level to insure that the requirements are being satisfied in an optimum fashion
- Generating cost estimates and comparisons to be used in determining the most economical concepts and designs
- Developing reliable cost estimating procedures to achieve optimum design concepts
- Providing the program director with the analytical tools for effective decision making

4.1.3 Management System

Grumman's current management system is the specific outgrowth of management techniques that have evolved throughout our history in aerospace. In particular, NASA contributed to the development of these systems under the LM Program. The continuing expansion and growth of our management system to its current status on the F-14 program is described in Fig. 4-10.

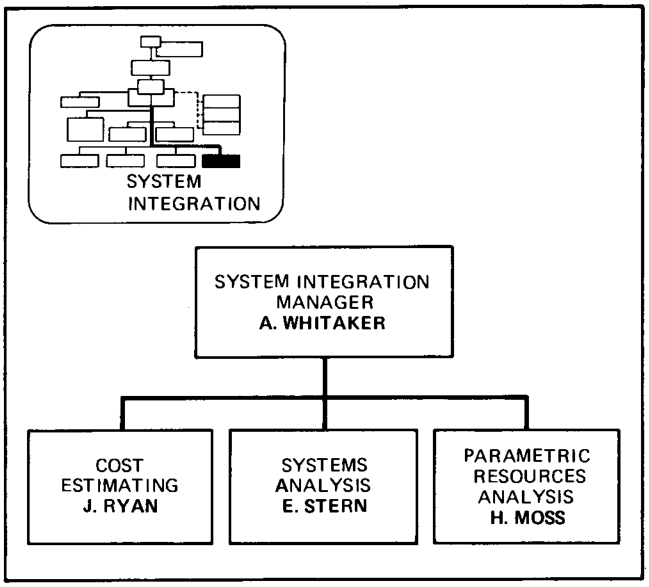


Fig. 4-9 System Integration Study Organization

In the shuttle study we employ a simplified version of our sophisticated F-14 management system. Our management system which is being used in the development of the F-14 high performance fighter has been adapted to be consistent with the size and complexity of the space shuttle Phase B study. Although the system was originally designed for a hardware development program, its inherent flexibility permitted us to tailor it to the space shuttle study as described herein. The basic system satisfies the latest DOD management criteria and has been reviewed by a Navy/DCAA validation team of Government experts which included NASA and USAF observers. This team was on-site from 18 August through 25 September 1969 and the favorable results of the survey are described in the Naval Air Systems Command "Report of Performance Measurement System Demonstration Conducted at Grumman Aerospace Corporation." The final validation survey to close out any remaining open items, will take place in May 1970.

Management control systems are documented by corporate procedures. Grumman's overall program management policies and practices are described in Grumman publication "Guidelines for Program Planning and Control." The F-14 program system has been documented in the "F-14 System Description Manual." Similar documentation of the adaptation of that system to space shuttle will be available.

To insure clear and uniform direction to all users, the implemented operating system is fully docu-

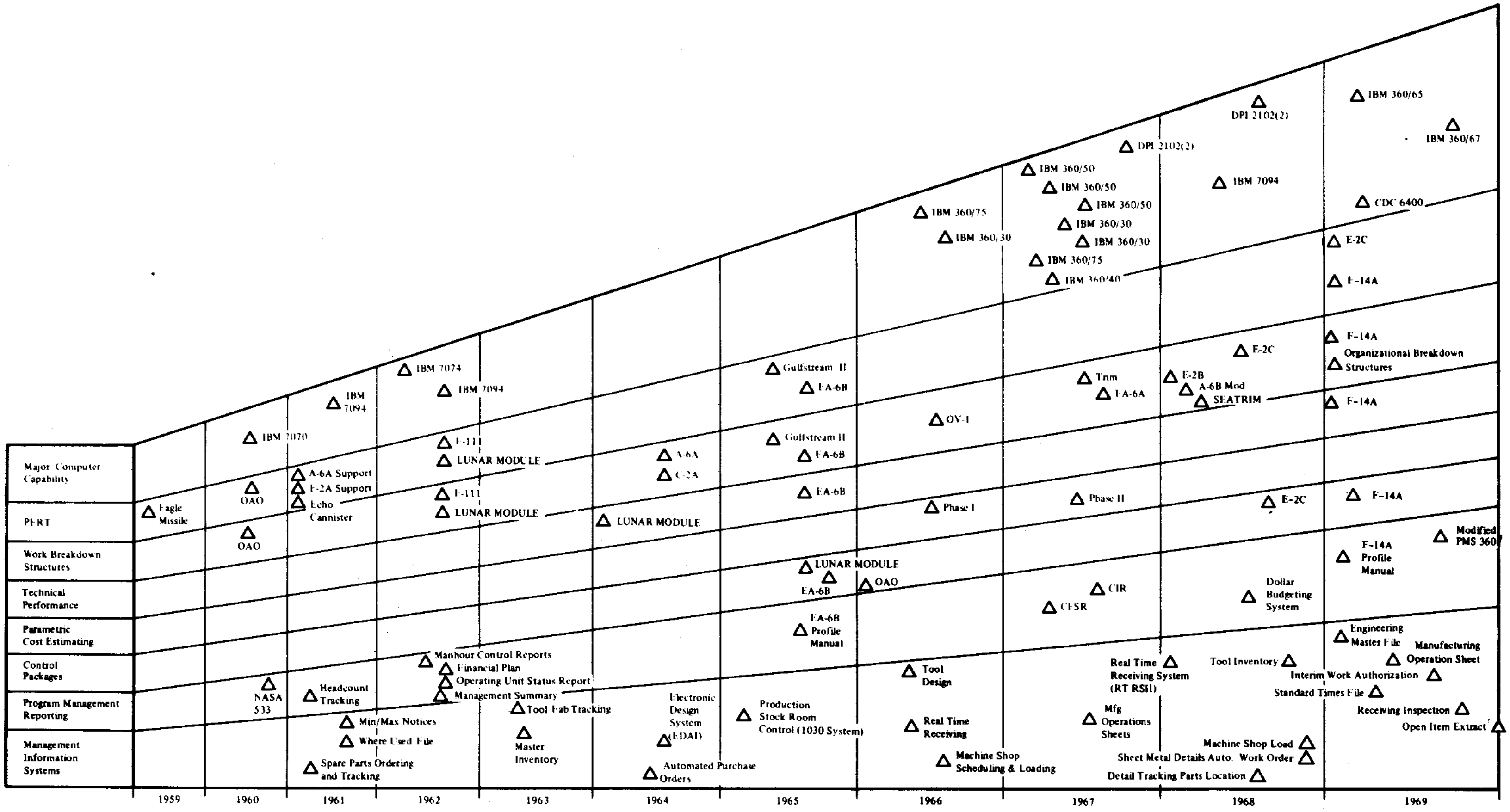


Fig. 4-10 Management Systems Growth. *Grumman's history of management systems showing a trend of continuous evolution and expansion on aerospace programs.*

mented by corporate procedures which are available for audit at any time. Our system provides the basis for defining the tasks to be accomplished, authorizing work, establishing budgets and monitoring performance. The system provides control with the needed flexibility to meet the shuttle program's changing demands.

Although this section portrays the procedural and mechanical elements of our management system, it must be stressed that it is the "people" of the corporation who implement and use the system who are the key to effective management.

Subsections 4.1.4 through 4.1.6 describe in detail the explicit application to the Phase B study of the system concepts. This system is operational as a part of preparing this proposal and will be exercised on continuing shuttle study activities prior to contract award.

4.1.3.1 Management System Objectives

The broad objectives of the space shuttle management system as applied to Phase B are as follows:

- Define the tasks to be done to meet the contract objectives
- Establish a formal plan for the execution of these tasks within the framework of the work breakdown structure
- Measure performance against that plan
- Provide applicable management reports to key levels of Grumman management and provide NASA reports from the same base data
- Provide the basis for initiating corrective action wherever necessary

The management system is described in the following sequence and displayed pictorially in Fig. 4-11.

- Task Organization – the manner in which the program is divided into manageable units
- Planning and Budgeting – the means by which schedules are created, budgets are established, and up-to-date projections are maintained
- Status and Analysis – the manner in which schedule and cost performance is measured against targets, and variances noted
- Reporting – The means whereby Grumman management and NASA are apprised of pertinent status and variances to enable timely corrective action to be undertaken

4.1.3.2 Task Organization

The first and most essential step required for system implementation is the development of a work breakdown structure (WBS), which identifies all work tasks required to achieve contract objectives. The WBS organizes, defines, and displays the relationship of these tasks, as well as providing the basis for the establishment of budgets and schedules, the collection of actual costs, and the measurement of performance.

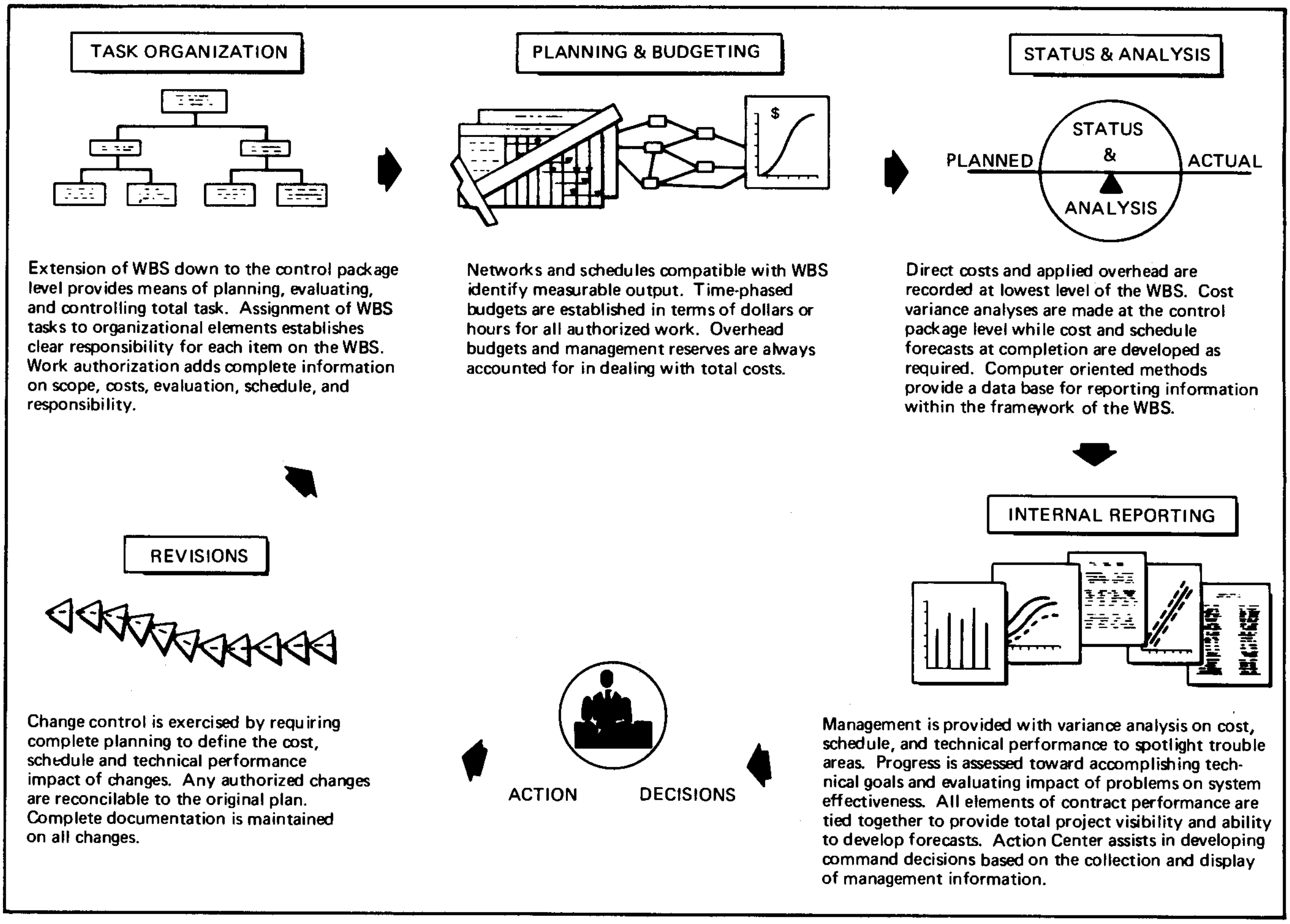
The detailed WBS for the space shuttle is presented and discussed in Subsection 4.1.4. For the Phase B effort, the WBS is a simplified, output-oriented (studies, documentation, etc.) organization of the RFP statement of work elements. It should be noted that the upper levels of the WBS will be expanded in a hardware-oriented breakdown for Phases C and D.

The organization is matrixed with the WBS to provide the basis for fully integrated planning and control. The WBS and the organization structure are used in combination to define manageable pieces of work. This concept is illustrated in Fig. 4-12. By identifying a specific unit of work in terms of what the task is, and defining the organization performing the work, a baseline is established for management control. Level four of the Grumman extended WBS is selected as the control level. At that level, the task and the responsibility are defined, thus identifying a specific, controllable unit of work, known as the control package. For each control package (defined in greater detail in Subsection 4.1.6), a concise task description is written, schedules, and budgets are established, and performance can be measured.

4.1.3.3 Planning & Budgeting

All work tasks are completely planned and scheduled to define their logical sequence and interfaces. Each control package is budgeted in terms of cost and schedule requirements.

All schedules, both summary and detailed, evolve from specific levels of the WBS. The initial step in the evaluation of the space shuttle schedules is the creation of a program logic network, appropriate to the size of the job, which depicts key study areas of the program and their interrelationships. The program master schedule is a derivative of pertinent portions of the logic network, as time-constrained by contractual schedule obligations. Also flowing from the logic network are more detailed schedules for each level four control package (Fig. 4-13). As the master schedule and detailed schedules are reviewed and modified, corresponding changes are made to the logic network to reflect



Extension of WBS down to the control package level provides means of planning, evaluating, and controlling total task. Assignment of WBS tasks to organizational elements establishes clear responsibility for each item on the WBS. Work authorization adds complete information on scope, costs, evaluation, schedule, and responsibility.

Networks and schedules compatible with WBS identify measurable output. Time-phased budgets are established in terms of dollars or hours for all authorized work. Overhead budgets and management reserves are always accounted for in dealing with total costs.

Direct costs and applied overhead are recorded at lowest level of the WBS. Cost variance analyses are made at the control package level while cost and schedule forecasts at completion are developed as required. Computer oriented methods provide a data base for reporting information within the framework of the WBS.

Management is provided with variance analysis on cost, schedule, and technical performance to spotlight trouble areas. Progress is assessed toward accomplishing technical goals and evaluating impact of problems on system effectiveness. All elements of contract performance are tied together to provide total project visibility and ability to develop forecasts. Action Center assists in developing command decisions based on the collection and display of management information.

Change control is exercised by requiring complete planning to define the cost, schedule and technical performance impact of changes. Any authorized changes are reconcilable to the original plan. Complete documentation is maintained on all changes.

Fig. 4-11 Program Management System Elements. *Management is provided with the information to plan, evaluate and control all phases of the program.*

changes in approach required to meet the desired schedule accomplishments. The specific schedules to be used for Phase B are displayed and discussed in Section 4.1.5 and 4.1.7. The measurement of selected technical achievements is interwoven with the scheduling system by establishing milestones which denote the accomplishment of specified technical outputs.

As each control package is defined and scheduled, estimates are made of required time-phased resource expenditures by element of costs. For each estimate, applicable labor rates and/or overhead burdens are applied to arrive at a projected dollar cost. Estimates are summarized through all levels of the WBS and are issued as a financial plan.

After negotiation and upon contract award, control package budgets are revised to reflect the negotiated scope and funding. A management reserve is retained under control of the program director. This budgeting cycle (as well as a control cycle which will be discussed in the following section) is illustrated in Fig. 4-14.

Each control package contains the time-phased cost budget, the schedule requirements, and the related technical task descriptions. The control packages to be used during Phase B are fully described in Subsection 4.1.6.

4.1.3.4 Status & Analysis

A flow diagram depicting the cost and schedule statusing system is illustrated in Fig. 4-15. A control data bank of schedule/cost plans and actuals is maintained for the space shuttle program. The plans are comprised of the detailed schedules and logic network, as well as the financial plan of anticipated costs. Bi-weekly reports will be generated during Phase B to reflect current measurement of actual accomplishments and costs as compared to schedule and budget.

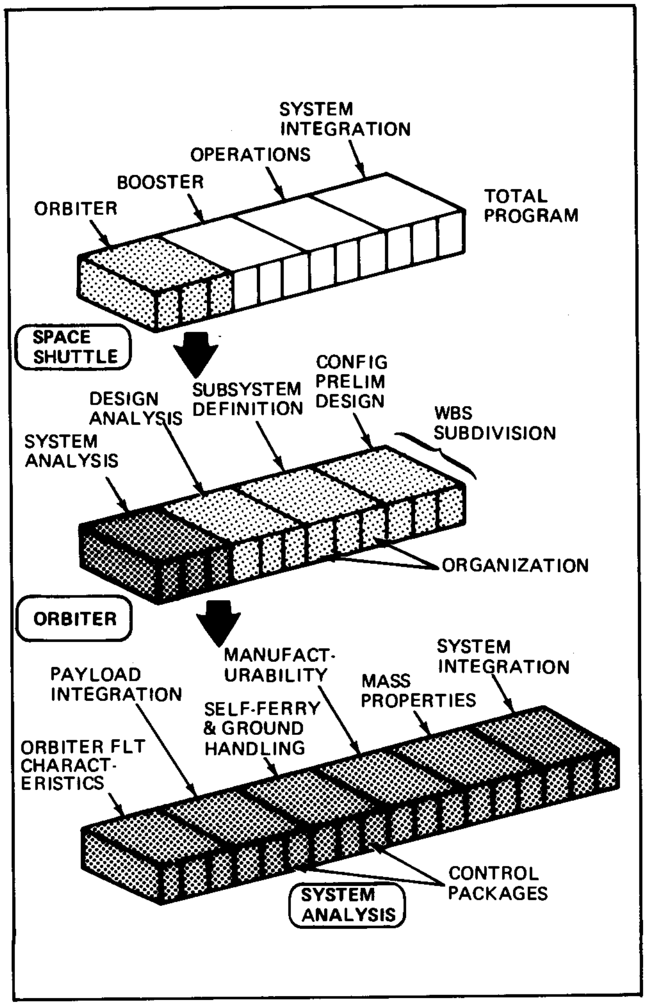


Fig. 4-12 Task/Organization Matrix. *The total program is detailed on manageable control packages for fully integrated planning and control.*

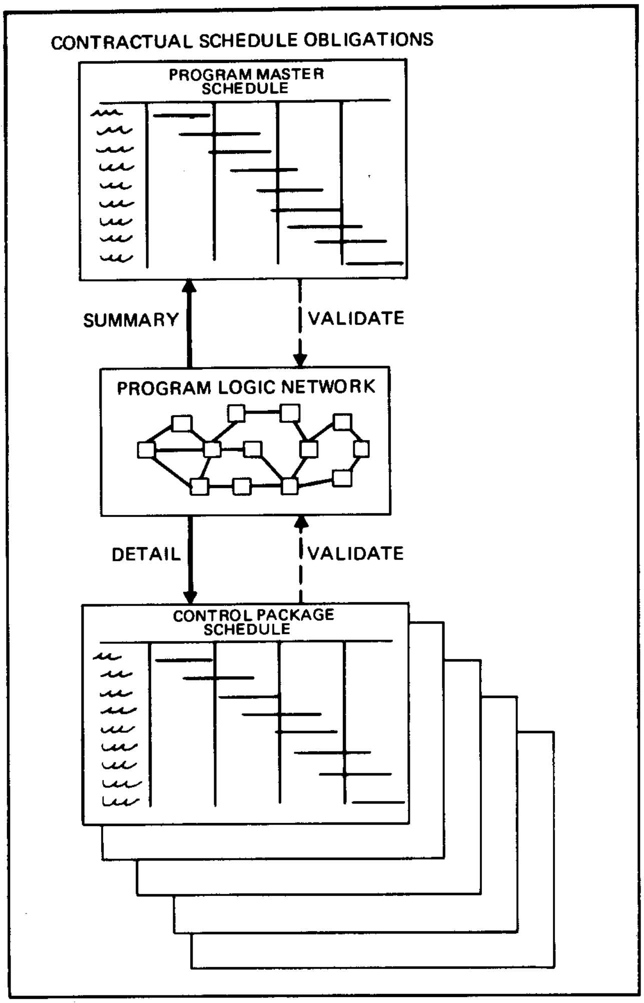


Fig. 4-13 Schedule Planning and Control. *The master schedule and the control package schedules are all derived from the program logic network.*

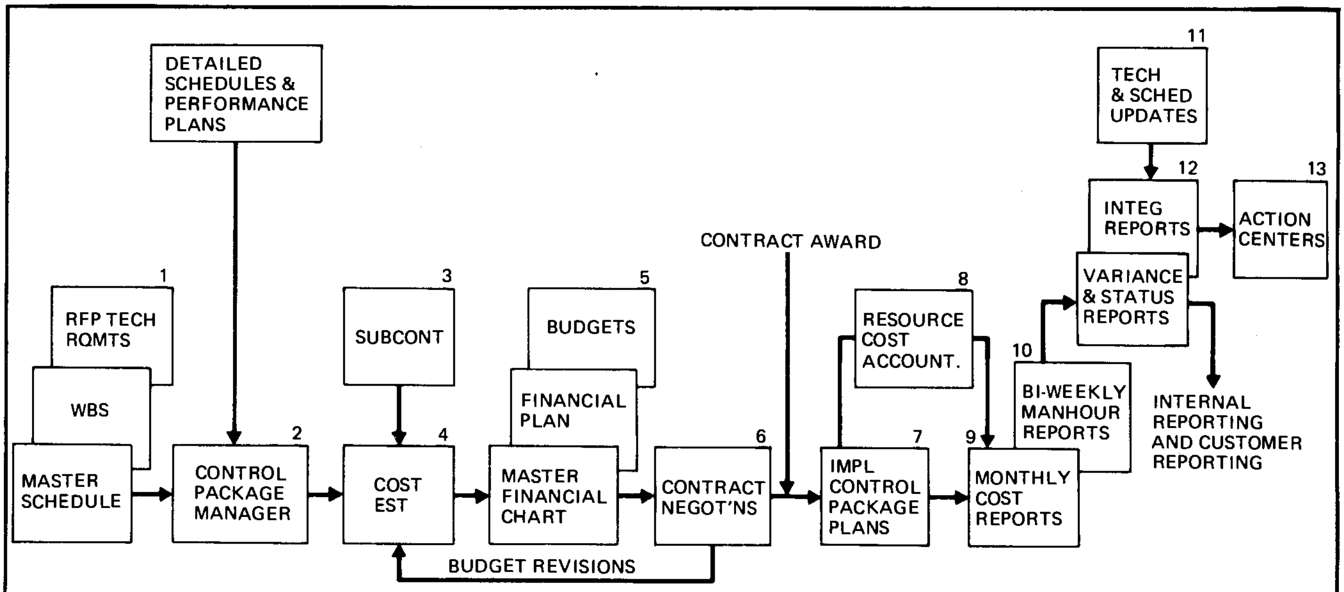
Scheduling status is measured by monitoring each milestone on every active control package. Every two weeks, a summary status of all control packages is reviewed with emphasis on their interactions and interfaces with each other. If any changes in the planning and implementation of the study are required as a result of NASA/Grumman redirection, they are also reviewed at this time. Following the bi-weekly review the program master schedule is updated to incorporate any changes resulting from redirection, as are affected control package schedules.

For accumulation of actual costs, Grumman uses a job order cost system which collects separately each element of incurred direct cost for performing a given task. These costs are reported as incurred.

On a bi-weekly basis, reports of actual labor expenditures (entitled Manpower Cost Reports) are generated for each control package and summarized WBS items.

All other elements of cost (in dollars) are reported on a monthly basis at the control package level. Material costs are recorded as material is applied, or as invoices are booked for payment of subcontract effort. Other costs (including travel and relocation expenses) are also reported. Indirect expenses (overhead), as applied to each element of direct cost are indicated. Corporate general and administrative (G&A) expense is shown as an application to each control package.

Each month, a summary of all costs incurred on the space shuttle program will be reported and



1. Baseline program data.
2. Assignment of responsibility in accordance with WBS.

3-4. Cost estimating by functional areas and subcontractors.

5. Development of cost documents for all management levels through established control centers.

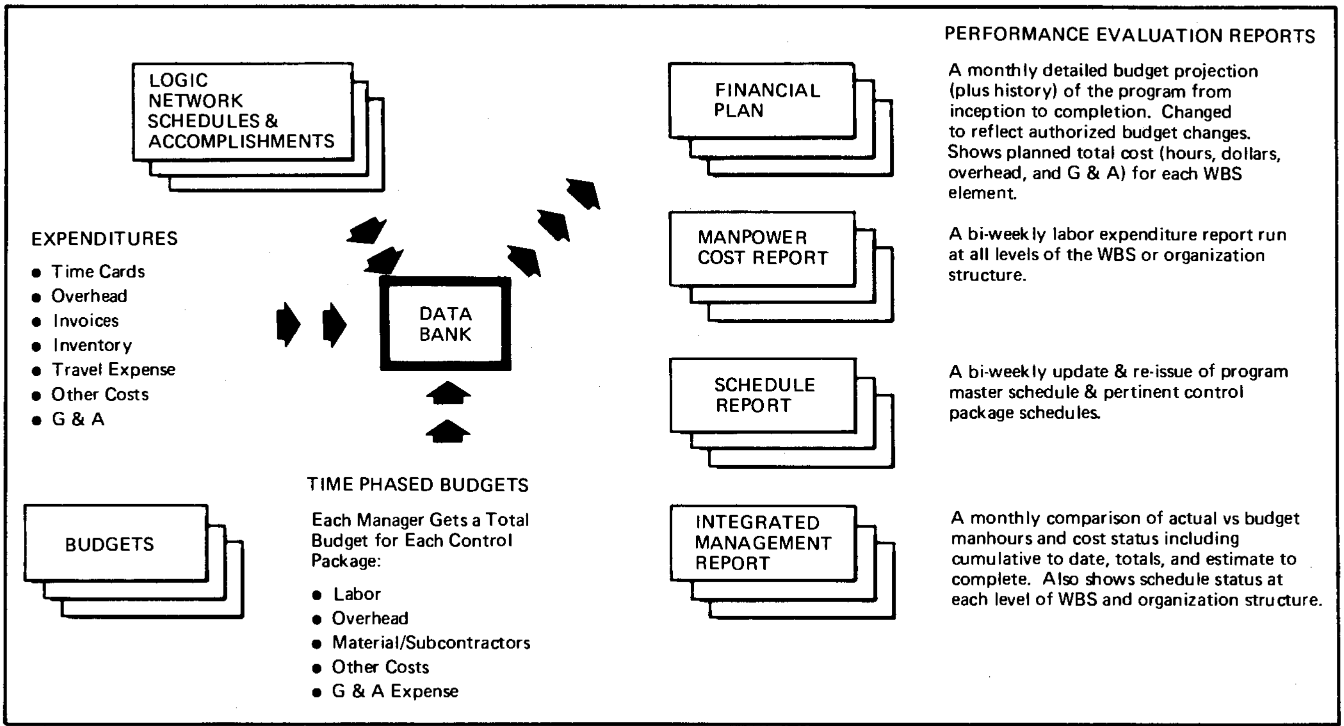
6. Submittal of costed detailed plans to customer. Budget revisions reviewed and approved by Program Management after negotiations.

7-10. Program Management authorizes and controls cost, scheduling, and performance through Control Packages. Cost accounting process allows constant control of program expenditures through established Action Centers. Resources accounted for on an "as used" basis.

11-12. Development of integrated reports correlating cost, schedule, and performance data. Single cost data bank plus time-phased budgets serve as basis for cost reporting to all levels of management and customer.

13. Reporting and analysis provides complete management visibility of critical areas.

Fig. 4-14 Cost Planning and Control Cycle. *Expenditures are budgeted and statused throughout the life of the contract.*



Each Manager Gets a Total Budget for Each Control Package:

- Labor
- Overhead
- Material/Subcontractors
- Other Costs
- G & A Expense

PERFORMANCE EVALUATION REPORTS

A monthly detailed budget projection (plus history) of the program from inception to completion. Changed to reflect authorized budget changes. Shows planned total cost (hours, dollars, overhead, and G & A) for each WBS element.

A bi-weekly labor expenditure report run at all levels of the WBS or organization structure.

A bi-weekly update & re-issue of program master schedule & pertinent control package schedules.

A monthly comparison of actual vs budget manhours and cost status including cumulative to date, totals, and estimate to complete. Also shows schedule status at each level of WBS and organization structure.

Fig. 4-15 Status Reports. *An integrated cost and scheduling reporting system provides WBS element status against plan.*

compared to budgets via an Integrated Management Report. This report also reflects schedule status of each control package for fully integrated cost and schedule reporting. These regularly scheduled reports form the basis of program reviews and analyses, and Grumman management and NASA reports.

The expenditure/schedule status of each control package is formally reviewed bi-weekly, with critical variances noted and analyzed so that problem areas can be brought to management's attention for action. Whenever appropriate, revised cost estimates-to-complete and schedule changes are processed through the planning and budgeting cycle and reflected in subsequent status reports.

4.1.3.5 Reporting

Every two weeks, the program director is apprised in writing of the cost/schedule status of each master schedule item, as well as the overall status of the entire program. In addition, management is immediately informed of any potential problems that may arise between scheduled reporting dates. Information displayed in the space shuttle action center is derived from the status reports. Scheduled status reviews and daily "stand-up" meetings in the action center complement the formal reporting system. It is an important feature of our approach that the manager responsible for a control package or control packages is provided with timely cost and schedule reports so that effective action may be taken.

Of particular significance is the fact that progress on schedules, costs and performance are reported daily to the president's office where they are publicly displayed. The program is also reviewed at a three-hour session every two weeks by senior Grumman management including the chairman, vice chairman, president, senior vice presidents and treasurer of the corporation.

Monthly status will be submitted to NASA via project progress and status reports in accordance with MA020M. Status presentations will be prepared for formal meetings with NASA at the end of the third, sixth, eighth and eleventh month of the study, as well as interim informal meetings at NASA's request (MA018M). Detailed logic networks, schedules and the WBS for Phases C and D will be submitted per schedule of program management plan (MA017M) and Phase C and D program cost and schedule estimate plans will be computer-processed and submitted to NASA in the format of Forms A, B, and D of MF003M. Per the requirements of MA016M, the Phase B final report will contain overall schedules and cost estimates for the development and operational phases of the program.

4.1.3.6 Action Center/Data Link

Grumman recognizes that a successful program requires a quick-response management information, communication, and decision flow-system. To achieve this quick response, action centers have been established and are operating in our major study and hardware programs. The action center for the space shuttle study program is established, is in place, and is operating.

The real-time status information presented in the action center provides management with sufficient insight for effective decision making. Data are statused on a daily basis to provide real-time quantitative visibility of program progress. The information is updated by the responsible party prior to a daily "standup meeting." Everyone sees and hears the same information.

The center is the focal point for:

- Operational planning
- Performance evaluation
- Problem solving
- Redirection of resources
- Information/communications
- Action assignment

The space shuttle action center also serves as our central location for display of working level information and status. Cognizant NASA personnel have ready access to the action center. A data link system with voice communication and "hardcopy" data transmission equipment is operational at Bethpage and is available to the shuttle program.

4.1.4 Work Breakdown Structure (WBS)

The work breakdown structure provides a baseline for Phase B planning and control. The importance of the work breakdown structure as the basis for the Grumman management control system has been explained in Subsection 4.1.3. The WBS provides the common framework required for integrated planning and control of costs and schedules. It was organized to align with the RFP SOW tasks and at the same time to conform with NASA program organization. Through logical subdivisions of the total program effort it provides the basis for establishing budgets and schedules, for evaluating performance, and for identifying responsibilities on clearly defined controllable units.

Grumman's study approach proposes to carry Designs 518 and 532 through the first 6 months of the study at which point the best features of the two will be combined with programmatic alternatives of phased implementation into a single design/development concept and approach. The majority of the study tasks on the two designs during the first 6 months are virtually identical and the two-design distinction disappears thereafter. Effective, efficient management is achieved by WBS planning and control that distinguishes between elements of work that are distinctly diffferent, i.e., orbiter, booster, integration, operations, etc., but not artifically separating the essentially common work pertaining to Designs 532 and 518.

As shown in Fig. 4-16 the total program (level 1) is divided into five major elements at level 2:

- Integration
- Orbiter
- Booster
- Operations
- Program management

Level 3 subdivides these elements into major areas of study consistent with the RFP SOW. Level 4 identifies each task contained in the RFP SOW under its appropriate area of study and is thus identified as the control package level. Each level 4 task (control package) is cross-referenced by the RFP SOW task number in addition to a WBS account number, thus pinpointing the direct relationship between SOW tasks and WBS items. Summary task descriptions along with milestone schedules and time-phased manpower requirements for each control package are presented in Subsection 4.1.6.

During the Phase B study, the WBS will be developed jointly by Grumman and NASA into a hardware-oriented family tree for Phase C/D control.

GRUMMAN LEVEL 1	GRUMMAN LEVEL 2	GRUMMAN LEVEL 3	GRUMMAN LEVEL 4		
			Control Package Description	C.P. Acct No.	SOW No.
Space Shuttle 1-001	Integration 2-001	Integration 3-001	System Safety Analysis	001	4.1.1
			Mission Analysis	002	4.1.2
			System Integration & ICD's (Incl CEI Spec)	003	4.1.3
			System Flight Characteristics	004	4.1.5
			Aborts	005	4.1.7
			Reliability & Quality	006	4.1.9
			Maintainability	007	4.1.10
			Ground & Flight Systems Optimization	008	4.1.12
			Cost & Programmatic Analysis	009	
	Orbiter 2-002	System Analysis 3-002	Integration	101	4.1.3
			Orbiter Flight Characteristics	102	4.1.5
			Payload Integration	103	4.1.6
			Self-Ferry & Ground Handling	104	4.1.11
			Manufacturability	105	4.1.13
		Design Analysis 3-003	Structure	110	4.2.1
			Materials	111	4.2.2
			Thermal Protection System	112	4.2.3
			Mass Properties	113	
		Subsystem Definition 3-004	Propulsion System	120	4.3.1
			Electro-Mechanical & Integrated Avionics	121	4.3.2
			Landing System	122	4.3.3
			Docking System	123	4.3.4
			ECS & Life Support System	124	4.3.5
			Power System	125	4.3.6
			Crew and Passenger Accommodations	126	4.3.7
			Launch System Interface	127	4.3.8
			Flight Control System	128	4.3.9
		Configuration Preliminary Design 3-005	Design	140	4.4
			CEI Specification	141	4.4
			Soft Mockups & Scale Models	142	4.4
			Configuration Preliminary Verification	143	4.5
	Booster 2-003	System Analysis 3-006	Integration	201	4.1.3
			Booster Flight Characteristics	202	4.1.5
			Self-Ferry & Ground Handling	204	4.1.11
			Manufacturability	205	4.1.13
			Unmanned Versus Manned Booster	206	4.1.8
		Design Analysis 3-007	Structure	210	4.2.1
			Materials	211	4.2.2
			Thermal Protection System	212	4.2.3
			Mass Properties	213	
		Subsystem Definition 3-008	Propulsion System	220	4.3.1
			Electro-Mechanical & Integrated Avionics	221	4.3.2
			Landing System	222	4.3.3
			ECS & Life Support System	224	4.3.5
			Power System	225	4.3.6
			Crew Accommodations	226	4.3.7
			Launch System Interface	227	4.3.8
			Flight Control System	228	4.3.9
		Configuration Preliminary Design 3-009	Design	240	4.4
			CEI Specification	241	4.4
			Soft Mockups & Scale Models	242	4.4
			Configuration Preliminary Verification	243	4.5
	Operations 2-004	Operations 3-010	Operations Analysis	300	4.1.4
			Operations Site Evaluation	301	4.1.14
			Ground Operations	302	4.4
			Logistics Support	303	4.4
			Ground Support Equipment	304	4.4
			Facilities	305	4.4
	Program Management 2-005	Program Management 3-011	Management	400	
			Configuration/Data & Reproduction	401	
			Supporting Research & Technology	402	4.6
			Acquisition Plans	403	4.7

Fig. 4-16 Space Shuttle System Program Definition Work Breakdown Structure (Phase B)

4.1.5 Logic Network/Milestone Schedule

Study area flow diagram (logic network) shows interrelationships of schedule events and identifies constraints. The Grumman plan and overall schedule for performing the Phase B study are depicted in Fig. 4-17. This study area flow diagram (logic net-

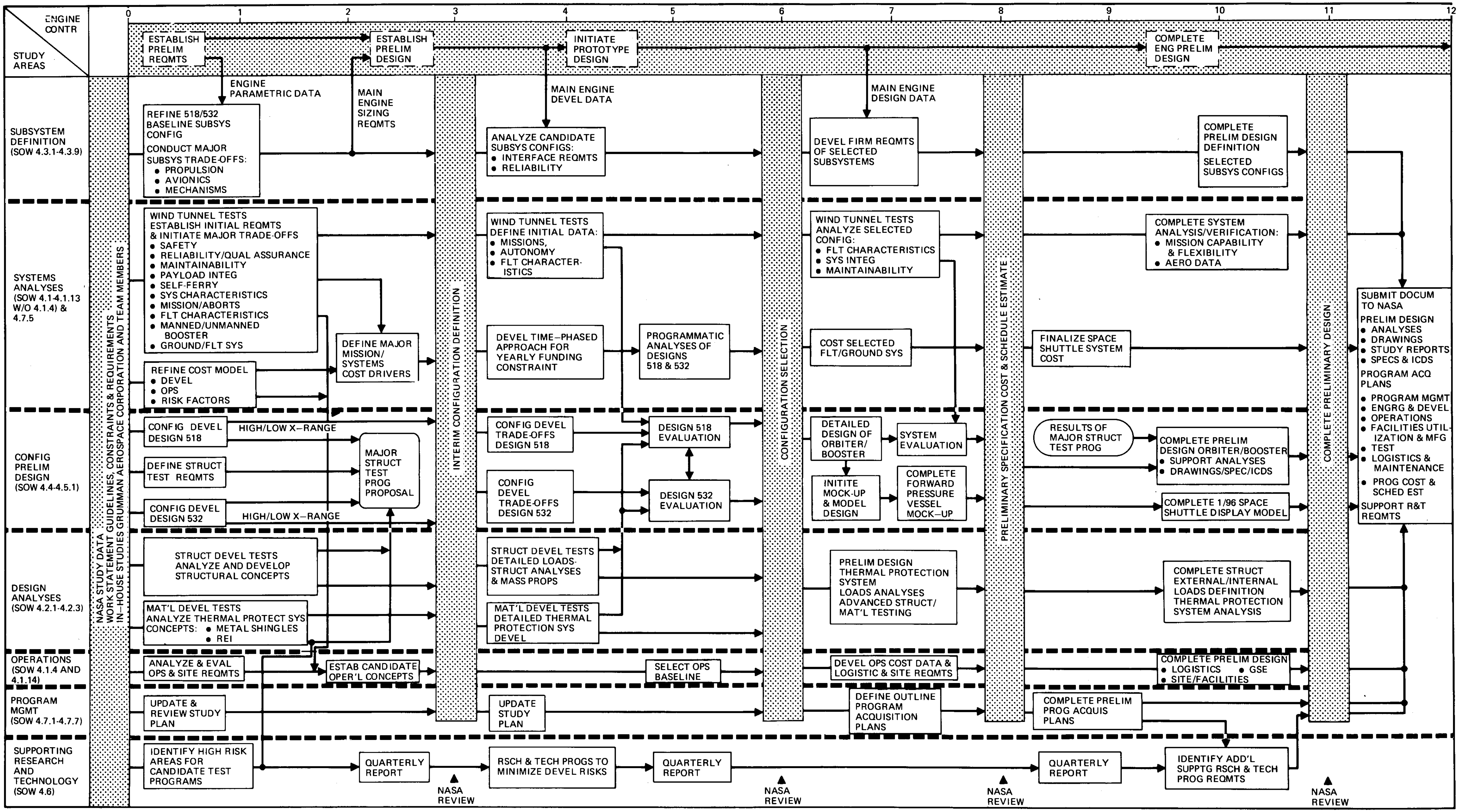


Fig. 4-17 Study Area Flow Diagram (Logic Network)

GRUMMAN

work) was developed by identifying and assessing the interrelationships and interdependencies of activities and events as outlined in Grumman's study approach. The logic network aligns these activities and events against the major study areas identifying interfaces and constraints within the program.

