NASA Conference Publication 3112, Vol. 3

Space Transportation Propulsion Technology Symposium

Volume 3—Panel Session Summaries and Presentations

Proceedings of a symposium held at the Pennsylvania State University State College, Pennsylvania June 25–29, 1990

NASA

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NASA Office of Space Flight
Washington, D.C.

Proceedings of a symposium held at
the Pennsylvania State University
State College, Pennsylvania
June 25–29, 1990

NASA
National Aeronautics and
Space Administration
Office of Management
Scientific and Technical
Information Program
1991

VOLUME 2

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INTRODUCTION

The Space Transportation Propulsion Technology Symposium (STPTS) was held at the Pennsylvania State University in University Park, PA, June 25-29, 1990. The Symposium consisted of a two-day plenary session, a one-day breakout session for the meeting of four individual panels, and a concluding morning session for the presentation of panel summary reports. In addition to the Symposium, the Second Annual Symposium of the NASA Propulsion Engineering Research Center at Penn State was held concurrently on the third day.

The STPTS Executive Summary, NASA Conference Publication 3112 Volume 1, contains the conclusions and recommendations of the Symposium participants as well as a description of the Symposium activities. The Symposium proceedings are organized in five sections and are contained in NASA Conference Publication 3112 Volumes 2 and 3.

Volume 2 of NASA Conference Publication 3112 includes Section 1, the plenary session presentations, and Section 2, the Second Annual Symposium of the NASA Propulsion Engineering Research Center at Penn State.

This document, Volume 3 of NASA Conference Publication 3112, contains the remainder of the STPTS proceedings. Section 3 contains the panel summary reports, Section 4 contains the papers and briefing materials presented to the four panels, and Section 5 contains the list of STPTS participants. Volumes 2 and 3 also contain the STPTS agenda, a description of the topics discussed by the four panels, and the table of contents for the other volume in the appendix.

SPACE TRANSPORTATION PROPULSION SYSTEMS SYMPOSIUM

Panel Topics

GENERAL CHAIRMAN
ROBERT SCHWINGHAMER

COCHAIRMEN
CHESTER VAUGHAN - JSC, WARREN WILEY - KSC

PROPULSION SYSTEM OPTIONS

CURRENT SYSTEMS
- o ELVs - Small, Med, Lrge
- o Shuttle - SSME, OMS, RCS, RSRM, ASRM
- o Upper Stages
- o Satellite/Space Probe Prop

NEXT GENERATION
(Candidates)
- o Shuttle Derivatives
- o Booster Propulsion (Liquid, Hybrid, Solid
- o Advanced Launch Systems
- o Unmanned Launch Vehicles and Upper Stages
- o Space Transfer Vehicles/Adv. Cryo. Propulsion
- o Adv. Manned Launch Sys. (Shuttle II, SSTO, Comb. Cycle Prop., Adv. Rockets)
- o NASP

ENVIRONMENTAL ISSUES

FOREIGN TECH.
- o Japanese o Russian
- o European o Other

FUTURISTIC SYSTEMS
(Candidates)
- o Nuclear Thermal Propulsion (Fission, Fusion)
- o Nuclear &Solar Electric
- o Adv. Propulsion Concepts

* Panel Rapporteur/Facilitator

SYSTEMS ENGINEERING & INTEGRATION

+ Len Worlund - MSFC
Phil Deans - JSC
Frank Berkopec - LeRC

(+ Panel Leader)

o Prelim Design Activities
- ° Conceptual Design (Phase A Studies)
- ° Pre Development/ Phase B Studies
- ° System Architecture
- ° Vehicle End-to-End Subsystem Interdependencies
- ° Trajectory/Performance Planning Options

o Phase C/D Activities
- ° Pre Development Technology Maturity
- ° PDR Penetration
- ° Modular vs LRU's
- ° FMEA/CIL
- ° Design Margin

o Flight System Evolution
- ° Uprating (Perf/Life)
- ° Cost Reduction
- ° Assured Access

* Irving Davids
* Carl Aukerman

DEVELOPMENT, MANUFACTURING & CERTIFICATION

+ Walt Karakulko - JSC
Paul Shuerer - MSFC
Steve Dick - SSC

o System Development
- ° Probabilistic Structural Analysis Methods
- ° Tech Trfr Methodology
- ° National Test Bed Concept
- ° Historical Problem Areas - Solutions Needed

o Mat'ls & Manufacturing
- ° Manu. Processes & Applications
- ° National Mat'ls Data Base
- ° NDE
- ° Concurrent Engineering

o Flight Certification
- ° Integration of Diagnostics into Test Process
- ° Life Cycle Cost Based Test Program Decisions
- ° Certification Test Requirements - Manrating
- ° Testing vs. Simulation

* Mel Bryant
* Bill Hope

OPERATIONAL EFFICIENCY

+ Don Nelson - JSC
Russ Rhodes - KSC
Marv Carpenter - SSC
Fred Huffaker - MSFC

o Pre-Launch Activities
- ° Operationally Efficient Propulsion Systems
- ° Facilities Requirements

o Flight Operations
- ° Data Acquisition
- ° Flight Control
- ° Weather Limitations/ All Weather Capability

o Mission Success Assurance
- ° Safety & Diagnostics
- ° Configuration Control

o Space Basing
- ° System Concepts
- ° Propellant Storage/Trfr

o Review Survey

o Subpanel Discussions on Ops Efficiency for:
- ° Shuttle Derivatives
- ° ELV's
- ° Upper Stages/Manned
- ° Satellites/Deep Space Probes

* Bill Dickinson
* Brenda Wilson

PROGRAM DEVELOPMENT & CULTURAL ISSUES

+ Ed Gabris - HQS
Chuck Eldred - LaRC
Harry Erwin - JSC
Gene Austin - MSFC

o Lessons Learned (Shortcomings)

o Requirements
- ° Shuttle Level II
- ° Fixed Capability
- ° ALS
- ° Environmental Consid/TQM
- ° Assured Access to Space

o Technology/Perf/Ops
- ° Tech Limited
- ° Perf Driven
- ° Labor Intensive
- ° Perf Margin
- ° Cost Driven
- ° Skeleton Crews

o Reliability/Safety
- ° By Test
- ° Redundancy
- ° Engine On/Off/Out
- ° Constraints (Redlines)
- ° Margin/Design
- ° Fault Tolerant Safety
- ° Hlth Monitoring

o Procurement/Contracting
- ° Competitive
- ° Mission Need Statement/A109
- ° Yr-to-Yr Funding
- ° IR&D
- ° Consortium
- ° Multi-Yr Funding
- ° Joint Funding
- ° IR&D

* Rodney Johnson
* Diane Gentry

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AGENDA

SPACE TRANSPORTATION PROPULSION TECHNOLOGY SYMPOSIUM

The Pennsylvania State University, University Park, PA 25-29 June 1990

Monday, 25 June

4:00-8:00	Registration: Badge, Agenda (final), Preprints, Banquet ticket, Visitor info, etc. (Coffee available)-Lobby, Nittany Lion Inn	PSU Staff
5:00-6:30	*Social Mixer* - Ticketed Participants & Guests-Colonial Room, Nittany Lion Inn	PSU Staff
6:30-8:00	*Dinner -Open Evening*	All

Tuesday, 26 June

7:00-8:00	*Breakfast: Waring Commons* (Registration Continues- Lobby, Kern Graduate Center)	PSU Staff

PLENARY SESSION- 112 Kern Graduate Center

8:00-8:15	Welcome and Announcements	R. Jacobs, PSU
8:15-9:00	Symposium Overview	
	-Call to Order, General Chairman's Remarks	R. Schwinghamer
	-Co-Chairmen's Comments	C. Vaughan, W. Wiley
	-Headquarter's Perspectives	D. Branscome
9:00-9:45	Keynote Address- James R. Thompson, Jr. NASA Deputy Administrator	All
9:45-10:00	*Break (Beverages available)*- Lobby, Kern Graduate Center	PSU Staff
10:00-12:30	Development of Symposium Themes	
	-Space Exploration Initiative	C.C. Priest, NASA HQ
	-National Space Transportation Strategy	D. Branscome, NASA HQ
	-Maintaining Technical Excellence	T. Davidson, AIA
	-Operational Efficiency - New Approaches to Future Propulsion Systems	R. Rhodes, KSC G. Wong, Rocketdyne
12:30-1:30	*Luncheon: Waring Commons*	PSU Staff

PROPULSION SYSTEM OPTIONS*: *Systems/Requirements Input to Panels

	CURRENT SYSTEMS - Input to Panels	
1:30-1:50	Expendable Launch Vehicle Propulsion	P. Fuller, Rocketdyne
1:50-2:10	Shuttle Propulsion Systems	R. Bardos, NASA HQ
2:10-2:50	Upper Stages/Propulsion	C. Gunn, NASA HQ J. Brown, P&W
2:50-3:10	Satellite/Spacecraft Propulsion	M. Dowdy, JPL
3:10-3:30	*Break (Beverages available)*- Lobby, Kern Graduate Center	
	NEXT GENERATION - Input to Panels	
3:30-4:10	Shuttle Derivatives - Manned	W. Ordway, JSC
	Unmanned	U. Heuter, MSFC

4:10-5:10	Booster Propulsion - Liquids/Hybrids Solids	U. Heuter, MSFC C. Clinton, MSFC R. Lund, Thiokol
5:10-5:30	ALS	J. Monk, MSFC
5:30-5:50	**ENVIRONMENTAL CONSIDERATIONS**	J. Jatko, NASA HQI
6:00-7:30	NASA Propulsion Engineering Research Center at Penn State- Facilities tour followed by: *Social Mixer: Wine & Cheese (Shuttle Buses will operate between Kern and Center facilities)* *Dinner on your own*	PSU Staff

Wednesday, 27 June

7:00-7:50	*Breakfast: Waring Commons* (Registration Continues- Lobby, Kern Graduate Center)	PSU Staff

PLENARY SESSION- 112 Kern Graduate Center

7:50-8:00	Announcements	
	NEXT GENERATION - Input to Panels (Cont'd)	
8:00-8:20	AF Space Systems Propulsion	D. Hite, AFAL
8:20-8:40	Unmanned Launch Vehicles/Upper Stages	C. Gunn, NASA HQ
8:40-9:20	Space Transfer Vehicles	F. Huffaker, MSFC B. Tabata, LeRC
9:20-9:40	Advanced Manned Launch Systems (AMLS)	D. Freeman, LaRC
9:40-10:00	National Aerospace Plane (NASP)	M. Tang, NASA HQ
10:00-10:20	*Break (Beverages available)*- Lobby, Kern Graduate Center	
10:20-11:20	**FOREIGN TECHNOLOGY** - Input to Panels	
	- Japanese Technology	C. Merkle, Penn State
	- Russian Technology	R. Jones, Rocketdyne
	- European, Other Technology	E. Rice, Orbitec
11:20-12:40	**FUTURISTIC SYSTEMS** - Input to Panels	
	- Nuclear and Solar Electric Propulsion	D. Byers, LeRC
	- Nuclear Thermal Propulsion	G. Bennett, NASA HQ
	- Fusion Propulsion	N. Schulze, NASA HQ
	- Advanced Propulsion Concepts	R. Frisbee, JPL
12:40-1:40	*Luncheon: Waring Commons*	PSU Staff

BREAKOUT SESSIONS

1:40-5:30	**PANELS CONVENE**- Various rooms, Willard Building (See enclosed map) Note: Computer chart making support available - 101A, Kern Graduate Center	Panel Leaders and Members

3:15-3:30	*Break (Beverages available)*- Lobby, Kern Graduate Center & 2nd floor, Willard Building	
5:30-6:00	Resolution of Issues (If Required)	Panel Leaders & Staff
6:00-7:00	*Social Mixer*- Lobby, Days Inn	PSU Staff
7:00-8:30	*Banquet*- Banquet Room, Days Inn Speaker: Mr. James McDivitt Senior Vice President Rockwell International	All

Thursday, 28 June

7:00-8:00	*Breakfast: Waring Commons* (Registration Continues- Lobby, Kern Graduate Center)	PSU Staff

BREAKOUT SESSIONS

8:00-2:00	**PANELS RECONVENE**- Various rooms in Willard Building Focus: Document Findings, Summarize, Prepare Briefings. Note: Computer Chart Making Support Available in 101A, Kern Graduate Center	Panel Leaders and Members
10:00-10:15	*Break (Beverages available)*- Lobby, Kern Graduate Center & 2nd floor, Willard Building	
12:00-1:00	*Luncheon:Waring Commons*	PSU Staff

PLENARY SESSION

2:00-5:30	NASA Propulsion Engineering Research Center at Penn State, Second Annual Symposium- Concurrent sessions in rooms 101 and 112, Kern Graduate Center (See enclosed agenda)	PSU Staff
(As Avail/Req'd)	Rapporteur's Perceptions and Critique of Panel Deliberations and Results	Council of Rapporteuers (Off Line to Staff)
3:30-3:45	*Break (Beverages available)*- Lobby, Kern	
6:00-7:30	*Picnic*- Lawn of Hetzel Union Building (Inside HUB if inclement weather)	PSU Staff

Friday, 29 June

7:00-8:00	*Breakfast: Waring Commons*	PSU Staff
8:15-9:00	*Speaker:* The Honorable Robert S. Walker, U.S. House of Representatives	All
9:00-9:30	Panel A Reports (to Plenary Session)	Panel A
9:30-10:00	Panel B Reports (to Plenary Session)	Panel B
10:00-10:15	*Break (Beverages available)*- Lobby, Kern Graduate Center	
10:15-10:45	Panel C Reports (to Plenary Session)	Panel C
10:45-11:15	Panel D Reports (to Plenary Session)	Panel D
11:00-12:00	Open Discussion, Summary of Conclusions and Closing Remarks (Revew of Findings, etc.)	R. Schwinghamer, C. Vaughan, W. Wiley
12:00-1:00	*Luncheon: Waring Commons/Symposium Adjournment*	

SECTION 3

PANEL SUMMARY REPORTS

SECTION 3.1

PROPULSION SYSTEMS OPTIONS PANEL

Space Transportation Propulsion Technology Symposium

PROPULSION SYSTEM OPTIONS PANEL

CHAIRMAN:	**Bob Zurawski - HQ**	**(202)**	**453-2261**
Co-Chairman:	**Eric Hyde - MSFC**	**(205)**	**544-1770**
	Sol Gorland - LeRC	**(216)**	**433-2449**

TOPIC	SPEAKER	ORG.	TELE. #
CURRENT SYSTEMS:			
Expendable Launch Vehicles	Paul Fuller	Rocketdyne	(818) 710-2596
Shuttle Propulsion:			
- SSME, RSRM, ASRM, OMS, RCS	Russ Bardos	NASA HQ/ME	(202) 453-2473
Upper Stages:			
- Upper Stage Projects (Solids)	Charlie Gunn	NASA HQ/ML	(202) 453-8739
- Cryo. Stage Prop. (RL-10 & Der.)	Jim Brown	Pratt&Whittney	(407) 796-7770
Satellite/Space Probe Propulsion	MacDowdy	JPL	(818) 354-2182
- Low Thrust Primary & Auxiliary			
NEXT GENERATION:			
Shuttle Derivatives			
- Manned SDV's	Wayne Ordway	NASA JSC	(713) 483-6626
- Unmanned SDV's (Shuttle C)	Uwe Hueter	NASA MSFC	(205) 544-8492
Booster Propulsion:			
- Liquid, Hybrid Boosters	Uwe Hueter	NASA MSFC	(205) 544-8492
- Solids	Rob Nichols	NASA MSFC	(205) 544-2681
	Bob Lund	Thiokol	(801) 863-3461
Heavy Lift Launch Vehicles:			
- Advanced Launch Systems, ALS Propulsion (STME)	Jan Monk	NASA MSFC	(205) 544-7110
Unmanned Launch Vehicles	Charlie Gunn	NASA HQ/ML	(202) 453-8719
AF Space Systems Propulsion	Dewey George	AFAL	(805) 275-5342
Space Transfer Vehicles:			
- Vehicle Concepts and Reqrmnts.	Fred Huffaker	NASA MSFC	(205) 544-8490
- Advanced Cryo. Propulsion Syst.	Bill Tabata	NASA LaRC	(804) 864-4502
Advanced Manned Launch Systems	Del Freeman	NASA LaRC	(804) 864-4502
- Shuttle II, SSTO Vehicles			
- Advanced Rockets			
- Combined Cycle Propulsion			
NASP	Ming Tang	NASA HQ/RN	(202) 453-2813

Space Transportation Propulsion Technology Symposium

PROPULSION SYSTEM OPTIONS PANEL

TOPIC	SPEAKER	ORG.	TELE. #
ENVIRONMENTAL CONSIDERATIONS:	Joyce Jatko	NASA HQ/NFX	(202) 453-1982
FOREIGN TECHNOLOGY:			
Japanese	Chuck Merkle	Penn State	(814) 863-1501
Russian	Bob Jones	Rocketdyne	(805) 371-7027
European, Other	Eric Rice	Orbitec	(608) 836-6684
FUTURISTIC SYSTEMS:			
Nuclear & Solar Electric Propulsion	Dave Byers	NASA LeRC	(216) 433-2447
Nuclear Thermal Propulsion	Gary Bennett	NASA HQ	(202) 433-2447
Fusion Propulsion	Norm Schulze	NASA HQ/Q	(202) 453-1554
Advanced Propulsion Concepts	Bob Frisbee	JPL	(818) 354-9276

SECTION 3.1.2

PROPULSION SYSTEM OPTIONS PANEL

SUMMARY REPORT

NASA **PROPULSION SYSTEM OPTIONS** PSU

GENERAL FINDINGS

- **NEED TO DEVELOP AND <u>ADOPT</u> A NATIONAL STRATEGIC PLAN FOR ROCKET PROPULSION**
  - R&T STRATEGY WITH TECHNOLOGY DEVELOPMENT THROUGH VALIDATION
  - EDUCATIONAL OBJECTIVES & FOCUS
  - NATIONAL PARTICIPATION, COORDINATION, PLANNING AND COOPERATION
  - REVITALIZE WORKFORCE, FACILITIES, AND TECHNOLOGY BASE
- **USE AERONAUTICS PROGRAM AS A MODEL FOR FUTURE SPACE TECHNOLOGY PROGRAM PLANNING/DEVELOPMENT**
  - TECHNOLOGY TRANSFER AND SPIN OFFS
  - STRATEGIC PLAN AND LEVEL FUNDING
  - GOVERNMENT/INDUSTRY/ACADEME INTERFACES
  - SHARE GOV'T/INDUSTRY/ACADEME TASKS AND FACILITIES (BETTER COORDINATION)
  - TEAMWORK (TEAMING/CONSORTIUMS)

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NASA **PROPULSION SYSTEM OPTIONS** PSU

GENERAL FINDINGS

- **USE BUILDING BLOCK APPROACH FOR SPACE TRANSPORTATION AND OPERATIONS INFRASTRUCTURE**
  - LAUNCH VEHICLES (HLLV, SHUTTLE DER., ETC.)
  - PROPULSION "MODULES"
  - COMMONALITY
  - BUILD ON WHAT WE HAVE, WHERE PRACTICAL
  - MINIMIZE COST
- **DESIGN SPACECRAFT/PROPULSION SYSTEMS FOR OPERATIONAL EFFICIENCY**
  - SIMPLIFIED, ROBUST DESIGNS (COMMONALITY & INTEGRATED FUNCTIONS)
  - APPLICATION OF TQM (INTERACTION OF OPERATIONS, DESIGN & MANUFACTURE FUNCTIONS/PERSONNEL)
  - INTEGRATED PROPULSION MODULE ENGINE (ALS EXAMPLE)
  - ENVIRONMENTALLY CLEAN SYSTEMS (LOX/H_2, OTHER)

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GENERAL FINDINGS

- **ESTABLISH USER ORIENTATION TO TECHNOLOGY PROGRAMS**
  - TIE TECHNOLOGY TO FLIGHT PROGRAMS AND USER NEEDS
    - MORE USER ORIENTED RESEARCH AND TECHNOLOGY PROGRAMS
    - OBTAIN USER'S SUPPORT IN TECHNOLOGY DEVELOPMENT, BUT PRESERVE AUTONOMY OF TECHNOLOGY DEVELOPERS
    - REEVALUATE RTOP SYSTEM
    - DEVELOP TECHNOLOGY TO "HANDOFF POINT"
    - PURSUE LONG RANGE TECHNOLOGY DEVELOPMENT PLANS/OBJECTIVES (AVOID "TECHNOLOGY GRASSHOPPER" SYNDROME)
- **EDUCATION ON SPACE PROGRAMS IS A MUST AT ALL LEVELS**
- **ENVIRONMENTAL CONSIDERATIONS BECOMING MORE IMPORTANT**
  - NEED TO BE AWARE OF POTENTIAL ENVIRONMENTAL IMPACTS AND PLAN FOR THEM
  - NEED TO BE PREPARED FOR POSSIBLE SCHEDULE AND COST CONSEQUENCES

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TRANSPORTATION - SHUTTLE

- **SHUTTLE PROPULSION ISSUES ARE CURRENTLY BEING WORKED**
  - RSRM, SRB, SSME, RCS
- **SUBSTANTIAL BUDGET SAVINGS BY EXTENDING SHUTTLE LIFE CYCLE BY 20 TO 40 YEARS (VS. NEW SHUTTLE II)**
  - SUBSYSTEM UPGRADES MANDATORY TO EXTEND LIFE
  - SRB CONTROL SYSTEM REDESIGN
    AFT SKIRT REDESIGN
    SSME ADVANCED FABRICATION
    INTEGRATED OMS/RCS
- **SUBSYSTEM UPGRADES/PRODUCT IMPROVEMENT COULD BENEFIT FROM TECHNOLOGY**

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TRANSPORTATION - ELV'S

- **EXISTING ELV FLEET NEEDS UPGRADE TO BE COMPETITIVE IN FUTURE; REQUIRES ENHANCING TECHNOLOGIES**
  - INTERNATIONAL COMPETITION THREATENS U.S. COMMERCIAL LAUNCH SERVICES
  - FOREIGN GOVERNMENT SUPPORTED OR STATE OWNED LAUNCH SERVICES
  - U.S. GOV'T. (NASA) BASIC AND APPIED RESEARCH FUNDING MAY HELP
  - RECOVERY OF NON-RECURRING COSTS/CULTURAL CHANGE PLAN NEEDED
- **DEVELOP & ADOPT A LONG RANGE, INDUSTRY/GOVERNMENT PLAN FOR NEXT GENERATION U.S. COMMERCIAL ELV DEVELOPMENT**
  - COMSTAC LEAD IN PLAN DEVELOPMENT
  - INTEGRATE NASA, ALS, SEI PLANS
  - IDENTIFY & PRIORITIZE ELV PROPULSION TECHNOLOGIES
- **HIGH PRIORITY ELV TECHNOLOGY NEEDS**
  - LIQUIDS - LOW COST LIQUID BOOSTER (LOX/H_2 AND LOX/RP)
  - UPPER STAGE (LOX/H_2 -30 TO 50K THRUST) PROPULSION
  - SOLIDS - CLEAN PROPELLANTS, LOW COST, HIGH RELIABILITY

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TRANSPORTATION - UNMANNED LAUNCH VEHICLES/UPPER STAGES

- **ESTABLISH NATIONAL CONSORTIUM FOR NEXT GENERATION SPACE TRANSPORTATION**
  - AGGREGATE NASA/DOD/ELV COMMERCIAL INDUSTRY REQUIREMENTS
  - AGREE ON COMMON PROPULSION ELEMENTS
  - AGREE ON SHARING OF MANAGEMENT; NON-RECURRING COSTS, PRIORITY OF PRODUCTION/LAUNCH ASSETS/FLIGHT FAILURE CORRECTIVE ACTIONS
- **DEVELOP AND PRODUCE COMMON VEHICLE ELEMENTS**
  - SOVIET MODEL (SL-16 BOOSTER/ENERGYA/ZENET COMMERCIAL ELV
- **HIGHER MISSION SUCCESS/LOWER TRANSPORTATION COSTS**
  - PROPULSION MAJOR COST DRIVER (36-41%)
  - PROPULSION SYSTEMS HAVE HIGHEST (FAILURE RATE (52%)
    - 2/3 IN ASSOCIATED SYSTEMS (FEED LINES, VALUES, ETC)
    - 3/4 AT START UP (TRANSIENTS)
    - NEED MORE FOCUS ON ENGINEERING DESIGN

TRANSPORTATION - UNMANNED LAUNCH VEHICLES/UPPER STAGES (cont'd)

- **ASSESS PROGRAM MANAGEMENT OF NEXT ENGINE DEVELOPMENT (FRESH PERSPECTIVE)**
  - MISSION SUCCESS VS. HIGHEST PERFORMANCE
  - PRODUCIBILITY VS. LOWEST WEIGHT; SMALLEST ENVELOPE
  - DURABILITY VS. FREQUENT FIELD CHANGE-OUT

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TRANSPORTATION - EVOLUTION

- **BUILD ON EXISTING CAPABILITIES WHERE PRACTICAL**
  - EXISTING PROPUSION SYSTEMS COULD HAVE WIDER POTENTIAL APPLICABILITY IF UPGRADED/MODIFIED USING NEW TECHNOLOGY
- **HEAVY LIFT LAUNCH CAPABILITIES FOR FUTURE**
  - REQUIRE RELIABLE, MAINTAINABLE TRANSPORTATION TO HAUL A VARIETY OF PACKAGES QUICKLY & CHEAPLY
  - CONSIDER ARCHITECTURAL STRATEGY WHICH UTILIZES SHUTTLE/SHUTTLE-DERIVED ELEMENTS
  - LIQUID ROCKET AND HYBRID BOOSTERS OFFER INCREASED CAPABILITY, HIGHER RELIABILITY AND LOWER OPERATIONAL COSTS
  - SOLID BOOSTERS REQUIRE NEW TECHNOLOGY TO CLEAN UP PROPELLANTS, LOWER COST AND IMPROVE RELIABILITY AND INCREASE CAPABILITY
- **LAUNCH VEHICLES WILL NEVER BE 100% RELIABLE**
  - PROGRAMS BUDGET FOR EVENTUAL FAILURE
  - DO NOT RELY ON SINGLE VEHICLE FOR TRANSPORTATION TO ORBIT

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NASA **PROPULSION SYSTEM OPTIONS** PSU

TRANSPORTATION - EVOLUTION (cont')

- **SOLID PROPULSION**
  - SOLIDS HAVE MULTIPLE USES FOR FUTURE
  - SOLVE CULTURAL, MANAGERIAL & ENGINEERING DATA BASE SHORTFALLS - KEY TECHNOLOGIES IDENTIFIED
  - NEW INITIATIVES TO REDUCE COST/ENHANCE RELIABILITY
  - AGGRESSIVELY PURSUE SOLUTIONS TO ENVIRONMENTAL & FLIGHT SAFETY ISSUES
    - CLEAN PROPELLANTS 9APPROACHES ALREADY FORMULATED)
    - THRUST TERMINATION/RESTART CAPABILITY
- **LONG LIFT, SPACE-BASED SYSTEMS REQUIRING MINIMUM MAINTENANCE, REUSE AND ROBOTIC SERVICING/REPAIR REQUIRE TECHNOLOGY DEVELOPMENT**
  - FUTURE SPACE EXPLORATION MISSIONS
  - REQUIRE TECHNOLOGY DEVELOPMENT

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ENVIRONMENTAL CONCERNS

- **ENVIRONMENTAL REQUIREMENTS ARE CHANGING RAPIDLY, IMPACTING EVERY ASPECT OF WHAT WE DO; INCREASING MATTER OF PUBLIC INTEREST/CONCERN**
  - AIR EMISSIONS RESTRICTIONS/REGULATION
  - PUBLIC CONCERN OVER NUCLEAR POWER/PROPULSION USE
  - HAZARDOUS WASTE MANAGEMENT REGULATIONS MORE RESTRICTIVE; DISPOSAL COSTLY
  - NATIONAL ENVIRONMENTAL POLICY ACT (SCHEDULE IMPACTS)
- **ENVIRONMENTAL ISSUES WILL IMPACT FUTURE PROGRAM COST/SCHEDULE/TESTING LOCATIONS**
- **NEED GREATER COOPERATION AMONG NASA CENTERS AND INDUSTRY**
  - TEST IN LESS ENVIRONMENTALLY SENSITIVE AREAS AND SHARE TEST FACILITIES
  - PLAN FOR ENVIRONMENTAL COMPLIANCE (COST/SCHEDULE)
  - ESTABLISH ENVIONMENTAL COMMITTEE/COORDINATION MECHANISM

FOREIGN TECHNOLOGY

- ASSESSMENT
  - MANY FOREIGN NATIONS STRIVING FOR INDEPENDENCE IN SPACE PROGRAM ACTIVITY
  - SOVIETS, JAPANESE, EUROPEANS, CHINESE AND MANY OTHERS ARE ADVANCING IN LAUNCH VEHCILE UTILIZATION, NEW LV TECHNOLOGIES AND LAUNCH CAPABILITIES
  - SUCCESSFUL APPROACHES INCLUDE MODULARITY, COMMONALITY AND MULTIPLE ENGINE USE ON STAGES
  - SYSTEMS IN MANY CASES ARE SIMPLE, USE PROVEN TECHNOLOGY, AND ARE HIGHLY RELIABLE
  - FOREIGN NATIONS USING TECHNOLOGY DEVELOPED IN US AND EUROPE
  - FOREIGN COMPETITION FOR COMMERCIAL LAUNCHES IS STEADILY INCREASING
- U.S. AEROSPACE INDUSTRY AND GOVERNMENT MUST BECOME MORE PROACTIVE IN SEEKING OUT/UTILIZING FOREIGN TECHNOLOGY
- MUST DEVELOP FOREIGN TECHNOLOGY ASSESSMENT DATA BASE DOCUMENT FOR US GOVERNMENT AND INDUSTRY USE

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NASA PROPULSION SYSTEM OPTIONS PSU

ADVANCE PROPULSION

- ADVANCED PROPULSION CAN PROVIDE MAJOR BENEFITS FOR FUTURE MISSIONS
  - NEAR-TERM SATELLITE STATION KEEPING WITH ELECTRIC PROPULSION ENABLES LONGER LIFE ON ORBIT OR PERMITS USE OF SMALLER (LESS EXPENSIVE) LAUNCH VEHICLES
  - ADVANCED CONCEPTS SUCH AS NUCLEAR THERMAL (NERVA), SOLAR AND NUCLEAR ELECTRIC PROPULSION (SEP & NEP), SOLAR SAILS, TETHERS AND EXTRATERRESTRIAL RESOURCE UTILIZATION CAN PROVIDE MAJOR REDUCTIONS IN MASS OR TRIP TIME FOR PILOTED MISSIONS
  - VERY ADVANCED CONCEPTS SUCH AS GAS-CORE NUCLEAR THERMAL AND FUSION MAY ENABLE FAST MARS MISSIONS
  - SEVERAL ADVANCED TECHNOLOGIES SYNERGISTIC WITH OTHER AGENCIES (e.g., DOE)
  - MAJOR LEVERAGE FOR FUTURE MISSIONS REQUIRES COMMITMENT TO TECHNOLOGY DEVELOPMENT NOW
    - DEVELOP NEAR-TERM CONCEPTS TO MEET INITIAL REQUIREMENTS
    - CONTINUE BASIC RESEARCH ON FAR-TERM CONCEPTS

SYSTEMS ENGINEERING
AND
INTEGRATION PANEL

PANEL ON

SYSTEMS ENGINEERING & INTEGRATION PANEL

CHAIRMAN: Len Worlund - MSFC
Co-Chairman: Phil Deens - JSC
Co-Chairman: Frank Berkopec -LeRC

TOPIC	*PANEL MEMBERS*
PRELIMINARY DESIGN ACTIVITIES (Worlund)	
Conceptual Design/Phase A Studies	R. Kramer (SRS)
Pre-Development/Phase B Studies	Garry M. Lyles (MSFC)
Systems Architecture	B. Masters (United Technologies)
Vehicle End-to-End Subsystem Interdependencies	Tom Mobley (Martin-Marietta)
Trajectory/Performance Planning Options	R. Richmond (MSFC)
	Luke A. Schutzenhofer (MSFC)
	D. Steinmeyer (MDAC)
	Frank E. Swalley (MSFC)
PHASE C/D ACTIVITIES (Berkopec - LeRC)	
Pre-Development Technology Maturity	J. Hemminger (LeRC)
PDR Penetration	James Hughes (GDC)
Modular vs LRU's	Frank Izquierdo
FMEA/CIL	Don Jones (Rockwell)
Design Margin	Craig Judd (AeroJet)
	Robert Lund (Thiokol)
	J. Moses (MSFC)
	Larry Wear (MSFC)
	Don Witt (Pratt & Whitney)
FLIGHT SYSTEM EVOLUTION (Deans - JSC)	
Uprating (Performance/Life)	James W. Akkerman (JSC)
Cost Reduction	Mary P. Cerimele (JSC)
Assured Access	Wayne Ordway (JSC)
	O. Glenn Smith (JSC)
	Robert M. Zubrin (Martin-Marietta)
	J. McCurry (Lockheed)
	J. Rymarcsuk (USAF)

Rapporteur: **Irving Davids**

Facilitator: **Carl Aukerman**

SYSTEMS ENGINEERING AND INTEGRATION PANEL

SUMMARY REPORT

SYSTEM ENGINEERING & INTEGRATION PANEL

JUNE 29, 1990

LEN WORLUND
FRANK BERKOPEC
PHIL DEANS

SYSTEM ENGINEERING AND INTEGRATION

SUMMARY CATEGORIES

1 - SAFETY & RELIABILITY

2 - PERFORMANCE / DESIGN OPTIONS

3 - COST

4 - TECHNOLOGY MATURATION PROCESS

1 - SAFETY & RELIABILITY

1A - IMPROVED PROPULSION SYSTEM RELIABILITY

1B - ASSURED ACCESS TO SPACE

1C - DESIGN MARGIN

1D - ACCEPTANCE TEST REQUIREMENTS

SYSTEM ENGINEERING AND INTEGRATION PANEL

NEED/ISSUE	IMPACT/SENSITIVITY	PROPOSED RESOLUTION
• IMPROVED PROPULSION SYSTEM OVERALL RELIABILITY	• MISSION SUCCESS • MISSION SAFETY • COST • DESIGN MARGINS	• SYSTEM APPROACH PROPULSION DESIGN - PROPULSION SYSTEM DEVEL (ie. NOT JUST ENGINE) - SYSTEM RELIABILITY - OPERATION/LIFE CYCLE COST ANALYSIS - CRITICAL COMPONENT REDUNDANCY MANAGEMENT • RISK ASSESSMENT METHODS/MANAGEMENT • HEALTH MONITORING/CONTROL • DESIGN BENIGN FAILURE MODES • FMEA/CIL • DEVELOP QUANTITATIVE METHODS/DATA FOR CRITERIA SELECTION - RELIABILITY REQUIREMENTS - SAFETY FACTORS - VERIFICATION/ACCEPTANCE - HM/C CAPABILITY

SYSTEM ENGINEERING AND INTEGRATION PANEL

NEED/ISSUE	IMPACT/SENSITIVITY	PROPOSED RESOLUTION
• ASSURED ACCESS TO SPACE FOR PEOPLE AND CARGO - HIGH RELIABILITY FOR LAUNCH VEHICLE - MAIN PROPULSION SYSTEM IMROVED RELIABILITY - MAIN PROPULSION SYSTEM SHUTDOWN 1ST STAGE ABORT CAPABILITY - RELIABLE HEALTH MONITORING/CONTROL - RELIABLE ABORT SENSING AND IMPLEMENTATION	• MISSION SUCCESS - LOSS OF HIGH VALUE/COST PAYLOADS, LOSS OF CREW - LARGE NUMBER OF LAUNCH FAILURES DRIVEN BY MPS FAILURE - SOME SYSTEMS i.e. SOLIDS (SRM, ASRM) CANNOT BE THRUST TERMINATED - LOW RELIABILITY, LATENT DEFECT UNDETECTED, PREMATURE FAILURE - INSTRUMENTATION LOWER THAN SYSTEM RELIABILITY, LOSS OF CREW/VEHICLE, LATENT DEFECTS UNDETECTED	• PERFORM MORE QUANTITATIVE ANALYSIS, IMPROVED RELIABILITY DIAGNOSTIC TOOLS i.e. PRA, CONTINUOUS LIFE CYCLE ESTIMATES • ENHANCED SYSTEM DESIGNS, REMOVAL OF CATASROPHIC FAILURE MODES, ASSURE BENIGN FAILURES • PURSUE ALTERNATE BOOSTER SYSTEMS (FOR SHUTTLE, ALS, PLS) • HEALTH DIAGNOSTICS, IMBEDDED INSTRUEMENTATION - FLIGHT PERFORMANCE MONITORING/DATA RECORDING - AUTONOMOUS PRE-FLIGHT SUBSYSTEM CHECK-OUT/VALIDATION (BITE)

SYSTEM ENGINEERING AND INTEGRATION PANEL

NEED/ISSUE	IMPACT/SENSITIVITY	PROPOSED RESOLUTION
• DEFINE REALISTIC DEFINITION OF DESIGN MARGINS BASED ON ROBUSTNESS TO NEW PROGRAMS/APPLICATIONS	• OVER-CONSERVATISM PENALIZING COST/PERFORMANCE • INADEQUATE MARGIN EXTENDING DEVELOPMENT OF DEGRADING RELIABILITY	• FULL IMPLEMENTATION OF FMEA/CIL AND RISK ANALYSIS TECHNIQUES - PROBABILITY DESIGN TECHNIQUES • DEVELOPMENT OF PROBABILISTIC RISK ASSESSMENT, QUANTITATIVE METHODS & DATA BASES FOR "RATIONAL CRITERIA SELECTION" FOR - RELIABILITY REQMTS - SAFETY FACTORS - VERIFICATION - PROCESS CONTROL - ACCEPTANCE TESTING - HEALTH MONITORING/ PERFORMANCE TREND ANALYSIS

SYSTEM ENGINEERING AND INTEGRATION PANEL

NEED/ISSUE	IMPACT/SENSITIVITY	PROPOSED RESOLUTION
• IDENTIFICATION OF PROPULSION SYSTEM DESIGN REQUIREMENTS FOR SYSTEMS THAT CAN NOT BE EITHER FULL SCALE ACCEPTANCE TESTED OR FLIGHT DEMONSTRATED - NUCLEAR - ORBITAL ASSEMBLY - REUSABLE ORBITING SYSTEMS	• INADEQUATE DESIGN REQUIREMENTS INCREASE COST/SCHEDULE DELAYS/PERFORMANCE OR OPERATIONAL CONSTRAINSTS	• DEVELOP DESIGN METHODOLOGY THAT QUANTIFY RELIABILITY W/O SYSTEM ACCEPTANCE TESTS • DEVELOP/DEMONSTRATE PROPULSION SYSTEM CERTIFICATION VERIFICATION APPROACH (EMPIRICAL/ANALYTICAL)

2 - PERFORMANCE / DESIGN OPTIONS

2A - GROWTH EVOLUTION

2B - PDR PROCESS

2C - PLANETARY DERIVED PROPELLANTS

SYSTEM ENGINEERING AND INTEGRATION PANEL

• STRATEGY TO PROMOTE EVOLUTION	• POTENTIAL BENEFITS FROM EVOLUTION - PERFORMANCE/LIFE - COST REDUCTION - OPERABILITY/ACCESS	• PLAN FUTURE EVOLUTION PROGRAM - USE MODULAR DESIGN APPROACH - CARRY HIGH PAYOFF TECHNOLOGIES IN PARALLEL - FULL-SCALE TESTING TO SUPPORT EVOLUTION - SET GOALS FOR GROWTH IN PROGRAM BENEFITS AND PRODUCT IMPROVE PROGRAM

SYSTEM ENGINEERING AND INTEGRATION PANEL

NEED/ISSUE	IMPACT/SENSITIVITY	PROPOSED RESOLUTION
• PDR PROCESS FAILS TO PREVENT LARGE NUMBER OF UNRESOLVED DESIGN ISSUES (RID'S) LATE IN DESIGN PROCESS.	• COST/SCHEDULE IMPACT • NON-OPTIMUM DESIGN, MANUFACTURABILITY, OPERABILITY, RELIABILITY, ETC.	• INVOLVE FULL CONCURRENT ENGINEERING TEAM AND REVIEWERS - REQUIREMENTS DEFINED - LESSONS LEARNED - CONCEPTUAL REVIEWS - PHASED PDR • BETTER QUANTIFY DESIGN REQUIREMENTS, SELECTION CRITERIA, PRIORITIES, AND TRADE OFF FACTORS

SYSTEM ENGINEERING AND INTEGRATION PANEL

NEED/ISSUE	IMPACT/SENSITIVITY	PROPOSED RESOLUTION
• UTILIZATION OF PLANETARY DERIVED PROPELLANTS	• MAJOR REDUCTION OF EARTH LAUNCHED MASS • MAJOR REDUCTION OF LAUNCH VEHICLE REQUIREMENTS	• STUDIES TO DETERMINE POTENTIAL PROPELLANTS • DEVELOP TECHNOLOGY FOR PROPELLANT PRODUCTION • DEVELOP TECHNOLOGY FOR PROPULSION SYSTEMS USING IN-SITU PROPELLANTS

3 - COST

3A - TECHNOLOGY FOR REUSE

3B - OPERABILITY

3C - MISSION & COST MODELS

3D - MAINTENANCE (MODULAR vs LRU)

3E - LOW COST SYSTEMS

SYSTEM ENGINEERING AND INTEGRATION PANEL

• TECHNOLOGY TO ALLOW PROPULSION SYSTEM RECOVERY/REUSE	• SOME STUDIES (I.E. ALS) HAVE IDENTIFIED THE REUSE OF PROPULSION SYSTEM COMPONENTS, ENGINES, FEED SYSTEMS, REG, TVC, CMS, ETC... AS A MAJOR POTENTIAL COST SAVINGS • KEY FEATURES ARE LIFE ENHANCEMENT OF CRITICAL COMPONENTS SUCH AS BEARINGS AND DETECTION OF SEA WATER INCURSION	• REUSABILITY SHOULD BE ADDRESSED IN TECHNOLOGY AND ADVANCED DEVELOPMENT PROGRAMS

SYSTEM ENGINEERING AND INTEGRATION PANEL

NEED/ISSUE	IMPACT/SENSITIVITY	PROPOSED RESOLUTION
• IMPROVE LAUNCH AND FLIGHT OPERABILITY, RELIABILITY, COST AND PERFORMANCE - SIMPLIFY SYSTEMS-REDUCE NUMBER OF PARTS, SYSTEMS - ELIMINATE HYDRAULICS - SIMPLE CONTROLS - ELIMINATE PRELAUNCH CHILL - ELIMINATE/SIMPLIFY PRESSURIZATION - REDUCED MANUAL OPERATIONS SHORTEN TEST TIME	• REDUCE LABOR INTENSIVE OPERATIONS, WEIGHT, NUMBER OF PARTS	- SINGLE ENGINEUPPER STAGE - NO PURGES/AUXILIARY FLUIDS - USE EMA TVC - ELIMINATE/SLOWDOWN VALVES - NO THRUST CONTROL AND P.U. - MIXED PHASE, 0 NPSP PUMPING - AUTOGENOUS H2 & O2 PRESSURIZATION - ELIMINATE HELIUM PRESSURIZATION - SLOW ENGINE START - AUTOMATE OPERATIONS - IHM - BUILT-IN-TEST - EMA VALVES

SYSTEM ENGINEERING AND INTEGRATION PANEL

NEED/ISSUE	IMPACT/SENSITIVITY	PROPOSED RESOLUTION
• MISSION AND COST ANALYSIS FIDELITY IS LOW - MISSION MODELS OVER AMBITIOUS - REQUIREMENTS/SYSTEMS COMPLEXITY UNDERESTIMATED - GOV'T/INDUSTRY MODELS DON'T CORRELATE - OPERATIONAL COSTS DRIVERS ARE UNDERESTIMATED - PROPULSION SYSTEM RECOVERY AND REFURB COST DATA BASE IS LIMITED - LCC ANALYSIS GROUND RULES CAN VARY BETWEEN PRELIMINARY DESIGN STUDIES	• PROGRAM COST ESCALATION - LOW COST AND HIGH USAGE ESTIMATES APPEAR AS "BUY-IN" - GOV'T/INDUSTRY LOSES CREDIBILITY - COST COMPARISONS OF PROPULSION SYSTEM OPTIONS CAN BE MISLEADING	• INTERACTIVE GOV'T/CONTR COST MODELS IN PHASE A&B - MAINTAIN BY NASA - CONSISTENT GROUND RULES • OPERATIONAL COST MODEL SHOULD BE VALIDATED • USE "CONCURRENT ENGINEERING" TO GET BETTER COST DATA • DRIVE EARLY STUDIES TO GREATER DETAIL - NO DOWN SELECT ON COST FOR SIGNIFICANT DEVEL • INCLUDE RISK CONTROL IN PROGRAM PLAN & COST ESTIMATES • COST & MISSION SENSITIVITY ANALYSIS

SYSTEM ENGINEERING AND INTEGRATION PANEL

NEED/ISSUE	IMPACT/SENSITIVITY	PROPOSED RESOLUTION
• PROPULSION SYSTEM MODULARITY APPROACH - ORBITAL REPLACEMENT - LINE REPLACEMENT - SHOP REPLACEMENT	• KEY INFLUENCE ON: - DEVELOPMENT APPROACH - PRODUCT IMPROVEMENT POTENTIAL - ASSEMBLY/OPERABILITY - MAINTAINABILITY - SYSTEM COST/PERFORMANCE	• ADD REQUIREMENTS FOR OPTIMIZING MODULARITY • EVALUATE MODULARITY APPROACH THROUGHOUT PROGRAM PHASES • SELECT MODULARITY APPROACH COMPATIBLE WITH OPTIMUM PROGRAM PLANS FOR: - DEVELOPMENT - ASSEMBLY/REMOVABLE - MAINTENANCE - PRODUCT IMPROVEMENT - FAULT DETECTION - FAULT TOLERANCE

SYSTEM ENGINEERING AND INTEGRATION PANEL

NEED/ISSUE	IMPACT/SENSITIVITY	PROPOSED RESOLUTION
• LOW COST PROPULSION SYSTEM HARDWARE	• RECOVERY AND REUSABILITY HAS PROVEN TO BE EXPENSIVE AND LABOR INTENSIVE	• SINGLE OUT TECHNOLOGY ALTERNATIVES THAT CAN DRIVE SYSTEM RECURRING COST DOWN TO EXPENDABLE LEVELS • IMPLEMENT TECHNOLOGY PROGRAMS TO WORK HIGH COST AREAS • PERFORM REQUIREMENTS ANALYSIS TO ENSURE REQUIREMENTS ARE "REAL"

4 - TECHNOLOGY MATURATION PROCESS

4A - TECHNOLOGY TRANSFER

4B - TECHNOLOGY APPROACH OF 30-YEAR PROGRAM (CHANGING TECHNOLOGY BASE)

4C - INTERCENTER PARTICIPATION

4D - DEMONSTRATED SYSTEM TECHNOLOGY

4E - FOCUS TECHNOLOGY THAT ADDRESSES USER REQUIREMENTS

4F - EXPERIENCE DATABASE

4G - NARROW OPTIONS IN PHASE A

SYSTEM ENGINEERING AND INTEGRATION PANEL

NEED/ISSUE	IMPACT/SENSITIVITY	PROPOSED RESOLUTION
• INADEQUATE TECHNOLOGY TRANSFER TO PHASE C PARTICIPANTS	• UNNECESSARY DUPLICATION OF TECHNOLOGY DEVELOP. • ADDED COST/RISK IN PHASE C	• DISTRIBUTE TECHNOLOGY PROJECTS, MITIGATE RISKS • IMPROVE COMMUNICATIONS TO PROPULSION COMMUNITY • REDUNDANT/PARALLEL CONTRACTS • FORM COMSORTIA • REQUIRE PRIVATE INDUSTRY INVESTMENT

SYSTEM ENGINEERING AND INTEGRATION PANEL

NEED/ISSUE	IMPACT/SENSITIVITY	PROPOSED RESOLUTION
• TECHNOLOGY DEVELOPMENT APPROACH FOR A 30 YEAR PROGRAM	• TECHNOLOGY/DESIGN ARE FROZEN EARLY - ELECTRONICS OBSOLETE EVERY 5 YEARS - MATERIAL IMPROVEMENTS EVERY 8 YEARS	• TECHNOLOGY FOCUS ON NEXT GENERATION • PROGRAM PROVIDE FOR BLOCK CHANGE NOT CONTINUOUS UPDATE • PROVIDE TEST BED IN PARALLEL WITH PROGRAM TO TEST EVOLUTIONARY CHANGES • DESIGN INTERFACES TO ACCEPT SUBSYSTEM EVOLUTION

SYSTEM ENGINEERING AND INTEGRATION PANEL

NEED/ISSUE	IMPACT/SENSITIVITY	PROPOSED RESOLUTION
• INTER CENTER PARTICIPATION IN PRELIMINARY DESIGN STUDIES - PERFORMANCE AND OPERATIONS REQUIREMENTS ESSENTIAL - STUDY FOCUSES ON REQUIREMENTS AND ISSUES - VARIOUS CENTERS HAVE VALID ISSUES/REQUIREMENTS	• LESS THAN OPTIMUM CONCEPT SELECTION - PHASE B REDESIGN DUE TO LATE INPUTS OF REQUIREMENTS - COMPROMISE DESIGN OR OPERATION TO "FIX" INTERFACE OR INTEGRATION PROBLEMS	• INCLUDE SUPPORTING CENTERS IN EARLY STUDIES • LEAD CENTER ASSURE SUPPORTING CENTER REQUIREMENTS - PRE PHASE A - PHASE A • CONDUCT QFD TO DEFINE REQUIREMENTS

SYSTEM ENGINEERING AND INTEGRATION PANEL

NEED/ISSUE	IMPACT/SENSITIVITY	PROPOSED RESOLUTION
• DEMONSTRATED SYSTEM TECHNOLOGY AND VALIDATED DESIGN REQUIREMENTS PRIOR TO PHASE C - TECH LEVEL 5 OR BETTER	• IMMATURE TECHNOLOGY INCREASES DEVELOPMENT COST/SCHEDULE RISK • IMMATURE TECHNOLOGY INCREASES DEVEL COST/SCHEDULE RISK	• IMPLEMENT SYSTEM TEST BED FOR CRITICAL TECHNOLOGIES SPACE ENGINE/SYSTEMS • CRYOGENIC STORAGE FOR 1 - 2 YEARS - TANKAGE/SHIELDING - VENT CONTROL - PRESSURIZATION - RELIQUIFICATION • MAINTAINABILITY - ROBOTIC REMOVAL /INSTALL ENGINE OR LRU • ORBITAL CRYOGENIC FLUID TRANSFER DEMONSTRATION • CHEMICAL - CLUSTER PLUG-NOZZLE - HIGH DENSITY METALLIZED PROPELLANTS BOOSTER • HYBRID/PRESSURE FED - HOT GAS PRESSURIZATION • HYBRID - LOX COMPATABILITY GRAIN • SOLID - CLEAN PROPELLANT • LIQUID - PROPELLANT METALLIZED

SYSTEM ENGINEERING AND INTEGRATION PANEL

NEED/IS	IMPACT/SENSITIVITY	PROPOSED RESOLUTION
• FOCUSED TECHNOLOGY THAT ADDRESSES USER REQUIREMENTS - TECHNOLOGY CYCLE TOO LONG - USER REQUIREMENTS NOT IDENTIFIED TO DEVELOPER	• FOCUSED TECHNOLOGY RESULTS NOT AVAILABLE TO USERS - INCREASED DEVEL RISK/COST - TECHNOLOGY ADVANCES NOT APPLIED	• TECHNOLOGY WORKING GROUPS SHOULD BE CO-CHAIRED BY USER - START OF PHASE A • GENERIC TECHNOLOGY ACCOMPLISHED BY TECHNOLOGIST • FOCUSED TECHNOLOGY IN PHASE B BY USER - LONGER PHASE B - DECREASED PROCURENMENT TIMELAG • CONCURRENT ENGR TEAM TO DEFINE TECH NEED WITH EARLY TRADE STUDIES • USE SYSTEM CONCEPTUAL DESIGN UPDATE TO DIRECT TECHNOLOGY DEVEL PROGRAM • USE SYSTEM DESIGN UPDATE AS MANAGEMENT TOOL FOR ASSESSING TECH DEVEL PROGRAM

SYSTEM ENGINEERING AND INTEGRATION PANEL

NEED/ISSUE	IMPACT/SENSITIVITY	PROPOSED RESOLUTION
• EXPERIENCE DATA BASE - A SPECIFIC EXAMPLE, THE "ALS RELIABILITY DATA BASE" ONLY ADDRESSED 90% OF FLIGHT DATA AND MANY DID NOT HAVE ANY SPECIFIC FAILURE DATA.	• INTERCHANGE OF EXPERIENCE IS POOR • LESSONS LEARNED NOT APPLIED - THERE ARE NO NONFLIGHT "LESSONS" IN THIS DATA BASE AND THIS DATA IS PRIMARILY STORED IN "HUMAN MEMORY"	• DEVELOP CONSISTENT DATABASE & DESIGN METHODOLOGIES • TECHNOLOGY TRANSFER PROGRAM • UTILIZE ELECTRONIC MEDIA • DEDICATED EFFORT TO GATHER "LESSONS LEARNED" (NOT VOL. EFFORT)

SYSTEM ENGINEERING AND INTEGRATION PANEL

NEED/ISSUE	IMPACT/SENSITIVITY	PROPOSED RESOLUTION
• NARROW OPTIONS AT THE END OF PHASE A TO A FEW MOST ATTRACTIVE CONCEPTS WHOSE TECHNOLOGY STILL NEED MATURING	• AVAILABLE R & T FUNDS ARE FOCUSED ON A FEW CONCEPTS AND NOT SPREAD OVER TOO MANY	• PHASE A STUDIES TO PICK UP ON A FEW PROMISING CONCEPTS EVEN THOUGH THEY NEED FURTHER MATURING - PHASE A TO START OUT WITH A BROAD RANGE OF CONCEPTS AND NARROW TO A FEW PROMISING CONCEPTS BY THE END OF STUDY.

