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SPACE TRANSFER VEHICLE CONCEPTS AND REQUIREMENTS STUDY

Phase I Final Report
Volume II, Book 4
Integrated Advanced Technology Development
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FOREWORD

This final report of the first phase of the Space Transfer Vehicle (STV) Concept and Requirements Study was prepared by Boeing for the National Aeronautics and Space Administration's George C. Marshall Space Flight Center in accordance with Contract NAS8-37855. The study was conducted under the direction of the NASA Contracting Officer Technical Representative (COTR), Mr Donald Saxton from August 1989 to November 1990, and Ms Cynthia Frost from December 1990 to April 1991.

This final report is organized into the following seven documents:

Volume I EXECUTIVE SUMMARY

Volume II FINAL REPORT
- Book 1 - STV Concept Definition and Evaluation
- Book 2 - System & Program Requirements Trade Studies
- Book 3 - STV System Interfaces
- Book 4 - Integrated Advanced Technology Development

Volume III PROGRAM COSTS ESTIMATES
- Book 1 - Program Cost Estimates (DR-6)
- Book 2 - WBS and Dictionary (DR-5)

The following appendices were delivered to the MSFC COTR and contain the raw data and notes generated over the course of the study:

Appendix A	90 day "Skunkworks" Study Support
Appendix B	Architecture Study Mission Scenarios
Appendix C	Interface Operations Flows
Appendix D	Phase C/D & Aerobrake Tech. Schedule Networks

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ACRONYMS

AC	attitude control
ACS	attitude control system
ALS	Advanced Launch System
APU	auxiliary power unit
ASIC	application-specific integrated circuit
ATC	active thermal control
ATDRSS	advanced TDRSS
BIT	built-in test
BOLT	Boeing Lunar Trajectory Program
CASE	computer-aided software engineering
CNDB	civil needs database
CNSR	comet nucleus sample return
CT	communications and tracking
CTE	coefficient of thermal expansion
DAK	double aluminized Kapton
DDT&E	design, development, test, and evaluation
(delta) T	change in event duration
(delta) V	change in velocity
DoD	Department of Defense
DMR	design reference missions
DRS	design reference scenario
DSN	deep space network
ECLSS	environmental control and life support system
EOS	Earth observing system
EPS	electrical power system
ESA	European Space Agency
ETO	Earth to orbit
EVA	extravehicular activity
FC	fluid control
FEPC	flight equipment processing center
FOG	fiber-optic gyro
FSD	full-scale development
GB	ground based
GC	guidance control
GEO	geosynchronous orbit
GLOW	gross liftoff weight
GNC	guidance, navigation, and control
GO	ground based, on orbit
GPS	global positioning system
GSE	ground support equipment
HEI	Human Exploration Initiative
HEO	high Earth orbit
HESR	Human Exploration Study Requirements
HLLV	heavy lift launch vehicle

ICI	Integrated Systems Incorporated
ILD	injection laser diode
IMU	inertial measurement unit
IUS	Inertial Upper Stage
IVA	intravehicular activity
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KSC	Kennedy Space Center
LAD	liquid acquisition device
LAN	local area network
LCC	life cycle cost
LCD	liquid crystal display
L/D	lift to drag
LECM	lunar excursion crew module
LED	light-emitting diode
LEO	low Earth orbit
LES	launch escape system
LEV	lunar excursion vehicle
LLO	low lunar orbit
LMS	lunar mission survey
LO	lunar orbiter
LOD	lunar orbit direct
LOI	lunar orbit injection
LOR	lunar orbit rendezvous
LOX/LH	liquid oxygen/liquid hydrogen
LTS	lunar transportation system
LTV	lunar transfer vehicle
MEOP	maximum expected operating pressure
MET	mission elapsed time
MEV	Mars excursion vehicle
MLI	multilayer insulation
MPS	main propulsion system
MSFC	Marshall Space Flight Center
MTPE	mission to planet Earth
MTV	Mars transfer vehicle
NEP	nuclear energy propulsion
NPSH	net positive suction head
NTR	nuclear thermal rocket
ORU	orbit replaceable unit
P/A	propulsion/avionics
PC	propulsion control
PCM	parametric cost model
PDT	product development team
PODS	passive orbital disconnect strut
PSS	planet surface system
PVT	pressure-volume-temperature

RCS	reaction control subsystem
RFP	request for proposal
RLG	ring laser gyros
RMS	remote manipulator system
RTV	room temperature vulcanizating
SB	space based
SEI	Space Exploration Initiative
SEP	solar energy propulsion
SEU	single-event upset
SG	space/ground
SIP	strain isolation pad
SIRF	spaceborne imaging radar facility
SIRTF	Space IR Telescope Facility
SLAR	side-looking aperture radar
SOS	silicon on sapphire
SRM	solid rocket motor
SSF	Space Station Freedom
STIS	Space Transportation Infrastructure Study
STS	space transportation system
STV	Space Transfer Vehicle
TDRSS	tracking and data relay satellite system
TEI	trans-Earth injection
TLI	translunar injection
TMI	trans-Mars injection
TPS	thermal protection system
TVC	thrust vector control
TVS	thermodynamic vent system
USRS	Upper Stage Responsiveness Study
VHM	vehicle health monitoring
VHMS	vehicle health management system
ZLG	zero lock gyro

4-1.0 TECHNOLOGY ASSESSMENT

Introduction. The Space Transfer Vehicle program provides both an opportunity and a requirement to increase our upper stage capabilities with the development and application of new technologies. Issues such as man rating, space basing, reusability, and long lunar surface storage times drive the need for new technology developments and applications. In addition, satisfaction of mission requirements such as lunar cargo delivery capability and lunar landing either require new technology development or can be achieved in a more cost-effective manner with judicious applications of advanced technology.

During the STV study, advanced technology development requirements and plans have been addressed by the Technology/Advanced Development Working Group composed of NASA and contractor representatives. This section and the following section (section 4-2.0) of the STV Final Report discuss the results to date of this working group. This section gives an overview of the technologies that have potential or required applications for the STV and identifies those technologies baselined for the STV. Figure 4-1.0-1 provides a list of the technology categories and Figure 4-1.0-2 shows the priority placed on those technology categories for either the space-based or ground-based options. Section 4-2.0 covers the plans and schedules for incorporating the technologies into the STV program.

STV program requirements drive both technology capabilities and schedules. Additionally, technology is available that, while not absolutely required, will provide substantial benefits to the STV program. STV requirements are contained in section 2-2.0 (System Requirements Document) and section 1-1.2.3 (Design Reference Missions).

4-1.1 PROPULSION

4-1.1.1 Main Engine

The objectives of main engine technology development are to develop deep throttling required for lunar landing, increase Isp and thus reduce IMLEO requirements, support reusability and low-maintenance requirements, ensure

1. Aerobrake (Aeroassist)
2. Cryogenic Primary & Auxilliary Propulsion
3. Vehicle Cryogenic Fluid Systems
4. Vehicle Avionics, Electrical Power & Software
5. Vehicle Structures, Cryogenic Tankage, & Auxiliary Equip.
6. Crew Modules & Systems (incl. Biconic Crew Module)

Current STV Study Analysis

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7. Evironmental Control & Life Support Systems (ECLSS)
8. Vehicle Fabrication, Assy., Servicing & Processing
9. Space Vehicle Orbit Launch & Mission Control
10. Vehicle Flight Operations (incl. Launch Escape Systems)
11. Artificial Gravity

12..-13. Advanced Propulsion Systems (Not adressed in STV Contract)

Figure 4-1.0-1. Technology Categories Listing

Categories:	(Priority Selected) Space	Ground
1. Aerobrake (modeling, design, M&P)	Highest	None
2. Cryogenic Primary/Auxiliary Propulsion	Highest	Highest
3. Cryogenic Fluid Supply Systems	Highest	Highest
4. Avionics, Power, & Software	Highest	Highest
5. Structure, Tankage, Auxiliary Equip.	High	High
6. Crew Module (structures, controls, TPS)	Higher	Highest
7. Environmental Control & Life Support	Higher	Higher
8. STV Fabrication & Assy./Processing	High	Higher
9. In-Space Orbit Launch & Mission Ctrl	Highest	High
10. STV In-Space Servicing & Processing	Highest	High
11. STV Flight Operations & LES	Higher	Highest
12. In-Situ Resources	Currently analyzed by Boeing-Huntsville team	
13. Nuclear Propulsion	Currently analyzed by Boeing-Huntsville team	
14. Artificial Gravity	Currently analyzed by Boeing-Huntsville team	
15. Other..	TBD	TBD

Figure 4-1.0-2. STV Technology Priority by Vehicle Type

compatibility with long-duration space exposure, provide engine instrumentation that supports vehicle health monitoring (VHM) requirements, and maintain or improve on the reliability of current systems.

One of the study groundrules was that the STV use LOX/LH2 as the main propulsion propellants. The current state of the art in upper stage class LOX/LH2 main engines is represented by the latest upgrade in the RL10 engine family produced by Pratt & Whitney. The RL10, an expander cycle engine, started development in 1958 with first flight on the Centaur in November 1963 and a first Apollo flight in January 1964. In October 1966, the first successful in-space restart of the engine was demonstrated.

The engine has undergone several upgrades with the RL10A-3, the RL10A-3-3, and the RL10-3-3A. An Isp of 444.4 seconds, thrust level of 73,395N (16,500 lbf), and expansion ratio of 61:1 characterize the RL10-3-3A, which first flew in June 1984. The first flight of the newest upgrade, the RL10A-4, is scheduled on the Atlas Centaur for fall of 1991. This engine has an Isp of 449.5 seconds, a thrust level of 90,076N (20,800 lbf), and an expansion ratio of 84:1 using an extendible nozzle. To date, 178 RL10's have flown with no in-flight failures. The demonstrated reliability (ground and space) is 0.9984.

Additional upgrades to the RL10 have been identified and various levels of development tests have been conducted. Restart capability has been demonstrated with up to 7 in-space restarts and up to 30 ground test restarts. The current class of RL-10s are full thrust engines without throttling capability; however, throttling ratios of up to 20:1 have been demonstrated in ground tests. Figure 4-1.1.1-1 gives an overview of the current RL10, projected RL10 upgrades, and a new engine being defined in the engine workshop activity being conducted by the Lewis Research Center.

Upgrades to the current RL10 capabilities are both required to satisfy STV mission requirements and the desired to reduce costs. Medium to deep throttling capability is required to initially provide (at 100% thrust) enough thrust to reduce gravity losses when leaving low Earth orbit and then to hover, reduce thrust, and accomplish the lunar landing (requiring throttling down to 20% (5:1)

	Engine RL10A-3-3A	Engine RL10A-4+	Engine RL10B-2	Advanced space engine
Isp (seconds)	444.4	449.5	468.3	481.0 (max)
Thrust (Newtons) (pounds of thrust)	73,395N 16,500 lbs)	90,076N (20,800 lbs)	97,698N (22,000 lbs)	66,723N (6-Eng. design) (15,000 lbs)
Deep throttling?	No	 No	Yes	Yes
Nozzle retraction?	No	Yes	Yes	Space-Based only
Expansion Ratio	61:1	84:1	Opt. for app	Optimum for application
Reliability Rating	.9999	.9999 (est)	.9999 (est)	Unknown
(91$) DDT&E Facilitization	N/A $65M	* $50M $65M	$200M $65M	* $500M-800M (SB config) $90M
(91$) First Unit Unit Cost (Avg) *	N/A $2.4M *	Unknown $2.7M	$3.5M * $2.9M	* $6.25 M TFU @ 95%λ $5.0M AUPC (150 units)
Available Technical maturity yr(s)	1984	1991 1991	1999 1994	2001-2 1997-98

* Vendor budgetary planning estimates (1990-91)

Figure 4-1.1.1-1. Cryogenic Engines CBA Input Data of thrust). Deep throttling has been demonstrated but is not currently available in off-the-shelf engines.

For the space-based STV, maintenance considerations must be addressed because of the high costs of space-based maintenance. The preferred approach to accomplishing main engine maintenance is to remove and replace the engine as a line replaceable unit. This requires design and verification of a simple interface/attachment method. Conceptual designs of a carrier plate concept containing all propellant and electrical connections in one interface have been identified. Advanced turbomachinery and seal technologies will improve system launch readiness and availability for both STV and Earth to orbit (ETO) systems.

Requirements for reusability, autonomy, and lunar surface stay times prior to engine restart for Earth return drive requirements for engine reliability and health monitoring capability. Additionally, the space-based concept requires compatibility with long-term exposure to space environments. Under an STV subcontract, Pratt & Whitney has identified RL10 health monitoring instrumentation concepts that will need to be further refined and demonstrated with highly reliable sensors and health monitoring architectures (e.g., dual redundancy). Reusability also drives requirements for multiple restart capability.

Increases in Isp can significantly reduce propellant requirements. Figure 4-1.1.1-2 shows ETO mass per mission as a function of Isp. A savings of 50 metric tons per mission is provided by an Isp increase from 440 seconds to 481 seconds. Increases in Isp at a given thrust can be accomplished by increasing the combustion chamber pressure (Pc) to between 400 and 1,500 psi and adjusting the area ratio accordingly. Higher area ratios (and higher Isp's) can be obtained by either decreasing the throat area (requiring a higher Pc), increasing the nozzle exit area, or a combination of the two. On a relatively small vehicle such as an upper stage, volume required for the engines and for the engine gimbaling envelope is limited so increased Pc is generally required. Increases in Pc will require advances in turbomachinery seals and bearings and chamber materials.

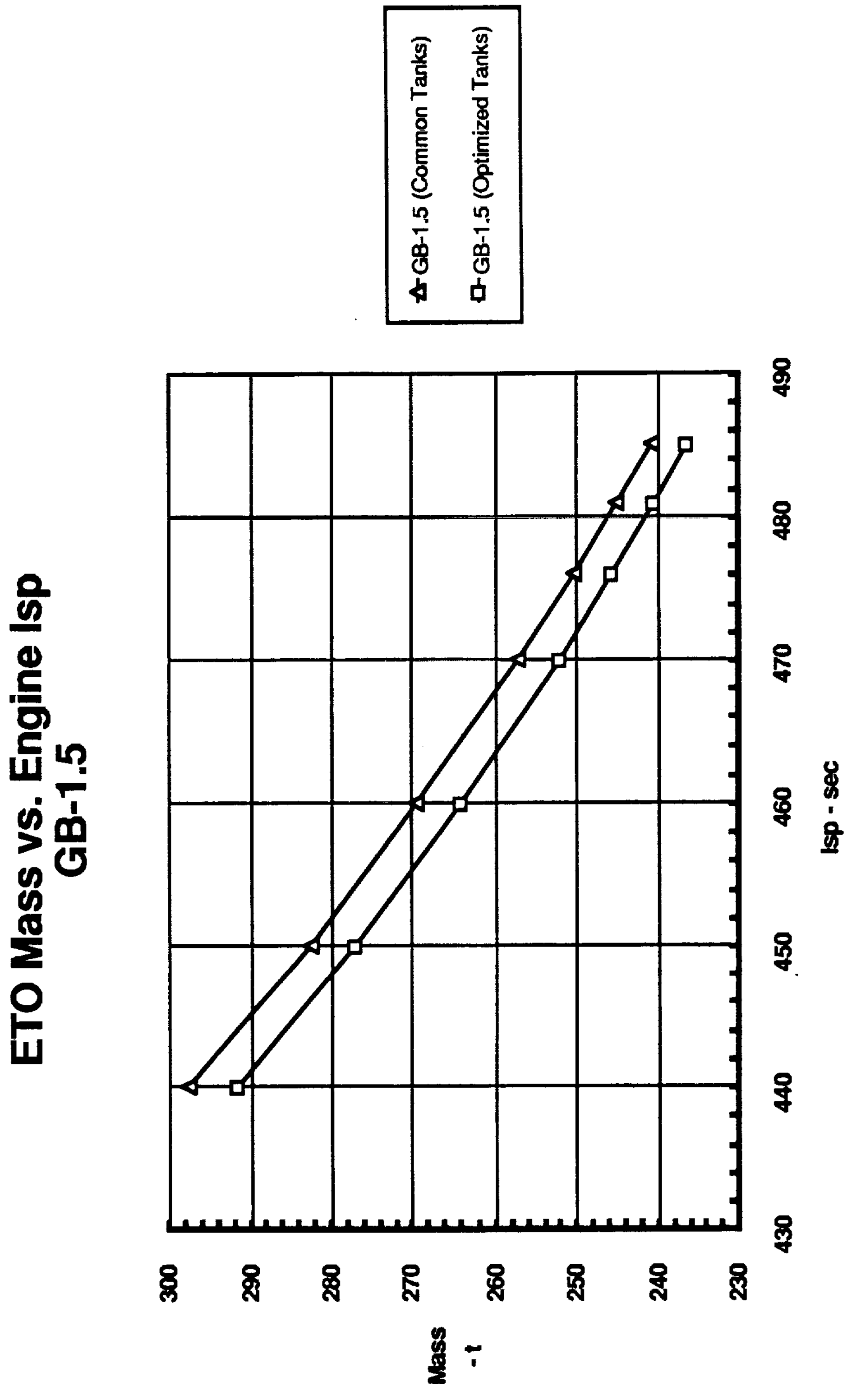


Figure 4-1.1.1-2. ETO Mass Versus Engine Isp

In summary, main engine development requirements include deep throttling capability, engine health monitoring capability, long-term compatibility to space exposure, and multiple restart capability. Also desired is high engine reliability, interface design to support a low/no maintenance support approach (line replaceable unit swap-out), and increases in engine Isp to reduce propellant mass requirements.

Two options for meeting these requirements were identified. One is an RL10 upgrade, the RL10B-2, with a maximum Isp of 470 seconds. The second option is an all new engine development. The RL10 upgrade is limited in terms of Pc increases and corresponding adjustments of the area ratio both by turbomachinery limitations and engine envelope considerations. Alternatively, development of a new engine is being investigated that will potentially provide Isp's up to 481 seconds at Pc's up to 1,500 psi. The difference in ETO mass required is approximately 12 metric tons more mass required per mission for the lower (470 second) Isp engine. Throttling capability, reliability, thrust level, engine restart, and other requirements for a new engine are all being currently defined through the STV study contracts and the engine workshop activity being conducted by Lewis Research Center. Costs for the two options are discussed in the Cost Estimates section (Volume III, section 1-3.0).

Throughout the study, ongoing support was provided to the Lewis Research Center engine workshop activity. For the STV study, use of a new engine was assumed with performance data based on an engine Isp of 481 seconds.

4-1.1.2 Attitude Control

The objective in attitude control is to develop the technology required for high performance gaseous O2/H2 thrusters in the 25- and 80-lb or the 75-lb range that integrate well with the rest of the vehicle and are instrumented to support VHM. Propellants for the attitude control system (ACS) were not baselined, so there was first the question of propellant selection and, secondly, the selection of the required hardware. Section 1-3.3 discusses the propulsion subsystem trade studies. O2/H2 was the propellant selected for the STV ACS, which will be used with gaseous O2/H2 thrusters.

The space-based STV requires thrusters in the 80-lb range. Two different systems have been used in the ground-based STV: one with 75-lb thrusters and one with 25-lb thrusters. The reason for the two systems on the ground-based concept is that the STV leaves elements, which include the 75-b thruster system, on the lunar surface upon lunar departure. The remaining ACS is controlling less mass and the thruster location provides a more significant moment arm; therefore, the lower, 25-lb thrusters are used. On the space-based concept, the main propulsion system (MPS), the ACS, and the power system are integrated. The ground-based concept has an integrated MPS, 25-lb thruster ACS, and power system with the 75-lb thruster ACS being integrated only with the MPS.