The logic network highlights the major tasks of the Work Breakdown Structure to be accomplished within each study area during each study phase while maintaining emphasis on the following primary study considerations:

- The in-depth design definition of the orbiter and booster vehicles supported by systems analysis, design analysis, and subsystem definition
- The definition of operations and development of the support system configuration
- The development of cost models, cost evaluation capability and program acquisition plans
- The definition of supporting research and technology requirements, and the development and evaluation of advanced technology concepts and techniques

In addition, the interface between the space shuttle system study and the engine development study effort is shown as a strong mutual interaction and constraint on both programs.

The time phasing of study activity is tied to the major NASA program reviews as key milestones. The study logic is most readily defined in terms of the major decisions and recommendations proposed for each of the review milestones.

- First Review/Orientation Meeting – At program initiation, the detailed study plan will be presented for NASA review and approval
- Second Review – Three months after program initiation. The two baseline vehicle configurations presented in the proposal will have been refined and the major performance parameters determined. The operations baseline will have been expanded into operational concepts for each phase of the mission. Preliminary propulsion tradeoffs will have been submitted. Initial cost evaluation models will have been developed and initial cost impacts of the configuration options determined. The constraints and risks associated with the pacing research and technology issues will have been identified. We will be prepared to define the initial configuration and subsystem alternatives for each vehicle configuration, to identify critical requirement constraints, and recommend modifications in the requirements baseline
- Third Review – Six months after program initiation. We will have performed initial configuration verification in the aerothermo, structural and material areas. We will have completed the major subsystem tradeoffs and arrived at a recommended configuration for Designs 518 and 532. Engine constraints will have been evaluated and measures devised to minimize the general technological development risk. The final cost model will have been completed and the cost impact of various technical and programmatic options evaluated. We will be prepared to present vehicle size, weight and performance data for Designs 518 and 532 and to present the total cost and funding rate requirements for each as well as total cost and funding rate implications of suggested programmatic alternatives. In general, we will present the data necessary to allow a selection of either Design 518 or Design 532 for further in-depth design for the remainder of the study. Our recommendation may include a combination of the best features of Designs 518 and 532 as well as programmatic alternatives having to do with phasing of elements of the shuttle system development which could be applicable to any system selected
- Fourth Review – Eight months after program initiation. Sufficient preliminary design of the selected design and support equipment, and sufficient planning of the selected development approach will have been performed to enable us to present initial design data and specifications, development schedules, cost data, and preliminary program acquisition plans as required by the NASA SOW

- Fifth Review – Eleven months after program initiation. The design, development, and operations planning will have been completed to a level of detail compatible with the Phase B study requirements. Final design data, specifications, schedules and program acquisition plans will be presented
- The formal submittal of all final reports and documentation will take place at the end of the 12th month

Study program major milestone schedule gives Grumman/NASA management total program visibility. The study program major milestone schedule (Fig. 4-18) represents a totally integrated summary level plan and establishes required dates for completion of contractual tasks. Major program milestones have been identified, and subordinate study

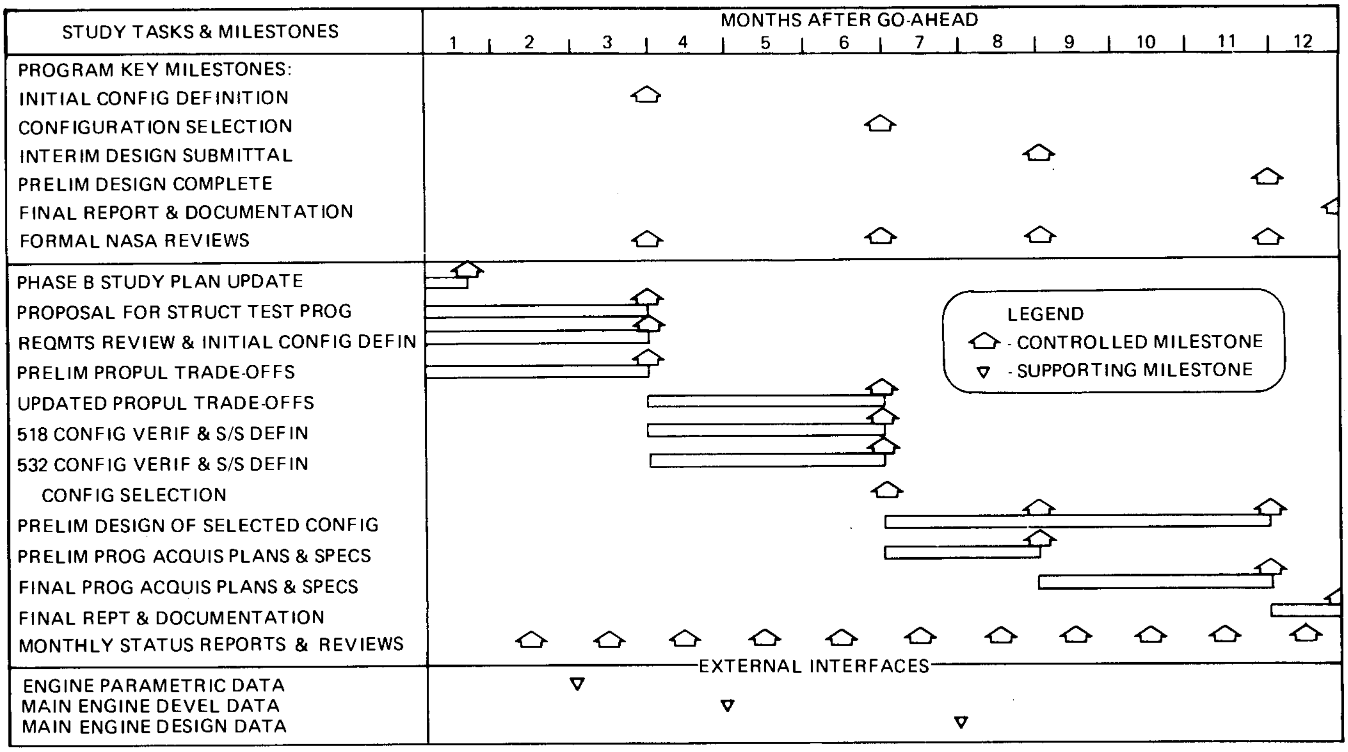


Fig. 4-18 Space Shuttle Phase B Study Program Major Milestone Schedule

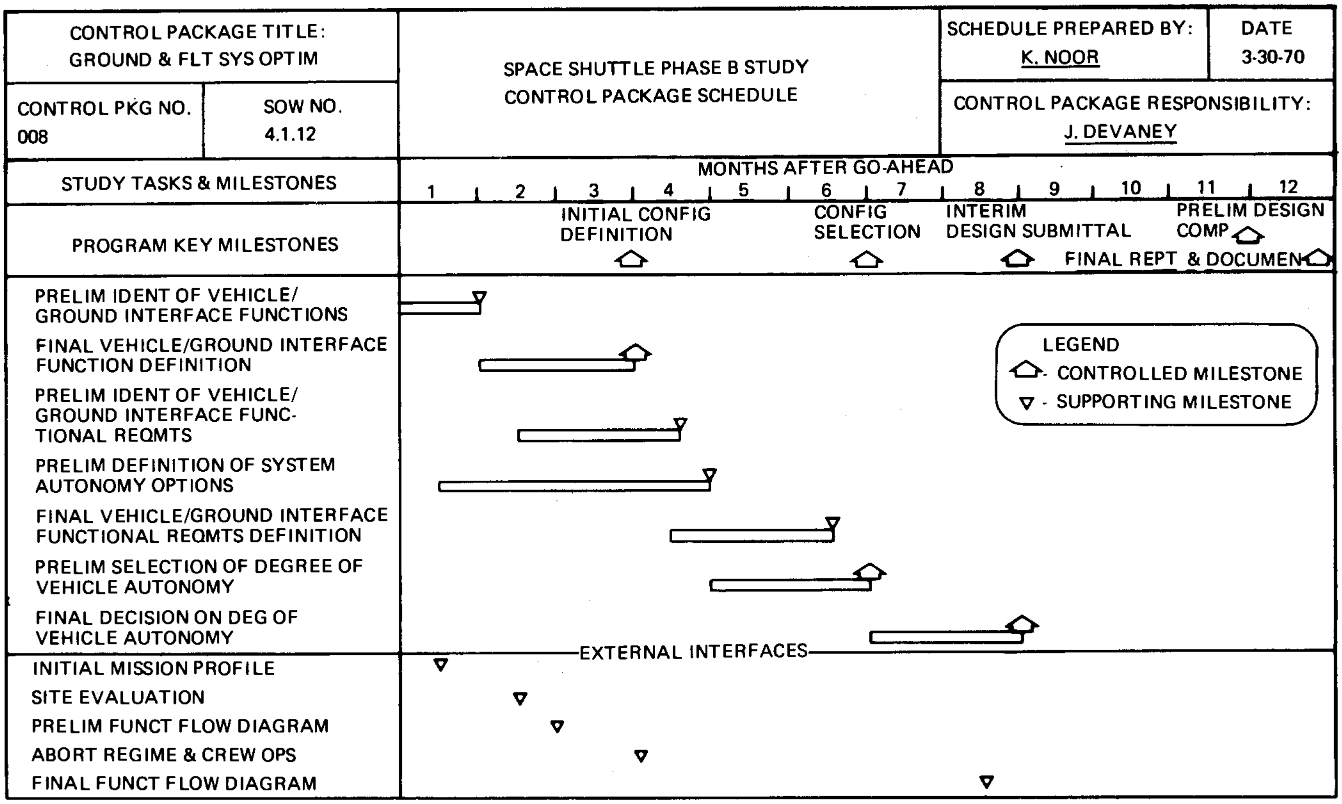
task milestones have been keyed to these in accordance with NASA format requirements.

The sample control package schedule for ground and flight systems optimization (Fig. 4-19) is one sample of the more detailed program milestone schedules in accordance with NASA format requirements. This schedule was developed at the control package level and indicates the level of detail developed to organize and manage the Phase B study effort. The complete set of schedules at this level will be provided with the updated study plan at the orientation meeting. The complete set (approximately 62 pages) is not included in this proposal because of page restrictions. However, schedule detail is provided herein at the control package level by the summary control package schedules discussed in Subsection 4.1.6.

4.1.6 Control Packages

Control package management ensures close control of program costs and schedules. To plan and control the program in sufficient detail, the system of control package management as described in Subsection 4.1.3, and the Work Breakdown Structure (WBS) described in Subsection 4.1.4, will be used. All program tasks have been defined and organized into individual control packages, each having been assigned a separate schedule and budget. Control packages have been developed for each major subdivision of program effort corresponding to level 4 of the WBS. The following summary presentations are listed by WBS account number and cross-referenced to RFP SOW paragraph numbers, where applicable:

- Task Descriptions – The study approach and rationale for each of the contractor tasks specified in Section 4.0, "Contractor Tasks" of the NASA SOW is presented in Section 2 of this proposal. Subsection 4.1.6.1 herein provides a further description of these tasks by presenting a summary list of the subtasks that make up each of the contractor tasks. This information, in combination with the task scheduling and manpower loading information presented herein constitutes a complete description of the tasks to be accomplished and how we will accomplish these tasks
- Summary control package schedules (Fig. 4-20) show significant events within each control package keyed to major program milestones. All schedule events have been presented in the form of inputs from and outputs to other areas, resulting in a totally integrated program schedule



CONTROL PACKAGE TITLE: GROUND & FLT SYS OPTIM

SPACE SHUTTLE PHASE B STUDY CONTROL PACKAGE SCHEDULE

SCHEDULE PREPARED BY: K. NOOR

DATE 3-30-70

CONTROL PKG NO. 008

SOW NO. 4.1.12

CONTROL PACKAGE RESPONSIBILITY: J. DEVANEY

Fig. 4-19 Space Shuttle Phase B Study Sample Control Package Schedule

- Manpower requirements for all control packages are presented in Table 4-1. These requirements were planned to ensure the proper staffing level needed to accomplish the scheduled tasks and milestones. The numbers include Grumman as well as subcontractor manpower requirements and are expressed in man months for each control package. Subtotals are provided for the major level 2 WBS elements (integration, orbiter, booster, operations, and program management)

The system of control package management as described above provides the detailed planning base necessary for Grumman and NASA management to ensure close control and accurate monitoring of program costs and schedules.

4.1.6.1 Task Descriptions

As indicated previously, one part of the complete description of contractor tasks to be accomplished is the list of subtasks for each task. Contractor tasks are identified in the NASA RFP SOW Section 4.0 and are applicable in almost all cases to both orbiter and booster. Our proposed WBS provides for distinction between orbiter, booster, integration, operations and program management and identifies the contractor tasks under each of these by a control package account number. The contractor tasks apply to both Designs 518 and 532 as discussed in Subsection 4.1.4 herein, and are presented below with the subtasks in bulleted form. For ready identification of the task with the WBS, the control package account number precedes the task identification and for convenience, the NASA RFP SOW paragraph number is shown in parenthesis after the task. All subtasks also apply to Designs 518 and 532 except where noted with an asterisk (*) for Design 532 alone.

001 System Safety Analysis (SOW para 4.1.1)

- Identify and classify: configuration, operation and mission payload hazards
- Conduct: tradeoffs affecting configurations and operational modes
- Analyze: gross hazards through failure modes and effects techniques
- Establish: remedial safety measures
- Document: tradeoff rationale
- Determine: preventive safety measures
- Track: catastrophic/critical hazards
- Report: safety review board findings

002 Mission Analysis (SOW para 4.1.2)

- Analyze: total mission requirements and mission/vehicle performance sensitivities
- Establish: flight profiles best satisfying performance, heating, loads and abort requirements
- Determine: performance sensitivities to variations in mission/vehicle parameters
- Identify: performance constraints
- Define: a design reference mission, critical design missions and a reference mission mix per vehicle
- Perform: mission applications analysis
- Define: mission requirements as a function of program phase*

003 System Integration (SOW para 4.1.3)

- Identify: all system/subsystem physical/functional requirements
- Establish: degree of centralization and application for decentralization
- Determine: desirability and feasibility of onboard checkout through built-in test and self-test
- Define: desired test levels, display requirements and crew test initiation
- Structure: a methodology to determine relationships between the shuttle and external/internal interfaces
- Prepare: preliminary interface control documentation for major physical/functional elements
- Maintain: a design data book
- Generate: non-CEI specifications

004 System Flight Characteristics (SOW para 4.1.5)

- Investigate: stability, control, handling qualities, loads, performance characteristics for all flight aspects and methods of control over cg ranges
- Evaluate: control system design and handling qualities from initial entry to landing using 6 degree-of-freedom fixed base simulator
- Conduct: integration, control law, function interface, manual participation and automation tradeoff optimization studies
- Establish: maximum cg ranges
- Conduct: aerothermal wind tunnel test program in accordance with program and schedule submitted and approved by NASA and submit all aerothermal data to NASA per SOW Appendix D
- Expand: aerothermal program for simulated rocket plume testing
- Conduct: orbiter only landing/reentry and transition studies
- Perform: staging and separation studies

005 Aborts (SOW para 4.1.7)

- Investigate: intact abort to provide crew recovery/cargo retrieval
- Derive: abort regimes
- Establish: applicable techniques (including ground facilities/other aids) for commitment and targeting
- Identify: mission abort capability limitations and constraints

006 Reliability and Quality (SOW para 4.1.9)

- Recommend: a design approach
- Perform: system/subsystem failure mode effects and single point failure analyses
- Assist: optimization of system design, redundancy and maintainability
- Evaluate and Document: effects of tradeoffs
- Conduct: off-the-shelf equipment suitability study*

007 Maintainability (SOW para 4.1.10)

- Establish: preliminary design criteria for short turnaround, refurbishment and maintenance ease, including launch pad unscheduled maintenance and replacement
- Support: design tradeoff studies
- Document: analyses and tradeoff results effecting maintainability

008 Ground and Flight Systems Optimization (SOW para 4.1.12)

- Analyze: all requirements the vehicle imposes on ground systems to determine on-board functions and required tradeoffs between additional vehicle requirements and increased cost/complexity of ground operations
- Determine: time phased degree of vehicle autonomy*

009 Cost and Programmatic Analysis

- Define: cost methodology
- Develop: a parametric design program
- Identify: program cost drivers
- Perform: a parametric design costing analysis
- Estimate: costs for configuration/operational approaches
- Develop: mission and economic analysis

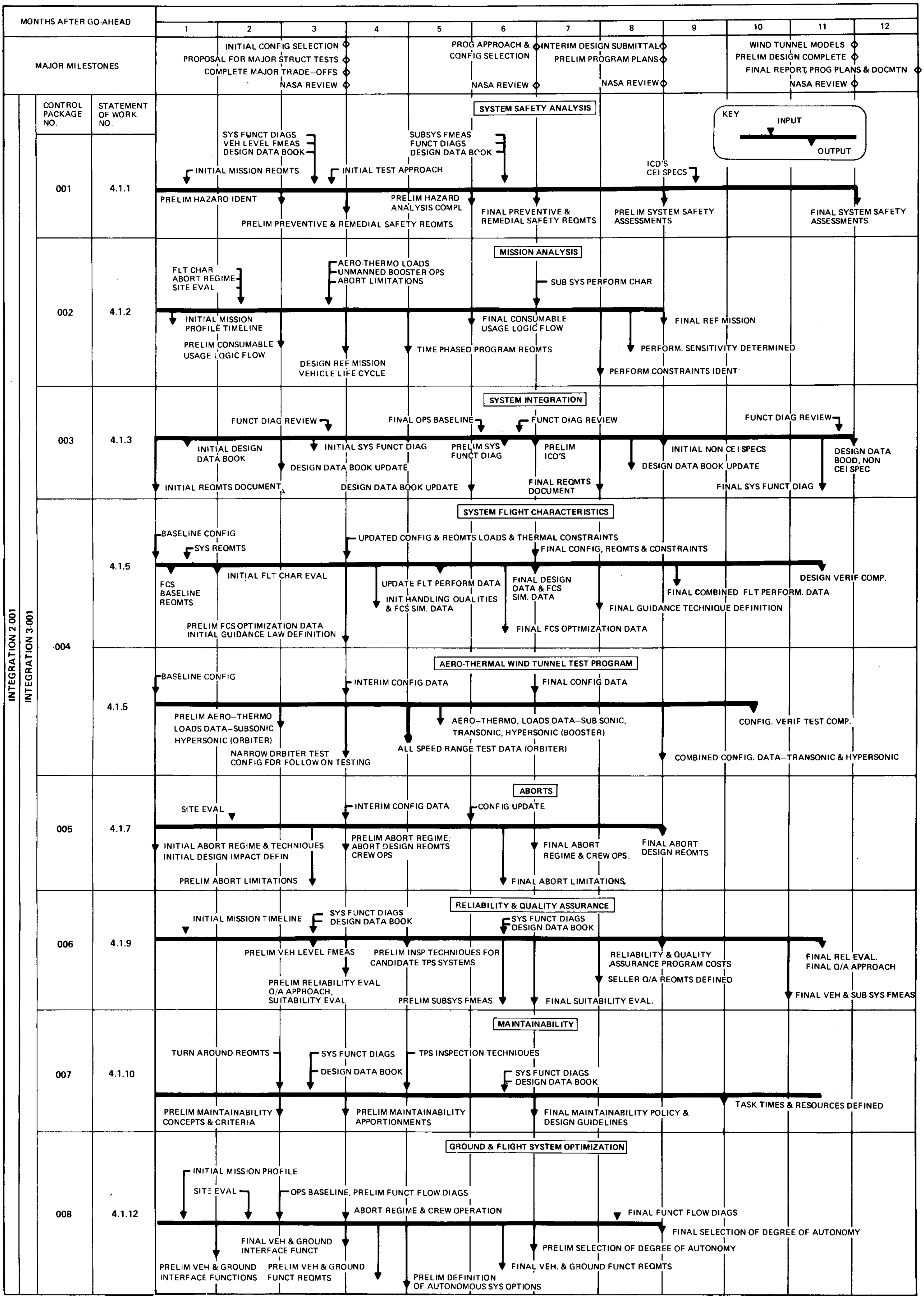


Fig. 4-20 Summary Control Package Schedules (Sheet 1 of 8)

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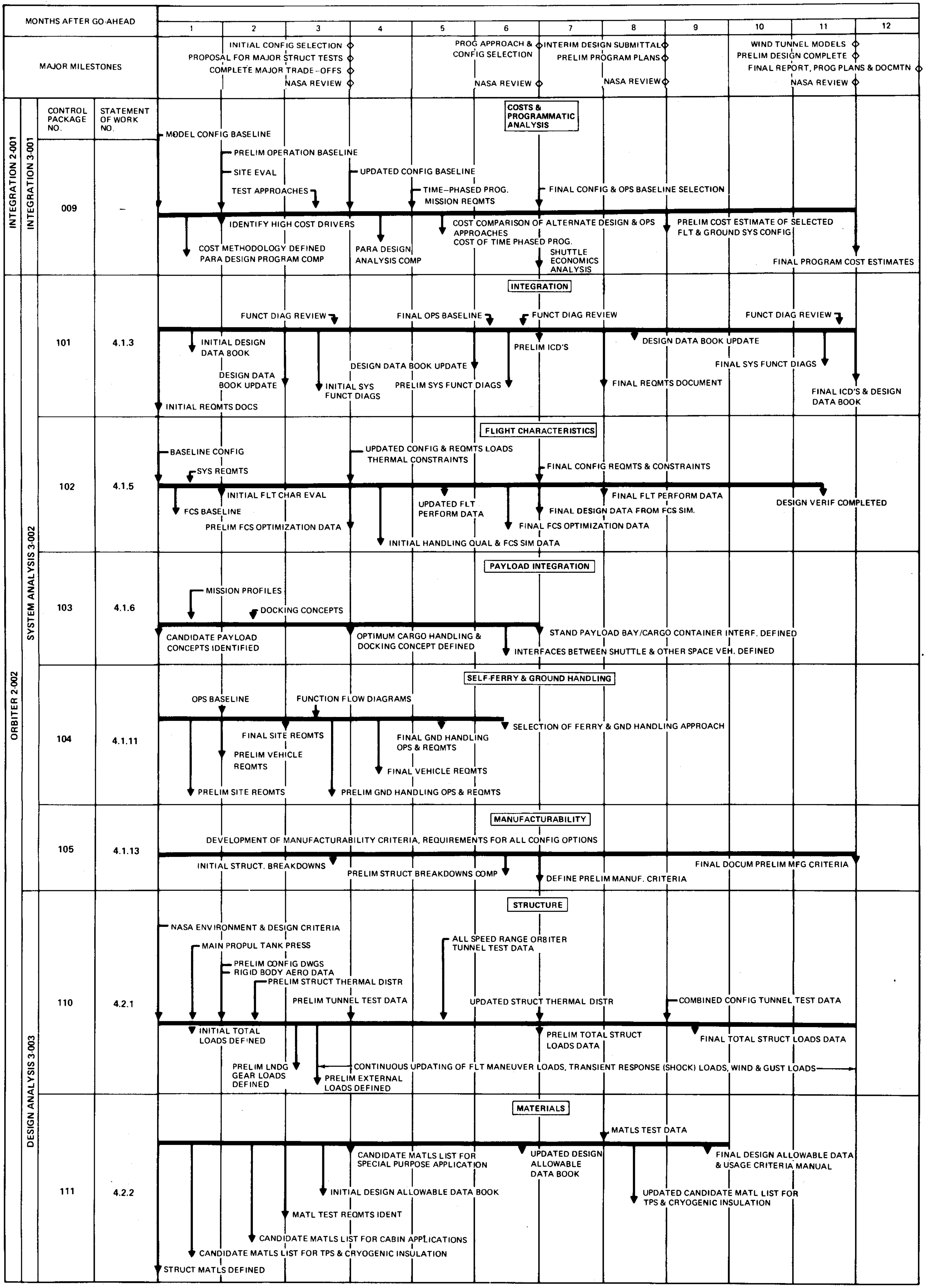


Fig. 4-20 Summary Control Package Schedules (Sheet 2 of 8)

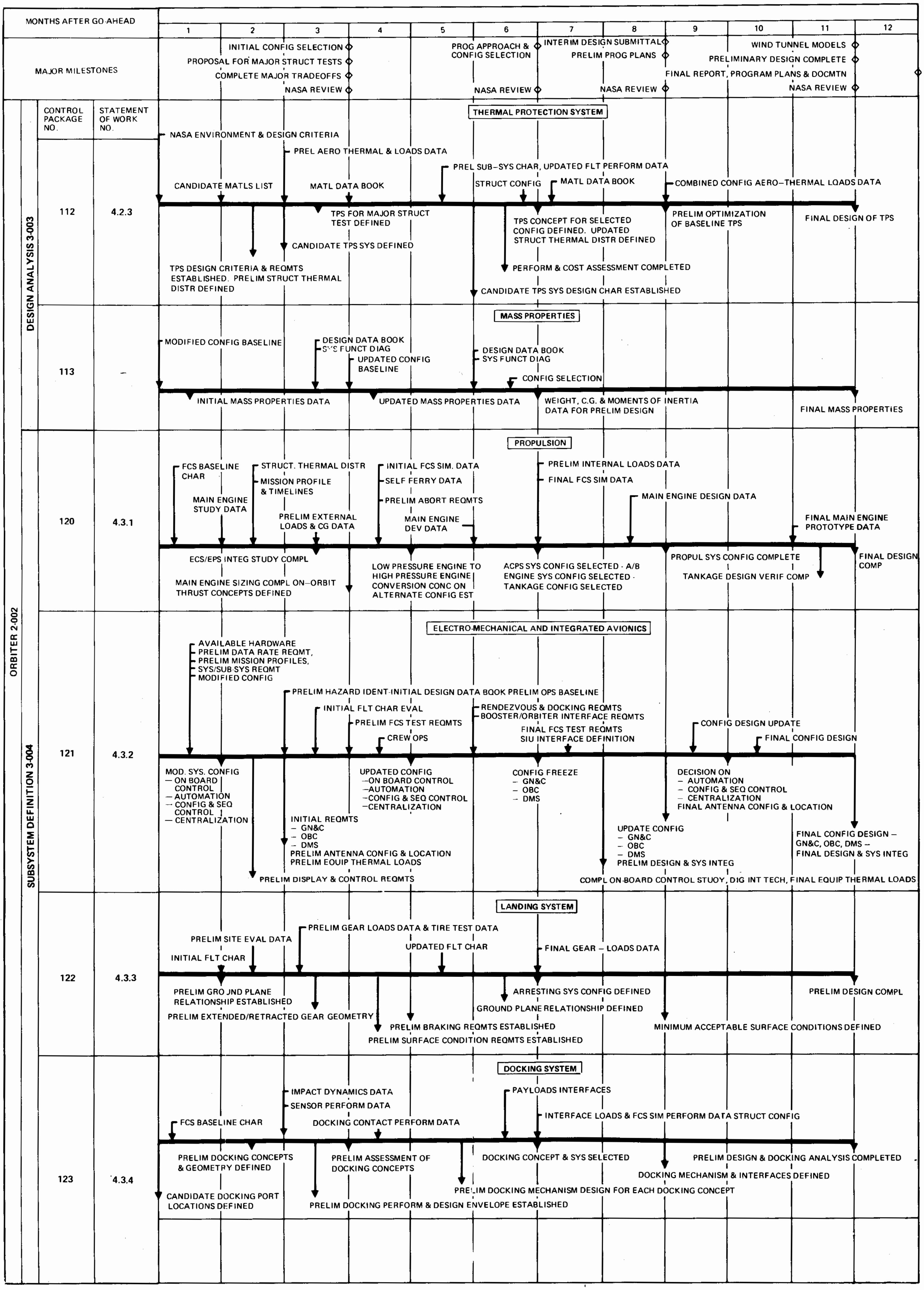


Fig. 4-20 Summary Control Package Schedules (Sheet 3 of 8)

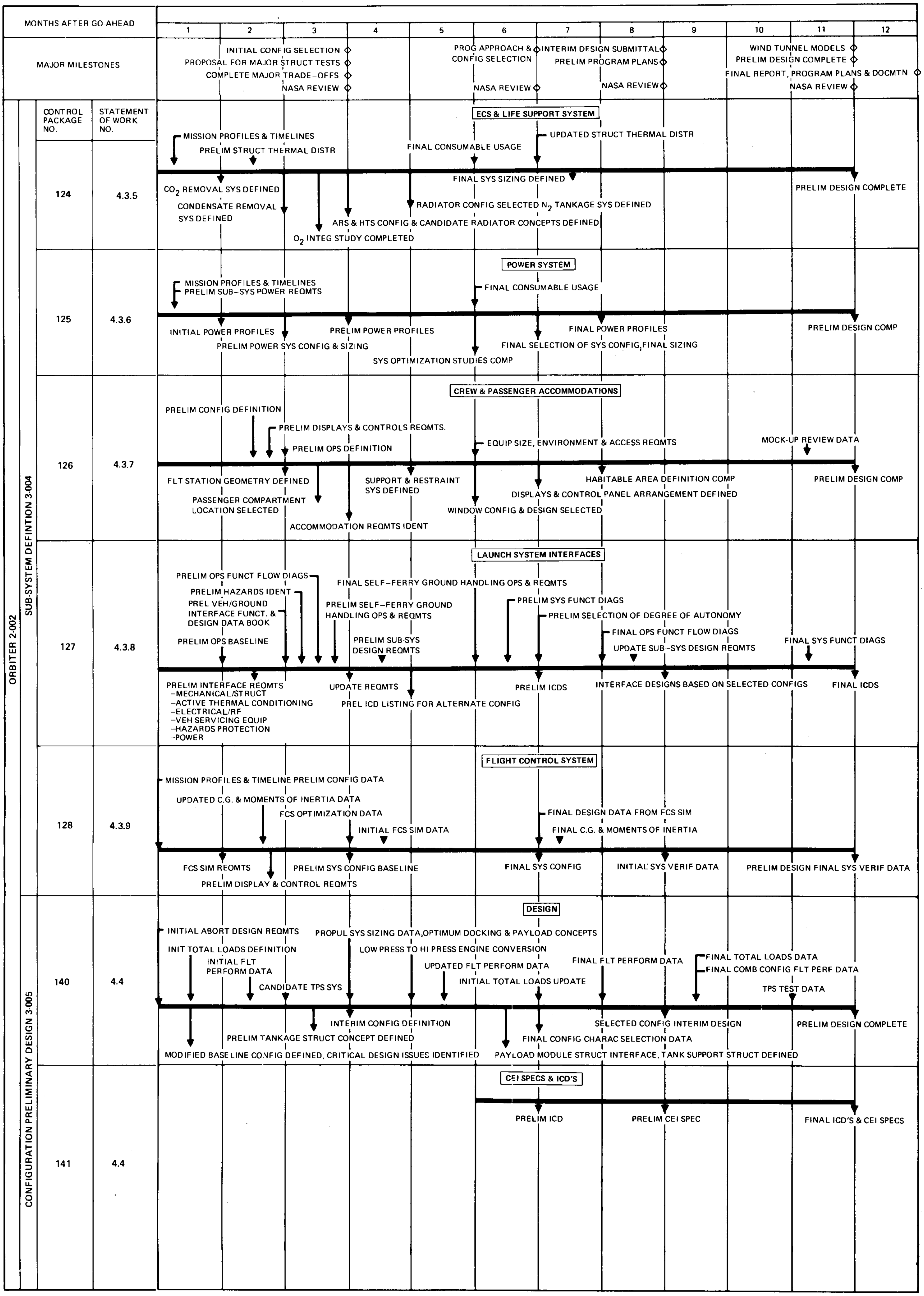


Fig. 4-20 Summary Control Package Schedules (Sheet 4 of 8)

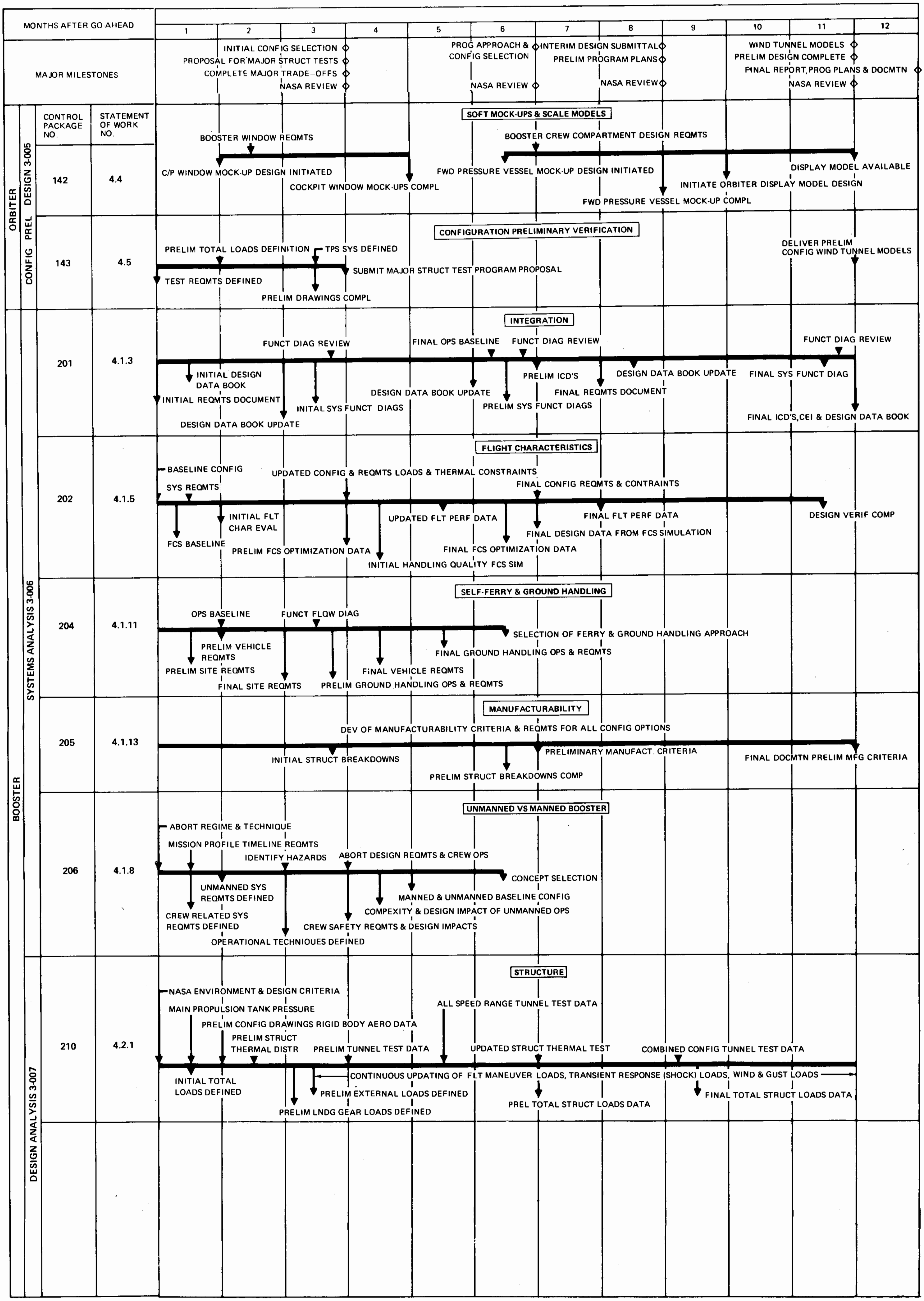


Fig. 4-20 Summary Control Package Schedules (Sheet 5 of 8)

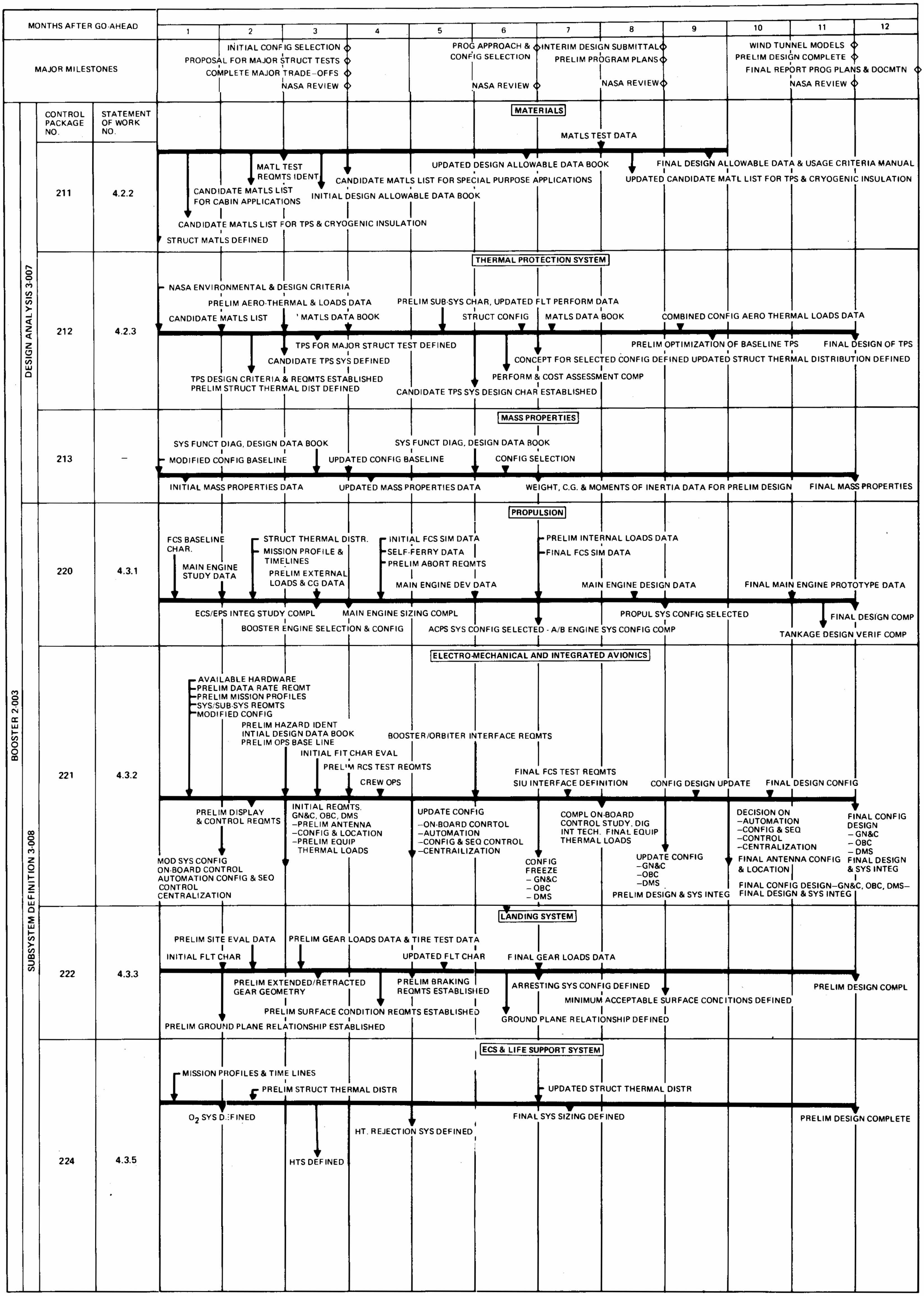


Fig. 4-20 Summary Control Package Schedules
(Sheet 6 of 8)