DEVELOPMENT, MANUFACTURING AND CERTIFICATION PANEL

PANEL ON

DEVELOPMENT MANUFACTURING & CERTIFICATION

Chairman: Walt Karakulko - JSC
Co-Chairman - Paul Shuerer - MSFC
Co-Chairman - Steve Dick - SSC

Topic	*Speaker*
SYSTEM DEVELOPMENT	
Probabilistic Structural Analysis Methods	Chris Chammis, (LeRC)*
Technology Transfer Methodology	Bill Boyd, (JSC)*
National Test Bed Concept	Pleddie Baker, (WSTF)*
Historical Problem Areas - Solutions Needed	John Griffin, (JSC)*
MATERIALS AND MANUFACTURING	
Manufacturing Processes & Applications	Paul Munafo, (MSFC)*
National Materials Data Base	David Pippen, (WSTF)*
NDE	Alex Vary, (LeRC)*
Concurrent Engineering	Chris Chammis, (LeRC)*
	Chip Jones, (MSFC)**
FLIGHT CERTIFICATION	
Integration of Diagnostics Into Test Process	E. G. Woods, (SSC)*
Life Cycle cost Based Test Program Decisions	J. H. Guin, (SSC)*
Certification Test Requirements - Manrating	Ron Weesner, (MSFC)*
	Orville Henson, (MSFC)*
	K. Kroll, (JSC)**
Testing vs Simulation	Charles Wood, (Rockwell)*

* *Coordinator*
** *Contributor*

Rapporteur: Bill Hope
Facilitator: Mel Bryant

DEVELOPMENT MANUFACTURING AND CERTIFICATION PANEL

SUMMARY REPORT

NASA

Space Transportation Propulsion
Technology Symposium

PSU

DEVELOPMENT, MANUFACTURING & CERTIFICATION PANEL REPORT

JUNE 29, 1990

W. KARAKULKO
Propulsion and Power Division
Johnson Space Center

SPACE TRANSPORTATION PROPULSION TECHNOLOGY SYMPOSIUM

DEVELOPMENT, MANUFACTURING, AND CERTIFICATION PANEL

CHAIRMAN: W. KARAKULKO - JSC
CO-CHAIRMAN: P. H.SHUERER - MSFC
CO-CHAIRMAN: J. S. DICK - SSC

- PARTICIPATING ORGANIZATIONS - GOVERNMENT
  - HEADQUARTERS
  - JOHNSON SPACE CENTER
  - LANGLEY RESEARCH CENTER
  - LEWIS RESEARCH CENTER
  - MARSHALL SPACE FLIGHT CENTER
  - STENNIS SPACE CENTER
  - WHITE SANDS TEST FACILITY
  - AIR FORCE ASTRONAUTICS LABORATORY
- PARTICIPATING ORGANIZATIONS - INDUSTRY
  - AEROJET TECHSYSTEM CO.
  - LOCKHEED
  - MARTIN MARIETTA
  - MCDONNELL DOUGLAS
  - PRATT AND WHITNEY
  - ROCKETDYNE
  - ROCKWELL INTERNATIONAL
  - SRS TECHNOLOGIES
  - THE MARGUARDT CO.
  - TRW
  - SVEREDRUP
- ACADEMIA
- TOTAL CONTRIBUTORS 50
- TOTAL PARTICIPANTS 45

SPACE TRANSPORTATION PROPULSION TECHNOLOGY SYMPOSIUM

DEVELOPMENT, MANUFACTURING, AND CERTIFICATION PANEL

LIST OF CONTRIBUTORS

GEORGE BAAKLINI	LERC	KEN KROLL	JSC
PLEDDIE BAKER	WSTF	RICHARD LA BOTZ	AEROJET
JAY BENNET	JSC	LUBERT LEGER	JSC
BILIGAR BHAT	MSFC	STAN LEVINE	LERC
WILLIAM BOYD	JSC	ERIC MADARAS	LARC
DAVID BROWER	LOCKHEED	JOHN MULCAHEY	NASA HQ
BUD CASTNER	JSC	PAUL MUNAFO	MSFC
CHRIS CHAMIS	LERC	JIM NEWELL	ROCKWELL
DON CHENEVERT	SSC	DAVID PIPPEN	WSTF
BRAD COWLES	PRATT & WHITNEY	STEVE RICHARDS	MSFC
STEVE DICK	SSC	W. POWERS	MSFC
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DALE FESTER	MARTIN MARIETTA	PAUL SCHUERER	MSFC
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ORVAL HENSON	MSFC	ALEX VARY	LERC
JOE HEYMAN	LERC	RAYMOND WALKER	PRATT & WHITNEY
DON HUNTER	PRATT & WHITNEY	RONALD WEESNER	MSFC
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SPACE TRANSPORTATION PROPULSION TECHNOLOGY SYMPOSIUM

DEVELOPMENT, MANUFACTURING, AND CERTIFICATION PANEL

TOPIC	*COORDINATOR*
SYSTEM DEVELOPMENT	
PROBABIL. STR. ANAL. METHODS	C. CHAMIS - LERC
TECHNOLOGY TRANSFER METHODOLOGY	W. BOYD - JSC
NATIONAL TEST BED CONCEPT	P. BAKER - WSTF
HISTORICAL PROBLEMS AREAS	J. GRIFFIN - JSC
MATERIALS AND MANUFACTURING	
MANUFACTURING PROCESSES	P. MUNAFO - MSFC
MATERIALS	D. PIPPEN - WSTF
NONDESTRUCTIVE EVALUATION	A. VARY - LERC
CONCURRENT ENGINEERING	C. CHAMIS - LERC
FLIGHT CERTIFICATION	
INTEGRATION OF DIAGNOSTICS INTO TEST PROCEDURES	E. WOODS - SSC
LIFE CYCLE COST BASED TEST PROGRAM DECISIONS	J. DICK - SSC
CERTIFICATION TEST REQUIREMENTS	S. RICHARDS - MSFC
TEST VS. SIMULATION	C. WOOD - ROCKWELL

SPACE TRANSPORTATION PROPULSION TECHNOLOGY SYMPOSIUM

DEVELOPMENT, MANUFACTURING, AND CERTIFICATION PANEL
TOPIC: PROBABILISTIC STRUCTURAL ANALYSIS METHODS FOR SPACE TRANSPORTATION PROPULSION SYSTEMS

ISSUES: CERTIFICATION OF SPACE TRANSPORTATION PROPULSION SYSTEMS

- IS COSTLY AND TIME CONSUMING
- IS DIFFICULT DUE TO UNCERTAINTIES IN ACTUAL OPERATING CONDITIONS
- NEEDS TO BE REPEATED FOR MODIFICATIONS TO EXISTING SYSTEMS AND FOR ENHANCED CAPABILITY IN OPERATING CONDITIONS

PROPOSED ACTIONS/PROGRAMS

- AUGMENTATION OF THE TWO ON-GOING NASA PROGRAMS (LERC & JPL)
- IMPLEMENTATION OF THE FOLLOWING NEW PROGRAMS:
  - MULTI-LEVEL SELF-ADAPTIVE SOFTWARE FOR GLOBAL / LOCAL NONLINEAR ANALYSIS
  - LIBRARY OF POSSIBLE FAILURE MODES
  - DECISION LOGIC FOR DAMAGE INITIATION / COALESCING / GROWTH
  - RISK MODELS / PROBABILISTICALLY-SELECTED TESTING / VERIFICATION / CERTIFICATION
  - GUIDELINES FOR HEALTH MONITORING

MAJOR OBJECTIVES

- AUTOMATED SOFTWARE PACKAGES FOR MULTI-LEVEL PROBABILISTICALLY-SIMULATED STRUCTURAL CERTIFICATION OF PROPULSION SYSTEMS

MAJOR MILESTONES

- MULTI-LEVEL PROBABILISTICALLY STRUCTURAL ANALYSIS METHODS - 1994
- LIBRARY OF POSSIBLE FAILURE MODES - 1994
- LOGIC FOR DAMAGE INITIATION / COALESCING / GROWTH - 1994
- SOFTWARE FOR COMPONENT / SYSTEM TESTING / VERIFICATION / CERTIFICATION - 1995
- STREAMLINED SOFTWARE FOR IN-SERVICE HEALTH MONITORING - 1995
- SOFTWARE VALIDATION - 1995

SPACE TRANSPORTATION PROPULSION TECHNOLOGY SYMPOSIUM

DEVELOPMENT, MANUFACTURING, AND CERTIFICATION PANEL TOPIC: TECHNOLOGY TRANSFER METHODOLOGY

ISSUES:

- INHERENT BARRIERS EXIST IN APPLYING NEW TECHNOLOGY
  - PERCEIVED HIGH RISK - LACK OF UNDERSTANDING / INVOLVEMENT BY USERS IN TECHNOLOGY DEVELOPMENT
  - "NOT INVENTED HERE" (NIH) SYNDROME
- INHERENT DIFFERENCES IN ENGINEERING APPROACH BETWEEN TECHNOLOGISTS AND SYSTEM DEVELOPERS - TECHNOLOGY DOES NOT MATCH NEED
  - TECHNOLOGISTS CONCENTRATE ON PERFORMANCE
  - DEVELOPERS WANT RELIABILITY AND LIFE

PROPOSED ACTIONS/PROGRAMS

- ESTABLISH CO-OWNERSHIP OF TECHNOLOGY PROGRAMS (TECHNOLOGIST/DEVELOPER)
  - MINIMIZES NIH SYNDROME AND PERCEIVED RISK
  - FORCES DIALOGUE BETWEEN TECHNOLOGISTS AND DEVELOPERS
- CHANGE THE SCOPE OF TECHNOLOGY PROGRAMS
  - REFOCUS THE EMPHASIS AS APPROPRIATE FROM PERFORMANCE TO RELIABILITY AND ROBUSTNESS
  - REQUIRE VALIDATION OF TECHNOLOGY AS PART OF THE TECHNOLOGY PROGRAM-- DON'T PLACE BURDEN ON SYSTEM DEVELOPERS
  - REDUCE "PAPER" TECHNOLOGY DEVELOPMENT
  - INSTITUTE STRUCTURED REPORTING OF RESULTS (IR&D)

MAJOR OBJECTIVES

- INDUCE MORE EFFECTIVE USE OF TECHNOLOGY
- ENSURE TECHNOLOGY DEVELOPMENT MATCHES USER NEEDS
  - APPLIED TECHNOLOGY - RESOLUTION OF PROBLEMS IN TODAY'S FLIGHT SYSTEMS
  - NEW TECHNOLOGY - DEVELOPMENT OF TECHNOLOGY FOR THE LONG-TERM BENEFIT OF THE AGENCY

MAJOR MILESTONES

- EARLY 1991 - TARGET NEW FY92 RTOPS FOR CO-OWNERSHIP, ASSURANCE OF VALIDATION AS PART OF RTOP SCOPE, AND IMPROVED REVIEW/REPORTING METHODS

SPACE TRANSPORTATION PROPULSION TECHNOLOGY SYMPOSIUM

DEVELOPMENT, MANUFACTURING, AND CERTIFICATION PANEL
TOPIC: PROPULSION TESTING

ISSUES:

- LACK OF NATIONAL PLAN FOR PROPULSION TESTING
  - AGING AND ATTRITION OF PROPULSION TEST FACILITIES
  - ATTRITION OF TECHNICAL SKILLS AND EXPERTISE
  - HIGH COST OF FACILITY DUPLICATION AT VARIOUS CENTERS

PROPOSED ACTIONS/PROGRAMS

- ESTABLISH TASK TEAM FOR DEFINITION OF TEST REQUIREMENTS & TEST CAPABILITIES
- ESTABLISH LEADERSHIP AT NASA HQ FOR ADVOCACY, IMPLEMENTATION AND MAINTENANCE OF PLAN
- ESTABLISH SUSTAINING WORKING GROUP TO SUPPORT ADVOCATE
- WORKING GROUP/HQ UPDATE REQUIREMENTS TO SUPPORT CoF & POP CALLS

MAJOR OBJECTIVES

- ENSURE THAT ADEQUATE PROPULSION TEST FACILITIES ARE AVAILABLE TO SUPPORT FUTURE SYSTEM DEVELOPMENT AND OPERATIONS
- DEVELOP AND MAINTAIN, WITHIN NASA AND THE PRIVATE SECTOR, THE SKILLS AND EXPERTISE REQUIRED FOR FUTURE SYSTEM DEVELOPMENT

MAJOR MILESTONES

- ESTABLISH HQ ADVOCATE 1990
- COMPLETE FACILITIES ASSESSMENT AND RECOMMENDATIONS 1991
- ESTABLISH WORKING GROUP 1992
- COMPLETE NATIONAL PROPULSION TEST PLAN 1993

SPACE TRANSPORTATION PROPULSION TECHNOLOGY SYMPOSIUM

DEVELOPMENT, MANUFACTURING, AND CERTIFICATION PANEL
TOPIC: HISTORICAL PROBLEM AREAS - SOLUTION NEEDED

ISSUES

- OUR FLIGHT SYSTEMS HAVE THE SAME PROBLEMS TODAY THAT THEY HAD 10-20 YEARS AGO
- THE MAJOR FAILURE MODE FOR PROPULSION SYSTEMS ON THE SHUTTLE IS FLUID LEAKAGE
- INADEQUATE LIFE, RELIABILITY, AND MAINTENANCE TECHNOLOGY FOR EXTENDED LIFE / MULTI-USE PROPULSION SYSTEMS - APPLIES TO GROUND AND SPACE BASED SYSTEMS
- FAILURE OFTEN RESULTS IN RESTRICTION OF DESIGNS AND MATERIALS FROM FLIGHT USE WITH RESULTING TECHNOLOGY STAGNATION

PROPOSED ACTIONS/PROGRAMS

- INITIATE DEVELOPMENT PROGRAMS TO ADDRESS THE SHUTTLE AND OTHER LONG LIFE SYSTEMS ISSUES
- FUND THE PROGRAMS AT A LEVEL SUFFICIENT TO RESULT IN REPRESENTATIVE HARDWARE THAT CAN BE DEMONSTRATED BY TEST
- ESTABLISH INDUSTRY / GOVERNMENT WIDE FORUM FOR DISCUSSION AND DOCUMENTATION OF "LESSONS LEARNED"

MAJOR OBJECTIVES

- LONG-LIFE CONTAMINATION-TOLERANT SEALS AND THERMAL CYCLE TOLERANT SEALS
- QUICK AND ACCURATE LEAK DETECTORS FOR GROUND USE
- LONG-LIFE COMBUSTION CHAMBERS
- CERAMIC AND COMPOSITE APPLICATION TECHNOLOGY FOR COMPONENTS TO IMPROVE CONTAMINATION, HEAT, AND WEAR, RESISTANCE AND PROPELLANT COMPATIBILITY
- ON-ORBIT LEAK DETECTORS & LOW-G LIQUID - GAS SEPARATORS
- ANALYTICAL TOOLS FOR EXTENDED LIFE CERTIFICATION
- LOW-G HEAT TRANSFER PHENOMENON CHARACTERIZATION

MAJOR MILESTONES

- INITIATE SHUTTLE SUPPORT PROGRAMS 1991
- INITIATE SSF - SUPPORT PROGRAMS 1992
- INITIATE MARS SUPPORT PROGRAMS 1995

SPACE TRANSPORTATION PROPULSION TECHNOLOGY SYMPOSIUM

DEVELOPMENT, MANUFACTURING, AND CERTIFICATION PANEL
TOPIC: MANUFACTURING PROCESSES

ISSUES

- PROCESS DEVELOPMENT FREQUENTLY LAGS BEHIND MATERIAL DEVELOPMENT
- HIGH FABRICATION COSTS
- FLEX JOINTS (BELLOWS) A CONTINUING PROBLEM
- SRM FABRICATION-INDUCED DEFECTS
- IN-SPACE ASSEMBLY WILL REQUIRE SIMPLIFIED DESIGNS

PROPOSED ACTIONS/PROGRAMS

- FABRICATE ADVANCED COMPOSITE DEMO ARTICLE (S)
- FABRICATE DEMO RCS THRUSTER USING IRIDIUM-COATED RHENIUM
- NEAR-NET SHAPE FABRICATION
- SMART MANUFACTURING
- DEVELOP NEW FLEX JOINT
- DESIGN AND TEST MODULAR COUPLINGS
- RHEOLOGY STUDY OF SOLID PROPELLANT FLOW CHARACTERISTICS
- COVALENT BONDING PROCESS FOR INSULATOR / PROPELLANT
- MANUFACTURE OF LARGE INTEGRATED COMPONENTS (MODULES)

MAJOR OBJECTIVES

- LARGE-SCALE DEMO ARTICLES
- REDUCED FABRICATION COSTS
- RELIABLE, EASY-TO-ASSEMBLE FLUID COUPLINGS
- IMPROVED SRM PROCESSING
- MODULAR COMPONENTS

MAJOR MILESTONES

- IMPROVED BELLOWS - 1993
- JOINING TECHNIQUE FOR RHENIUM THRUSTERS - 1993
- SIMPLIFIED COUPLINGS - 1994
- NET-SHAPE HARDWARE DEMO - 1994
- RHEOLOGY STUDY OF PROPELLANT CASTING - 1995
- CERAMIC MATRIX COMPOSITE ROTOR - 1996

SPACE TRANSPORTATION PROPULSION TECHNOLOGY SYMPOSIUM

DEVELOPMENT, MANUFACTURING, AND CERTIFICATION PANEL
TOPIC: MATERIALS

ISSUES:

- MATERIALS RESEARCH IS FRAGMENTED AND OFTEN AIMED AT SOLVING A SPECIFIC PROBLEM FOR A SPECIFIC PROGRAM
- VAST AMOUNT OF DATA, BUT IT IS POORLY ORGANIZED, OFTEN APPEARS CONTRADICTORY
- NEW SEI REQUIREMENTS, SUCH AS LONG LIFE AND HIGH TEMPERATURES OF NUCLEAR PROPULSION SYSTEMS, WILL DEMAND NEW MATERIALS

PROPOSED ACTIONS/PROGRAMS

- ESTABLISH OVERALL SPACE PROPULSION MATERIALS DEVELOPMENT PLAN BASED ON PRESENT AND FUTURE SYSTEM NEEDS
- STANDARDIZE TEST METHODOLOGY AND EQUIPMENT TO ELIMINATE DATA VARIABILITY
- ESTABLISH A NATIONAL MATERIALS DATA BASE THAT CAN PROVIDE DESIGNERS AND USERS WITH DETAILED PHYSICAL AND MECHANICAL CHARACTERISTICS, FLAMMABILITY, PROPELLANT COMPATIBILITY, ETC. AS WELL AS A CATALOG OF NATIONAL EXPERTS IN MATERIALS TECHNOLOGY

MAJOR OBJECTIVES

- AN ONGOING PROGRAM TO CONTINUALLY DEVELOP NEW MATERIALS AND UPDATE METHODOLOGY TO CHARACTERIZE THESE MATERIALS
- WEAR-RESISTANT AND INERT MATERIALS FOR MECHANICAL COMPONENTS
- MATERIALS THAT CAN WITHSTAND TEMPERATURES IN EXCESS OF 3000 $^{\circ}$K
- IDENTIFY DATA GAPS AND INITIATE PROGRAMS TO FILL THEM

MAJOR MILESTONES

- PLAN - 1991
- NATIONAL DATA BASE - 1993

SPACE TRANSPORTATION PROPULSION TECHNOLOGY SYMPOSIUM

DEVELOPMENT, MAUFACTURING, AND CERTIFICATION PANEL
TOPIC: NONDESTRUCTIVE EVALUATION

ISSUES

- CURRENT NDE TECHNOLOGY IS INADEQUATE FOR PRECISE MATERIALS CHARACTERIZATION AND PROCESS CONTROL
- DATA BASE FOR DEVELOPING STANDARDS AND CERTIFICATION DOES NOT COVER CRITICAL PROPULSION COMPONENTS
- NDE AND DESIGN NEED TO BE INTEGRATED FOR ENHANCING COMPONENT INSPECTABILITY

PROPOSED ACTIONS/PROGRAMS

- INITIATE A PROGRAM TO CORRELATE NDE PARAMETERS TO DESTRUCTIVELY MEASURED MATERIALS PROPERTIES
- DEVELOP IN-SITU NDE MONITORING WITH AUTOMATED FEEDBACK FOR PROCESS CORRECTION
- ESTABLISH DATA BASE FOR STANDARDS AND CALIBRATION METHODOLOGIES
- DEVELOP A PROTOTYPE MONITORING SYSTEM FOR ENGINE TEST ENVIRONMENT
- IDENTIFY - HIGH RISK / PAY-OFF COMPONENTS / STRUCTURES

MAJOR OBJECTIVE

- DEVELOP AND IDENTIFY INNOVATIVE NDE TECHNIQUES TO MEET THE CHALLENGE OF EXISTING AND ADVANCED SPACE PROPULSION

MAJOR MILESTONES

- IDENTIFY NDE IMPERATIVES FOR TERRESTRIAL AND SPACE APPLICATIONS - '92
- INTEGRATE NDE, MATERIALS PROCESSING AND ANALYSIS/DESIGN ACTIVITES - '93

SPACE TRANSPORTATION PROPULSION TECHNOLOGY SYMPOSIUM

DEVELOPMENT, MANUFACTURING, AND CERTIFICATION PANEL
TOPIC: CONCURRENT ENGINEERING

ISSUES

FROM MISSION REQUIREMENTS TO SYSTEM IN-SERVICE DEVELOPMENT CYCLE IS:

- INADEQUATE FOR SIMULTANEOUS INTERACTION AMONG PARTICIPATING DISCIPLINES
- INFLEXIBLE FOR ADAPTING TECHNOLOGY ADVANCEMENTS INTO A DISCIPLINE
- BASED ON AD-HOC REVISIONS, TO RESOLVE CONTINUOUSLY SURFACING PROBLEMS
- TIME CONSUMING
- COSTLY OVER THE TOTAL SYSTEM DEVELOPMENT CYCLE
- RELIANT ON EXTENSIVE COMPONENT TESTING FOR VERIFICATION AND SIMULATED PROOF TESTING, FOR SYSTEM VERIFICATION

PROPOSED ACTIONS/PROGRAMS

- COMPUTATIONAL SIMULATION OF THE CONCURRENT ENGINEERING PROCESS
- VERIFICATION ON EXISTING PROPULSION SYSTEM

MAJOR OBJECTIVES

- DEVELOP PLANS / ENVIRONMENT TO NURTURE CONCURRENT ENGINEERING MINDSET
- DEVELOP DISCIPLINE-SPECIFIC SOFTWARE SIMULATIONS WITH INTERFACING CAPABILITY
- DEVELOP SMART NEURAL NETS FOR EVALUATION OF LOCAL / GLOBAL EFFECTS
- INCORPORATE ABILITY TO AUTOMATICALLY FOCUS ON PRIORITY DISCIPLINE TASKS, PROBLEM AREAS, AND STRATEGIC ISSUES.
- INCORPORATE LOGIC TO IDENTIFY CRITICAL FABRICATION SUPPORT FOR MAXIMUM COST BENEFITS
- INCORPORATE PARALLEL PROCESSING.

MAJOR MILESTONES

- DISCIPLINE-SPECIFIC MODULES -- 1993
- NEURAL NETS -- 1994
- VERIFICATION -- 1995

SPACE TRANSPORTATION PROPULSION TECHNOLOGY SYMPOSIUM

DEVELOPMENT, MANUFACTURING, AND CERTIFICATION PANEL
TOPIC: INFUSION OF INSTRUMENTATION TECHNOLOGY INTO OPERATIONAL TEST PROGRAMS

ISSUES

- THE INTERFACES OF TECHNOLOGY DEVELOPMENT, ADVANCED DEVELOPMENT AND OPERATIONAL ACTIVITIES ARE NOT CLEARLY DEFINED
- THE TEST TECHNOLOGY DEVELOPMENT AND VALIDATION SHOULD LEAD THE DESIGN PHASE 2 TO 3 YEARS AS A MINIMUM
- THERE ARE MANY DIFFERENCES IN THE WAY TECHNOLOGISTS AND TEST OPERATORS PERCIEVE PROGRAM PROBLEMS
- THE TRANSFER PROCESS OF TECHNOLOGY TO OPERATIONS REQUIRES MAJOR RE-EVALUATION AND MODIFICATION

PROPOSED ACTIONS/PROGRAMS

- ESTABLISH A PROPULSION INSTRUMENTATION TECHNOLOGY WORKING GROUP
- DEVELOP MORE AWARENESS, UNDERSTANDING, AND COMMUNICATIONS BETWEEN TECHNOLOGY AND OPERATIONAL ELEMENTS THROUGH JOINT WORKSHOPS AND PROJECTS PREVENTING "BLIND SPOTS"
- INCREASE THE TECHNOLOGY FUNDING AND PHASE IN EARLY INTO PROGRAM, BUT PLAN ON PERIODIC OPERATIONAL IMPROVEMENT PHASES
- ESTABLISH "TEAM WORK" WITH "OWNERSHIP" RECOGNITION. MORE EMPHASIS IS REQUIRED ON INTEGRATING THE PROCESSES
- DEVELOP TECHNOLOGY TRANSFER PROGRAM TO TRANSFER COMMERCIAL TECHNOLOGY INTO NASA
- ESTABLISH USER RECOGNIZED VALIDATION AND PROOF OF UTILITY METHOD

MAJOR OBJECTIVES

- A LONG-RANGE PLAN TO PROVIDE CONTINUAL IMPROVEMENTS IN THE TECHNOLOGY / OPERATIONS TRANSFER PROCESS.

MAJOR MILESTONES

- ESTABLISH WORKING GROUP - SEPTEMBER 1990
- DEVELOP LONG-RANGE PLAN - MARCH 1991
- IMPLEMENTATION - OCTOBER 1991 - - - - -

SPACE TRANSPORTATION PROPULSION TECHNOLOGY SYMPOSIUM

DEVELOPMENT, MANUFACTURING, AND CERTIFICATION PANEL
TOPIC: CERTIFICATION TEST REQUIREMENTS

ISSUES:

- NO INDUSTRY / GOVERNMENT-WIDE RECOGNIZED METHODOLOGY
- CURRENT APPROACH IS HEAVILY DEPENDENT ON EXPENSIVE AND TIME CONSUMING TEST PROGRAMS
- NO QUANTIFICATION OF ENGINE RELIABILITY
- NO SPACE-BASED ENGINE OR SYSTEM CRITERIA EXIST

PROPOSED ACTIONS/PROGRAMS

- ESTABLISH NASA / INDUSTRY CERTIFICATION WORKING GROUP
- PERFORM A SURVEY OF METHODS, TOOLS, DATA, ETC
- DEVELOP REQUIREMENTS FOR FUTURE ETO AND SPACE-BASED SYSTEM
- DEFINE AND VERIFY METHODOLOGY AND TOOLS

MAJOR OBJECTIVES

- JUSTIFIABLE REQUIREMENTS FOR FUTURE ETO AND SPACE-BASED PROPULSION SYSTEMS CERTIFICATION
- METHODOLOGY WHICH QUANTIFIES SYSTEM RELIABILITY AND OPTIMIZES REQUIRED TESTING

MAJOR MILESTONES

- SURVEY COMPLETED - 1991
- REQUIREMENTS DEFINED - 1993
- METHODOLOGY DEFINED AND VERIFIED - 1996

SPACE TRANSPORTATION PROPULSION TECHNOLOGY SYMPOSIUM

DEVELOPMENT, MANUFACTURING, AND CERTIFICATION PANEL
TOPIC: TEST VS. SIMULATION

ISSUES:

- RELIANCE ON ANALYSIS INSTEAD OF TESTING FOR CERTIFICATION CREATES MAJOR PROGRAM RISKS
- SPACE FLIGHT ENVIRONMENTAL EFFECTS CANNOT BE ACCURATELY SIMULATED
- COMPLEXITY OF INTERACTIVE CHARACTERISTICS OF VARIOUS SUBSYSTEMS CANNOT BE ACCURATELY SIMULATED
- TECHNOLOGY FOR FLUID MANAGEMENT (PARTICULARLY CRYOS) IN SPACE IS INADEQUATE
- ADVANCED PROPULSION SYSTEMS MAY REQUIRE TEST FACILITIES MORE COMPLEX OR UNIQUE THAN PRESENTLY AVAILABLE

PROPOSED ACTIONS/PROGRAMS

- PERFORM GROUND AND FLIGHT EXPERIMENTS TO CHARACTERIZE LOW-G FLUID BEHAVIOR AND HEAT TRANSFER
- DEVELOP COMPREHENSIVE COMPONENT AND SYSTEM MODELS THAT ADDRESS FLUID DYNAMICS, THERMODYNAMICS, AND MECHANICAL PERFORMANCE IN ALL FLIGHT REGIMES
- VERIFY MODELS BY TEST

MAJOR OBJECTIVES

- A COMPREHENSIVE DATA BASE IDENTIFYING SPACE ENVIRONMENT AND ITS EFFECTS ON PROPULSION SYSTEM FLUIDS
- DEFINITION OF DESIGN AND GROUP TEST PARAMETERS FOR SPACE-BASED PROPULSION SYSTEMS AND PROPELLANT RESUPPLY SYSTEMS
- CAPABILITY TO SIMULATE COMPLEX INTERACTIONS BETWEEN SUBSYSTEMS IN SPACE FLIGHT ENVIRONMENT
- INCLUDE GROUND PROPULSION SYSTEM TESTING IN ALL FUTURE PROGRAM PLANS

MAJOR MILESTONES

- ESTABLISH WORKING GROUP TO DEFINE THE REQUIRED TECHNOLOGY PROGRAM - 1991
- FLIGHT EXPERIMENTS PLANNED, OTHERS MAY BE REQUIRED
  - TPCE 1991
  - CONE 1995
  - CTE 1996
  - COLD-SAT 1998

SPACE TRANSPORTATION PROPULSION TECHNOLOGY SYMPOSIUM

DEVELOPMENT, MANUFACTURING, AND CERTIFICATION PANEL

CONCLUSIONS

- TECHNOLOGISTS TEND TO OVERLOOK MUNDANE UNGLAMOROUS PROBLEM AREAS AND THIS IS WHY WE STILL STRUGGLE WITH PROBLEMS LIKE LEAKING VALVES AND COUPLINGS, IRON NITRATE CONTAMINANTS, AND EXTENSIVE CHECKOUT, OPERATIONS.

- THERE OFTEN EXISTS A GAP BETWEEN TECHNOLOGY PRODUCTS AND PROGRAM NEEDS. ADVANCED DEVELOPMENT PROGRAMS SHOULD BE SUPPORTED (FUNDED) TO BRIDGE THIS GAP, OR THE TECHNOLOGIST SHOULD MAKE HIS PRODUCTS READILY USEABLE BY THE SYSTEM DEVELOPER.

- CULTURAL AND PROGRAMMATIC BARRIERS EXIST TO EFFICIENT TECHNOLOGY TRANSFER. RESPONSIBLE AND DEDICATED NASA-WIDE WORKING GROUPS ARE RECOMMENDED FOR VARIOUS DISCIPLINES TO PLAN SPECIFIC PROGRAMS -- AN INDICATION THAT THERE IS A LOT OF IMPORTANT INFORMATION THAT IS NOT SHARED ROUTINELY, AND THAT A STRONG NIH SYNDROME EXISTS AND MUST BE OVERCOME.

- OUR PROPULSION SYSTEM TEST FACILITIES ARE AGING AND NEED TO BE UPGRADED. SEI CANNOT SUCCEED WITHOUT EFFICIENT AND COST EFFECTIVE TEST FACILITIES.

- CERTIFICATION FOR SPACE-BASED/LONG DURATION FLIGHT PROPULSION SYSTEMS WILL BE A MAJOR ISSUE AND WE WILL NEED TO AUGMENT OUR CURRENT METHODOLOGY TO ACCOMMODATE IT -- SOME NEW MATERIALS, TEST/NDE METHODS, AND ANALYTICAL APPROACHES.

OPERATIONAL EFFICIENCY

PANEL

PANEL ON

OPERATIONAL EFFICIENCY

Chairman: Don Nelson - JSC
Co-Chairman - Russ Rhodes - KSC
Co-Chairman - Marv Carpenter - SSC
Co-Chairman - Fred Huffaker - MSFC
Co-Chairman - Charles Holliman - HQ

Topic

SHUTTLE DERIVATIVES

Pre-Launch Activities
Flight Operations
Mission Success Assurance
Space Basing

ELVs

Pre-Launch Activities
Flight Operations
Mission Success Assurance
Space Basing

UPPER STAGES/MANNED DEEP SPACE PROBES

Pre-Launch Activities
Flight Operations
Mission Success Assurance
Space Basing

UPPER STAGES/MANNED DEEP SPACE PROBES

Pre-Launch Activities
Flight Operations
Mission Success Assurance
Space Basing

Panel Members

Robert Bush, (SSC)
Ray Byrd, (Boeing)
Marv Carpenter, (SSC)
Don Chenevert, (JSC)
Mac Dowdy, (JPL)
John Ernst, (HQ)
Del Freeman, (LaRC)
Paul Fuller, (Rocketdyne)
Fred Huffaker, (MSFC)
Dale Joyce, (Ford)
Dave Lemoine, (P&W)
Victor Mosley, (Ford)
Ron Pauckert, (Rocketdyne)
W. T. Powers, (MSFC)
Ray Randolph, (Rockwell)
Russ Rhodes, (KSC)
Bob Sackheim, (TRW)
Bill Tabata, (LeRC)
Jim Taylor, (SSC)
Doug Thorp, (Lockheed)
Bob Vacek, (Edwards AFB)
Glenn Waldrop, (Rocketdyne)
George Wong, (Rocketdyne)
Charles Wood, (SSC)

Rapporteur: Brenda Wilson
Facilitator: Bill Dickenson

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SECTION 3.4.2

OPERATIONAL EFFICIENCY PANEL

SUMMARY REPORT

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PANEL ON OPERATIONAL EFFICIENCY

CHESTER VAUGHAN
NASA JSC
6/29/90

PANEL ON OPERATIONAL EFFICIENCY

- TWO SUBPANELS OPERATED IN PARALLEL
  - UPPER STAGES - FRED HUFFAKER MSFC
  - ELV'S AND SHUTTLE DERIVED VEHICLES
    - RUSSEL RHODES, KSC
- WHITE PAPERS PRESENTED TO EACH PANEL FOLLOWED BY DISCUSSIONS RESULTING IN PRESENTATION CHARTS
- ANSWERS TO THE PRE-CONFERENCE SURVEY SENT OUT BY DON NELSON WILL BE COMPILED AND DISTRIBUTED POST CONFERENCE

UPPER STAGE OPERATIONAL EFFICIENCY SUB-PANEL

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GOALS

OPERATIONS EFFICIENCY/UPPER STAGE

ROCKET ENGINE

- USA PREEMINENCE IN HIGH PERFORMANCE ROCKET ENGINE (WITH EMPHASIS ON LOX-HYDROGEN) DEVELOPMENT, PRODUCTION, TESTING AND UTILIZATION FOR INTERNATIONAL, NATIONAL, AND COMMERCIAL UTILIZATION WITH OPERABILITY, LOW COST, RELIABILITY, AND SAFETY

- NASA EVOLVE ALTERNATIVE SPACE TRANSPORTATION ENGINE TECHNOLOGIES TO MEET NATIONAL MISSION AND SPACE EXPLORATION REQUIREMENTS FOR MAN RATING, EXTENDED MISSION DURATION, THROTTLING, AND SPACE BASED OPERATIONS FOR CRYOGENIC, STORABLE AND NUCLEAR SYSTEMS

PROPULSION SYSTEMS

- NASA DEVELOP PROPULSION INTEGRATION/SUPPORT SYSTEMS TECHNOLOGIES IN PARALLEL WITH ENGINE SYSTEMS INCLUDING CRYOGENIC FLUID MANAGEMENT, SYSTEM HEALTH MONITORING/CONTROL ELECTRO MECHANIC ACTUATORS, O_2/H_2 RCS, ADVANCED MATERIALSAND HIGH RELIABILITY FLUID CONTROL COMPONENTS AS REQUIRED TO MEET NATIONAL MISSIONS AND SPACE EXPLORATION. INSURE THAT THIS TECHNOLOGY CATEGORY HAS A HOME IN CODE R.

- NASA DEVELOP LOW THRUST PROPULSION TO MAXIMIZE EARTH-ORBIT AND PLANETARY ECONOMICS/PERFORMANCE

OBSERVATIONS/ISSUES

1. AS TQM HAS PROVEN TO MANY, CONTINUOUS INTERACTION BETWEEN "USERS" AND SUPPLIERS IS NECESSARY TO PROVIDE A BETTER PRODUCT. NUMEROUS WEAKNESSES HAVE BEEN NOTED WITH THE EXISTING TECHNOLOGY PLANNING PROCESS. RECOMMEND WE SET UP POINTS OF CONTACT IN THE NASA CENTERS/HDQ'S AND INDUSTRY TO INSURE CONTINUOUS DIALOGUE.

2. TECHNOLOGY NEEDS TO BE DIRECTED NOT ONLY TO REUSABLE SPACE-BASED PROPULSION SYSTEMS, BUT ALSO TO IMPROVING THE CAPABILITY OF EXPENDABLE SYSTEMS.

3. THE STS SHOULD INCLUDE CONSIDERATION FOR BOTH DIRECT LAUNCH AND EARTH ORBIT ASSEMBLY MISSIONS.

4. EMPHASIS AT THIS SESSION WAS ON CHEMICAL PROPULSION; NEED TO HAVE MORE CONSIDERATION FOR NUCLEAR/ELECTRIC ENGINES AND SYSTEMS

5. INFORMATION AVAILABLE AT THIS CONFERENCE DID NOT INCLUDE SYSTEM ENGINEERING DATA ON THE TOTAL SYSTEM. NASA NEEDS TO BE CAREFUL AND NOT SUB-OPTIMIZE.

6. THE SPACECRAFT PROPULSION SYSTEM IS THE FINAL "STAGE" AND THE HIGHEST LEVERAGE LINK IN THE SPACE TRANSPORTATION SYSTEM (UP TO 80% OF INJECTED MASS IS PROPULSION). UNIQUE LOW THRUST TECHNOLOGY NEEDS SHOULD BE INCLUDED.

7. NEEDS FOR THE COMMERCIAL OPERATIONS SHOULD BE CONSIDERED IN ANY NEW ENGINE DEVELOPED FOR EXPLORATION.

8. RELIABILITY AND SAFETY IS OBTAINED BY THE PROPER BLEND OF:
   - SIMPLICITY
   - DESIGN MARGIN
   - REDUNDANCY
   - MAINTAINABILITY

9. DESIGN TO MINIMIZE THE REQUIREMENT FOR MAINTENANCE

10. DESIGN TO ACCOMMODATE ORBITAL AND GROUND MAINTENANCE OF SELECTED ITEMS WITH:
    - APPROPRIATE ACCESSIBILITY
    - EASE OF FAULT ISOLATION AND DETECTION

11. LONG DURATION MARS/PLANETARY MISSION PROPULSION SYSTEM NEEDS 12-18+ MONTHS SPACE ENVIRONMENT TEST/DEMONSTRATION AND HOT FIRE CHECKOUT PRIOR TO CRITICAL USE COMMITMENT

OPERATIONAL EFFICIENCY
UPPER STAGE PANEL
TECHNICAL NEEDS

TECH/DEMO NEEDS	NAT'L	LUNAR	MARS	1 ENABLING	2 ENHANCING	3 DESIRABLE	COMMENTS
• ENGINE PROPULSION							NATIONAL MISSION INTERNATIONAL COMPETITION
- LOX-LH_2 RL-IO UPGRADE (35K)	93			✓			
- RL-10 SPACE BASED DEMO (MARGIN/ CONFIDENCE)		94	94	✓			1 YEAR VACUUM TEST LEVEL 4/5 GROUND TEST DEMO, HEALTH MONITORING
- ALTERNATE ENGINE • SPACE BASED (15-35K)		97	97	✓	✓		MAN RATING, THROTTLE/LANDER, SEI PERFORMANCE
• THROTTLING							
- IME-COMPACT ENGINE		97			✓		INTEGRATED MAIN ENGINE
- SPACE BASED ENGINE- (200K)			08			✓	MARS TMI-90 DAY REPORT
- GROUND TEST BED LeRC		95		✓			HARDWARE AVAIL 93
- ENGINE TECHNOLOGIES							
• EMA ELECTRO-MECHANICAL ACTUATORS	93	95	95	✓			
• PURGELESS ENGINE	93	95	95				
• EXTENDABLE/ RETRACTABLE NOZZLE	EXTEND 93	RETRACT 96	RETRACT 10	✓			A/R 200 TO 1 IN 93, OK FOR MARS
• ZERO NPSP		96	96	✓			He ELIMINATION
• STORABLE ENGINE- (15-30K) - THROTTLE - FAULT TOLERANT		95	95	✓	✓		LONG MARS SURFACE STAYS

OPERATIONAL EFFICIENCY
UPPER STAGE PANEL
TECHNICAL NEEDS

TECH/DEMO NEEDS	NAT'L	LUNAR	MARS	1 ENABLING	2 ENHANCING	3 DESIRABLE	COMMENTS
• NUCLEAR THERMAL ROCKET NTR	?	2016			✓		INTEGRATED VEHICLE
• MTV ENGINE GROUND TEST	?	2010					THERMAL CONTROL
• RADIATION SHIELDING	?	2010					SSF SAFETY ORBITS
• PROPULSION SUPPORT							
- MAT'L & PROCESSES	93	96					
- HEALTH MONITOR/ CONTL	93	96					
• BIT	93	96					
• DIAGNOSTICS	93	96					
- SENSORS	93	96					
• ENGINE	93	96					
• PROPELLANT/VEHICLE	93	96					
- VEHICLE/ENGINE INTERFACE	93	96					
• ZERO LEAK QUICK DISCONNECTS	93	96					
- CRYO FLUID MGM'T	97	97					GROUND TEST BED-1991 FLIGHT EXPERIMENTS START 1991
• INSULATION	97	97					
• SETTLING	97	97					
• RESIDUAL DISPOSAL	97	97					
• GAGING	97	97					
• FILL/REFILL	97	97					
• CHILL DOWN	97	97					
• FLUID TRANSFER	97	97					

OPERATIONAL EFFICIENCY
UPPER STAGE PANEL
TECHNICAL NEEDS

TECH/DEMO NEEDS	NAT'L	LUNAR	MARS	1 ENABLING	2 ENHANCING	3 DESIRABLE	COMMENTS
• INTEGRATED PROPULSION SYSTEMS (FLUID/GASSES)		95					
- O_2/H_2 RCS (LARGE)		95	95		✓		25-500LBS.
- FUEL CELLS		95	95		✓		PROPELLANT GRADE LIQUIDS
- MAIN PROPULSION SUPPORT		95	95		✓		

OPERATIONAL EFFICIENCY
UPPER STAGE PANEL
TECHNICAL NEEDS

TECH/DEMO NEEDS	NAT'L	LUNAR	MARS	1 ENABLING	2 ENHANCING	3 DESIRABLE	COMMENTS
• SPACE BASED OPS							
- ROBOTICS		99	10	✓			
- SPACE TUG		99	10	✓			
- EVA/IVA		99	10	✓			
- POWER		99	10	✓			
- WORKSTATIONS/ CONTROL		99	10	✓			
- COMMUNICATIONS/ DATA MGM'T		99	10	✓			
- KEEL/HANGAR SSF-SUPPORT		LOWER 2000	UPPER 2011	✓			
• UNIVERSAL DATA INFORMATION SYSTEM		95	95		✓		SIMILAR TO ALS-UNIS
• HIGH RELIABILITY FLUID COMPONENTS - LUNAR/MARS		96	96				

OPERATIONAL EFFICIENCY
UPPER STAGE PANEL
TECHNICAL NEEDS

TECH/DEMO NEEDS	NAT'L	LUNAR	MARS	1 ENHANCING	2 ENABLING	3 DESIRABLE	COMMENTS
• <u>SPACECRAFT PROP</u>							
• ADV. CHEM PROP (LOW THRUST) • APS • ACS • APOGEE • PLANETARY • RETRO, ASCENT • DESCENT	1994	1994			✓		- INCR. P/L TO BOL MASS RATIO - MIN. CONTAMINATION - LONG LIFE/INCR. RELIABILITY - REDUCE TOTAL SYS COST (INCL L/V) - ENABLE SPACE BASING/RE-USABILITY
• ELECTRIC PROP • STATION KEEPING • ORBIT TRANSFER • PLANETARY (DELTA V)	1995	1996	1997		✓		MAY BE ENABLING (TRIP TIME) - INCR. P/L FRACTION - MINIMAL PLANETARY TRIP TIME - REDUCE OVERALL SYSTEM COST - COULD ENHANCE ROBOTIC MISSIONS

UPPER STAGE OPERATIONAL EFFICIENCY SUB-PANEL

BACK-UP CHARTS

GUIDELINES FOR LUNAR/MARS INPUT

MILESTONES	YR
LUNAR PROGRAM	1995
PDR	1996
CDR	1996-7
FIRST TEST FLIGHT	2002
CARGO TO MOON	2003
MAN TO MOON	2004

ARCHITECTURE, "90 DAY IN-HOUSE STUDY CONCEPT & CONTENT"

SPACECRAFT PROPULSION NEEDS

THE SPACE TRANSPORTATION SYSTEM TECHNOLOGIES MUST ADDRESS SPACECRAFT PROPULSION TECHNOLOGY DRIVERS:

☞ MAXIMIZE PAYLOAD MASS FRACTION
- HIGHER SPECIFIC IMPULSE
- OPTIMUM PACKAGING
  (VERY DIFFICULT TO PACKAGE LOW DENSITY SYSTEMS EFFECTIVELY)
- LIFE

☞ ESTABLISH MISSION COMPATIBILITY/INTEGRATION CRITERIA
- CONTAMINATION
  - EARTH OBSERVATION PAYLOADS
  - PLANETARY
- THERMAL
- CONTROLS
- POWER
  - MAXIMIZE SPECIFIC POWER FOR ELECTRIC PROPULSION
- PROPULSION/PAYLOAD INTERACTIONS

☞ DEVELOP LOGISTICS & SERVICING CRITERIA
- MINIMUM PRE-LAUNCH COMPLEXITY
  (E.G. ON-PAD PRESSURIZATION/LOADING)
- IN-SPACE SERVICING & REPAIR
- COMPATIBILITY WITH SPACE NODES
  - MECHANICAL INTERFACES/DOCKING
  - CONTROLS
  - RF/DATA LINKS
  - SAFETY

LOW THRUST PROPULSION SYSTEM TECHNOLOGY DRIVERS

	LEO	EARTH ORBITAL LOGISTICS GROUND	EARTH ORBITAL LOGISTICS STATE	HEO	PLANETARY ROBOTICS	SEI	DOD
ACS	✓			✓	✓	✓	
APS	✓						
STATION KEEPING				✓			
ORBIT CHANGE/ DRAG MAKE UP	✓						
RETRO MANEUVERS					✓	✓	
PLANETARY LANDERS					✓	✓	
PRIMARY ΔV				✓		✓	
AEROBRAKE COUPLING					✓	✓	
ARTIFICIAL GRAVITY						✓	
ON-ORBIT/IN-FLIGHT SERVICING/SPACE BASING RE-USABILITY	✓	✓	✓	✓	✓	✓	
PRE-LAUNCH OPERATIONS		✓			✓	✓	

PROPULSION SYSTEM DESIRED FEATURES

Improve Launch Processing, Performance, Cost, Reliability, Safety

- Simplified Subsystems
  - Single Engine
  - No Active Thrust Control
  - No Propellant Utilization
  - No Prelaunch Chilldown
  - Low NPSP, Simplified Pressurization
  - Simplified Environmental Control (No Purges)
  - Electromechanical Valve Controls
  - EMA TVC
  - All Welded System
  - Redundant Seals at Seperable Connections (i.e. lipseals)
  - Integral Heat Exchangers for Warming Pressurant Gas or
  - Autogenous H2 and O2 Pressurization Systems

- Enhanced Checkout, System Monitoring
  - IHM - Integrated Health Monitoring
  - BIT - Built in Test
  - Automatic Operations, Checkout

- Minimal/No Catastrophic Failure Modes

- Robust Margins

- Fault Tolerance

OPERATIONAL EFFICIENCY PANEL
COMBINED ELV AND SHUTTLE DERIVATIVE SUBPANELS

AGENDA AND SUMMARY

1. PANEL ATTENDEES: 40 TO 50

2. WHITE PAPERS PRESENTED

   - PROVOCATIVE, FRESH, INNOVATIVE IDEAS DEPARTING FROM CONVENTIONAL THINKING

3. FOCUSED DISCUSSION ON PROPULSION SYSTEMS OPERATIONAL EFFICIENCY IN FIVE AREA

4. OPERATIONAL EFFICIENCY QUESTIONNAIRE SURVEY

   - o 16 QUESTIONS TO PROVIDE VISIBILITY OF PANEL PARTICIPANTS' OPINIONS AND UNDERSTANDING OF SYSTEMS CONFIGURATION EFFECTS ON OPERATIONAL EFFICIENCY

   - o PANEL CONCENSUS EXAMPLES:

     - FOR FUTURE SYSTEMS OPERATIONAL EFFICIENCY MUST BE "DESIGNED-IN," NOT ADDED SUBSEQUENT TO VEHICLE CONCEPT

     - EXISTING LAUNCH VEHICLES ARE NOT OPERATIONALLY EFFICIENT

     - TO ACHIEVE OPERATIONAL EFFICIENCY USER REQUIREMENTS AND EXPERIENCE MUST BE REFLECTED IN CONCEPTUAL DESIGN AND DEMONSTRATED DURING DEVELOPMENT

     - VEHICLES PRESENTLY UNDER DEVELOPMENT ARE NOT INCORPORATING THE PROCESS FOR OPERATIONAL EFFICIENCY

5. DEVELOPED COMPREHENSIVE LIST OF OPERATIONS TECHNOLOGY NEEDS

   - o EXISTING CLASS OF ETO VEHICLES (15-20)

   - o FUTURE-CLASS OF ETO VEHICLES (25-30)

   - o OVERALL NEW APPROACHES ENDORSED BY THE SUBPANEL (6)

6. OPERATIONS MANAGEMENT PERSPECTIVE

   - o ESTABLISH A MEANS OF GETTING FIELD OPERATIONS NEEDS INTO TECHNOLOGY AND DEVELOPMENT PROGRAMS (CSTI)

   - o NEED CONTINUING OPERATIONS REVIEW MEETINGS TO ASSESS, REFINE AND PRIORITIZE TECHNOLOGY LIST

   - o RECOMMEND OPERATIONS PROGRAM ORGANIZATION, FUNDINGS, BUDGET AND MANAGEMENT ... OEPSS

     - FOCUS ON EFFICIENT PROPULSION INTEGRATION

     - INCLUDE OPERATIONS NEEDS IN DESIGN PROCESS

     - ESTABLISH MANAGEMENT STRUCTURE, AND NASA CENTER ROLE, MISSION, AND PROCUREMENT

7. STS PROPULSION TECHNOLOGY SYMPOSIUM, JUNE 25, 1990

- o VITAL NEED FOR OPERATIONS FORUM ACCOMPLISHED AT PENN STATE
- o BROAD "GRASS-ROOTS" SUPPORT FOR OPERATIONS EFFICIENCY EXPRESSED
- o CONTINUING NEED FOR FORUM AND ACTION REVIEW IDENTIFIED
    - GOOD START AND FIRST STEP IN PROCESS .....
    - NEED YEARLY PLANNED REVISIT .....
    - BIG JOB AND TOO LITTLE TIME FOR PANEL MEETINGS .....
    - HOPE WE TAKE NEXT STEP TO COMPLETE PROCESS AND SET TONE FOR FUTURE MEETINGS.....
    - COMPLETED PANEL MINUTES AND MATERIALS PACKAGE SUBMITTED

SPACE TRANSPORTATION PROPULSION TECHNOLOGY SYMPOSIUM PENNSYLVANIA STATE UNIVERSITY

OPERATIONAL EFFICIENCY PANEL ELV SUBPANEL SESSION June 27-28, 1990

Wednesday, June 27, 1990 - Willard Building, Room 260, 1:50 p.m.

The panel convened at the Willard Building, Room 260, 1:50 p.m., June 27, 1990. Russ Rhodes, acting as moderator, opened the session with a presentation of the panel agenda. This panel session included "ELS Operational Efficiency" and "Shuttle Derivative" panel participants because Don Nelson, panel leader for SD was ill and could not attend. Bill Dickinson served as rapporteur.

The following White Papers were presented:

1. Designing Liquid Rocket Engines for Operationally Efficient Propulsion System - Dave Lemoine, Pratt & Whitney Aircraft

    - o Program development teams must have dedicated Operations Managers
    - o TQM was applied over a long period to reduce the maintenance MHS-to-flight hours ratio on turbojet engines from 3:1 to about .8:1
    - o This approach holds great promise to enhance launch vehicle operational efficiency
    - o Required:
        - define requirement
        - document lessons learned
        - get hands on user input
        - establish accessible data base
        - publish broadly in aerospace industry
        - mandate requirements
        - involve hands-on users in selection/evaluation process
        - establish contractor dialogue
        - sensitize senior management
        - allocate development funding

2. The Propulsion System is the Key to Airline-Like Operations - Chuck O'Brien, Gencorp Aerojet

- o The figure of merit is life cycle cost per pound of payload delivered to LEO
- o Current operational system is costly and labor intense
- o Current practice drives cost - 1970 technology and operations
- o Multiple stages is major cost driver
- o Ultimate goal is fully automated operations
- o Technologies have emerged to allow SSTO
- o Efficient propulsion system operations; the challenge is here and we must meet it
- o Even though we've made studies in Operational Efficiency with ALS, we have a long way to go
- o There must be new, upfront financing of operability development

3. Space Shuttle with Common Fuel Tank for Liquid Rocket Booster & Main Engines (Super Tanker Space Shuttle) - Doug Thorpe, Lockheed Space Operations, Co.

- o One single set of propellant tanks for entire launch propulsion
- o 2/3 wt. of tank - mounted engines staged after boost phase
- o Reliability can reach .9997
- o SRB HCL and ALO are unacceptable environmental pollutants - Super Tanker eliminates - all LO2/LH2
- o Current STS cost $273.5M/flight ($5470/lb to LEO)
  STS Super Tanker cost ($3300/lb to LEO)
- o Super tanker flow approximately 45 days or mission every ten days

3a. Determining Criteria for Single Stage to Orbit - Doug Thorpe, LSOC

- o SSTO flow - launch 24 hours after start of super tanker offload
- o Benefits - extreme reduction in processing time
  - internationally competitive
- o Must incorporate OEPSS technologies
- o $1350/lb to LEO

4. Propulsion Technologies for Near Term - Gopal Mehta, General Dynamics

   o Current vehicles are prime candidates for development of new technologies which benefit near-term commercial as well as far-term national needs
   o Provides "lessons learned" for future new vehicles to achieve integrated design
   o Use Atlas E for Booster Recovery Module (BRM) development and flight test proposed
   o More emphasis needed on developmental programs

5. Operationally Efficient Propulsion System Study (Ground Operations Concerns/Problems) - Glen Waldrop, Rocketdyne

   o Contemporary operations are a "nightmare" of interrelated, complex management and technical interfaces
   o "Big Hitter" is closed aft compartment as one of 25 "operational concerns" identified and discussed in OEPSS
   o Hydraulics and hypergols are also surprisingly large detractors from operational efficiency

6. Operationally Efficient Propulsion System Study (New Technologies) - George Wong, Rocketdyne Division of RI

   o Discussed causes and effects of the 25 operational concerns
   o The 25 concerns represent probably two or more days of detailed discussion needed at some future meeting/discussion
   o Samples:
     - Separate engine He systems
       - 7 He tanks
       - 63 valves, regulators, filters and PCA
       - Many leakage and maintenance requirements
     - Integrated He system
       - 1 He tank
       - 9 Valves, regulators, filters, etc.
       - 1 PCA controller
       - Greatly reduced leakage and maintenance requirements
   o The study identifies significant requirements for future technologies developments
   o These technologies are applicable to numerous existing and conceptual vehicles

7. John C. Stennis Space Center Roles and Missions - Don Chenevert, SSC

- o SSC has many elements in common with KSC for developing operational efficiency
  - Plume diagnostic test program to assess safety and enable shutdown - elements, materials, frequency, spectrum
  - H2 sensing development - leak detection-smart sensors
  - Thermal infrared imaging technology development - STS ice detection and thermal anomaly assessment
- o Developmental programs usually ignore/forget to fund development testing. This item must be included in all future new programs
- o H2 sensing on-flight hardware is a good topic for a future engine technology conference
- o The needs for propulsion test technology have been neglected and must be recognized to achieve near-term and future operational efficiency in propulsion
- o For relatively small, constant dollars, a number of applied technology development and technology transfers can be made into propulsion testing
- o Technology needs in propulsion test technology:
  - Non-intrusive diagnostic sensors and systems
    - o Plume diagnostic techniques
    - o Gas and leak detection
    - o Multi-spectral imaging technology
  - Expert system test data knowledge systems and test techniques
  - Studies to optimize propulsion test operations and work flow
  - Cryogenic and future propellant storage, handling, operations, instrumentation, and automated operations
  - Ground support equipment interface and operational development

8. Weather Prediction for Launch Support (Weather Support Office) - Jack Ernst, NASA Headquarters

- o Adverse weather impact is an additional unlisted operational impact - lightning within five miles, upper winds, rain, wind, etc.
- o KSC has 80-90 thunderstorm days/year

- o Advisories stop propellant, ordnance, hypergol, rollout, aircraft operations - immense potential impact on operational efficiency, 13.5% lost MHs in July; 11% in August, etc.
- o A message is the incentive to eliminate ordnance, hypergols, and utilize clean-plume propellants to minimize lightning trigger

9. Propulsion Ground Testing (Simulation Capability Assessment) - Charles Wood, Rockwell

- o Risk level defined - hardware replacement and repair affected - over 200 on Saturn program
- o Propulsion related simulation technology development is needed in some areas
- o System testing has prevented catastrophe and mission loss events
- o Unusual test facilities and systems may be needed
  - e.g., we lost lots of time on leakage - i.e. "no leak" connectors should be developed

OPERATIONAL EFFICIENCY PANEL SURVEY

A primary goal of this Space Transportation Propulsion Technology Symposium is to identify technology gaps, if any, between the user's needs and the technology developers. Flight and ground systems (total system end-to-end, whether in space or on ground, without regard to contractor or Center interfaces) operability can be determined by many ways, how well were functions integrated to minimize components and systems; how well were components and systems instrumented and automated by health monitoring and diagnostic systems; how well was new technology applied to eliminate hands-on inspection and testing; and how well was new technology applied to eliminate traditional concepts/approaches that result in greater simplicity to overall Space Vehicles.

Please answer the following questions, which will provide visibility concerning the above process and allow proper communication during this subpanel session. It can also be used to develop findings and observations for panel output.

The following questions address the propulsion aspects of space vehicles:

1. Do you believe that operations efficiency is only a function of flight or ground operations work control?

   Yes_____ No_____

2. Do you agree that vehicle system and component design are key to improving operational efficiency?

   Yes_____ No_____

3. Do you believe that experience from the hands-on user must be provided as visibility back to the Advanced Conceptual Designer to provide measurable progress in increased operability?

   Yes_____ No_____

4. Do you believe current space vehicles are designed operationally efficient?

   Yes_____ No_____

5. Do you believe the next generation conceptual vehicles are being designed operationally efficient?

Shuttle C: Yes_____ No_____

ALS: Yes_____ No_____

NASP: Yes_____ No_____

AMLS: Yes_____ No_____

6. Is TQM really being implemented by the procuring agent (NASA or Air Force)?

Yes_____ No_____

7. To be competitive in the world, during the next 20-30 years, in space propulsion, should this country strive for a level of operability to accomplish:

2 launches per year _____	Using: One launch pad_____
12 launches per year_____	Using: Two launch pads_____
24 launches per year_____	
52 launches per year_____	
100 launches per year_____	
360 launches per year_____	

8. Do you believe the Government requires new organization structuring within the NASA to produce operationally efficient space vehicles in the future?

Yes_____ No_____

9. Should procurement practices be changed to allow a non-constrained more creative environment during the conceptual and advanced design phases of new programs, resulting in greater operational efficiencies?

Yes_____ No_____

10. Is there, or should there be, a great difference in the design for man-rating vs. non-man rated?

Yes_____ No_____

11. Do you agree that space-based propulsion systems should be designed to require no-hands-on functions to verify system is ready for servicing and launch?

Yes_____ No_____

12. Do you believe that Space Shuttle operational efficiencies problem/concerns have been addressed in the next generation design concepts providing operational efficient solutions?

Yes_____ No_____

If yes - which programs and where?

13. Do you agree that a space-based propulsion system concept should be demonstrated on earth-to-orbit missions first to allow adequate understanding and visibility of overall performance (all aspects) before commiting to space-based?

Yes_____ No_____

14. Do you believe the propulsion discipline needs a method to measure operability (like reliability or performance) so that this function can be properly managed?

Yes_____ No_____

15. Do you agree that hands-on functions like mating, testing, and inspection should be designed out or minimized to allow increased operability for ETO and to enable space basing?

Yes_____ No_____

16. For the far term propulsion development, do you agree that we should plan on utilizing the planets and asteroids for providing source material, ie., feed stock for propulsion concepts to allow man's expanding his flight profile in space. Perform research and technology development to use these elements that are plentiful at each major heavenly body?

Yes_____ No_____

____

SIGNATURE AND ORGANIZATION

OPERATIONAL EFFICIENCY QUESTIONNAIRE SURVEY

Summary - 28 Responses

QUESTION	YES	NO	NO COMMENT	
1	2	26		
2	28			
3	28			
4		28		
5 Sh C	1	21	6	
ALS	10	16	2	
NASP	3	14	11	
AMLS	5	12	11	
6	4	22	2	
7 2-0				Pads 1-4
12-0				2-20
24-5				No Preference 4
52-12.5				
100-6.5				
360-3				
8	25	2	1	
9	28			
10	4	24		
11	27	1		
12	7	19	1 (1-Partially)	
13	22	5	1	
14	28			
15	27		1	
16	26	1	1	

Question 7 provides interesting insight into panel opinion on launch rate/year/pad. The following is a supplementary tabulation of those who signified pad quantity on the questionnaire:

50/Yr/Pad	25-26/Yr/Pad	12/Yr/Pad	180/Yr/Pad	360/Yr/Pad
9	8	5	1	1

EXISTING CLASS ELV UPGRADES

- o EMA - top priority - all agreed to high importance/desirability
- o Need splinter group conferences on potential upgrades for existing ELVs
  - Health monitoring
- o Recover boosters? Depends on systems. Concensus did not clearly defend water recovery - Item deleted
- o Expert systems and smart BIT added to integrated health monitoring
- o Insensitive ordnance devices - laser initiated devices
- o No purge pump seals
- o No purge combustion chamber (start - shutdown)

Thursday, June 28, 1990, a.m. Sub Panel Meeting - Willard Building, Room 260

Continuation of yesterday's work: "Existing Class ELV Upgrades"

Big Objective: Identify technologies to pursue, to enable operational efficiency in launch vehicles; i.e., technologies that need development and/or maturation to enable their use (Ref. A.1 & A.2)

Big point: we need engine/propulsion modules to use as building blocks for an entire vehicle family.