No gaseous O2/H2 thrusters are currently available. Work was initially started on this type of thruster for the Space Station. Thrusters from Rocketdyne, Aerojet, and Bell underwent substantial testing. An overview of these efforts is discussed below. This system was later deleted from the Space Station program and will still require some development.

Aerojet developed and tested a 25 lbf gaseous O2/H2 thruster that was tested over a mixture ratio range from 2.2:1 to 8:1. Chamber life analysis found that the requirements for 500 deep thermal cycles could easily be met. The updated life prediction was on the order of 2,000 deep thermal cycles with an effectively infinite impulse bit capability. Aerojet then had a follow-on contract to work on a thruster designed specifically for an 8:1 mixture ratio. The 8:1 mixture ratio was desired so that the electrolysis products of water at the Space Station could be used for propellants. Figure 4-1.1.2-1 shows the gaseous O2/H2 thruster developed in the follow-on contract.

Rocketdyne also developed and tested a 25-lbf gaseous O2/H2 thruster. The accumulated firing time exceeded 24 hours, which included over 1 million lbf-seconds at mixture ratios from 3 to 4:1 to 8:1 and over 10,500 starts. Testing was done for both full thermal cycles (≥3,000 cycles) and for pulses (≥10,000). Temperatures observed during thermal transient testing (e.g., test 024) were indicative of unlimited life. Rocketdyne also had a follow-on contract for further thruster work.

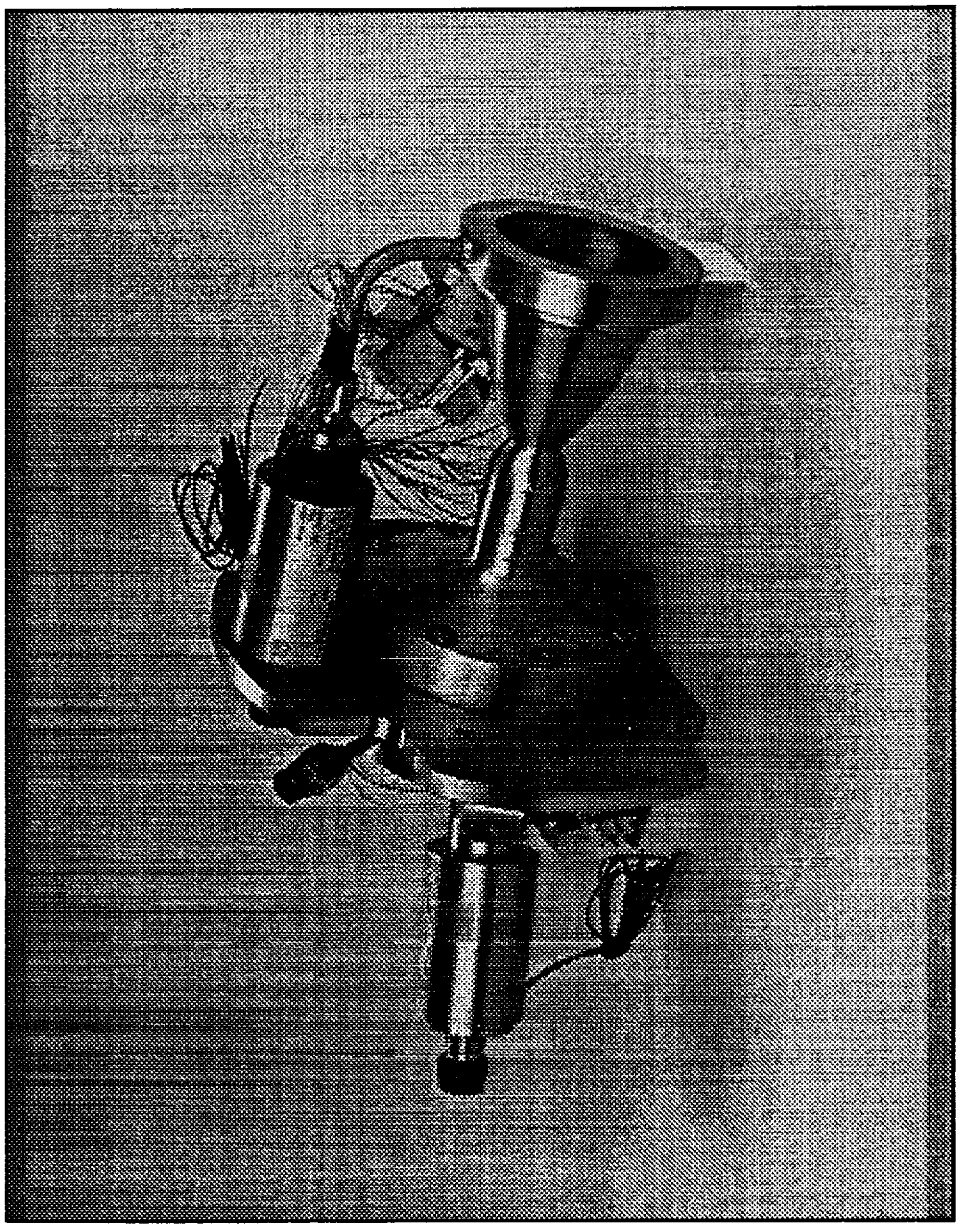


Figure 4-1.1.2-1. Gaseous O_2/H_2 Thruster

Bell developed a 50-lbf gaseous O2/H2 reverse flow thruster where the fuel is injected backwards into the chamber to cool the combustor wall. This thruster was tested at mixture ratios of 4:1 and 8:1 and demonstrated capability for extended operation (tests included at least one 1,000-second firing and 225,000-lb-second impulse operations).

In summary, sufficient capability to develop the thrusters is available. No major technical hurdles have been identified and the primary technology has been demonstrated. The thrusters will need to be developed for STV, but there is a substantial database on which to draw.

Development will also be required for the ACS propellant accumulator. The accumulator will draw low-pressure propellant from common main propulsion/ACS tankage for accumulation as a supercritical , high pressure fluid in the ACS accumulator.

4-1.2 CRYOGENIC FLUID SYSTEMS

The objectives for cryogenic fluid systems technology development is to support STV mission requirements for long-duration storage of cryogenic fluids (e.g., on the lunar surface); in-space cryogenic fluid transfer, and make and break of cryogenic fluid connections (multiple times for space-based concepts). Tank venting and propellant level gaging is also required. Additionally, a common fuel, common supply equipment, redundant, integrated propulsion/RCS has great potential to reduce operational complexity. Integration of the power system with the integrated propulsion/RCS is a possible growth candidate but was not baselined for the STV.

The state of the art in insulation systems is double aluminized Kapton (DAK) blankets with Dacron net spacers between the blankets, also known as multilayer insulation (MLI). This insulation has been flown on Centaur for cryogenic tank insulation and is used in several other applications (e.g., the Inertial Upper Stage (IUS)) for avionics and structural insulation. MLI used for cryogenic tank insulation has traditionally required a ground helium purge of the blankets to prevent condensation and freezing. MLI is most effective in space where the volume between the layers is evacuated.

Use of foam/MLI insulation has been proposed. In this concept, an isocyanurate foam is either sprayed on (sprayed on foam insulation (SOFI)) or machined and attached to the cryogenic tanks with MLI attached over the foam. Foam/MLI provides better insulation than helium-purged MLI alone. Use of foam also allows a (less expensive and less operationally complex) GN2 ground purge instead of a helium purge. This combined concept provides good insulation on both the ground (Earth) and in space.

The state of the art in propellant gaging used to determine the amount of propellant in a tank is represented by either point sensors or capacitance probes. Both of these require the vehicle to perform a settling burn to move the propellant to one end of the tank. Point sensors are used in the STS external tank where propellant quantity is measured in discrete increments as successively lower point sensors are unwetted during propellant use. The Centaur uses a capacitance probe. The probe is successively unwetted along its length as the propellant level drops during propellant use; the change in capacitance of the probe is measured and related to propellant level.

Several concepts for zero gravity propellant gaging have been proposed and investigated to some level. Acoustic methods have been examined but proved to be too sensitive to tank geometry. Nucleonic methods are where radioactive sources are mounted on one side of the tank and sensors on the other side. The absorption of radioactivity by the propellant is measured and relates fairly closely to the remaining propellant mass.

The nucleonic approach has been used on small storable propellant tanks on some satellite programs, for oil-level gaging on the F-104 airplane, and for various other applications. Accuracies of 1% to 2% have been achieved; however, scaling up of this approach introduces some concerns. A larger tank provides more attenuation of the radiation and either requires stronger radioactive sources, with resulting handling and political concerns, or more sensitive sensors with resulting signal-to-noise ratio problems. The signal-to-noise problems are especially of concern out past the Van Allen belts where the background radiation is higher. An additional concern with stronger sources is the issue of undesired propellant heating.

The method proposed for the STV is the pressure-volume-temperature (PVT) method. With this approach, a small piston is used to rapidly perturb the tank internal volume. With the change in volume, a corresponding change in tank internal pressure and temperature is measured. These changes can be related to the internal density in the tank and the remaining propellant mass can be determined. PVT systems are being developed by Ball Aerospace for JSC.

The state of the art in cryogenic fluid connectors is represented by the STS external tank umbilical connectors. These connectors are not designed for multiple mate and demate operations, which are required by the STV. New development is required in this area.

Similarly, there is no state of the art in zero gravity cryogenic fluid transfer. The current approach for the STV is to perform all required fluid transfers either during main propulsion burns or during ACS burns, which may include settling burns conducted for the primary purpose of aiding propellant transfer. Experiments have been planned (e.g., Coldsat) to support development in this area.

The final major area in cryogenic fluid systems of interest for the STV is tank pressure control. The state of the art in this area is represented by the use of settled venting to control pressure buildup. With this approach, a settling burn is conducted to move the liquid propellant to one end of the tank while gas is vented from the other end to control pressure. Two alternatives to this technique have been suggested. The first is refrigeration control where the propellant is refrigerated as required to reduce pressure. Problems with this approach are in the power requirements to refrigerate liquids already at extremely low temperatures.

The second concept is the thermodynamic vent system (TVS). With this concept, a quantity of gas/liquid mixture is expanded to the point where primarily gas remains, which is then vented. This expansion draws heat from the propellant remaining in the tank and thus primarily gas is vented and at the same time heat is removed from the tank. The TVS also provides for propellant mixing to reduce temperature stratification. A TVS was developed for the Shuttle/Centaur program and tested extensively on the ground. However, with the cancellation of the program, the TVS was not tested in space. The TVS approach has been baselined for the STV.

In summary, several advances are required for cryogenic fluid systems. MLI/foam combination insulation systems, PVT propellant gaging, reusable and reliable cryogenic connectors, and TVS pressure control are all baselined for the STV and need development. In addition, zero gravity cryogenic fluid transfer development would be applicable to the STV.

4-1.3 AEROASSIST AND AEROMANEUVER

The ground-based STV concept requires a reentry crew module, and the space-based STV concept uses an aerobrake for LEO capture. The objectives for technology development in the aeroassist and aeromaneuver category is to provide advances in thermal protection systems (TPS) both for heat-protection requirements and for simplification of operational requirements. Development is required in tile and supporting structure materials, seals, and tile attachment methods. Thermal and stability modeling will also be required to verify and validate both biconic and aerobrake design parameters.

4-1.3.1 Materials and Structure

The shuttle represents the state of the art in TPS. Fibrous refractory composite insulation tiles are used over the aluminum structure for protection from reentry heating, except for the wing leading edges, which are made from advanced carbon-carbon. AFRSI (or Q felt), a flexible quilted quartz cloth, is used in more benign regions.

A distinction must be made between different TPS approaches. Options include both hot and cold structure approaches. In hot structures, the thermal and aerodynamic loads are accommodated with the same structure. In the cold structure approach, the structure that carries the aerodynamic loads is different from the structure that carries the thermal loads. The shuttle uses a cold structure approach (fibrous refractory composite insulation tiles for thermal loads over the aluminum structure that carries aerodynamic loads) except at the wing leading edges, which consist of the hot structure using advanced carbon-carbon.

Figure 4-1.3.1-1 contains a summary list of the materials with possible applicability for the STV. In general, ablators tend to be heavy, used in an expendable mode that requires additional refurbishment, and many contain organics that can outgas in space and pollute the local environment. Ablator thickness and material can be selected to support higher maximum temperature and heating loads than reusable tile materials but, based on the above considerations, were considered only if tile materials with the required capabilities were not available.

Under the refractory heat shield grouping are some of the many materials available for use in either hot or cold structure applications. Solid solution strengthened superalloys such as Inconel 617 or 625 and Hastelloy X exhibit the highest temperature resistance in the range of 1,800° to 2,200°F but have relatively low yield strengths. Precipitation hardened superalloys include materials such as Rene 41, Inconel 718, Waspaloy, M252 alloy, Udimet 500, and Haynes 263. These materials exhibit temperature resistance in the 1600° to 1900°F range and tend to have better strength characteristics. Conventional ingot melted alloys such as the various alpha-beta, near-alpha, and beta titanium alloys have temperature resistances in the 800° to 1000°F range.

In the Validated Cross Section program (contract number F33615-82-C-3202, Boeing Aerospace & Electronics with Air Force Wright Aeronautical Laboratories), a cryogenic tank cross section was developed with an Inconel 718 honeycomb lower surface. This tank was successfully tested to 1400°F. However, with STV aerobrake and reentry crew module temperature requirements in the 2,000° to 3500°F range and so the cold structure approach was selected.

Figure 4-1.3.1-2 lists issues for the materials that were primarily considered for the TPS. Concerns related to use of these materials is shown in Figure 4-1.3.1-3. Equilibrium temperatures for the (space-based concept) aerobrake are shown as a function of lift to drag in Figure 4-1.3.1-4 and as a function of ballistic coefficient in Figure 4-1.3.1-5, both with material limits noted.

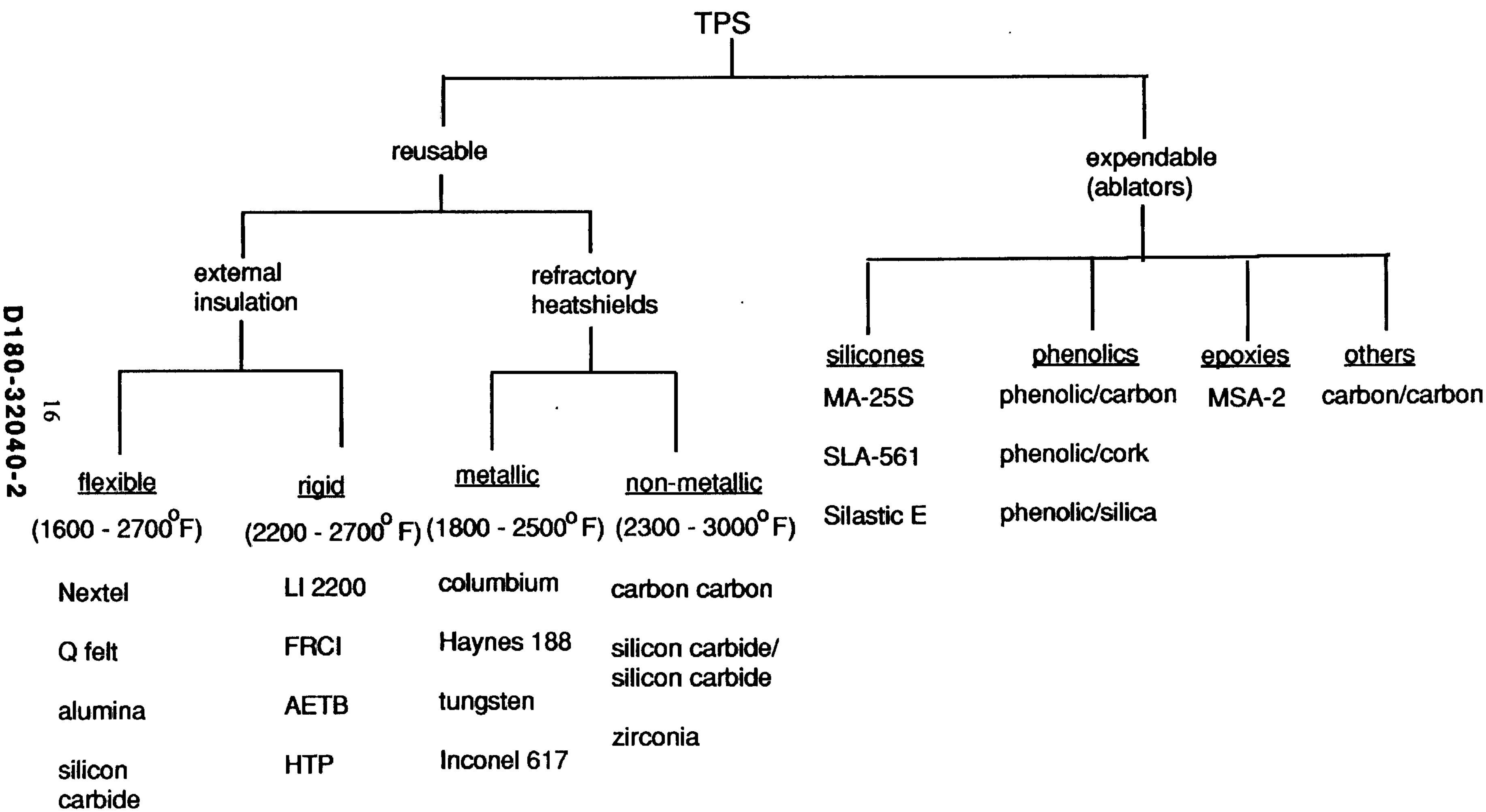


Figure 4-1.3.1-1. TPS Materials Options Tree

Material	Density (lb/ft3)	Max Temp °F	Issues
Advanced Carbon-Carbon	101	3200	Oxidation protective coating damage
Advanced Space Shuttle Tile (AETB)	12	2750	Small, bonded tiles, repair issues
Silicon Carbide/Silicon Carbide Composites	156	<3500	Attachment issues, need insulation
Boeing Zirconia/Hafnia Layered Fibrous Ceramics	16- 30	>3500	Large acreage potential, testing planned for '91
Flexible Insulation Blanket (TABI)	8	2600	Candidate for outer edges
Black Glas Ceramic Matrix Composite (Allied Signal)	137	<3500	Candidate for impact resistant skin. High carbon content silica matrix does not exhibit catastrophic softening

Figure 4-1.3.1-2. Aerobrake Materials Issues

AEROBRAKING MATERIALS CONCERNS

Material	Max Temp °F	Design concerns
Advanced Carbon-Carbon	3200	High temperature fasteners No insulation required
Advanced Space Shuttle Tile (AETB)	2750	No durability CTE mismatch with structural wall
Silicon Carbide/Silicon Carbide Composites	<3500	High temperature fasteners required
Boeing Zirconia/Hafnia Layered Fibrous Ceramics	>3500	Testing required Certification required
Flexible Insulation Blanket (TABI)	2600	Potential heat shorts at attachments Dynamic flutter
Black Glas Ceramic Matrix Composite (Allied Signal)	<3500	High temperature fasteners required Large components must be demonstrated Design allowables require developmental material