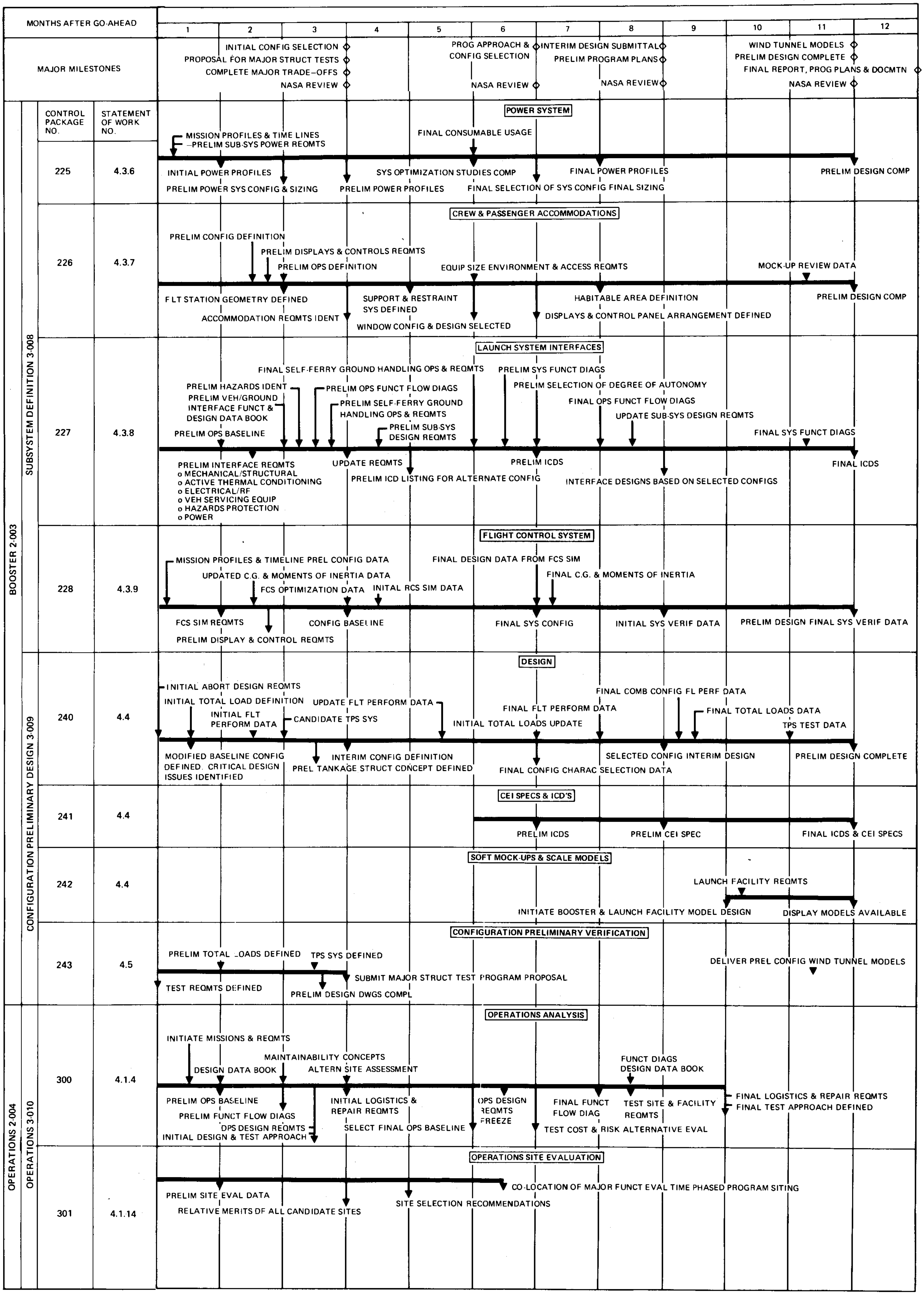


Fig. 4-20 Summary Control Package Schedules
(Sheet 7 of 8)

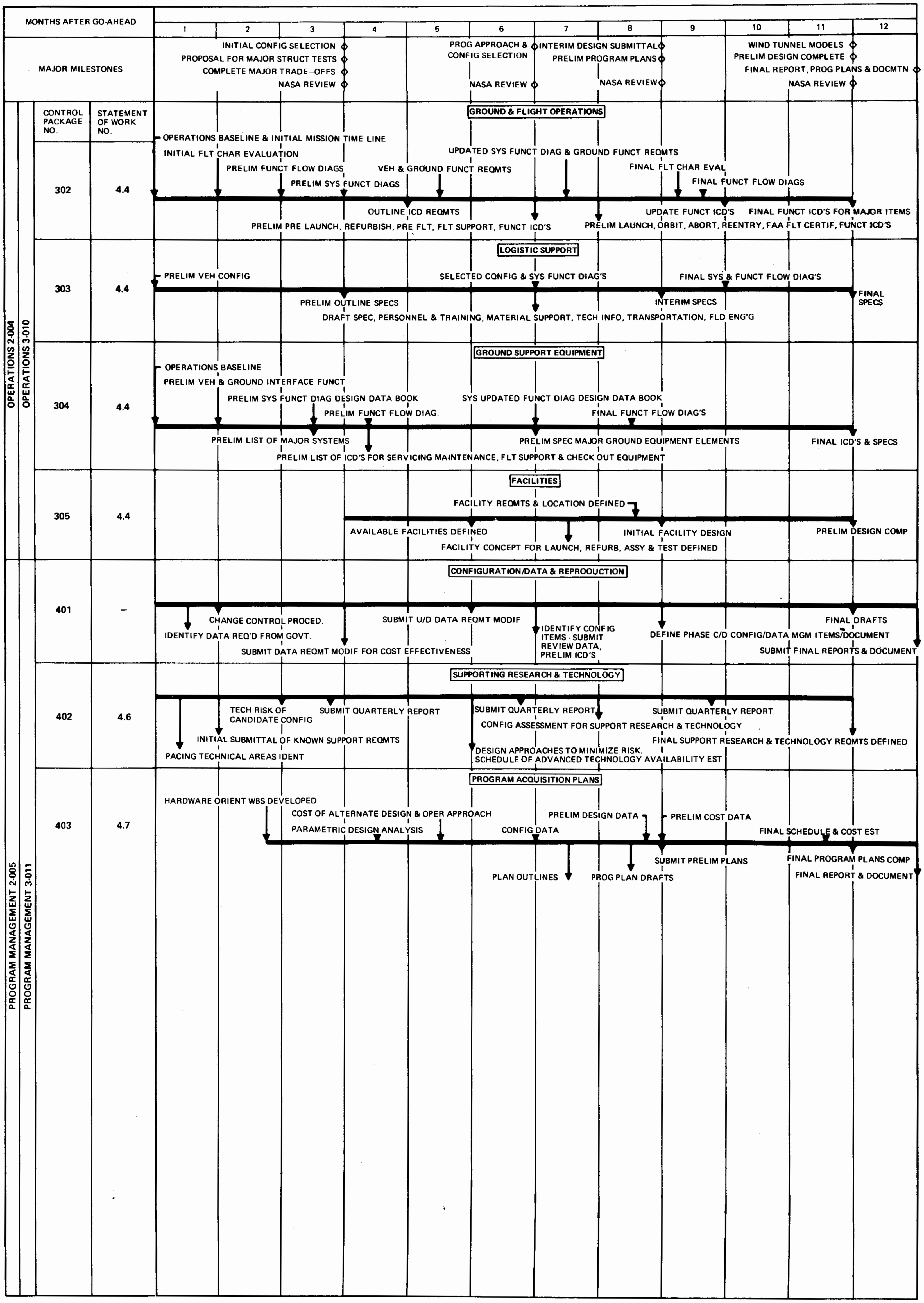


Fig. 4-20 Summary Control Package Schedules (Sheet 8 of 8)

Table 4-1 Direct Manpower Requirements

Sow No.	Acct. No.	Control Package Description	Months After Go-Ahead 1	2	3	4	5	6	7	8	9	10	11	12	Assoc Contr Man Months	Grumman Man Months	Total Man Months
INTEGRATION																	
4.1.1	001	SYSTEM SAFETY ANALYSIS	2	2	2	2	2	2	2	2	2	2	2			22	22
4.1.2	002	MISSION ANALYSIS	2	4	4	4	4	4	4	4	3					33	33
4.1.3	003	SYSTEM INTEGRATION & ICD'S (INCL NON CEI SPEC)	4	4	4	5	6	7	7	7	8	8	8		24	44	68
4.1.5	004	SYSTEM FLIGHT CHARACTERISTICS	3	3	3	6	7	7	8	8	8	6	3		12	50	62
4.1.7	005	ABORTS	2	3	3	3	3	3	3	2						22	22
4.1.9	006	RELIABILITY & QUALITY	2	2	2	2	2	2	2	2	2	2	2			22	22
4.1.10	007	MAINTAINABILITY	1	1	1	1	1	1	1	1	1	1	1			11	11
4.1.12	008	GROUND & FLIGHT SYSTEMS OPTIMIZATION	1	2	3	3	3	3	3	3	2				12	11	23
	009	COST AND PROGRAMMATIC ANALYSIS	3	4	4	4	4	4	4	4	4	4	2	1	42	SEE NOTE 1	42
		SUBTOTAL	20	25	26	30	32	33	34	33	30	23	18	1	90	215[3]	305
ORBITER																	
4.1.3	101	INTEGRATION	5	5	6	7	7	7	7	6	6	6	6	1	24	45	69
4.1.5	102	ORBITER FLIGHT CHARACTERISTICS	11	16	21	26	26	26	26	21	16	11	6	3		209	209
4.1.6	103	PAYLOAD INTEGRATION	3	4	4	4	4	4	4						14	13	27
4.1.11	104	SELF-FERRY & GROUND HANDLING	½	½	½	½	½	½								3	3
4.1.13	105	MANUFACTURABILITY		¼	¼	¼	¼	¼	¼	¼	¼					2	2
4.2.1	110	STRUCTURE	11	11	11	11	13	14	14	14	10	9	6	1		125	125
4.2.2	111	MATERIALS	7	7	7	6	5	5	3	2	2				36	8	44
4.2.3	112	THERMAL PROTECTION SYSTEM	11	13	14	14	14	14	14	14	14	14	10	1	60	87	147
	113	MASS PROPERTIES	3	3	3	3	3	3	3	3	3	3	3			33	33
4.3.1	120	PROPULSION SYSTEM	7	9	10	10	10	10	10	10	10	7	7	1	12	89	101
4.3.2	121	ELECTRO-MECHANICAL & INTEGRATED AVIONICS	16	16	26	26	26	26	26	28	28	28	18	2	178	88	266
4.3.3	122	LANDING SYSTEM	1	1	1	1	1	2	2	1	1	1	1		2	11	13
4.3.4	123	DOCKING SYSTEM	1	1	1	1	1	1	1	1	1	1	1			11	11
4.3.5	124	ECS & LIFE SUPPORT SYSTEM	1	1	1	1	2	2	2	2	2	1	1			16	16
4.3.6	125	POWER SYSTEM	1	1	1	1	1	1	1	1	1	1	1			11	11
4.3.7	126	CREW AND PASSENGER ACCOMMODATIONS	1	1	2	2	4	4	4	4	4	4	3			33	33
4.3.8	127	LAUNCH SYSTEM INTERFACES				½	½	½	½	½	½	½				3½	3½
4.3.9	128	FLIGHT CONTROL SYSTEM	5	8	9	11	11	12	12	12	12	12	12	1	84	33	117
4.4	140	DESIGN	6	8	10	10	12	12	12	12	12	12	12	2	48	72	120
4.4	141	CEI SPECIFICATION						1	1	2	2	3	3	2		14	14
4.4	142	SOFT MOCKUP & SCALE MODELS		3	6	10		4	8	8	5	5	5	1		55	55
4.5	143	CONFIGURATION PRELIMINARY VERIFICATION	½	½	½											1½	1½
		SUBTOTAL	91	109¼	134¼	145¼	141¼	149¼	150¾	141¾	129¾	118½	95	15	458	963	1421
BOOSTER																	
4.1.3	201	INTEGRATION	2	2	2	2	2	2	2	2	2	2	2	1	12	11	23
4.1.5	202	BOOSTER FLIGHT CHARACTERISTICS	9	11	13	18	18	18	18	13	9	5	3	1	114	22	136
4.1.11	204	SELF-FERRY & GROUND HANDLING	¼	¼	¼	¼	¼	¼								1½	1½
4.1.13	205	MANUFACTURABILITY		¼	¼	¼	¼		¼	¼						1½	1½
4.1.8	206	UNMANNED VERSUS MANNED BOOSTER	¼	¼	¼	¼	¼	¼								1½	1½
4.2.1	210	STRUCTURE	3	4	4	4	4	4	4	4	4	4	3	1	36	7	43
4.2.2	211	MATERIALS	1	1	1	1	1	1	1	1						8	8
4.2.3	212	THERMAL PROTECTION SYSTEM	1	1	1	1	1	1	1	1	1	1	1			11	11
	213	MASS PROPERTIES	2	2	2	2	2	2	2	2	2	2	2	1	12	11	23
4.3.1	220	PROPULSION SYSTEM	5	7	7	7	7	7	7	7	7	7	6	1	24	51	75
4.3.2	221	ELECTRO-MECHANICAL & INTEGRATED AVIONICS	1	2	2	2	3	3	3	3	2	2	1		12	12	24
4.3.3	222	LANDING SYSTEM	1	1	1	1	1	1	1	1	1	1	1		10	1	11
4.3.5	224	ECS & LIFE SUPPORT SYSTEM	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼				2½	2½
4.3.6	225	POWER SYSTEM	¼	¼	¼	¼	¼	¼	¼	¼	¼	¼				2½	2½
4.3.7	226	CREW ACCOMMODATIONS	1	1	1	1	1	1	1	1	1	1	1			11	11
4.3.8	227	LAUNCH SYSTEM INTERFACE				½	½	½	½	½	½	½	½			4	4
4.3.9	228	FLIGHT CONTROL SYSTEM	2	4	4	4	4	4	4	4	4	4	3		36	5	41
4.4	240	DESIGN	4	6	6	8	8	8	8	8	8	8	8	1	60	21	81
4.4	241	CEI SPECIFICATION						1	1	1	2	2	2	1		10	10
4.4	242	SOFT MOCKUPS & SCALE MODELS		1	1	1				1	1	1	1	1		8	8
4.5	243	CONFIGURATION PRELIMINARY VERIFICATION	½	½	½											1½	1½
		SUBTOTAL	33½	44¾	46¾	53¾	53¾	54½	54¼	50¼	45	41	34½	8	316	204	520
OPERATIONS																	
4.1.4	300	OPERATIONS ANALYSIS	3	6	6	8	8	9	9	9	9	8	8	1	24	60[4]	84
4.1.14	301	OPERATIONS SITE EVALUATION	3	3	3	3	3	1	1	1	1	1	1	1		22	22
4.4	302	GROUND OPERATIONS	2	2	2	2	3	4	7	7	7	7	7	1	24	27	51
4.4	303	LOGISTICS SUPPORT	2	2	2	2	2	4	6	7	7	7	7	1	24	25	49
4.4	304	GROUND SUPPORT EQUIPMENT		1	1	1	2	3	3	3	3	3	3	2		25	25
4.4	305	FACILITIES		1	1	1	1	1	1	1	1	1	1	1		11	11
		SUBTOTAL	10	15	15	17	19	22	27	28	28	27	27	7	72	170	242
PROGRAM MGMT																	
	400	MANAGEMENT	14	14	14	14	14	14	14	14	14	14	14	7		161	161
	401	CONFIGURATION/DATA & REPRODUCTION	1	2	2	3	3	3	3	3	3	3	3	3		32	32
4.6	402	SUPPORTING RESEARCH & TECHNOLOGY	1	1	1	1	1	1	1	1	1	1	1	1		12	12
4.7	403	ACQUISITION PLANS	1	2	3	3	5	5	10	10	10	10	10	10		79	79
		SUBTOTAL	17	19	20	21	23	23	28	28	28	28	28	21		284	284
		TOTAL MAN MONTHS	171½	213	242	267	269	281¾	294	281	260¾	237½	202½	52	936	1836[2]	2772

NOTE
1 Approximately (156) man months of indirect labor will be used to perform this task.
2 Includes (120) man months of Grumman data systems
3 An additional (36) man months of indirect labor from the parametric resource analysis group will be used to perform the integration task.
4 An additional (36) man months of indirect labor from the parametric resource analysis group will be used to perform the operations analysis task.

- Prepare: preliminary and final program cost estimates for selected shuttle system

101 Integration (SOW para 4.1.3) (See Task 003)

102 Orbiter Flight Characteristics (SOW para 4.1.5) (See Task 004)

103 Payload Integration (SOW para 4.1.6)

- Analyze: space station, science modules, unmanned satellites, ground facilities and service interfaces with the shuttle
- Define: standard interface between shuttle payload bay and container modules
- Determine: payloads not requiring containers, number of container designs and quantity thereof
- Examine: impact of container growth to 22 feet in standard interface*

104 Self-Ferry and Ground Handling (SOW para 4.1.11)

- Ensure: vehicle design considers all aspects of self-ferry
- Assess: requirements to support design, development, test and operation

105 Manufacturability (SOW para 4.1.13)

- Establish: preliminary criteria for system design
- Conduct: design/manufacturability tradeoff studies using established criteria
- Document: studies accomplished

110 Structure (SOW para 4.2.1)

- Divide: system into major/sub structural assemblies and components and determine critical design conditions and materials requirements using NASA supplied design and natural environments criteria
- Determine: loads envelope (rigid body and dynamic loads) prelaunch to landing
- Present: selection rationale for primary structural assemblies/subassemblies
- Show: typical cross sections of total vehicle structure with sufficient assembly/manufacturing method details
- Calculate: loads using design wind profiles
- Consider: fatigue effects, low frequency structural dynamics, high frequency vibration, aeroelastic, shock and corrosive environment effects on structural design conditions and material requirements
- Conduct: analysis showing design provides sufficient safety margin for adequate strength, rigidity and personnel safety at all times
- Conduct: laboratory testing to substantiate analyses (where required) and provide a basis for weight estimates
- Conduct: cryotank thermal insulation (purge/insulation demonstration), structural methods (compression dome pressure), panel (temperature, shock and thermal conductivity) and insulation/adhesive materials tests
- Provide: a final report with loads and strength sections for methods, data assumptions and analyses, test results which are comprehensive and detailed to support preliminary design

111 Materials (SOW para 4.2.2)

- Identify and evaluate: candidate materials on basis of weight, reliability, temperature limitation and extended life
- Determine: design allowables on basis of application, environment, testing, manufacturing and extended life
- Specify: materials considering flammability, outgassing characteristics, corrosion resistance and stress corrosion
- Evaluate: advanced materials requiring technology developments for system design/performance improvements and define requirements for technology problems

112 Thermal Protection System (TPS) (SOW para 4.2.3)

- Perform: thermal analysis before defining TPS
- Analyze: candidate thermal protection concepts (active/passive), materials, and installation techniques in terms of weight, cost technology status, fabrication, maintenance, reusability, inspection and refurbishment requirements
- Compare: candidate TPS material performance to withstand ground/flight environments and abort techniques
- Define: cooling, insulation and attachment techniques
- Assess: application of TPS for meteoroid, space debris and radiation protection
- Determine: best locations for antennas/other critical surface discontinuities
- Select: TPS design and material consistent with multi-mission design criteria

- Interpret: uniformly, property degradation data obtained from cyclic exposures to representative environments for maintenance inspection practice design/development
- Analyze: TPS thermal control aspects for nominal/off-nominal conditions
- Consider: purging provisions during all appropriate mission phases
- Conduct: test program on selected TPS's in realistically simulated reentry environment to verify analysis/provide substantive weight estimates
- Conduct: thermal/acoustic/vibration and reentry simulation test of GE ruggedized external insulation (REI) panels
- Conduct: temperature/static loading tests of one super-alloy and one columbium TPS panel

113 Mass Properties

- Identify and update: required mass properties data
- Provide: weight, cg and moments of inertia data and substantiation for preliminary design
- Provide: final data in required reporting format

120 Propulsion Systems (Determine requirements for and define) (SOW para 4.3.1)

- Main Propulsion System
  - Analyze: systems (including effects of engine-out capability, pressurization, propellant management/usage/handling, thermal control and integration) considering operating percent of thrust range, performance, engine length, gimballing restraints and cg location
  - Determine: optimum expansion ratio maintaining engine commonality
  - Analyze: engine-out and propellant-jettison capability and emergency dumping
  - Evaluate: practicality of draining and purging main tanks after landing/prior to reloading
  - Define: total environment, thermal control, propellant boiloff/losses over mission duty cycle
  - Define: design, hardware criteria, operational and redundance requirements for propellant loading feed and utilization and pneumatics
  - Conduct: uprated J-2S and F-1 engine study*
- Attitude Control Propulsion System (ACPS)
  - Determine: vehicle control requirements for liftoff and boost, separation, orbit insertion and circularization, coast and transfer trajectories, rendezvous, docking, orbit maintenance retrograde and reentry
  - Consider: redundancy requirements specified in SOW Appendix C
  - Translate: vehicle control requirements to ACPS requirements for total thrust and torque per axis, total impulse per axis, duty cycle per axis, min/max impulse bit per axis, volume/weight limitations and vehicle sensitivities, allowable thrust and specific impulse limitations per axis
  - Conduct: analyses/design/tradeoff studies to configure candidate systems to translated requirements
  - Consider: a low pressure ACPS and maximum utilization of residuals and boiloff
  - Select: an ACPS concept
  - Describe: selected system in terms of specifications, interface weights and volumes
- Orbit Maneuvering System (OMS) – (Orbiter only task)
  - Determine: OMS requirements for thrust levels, total impulse, and number of starts
  - Conduct: tradeoff studies to determine if main propulsion/ACPS or separate system should perform on-orbit maneuver functions
  - Consider: operational flexibility, safety, weight and total system performance primary for system definition
  - Generate: system description including specifications, weights, volumes and interface
- Air-Breathing System
  - Define: type and thrust level of the ferry, go-around or landing assist engines, performance, location, tankage and fuel feed, deployment techniques, pressurization, lubrication system, instrumentation, data display and control requirements of these engines
  - Evaluate: practical use of hydrogen/standard (JP) fuels
  - Recommend: preferred fuel and its phase
  - Perform: tradeoff studies of baseline requirements for go-around, powered approach, and no air-breathing propulsion
  - Analyze: practicality of using common engines for booster and orbiter
  - Determine: modifications of jet engines for hydrogen fuels and vehicle integration requirements
  - Review: available engine applicability
- Cryogenic Tankage System
  - Define: system emphasizing configurations, residuals, system thermodynamics, thermal propulsion pressurization requirements, fluid dynamics, liquid transfer, zero g venting, quantity gaging, servicing, ground and inflight dumping and compatible material selection
  - Conduct: feasibility study to establish common tankage for propulsion/fuel cells considering ultra pure reactant requirements

  - Optimize: total system from weight standpoint considering maximum integration to minimize fluid losses through venting
- Engines/Vehicle Integration
  - Conduct: analyses and studies to support NASA development programs
  - Make available: data in accordance with SOW Appendix F for proper/timely engine definition and vehicle integration
  - Evaluate: results of engine parametric analysis as it effects vehicle requirements
  - Recommend: operating parameters and changes from baseline engine size

121 Electromechanical and Integrated Avionics (SOW para 4.3.2)

- Define: functions and requirements including functions of guidance and control, navigation, communications, on-board checkout, configuration and sequencing control, displays, data management, target tracking and sensors, automatic landing system, and other functions requiring computational capability and exchange of data between systems
- Determine: desirable and feasible amount of onboard control and automation considering subsystem concepts, system concepts, requirements, crew integration including investigations and tradeoff studies of crew size/skills, workload system complexity, checkout and inflight status monitoring and costs
- Determine: use of like components for booster and orbiter
- Consider: electromagnetic interference and establish EMI standards
- Specify: verification testing for individual assemblies and system for low-level signal requirements
- Study: baseline (first generation) system design
- Recommend: a preliminary avionics system point design
- Identify and describe: subsystem configurations
- Prepare: functional block diagrams and performance specifications for each subsystem
- Identify: anticipated high-risk areas, critical problem areas, and required technology advances for each subsystem
- Perform: centralization of functions tradeoff study
  - Establish degree of centralization
  - Consider: applications where centralization/decentralization is desirable
  - Define: computer organization/hierarchy and comparative evaluation of centralized vs other concepts
  - Consider: high degree of on-board control and short turnaround time system design requirement effects
  - Establish: level of system information necessary for flight crew fault and failure isolation to satisfy ground service/turnaround requirements
- Perform: digital interface techniques tradeoff study
  - Consider: multiplexed and non-multiplexed data bus techniques
  - Investigate: logic complexity, software requirements, data rate, electromagnetic compatibility, reliability, flexibility
- Perform: modular design tradeoff study
  - Recommend: extent of modularization for avionics packaging and package installation
  - Consider: standard techniques for packaging, mounting, cooling, interconnections, circuit design, parts selection
  - Consider: standard techniques for heating, interface and inter/intra equipment and vehicle wiring
  - Study: modular checkout and maintenance approaches
- Perform: power condition tradeoff study
  - Consider: both overload and short circuit protection centralization vs incorporation of power in systems
  - Establish: for power distribution power quality requirements of ripple limits, transients, interruption and conductor interference effects
- Perform: on-board checkout tradeoff study
  - Determine: desirability and feasibility of built-in test and built-in self-test
  - Define: desired test levels, display and recording requirements, extent of trend data analysis, and crewman participation in test initiation and stimulus generation
  - Perform: a reduced ratings study*
- Perform: configuration and sequencing control tradeoff study
  - Recommend: degree of crew participation criteria
  - Compare: alternate automatic/manual techniques assessing cost and system complexity
- Perform: redundancy techniques tradeoff study
  - Recommend: for each shuttle application redundancy techniques to be implemented
  - Examine: active vs inactive redundancy
  - Consider: circuit complexity, malfunction detection, performance degradation, and crew participation for determination of redundancy techniques

- Perform: Integrated displays and controls tradeoff study
  - Establish: crew decision and control requirements
  - Evaluate: human factors
  - Consider: redundant multi-purpose computer operated displays for system status and flight path information
- Perform: sensors and actuators tradeoff study
  - Determine: sensor and actuator integration
  - Consider: operating parameters input/output characteristics, power and control vs existing design interfacing requirements
  - Evaluate: desirability of integrating flight safety items
- Perform: integrated vs conventional approach tradeoff study
  - Prepare: estimates for recommended system configuration, including cost, size, weight, power and schedule
  - Compare: integrated vs conventional modular approach
- Perform: shuttle-ground communication interface tradeoff study
  - Define: requirements for and interface with ground facilities and communication satellites for communications, data transmission and tracking

122 Landing System (SOW para 4.3.3)

- Define: system type and characteristics considering dynamics, structural analysis, weight, volume, stowage, location and environmental control
- Conduct: compatibility tradeoff study of recommended system for minimum acceptable landing surface conditions and vehicle touchdown characteristics
- Define: deceleration parachutes or devices if applicable

123 Docking System (SOW para 4.3.4)

- Analyze: automatic approach/docking capability assessing for various docking options operational/safety aspects of shuttle docked with space station/orbiting vehicle and deployed payload docked with station/orbiting vehicle/space base
- Conduct: tradeoff study to determine the extent to which docked vehicle stabilization is a shared or complementary function and how docking mechanism is effected, considering soft or flexible docking, amount of automation, complexity degree, costs and other tradeoffs

124 Environmental Control and Life Support (SOW para 4.3.5)

- Perform: analysis and definition of all elements involved in environmental control, thermal control, water and waste management and life support subsystems including requirements for cargo compartment investigations of environmental control, life support and interface
- Provide: water and oxygen supply, atmosphere revitalization, waste management facilities, shuttle temperature maintenance, and maintenance of a shirtsleeve environment/temperature, atmospheric pressure and composition in the design
- Study: system design simplification*

125 Power System (SOW para 4.3.6)

- Analyze: and recommend an integrated power system
- Conduct: studies and analysis to establish operating profiles and recommend generation, distribution, conditioning and control elements for all on-board electric and hydraulic power
- Conduct: a reduced ratings study*

126 Crew and Passenger Accommodations (SOW para 4.3.7)

- Perform: human factor oriented tradeoff studies for crew habitation and working conditions
- Provide: an all mission phase design approach for maximum work efficiency, minimum fatigue, adequate rest, diversion, maximum safety and an optimum tunnel configuration for access between crew and passenger compartments
- Prepare: crew compartment and instrument panel layouts
- Analyze: optimum 12 passenger accommodations and permanent seating vs palletized cargo compartment accommodation considering permanent accommodations for 2 passengers via tradeoff studies
- Identify: GFE hardware installations
- Examine: payload configurations

127 Launch System Interfaces (SOW para 4.3.8)

- Define: for all flight systems ground/system interface requirements during prelaunch and launch operations
- Identify: all physical connections for structural support and stabilization, power, communications, control, checkout, propellants, fluids and gases

128 Flight Control System (FCS) Includes Attitude Control Propulsion and Aerodynamic System (SOW para 4.3.9)

- Determine and Define: FCS subsystems and interfaces (including requirements) through analysis of system performance, stability, power requirements, duty cycle, fail safe features and static/dynamic structural loads
- Conduct: FCS simulator/mockup system testing

140 Design (SOW para 4.4)

- Conduct: design sensitivity study leading to Grumman/NASA requirements freeze (at 3-month review) for Designs 518/532 operations concept
- Conduct: configuration sizing/vehicle design study leading to Grumman/NASA design selection (at 6-month review) for Designs 518/532
- Conduct: continued configuration/vehicle study of selected orbiter/booster design leading to preliminary design (8 month) review
- Conduct: continued configuration/vehicle design study leading to preliminary flight vehicle design drawings, supporting preliminary design analysis, definition of all flight hardware to level 6 (assemblies), and identification of new hardware/software and modifications/additions made to existing flight hardware
- Provide: necessary drawings and layouts to support system analysis, design analysis and subsystem analysis studies

141 CEI Specifications (SOW para 4.4)

- Prepare and submit: preliminary ICDs for Designs 518/532 (180 DAC), preliminary systems/booster, end item/orbiter, end item/operations specifications (240 DAC), and final ICD's systems/booster, end item/orbiter and end item/operations specifications (360 DAC)

142 Soft Mockups and Scale Models (SOW para 4.4)

- Design and fabricate: a full scale cockpit window configuration mockup for combined orbiter/booster visibility studies, a full scale forward pressure vessel mockup for internal arrangement studies and a 1/96 scale engineering/display model of selected design for delivery to NASA at Phase B completion

143 Configuration Preliminary Verification (SOW para 4.5)

- Provide: to NASA preliminary design configuration wind tunnel models used for wind tunnel testing
- Propose: in accordance with SOW Appendix F, a major structural subassembly test program
- Identify: all test setups, facilities and other items needed and order test priority

201 Integration (SOW para 4.1.3) (See Task 101)

202 Booster Flight Characteristics (SOW para 4.1.5) (See Task 102)

204 Self Ferry and Ground Handling (SOW para 4.1.11) (See Task 104)

205 Manufacturability (SOW para 4.1.13) (See Task 105)

206 Unmanned vs Manned Booster (SOW para 4.1.8) (Booster Only)

- Conduct: manned vs unmanned booster tradeoff studies to abort, ferry-flight and normal-launch phases
- Define: requirements imposed on systems for manned operations and evaluate required operational technique feasibility

210 Structure (SOW para 4.2.1) (See Task 110)

211 Materials (SOW para 4.2.2) (See Task 111)

212 Thermal Protection System (SOW para 4.2.3) (See Task 112)

213 Mass Properties (See Task 113)

220 Propulsion System (SOW para 4.3.1) (See Task 120)

221 Electromechanical and Integrated Avionics (SOW para 4.3.2) (See Task 121)

222 Landing System (SOW para 4.3.3) (See Task 122)

224 ECS and Life Support System (SOW para 4.3.5) (See Task 124)

225 Power System (SOW para 4.3.6) (See Task 125)

226 Crew Accommodations (SOW para 4.3.7) (See Task 126)

227 Launch System Interface (SOW para 4.3.8) (See Task 127)

228 Flight Control System (SOW para 4.3.9) (See Task 128)

240 Design (SOW para 4.4) (See Task 140)

241 CEI Specifications (SOW para 4.4) (See Task 141)

242 Soft Mockups and Scale Models (SOW para 4.4) (See Task 142)

243 Configuration Preliminary Verification (SOW para 4.5) (See Task 143)

300 Operations Analysis (SOW para 4.1.4)

- Analyze: launch, mission and ground turnaround operations, support and logistics concept costs and efficiencies for preliminary design impact
- Estimate: site manpower requirements (to meet SOW para 4.7.7 and Appendix D)
- Identify: vehicle features impacting ground/flight operational characteristics and turnaround times
- Establish: test approach

301 Operations Site Evaluation (SOW para 4.1.14)

- Evaluate: merits of various operations sites
- Evaluate: co-location of assembly, test and operations sites
- Evaluate: phased site location concept *

302 Ground and Flight Operations (SOW para 4.4)

- Prepare and Submit: preliminary functional ICD covering ground and flight operations (180 DAC) and finalized ICD for selected design (360 DAC)

303 Logistics and Support (SOW para 4.4)

- Prepare: preliminary non-CEI specifications for the logistics system (240 DAC), and finalized non-CEI specs (360 DAC) defining all major ground equipment to level 5 (subsystems) and identification of new hardware/software and modifications/additions to existing ground equipment

304 Ground Support Equipment (SOW para 4.4)

- Conduct: equipment design study leading to preliminary equipment drawings, supporting preliminary design analysis, definition of all major ground equipment to level 5 (subsystems) and identification of new hardware/software and modifications/additions to existing ground equipment
- Prepare and Submit: preliminary ground equipment ICD's (180 DAC), preliminary non-CEI specifications for major ground equipment elements (including servicing maintenance, checkout, transportation and handling) used by selected design (240 DAC), and final ICD's and CEI's (360 DAC)

305 Facilities (SOW para 4.4)

- Conduct: study for selected design leading to preliminary facility design drawings, supporting facility design analysis, definition of all major ground facilities to level 5 (subsystems) and identification of new facilities and modifications/additions to existing facilities
- Prepare and Submit: preliminary shuttle/launch facility ICD's (180 DAC), preliminary non-CEI specifications (Part I) covering new facilities and modifications/additions to existing facilities for selected design (240 DAC), final ICD's and CEI's (360 DAC)

400 Management

- Update: Phase B study plan as required
- Provide: interface and overall study coordination with NASA/DOD, and cooperation/participation in exchange/integration of information with other government contractors as required
- Determine, Organize and Administer: resources required for program conduct
- Plan, Direct and Coordinate: total program effort
- Monitor and Control: program expenditures
- Develop Phase C/D: WBS (with NASA), management system and plans
- Direct: material preparation for NASA reviews
- Approve and Submit to NASA: monthly progress reports and the final Phase B report including cost and schedule data

401 Configuration/Data Management

- Establish and Maintain: standard procedures for data preparation, change control procedures for NASA approved documents and a data file and retrieval system

- Identify: configuration items/documentation and cost effective data requirement modifications

- Assemble: formal review documentation
- Provide: data schedules, status, Phase C/D configuration/data management plans
- Deliver: data per contract requirements

402 Supporting Research and Technology (SOW para 4.6)

- Identify and Define: technology to further enhance design or decrease development risk
- Submit: to NASA need for technological data indicating specific range of data requirements

403 Program Acquisition Plan (SOW para 4.7)
- Prepare and Provide: preliminary program plan for development and operations reflecting analysis results, identifying cost drivers, tradeoffs and innovations to obtain minimum program cost
- Submit: a program management plan
  - Depict: the management approach
- Submit: an engineering development plan
  - Depict: the design effort approach
  - Provide ground/flight operation recommendations
  - Generate: a data relay satellite plan
  - Provide: a method using data generated during development/qualification programs to establish system/subsystem operative regime and capability and to provide a data source for program operational aspects determination
- Submit: a facility utilization and manufacturing plan
  - Propose: solutions to major manufacturing problems involved in producing the shuttle
  - Identify: and justify new facility requirements by analytical study
  - Identify: required major facilities for development, test, manufacture and operations
  - Identify: required Government-furnished equipment and long lead facility/equipment items
- Submit: test plan
  - Describe: overall test program
  - Identify and Evaluate: test facility requirements
  - Delineate: vendor, pre-installation, system buildup and integral vehicle test programs
  - Show: proposed test/checkout plan reduced costs compared to previous programs
  - Develop: documentation system
- Submit: a logistics and maintenance plan
  - Develop: plan identifying maintenance/logistics requirements necessary for development, test and operations support
  - Evaluate: in sufficient depth to identify requirements significantly affecting feasibility and cost
- Submit: a program costs and schedule estimates plan
  - Provide: cost estimates at level/in manner described in SOW Appendix D

4.1.7 Summary Phase B Test Plan

In accordance with the requirements of DRD Number TM003M, a Phase B Test Plan will be submitted as a part of the updated Phase B Study Plan at the Orientation Meeting. The data presented in Figure 4-21 for information purposes is a summary of the Phase B testing planned in response to NASA RFP SOW paragraphs 4.1 through 4.4. This data is based on effort planned at the control package level discussed in subsection 4.1 herein and is consistent with the requirements established by the Program Master Schedule. These tests consist of effort in the following areas and the participation by General Electric and Northrop is noted:

- TPS Heat Shield Panel Tests
- Structural and Cryotank Element Tests
- Fixed Base Flight Control System Simulation
- Aerothermal Wind Tunnel Investigations

4.1.8 Subcontract Plan

We have organized a team of aerospace leaders who have made their talents and resources available to this study effort to specifically complement and reinforce our technical expertise. During the Phase B study, associate contractors will be responsible for supporting Grumman in key areas as follows:

- General Electric: Thermal protection system, integrated avionics, flight control subsystem, data management subsystem, and shuttle mission economic analysis
- Northrop: Low speed and hypersonic aerodynamics design and test, reentry control system technology and large structures
- Eastern Airlines: Maintenance and logistics concepts, ground operations
- Aerojet-General: Pressure vessels, cryogenics, and large rocket propulsion

This is described in Table 4-2. These associates as well as personnel from the Chrysler Corporation have contributed to this proposal.