- o From Shuttle C point of view, should the ASRM type expenditure be continued?
  - Concensus agrees ASRM was major NASA management decision for a variety of reasons and is irreversible
  - Panel was essentially liquid propulsion specialists who recognize another variety of operational and performance factors that would eliminate SRBs if the management environment would allow. The panel does not like the SRM approach.
  - Panel agrees new solid propulsion will ultimately be as expensive as an entirely new booster such as LRB
  - ASRM negatives include:
    - Safety - uncontrollable performance envelope
    - Large environmental pollutant - HCL, AL0, ozone layer, acid rain
  - Panel agrees funds could be better allocated to a liquid propulsion booster system

OPERATIONS TECHNOLOGY APPLICATION

- No purge pump seals
- No purge combustion chamber (start - shutdown)
- Oxidizer-rich turbine, LOX turbopump (high developmental concern noted)
- Hermetically sealed inert engine and tanks (prelaunch)
- Combined O2/H2, MPS, OMS, RCS, fuel cell, thermal control systems
- Flash boiling tank pressurization
- Zero - NPSH pumps (tank head pressure start)
- Electric Motor Actuator (EMA)
- No leakage mechanical joints
- Automated self-diagnostic condition monitoring system

EXISTING SYSTEMS

- o Insensitive ordnance devices
  - Laser initiated ordnance
- o Multiple turbopumps - one shaft
- o Ground based systems - upgrade
- o Quick disconnects
- o Heat shields - improve/upgrade
  - Accessibility
  - Eliminate
- o Integrated designs - propulsion module
  - Possibly multiple chambers
    - use existing hardware - develop and demonstrate
    - includes tank
- o Insulation to eliminate Liquid Air
- o Contamination tolerant hardware/processes; i.e., welds, brazes, cleanroom operations
- o Improve hydrogen detection techniques
  - Discrete sensors
  - Area scanning
  - Quick response
  - Minimum calibration
  - Helium detection with high helium background
- o Nozzle cracking prevention
- o Non-Destructive, non-intrusive techniques for inspections - welds
  - Upgrade existing techniques
  - In-place
  - Real time

- Improve vacuum jacketed lines
  - Physical robustness
  - Eliminate

- Tracking operations maintenance data - problem database
  - Improve problem visibility
  - Manage information
  - User and depot level information
  - Measurement
  - Paperless Systems

- Fluid components internal self leak and functional test

NEXT GENERATION AND FUTURE CLASS ELVs

- o Panel re-examined Ref. A.1 chart and annotated Ref. B for new systems
- o Built Ref. B.1 chart and B.1 (cont.)
- o Does manrating drive any unique technologies? No unique technologies are seen; only a philosophical consideration for cheap payloads such as propellant tankers.
- o Does space-based drive any unique problems or new technologies?
  - Propellant Transfer
  - Hands-off test and verification (fully automated)
  - Propellant quantity monitoring
- o Should the STEP program continue in its present approach (self-imposed artificial interfaces and constraints [traditional approach])?
  - Panel believes the STEP program should be revisited and reassessed for definition and requirements envelope

Reference B

FUTURE LAUNCH SYSTEMS
PROPULSION SYSTEM OPERATIONS TECHNOLOGY

- o No purge pump seals
- o No purge combustion chamber (start - shutdown)
- o Oxidizer-rich turbine, LOX turbopump for elimination of purge (development difficulty noted)
- o Hermetically sealed inert engine and tanks (prelaunch)
- o Combined O2/H2, MPS, OMS, RCS, fuel cell, thermal control systems
- o Flash boiling tank pressurization
- o Zero - NPSH pumps (tank head start)
- o Large flow-range pumps
- o Differential throttling
- o Electric Motor Actuator (EMA)
- o No leakage mechanical joints
- o Automated self-diagnostic condition monitoring system
- o Integrated modularized propulsion module concept
- o Anti-geyser, LOX tank aft propulsion concept
- o Fluid components internal self leak and functional test

NEXT GENERATION AND FUTURE CLASS ELVs

- Robust to weather - define real requirements and/or design to accept lightning
  - Ordnance
  - Electronics
  - Range safety systems
  - Solid propellants
  - Propellant transfer

- Automated rollout, checkout, fueling
  - Eliminate all hands-on following vehicle rollout

- No bleeds

- Tank head start
  - No spin assist system
  - Idle mode start (tank head idle) - to delete pressurization system

- Eliminate aft propulsion compartment
  - Robust to natural, induced environments

- Fuel and oxidizer, liquid form only at launch pad (minimize number of fluids to load at Pad)

- Integrated launch pad and operations facilities rather than distributed (Philosophy Issue)

- Totally integrated logistics support system

- Slush hydrogen - operationally efficient processing technology and near triple point oxygen and other near future propellants

NEXT GENERATION AND FUTURE CLASS ELVs (Cont.)

- Determine impact and costs of improving and understanding of required operations before incorporating in baseline designs of next generations systems
- Low cost, disposable disconnects
- Low cost, disposable propulsion
  - Solid motor philosophy towards liquids
  - Two applications:
    - valuable payloads
    - low cost payloads

OVERALL NEW APPROACHES THE SUBPANEL WOULD LIKE TO ENDORSE FOR FURTHER STUDY AND SUPPORT

- o Single stage to orbit
- o Integrated propulsion module concept
- o Flight testing of new technology by contracting to commercial
- o Combining air breating and rocket modes during booster flight
- o Use of consortum team approach of total vehicle propulsion concepting and advanced design (real TQM)
- o Propellant combination for ETO should be H2/O2 for all new vehicles
- o All fluid systems functions be integrated to use only one fuel and one oxidizer management system
- o Totally phase out the use of toxic/environmentally damaging propellant
- o Composite tanks and lines/components (single stage enabling)
- o Recommend Deming/TQM methods be employed to develop more operationally efficient procedures/processes
- o Dedicated "Operations" testbed; integrated propulsion ground and flight systems
- o Operations steering committee, ongoing - plans and actions
- o Universal integrated launch facility
- o Totally integrated logistic support system
- o Revisit range safety requirements for flight propellant dispersion systems and safety factor requirements on ground support systems; improve operational efficiency

MANAGEMENT AREA FOR OPERABILITY

- Need accepted technique to measure operability
- Need user group to continue visibility forcing function, i.e., OEPSS type activity on-going, i.e., annual propulsion systems operational efficiency working group
  - This should be an organized effort
  - NASA Center role should be expanded to include this function
  - Contractors suggest expanded effort
- There should be an organized review (broad participation like this one) of user needs vs. focused technology work to keep proper focus on real needs
- Where do we go from here? We need organized approach to working each technology item, i.e., sponsor, leader to manage the funding, contracting and perform technical lead to develop and mature (including flight test in some cases)
  - Need a plan
    - Operations ADP, KSC, HQ, AFAL, LeRC, JSC, etc. i.e., Air Force ADPs and EMA project
- Transfer of knowledge to next generation personnel
- Experienced operations level position at HQS
- Funding should be allocated proportionally to operations concurrent engineering (managed only by operating center - not design center)
- Expand design and experiments of system and components for all projects to provide a data base of understanding to allow good operational decision making (limit testing)
- Implement probabilistic design/manufacturing process (test to failure)
- Need thorough technology maturation process including flight test in some cases
- Promote commonality
  - Assure adequate spares
  - Assure uniform, adequate specs and standards

SECTION 3.5

PROGRAM DEVELOPMENT AND CULTURAL ISSUES PANEL

PANEL ON PROGRAM DEVELOPMENT & CULTURAL ISSUES

CHAIRMAN: Ed. Gabris - Hqs
Co-Chairman: Chuck Eldred - LaRC
Co-Chairman: Harry Erwin - JSC
Co-Chairman: Eugene Austin - MSFC

CURRENT PROGRAMS | **FUTURE PROGRAMS (ALS ENVIRONMENT)**

LESSONS LEARNED (SHORTCOMINGS)
Roth, G. E. (NASA Hqts.)

TOPIC	*SPEAKER*	*TOPIC*	*SPEAKER*
REQUIREMENTS			
Space Shuttle	(LSOC) Ed Andrews	ALS	(GDC) W. Strobl
Fixed Capability	(LSOC) Ed Andrews	Environmental Considerations/TQM	(GDC) W. Strobl
Performance Driven	(LSOC) Ed Andrews	Assured Access to Space	(GDC) W. Strobl
TECHNOLOGY/PERFORMANCE/OPERATIONS			
Technology Limited	(Hqs. Shuttle Office)	Performance Margins	(ALS Contractors)
Performance Driven	(ANSER) W. Dankhoff	Cost Driven	(P&W) D. Connell (Rocketdyne) D. Fulton (Aerojet) C. Lacefield
Labor Intensive	(VITRO) H. Clark	Skeleton Crews	(VITRO) H. Clark
RELIABILITY/SAFETY			
By Test Redundancy Engine on/off/out Constraints (redlines)	(MSFC) R. Weesner	Margin/Design Fault Tolerant Design Safety Health Monitoring	(MSFC) R. Weesner
PROCUREMENT/CONTRACTING			
Competitive Approach	(Hqs.) Carol Saric	Consortium Approach	(MSFC) S. Morea
Mission Need Statement/A109	(Hqs.) Carol Saric	Joint Funding (JPO Approach)	(MSFC) S. Morea
Year-to-year Funding	(Hqs.) M. Peterson	Multi-Year Funding	(Hqs.) M. Peterson

AIA Key Technologies Funding Strategy (Hqs.) D. Stone (AIA) Dick Hartke (AIA) Tom Davidson

Rapporteur: Diane Gentry

Facilitator: Rodney Johnson

SECTION 3.5.2

PROGRAM DEVELOPMENT AND CULTURAL ISSUES PANEL SUMMARY REPORT

NASA **PROGRAM DEVELOPMENT & CULTURAL ISSUES** PSU

CULTURE CHANGE IS ESSENTIAL

DO A GOOD JOB OF PROGRAM PLANNING

- NEED TO SPEND THE NECESSARY TIME TO WELL UNDERSTAND WHAT WE ARE GOING TO DO
  - NEED TO SPEND TIME TO DO IT RIGHT NOT DO IT OVER
  - NEED TO MAKE INVESTMENT IN TECHNOLOGY & ADVANCE DEVELOPMENT
  - NEED TO UNDERSTAND "SHOULD COST"
- MAKE CONTIGENCY PLANS (BUDGET, TECHNOLOGY SCHEDULE)

NASA **PROGRAM DEVELOPMENT & CULTURAL ISSUES** PSU

CULTURE CHANGE IS ESSENTIAL

PAY ATTENTION TO OUR CUSTOMER

- MAINTAIN PROGRAM CREDIBILITY
  - -- BE TRUTHFUL DON'T OVERSELL
- EDUCATION
- STOP "NASA BASHING"
- REACH OUT EMPHASIS

NASA **PROGRAM DEVELOPMENT & CULTURAL ISSUES** PSU

CULTURE CHANGE IS ESSENTIAL

OVER COME MICRO MANAGEMENT

- NEED TO GIVE PEOPLE THE RESPONSIBILITY TO DO THE JOB -- THAN LET THEM DO IT
- IT IS THE SENSE OF CONGRESS THAT R139 SHOULD BE 150K
- OMB, GAO, OTA, SPACE COUNCIL, LOWEL WOOD, STAFFERS, CONGRESS, PRESS . . . .
- LETS STUDY IT --- AGAIN
- LETS FORM A COMMITTEE . . .

NASA **PROGRAM DEVELOPMENT & CULTURAL ISSUES** PSU

CULTURE CHANGE IS ESSENTIAL

PAY ATTENTION TO REAL PROGRAM REQUIREMENTS

- DESIGN - IN
  - MARGINS
  - LOW-COST
  - OPERABILITY
- JUST SAY NO"
  - MAINTAIN COST/SCHEDULE CREDIBILITY
  - AVOID "CAN DO"
  - AVOID "GET BY"
- PROCESS CHANGES
  - STREAMLINE ACQUISITION
  - ZERO-BASE CONTRACT SPECIFICATIONS
  - ELIMINATE OPPORTUNITY / ABILITY TO INSPECT / TEST
  - STABLE (MULTI-YEAR) FUNDING
  - HOW MANY PEOPLE ARE REALLY REQUIRED
- UTILIZE TECHNOLOGY
  - ELIMINATE PROBLEM SUBSYSTEMS/PROCESSES
  - IMPROVE MANUFACTURING
  - AUTOMATE INFORMATION PROCESSING; PAPERLESS SYSTEM

NASA **PROGRAM DEVELOPMENT & CULTURAL ISSUES** PSU

CULTURE CHANGE IS ESSENTIAL

MAKE NASA A TQM ORGANIZATION

- TOP MANAGEMENT COMMITTMENT
- LISTEN TO STAFF
- COOPERATIVE CONTRACTOR ENVIRONMENT

NASA PSU

PROGRAM DEVELOPMENT & CULTURAL ISSUES

PLANNING	–	NEED TO SPEND THE NECESSARY TIME TO WELL UNDERSTAND WHAT WE ARE GOING TO DO.
ADVOCACY	–	NEED TO GIVE ALOT MORE ATTENTION TO SELLING OUR PROGRAM
MICRO-MANAGEMENT	–	WE NEED TO GIVE PEOPLE THE RESPONSIBILITY TO DO A JOB - THAN LET THEM DO IT!

NASA PSU

PROGRAM DEVELOPMENT & CULTURAL ISSUES

CURRENT BUDGET PROCESS DICTATES A "GET-BY" PROGRAM-REDUCING UP-FRON COSTS - IGNORING OPS - COST IMPLICATIONS

OPERABILITY MUST BE DESIGNED-IN - DIFFICULT TO RETROFIT INTO EXISTING SYSTEM

"SPACE CULTURE" MUST CHANGE!

SECTION 4

PANEL SESSIONS

SECTION 4.1

SYSTEMS ENGINEERING AND INTEGRATION PANEL

SYSTEMS ENGINEERING AND INTEGRATION PANEL
GUIDELINES FOR PANEL ACTIVITIES

LEN WORLUND - MSFC - CHAIRMAN
PHIL DEANS - JSC - CO-CHAIRMAN
FRANK BERKOPEC - LeRC - CO-CHAIRMAN
IRVING DAVIDS - RAPPORTEUR
CARL AUKERMAN - RAPPORTEUR

- DIVIDED INTO THREE SUBPANELS FOR PRE-SYMPOSIUM ACTIVITIES

  PRELIMINARY DESIGN ACTIVITIES - LEN WORLUND - LEADER
  PRE-PHASE C/D ACTIVITIES - FRANK BERKOPEC - LEADER
  FLIGHT SYSTEM EVOLUTION - PHIL DEANS - LEADER

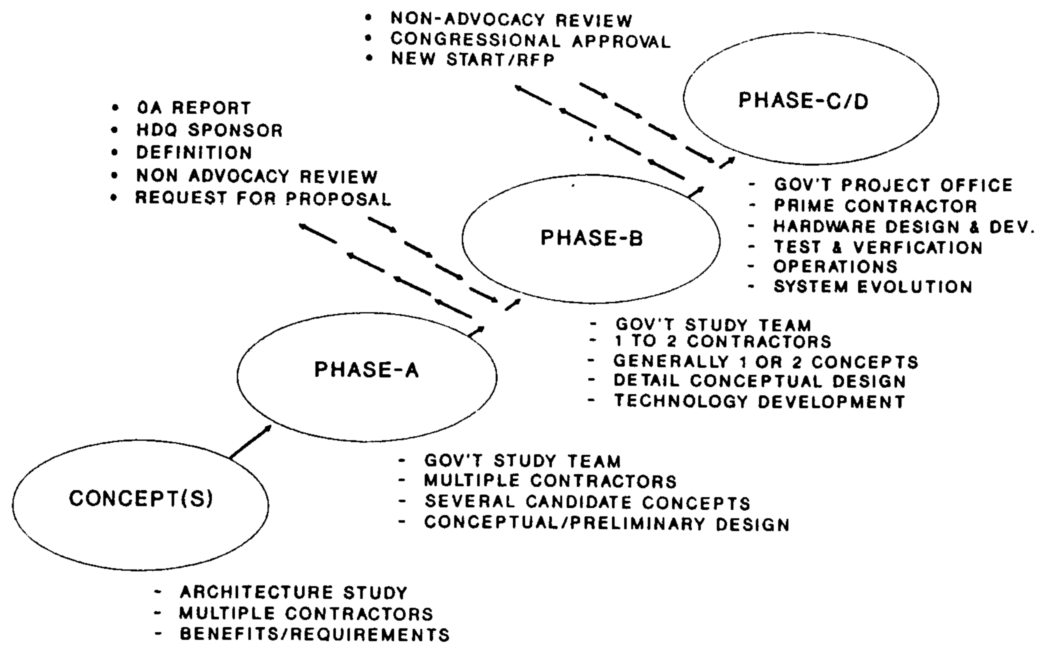
- PRELIMINARY DESIGN ACTIVITIES - LEN WORLUND - LEADER
  - CONCEPTUAL DESIGN - (PHASE A STUDIES)
  - PRE DEVELOPMENTS/PHASE B STUDIES
  - SYSTEM ARCHITECTURE
  - VEHICLE END TO END - SUB-SYSTEMS-INTERDEPENDENCIES
  - TRAJECTORY/PERFORMANCE PLANNING OPTIONS

SYSTEMS ENGINEERIGN AND INTEGRATION PANEL
GUIDELINES FOR PANEL ACTIVITIES

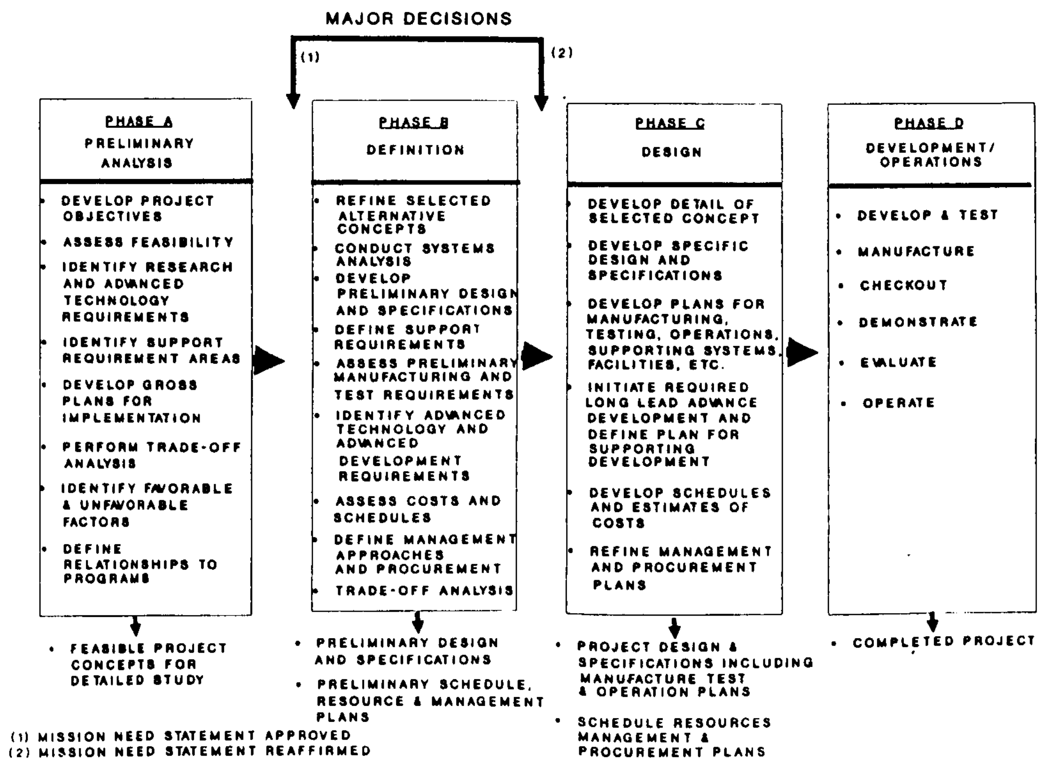
- PHASE C/D ACTIVITIES - FRANK BERKOPEC - LEADER
  - PRE DEVELOPMENT TECHNOLOGY MATURITY
  - PDR PENETRATION
  - MODULAR VS LRU'S
  - FMEA/C/L
  - DESIGN MARGIN

- FLIGHT SYSTEM EVOLUTION - PHIL DEANS - LEADER
  - UPRATING (PERF/LIFE)
  - COST REDUCTION
  - ASSURED ACCESS

CONCEPT TO HARDWARE



MAJOR ACTIVITIES AND OUTPUTS OF PROJECT PHASES



SYSTEM ENGINEERING AND INTEGRATION PANEL

GUIDELINES FOR PANEL ACTIVITIES - SCHEDULE

JUNE 27	1:30 - 1:50 PM	GUIDELINE FOR PANEL ACTIVITY
	1:50 - 3:00 PM	PRELIMINARY DESIGN ACTIVITIES SUBPANEL REPORT
	3:00 - 4:30 PM	PHASE C/D ACTIVITIES SUBPANEL REPORT
	4:30 - 6:00 PM	FLIGHT SYSTEM EVOLUTION SUBPANEL PRESENTATIONS
JUNE 28	8:00 - 12:00 AM	DISCUSSION o ADDITIONS DELETION TO SUBPANEL REPORTS o TECHNICAL ISSUES RELEVANT TO FUTURE PROPULSION CAPABILITIES o TECHNOLOGY GAPS o AGENCY INSTITUTIONAL CAPABILITIES o TECHNOLOGY TRANSFER TO ALL PROGRAM PHASES
	1:00 - 2:00 PM	DRAFT PANEL FINDINGS
	2:00 - 4:00 PM	FINALIZE VU-GRAPH OF FINDINGS
JUNE 29	8:00 - 8:30 AM	PANEL REPORT TO PLENARY SESSION

SYSTEM ENGINEERING AND INTEGRATION PANEL
PRELIMINARY DESIGN ACTIVITIES

NEED/ISSUE	IMPACT/SENSITIVITY	PROPOSED RESOLUTION
- OVER-AGGRESSIVE TECHNOLOGY SELECTION BASED ON OPTIMISTIC PREDICITONS	- RISK OF PERFORMANCE SHORTFALLS - RISK OF DELAYS & COST ESCALATION	- REQUIRE RISK CONTROLS - ADD PARALLEL DEVELOPMENT OF CONVENTIONAL TECHNOLOGY TO KEY DECISION POINTS IN ADVANCED TECHNOLOGY PROGRAMS - COMPARE ALTERNATIVES ON TOTAL LIFE CYCLE COST, INCLUDING RISK CONTROLS - INVEST IN EARLY TECHNOLOGY DEVELOPMENT & SCREENING

SYSTEM ENGINEERING AND INTEGRATION PANEL
PRELIMINARY DESIGN ACTIVITIES

NEED/ISSUE	IMPACT/SENSITIVITY	PROPOSED RESOLUTION
- INTER CENTER PARTICIPATION IN PRELIMINARY DESIGN STUDIES • PERFORMANCE AND OPERATIONS REQUIREMENTS ESSENTIAL • STUDY FOCUSES ON REQUIREMENTS AND ISSUES • VARIOUS CENTERS HAVE VALID ISSUES/REQUIREMENTS	- LESS THAN OPTIMUM CONCEPT SELECTION • PHASE B'REDESIGN DUE TO LATE INPUTS OF REQUIREMENTS • COMPROMISE DESIGN OR OPERATION TO "FIX" INTERFACE OR INTEGRATION PROBLEMS	- INCLUDE SUPPORTING CENTERS IN EARLY STUDIES - LEAD CENTER ASSURE SUPPORTING CENTER REQUIREMENTS • PRE-PHASE A • PHASE A

SYSTEM ENGINEERING AND INTEGRATION PANEL
PRELIMINARY DESIGN ACTIVITIES

NEED/ISSUE	IMPACT/SENSITIVITY	PROPOSED RESOLUTION
- DEMONSTRATED SYSTEM TECHNOLOGY AND VALIDATED DESIGN REQUIREMENTS PRIOR TO PHASE C	- IMMATURE TECHNOLOGY INCREASES DEVEL COST/ SCHEDULE RISK - UNVALIDATED REQUIREMENT INCREASES COST/SYSTEM COMPLEXITY	- IMPLEMENT SYSTEM TEST BED FOR CRITICAL TECHNOLOGIES SEI - CRYOGENIC STORAGE FOR 1 - 2 YEARS • TANKAGE/SHIELDING • VENT CONTROL • PRESSURIZATION • RELIQUIFICATION - MAINTAINABILITY • ROBOTIC REMOVAL/ INSTALL ENGINE OR LRU - ORBITAL CRYOGENIC FLUID TRANSFER DEMONSTRATION - CHEMICAL • CLUSTER PLUG-NOZZLE BOOSTER - HYBRID/PRESSURE FED • HOT GAS PRESSURIZATION - HYBRID • LOX COMPATIBILITY GRAIN - SOLID • CLEAN PROPELLANT

SYSTEM ENGINEERING AND INTEGRATION PANEL
PRELIMINARY DESIGN ACTIVITIES

NEED/ISSUE	IMPACT/SENSITIVITY	PROPOSED RESOLUTION
- TECHNOLOGY DEVELOPMENT APPROACH FOR A 30 YEAR PROGRAM	- TECHNOLOGY/DESIGN ARE FROZEN EARLY • ELECTRONIC OBSOLETE EVERY 5 YEARS • MATERIAL IMPROVEMENTS EVERY 8 YEARS	

SYSTEM ENGINEERING AND INTEGRATION PANEL
PRELIMINARY DESIGN ACTIVITIES

NEED/ISSUE	IMPACT/SENSITIVITY	PROPOSED RESOLUTION
- IDENTIFICATION OF PROPULSION SYSTEM DESIGN REQUIREMENTS FOR SYSTEMS THAT CAN NOT BE ACCEPTANCE TESTED • NUCLEAR • ORBITAL ASSEMBLY • REUSABLE ORBITING SYSTEMS	- INADEQUATE DESIGN REQUIREMENTS INCREASE COST/SCHEDULE DELAYS/ PERFORMANCE OR OPERATIONAL CONSTRAINSTS	- DEVELOP DESIGN METHODOLOGY THAT ASSURE RELIABILITY W/O SYSTEM ACCEPTANCE TESTS

SYSTEM ENGINEERING AND INTEGRATION PANEL
PRELIMINARY DESIGN ACTIVITIES

NEED/ISSUE	IMPACT/SENSITIVITY	PROPOSED RESOLUTION
- DEMONSTRATED ENABLING COMPONENT TECHNOLOGY PRIOR TO PHASE B	- TECHNOLOGY DEFICIENCY COMPLICATES SYSTEM CONCEPT DESIGN	- INITIATE TECHNOLOGY EFFORTS TO PROVIDE DESIGN CRITERIA SEI - ZERO G MASS GAGE - VENT CONTROL OF CRYOGENS - COUPLING INTEGRITY DESIGN METHODOLOGY - ELECTRO/MECHANICAL ACTUATORS BOOSTER - PRESSURANT HIGH RATE HEAT SOURCE - GG CYCLE HYBRID INJECTOR

SYSTEM ENGINEERING AND INTEGRATION PANEL
PRELIMINARY DESIGN ACTIVITIES

NEED/ISSUE	IMPACT/SENSITIVITY	PROPOSED RESOLUTION
- NARROW OPTIONS IN TIMELY MANNER	- INADEQUATE FUNDING TO SURFACE TECHNICAL ISSUES PRIOR TO DEVELOPMENT DECISION - TRUE DISCRIMINATORS NOT IDENTIFIED	- DOWNSELECT IN PHASE A - UTILIZE MULTIPLE PARTICIPANT TEAMS - ALLOW TEAMS/CONSORTIUM

SYSTEM ENGINEERING AND INTEGRATION PANEL
PRELIMINARY DESIGN ACTIVITIES

NEED/ISSUE	IMPACT/SENSITIVITY	PROPOSED RESOLUTION
- GOOD/ACCESSIBLE TECHNICAL MEMORY/LESSONS LEARNED	• POOR EXPERIENCE INTERCHANGE • LESSONS LEARNED NOT APPLIED	• DEVELOP/MAINTAIN CONSISTENT DATA BASE OR DESIGN METHODOLOGIES • FOSTER INTERCHANGE • TECHNOLOGY TRANSFER PROGRAM • APPLY MODERN DATA HANDLING TECH' - ELECTRONIC MEDIA - NATIONAL DATA NETWORK

SYSTEM ENGINEERING AND INTEGRATION PANEL
PRELIMINARY DESIGN ACTIVITIES

NEED/ISSUE	IMPACT/SENSITIVITY	PROPOSED RESOLUTION
- MISSION AND COST ANALYSIS FIDELITY IS LOW • MISSION MODELS OVER AMBITIOUS • REQUIREMENTS/ SYSTEMS COMPLEXITY UNDERESTIMATED • GOV'T/INDUSTRY MODELS DON'T CORRELATE • OPERATIONAL COSTS DRIVERS ARE UNDERESTIMATED	- PROGRAM COST ESCALATION • LOW COST AND HIGH USAGE ESTIMATES APPEAR AS "BUY-IN" • GOV'T/INDUSTRY LOSES CREDITABILITY	- INTERACTIVE GOV'T/ CONTR COST MODELS IN PHASE A & B - OPERATIONAL COST MODEL SHOULD BE VALIDATED - USE "CONCURRENT ENGINEERING" TO GET BETTER COST DATA - DRIVE EARLY STUDIES TO GREATER LEVEL OF DETAIL - INCLUDE RISK CONTROL IN PROGRAM PLAN & COST ESTIMATES - COST SENSITIVITIES - MISSION MODEL SENSITIVITY ANALYSIS

SYSTEM ENGINEERING AND INTEGRATION PANEL
PRELIMINARY DESIGN ACTIVITIES

NEED/ISSUE	IMPACT/SENSITIVITY	PROPOSED RESOLUTION
- FOCUSED TECHNOLOGY THAT ADDRESSES USER REQUIREMENTS • TECHNOLOGY CYCLE TOO LONG • USER REQUIREMENTS NOT IDENTIFIED TO DEVELOPER	- FOCUSED TECHNOLOGY RESULTS NOT AVAILABLE TO USERS • INCREASED DEVEL RISK/COST • TECHNOLOGY ADVANCES NOT APPLIED	- TECHNOLOGY WORKING GROUPS SHOULD BE CO-CHAIRED BY USER • START OF PHASE A - GENERIC TECHNOLOGY ACCOMPLISHED BY TECHNOLOGIST - FOCUSED TECHNOLOGY IN PHASE B BY USER • LONGER PHASE B • DECREASED PROCUREMENT TIMELAG - CONCURRENT ENGR TEAM TO DEFINE TECH NEED WITH EARLY TRADE STUDIES - USE SYSTEM CONCEPTUAL DESIGN UPDATE TO DIRECT TECHNOLOGY DEVEL PROGRAM - USE SYSTEM DESIGN UPDATE AS MANAGEMENT TOOL FOR ASSESSING TECH DEVEL PROGRAM

PRESENTATION 4.1.2

SYMPOSIUM ON SPACE TRANSPORTATION PROPULSION SYSTEMS TECHNOLOGY

SYSTEMS ENGINEERING AND INTEGRATION PANEL

PHASE C/D ACTIVITIES SUBPANEL

FRANK IZQUIERDO (KSC)
DON WITT (P&W)
ROBERT LUND (THIOKOL)
JOE HEMMINGER (LERC)
LARRY WEAR (MSFC)
JAMES HUGHES (GDC)
CRAIG JUDD (AEROJET)
DON JONES (ROCKWELL)
JIM MOSES (MSFC)
FRANK BERKOPEC (LERC)

NASA OFFICE OF SPACE FLIGHT
NASA OFFICE OF AERONAUTICS, EXPLORATION AND TECHNOLOGY

PENNSYLVANIA STATE UNIVERSITY
JUNE 25-29, 1990

AGENDA

- PREDEVELOPMENT TECHNICAL MATURITY
- PDR PENETRATION
- MODULAR VS LRU'S
- FMEA/CIL
- DESIGN MARGIN

PREDEVELOPMENT TECHNICAL MATURITY: HOW IS WHAT WE ARE DOING AND WHAT WE KNOW IN PREDEVELOPMENT ACTIVITY JUDGED READY ENOUGH IN TECHNICAL MATURITY TO BE INCLUDED IN AN ACTUAL DEVELOPMENT? HOW IS READY ENOUGH DEFINED? HOW DO WE ASSESS IT? HOW DO WE HAVE ENOUGH CONFIDENCE IN THE MATURITY TO ADVOCATE IT BE INCLUDED IN THE DEVELOPMENT? WHAT IS THE "CUTOFF" FOR PHASE C/D? HOW IS THE TECHNOLOGY ADEQUATELY TRANSFERRED TO THE PROGRAM?

PDR PENETRATION: WHAT IS A PDR? IS THERE A GENERALLY ACCEPTABLE/ACCEPTED UNDERSTANDING OF THE PDR? WHAT ARE ITS CHARACTERISTICS? HOW DO WE DO AN ADEQUATE JOB IN THE PDR (HOW DO WE AVOID DOING A SUPERFICIAL JOB)? HOW IS THE PDR LINKED/COUPLED TO THE SPECIFICATIONS, CONTRACTS, AND SO FORTH? WHAT ARE THE COST AND SCHEDULE FACTORS ASSOCIATED WITH A PDR?

MODULAR VS. LRU'S: WHAT IS THE DEFINITION OF A PROPULSION SYSTEM AND HOW IS IT IMPLEMENTED? DO WE LOOK AT THE PROPULSION SYSTEM AS A MODULAR ASSEMBLY, INCLUDING ELEMENTS OF THE ENGINES, TO BE BUILT UP OR ARE WE RESTRICTED TO, AND SATISFIED WITH, LINE REPLACABLE UNITS? WHAT IS THE FUTURE OF MODULAR CONCEPTS? IS THIS A DESIGN ISSUE, AN OPERATIONS ISSUE, A MAINTENANCE ISSUE? IS THIS CONSIDERATION APLICABLE TO OTHER THAN UPPER STAGES? IS THIS A COST ISSUE?

FMEA/CIL: HOW DOES THE FMEA/CIL AFFECT THE FDR/CDR, PHASE C/D? SHOULD IT BE DONE IN PARALLEL WITH THE PDR ACTIVITIES AND BE CONCURRENT TO THE PDR WHEN COMPLETED? WHAT IS THE EXPECTED EFFECT OF SPACE BASING ON THE OUTPUT?

DESIGN MARGIN: WHAT DOES DESIGN MARGIN ENTAIL? HOW CAN "MARGIN" BE IMPLEMENTED IN TERMS OF OPERABILITY, COST, AND PERFORMANCE (NOT JUST DESIGN MARGIN)?

PREDEVELOPMENT TECHNICAL MATURITY

- At initiation of Phase C/D, technical maturity of concept must be sufficient to provide confidence in meeting performance, cost, schedule

  Exception: Where need outweighs risk

- Demonstrated (verifiable and repeatable):

  principle of operation
  performance characteristics
  physical characteristics

  by: rigorous analysis
  hardware test
  (and/or prior development similarity)

- Complex hardware/concepts require long predevelopment (technology) program; SSME/High chamber pressure rocket program, for example
- Demonstrations of technology necessary before commitment to phase C/D. Post demonstration activities must be continued to get important, sufficient data for full evaluation of technology
- Demonstrate technology at highest practical level
- Expose problems at lowest level

PREDEVELOPMENT TECHNICAL MATURITY

- Carry along high risk, ~~high-payoff~~ technologies ~~as backups~~ during technology phase and development phase

  Demonstration not <u>necessary</u> to be carried in parallel with Phase C/D development, but needs to be planned to be done in timely fashion (need to have confidence)

- "Adequate" Predevelopment Technical Maturity requires wide dissemination of government-sponsored technology
- Technology transfer techniques (some/all):

  Distribute technology projects/hands-on experience necessary

  Keep community wired in on real-time basis/communicate completely, across the board

  Have redundant/parallel contracts

  Form consortia – competition is now on different levels (national/international); requires <u>serious</u> reconsideration of procurement rules and regulations

  Use IR&D to catch up if falling behind competitively

PREDEVELOPMENT TECHNICAL MATURITY

- Technical Maturity Definition/Specification:

Level	1	Basic Principles Observed and Reported
	2	Technology Concept/Application Formulated
	3	Analytical and Experimental Critical Function and/or Characteristic Proof-of-Concept
	4	Component and/or Breadboard Validation in Laboratory
	5	Component and/or Breadboard Demonstrated in Relevant Environment
	6	System Validation Engineering Model Demonstrated in Relevant/Simulated Environment
	7	System Validation Engineering Model Demonstrated in Actual Environment

- Level 6 expected prior to phase C/D development

PREDEVELOPMENT TECHNICAL MATURITY

- New awareness of Reliability, Low Cost, Robustness

  Obtain a lot of needed data (both analytic and test; comparable results verify analytic capability)

  Demonstrate required reliability before delivery

- Probabilistic design approach, new culture taking hold (was done on XLR132, NERVA)

  Points to technology holes prior to phase C/D

  As yet, no quantifiable reliability goal/confidence level

PRELIMINARY DESIGN REVIEW

- Mandatory; Major program milestone
- Done to assess if activities are going in the proper direction (before the point of no return, without more dollars and time, is passed)
- More than a review of the preliminary design

  Content not substantially different than critical design review

  Needs a name consistent with what it is intended to do
- Objectives:

  Assure the specification requirements are being correctly interpreted and implemented

  Review the design for compliance with requirements, adherence to acceptable design practice, and compatability with the current technology

  Determine that the program plan is consistent with requirements

  Determine that the design and program plan are compatible in terms of program risk

PRELIMINARY DESIGN REVIEW

- Technical Products furnished as part of the PDR include:

  Specification Compliance Matrix Document
  Preliminary Design Drawings and Drawing Tree
  Preliminary Materials and Process Specifications
  Technical Procurement Specifications
  Electrical Power Requirements Data
  Electrical Signal Interface Data
  Verification Plan
  Test and Analysis Reports (Structural, Thermal, Fluid Dynamics, etc.)
  Material Identification and Usage List
  Packaging and Transport, Preliminary Analysis and Concept Report
  Critical Process Documentation
  Pressure Vessel Data, Development
  Failure Mode and Effects Analysis Report
  Fabrication Plan
  Cost Plan
  Single Failure Point Summary Report
  Hazard Analysis Report
  Analysis Data, EEE Part Application
  End Item List, Electrical, Electronic, Electromechanical (EEE Parts, "Where Used"

PRELIMINARY DESIGN REVIEW

- PDR generally characterized by:

    Concentration on critical items

    Design of critical items with substantiating layouts and analyses

    Design issues identified

    Prototype drawings of hardware identified as necessary to be built and tested before CDR

- PDR can/should be (shall be) a series of incremental PDR's

    Program complexity

    Schedule demands

- Conducting PDR

    Maintain an overall integrated systems view (PDR Board, RID Board)

    Establish as high priority for participants

    Participant must do their homework: Review <u>all</u> data before PDR

    Participants: design team. analysts, project team, review team, fabricators, management

    Review team: specialists not on this project; must be familiar with the specification requirements and the higher level integration of the item under review; conducts all incremental PDR's

    Consortia: all companies have a task, all have oversight of project, all participate in PDR's

PRELIMINARY DESIGN REVIEW

- PDR meeting/follow on:

    Presentation summarizing data package

    Verbal interchange

    Identification of discrepancies, actions necessary, schedule, responsible parties

    Review of completed actions

MODULAR vs LRU's

- There are a number of possible propulsion system architectures
- Space Basing requires a whole new approach -- totally different work environment
- Drivers include logistics, cost

  Eliminate/Limit EVA/Hands-on in-space operations
- LRU's

  LRU's may be substantially the whole engine (removable heat shields, nozzles)

  High failure-rate units as LRU's

  Specific to application

  Choice depends upon: Logistics
  Cost
  Complexity

  Verification of system integrity after LRU replaced?
- Trend/desire to integrate the propulsion system @ one level (ETO)

  Minimized, simplified vehicle/propulsion module integration

  Incremental unit may be a propulsion module

MODULAR vs LRU's

- Integrated system must meet requirements

  Modular system development must include all elements
- Evolutionary trend toward modular elements

  Robotics for assembly, servicing, etc.
- Modular systems/Distributed propulsion system

  Russians, Chinese, French

  Tailors propulsion <u>system</u> to specific vehicle; limits wider usage

  Unit qualification for a number of applications (building block/tinker toy approach)
- Modular systems/clustered engines

  Bigger statistical base (reliability data)

  Potentially higher reliability

  Potentially eliminates gimballing
- Modular systems/plug nozzle

  Altitude compensation

MODULAR vs LRU's

- Modular systems

  We frequently underestimate the job in including qualified hardware into a <u>new</u> application (a new system)

  Every application must be evaluated on its own

FMEA/CIL

- FMEA guides technical decisions

  Drives Margins of Safety/Design Margins

- FMEA earlier than PDR as part of technical maturity decision

  FMEA usually a PDR product

  Probability of failure - what do we need to understand?

  Identifies data required during Phase C/D

- CIL evolves from FMEA

  Vehicle level criticality; loss of: vehicle
crew
mission

- Space basing

  Failure impacts more severe

  Space based "GSE" (need better description, space support equipment, SSE?); traditional qualification is inadequate

DESIGN MARGIN

- Margin: Protection from unknown
- Margins based on historical data, understanding often incomplete
- Test to failure (successful failures)

  Need to do it for the data

  Should be done more frequently (costly)

- Verified, Full-up, Probabilistic technique - - 5 to 10 years to full implementation estimated today

  Divides margins to elemental level; identifies verification needs

  Meet a reliability goal – results in known margin

  Tie cost, performance, reliability together

- Focus on Space Exploration Initiative

  New approach

- Robust designs will help alleviate cost overruns

N91-28236

PRESENTATION 4.1.3

HEAVY-LIFT LAUNCH VEHICLE PROPULSION CONSIDERATIONS

SPACE TRANSPORTATION PROPULSION TECHNOLOGY SYMPOSIUM
PENNSYLVANIA STATE UNIVERSITY

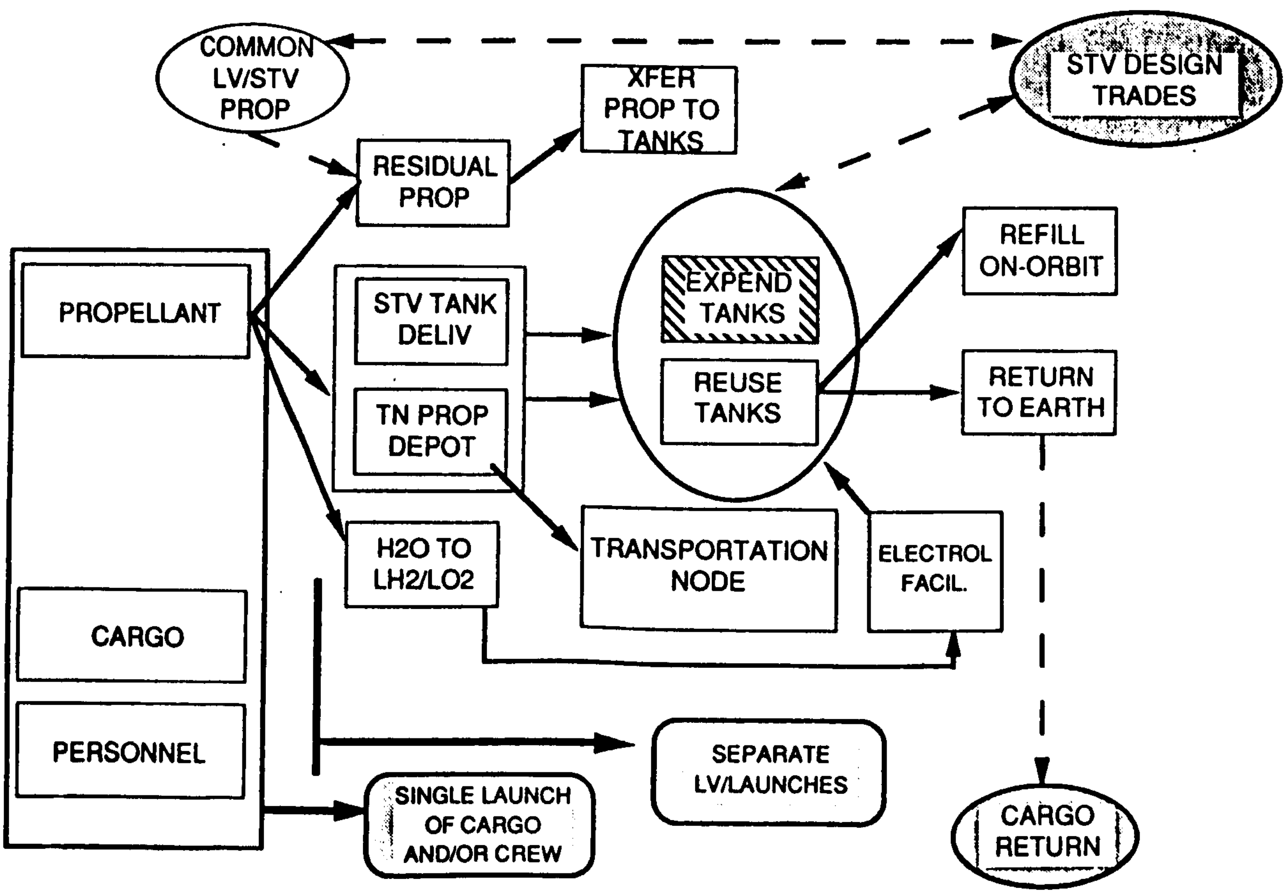
NASA / JOHNSON SPACE CENTER
SYSTEMS ENGINEERING DIVISION

WAYNE L. ORDWAY
JUNE 1990

PRESENTATION OVERVIEW

- TRANSPORTATION SYSTEM ISSUES
- STUDY OBJECTIVES
- ETO SYSTEM REQUIREMENTS
- LAUNCH VEHICLE SIZING RESULTS
- HLLV THRUST REQUIREMENTS
- PROPULSION SYSTEM RELIABILITY
- PROPULSION ISSUES

TRANSPORTATION SYSTEMS FOR LUNAR / MARS OUTPOST MUST BE TREATED AS AN INTEGRATED SYSTEM



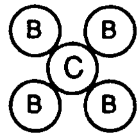
STUDY OBJECTIVES

- INVESTIGATE ETO OPTIONS WHICH
  - MIMIMIZE ON-ORBIT OPERATIONS AND IMPACTS TO SSF
    - DIRECT LAUNCH
    - AUTOMATED RENDEZVOUS/DOCKING OF ASSEMBLED ELEMENTS
  - HAVE REASONABLE CAPABILITY TO SUPPORT MARS MISSIONS
  - MINIMIZE MASS IN LEO
- CONSIDER POTENTIAL SYNERGISM WITH STS

TRANSPORTATION SYSTEM REQUIREMENTS

- MODULAR, TO BE OPERATED ROUTINELY IN ITS MINIMAL CONFIGURATION
- SIZED TO ENABLE A LUNAR MISSION IN A SINGLE LAUNCH, AND ALLOW A REASONABLE MARS CAPABILITY
- LEO MASS BREAKPOINTS
  - TOTAL LUNAR MISSION MASS 450K
  - PROPELLANT MASS 300K
  - INERT MASS 150K
- TYPICAL MARS MISSION TOTAL MASS > 2.0 M lbs
- AEROBRAKED SYSTEMS RESULT IN LARGE VEHICLES (LUNAR-62 X 50 ft; MARS 170 X 115 ft)
  - ASSEMBLED IN LEO
  - DEPLOYED

SINGLE CORE / 4 BOOSTER HLLV SIZING

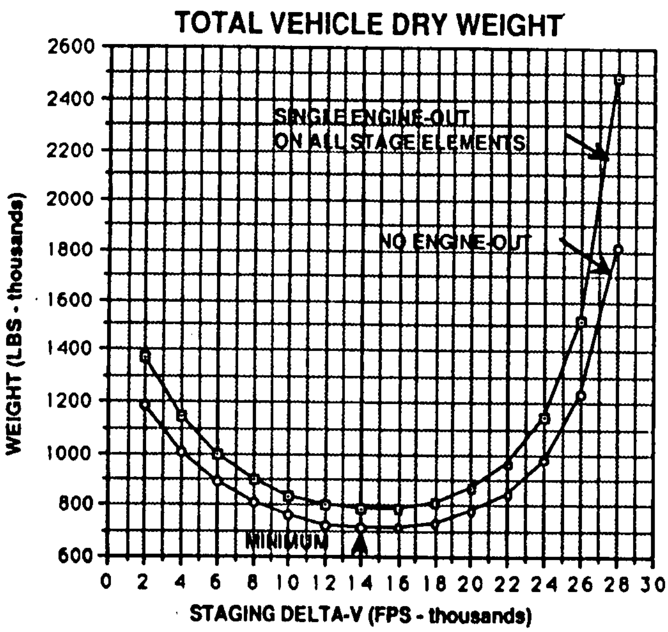


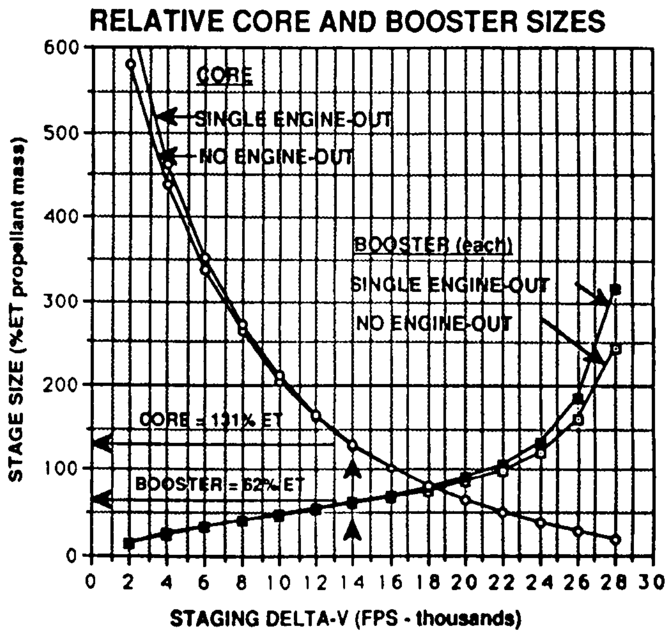
SIZING CRITERIA

- 450,000 LB LIFT CAPABILITY
- TOTAL DELTA-V + 2% RESERVE = 29,000 fps
- T / W lift-off = 1.4

ASSUMPTIONS

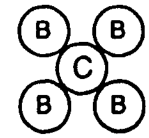
- STME TECHNOLOGY
- ENGINE T / W = CONSTANT
- ENGINE-OUT THROTTLE-UP = 33%





WITH A VEHICLE SIZED FOR MINIMUM DRY WEIGHT, THE PENALTY FOR SINGLE ENGINE-OUT CAPABILITY IS A 10% INCREASE IN DRY WEIGHT AND A 3% INCREASE IN TOTAL REQUIRED PROPELLANT (ADDITIONAL12% OF ET).

SINGLE CORE / 4 BOOSTER HLLV SIZING



SIZING CRITERIA

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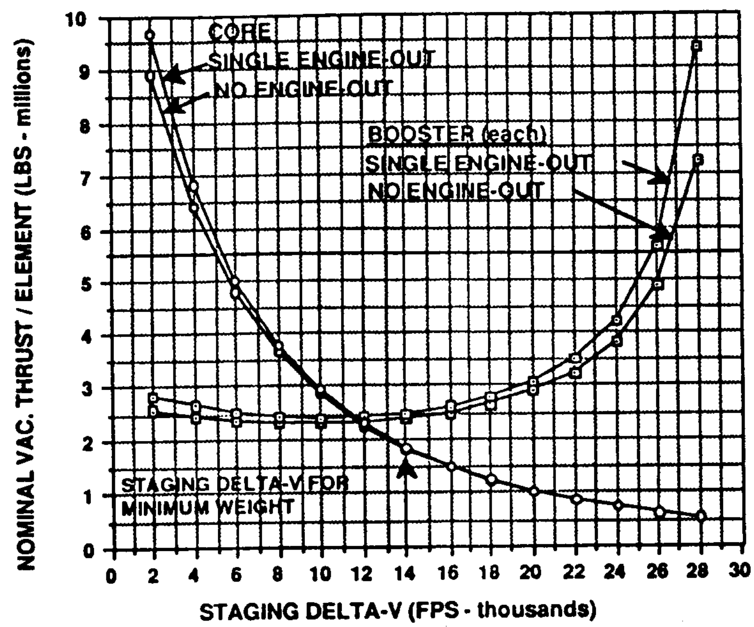
- ENGINE T / W = CONSTANT
- ENGINE-OUT THROTTLE-UP = 33%

NOMINAL VACUUM THRUST REQUIREMENTS



FOR THE MINIMUM DRY WEIGHT DESIGN, NOMINAL OPERATION THRUST (VAC) REQUIREMENTS ARE INCREASED BY 31K LBS ON THE CORE AND BY 100K LBS ON EACH BOOSTER WITH SINGLE ENGINE-OUT CAPABILITY.

SINGLE CORE / 4-BOOSTER HLLV SUMMARY

RESULTS SUMMARY	CORE	BOOSTER	STS LRB
SIZE (%ET Prop. Mass)	131	62	45
NOMINAL THRUST (MLbs-Vac.)	1.851	2.499	2.320
DRY WEIGHT (Lbs-thousands)	188.1	134.9	122.8

#	HLLV MODULAR BOOSTER (SINGLE ENGINE-OUT)				PROPOSED STS LRB (NO ENGINE-OUT)			
BSTRs	L.O.* T / W	STAGING DV (Fps)	GLOW (MLbs)	LIFT (KLbs)	L.O.* T / W	STAGING DV (Fps)	GLOW (MLbs)	LIFT (KLbs)
1	1.05	8,890	3.59	153.1	1.10	6,760	3.28	131.4
2	1.22	11,215	4.83	262.8	1.34	8,775	4.21	225.4
3	1.33	12,810	6.07	369.8	1.49	10,250	5.14	312.3
4	1.40	14,000	7.30	450.0	1.60	11,430	6.05	378.4

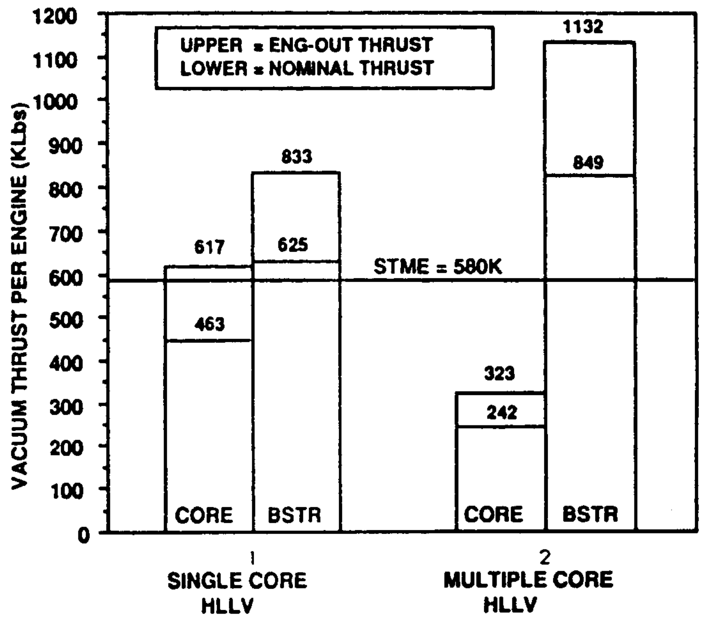
* FOR T / Ws < 1.4, MARGINS ADDED TO TOTAL DELTA-V FOR INCREASED LOSSES

A MODULAR HLLV OPTIMIZED FOR 450K LBS LIFT CAPABILITY CAN ENABLE A SINGLE LAUNCH LUNAR MISSION WHILE PROVIDING VERSATILE LIFT PERFORMANCE. USE OF THE PROPOSED STS LRB AS AN INTERIM BOOSTER OFFERS SYNERGISM WITH THE SPACE SHUTTLE.