Figure 4-1.3.1-3. Aerobrake Materials Concerns

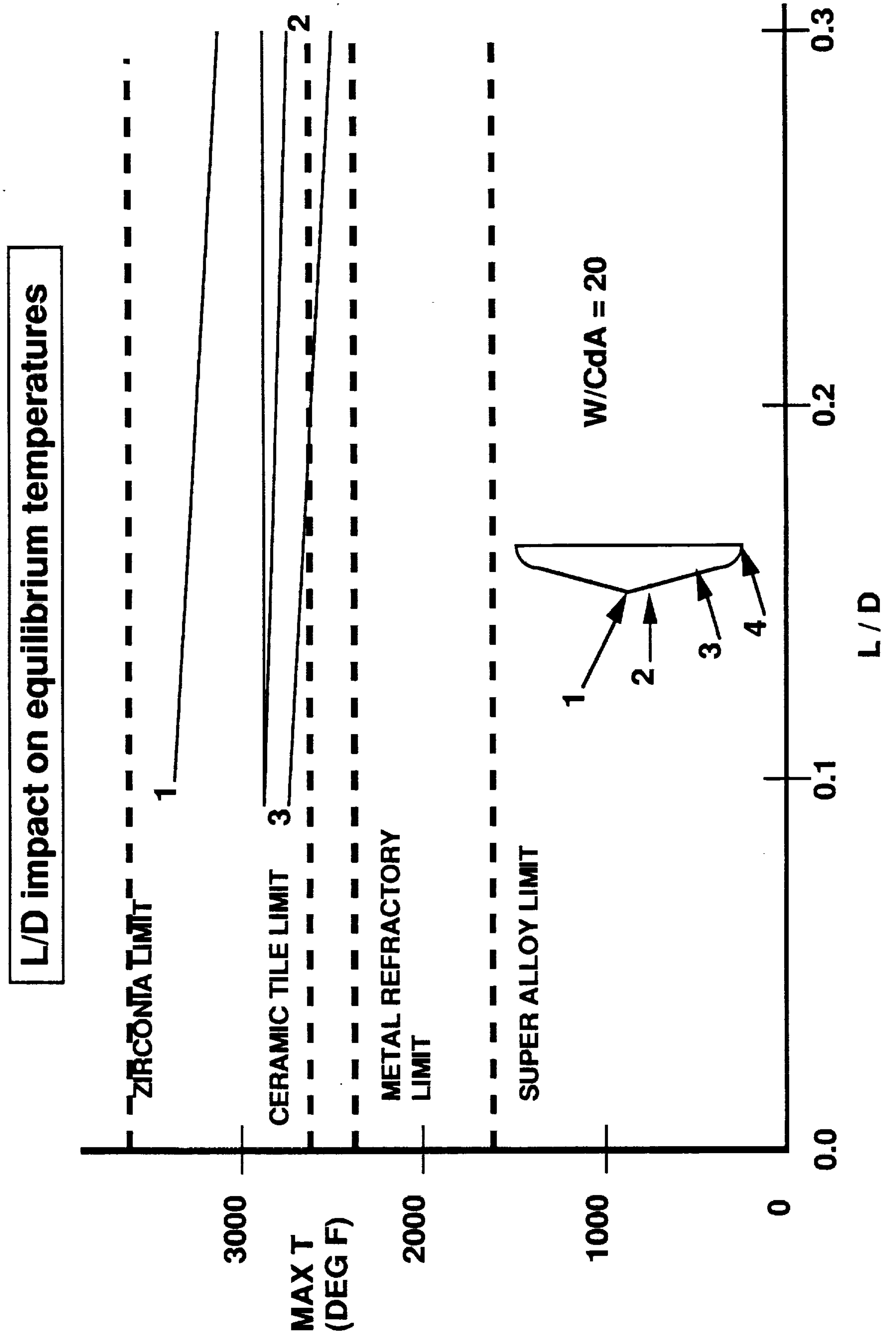


Figure 4-1.3.1-4. Aerobrake Equilibrium Temperature - L/D

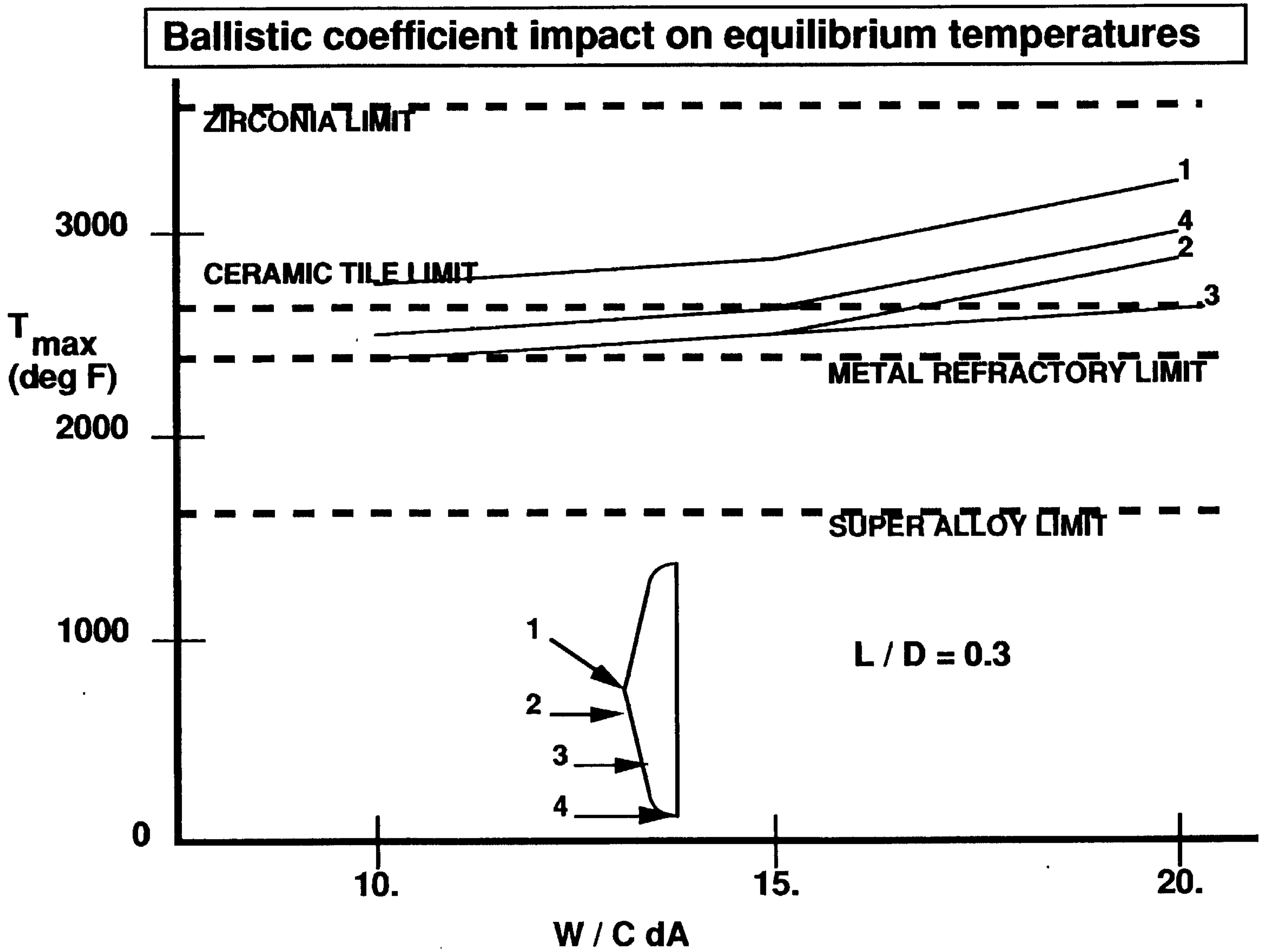


Figure 4-1.3.1-5. *Aerobrake Equilibrium Temperature - Ballistic Coefficient*

Equilibrium temperatures are shown for the (ground-based concept) biconic reentry crew module in Figure 4-1.3.1-6 with material limits noted. As can be seen from these figures, Zirconia will satisfy the requirements except for in the areas of the biconic nosecap. Options for use in this area include either an easily replaced sacrificial nose ablator or active cooling of the nosecap. One method of active cooling is to use Zirconia ceramic with a higher porosity than might be used elsewhere on the body and pump water through it to transpiration cool the vehicle nose.

Again, there are many material options for the underlying structure. The most commonly used material is aluminum as used on the shuttle. Aluminum presents a thermal expansion mismatch with the available tile materials requiring strain isolation between the structure and the tiles. Composite materials offer an alternative.

A wide variety of material systems are included in two categories of resin-matrix composites. Matrix materials include (1) thermosets such as epoxies, bismaleimides, polyimides, phenolics, and polyesters and (2) thermoplastics such as polyphenylene sulfide, polyetheretherketone, polyamideimide, and nylon. Reinforcement fibers used include graphite, boron, ceramic, and aramid. The reinforcement may consist of continuous fibers oriented in predetermined directions or randomly oriented discontinuous (chopped) fibers embedded in the matrix material.

Thermoset plastics develop their molecular structure upon curing. Once crosslinked (hardened) these polymers will decompose rather than melt when heated. Thermoplastics melt at high temperature and regain rigidity upon cooling. Because of this characteristic, processing of thermoplastic matrix composites differ from those of thermosets. Thermoplastics are heated and then formed and fused together under pressure in very short periods of time. Thermosets are formed to shape at room temperature and cured using heat and pressure.

A fabrication method where fiber orientation can be quite accurately controlled is ply layup. Ply layup using thermoset matrix is the most widely used form of continuous fiber resin matrix composites. Different layers can use unidirectional

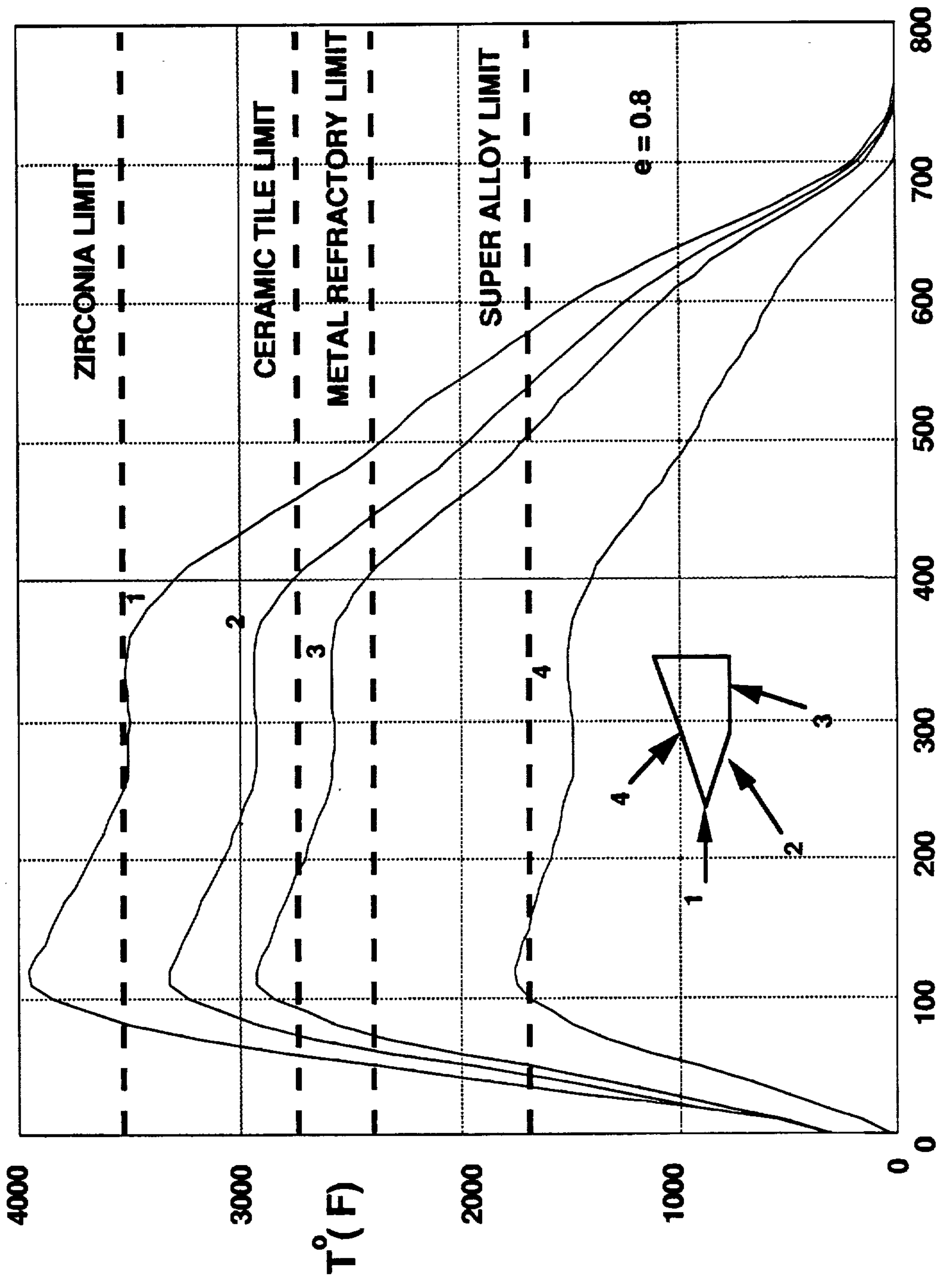


Figure 4-1.3.1-6. Biconic Equilibrium Temperatures

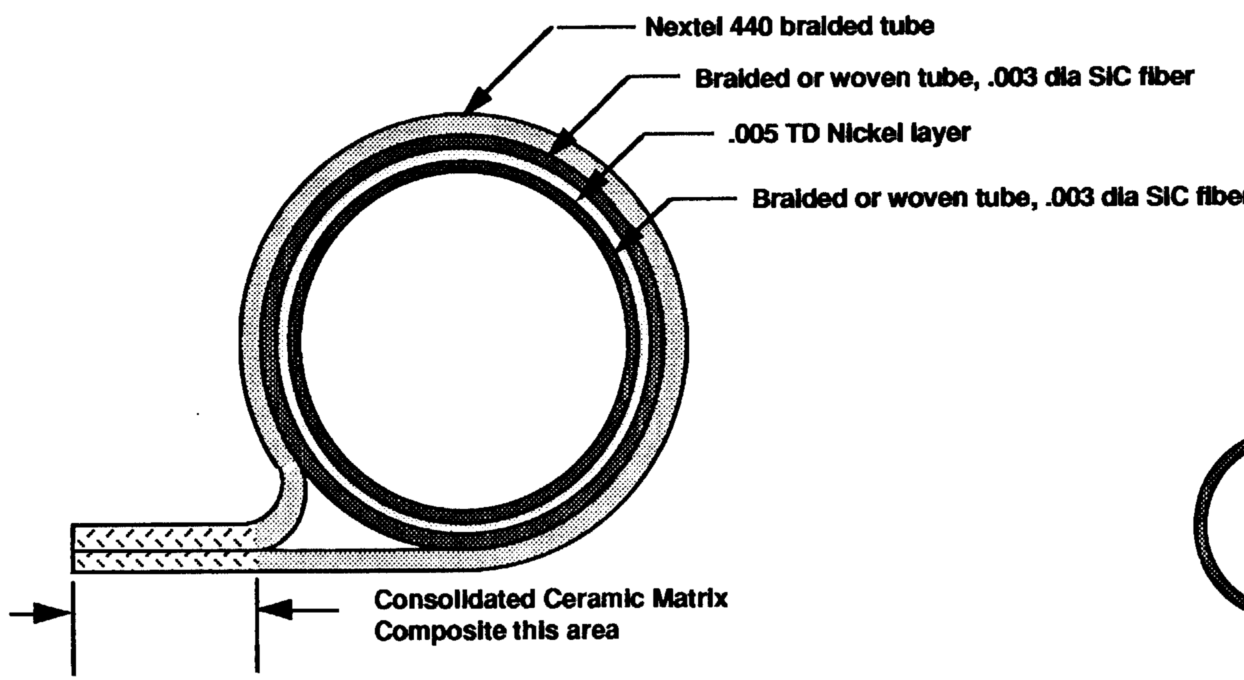
fibers or woven fibers. By selective orientation of the fibers in the different layers, mechanical properties including the coefficient of thermal expansion can be tailored. Thus, taking advantage of this process, thermal expansion mismatches between the TPS tiles and underlying structure can be virtually eliminated. The STV baselined a thermoset graphite polyimide (Gr/Pi) structure with a Gr/Pi honeycomb core and Gr/Pi facesheets because of: (1) surface temperature properties, (2) the capability to tailor the thermal expansion characteristics, and (3) the lightest weight.

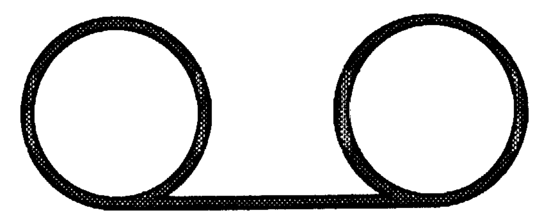
4-1.3.2 Attachment and Seals

The state of the art, indeed the only current and comparable system, of structure underlying a reentry TPS is the shuttle. The shuttle uses a cold structure concept except on the wing leading edges where the thermal loads and the aerodynamic loads are not handled by the same structure. In this situation, an aluminum structure underlies the rigid tile insulation. Strain isolation pads are necessary to accommodate thermal expansion mismatch between the tiles and the structure. Attachment of the tiles to the structure is a time-consuming process. Nomex strain isolation pads are first bonded to the aluminum structure with room temperature vulcanizating (RTV). The tiles are then attached to the pads with RTV. Gaps between the tiles are necessary to accommodate thermal expansion and these gaps are filled with various fillers (depending on location) such as Nextel.

Mechanical attachment of the Zirconia TPS to the underlying STV structure is desired to facilitate maintenance and refurbishment. Zirconia is a ceramic that is processed and manufactured at a relatively low temperature (approximately 800°F). A high-temperature metallic honeycomb (e.g., titanium) can be cast into the back surface of the ceramic. Metallic facesheets with integral mechanical fasteners can then be attached to the metallic honeycomb and with these fasteners, connected to the underlying structure.

Conceptual designs of high-temperature seals have been developed for the NASP program. Figure 4-1.3.2-1 shows an example of a seal envisioned for use on the aerobrake joints and penetrations. More work needs to be done in the areas of high-temperature seals and sealants for spaces between tiles.





Developed for other high temperature uses such as NASP these high temperature seals will prevent gas flow at joints

Figure 4-1.3.2-1. Aerobrake Seals

4-1.4 AVIONICS

Avionics is probably the area of most rapid technology advancement. The objectives for avionics technology development are to develop highly reliable, low-maintenance avionics capable of safe, autonomous operations and compatible with long-duration space exposure. Reductions in avionics power requirements and weight are also desired. Avionics technology can be addressed in three categories: components, networks, and the avionics subsystem-oriented areas.

Avionics Components. In application specific integrated circuits (ASIC), the state of the art is very large integrated circuits. ASICs use a chip with approximately 90% high-density standard cells such as ROMs, RAMs, ALUs, FIFOs, multiplers, and dual-port RAMs. Application specific designed circuits are then added as the top layer on the chip This allows a single chip to support both standardized and unique functions resulting in less chips and a lower part count and low-cost prototyping. Typical devices have more than 50,000 gates and can operate above 50 MHz. Reliability is enhanced by reducing the number of onboard connections. Packaging is enhanced, again by reducing part count, and power requirements are lower.