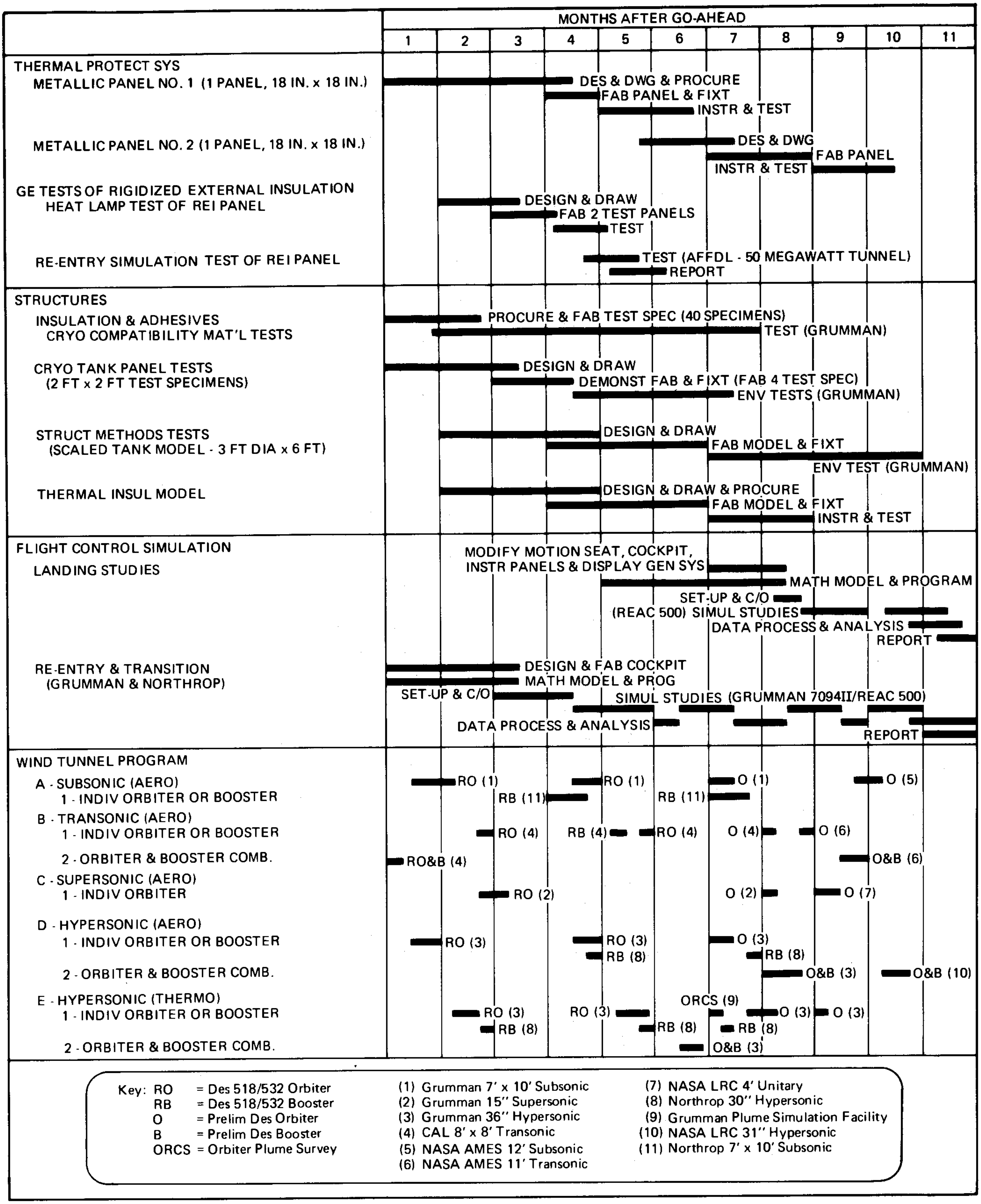


Fig. 4-21 Phase B Summary Test Program

Table 4-2 Associate Contractor Expertise

	General Electric	Eastern	Northrop	Aerojet General
Integrated avionics	●			
Thermal protection	●		●	
Low-cost operation	●	●	●	●
Hypersonics			●	
Re-entry	●		●	
Boosters			●	
Tankage				●
Major structures			●	●
Test equipment	●	●		●
Weight control			●	●
Aero testing			●	
Vehicle design			●	
Propulsion integration				●
Flight Control systems	●	●	●	
Economic analysis	●			

4.1.8.1 General Electric

General Electric brings to the Grumman team the resources and integrated avionics capability of the Aerospace divisions at Utica, New York and Valley Forge, Pennsylvania. Their Reentry and Environmental Systems Division at Philadelphia brings outstanding reentry and thermal protection know-how. General Electric has designed, developed and flown avionic systems in both spacecraft and aircraft. They have pioneered in developing thermal protection systems including ablatives, heat sink and metallic structures for temperature control during reentry using one of the world's foremost testing and development facilities. General Electric's TEMPO (Center for Advanced Studies) at Santa Barbara, California, brings operations and mission analysis experience on a world-wide scale to the Grumman team.

During the Phase B study, GE will provide preliminary design data and assist Grumman in the definition of the functions and interface requirements of the components of the integrated avionics system. Included in this effort will be tradeoff studies on centralization of functions and digital interface techniques.

General Electric will have primary responsibility for the flight control and data management subsystems. In addition, GE will assist in the shuttle safety, reliability and maintainability analysis and the optimization of the flight ground system complex.

General Electric will assist in the design analysis and configuration preliminary design of the orbiter and booster thermal protection system (TPS). They will develop thermal materials candidates considering availability, reliability and manufacturing costs and will perform in-depth aerothermal predictions, structural analyses and will define orbiter TPS concepts. They will also run tests on reusable external installation panels for the TPS test program.

General Electric TEMPO will analyze potential national application of the space shuttle in terms of traffic rates, orbit inclination and altitude and payload size, density and shape. They will evaluate the present national launch vehicle inventory in terms of cost including hardware, GSE, facilities and training. GE will analyze the degree of substitution of present launch vehicle inventory by space shuttles of several size and estimate the cost savings. They will utilize payloads defined above, analyze merits of in-orbit maintenance and/or return to ground for refurbishment. GE will integrate all of these tasks into a total space shuttle economic analysis and evaluate its impact on future NASA and DOD space expenditures.

4.1.8.2 Northrop Corporation

Northrop experience with the M2-F2 and HL-10 lifting bodies in supersonic and subsonic flight provides practical experience in the operation of space shuttle-related vehicles. This work has considered cross-range tradeoffs together with ablative and radiative thermal systems for integrated launch and reentry vehicles. Northrop has developed a computerized temperature rate flight control system (TRFCS) which integrates trajectory control, energy management, stability and guidance to provide reentry vehicle safety by flying a temperature-controlled trajectory. Northrop is experienced in large structures and is presently in full production on the world's largest fuselage: the 154-foot-long 747 central fuselage section.

During the Phase B study, Northrop will assist in the design of booster aerodynamic configurations providing general arrangement, inboard profiles, mass properties, weight, balance and structural arrangement and design. Analyses of booster configurations will be done to determine aerodynamic coefficients, and stability and control parameters. Wind tunnel development testing will be performed. In addition, Northrop will design a TRFCS for the orbiter and booster with an in-depth performance evaluation and sensitivity analysis. Northrop will assist Grumman in reducing the cost of large structures drawing heavily on their 747 fuselage and other large structure production experience. They will provide hypersonic aero and aerothermodynamic analyses as required.

4.1.8.3 Eastern Airlines

Eastern was the top-rated 1969 carrier of eleven rated in on-time performance and schedule completion. Eastern's operations capability is further evidenced by their attaining the highest safety record of all the free world's trunk airlines. Eastern brings the discipline of operations and maintenance economy to Grumman's Phase B space shuttle team.

Eastern's commercial experience will be integrated with comparable operations experience that Grumman has gained in its deployment and support of weapon systems and space vehicles. During Phase B, Eastern will:

- Develop low cost maintenance and logistic concepts, procedures, skills and controls for the space shuttle
- Develop and define ground and flight requirements in such areas as base operations, payload handling, mission control turnaround time and vehicle checkout

4.1.8.4 Aerojet-General

Aerojet-General is a leader in the design and manufacture of pressure vessels, rocket engines and cryogenic systems. Aerojet-General designed and manufactured large rocket case sections for the solid-fueled 260 in. diameter, Polaris and Minuteman missiles. They engineered and fabricated the liquid rocket tanks for the LM ascent and descent stages. Aerojet-General will bring to Grumman's space shuttle team additional cryogenic experience derived from their nuclear engine, M-1 engine and other related programs. Their manufacturing expertise covers thin wall metal tanks as well as large filament-wound structures. Aerojet-General has more than 20 years of related system analysis, GSE and test experience.

During the Phase B study, Aerojet-General will work with Grumman in the following areas:

- Design of large, insulated LH_2 and LO_2 tankage for the orbiter and booster vehicles
- Reduction of tank weight through the use of filament-wound metal structures
- Reduction of cost through selective use of large vessel manufacturing engineering and methods know-how
- Assistance in the solution of cryogenic problems, design of line runs, components and fluid dynamics
- Establishment of minimum cost test programs including related GSE and large structure handling equipment.

Grumman will effectively combine efforts of GE, Northrop, Eastern & Aerojet-General. Key management and technical personnel of each of our associate contractors will be in residence at Bethpage during Phase B. They will work under the technical supervision of Grumman's Phase B study director. In this manner, Grumman will solve the problem imposed by geography and coordination of the efforts of four large corporations. This is described Section 4.1.2.

Mr. R. H. Bolton is responsible for contractual direction and performance of our associates. In-scope Grumman technical direction will flow through the Deputy Director, T. J. Kelly or Assistant Director, F. Raymes via signed documentation to the senior resident associate.

Contact for information, but not direction, is permitted directly between Grumman and associate technical groups. This provides an efficient close-knit team for Grumman and offers NASA single-point visibility for effective control.

During the preparation of this proposal Grumman has worked closely with these companies to define their responsibilities for the Phase B study. This has enabled us to reach an agreement with each on the allocation of funds as shown in Section 6.1.3. Thus, subject only to NASA concurrence, Grumman and its associates will be ready to start work immediately upon receipt of Grumman's Phase B go-ahead from NASA. All arrangements have been made to physically and organizationally accommodate associate resident personnel.

Co-location of key personnel at Bethpage will also facilitate reporting to the NASA centers and will significantly improve Grumman responsiveness to NASA technical and program direction during Phase B. All technical reporting from our associates will be as part of the Grumman team. There will be a single Grumman Phase B study report.

4.1.9 Documentation Delivered by Grumman

Deliverable documentation is prepared and furnished in accordance with data requirements list (DRL) Number M010 and its specified data requirements Descriptions (DRD's) as summarized in Fig. 4-22.

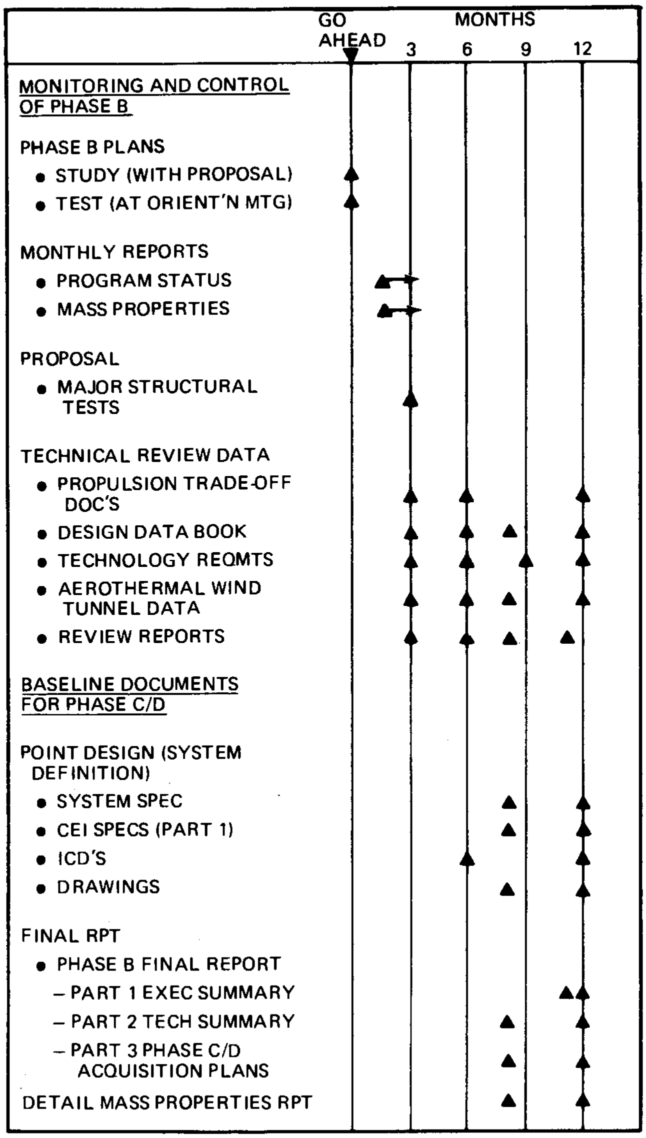


Fig. 4-22 Deliverable Documentation

Grumman will review all applicable documents and directives and will make recommendations for significant cost effective modifications in achieving the stated objectives for the documents as appropriate to the Space Shuttle Program. Upon NASA approval of the recommendations, the "DRL Configuration Chart" will be amended accordingly and the modified documents will be implemented. Grumman's successful experience and current activities in reducing data costs are described in Subsection 2.7.1.2.

Subsequent to document delivery, changes are rigorously controlled by LM Program type procedures to ensure accurate and timely dissemination of authorized revisions to all recipients of the original document.

Preliminary Design and Analysis Results are Formally Documented. The results of system analyses, design analyses, and subsystem analyses are formalized into a point design as defined in a logical series of control documents. Format and content of the documents provides for early configuration baseline identification and subsequent change control to progressively lower levels.

Specifications are the prime documents for definition and control of the technical requirements. The space shuttle system specification defines the entire system and is the "top" specification from which all requirements flow. It includes a specifications tree, Fig. 4-23, which identifies end items down to level 6 (assembly) for vehicles and to level 5 (subsystem) for ground equipment. Design and performance of the orbiter, the booster and the other end items identified in the specifications tree are defined and controlled by contract end item (CEI) specifications, part I.

The specification requirements are expanded to progressively lower levels by engineering drawings prepared in accordance with DRL item number 20. Interface control documents complement the specification and drawings to define and control the interfaces between related systems and end items. Detailed backup data is continuously maintained current in the design data book as well as being presented at informal and formal technical reviews.

These point design documents, when coupled with the final report (which includes the acquisition plans), provide a formal record of the Phase B study and furnish a baseline for the follow-on Phase C/D.

4.1.10 Required Documentation

During the Phase B Study Grumman will require certain documentation from NASA and DOD to complement our in-house efforts.

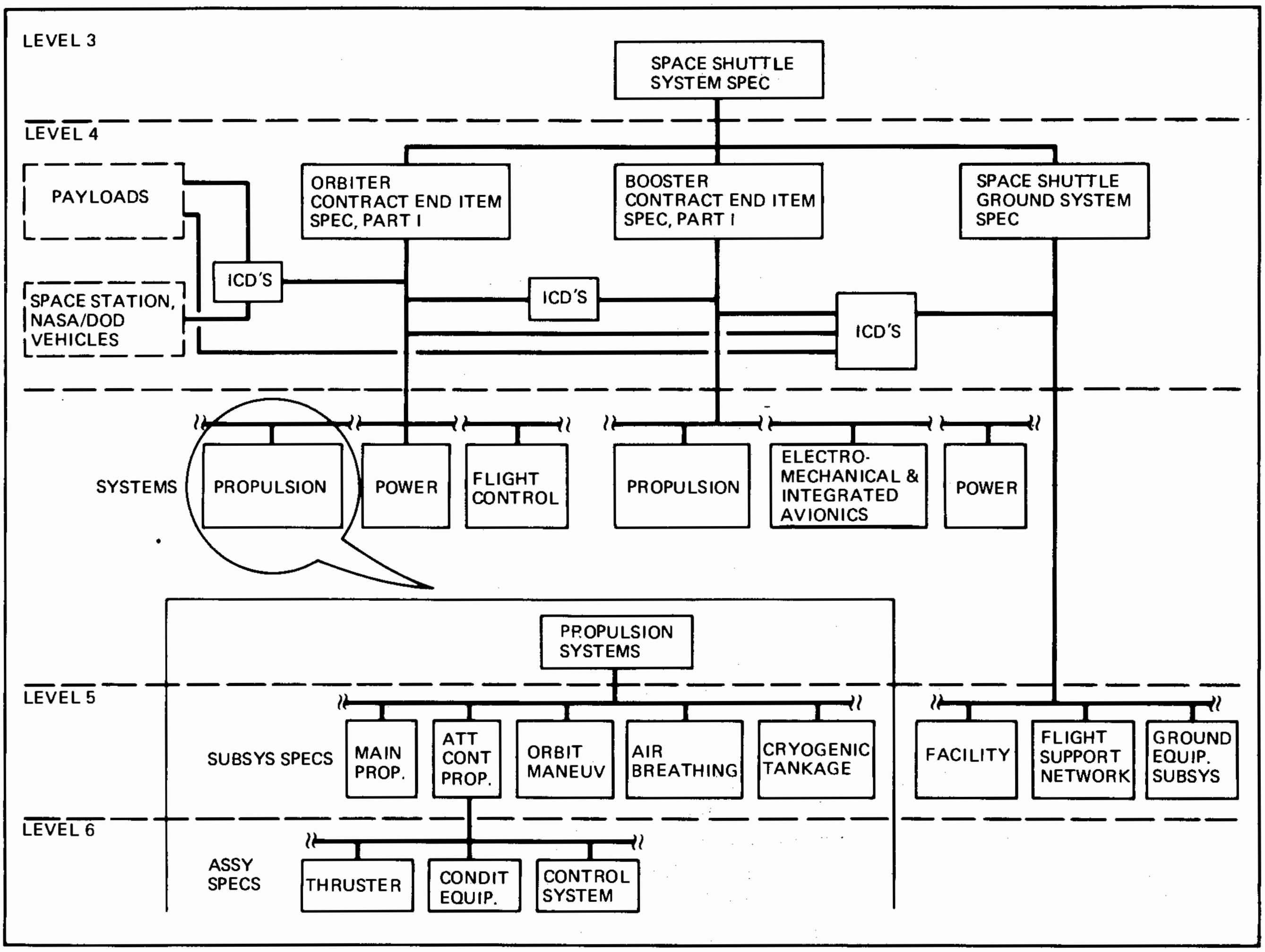


Fig. 4-23 Specification Tree

A preliminary list of such documentation, as identifiable at this time, is delineated below. As the study progresses and more specific needs are identified, the list will be amplified.

- LRC Documentation:
  - Shuttle Design Criteria and Natural Environments Criteria
  - NASA Shuttle Mission Studies Progress Reports
- MSC Documentation:
  - Results from Phase B Space Station/Space Base Study
  - Reports on the Data Relay Satellite System Phase A Studies
- MSFC Documentation:
  - Phase B Engine Study results
  - Results of Shuttle Flight Control Study
- KSC Documentation:
  Results of studies conducted for:
  - Mechanical Systems Readiness Techniques
  - Rapid Propellant Loading Techniques
  - Handling of Cargo and Expendables
- NASA Facilities Documentation: Information on the identity and location of NASA ground assets at KSC, WTR, Michoud, etc. including "as-built" drawings for the facilities.
- DOD Documentation: Maintenance Data; AFM 66-1 and Navy 3-M summaries for selected aircraft.

In addition to the above list, supporting research and technology needs and requirements, developed during the Phase B Study effort, will be formally reported quarterly in accordance with DRL item number 8.

4.2 APPLICATION OF RELATED EFFORT

4.2.1 Grumman's Program for Acquiring & Applying Information from Shuttle-Related Efforts.

The Supporting Research and Technology (SR&T) Office will guide Grumman's and its Associates' shuttle-related IR&D programs and provide the link between these in-house activities, outside related programs and the mainstream Grumman shuttle study. The emphasis in the SR&T program will be on those aspects of shuttle development where the technical risk is the highest. Quarterly reports will be submitted to NASA describing the status and accomplishments of our IR&D programs and identifying areas where additional work is required (see subsection 2.6).

4.2.2 SR&T Program – Organization, Structure and Functions

The SR&T Office (see Fig. 4-24) will assure the cross-flow of information between the shuttle program and related Grumman-, associate- and Government-funded programs.

The SR&T Manager, A.J. Katz, reports directly to the program director's office, providing two distinct advantages. First, it gives him rapid access to the latest status and planning information from the program management point of view. Second, it links the shuttle program organizationally to its supporting IR&D programs, assuring a closely coordinated working arrangement between the two. The result is a total Grumman program of optimum output.

The SR&T specialists group is the functional arm of the organization. It consists of technical specialists from Grumman and its associates, organized to correspond to the seven technology areas of the NASA space shuttle steering group.

The functions of the specialists group consist of the following:

- To recommend research and technology programs where needed to support the shuttle program
- To provide technical guidance to shuttle-related in-house R&D programs to assure maximum shuttle advantage
- To recommend and initiate new R&D programs in-house as the need arises
- To establish and maintain a close working relationship with NASA and Air Force groups involved in shuttle SR&T
- To maintain continuing contact with other contractors involved in shuttle-related activities (e.g., shuttle engine development program, space station Phase B studies, F-14 program etc.)
- To bring to the shuttle technical personnel working on the Phase B study the best of the above in-house and outside activities, and to take from the shuttle technical personnel recommendations and ideas for inclusion in in-house R&D programs and NASA and AF activities

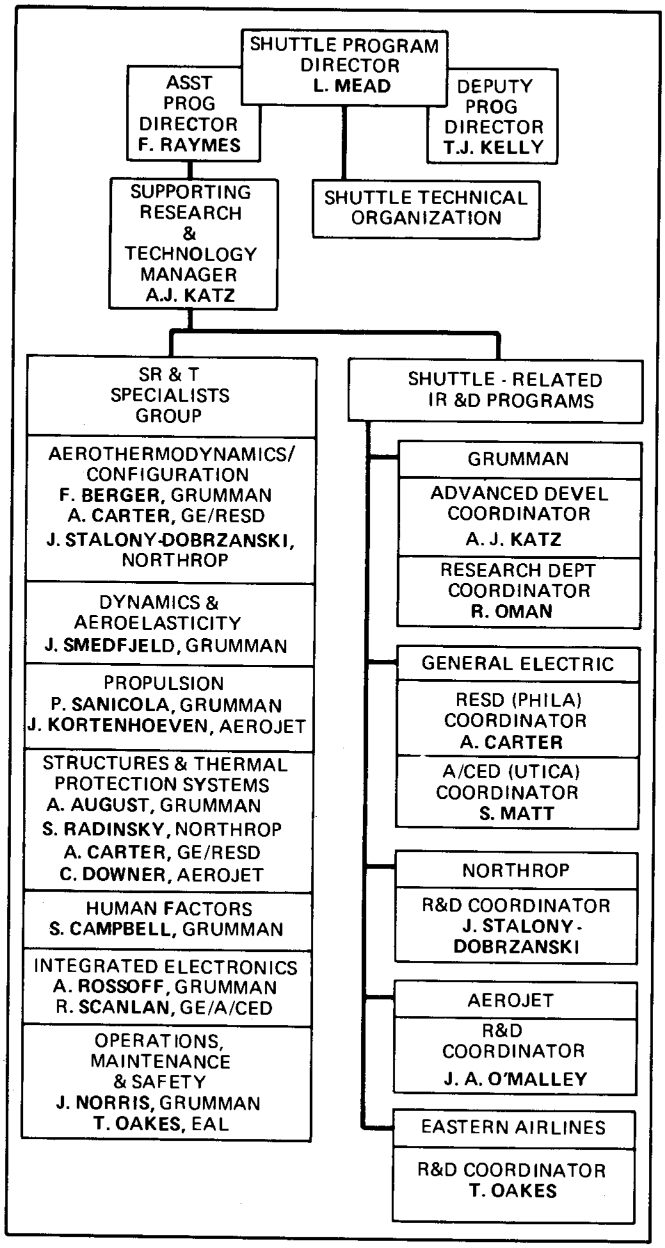


Fig. 4-24 Supporting Research & Technology Organization

4.2.3 Company-Sponsored Research & Development Programs, Funded Contracts & Bid & Proposal Activities

The total expenditure for shuttle-related IR&D programs by Grumman and its Associates will exceed $8 million in 1970. We anticipate a similar level of effort in 1971. The selection of programs was based on providing maximum support in the high risk technical areas. These programs provide a way of substantiating selected shuttle approaches or looking into alternates to solutions where uncertainties still exist.

In addition, several of the major contracted programs being conducted by Grumman, General Electric, Aerojet-General and Northrop, such as the F-14, Mk 12, ABRES and lifting body flight programs, will provide ideas and technical data to supplement the shuttle study. We do not attempt to estimate the extent of support, but merely to call attention to technical areas of potential shuttle relevance.

4.2.3.1 IR&D Programs

During 1970, Grumman will conduct the following shuttle-related IR&D programs:

- Thermal Protection System Development – This program concentrates on the establishment of the mechanical, physical and general design properties of metallic thermal control systems. Emphasis is placed on Columbium and TD Nichrome. Haynes-188 will be used to study the feasibility of preliminary concepts with subcomponent tests. Full-scale panels will be fabricated and tested to verify the design concepts. Special attention is being given to environmental effects, reusability and reproducibility to establish confidence in a baseline performance level
- Hypersonic Aerothermodynamics – The basic problems in aerodynamic and thermodynamic performance prediction in the hypersonic flow regime are being studied in a combined analytical/experimental program. Aerodynamic studies of shock envelope and flow field construction, 3D non-linear method of characteristics, hypersonic thin shock layer theory applied to 3D configuration, surface pressure and streamline computational methods and control effectiveness of flaps and jets are part of the program. In thermodynamics, the problems of separated flow and reattachment effects on leeward surfaces, interference region heat transfer, improved boundary layer definition including skin friction drag, and leeward surface heating at low α with attached flow, including cross-flow induced vortex flow patterns are under investigation
- Wind tunnel testing activities include development of high energy aerodynamic test facilities, techniques for design and instrumentation of electro-formed force and heat transfer models, testing of candidate reentry vehicle configurations with variable components, correlation of thermocouple data with phase-change paint techniques, and correlation of analysis by model tests
- Cryogenic Insulation Development – This program is aimed at developing reusable, zero-maintenance insulations for cryogenic storage. Internal and external insulations are to be evaluated. Candidate schemes for internal use include evacuated and filled-core honeycomb and vapor barrier honeycomb. External insulation studies are concerned with purging for moisture removal, perforation for reduction of off-gassing and absorbed gas effects, spacing and attachment schemes, and minimization of penetration effects. The program is analytical and experimental
- Quantitative Systems Synthesis – This project makes use of several innovative concepts of the mathematical theory of systems analysis, combined with very efficient use of modern computational facilities. Methods have been developed to encourage interaction between the design engineer, a live model of the shuttle system, and a set of mathematical tools implanted in the computer. The interface is user-oriented in real time, and the computer continuously re-evaluates the entire system as the user refines and revises the system model. The method has proved very effective in several applications to the F-14, and we now have an early version of the shuttle system operating

In addition to the above, the following shuttle-related IR&D programs are in progress:

- Structural Mechanics – Flutter Analyses of Multiple Nonplanar Interfering Surfaces and of General Wing/Control Surface Configurations; Crack Propagation Under Spectrum Loading; Structural Weight Optimization; Finite Element Thermo-Structural Analysis; Flexible Vehicle Gust Response Analysis; Space Station Structural Dynamics; Plastic and Large Deflection Analysis (FE Methods); Analysis of Shell Structures (Static and Dynamic)

- Guidance, Navigation & Control – Reentry, Transition and Landing Simulation Studies on Grumman and Northrop Fixed Base Simulators; Autonomous Navigation Systems; Electronic Primary Flight Control Systems; Automatic Landing and Docking Systems; Reentry Trajectory Optimization; Optimal Estimation; Space Flight Trajectory Optimization; Optical Signal Processing and Pattern Recognition
- Reliability/Maintainability – Long life Assurance; Use of Spacecraft On-board Checkout for Ground and Flight Checkout; On-Board Checkout and System Interface Requirements
- Thermal Control – Heat Pipe Radiator Design, Fabrication and Test; High Temperature Coatings Evaluation; Variable Conductance Heat Pipe Flight Experiment; Thermal Properties Measurement and Thermal Control Techniques
- Aerodynamics – Optimal and Suboptimal Control for Aircraft; Time Dependent Calculation of Mixed Flow Fields; Computer-Aided Aerodynamic Configuration Design
- Materials & Processes – High-Temperature Materials Development; Graphite Composites and Hybrids; Boron Composites; Stresskin Fabrication; High Temperature and Teflon-Lined Bearings; Advanced Composite Materials and Technology; Glass and Glass Ceramics; Metal-Matrix Composites; Materials Joining; Stress Corrosion Cracking; High-Temperature Oxidation
- Mechanical Systems – Reusable Energy Absorbers for Space Application; Tire, Wheel and Brake Evaluation Tests in conjunction with Goodyear Corporation
- Electrical Power – Solid State Electric Power Control/Distribution; Binary Power Regulator

General Electric, Philadelphia, will conduct the following shuttle-related IR&D programs during 1970:

- Non-Metallic Reradiative Thermal Protection System (TPS) Development – GE will develop and characterize a non-metallic reradiative material applicable to the space shuttle TPS. This development is based on the use of quartz-reinforced high temperature silicone resin systems stabilized through the incorporation of devitrification inhibitors. A panel of a space shuttle orientated design will be fabricated and tested for comparison to other non-metallic systems
- Metallic Coating System for High Temperature Oxidation Protection – This program is designed to develop a metallided surface alloying system for thermal protection of the space shuttle. Coating processes for Columbium and Tantalum alloys will be developed through electrolytically depositing high temperature oxidation resistant compounds and alloys on refractory metal samples of a wide variety

  Other surface alloying treatments which will be evaluated are:

  - Berylliding
  - Aluminiding
  - Siliciding
  - Ytriding
  - Zirconiding
  - Hafniding
  - Duplex Metalliding

Special attention is being given to determining suitable nondestructive techniques and equipment to be used to detect surface defects on metallided samples.

- Passive Transpiration Cooling System Development – This study is to define the most attractive transpirant and carrier matrix for the space shuttle program and to select a primary and secondary combination choice based on experimental and analytical evaluations. A prototype panel will be designed and fabricated utilizing the optimized systems approach

In addition, General Electric, Philadelphia, is conducting space shuttle TPS IR&D programs in carbon/carbon materials development, omniweave technology for 3-D weave geometries, ablative systems attachment concepts, polymide composites for high-temperature structural applications, nondestructive testing for materials performance assessment, graphite vaporization evaluation and analysis, high-strength materials failure criteria, advanced nose application of carbon-fiber materials, free standing shells using advanced weaving concepts.

General Electric, Utica, is conducting the following R&D programs related to space shuttle integrated electronics: Design and Feasibility Demonstration of Data Bus Systems; Wide Band Data Transmission; Automatic Data Monitoring System Feasibility; Universal Checkout Console System Development; On-board Distributed Processor/Interface Module; Microelectronics Read Only Memory System; Memory and Memory Interface Circuit Development; Development of LSI Chips; Flight Control System Techniques and Computations, Sensors and Actuators Development; Image Generation Techniques for Displays Systems; Improvement of Electronic Attitude Director Indicator.

The Northrop Corporation's Aviation Division has the following R&D programs in progress: Low Weight/Low Cost Advanced Structural Design Concepts; Structural and Dynamic Analyses of Advanced Composite Material Structures; Redundant Structures Analysis; Application of Graphite Structures to Advanced Designs; Applications of Advanced Composite Materials to Advanced Structures; Nor-Ti-Bond Fabrication of High Temperature Honeycomb Structural Shapes; Afterbody Drag of Highly Maneuverable Aerospace Vehicles; Subsonic and Supersonic Fuselage Flow Field Predictions; The Treatment of Transonic Flow Problems by the Non-Steady Approach Transonic Airfoil Design; Vehicle Maneuvering Programs for Optimum Climbs; Optimization Program – Variable End Point Constraint; M2-F2/HL-10 Lifting Body Research Vehicles.

Aerojet-General has the following IR&D programs in progress: Hydrogen Embrittlement studies; Hydrostatic Bearing Development; Propellant Technology Development with LH_2; LH_2 Combustion Stability Studies; Chamber Pressure Studies with LOX pressures in excess of 3000 psi; Advanced Cryogenic Rocket Studies; Thick Wall Filament Wound Pressure Vessels; Advanced Filament Wound Machine Development; Aircraft Components and Related Structures; Composite Tankage Development; Composite Aircraft Structures; Composite Analytical Methods; Filament Wound Vessel Qualification; Cost Reduction for Filament Wound Vessels; Composite Boron Glass Fibers; Boron Fiber Studies; Controlled Expulsion Die Bonding; Explosive Welding of Dissimilar Metals.

4.2.3.2 Funded Programs

The following is a partial listing of current Grumman Government-funded hardware programs and studies from which information and data of value to the shuttle study can be expected.

- F-14
  - Boron Composite Horizontal Tail–Static and fatigue testing during 1970
  - Poly-X Wire–lighter and easier to handle than H-film wire
  - Titanium Hot Forming–development of fabrication techniques and equipment
  - Inlets and Nozzle Design – verification on 3/4 scale F-14 model in Ames Research Center Low Speed Tunnel
  - Built-in test capability in electronics equipment
  - Maintainability – Versatile avionics shop test (VAST) system application
  - E-Beam Welding of Titanium Structure – development of production techniques, cost verification
- A-6A – All-weather carrier-based attack aircraft. Features complex computer navigation system, high overall operational reliability
- E-2A – Airborne tactical data system. Flying command and control center with large general-purpose computer
- C-2A – Carrier-on-board-delivery aircraft. Cargo and personnel delivery between shore points and carrier deck
- Grumman LM Program – the Apollo flights will provide additional performance data of the LM hardware which will be used to correlate and upgrade design and analysis techniques

Additionally, the following funded study programs at Grumman are sources for shuttle-relevant data:

- Boron composites
- Boron repair
- Packaging criteria for electronics items
- Laser welding manufacturing technology
- Advanced chem milling processes development
- Life analysis methods for aircraft structures

General Electric is conducting the following contract programs that will be reviewed for shuttle support:

- Graphite Melt Behavior – Investigate triple point phenomena – determine phase diagram for graphite in triple point regime
- Erosion at Hypervelocity – Determine performance of materials and key parameters under high thermal flux/erosion environment
- Graphite NDT Methods – Application of advanced NDT interrogative and interpretive techniques to graphite flaw detection
- Graphite Materials – Determination of cost effective screening/design data for graphites and carbon/carbon structures
- Ablative Materials – For high heat loads – Development and evaluation of Thermal Protection Systems for high integrated heating entry condition

- Street G – Determination of effect of asymmetric transition on static stability and angle of attack effect on transition
- Omniweave Composites – Development of improved multidimensional reinforced carbon/carbon composites for advanced thermal protection systems
- Evaluation of Omniweave – Development of advanced launch vehicle/structure applications
- Improved Graphites – Development of high strength carbon/carbon systems for nose tip applications
- Nondestructive Technology – For rocket motors critique and theoretical assessment of existing NDT techniques – Scout vehicles

Northrop has the following shuttle-related funded work in progress:

- Techniques for Diffusion-Bonding Titanium Shapes and Panels
- Flightworthy Graphite-reinforced Primary Structural Assemblies
- Design and Acoustic Fatigue Characteristics of Composite Material Joints
- M2-F2/HL-10 Lifting Body Vehicle Flight Research
- Differential Maneuvering Simulator

Aerojet-General has the following shuttle-related funded work in progress:

- Design study for large LOX and LH_2 engine
- Advanced liquid propulsion technology
- Development of large size bellows and seals for LOX and LH_2 service
- Effects of material and process variables on filament wound structures
- Design improvements in liners for glass fiber filament wound tanks to contain cryogenic fluids

4.2.3.3 Related B&P Effort 1970

We have already expended effort responding to separate related study requests. We will continue to pursue these studies as well as continue our on-going efforts in preparation for the final procurement. This latter on-going effort will be devoted to such areas as:

- Phase C/D type refinements and tradeoffs in candidate configurations as Phase B activity finalizes
- Detailed requirements and specification criteria for subsystems
- Interface definitions for ground and flight operations
- Refinement of Design Reference Mission Profiles
- Continued Systems Analysis

The value of this effort is expected to reach \$6 million in 1970 with a like amount in 1971.

CAPABILITY, EXPERIENCE & PERFORMANCE

5 – CAPABILITY, EXPERIENCE, & PERFORMANCE

Over the past 40 years, Grumman has designed, developed, and produced a diversified series of transportation vehicles including:

- Lunar Module (LM) – The first manned spacecraft designed to operate only in space
- Orbiting Astronomical Observatory (OAO)
- Apollo Applications Program (AAP) – Definition studies to modify Apollo hardware to transport the Apollo Telescope Mount into orbit
- A-6A Intruder – The first all-weather attack system capable of detecting, identifying, and destroying targets under zero-visibility conditions (in service)
- EA-6B – A tactical aircraft with electronic surveillance and countermeasures systems to protect strike aircraft in enemy radar areas
- E-2A/B/C Hawkeye – All-weather airborne tactical data system aircraft (E-2A in service)
- C-2A Greyhound – A modern, efficient utility transport for carrier resupply (in service)
- Gulfstream II – The world's fastest, longest-range corporate jet transport (in service)
- PX-15 Ben Franklin – The submersible that made a 1444 n mi underwater Gulf Stream drift mission from Florida to Nova Scotia

Currently under development are:

- F-14 – The new all-weather Mach 2 + carrier-based air superiority fighter
- Tracked Air Cushion Research Vehicle (TACRV) – An advanced concept for a 300 mph high-speed train

In developing, producing, and placing such vehicles into service, we have, validated, with today's technology, many of the concepts for an economical space transportation system with low-cost, airline-type operation, flexibility for a variety of payloads, and full reusability. Further, Grumman designs the support system concurrently with the vehicle to insure operational capability, maintainability and low operating costs.