THRUST REQUIREMENTS FOR 450KLB LIFT HLLVs

HLLV CONCEPT	TOTAL CORE VAC. THRUST (KLbs)	TOTAL BOOSTER VAC. THRUST (KLbs)
SINGLE CORE	1,851	2,499
MULTIPLE CORE	969	3,395

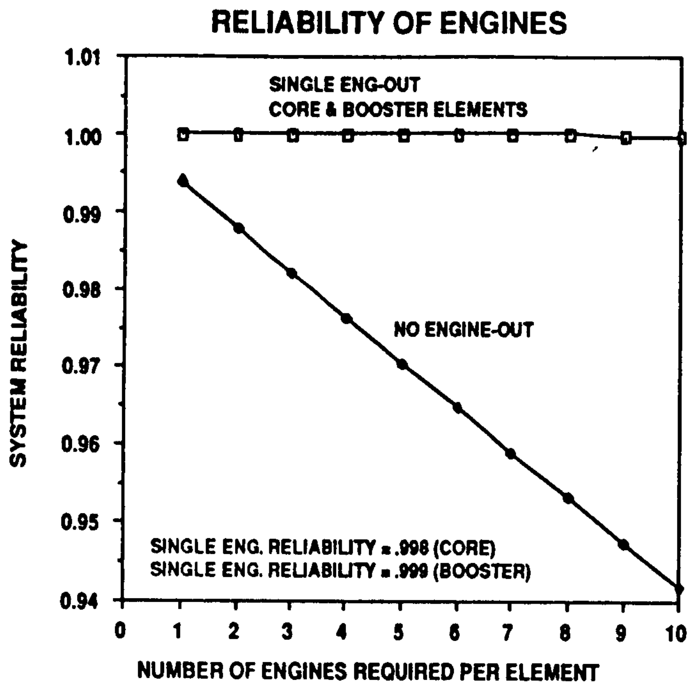
ENGINE THRUST REQUIREMENTS *

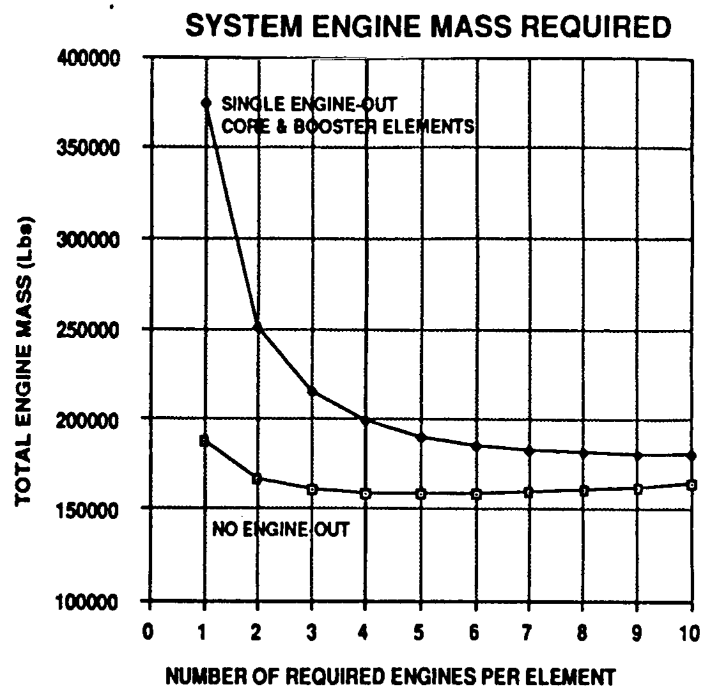


* 4 ENGINES PER STAGE
SINGLE ENG-OUT THROTTLE-UP = 33%

HLLVs REQUIRE ENGINE THRUST LEVELS GREATER THAN THE REFERENCE SPACE TRANSPORTATION ENGINE FOR REASONABLE NUMBERS OF ENGINES PER STAGE.

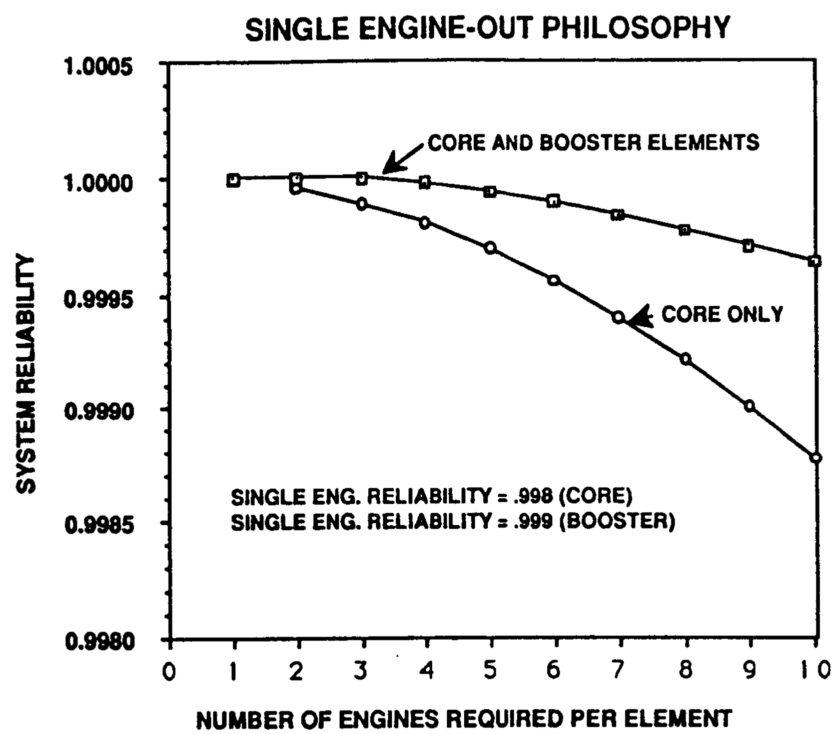
SINGLE CORE / 4-BOOSTER HLLV





THE SYSTEM RELIABILITY CAN BE SUBSTANTIALLY INCREASED WITH SINGLE ENGINE-OUT CAPABILITY ON THE CORE AND BOOSTER ELEMENTS. WITH FEWER ENGINES, RELIABILITY INCREASES BUT WITH THE PENALTY OF INCREASED SYSTEM MASS.

SINGLE CORE / 4-BOOSTER HLLV



THE APPROACH TO ENGINE-OUT CAPABILITY REMAINS AN ISSUE AND NEEDS TO BE ASSESSED. HIGH RELIABILITY IS OBTAINABLE WITH CORE ENGINE-OUT CAPABILITY ONLY BUT REQUIRES SUBSTANTIAL CORE FUEL MARGINS TO COVER BOOSTER ENGINE-OUT.

HLLV PROPULSION ISSUES

- o HLLV SYSTEMS NEED HIGH RELIABILITY
  - FAULT TOLERANT SYSTEMS / ENGINE-OUT CAPABILITY
  - RELIABLE THROTTLING CAPABILITY
  - ONBOARD CHECK-OUT / HEALTH MONITORING AND CONTROL
- o APPROACH TO ENGINE-OUT PROTECTION
- o REFERENCE STME THRUST LEVEL APPEARS TOO LOW
- o DESIGN TRADES TO FACILITATE SYSTEMS ANALYSIS
  - ENGINE RECOVERY VS. EXPENDABILITY
  - DESIGN REQUIREMENTS FOR REUSABILITY
  - ENGINE SCALING RELATIONS WITH THRUST LEVEL (Weight, Isp, Pc, Mixture Ratio, Throttling Capability)
  - THROTTLING
    - System Capability vs. Complexity
    - Step Throttle vs. Continuous (g-limiting)
  - ENGINE GIMBALLING VS. DIFFERENTIAL THRUST FOR CONTROL
  - ENGINE UPRATE CAPABILITY VS PROPULSION DESIGN (GROWTH)
    - o
    - o
    - o

N91-28237

PRESENTATION 4.1.4

Humans to Mars in 1999!

Robert Zubrin and David Baker
Martin Marietta Astronautics

Can the United States send humans to Mars during the present decade? Absolutely. We have developed a set of vehicle designs and a mission architecture that can make this possible. Moreover the plan we propose is not merely a "flags and footprints" one shot expedition, but puts into place immediately an economical method of Earth-Mars transportation, real surface exploratory mobility, and significant base capabilities that can rapidly evolve into a mostly self-sufficient Mars colony.

Here's how it works. In December 1996 a single shuttle derived heavy lift launch vehicle such as that shown in fig.1 lifts off from Cape Canaveral and fires a 40 metric ton unmanned payload off on a trajectory to Mars, where it aerobrakes into orbit and lands 8 months later. This unmanned payload consists of the following: (1) an *unfueled* two-stage ascent and Earth return vehicle (fig.2) employing methane/oxygen engines and including a life support system and enough whole food for four people for 9 months, plus some dehydrated emergency rations; (2) 5.8 metric tons of liquid hydrogen; (3) a 100 kWe nuclear reactor mounted within a small methane/oxygen internal combustion driven unpressurized utility truck; (4) a small set of compressors and automated chemical processing unit; and (5) a few small scientific robotic rovers.

As soon as the payload is landed, the reactor is driven a few hundred yards away from the landing site and lowered off the truck into either a natural depression in the terrain or one created by the robots (teleoperated from Earth) with the aid of a few sticks of dynamite. Its radiators are then deployed and a cable run back to the lander. Then the reactor, which has not yet been used, is started up to provide 100 kilowatts of electric power to the site facilities. The compressors are then run to acquire carbon dioxide out of the martian atmosphere (which is 95% CO_2.) With the help of a catalyst, this CO_2 can be made to react with the 5.8 metric tons of hydrogen cargo, transforming it in a few days into 37.7 metric tons of methane and water. This being accomplished, we no longer have to worry about how to store our super-cold liquid hydrogen on the surface of Mars. Next, the chemical plant goes to work, electrolysizing the water into hydrogen and oxygen. The oxygen is stored as a liquid, and the hydrogen is reacted with more CO_2 to create more methane and water, and so forth. Additional oxygen is produced by directly decomposing atmospheric CO_2 into oxygen and carbon monoxide, storing the oxygen and dumping the CO. In the course of a year, about 107 metric tons of methane/oxygen propellant is produced.

This may sound somewhat involved, but actually the chemical processes employed are 19th century technology. The 100 kWe nuclear unit isn't, but we've operated practical nuclear reactors since 1954, and the SP-100 in particular is currently scheduled to be ground tested in 1995, so that with an accelerated program either it or an alternative design can certainly be made ready in time for this mission.

Meanwhile, back on Earth, flight controllers have been watching to make sure that the propellant production operation is completed successfully. If it has, then in January 1999 two more heavy lift boosters will rise from the Cape within a few weeks of each other. One of them has an unmanned payload identical to the one launched in 1996. The other payload is a manned spacecraft (fig.3) looking somewhat like a giant hockey puck 27.5 feet in diameter and 16 feet tall. Its habitation deck contain some 594 square feet of floor space, allowing it to accommodate a crew of four, while an additional deck is available for cargo. With a weight of 38 metric tons (including aerobrake, landing propellant, provisions, and a pressurized methane/oxygen gas turbine/electric driven ground car) it is light enough that the booster upper stage can project it directly onto a six month transfer orbit to Mars without any Earth orbit refueling or assembly.

Once on its way to Mars, the manned habitat pulls away from the expended booster upper stage that launched it, but they are still connected by a tether about 1500 yards long. With the help of this tether, the empty upper stage can be used as a counterweight, and the assembly is spun up at one revolution per minute to provide a level of artificial gravity equal to the 3/8 g found on the surface of Mars. When the manned craft arrives at Mars, the tether and upper stage are discarded, and the ship aerobrakes into orbit and then lands in the immediate vicinity of the now fully fueled ascent vehicle that has been waiting for it since 1997. The landing is safe because the robotic rovers sent out in the advance landing have identified and given extensive characterization of the best landing site in the vicinity, and laid out radar beacons to guide the terminal descent.

In 1976, the United States sent two Viking probes to Mars, and landed them right on their designated target areas. With the help of the landing beacons, superior technology, advance meteorological data from the ground site, and the on the spot decision making capability of a human pilot, we will vastly exceed the degree of landing precision demonstrated by Viking.

But even if we missed by a considerable distance, the mission plan has built into it three layered fall back options, a defense in depth to assure the safe return of the crew. First, the manned spacecraft carries with it a pressurized rover with a one-way range of 600 miles, so if the landing was not misdirected by a distance greater than this, the crew could still drive over to their return vehicle. Second, if by some inconceivable mischance the crew misses its landing site by a distance greater than 600 miles, they can still direct the second unmanned payload (which has been following them out a few days behind) to land near them. It contains a propellant factory of its own, and can thus act as an emergency backup. Finally, if all else fails, the crew has with them in their habitat enough supplies to last them until a relief expedition can be sent out two years later.

However, assuming that the manned landing has been carried out correctly at the prepared site, and the flight readiness of the 1996/97 ascent vehicle is verified, the 1999 unmanned lander will be directed to a second landing site 500 miles away from the first. There it will begin manufacturing propellant for the second manned mission, which will be sent out in 2001.

Thus each manned Mars mission requires just two heavy lift booster launches; one to deliver a ride home, and the other to create a new outpost or add to a existing base on Mars. This is much more economical than conventional mission plans in which all the propellant is brought from Earth, which typically require 4 to 7 heavy lift booster launches for each mission. The mission plan we propose is better than a conventional plan in another way: we bring all of our crew and their hardware to the surface where they can do their job of exploring Mars and learning how to live on another world. The conventional plan requires leaving a mothership in orbit around Mars, whose crew will accomplish little except soak up cosmic rays. The crew on the surface is protected by Mars' atmosphere from most of the solar flares hazard, and with the help of some sandbags placed on top of their landed habitats, can be protected from cosmic rays as well. The vulnerability of the crew of the orbiting mothership tends to create an incentive to limit the stay time of a conventional mission at Mars. This leads to very inefficient missions. After all, if it takes a year and a half of round trip flight time to travel to Mars, it's rather unreasonable to limit the stay at the destination to 30 days. A not too rough analogy to such a mission would be planning Christmas vacation in Hawaii but arranging the itinerary to include 9 days of transferring around airports going out and back, and half a day at the beach! Yet that is how the conventional mission plans are structured. Worse yet, in their rush to get back from Mars, the conventional mission planners are forced to take disadvantageous high energy orbits which require a lot more propellant as well as a swingby of the planet Venus where the Sun's radiation is twice that at Earth. In the plan we offer, the crew will spend 500 days on the surface of Mars and only 12 to 16 months in round trip interplanetary cruise, traveling via the most efficient, "minimum energy" orbit possible.

During their 500 day stay on the surface of Mars, the crew will be able to accomplish a great deal of exploration. Using 11 of the 107 metric tons of methane/oxygen propellant to power their ground car, they will be able to travel over 10,000 land miles (without propellant recycling) at speeds of over 20 miles an hour, ranging out from their base 300 miles in any direction. If a condenser is added to capture for later recycling the water vapor in the ground car engine exhaust, the 10,000 land miles available to the ground car can be increased ten-fold. Once the second lander's propellant production operation is well underway, they can even drive over to use it as a second base for forays. Thus about 500,000 square miles of territory will be available for exploration for the first mission crew alone. With a crew of four, a large landed habitat/laboratory, and a substantial power source, a large variety of scientific investigations can be accomplished. In addition to searching for past or present life and clues to the planet's geologic history, one key item on the exploratory parties agenda will be to locate pockets of readily exploitable water ice. Once native water is available, it will no longer be necessary to ship hydrogen from Earth, and future missions and settlements can be made independent of Earth for their transportation and life support consumables. But even on this first mission, an inflatable greenhouse can be set up and extended experiments undertaken in growing food crops. If successful, the greenhouse can even be left in operation after the crew departs, allowing research to continue telerobotically from Earth, and perhaps providing future crews with both food and earthly fragrances.

At the conclusion of the 500 days on the surface, the crew will climb into the methane/oxygen ascent vehicle and rocket back to Earth, where they will aerobrake into orbit and rendezvous with either the Space Station or be picked up by a Shuttle. Quarters aboard the ascent vehicle will be somewhat cramped, but no more so than in a the Space Shuttle. The return trip will be carried under zero-gravity conditions, but it will only last about 6 months, and Mir cosmonauts have proven that zero-gravity exposure of such length can be tolerated by humans without excessive physiological harm.

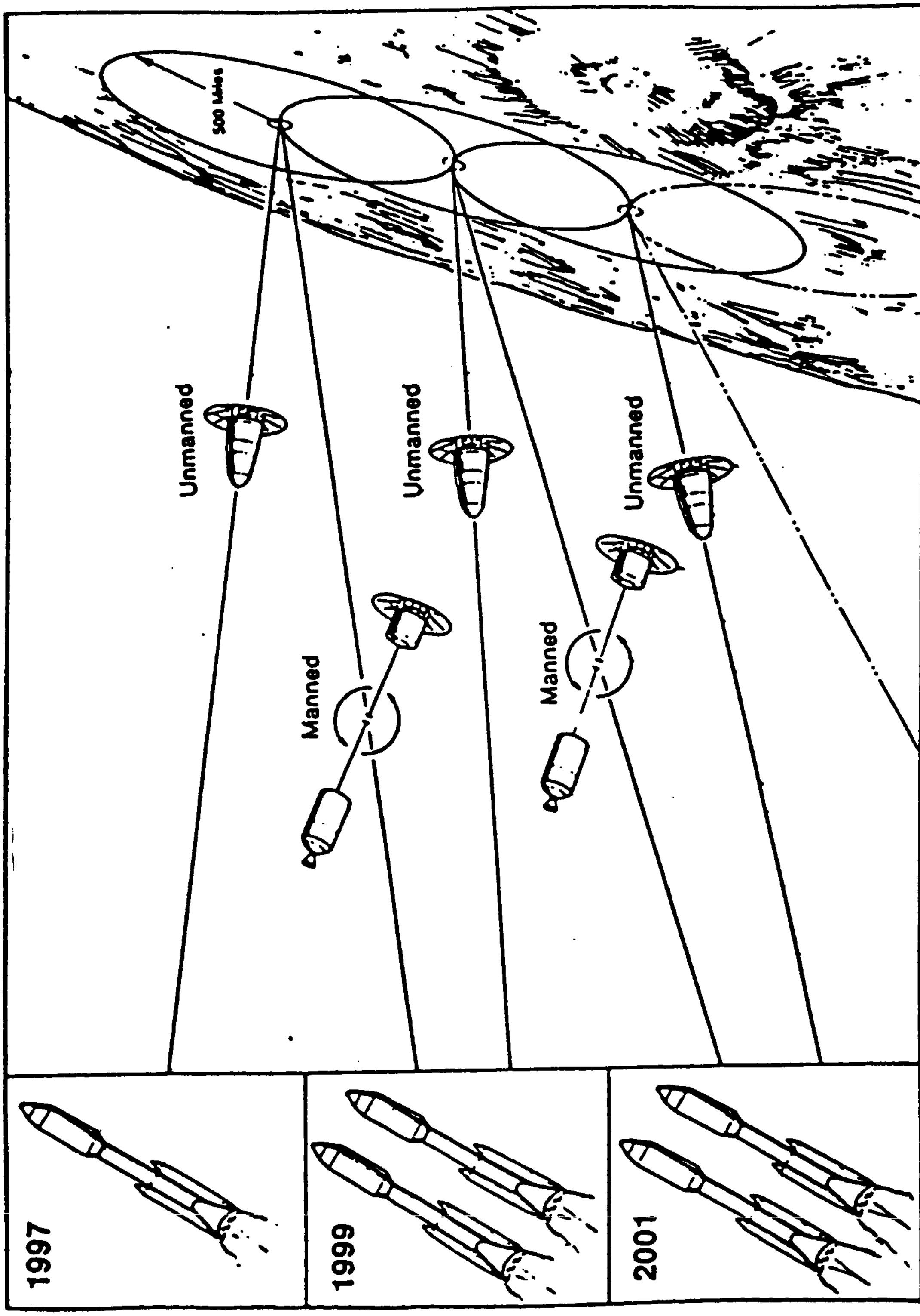
Both the habitat craft and the Earth return vehicle contain water jacketed "storm shelters" that the crew can retreat into in the event of a solar flare. Since the crew only spends 12 to 16 months in space, this reduces the expected radiation dose they will receive over the course of the 3 year round trip mission to about 50 Rem. Such a dose will have no prompt effects, but will increase the probability that an individual contracts cancer at some point later in his or her life by about 1.5%. This is not a risk to be taken lightly, but it can be taken in stride along with the other risks of launch and space travel, and it seems clear that it will not prevent the stepping forward of any number of fully qualified volunteers ready to undertake the hazard for the sake of the prize.

Not too long after the mission 1 crew has departed Mars, the mission 2 crew will arrive and land their habitat near the unmanned ascent vehicle that had been sent out following the mission 1 crew in 1999. Accompanying them will be a third unmanned ascent vehicle/fuel factory payload which will be landed at a new site 500 miles further along, to be used for return by the mission 3 crew which will depart Earth in 2003. Thus every two years a new base will be established and its vicinity explored, and before long a string of small bases will dot the map of Mars, separated by distances within the capability of available ground transportation. Rapid crew transfer between inhabited bases separated by long distances will be made possible by the introduction of a small rocket propelled flying vehicle. Just as towns in the western United States developed around forts and outposts, some of these Martian outposts will be seeds for future Martian towns. As information returns about each site, future missions may be sent back to selected prior landing sites and larger bases will begin to grow as warranted. With just two boosters being launched every two years, the total launch requirement needed to sustain this program of exploration averages to only one launch per year!

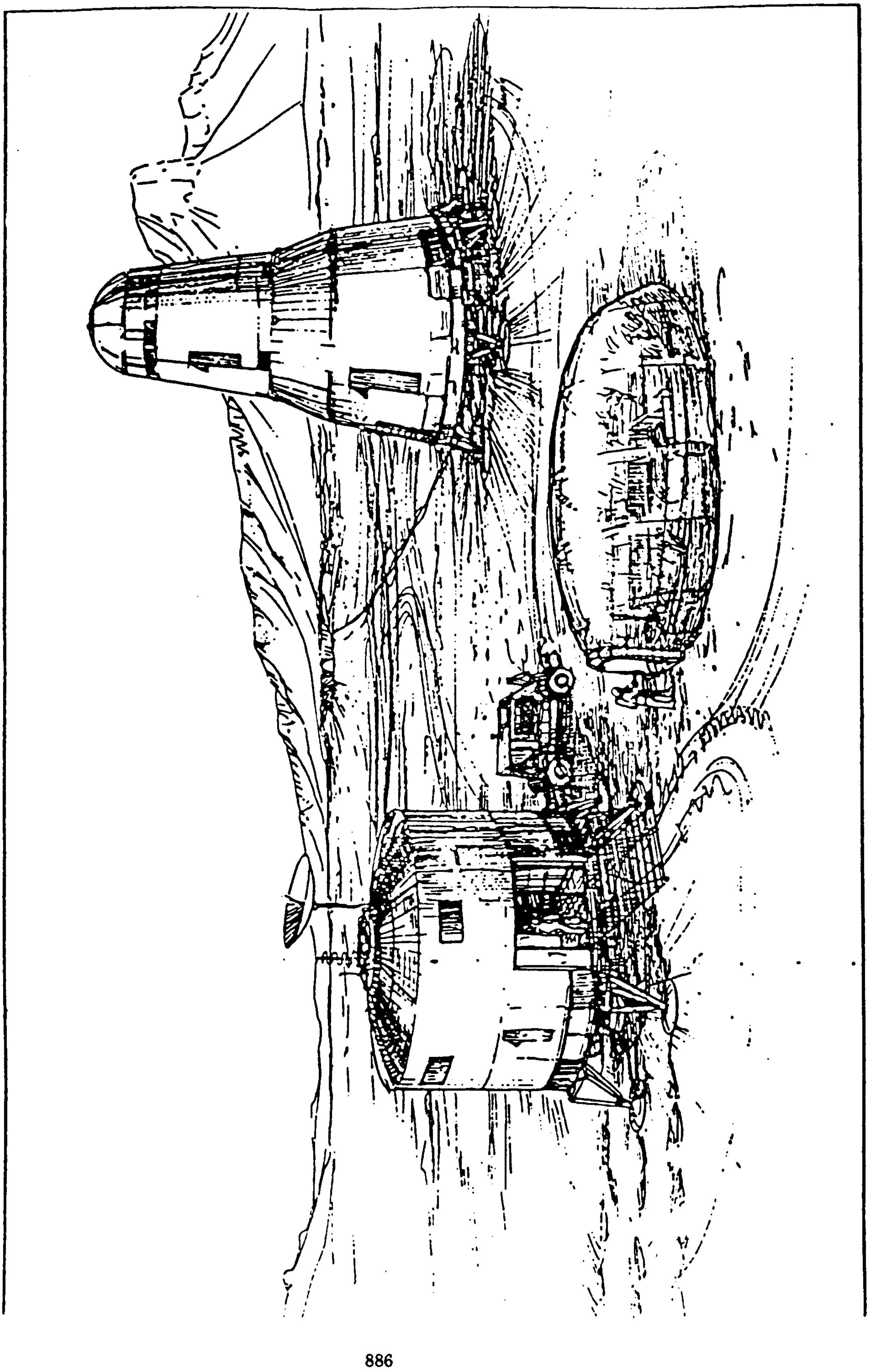
At some point after the commencement of this program, a new technology, nuclear thermal rockets (NTR, which was tested in the U.S. during the 1960s under the NERVA and ROVER programs), will come into use that will allow us to greatly increase the payload transferable to Mars with each launch. If we stick with our early plan of two launches per mission, this will allow us to increase our crew complement of each flight to 12 or more. Alternatively, if the size of the missions are kept the same, using NTR will allow us to launch each mission with a single booster, instead of split between two. NTRs can also be designed to use martian CO_2 as their propellant. Since this can be acquired at low energy cost through direct compression out of the atmosphere, rocket vehicles so equipped will give Mars explorers complete global mobility, allowing them to hop around the planet in a craft that can refuel itself each time it lands. With the help of NTR, large habitations and massive amounts of equipment can be sent to Mars. A few such payloads landed at the same site can provide the basis of the first permanent martian settlement during the 2010-2020 decade, with a population on the order of 100 people.

There is nothing in the program we have laid out that cannot be done for reasonable cost during the schedule indicated. The booster we propose uses off the shelf shuttle technology and would also be ideal for supporting lunar missions. The same habitation we propose for Mars could also be used to great advantage on the Moon. The second stage of the Mars ascent vehicle is sized to function equally well as a lunar ascent vehicle. Aerobraking efficiencies and the ability to acquire return propellant directly from Mars' atmosphere actually make Mars missions lighter than equivalent lunar missions! Thus, with a Mars exploration launch requirement of only one launch per year, and a great deal of commonality of the required hardware, there is no reason whatsoever to postpone the exploration of Mars until after several decades of lunar base build up. Rather the two programs can be carried out concurrently.

Humans to Mars in 1999! Its possible. Let's do it!

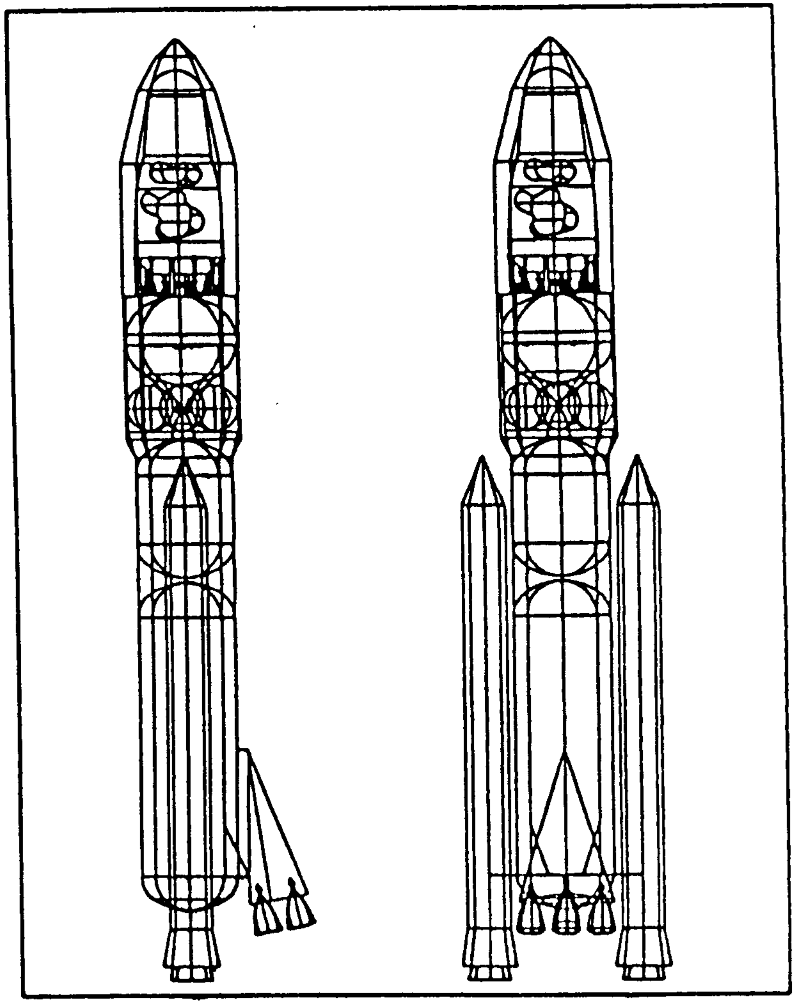


500 Miles
Unmanned
Unmanned
Unmanned
Manned
Manned
1997
1999
2001



Ares Launch Vehicle Definition

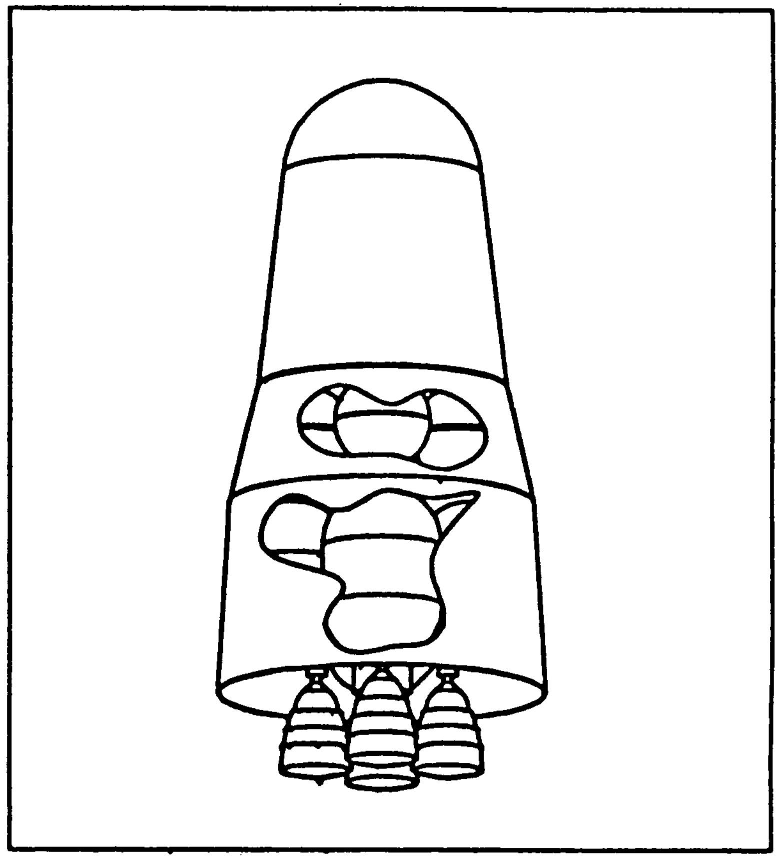
Payload Capabilities (All Weights in tonnes)	
Trans-Mars ($C_3 = 15\ km^2/sec^2$)	47.2
Trans-Lunar (5 day transfer)	59.1
LEO (160 by 160 Nmi, 28.5 degrees)	121.2
Height (m)	82.3
Gross Mass (Without Payload)	2,194.6
Stage-0	
2 Advanced Solid Rocket Boosters	1,214.5
Stage-1	
External Tank (Including Residuals)	35.6
SSME Engine Pod (4 SSME's)	28.6
Usable Propellant in ET	723.5
Total SSME Thrust (kN, 104%)	8,706
Specific Impulse (sec)	453
Staging Relative Velocity (m/s) (LEO to Mars Range)	4232 to 5450
Stage-2 (Ignited Sub-Orbital)	
Usable Propellant	158.8
Inert Mass	13.2
Single Engine Thrust (kN)	1,113
Specific Impulse (sec)	465
Payload Fairing	20.4



MARTIN MARIETTA

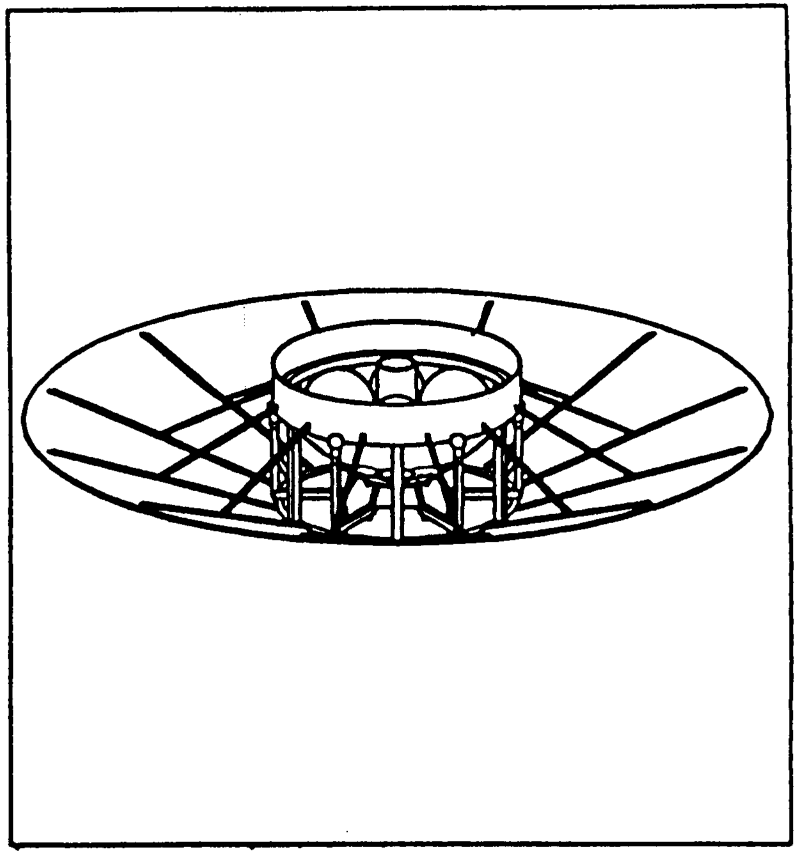
Earth Return Vehicle Definition Sheet

Round Trip Payload	
Crew Cab (All Masses In tonnes)	7.10
RCS System	0.40
Biconic Brake (20%)	2.45
Stage-1 Dry (Expended Mars Suborbital)	6.33
Stage-2 Dry	1.77
Mars-Bound Only Payload	
Hydrogen for Propellant Prod.	5.80
SP-100 Reactor	4.50
Earth-Bound Only Payload	
Crew	0.30
Suits	0.30
Consumables	1.60
Soil Samples	0.10
Stage-1 Propulsion System	
Usable Propellant (From H2 & Atm)	70.16
Inert Mass	8.85
Total Engine Thrust (lbs)	191,784
Specific Impulse (sec)	373
Propellant Type	CH4/O2
Stage-2 Propulsion System	
Usable Propellant (From H2 & Atm)	22.17
Inert Mass	2.56
Total Engine Thrust (lbs)	20,382
Specific Impulse (sec)	373
Propellant Type	CH4/O2



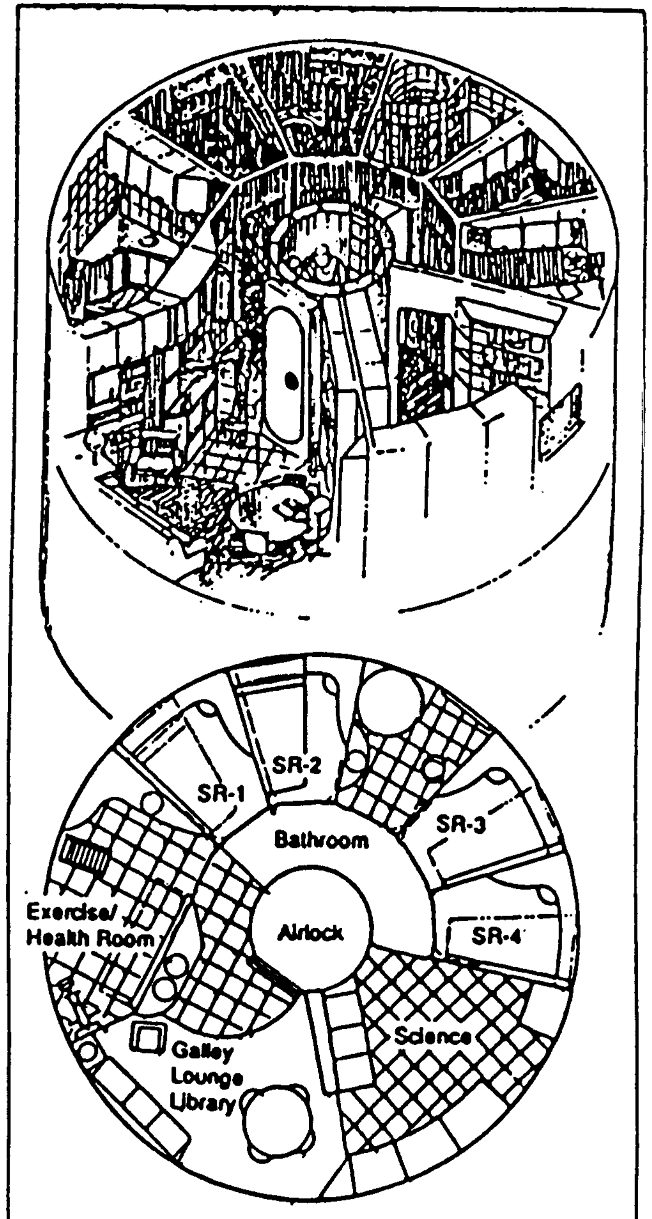
Common Aerobrake and Landing Stage Definition

Gross Mass (All Masses in tonnes)	11.81
Mars Aerobrake (Flex-Fabric)	5.96
(Based on 15% of Gross @ Entry)	
(Diameter is 23 meters Deployed)	
Landing Propulsion Stage	5.85
Usable Propellant	3.85
Inert Mass	2.00
Tanks	0.15
Engine	0.67
Structure	0.23
Landing Legs	0.61
Avionics & Other Fixed Mass	0.20
Unusable Propellant	0.06
Reserve Propellant	0.08
Total Engine Thrust (lbs)	44,267
Specific Impulse (sec)	450
Propellant Type	H2/O2

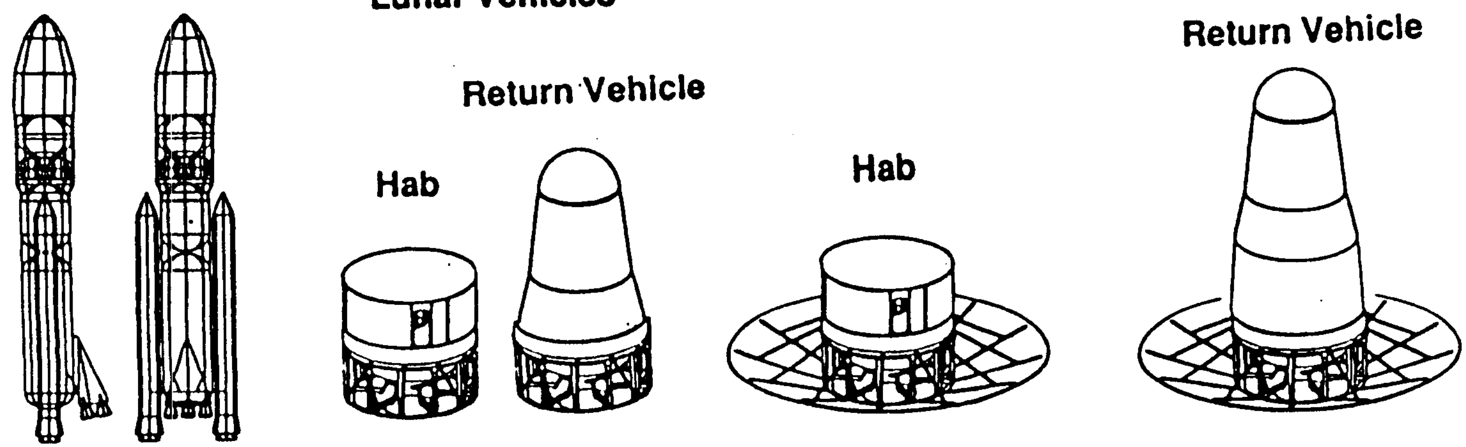


Habitation Mass Definition Sheet

Gross Mass (All Units in tonnes)	26.00
Main Structure (Weldalite)	6.44
Barrel Section Wall	1.97
Decks (3)	2.53
Central Airlock/Rad Shelter	1.54
4 Perimeter Airlock Doors	0.40
Interior Fittings	4.19
Walls	0.08
Furniture	0.45
Science Equipment	0.30
Exercise & Health	0.20
Plumbing & Lighting	0.10
Replacement Air (3 charges)	0.81
Solar Panel on Roof	0.25
Life Support System (Closed for Water and O2)	2.00
Consumables for Crew (Whole Food)	8.76
Crew	0.30
Personal Effects	0.30
Space Suits	0.30
Pressurized Rover	1.60
Deployed Surface Science	0.20
Contingency	3.90



Lunar/Mars Direct Exploration Vehicles



- Common Systems Defined to Explore and Colonize the Moon and Mars
- IMLEO is the SAME for either Mars or Lunar Missions
- No LEO Assembly Required: Launch Direct to Moon or Mars
- ETO Vehicle is Inline Shuttle-C with Earth-Escape 2nd Stage on Top
  ETO Configuration Optimized not to LEO but to Earth Escape
- Mars Mission has Simple Tether Application to Achieve 3/8 g Gravity
- Mars Mission Combines Earth Hydrogen with Martian CO_2 to Create
  Methane and Oxygen (One kg of H_2 Creates 18 kg of Propellant)
- Surface Habitation and Crew Return Vehicles are Reusable
- No Orbiting Vehicles at Mars or Moon: All Elements go to Surface

MARTIN MARIETTA

DEVELOPMENT, MANUFACTURING AND CERTIFICATION PANEL

PROBABILISTIC STRUCTURAL ANALYSIS METHODS FOR SPACE TRANSPORTATION PROPULSION SYSTEMS

N91-28238

C. C. CHAMIS
NASA Lewis Research Center
Cleveland, Ohio

Prepared For The
Space Transportation Propulsion Technology Symposium
Penn State University, June 25-29, 1990

PROBABILISTIC STRUCTURAL ANALYSIS

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PRESENTATION OUTLINE

- ISSUES
- STATE-OF-THE-ART
- NEEDS IDENTIFIED
- PROPOSED PROGRAM
- SUMMARY

ISSUES

CERTIFICATION OF SPACE TRANSPORTATION PROPULSION SYSTEMS:

* IS COSTLY.

* IS TIME CONSUMING.

* IS DIFFICULT DUE TO UNCERTAINTIES IN ACTUAL OPERATING CONDITIONS.

* NEEDS TO BE REPEATED FOR:

  - *MODIFICATIONS TO EXISTING SYSTEMS.*
  - *UPDATED CHANGES IN OPERATING CONDITIONS.*

CERTIFICATION: STATE-OF-THE-ART

* ***CERTIFICATION OF PROPULSION SYSTEMS IS DONE ON THE BASIS OF:***

  - MEETING LIMIT LOAD CONDITIONS.
  - AVAILABILITY OF TECHNOLOGY BASE THAT CAN BE SAFELY EXTRAPOLATED WITHIN THE LIMITS.

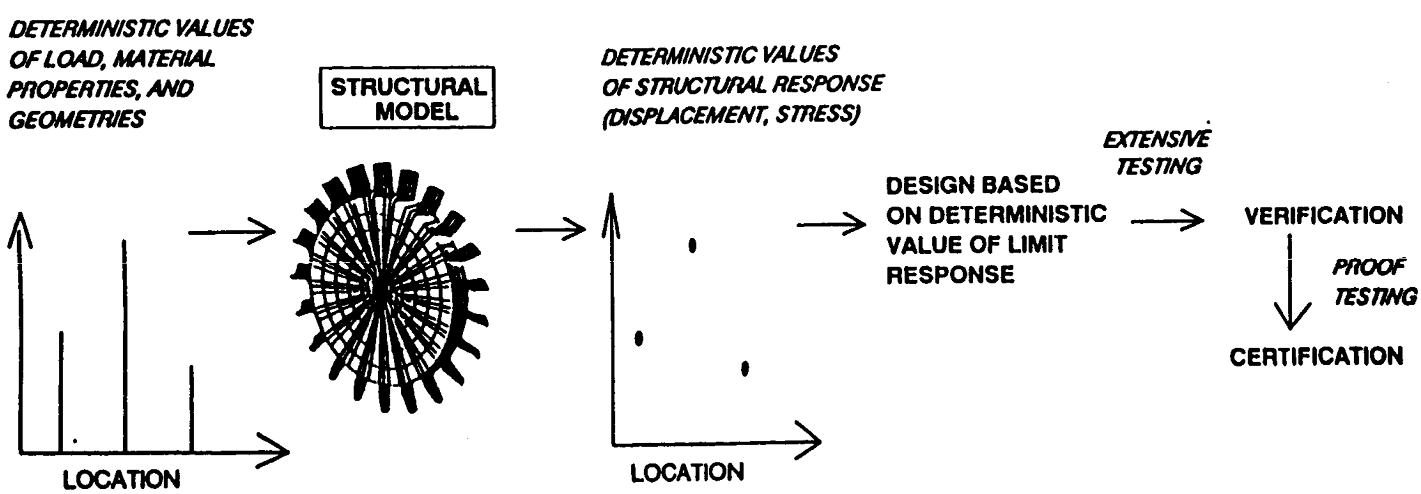
* ***THE RELIANCE IS ON***

  - DETERMINISTIC STRUCTURAL RESPONSE.
  - EXTENSIVE TESTING FOR VERIFICATION.
  - PROOF TESTING FOR CERTIFICATION.

* ***THE CERTIFICATION METHODOLOGY PROVIDES LITTLE GUIDANCE FOR HEALTH MONITORING.***

DETERMINISTIC CERTIFICATION METHODS: STATE-OF-THE-ART

CURRENT DESIGNS ARE BASED ON DETERMINISTIC STRUCTURAL ANALYSIS WITH TEST-INTENSTIVE VERIFICATION AND PROOF TESTING FOR CERTIFICATION.

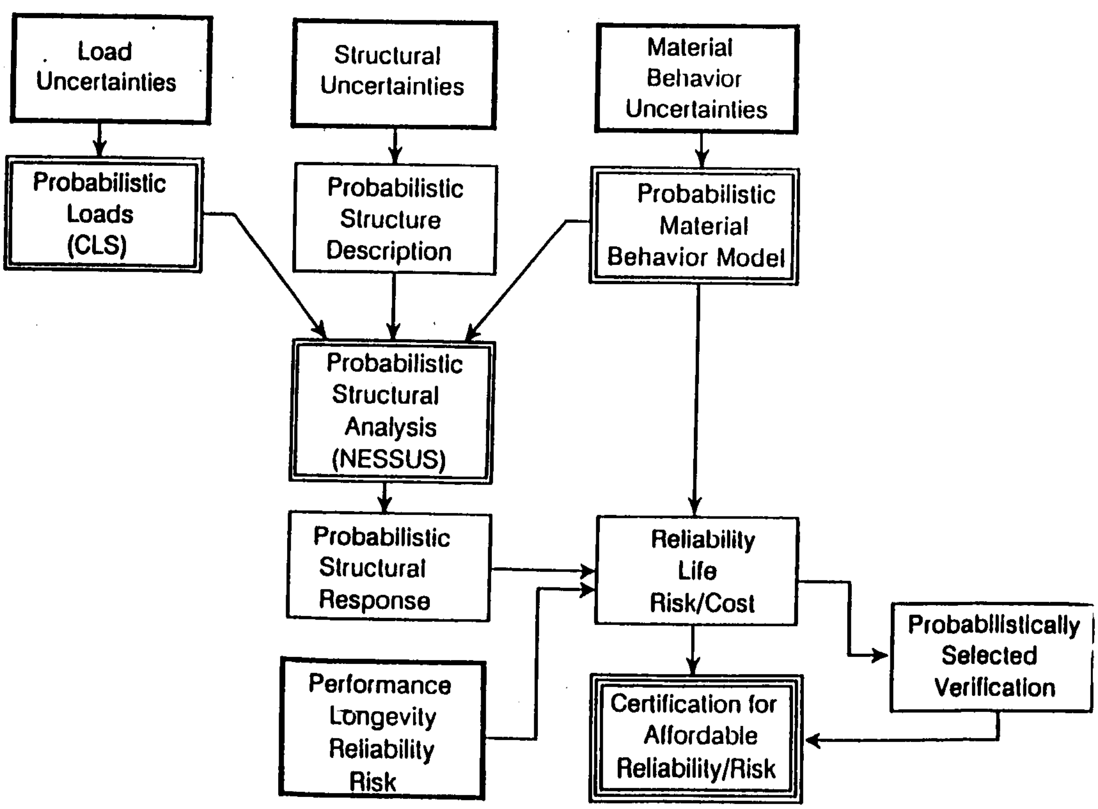


PROBABILISTIC SIMULATION IS THE RATIONAL ALTERNATIVE IN THE ABSENCE OF TRADITIONAL TECHNOLOGY BASE FOR ADVANCED VEHICLE SYSTEMS WHICH ARE DRIVEN BY:

- *High Risk*
- *Quantum Performance Improvements*
- *Short Schedules*
- *Limited Resources*

PROBABILISTIC STRUCTURAL ANALYSIS METHODS

ON-GOING PROGRAMS AT NASA LEWIS RESEARCH CENTER

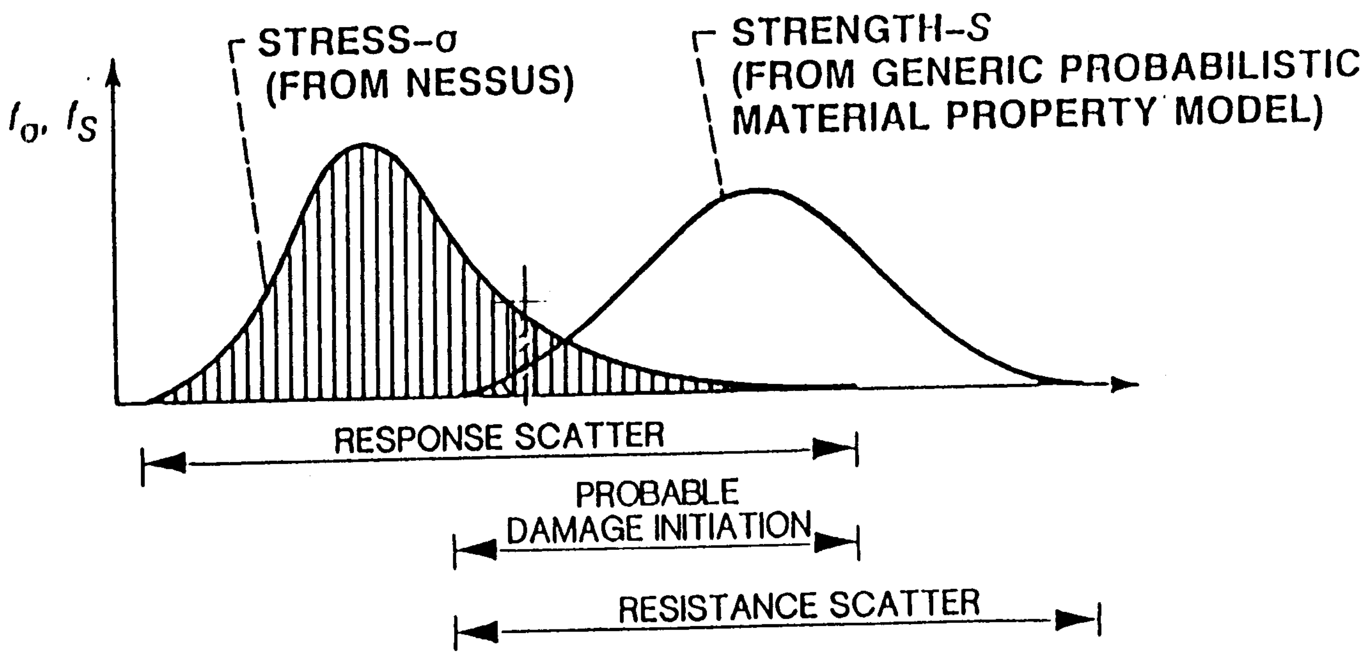


PROBABILITY OF FAILURE - DAMAGE INITIATION

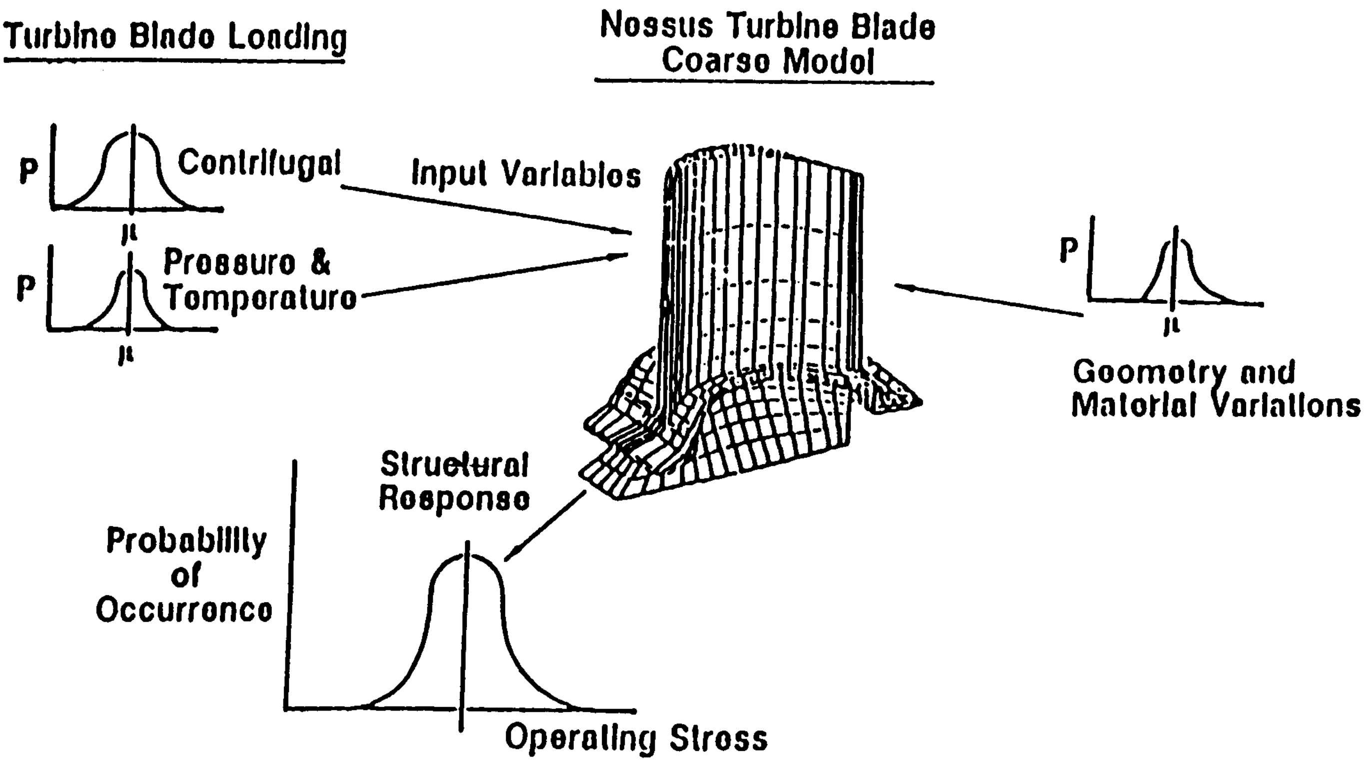
$$P_f = P(\sigma \geq S)$$

P_f — PROBABILITY OF FAILURE; σ — STRESS; S — STRENGTH

$$P_f = \int_{-\infty}^{\infty} \left(\int_{-\infty}^{x} f_S(s)\, ds \right) f_\sigma(x)\, dx$$



Component Response Analysis Using CLS Coupled With PSAM



LeRC Contracts

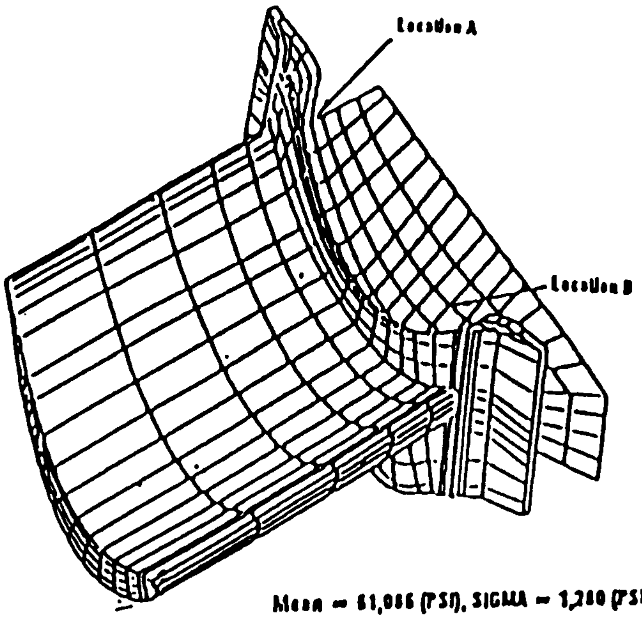
CLS – Composite Loads Spectra
PSAM – Probabilistic Structural Analysis Methods – SWRI

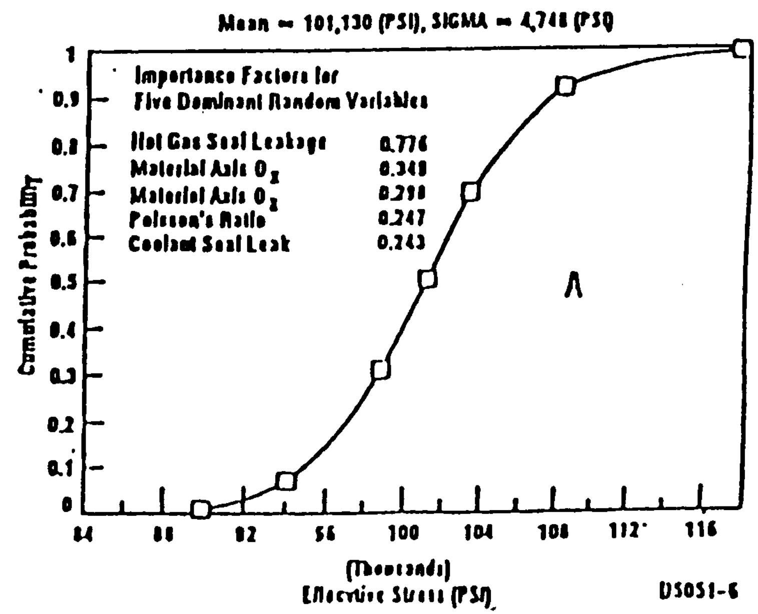
Rockwell International

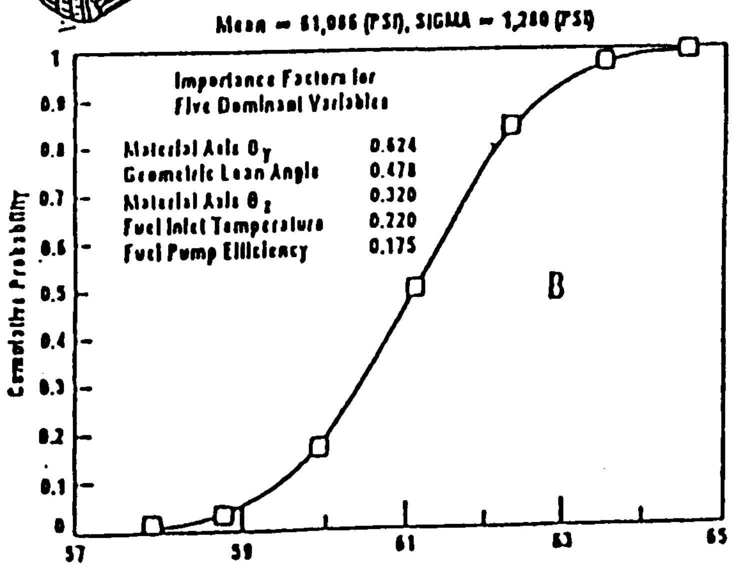
Random Variables Considered and Their Statistics