The baselined integrated circuits for the STV are radiation hardened and single-event upset (SEU) tolerant chips and wafers. Radiation hardness requires special design, layout features, and materials. SEU results in a memory state change from passage of galactic cosmic ray particles (electrons, protons, and nuclei of all elements) or solar flare (lower energy protons and alpha particles) through the memory cell. Submicron CMOS/silicon on sapphire (SOS) provides more radiation resistance than silicon alone. With long durations in space and on the lunar surface, and subsequent extended exposure to radiation, SOS is seen as providing a substantial benefit to the STV.

Traditional integrated circuits are produced by slicing a wafer of material off of a cylinder of the material. The wafer is then usually cut into rectangles, circuits are etched, and then the leads are attached. With the use of SOS wafer scale integration, the full wafer itself is used and these wafers can then be stacked like pancakes. This will allow what once were several boards to be combined on one wafer, with the resulting increases in reliability due to the reduction in outside connections. Processing density is increased and packaging is made much simpler, reducing volume requirements and enhancing maintenance, not to mention performance ranges of minisupercomputers in a "tuna can."

Fiber-optics sensors in conjunction with sensor networks show promise in reducing cost and weight and increasing reliability. Fiber-optic sensors are impervious to electrostatic discharge problems and also enhance safety by reducing electrical components in the vicinity of hazardous fluids. Sources include light emitting diodes (LED), currently used in a number of applications with PIN diodes used as receivers. Injection laser diodes (ILD) provide a stronger source with a coherent, monochrome light. These may be of benefit in a short-haul sensor network (less than 100m) when combining several sensors that use one source. Avalanche diodes, not yet space qualified, provide a more sensitive although less stable receiver. For many applications, the fiber-optic sensor concept is fairly simple using two coils: one sensing amplitude changes in the sensed parameter (temperature and pressure) and the other a time-delayed reference. The receiver senses the two light pulses to measure changes in sensed conditions independent of source or network variations.

One area of promise is the development of neural networks, which (with input data from multiple sensors) can generate an output signature for specific flight elements or for the entire vehicle. For example, multiple temperature measurements across a tank can be combined within a neural network with the output consisting of a tank signature (such as OK or not OK), localized hot spot, or localized cold spot. Neural networks also show promise in the area of fault tolerance with the large number of processing sites and interconnectivity making a failure in any individual neural site relatively unimportant. Neural networks show promise as a component in the vehicle health management system (VHMS) and in support of vehicle autonomy.

Navigation instrument advances have been baselined for the STV. The state of the art in gyros is represented by ring laser gyros (RLG). RLGs have flown on Boeing 757 and 767 commercial airplanes and have been used in space applications for the Ariane 4. RLGs use a single laser light source that sends laser beams in opposite directions around either a triad or rectangle of mirrors. A rotation of the RLG in the measured axis respectively lengthens and shortens the distance that the beams sent in opposite directions travel. This then creates a phase difference between the two beams of light that is measured and related to the rotation.

RLG accuracies are in the 0.01 to 0.02 degrees per hour range. Most RLGs are dithered or vibrated to prevent phase lock between the two light beams. Litton has produced a zero lock gyro (ZLG) that does not require dithering. This is accomplished by altering the plane (rectangle of mirrors) across one diagonal to change light polarization and addition of a Faraday coupler. An evacuated resonant cavity is used to house the optics. The cavities are relatively insensitive to thermal effects; however, path length controllers are used to negate any changes in the optical path distance.

Fiber-optic gyros (FOG) work on somewhat the same principle as RLGs; however, a winding (≈ 400m) of fiber-optic cable is used for the light path instead of the mirror system. Litton has tested FOGs down to an accuracy of 0.1 degree per hour with development work still being required. FOGs have the potential to have a higher reliability and lower weight. Dithering mechanisms, mirrors, and path length controllers are not required, thus reducing weight and, with fewer parts, increasing reliability. Also with the reduction in electrical parts, susceptibility to radiation induced SEUs is greatly reduced. Figure 4-1.4-1 provides an overview of the mechanical, RLG, and FOG gyrometers. The STV has baselined RLGs in a six RLG, six accelerometer skewed axis hexad inertial measurement unit; however, FOGs will be maintained as an option.

The state of the art in radar used for rendezvous and docking and potentially landing is the range/range rate Doppler radar used by the shuttle. STV will also use Doppler radar. Space-based Doppler radar as used in the shuttle is still fairly crude and will require further development. Advanced radar systems use a phased array of sensors place about the vehicle. Angle, range, and rates are resolved by sensing the phase difference among the multiple sensors. This eliminates the need for a bulky pedestal-mounted motor-driven dish. The STV may also include side-looking aperture radar (SLAR). SLAR is used on the

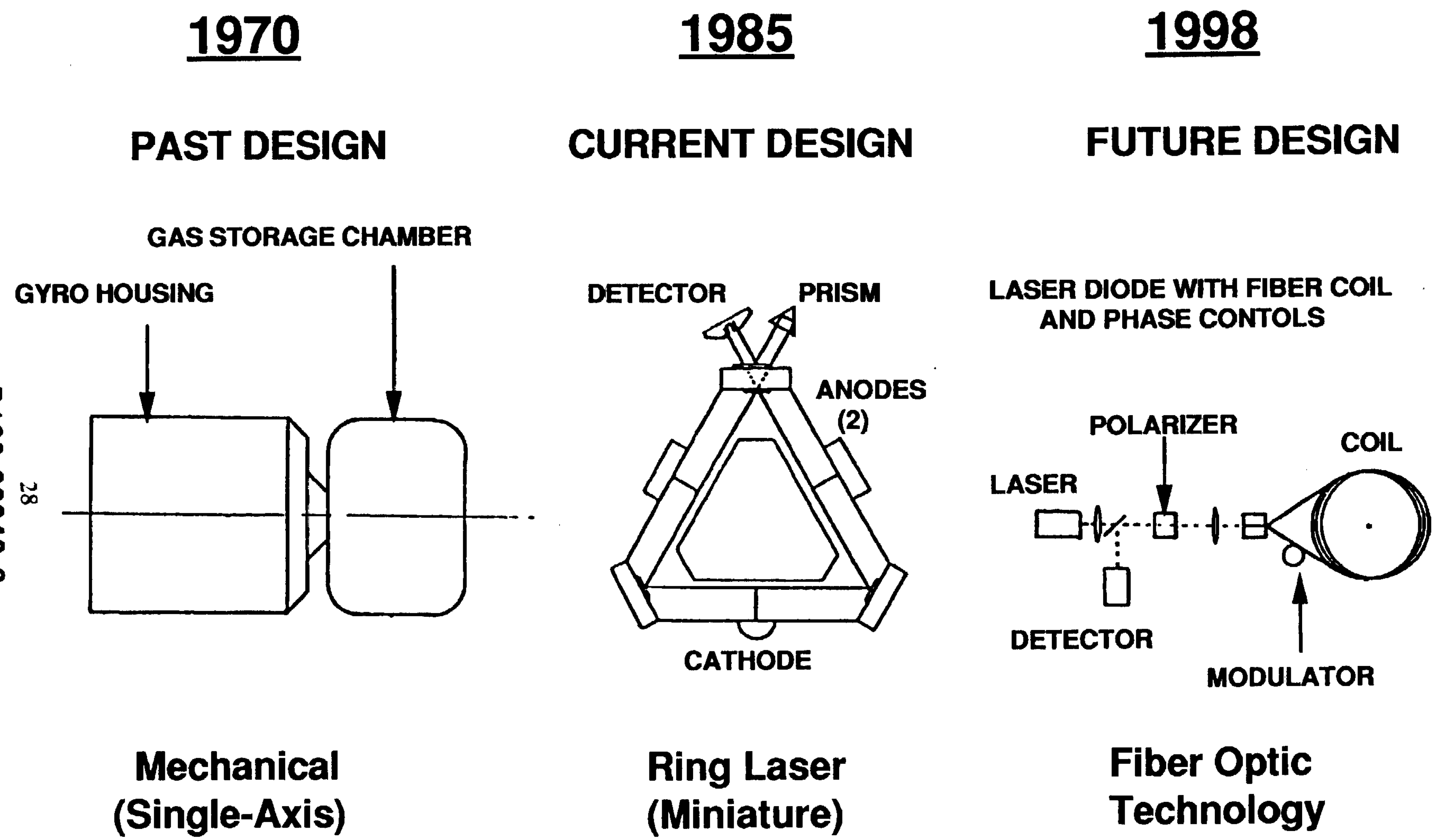


Figure 4-1.4-1. Inertial Measurement Hardware Evolution

Magellan spacecraft to map the surface of Venus. With multiple lunar orbit passes, the SLAR can build a map of the lunar surface terrain height features to support landing decisions.

Avionics Networks. Sensor networks include fiber-optic sensors, smart sensors, analog multiplexing techniques, digital multiplexing techniques, network components (wire/fiber media and connectors), and network interface units. Several fiber-optic sensors can be placed on a single network (transmit/receive) of fiber-optic cables. A network interface unit can then be used as a preprocessor, combining the information from several sensors, performing analog to digital conversions, and outputting the digital data information on a digital data bus. Benefits of using a sensor network of fiber-optic sensors or multisensors includes the reduction of weight and increases in reliability associated with reductions in the number of point-to-point wirings commonly used in current connection approaches. In addition, fiber-optic sensors can enhance safety when used to sense propellant levels without using electrical components within the tank.

Also of interest for the STV are higher speed digital data buses. Data buses again reduce point-to-point wiring and the associated reliability and weight concerns. To support the concept of "modular avionics," which allows technology changes, upgrades, and growth add-ons, the embedded networks must have high channel capacity, be very robust, and damage tolerant. A zero-downtime network will support long-duration missions with multiple sorties without maintenance. Fiber-optic digital data distribution networks (100 to 1,000 MIPs, multiple wavelength, active redundant) with separation of flight critical data from non-flight critical data are baselined. Depending on the physical size of each flight element of the space vehicle, the network may be either a linear bus, ring implementation, or a combination of both.

A third area of importance is the standardization of digital interfaces. Standardized interfaces support common test interface equipment and generally lower costs. In-space assembly or mate/demate/remate of flight elements is facilitated by standard interconnection systems. These in-space interfaces could be further eased if the digital data interface did not require electrical feedthroughs. An optical window with free space IR signals eliminates critical alignment requirements for mating pins and sockets of electrical contacts. If electrical power is not self-contained, the electrical power could be transferred across the interface by transformer action of a outside primary winding in close proximity to an inside secondary winding.

Avionics Subsystem Areas. STV autonomy requirements and the long durations spent in space will require a VHMS. VHM provides better vehicle availability and lower costs through automated launch processing. The operational status of the vehicle can be determined through all mission phases based on previous operating performance and built-in test (BIT). VHM also supports maintenance with fault isolation.

The VHMS is essentially distributed throughout the entire vehicle. VHMS consists primarily of sensing and monitoring functions and management functions. Sensing is primarily the domain of the avionics subsystem with monitoring being either a hardware or software area. The management functions can be software-based mission management rules and hardware based such as hardware-driven reconfiguration. VHMS is a concern of software and the entire avionics architecture as well as individual avionics components. Lewis Research Center has conducted some workshop activity with the intention of supporting an initiative in this area.

The state of the art in fault tolerant systems is represented by the shuttle. The shuttle uses a combination of hardware and software for fault tolerance in the flight critical subsystems. For example, four computers with software voting are all active. Failed computers are identified to the flight crew deck and may be taken off line. All four strings control the four inputs to flight actuators. An erroneous command is simply overpowered by three correct commands. The voting approach provides better vehicle stability than reconfiguration (either string or component), especially during highly time critical events such as major burns. Fault tolerant avionics in conjunction with common modules support mission success and vehicle maintenance. The STV has baselined a primarily photonic avionics system using common, avionics modules providing hardware voting. Application programers will not need to provide software for the voting.

Finally in the area of communication and tracking, the STV has baselined a radio/laser communication systems. A laser provides radiation-tolerant, high-speed secure communications and will be used for vehicle-to-vehicle, vehicle-to-ground, and other communications. Laser will also be used for docking. The state of the art in laser communications is Navy ship-to-ship antijam, secure links. These systems are point to point and require line of sight between sender and receiver. Radio communication data rates have been steadily increasing as a result of electronics technology and data- encoding schemes that increase the link margin between terminals. Adaptive communications provide robust link in presence of solar activity. Data compression hardware is reducing bandwidth requirements. For example, video compression chips can reduce the bandwidth requirements of NTSC (color) video by a factor of six.

The state of the art in communications support satellite systems is represented by the tracking and data relay satellite system (TDRSS). TDRSS has the capability to handle communications in the 300-Mbps range; however, subtracting the communications overhead leaves an approximate 180-Mbps data rate available for sending information. Availability of TDRSS is also a concern. Advanced TDRSS (ATDRSS) will be able to support a much higher data rate that STV will use to support color video, high amounts of scientific data transmittal, and so forth.

4-1.5 SOFTWARE

Software is characterized by the avionics. The primary new technology objective in software development is to develop adaptive GN&C algorithms with appropriate validation and verification methods. Adaptive GN&C also needs to be integrated with the appropriate sensor networks.

The state of the art in software is that used in the shuttle software/avionics design. The shuttle used the HAL/S software language, a language developed for, and used only on, the shuttle. Some manned Earth aircraft have been built for DoD agencies that incorporate new GN&C software, but these systems are classified or not man rated for space.

In the area of software development, an informal survey conducted by Boeing in 1988 identified approximately 640 different software development methodologies, the process by which software is designed and documented. Software development methodology is application dependent. Detailed functional analysis and software requirements will drive STV development methodologies.

There has been some work done in computer-aided software engineering (CASE). Integrated Systems Incorporated (ICI) has developed a series of software tools, primarily Matrix X, Autocode, and Hyperbuild, that have shown success in automated code generation for controls applications. These tools generate the necessary algorithms, but additional engineering is required to convert the algorithms to hard real-time (operations in the millisecond range) flight software. The ICI software-generation tools have had success in the laboratory in generating soft real-time (operations in the tenth of a second range) software, but engineering is still required for the final move to hard real-time code. With the AC100 hardware, the ICI software tools, and Boeing-added interface features, an applications generator has been developed that has been used for 1-1/2 to 2 years in the Space Station Freedom software support environment.

The state of the art in software control is either the cyclic executive used on the shuttle or standard task scheduling. Standard tasking is the normal event-driven, general-purpose tasking that the computing industry has known about for decades. Standard task scheduling is an asynchronous mechanism where the tasks are not cyclically scheduled but scheduled on an event such as a keystroke on a keyboard. The cyclic executive is driven by a timer interrupt and scheduling essentially cycles through a table of operations to be performed. Standard task scheduling and cyclic scheduling are sometimes used for applications in the same vehicle but are run on separate computers.

STV will be using the Ada language. Ada provides an Ada task scheduler, which is essentially a part of the executive program. The individual user must provide the additional executive functions required for the specific application. Ada is expected to reduce software maintenance requirements and commonality across development programs.

4-1.6 POWER

Objectives for power technology development are to support lightweight, reliable, power equipment development that integrates well with the vehicle, supports the total and peak loading requirements, and is instrumented to support VHM. The STV power subsystem baseline consists of fuel cells with lithium thionyl chloride ($LiSOCl_2$) batteries for handling peak loads required by the thrust vector control (TVC) system. With this approach, the fuel cells do not need to be sized for the high TVC load levels required over an extremely small portion of the mission. An alternative to using batteries for peak loading is to use a low-speed power source system to supply TVC power.

Batteries. The state of the art in space-qualified batteries are the silver zinc (AgZn) batteries used on the IUS (and the shuttle). The IUS batteries made by Yardney come in 13-, 100-, 140-, and 170-amp-hour sizes with two individual batteries being used in parallel to make up each of the 100-, 140-, and 170-amp-hour batteries. The batteries have an energy density in the range of 110 to 132 watt-hours/kg. While the storage life of the batteries is on the order of 10 years, the active life of the battery is from 35 to 90 days. This presents problems during launch delays where a swapout of the battery complement is required for extended delays.

AgZn batteries have a voltage dip characteristic caused by a peroxide charge associated with initial use. This characteristic can be handled in several ways. For ordnance type functions where sufficient, immediate power to ordnance devices is required, the batteries are predischarged to about 50% of capacity prior to use. Other techniques for handling the voltage dip is to bring the battery on line in parallel with another power source already on line or to incrementally add loads to the bus supplied by the battery.

Redundant pressure relief vents are provided on the AgZn battery; each cell is vented and the battery itself is vented. Several tests have been conducted with induced shorts to investigate the possibility of battery explosions. In tests where the battery case pressure relief device was failed closed, the leads from the individual cells to the electrodes melted open when the current was in the range of 400 to 800 amps. Additionally, the battery lid is more flexible than the case and will bow, letting gases vent past the O-rings. In summary, AgZn batteries are safe but tend to be relatively heavy and have operational problems related to active life considerations.

One option for future AgZn batteries is to extend the active life. The zinc electrodes develops dendrites that eventually will work through the separator material to contact the other electrode resulting in a short. Addition of separator material layers can extend the active life by providing more mechanical resistance to dendrites contacting the silver electrodes.

Currently in development by SAFT of France for Centaur is a 250-amp-hour $LiSOCl_2$ battery. Planned for qualification in December 1991, the $LiSOCl_2$ battery features an energy density of approximately 242 watt-hours/kg, almost twice that of the AgZn batteries with the resulting reduction in weight for the required power. JPL is also running a backup development effort with AlliantTechSystems and Yardney Technical Products. The JPL effort should qualify batteries within 6 months to 1 year after the qualification of the SAFT battery.

$LiSOCl_2$ batteries have superior life characteristics with an active life of approximately 7 years at 0°C and 1 year at ambient, precluding the operational concerns with battery swapout found with the AgZn batteries. The $LiSOCl_2$ batteries also show initial voltage dip characteristics, which can probably be handled in the same manner as with the AgZn batteries. In cases of a short and a thermal runaway condition, there have been some concerns with safety of the $LiSOCl_2$ batteries. Lithium is noxious and release of lithium into the immediate atmosphere is a concern. The SAFT battery features a soft plug or diaphragm with overpressure resulting in a guillotine puncturing the diaphragm for pressure release. Making the soft plug stiff enough to allow operation over a temperature range while not being too stiff to allow pressure relief when required is a design concern.

Power Source System. The low-speed power source system is an alternative approach to powering the TVC. Gaseous hydrogen is tapped off the autogenous tank pressurization line to drive a pneumatic gear motor, which in turn drives a wound-field generator. The third major component of the system is the generator control unit. Such systems are used in commercial aircraft and are well understood. The main difference between the existing systems and a proposed system is the hydrogen environment of the latter. Materials compatibility of STV power source system components would require development. This power source would use less than 10% of the energy in the GH2 pressurization line. Produced power would also be available for MPS valves, engine valves, and other sources.

Fuel Cells. Fuel cells use an electrochemical reaction to produce power. Gaseous O2 and H2 come into contact with their respective electrodes and combine, producing power and, as a byproduct, potable water. The state of the art in fuel cells is represented by the shuttle fuel cells made by International Fuel Cells, a subsidiary of United Technologies. The liquid O2 and H2 are stored in dewars, double-walled tanks with a vacuum between the walls. Heaters on the tanks are used to generate the gas, which is then drawn off for the reaction. The shuttle uses three fuel cells, any one of which can provide sufficient power (double redundancy). The three fuel cells weigh 273 kg, O2 tanks weigh 193 kg, H2 tanks weigh 207 kg, and the associated plumbing and mechanical hardware weigh 373 kg. With 355 kg of LOX and 42 kg of LH2, the total system weight is 1,443 kg.