The balance of this section addresses the specific capabilities, experience, and performance of past and current R&D programs that bear on this study.

5.1 EXPERIENCE AS PRIME CONTRACTOR, ASSOCIATE, OR SUBCONTRACTOR

This subsection presents Grumman's experience and current status as a prime contractor on seven recent major programs in terms of cost, schedule, and technical performance. It covers:

- Space Programs: LM, Lunar Module/Project Apollo; OAO, Orbiting Astronomical Observatory; and AAP, Apollo Applications Program
- Aircraft Programs: F-14A Mach 2 + air superiority fighter; EA-6B electronic countermeasures aircraft; E-2B airborne early warning aircraft; E-2C advanced airborne early warning aircraft

Graphic presentations of growth of cost to the Government utilize data reported to the customer via NASA 533 and DOD 1097/CIR/ CFSR/PMP reports. Cost growth due to inflation has not been separately assessed.

5.1.1 Lunar Module (LM)

The LM program required development and fabrication of a complex manned spacecraft. Twenty-nine cost-type major subcontracts and many minor subcontracts represent approximately 50 percent of the total program cost. Most major subsystems required state-of-the-art development against schedules controlled not only by the LM contract, but the Apollo program.

5.1.1.1 Contract Award & Structure

The competitively awarded LM contract, NAS 9-1100, was signed in January 1963 for an estimated cost of $362.5 million and a fixed fee of $25.4 million (7 percent of estimated cost). It covered the design and fabrication of 11 vehicles plus their launch and lunar landing mission support. The program has matured in 7 years through identifiable phases, as discussed in Subsection 5.1.1.2. Scope was redefined in 1965 to a 15-vehicle program with a projected completion date of December 1969. As a result of the success of Project Apollo, the LM effort has evolved into a 13-vehicle/base plan program. The estimated target price at completion in 1972 of this program is $2.1 billion, under combined CPFF/CPIF contract arrangement.

The incentive portion of the contract includes a 2000-point scoring system for measuring technical and schedule performance. It also includes an interrelated cost incentive providing for a maximum fee of 15 percent, a target fee of 12 percent and a minimum fee of 4 percent.

5.1.1.2 Contract Performance

COST GROWTH – Growths and trends for projected and actual costs to the Government as a function of time from contract award, related to the four phases of the program, are presented graphically in Fig. 5-1 and discussed in the following text.

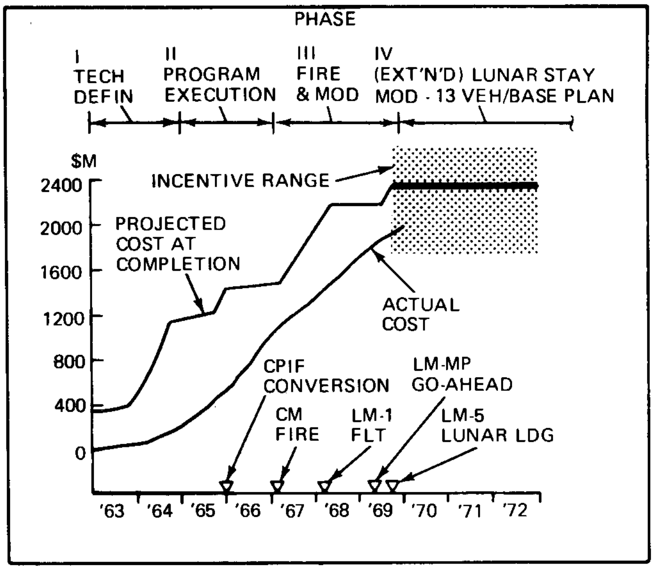


Fig. 5-1 Cost Trends – LM

PHASE I – TECHNICAL DEFINITION – As a result of studies conducted by an integrated NASA/Grumman team, the technical approach was firmed by the end of 1963. Related test programs and vehicle delivery schedules were firmed during the first half of 1964.

The increase in anticipated cost and fee associated with the technical definition (Fig. 5-1) was estimated in September 1964 at $1.112 billion (NASA 533) and refined to $1.378 billion in November 1964 in the form of a firm CPFF proposal. It included 82 contract changes plus an allowance for future changes which was not negotiated, as NASA wished to consider a change to CPIF.

PHASE II – PROGRAM EXECUTION – During 1965 and 1966, intensive NASA/Grumman effort was expended to reflect the technical definition and incorporate meaningful incentives on cost, schedule, and flight performance. In December 1965, a combined CPFF/CPIF contract was negotiated for $1.372 billion. The agreed-to cost, less fee, was very close to that projected 13 months earlier in the CPFF proposal. A week later, the contract cost target and fee was increased to $1.445 billion by the addition of LM's 12 through 15 with a projected completion date of December 1969. In 1966, 322 contract change authorizations (CCA's) were received, resulting in a revised anticipated price at completion of $1.478 billion (NASA 533).

PHASE III – FIRE & MODIFICATION – Following the Apollo fire in January 1967, four months were devoted to an intensive review of safety aspects and identification of required vehicle changes. In December 1967, most changes were negotiated for a revised combined CPFF/CPIF price of $1.881 billion with a contract end date of December 1970. The period to July 1969 was devoted to supporting mission requirements culminating in the first lunar landing on 20 July 1969.

PHASE IV – EXTENDED LUNAR STAY MODIFICATION – In 1969 major efforts were instituted to modify the LM vehicle for extended lunar stay missions. The currently defined costs for these efforts are included in our estimated cost of completion.

It is anticipated that the combined contract target price will be revised to $2.1 billion, and the total cost to the Government will be $2.35 billion. The currently defined program runs through the end of 1972. A contractually oriented summary of the cost growth of the LM program, in being, or to be negotiated, is presented in Table 5-1.

The incentive contract arrangement consummated between Grumman and MSC in December 1965 provides for a cost "range of incentive effectiveness" within which the contractor will share with the Government bonus or penalties. The "range" of the cost incentive band extends from 80 to 135 percent of target cost. Fee earnings are related to the contractor's performance position within this cost range of

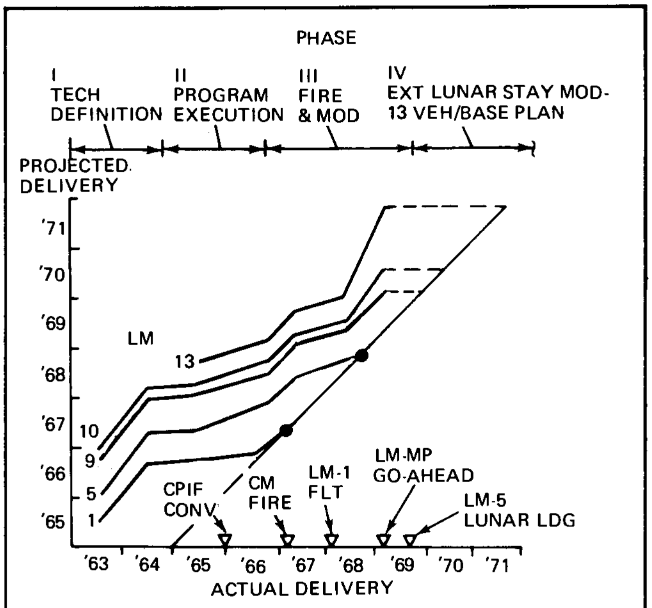
Table 5-1 13 Vehicle/Base Plan

Scope	$ Millions	Total
Basic Contract -CPFF	$387.9	
Addition to CPFF	74.6	$ 462.5 CPFF
Program Reorientation/ CPIF (11 LMs)	$909.5	
Four Additional LMs	72.8	
Crew Safety & Other Mods	155.2	
Extended Lunar Stay	186.7	
Other Program Changes	313.3	$1,637.5 CPIF
Combined Contract Target Price		$2,100.0
Increase over Target Price		$ 250.0

incentive effectiveness as well as the interrelated technical and performance incentives.

As presently projected, Grumman will be well within the higher limit of this incentive band which is estimated to be $2.6 billion. The LM program has not only achieved the national goal of landing men on the moon and returning them safely to earth, but has accomplished this within the incentive cost limits.

DELIVERY PERFORMANCE – LM delivery performance is presented graphically in Fig. 5-2. Basic delivery schedules were established in Phase I, concurrent with the evaluation of the vehicle design and program development. Minor schedule changes were made up to the time of the command module fire. Changes resulting from the fire, Phase III, caused an 11-month extension to the contract delivery dates. Program changes in the extended lunar stay mission capability have again extended the deliveries. Fig. 5-2 shows contract delivery dates, actual vehicle deliveries and their associated Apollo project launch dates. While LM-1 was delivered some 6 months after the contract delivery date, subsequent deliveries have been made essentially on schedule. At the time Apollo 8 mission was being considered for revision in early August 1968, LM-3 was 4 to 5 weeks late in the KSC flow. This was part of the basis for deciding on the C′ lunar mission for Apollo 8. LM-3 was then reassigned to Apollo 9. In all cases the vehicles supported all NASA objectives. No delays to launch were caused by LM prelaunch checkout problems. A corollary to the timely vehicle arrivals was the major achievement of subsystem hardware delivery from the many subcontractors.



Description	Contract	Actual	Flight	
1 LM-1	Dec '66	Jun '67	Jan '68	
2 LM-2	Feb '68	Feb '68	Deleted	
3 LM-3	May '68	Jun '68	Mar '69	
4 LM-4	Aug '68	Oct '68	May '69	
5 LM-5	Jan '69	Jan '69	Jul '69	
6 LM-6	Apr '69	Mar '69	Nov '69	
7 LM-7	Jun '69	Jun '69	Apr '70	
8 LM-8	Nov '69	Nov '69	Sep '70	
9 LM-9	May '70		Feb '71	BASE PLAN ALT 3
10 LM-10	Oct '70		Jul '71	
11 LM-11	1 Mar '71		Mar '72	
12 LM-12	1 Jul '71		Jan '74	
13 LM-13	15Nov'71		Jul '74	
14 LM-14	Stop Wk	7 Jan '70		
15 LM-15	Stop Wk	15Aug'69		

Fig. 5-2 LM Delivery Schedule

TECHNICAL PERFORMANCE – The achievement of schedule and technical performance on the LM program is measured by the number of incentive points earned. The contract provides for a total of 2000 incentive points. By 30 March 1970, Grumman anticipates that 1102 incentive points will have been earned out of a potential 1456 points available at that time, for an overall program performance rating of 76 percent.

Technical excellence of the LM flights conducted to date is indicated by the flight performance incentive points earned as shown in Table 5-2.

The success of each succeeding flight enabled NASA to program the flow of flight objectives on a success-oriented basis, leading to the lunar landings. No mission events had to be repeated for added flight confidence. This flight success represented a tremendous economy to the Apollo program and assured the national achievement of a man on the moon in the 1960 decade.

Table 5-2 Flight Performance Incentive Points

Flight Vehicle	Flight Performance Incentive Points		
	Allocated	Earned	Rating, %
LTA 2R	5	5	100
LTA 10R	8	8	100
LM-1	61	52	85.2
LM-3	102	102	100
LM-4	103	99	96.1
LM-5	150	150	100
LM-6	100	100	100
Total	529	516	97.5%

5.1.2 Orbiting Astonomical Observatory (OAO)

The OAO is a precisely stabilized, 4400-pound satellite capable of conducting a variety of astronomical observations with numerous experimental packages. NASA says "The OAO II is the most complex unmanned spacecraft ever orbited and the achievements have prompted astronomers to rank the OAO with the invention of the telescope in its importance to astronomy." This satellite (OAO II) has far exceeded its original design life of 30 days. It is now in its 16th month of operation, providing astronomical data impossible to obtain from other than a space observatory.

5.1.2.1 Contract Award & Structure

The OAO letter contract, NAS 5-814, was entered into between NASA/Goddard and Grumman as prime contractor in November 1960. This competitively awarded contract called for the design and fabrication of a prototype and two OAO flight vehicles. Price negotiations based on using off-the-shelf hardware were conducted in mid-1961. A CPFF contract with an estimated cost of $30 million plus a 6.8 percent fixed fee of $2.05 million was executed in October 1961. In 1965 two additional contracts, NAS 5-9079 and NAS 5-9166, were negotiated on a sole source basis for fabrication of an additional flight OAO and refurbishment of a prototype into a flight article. NAS 5-9079 was a $15.3 million CPIF contract including an 8 percent target fee with cost incentivized on the basis of 85/15 overrun share and 65/35 underrun share. NAS 5-9166, for the refurbishment of the prototype OAO, was a CPFF contract for $9.1 million including a 7 percent fee.

5.1.2.2 Contract Performance

COST GROWTH – Cost growth from an initial $32 million to the current forecast of $230 million, related to the four phases of program evolution, is presented graphically in Fig. 5-3 and discussed in the following text.

PHASE I – TECHNICAL DEFINITION – As engineering development progressed through late 1961 and early 1962, it became evident that the original concept of using off-the-shelf hardware for spacecraft fabrication would not meet the stringent performance and reliability needs. Redefinition of the spacecraft design requirements led to contract restructuring. The prime contract was converted from a CPFF type to a $65 million target cost CPIF type with multiple incentives covering cost and delivery.

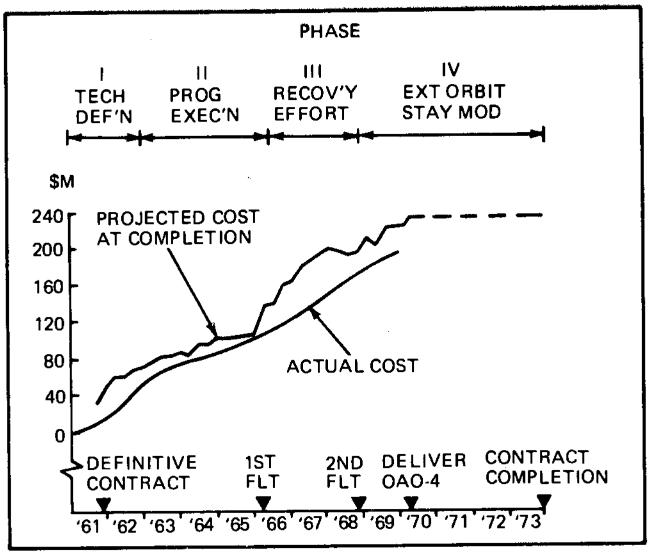


Fig. 5-3 Cost Trends – OAO

Cost incentives provided a linear decline in fee from $2.7 to $2 million if costs should increase from $65 to $73 million. Incentive for delivery placed a $50,000 value on each of six milestones beginning with the air bearing table test and ending with the thermal vacuum test of the second OAO. Consistent with prime contract redefinition, Grumman negotiated CPIF subcontracts with its major suppliers.

PHASE II – PROGRAM EXECUTION – During 1963 through 1965, the primary effort was development and qualification of spacecraft components and fabrication/integration of the prototype. The program was expanded by incorporation of 173 contract changes covering spares and field support, and two additional flight spacecraft: one a refurbishment of the prototype and the second a new build.

PHASE III – RECOVERY EFFORT – In April 1966, the first OAO was launched and with all subsystems working and initial stabilization accomplished, high-voltage arcing damaged the data-handling equipment. Loss of function occurred 3 days following launch. The necessary resources of NASA and Grumman were immediately addressed to problem identification, solution, and hardware modification.

On 7 December 1968, the OAO II was launched with a success criterion of 30 days with 50 hours for experiments. This criterion was achieved on January 7, 1969. Successful operation continues to date.

In January 1969, negotiations were concluded for spacecraft modification. The three separate OAO contracts were combined into a single CPFF contract for a total cost of $190.4 million and 5.2 percent fee of $10 million. The contract includes recognition of a projected underrun of $0.3 million and $1.2 million for the two follow-on contracts.

PHASE IV – EXTENDED ORBITAL STAY MODIFICATIONS – Due to the success of the OAO II mission, the program has been extended, and a two-year success criterion established. Through extraordinary cost effectiveness, this program extension entails only a modest cost growth to an estimated $230 million.

A contractual and phase-oriented summary of the cost growth of the OAO program either in being, or to be negotiated, is presented in Table 5-3.

DELIVERY PERFORMANCE – The delivery dates established in 1961 were redefined in 1962 with six bonus milestones. The sixth milestone was subsequently deleted during the January 1969 negotiations. Performance against the delivery milestones is shown in Fig. 5-4.

Table 5-3 Contractual Cost Breakdown - OAO

Scope	$ Millions	Total
Phase I - Technical Definition		
Basic Contract	$ 32.0	
Redefinition	36.0	$ 68.0
Phase II - Program Execution		
173 Contract Changes	$ 17.2	
Spares	5.7	
Support	2.6	
Additional Spacecraft	15.3	
Refurbished Prototype	9.1	
Increased Over Target Cost	20.0	$ 69.9
Phase II - Recovery Effort		
Recovery -introduced changes incorporated in Combined Contract	$ 62.5	$ 62.5
Phase IV - Extended Orbital Stay Mod		
Ground Station	$ 1.0	
Contract Changes	2.0	
Mission Operation & Support	26.4	$ 29.4
Total		$ 229.8

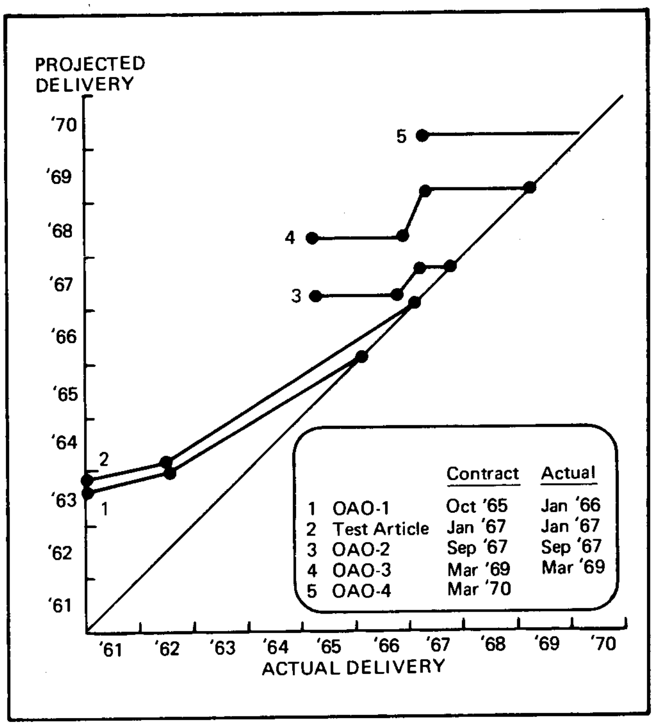


Fig. 5-4 OAO Delivery Schedule

After the first flight in 1966, delivery dates for all follow-on spacecraft were revised. Spacecrafts II and III were delivered in accordance with the revised schedule. Spacecraft IV is ready for delivery on schedule in March 1970.

TECHNICAL PERFORMANCE – The first OAO attained initial stabilization prior to high-voltage arcing resulting in loss of operation after three days. The second OAO has exceeded the design life beyond all expectations and is in its 16th month of successful operation. New performance criteria of two operating years have been established for follow-on flights.

5.1.3 Apollo Applications Program (AAP)

The Apollo Applications Program was initiated by NASA as a program to utilize Apollo hardware, technology, and capabilities as a base for further development of manned space flight. Results of the various study phases led to the objective of modifying a LM ascent stage (LM-A) to transport the Apollo Telescope Mount (ATM) to the Orbital Assembly for a 56-day earth orbital mission.

The LM-A was to have capability of executing an unmanned rendezvous and a remotely controlled docking. Stowage volume and handling capabilities for replacement of film and camera were to be provided in the Crew Provisions Stowage Module (CPSM). Capability for astronaut operation of the ATM experiments would be provided in the ATM Control and Display Console in the environmentally controlled LM-A cabin.

5.1.3.1 Contract Award & Structure

The initial NASA/MSC Phase A concept feasibility study contract, NAS 9-3681, was awarded noncompetitively in October 1964 for a fixed price of $696,000. The study was completed satisfactorily in July 1965.

The AAP Phase B preliminary definition study was a follow-on award by NASA/MSC in July of 1965 under contract NAS 9-4983 for a fixed price of $3.9 million. The study was completed satisfactorily in February 1967.

The CPFF AAP Phase C final definition study was a further follow-on award by NASA/MSC in November 1966 under Contract NAS 9-6608. With the initial award and 10 modifications, the final contract cost was $8.2 million with a 7 percent fee of $600,000. The fee was subject to a downward adjustment if less than the minimum hours were expended. No fee increase up to the maximum hours was included. In the event additional effort was required over and above the maximum hours, the contract would be bilaterally modified to reflect an appropriate increase in hours and dollars. This contract was satisfactorily completed in October 1968 at lower than contract value.

The follow-on Phase D hardware NAS/MSFC letter contract, NAS 8-25000, was awarded in October 1968 for two flight articles plus supporting documentation and equipment. This CPFF letter contract was negotiated in June 1969 at a CPFF/AF of $81.4 million for the first flight article. The award fee (AF) of 1.3 percent ($975,000) could be earned by attainment of:

- Fundamental management performance objectives, 38.5 percent
- Successful accomplishment of flight performance objectives , 61.5 percent

This contract, while still in letter form, and before option exercise for the second flight article, was terminated on 23 July 1969 at the convenience of NASA due to their decision to change the AAP-4 mission concept from a "wet" workshop to a "dry" workshop which eliminated the need for a LM-A vehicle. All efforts were on schedule at the time of termination.

COST GROWTH – Phases A and B were successfully completed without the necessity for additional funding. Phase C was completed on schedule with a net cost underrun of $273,000, and a fee refund of $6,319. With rigid budgetary controls, Phade D, which was funded at $12.9 million for work up to May 31, 1969, had expended only $8.3 million at the time of termination on 23 July 1969. This permitted the deobligation of $2.3 million which was refunded to NASA. Termination activities, including disposition of inventory and settlement of subcontractors' claims is essentially complete. It is anticipated that final negotiations will be complete by mid-1970. Fig. 5-5 illustrates the cost performance.

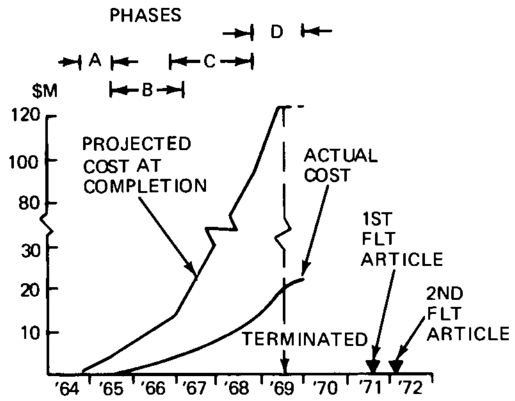


Fig. 5-5 Cost Trends – AAP

DELIVERY PERFORMANCE – The documentation and hardware contractually required during Phases A, B, C, and D of the AAP program were delivered on schedule up to the date of termination. Since Phase D was terminated prior to first article delivery, no graphic presentation for delivery performance is included. At time of termination all milestones had been met.

TECHNICAL PERFORMANCE – There were no variances or deviations from contract requirements.

5.1.4 F-14A Program

Grumman's most recent major prime contract is for the development of the Navy's next Mach 2+ air superiority fighter. Under this contract, Grumman has total weapon system performance responsibility. Test schedules are extremely compressed. Long-term, follow-on production options are committed to a magnitude of $2 billion.

5.1.4.1 Contract Award & Structure

The F-14A contract, N00019-69-C-0422, was entered into between the Naval Air Systems Command and Grumman in February 1969 for a target price of $443 million. This fixed price, multi-incentive, competitively won contract, commits Grumman to complete an engineering development, test, and evaluation program in early 1973 including production of the first six evaluation aircraft. It also requires system test and evaluation, engineering and management data,tooling, and integrated logistic support management. Dollar limitations in the amount of $29.6 million have been established to date for the logistic support (hardware and software) required for the engineering development/ evaluation program.

The Lot I contract incentive structure establishes a cost ceiling to the Government of 125 percent of contractor target cost, with an incentive sharing arrangement interrelating aircraft weight and flight achievement (technical) with cost achievement. Cost sharing based on target technical performance is 70 percent Navy – 30 percent Grumman. Based on technical performance achievement, the target profit of 10 percent may be increased to 12.5 percent or decreased to 5 percent. Additionally, the contract contains the following unique provisions:

- Maximum price options for purchase of an additional 463 aircraft in eight production lots over nine calendar years. Lots may vary in quantity by 50 percent up or down. Computerized programs will provide the Navy with the adjusted maximum price for variations in lot quantity within the plus or minus 50 percent limits
- Delivery of flight demonstrated aircraft to Board of Inspection and Survey (BIS) trials 17 months after first flight. Penalty, via the liquidated damages clause, of $6000/day/aircraft ($3 million maximum) for late delivery to BIS
- Direction by the Government for Grumman to perform engineering, development, prototype installation, and test for incorporation of an advanced technology engine under an established ceiling price
- Minimization of actions under the "changes" clause
- Maximum prices established for aircraft Lots VI, VII, and VIII subject to adjustment for abnormal fluctuations in national economy. Formulas define how labor and material fluctuations are measured
- Signed "Agreements of Responsibility" between Grumman and four major Government-subsystem suppliers

5.1.4.2 Contract Performance

COST GROWTH – Projected and actual program costs for the contractually required engineering development and evaluation of the F-14A as a function of time are shown in Fig. 5-6.

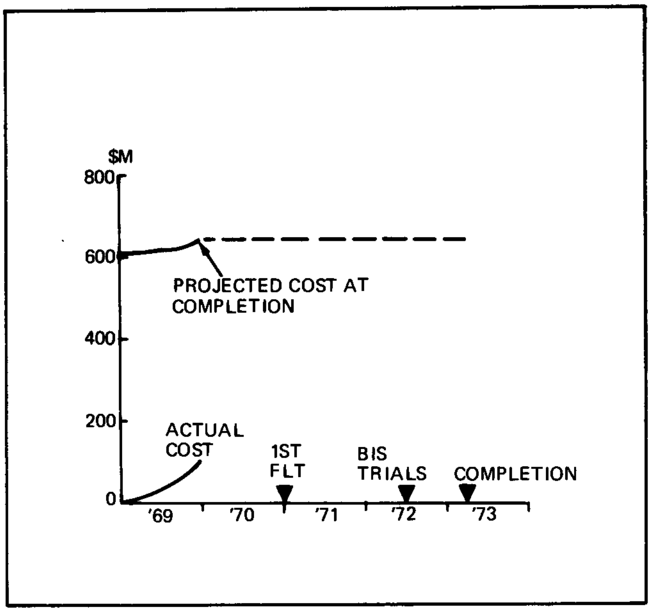


Fig. 5-6 Cost Trends – F-14A Engineering Development/Evaluation

Table 5-4 presents the breakdown categorizing areas of cost growth depicted in Fig. 5-6.

Growth in cost stems from:

- Scope changes – i.e. GFE to CFE change actions and added requirement in system support in the magnitude of $20 million
- Abnormal nationwide economic escalation (from a predicated 4 percent to an actual 7 percent)
- Burden rate increase because of reduction in business volume

SCHEDULE PERFORMANCE – A Navy management evaluation team spent 6 weeks at Grumman reviewing the F-14 management system. In the

Table 5-4 F-14A Engineering Development/Evaluation

Scope	Original Estimate, $ M	Current Projection, $ M
Engineering Development/Evaluation (17 A/C & Associated Test & Effort)	$ 562.0	$ 571.2
Separately Ordered Program Support for Engineering Development Evaluation		
Spares	$ 13.2	$ 12.9
SSE (GSE)	$ 21.7	36.1
Publications	5.0	5.0
Other	5.3	4.8
	$ 607.2	$ 630.0
Increase over Target Price		$ 15.4

Naval Air Systems Command "Report of Performance Measurement System Demonstration Conducted at Grumman Aerospace Corporation," dated 25 September 1969, schedule planning and control were stated to be one of the strongest elements of the system.

As indicated on Fig. 5-7, the aircraft mockup review was completed on schedule. Engine inlet ground tests were completed ahead of schedule. The system integration test stand (SITS) which simulates avionics performance was delivered on schedule and is now operational at the Naval Missile Center, Pt. Mugu. An engineering mockup and manufacturing aid (EMMA), fabricated from production drawings is near completion and will prove out all electrical and hydraulic installations prior to installing in aircraft No. 1. Assembly of the forward module of aircraft No. 1 is on schedule. Fabrication of the wing pivot development and test hardware is completed and is undergoing static and fatigue tests.

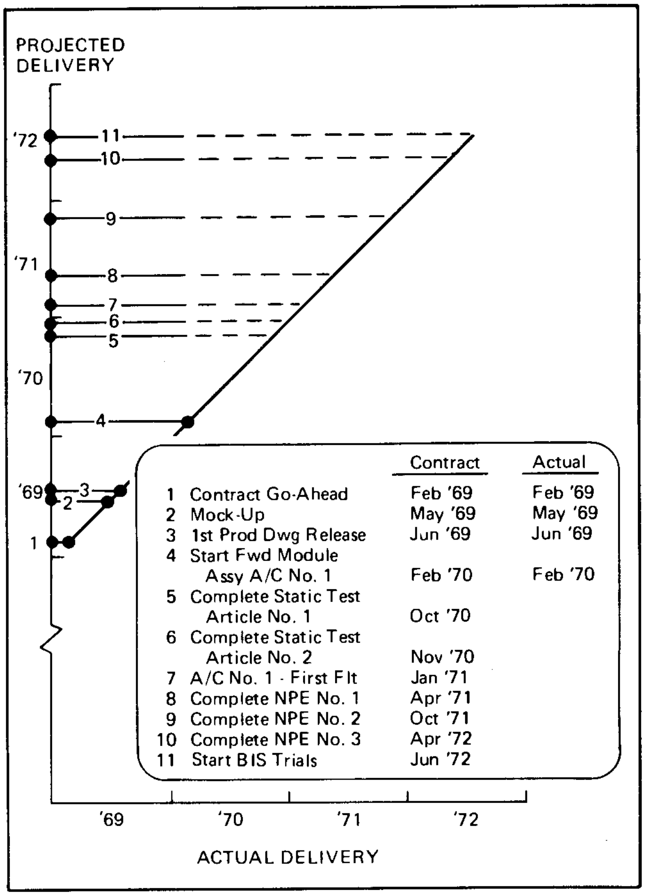
TECHNICAL PERFORMANCE – Weight targets have been established for each piece of structure and subsystem, including fuel. As of this date the F-14 aircraft has drawings released for almost 70 percent of the total structural weight and the aircraft is only 140 lb over the original target weight of 53,500 lb. Wind tunnel analyses, confirmed by NASA, indicate no significant aerodynamic problems. We believe these to be unique commendable achievements in today's aerospace environment and an indication of the technical and management controls we can bring to bear on a program of this magnitude – all of which is directly applicable to the cost of design and development of the shuttle system.

5.1.5 EA-6B Aircraft

The EA-6B is a four-place tactical electronic countermeasures (ECM) aircraft designed to protect carrier and advanced base strike aircraft operating in environments of sophisticated enemy radar threat.

5.1.5.1 Contract Award & Structure

In July 1965 Grumman was awarded Naval Air Systems Command contract, NOw 65-0587-c, for Contract Definition Phase (CDP) studies of an advanced tactical electronic warfare aircraft and system. Grumman's final report, responding to the 20 definition requirements of DOD Directive 3200.9, was submitted in November 1965. A letter contract, N00019-67-C-0078, was issued to Grumman in August 1966, on a noncompetitive basis, for development of a four-place EA-6B aircraft and a tactical jamming system. This letter contract was definitized in January 1968 on a cost-plus-incentive fee



		Contract	Actual
1	Contract Go-Ahead	Feb '69	Feb '69
2	Mock-Up	May '69	May '69
3	1st Prod Dwg Release	Jun '69	Jun '69
4	Start Fwd Module Assy A/C No. 1	Feb '70	Feb '70
5	Complete Static Test Article No. 1	Oct '70	
6	Complete Static Test Article No. 2	Nov '70	
7	A/C No. 1 - First Flt	Jan '71	
8	Complete NPE No. 1	Apr '71	
9	Complete NPE No. 2	Oct '71	
10	Complete NPE No. 3	Apr '72	
11	Start BIS Trials	Jun '72	

Fig. 5-7 F-14 Delivery Schedule

basis in the amount of $204.2 million consisting of a $176.2 million target for aircraft and system development, and $28 million for partial provisioning of system support items. The definitive contract included five prototype aircraft for flight test and various test articles, tooling, test equipment and support items.

Earned fee is based on an incentivized weighted matrix of cost, schedule and technical performance. The incentivized technical/schedule items closely correspond to the major elements of program risk identified in the DOD EA-6B Development Concept Paper (DCP). Incentive levels include 6 characteristics of vehicle performance, 17 items of system performance and reliability, and 5 delivery milestones.

These parameters are related to cost performance through a matrix which increases, or decreases, target fee based on technical/schedule performance and further adjusts the resultant fee, through varying penalty rates, based on cost performance. At 139 percent of target cost, the earned fee is zero, independent of technical/schedule achievement.

The projected cost over target for aircraft/system development is within the initial band of the cost incentive matrix and considerably below the point at which maximum penalty becomes effective.

5.1.5.2 Contract Performance

COST GROWTH – Trends for projected and actual costs as a function of time are shown in Fig. 5-8.

Since definitization, the Navy has authorized changes in scope of some $0.6 million and increased the estimated value of system support by $27.7 million to permit ordering of the complete family of required support items. In addition, Grumman has projected an increase over target cost for aircraft/system development of $16.4 million ($20.5 million estimated cost increase offset by target performance for penalty at 20 percent) due, in most part, to subcontractor cost increases associated with difficulties encountered during state-of-the art development of the required high-powered traveling-wave tubes. The balance of this average is referable to increases in projected labor and overhead rates and to additional costs encountered during support of required test programs. The major elements of cost are identified in Table 5-5.

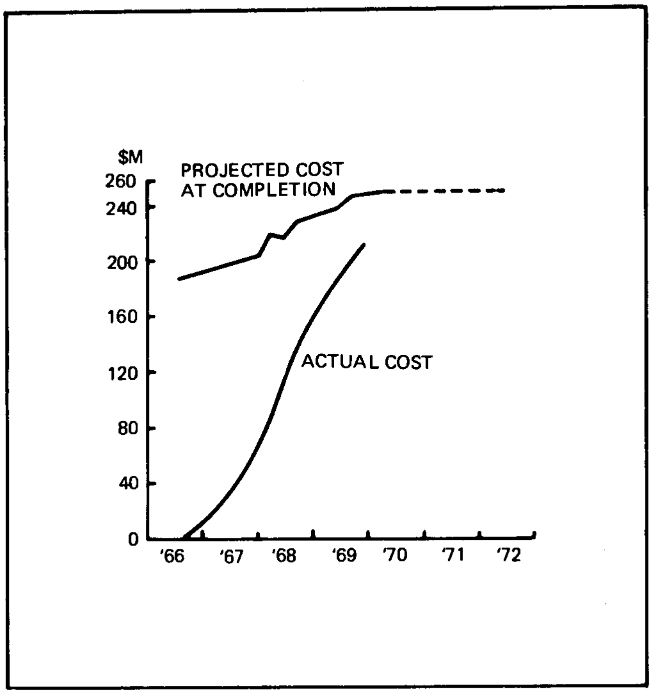


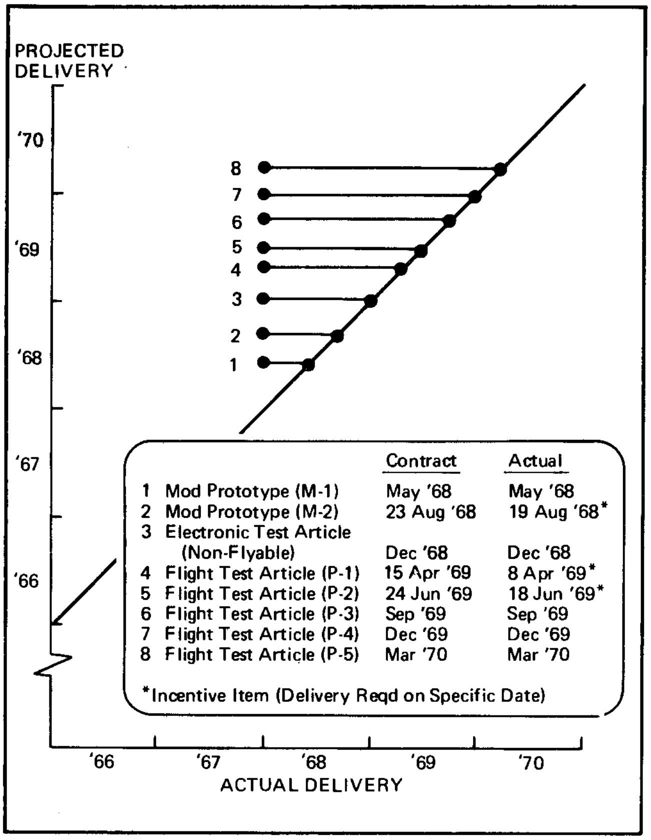
Fig. 5-8 Cost Trends—EA-6B

DELIVERY PERFORMANCE – All deliveries to date have been made on or ahead of schedule. Alternate work-around plans were used to overcome subcontractor development schedule delays. The DOD review milestone of seven months of successful flight test using the system prototype aircraft was achieved on schedule with excellent technical results. The preproduction aircraft and system was recently deemed ready for BIS trials on the scheduled date of 1 May 1970. The contractor's on-schedule performance throughout the incentivized development program is shown in Fig. 5-9.

TECHNICAL PERFORMANCE – Development test results and the several Navy/Government evaluations to date have confirmed the excellent technical performance of both aircraft and system:

Table 5-5 Contractual Cost Breakdown - EA-6B

Scope	At Definitization $ M	Current Projection, $ M
Aircraft/Systems Development	$ 176.2	$ 176.8
Separately Ordered Program Support		
Spares	6.0	18.3
SSE (GSE)	20.1	34.3
Other	1.9	3.1
	$ 204.2	$ 232.5
Increase over Target Price		$ 16.4



		Contract	Actual
1	Mod Prototype (M-1)	May '68	May '68
2	Mod Prototype (M-2)	23 Aug '68	19 Aug '68*
3	Electronic Test Article (Non-Flyable)	Dec '68	Dec '68
4	Flight Test Article (P-1)	15 Apr '69	8 Apr '69*
5	Flight Test Article (P-2)	24 Jun '69	18 Jun '69*
6	Flight Test Article (P-3)	Sep '69	Sep '69
7	Flight Test Article (P-4)	Dec '69	Dec '69
8	Flight Test Article (P-5)	Mar '70	Mar '70

*Incentive Item (Delivery Reqd on Specific Date)

Fig. 5-9 EA-6B Delivery Schedule

- Vehicle performance and structural strength have equalled the specification values established at program inception. Of particular significance is "weight empty" which exhibits an actual value some 2000 pounds under specification value
- Specified values for effective radiated power have been met and, in one band, exceeded by a factor of four
- Measured direction-finding accuracy exceeds specification by a considerable margin
- Initial demonstrations indicate that major system reliability and navigation accuracy will meet, or exceed, specifications
- All operational modes, manual, semi-automatic and automatic, have demonstrated the desired performance levels

Recently, in accordance with DOD direction, the preproduction system aircraft conducted a series of tactical jamming flights in the dense radar environment of Eglin AFB. Test results, in all operational modes, indicated excellent technical results which, in the opinion of observers, are orders of magnitude better than previous ECM capability.