No.	Random Variable	Type	Affected FEM Quantities	Mean	Standard Deviation
1	Material axis Z	Material	Anisotropic	-0.087266 radian	0.087644
2	Material axis Y	orientation	material	-0.034907	0.087644
3	Material axis X	Effects	Orientation angles	-0.052360	0.087644
4	Elastic modulus	Material	Elastic constants	18.38E6 psi	0.4605E6
5	Poisson's ratio	properties		0.386	0.00966
6	Shear modulus			18.63E6 psi	0.046876E6
7	Geometric lean	Geometrical	Node coordinates	0 deg	0.14 deg
8	Geometric tilt	variations		0 deg	0.14 deg
9	Geometric twist			0 deg	0.30 deg
10	Mixture ratio	System	Pressure, temperature,	0.0	0.02
11	Fuel inlet pressure	Independent	centrifugal force	30.0 psi	5.00
12	Oxidizer inlet pressure	loads		100.00 psi	26.00
13	Fuel inlet temperature			37 °R	0.60
14	Oxidizer inlet temperature			- 164 °R	1.33
15	Pump efficiency	Component	Pressure, temperature,	1.00	0.008
16	Head coefficient	Independent loads	centrifugal force	1.024	0.008
17	Coolant seal leakage	Local effects	Temperature	1.0	0.10
18	Hot gas seal leakage			1.0	0.05

Rockwell International

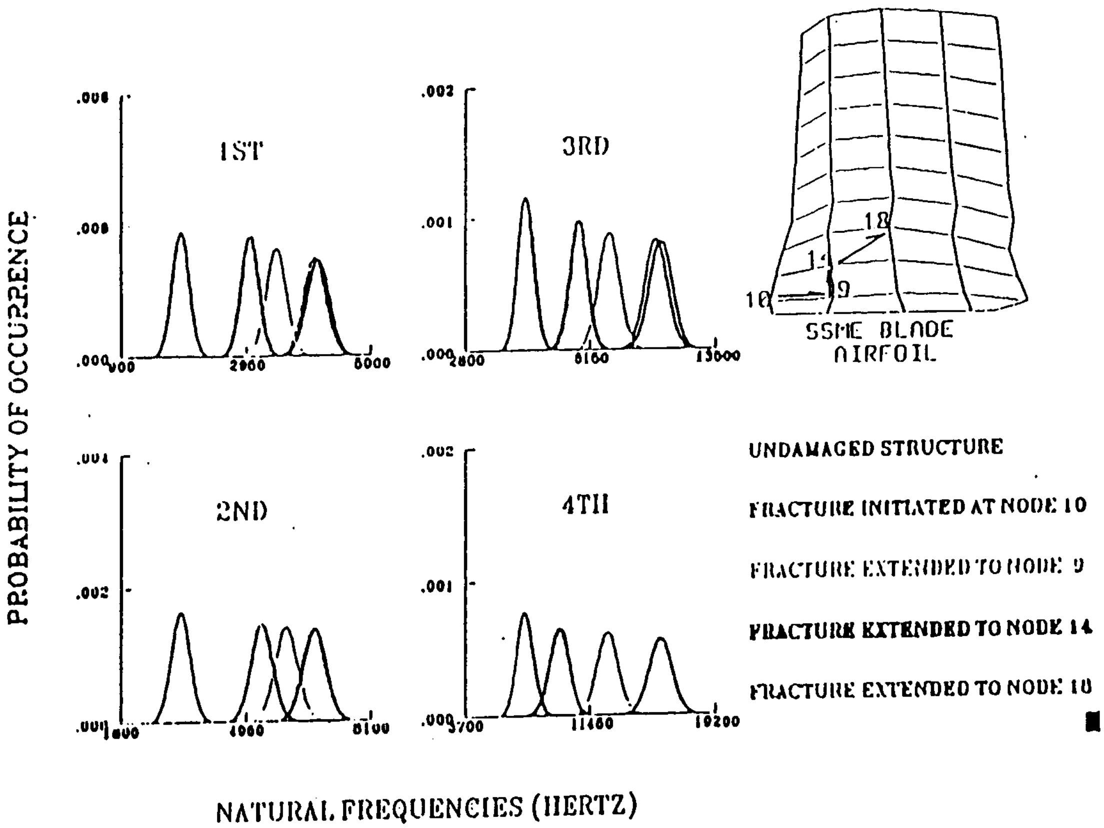




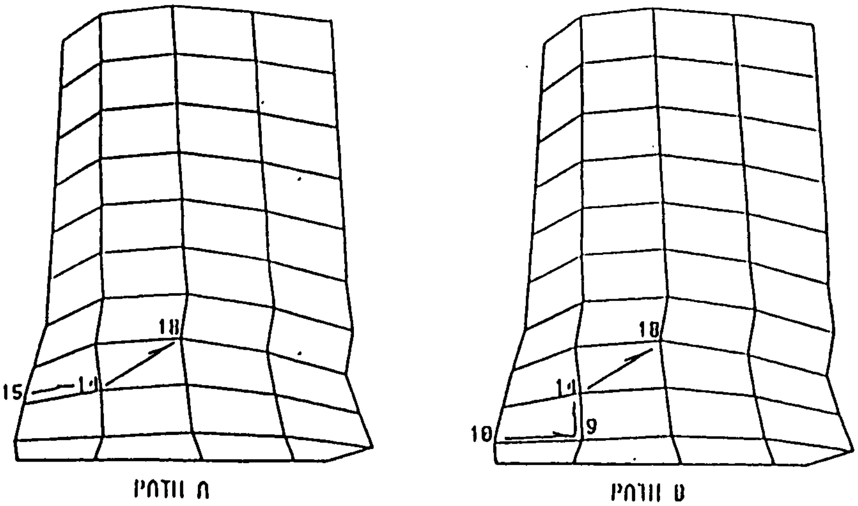


TYPICAL STRESS RESPONSE FOR 2nd STAGE BLADE

NATURAL FREQUENCIES DECREASES AS FRACTURE PROGRESSES



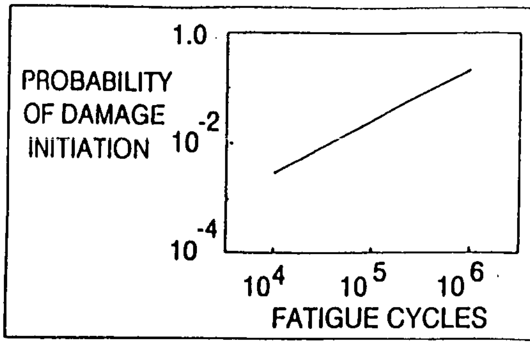
PROBABILITY OF COMPONENT DAMAGE PROPAGATION PATH CAUSED BY 100,000 FATIGUE CYCLES



PROBABILITY OF
PATH A OCCURS
= 0.00001

PROBABILITY OF
PATH B OCCURS
= 0.0002

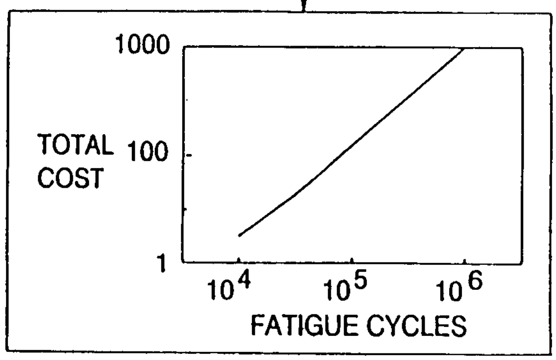
PROBABILISTIC RISK-COST ASSESSMENT



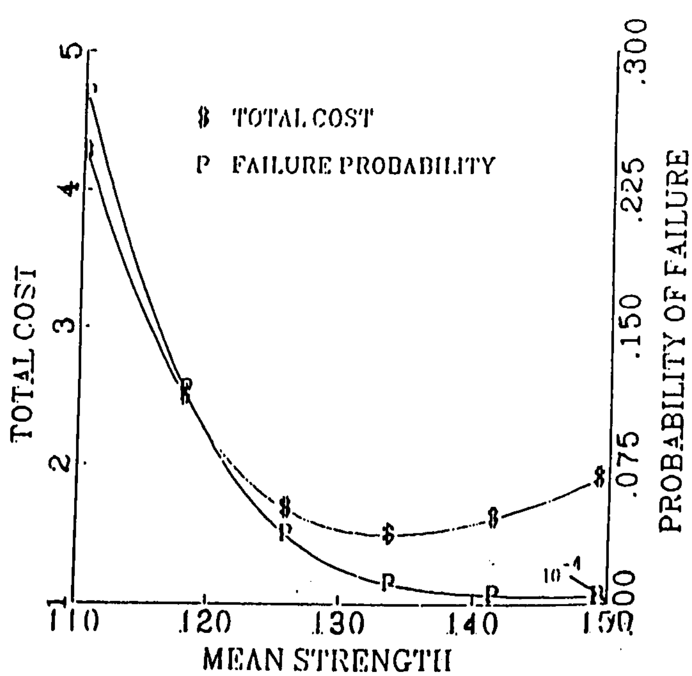
TOTAL COST

= COST FOR COMPONENTS
SERVICE READINESS

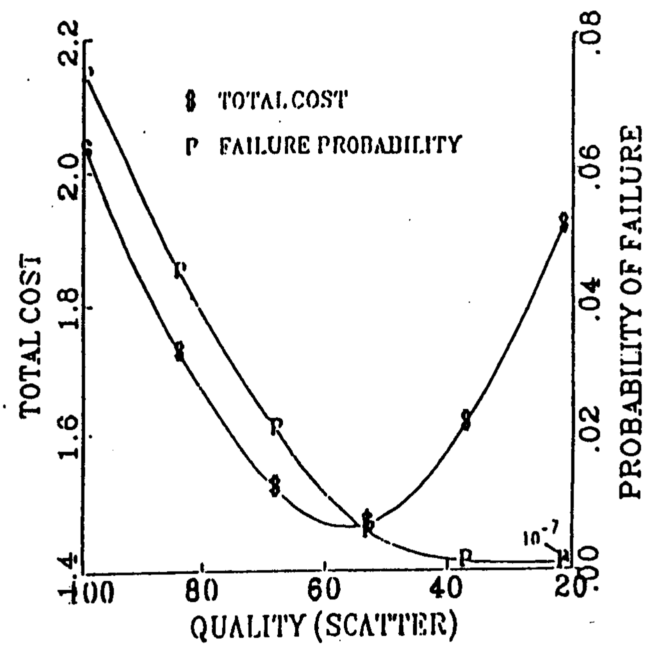
+ PROBABILITY OF DAMAGE INITIATION
* CONSEQUENTIAL COST DUE TO
DAMAGE INITIATION



THE TOTAL COST TO IMPROVE THE STRUCTURAL RELIABILITY CAN BE QUANTIFIED IN TERMS OF MEAN STRENGTH (GIVEN QUALITY)



THE TOTAL COST TO IMPROVE THE STRUCTURAL RELIABILITY CAN BE QUANTIFIED IN TERMS OF QUALITY CONTROL (GIVEN MEAN STRENGTH)



STRUCTURES DIVISION

NASA Lewis Research Center

SSME STRUCTURAL DURABILITY

PROBABILISTIC STRUCTURAL ANALYSIS METHODS DEVELOPMENT

FY90 Add component risk assessment capability

- *State-of-the-art method*
- *Incorporate uncertainties in a multifactor interaction equation for material strength degradation*
- *Probabilistic nonlinear constitutive relationships*

FY91 Add system risk assessment capability

- *Fault tree concepts*
- *Global model concepts*

FY92 Develop qualification/certification capability

- *Incorporate structural fracture concepts*
- *Probabilistic progressive fracture*
- *Probabilistic life/durability*

FY93 Develop system health monitoring criteria

- *Inspection criteria/intervals*
- *Updated life*
- *Retirement for cause*

NEEDS IDENTIFIED

FOR MULTI-LEVEL PROBABILISTICALLY SIMULATED CERTIFICATION OF PROPULSION SYSTEMS

* COMPUTATIONAL METHODS NEED TO BE DEVELOPED FOR CONDUCTING PROBABILISTIC ANALYSES AT VARIOUS LEVELS OF THE SYSTEM (SUB-COMPONENT, COMPONENT, SYSTEM).
* SMART DECISION-ORIENTED CODES NEED TO BE DEVELOPED FOR AUTOMATED, FAST, AND EFFICIENT PROBABILISTIC ANALYSIS AT ALL LEVELS OF THE SYSTEM.
* AUTOMATED SELF-ADAPTIVE CODES NEED TO BE DEVELOPED FOR PERFORMING GLOBAL/ LOCAL NONLINEAR ANALYSES.
* A GLOBAL/LOCAL DAMAGE INITIATION LIBRARY IS NEEDED WITH CAPABILITY FOR AUTOMATIC IDENTIFICATION OF APPLICABLE DAMAGE INITIATION MECHANISMS.
* COMPUTATIONAL METHODOLOGIES NEED TO BE DEVELOPED FOR PROBABILISTIC ASSESSMENT OF PROGRESSIVE DAMAGE GROWTH AND GLOBAL/LOCAL DAMAGE COALESCING.
* RISK MODELS NEED TO BE DEVELOPED FOR PROBABILISTICALLY QUANTIFYING RELIABILITY, RISK, AND COST.
* SIMULATION METHODS ARE NEEDED FOR DEVELOPING DATA/RESULTS REQUIRED FOR SYSTEM VERIFICATION.
* PROBABILISTIC METHODS NEED TO DEVELOPED FOR DETERMINING CRITERIA AND SELECTING MINIMUM NUMBER OF TESTS REQUIRED FOR SYSTEM VERIFICATION.
* METHODOLOGIES ARE NEEDED FOR SYSTEM VERIFICATION USING EXISTING/NEW TECHNIQUES/EQUIPMENT.
* QUANTIFIABLE CERTIFICATION CRITERIA MUST BE DEVELOPED. PROBABILISTIC SIMULATION WILL ACCOMPLISH THIS GOAL.
* MATHODOLOGIES NEED TO BE DEVELOPED FOR HEALTH MONITORING BASED ON PROBABILISTICALLY QUANTIFIED RELIABILITY AND RISK.

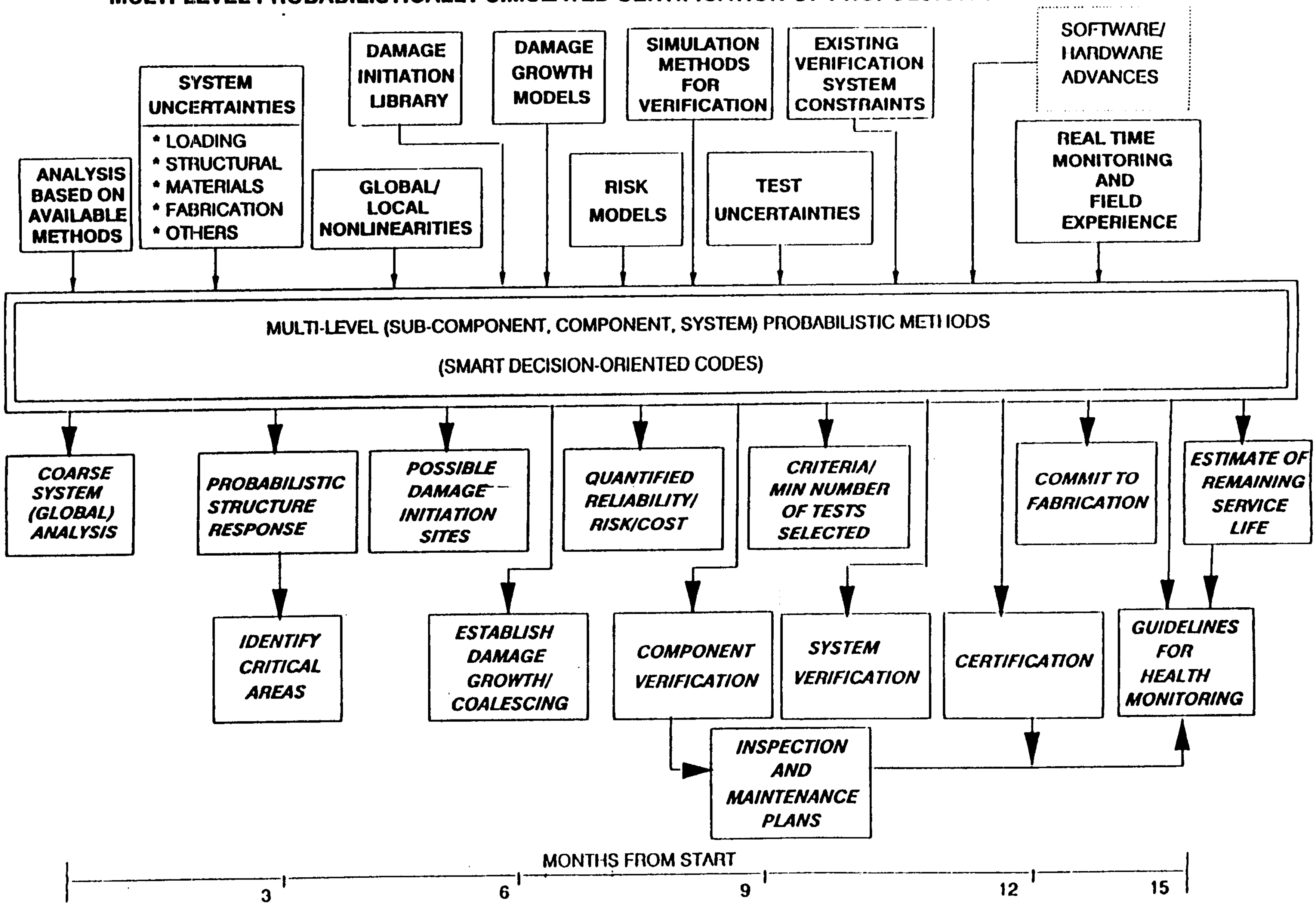
PROPOSED PROGRAM

MAJOR OBJECTIVE:

SOFTWARE SYSTEM TO PROBABILISTICALLY SIMULATE CERTIFICATION OF SPACE TRANSPORTATION PROPULSION STRUCTURAL SYSTEMS.

PROPOSED PROGRAM: BLOCK DIAGRAM

MULTI-LEVEL PROBABILISTICALLY SIMULATED CERTIFICATION OF PROPULSION SYSTEMS



PROPOSED PROGRAM

MULTI-LEVEL PROBABILISTICALLY SIMULATED CERTIFICATION OF PROPULSION SYSTEMS

OBJECTIVE: Automated software packages for multi-level system probabilistic structural integrity, progressive damage and risk analyses required for testing, verification, certification and guidance for health monitoring of propulsion systems.

JUSTIFICATION: Propulsion systems are presently certified based on deterministic structural analysis, local failure models, a large experimental database, and gradually increasing confidence based on qualitative judgement and continually increasing in-flight experience. This results in certification of designs which do not account for realistic load, material characteristics and responses. Such a practice is very expensive and inefficient. An economically attractive alternate based on modelling for actual operating conditions is by probabilistic analysis.

APPROACH: Research will be conducted to develop efficient, automated, cost-effective probabilistic structural analysis methods. The research activities will consist of (1) telescopic analysis capability for analyzing propulsion systems at various structural detail levels, automatically with a minimum number of system parameters, (2) smart solver codes for efficient solutions with automated identification of minimum number of degrees of freedom required to capture the physics of the system, (3) automated nonlinear global/local structural analysis with user-independent decision making for solution of nonlinearities and damage-critical areas, (4) damage initiation library for identifying material/structure/load-specific damage sites/types, (5) damage growth and pattern for predicting site and type of failure, (6) risk models for predicting cost/reliability/insurance, (7) simulation methods for generating data/results required for verification, (8) criteria and test selection for identification of suitable minimum experiments, (9) verification using existing systems, (10) certification based on quantifiable reliability and risk levels, and (11) guidance for health monitoring based on probabilistically quantified risk.

RESOURCES: $25M over a 5-year period (See attached time schedule chart)

PROPOSED PROGRAM: TIME SCHEDULE AND RESOURCES

MULTI-LEVEL PROBABILISTICALLY SIMULATED CERTIFICATION OF PROPULSION SYSTEMS

RESEARCH ACTIVITY	YEARS FROM START ($ M)					TOTALS PER ACTIVITY ($ M)	TARGET GOALS
	1	2	3	4	5		
1. TELESCOPIC ANALYSIS CAPABILITY	0.5	1	0.5			*2*	MIN HUMAN INTERACTION
2. SMART SOLVERS	0.3	0.7	0.8	0.2		*2*	MIN TURNAROUND TIME
3. AUTOMATED NONLINEAR GLOBAL/LOCAL ANALYSIS		0.8	0.8	0.4		*2*	USER-TRANSPARENT COMPLETE ANALYSIS
4. DAMAGE INITITATION LIBRARY	0.2	0.8	0.7	0.3		*2*	AUTOMATED FAILURE MODE INDENTIFICATION
5. DAMAGE GROWTH AND PATTERN		0.5	1	0.5		*2*	DEVELOPMENT OF INSPECTION AND MAINTAINENCE PLANS
6. RISK MODELS		0.5	1.5	1		*3*	MORE RELIABLE ESTIMATE OF REMAINING SERVICE LIFE
7. SIMULATION METHODS FOR VERIFICATION				1.5	0.5	*2*	COMPONENT VERIFICATION
8. CRITERIA & SELECTION OF TESTS			0.8	0.9	0.3	*2*	CRITERIA AND MIN NUMBER OF TESTS
9. VERFICATION USING EXISTING SYSTEMS				1	2	*3*	DEMONSTRATION OF METHODS/RESULTS
10. CERTIFICATION METHODOLOGIES				1	2	*3*	CERTIFICATION
11. HEALTH MONITORING					2	*2*	GUIDANCE FOR HEALTH MONITORING
TOTALS PER YEAR ($ M)	*1*	*4.3*	*6.1*	*6.8*	*6.8*	*25*	

PROGRAM IMPLEMENTATION

* MULTI-INSTITUTION PARTICIPANT DEVELOPMENT.
  (DIFFERENT INSTITUTIONS DEVELOP DIFFERENT PARTS.)

* ANNUAL RELEASES WITH PROGRESSIVE SOPHISTICATION CAPABILITY.

* WORKSHOPS FOR NEW CAPABILITY USER INSTRUCTIONS.

* EARLY-ON ADAPTATION INTO PRELIMINARY AND FINAL DESIGN ENVIRONMENTS.

* VERIFICATION/COMPARISON WITH PAST DESIGN AND FIELD EXPERIENCE AT USERS FACILITY.

* FORMATION OF PARTICIPANTS' USERS GROUP.

* FORMATION OF SOFTWARE MAINTENANCE INSTITUTION.

SUMMARY

CERTIFICATION OF SPACE TRANSPORTATION PROPULSION SYSTEMS:

* **ISSUES:**
  - COST/TIME/ACTUAL OPERATING CONDITIONS.

* **STATE-OF-THE-ART**
  - CERTIFICATION/DETERMINISTIC METHODS/PROBABILISTIC STRUCTURAL ANALYSIS METHODS.

* **NEEDS IDENTIFIED**
  - PROBABILISTIC METHODS FOR UNCERTAINTIES IN LOADING/STRUCTURE/MATERIAL/DAMAGE/FABRICATION.
  - PROBABILISTIC RISK MODELS/TEST SELECTION/VERIFICATION/CERTIFICATION.
  - GUIDANCE FOR HEALTH MONITORING.

SUMMARY (CONTINUED)

* **PROPOSED PROGRAM**

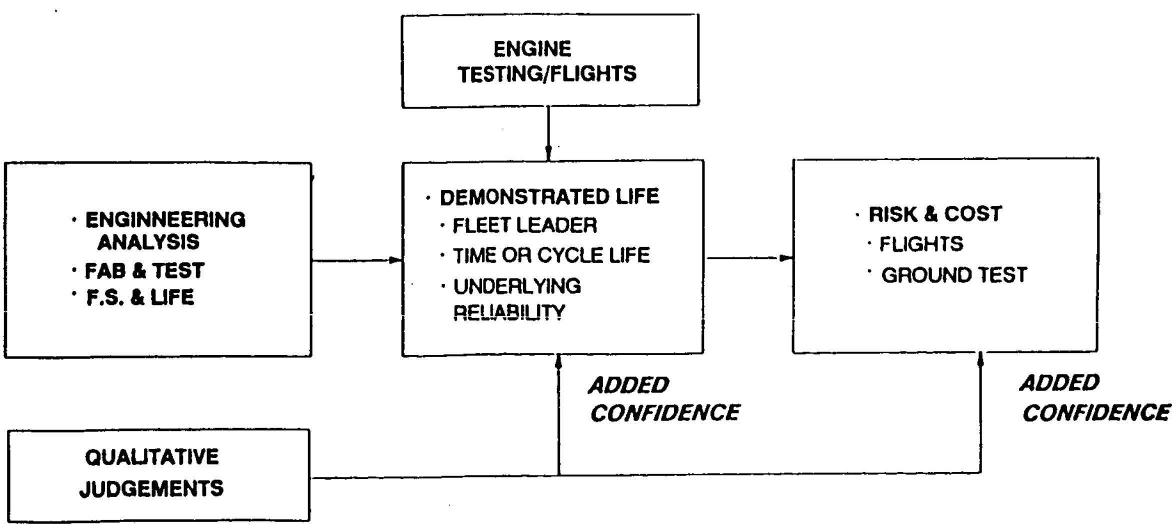
  - OBJECTIVE: PROBABILISTICALLY SIMULATED CERTIFICATION.
  - JUSTIFICATION: ACTUAL OPERATING CONDITIONS/QUANTIFIABLE RISK/ DECISION-ORIENTED SMART CODES/LESS COST/ GUIDANCE FOR HEALTH MONITORING.
  - APPROACH: 11 RESEARCH ACTIVITIES.
  - TIME SCHEDULE AND RESOURCES: $25M OVER A 5-YEAR PERIOD.

* **IMPLEMENTATION**

  - INCORPORATION INTO A DESIGN ENVIRONMENT.
  - EDUCATION TO USERS.
  - VERIFICATION/COMPARISON WITH PAST DESIGN AND FIELD EXPERIENCE.

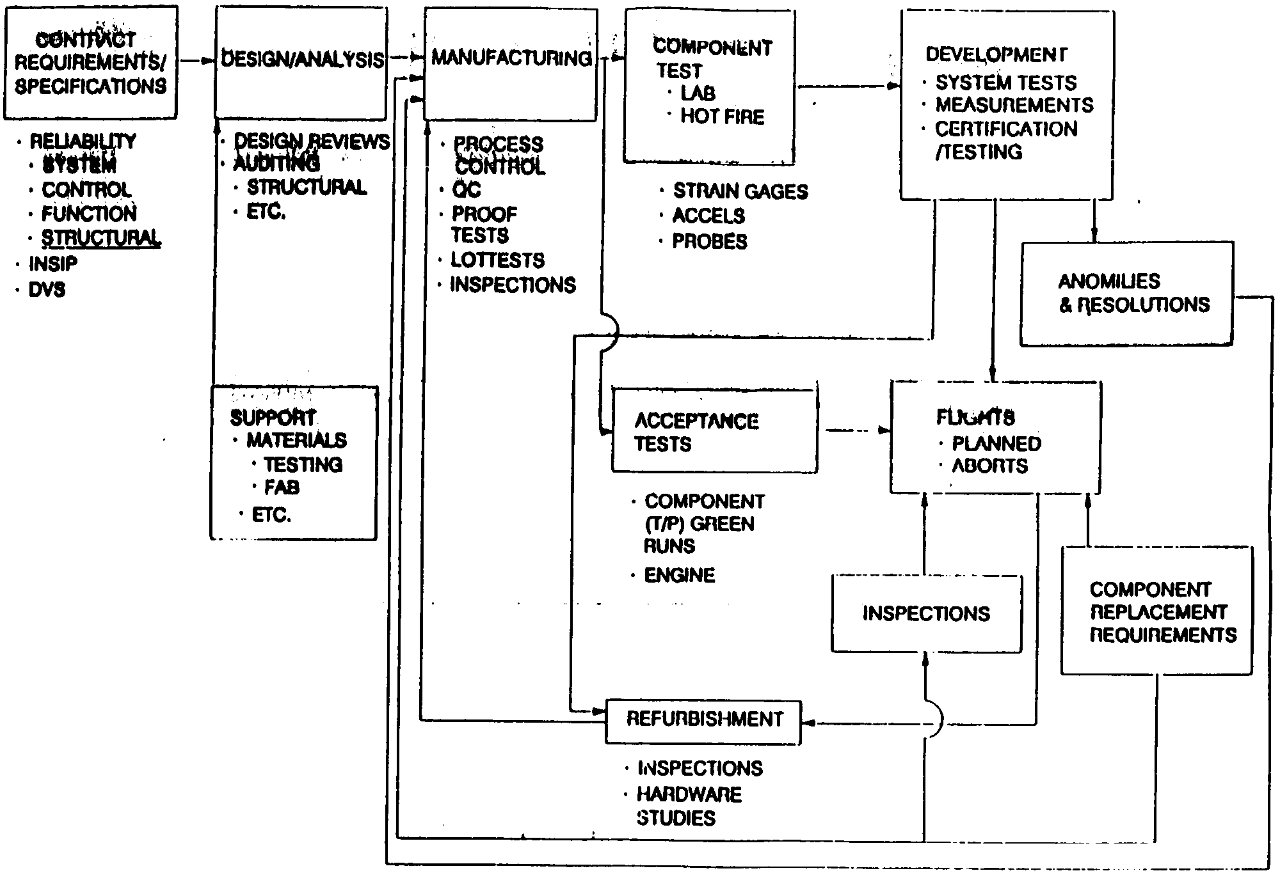
LIQUID ROCKET PROPULSION

CURRENT DETERMINISTIC APPROACH



LIQUID ROCKET PROPULSION
CURRENT CERTIFICATION PROCESS

GOAL: QUANTIFIED DECISION PROCESS FOR RISK & COST BASED ON TOTAL PROCESS



PROPOSED PROGRAM

MULTI-LEVEL PROBABILISTICALLY SIMULATED CERTIFICATION OF PROPULSION SYSTEMS

OBJECTIVE: AUTOMATED SOFTWARE PACKAGES FOR INTEGRATED SYSTEM LIFE CYCLE MULTI-LEVEL PROBABILISTIC STRUCTURAL INTEGRITY, PROGRESSIVE DAMAGE AND RISK ANALYSES REQUIRED FOR CERTIFICATION AND HEALTH MONITPRING OF PROPULSION SYSTEMS.

JUSTIFICATION:

- DESIGN FOR REALISTIC IN-FLIGHT ENVIRONMENT
- QUANTIFIABLE RELIABILITY/RISK/COST
- DECISION-ORIENTED SMART CODES
- LESS COST
- GUIDANCE FOR HEALTH MONITORING

PROPOSED PROGRAM (CONTINUED)

MULTI-LEVEL PROBABILISTICALLY SIMULATED CERTIFICATION OF PROPULSION SYSTEMS

APPROACH:

- TELESCOPIC ANALYSIS CAPABILITY
- SMART SOLVER CODES
- AUTOMATED NONLINEAR GLOBAL/LOCAL STRUCTURAL ANALYSIS
- DAMAGE INITIATION LIBRARY
- DAMAGE GROWTH AND PATTERN
- RISK MODELS
- SIMULATION METHODS FOR VERIFICATION
- CRITERIA AND TEST SELECTION
- VERIFICATION USING EXISTING SYSTEMS
- CERTIFICATION
- HEALTH MONITORING

RESOURCES: $25M OVER A 5-YEAR PERIOD

PROPOSED PROGRAM

MULTI-LEVEL PROBABILISTICALLY SIMULATED CERTIFICATION OF PROPULSION SYSTEMS

OBJECTIVE: AUTOMATED SOFTWARE PACKAGES FOR INTEGRATED SYSTEM LIFE CYCLE MULTI-LEVEL PROBABILISTIC STRUCTURAL INTEGRITY, PROGRESSIVE DAMAGE AND RISK ANALYSES REQUIRED FOR CERTIFICATION AND HEALTH MONITPRING OF PROPULSION SYSTEMS.

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APPROACH:

- TELESCOPIC ANALYSIS CAPABILITY
- SMART SOLVER CODES
- AUTOMATED NONLINEAR GLOBAL/LOCAL STRUCTURAL ANALYSIS
- DAMAGE INITIATION LIBRARY
- DAMAGE GROWTH AND PATTERN
- RISK MODELS
- SIMULATION METHODS FOR VERIFICATION
- CRITERIA AND TEST SELECTION
- VERIFICATION USING EXISTING SYSTEMS
- CERTIFICATION
- HEALTH MONITORING

RESOURCES: $25M OVER A 5-YEAR PERIOD

PROBABILISTIC STRUCTURAL ANALYSIS METHODS FOR SPACE TRANSPORTATION PROPULSION SYSTEMS

ISSUES: ***CERTIFICATION OF SPACE TRANSPORTATION PROPULSION SYSTEMS:***

* IS COSTLY AND TIME CONSUMING.
* IS DIFFICULT DUE TO UNCERTAINTIES IN ACTUAL OPERATING CONDITIONS.
* NEEDS TO BE REPEATED FOR MODIFICATIONS TO EXISTING SYSTEMS AND FOR ENHANCED CAPABILITY IN OPERATING CONDITIONS.

PROPOSED ACTIONS/PROGRAM:

* CONTINUATION/AUGMENTATION OF ON-GOING NASA PROGRAMS.
* MULTI-LEVEL SELF-ADAPTIVE SOFTWARE FOR GLOBAL/LOCAL NONLINEAR ANALYSIS.
* LIBRARY OF POSSIBLE FAILURE MODES.
* DECISION LOGIC FOR DAMAGE INITIATION/COALESCING/GROWTH.
* RISK MODELS/PROBABILISTICALLY SELECTED TESTING/VERIFICATION/CERTIFICATION.
* GUIDELINES FOR HEALTH MONITORING.

MAJOR OBJECTIVE:

* **MULTI-LEVEL PROBABILISTICALLY SIMULATED CERTIFICATION FOR SPACE TRANSPORTATION PROPULSION STRUCTURAL SYSTEMS.**

MAJOR MILESTONES:

* MULTI-LEVEL PROBABILISTIC STRUCTURAL ANALYSIS METHODS.
* LIBRARY OF POSSIBLE FAILURE MODES.
* LOGIC FOR DAMAGE INITIATION/COALESCING/GROWTH.
* SOFTWARE FOR COMPONENT/SYSTEM TESING/VERIFICATION/CERTIFICATION.
* STREAMLINED SOFTWARE FOR IN-SERVICE HEALTH MONITORING.
* SOFTWARE VALIDATION.

N91-28239

PRESENTATION 4.2.2

TECHNOLOGY TRANSFER METHODOLOGY

WILLIAM C. BOYD

JOHNSON SPACE CENTER

JUNE 25 - 29, 1990

SPACE TRANSPORTATION PROPULSION TECHNOLOGY SYMPOSIUM

JUNE 25 - 29, 1990

DEVELOPMENT, MANUFACTURING, AND CERTIFICATION PANEL

TOPIC: TECHNOLOGY TRANSFER METHODOLOGY

COORDINATOR: BILL BOYD, JSC

CONTRIBUTORS: RICH LABOTZ, AEROJET TECHSYSTEMS

DON CONNELL, PRATT & WHITNEY

KEN KROLL, JSC

SPEAKERS: BILL BOYD

RICH LABOTZ

TECHNOLOGY TRANSFER METHODOLOGY

AGENDA

O INTRODUCTION	BILL BOYD
O BACKGROUND	
O TOPIC FOCUS	

- O TECHNOLOGIST'S VIEW — RICH LABOTZ
  - O FINDING A HOME FOR TECHNOLOGY
  - O OBSERVATIONS AND RECOMMENDATIONS
- O SYSTEM DEVELOPER'S VIEW — BILL BOYD
  - O PROVIDING A HOME FOR TECHNOLOGY
  - O OBSERVATIONS AND RECOMMENDATIONS
- O DISCUSSION — ALL

INTRODUCTION

- O BACKGROUND
  - O DESIRABLE FEATURES OF FUTURE PROPULSION SYSTEMS
    - O SAFE
    - O HIGH PERFORMING
    - O LIGHT WEIGHT
    - O SIMPLE IN DESIGN
    - O RELIABLE
    - O LOW IN COST
    - O OPERATIONALLY FLEXIBLE & EFFICIENT
  - O ALL STRONGLY DRIVEN BY AVAILABILITY OF USEFUL TECHNOLOGIES
  - O AVAILABILITY DRIVEN BY "EFFICIENT TECHNOLOGY TRANSFER" FROM THE TECHNOLOGISTS TO THE SYSTEM DEVELOPERS - THE USERS
  - O HISTORICAL DATA:
    - O "NEW" TECHNOLOGIES SELDOM UTILIZED IN NEW SYSTEM DEVELOPMENTS
- O FOCUS OF THIS TOPIC:
  - O UNDERLYING ISSUES AND BARRIERS
  - O POSSIBLE APPROACHES TO IMPROVE TECHNOLOGY TRANSFER

TECHNOLOGY TRANSFER METHODOLOGY

AGENDA

O INTRODUCTION	BILL BOYD
O BACKGROUND	
O TOPIC FOCUS	
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O OBSERVATIONS AND RECOMMENDATIONS	
O SYSTEM DEVELOPER'S VIEW	BILL BOYD
O PROVIDING A HOME FOR TECHNOLOGY	
O OBSERVATIONS AND RECOMMENDATIONS	
O DISCUSSION	ALL

TECHNOLOGY TRANSFER METHODOLOGY

"PROVIDING A HOME FOR TECHNOLOGY"

- O ISSUES FOR NEW SYSTEM DEVELOPMENT
- O THE DEVELOPERS PERSPECTIVE
- O ONE VIEW OF THE TECHNOLOGY UTILIZATION PROCESS
- O BARRIERS TO PROVIDING A HOME FOR TECHNOLOGY
- O INCENTIVES TO USE NEW TECHNOLOGY
- O EXAMPLE OF TECHNOLOGY TRANSFER THAT MAY WORK
- O RECOMMENDATIONS

ISSUES FOR NEW SYSTEM DEVELOPMENT

- O TECHNOLOGY IMPLEMENTATION IS INDEED NEED DRIVEN
- O DEVELOPMENT MUST RESULT IN A "ROBUST" SYSTEM
  - O RELIABLE
  - O LONG-LIFE
  - O LOW COST
  - O PERFORMANCE MARGIN
- O APPLIED TECHNOLOGY MUST BE MADE AVAILABLE
  - O RESOLUTION OF PROBLEMS AS THEY ARISE IN OPERATION

THE DEVELOPERS PERSPECTIVE

- O INHERENT DIFFERENCE IN ENGINEERING APPROACH BETWEEN TECHNOLOGISTS AND DEVELOPERS
  - O TECHNOLOGISTS CONCENTRATE ON PERFORMANCE
  - O DEVELOPERS WANT RELIABILITY AND LIFE
- O TECHNOLOGY PROGRAMS OFTEN DEAD-ENDED
- O TECHNOLOGY OFTEN DOES NOT ADDRESS THE REAL NEEDS
- O NEW SYSTEM DEVELOPMENT PROGRAMS MUST AIM AT LOW RISK
- O SYSTEM DEVELOPMENT CANNOT AFFORD THE BURDEN OF TECHNOLOGY VALIDATION
- O INNOVATION CANNOT BE FORCED - <u>MUST DO WHAT'S RIGHT</u>

BARRIERS TO PROVIDING A HOME FOR TECHNOLOGY

- O PERCEIVED HIGH RISK
  - O LEVEL OF TECHNOLOGY MATURITY
- O NOT INVENTED HERE
  - O DESIRE FOR "HANDS ON"
  - O WOULD RATHER IT HAD BEEN DONE "OUR WAY"
- O "OFF-THE-SHELF"-ITIS
  - O ECONOMICS
  - O TECHNICAL ADEQUACY OF IN-PLACE CAPABILITIES
  - O SHORT LEAD TIME
- O DEVELOPMENT MANAGERS TYPICALLY NOT TRAINED TO BE VISIONARY

INCENTIVES TO USE NEW TECHNOLOGY

- O POSITIVE INCENTIVES
  - O TECHNOLOGY VALIDATED
  - O TECHNOLOGY UNDERSTOOD
  - O CONFIDENCE IN THE TECHNOLOGIST
  - O TECHNICAL SUPERIORITY
  - O FEELING OF OWNERSHIP
- O OTHER INCENTIVES
  - O TECHNOLOGISTS FEEL THREAT
  - O IMPOSED "FROM ABOVE"

TECHNOLOGY TRANSFER EXAMPLE

- O ADVANCED THRUSTER CHAMBER MATERIALS
  - O IRIDIUM/RHENIUM CHAMBER TECHNOLOGY DEVELOPED BY LERC
  - O JSC INITIATING VALIDATION OF APPLICATION TO SHUTTLE RCS VERNIER
- O VALIDATION PROGRAM OBJECTIVE - MAKE THE VERNIER MORE ROBUST
  - O IMPROVE DURABILITY, AND THUS LIFE, OF THE VERNIER
  - O SAVE VERNIER REFURB COSTS AND ORBITER TURNAROUND TIME
- O ASPECTS OF THIS TRANSFER
  - O INITIAL TECHNOLOGY OBJECTIVE TO MAXIMIZE PERFORMANCE
  - O GOAL TO ACHIEVE DURABILITY IDENTIFIED LATE IN PROGRAM
  - O PERCEIVED NEED TO JUSTIFY TECHNOLOGY EXPENDITURES
  - O VALIDATION TO BE DONE BY DEVELOPERS - GOOD
  - O VALIDATORS COMING IN "GREEN" - NOT SO GOOD

RECOMMENDATIONS

- O ESTABLISH CO-OWNERSHIP OF TECHNOLOGY PROGRAMS
  - O MINIMIZES NIH SYNDROME
  - O FORCES DIALOGUE BETWEEN TECHNOLOGISTS AND DEVELOPERS
- O RE-FOCUS THE EMPHASIS AS APPROPRIATE FROM PERFORMANCE TO RELIABILITY AND ROBUSTNESS
- O CHANGE THE SCOPE OF TECHNOLOGY PROGRAMS
  - O REQUIRE VALIDATION OF TECHNOLOGY AS PART OF THE TECHNOLOGY PROGRAM - DON'T PLACE BURDEN ON SYSTEM DEVELOPERS
  - O ELIMINATE "PAPER" TECHNOLOGY DEVELOPMENT
  - O MAY REQUIRE REDUCING NUMBER OF TECHNOLOGY PROGRAMS
- O START PROCESS WITH PROPOSED NEW FY92 RTOPS

9-14-87

INFLUENCE OF PREDEVELOPMENT ACTIVITY
ON ACTUAL-TO-PROPOSED COST RATIO
(DDT&E FIRST UNIT COSTS, AS OF 1983)

PROGRAM	SUBSYSTEM	PROPOSED COST($M)	ACTUAL COST($M)	COST RATIO	PREDEVELOPMENT ACTIVITY
APOLLO	SPS ENGINE	19.1	85	4.5	NONE
	CM RCS ENG	4.9	22.6	4.6	LIMITED
	SM RCS ENG	8.8	29.4	3.3	LIMITED
	CRYO STORAGE	5.5	16	2.9	SOME
	FUEL CELL	20	50	2.5	SOME
SHUTTLE	RCS PRIMARY	8.9	51.4	5.8	LIMITED
	RCS VERNIER	2.5	11.1	4.4	LIMITED
	APU	10.5	42	4.0	LIMITED
	CRYO STORAGE	6.5	14.9	2.3	EXTENSIVE
	FUEL CELL	9.8	19.5	2.0	EXTENSIVE
	OMS ENGINE	19.8	42	2.1	EXTENSIVE
	OMS POD	75	130	1.7	EXTENSIVE

PRESENTATION 4.2.3

GENCORP
AEROJET

Propulsion Division

N91-28240

Technology Transfer Methodology

Rich La Botz
Director, Technology Development

Technology Transfer Methodology

- Introductory Comments
- Life and Death Issues
- Problems in Economics
- Barriers to Finding a Home
- Observations
- More Observations
- A Current Example
- Recommendations

Life and Death Issues

Conception to Maturity (Flight)

- Typically 8-12 Years
- Trend Is Wrong

There Are Few Survivors

- Juvenile Mortality Rates Are High (>90%)
- Many Deaths Are Warranted
- Some Deaths Are Untimely
- Technology Is Cheap, Development Costs Money
- Orphans Always Die
- Nurturing Parents Are Critical

Resurrection Is A Fact

- New Missions (HIPERTHIN)
- New Supporting Technology (E.P.)

Problems in Economics

Low Production Quantities Discourage Change

- Amortized Cost of Change Is High
- Products Have Long Lives
- Few New Systems
- No Payback for Incremental Improvements

Market for Propulsion Is Parochial (Fragmented), Short-Sighted

- No Significant Pooling of Interests, Resources
- Acquisition Costs Overshadow Life Cycle Costs

Observations

- Implementation Is Need Driven, Not Technology Driven
- Typical Drivers
  - Failure (STS Vernier Engines)
  - New Requirements (SDI - HIPERTHIN Injectors)
  - External Influences (Vendor Disappears, Environmental)

More Observations

Inhibitors to Using Improved Technology in Development

- NIH
- Caution (Perceived Risk)
- Ineffective Marketing (Technical Superiority Loses to Technical Adequacy + Superior Marketing)
- Ignorance (Not Stupidity)
- Lack of Vision (Requirements Growth Unrecognized)
- Funding (Off the Shelf Cheaper)

Technology Transfer – A Current Example

Technology – Ir/Re Chambers For Small Bipropellant Space Engines (0.5-1000 lbf)

Benefits – Improved Performance
5 lbf, + 25 sec Is
100 lbf, + 10-15 sec Is

– Longer Life (10X)

– Wider Margins

Technology Development

1984 – Present

LeRC Primary Funding Source
Also JPL, Aerojet IR&D, SBIR Contracts

Technology Application Opportunities

1987 – Proposed CRAF Mission

MM II Propulsion From FRG (MBB)

MBB 400N Engine Inadequate ($I_s = 308$)

JPL Funds Aerojet 400N Ir/Re Demo Engine

$I_s = 323$ sec

Duration = 15,000 sec (Funding Limited)

$T_{wall} = 3500°F$ (800°F Margin)

Program Terminated

– "German Engine To Be Used"

– CRAF Slips, Lower Energy Requirements

Technology Application Status

1990 – MMII Propulsion

- FRG 400N Engine Being Replaced
- Ir/Re A Candidate If Readiness Can Be Demonstrated

– STS Vernier Engines

- Improved Life and Margin Chambers Being Considered
- Ir/Re A Strong Candidate

Assessment and Recommendations

- Positive Factors
  - Major Technology Improvement
  - Very Positive Results to Date
  - Concerned Parents (Byers at LeRC, Aerojet)
  - Broad Applicability With Payoff
- Negative Factors
  - Highly Fragmented Market (1's and 2's)
  - Currently Not Need Driven
- Recommendation
  - NASA Recognize and Fill Gap Between Code R Charter and Fragmented User Codes (i.e., Combine Needs)

Recommendations

- Goal - More Effective Use of New Technology
- Approach - Develop Co-Ownership of Technology
  (Minimize NIH, Ignorance, etc.)
- Technique - Co-Sponsorship of Technology
  (Code R vs. E, M, etc.)

Recommendations (Cont)

Co-Sponsorship of Technology

- Code R Budget
  - 1/3 Unrestricted "Blue Sky Technology"
  - 2/3 Restricted to Co-Signing, Co-Sponsorship With Other Codes
- Other Codes
  - Given Budget "Set-Aside" Equal to Code R Restricted 2/3, "Set-Aside" Budget Must be Spent in Code R with Co-Signing, Matching Code R Funds

Recommendations (Cont)

- Benefits of "Co-Signed" Technology
  - User Code Has Ownership
  - User Code Has Input on Technology Direction
  - Code R Sees Substantial Budget Enhancement
  - Forces Continuing Technologist/User Dialog

- Drawbacks of Suggested Approach
  - Adds Complexity to Administration
  - Nothing Is as Simple as It Appears

N91-28241
PRESENTATION 4.2.4

NATIONAL TEST BED CONCEPT

COORDINATOR: PLEDDIE BAKER
NASA-WHITE SANDS TEST FACILITY

CONTRIBUTOR: ROGER MEYER
LESC-WHITE SANDS TEST FACILITY

CONTRIBUTOR: MELVIN McILWAIN
AEROJET-PROPULSION DIVISION

Space Transportation Propulsion Technology Symposium

NASA **ISSUES** PSU

- HIGH COST OF PROPULSION TESTING
- ATTRITION OBSOLESCENCE AND NONEXISTENCE OF PROPULSION TEST FACILITIES
- ATTRITION OF TECHNICAL SKILLS AND EXPERTISE OF PROPULSION TEST PERSONNEL

Space Transportation Propulsion Technology Symposium

NASA

HIGH COST OF PROPULSION TESTING

PSU

- COUNTER-PRODUCTIVE COMPETITION BETWEEN CENTERS
- USE OF OTHER GOVERNMENT FACILITIES
  - VERY HIGH COST OF TESTING
  - SCHEDULE CONFLICTS
  - LIMITED TECHNICAL SKILL/KNOWLEDGE TRANSFER
- FUNDING OF FACILITIES/EQUIPMENT IN PRIVATE SECTOR
  - BIASES COMPETITION ON NEW PROGRAMS
  - DIFFICULT FOR OTHER CONTRACTORS TO USE
  - DIFFICULT TO RELOCATE
  - HIGH COST OF TESTING AND MAINTENANCE

Space Transportation Propulsion Technology Symposium

NASA

ATTRITION, OBSOLESCENCE, AND NON-EXISTENCE OF PROPULSION TEST FACILITIES

PSU

- ENVIRONMENTAL RESTRICTIONS/IMPACTS
- ENCROACHMENT BY PRIVATE SECTOR
- AGING AND/OR OBSOLETE
- INEFFICIENT
- LIMITED OR NONEXISTENT CAPABILITIES

Space Transportation Propulsion Technology Symposium

NASA

ATTRITION OF TECHNICAL SKILLS AND EXPERTISE OF PROPULSION TEST PERSONNEL

PSU

- LOSS OF SKILLS AND EXPERTISE DURING LONG-LIFE PROGRAMS
- LITTLE EXPERIENCE GAINED/TRANSFERRED WHEN TESTING AT OTHER GOVERNMENT FACILITIES
- INADEQUATE TRANSFER OF PRACTICAL KNOWLEDGE AND OPPORTUNITY FOR HANDS-ON EXPERIENCE
- DECLINING NUMBER OF TECHNICAL PERSONNEL AVAILABLE

Space Transportation Propulsion Technology Symposium

NASA

OBJECTIVES

PSU

- DEVELOP WITHIN NASA A NATIONAL TEST BED FOR PROPULSION SYSTEM TESTING
- EFFICIENTLY UTILIZE NASA's LIMITED FUNDING FOR FUTURE PROPULSION SYSTEM DEVELOPMENT AND SUSTAINED FLIGHT SUPPORT
- ENSURE ADEQUATE TEST FACILITIES ARE AVAILABLE WITHIN NASA TO SUPPORT FUTURE PROPULSION SYSTEMS
- DEVELOP AND MAINTAIN WITHIN NASA AND THE PRIVATE SECTOR THE TECHNICAL SKILLS AND EXPERTISE FOR FUTURE PROPULSION SYSTEM DEVELOPMENT

Space Transportation Propulsion Technology Symposium

NASA **PROPOSED ACTIONS AND PROGRAMS** PSU

- ESTABLISH WITHIN NASA HQ ONE ORGANIZATION RESPONSIBLE FOR ADMINISTERING ALL NASA PROPULSION TESTING

- ESTABLISH AN INDEPENDENT REVIEW ORGANIZATION TO:
  - INVENTORY EXISTING NASA TEST FACILITIES AND THEIR CAPABILITIES
  - DETERMINE THEIR FUTURE USABILITY
  - COMPARE THEIR CAPABILITIES/USABILITY TO THE NEED FOR FUTURE PROPULSION SYSTEM TESTING
  - RECOMMEND TYPE/SIZE PROPULSION SYSTEM BEST TESTED AT EACH FACILITY
  - RECOMMEND MODIFICATIONS/ADDITIONS TO BE MADE TO EACH FACILITY

Space Transportation Propulsion Technology Symposium

NASA **PROPOSED ACTIONS AND PROGRAMS (CONTINUED)** PSU

- ESTABLISH A NATIONAL TEST BED FOR PROPULSION SYSTEM TESTING
  - FACILITIES WHICH WILL BE INCLUDED
  - TYPE/SIZE OF PROPULSION SYSTEMS WHICH WILL BE TESTED AT EACH
  - MODIFICATIONS/ADDITIONS WHICH WILL BE MADE TO EACH AND WHEN

- ESTABLISH A "JANNAF LIKE" FORUM OF REPRESENTATIVES FROM THESE TEST FACILITIES TO ENHANCE THE TRANSFER OF PROPULSION TEST TECHNOLOGY AND INFORMATION

- ESTABLISH AND FUND A PROGRAM TO STIMULATE INTEREST AT ALL LEVELS OF EDUCATION IN MATH, SCIENCE, AND SPACE

NASA

MAJOR MILESTONES

PSU

- NASA HQ COMMITMENT TO A NATIONAL TEST BED FOR PROPULSION TESTING - LATE FY 90
- NASA HQ COMMITMENT/FUNDING TO AN EDUCATIONAL PROGRAM TO STIMULATE INTEREST AT ALL LEVELS IN MATH, SCIENCE, AND SPACE - LATE FY 90
- REVIEW COMPLETED, NATIONAL TEST BED ESTABLISHED, RESPONSIBILITIES ASSIGNED - LATE FY 91
- JOINT NASA "JANNAF LIKE" WORKING GROUPS FORMED AND FUNCTIONING - EARLY FY 92
- MODIFICATIONS AND ADDITIONS TO EXISTING TEST FACILITIES - FY 92-96

Historical Problem Areas
Lessons Learned

N91-28242

Coordinator: John W. Griffin - NASA/JSC

Presenter: Bob Sackheim - TRW

- Long Life Spacecraft Propulsion Systems

Presenter: Dale Fester - Martin Marietta

- Launch Vehicles & Reusable Systems

Historical Problem Areas
Introductory Comments

- RELIABILITY Not Efficiency Is More Critical for Future Long Life/Reusable Propulsion Systems
  - Can Plan for Low Efficiency But Not UNPREDICTABLE Performance
  - Orbital Maintenance Is A Total Unknown - Tremendous Design/Logistics Implications
  - Space Shuttle Is BEST Reusable/Long Life System Available - Maintenance Level Unacceptable for Orbital Use

Historical Problem Areas
Introductory Comments

- Primary RELIABILITY Deficiencies
  - MATERIALS - Propellant, Thermal, Wear, Contamination, Space Environment Compatibility
  - SIMPLE Designs
    - Commonality, Integrated Systems, Orbital Maintenance - Often Impact Design Simplicity
  - MATURE Hardware - Properly Tested and Analyzed Prior to Operational Commitment
  - Firm Definition of Design REQUIREMENTS and Technology Assessment Before Design Commitment
    - Environments - Internal & External - Especially Critical

PRESENTATION 4.2.6

TRW

STPSS Panel on Development, Manufacturing, and Certification

Historical Problem Areas–Lessons Learned for Spacecraft Propulsion Systems

R. L. Sackheim
TRW Space & Technology Group
June 25–29, 1990

Historical Problem Areas and Lessons Learned for Space Propulsion Systems

Applications

- Upper stages
- Orbit maneuvering and/or space transfer vehicles
- Low-earth-orbit spacecraft
- High-altitude satellites
- Planetary exploration spacecraft

Typical mission level propulsion requirements

- Attitude control/momentum management
- Orbit adjust/drag make up
- Stationkeeping
- Perigee/apogee orbit injection

Typical Space Propulsion Systems Currently in Use

TRW

Earth storable bipropellant

Monopropellant hydrazine

Cold gas

Solid kick motors

What Are the Issues?

Many problems keep recurring on operational systems

Lacking discipline and organized methodology to get full benefits from past lessons learned

Too much money spent on paper studies and associated processes

No enough money spent on propulsion system/device certification through realistic testing

Experience keeps telling us to validate design over full range of operating conditions

Need to demonstrate adequate margins

Need to conduct adequate test programs that validate:

- Selection of materials and processes
- Full range of realistic operating conditions (temperatures, pressures flow rates, mixture ratio, pressurant gas saturation, etc.)
- Design margins and robustness over range of potential operating conditions

TRW

What Are the Issues? (Continued)

Must address issue of the cost of adequate testing during early development versus cost of solving problems later in certification cycle

Assessment of analysis and simulation versus testing: what is proper mix and how to make these efforts more complementary

Concentrate on fewer but higher quality technology and development programs

How can NASA and their supporting contractors make better use of test beds to address common recurring problems?

Examples abound of many unresolved recurring issues (e.g., adiabatic compression detonation, leakage, thermal control, inadequate materials, fracture mechanics, earth storable propellants residue buildup, etc.)

Historical Problems–Lessons That Should Have Been Learned

General problem areas

Materials compatibility

- Propellant chemical compatibility with storage and feed system materials
- Hot gas materials compatibility with thrust chambers, injectors, valves, etc.

Contamination problems

- Residue accumulation in earth storable (N_2O_4, MMH, and N_2H_4)
- Particulate and NVR buildup
- Wear debris contamination (valves, regulators, etc.)