The concerns with the current fuel cells are propellant quality and restart. Current electrodes can be poisoned by impurities within the reactants and require particularly clean O2/H2. Some development has been conducted to change the platinum and/or other rare earth components of the electrodes to allow use of propellant grade LOX/LH2. A single fuel source would reduce operational complexity and the weight associated with the dedicated dewars and plumbing required for the current systems. Integration of the fuel cell supply system with the integrated main propulsion/ACS is a potential growth option and provisions for integrating the systems should be considered in design. However, integration of the system is not currently baselined.

Problems with fuel cell restart are not fully understood. Between the electrodes is a separator material that needs to be moist to provide some electrical contact for starting fuel cell operation. One possibility for the fuel cell restart problems is that this separator material drys out and may not provide sufficient electrical contact to get the reaction running.

4-1.7 CREW MODULE SYSTEMS

Crew module designs need to be directed at special crew safety and comfort requirements of a deep space transportation vehicle. Crew modules must comply with NASA STD 3000 requirements. Additionally, crew module reuse will impose operational refurbishment requirements such as easy access and replacement. Effective radiation protection, high-reliability environmental control, fault tolerant backup systems, easily maintainable life support system elements, appropriate abort/emergency equipment, and sealed redundant control capability are required. Crew module architectures will require physical partitioning of primary and backup fluid supplies so failure of one system will not cause failure of the backup system.

The state of the art in environmental control and life support systems (ECLSS) is represented by the shuttle. A cabin atmosphere of 79% nitrogen and 21% oxygen is maintained at 14.7 psi. The atmosphere is supplied by a redundant O2/N2 supply system and an additional O2 emergency supply system is provided. The oxygen is carried in cryogenic form and tank heaters are used to produce gas as required with tank pressure maintained between 5,757 and 5,875 kPa (835 to 852 psi). N2 is carried as a gas at 22,700 kPa (3,300 psi). Sensors monitor cabin O2 partial pressure with O2 and N2 valves used to maintain the O2 partial pressure at 24 kPa (3.45 psi).

Atmospheric revitalization is accomplished by using fans to circulate the air through lithium hydroxide and activated charcoal filters. The lithium hydroxide reacts with metabolic byproduct CO2 to form lithium carbonate and water vapor. An air and water separator acts to remove humidity from the air. A centrifugal fan directs water condensate to the outside walls where pitot tubes draw off the water. The activated charcoal removes odors in the air. Trace contaminant control is accomplished with an ambient temperature catalytic oxidizer that primarily serves to remove any CO in the air.

Thermal control of the cabin is accomplished with a series of pipes and heat exchangers using water as the active fluid. Byproduct water (75 kg) from the fuel cells is stored in a tank and pumped through the supply/heat exchanger system. This water is then passed through a mid-fuselage water/Freon 21 heat exchanger and the excess heat is radiated to space through the Freon 21 radiators located in the cargo bay doors.

For fire detection and suppression, the shuttle uses ionization detectors located in each of the three avionics bays to sense combustion byproducts. Fire suppression is accomplished by means of both manual and switch activated fire extinguishers.

Current technologies are based on the shuttle, Skylab, and previous short duration Apollo hardware designs of 15 to 25 years ago. Several of the technologies used on the shuttle are available for use on the STV. Primary areas of concern with shuttle systems are the waste water dump where problems with freezing dump lines have been encountered. In the air and water separator, problems have occurred with blockage of the pitot tubes drawing off the separated water. The STV commode may be of a new design to provide a lighter, simpler system, possibly similar to that used on Skylab. The STV galley can be primarily off-the-shelf equipment packaged for the STV.

The state of the art in crew controls and displays is represented by reconfigurable liquid crystal displays (LCD). The LCDs can display graphical or numerical data and are driven by separate controllers for redundancy. The displays and pushbuttons are reconfigurable and would assist in reducing information overload by presenting only data applicable to the current flight phase. This technology requires low power and is state of the art in current military and commercial systems.

4-1.8 STRUCTURES, TANKAGE, AND AUXILIARY EQUIPMENT

Current structural technologies are based on the shuttle and advanced military airplane structures, which are proprietary or classified. Development of structural materials and methods will be required for the STV.

Composite putrusion/rib processes where composite fibers are pulled through a heated die and a resin bath will be used to build structural ribs. Additional development on metal-to-composite integration and advanced materials bonding will be required. Another development area is in the area of smart structures, such as the aerobrake with embedded sensors to relay information on material heating loads, degradation, maintenance requirements, and so forth. The STV will use aluminum-lithium (Al/Li) tankage with composite interstages. Al/Li provides a lighter, stronger tank structure. Development and verification of Al/Li welding processes is required and is being conducted for the HLLV program.

Auxiliary equipment such as disconnects and advanced materials fasteners are required. The aerobrake requires large hinges for packaging in the HLLV payload shroud and will need reliable hinges and deploy mechanisms. Cryogenics, electrical, and structural disconnects are required for tank staging and GB/GO concept vehicle staging of landing legs and engines.

A launch escape system (LES) is required for the GB/GO option. This system will act to pull (or push) the crew and crew module away from the launch vehicle in the event of a booster failure. LES development will be required for a system that integrates with both the STV and the booster and provides escape for the crew in time and within acceleration limits. Sensing of imminent booster failure will be required for activation of the LES.

4-1.9 TECHNOLOGY ASSESSMENT SUMMARY

Figures 4-1.9-1 through 4-1.9-20 provide a summary of the technology areas discussed above that require development to support the STV program. Also included are other space architecture elements that will benefit from the development of the selected technology.

Building Block	Space Transportation - Lunar Transportation System (LTS) Advanced Development Priority # 1 (tied with second place)		
Category	Cryogenic Propulsion	Area	Engine with Deep Throttling and Higher Isp Performance
Requirement	All LTS vehicle candidate configurations require special performance capabilities from the engines for the Lunar landing and takeoff and space storage phases of the mission.		
Inputs Needed	1) Deep Throttling 2) Modular Construction 3) Reliable Disconnects 4) High-temp. Bearings & Seals 5) Health Mgmt. Sensors & Controls 6) Expander Cycle/Pump Improvement		
State-of-the-Art (T-R-L)	Current technologies are based on Pratt & Whitney RL10-3-3 derivative used on Centaur upper stages. There has been some development done on the RL10 derivative engines (-A4 & -B2) without <u>deep</u> throttling. The AETB is important for component testing & data.		
Improvement Required	Engine selection is dependent on the number of engines in an LTS configuration and the vehicle propellant capacity related to a payload delivery goal (33 Mt to the Lunar surface). The LTS requirements are dependent upon an engine with a 468 to 481 Isp range.		
Architecture Dependency	All LTS vehicle configurations require an engine within the 468 to 481 Isp range to deliver the large payloads currently specified by the STV study sources at JSC/MASE.		
Development Time Required	5 Years (1992 to 1996) for the Lunar system; Mars - 10 Yrs.	Mission Need (start of C/D)	April, 1997
Benefits/ Spinoffs	The HLLV upper stage and STV space tug vehicles will require a more powerful engine without deep throttling, so only some of the technology improvements will be applicable. This is primarily an enabling technology for the Lunar and Mars landers.		

Figure 4-1.9-1. Main Propulsion Advanced Development Summary

Building Block	**Space Transportation - Lunar Transportation System (LTS) Advanced Development Priority # 1 (tied with second place)**		
Category	**Cryogenic Propulsion**		
Area	**Engine with Deep Throttling and Higher Isp Performance**		
Requirement	**All LTS vehicle candidate configurations require special performance capabilities from the engines for the Lunar landing and takeoff and space storage phases of the mission.**		
Included Technologies	**1) Advanced Expander/Throttling Tests 2) No-intrusive Sensors Fusion/Testbed 3) High Temp. Bearings Improvement 4) Engine Mission Life Testbeds 5) Long Term Exposure Verification 6) Extendable, Large Nozzel**		
State-of-the-Art (T-R-L)	**Current technologies are based on Pratt & Whitney RL10 derivatives used on Centaur upper stages. There has been some development done on the RL10 derivative engines (-A4 & -B2) without <u>deep</u> throttling. Current TRL is estimated to be at level 3 (2 for sensors).**		
Architecture Dependency	**All LTS vehicle configurations require an engine within the 468 to 481 Isp range to deliver the large payloads currently specified by the STV study sources at JSC/MASE.**		
Development Time Required	**3 Years (1992 to 1994) for the Lunar system; Mars - 8 Yrs.**	**Mission Need (start of C/D)**	**April, 1997**
Benefits/ Spinoffs	**The HLLV upper stage and STV space tug vehicles will require a more powerful engine without deep throttling, so only some of the technology improvements will be applicable. This is primarily an enabling technology for the Lunar and Mars landers.**		

Figure 4-1.9-2. Main Propulsion Technology Summary

Building Block	**Space Transportation - Lunar Transportation System (LTS) Advanced Development Priority # 2 (tied with first place)**		
Category	**Cryogenic Fluid Management**	**Area**	**Long Term Storage and Fluid Management**
Requirement	**All LTS and space-based STV systems require cryogenic fluid storage and controls up to 9 months duration in earth, low gravity, and Lunar gravity environments. Needed are specific testing data and design solutions for this critical performance/maintenance area.**		
Inputs Needed	**1) Tests & Simulations of Cryo Fluids in Low-G 2) TPCE & SOFTE Testing Completed 3) More Reliable Disconnects & Valves 4) Active/Passive Thermal Vent/Mix 5) Liquid Acquisition Management 6) Thermal Mapping & Testing**		
State-of-the-Art (T-R-L)	**Current technologies are based on equipment and methods used on Centaur Program upper stages and the STS Orbiter. Some development has been done on COLD-SAT Program studies which relates to LTS <u>tanker</u> requirements, but analysis is not finished.**		
Improvement Required	**Cryogenic engines require a highly reliable and flexible fuel storage and supply system for all LTS/STV derivatives. Current STS Orbiter and Centaur ground checkout problems and system faults highlight the urgency of this subsystem development being supported.**		
Architecture Dependency	**All LTS vehicle configurations with cryogenic engines need a safe, reliable, maintainable, fluid management and storage system. This technology area is a No. 1 maintenance and fault isolation item in repair and refurbishment timelines for the current STS Orbiters.**		
Development Time Required	**5 Years (1992 to 1996) for the Lunar system; Mars - 10 Yrs.**	**Mission Need (start of C/D)**	**April, 1997**
Benefits/ Spinoffs	**Every vehicle with cryogenic fluids in the architecture (HLLV, HLLV upper stage, Mars lander, Biconic PLS, both LTS basing concepts, the Cargo Transfer Vehicle, and some Lunar surface system vehicles) can benefit from this advanced development effort.**		

Figure 4-1.9-3. Cryogenic Fluid Management Advanced Development Summary

Building Block	Space Transportation - Lunar Transportation System (LTS) Advanced Development Priority # 2 (tied with first place)		
Category	Cryogenic Fluid Management		
Area	Long Term Storage and Fluid Management		
Requirement	All LTS and space-based STV systems require cryogenic fluid storage and controls up to 9 months duration in earth, low gravity, and Lunar gravity environments. Needed are specific testing data and design solutions for this critical performance/maintenance area.		
Included Technologies	1) Tests & Simulations of Cryo Fluids in Low-G 2) Verify Long Term Fluids Management 3) Damage Protection Methods Verification 4) Active/Passive TVS Testbeds 5) Reusable Seal M&P/Leak Sensors 6) Verify Coupler/Transfer Methods		
State-of-the-Art (T-R-L)	All LTS vehicle configurations with cryogenic engines need a safe, reliable, maintainable, fluid management and storage system. This technology area is a No. 1 maintenance cost reduction target for LTS vehicles. The technology readiness level ranges from 3 to 5.		
Architecture Dependency	This technology area is a current high maintenance and fault isolation item in repair and refurbishment timelines for the current STS Orbiters. Improvement to existing and future Space Transportation elements fluid management must be accomplished to reduce costs.		
Development Time Required	6 Years (1992 to 1997) for the Lunar system; Mars - 10 Yrs.	Mission Need (start of C/D)	April, 1997
Benefits/ Spinoffs	Every vehicle with cryogenic fluids in the architecture (HLLV, HLLV upper stage, Mars lander, Biconic PLS, both LTS basing concepts, the Cargo Transfer Vehicle, and some Lunar surface system vehicles) can benefit from this advanced development effort.		

Figure 4-1.9-4. Cryogenic Fluid Management Technology Summary

Building Block	Space Transportation - Lunar Transportation System (LTS) Advanced Development Priority # 3		
Category	Aeroassist/Aeromaneuver	Area	Thermal Protection Modeling and Materials
Requirement	All LTS vehicle candidate configurations require aeroassist modeling and selection of cost effective thermal protection materials to operate at the earth capture phase of the mission.		
Inputs Needed	1) Mirror High Density Refractory (HDR) Tiles 2) Mapping & Stability Modeling 3) Wind Tunnel/TPS Test Facilities Capability 4) High-temperature Sealants 5) Mechanical Attachment 6) Advanced Fiber Ceramics (M&P)		
State-of-the-Art (T-R-L)	Current technologies are based on STS Orbiter designs (tiles and sealants) and prior Apollo Program ablatives. There has been some work done by the DoD/DARPA on advanced TPS materials. Very little modeling has been accomplished using the latest LTS designs.		
Improvement Required	Thermal modeling is desired to verify and validate both biconic and aerobrake design parameters. There are no national test facilities to handle the large scale ground testing. Tile/paneling materials and process (M&P) development testing is a critical long lead item.		
Architecture Dependency	Both the aerobrake and advanced biconic crew module reusable elements of LTS/Mars vehicles require these technologies for safe return of the crew and expensive hardware.		
Development Time Required	5 Years (1992 to 1996) for the Lunar system; Mars - 10 Yrs.	Mission Need (start of C/D)	April, 1997
Benefits/ Spinoffs	The HLLV reuseable propulsion/avionics (P/A) module will require advanced aeroassist modeling, national test facilities, and M&P development to reduce operations costs. In addition, the Personnel Launch System and DoD/SDIO vehicle developments will benefit.		

Figure 4-1.9-5. Aeroassist Advanced Development Summary

Building Block	**Space Transportation - Lunar Transportation System (LTS) Advanced Development Priority # 3**		
Category	**Aeroassist/Aeromaneuver**		
Area	**Thermal Protection Modeling and Materials**		
Requirement	**All LTS vehicle candidate configurations require aeroassist modeling and selection of cost effective thermal protection materials to operate at the earth capture phase of the mission.**		
Included Technologies	**1) Heat Prediction & Mapping 2) Aero/Stability Modeling & Testing 3) Atmospheric Physics Simulations 4) High-temp. Sealant Development 5) Active Cooling Options Testing 6) Mirror HDR Materials Tests (M&P)**		
State-of-the-Art (T-R-L)	**Current technologies are based on new AFE designs (tiles and sealants) and STS Orbiter TPS materials and systems. There has been some work done by the DoD/DARPA on advanced TPS materials. Current technology readiness level is estimated at level 2.**		
Architecture Dependency	**Both the aerobrake and advanced biconic crew module reusable elements of LTS/Mars vehicles require these technologies for safe return of the crew and expensive hardware.**		
Development Time Required	**4 Years (1992 to 1995) for the Lunar system; Mars - 12 Yrs.**	**Mission Need (start of C/D)**	**April, 1997**
Benefits/ Spinoffs	**The HLLV reuseable propulsion/avionics (P/A) module will require advanced aeroassist modeling, national test facilities, and M&P development to reduce operations costs. In addition, the Personnel Launch System and DoD/SDIO vehicle developments will benefit.**		

Figure 4-1.9-6. Aeroassist Technology Summary

Building Block	Space Transportation - Lunar Transportation System (LTS) Advanced Development Priority # 4		
Category	Vehicle Avionics/Power	Area	Advanced Components, Packaging, & Distribution
Requirement	All LTS vehicle candidate configurations require reliable/maintainable power control and distribution, fault-tolerant avionics, reliable networks/buses, and effective packaging.		
Inputs Needed	1) Application Specific Integrated Circuits 2) Reliable, Autonomous GN&C Architecture 3) High-reliability, AutomatedTest Capability	4) Fiber Optic Components/Circuits 5) Fault-tolerant Power Distribution 6) Parallel/Vector/Neural Processing	
State-of-the-Art (T-R-L)	Current technologies are based on STS Orbiter avionics and power control architectures. Some unmanned spacecraft have been built for NASA and the DoD agencies which incorporate more sophisticated equipment, but are not man-rated for space.		
Improvement Required	Avionics architectures need to be more responsive to the manned systems requirements; must be highly reliable and, at the same time, SIMPLE in design to be maintained and operated as a reuseable system in an extended operational space radiation environment.		
Architecture Dependency	All architecture systems related to manned flight launch, transit, landing, ascent, or surface systems require the avionics and power management to be reliable and easily to maintain. These systems must also at a reasonable cost with short turnaround time.		
Development Time Required	5 Years (1992 to 1996) for the Lunar system; Mars - 10 Yrs.	Mission Need (start of C/D)	April, 1997
Benefits/ Spinoffs	HLLV, SSF upgrades, Lunar Surface Systems, MTV's will require cost effective avionics, reliable power management, quick fault isolation test capability, standardized data bus & network components, and accurate GN&C capabilities. PLS & ACRV will also benefit.		

Figure 4-1.9-7. Avionics and Power Advanced Development Summary

Building Block	Space Transportation - Lunar Transportation System (LTS) Advanced Development Priority # 4		
Category	Vehicle Avionics/Power		
Area	Advanced Components, Packaging, & Distribution		
Requirement	All LTS vehicle candidate configurations require reliable/maintainable power control and distribution, fault-tolerant avionics, reliable networks/buses, and effective packaging.		
Included Technologies	1) Wafer Technology Hardware 2) Advanced Navigation Instruments 3) Standard Interfaces Development 4) Fiber Optic Components Development 5) Fault-tolerant, "Voter" Testbed 6) Adaptive Guidance Development		
State-of-the-Art (T-R-L)	Current technologies are based on military and commercial aircraft components. Some unmanned spacecraft have been built for NASA and the DoD agencies which incorporate advanced technologies, but are not man-rated for space. TRL is estimated at levels 3-4.		
Architecture Dependency	All architecture systems related to manned flight launch, transit, landing, ascent, or surface systems require the avionics and power management to be reliable and easily to maintain. These systems must also at a reasonable cost with short turnaround time.		
Development Time Required	4 Years (1992 to 1995) for the Lunar system; Mars - 8 Yrs.	Mission Need (start of C/D)	April, 1997
Benefits/ Spinoffs	HLLV, SSF upgrades, Lunar Surface Systems, MTV's will require cost effective avionics, reliable power management, quick fault isolation test capability, standardized data bus & network components, and accurate GN&C capabilities. PLS & ACRV will also benefit.		