5.1.6 E-2B Hawkeye Aircraft

The E-2B aircraft is an advancement of the proven E-2A carrier-based airborne early warning system which was developed and produced by Grumman in the early 1960's. The E-2B program, scheduled to run until late 1972, incorporates a new state-of-the art microminiaturized programmable computer into the airborne tactical data system.

5.1.6.1 Contract Award & Structure

The E-2B letter contract, N00019-67-C-0657, was awarded to Grumman on a non-competitive basis by the Naval Air Systems Command in December 1967. In June 1969 it was definitized as a fixed price incentive contract of $87 million. It covers the fabrication, integration,test and installation of new equipment in a number of existing E-2A systems and associated support commodities in the Government inventory. The contract incentive structure is related to cost only, with a ceiling established at 112 percent of target cost.

5.1.6.2 Contract Performance

COST GROWTH – Fig. 5-10 shows actual and projected cost to the Government versus time. Cost growth has occurred in the system support area resulting from provisioning policy changes as shown in Table 5-6.

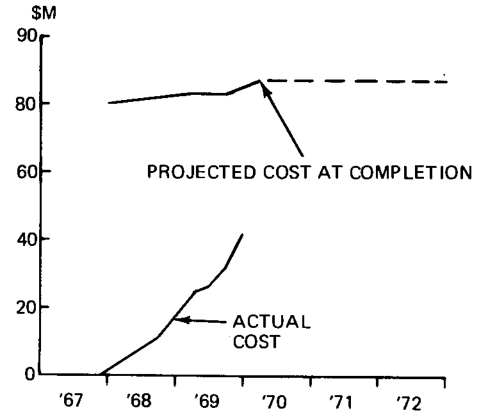


Fig. 5-10 Cost Trends – E-2B

Table 5-6 Contractual Cost Breakdown – E-2B

Scope	Original Estimate, $ M	Current Projection, $ M
Definitive Contract	$ 63.3	$ 61.4 Target Price
Separately Ordered Program Support		
Spares	$ 17.0	$ 22.0
Training	0	.3
Repair & Modification of GFE	Unkown	3.3
	$ 80.3	$ 87.0

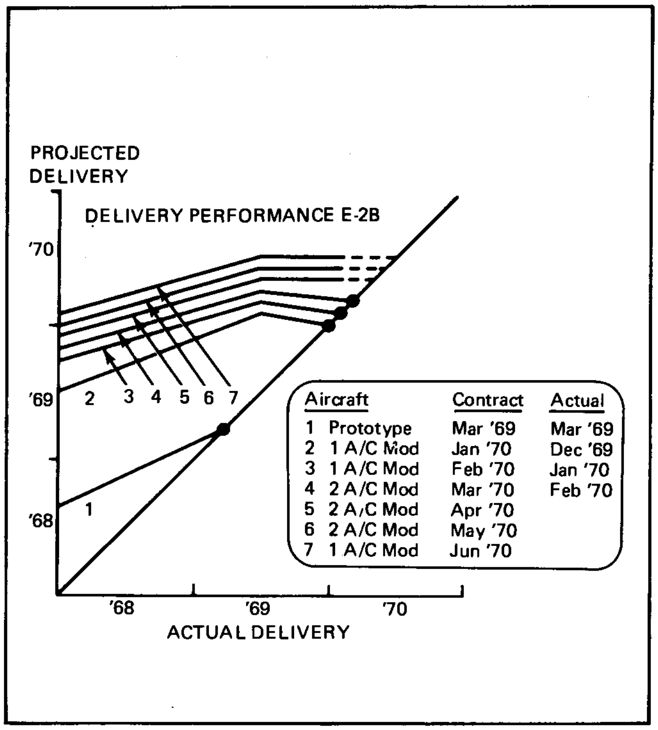
DELIVERY PERFORMANCE - The E-2B delivery schedule projected originally in the letter contract and the revised schedule of the definitized contract is shown in Fig. 5-11. The slight knee appearing on this figure represents resolution of the Navy's desired delivery schedule versus the later-than-planned award of the letter contract.

CONTRACT DEVIATIONS – No performance specifications have had to be modified. Subsequent to the initiation of the program fabrication phase, minor deviations from equipment specification requirements were granted, (e.g. magnetic tape storage temperature requirement reduced from 85°C to 71°C, and electrical wire routing).

TECHNICAL PERFORMANCE – The acceptance test program to which each modified aircraft, with full-up systems is subjected, correlates to the initial aircraft sell-off tests. The tests require a system checkout in a complete mission-ready environment including performance of command and control functions. The checkout involves ground and in-flight performance tests. This includes a 100 hour failure-free bench test for each computer and power supply prior to acceptance. The new and modified systems have performed to expectations during the test phases.

5.1.7 E-2C Hawkeye Aircraft

The E-2C engineering development program is a logical follow-on to the carrier-based E-2A/E-2B airborne early warning system aircraft. Grumman will design, develop, integrate and test a new command and control system consisting of six major electronic subsystems. Two E-2A aircraft will be modified to the E-2C prototype configuration. In addition, Grumman will design, develop, fabricate and test support commodities, and provide weapon system/VAST interface.



Aircraft	Contract	Actual
1 Prototype	Mar '69	Mar '69
2 1 A/C Mod	Jan '70	Dec '69
3 1 A/C Mod	Feb '70	Jan '70
4 2 A/C Mod	Mar '70	Feb '70
5 2 A/C Mod	Apr '70	
6 2 A/C Mod	May '70	
7 1 A/C Mod	Jun '70	

Fig. 5-11 E-2B Delivery Schedule

5.1.7.1 Contract Award & Structure

The E-2C letter contract, N00019-68-C-0542, with a maximum price, exclusive of program support, of approximately $143 million was awarded by the Naval Air Systems Command on a non-competitive basis in June 1968. This contract will be definitized as a fixed price type with the incentive structure based on cost only. Anticipated definitization date is 1 May 1970 with program completion scheduled for late 1973. Follow-on production is provided for in the letter contract by options for procurement of 10 aircraft at a ceiling price of $120 million to be exercised by 1 September 1970 and 18 aircraft at a ceiling price of $166 million to be exercised by 1 September 1971.

5.1.7.2 Contract Performance

COST GROWTH – Cost to the Government as a function of time from the original to the current estimate is shown in Fig. 5-12. The cost impact for the major areas of directed scope change is presented in Table 5-7.

Additional requirements in the form of PDS, ASQ-( ) and VAST alternate equipment has caused the growth of the SSE estimate. While the difference in cost between our original and current estimate is identified as cost growth, this may not be cost growth to the customer who originally intended to procure this added effort from an alternate source.

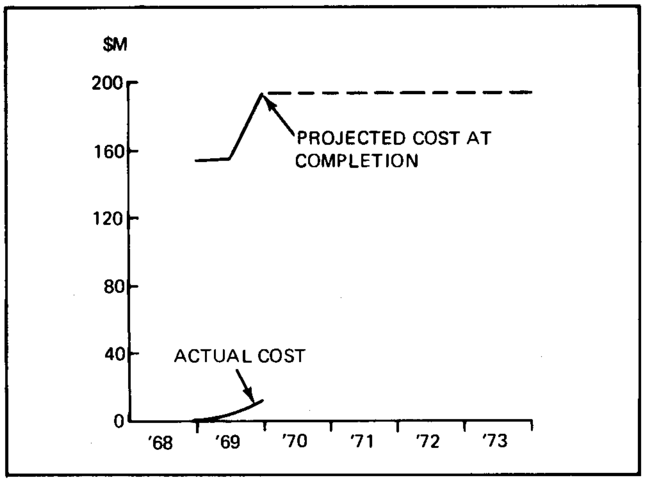


Fig. 5-12 Cost Trends – E-2C

Table 5-7 Contractual Cost Breakdown – E-2C

Scope	Original Estimate, $ M	Current Projection, $ M
Engineering Development Mod. of 2 A/C System Test & Evaluation - Max. Price	$ 143.0	$ 143.0
Addition of Passive De-Tection Subsystem (PDS) Max Price	No Reqmt	22.0
Change of ASQ( ) from GFE to CFE	No Reqmt	7.1
Separately Ordered Program Support		
Spares	.9	.9
SSE (GSE)	9.8	20.6
Other	.5	.5
	$ 154.2	$ 194.1

DELIVERY PERFORMANCE – No E-2C program milestones have been missed, as confirmed by contract performance evaluation report forwarded by NAVAIRSYSCOM letter MAT023/082: WDB, dated 15 August, 1969. Fig. 5-13 depicts the schedule of events to complete the E-2C engineering development program.

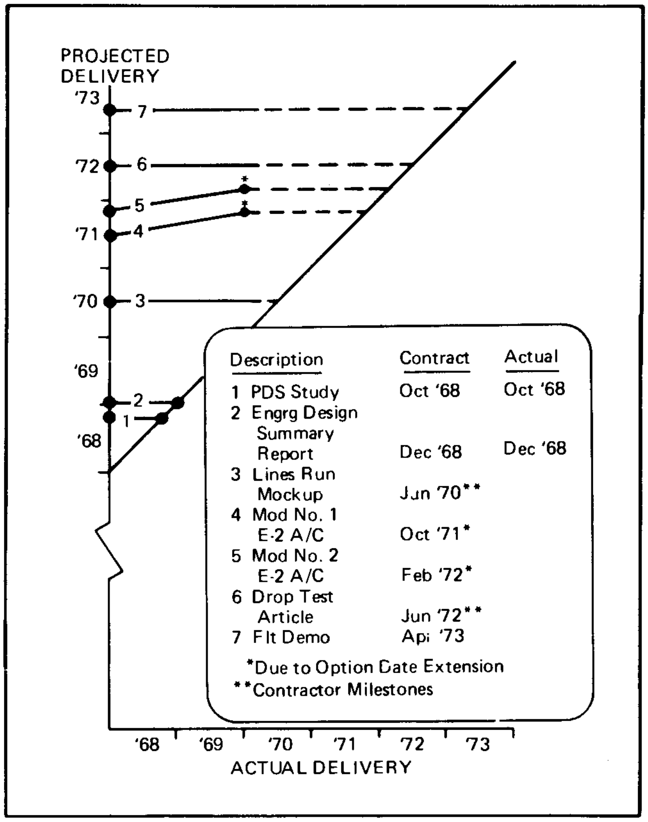
TECHNICAL PERFORMANCE – Progress towards attainment of technical requirements have been satisfactory despite some delays in receipt of incremental funds required by contract. By the selective rearrangement of work tasks and the employment of work-arounds, all major technical objectives have been met. This contract's technical features are unique, within the E-2 series. The requirements are predicated on a total weapons systems concept instead of the earlier conventional individual subsystem specification approach. Thus, flexibility is provided to maximize tradeoffs, to attain technical excellence at lowest cost with on-time deliveries.

5.1.8 Contract Management

Summary information presented in this subsection describes management concepts and methods used for current status determination of cost/schedule/technical performance. It is addressed in greater detail in Section 4.

Grumman's integrated management system provides current status of cost, schedule and technical performance in a form permitting early recognition of problems. Visibility of contract progress is available against a retained baseline of original performance budgets.

The management system ties the three elements of cost, schedule and technical performance together through the media of work breakdown structure and control package. Variance analysis reports of significant deviations are prepared. Plans for corrective action are developed. The system provides



Description	Contract	Actual
1 PDS Study	Oct '68	Oct '68
2 Engrg Design Summary Report	Dec '68	Dec '68
3 Lines Run Mockup	Jun '70**	
4 Mod No. 1 E-2 A/C	Oct '71*	
5 Mod No. 2 E-2 A/C	Feb '72*	
6 Drop Test Article	Jun '72**	
7 Flt Demo	Apr '73	

*Due to Option Date Extension
**Contractor Milestones

Fig. 5-13 E-2C Delivery Schedule

a means of identifying program progress and alerting corporate management and NASA to potential program difficulties.

Each new program has brought new ideas to the control process. This evolving management system allows "current status" to approach constantly closer to the ideal of "real time." Progessively added elements of sophistication can be seen in the management systems growth diagram in Section 4.

The system to be used on the Phase B study is a simplified version of that currently working successfully on the F-14. It has been reviewed favorably by a Navy validation team of Government experts including NASA and USAF observers. This team was on-site from 18 August through 25 September 1969. The favorable results of the survey are presented in the Naval Air Systems Command *"Report of Performance Measurement System Demonstration conducted at Grumman Aerospace Corporation,"* dated 25 September 1969. Originally developed for control of hardware programs, the system has been modified to the specific needs of this study. Key elements of this system now in use on the F-14 program are work breakdown structures, control packages, budgets and schedules.

Current status information alone does not ensure timely action. Top management attention must be applied on a regular basis. Bi-weekly schedule/cost/technical review meetings serve this purpose on the LM and F-14 programs. The space shuttle program will follow this practice.

An action center/data link system for space shuttle activity will be located in Grumman's Plant 25, and in associate contractor plants to provide real-time information to Grumman, its associates and NASA. Voice and "hardcopy" networks will facilitate communication and visibility of identical information at separate action centers. These concepts are currently functioning as invaluable management tools on the F-14 and LM programs.

5.1.9 Experience in Overcoming Program Difficulties

Grumman management has learned from experience the importance of attacking a problem instantly and with total resources. Problem solutions in a variety of categories are presented in the following paragraphs to demonstrate this capability:

Grumman will reassign high-level executives to ensure total resource commitment to solving a problem. Slipping LM schedules impelled the president of Grumman to canvass the company for broadly experienced managers who could stabilize the slippage and shorten delivery time. These proven managers were assigned to particular vehicles and stayed with them through launch. LM schedules were stabilized.

Grumman will make radical system changes to meet problem demands. Ineffective assignment of cost responsibility at working management levels caused a widening gap between cost prediction and experience on LM. At NASA's request, a joint NASA/Grumman investigating team was formed. Its findings resulted in implementation of a work package management system. Management expectations were clarified and communicated to first line supervision and problems were surfaced. Cost control was tightened. NASA contractor performance evaluation report (DD-I&L (SA) 699) covering 10/4/65 to 9/30/67 stated: "Grumman proceeded to do an excellent job of developing and utilizing work packages."

Grumman will make organizational changes for problem solutions. LM sucontractors were out of control. No one individual was accountable for subcontractor management of cost, schedule and technical performance. A subcontracts manager was appointed, reporting directly to the LM program director. Project managers were appointed for each major subcontract, responsible for cost, schedule and technical performance. Schedule and cost overruns of major subcontractors were greatly reduced. Technical communications were made schedule and cost sensitive.

Grumman will improvise systems to solve technical problems. Growth in F-14 aircraft weight started to exceed allowable limits during the early detail design phase. A system was devised to predict the eventual gross takeoff weight of the aircraft, and assign weight targets to each piece of structure and subsystem. Individuals were appointed with responsibility for meeting weight targets. The project director halted structural design effort until weight problems were eliminated. This weight "scrubbing" took approximately one month. Weight bogies have not been exceeded since.

Grumman solves serious hardware problems with broad-front round-the-clock crash programs. LM-1

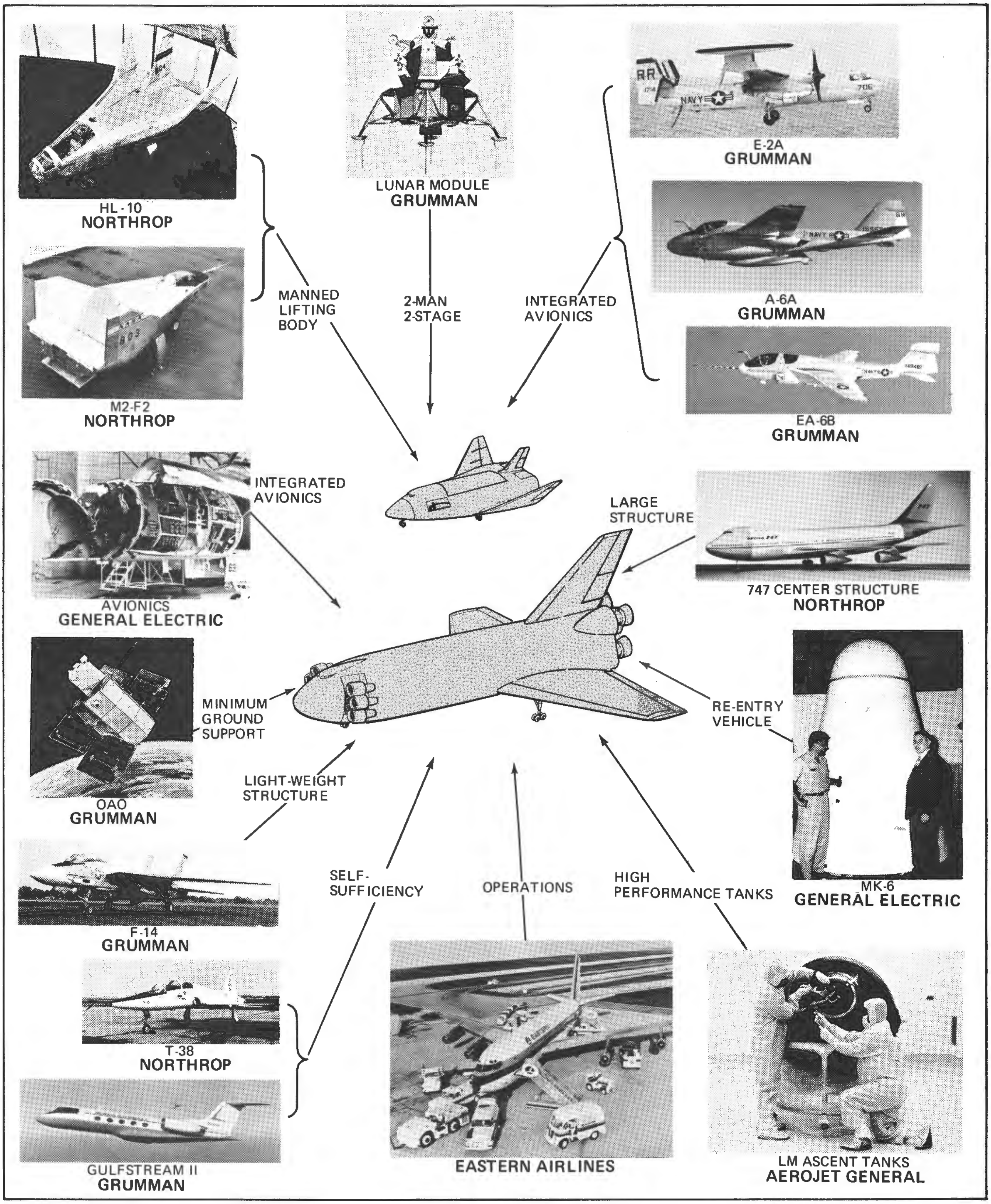


FIG. 5-14 OUR PRODUCTS PROVIDE RELEVANT EXPERIENCE

developed main propellant line leaks at Cape Kennedy. The program director appointed and led a task force of top engineering and manufacturing specialists. Seven-day week, round-the-clock planning, coordination, and daily follow-up solved the problem. Local repairs were inadequate. Lines were redesigned to replace mechanical with welded joints. In 20 days the rigid, zero-tolerance lines were in place with leaks eliminated.

The preceding briefs show Grumman's challenge/response pattern to unusual emergencies. Other patterns have recurred often enough that operating techniques for solutions have solidified into permanent arrangements. These include:

- Quick response center – An aggregate of people resident in a single area and with a wide diversity of talents who can tackle specific problems aided by zero-length lines of communication
- Daily stand-up meetings & chit-book work assignments – A system of action center meetings and a work assignment technique that addresses problems daily and eliminates confusion and delay.
- Bi-weekly meetings of Senior Mangement Review Board. High-level management are forced into involvement.

5.1.10 Relationship to Shuttle Requirements

The composite related experience of Grumman and its associates: General Electric (avionics and reentry), Northrop (large structures), Eastern Airlines (operations) and Aerojet General (large rocket engines and cryrogenics) encompasses the full spectrum of required shuttle technology. The main technological shuttle-related aspects of the programs on which our team has demonstrated its capabilities are presented in Section 3 and shown in Fig. 5-14.

5.2 CORPORATE INTEREST

The space shuttle system is both an aircraft and a spacecraft. As Grumman President L. J. Evans stated at the NASA/Industry Briefing on 6 Feb 1970, "The space shuttle will bring together the best of technologies from both astronautics and aeronautics. In fact, this program will require the best of both sciences to ensure its success. We are pleased to see the re-emphasis on aeronautics and see an exciting future in the space shuttle program as a complete, reliable, and simple space transportation system. It provides the means of carrying useful things into space in sufficient quantity, in an efficient, economical, safe and routine manner; an opportunity to tie our space environment closer to our world in a genuine practical sense. It in fact brings to mind the first practical automobile, or the Wright Brothers flyer."

Grumman has, in the past, focused its attention on producing practical, operational, high performance aircraft and spacecraft. It has already applied this technology to other diverse items such as underwater research (the Ben Franklin submersible), the human organ transporter (ESOT), and high speed ground transportation (the TACRV). The space shuttle program is consistent with this trend and the current reordering of national priorities. It will combine and in fact demand the best from aeronautical and space technology to exploit orbital space in consonance with the accelerating awareness of mankind's interrelation with his environment. We are enthusiastic about the prospects of routine orbital operations where sizable payloads can be returned to earth and where specialists not requiring the diverse capabilities of our astronauts can be usefully employed.

Our current business backlog, although significantly reduced, still provides a solid business and financial future. This reduction does, however, offer immediately available resources and a more than usual motivation to perform a superior study and move on to the hardware and operational phases of the program. It is very important to note that the technical challenges of Grumman's programs attract top personnel. We have not lost any competence due to layoffs or business declines. People continue to be our greatest strength.

The impact of the present stretchout of NASA and DOD programs is accentuated by the fact that Grumman will have completed and delivered all spacecraft, both LM and OAO, by the end of calendar year 1971. *GRUMMAN MUST ACQUIRE A SIGNIFICANT ROLE IN THE SPACE SHUTTLE OR, IN FACT, BE OUT OF THE SPACECRAFT BUSINESS.*

Grumman currently has 350 people on the shuttle proposal study effort. Over the past 10 years, Grumman has invested more than $41 million in facilities and equipment for space programs. These people and physical resources coupled with those of our associates, General Electric, Eastern Airlines, Northrop, and Aerojet-General will be applied to the Phase B study and follow-on hardware phases, with the same priority and dedication demonstrated on LM and F-14.

The Grumman Aerospace Corporation is committed to the space shuttle program and the national space effort as a whole.

5.3 CORPORATE PERSONNEL POLICY & LABOR RELATIONS

Corporate management of Grumman and our associate team members, will participate directly in the Phase B study. Our history has shown that top management involvement is not only desirable, but mandatory to a successful program. Fig. 5-15 shows Grumman's corporate organization. Fig. 5-16 shows corporate management's relationship to organizational elements that will perform the Phase B definition study.

Re-organizations occurred at Grumman during 1969 to ensure corporate emphasis and concentrated management visibility. The Executive Operations Board, consisting of key Vice Presidents, was formed to ensure better corporate communication and cross-program involvement. Members of the Board are:

- William M. Zarkowsky – Senior Vice President: Aircraft, Marine and Ocean Systems Programs (Chairman)
- Joseph G. Gavin Jr – Senior Vice President: Space Programs (Vice-Chairman)
- I. Grant Hedrick – Senior Vice President: Technical Operations
- Corwin H. Meyer – Vice President: Product Operations
- John O'Brien – Administrative Vice President
- G. Thomas Rozzi – Vice President: Personnel Services
- Thomas P. Cheatham – Vice President: Grumman Corporation

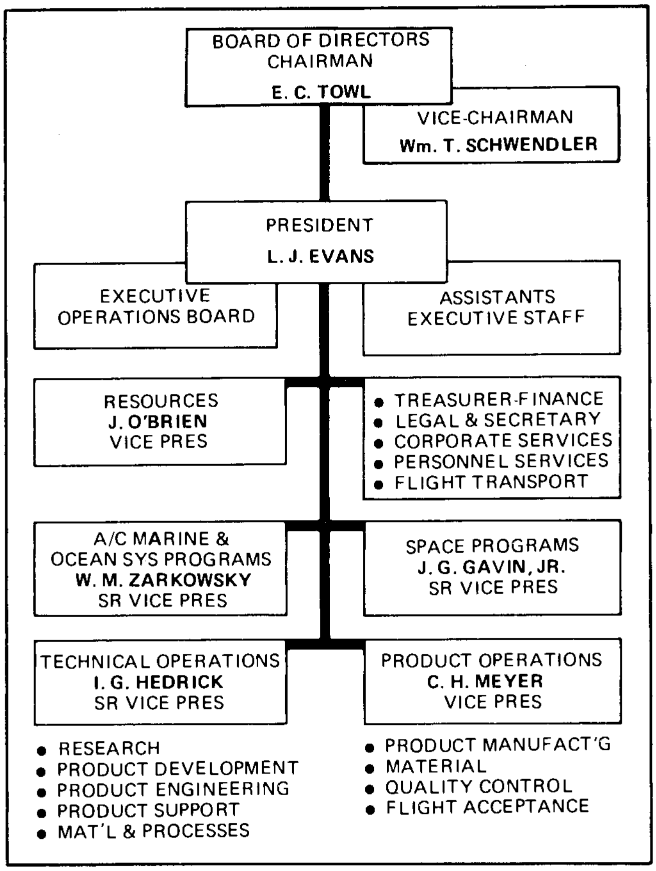


Fig. 5-15 Grumman Aerospace Corporation. *Guides And Directs Phase B Definition Study*

Over and above formal relationships, the President of the Grumman Aerospace Corporation, L. J. Evans, has and will continue to exert his personal influence to guarantee program success.

The shuttle program at Grumman is under highly capable leadership which provides an excellent balance of aircraft and spacecraft experience.

- J. G. Gavin, Jr. – Senior Vice President: Space Programs – leader of the LM program from its inception. Mr. Gavin is the corporate focal point for direction of all space programs
- I. G. Hedrick – Senior Vice President: Technical Operations – nationally acknowledged authority in the field of aircraft and spacecraft structural design. As director of the entire technical resources of the company he will provide corporate overview for the space shuttle
- L. M. Mead – Vice President: Director Space Shuttle – directed the entire conceptual study leading to the F-14. Mr. Mead will direct the Grumman and related subcontractor efforts for the Phase B study

These leaders will be assisted by seasoned and professionally qualified personnel. The team is already operational and supported by all corporate resources. Our corporate management, and the managements of our associates, guarantee that the people and resources are available. Once key people are assigned to the program, they will remain with the program until all major milestones are met.

5.3.1 Labor Relations

Labor stability is one of Grumman's strong points. Throughout our history, the company has never had a labor work stoppage. Exceptional longevity of service also speaks well for a company's ability to consistently work with its employees to accomplish mutual goals.

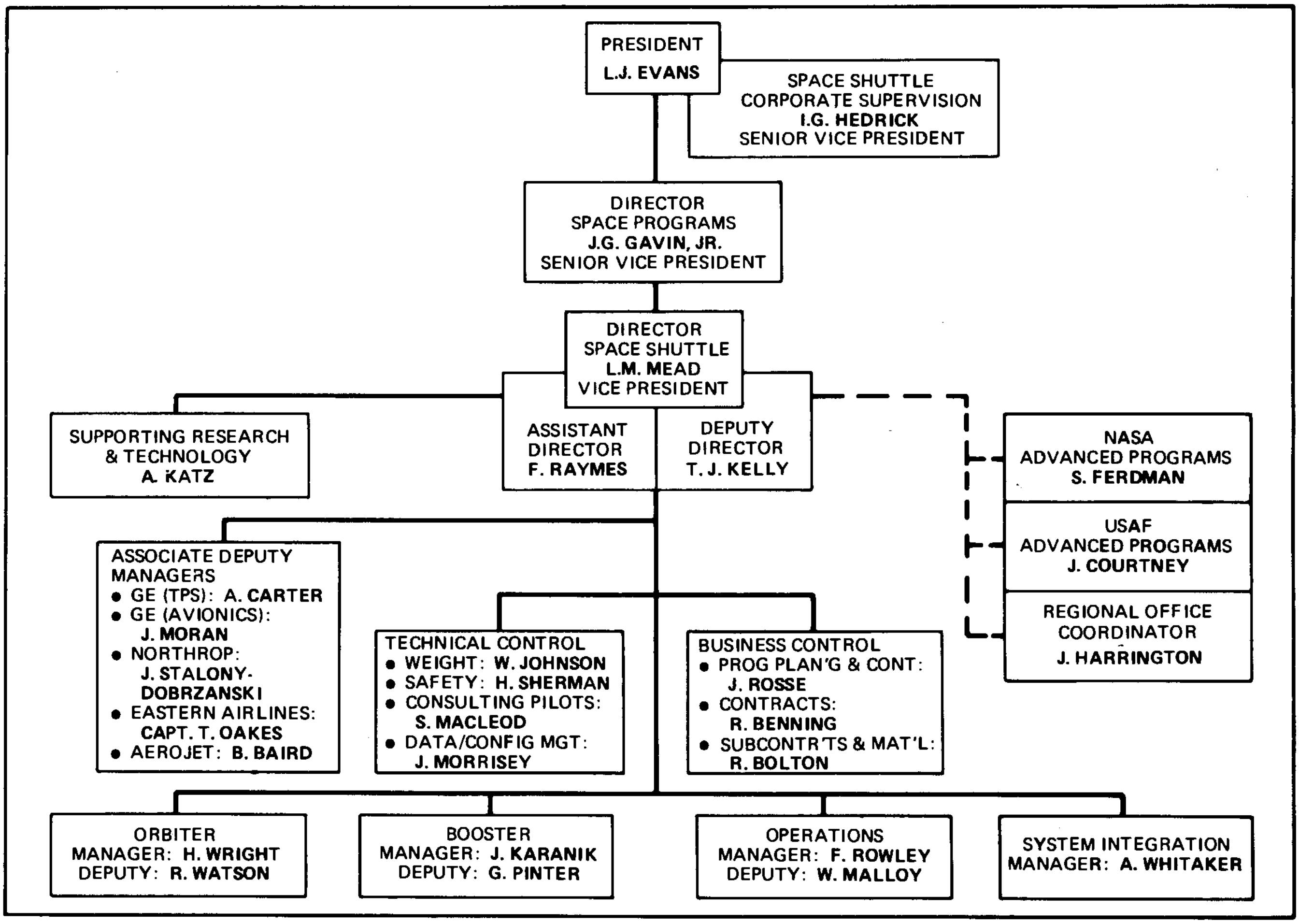


Fig. 5-16 Phase B Organization. *Top Management Has A Direct Interface With The Organizational Elements Of Phase B Definition Study*

At the end of 1969, Grumman had 32,000 people

- 9934 with more than 10 years service
- 3578 with more than 20 years service
- 1692 with more than 25 years service

There is no potential labor condition at the Grumman Corporation or associates that would in any way adversely affect the space shuttle program.

5.3.2. Equal Opportunity Policies

The Grumman Aerospace Corporation is an equal opportunity employer in full compliance with civil rights legislation and the Office of Federal Contract Compliance's recommendations. The corporation has committed itself in good faith to a series of affirmative policies and programs:

- The opportunity development department, reporting directly to the president, places key emphasis on personnel relations and practices, promotional opportunities, and skill development. A promotion review board within this department, formulates and audits promotional policy. Any employee may apply for a supervisory position
- The personnel department, following a related policy, verifies internally available skills before recruiting outside employees
- A termination review board with minority group membership ensures that the termination and recall of employees is achieved in a fair and objective manner
- Cooperating with the National Alliance of Businessmen (NAB), over one million dollars was invested in offering training in 13 skill categories to 270 disadvantaged people from minority groups. Despite poverty and educational deprivation, 200 people completed the training. One hundred of this group are still employed at Grumman. The remainder, we believe were

helped to a significant extent by the program. In addition, some 300 supervisors received "sensitivity" training to increase their understanding of disadvantaged people

5.4 GOVERNMENT/CONTRACTOR PAST RELATIONSHIPS

The Grumman Corporation has always believed in the doctrine of operating in an open and frank manner with its customers. Government representatives have been "on-board" at Grumman continuously since November 6, 1933. At the present time, 44 NASA, 290 Navy, 35 DCAA and 6 other governmental representatives are in residence at Grumman. The Government is equally well represented at the facilities of our associate contractors.

Grumman's ability to respond to customer requirements in the matter of deliveries is exemplified by our ability to advance shipping schedules when necessary. The office of the Commandant of the Marine Corps stated that "Navy/Marine Corps acceptance of first new EA-6A of fiscal year 1968 procurement one month ahead of schedule (is) noted with pleasure. This effort (is) considered to be a significant achievement."

Col. James A. McDivitt recently wrote in connection with the Lunar Module/Lunar Roving Vehicle interface that "... the Grumman Aerospace Corporation is to be commended for their cooperation in assisting with the interface design and for their willingness to work long hours to deliver the interface tooling."

The close cooperation of Grumman and NASA personnel is evidenced by their joint approval of LM operating procedures. In addition, there is a close working relationship with NASA's data managers to reduce the cost of hard-copy distribution by the use of microfilm, particularly in the area of acceptance data packages. To date over 5 million frames of microfilm have been delivered.

The Naval Plant Representative Office at Grumman has formed an F-14 management system maintnance and surveillance team which makes periodic reports on discrepancies and corrective actions. Team members are permitted free access to program information as well as the action center, where progress is graphically displayed. We will provide similar visibility for the shuttle program.

The Northrop Corporation Aircraft Division in accomplishing the M2-F2/HL-10 lifting body research vehicle contract, acquired an outstanding rapport with NASA personnel. Frequent meetings between NASA and Northrop counterparts resulted in early anticipation and solution of problems, and timely review and concurrence on design philosophies and concepts.

Capt. E. C. Waller, USN, wrote in connection with the General Electric P-3C program: "... I have been greatly impressed by the quality of your equipment, the understanding, realism, and honesty of your management personnel, and your dynamic response to technical problem solving..."

We are proud that the complete cooperation that exists between Government and Grumman personnel at all organizational levels has been a significant factor in the successful performance of our contractual obligations.

5.5 PARTICIPATION IN GOVERNMENT SMALL BUSINESS & LABOR SURPLUS AREA PROGRAMS

It is Grumman's belief and practice that active involvement with small business and labor surplus area firms is vital to our success and the health of the nation's economy. Grumman can demonstrate nationwide involvement with small business and labor surplus area concerns.

The Small Business Office, (SBO), a part of the Material Department, is responsible for our involvement with small business firms. It is a policy of the SBO that all outside firms have the opportunity to participate in the small business program. A microfilm file is maintained on over 14,000 aerospace-related firms. Grumman attempts to ensure a stable financial relationship by providing reasonable progress payments. Small firms are allowed to work within their financial capabilities without undue risk, thereby opening to them technological fields usually reserved for larger firms.

Approximately $87 million in business was awarded through 47 major contracts of $500,000 or more in 1969, to firms in labor surplus areas with moderate or greater unemployment. In the same year, payments were made to 4394 small business firms in 46 states and the District of Columbia.

Our record of payments to small business firms is as follows: (see map below)

Year	Total Payments	Payment to Small Business Firms
1967	\$592,741,578	\$156,185,823
1968	\$634,846,222	\$153,200,494
1969	\$506,556,148	\$100,246,205

On 17 March 1970, the Grumman Aerospace Corporation was presented a certificate of appreciation for our participation in the small business subcontract program by the New York area administrator of the Small Business Administration.

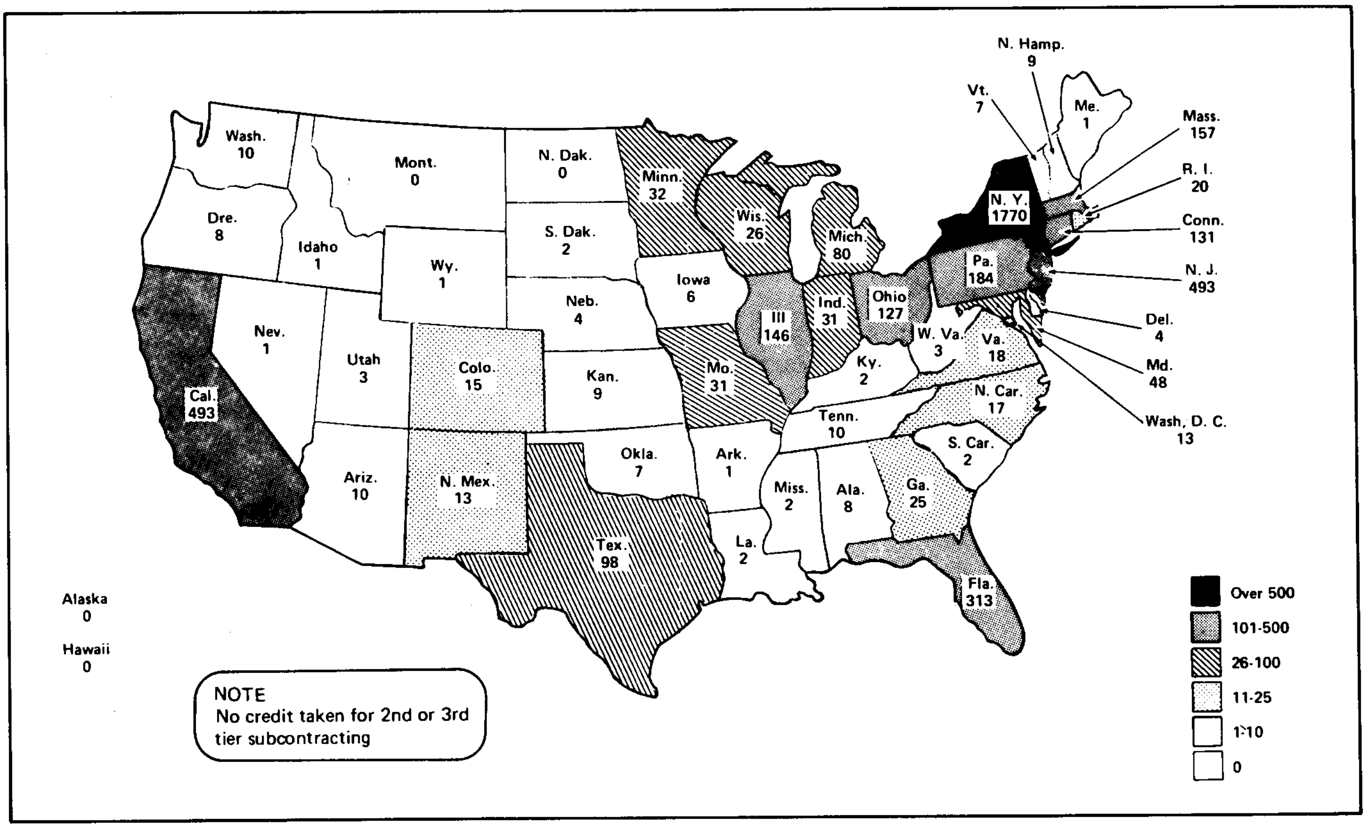
As a public corporation, Grumman is committed to programs ranging in scope from the defense of our country to the exploration of our environment; as an employer of individuals, we are committed to directly influencing specific employees in achieving a greater personal reward and participation in national affairs and economic life.
Grumman's Training and Development Department promotes a broad program of employee improvement. In each of the past three years, the Company has spent more than \$1 million on these programs.