Pneumatic/feed system flow instabilities leading to fatigue and premature component wear out

Other system instabilities

- Combustion (rocket engine)
- Thermal
- Fuel slosh (impact on vehicle dynamics)

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Some Examples of Lessons Learned From Past Spacecraft Propulsion System Problems

Problem	System Type	Examples From Past Programs	Solution
N_2H_4 and earth storable residue accumulation and associated flow decay	Monopropellant N_2H_4 N_2H_4/MMH	INTELSAT IV, P-95, ATS-V1, Gemini, Symphonie, Space Shuttle	Minimum propellant exposure during ground/test operations, cleanliness control, thermal conditioning and careful selection of materials
Shell 405 catalyst breakup	N_2H_4	P-95, Classified spacecraft	Catalyst bed/reactor design, heated catalyst beds
Hot restart sensitivity (potentially destructive worst-case thermal duty cycles)	N_2H_4, N_2O_4/MMH	INTELSAT-IV, Galileo, TDRS	Improved engine thermal design, higher operating margins and proper thermal installation
Freeze-thaw damage	N_2H_4 and N_2O_4	ATS-VI, Classified flight spacecraft failure	Redundant heaters/controls

Some Examples of Lessons Learned From Past Spacecraft Propulsion System Problems (Continued)

Problem	System Type	Examples From Past Programs	Solution
Catalyst bed self-poisoning	N_2H_4	P-95, Voyager, FLTSATCOM, DSP	Catalyst bed heaters and purified (analine-free) N_2H_4
Thruster nitriding and/or high temperature corrosion	N_2H_4, N_2H_4/MMH	DSCS-III, Space Shuttle APU, Gemini	Use more compatible materials and protective coatings
Plugging of injector feed tubes/valves with catalyst fines	N_2H_4	INTELSAT-III, Voyager	Injector orientation during dynamic excitation
Fuel slosh destabilization	All liquids	TACSATCOM, INTELSAT-IV, INSAT	Better total dynamic characterization of spacecraft under all realistic conditions

TRW

Some Examples of Lessons Learned From Past Spacecraft Propulsion System Problems (Continued)

Problem	System Type	Examples From Past Programs	Solution
Combustion instabilities	All rockets	F-1, Titan, Atlas, Galileo, Apollo, Minuteman, Space Shuttle, etc.	Analyses and extensive characterization/validation test programs. Design modifications (feed system, baffles, acoustic cavities, resonators, etc.) as required
Exhaust plume interference	All rockets	SATCOM, Voyager	More accurate analyses and test to locate thrusters in safe/acceptable orientation
Composite rocket nozzle failure	Solid rocket motor nozzles	PAM-D motors on Westar and Palapa	Better testing (more comprehensive) and better materials
Thruster instabilities and thermal runaway	N_2O_4/MMH	Galileo, INTELSAT-VI, MILSTAR, INSAT, Mars Observer	More realistic test characterization and better design

Some Examples of Lessons Learned From Past Spacecraft Propulsion System Problems (Continued)

Problem	System Type	Examples From Past Programs	Solution
Improper operation on-orbit by ground controllers leads to failure	N_2O_4/MMH	INSAT-1A, INTELSAT-VI, many other flight spacecraft	More rigorous flight operations procedures and controls
Component failures on-orbit	N_2O_4/MMH, N_2H_4, cold gas, vaporizing NH_3	Mariner, Viking, Ariane, Centaur, Gemini, Apollo, FLTSATCOM, etc.	Redundant components with switching logic. Simpler system design with less components (e.g., blowdown pressurization)

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Near-Term and Future Spacecraft Propulsion System Concerns

Future mission requirements

- Single mission versus reusable designs (space basing)
- More complex environmental requirements for reusable systems–multiple launch and landings and space basing requirements
- Longer life times–mission reliability
- Use of composite propellant and pressurant storage vessels–fracture mechanics and determination of incipient failure thresholds for space based and reusable systems
- Micrometeroid and orbital debris protection of pressure vessels (space based reusable systems)
- Reliable nondestructive testing (NDE) on-orbit for space based long-life systems

Near-Term and Future Spacecraft Propulsion System Concerns (Continued)

Future mission requirements (continued)

- On-orbit repair and replacement including safe operations, logistics, spares provisioning, etc. on orbit
- On-orbit refueling
- Health monitoring and automatic fault detection/isolation and corrective action on orbit
- Development of new and better materials, coatings, processes, etc.

Future environmental impact concerns

- Need to assess realistic hazard levels and environmental impacts of earth storable propellants
- Relook at environmental impacts, life-cycle costs, and mission performance tradeoffs between solids, earth storable, space storable, and cryogenic propulsion systems for future spacecraft propulsion systems

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Some Candidate Programs

Develop standards to resolve lingering and costly issues identified in past lessons learned

Characterize and develop higher energy space storable propulsion systems

Extensive life and margin mapping tests for new development items

Develop space basing technologies

- On-orbit refueling
- Repair and refurbishment logistics
- Establish some reusability limits

Some Candidate Programs (Continued)

Develop high strength, light weight composite tanks

Develop advanced high temperature thrust chamber and rotating machinery materials and coatings

Develop reliable simple on-orbit propellant gauging

Establish reliable repeatable on-orbit NDE techniques for pressure vessels

TRW

Concluding Remarks

Concentrate funding where it does the most good for solving technology issues and the real hardware design problems

There really are plenty of lessons that have been learned from past problems

Need to generate and provide better data base of past lessons learned

More NASA-industry team work will help identify and resolve the recurring problems

Earlier and more comprehensive test programs to resolve recurring problems and address the newer requirements

N91-28243

PRESENTATION 4.2.7

HISTORICAL PROBLEM AREAS - LESSONS LEARNED

EXPENDABLE AND REUSABLE VEHICLE PROPULSION SYSTEMS

STPSS PANEL ON DEVELOPMENT, MANUFACTURING AND CERTIFICATION

June 25 - 29, 1990

Dale A. Fester
Martin Marietta Astronautics Group

MARTIN MARIETTA

Expendable Launch Vehicle Lessons Learned

- Avoid Single String Systems
- Design Must Be Inspectable
- Qual By Flight Usage Not Acceptable
  - No Margin Demonstrated
  - Must Qualify All Components to Needed Level
  - Either Meet Specs or Change Specs
- Use All-Welded Feed Systems
  - Maintenance of Cleanliness During Changeout
  - Scavenging Components as Source of Spares
  - Multiple Checking Wears Things Out

Expendable Launch Vehicle Lessons Learned (concl)

- **Dynamic Envelope Must Accommodate**
  - Stacking of Tolerances
  - Deflections
  - Margin
- **Provide Needed Instrumentation**
  - Must Know Flight Environments for Every System
- **Overall Systems Integrator Needed (Also Applies to Reusable Systems)**
  - Interfaces Between Independent Contractors
  - Integrate 2 to 3 Sigma Parts
- **Concerns**
  - Pogo Suppression
  - Pyrotechnics Checkout
  - Proper Circuit Testing

Upper Stage/Transfer Vehicle Lessons Learned

- **Must Meet Safety Requirements**
  - Difficult for New Vehicle & Almost Impossible for Prior Design ELV-Launched Vehicle
  - Vehicle Really a Space-Operating LV
  - Across Board Two Failure Tolerance May Not Be Reasonable
- **Should Not Let Politics Drive Systems**

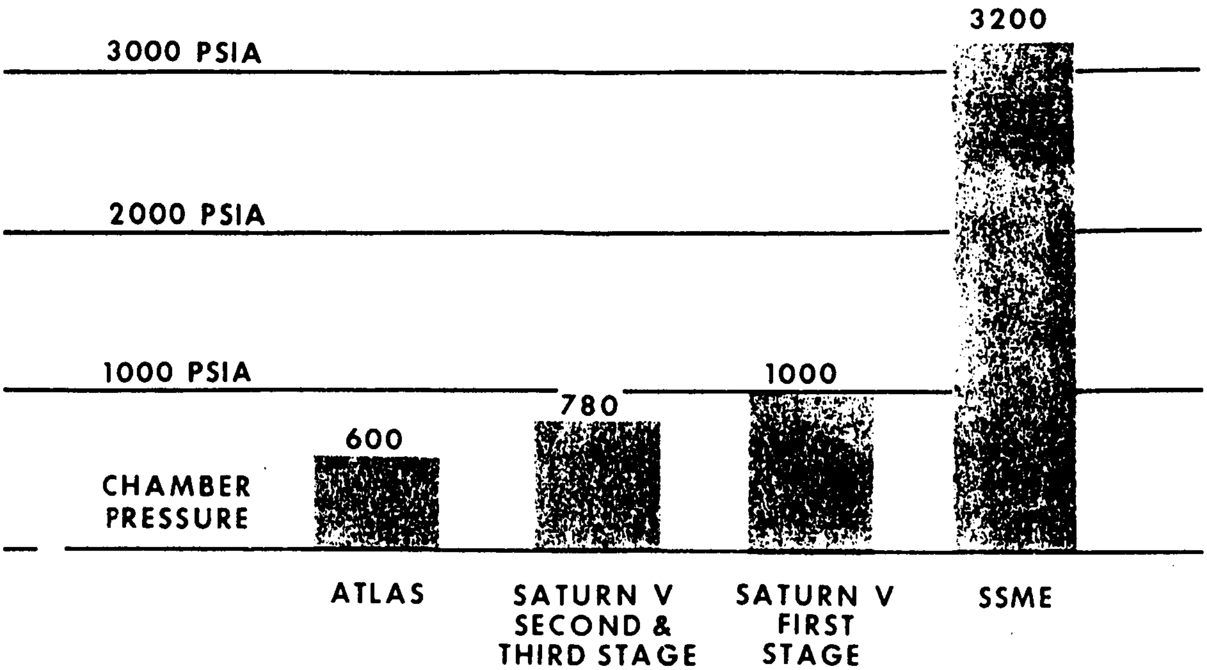
Shuttle Systems - Dynamics

- **External Tank**
  - Propellant Dynamics During ET/Orbiter Separation for RTLS
  - Required Low-g Drop Tower & KC-135 Testing
  - RCS Orbiter Translation & Aerodynamic Forces Sufficient For Separation
- **External Tank**
  - Had Natural Convection Recirculation System
  - Replaced With Bubbling Helium Up Feedline (Saved 400 lbm)
- **RCS Tanks**
  - Extensive Ground Development Program (Element, Subsystem, System)
  - Structural Fatigue and Flow Dynamics
    - Vibration Testing
    - Flow Splitting In Multiple Paths
    - Simultaneous Thruster Firing

Shuttle Systems - Reuse

- **External Tank**
  - One of Best Performers Since Not Reused
- **RCS Tanks (OMS Tanks)**
  - Specifically Developed for Orbiter
  - Extensive Ground Development Program (Element, Subsystem, System)
  - Qualified for Full 100-Mission Life
  - Included Structural Fatigue & Flow Dynamics Testing
  - Excellent Reuse History
  - N2O4 Flow Decay No Problem
    - Use Proper Purity & Handling
    - Follow Established Processes & Procedures
- **Components**
  - Many Were Really Expendable Component Designs
  - Others Were Exponential Extrapolations (e.g. SSME)
  - Usually Not Qualified for Full Duration & Operating Environments
  - Result: Rebuild Rather than Reliable Reuse

HIGH PRESSURE OPERATION REDUCES WEIGHT, COST



Reusable System Issues & Lessons Learned

- **Material Property Database Lacking for Operational Environments**
  - Both Fatigue & Flow Life
  - Data Was Extrapolated or Estimated
  - Didn't Understand Reuse & Long Life
  - Verification/Diagnostics Not Available
- **Life Unknown**
  - Design to Life with Margin to Cover Unknowns
  - Margin Must Include Degradation
    - Debris
    - Wear & Tear
    - Atomic Oxygen
  - Qualify for Full Duration
  - Fleet Leader Concept Has Shortcomings

Summary

- Need Materials Property Database Covering Operational Environments
- Need Fault Tree
  - Does Fix Ripple Through System & Cause Problem
- Need Accurate Lessons-Learned Database (Must Transfer to Young Engineers)
- Two Major Issues Are Long Life & Reusability
  - Need History & Diagnostics
  - Technology Process Inadequate

N91-28244

PRESENTATION 4.2.8

MANUFACTURING PROCESSES

COORDINATOR:	PAUL MUNAFO	NASA/MSFC
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	STAN LEVINE	NASA/LeRC
	RAY WALKER	P&W/WEST PALM BEACH
	JOHN WOOTEN	ROCKWELL/ROCKETDYNE

MANUFACTURING PROCESSES

ISSUES

- PROCESS DEVELOPMENT FREQUENTLY LAGS BEHIND MATERIAL DEVELOPMENT
- HIGH FABRICATION COSTS
- FLEX JOINTS (BELLOWS) A CONTINUING PROGRAM
- SRM FABRICATION-INDUCED DEFECTS
- IN-SPACE ASSEMBLY WILL REQUIRE SIMPLIFIED DESIGNS

PROPOSED ACTIONS/PROGRAMS

- FABRICATE ADVANCED COMPOSITE DEMO ARTICLE(S)
- FABRICATE DEMO RCS THRUSTER USING IRIDIUM-COATED RHENIUM
- NEAR-NET SHAPE FABRICATION
- SMART MANUFACTURING
- DEVELOP NEW FLEX JOINT
- RHEOLOGY STUDY OF SOLID PROPELLANT FLOW CHARACTERISTICS
- COVALENT BONDING PROCESS FOR INSULATOR/PROPELLANT
- MANUFACTURE OF LARGE INTEGRATED COMPONENTS (MODULES)

MANUFACTURING PROCESSES (CONT'D)

MAJOR OBJECTIVES

- o LARGE-SCALE DEMO ARTICLES
- o REDUCED FABRICATION COSTS
- o RELIABLE, EASY-TO-ASSEMBLY FLUID COUPLINGS
- o IMPROVED SRM PROCESSING
- o MODULAR COMPONENTS

MILESTONES

IMPROVED BELLOWS	1993
JOINING TECHNIQUE FOR RHENIUM THRUSTERS	1993
SIMPLIFIED COUPLINGS	1994
NET-SHAPE HARDWARE DEMO	1994
RHEOLOGY STUDY OF PROPELLANT CASTING	1995
CERAMIC MATRIX COMPOSITE ROTOR	1996

MANUFACTURING PROCESSES

RECOMMENDATIONS/FINDINGS

O ESTABLISH BROAD-BASED PEER GROUPS TO REVIEW TECHNOLOGY DEVELOPMENT PROGRAMS

- o PROGRAM MANAGER AS FOCAL POINT
- o FELLOW TECHNOLOGISTS (M'F'G, MAT'LS, NDE)
- o USERS/DESIGNERS
- o GUIDE THE DEVELOPMENT PROCESS
- o INDEPENDENT TEAM FOR PROGRAMMATIC DECISIONS
- o FUNCTIONS THROUGHOUT PROGRAM -- FROM ADVOCACY TO IMPLEMENTATION

MANUFACTURING PROCESSES

RECOMMENDATIONS/FINDINGS (CONT'D)

O IMPLEMENT REVIEW/REPORTING SYSTEM SIMILAR TO THAT NOW USED IN IR&D

- o CURRENT AND PLANNED PROGRAMS
- o STANDARD FORMAT
- o COULD REPLACE ANNUAL SYMPOSIA

O INCORPORATE TECHNOLOGY TRANSFER INTO DEVELOPMENT PLAN FOR IMPROVED EQUIPMENT

- o WOULD PROVIDE "PEER" SUPPORT FOR CONTINUED DEVELOPMENT
- o WOULD ASSURE CONSISTENCY BETWEEN DEVELOPED EQUIPMENT AND USER NEEDS
- o WOULD PROVIDE FOR ORDERLY, PLANNED TRANSFER OF RESPONSIBILITY FROM DEVELOPER TO USER

MANUFACTURING PROCESSES

RECOMMENDATIONS/FINDINGS (CONT'D)

- O HARDWARE DEMONSTRATION PROGRAMS SHOULD BE PERFORMED FOR COMPOSITES
  - o SHOULD NOT STOP AT THE COUPON LEVEL
  - o "PHASE 2 OFTEN NOT FUNDED"
  - o DEMO ARTICLES SHOULD BE USED FOR PROPERTY DETERMINATION
  - o INVOLVE PROPULSION/DESIGN ELEMENTS
- O PROPULSION SYSTEMS FOR IN-SPACE ASSEMBLY SHOULD BE DESIGNED TO MINIMIZE COMPLEX OPERATIONS
  - o MODULAR DESIGN
  - o EASY-TO-ASSEMBLE COUPLINGS

FABRICATE ADVANCED COMPOSITE DEMOS

ISSUES	MAJOR OBJECTIVES
o Full-scale fabrication not demonstrated for advanced composites. o Properties obtained from coupons not representative.	o Full scale demo articles for advanced compostites. o Component tests. o Destructive evaluation of mechanical properties.
CANDIDATE PROGRAMS	**SIGNIFICANT MILESTONES**
o Screen and match materials/components. o Subscale feasibility tests. o Select demo article configuration(s). o Build and test demo articles. o Destructive evaluation.	o Screen and match: 1991-1992 o Select demo articles: 1993 o Build and test: 1996 ⟶

FABRICATION OF RCS THRUSTERS

Issues	Major Objectives
o Advanced (optimized) thrusters require material combinations which currently can not be welded.	o Develop joining techniques for rhenium thrusters.

Candidate Programs	Schedule
o Select candidate materials to join to rhenium. o Select candidate joining processes. o Fabricate and evaluate samples. o Transfer findings to hardware fabrication program.	o Material selecton: 1991 o Process selection: 1991 o Sample fabrication/evaluation: 1992 o Hardware applications: 1993

NEAR-NET SHAPE FABRICATION PROCESSES

Issues	Major Objectives
o High fabrication costs for complex components.	o State-of-the-art of near-net shape forming processes. o Choose most promising applications. o Demonstration tests. o Technology transfer.

Candidate Programs	Schedule
o Literature survey. o Prioritize candidate processes and applications. o Conduct/evaluate fabrication requirements. o Fabricate and test component.	o Literature survey: 1991-1992 o Fabrication experiments: 1992-1993 o Demonstration tests: 1993-1994 o Program implementations: 1994 ——→

SMART MANUFACTURING TECHNOLOGY

Issues

- High Fabrication costs for Low-Volume-Components.

Major Objectives

- Cost-effective manufacturing in a low-volume production environment.
  - Analytically-based process development.
  - Rapid transition from laboratory to manufacturing.

Candidate Programs

- Computer simulation of manufacturing processes.
- Material processing data base.
- Process control utilizing process sensor technology.
- Standardization of computer language.
- Rapid prototyping by stereolithography.
- Flexible processing cells.

Schedule

- Identify near-term applications: 1992
- SRM, ALS, External Tank applications: 1992 →
- SEI: Long term

MODULAR ASSEMBLY

Issues

- Frequent flex joint (bellows) problems.
- Current manufacturing procedures too complex for in-space assembly.

Major Objectives

- High-reliability flex joints.
- Modular components.
- Simple-to-assemble couplings.

Candidate Programs

- Improved bellows fabrication.
- Design/Test snap-together couplings.
- Manufacture of large integrated components (modules).

Schedule

- Bellows fabrication optimized: 1993
- Simplified couplings: 1994
- Demo modular components: Long term

SRM MANUFACTURING TECHNOLOGY

ISSUES

1. Debonds at insulator (propellant and insulator) case interfaces.
2. Flow-induced anomalies in the propellant during casting result in localized fast burning areas.
3. Continuous Casting:
   a: Scale-up effect unknown on physical properties when comparing subscale to fullscale.
   b: Orientation (radial vs. circumferential vs. axial) effect on mechanical and ballistic properties not known.

MAJOR OBJECTIVES

1. Improved bonding methods.
2. Improved understanding of flow during casting, leading to improved ballistic and mechanical properties of propellant.
3. Determine the mechanism that leads to the scale-up and orientation variability phenomena; develop processes that will provide more homogenous propellant.

CANDIDATE PROGRAMS

1. Develop an insertion material to form covalent bonds with the two materials.
2. Rheology study of propellant flow during casting.
3. Analytical study of scale-up and orientation phenomena; empirical, configuration-specific determination of optimum processing for specific SRM designs.

SCHEDULE

1. Continuous through 1995.
2. Continuous through 1995.
3. Analytical study: Contiuous through 1996.
   Emprical study: Early in production.

N91-28245

PRESENTATION 4.2.9

MATERIALS SUB-PANEL

DAVID PIPPEN - COORDINATOR
NASA - WHITE SANDS

BIL BHAT
NASA - MARSHALL

BRAD COWLES
PRATT & WHITNEY

* BOB DRESHFIELD
NASA - LEWIS

BOB JEWETT
ROCKETDYNE

* PRESENTOR

MATERIALS
GENERAL ISSUES

- UNIQUE OPERATING/ STORAGE ENVIRONMENTS
  - VERY HIGH TEMPERATURE GRADIENTS
  - ULTRA-HIGH TEMPERATURE (NUCLEAR)
  - HYDROGEN, OXYGEN, VACUUM, OTHERS
- ADAPT EXISTING MATERIALS/ DEVELOP ROCKET MATERIALS
  - VERY FEW "ROCKET" UNIQUE MATERIALS DEVELOPED
  - DESIGN COMPROMISE VS COST AND SCHEDULE
- LONG LEAD TIME FOR NEW MATERIALS
  - 7 - 15 YEARS FROM LAB IDENTIFICATION
- HIGH COST
  - DEVELOPMENT COSTS
  - SMALL MARKET
- INTEGRATION OF MATERIALS DEVELOPMENT AND MANUFACTURING TECHNOLOGY
- AVAILABILITY OF MATERIALS DATA

MATERIALS

TECHNICAL ISSUES

MATERIALS CHARACTERIZATION FOR OPERATING AND STORAGE ENVIRONMENTS
- PROPELLENTS, COMBUSTION GASSES
- SPACE
- LUNAR, MARS, OTHER

ADVANCED MATERIALS DEVELOPMENT
- COMBUSTOR
- TURBINE
- BEARINGS
- ULTRA-HIGH TEMPERATURES (NUCLEAR)
- HIGH SPECIFIC STRENGTH/ STIFFNESS
- ELECTRICALLY CONDUCTIVE POLYMERS

AVAILABILITY AND DISSEMINATION OF MATERIALS PROPERTIES
- DATA BASE

ADVANCED MATERIALS TEST FACILITIES

FIRE HAZARDS
- IGNITION, COMUSTION
- DETECTION
- EXTINGUISHMENT

PROPELLENTS
- GELS
- SOLIDS

MATERIALS

MAJOR OBJECTIVES

MATERIALS CHARACTERIZATION
- COMPOSITES
- OPERATING AND STORAGE ENVIRONMENTS
- TEST AND EVALUATION TECHNOLOGIES
- ADVANCED FACILITIES

ADVANCED MATERIALS DEVELOPMENT
- COMPOSITES
- ENVIRONMENTALLY RESISTANT MATERIALS
- ELECTRICALLY CONDUCTIVE POLYMERICS

MATERIALS DATA BASE DEVELOPMENT/ MAINTENANCE
- PHYSICAL PROPERTIES
- MECHANICAL PROPERTIES
- ENVIRONMENTAL EFFECTS

MATERIALS

CANDIDATE PROGRAMS

MATERIALS CHARACTERIZATION

- COMPOSITES
  - * METALLIC MATRIX
  - * INTERMETALLIC MATRIX
  - * CERAMIC MATRIX
  - * POLYMERIC MATRIX
- ENVIRIONMENTAL BEHAVIOR

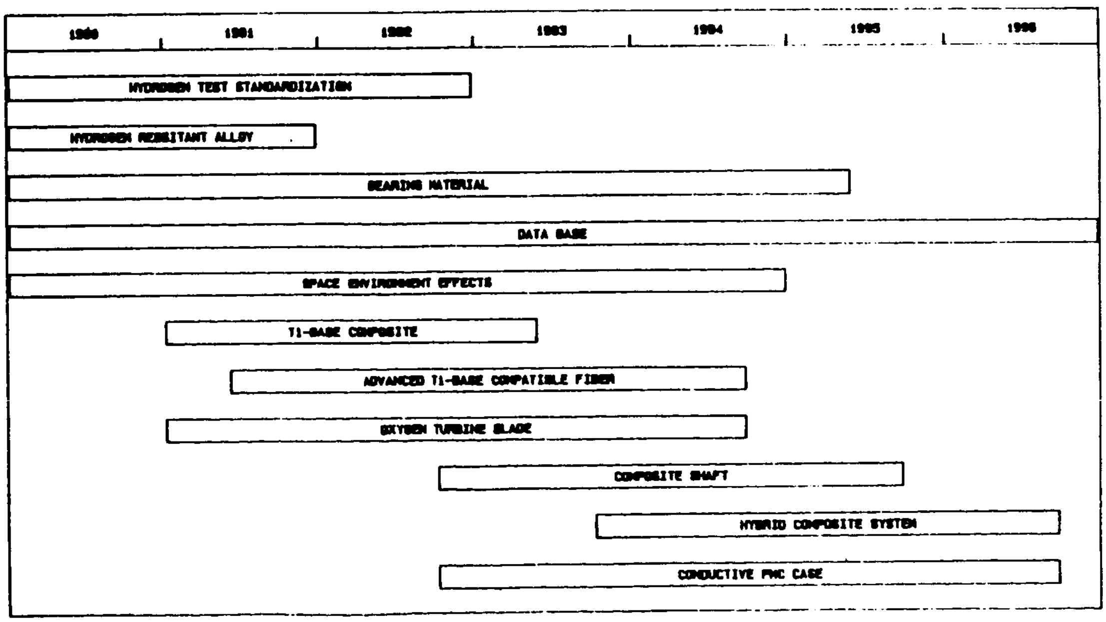
ADVANCED MATERIALS DEVEOPMENT

- COMPOSITES
  - * SHAFTS
  - * THRUST CHAMBER LINER
  - * HOUSINGS
  - * TURBINE BLADES, VANES
  - * IMPELLERS
  - * CASES
- BEARINGS
- ULTRA-HIGH TEMPERATURE MATERIAL SYSTEMS

AEROSPACE MATERIALS DATA BASE

- PHYSICAL, MECHANICAL PROPERTIES
- ENVIRONMENTAL BEHAVIOR

MATERIALS



N91-28246

PRESENTATION 4.2.10

SPACE TRANSPORTATION PROPULSION SYSTEMS SYMPOSIUM

DEVELOPMENT, MANUFACTURING, AND CERTIFICATION PANEL

NONDESTRUCTIVE EVALUATION SUB-PANEL MEMBERS

ALEX VARY, LEWIS RESEARCH CENTER, COORDINATOR

GEORGE BAAKLINI, LEWIS RESEARCH CENTER, CONTRIBUTOR

JOSEPH HEYMAN, LANGLEY RESEARCH CENTER, CONTRIBUTOR

ERIC MADARAS, LANGLEY RESEARCH CENTER, CONTRIBUTOR

CHARLES SALKOWSKI, JOHNSON SPACE CENTER, CONTRIBUTOR

BERT WESTON, PRATT & WHITNEY AIRCRAFT, CONTRIBUTOR

KEN WOODIS, MARSHALL SPACE FLIGHT CENTER, CONTRIBUTOR

SPACE TRANSPORTATION PROPULSION SYSTEMS SYMPOSIUM

DEVELOPMENT, MANUFACTURING, AND CERTIFICATION PANEL

NONDESTRUCTIVE EVALUATION (NDE) SUB-PANEL

OVERALL GOALS

- MEET THE CHALLENGES OF ADVANCED SPACE PROPULSION WITH INNOVATIVE NDE CONCEPTS
- INCORPORATE NDE IN MATERIALS DEVELOPMENT, TESTING, AND COMPONENT DESIGN/ANALYSIS
- ASSURE HIGHEST POSSIBLE QUALITY BY IN-PROCESS MONITORING OF MANUFACTURING STAGES
- DEVELOP TECHNIQUES FOR VERIFICATION OF FAULT-TOLERANCE OF CRITICAL COMPONENTS
- UTILIZE IN-SITU NDE FOR DETERMINING ON-ORBIT, IN-FLIGHT SERVICE REQUIREMENTS

MAJOR NASA PROGRAMS REQUIRING NDE

- HIGHTEMP — HIGH TEMPERATURE MATERIALS INITIATIVE
- NASP — NATIONAL AEROSPACE PLANE
- HSCT — HIGH SPEED CIVIL TRANSPORT
- RSRM — REUSABLE SOLID ROCKET MOTORS
- ASRM — ADVANCE SOLID ROCKET MOTORS
- ALS — ADVANCED LAUNCH SYSTEMS
- SSME — SHUTTLE MAIN ENGINE
- SSF — SPACE STATION FREEDOM
- EOS — EARTH OBSERVATIONAL SATELLITES
- GCTI — GLOBAL CHANGE TECHNOLOGY INITIATIVE
- SEI — SPACE EXPLORATION INITIATIVE

SPACE TRANSPORTATION PROPULSION SYSTEMS SYMPOSIUM

DEVELOPMENT, MANUFACTURING, AND CERTIFICATION PANEL

NONDESTRUCTIVE EVALUATION (NDE) SUB-PANEL

MAIN ISSUES

- MATERIALS CHARACTERIZATION
- REDUCTION OF MANUFACTURING DEFECTS
- STANDARDS AND CERTIFICATION
- ADVANCED NDE TECHNIQUES
- DESIGNING FOR INSPECTABILITY

STPSS NONDESTRUCTIVE EVALUATION (NDE) SUB-PANEL

MATERIALS CHARACTERIZATION - ISSUES

- NONDESTRUCTIVE ASSESSMENT AND VERIFICATION OF PHYSICAL AND MECHANICAL PROPERTIES
- NONDESTRUCTIVE ASSESSMENT OF DAMAGE ACCUMULATION AND DEGRADATION OF PROPERTIES
- INCORPORATION OF NDE INFORMATION IN CONSTITUTIVE MODELLING AND PERFORMANCE PREDICTION

MATERIALS CHARACTERIZATION - OBJECTIVES

- ESTABLISH CORRELATIONS/THEORY, CAPABILITIES AND LIMITATIONS OF NDE TECHNIQUES
- METHODS FOR EVALUATING/VERIFYING BOND QUALITY/INTEGRITY, COHESIVE/ADHESIVE STRENGTH
- DETERMINATION OF SUSCEPTIBILITY TO AND EMBRITTLEMENT BY EXPOSURE TO HYDROGEN
- ENHANCEMENT OF FRACTURE ANALYSIS AND CONSTITUTIVE MODELLING PERFORMANCE PREDICTIONS

STPSS NONDESTRUCTIVE EVALUATION (NDE) SUB-PANEL

REDUCTION OF MANUFACTURING DEFECTS - ISSUES

- APPLY NDE METHODS TO AUGMENT MATERIALS DEVELOPMENT AND PROCESSING RESEARCH
- DEVELOP NDE METHODS FOR IMPROVING PROCESSING AND FABRICATION OF NEW MATERIALS

REDUCTION OF MANUFACTURING DEFECTS - OBJECTIVES

- EVOLVE, CALIBRATE, APPLY NDE TECHNOLOGY FOR DEFECT CHARACTERIZATION IN PROCESS CONTROL
- UTILIZE NDE INFORMATION TO DETERMINE DETRIMENTAL PROCESSING/FABRICATION PARAMETERS
- ENHANCE ACCEPTANCE AND RELIABILITY OF NEW MATERIAL SYSTEMS, E.G., ADVANCED COMPOSITES
- ENHANCE ACCEPTANCE AND RELIABILITY OF ADVANCED ALLOY PROCESSING AND JOINING METHODS

STPSS NONDESTRUCTIVE EVALUATION (NDE) SUB-PANEL

STANDARDS AND CERTIFICATION - ISSUES

- DEVELOPMENT OF CALIBRATION METHODS AND STANDARD PROCEDURES FOR NEW MATERIALS
- DEVELOPMENT OF COMPREHENSIVE DATA BASE FOR PROBABILITY-OF-DETECTION STATISTICS
- DEVELOPMENT OF PERSONNEL TRAINING AND AUTOMATED/ROBOTIC INSPECTION/ASSESSMENT METHODS

STANDARDS AND CERTIFICATION - OBJECTIVES

- CONSISTENT STANDARDS FOR NDE EQUIPMENT/METHOD CERTIFICATION AND CALIBRATION
- CORRECT INTERPRETATION, ENHANCED PRECISION, AND CORRECT PREDICTIONS FROM NDE DATA
- IMPROVED PROBABILISTIC APPROACHES IN CONCORDANCE WITH PROBABILISTIC FRACTURE ANALYSIS
- ACCOMMODATION OF UNIQUE/COMPLEX COMPONENT CONFIGURATIONS AND INTERNAL ARCHITECTURES

STPSS NONDESTRUCTIVE EVALUATION (NDE) SUB-PANEL

ADVANCED NDE TECHNIQUES - ISSUES

- INTERMITTENT/CONTINUOUS HEALTH/DEGRADATION MONITORING OF MATERIALS/STRUCTURES
- HEALTH/DEGRADATION MONITORING IN HIGH-TEMPERATURE, HOSTILE SERVICE ENVIRONMENTS
- SPECIAL INSPECTION/MONITORING NEEDS FOR NUCLEAR PROPULSION AND ENERGY CONVERSION

ADVANCE NDE TECHNIQUES - OBJECTIVES

- CONCEPTION/DEVELOPMENT OF SMART MATERIALS/STRUCTURE WITH IMPLANTED PROBES/SENSORS
- IN-SITU MONITORING OF IMPACT RESPONSE, SERVICE DEGRADATION OF CRITICAL STRUCTURES
- REAL-TIME MONITORING OF TEST-BED AND IN-SERVICE ENGINE FIRINGS AND OPERATION
- ANTICIPATE AND REDUCE RISKS OF LEAKS, CONTAMINATION, EXPLOSION, RADIATION HAZARDS

STPSS NONDESTRUCTIVE EVALUATION (NDE) SUB-PANEL

DESIGNING FOR INSPECTABITY - ISSUES

- ANTICIPATION OF NDE REQUIREMENTS IN COMPONENT DESIGN FOR ENHANCED INSPECTABILITY
- DESIGN MODIFICATIONS FOR INCORPORATION OR RETROFITTING OF NDE INSTRUMENTATION
- INTEGRATION OF NDE PROBES, SENSORS, OR INDICATORS IN MATERIALS AND COMPONENTS

DESIGNING FOR INSPECTABILITY - OBJECTIVES

- ASSURE ACCESS TO CRITICAL REGIONS FOR FLAW DETECTION AND HEALTH MONITORING
- ASSURE PRECISE MATERIAL PROPERTIES VERIFICATION AND DEGRADATION/DAMAGE ASSESSMENT
- CONFIRM INTERNAL MATERIAL CONDITIONS ASSUMED IN FRACTURE AND CONSTITUTIVE MODELS

STPSS NONDESTRUCTIVE EVALUATION (NDE) SUB-PANEL

CANDIDATE PROGRAMS/MILESTONES

- MATERIALS CHARACTERIZATION TECHNIQUES FOR HITEMP CERAMIC AND METAL MATRIX COMPOSITES
- CONSTITUTIVE MODELING, COMPONENT DESIGN, AND LIFE PREDICTION USING ADVANCED NDE METHODS
- COMPREHENSIVE CALIBRATION STANDARDS AND PROBABILITY-OF-DETECTION FOR NEW MATERIALS
- IMPLANTED SENSOR AND DESIGN-FOR-INSPECTABILITY ENHANCEMENT/RETROFITTING TECHNOLOGY
- QUANTITATIVE ASSESSMENT OF BOND STRENGTH IN ADHESIVE JOINTS, E.G., ASRM, RSRM CASES
- ASSESSMENT OF SUSCEPTIBILITY AND HYDROGEN EMBRITTLEMENT IN SSME AND SSF POWER MODULES
- WELD PROCESS CONTROL AND INSPECTION FOR CRITICAL POWER AND PROPULSION SYSTEM COMPONENTS
- INSPECTION FOR FILAMENT-WOUND AND THIN-WALL PRESSURE VESSELS, E.G., SSF, EOS, ALS, HSCT
- ADVANCED METHODS FOR DEGRADATION ASSESSMENT: CHEMICAL, THERMAL, AND MECHANICAL
- METHODS FOR MONITORING PROPULSION AND AERODYNAMIC COMPONENTS AT EXTREME TEMPERATURES

STPSS NONDESTRUCTIVE EVALUATION (NDE) SUB-PANEL

CANDIDATE PROGRAMS/MILESTONES

o PROGRAMS/MILESTONES UNIQUE TO SOLID PROPULSION

- PROPELLANT AGING INSPECTION, PROPELLANT DEFECTS, IGNITER INTEGRITY
- CASE-LINER-PROPELLANT BONDLINE INTEGRITY, ADHESIVE STRENGTH MEASUREMENTS
- ADVANCED COMPOSITE STRUCTURAL MATERIALS INSPECTION
- REAL-TIME INSULATION CHARACTERIZATION AND EROSION MONITORING
- CASE IMPACT DAMAGE ASSESSMENT, METAL/COMPOSITE CASE INTEGRITY/DAMAGE
- RESIDUAL STRESS MEASUREMENTS: IN METALLIC/COMPOSITE STRUCTURES, BONDLINES
- SPECIFIC METHODS FOR CRITICAL FASTENERS, O-RINGS, NOZZLES, EXIT CONES

STPSS NONDESTRUCTIVE EVALUATION (NDE) SUB-PANEL

CANDIDATE PROGRAMS/MILESTONES

o PROGRAMS/MILESTONES UNIQUE TO LIQUID PROPULSION

- INJECTOR/MANIFOLD ASSEMBLY, COOLING PASSAGE, TURBOMACHINERY INTEGRITY
- THERMAL PROTECTION SYSTEM BOND INTEGRITY
- STRESS CORROSION CRACKING, LEAK CHECKING, AND HYDROGEN EMBRITTLEMENT
- TANKAGE, WELDS, AND BRAZED JOINTS FLAWS/INTEGRITY (THIN WALLED STRUCTURES)
- RESIDUAL MOISTURE IN ENGINE COMPONENTS, VALVE CONTAMINATION
- COATED SUBSTRATES: CERAMIC COATED TURBINE BLADES, COPPER/GOLD PLATINGS
- DATABASE ON CORRELATION BETWEEN ACTUAL AND PREDICTED WELD DEFECTS/CRITICALITY

STPSS NONDESTRUCTIVE EVALUATION (NDE) SUB-PANEL

CANDIDATE PROGRAMS/MILESTONES

o GENERAL PROGRAMS/MILESTONES FOR SPACE SYSTEMS

- DEFINITION OF SPECIFIC/UNIQUE ON-ORBIT, IN-SPACE, EXTRATERRESTRIAL NDE NEEDS
- DELINEATION BETWEEN ON-ORBIT AND SAMPLE RETURN FOR TERRESTRIAL INSPECTIONS
- ON-ORBIT, IN-SPACE HEALTH MONITORING OF ENGINE/MOTOR/PROPULSION COMPONENTS
- ON-ORBIT NDE TOOL KITS, ROBOTIC/AUTOMATED NDE, ASTRONAUT NDE SPECIALISTS
- APPLICATIONS OF SMART MATERIALS, IMPLANTED SENSORS, AUTONOMOUS EXPERT SYSTEMS
- DATABASE FOR NDE POD STATISTICS, STANDARDS/METHODS FOR 90/95 DETECTION
- CALIBRATION STANDARDS, INSPECTOR/SUPPLIER CERTIFICATION, EDUCATION/TRAINING
- INSITU MONITORING/FEEDBACK DURING PROCESSING, FABRICATION, FLIGHT OPERATION

STPSS NONDESTRUCTIVE EVALUATION (NDE) SUB-PANEL

NDE TECHNOLOGY POTENTIALS

o ULTRASONIC METHODS FOR CHARACTERIZING MICROSTRUCTURE AND MECHANICAL STRENGTH/MODULI

o COMPUTED TOMOGRAPHY FOR INTERNAL ARCHITECTURE AND INPUT TO PERFORMANCE/LIFE ANALYSIS

o PIEZO-FIBER, FIBER-OPTICS, ELECTRO-FILMS FOR SMART MATERIALS AND INSITU EVALUATIONS

o ULTRASONIC AND MULTIPARAMETER NEURAL NETWORKS FOR EVALUATING BONDED JOINT STRENGTH

o ELECTROMAGNETIC AND ULTRASONIC METHODS FOR HYDROGEN AND ENVIRONMENTAL EMBRITTLEMENT

o MICROFOCUS RADIOGRAPHY, ACOUSTIC MICROSCOPY, HOLOINTERFEROMETRY FOR WELD INSPECTION

o SCANNING LASER SPECTROSCOPY, THERMOMICROSCOPY FOR SURFACE CONTAMINATION/DEGRADATION

o ACOUSTIC EMISSION AND LASER ULTRASONICS FOR MONITORING HEALTH OF PROPULSION SYSTEMS

o MULTIPARAMETER ANALYTICAL NDE METHODS FOR PROCESS CONTROL AND MATERIALS CERTIFICATION

N91-28247

PRESENTATION 4.2.11

CONCURRENT ENGINEERING

C. C. CHAMIS
NASA Lewis Research Center
Cleveland, Ohio

Prepared For The
Space Transportation Propulsion Technology Symposium
Penn State University, June 25-29, 1990

CONCURRENT ENGINEERING

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	S. SINGHAL	SVERDRUP TECHNOLOGY BROOK PARK, OHIO

PRESENTATION OUTLINE

- ISSUES
- STATE-OF-THE-ART
- NEEDS IDENTIFIED
- PROPOSED PROGRAM
- SUMMARY

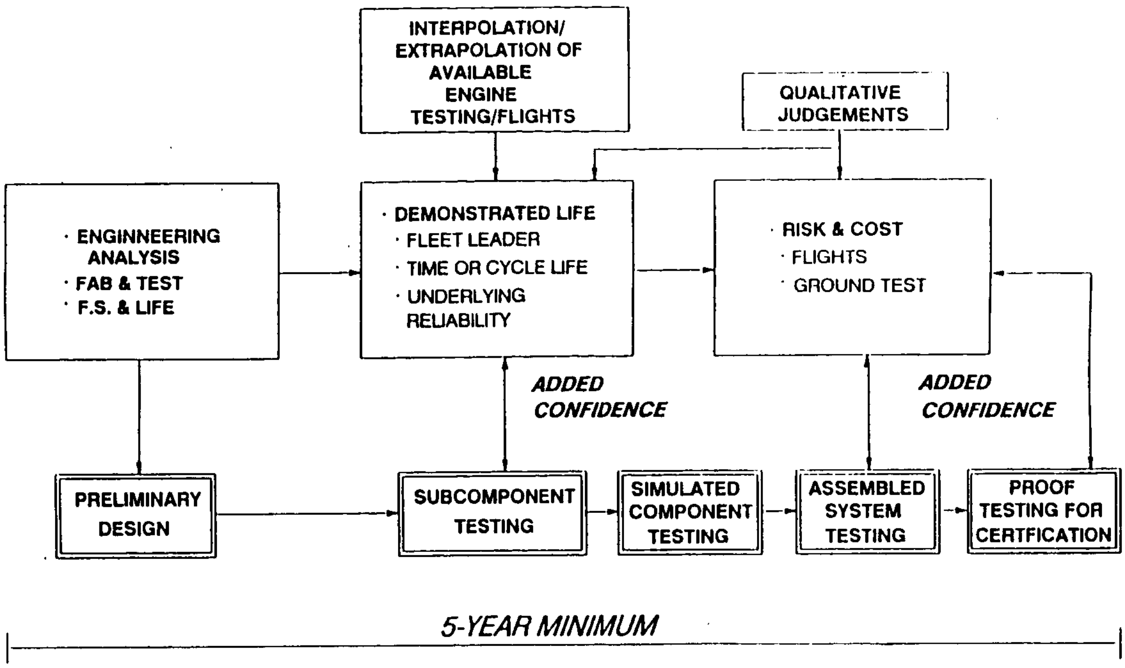
ISSUES

FROM MISSION REQUIREMENTS TO SYSTEM IN-SERVICE DEVELOPMENT CYCLE IS:

* INADEQUATE FOR SIMULTANEOUS INTERACTION AMONG PARTCIPATING DISCIPLINES.
* INFLEXIBLE FOR ADAPTING TECHNOLOGY ADVANCEMENTS INTO A DISCIPLINE.
* BASED ON AD-HOC REVISIONS, TO RESOLVE CONTINUOUSLY SURFACING PROBLEMS.
* TIME CONSUMING.
* COSTLY OVER THE TOTAL SYSTEM DEVELOPMENT CYCLE.
* RELIANT ON EXTENSIVE COMPONENT TESTING FOR VERIFICATION AND SIMULATED PROOF TESTING FOR SYSTEM VERIFICATION.

LIQUID ROCKET PROPULSION

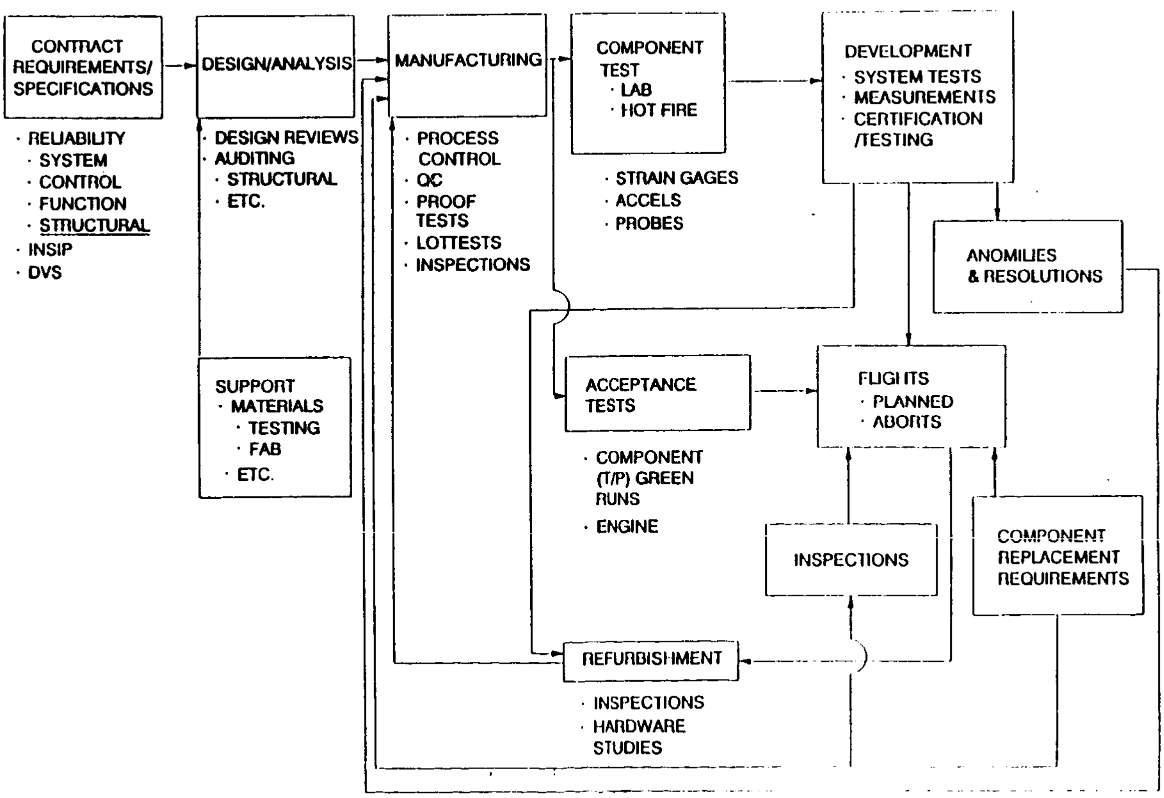
CURRENT DEVELOPMENT APPROACH



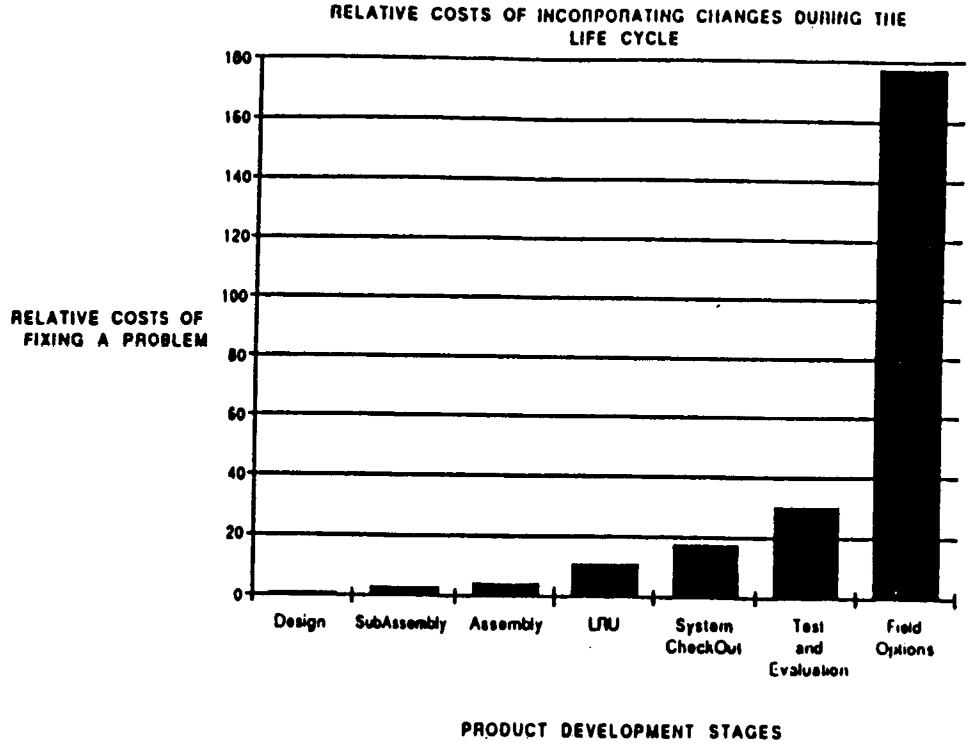
LIQUID ROCKET PROPULSION

CURRENT CERTIFICATION PROCESS

GOAL: QUANTIFIED DECISION PROCESS FOR RISK & COST BASED ON TOTAL PROCESS



COSTS OF ENGINEERING CHANGES



CONCURRENT ENGINEERING: STATE-OF-THE-ART

* *MISSION REQUIREMENTS IDENTIFY PARTICIPATING ENGINEERING DISCIPLINES AND RESPECTIVE TASKS.*

* *EACH DISCIPLINE PERFORMS RESPECTIVE TASK INDEPENDENTLY, OFTEN LEAVING CONTRADICTORY SET OF REQUIREMENTS FOR DIFFERENT DISCIPLINES UNRESOLVED.*

* *OVERLAPPING DISCIPLINES INTERACT ON AS-NEEDED BASIS TO ASSESS COMPATIBILITY WITH EACH OTHER.*

* *ITERATIONS AMONG PARTICIPATING DISCIPLINES ARE USUALLY KEPT TO A MINIMUM.*

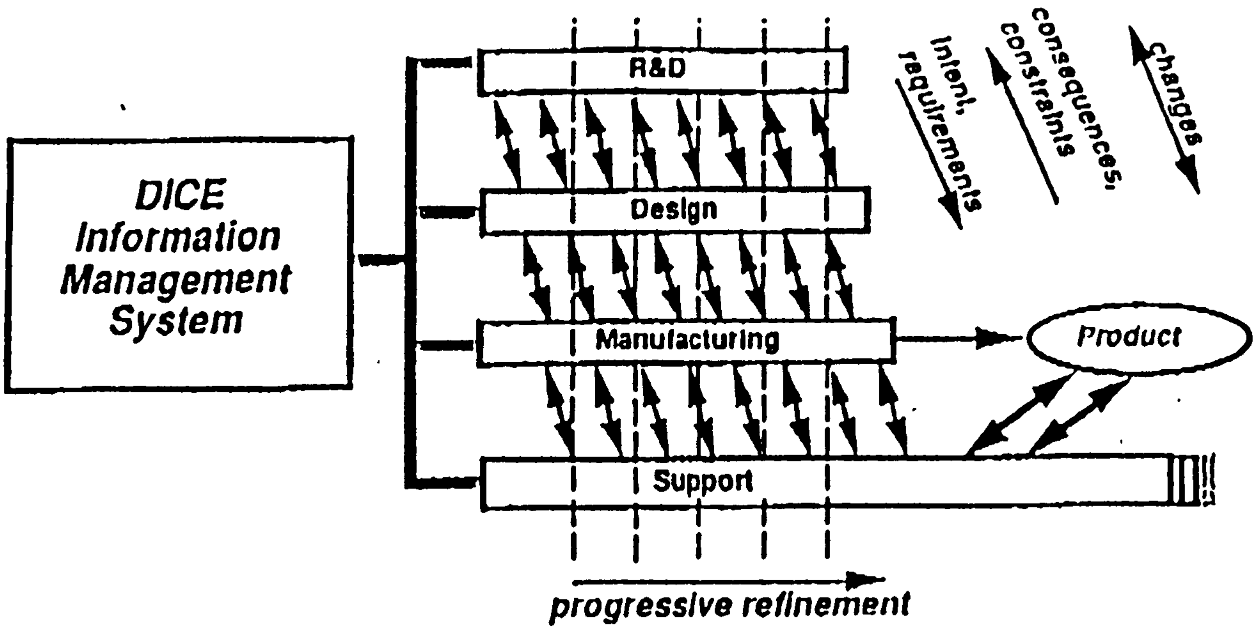
* *INTERFACING ANOMALIES ARE IRONED OUT DURING FABRICATION AND VERIFICATION TESTING.*

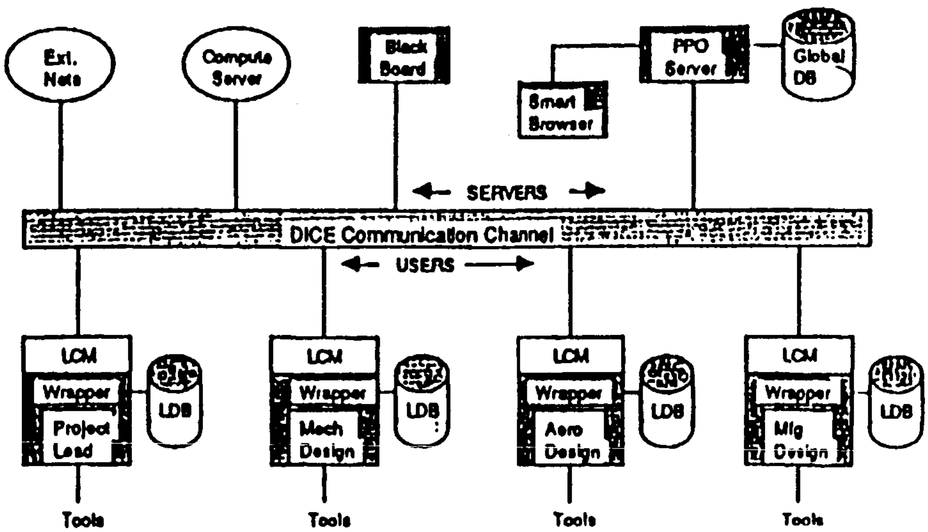
* *MODIFICATIONS TO REMEDY SHORTCOMINGS IDENTIFIED DURING OPERATIONS ARE DIRECTED TO AND RESOLVED BY SELECT DISCIPLINES ONLY.*

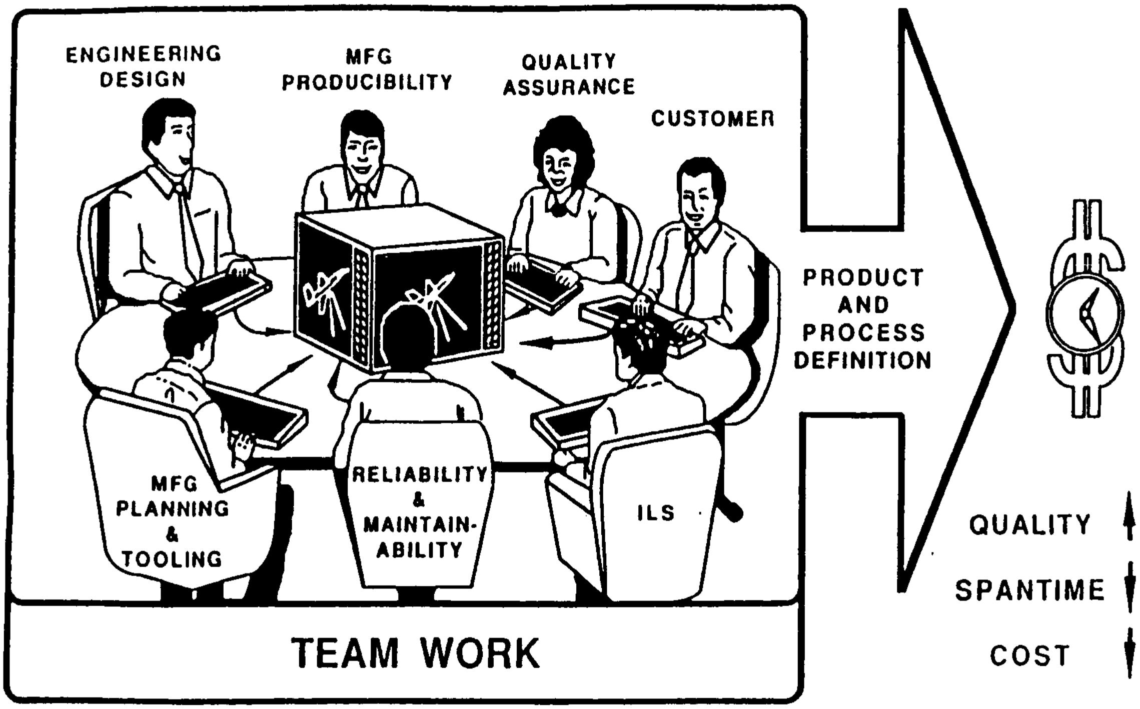
* *IMPACT OF REVISIONS ON OTHER DISCIPLINES IS NOT GIVEN DUE CONSIDERATIONS, INCREASING IMBALANCE IN THE DESIGN.*

DICE - DARPA INITIATIVE

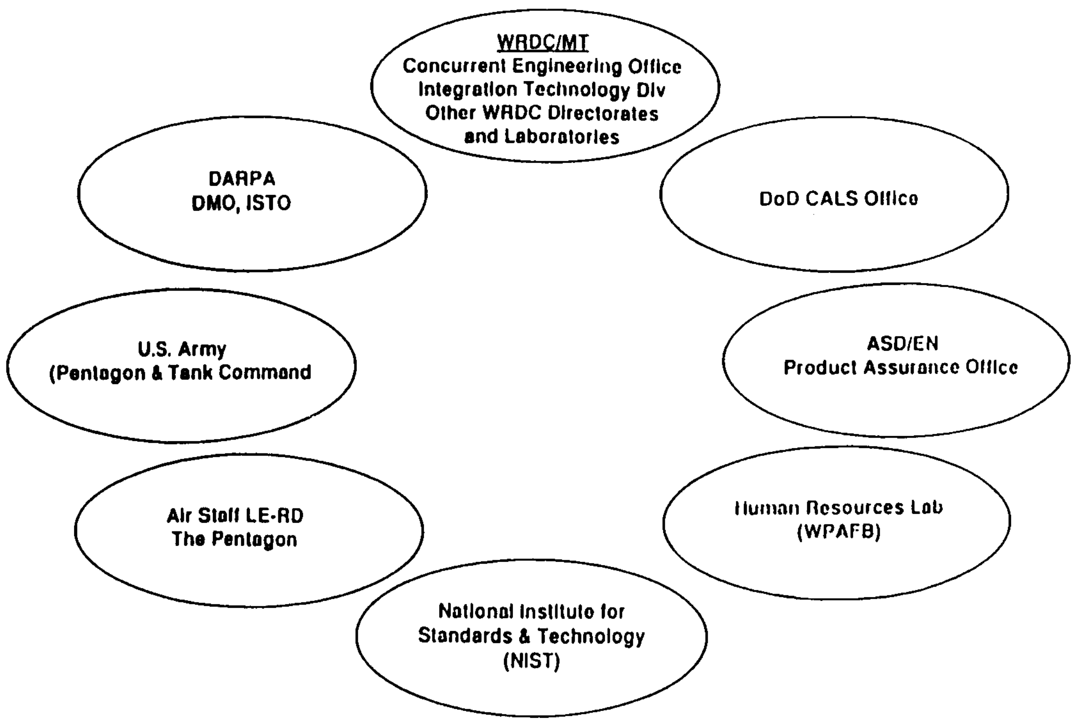
(ON-GOING PROGRAM - GE PRIME WITH U OF WEST VIRGINIA)



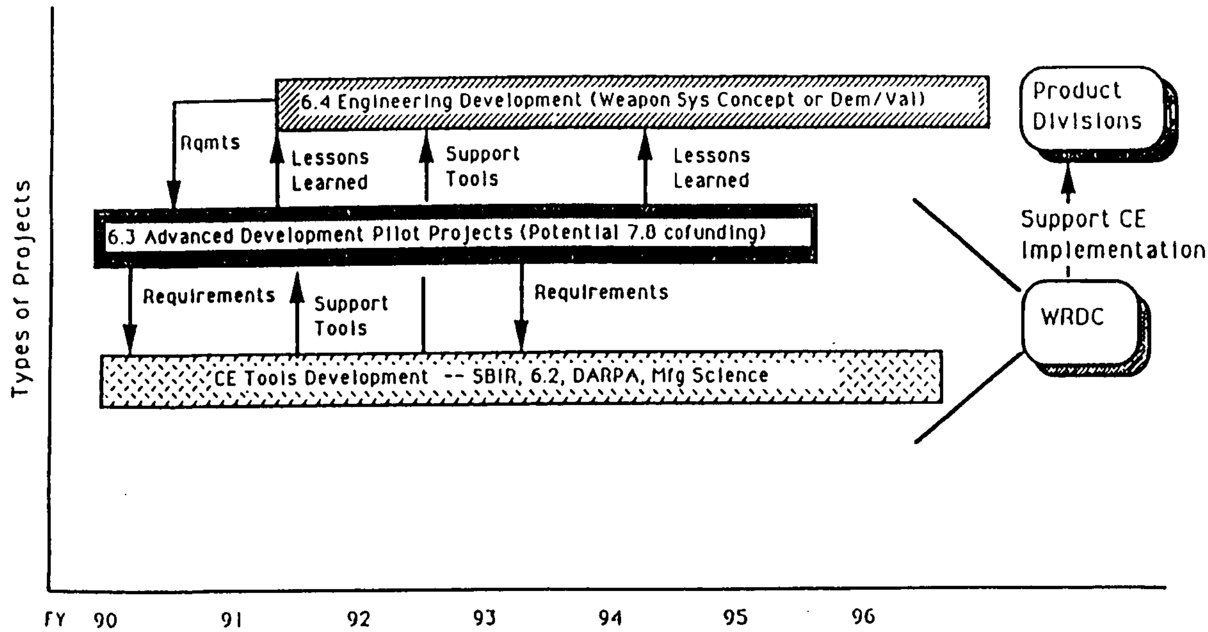




CONCURRENT ENGINEERING



KEY GOVERNMENT PARTICIPANTS



Concurrent Engineering Project Development Strategy

- CHANGE THE CULTURE - A WAY OF LIFE
- COMMIT FULLY TO AFSC'S POLICIES AND GOALS
- KNOW AND SATISFY OUR CUSTOMER'S NEEDS
- DELEGATE RESPONSIBILITY AND AUTHORITY - ACCEPT ACCOUNTABILITY
- GIVE EVERYONE A STAKE IN THE OUTCOME
- SET GOALS, COMPETE, MEASURE PROGRESS, AND REWARD
- CREATE A CLIMATE OF PRIDE, PROFESSIONALISM, EXCELLENCE AND TRUST
- STRIVE FOR CONTINUOUS IMPROVEMENT - MAKE IT BETTER

ASD TOTAL QUALITY MANAGEMENT PRINCIPLES

- AN ATTITUDE CHANGE PRIOR TO AN ACTION CHANGE
- A CONSCIOUS EFFORT TO IMPROVE THE WAY WE DO BUSINESS
- A METHOD OF CORRECTING ERRORS AND PREVENTING THEM
- A STREAMLINING EFFORT TO DO AWAY WITH UNNECESSARY PROCESSES, PROCEDURES, AND BUREAUCRACIES; AND LEAVE TIME TO DO WHAT IS IMPORTANT PROPERLY
- A TOOL TO BE USED BY THE PEOPLE TO MAKE ASD THE BEST AT WHAT WE DO, AND KKEP US THERE (CONTINUAL IMPROVEMENT)

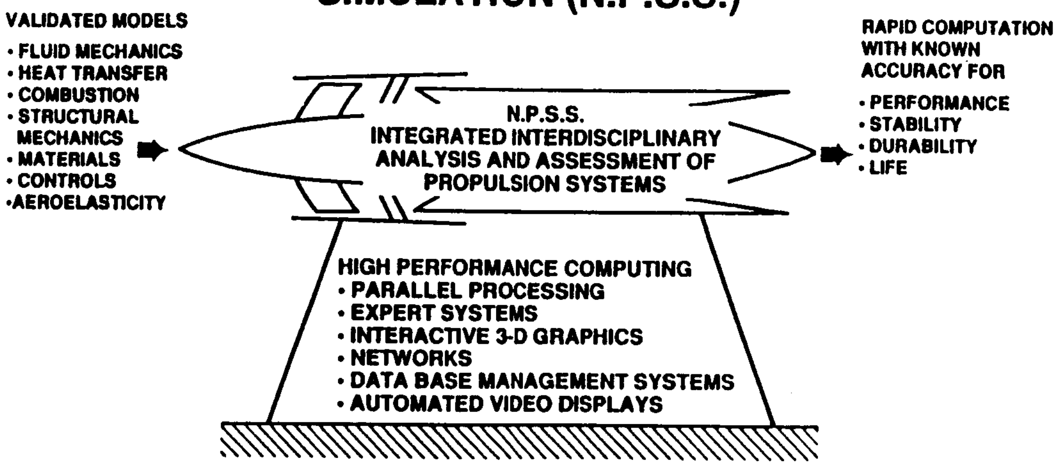
ASD VIEW OF TOTAL QUALITY MANAGEMENT

ON-GOING RELATED ACTIVITIES AT NASA LEWIS RESEARCH CENTER

* NPSS - NUMERICAL PROPULSION SYSTEM SIMULATOR

* ESCS - ENGINE STRUCTURES COMPUTATIONAL SIMULATOR

NUMERICAL PROPULSION SYSTEM SIMULATION (N.P.S.S.)