Figure 4-1.9-8. Avionics and Power Technology Summary

Building Block	Space Transportation - Lunar Transportation System (LTS) Advanced Development Priority # 5		
Category	System Software	Area	Flight & Ground Software, Test Application Software
Requirement	All LTS vehicle candidate configurations require flight software which is tailored to the "real-time compilers" and network systems. Software is characterized by the avionics.		
Inputs Needed	1) Compiler-specific Flight Programs 2) Expert Systems Test Software 3) Autonomous GN&C Algorithms/Test 4) Voting System Software (VHMS) 5) Computer-Aided Software Development 6) Neural Logic Application Software		
State-of-the-Art (T-R-L)	Latest technologies are based on STS Orbiter software/avionics architecture design. Some manned earth aircraft have been built for the DoD agencies which incorporate new GN&C and data bus software, but these systems are classified or not man-rated for space.		
Improvement Required	Software functions need to be responsive to the manned space system safety & abort requirements; software must be modular enough to be easily verified and maintained for inevitable mission profile changes and avionics subsystems upgrade.		
Architecture Dependency	All architecture systems related to manned flight launch, transit, landing, ascent, or test, and surface systems require the selected application softwares to be reliable, maintainable, and modular with standardized interface/network functions.		
Development Time Required	5 Years (1992 to 1996) for the Lunar system; Mars - 10 Yrs.	Mission Need (start of C/D)	April, 1997
Benefits/ Spinoffs	The greatest near-term benefits in software will most likely be to the HLLV command software (mission control), PLS (flight & ground), and ACRV. Longer-term benefits will include the commonalities with Mars vehicles and future planetary surface systems.		

Figure 4-1.9-9. Software Advanced Development Summary

Building Block	**Space Transportation - Lunar Transportation System (LTS) Advanced Development Priority # 5**		
Category	**System Software**		
Area	**Flight & Ground Software, Test Application Software**		
Requirement	**All LTS vehicle candidate configurations require flight software which is tailored to the "real-time compilers" and network systems. Software is characterized by the avionics.**		
Included Technologies	**1) Parallel Processing Software Testing 2) Expert Systems Software Demo.'s 3) Autonomous GN&C Simulations 4) Voting System Software Testbed 5) AI/Neural Database Development 6) Neural Logic Software Development**		
State-of-the-Art (T-R-L)	**Latest technologies are based on military and commercial application software projects. Some manned vehicle software technology applications have been developed for DARPA which incorporate neural/AI software. The TRL estimate is at level 3 (2 for GN&C).**		
Architecture Dependency	**All architecture systems related to manned flight launch, transit, landing, ascent, or test, and surface systems require the selected application softwares to be reliable, maintainable, and modular with standardized interface/network functions.**		
Development Time Required	**5 Years (1992 to 1996) for the Lunar system; Mars - 11 Yrs.**	**Mission Need (start of C/D)**	**April, 1997**
Benefits/ Spinoffs	**The greatest near-term benefits in software will most likely be to the HLLV command software (mission control), PLS (flight & ground), and ACRV. Longer-term benefits will include the commonalities with Mars vehicles and future planetary surface systems.**		

Figure 4-1.9-10. Software Technology Summary

Building Block	Space Transportation - Lunar Transportation System (LTS) Advanced Development Priority # 6		
Category	Crew Module Systems	Area	Advanced Control Consoles, ECLSS, Crew Support
Requirement	Manned LTS vehicle candidate configurations require reliable and highly operable life support systems, controls, and crew provisions in a restricted operations environment.		
Inputs Needed	1) Easily Maintainable LSS Elements 2) Sealed, Redundant Control Capability 3) High-reliability Environment Control 4) Effective Radiation Protection 5) Fault-tolerant Backup Systems 6) Abort/Emergency Equipment		
State-of-the-Art (T-R-L)	Current technologies are based on STS Orbiter, MIR station, Spacelab, and previous short-duration Apollo hardware designs of 15 to 25 years ago. Some Space Station Freedom (SSF) ECLSS research and development has been accomplished (to PDR).		
Improvement Required	Crew module designs need to be directed at the special crew safety and comfort requirements of a deep space transportation vehicle. There will most likely not be close in-flight rescue or supply systems that could respond within 24 hours of an emergency.		
Architecture Dependency	All space crew module or personnel transit systems which must comply with NASA STD 3000 and reusable crew cabin operational refurbishment requirements are effected.		
Development Time Required	6 Years (1992 to 1997) for the Lunar system; Mars - 12 Yrs.	Mission Need (start of C/D)	April, 1997
Benefits/ Spinoffs	The greatest benefits will be to the Personnel Launch System and the Mars transportation crew module(s). There are also benefits to SSF upgrades and international systems with crew cabins like Hermes. NASP and ACRV crew cabin upgrades will be benefit recipients.		

Figure 4-1.9-11. Crew Module Systems Advanced Development Summary

Building Block	Space Transportation - Lunar Transportation System (LTS) Advanced Development Priority # 6		
Category	Crew Module Systems		
Area	Advanced Control Consoles, ECLSS, Crew Support		
Requirement	Manned LTS vehicle candidate configurations require reliable and highly operable life support systems, controls, and crew provisions in a restricted operations environment.		
Included Technologies	1) Molecular Sieve Development 2) Smart Glove Control Experiments 3) Voice Activation Software 4) Radiation Protection Packaging 5) Flat Panels & Reconfigurable Displays 6) Improved Comode & Medical Equip.		
State-of-the-Art (T-R-L)	Current technologies are based on STS Orbiter, MIR station, Spacelab, and previous short-duration Apollo hardware. Some Space Station Freedom (SSF) ECLSS research and development has been accomplished (to PDR). Current TRL is estimated at level 4.		
Architecture Dependency	All space crew module or personnel transit systems which must comply with NASA STD 3000 and reusable crew cabin operational refurbishment requirements are effected.		
Development Time Required	5 Years (1992 to 1996) for the Lunar system; Mars - 10 Yrs.	Mission Need (start of C/D)	April, 1997
Benefits/ Spinoffs	The greatest benefits will be to the Personnel Launch System and the Mars transportation crew module(s). There are also benefits to SSF upgrades and international systems with crew cabins like Hermes. NASP and ACRV crew cabin upgrades will be benefit recipients.		

Figure 4-1.9-12. Crew Module Systems Technology Summary

Building Block	Space Transportation - Lunar Transportation System (LTS) Advanced Development Priority # 7		
Category	Vehicle Health Mgmt. System (VHMS)	Area	Sensors, Networks, Database, Control Software
Requirement	LTS vehicle candidate configurations require reliable, accurate, cost effective, safe, and flexible fault management and health monitoring equipment for extended Lunar missions.		
Inputs Needed	1) High Reliability VHMS Sensors 2) Expert Systems Test Software 3) Artificial Intellegence (Learning) 4) Network Interface Units & Fiber Optics 5) Reliable Mass Memory Units & Processing 6) Neural Networks & Sensor Fusion		
State-of-the-Art (T-R-L)	Current technologies are based on some manned earth aircraft which have been built for the DoD agencies. These projects incorporate new VHMS designs, but the systems are classified or not man-rated for space (unmanned space platforms).		
Improvement Required	VHMS functions and hardware need to be responsive to the manned space system safety & abort requirements; they must be high-reliability rated, ruggedized, and single-event disruption immune to survive the environmental hazards of prolonged space exposure.		
Architecture Dependency	All architecture systems related to manned flight launch, transit, landing, ascent, or test, and surface systems require VHMS to be safe, reliable, and maintainable, as well as to cost effectively accomplish refurbishment and system checkout tasks.		
Development Time Required	5 Years (1992 to 1996) for the Lunar system; Mars - 10 Yrs.	Mission Need (start of C/D)	April, 1997
Benefits/ Spinoffs	Near-term benefits in technology application will most likely be to the HLLV/PLS (flight & ground checkout) and ACRV health management (while in space storage). Long-term benefits will include Mars and future planetary surface systems VHMS applications.		

Figure 4-1.9-13. VHMS Advanced Development Summary

Building Block	Space Transportation - Lunar Transportation System (LTS) Advanced Development Priority # 7		
Category	Vehicle Health Mgmt. System (VHMS)		
Area	Sensors, Networks, Database, Control Software		
Requirement	LTS vehicle candidate configurations require reliable, accurate, cost effective, safe, and flexible fault management and health monitoring equipment for extended Lunar missions.		
Included Technologies	1) Improved Sensors Reliability 2) Expert Systems Software Demo.'s 3) Artificial Intellegence Testbed 4) Logic Circuits Development & Testing 5) VHMS Database Spec. & Control S/W 6) Common Module & Sensor Fusion Testbed		
State-of-the-Art (T-R-L)	Current technologies are based commercial projects and aircraft which have been built for DoD agencies. These projects incorporate new VHMS concepts, but the systems have low capability, or not man-rated for space (unmanned). Current TRL is estimated at level 3.		
Architecture Dependency	All architecture systems related to manned flight launch, transit, landing, ascent, or test, and surface systems require VHMS to be safe, reliable, and maintainable, as well as to cost effectively accomplish refurbishment and system checkout tasks.		
Development Time Required	4 Years (1992 to 1995) for the Lunar system; Mars - 8 Yrs.	Mission Need (start of C/D)	April, 1997
Benefits/ Spinoffs	Near-term benefits in technology application will most likely be to the HLLV/PLS (flight & ground checkout) and ACRV health management (while in space storage). Long-term benefits will include Mars and future planetary surface systems VHMS applications.		

Figure 4-1.9-14. VHMS Technology Summary

Building Block	Space Transportation - Lunar Transportation System (LTS) Advanced Development Priority # 8		
Category	Integrated Propulsion, RCS, Power Systems	Area	Common LO_2/LH_2 Fuels and Fluid Management
Requirement	All LTS and space-based STV systems require cryogenic fluid supply and controls up to 9 months duration in earth, low gravity, or Lunar gravity environments. Needed is a common equipment fuel and feed system which is easier to fuel and maintain.		
Inputs Needed	1) Advanced O_2/H_2 Thruster Development 2) Pressurization/Control Testing 3) Disconnect & Valve Commonality 4) Fault-tolerant Cross Feed Capability 5) Computer-Aided Design Databases 6) Integrated Systems Testbed		
State-of-the-Art (T-R-L)	Current technologies are based on equipment and methods used on several upper stages and the STS Orbiter. Some development has been done on the Space Station Freedom Program C/D which relates to LTS requirements, but it was cancelled.		
Improvement Required	Current mixed fuel systems are toxic, maintenance intensive, hard to refurbish if contaminated, and less desireable for in-space fuel supply requirements. Lunar in-situ resource capability of producing LO_2 may make this technology look even more desireable.		
Architecture Dependency	All LTS vehicle configurations with cryogenic fluids could benefit from a common fuel, common supply equipment, redundant, integrated propulsion/reaction control/power system. This technology area has great potential to reduce total operational complexity.		
Development Time Required	6 Years (1992 to 1997) for the Lunar system; Mars - 10 Yrs.	Mission Need (start of C/D)	April, 1997
Benefits/ Spinoffs	Most vehicles with cryogenic fluids in the architecture (HLLV upper stage, Mars lander, Biconic PLS, both LTS basing concepts, the Cargo Transfer Vehicle, and some Lunar surface hoppers) can benefit from this advanced development effort.		

Figure 4-1.9-15. Integrated Systems Advanced Development Summary

Building Block	Space Transportation - Lunar Transportation System (LTS) Advanced Development Priority # 8		
Category	Integrated Propulsion, RCS, Power Systems		
Area	Common LO_2/LH_2 Fuels and Fluid Management		
Requirement	All LTS and space-based STV systems require cryogenic fluid supply and controls up to 9 months duration in earth, low gravity, or Lunar gravity environments. Needed is a common equipment fuel and feed system which is easier to fuel and maintain.		
Included Technologies	1) Advanced O_2/H_2 Thruster Components 2) Integrated Manifold Methods 3) Disconnect & Valve Standardization 4) Fault-tolerant Cross Feeds Testing 5) Acquisition/Transfer Experiments 6) Integrated Systems Testbed		
State-of-the-Art (T-R-L)	Current technologies are based on equipment and methods used on several upper stages and the STS Orbiter. Some development has been done on Space Station Freedom which relates to LTS requirements, but it was cancelled. The TRL is estimated at level 4-5.		
Architecture Dependency	All LTS vehicle configurations with cryogenic fluids could benefit from a common fuel, common supply equipment, redundant, integrated propulsion/reaction control/power system. This technology area has great potential to reduce total operational complexity.		
Development Time Required	3 Years (1992 to 1994) for the Lunar system; Mars - 8 Yrs.	Mission Need (start of C/D)	April, 1997
Benefits/ Spinoffs	Most vehicles with cryogenic fluids in the architecture (HLLV upper stage, Mars lander, Biconic PLS, both LTS basing concepts, the Cargo Transfer Vehicle, and some Lunar surface hoppers) can benefit from this advanced development effort.		

Figure 4-1.9-16. Integrated Systems Technology Summary

Building Block	**Space Transportation - Lunar Transportation System (LTS) Advanced Development Priority # 9**		
Category	**Structures, Tankage, & Auxiliary Equipment**	**Area**	**Advanced Composites, Smart Structure, Dissimilar Materials**
Requirement	LTS vehicle core elements, tankage, and aerobrakes require structural modeling and selection of strong, flexible materials to operate in all phases of the Lunar mission.		
Inputs Needed	1) Graphite Polyimide Shapes & Processes 2) Modular Deployment/Vehicle Structures 3) Large Stuctures Test/Tooling Capability 4) Imbedded, "Smart" Sensors (VHMS) 5) Aluminum-Lithium Welding Methods 6) Advanced Materials Bonding (M&P)		
State-of-the-Art (T-R-L)	Current technologies are based on STS Orbiter stuctural materials or advanced military airplane stuctures which are proprietary or classified. Very little M&P testing has been accomplished using the latest LTS or Mars System advanced structural designs.		
Improvement Required	Structural modeling is desired to identify and study tankage, stage and aerobrake safe design parameters. There are few national test facilities to handle the large scale dynamic testing. Dissimilar integration of materials M&P development is a long lead item.		
Architecture Dependency	The tankage, aerobrake and advanced biconic crew module reusable elements of LTS/Mars vehicles require these technologies for developing strong, high quality, and repairable deep space transportation system vehicles.		
Development Time Required	5 Years (1992 to 1996) for the Lunar system; Mars - 10 Yrs.	**Mission Need (start of C/D)**	April, 1997
Benefits/ Spinoffs	The HLLV tankage and structures development will benefit from these advanced development analytical efforts and static/dynamic tests. All space elements exposed to space debris, oxidation, and radiation/thermal cycles will benefit from these efforts.		

Figure 4-1.9-17. Structures Development Summary

Building Block	Space Transportation - Lunar Transportation System (LTS) Advanced Development Priority # 9		
Category	Structures, Tankage, & Auxiliary Equipment		
Area	Advanced Composites, Smart Structure, Dissimilar Materials		
Requirement	LTS vehicle core elements, tankage, and aerobrakes require structural modeling and selection of strong, flexible materials to operate in all phases of the Lunar mission.		
Included Technologies	1) Composites Pultrusion/Rib Processes 2) Metal Matrix Materials (M&P) 3) Metal-to-composites Integration Tests 4) Imbedded Fiber Optic/Sensor Panels 5) Aluminum-Lithium Welding Tests 6) Advanced Materials Bonding (M&P)		
State-of-the-Art (T-R-L)	Current technologies are based on STS Orbiter stuctural materials or advanced military airplane stuctures which are proprietary or classified. The TRL is estimated at levels 6-8.		
Architecture Dependency	The tankage, aerobrake and advanced biconic crew module reusable elements of LTS/Mars vehicles require these technologies for developing strong, high quality, and repairable deep space transportation system vehicles.		
Development Time Required	3 Years (1992 to 1994) for the Lunar system; Mars - 8 Yrs.	Mission Need (start of C/D)	April, 1997
Benefits/ Spinoffs	The HLLV tankage and structures development will benefit from these advanced development analytical efforts and static/dynamic tests. All space elements exposed to space debris, oxidation, and radiation/thermal cycles will benefit from these efforts.		

Figure 4-1.9-18. Structures Technology Summary

Building Block	Space Transportation - Lunar Transportation System (LTS) Advanced Development Priority # 10		
Category	Structures, Tankage, & Auxiliary Equipment	Area	High-reliability Hinges, Latches, and Deploy Mechanisms
Requirement	LTS vehicle core elements, tankage, and aerobrakes require effective and reliable staging attachment/detachment and deploy mechanisms for Lunar and STV missions accomplishment.		
Inputs Needed	1) Fault-tolerant Disconnect Verification 2) Advanced, Redundant Latching Concepts 3) Large Aerobrake Hinge Testbed 4) In-space Interfaces Verification 5) Non-explosive Detachment Methods 6) Advanced Materials (M&P)		
State-of-the-Art (T-R-L)	Current technologies are based on STS Orbiter staging or attachment hardware as well as varius unmanned satellite and upper stage hardware. Very little M&P testing has been accomplished using the latest LTS or Mars System tankage or vehicle staging concepts.		
Improvement Required	Hardware model testing is desired to identify and study tankage, stage and aerobrake safe separation concepts. Expansion of existing SSF test projects in the mechanisms area is desired to cover other critical LTS and Mars system development requirements.		
Architecture Dependency	The tankage, aerobrake/biconic crew module and stage reusable elements of LTS/Mars vehicles require these technologies for developing reliable, man-rated, and repairable space transportation mechanical interface, assembly and detachment hardware.		
Development Time Required	5 Years (1992 to 1996) for the Lunar system; Mars - 10 Yrs.	Mission Need (start of C/D)	April, 1997
Benefits/ Spinoffs	The HLLV tankage and structures separation/connect design will benefit from the testing of large scale latches and deployment mechanisms. All space elements requiring staging in a potential debris and critical mechanical interface environments will benefit.		

Figure 4-1.9-19. Mechanisms Advanced Development Summary

Building Block	Space Transportation - Lunar Transportation System (LTS) Advanced Development Priority # 10		
Category	Structures, Tankage, & Auxiliary Equipment		
Area	High-reliability Hinges, Latches, and Deploy Mechanisms		
Requirement	LTS vehicle core elements, tankage, and aerobrakes require effective and reliable staging attachment/detachment and deploy mechanisms for Lunar and STV missions accomplishment.		
Included Technologies	1) Fault-tolerant Disconnects Testing 2) Advanced Latching Components Test 3) Large Aerobrake Hinge Demonstration 4) In-space Interfaces Simulations 5) Launch Escape Modeling 6) Advanced Materials/Fasteners (M&P)		
State-of-the-Art (T-R-L)	Current technologies are based on STS Orbiter staging or attachment hardware as well as varius unmanned satellite and upper stage hardware. SSF technology testing could be expanded to incorporate some LTS/Mars concepts. The TRL is estimated at levels 3 to 7.		
Architecture Dependency	The tankage, aerobrake/biconic crew module and stage reusable elements of LTS/Mars vehicles require these technologies for developing reliable, man-rated, and repairable space transportation mechanical interface, assembly and detachment hardware.		
Development Time Required	5 Years (1992 to 1996) for the Lunar system; Mars - 10 Yrs.	Mission Need (start of C/D)	April, 1997
Benefits/ Spinoffs	The HLLV tankage and structures separation/connect design will benefit from the testing of large scale latches and deployment mechanisms. All space elements requiring staging in a potential debris and critical mechanical interface environments will benefit.		

Figure 4-1.9-20. Mechanisms Technology Summary

4-2.0 ADVANCED INTEGRATED TECHNOLOGY PLANNING

Introduction. During the STV study, advanced technology development requirements and plans have been addressed by the Technology/Advanced Development Working Group composed of NASA and contractor representatives. This section and the preceding section (section 4-1.0) of the STV Final Report discuss the results to date of this working group.