Each year some 14,000 employees have taken advantage of the training facilities. The professional development program is currently training 75 promising young people in business, engineering and manufacturing technology.

The evening scholarship program attracts corporate-wide involvement. Over \$2 million has been spent on this program in the last three years.

In addition, Grumman offers some 50 free technical courses to its employees. In 1969, 1155 students participated.

The company also makes widespread contributions to worthy causes of an institutional nature: hospitals, colleges and charitable organizations.



NOTE
No credit taken for 2nd or 3rd tier subcontracting

RESOURCES & SCHEDULES

6 – RESOURCES AND SCHEDULES

Grumman is financially healthy and in a favorable position to commit major resources to a new program. There are no current R&D programs with latent development costs or personnel problems to complete for these resources. The F-14 is past the peak of design effort and progressing on schedule; the LM has made an orderly transition to an extended schedule and has no serious development or production problems.

Grumman has assigned to the Phase B study key management and technical people possessing major R&D program experience (see Section 3 for resumes). Our Associates bring to bear specialized technical skills and resources which complement Grumman.

Detailed information is provided under subsections as follows:

6.1 COST PROPOSAL

Grumman Aerospace Corporation proposes to perform the Space Shuttle System Program Definition (Phase B) for a firm fixed price of $8,006,287. This proposal is firm for a period of 120 days following submittal. Complete information in response to Paragraph 9.a. of Enclosure 2 to the RFP is provided in this Section.

6.1.1 Salaries & Wages

The estimated totals for direct labor classifications are presented in Table 6-1 (DD-633-4). These totals are supported by the cost/price summary Table 6-2. The analysis of manpower requirements (time-phased man-loading) by Statement of Work tasks is presented in Section 4.

6.1.2 Rates

6.1.2.1 Overhead & G&A Rates

Negotiations have just been completed with the Naval Plant Representative Office, Bethpage, for forward pricing purposes through calendar year 1971. Certified copy of the approved rates is not yet available. Table 6-3 shows the current direct, overhead and G&A rates. The overhead period coincides with the calendar year. The basis of application of overheads is as follows:

- Engineering and manufacturing overheads are applied to direct labor dollars exclusive of the premium portion of overtime expenditures
- Material overhead is applied to direct materials costs charged to work in process with the following exclusions:
  - Employee relocation
  - Employee travel
  - Insurance
  - Gulfstream and Ag-Cat engines and propellers
  - Job shopper effort including Grumman Data Systems job shopper effort
- General and administrative overhead is applied to total cost with certain exclusions: Gulfstream and Ag-Cat engines and propellers, and premium pay

6.1.2.2 Expenditure Rate

Table 6-4 shows the cumulative planned expenditures and commitment rate for the proposed Phase B study.

6.1.3 Subcontracting Or Other Arrangements

Commerical Printing	$72,000
Wind Tunnel Rental	$230,000
	$302,000

The total of $302,000 is carried forward to block 1(b) on form DD 633-4. The cost estimate for commerical preparation and printing for the Phase B final report is based on an estimated 6000 page count for three volumes at an average of $12.00 per page. The wind tunnel rental is based on approximately 115 hours at $2000/hour at Cornell or equivalent facility.

Manning levels and estimated cost of major subcontracts in Phase B are shown below. The description of subcontractor effort and time-phased manloading by task are presented in Subsection 4.1 of the proposal. The estimated cost is carried forward to block 9 (other direct cost) on form DD 633-4. See Subsection 6.1.6 for costing methodology.

Subcontract	Man Months	Estimated Cost (to Grumman)
GE, Avionics & Shuttle Economics	336	$1,000,000
GE, Reentry Systems	144	400,000
Northrop	336	1,000,000
Eastern Air Lines	84	200,000
Aerojet	36	100,000
Grumman Data Systems	120	250,000
		$2,950,000

The basis of application of burden rates to material, subcontract and job shopper effort is described in Subsection 6.1.2.1. Grumman believes that profit should be paid on a total program basis, and that within this total appropriate portions should be subcontracted. Since this subcontracting does not diminish the responsiblity of the prime contractor, or reduce the difficulty of fulfilling his responsibility, it should not affect the profit earned. A contrary system would tend to put a premium on companies attempting to become self-sufficient.

6.1.4 Material

Major items of purchased parts and raw materials and their estimated cost are summarized below. These are engineering estimates subject to refinement. Material overhead is applied to these costs as explained in Subsection 6.1.2.1.

Purchased Parts	
Cryogenic expendables Liquid hydrogen Liquid nitrogen Liquid oxygen Gaseous nitrogen	$4,000
Cryogenic tanks for insulation model	$3,000
Structural materials, panels, insulation and adhesives	9,100
Various parts and components for cabin studies; connectors, lines and plugs for camera and TV hookup, etc.	8,500
Misc presentation materials	3,000
Estimated Total, Purchased Parts	$27,600

Raw Materials	
Materials to support wind tunnel tests Nicklechromium plating sheet metal for models, strain gage wire, etc.	$11,700
Metalized Plating for approximately four flush antenna models	10,000
Plastic and other model material for fabrication of following models: – Erect and mate (VAB) 1/96 scale – Inspection, maintenance, repair building facility – 1/96 scale – Launch Pad – Mobile launcher, swing arms, etc., 1/96 scale – Payload container – 1/48 scale	3,000
Manufacturing material for mockup and Test fixtures	2,000
Estimated Total, Raw Materials	$26,700

6.1.5 Travel & Subsistence

Table 6-5 shows the estimated number of trips and the cost breakdown therefore.

6.1.6 Other Direct Costs

For costing purposes the major subcontracting effort of $2,950,000 included in this proposal (reference Subsection 6.1.3) is job shopper effort and shown in block 9 of form DD 633-4.

6.1.7 Taxes

The following taxes are included in the (overhead) cost of this proposal: Unemployment insurance, sales and use, franchise, social security, real estate and personal property.

6.1.8 Royalty Information

The proposal contains no cost or charges for royalties.

6.1.9 Terms and Conditions

As stated in the proposal transmittal letter, Grumman agrees to accept, in any contract resulting from this proposal, the terms and conditions of the contract schedule, general provisions, and the Statement of Work contained in the RFP.

Table 6-1 NASA DD 633-4 Form

DEPARTMENT OF DEFENSE
CONTRACT PRICING PROPOSAL
(RESEARCH AND DEVELOPMENT)

Form Approved
Budget Bureau No. 22-R100

This form is for use when *(i)* submission of cost or pricing data *(see NASA PR 3.807-3)* is required and *(ii)* substitution for the DD Form 633 is authorized by the contracting officer.

PAGE NO. 1
NO. OF PAGES 2

NAME OF OFFEROR
GRUMMAN AEROSPACE CORPORATION

HOME OFFICE ADDRESS *(Include ZIP Code)*
South Oyster Bay Road
Bethpage, Long Island, New York 11714

SUPPLIES AND/OR SERVICES TO BE FURNISHED
Space Shuttle System Program
Definition (Phase B) Study

DIVISION(S) AND LOCATION(S) WHERE WORK IS TO BE PERFORMED
Bethpage, Long Island, New York

TOTAL AMOUNT OF PROPOSAL
$ 8,006,287

GOVT SOLICITATION NO.
10-8423

DETAIL DESCRIPTION OF COST ELEMENTS

	EST COST ($)	TOTAL EST COST[1]	REFERENCE[2]
1. DIRECT MATERIAL *(Itemize on Exhibit A)*			
a. PURCHASED PARTS	27,600		6.1.4
b. SUBCONTRACTED ITEMS	302,000		6.1.3
c. OTHER - (1) RAW MATERIAL	26,700		6.1.4
(2) YOUR STANDARD COMMERCIAL ITEMS	0		
(3) INTERDIVISIONAL TRANSFERS *(At other than cost)*	0		
TOTAL DIRECT MATERIAL		356,300	
2. MATERIAL OVERHEAD 3 *(Rate* 5.8 *% X $ base =)*		20,665	

3. DIRECT LABOR *(Specify)*	ESTIMATED HOURS	RATE/ HOUR	EST COST ($)	TOTAL EST COST	REFERENCE
Engineering	194,215	6.620	1,285,643		
Manufacturing	45,725	4.392	200,803		
Management	26,040	7.244	188,641		
TOTAL DIRECT LABOR				1,675,087	

4. LABOR OVERHEAD *(Specify department or cost center)* 3	O.H. RATE	X BASE =	EST COST ($)	TOTAL EST COST	REFERENCE
Engineering	82.212	1,285,643	1,056,965		
Manufacturing	133.420	200.803	267,911		
TOTAL LABOR OVERHEAD				1,324,876	

	EST COST ($)	TOTAL EST COST	REFERENCE
5. SPECIAL TESTING *(Including field work at Government installations)*			
Not Applicable to Phase B			
Definition Study			
TOTAL SPECIAL TESTING		0	
6. SPECIAL EQUIPMENT *(If direct charge) (Itemize on Exhibit A)*		0	
7. TRAVEL *(If direct charge) (Give details on attached Schedule)*			
a. TRANSPORTATION	78,450		6.1.5
b. PER DIEM OR SUBSISTENCE	20,980		6.1.5
TOTAL TRAVEL		99,430	
8. CONSULTANTS *(Identify - purpose - rate)*			
	0		
TOTAL CONSULTANTS		0	
9. OTHER DIRECT COSTS *(Itemize on Exhibit A)*		2,950,000	6.1.6
10. *TOTAL DIRECT COST AND OVERHEAD*		6,426,358	
11. GENERAL AND ADMINISTRATIVE EXPENSE *(Rate* 13.26 *% of cost element Nos.* 10 *)* 3		852,085	
12. ROYALTIES 4		0	
13. *TOTAL ESTIMATED COST*		7,278,443	
14. FEE OR PROFIT		727,844	
15. *TOTAL ESTIMATED COST AND FEE OR PROFIT*		8,006,287	

This proposal is submitted for use in connection with and in response to *(Describe RFP, etc.)*
NASA HQ RFP #10-8423 Dated 20 February 1970
and reflects our best estimates as of this date, in accordance with the instructions to offerors and the footnotes which follow.

TYPED NAME AND TITLE
Joseph G. Gavin, Jr., Senior Vice President

SIGNATURE
Joseph G Gavin Jr

NAME OF FIRM
Grumman Aerospace Corporation

DATE OF SUBMISSION
March 30, 1970

DD FORM 1 APR 68 633-4 (NASA EDITION)

Table 6-1 NASA DD 633-4 Form (Contd)

EXHIBIT A - SUPPORTING SCHEDULE *(Specify. If more space is needed, use blank sheets)*

COST EL NO.	ITEM DESCRIPTION *(See footnote 5)*	EST COST *($)*
	(See Reference on Page 1)	

I. HAVE THE DEPARTMENT OF DEFENSE, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, OR THE ATOMIC ENERGY COMMISSION PERFORMED ANY REVIEW OF YOUR ACCOUNTS OR RECORDS IN CONNECTION WITH ANY OTHER GOVERNMENT PRIME CONTRACT OR SUBCONTRACT WITHIN THE PAST TWELVE MONTHS?

☒ YES ☐ NO *If yes, identify below.*

NAME AND ADDRESS OF REVIEWING OFFICE *(Include ZIP Code)*: Defense Contract Audit Agency (See Section 6.1.2)

TELEPHONE NUMBER/EXTENSION: (516) 575- 1980

II. WILL YOU REQUIRE THE USE OF ANY GOVERNMENT PROPERTY IN THE PERFORMANCE OF THIS PROPOSED CONTRACT?

☒ YES ☐ NO *If yes, identify on a separate page.* See Section 6.5

III. DO YOU REQUIRE GOVERNMENT CONTRACT FINANCING TO PERFORM THIS PROPOSED CONTRACT?

☒ YES ☐ NO *if yes, identify:* ☐ ADVANCE PAYMENTS ☒ PROGRESS PAYMENTS *OR* ☐ GUARANTEED LOANS

IV. DO YOU NOW HOLD ANY CONTRACT *(or, do you have any independently financed (IR & D) projects)* FOR THE SAME OR SIMILAR WORK CALLED FOR BY THIS PROPOSED CONTRACT?

☐ YES ☒ NO *If yes, identify* See Section 4.

V. DOES THIS COST SUMMARY CONFORM WITH THE COST PRINCIPLES SET FORTH IN NASA PR, PART 15 *(see 3.807-2(c)(2))*?

☒ YES ☐ NO *If no, explain on a separate page.*

INSTRUCTIONS TO OFFERORS

1. The purpose of this form is to provide a standard format by which the offeror submits to the Government a summary of incurred and estimated cost (*and attached supporting information*) suitable for detailed review and analysis. Prior to the award of a contract resulting from this proposal the offeror shall, under the conditions stated in NASA PR 3.807-3, be required to submit a Certificate of Current Cost or Pricing Data (see NASA PR 3.807-3(e) and 3.807-4).

2. As part of the specific information required by this form, the offeror must submit with this form, and clearly identify as such, cost or pricing data (that is, data which is verifiable and factual and otherwise as defined in NASA PR 3.807-3(e)). In addition, he must submit with this form any information reasonably required to explain the offeror's estimating process, including:
   a. the judgmental factors applied and the mathematical or other methods used in the estimate including those used in projecting from known data, and
   b. the contingencies used by offeror in his proposed price.

3. When attachment of supporting cost or pricing data to this form is impracticable, the data will be specifically identified and described *(with schedules as appropriate)*, and made available to the contracting officer or his representative upon request.

4. The format for the "Cost Elements" is not intended as rigid requirements. These may be presented in different format with the prior approval of the contracting officer if required for more effective and efficient presentation. In all other respects this form will be completed and submitted without change.

5. By submission of this proposal, offeror, if selected for negotiation, grants to the contracting officer, or his authorized representative, the right to examine, for the purpose of verifying the cost or pricing data submitted, those books, records, documents and other supporting data which will permit adequate evaluation of such cost or pricing data, along with the computations and projections used therein. This right may be exercised in connection with any negotiations prior to contract award.

FOOTNOTES

1 Enter in this column those necessary and reasonable costs which in the judgment of the offeror will properly be incurred in the efficient performance of the contract. When any of the costs in this column have already been incurred (e.g., on a letter contract or change order), describe them on an attached supporting schedule. Identify all sales and transfers between your plants, divisions, or organizations under a common control, which are included at other than the lower of cost to the original transferor or current market price.

2 When space in addition to that available in Exhibit A is required, attach separate pages as necessary and identify in this "Reference" column the attachment in which information supporting the specific cost element may be found. No standard format is prescribed; however, the cost or pricing data must be accurate, complete and current, and the judgment factors used in projecting from the data to the estimates must be stated in sufficient detail to enable the contracting officer to evaluate the proposal. For example, provide the basis used for pricing materials such as by vendor quotations, shop estimates, or invoice prices; the reason for use of overhead rates which depart significantly from experienced rates (reduced volume, a planned major rearrangement, etc.): or justification for an increase in labor rates (anticipated wage and salary increases, etc.). Identify and explain any contingencies which are included in the proposed price, such as anticipated costs of rejects and defective work, or anticipated technical difficulties.

3 Indicate the rates used and provide an appropriate explanation. Where agreement has been reached with Government representatives on the use of forward pricing rates, describe the nature of the agreement. Provide the method of computation and application of your overhead expense, including cost breakdown and showing trends and budgetary data as necessary to provide a basis for evaluation of the reasonableness of proposed rates

4 If the total royalty cost entered here is in excess of $250 provide on a separate page (or on DD Form 783, Royalty Report) the following information on each separate item of royalty or license fee: name and address of licensor; date of license agreement; patent numbers, patent application serial numbers, or other basis on which the royalty is payable; brief description, including any part or model numbers of each contract item or component on which the royalty is payable; percentage or dollar rate of royalty per unit; unit price of contract item; number of units; and total dollar amount of royalties. In addition, if specifically requested by the contracting officer, a copy of the current license agreement and identification of applicable claims of specific patents shall be provided.

5 Provide a list of principal items within each category indicating known or anticipated source, quantity, unit price, competition obtained, and basis of establishing source and reasonableness of cost.

Table 6-2 Cost Price Summary

Cost Elements	Rates*	Man-hrs	Cost, $
Grumman Direct Labor			
Engineering			
● Design	$6.6578	166,315	$1,107,291
● Flight Test	6.6472	9,300	61,819
● Reproduction	4.779	1,860	8,889
● Support	6.4304	16,740	107,644
Subtotal		194,215	1,285,643
Engrg Overhead	82.2121		1,056,965
Manufacturing			
● Production	4.2250	37,200	157,170
● Quality Control	4.9671	1,705	8,469
● Mfg Mgmt	4.9445	3,410	16,861
● Tool Design	5.3674	3,410	18,303
Subtotal		45,725	200,803
Mfg Overhead	133.42%		267,911
Prog Mgmt	7.2759	24,180	175,931
Mat'l/Subcontract Mgmt	6.8333	1,860	12,710
Subtotal		26,040	188,641
Grumman Direct Labor			
Total Direct Labor		265,980	1,675,087
Total Overhead			1,324,876
Direct Mat'l			356,300
Mat'l Overhead	5.8%		20,665
Travel			99,430
Other Direct Costs			2,950,000
Subtotal Cost			6,426,358
G & A	13.26%		852,085
Total Est Cost			7,278,443
Profit	10%		727,844
Total Est Cost & Profit			8,006,287

*Rates shown are weighted averages of negotiated rates for calendar years 1970 and 1971.

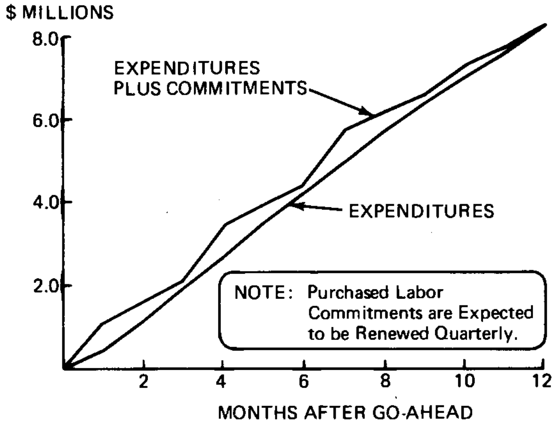
Table 6-3 Direct Labor Overhead and G & A Rates

Element of Cost	1966	1967	1968	1969	1970	1971	1972
Engineering							
● Engineering Design	4.98(1)	5.44	5.62	5.97	6.47	6.97	7.42
● Flight Test	-	4.85	5.00	5.43	6.49	6.90	7.32
● Service/Reproduction	3.59(1)	3.74	3.92	4.26	4.65	4.96	5.26
● Support	-	5.11	5.36	5.82	6.26	6.72	7.17
● Tool Design	-	4.85	4.98	5.24	(2)	(2)	(2)
Engineering Overhead, %	**69.04**	**66.59**	**70.80**	**67.47**	**79.5**	**86.4**	**89.9**
Manufacturing							
● Production	3.08	3.22	3.35	3.72	4.12	4.40	4.68
● Support Fabrication	-	3.16	3.32	3.71	4.02	4.24	4.52
● Quality Control	3.65	3.81	3.99	4.38	4.84	5.19	5.52
● Shipping	2.68	2.93	3.15	3.40	3.70	3.94	4.19
● Tool Fabrication	3.05	3.45	3.63	4.11	4.28	4.58	4.89
● Tool Design	(2)	(2)	(2)	(2)	5.24	5.59	5.98
● Manufacturing Management	-	-	(3)	(3)	4.81	5.18	5.53
Manufacturing Overhead, %	**133.82**	**140.06**	**143.62**	**163.80**	**132.1**	**135.5**	**140.9**
Management							
● Program Coordination	6.00	4.24	5.67	6.29	7.09	7.59	8.05
● Manufacturing Management	-	-	3.90	4.26	(3)	(3)	(3)
● Support/Material	-	-	4.48	4.94	(4)	(4)	(4)
● Support/Logistics	-	-	-	-	4.69	5.02	5.31
● Material Coordination	-	-	-	-	6.68	7.14	7.62
G & A Rate, %	**8.24**	**9.11**	**9.85**	**11.83**	**12.9**	**13.9**	**14.4**
IR&D (Included in G & A), %	**.51**	**.55**	**.64**	**.87**	**1.2**	**1.3**	**-**
Material Overhead, % (5)	**-**	**-**	**-**	**-**	**5.8**	**5.9**	**6.1**

(1) Composite Rate. In 1967 classes of Engineering Labor Rates Were Established.
(2) On 1 Jan 1970, Tool Design Labor was changed to absorb Manufacturing Overhead.
(3) On 1 Jan 1970, Manufacturing Management Labor was changed to absorb Manufacturing Overhead.
(4) On 1 Jan 1970, Support/Material Labor was separated into the Support/Logistic & Material Coordination labor classes.
(5) On 1 Jan 1970, a Material Overhead was established.

Table 6-4 Expenditure Rate

Month After Go-Ahead	Expenditures	Grumman Commitment	Expenditures Plus Commitments
1	486,517	679,000	1,165,517
2	1,242,548	409,000	1,651,548
3	2,019,213	141,000	2,160,213
4	2,841,014	776,000	3,617,014
5	3,587,318	461,000	4,048,318
6	4,351,879	150,000	4,501,879
7	5,114,028	801,000	5,915,028
8	5,894,738	499,000	6,393,738
9	6,597,145	240,000	6,837,145
10	7,224,079	305,000	7,529,079
11	7,730,027	139,000	7,869,027
12	8,006,287	0	8,006,287



6.1.10 Profit

Recognizing the importance of this study to the fulfillment of the Nation's space goals, Grumman has committed its most experienced people to this study. It is noted, however, that by doing this, the cost per hour we can expect will be greater than the cost per hour we have used in pricing this proposal. This is not unusual since, as a matter of policy, we use corporate average labor and overhead rates for proposal purposes.

A profit objective of 15 percent is considered appropriate for a prospective fixed price contract under normal conditions when the following major factors are considered:

- Assumption of cost risk
- Complex technical task to be accomplished
- High quality of resources required

In view of the NASA funding level indicated in the RFP, Grumman is willing to deviate from the normal procedure for establishing a profit objective and has therefore priced the proposal to yield a profit of $727, 844 (10 percent).

In view of the anticipated cost differential, we expect that most or all of our profit dollars will be consumed in the conduct of the study.

Table 6-5 Travel & Subsistence

Destination	No. of Man Trips	Transportation		Subsistence (@ $20/Day)		Total Cost, $
		Fare $	Cost $	Days	Cost $	
Washington, D.C.*	25	–	–	25	500	500
NASA Center	428	160**	68,480	856	17,120	85,600
NASA KSC*	20	–	–	40	800	800
California	22	300	6,600	44	880	7,480
Florida	10	160	1,600	20	400	2,000
Ohio	10	70	700	20	400	1,100
Virginia	10	55	550	20	400	950
Pennsylvania	4	30	120	8	160	280
New York	8	50	400	16	320	720
					Total	$99,430

*Transportation assumed to be via company aircraft which is an indirect expense.

**This is the mean cost of fares from Bethpage to Houston, Texas and Huntsville, Alabama.

6.1.11 Additional Information

Government agencies having plant cognizance are:

	Factor	Government Agency
(a)	Government contract administration (1)	Naval Air Systems Command Naval Plant Representative Off (NAVPRO) Grumman Aerospace Corporation Bethpage, New York, 11714 Captain Andrew Yates
(b)	Government-owned facility management, utilization and maintenance	
(c)	Material, reliability and quality control inspection	
(d)	Inspection for Government acceptance (2)	
(f)	Utilization of small business and labor surplus area firms	
(h)	Government Audits	Defense Contract Audit Agency New York Region Resident Audit Office Grumman Aerospace Corporation Mr. Gilbert Olin
(e)	Labor and Industrial relations	Defense Contract Administration Services Region New York, N.Y. 10013
(g)	Industrial and Personnel Security	

NOTES

(1) On-site Government contract administration for NAS 9-1100 is provided by the Resident Apollo Spacecraft Program Office (RASPO)

(2) NAVPRO except (a) contract NAS 9-1100 where joint NAVPRO/RASPO acceptance is performed and (b) where procuring activity reserves acceptance for itself.

6.2 FINANCIAL STATUS

Grumman is financially sound and able to undertake the Space Shuttle System Program Definition - Phase B, as well as major elements of any subsequent phase. We have experienced an orderly growth rate and have operated on a profitable basis for every year of our existence. Financial highlights for the last four years are shown in Table 6-6. Current financial statements are presented in Tables 6-7 and 6-8.

Table 6-6 History of Sales & Income

	$1,000s			
Item	1966	1967	1968	1969
Sales	1,059,379	968,596	1,152,571	1,180,328
Net Income	27,622	21,451	19,037	22,088
Working Capital	70,533	118,502	108,674	104,398
Total Assets	286,251	315,335	354,346	372,673
Total Net Worth	113,861	130,687	143,034	157,914
Long-Term Debt/Net Worth	0.27	0.61	0.55	0.47

Table 6-7 Grumman Corporation & Subsidiaries Consolidated Statement of Income, Year Ended 31 Dec 1969

INCOME	
Sales	$1,180,328,130
Other Income	2,291,397
	1,182,619,527
COSTS AND EXPENSES	
Wages, Materials, & Other Costs & Expenses	1,132,805,135
Interest	5,226,678
Provision for Federal Taxes on Income	22,500,000
	1,160,531,813
NET INCOME	$ 22,087,714

It should be noted that, effective 1 July 1969, the Grumman Aerospace Corporation was created as a wholly owned subsidiary of the Grumman Corporation, formerly the Grumman Aircraft Engineering Corporation. The financial data prior to 1969 reflects that of the Grumman Aircraft Engineering Corporation and subsidiaries. The financial data for 1969 reflects the operations of the Grumman Corporation and subsidiaries.

Table 6-8 Grumman Corporation & Subsidiaries Consolidated Balance Sheet, Year Ended 31 Dec 1969

Assets	
Current Assets	
• Cash	6,839,560
• Accounts receivable including unbilled charges	139,952,860
• Inventories, less progress payments	89,398,708
• Prepaid expenses & miscellaneous deposits	1,683,611
Total Current Assets	**237,874,739**
Property, Plant, & Equipment (at cost)	
• Buildings	61,651,833
• Machinery & equipment	145,781,040
• Leasehold improvements	14,417,485
– Less accumulated depreciation & amortization	-99,236,312
• Construction in progress	2,937,337
• Construction funds held by trustee	916,151
• Land	3,470,536
Total Property, Plant, & Equipt	**129,938,070**
Other Assets & Deferred Charges	**4,859,977**
TOTAL	**$372,672,786**

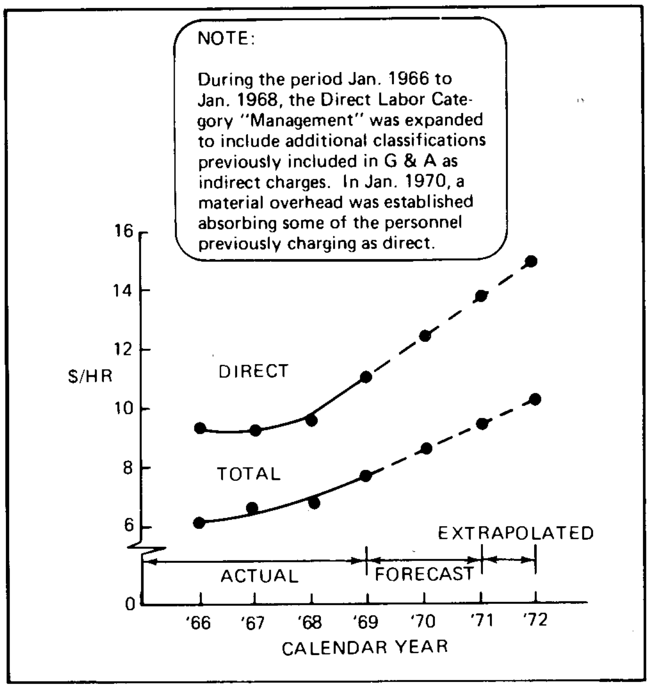
Liabilities & Shareholders' Equity	
Current Liabilities	
• Notes payable to banks & others, including installments due within one year on long-term liabilities	31,500,353
• Accounts payable & accrued wages	81,761,800
• Federal income & other taxes, & renegotiation	8,554,085
• Other liabilities	11,660,696
Total Current Liabilities	**133,476,934**
Long-Term Liabilities	
• 5% Notes due in annual installments of $2,000,000 to 1 Aug 1978	16,000,000
• 4¼% Convertible subordinated debentures due 1 Sept 1992	49,488,000
• Lease obligations through 1987	7,864,542
• Other	1,311,813
Total Long-Term Liabilities	**74,664,355**
Deferred Income-Investment Tax Credit	**5,276,571**
Minority Interest in Net Assets of Consolidated Subsidiary Company	1,341,363
Shareholders' Equity	
• Preferred stock: authorized 1,000,000 shares of $1.00 par value; none issued	–
• Common stock: authorized 20,000,000 shares of $1.00 par value. Issued 1969; 7,249,156 shares.	33,763,865
• Earnings retained for use in the business	127,141,344
– Less cost of common stock in treasury: 1969; 115,300 shares	-2,991,646
Total Shareholders' Equity	**157,913,563**
TOTAL	**$372,672,786**

Capital requirements have been readily satisfied whenever required, primarily through internal operations and short-term borrowing. Present formal short-term credit lines allow us to exceed $100 million. Our financial soundness is exemplified by the ready market acceptance of a $50 million convertible subordinate debenture bond issue at a very favorable interest rate of 4 1/2% in 1967.

Grumman is not involved in any endeavors that are likely to cause a financial burden in the foreseeable future. Each of our associate contractors presents a sound financial picture, and details of their performance are available on request.

6.3 OVERHEAD, G&A, LABOR RATES & IR&D

Company history and projections of direct labor cost and overhead rates are shown in Table 6-7. In addition, Figure 6-1 presents curves of composite labor cost per hour through G&A. Data from which the curves were developed is available on request.



NOTE:

During the period Jan. 1966 to Jan. 1968, the Direct Labor Category "Management" was expanded to include additional classifications previously included in G & A as indirect charges. In Jan. 1970, a material overhead was established absorbing some of the personnel previously charging as direct.

Fig. 6-1 **Direct Labor Rate vs Total Labor Rate Through G&A**

The basic objectives of Grumman's IR&D programs is to develop advancements in scientific and engineering knowledge that have potential application to current or projected national and corporate goals.

Our IR&D and B&P costs are included in the application of the G&A rate to all Government contracts. It has been our policy since 1961 to negotiate advanced agreements for both IR&D and B&P. The 1970 agreement is scheduled to be negotiated within a few weeks with a team consisting of representatives of NASA, USAF, USN, and possibly the Department of Transportation. We have recently submitted an updated proposal in preparation for this negotiation. As indicated in the update, we intend to spend approximately $20 million in B&P and IR&D on space systems for calendar 1970 - of which approximately $10 million is planned for the space shuttle system. The application of this related work to the Phase B study will provide maximum support in the high-risk technical areas. In addition Grumman's associates bring to bear significant related effort.

Table 6-9 presents historical and projected IR&D expenditures. The 1970 and 1971 forecasts reflect compliance with Section 493 of P.L. 91-121 and NASA Procurement Regulation Directive 70-1, dated 26 January 1970.

6.4 RESOURCE ESTIMATING TECHNIQUES

Grumman's methodology for realistic cost and schedule estimating has evolved through lessons learned on past programs. The major emphasis throughout the study will be applied to cost, risk and programmatic tradeoff analyses, since low cost characteristics must be designed into the program from the beginning. The combined experience of Grumman and its Associates (General Electric, Northrop, Eastern Airlines and Aerojet-General) provides the required technical base from which rigorous and timely cost predictions will be made. Through comparative analysis, realistic cost assessments will help provide technical and program direction toward achievement of the study goal.

Table 6-9 IR&D Expenditures

Year	% Sharing Arrngmt Govt/ GAC	Negotiated Budgeted Values	Govt Ceiling **	Total Expend	% (incl. in G & A Rate)
		$1000s			
1966	75/25	6,500	4,875	6,532	0.51
1967	75/25	7,000	5,250	7,043	0.55
1968	75/25	9,000	6,750	9,275	0.64
1969	75/25	11,667	8,750	11,397	0.87
1970*	75/25	12,979	9,734	–	1.20
1971*	75/25	13,520	10,140	–	1.30

* Forecast

** Represents maximum expenditures negotiated for inclusion in G & A cost

Pertinent aspects of resource estimating techniques discussed on the following pages are:

- Design, cost, schedule integration
- The shuttle cost model
- DDT&E and production cost analysis process
- Operations cost
- Schedule
- Risk/uncertainty assessment

6.4.1 Design, Cost, Schedule Integration

Fig. 6-2 illustrates the study management structure used successfully at Grumman on the F-14 system Definition and many past study efforts. It provides direct integration of cost estimation into the design study activities at all levels allowing cost to be a prime factor in the design selection and integration process. Also, it provides management with a direct path of communications to receive both cost and design information for evaluation and to direct continued design and analysis activities. The indicated central management function is provided through the systems integration manager whose duties are detailed in Section 4.

Tradeoffs are carried out at all levels of the study using cost models compatible with the engineering design detail and program definition available at that level. The tradeoffs are structured to reflect the space shuttle system requirements in the prime areas of performance, cost, and schedule. The studies to be performed are detailed in Section 2.

Gross tradeoff analyses utilizing the parametric resource estimating models discussed in Subsection 6.4.2 and parametric design (and systems analysis)

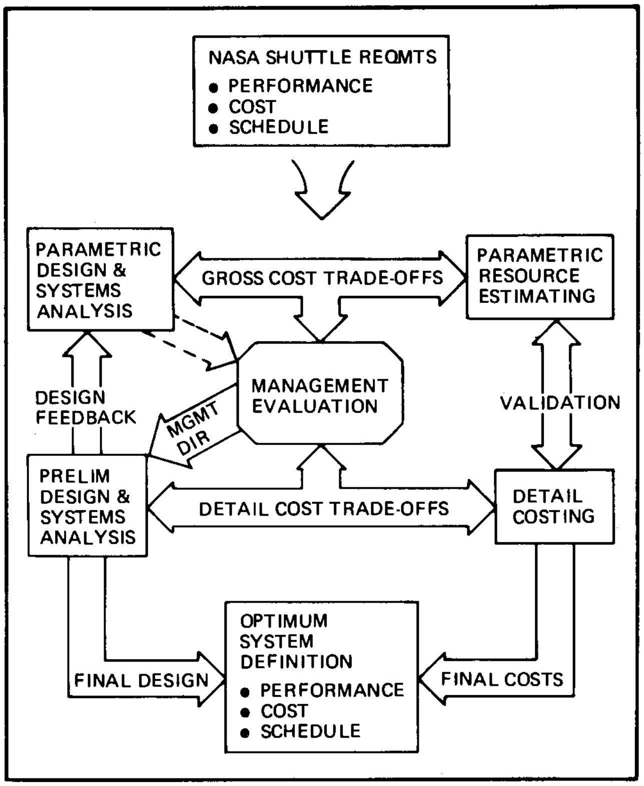


Fig. 6-2 Integrated Design Cost Flow

models detailed in Section 2 interact directly during the design optimization process. At the detail cost tradeoff level, where preliminary design and system analysis detail is available, Grumman central pricing cost estimates are used. At all levels of cost estimating at Grumman, engineers with advanced training in both business and costing practices participate in the estimating process to assure a sound technical basis for realistic cost.

An example particulary pertinent to the space shuttle system occurred during the F-14 definition study. Early parametric analysis determined incompatibility between the customer's system mission requirements and vehicle size. The conflict was essentially between requirements for a multimission role and desired vehicle weight. The solution is an example of the pay-off of the design-cost tradeoff process. By evaluating the alternative whereby payload equipment required for all primary missions are mounted internally but mission peculiar equipment is mounted on external "rails," design weight goals were achieved with the use of parametric models. On the basis of tradeoff analyses, it was determined that the added cost associated with the required design, procurement and operational costs for the "rail" system were lower than the costs associated with added aircraft weight that would have been necessary for a vehicle with full internal payload capability.

The parametric design and costing methods provide the short turnaround time and consistency of analysis necessary for the study of tradeoffs when little detailed design information is available. These methods can be applied to most subsystems of the space shuttle system but care must be exercised in those areas where extrapolation from the statistical state-of-the-art data base is required, for example, the thermal protection system. Here, design feedback will provide continual updating of the parametric design base from which costs can be estimated.

Through this closely controlled, iterative and highly integrated study process, the system definition will evolve in terms of the NASA space shuttle requirements of design, costs and schedule. The final cost summary, so critical to the planning of an economical space transportation system in an environment of budget austerity, will show total and time phased expenditures. These are handled explicitly in our present cost models and will be presented at the end of Phase B in a hardware-oriented work breakdown structure, grouped into nonrecurring (DDT&E), recurring (production) and recurring operations costs.

6.4.2 Space Shuttle System Cost Model

The cost model that will be used in the comprehensive tradeoff analysis will include all aspects of program cost so that the full cost ramifications of any design decision can be determined. Fig. 6-3 illustrates the detailed cost elements included in the model (shown as Level 5) and the increasingly aggregated cost categories culminating at Level 3, the total project, or life-cycle cost. Costs are identified as recurring or nonrecurring and correspond to the elements included in these categories in the Program Cost and Schedule Estimates Plan, MF003M. The model will also time phase costs using a technique developed by Grumman which will be modified to include explicit consideration of estimate variability. The latter feature is described in "Space Program Costing," PDR-OP-T69-63, which was prompted by NASA's report "Specification for Contractor Presentation of Cost and Schedule Plans for New Space Projects."