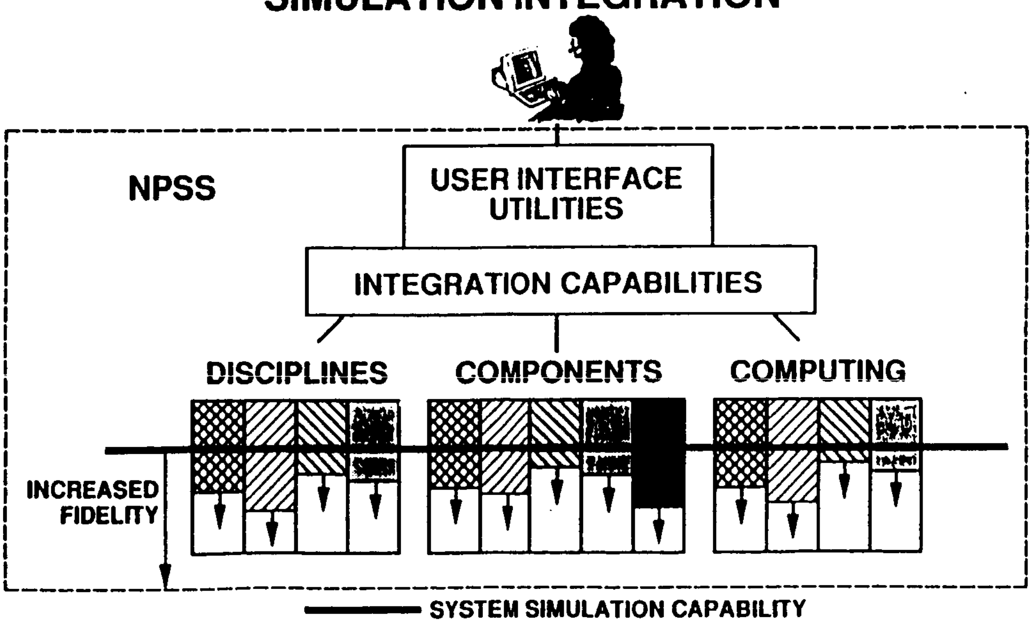


A NUMERICAL TEST CELL
FOR AEROSPACE PROPULSION SYSTEMS

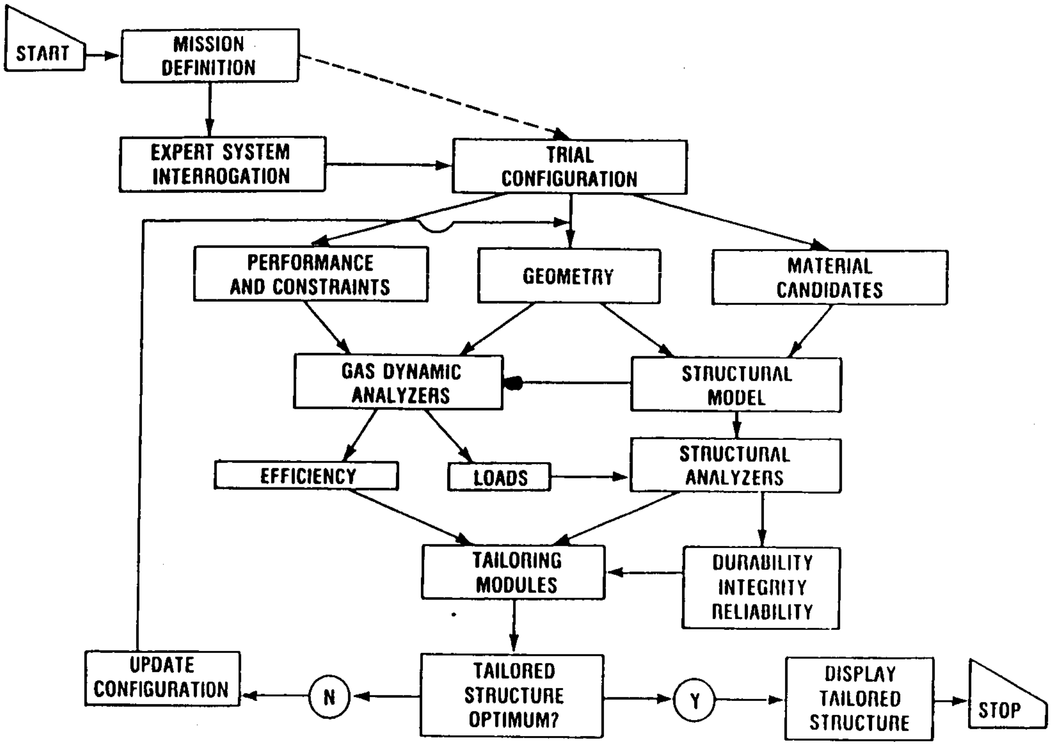
National Aeronautics and Space Administration
Lewis Research Center

INTERDISCIPLINARY TECHNOLOGY OFFICE NASA

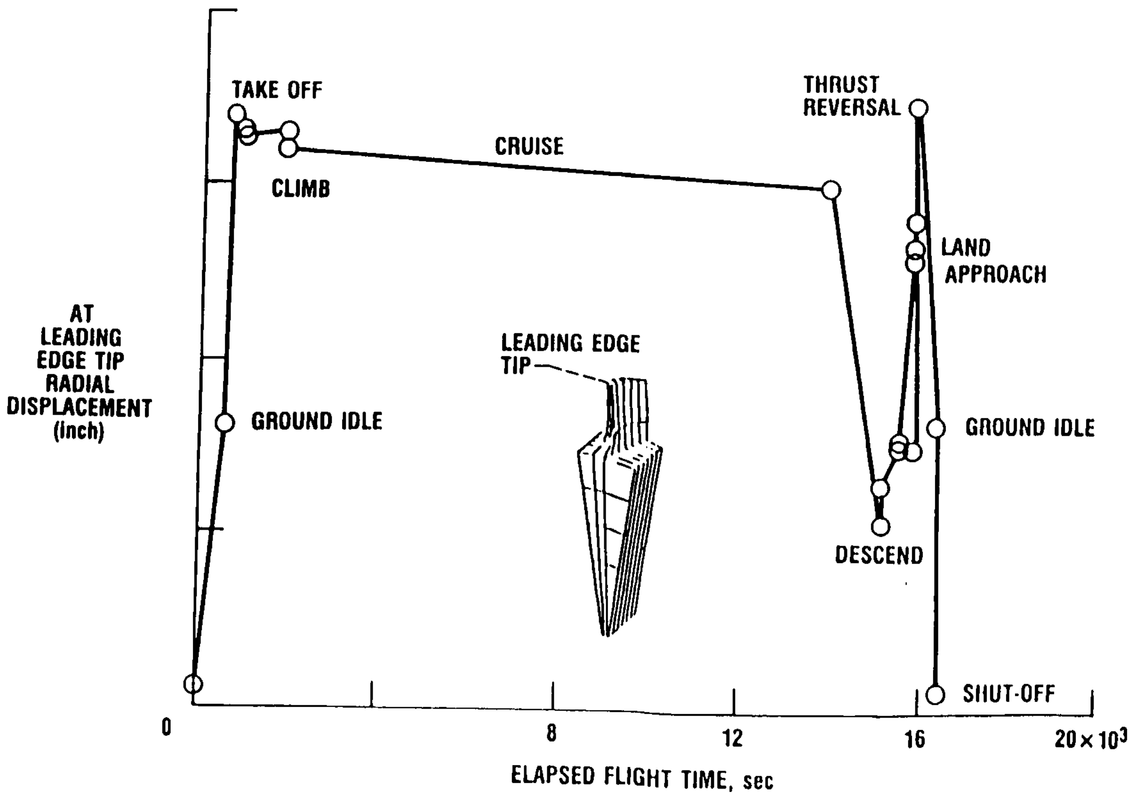
NUMERICAL PROPULSION SYSTEM SIMULATION INTEGRATION



ENGINE STRUCTURES COMPUTATIONAL SIMULATOR (ESCS)
SIMULATION PROGRESSION DIAGRAM



ESCS SAMPLE RESULTS FOR FLIGHT MISSION SIMULATION



NEEDS IDENTIFIED

FOR COMPUTATIONAL SIMULATION OF CONCURRENT ENGINEERING

* NEED TO DEVELOP COUPLED MULTI-DISCIPLINARY SOFTWARE SYSTEMS FOR SIMULTANEOUS INTERACTION AMONG PARTCIPATING DISCIPLINES THROUGH DISCIPLINE-SPECIFIC WORK STATIONS.

* NEED TO DEVELOP AUTOMATED COMMUNICATION LINKS TO INITIATE AND CARRY ACTIVITY IN EACH DISCIPLINE TASK SIMULTANEOUSLY, ALLOWING UNINTERRUPTED INTERACTION AND FEEDBACK BETWEEN TASKS.

* NEED TO DEVELOP SMART NEURAL NETS FOR INFORMATION PROCESSING WITHIN THE DATA BASE AND COMMUNICATION LINKS FROM/TO THE DISCIPLINE TASK.

* NEED TO DEVELOP ADAPTIVE METHODS TO CONTINUOUSLY UPGRADE THE DATA BASE FOR UPDATES IN EACH DISCIPLINE TASK AS WELL AS FOR NEW TECHNOLOGIES/MATERIALS/OTHER RELEVENT INVENTIONS.

* NEED TO DEVELOP ZOOMING METHODS TO QUICKLY AND AUTOMATICALLY FOCUS ON TO PRIORITY DISCIPLINE TASKS, PROBLEM AREAS, AND STRATEGIC ISSUES.

* NEED TO DEVELOP CAPABILITY FOR EFFICIENT AND INTERACTIVE MULTI-DISCIPLINARY GRAPHIC DISPLAYS AT ALL STAGES OF THE SYSTEM DEVELOPMENT CYCLE.

* NEED TO DEVELOP METHODS TO VERIFY SYSTEM IN-SERVICE, WHILE ASCERTAINING BALANCE WITH RESPECT TO ALL THE DISCIPLINES INVOLVED.

* NEED TO CONFIGURE PARALLEL PROCESSORS WITH RESPECTIVE SOFTWARE FOR THE DEVELOPMENT OF THE CONCURRENT ENGINEERING SOFTWARE.

PROPOSED PROGRAM

MAJOR OBJECTIVE:

INTEGRATED SOFTWARE PACKAGES FOR THE COMPUTATIONAL SIMULATION OF THE MULTI-DISCIPLINARY PROCEDURE THROUGH WHICH PROPULSION SYSTEMS ARE DEVELOPED, INSTALLED, OPERATED, AND MAINTAINED.

PROPOSED PROGRAM

COMPUTATIONAL SIMULATION OF CONCURRENT ENGINEERING FOR PROPULSION SYSTEMS

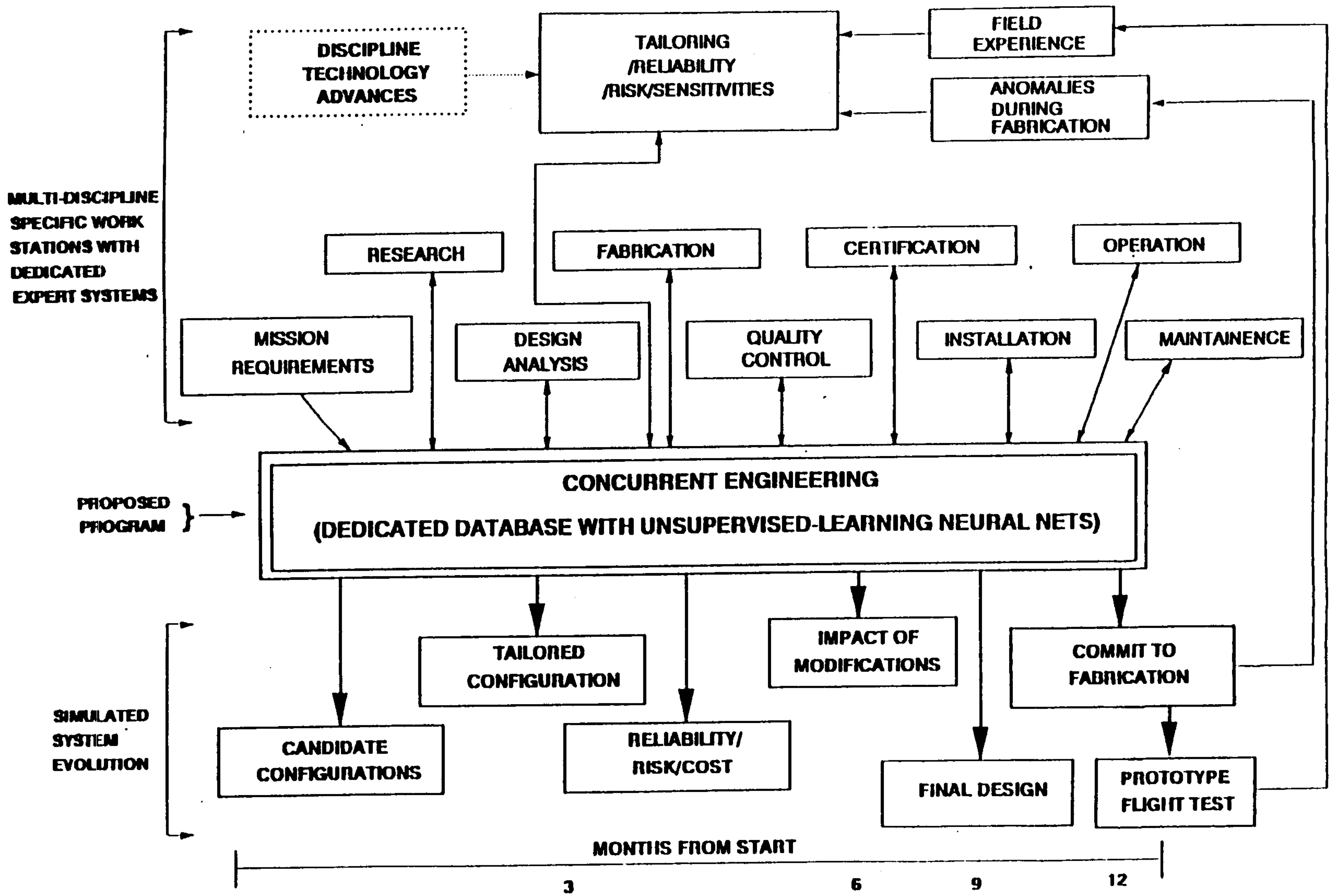
OBJECTIVE: Integrated software packages for the computational simulation of the multi-disciplinary procedure through which propulsion systems are developed, installed, and operated.

JUSTIFICATION: Propulsion systems are presently developed by a loosely integrated procedure where each participating discipline (research, design, analysis, fabrication, quality control/assurance, operation, and maintenance) performs its assigned task independently. This is followed by common boundary iteration to establish interdiscipline compatibility. The adequacy of the system is subsequently evaluated by extensive sub-component, component, and system tests. The result is a development process which is lengthy, costly, makes ineffective use of engineering talent, is inflexible with respect to incorporation of new technological advancements and materials, and is inadequate for apriori assessment of operating and maintenance difficulties. A viable alternative is an integrated software system where all the participating disciplines interact simultaneously through discipline-dedicated work stations using a common database.

APPROACH: Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) concepts will be used in conjunction with discipline-specific computational simulation methods to develop an integrated software package to computationally simulate the multi-discipline process for developing, installing, and operating propulsion systems. (See attached block diagram.) The software will consist of (1) workstation with discipline-specific modules and dedicated expert systems, (2) communication links for interactive multi-discipline workstations, (3) unsupervised-learning neural net, (4) adaptive methods for condensing and incorporating information as the system evolves, (5) zooming methods, (6) graphic displays, and (7) tapes for numerically controlled computer hardware. The software system will be verified by applying it to simulate existing propulsion systems with flight service.

RESOURCES: $100M over a 5-year period (see attached schedule chart)

PRPOSED PROGRAM: BLOCK DIAGRAM
COMPUTATIONAL SIMULATION OF CONCURRENT ENGINEERING



PROPOSED PROGRAM: TIME SCHEDULES AND RESOURCES

COMPUTATIONAL SIMULATION OF CONCURRENT ENGINEERING

ACTIVITY	YEARS FROM START ($ M)					TOTALS PER ACTIVITY ($ M)	TARGET GOALS
	1	2	3	4	5		
1. DISCIPLINE-SPECIFIC MODULES/EXPERT SYSTEMS	4	5	6	1		16	AUTOMATION WITH MIN HUMAN ERRORS
2. MODULE DATABASE INTERFACING		4	5	2		11	FINAL SYSTEM WITH MIN ITERATIONS
3. ADAPTIVE INFORMATION CONDENSERS/EXPENDERS	4	4	5	3		16	MAX FLEXIBILITY FOR ADOPTING NEW TECHNOLOGIES
4. DATABASE WITH ADAPTIVE NEURAL NETS	5	5	6	8	2	26	MOST COST-EFFECTIVE SYSTEM DEVELOPMENT
5. PARALLEL PROCESSING		5	6	7	3	21	MIN COMPUTATIONAL TIME
6. VERIFICATION					10	10	CERTIFICATION
TOTALS PER YEAR ($ M)	13	23	28	21	15	100	

PROGRAM IMPLEMENTATION

* NASA FULL COMMITMENT.
* MULTI-INSTITUTION PARTICIPANT DEVELOPMENT.
  (DIFFERENT INSTITUTIONS DEVELOP DIFFERENT PARTS.)
* CONTINUATION/AUGMENTATIONS/INTEGRATION OF ON-GOING RESEARCH AT LEWIS ON
  - *NPSS - NUMERICAL PROPULSION SYSTEM SIMULATOR.*
  - *ESCS - ENGINE STRUCTURES COMPUTATIONAL SIMULATOR.*
* ANNUAL RELEASES WITH PROGRESSIVE SOPHISTICATION CAPABILITY.
* WORKSHOPS FOR NEW CAPABILITY USER INSTRUCTIONS.
* EARLY-ON ADAPTATION INTO PRELIMINARY AND FINAL DESIGN ENVIRONMENTS.
* VERIFICATION/COMPARISON WITH PAST DESIGN AND FIELD EXPERIENCE AT USERS FACILITY.
* FORMATION OF PARTICIPANTS' USERS GROUP.
* FORMATION OF SOFTWARE MAINTENANCE INSTITUTION.

SUMMARY

COMPUTATIONAL SIMULATION OF CONCURRENT ENGINEERING

* **ISSUES:**
  - BALANCE/FLEXIBILITY/TOTAL LIFE CYCLE COST/TIME DELAYS/REVISIONS.

* **STATE-OF-THE-ART**
  - OF CURRENT PROCESS OF PUTTING THE SYSTEM IN SERVICE, STARTING FROM MISSION REQUIREMENTS/ DICE-DARPA CONCURRENT ENGINEERING PROGRAM.

* **NEEDS IDENTIFIED**
  - MULTI-DISCIPLINARY EXPERT SYSTEMS/COMMUNICATION LINKS.
  - DATA BASE WITH SMART NEURAL NETS AND ADAPTIVE METHODS.
  - ZOOMING METHODS AND GRAPHIC DISPLAYS.
  - VERIFICATION.

SUMMARY (CONTINUED)

* **PROPOSED PROGRAM**
  - OBJECTIVE: COMPUTATIONAL SIMULATION OF CONCURRENT ENGINEERING.
  - JUSTIFICATION: FASTER DEVELOPMENT CYCLE/LESS TOTAL SYSTEM LIFE CYCLE COST/ EFFECTIVE USE OF ENGINEERING TALENT/FLEXIBLE FOR INCORPORATING NEW TECHNOLOGIES/BALANCED SYSTEM DEVELOPMENT.
  - APPROACH: 6 MAJOR ACTIVITES.
  - TIME SCHEDULE AND RESOURCES: $100M OVER A 5-YEAR PERIOD.

* **IMPLEMENTATION**
  - INCORPORATION OF TOTAL SYSTEM LIFE CYCLE PROCESS INTO CURRENT PHILOSOPHY.
  - EDUCATION, BOTH AT THE ENGINEERING AS WELL AS THE MANAGEMENT LEVELS.
  - VERIFICATION/COMPARISON WITH PAST PROJECT ENGINEERING & MANAGEMENT PRACTICE.

PROPOSED PROGRAM

FOR COMPUTATIONAL SIMULATION OF CONCURRENT ENGINEERING FOR PROPULSION SYSTEMS

OBJECTIVE:

INTEGRATED SOFTWARE PACKAGES FOR THE COMPUTATIONAL SIMULATION OF THE MULTI-DISCIPLINARY PROCEDURE THROUGH WHICH PROPULSION SYSTEMS ARE DEVELOPED, INSTALLED, AND OPERATED.

JUSTIFICATION:

- FASTER DEVELOPMENT CYCLE
- LESS TOTAL SYSTEM LIFE CYCLE COST
- EFFECTIVE USE OF ENGINEERING TALENT
- FLEXIBLE FOR INCORPORATING NEW TECHNOLOGIES
- BALANCED SYSTEM DEVELOPMENT FOR TOTAL LIFE CYCLE

APPROACH:

- MULTIDISCIPLINARY EXPERT SYSTEMS
- COMMUNICATION LINKS
- SMART NEURAL NETS
- ADAPTIVE METHODS
- ZOOMING METHODS
- GRAPHIC DISPLAYS
- VERIFICATION

RESOURCES:

$100M OVER A 5-YEAR PERIOD

LIFE CYCLE COST BASED PROGRAM DECISIONS

N91-28248

J. S. DICK
JUNE 26, 1990

- BACKGROUND
  - SPACE PROPULSION FACILITY ASSESSMENT TEAM FINAL REPORT
- CHANGES
  - ADVANCED LAUNCH SYSTEM
  - NATIONAL AEROSPACE PLANE
  - SPACE EXPLORATION INITIATIVE
- LIFE CYCLE COST ANALYSIS RATIONALE
- RECOMMENDATION TO PANEL

1983 - FACILITY ASSESSMENT TEAM

- CHARTER
- KEY ISSUES
- TEST FACILITY VARIABLES
- SCOPE
- LAUNCH VEHICLE PROPULSION PROGRAMS
- ORBITAL TRANSFER PROPULSION PROGRAMS
- SPECIALIZED VEHICLE PROPULSION PROGRAMS
- SPACE STATION AUXILIARY PROPULSION PROGRAMS

- LARGE ENGINE THRUST LEVEL - PROGRAMS & FACILITY NEEDS
  - DEFICIENCIES
- MEDIUM ENGINE THRUST LEVEL - PROGRAMS & FACILITY NEEDS
  - DEFICIENCIES
- LOW ENGINE THRUST LEVEL
- CONCENTRATE ON FACILITIES AT GOVERNMENT SITES
- CONCLUSIONS

ASSESSMENT TEAM CHARTER

ASSESS STATUS OF NATION'S LIQUID CHEMICAL SPACE PROPULSION TEST FACILITIES AND THEIR ADEQUACY TO SUPPORT CURRENT, NEAR-TERM, AND LONG-RANGE NATIONAL PROGRAM REQUIREMENTS.

KEY ISSUES

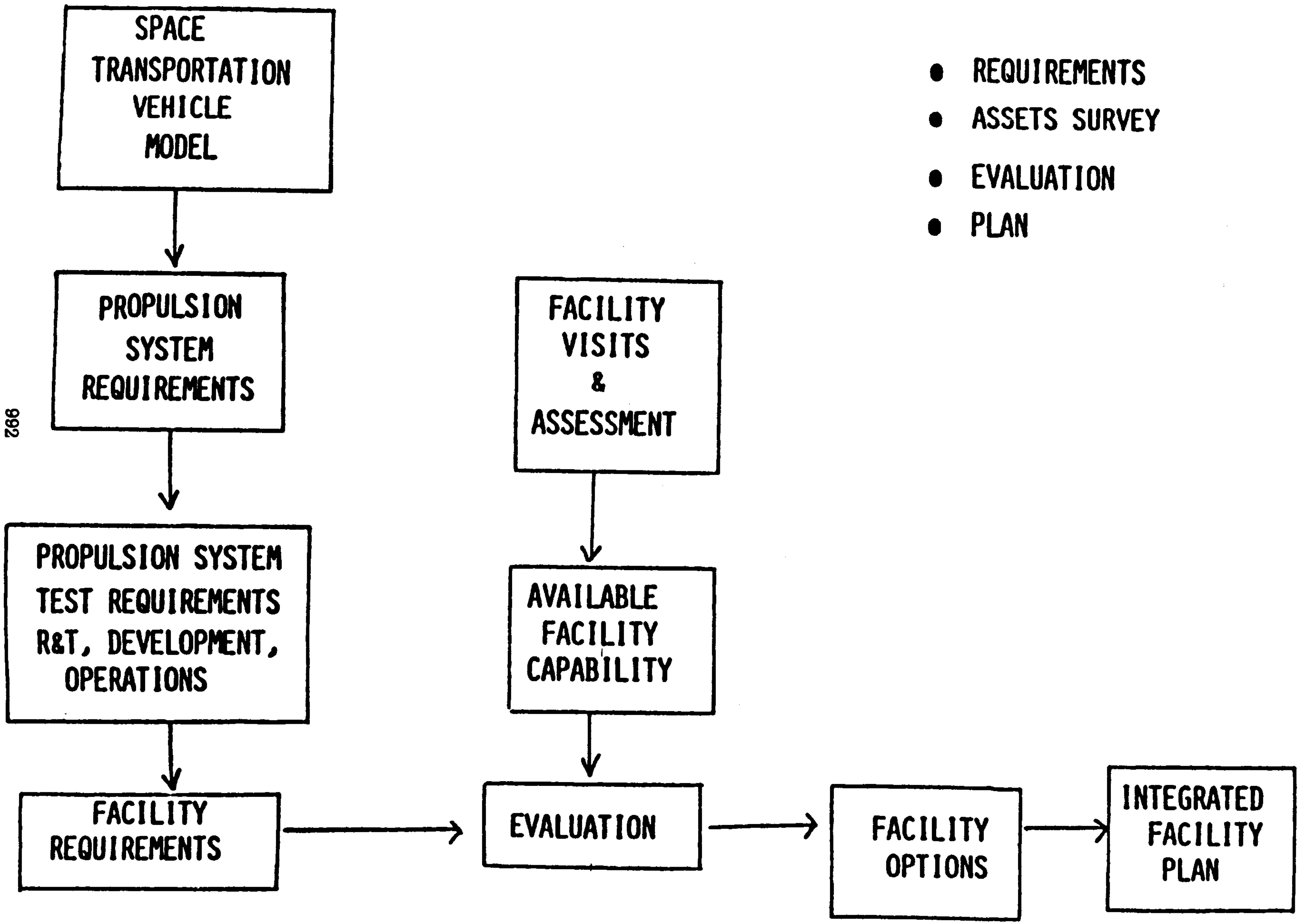
- WHAT FACILITIES ARE REQUIRED?
- WHAT FACILITIES ARE AVAILABLE?
- WHAT ARE THE FACILITY DEFICIENCIES?
- HOW CAN THE DEFICIENCIES BE ACCOMMODATED?
- WHAT IS THE PROPER BALANCE BETWEEN GOVERNMENT AND CONTRACTOR FACILITIES?
- WHY SIMILAR FACILITIES?

LIQUID CHEMICAL SPACE PROPULSION TEST FACILITY VARIABLES

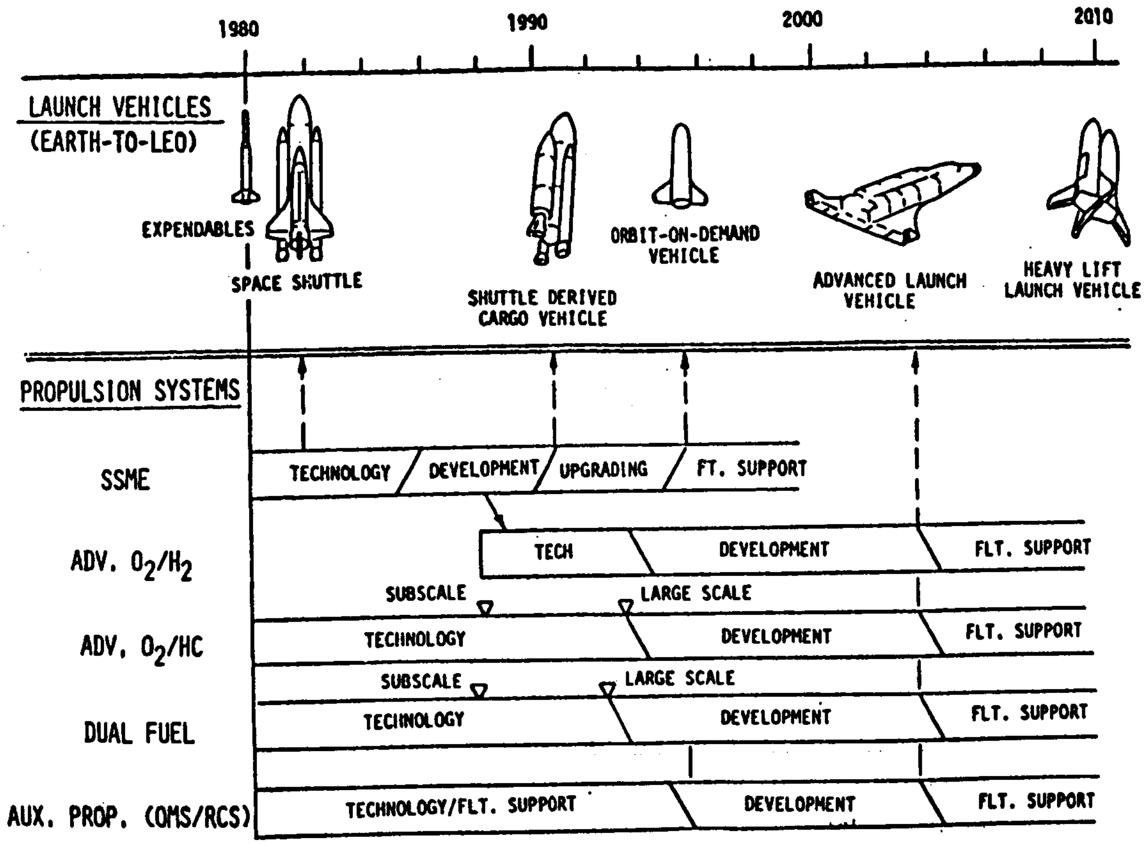
VARIABLES	RANGE/SCOPE
THRUST (LBS.)	MINI (10^1) (RCS) LOW (10^3) (ALTITUDE ADJ.) MODERATE (10^4) (OTV) LARGE (10^6) (SSME)
PROPELLANTS	CRYOGENIC STORABLES (MONOPROPELLANT, BIPROPELLANT)
RUN TANKAGE	MEDIA VOLUME PRESSURE
PRESSURANT	MEDIA CAPACITY PRESSURE
TEST PRESSURE	SEA LEVEL ALTITUDE
DATA ACQUISITION	NO. CHANNELS ANALOG/DIGITAL FREQUENCY/SAMPLE RATE OBSOLESCENCE MODERNIZATION PLANS
SYSTEM LEVEL	COMPONENTS ENGINES PROPULSION SYSTEMS STAGES
DUTY CYCLE	MIN./MAX. BURN DURATION THRUST RANGE MISSION DURATION

SCOPE

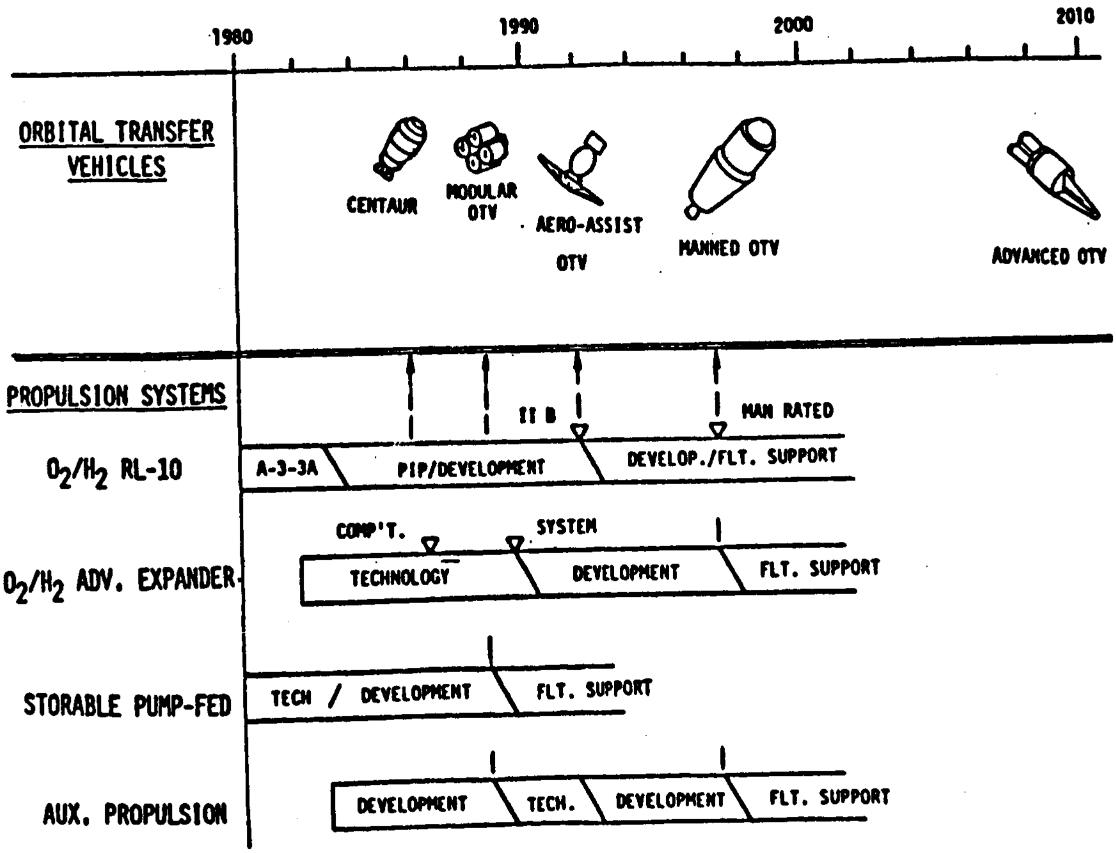
- REQUIREMENTS
- ASSETS SURVEY
- EVALUATION
- PLAN



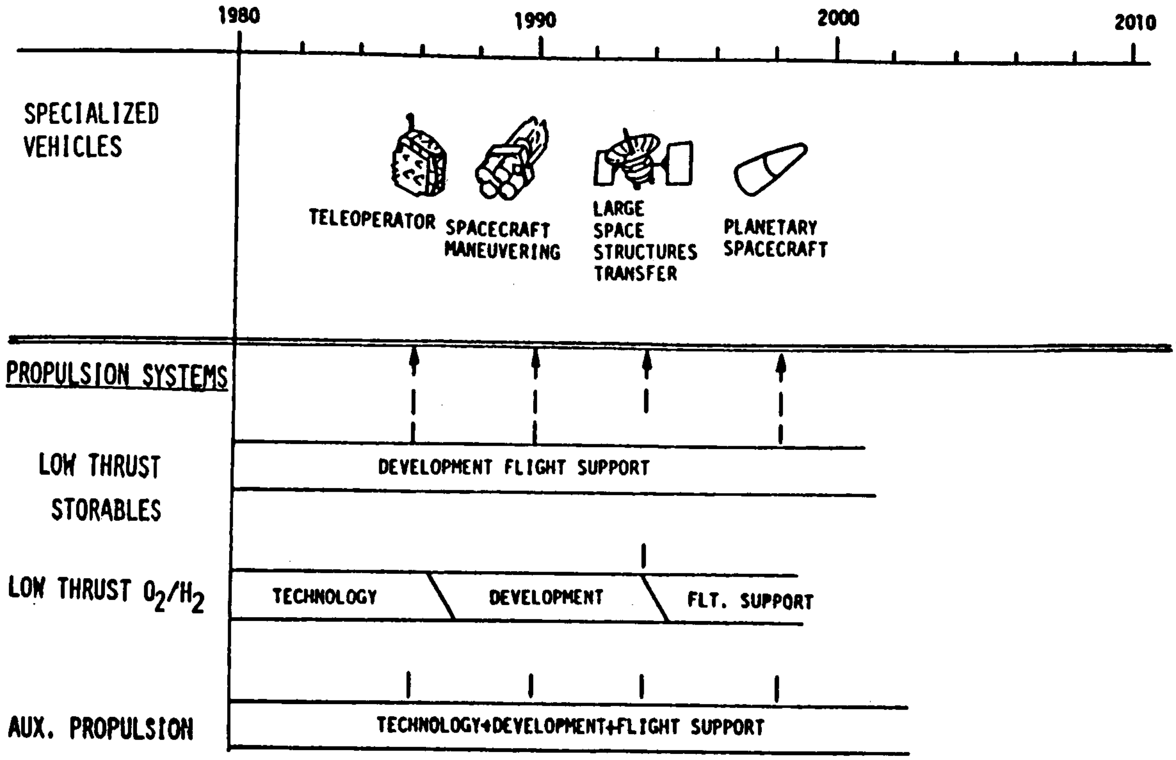
LAUNCH VEHICLE PROPULSION PROGRAMS



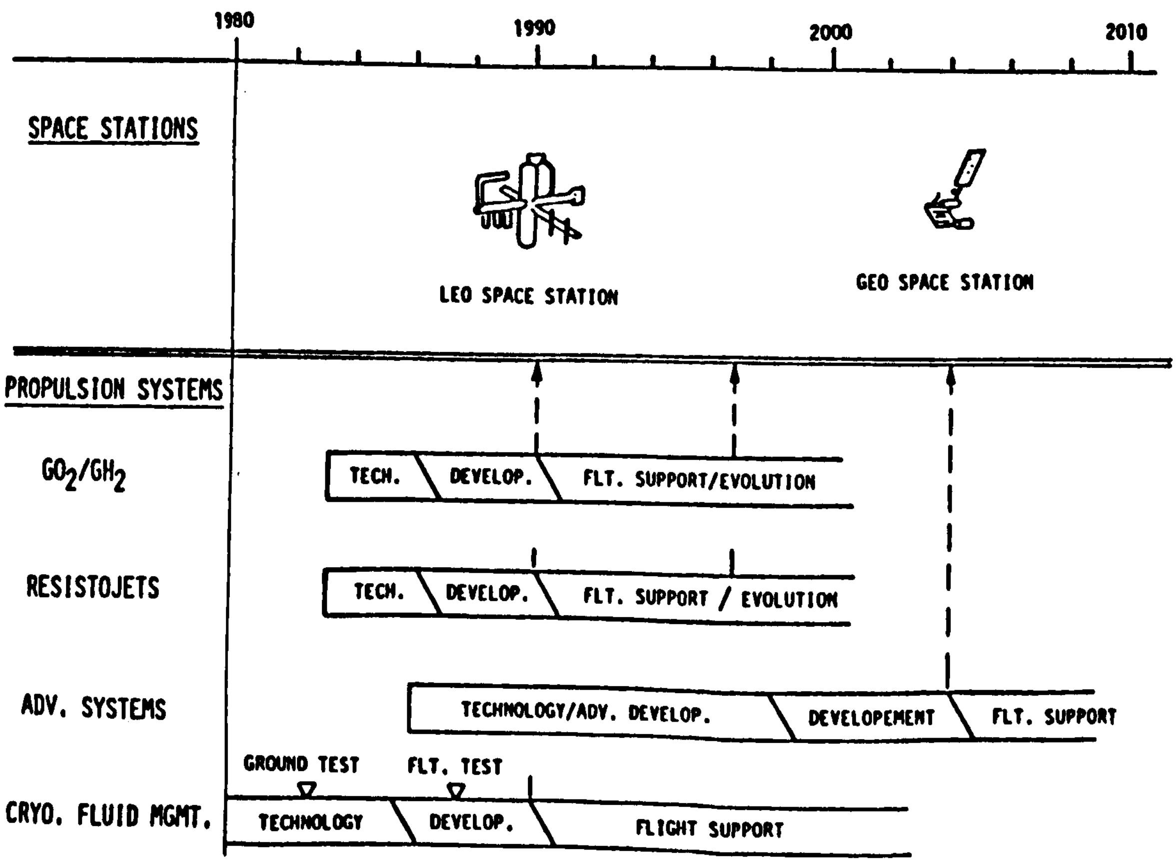
ORBITAL TRANSFER PROPULSION PROGRAMS



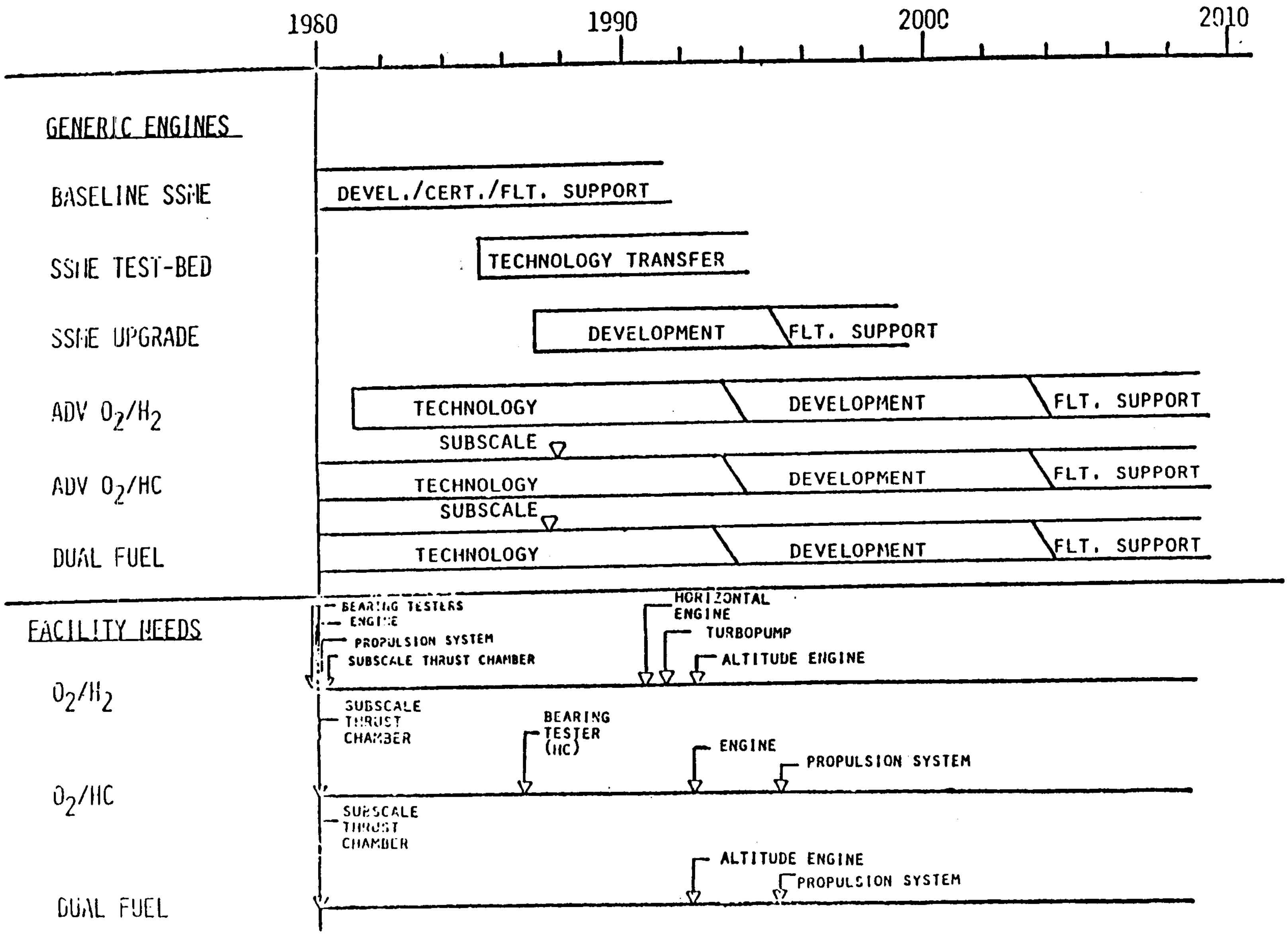
SPECIALIZED VEHICLE PROPULSION PROGRAMS



SPACE STATION AUXILIARY PROPULSION PROGRAMS



LARGE ENGINE THRUST LEVEL - PROGRAMS AND FACILITY NEEDS



LARGE ENGINE THRUST LEVEL
SYSTEM LEVEL SUMMARY

GENERIC ENGINES	LOCATION		
	AFRPL	MSFC	NSTL
SSME CURRENT BASELINE	N/A	N/A	B-2
TECHNOLOGY TEST BED	←	NONE REQUIRED	→
HORIZONTAL TEST	TS1-56 ***	S-1C**	B-1** B-2*
ADVANCED O_2/H_2	N/A	S-1C**	B-1** B-2
ADVANCED O_2/HC	N/A	S-1B* S-1C*	B-1* B-2*
DUAL FUEL	N/A	S-1C**	B-1** B-2*

* MINOR DEFICIENCIES (STRUCTURAL, PIPING OR SYSTEM)

** MODERATE DEFICIENCIES (STRUCTURAL, PIPING OR SYSTEM PLUS UPGRADE FUEL SYSTEM)

*** MAJOR DEFICIENCIES (STRUCTURAL, PIPING OR SYSTEM PLUS LACKS FUEL CAPABILITY)

LARGE ENGINE THRUST LEVEL

ENGINE LEVEL SUMMARY

GENERIC ENGINE	LOCATIONS ROCKETDYNE	MSFC	NSTL	AEDC	AFRPL
SSME BASELINE	A-3	N/A	A-1 A-2	N/A	N/A
SSME TECHNOLOGY TEST BED	A-3	S-1C **	A-1 A-2 B-1 ** B-2 *	J-4 **	N/A
SSME UPGRADING					
• ALTITUDE TEST	A-3 ***	S-1C ***	A-1 *** B-1 *** A-2 *** B-2 ***	J-4 *	N/A
• SEA LEVEL TEST (VERT)	A-3	S-1C **	A-1 B-1 ** A-2 B-2 *	J-4 **	N/A
• SEA LEVEL TEST (HORIZ.)	A-3 *	S-1C **	A-1 * B-1 ** A-2 * B-2 *	N/A	TS 1-56***
ADVANCED O_2/H_2	A-3	S-1C **	A-1 B-1 ** A-2 B-2 *	J-4 **	N/A
ADVANCED O_2/Hc	A-3 ***	S-1C * F-1 * S-IB **	A-1 ** B-1 * A-2 ** B-2 *	J-4 **	N/A
DUAL FUEL	A-3 ***	S-1C *	A-1 ** B-1 * A-2 ** B-2 *	J-4 **	N/A

LARGE ENGINE THRUST LEVEL

COMPONENT LEVEL SUMMARY

GENERIC ENGINES	COMBUSTION DEVICES (GAS GENERATORS, PRE-BURNERS, TURBINE BLADES, HEAT EXCHANGERS, THRUST CHAMBERS, NOZZLES)	BEARINGS	TURBOPUMPS
O_2/H_2	MSFC * ROCKETDYNE	MSFC ROCKETDYNE	ROCKETDYNE * NO GOV'T TEST SITE
O_2/HC	MSFC * ROCKETDYNE	MSFC ROCKETDYNE	(Hi Pc 3000 psi) ROCKETDYNE * NO GOV'T TEST SITE

* MINOR DEFICIENCIES (STRUCTURAL, PIPING OR SYSTEM)

** MODERATE DEFICIENCIES (STRUCTURAL, PIPING OR SYSTEM PLUS UPGRADE FUEL SYSTEM)

*** MAJOR DEFICIENCIES (STRUCTURAL, PIPING OR SYSTEM PLUS <u>LACKS</u> FUEL CAPABILITY)

LARGE ENGINE THRUST LEVEL

DEFICIENCY #1 - SSME TEST STANDS

REQUIREMENT: SSME TEST OPERATIONS REQUIRE MAINTAINING MORE THAN TWO ACTIVE TEST STANDS TO SUPPORT (1) THE PRODUCTION PROGRAM (INCLUDING ENGINE REBUILDS), (2) SOLVING CURRENT ENGINE PROBLEMS, (3) THE ENGINE PRODUCT IMPROVEMENT PROGRAM, (4) AN SSME TECHNOLOGY TEST BED, AND (5) THE NEED TO MAINTAIN SUFFICIENT TEST POSITIONS TO PROTECT THE ON-GOING STS OPERATIONAL PROGRAM.

FACILITY DEFICIENCY: PLANNED CLOSING OF ROCKETDYNE'S (RKD'S) A-3 TEST POSITION, LEAVES ONLY NSTL A-1 AND A-2.

OPTIONS FOR ADDITIONAL TEST STANDS:

	PRO	CON
• RETAIN RKD A-3.	• EXISTING OPERATION.	• OPERATING COST.
• ACTIVATE NSTL B-2 OR B-1 FOR SINGLE ENGINE TESTING.	• ACTIVE LOX/LH_2 TEST SITE. • LOW OPERATING COST (COST SHARED WITH A-1/A-2).	• INITIAL FACILITY INVESTMENT COST (LOW).
• ACTIVATE MSFC S-IC FOR SINGLE ENGINE TESTING.	• DEVELOP & MAINTAIN IN-HOUSE ENGINEERING EXPERTISE & CAPABILITY. • LOW OPERATIONAL COST.	• INITIAL FACILITY INVESTMENT COST (MODERATE).

LARGE ENGINE THRUST LEVEL

DEFICIENCY #1 (CONT'D.)

RECOMMENDATION:

- A COMPARATIVE STUDY BE MADE IMMEDIATELY OF THE ABOVE OPTIONS TO DETERMINE THE NUMBER AND LOCATION OF TEST STANDS CONSIDERING THE PROPOSED PHASE-OUT OF RKD'S A-3 TEST STAND AND THE REQUIREMENT TO IMPLEMENT AN SSME TECHNOLOGY TEST BED. (A JOINT OSF/OAST STUDY).

- PRESERVE NSTL B-2 TEST POSITION IN CURRENT CONFIGURATION UNTIL COMPARATIVE STUDY IS COMPLETE AND FINAL DECISION IS MADE.