The objective for the Integrated Advanced Technology Development Plan is to provide planning to support technology funding levels and development schedules required to ensure that technology for the STV program will be ready for application within STV schedule constraints. With this in mind, readiness levels for the technology identified in section 4-1.0 is presented along with an integrated phase C/D technology network plan. Figure 4-2.0-1 gives a definition of the technology readiness level definitions used in the schedules. The general objective of the planning is to have the required technology at a technology readiness level of 6 by 1996.

4-2.1 PROPULSION

The objectives of main engine technology development are to develop deep throttling, increase Isp, support reusability and low-maintenance requirements, ensure compatibility with long-duration space exposure, provide engine instrumentation that supports VHM requirements, and maintain or improve on the reliability of current systems. Technology development is required in the areas of high-speed turbopump seals and bearings and in seals and materials compatible with long-term space exposure. Standardized, simple interfaces and disconnects are required and non-intrusive main engine sensor development is needed. The main engine technology plan and estimated resource requirements are shown in Figure 4-2.1-1.

The objective in attitude control is to develop the technology required for high-performance gaseous O2/H2 thrusters that integrate well with the rest of the vehicle and are instrumented to support VHM. Additionally, the ACS propellant accumulator fluid system will require development. Figure 4-2.1-2 presents the

Level	Level Description
1	Basic Principles Observed and Reported
2	Conceptual Design Formulated
3	Conceptual Design Tested Analytically or Experimentally
4	Critical Function/Characteristic Demonstration
5	Component Brassboard Tested in Relevant Environment
6	Prototype/Engineering Model Tested in Relevant Environment
7	Engineering Model Tested in Space
8	"Flight-Qualified" System
9	"Flight-Proven" System

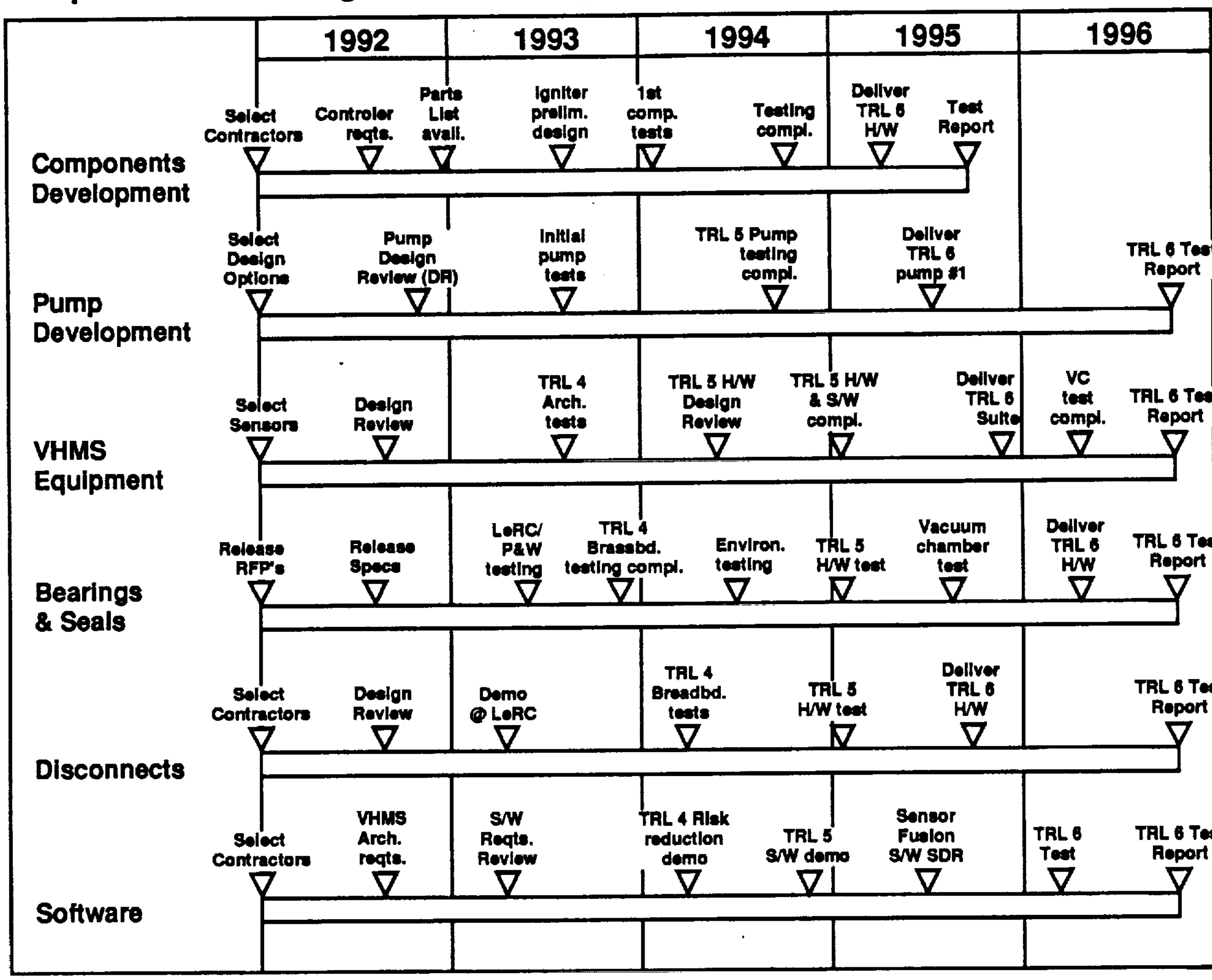
Technology Development

Advanced Development

Flight Systems

Figure 4-2.0-1. Technology Maturity Levels

Propulsion/Main Engine Technology Development



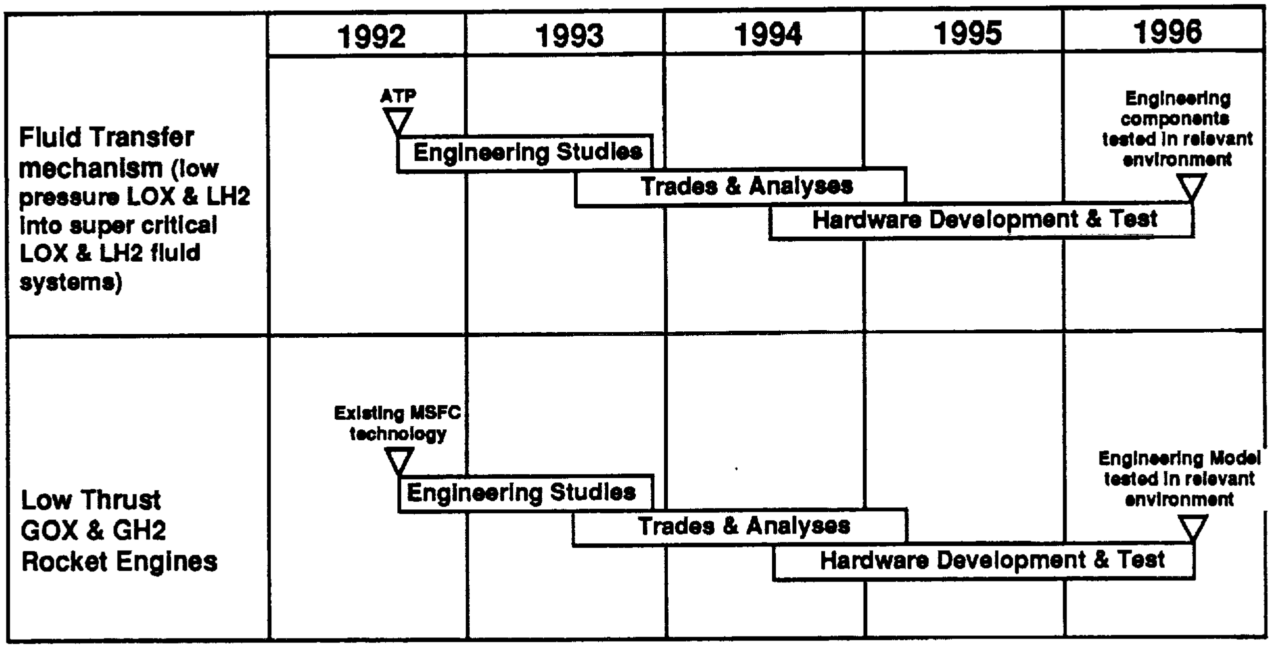
- **Estimated Resource Requirements - 1991 Dollars in Millions**

ETP	15.0	10.0	10.0	--	--
Advanced Development	5.0	10.0	30.0	36.0	46.0

- **Excludes the Advanced Expander Testbed Funding (AETB), which is already in process**

Figure 4-2.1-1. Main Engine Technology Development

Attitude Control System (ACS) Technology Development



• **Estimated Resource Requirements - 1991 Dollars in Millions**

ETP *	0.1	0.1	0.2	0.2	0.5
Advanced Development	--	0.2	1.0	2.0	3.0

* Input from Aerojet, first four years only for Lewis Research Center support on ETP projects.

Figure 4-2.1-2. Attitude Control System Technology Development technology schedule and estimated resource requirements for attitude control technology and advanced development.

4-2.2 CRYOGENIC FLUID SYSTEMS

In the area of cryogenic fluid systems, development is required for pressure control with the thermodynamic vent system, propellant gaging with the PVT gaging system, and zero gravity fluid transfer, which is required for the space-based vehicle concept. Reliable, reusable cryogenic valves and disconnects are required and the combined MLI/foam insulation system requires development. Figure 4-2.2-1 presents the technology schedule and estimated resource requirements for cryogenic fluid systems technology and advanced development.

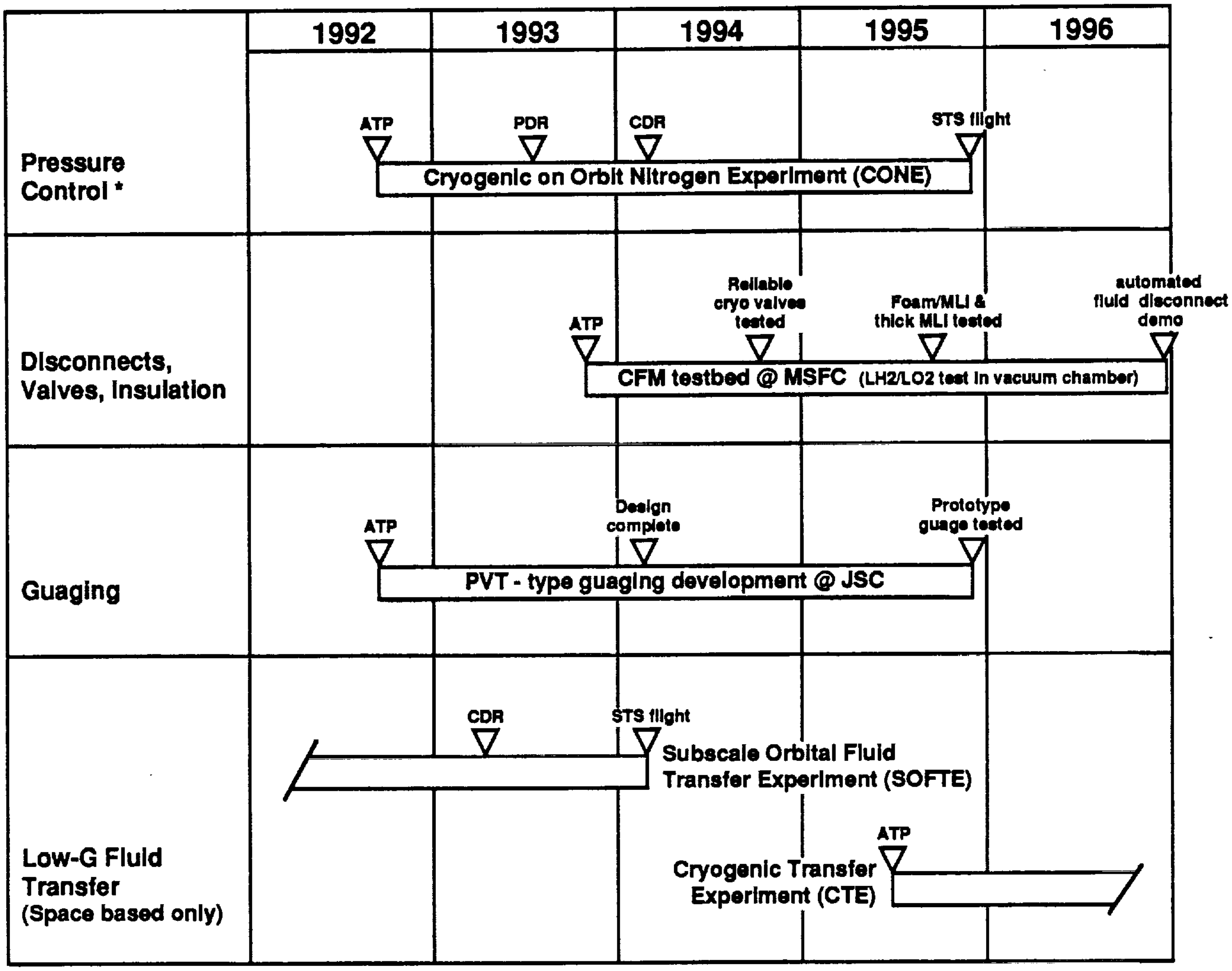
4-2.3 AEROASSIST AND AEROMANEUVER

The objectives for technology development in the aeroassist and aeromaneuver category is to provide advances in thermal protection systems (TPS) both for heat-protection requirements and for simplification of operational requirements. Development is required in tile and supporting structure materials, seals, and tile attachment methods. Thermal and stability modeling will also be required to verify and validate both biconic and aerobrake design parameters. Figure 4-2.3-1 shows the development requirements for aeroassist structures, materials, and seals and those for aeroassist modeling are shown in Figure 4-2.3-2.

4-2.4 AVIONICS

The objectives for avionics technology development are to develop highly reliable, low-maintenance avionics capable of safe, autonomous operations compatible with long-duration space exposure. Reductions in avionics power requirements and weight are also desired. Development is required in photonics, avionics networks and data buses, vehicle health monitoring system sensors and networks, and modularity of components with standardized interfaces. Laser communications capability and ATDRSS compatibility are also required. Figure 4-2.4-1 shows the development schedule and estimated resources for the avionics.

Cryogenic Fluid Systems Technology Development



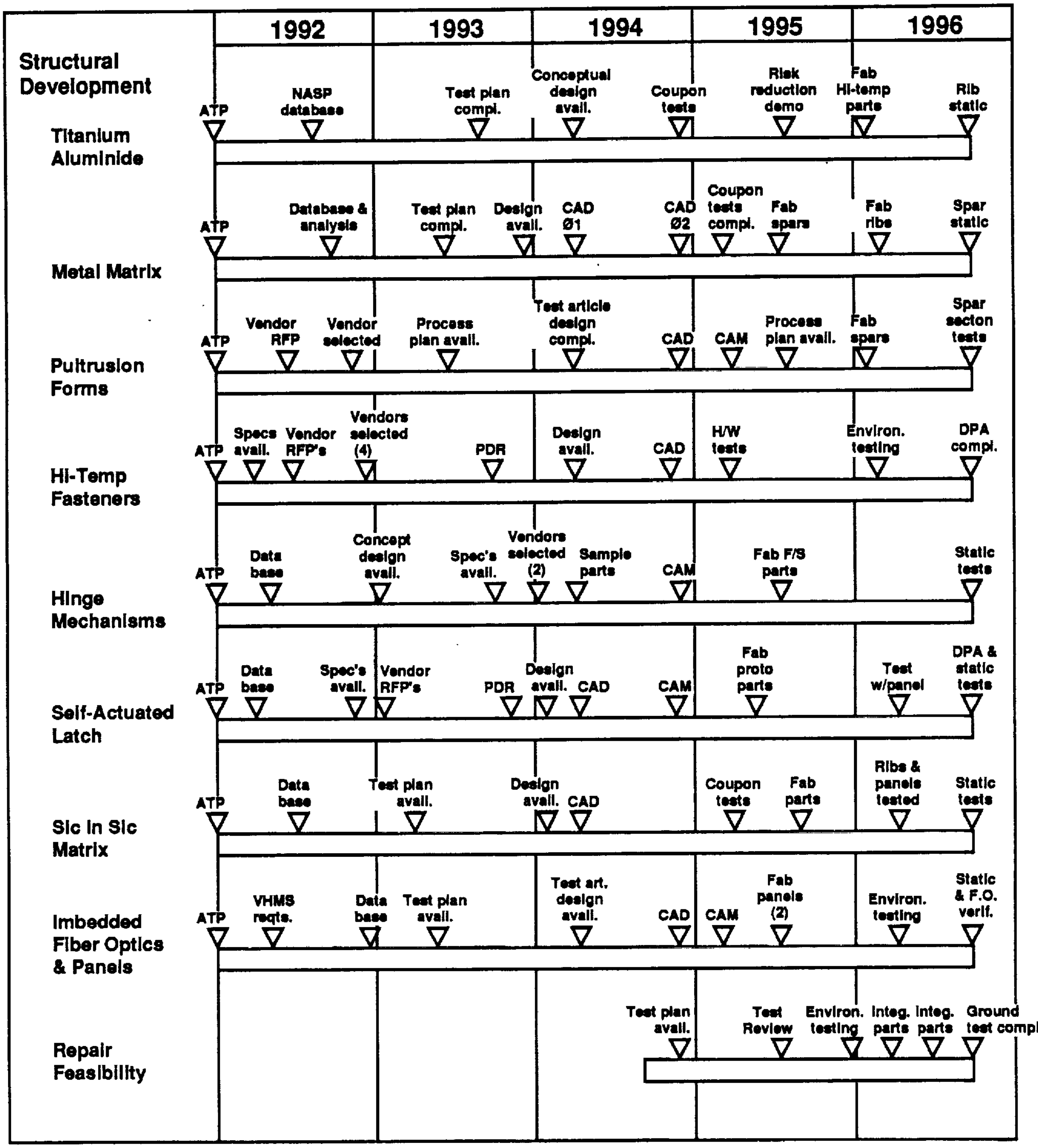
- **Estimated Resource Requirements - 1991 Dollars in Millions**

ETP *	6.8	16.0	21.5	9.2	--
Advanced Development *	–	0.5	2.0	13.0	18.5

* Does not include STS transportation costs for experiment flights (NASA supplied services