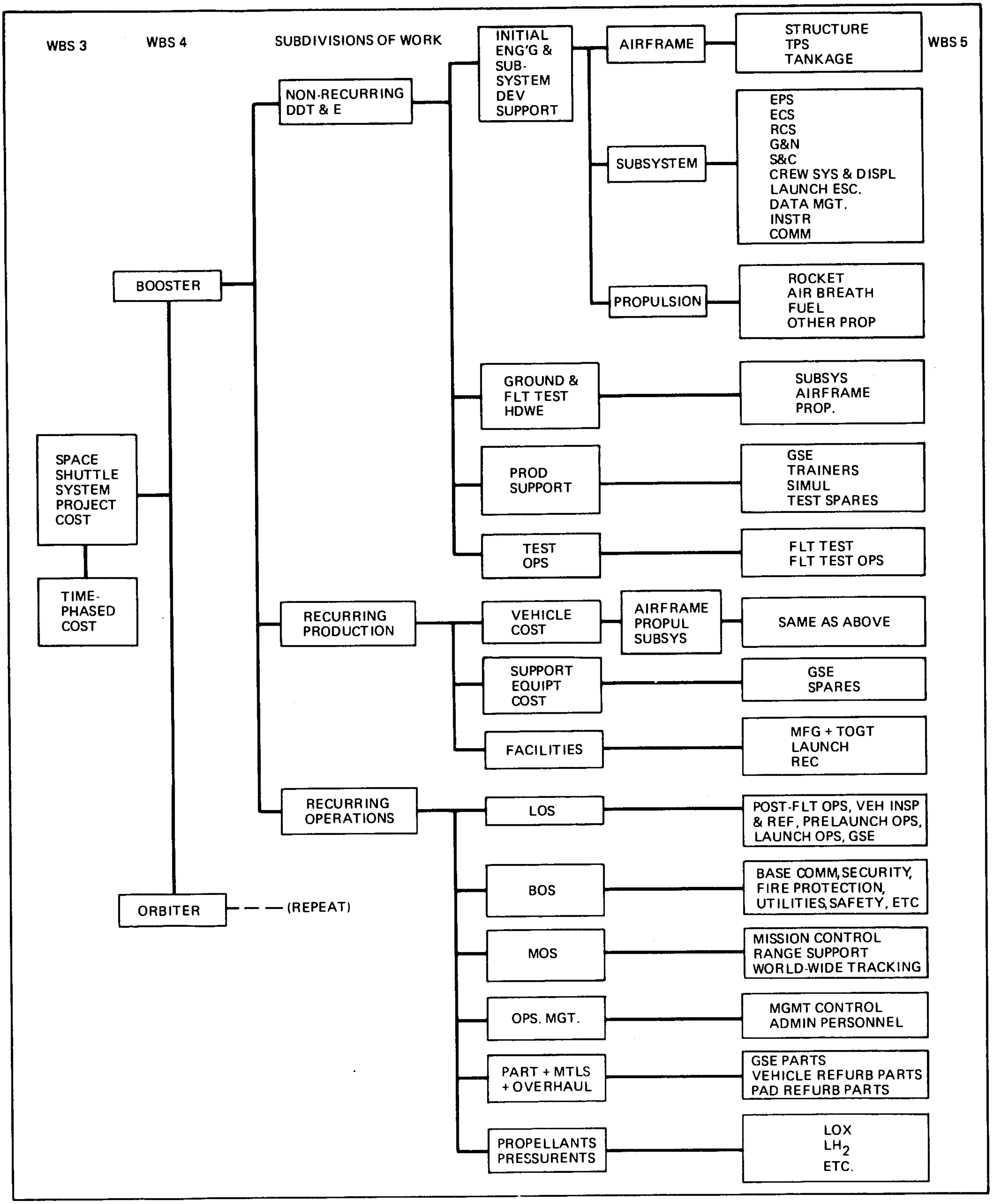


Fig. 6-3 Estimating Tree

WBS Level 5 is the keystone cost level for performing cost tradeoffs, for it is at this level that sufficient detail is provided to perform the analyses. Accordingly, the cost elements of this level have been structured to give maximum insight into the critical requirements of each subsystem and further, to allow their aggregation into the higher WBS levels. These costs will also be used as the cost components of the comprehensive study flow, discussed in Subsection 2.1 and depicted in Fig. 2-3.

The presently operating model, tailored specifically for the space shuttle system will be updated early in Phase B as the WBS for Phase C/D is fully defined. Our current shuttle cost model is a composite of presently available aircraft, spacecraft, and propulsion cost models such as: PRC-547, Rand, Air Force, Grumman ORM and PACE, as well as vendor estimates; in addition, associate experience, such as Northrop's with large structure manufacturing (747) will provide valuable inputs to the cost model. This will be modified and expanded to meet the specific requirements of advanced booster and orbiter technologies. The model is adaptive in that, as additional cost data becomes available, it can be incorporated immediately.

6.4.3 DDT&E And Production Cost Analysis Process

The preceding section described the space shuttle system cost model. This section will descibe the application of the model to the determination of the DDT&E and production costs. During the Phase B study, all available cost estimating procedures will be used to ensure maximum cost credibility for the design selected. The process is shown on Fig. 6-4.

The study process, using this model, is iterative and based on vehicle design analyses. Initially, the objective is to perform all necessary cost analyses at the NASA identified WBS Level 5. Where necessary, as directed by the major cost driver identified early in the program, analyses will be conducted at lower levels of the WBS.

To develop reliable cost estimates, continual comparisons will be made of available cost data and estimates derived from cost estimating relationships. In this manner, anomalies will be highlighted for further study. To resolve these anomalies, Grumman functional departments, associates, and vendors will be required to examine their estimates and/or proceed to a deeper level of detail in that specific area. This may be expected for example, in the analysis of the thermal protection system where new materials and manufacturing processes may be required, the cost of which are beyond the range of available statistical data. Additional component testing may also be required and/or additional vendor discussions may be necessary to provide the high degree of expertise necessary to assure a more credible estimate. When preliminary design inputs are available, the primary cost process will proceed through the functional estimate path shown in Fig. 6-4, with check and balance provided by continual use of the parametric cost estimates.

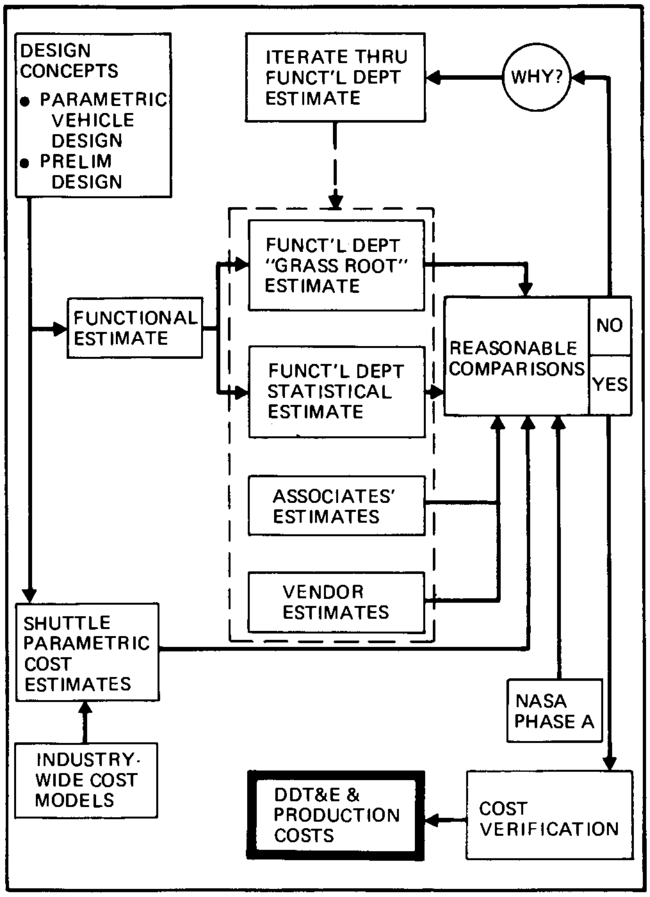


Fig. 6-4 Cost Analysis Process

Grumman believes that the multiple cost estimating technique described above and illustrated in Figure 6-4 produces a high level of credibility.

6.4.4 Operations Costs

Space shuttle system operational costs will be monitored throughout the Phase B study in order to influence the system design studies and program direction by assessing the total cost of operational capability. The operational costing effort is integrated into the analytical evaluation effort to:

- Provide the cost data for all the major elements of each operations support concept
- Provide the criteria by which the relative efficiency of the proposed operational concepts will be evaluated

The tool for this effort is the Grumman space shuttle system operations resource model – a computer simulation model based upon techniques validated in the successful prediction of resource requirements in such complex aircraft system as the A-6, S-2, and E-2. This model accepts estimates or actual data of the vehicle's reliability, maintainability, operability, and supportability characteristics and after operating on them, provides a definition of the resources required for a given support environment. Eastern Airlines will provide a significant contribution to the concepts and cost estimates required to exercise the model.

In the costing program, each element of the support operations will be compared with similar elements in other aerospace programs. While some of the space shuttle system design and operational characteristics are different from other programs virtually all of the specific hardware and resource elements have analogues in other aircraft and spacecraft programs. Total cost is obtained by summing all the element costs into a total cost package. These cost packages will include the cost totals for all the standard operating cost elements, ie., facilities, manpower, spare parts, test equipment, etc., and any other elements unique in the space shuttle system.

The resource model will be used to analyze a number of support concepts to determine the one most effective within the operations requirements and budget constraints of the space shuttle system. Fig. 6-5 depicts the interactions between the costing procedure and the operations resource analysis.

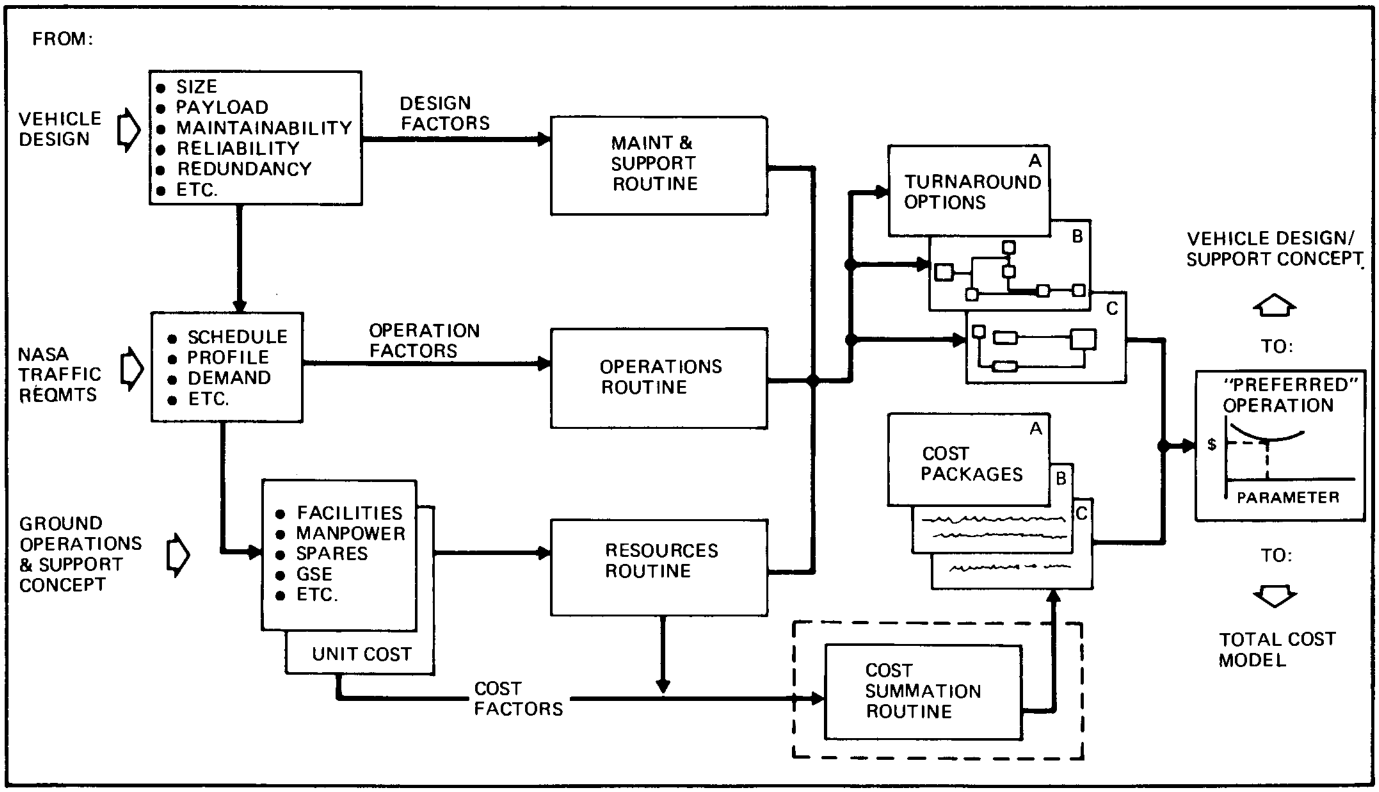


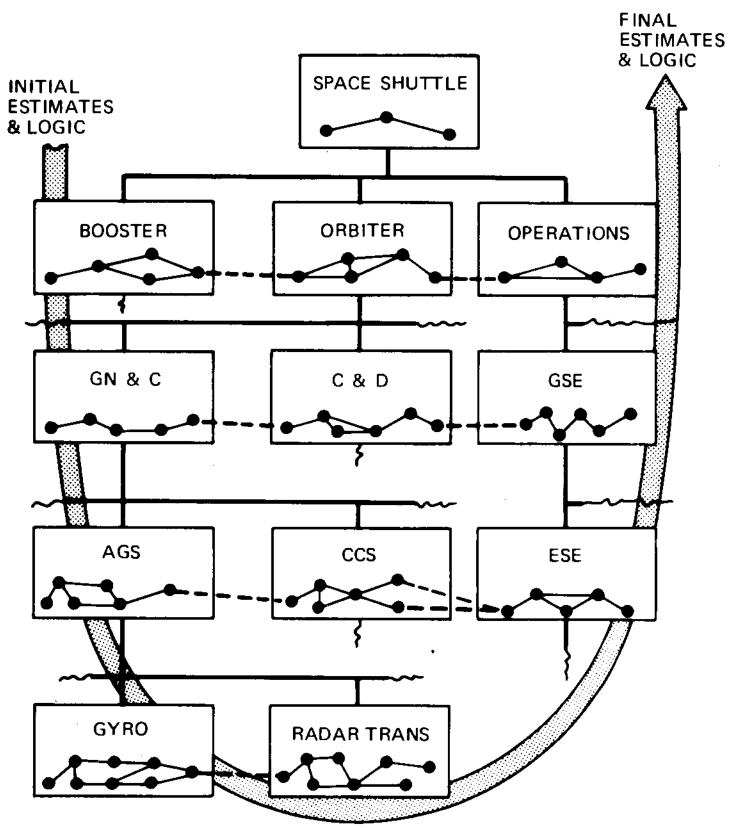
Fig. 6-5 Space Shuttle Operations Resource Model Functional Flow

6.4.5 Schedule

Grumman utilizes operationally proven schedule development techniques that employ logic network development, critical path analysis, and comparative time estimating. This approach will be used to develop a realistic space shuttle program schedule. Concurrent with the refinement of program rationale, a series of integrated/interlocked hardware-oriented logic networks are developed. These networks tie together discrete program tasks, interfaces, NASA established requirements, and resources; i.e., locations facilities and equipment. As illustrated in Fig. 6-6, the series of logic networks commence at the program level and tier down through the assembly/component level of the work breakdown structure.

Initially, a summary shuttle program logic network integrating the orbiter, booster, and operations will be developed and expanded to include the major efforts associated with design, development, production, and test of hardware items facilities, sites, and logistics. Control milestones and important interface constraints are highlighted. Activity estimates are added to the network from historical data (extrapolated as required), NASA and functional organizations, and are tested using critical path analysis to obtain a preliminary optimized baseline schedule and to evaluate the feasibility of the mid-1977 IOC.

As the Phase B study evolves, more in-depth data on subsystems, assemblies, and components is available so that lower tier logic networks can be developed and detailed activity functional time estimates obtained. The detailed logic networks are time/logic tested in conjunction with the preliminary baseline schedule and actual times experienced for similar activities on other Grumman, NASA and subcontractor space programs. Extensive critical path analysis is applied to determine the particular sequence of program activities that comprise the most rigorous time constraints. Tradeoff analysis is accomplished



LOGIC DIAGRAMS	NASA WBS LEVELS	SCHEDULES
Des/Devel, Prod., Test, Operations, Control Milestones, GFE, S/C, Sites, Interfaces	3	Project (summary)
Orbiter, Booster, Operations, Logistics, Facilities	4	System/ Module
Major Hardware, Software, Prototypes, GSE, Specs	5	Subsystem
Detail Hardware Tooling, Drawings, PO's	6	Assembly
Long Lead & State of Art Components PO's, Deliveries	7	Component

Fig. 6-6 Logic Networks & WBS (NASA) Level Correlation

at all level logic networks with the main objective to optimize time/resource/technical performance characteristics.

A firm baseline schedule is finalized and integrated milestone schedules are developed for each level of the WBS, as illustrated in Fig. 6-6.

Grumman electronic data processing (Grumman's PMS 360-DOD approved) is used to facilitate logic network data and tradeoff analyses.

6.4.6 Risk/Uncertainty Assessment

Risk and uncertainty have already been addressed directly during the current Grumman study effort, in the formulation of alternative space shuttle development program Design 532. This design is offered as an alternative to Design 518 because Grumman believes it significantly reduces program risk. In developing the alternative, those technical areas that require the greatest advance in the state of the art were identified early:

- Reusable structure and heat protection system
- Development of large-scale LOX/LH_2 cryogenic tankage
- Development of a new high-pressure, high-performance LOX/LH_2 engine

A design was suggested which would decrease the risk of these items delaying the achievement of program objectives or of exceeding annual budgetary constraints.

Reduction in risk would be achieved by:

- Decoupling booster and orbiter development so that the ramification of difficulties in either vehicle would not extend to the other
- Utilizing existing engine technology while booster and orbiter development is underway
- Using advanced engine technology in the orbiter after demonstrating flight capabilities

This type of analysis will be used throughout the Phase B study. Computer routines will address risk/uncertainty problems as shown in Fig. 6-7.

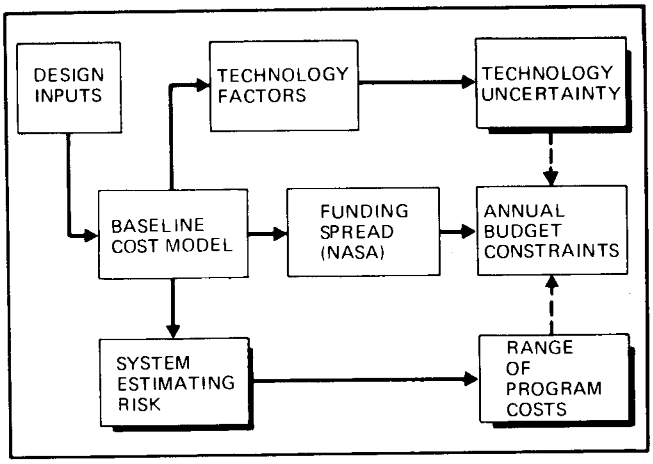


Fig. 6-7 Cost of Risk & Uncertainty

One such routine, presently operational at Grumman, uses Monte Carlo techniques and risk probability distributions to determine the probable range of total program cost resulting from variability in estimates of system design, performance, and programmatic parameters. A second routine, currently being developed, will address technological uncertainties by establishing relationships between costs and advances in the state of the art. These relationships will be used in determining the cost of those components of the space shuttle system which represent considerable technical advance; e.g., the thermal protection system and integrated avionics system.

The areas of high technological risk will be identified as early as possible. Alternative program options will be examined in terms of their ability to reduce risk and their associated costs will be determined. The selected program option must minimize risk with reasonable costs in order to provide the confidence required to achieve successful system development. The baseline model, together with the above subroutines, will provide a comparative analysis of the effects on total cost of the risks and uncertainty inherent in the development of alternative space shuttle system concepts. One method to reduce the effect of technological risk is to consider parallel development programs for high risk areas. The attendant dual cost can then be traded off against the reduction in schedule risk. Tradeoffs will be provided to lend insight into the selection of the acceptable levels of risk and cost. Previously, when there was uncertainty in estimating system requirements and large advances in technology, these areas became submerged in the total program estimates and their ramifications were hidden. The risk and uncertainty routines will give a greater understanding of the cost of reducing risk. It is only when risk and uncertainty are treated separately that they can be isolated and analyzed as to the program implications.

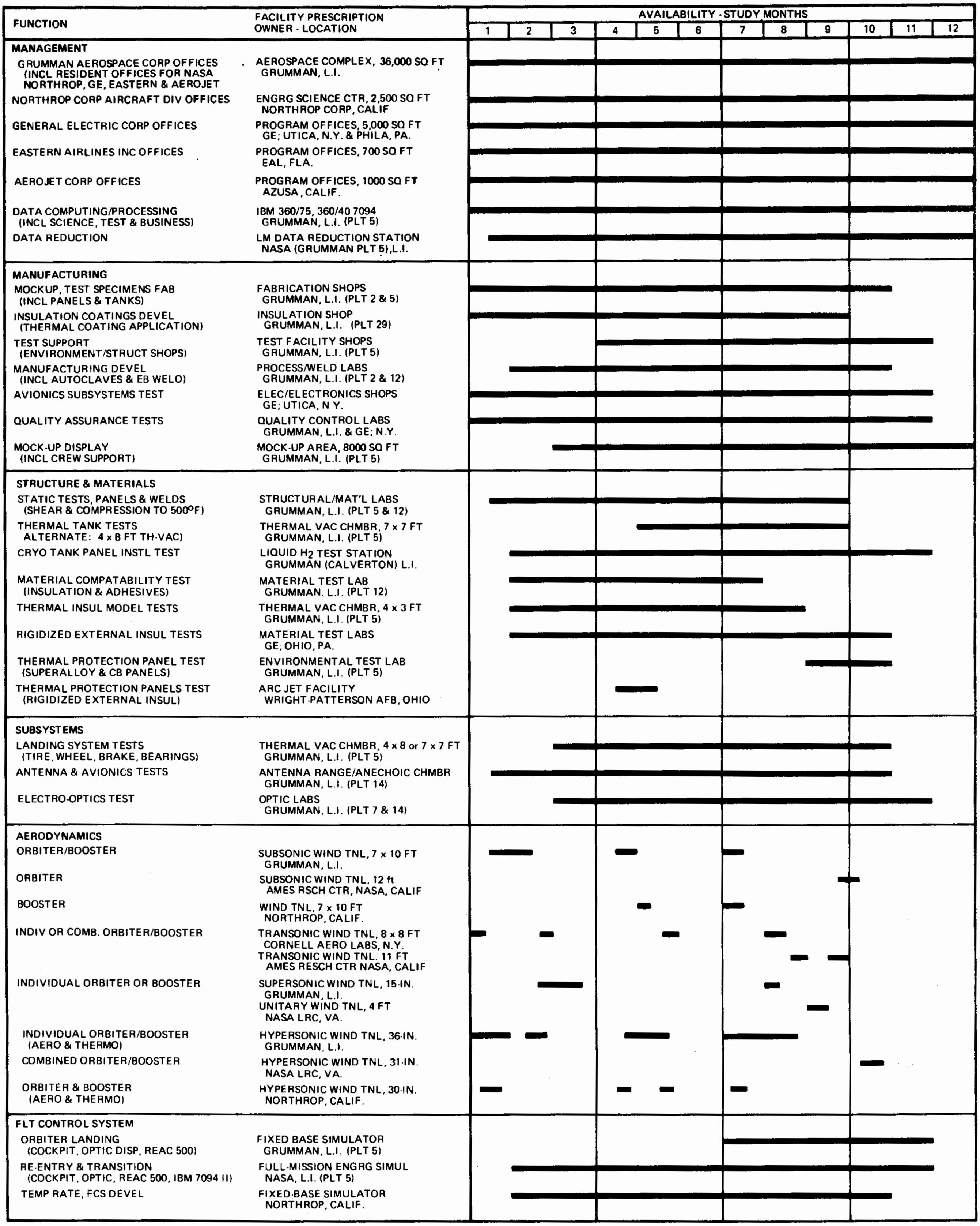
It is essential to relate schedule risk defined as the probability of not meeting a scheduled milestone within cost. Grumman is currently developing a network analysis algorithm which will accomplish this. The algorithm, when operational, will minimize the total program cost subject to a given schedule. If the schedule is relaxed, i.e., schedule risk decreases, the procedure computes the change in overall cost. Many of the system development risk costs will be derived from an evaluation of the uncertainty in meeting specified schedules.

6.4.7 Summary

The procedure described above has evolved over the past 10 years and has been successfully applied in the recent past. A-X, VSX, and most recently, the VFX (F-14) designs were synthesized with the aid of the cost analysis process described. While the uniqueness of the space shuttle system, with reference to its large development and limited production requirements, introduces some difficulty into the analysis process its transferability to the shuttle Phase B study has already been established. The results obtained from the Grumman study effort currently underway attest to this. Some problems do exist, however. The lack of representative cost estimating relationships, a condition not found with aircraft cost analysis, is recognized. Addressing this problem will be a first priority during the pre-Phase B study period and will continue into the study period itself.

6.5 FACILITY REQUIREMENTS

The contractor proposes to use in the performance of the contract on a rent-free non-interference basis property accountable under Facilities Contract N-00019-69-C-9032 (NASC Cognizance) and Contract NAS 9-1100 (MSC Cognizance). In addition, off-site government test facilities will be required as described in the accompanying Fig. 6-8 which lists the specific facility requirements for the Phase B program. All of the private facilities are well within the available capabilities of the Grumman team and are committed to the program. The NASA and USAF facilities listed are not committed. No new facilities or major modifications or new special test equipment are required.



FUNCTION	FACILITY PRESCRIPTION OWNER - LOCATION
MANAGEMENT	
GRUMMAN AEROSPACE CORP OFFICES (INCL RESIDENT OFFICES FOR NASA NORTHROP, GE, EASTERN & AEROJET	AEROSPACE COMPLEX, 36,000 SQ FT GRUMMAN, L.I.
NORTHROP CORP AIRCRAFT DIV OFFICES	ENGRG SCIENCE CTR, 2,500 SQ FT NORTHROP CORP, CALIF
GENERAL ELECTRIC CORP OFFICES	PROGRAM OFFICES, 5,000 SQ FT GE; UTICA, N.Y. & PHILA, PA.
EASTERN AIRLINES INC OFFICES	PROGRAM OFFICES, 700 SQ FT EAL, FLA.
AEROJET CORP OFFICES	PROGRAM OFFICES, 1000 SQ FT AZUSA, CALIF.
DATA COMPUTING/PROCESSING (INCL SCIENCE, TEST & BUSINESS)	IBM 360/75, 360/40 7094 GRUMMAN, L.I. (PLT 5)
DATA REDUCTION	LM DATA REDUCTION STATION NASA (GRUMMAN PLT 5),L.I.
MANUFACTURING	
MOCKUP, TEST SPECIMENS FAB (INCL PANELS & TANKS)	FABRICATION SHOPS GRUMMAN, L.I. (PLT 2 & 5)
INSULATION COATINGS DEVEL (THERMAL COATING APPLICATION)	INSULATION SHOP GRUMMAN, L.I. (PLT 29)
TEST SUPPORT (ENVIRONMENT/STRUCT SHOPS)	TEST FACILITY SHOPS GRUMMAN, L.I. (PLT 5)
MANUFACTURING DEVEL (INCL AUTOCLAVES & EB WELD)	PROCESS/WELD LABS GRUMMAN, L.I. (PLT 2 & 12)
AVIONICS SUBSYSTEMS TEST	ELEC/ELECTRONICS SHOPS GE; UTICA, N Y.
QUALITY ASSURANCE TESTS	QUALITY CONTROL LABS GRUMMAN, L.I. & GE; N.Y.
MOCK-UP DISPLAY (INCL CREW SUPPORT)	MOCK-UP AREA, 8000 SQ FT GRUMMAN, L.I. (PLT 5)
STRUCTURE & MATERIALS	
STATIC TESTS, PANELS & WELDS (SHEAR & COMPRESSION TO 500°F)	STRUCTURAL/MAT'L LABS GRUMMAN, L.I. (PLT 5 & 12)
THERMAL TANK TESTS ALTERNATE: 4 x 8 FT TH-VAC)	THERMAL VAC CHMBR, 7 x 7 FT GRUMMAN, L.I. (PLT 5)
CRYO TANK PANEL INSTL TEST	LIQUID H_2 TEST STATION GRUMMAN (CALVERTON) L.I.
MATERIAL COMPATABILITY TEST (INSULATION & ADHESIVES)	MATERIAL TEST LAB GRUMMAN. L.I. (PLT 12)
THERMAL INSUL MODEL TESTS	THERMAL VAC CHMBR, 4 x 3 FT GRUMMAN, L.I. (PLT 5)
RIGIDIZED EXTERNAL INSUL TESTS	MATERIAL TEST LABS GE; OHIO, PA.
THERMAL PROTECTION PANEL TEST (SUPERALLOY & CB PANELS)	ENVIRONMENTAL TEST LAB GRUMMAN, L.I. (PLT 5)
THERMAL PROTECTION PANELS TEST (RIGIDIZED EXTERNAL INSUL)	ARC JET FACILITY WRIGHT-PATTERSON AFB, OHIO
SUBSYSTEMS	
LANDING SYSTEM TESTS (TIRE, WHEEL, BRAKE, BEARINGS)	THERMAL VAC CHMBR, 4 x 8 or 7 x 7 FT GRUMMAN, L.I. (PLT 5)
ANTENNA & AVIONICS TESTS	ANTENNA RANGE/ANECHOIC CHMBR GRUMMAN, L.I. (PLT 14)
ELECTRO-OPTICS TEST	OPTIC LABS GRUMMAN, L.I. (PLT 7 & 14)
AERODYNAMICS	
ORBITER/BOOSTER	SUBSONIC WIND TNL, 7 x 10 FT GRUMMAN, L.I.
ORBITER	SUBSONIC WIND TNL, 12 ft AMES RSCH CTR, NASA, CALIF
BOOSTER	WIND TNL, 7 x 10 FT NORTHROP, CALIF.
INDIV OR COMB. ORBITER/BOOSTER	TRANSONIC WIND TNL, 8 x 8 FT CORNELL AERO LABS, N.Y. TRANSONIC WIND TNL, 11 FT AMES RESCH CTR NASA, CALIF
INDIVIDUAL ORBITER OR BOOSTER	SUPERSONIC WIND TNL, 15-IN. GRUMMAN, L.I. UNITARY WIND TNL, 4 FT NASA LRC, VA.
INDIVIDUAL ORBITER/BOOSTER (AERO & THERMO)	HYPERSONIC WIND TNL, 36-IN. GRUMMAN, L.I.
COMBINED ORBITER/BOOSTER	HYPERSONIC WIND TNL, 31-IN. NASA LRC, VA.
ORBITER & BOOSTER (AERO & THERMO)	HYPERSONIC WIND TNL, 30-IN. NORTHROP, CALIF.
FLT CONTROL SYSTEM	
ORBITER LANDING (COCKPIT, OPTIC DISP, REAC 500)	FIXED BASE SIMULATOR GRUMMAN, L.I. (PLT 5)
RE-ENTRY & TRANSITION (COCKPIT, OPTIC, REAC 500, IBM 7094 II)	FULL-MISSION ENGRG SIMUL NASA, L.I. (PLT 5)
TEMP RATE, FCS DEVEL	FIXED-BASE SIMULATOR NORTHROP, CALIF.

Fig. 6-8 Facility Requirements - Phase B

CERTIFICATIONS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CERTIFICATIONS

This form is to be completed, signed and returned with the bid or proposal.

BIDDER OR OFFEROR REPRESENTS: (Check as appropriate)

1. That he is a (X) MANUFACTURER, ( ) REGULAR DEALER, ( ) CONSTRUCTOR CONTRACTOR, ( ) SERVICE CONTRACTOR, as defined in the NASA Procurement Regulation 12.603-1, 12.603-2, 1.204 and 1.229, respectively.

2. (a) That he ( ) has (X) has not employed or retained any company or person (other than a full-time bona fide employee working solely for the bidder or offeror) to solicit or secure this contract, and (b) that he ( ) has (X) has not paid or agreed to pay any company or person (other than a full-time bona fide employee working solely for the bidder or offeror) any fee, commission, percentage or brokerage fee, contingent upon or resulting from the award of this contract; and agrees to furnish information relating to (a) and (b) above as requested by the Contracting Officer. (For interpretation of the representation, including the term "bona fide employee", see Code of Federal Regulations, Title 44, Part 150.) (January 1964)

NOTE: If the bidder or offeror, by checking the appropriate box provided therefor in his bid or proposal, has represented that he has employed or retained a company or person (other than a full-time employee) to solicit or secure this contract, he may be requested by the Contracting Officer to furnish with his bid or proposal a completed Standard Form No. 119 (Contractor's Statement of Contingent or Other Fees for Soliciting or Securing Contract). If the bidder or offeror has previously furnished a completed Standard Form No. 119 to the office issuing this invitation for bids or request for proposals, he may accompany his bid or proposal with a signed statement, in lieu of Standard Form No. 119, (a) indicating when such completed Form was previously furnished, (b) identifying by number the previous invitation, request for proposals, or contract in connection with which such Form was submitted, and (c) representing that the statements in such previously furnished Form are applicable to this bid or proposal. (February 1962)

3. That he operates as ( ) AN INDIVIDUAL, ( ) A PARTNERSHIP, (X) A CORPORATION, incorporated in the State of New York.

4. (a) That he ( ) is (X) is not a small business concern. A small business concern is a concern that is independently owned and operated, is not dominant in the field of operation in which it is bidding on Government contracts, and, with its affiliates, can further qualify under the criteria as prescribed by the Small Business Administration.

See Code of Federal Regulations, Title 13, Part 121, as amended which contains detailed industry definitions and related procedures.

(b) If he is a small business concern and is not the manufacturer of the supplies offered, he also represents that all supplies to be furnished hereunder ( ) will ( ) will not be manufactured or produced by a small business concern in the United States, its territories, its possessions, or the Commonwealth of Puerto Rico, states has ( ) has not ( ) been refused a Certificate of Competency by the Small Business Administration.

5. That he (X) has ( ) has not participated in a previous contract or subcontract subject to either the Equal Opportunity clause herein or the clause originally contained in Section 301 of Executive Order 10925; that he (X) has, ( ) has not, filed all required compliance reports; and that representations indicating submissions of required compliance reports, signed by proposed subcontractors, will be obtained prior to subcontract awards. (The above representation need not be submitted in connection with contracts or subcontracts which are exempt from the clause.) (July 1968)

6. That each end product, except the end products excluded below, is a domestic source end product (as defined in the contract clause entitled BUY AMERICAN ACT); and that components of unknown origin have been considered to have been mined, produced, or manufactured outside the United States.

EXCLUDED ITEMS: ______________________________

CERTIFICATE OF INDEPENDENT PRICE DETERMINATION (JUNE 1964)

(a) By submission of this bid or proposal, each bidder or offeror certifies, and in the case of a joint bid or proposal, each party thereto certifies as to its own organization, that in connection with this procurement:

(1) the prices in this bid or proposal have been arrived at independently, without consultation, communication, or agreement, for the purpose of restricting competition, as to any matter relating to such prices with any other bidder or offeror or with any competitor;

(2) unless otherwise required by law, the prices which have been quoted in this bid or proposal have not been knowingly disclosed by the bidder or offeror and will not knowingly be disclosed by the bidder or offeror prior to opening in the case of a bid, or prior to award, in the case of a proposal, directly or indirectly to any other bidder or offeror or to any competitor; and

(3) no attempt has been made or will be made by the bidder or offeror to induce any other person or firm to submit or not to submit a bid or proposal for the purpose of restricting competition.

(b) Each person signing this bid or proposal certifies that:

(1) he is the person in the bidder's or offeror's organization responsible within that organization for the decision as to the prices being bid or offered herein and that he has not participated, and will not participate, in any action contrary to (a)(1) through (a)(3) above; or

(2) (a) he is not the person in the bidder's or offeror's organization responsible within that organization for the decision as to the prices being bid or offered herein but that he has been authorized in writing to act as agent for the persons responsible for such decision in certifying that such persons have not participated, and will not participate, in any action contrary to (a)(1) through (a)(3) above, and as their agent, does hereby so certify; and (b) he has not participated, and will not participate, in any action contrary to (a)(1) through (a)(3) above.

(c) This certification is not applicable to a foreign bidder or offeror submitting a bid or proposal for a contract which requires performance or delivery outside the United States, its possessions, and Puerto Rico.

(d) A bid or proposal will not be considered for award where (a)(1), (a)(3), or (b) above has been deleted or modified. Where (a)(2) above has been deleted or modified, the bid or proposal will not be considered for award unless the bidder or offeror furnishes with the bid or proposal a signed statement which sets forth in detail the circumstances of the disclosure and the Administrator, or his designee, determines that such disclosure was not made for the purpose of restricting competition.

Grumman Aerospace Corporation
Organization

By ______________
Signature

Joseph G. Gavin, Jr.
Typed Name

Senior Vice-President
Title

March 25, 1970
Date

IFB/RFP No. 10-8423

Enclosure No. 6

CERTIFICATION OF NONSEGREGATED FACILITIES (MAY 1968)

(Applicable to contracts, subcontracts, and agreements with applicants who are themselves performing federally assisted construction contracts, exceeding $10,000 which are not exempt from the provisions of the Equal Opportunity clause.) By signing this form, the bidder, offeror, applicant, or subcontractor certifies that he does not maintain or provide for his employees any segregated facilities at any of his establishments, and that he does not permit his employees to perform their services at any location, under his control, where segregated facilities are maintained. He certifies further that he will not maintain or provide for his employees any segregated facilities at any of his establishments, and that he will not permit his employees to perform their services at any location, under his control, where segregated facilities are maintained. The bidder, offeror, applicant, or subcontractor agrees that a breach of this certification is a violation of the Equal Opportunity clause in this contract. As used in the certification, the term "segregated facilities" means any waiting rooms, work areas, rest rooms and wash rooms, restaurants and other eating areas, time clocks, locker rooms and other storage or dressing areas, parking lots, drinking fountains, recreation or entertainment areas, transportation, and housing facilities provided for employees which are segregated by explicit directive or are in fact segregated on the basis of race, creed, color, or national origin, because of habit, local custom or otherwise. He further agrees that (except where he has obtained identical certification from proposed subcontractors for specific time periods) he will obtain identical certifications from proposed subcontractors prior to the award of subcontracts exceeding $10,000 which are not exempt from the provisions of Equal Opportunity clause; that he will retain such certifications in his files; and that he will forward the following notice to such proposed subcontractors (except where the proposed subcontractors have submitted identical certifications for specific time periods):

NOTICE OF PROSPECTIVE SUBCONTRACTORS OF REQUIREMENT FOR CERTIFICATION OF NONSEGREGATED FACILITIES

A Certification of Nonsegregated Facilities, as required by the May 9, 1967, order on Elimination of Segregated Facilities, by the Secretary of Labor (32 Fed. Reg. 7439, May 19, 1967), must be submitted prior to the award of a subcontract exceeding $10,000 which is not exempt from the provisions of the Equal Opportunity clause. The certification may be submitted either for each subcontract or for all subcontracts during a period (i.e., quarterly, semiannually, or annually). (Note: The penalty for making false statements in offers is prescribed in 18 U.S.C. 1001.)

Firm Grumman Aerospace Corporation

Name Joseph G. Gavin, Jr.

Title Senior Vice-President

Date: March 25, 1970

NASA — MSC — Coml., Houston, Texas