Figure 4-2.2-1. Cryogenic Fluid Systems Technology Development

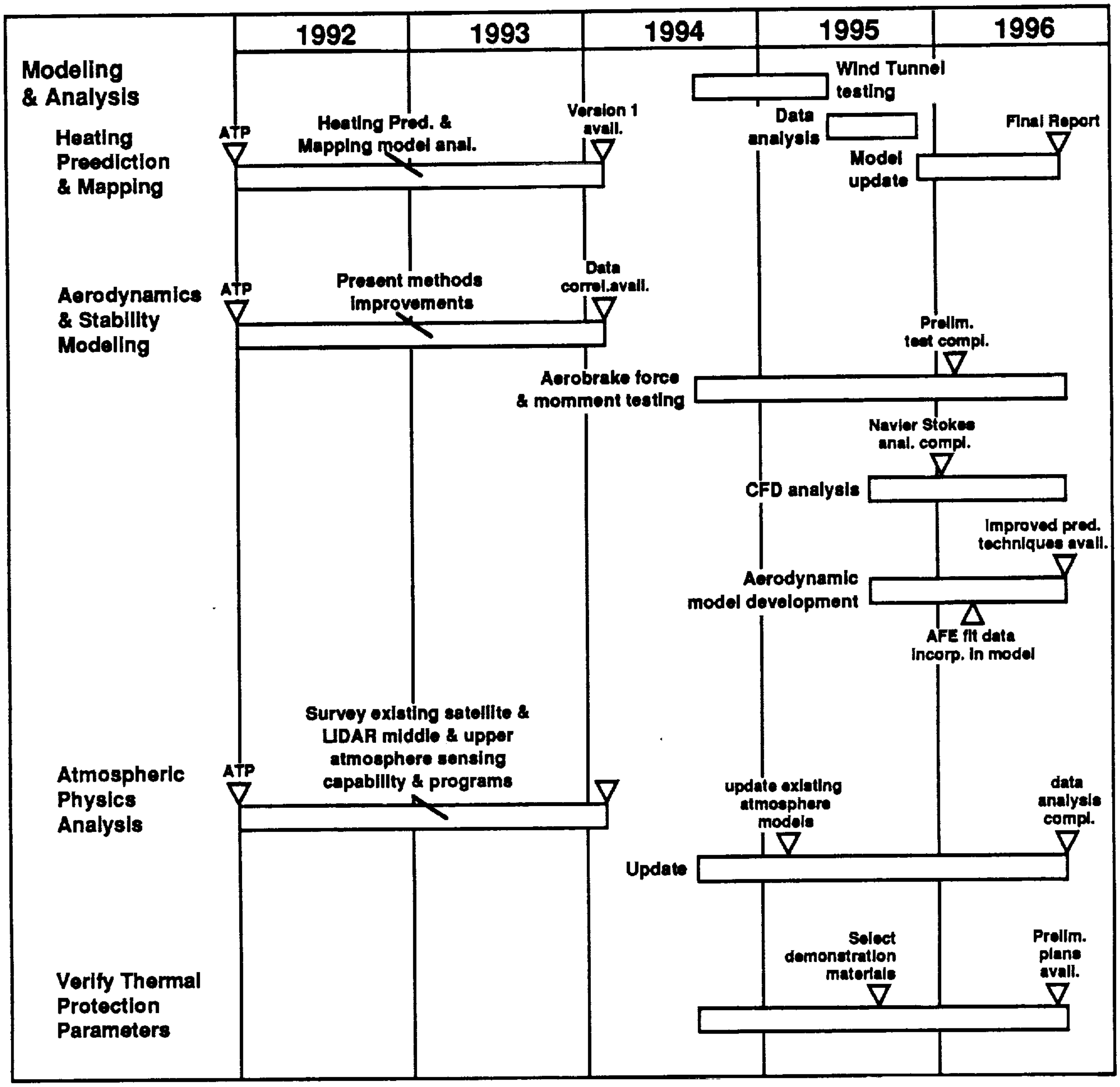
Aeroassist/Aeromaneuver Technology Development



• Estimated Resource Requirements Included in Figure 4-2.3-2.

Figure 4-2.3-1. Aeroassist and Aeromaneuver Technology Development

Aeroassist/Aeromaneuver Technology Development



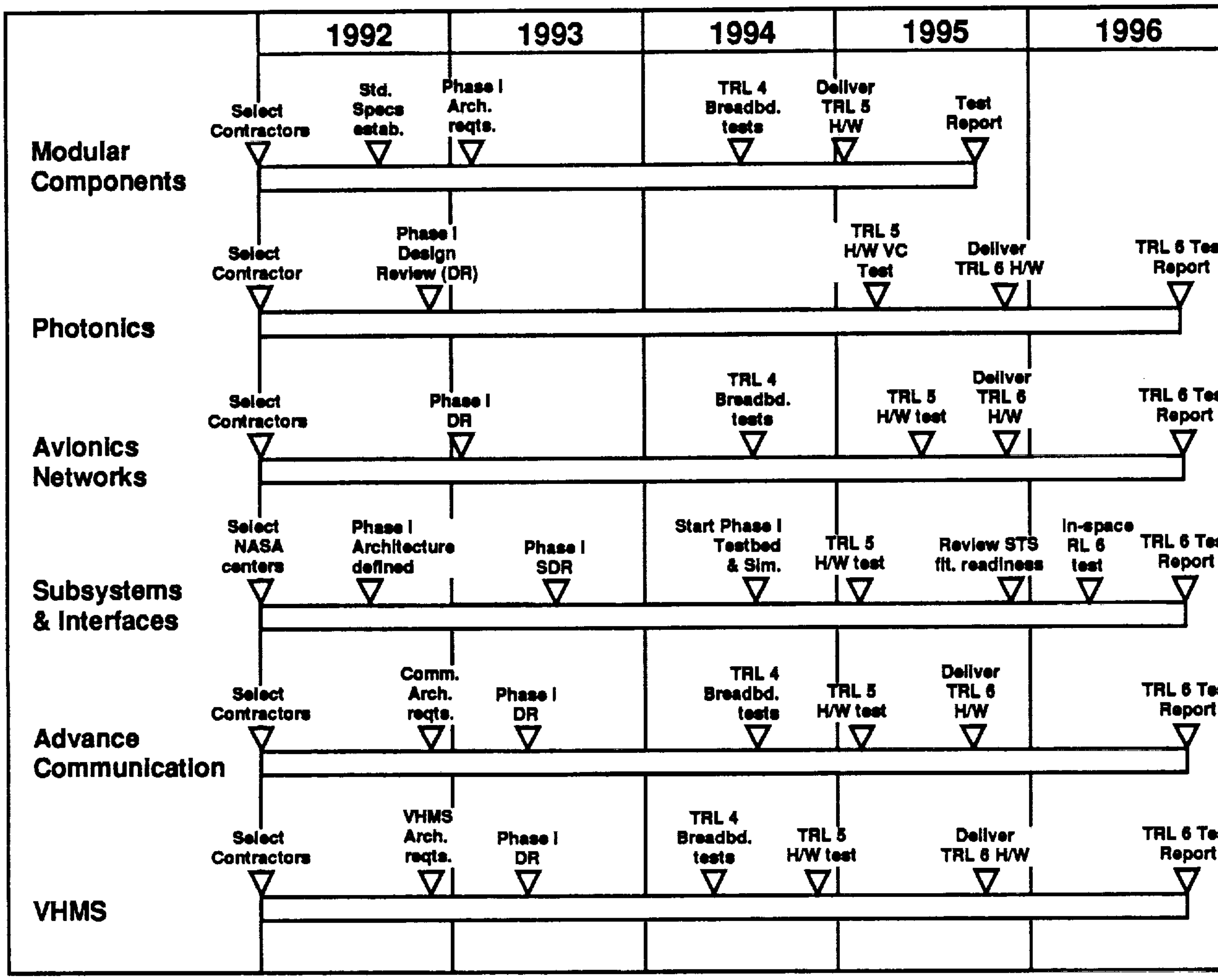
• **Estimated Resource Requirements - 1991 Dollars in Millions**

	1992	1993	1994	1995	1996
ETP *	8.5	5.0	2.0	3.5	2.0
Advanced Development	2.5	1.0	6.0	8.0	12.0

* Excludes the Aeroassist Flight Experiment (AFE) project which is already under way; AFE 2 required in FY 1999

Figure 4-2.3-2. Aeroassist and Aeromaneuver Technology Development - Modeling and Analysis

Avionics Technology Development



• **Estimated Resource Requirements - 1991 Dollars In Millions**

ETP	4.9	6.0	17.0	11.5	8.7
Advanced Development	1.6	6.0	17.5	34.5	26.0

• **Excludes the Advanced Expander Testbed Funding (AETB), which is already in process**

Figure 4-2.4-1. Avionics Technology Development

4-2.5 SOFTWARE

The software architecture (integration technology) effort with a focus on infrastructure interfaces is required for development of the initial software requirements and specification documents prior to preliminary design review. Risk reduction is being accomplished by prototyping algorithms with software prior to preliminary design review. Figure 4-2.5-1 presents the schedule and estimated resources for the software effort.

4-2.6 POWER

The baselined STV power system does not require new technology development. Shuttle fuel cell technology along with the batteries currently being developed by SAFT will support STV power system requirements.

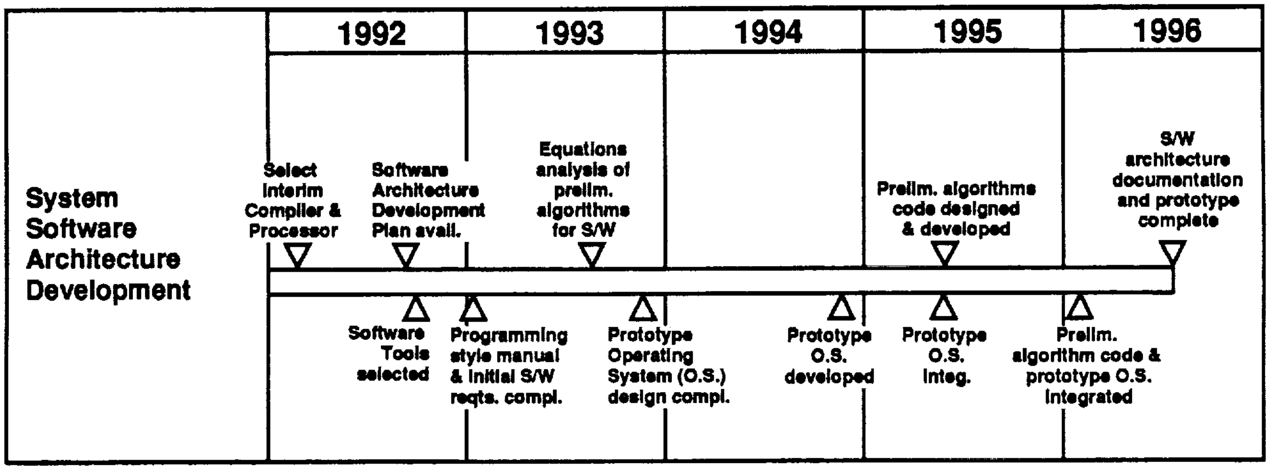
4-2.7 CREW MODULE SYSTEMS

Most of the crew systems can use currently existing technology. Development is required only in the area of a lightweight, simple commode and in crew consoles and displays. Figure 4-2.7-1 shows the technology/advanced development schedule and estimated resource requirements for these areas.

4-2.8 STRUCTURES, TANKAGE, AND AUXILIARY EQUIPMENT

In the area of tankage, development is required in the thin walled Al-Li tanks. Figure 4-2.8-1 shows the schedule and estimated resource requirements for development of the tanks. Aerobrake structural development is covered in section 4-2.3. The LES requirement was not identified until late in the study and was not estimated. Auxiliary equipment such as disconnects and hinges is generally covered under the associated section such as cryogenic fluid connectors being covered in the cryogenic fluid systems.

Software Technology Development



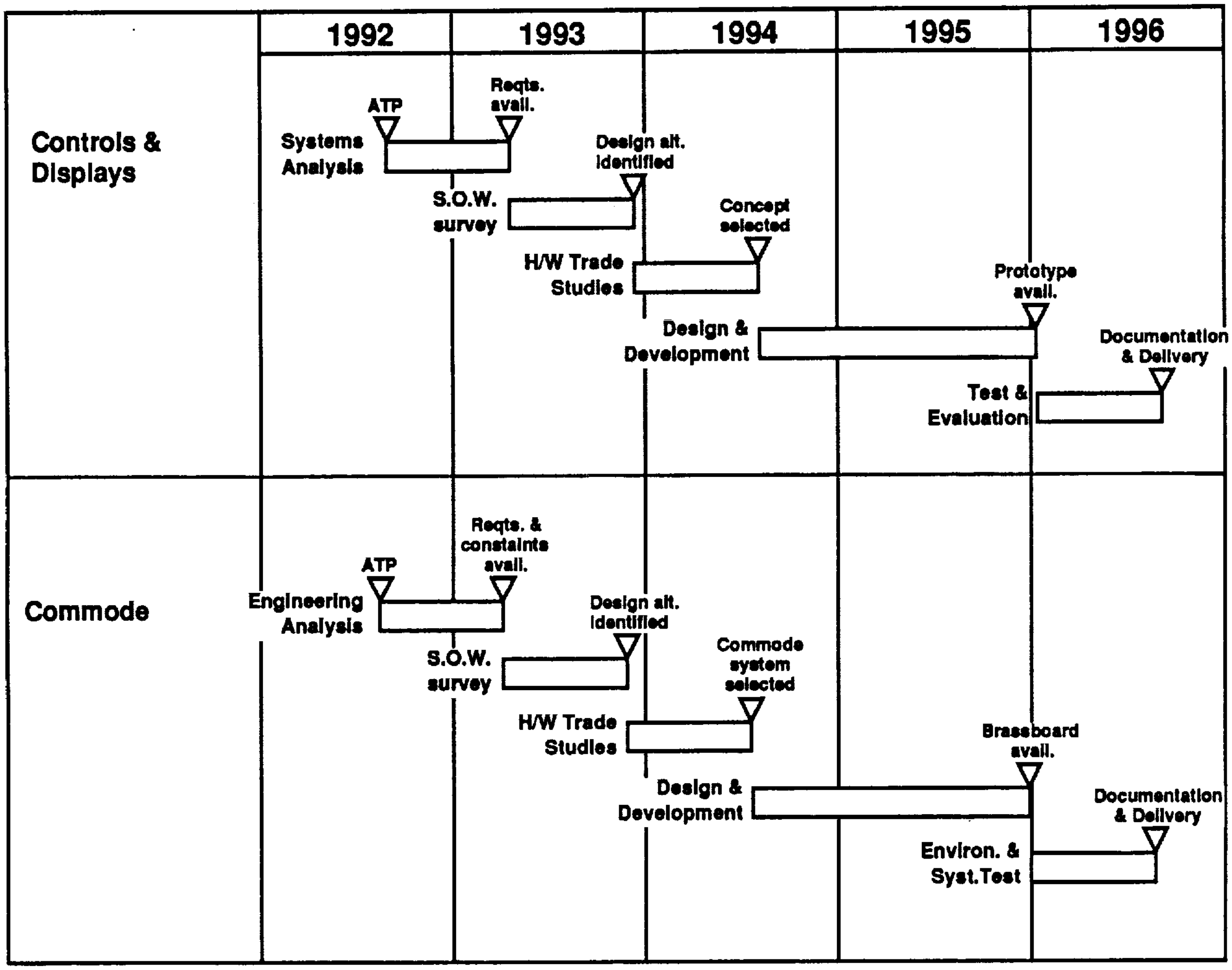
• Estimated Resource Requirements - 1991 Dollars in Millions

ETP	6.0	6.0	3.0	2.0	2.0
Advanced Development	2.0	6.0	10.0	10.0	5.0

Note: Prototyping is of high risk software and latest technology algorithms to support risk reduction.

Figure 4-2.5-1. Software Prototype Development

Crew Module Systems Technology Development



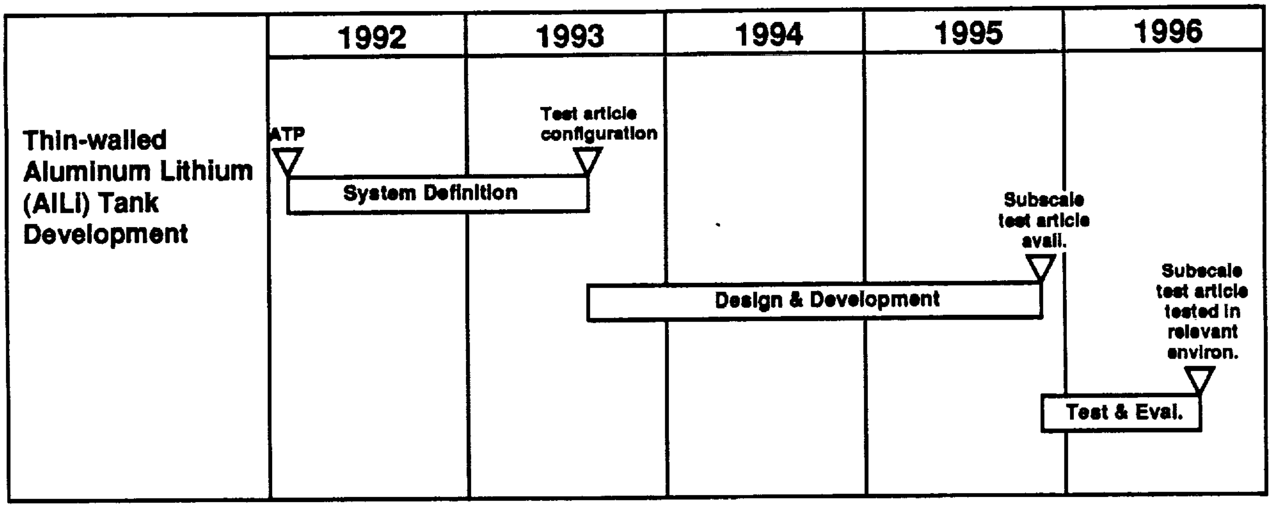
• Estimated Resource Requirements - 1991 Dollars in Millions

ETP (see above)	3.0	10.0	8.5	1.0	--
Advanced Development *	2.0	1.5	12.0	12.5	15.0

* Note: Systems architecture and integration contracts/TD's

Figure 4-2.7-1. Crew Module Systems Technology Development

Structural Tankage Technology Development



• Estimated Resource Requirements - 1991 Dollars in Millions

ETP *	4.5	3.5	3.0	2.0	1.0
Advanced Development	1.0	3.5	5.0	4.0	3.0

* Welding, composites, LAD, and TVS technology projects

Figure 4-2.8-1. Structural Tankage Technology Development

4-2.9 PHASE C/D DEVELOPMENT PLAN

Integrated phase C/D schedules were developed using an automated project management scheduling system called Open Plan. The software is a highly powerful critical path method system with the capability to do scheduling in days, hours, or minutes; report progress by actual dates and expected finish dates; define resource loading; allow design of output (schedules, reports, and networks); and features a variety of code fields in which you can sort select and print any part of the schedule or report.

The network included in this report was created in Open Plan, which provided a critical path analysis of the STV full-scale development program and the ability to add resources, milestone data, and graphic output for all levels of schedules and networks. The scheduling system uses a common database for all levels of schedules, from Tier I to Tier IV, ensuring consistency and traceability of all schedule and network information.

Open Plan is user friendly software with menu-driven input screens, over 60 standard reports, schedules and logic drawings, and the ability for the user to define any of the screens, menus, and reports. Networks and listings were produced for the aerobrake phase C/D development and the entire STV program. These documents are delivered with the final report cost volumes.

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16. Abstract

This report presents the results of systems analyses and conceptual design of space transfer vehicles (STV). The missions examined included piloted and unpiloted lunar outpost support and spacecraft servicing, and unpiloted payload delivery to various earth and solar orbits. The study goal was to examine the mission requirements and provide a decision data base for future programmatic development plans. The final lunar transfer vehicles provided a wide range of capabilities and interface requirements while maintaining a constant payload mission model. Launch vehicle and space station sensitivity was examined, with the final vehicles as point designs covering the range of possible options. Development programs were defined and technology readiness levels for different options were determined. Volume I presents the executive summary, Volume II provides the study results, and Volume III the cost and WBS data.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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