LARGE ENGINE THRUST LEVEL

DEFICIENCY #2 - HORIZONTAL SSME TESTING

REQUIREMENT: HORIZONTAL ORBIT-ON-DEMAND CONCEPTS REQUIRE RAPID ENGINE START-UP AND OPERATION IN HORIZONTAL POSITION.

FACILITY DEFICIENCY: HORIZONTAL TEST POSITION FOR SSME/SSME DERIVATIVE ENGINE ≈ 1990.

OPTIONS:

OPTIONS	PRO	CON
• RKD A-3	• DEVELOPMENT ENGR. SUPPORT	• INVESTMENT COST FOR MODS.
• MSFC S-IC	• DEVELOPMENT ENGR. SUPPORT	• INVESTMENT COST FOR MODS. AND REACTIVATION.
• NSTL A-1/A-2 B-1/B-2	• LOW OPERATING COST (SHARED FACILITY)	• INVESTMENT COST FOR MODS.
• RPL 1-56	• EXISTING HORIZONTAL TEST SITE	• INVESTMENT COST TO ADD LH_2 CAPABILITY AND REACTIVATION.

RECOMMENDATION:

- CONTINUAL REVIEW OF ORBIT-ON-DEMAND REQUIREMENTS, INITIATE A FACILITY STUDY TRADE ≈ 1985/6.

DEFICIENCY #3 - MSFC "BACKYARD CAPABILITY"

REQUIREMENT: ADEQUATE SPECIALIZED "BACKYARD" FACILITIES ARE REQUIRED TO ENABLE MSFC TO ACCOMPLISH LEAD ROLE IN COMPONENT LEVEL TESTING FOR SSME AND ADVANCED ENGINE TECHNOLOGY DEVELOPMENT. SPECIFICALLY: (1) LH_2 TESTING OF LARGE BEARINGS 50 MM, WITH RADIAL AND AXIAL LOAD AT SPEEDS 40,000 RPM AND (2) HIGH PRESSURE 3500 PSI O_2/H_2 TESTING OF TURBINE DRIVE COMBUSTION TECHNOLOGY, ADVANCED CHAMBER COMBUSTION TECH, EXHAUST PLUME ANALYSIS.

FACILITY DEFICIENCY: 1) NO H_2 TEST OPERATION PERMITTED AT MSFC's BEARING TEST STAND, TP-500, UNTIL A PRESSURIZED TERMINAL ROOM IS CONSTRUCTED. (SAFETY ISSUE)
2) CURRENT IDENTIFIED WORK LOAD FOR HI PRESS O_2/H_2 TESTING REQUIRES TWO TEST POSITIONS - ONLY ONE AVAILABLE (TP 116). THEREFORE, TECHNOLOGY TEST PROGRAMS ARE DELAYED AND/OR DEFERRED TO ACCOMODATE SPECIFIC ON-GOING PROGRAM DEVELOPMENT ACTIVITIES (SSME TURBINE BLADE TEST) OR UNSCHEDULED ANOMALY RESOLUTIONS (STS OVERPRESSURE PROBLEM).

OPTIONS:	PRO	CON
• MSFC TP 500 & 115	• DEVELOP & MAINTAIN IN-HOUSE TECHNICAL EXPERTISE CONSISTENT WITH ETO ENGINE DEV. ROLE. • IMPROVED CAPABILITY FOR ANOMALY RESOLUTION. • EXISTING SUPPORTING FACILITIES ARE AVAILABLE. • LOW OPERATIONAL COST.	• NONE

LARGE ENGINE THRUST LEVEL

DEFICIENCY #3 (CONT'D.)

OPTIONS (CONT'D):

	PRO	CON
• OTHER GOVERNMENT SITES.	• NONE.	• BASIC TEST CAPABILITY DOES NOT EXIST.
• CONTRACTOR SITES.	• EXPAND INDUSTRY BASE AT ONE CONTRACTOR (PROBABLY RKD.)	• INVESTMENT COST SIGNIFICANT. • OPERATING COST.

RECOMMENDATION:

IMPLEMENT FY 1985 CoF MODIFICATION FOR MSFC'S TP 500 & 115.

LARGE ENGINE THRUST LEVEL

ISSUE #4 - ENVIRONMENTALLY COMPLIANT TEST SITES

REQUIREMENT: ADEQUATE ETO ENGINE AND SYSTEM LEVEL TEST SITES ARE REQUIRED TO MEET NATIONAL NEEDS. THEY MUST COMPLY WITH ENVIRONMENTAL REQUIREMENTS.

FACILITY CONCERN: ENVIRONMENTAL CONSTRAINTS LIKELY TO INCREASE FOR TEST SITES LOCATED ADJACENT TO POPULATED AREAS CURRENTLY EXPERIENCING ENVIRONMENTAL CONSTRAINTS ON ENGINE LEVEL TEST AT SEVERAL TEST SITES, E.G. ROCKETDYNE AT SANTA SUZANNA RESTRICTED TO TEST OPERATIONS DURING DAY LIGHT HOURS.

OPTIONS:

	PRO	CON
• RELOCATE RKD A-3 TEST OPERATIONS.	• ELIMINATES ENVIRONMENTAL PROBLEMS.	• REQUIRES ALTERNATE SITE.
• PROTECT BUFFER ZONE AT ISOLATED TEST SITES.	• PROTECTS CRITICAL NATIONAL ASSET.	• LOCAL PRESSURE FOR LAND USE.

RECOMMENDATION:

PROTECT NSTL BUFFER ZONE AND PRESERVE OTHER EXISTING GOVERNMENT REMOTE TEST SITES (MSFC).

LARGE ENGINE THRUST LEVEL

DEFICIENCY #5 - LOX/HYDROCARBON TEST SITE

REQUIREMENT: ADVANCED EARTH TO ORBIT TRANSPORTATION SYSTEMS WILL REQUIRE THE DEVELOPMENT OF LARGE HYDROCARBON AND/OR DUAL FUEL ENGINES @ Hi Pc. TEST AT ALTITUDE CONDITION MAY BE REQUIRED.

FACILITY DEFICIENCY: NO FACILITY HAS CAPABILITY TO MEET BOTH PROPELLANT AND ALTITUDE REQUIREMENTS.

OPTIONS:

	PRO	CON
• GOV'T. TEST SITES AEDC, MSFC, NSTL, RPL.	• BUILDS ON EXISTING OPERATIONAL BASE.	• INVESTMENT COST.
• CONTRACTOR TEST SITES. AEROJET, PRATT, RKD.	• MAINTAIN INDUSTRY CAPABILITY.	• INVESTMENT COST. • COST OF OPERATION.

RECOMMENDATION:

INITIATE A TECHNICAL FEASIBILITY/FACILITY TRADE STUDY IN 1984 TO ESTABLISH A TEST PHILOSOPHY, i.e., ENGINE/COMPONENT TEST BED VIS-A-VIS COMPONENT LEVEL TESTING, TO SUPPORT A CoF PER IN FY 1987.

LARGE ENGINE THRUST LEVEL

DEFICIENCY #6 - ADVANCED ENGINE TURBOPUMP TESTING

REQUIREMENT: ADVANCED O_2H_2, O_2/HC AND/OR DUAL FUEL EARTH TO ORBIT ENGINES REQUIRE TURBOPUMP TESTING.

FACILITY DEFICIENCY: EXISTING CONTRACTOR FACILITY HAS NOT SATISFACTORILY DEMONSTRATED THIS CAPABILITY. TEST POSITION IS PROJECTED TO BE CLOSED BY 1986 AND CRITICAL HIGH PRESSURE TANKAGE LIKELY TO BE MOVED TO OTHER LOCATIONS. NO ALTERNATE GOV'T. TEST POSITION EXISTS.

OPTIONS:

	PRO	CON
• RKD A-3	• CURRENTLY EXISTING FACILITY.	• FACILITY LIKELY TO BE CLOSED IN SPITE OF THIS REQUIREMENT. • OPERATIONS COST.
• MSFC	• SUPPORTS ETO DEVELOPMENT RESPONSIBILITY. • BUILDS ON EXISTING CAPABILITY BASE.	• INITIAL INVESTMENT COST.
• NSTL	• UTILIZES EXISTING PROPELLANT SUPPLY FACILITIES.	• INITIAL INVESTMENT COST.
• TEST BED ENGINE	• MAY BE ONLY PRACTICAL SOLUTION AT REASONABLE COST.	• TURBOPUMP TESTS MUST BE ACCOMPLISHED IN CONJUNCTION WITH ENGINE SYSTEM TESTS.

LARGE ENGINE THRUST LEVEL
DEFICIENCY #6 (CONT'D.)

RECOMMENDATION:

CONDUCT TRADE STUDY TO ESTABLISH TECHNICAL FEASIBILITY AND COST ESTIMATES FOR TURBOPUMP TEST METHOD TO SUPPORT AN FY 1987 CoF PROJECT. THIS STUDY SHOULD BE INITIATED AS AN INTEGRAL PART OF THE PRIOR ENGINE ISSUE.

CATEGORIZATION OF GOVERNMENT FACILITIES

I. ACTIVE - IN CURRENT USE.

II. RETAIN IN CURRENT STATUS FOR POTENTIAL FUTURE USE
- NOT UNIQUELY REQUIRED BY VEHICLE MODEL.
- ASSET OF POTENTIAL VALUE TO FUTURE PROGRAM.
- COSTLY TO DUPLICATE, CONTAIN EXPENSIVE, LONG-LEAD HARDWARE.

- STANDBY - MAINTAIN TO PERMIT RAPID ACTIVATION.
- DOWNMODE - MAINTAIN AT MINIMUM LEVEL TO ARREST DETERIORATION.

III. RETAIN AS A SOURCE OF HARDWARE
- NOT REQUIRED BY VEHICLE MODEL.
- CONTAIN EXPENSIVE, LONG-LEAD HARDWARE.

IV. INDICATE TO CONTROLLING GOVERNMENT ORGANIZATION THAT FACILITY RETENTION FOR PROPULSION PURPOSES CANNOT BE JUSTIFIED
- NOT REQUIRED BY VEHICLE MODEL.
- INCLUDE FACILITIES AT NASA, DOD, AND DOE LOCATIONS AND GOVERNMENT FACILITIES AT CONTRACTOR LOCATIONS.

MEDIUM ENGINE THRUST LEVEL - ENGINE CHARACTERISTICS

	THRUST FULL/LOW (LBS.)	Pc (PSIA)	EXPANSION RATIO	DURATION CLASS (SEC.)
O_2H_2				
RL-10 IIB	15,000/1500	400	205	1,400
ADV EXPANDERS	15,000/500	2,000	1,000	1,800
	3,000/500	2,000	1,000	1,800
ADV OMS	6,000	500	300	600
N_2O_4/MMH				
ADV PUMP-FED	3,750	1,500	400	1,000
CURRENT OMS	6,000	125	55	600
ADV OMS	6,000	1,500	400	600
O_2/HC				
ADV OMS	6,000	600	300	600

MEDIUM ENGINE THRUST LEVEL - ENGINE LEVEL TEST CAPABILITY

PROPULSION SYSTEM	FACILITY	AEDC	RPL	GSFC	JAF	JPL	JSC	LeRC	LeRC P.B.	MSFC	NSTL	WSTF	ALRC	BELL	BOE.	HAM. STD.	TMC	PWA	RKD	RR	TRW
O_2/H_2	RL-10 IIB	A	A					P	SP	P	P	A	P					P	P		A
	ADV EXPANDER	A	A					P	SP	P	P	A	P					P	P		A
	OMS	A	A					P	SP	P	P	A	*	A				P	P		A
N_2O_4/MMH	OMS	*	*					P				*	*	A				A	*		*
	ADV PUMP-FED	*	*			*		P				*	*	*				A	*		*
O_2/HC	OMS	*	*					P				*	*	A				A	*		*

* FULL EXISTING CAPABILITY

A EXIST. ALTITUDE CAPABILITY

P EXIST. PROPELLANT SYSTEM

S TEST STAND IN PLACE

ENGINE CLASS	FEED SYSTEM		BEARING TESTERS	TURBO-PUMPS	THRUST CHAMBERS	NOZZLES	ENGINE TEST S.L.	ENGINE TEST ALTITUDE	STAGE TEST S.L.	STAGE TEST ALTITUDE
O_2H_2	PUMP FED	GOV'T	LeRC		LeRC MSFC		LeRC MSFC NSTL	AEDC J-4	AFRPL MSFC WSTF NSTL	AEDC AFRPL WSTF
		CONTR.	R/D	BELL R/D	R/D		ALRC R/D BELL		ALRC R/D BELL	
N_2O_4/MMH	PUMP FED	GOV'T			AFRPL LeRC		AFRPL LeRC WSTF	AEDC J-3 AFRPL JPL WSTF	AFRPL WSTF	AEDC AFRPL WSTF
		CONTR.	R/D	BELL R/D	BELL R/D	ALRC BELL R/D	ALRC BELL R/D TRW	ALRC BELL R/D TRW	ALRC BELL R/D TRW	
	PRESS. FED	GOV'T	N/A	N/A	RPL LeRC WSTF	AEDC AFRPL WSTF	AFRPL LeRC WSTF	AEDC J-3 AFRPL WSTF	AFRPL WSTF	AEDC AFRPL WSTF
		CONTR.	N/A	N/A	ALRC R/D BELL TRW	ALRC TRW R/D	ALRC BELL R/D TRW	ALRC R/D TRW	ALRC R/D BELL TRW	
O_2/HC	PUMP FED	GOV'T	LeRC		LeRC MSFC		LeRC MSFC NSTL	AEDC J-3	AFRPL MSFC WSTF NSTL	AEDC AFRPL NSTL
		CONTR.	ALRC R/D	ALRC BELL R/D	ALRC R/D	ALRC	ALRC BELL R/D	ALRC	ALRC BELL R/D	

MEDIUM ENGINE THRUST LEVEL
DEFICIENCY #1 - ENGINE ALTITUDE TESTING

REQUIREMENT:

VERY HIGH EXPANSION RATIO (E) ENGINES ARE REQUIRED FOR FUTURE HIGH PERFORMANCE OTV'S (MID-1990'S) AND FOR ETO VEHICLES ORBIT MANEUVERING SYSTEMS (OMS) (POST 2000)

- RL-10B (PRODUCT IMPROVEMENT PROGRAM (PIP)) NEED DATE: 1986
- ADV EXPANDER NEED DATE: 1989

DEFICIENCY:

CAPABILITY TO TEST HIGH ϵ DUAL THRUST ENGINES THROUGH FULL MISSION DUTY CYCLES CURRENTLY EXISTS ONLY AT AEDC J-4.

OPTIONS:	PRO	CON
• MODIFY P&W TEST STAND E-6	ACCOMMODATES CURRENT SCHEDULE	• NOT AVAILABLE TO OTHER CONTRACTORS • DOES NOT SATISFY MISSION DURATION REQUIREMENTS
• USE AEDC J-4 FOR ALL HIGH ϵ TESTING	• NO CoFF FUNDING REQUIRED	• VERY HIGH OPERATING COSTS (CHARGES) • PRIORITIES/SCHEDULING PROBLEMS • SINGLE POINT FAILURE
• MODIFY OTHER GOVERNMENT FACILITY (AEDC J-3, WSTF, LeRC, MSFC, NSTL.	COST EFFECTIVE LONG-TERM SOLUTION	REQUIRES NEAR TERM CoFF FUNDING (FY 1985)

MEDIUM ENGINE THRUST LEVEL

DEFICIENCY #1 (CONT'D.)

RECOMMENDATION:

- ACCOMMODATE NEAR TERM TEST REQUIREMENTS (RL-10 IIB PIP) AT AEDC J-4.
- CONDUCT TRADE STUDY TO DETERMINE MOST COST/SCHEDULE EFFECTIVE LOCATION FOR PERMANENT HIGH ALTITUDE TEST FACILITY(S), WHICH CAN ALSO ACCOMMODATE HIGH ϵ NOZZLE TESTING
- COMPLETE STUDY IN TIME TO IMPACT FY 86 CoFF (COULD MEET RL-10 IIB PIP REQUIREMENTS, IF DELAYED)

MEDIUM ENGINE THRUST LEVEL

ISSUE #1 - ENGINE TESTING

CONSIDERATION OF POTENTIAL FACILITIES

MINOR MODS	MODERATE MODS	MAJOR
	AEDC (J-3)	MSFC
	LeRC (PSL)	NSTL
	WSTF	
	P&W	ALRC
		BELL
		RKD
		TRW

MEDIUM ENGINE THRUST LEVEL

DEFICIENCY #2 - NOZZLE TESTING

REQUIREMENT:

HIGH EXPANSION RATIO (ε) ENGINES REQUIRED FOR FUTURE HIGH PERFORMANCE OTV'S (MID-1990'S) AND ETO VEHICLE ORBIT MANEUVERING SYSTEMS (OMS) (POST 2000)

DEFICIENCY:

CAPABILITY TO TEST HIGH ε NOZZLES AT ALTITUDE WITH PRESSURE FED THRUST CHAMBERS DOES NOT EXIST AT ANY TEST FACILITY - INITIAL NEED DATE (R&T): 1988

OPTIONS:

	PRO	CON
• PROVIDE HIGH PRESSURE TANKAGE TO AEDC (J-3) OR WSTF	PROVIDES REQUIRED CAPABILITY	COST OF HIGH PRESSURE TANKS
• TEST AT ENGINE LEVEL AT GOVERNMENT FACILITY.	LOW PRESSURE TANKS IN PLACE OR AVAILABLE	PUMP LIFE/MAINT./CONTROL
• TEST SUBSCALE HARDWARE AT LeRC, ALRC,, RKD	IN-PLACE CAPABILITIES	EXTRAPOLATION OF RESULTS TO FULL SCALE NOZZLES

RECOMMENDATION:

CONDUCT STUDY IN CONJUNCTION WITH ENGINE SYSTEM TEST FACILITY OPTIONS TO DEVELOP MOST COST EFFECTIVE SOLUTION

MEDIUM ENGINE THRUST LEVEL

ISSUE #2 - NOZZLE TESTING

CONSIDERATION OF POTENTIAL FACILITIES

MINOR MODS	MODERATE MODS	MAJOR MODS
	E.G., PROPELLANT SYS	E.G., ALTITUDE SYSTEM
	AEDC J-4	MSFC
	AEDC J-3	NSTL
	AFRPL	
	LeRC PSL	
	WSTF	
	ALRC	BELL
	P&W	RKD

MEDIUM ENGINE THRUST LEVEL

DEFICIENCY #3 - TURBOMACHINERY TESTING

REQUIREMENT: DEVELOP TECHNOLOGY FOR HIGH PRESSURE, HIGH SPEED TURBOPUMPS REQUIRED FOR HIGH PERFORMANCE OTV ENGINES (MID-1990'S) AND ORBIT MANEUVERING SYSTEM ENGINES (POST 2000).

DEFICIENCY:
- NO GOVERNMENT CAPABILITY EXISTS AT REQUIRED PRESSURES AND SPEEDS
- CONTRACTOR CAPABILITY EXISTS ONLY AT ROCKETDYNE

OPTIONS:

OPTION	PRO	CON
• RELY ON RKD FOR TECHNOLOGY AND DEVELOPMENT	• MINIMUM INVESTMENT	• LIMITED GOVERNMENT EXPERTISE • NO CONTRACTOR COMPETITION
• PROVIDE CAPABILITY WITHIN GOVERNMENT	• PROVIDES EXPERTISE THRU "BACKYARD" CAPABILITY • MINOR MOD • AVAILABLE TO ALL CONTRACTORS • SUPPORTS PROGRAM REQUIREMENT WITH TECHNOLOGY	o NONE

RECOMMENDATION: FUND FY 85 LeRC CofF SUBMISSION TO SUPPORT LeRC'S R&T RESPONSIBILITY.

MEDIUM ENGINE THRUST LEVEL

ISSUE #3 - TURBOMACHINERY TESTING

CONSIDERATION OF POTENTIAL FACILITIES

MINOR MODS	MODERATE MODS	MAJOR MODS
AFRPL		
JPL-ETS		
JSC-TTA		
LeRC		
MSFC		
WSTF		
ALRC		
P&W		
RKD		

MEDIUM ENGINE THRUST LEVEL

DEFICIENCY #4 - BEARING TESTER

ISSUE

REQUIREMENTS:

ADV HIGH PRESSURE PUMP-FED N_2O_4/MMH ENGINES REQUIRED FOR FUTURE HIGH PERFORMANCE OTV'S AND FOR ETO VEHICLE ORBIT MANEUVERING SYSTEMS (OMS) BY MID-1990'S

DEFICIENCY:

CAPABILITY TO TEST SMALL, HIGH SPEED N_2O_4 AND MMH BEARINGS DOES NOT EXIST AT ANY GOVERNMENT FACILITY--ONLY AT ROCKETDYNE

OPTIONS:

	PRO	CON
PROVIDE CAPABILITY AT LeRC OR RPL	AVAILABLE TO TEST ALL CONTRACTOR DESIGNS. MINIMUM EXPENSE TO INSTALL	NONE

RECOMMENDATION:

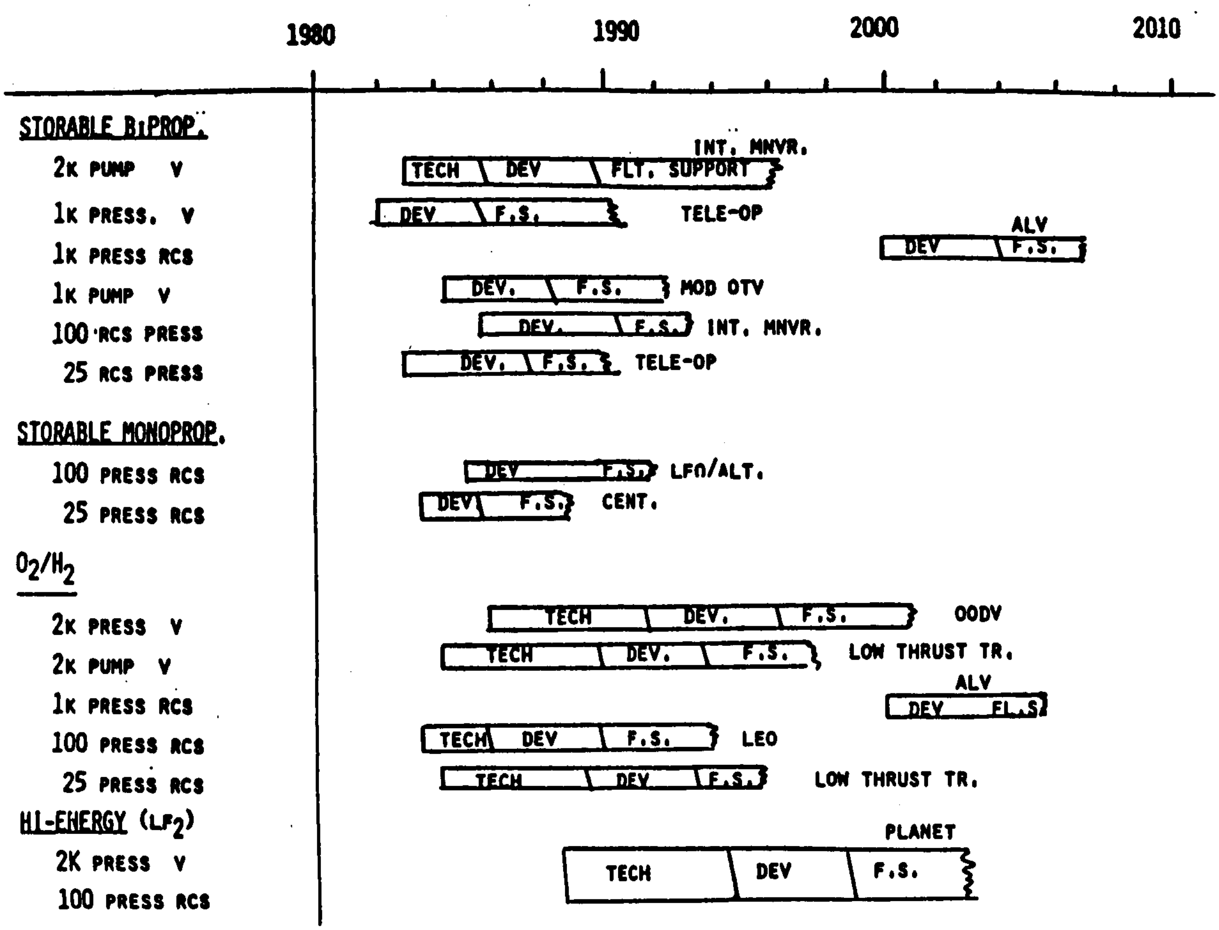
PROVIDE CAPABILITY AT LeRC OR AFRPL FOR BEARING R&T (NEED DATE: 1985)
OAST AND AFRPL DETERMINE BEST LOCATION PRIOR TO JAN. 1984.

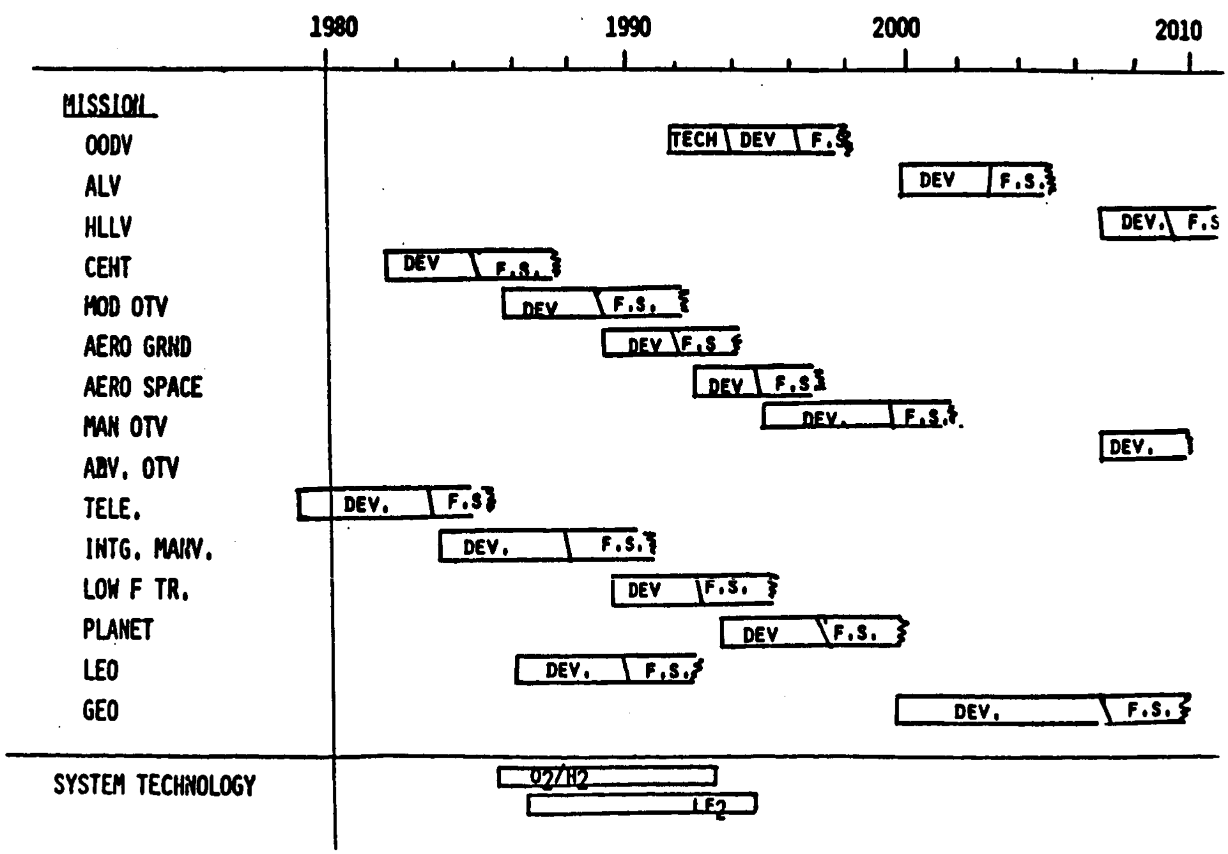
MEDIUM ENGINE THRUST LEVEL

ISSUE #4 - BEARING TESTER

CONSIDERATION OF POTENTIAL FACILITIES

MINOR MODS	MODERATE MODS	MAJOR MODS
LeRC		
AFRPL		
MSFC		
JPL-ETS		
JSC		
WSTF		
ALRC		
RKD		
P&WA		


1980
1990
2000
2010
STORABLE BIPROP.
2K PUMP V
1K PRESS. V
1K PRESS RCS
1K PUMP V
100 RCS PRESS
25 RCS PRESS
INT. MNVR.
TECH
DEV
FLT. SUPPORT
DEV
F.S.
TELE-OP
ALV
DEV
F.S.
DEV.
F.S.
MOD OTV
DEV.
F.S.
INT. MNVR.
DEV.
F.S.
TELE-OP
STORABLE MONOPROP.
100 PRESS RCS
25 PRESS RCS
DEV
F.S.
LEO/ALT.
DEV
F.S.
CENT.
O2/H2
2K PRESS V
2K PUMP V
1K PRESS RCS
100 PRESS RCS
25 PRESS RCS
TECH
DEV.
F.S.
OODV
TECH
DEV.
F.S.
LOW THRUST TR.
ALV
DEV
FL.S.
TECH
DEV
F.S.
LEO
TECH
DEV
F.S.
LOW THRUST TR.
HI-ENERGY (LF2)
2K PRESS V
100 PRESS RCS
PLANET
TECH
DEV
F.S.


1980
1990
2000
2010
MISSION
OODV
ALV
HLLV
CENT
MOD OTV
AERO GRND
AERO SPACE
MAN OTV
ADV. OTV
TELE.
INTG. MANV.
LOW F TR.
PLANET
LEO
GEO
TECH
DEV
F.S
DEV
F.S.
DEV.
F.S
DEV
F.S.
DEV
F.S.
DEV
F.S
DEV
F.S
DEV.
F.S.
DEV.
DEV.
F.S
DEV.
F.S.
DEV
F.S.
DEV
F.S.
DEV.
F.S.
DEV.
F.S.
SYSTEM TECHNOLOGY
O2/H2
LF2

SCHEDULE SUMMARY

- ALL PLANNED VEHICLES REQUIRE ENGINES IN THE 2000 LBS OR LESS CLASS
  - 13 NEW ENGINE DEVELOPMENTS REQUIRED.
- ALL PLANNED NEW VEHICLES (17 TOTAL) REQUIRE NEW SYSTEMS (WHICH INVOLVE SYSTEM LEVEL TESTS) BETWEEN 1983 AND 2010.
- IN 1985 - 1990 TIME PERIOD:
  11 NEW ENGINE DEVELOPMENTS
  8 NEW SYSTEMS
- THESE PROGRAMS WILL RESULT IN SIGNIFICANT FACILITY TEST LOADS.

LOW ENGINE THRUST LEVEL SUMMARY ASSESSMENT

ENGINE CLASS	ASSESSMENT
BIPROP STORABLE 2K & LESS	• NO DEFICIENCY. • MULTIPLE GOVERNMENT & INDUSTRY SITES AVAILABLE. • CURRENTLY UNDERUTILIZED - SEVERAL ALREADY INACTIVE.
MONOPROP (N_2H_4) 100 & LESS	• NO DEFICIENCY. • MULTIPLE GOVERNMENT & INDUSTRY SITES AVAILABLE.
O_2/H_2 2K & LESS	• TWO CONTRACTORS WITH CAPABILITY (AEROJET AND ROCKETDYNE. • INADEQUATE CAPABILITY AT GOVERNMENT SITES.
HIGH ENERGY (LF_2) 2K & LESS	• NO DEFICIENCY. • GOVERNMENT & INDUSTRY SITE AVAILABLE. • CURRENTLY INACTIVE BUT CAPABILITY SHOULD BE RETAINED.

LOW ENGINE THRUST LEVEL

CLASSIFICATION OF GOV'T. FACILITIES

SIGNIFICANT DIFFERENCES IN SUITABILITY FOR LOW THRUST ENGINES DUE TO SIZE, PRIMARY FUNCTION, CENTER ROLE AND FACILITY CHARTER.

- TECHNOLOGY DEVELOPMENT (R&T)
  - LeRC
  - RPL
- FLIGHT PROGRAM SUPPORTING DEVELOPMENT ("BACKYARD")
  - JSC - TTA
  - MSFC
  - JPL *
- GOVERNMENT-OWNED TEST SERVICE SITES
  - JSC - WSTF
  - NSTL
  - AEDC
  - JPL *

* CURRENTLY UNDERUTILIZED FOR PROGRAM SUPPORT AND IS BIDDING FOR USE AS A TEST SERVICE SITE.

LOW ENGINE THRUST LEVEL

RATIONALE FOR EXISTENCE OF SIMILAR GOV'T. FACILITIES

- TECHNOLOGY DEVELOPMENT (R&T)
  - PROVIDE TECHNICALLY COMPETENT PROCUREMENT & MANAGEMENT OF CONTRACTED R&T PROGRAMS.
  - PROVIDE COMPARATIVE EVALUATION OF COMPETING CONCEPTS.
  - ALLOW INNOVATIVE IDEAS TO BE EXPLORED AT LOW COSTS.
  - PERFORM IN-HOUSE R&T.
- FLIGHT PROGRAM SUPPORTING DEVELOPMENT ("BACKYARD")
  - PROVIDE TECHNICALLY COMPETENT PROCUREMENT & MANAGEMENT OF CONTRACTED FLIGHT HARDWARE PROGRAMS.
  - PROVIDE REAL-TIME ENGINEERING INVESTIGATIVE SUPPORT.
  - ASSIST IN DEVELOPMENT & REFINEMENT OF MISSION RULES & CONTINGENCY PROCEDURES.
- GOVERNMENT OWNED TEST SERVICE SITES
  - PREVENTS REQUIRING CONTRACTORS TO HAVE FULL-UP FACILITIES IN ORDER TO BE COMPETITIVE. USE AS REQUIRED TO PREVENT BUILDING OF NEW FACILITIES AT NON-GOVERNMENT SITE.

RECOMMENDATIONS

O_2/H_2 DEFICIENCIES AT GOVERNMENT SITE

- TECHNOLOGY DEVELOPMENT (R&T)

  LeRC

  - IMPLEMENTATION OF APPROVED FY 1984 CoF ($995.K) AT LeRC WILL INCREASE TOTAL CAPABILITY FROM NONE TO ONE HOUR DURATION.
  - RECOMMEND CONTINUE.

  RPL

  - IMPLEMENTATION OF REQUESTED FY 1985 MCP ($5.M) AT RPL TO INCREASE ALTITUDE DURATION CAPABILITY FROM 15 MIN. TO 5 HOURS.
  - RECOMMEND CONSIDER USE OF JPL IN LIEU OF MOD AT RPL (CAPABILITY REQUIRED).

- FLIGHT PROGRAM SUPPORTING DEVELOPMENT ("BACKYARD")

  JSC

  - NO CRYO ENGINE CAPABILITY AT ALL AT TTA - UNDERSUPPORTS JSC CENTER ROLE AS FLIGHT PROGRAM DEVELOPMENT AND MANAGEMENT CENTER.
  - RECOMMEND FY 1985 CoF UPGRADE BY ADDING CAPABILITY FOR SUB-SCALE ENGINES (BELOW 250 LB. THRUST).

  MSFC

  - NO APPROPRIATE ENGINE ALTITUDE CAPABILITY AT MSFC - UNDERSUPPORTS MSFC CENTER ROLE AS FLIGHT PROGRAM DEVELOPMENT AND MANAGEMENT CENTER.
  - RECOMMEND THAT MSFC IDENTIFY BEST METHOD AND INCLUDE IN FY 1986 CoF.

- GOVERNMENT-OWNED TEST SERVICE SITES

  JPL

  - JPL HAS TOTAL CAPABILITY EXCEPT FOR RUN DURATION (3 MINUTE CAPABILITY VS. HOUR(S) REQUIREMENT) DUE TO LIMITED VOLUME HIGH PRESSURE LH_2 TANKAGE.
  - RECOMMEND APPROVE RELOCATION OF SURPLUS LH_2 TANKAGE SYSTEM @ NTS TO INCREASE JPL'S CAPABILITY TO 2 HOURS AND PROVIDE TOTAL LOW THRUST CAPABILITY AT VERY LOW COST ($100.K).

  WSTF, NSTL, MSFC

  - IMPLEMENTATION OF OTV FACILITY DECISION WILL ALSO PROVIDE FULL SCALE LOW THRUST CAPABILITY AT ONE OF THESE SITES.

CONCENTRATE ON FACILITIES AT GOVERNMENT SITES

- SPECIFICALLY: MAJOR, EXPENSIVE, ENGINE & STAGE FACILITIES.
- GOVERNMENT FACILITIE77S (AT GOVERNMENT SITES) AVAILABLE TO ALL USERS
  - CONTRACTOR & GOVERNMENT
  - R&T, R&D, OPERATIONAL PROGRAMS
- GOVERNMENT FACILITIES AT CONTRACTOR SITES GENERALLY LIMITED TO HIS USE
  - ALTERS COMPETITIVE ADVANTAGE
  - REDUCES HEALTH OF INDUSTRY

TEAM RESULTS

- DETERMINED STATUS OF NATIONAL PROPULSION TEST FACILITIES (COMPILED FACILITY DATA PACKAGE).
- DEVELOPED BASELINE SPACE TRANSPORTATION VEHICLE MODEL.
- ESTABLISHED TEST REQUIREMENTS FOR THE GENERIC PROPULSION SYSTEMS IN THE VEHICLE MODEL.
- DEVELOPED INTEGRATED FACILITY PLAN (SHORT/LONG TERM).
- IDENTIFIED SURPLUS EQUIPMENT AVAILABLE FOR UTILIZATION AT OTHER FACILITIES.
- PROVIDED ASSESSMENT OF PROPULSION INDUSTRY HEALTH.
- ENHANCED COMMUNICATION CHANNELS BETWEEN LIQUID ROCKET TEST ORGANIZATIONS.

RECOMMENDATIONS:

- HQS. PROGRAM OFFICES PROVIDE MEANS OF DEVELOPING AND MAINTAINING INTEGRATED "TOP LEVEL PLANS".
  - REQUIRES TOP MANAGEMENT INVOLVEMENT.
  - REQUIRES DEDICATED LEAD STAFF.
  - MUST BE DEVELOPED BY THOSE RESPONSIBLE FOR MANAGING THE EXECUTION OF THE PLAN.
  - OFTEN REQUIRES INVOLVEMENT AND INTERACTION OF MORE THAN ONE HQS. PROGRAM OFFICE/SOMETIMES DOD.
- PLANS SHOULD INCLUDE:
  - NATIONAL MISSION REQUIREMENTS.
  - PROGRAM OBJECTIVES, APPROACHES, MAJOR MILESTONE, ETC.
  - CENTER RESPONSIBILITIES.
  - TECHNOLOGY REQUIREMENTS.
  - FACILITY REQUIREMENTS.
- INTEGRATED FACILITY PLANNING
  - DRIVEN AND SUPPORTED BY INPUTS FROM PROGRAM PLANS.
  - MUST INCLUDE PROGRAM MANAGEMENT AND FACILITY MANAGEMENT.
  - CONSIDERATION OF FACILITY OPTIONS/BY TRADE-OFF STUDIES.
  - EARLY R&D FUNDS NEEDED TO BE EFFECTIVE.
  - CENTRALLY (HQS) CONTROLLED REVIEW OF TRADE-OFF STUDY RESULTS AND CONCLUSIONS.

TEAM OBSERVATIONS OF NASA PLANNING

- A GENERALLY ACCEPTED TOP-LEVEL SPACE TRANSPORTATION SYSTEM PLAN DOES NOT EXIST; WOULD INCLUDE:
  - MISSION OBJECTIVES AND REQUIREMENTS
    - MAJOR EXCEPTION PERMANENT MAN OCCUPANY OF SPACE.
  - PROGRAM PLANS/MAJOR MILESTONES
    - PLANS FOR APPROVAL OF ONGOING PROGRAMS ARE INADEQUATE.
    - FUTURE PROGRAM PLANS ARE NEAR NONEXISTENT.
- THERE IS NO CLEAR ORGANIZATION MECHANISM TO DEVELOP AND VALIDATE PLANS
  - AD HOC PROPULSION FACILITY TEAM - REQUIRED TO DEVELOP PLAN FOR PROPULSION PROGRAM.
  - REVIEW AND CONCURRENCE BY TOP NASA AND AF MANAGEMENT INCOMPLETE.
- GOOD FACILITY PLANNING AND APPROVAL
  - REQUIRES ADEQUATE AGENCY/CENTER MISSION OBJECTIVES AND PROGRAM PLANS.

CONCLUSIONS

- ADEQUATE FACILITIES ARE AVAILABLE AT BOTH THE GOVERNMENT AND CONTRACTOR SITES TO SATISFY THE TESTING NEEDS OF SMALL ENGINES (SPACECRAFT ATTITUDE CONTROL AND MANEUVERING) FOR FORESEEABLE FUTURE.

  ONE EXCEPTION IS DEFICIENCY IN LOX/LH_2 TEST CAPABILITY.

- MODIFICATIONS AND ADDITIONS TO EXISTING FACILITIES ARE REQUIRED TO ADEQUATELY SUPPORT THE TEST REQUIREMENTS FOR DEVELOPING AND OPERATING HIGH PERFORMANCE MEDIUM THRUST ENGINES FOR FUTURE SPACE VEHICLES (OTV, ETC.).

  THERE ARE SPECIFIC NEEDS FOR IMPROVED COMPONENT TEST FACILITIES, AND ENGINE/ PROPULSION SYSTEM ALTITUDE TEST FACILITIES.

- THE PRESENT THREE ACTIVE TEST STANDS (TWO AT NSTL AND ONE AT ROCKETDYNE, SSFL) MAY NOT BE ADEQUATE OR OPTIMUM TO SUPPORT ALL THE TEST NEEDS OF THE SSME AND SSME DERIVATIVE ENGINE PROGRAMS. OPTIONS BEING CONSIDERED FOR TEST STAND MODIFICATIONS AT NSTL AND MSFC COULD SATISFY THIS NEED.

- PRESENT ACTIVE OR STANDBY LARGE ENGINE TEST FACILITIES ARE NOT CONFIGURED TO SATISFY NEEDS OF AIR FORCE "ORBIT-ON-DEMAND" VEHICLE.

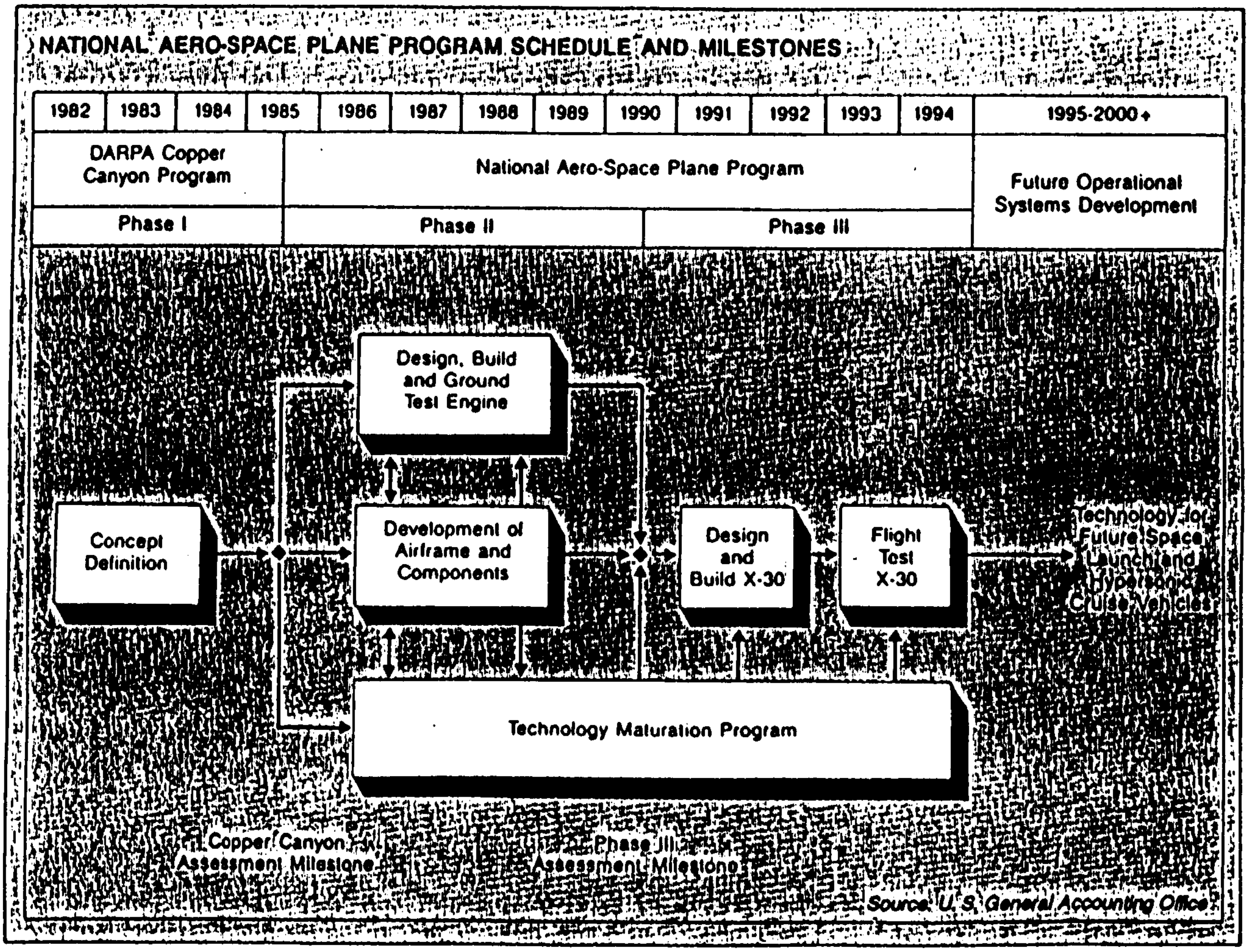
- THERE IS IMMEDIATE NEED FOR IMPROVEMENTS AND ADDITIONS TO SEVERAL CENTER "BACKYARD" FACILITIES TO SUPPORT TECHNOLOGY ADVANCEMENT TESTING, AND SHUTTLE DEVELOPMENT AND OPERATIONS PROGRAMS SUPPORT.

- THERE ARE A LARGE NUMBER OF MEDIUM AND LARGE THRUST ENGINE AND SYSTEM TEST STANDS NOT IN ACTIVE USE AT BOTH GOVERNMENT AND CONTRACTOR SITES. MANY ARE BEING MAINTAINED; A FEW NOT. SOME SHOULD CONTINUE TO BE MAINTAINED BECAUSE OF LARGE INVESTMENT COST AND UNKNOWN FUTURE; OTHERS KEPT FOR SPARE PARTS; AND OTHER HAVE NO POTENTIAL USE AND SHOULD BE MADE AVAILABLE FOR DISPOSITION.

CHANGES

- NATIONAL AEROSPACE PLANE
- ADVANCED LAUNCH SYSTEM
- SPACE EXPLORATION INITIATIVE

NATIONAL AERO-SPACE PLANE



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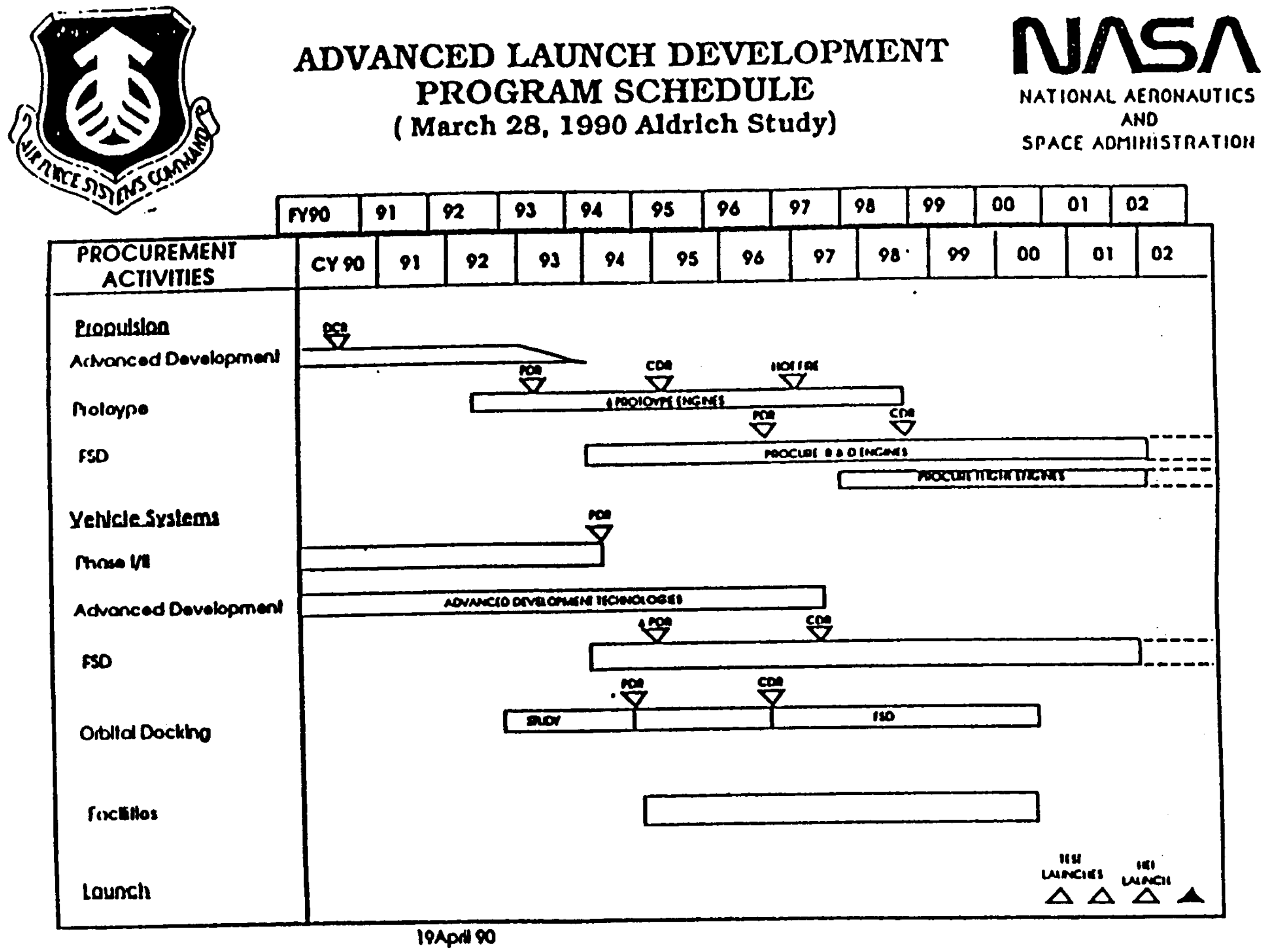
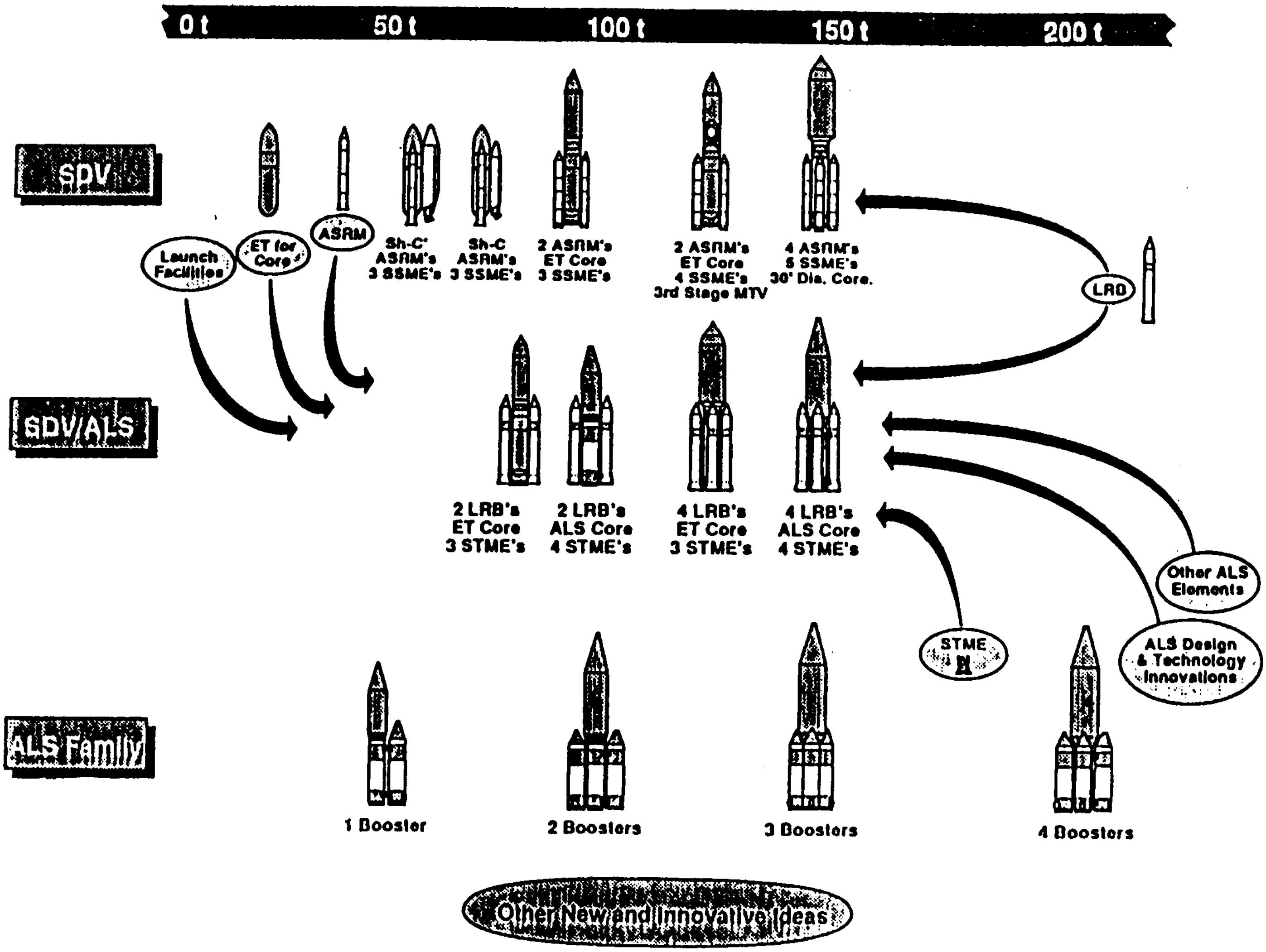
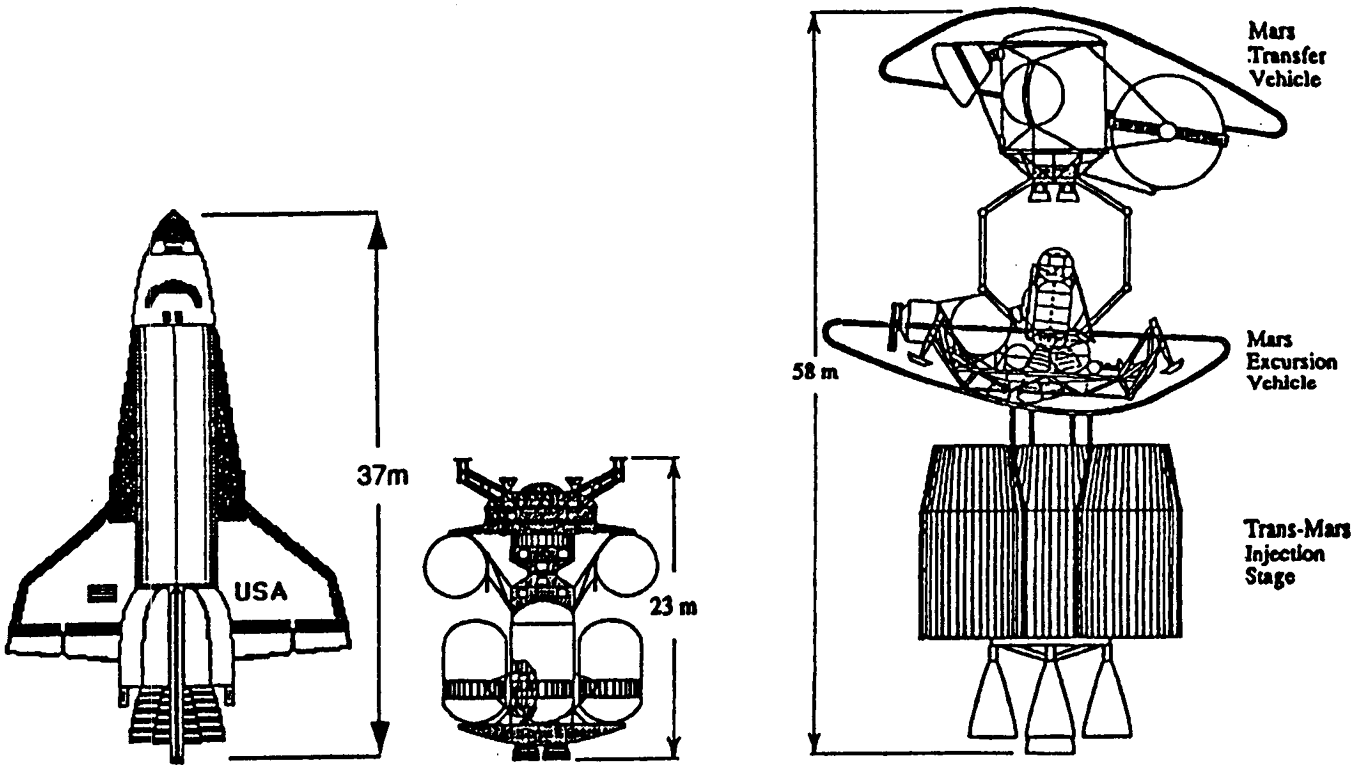
ADVANCED LAUNCH SYSTEM



SEI Candidate Unmanned Vehicles



SHUTTLE AND LUNAR/MARS TRANSFER VEHICLES



Space Shuttle
Mass = 92 metric tons
(Payload = 22 metric tons)

Lunar Transportation System
Mass = 200 metric tons

Mars Transportation System
Mass = 800 metric tons

LRB/SDV OPTIONS

BOOSTER
- EXP SH NOZ SSME

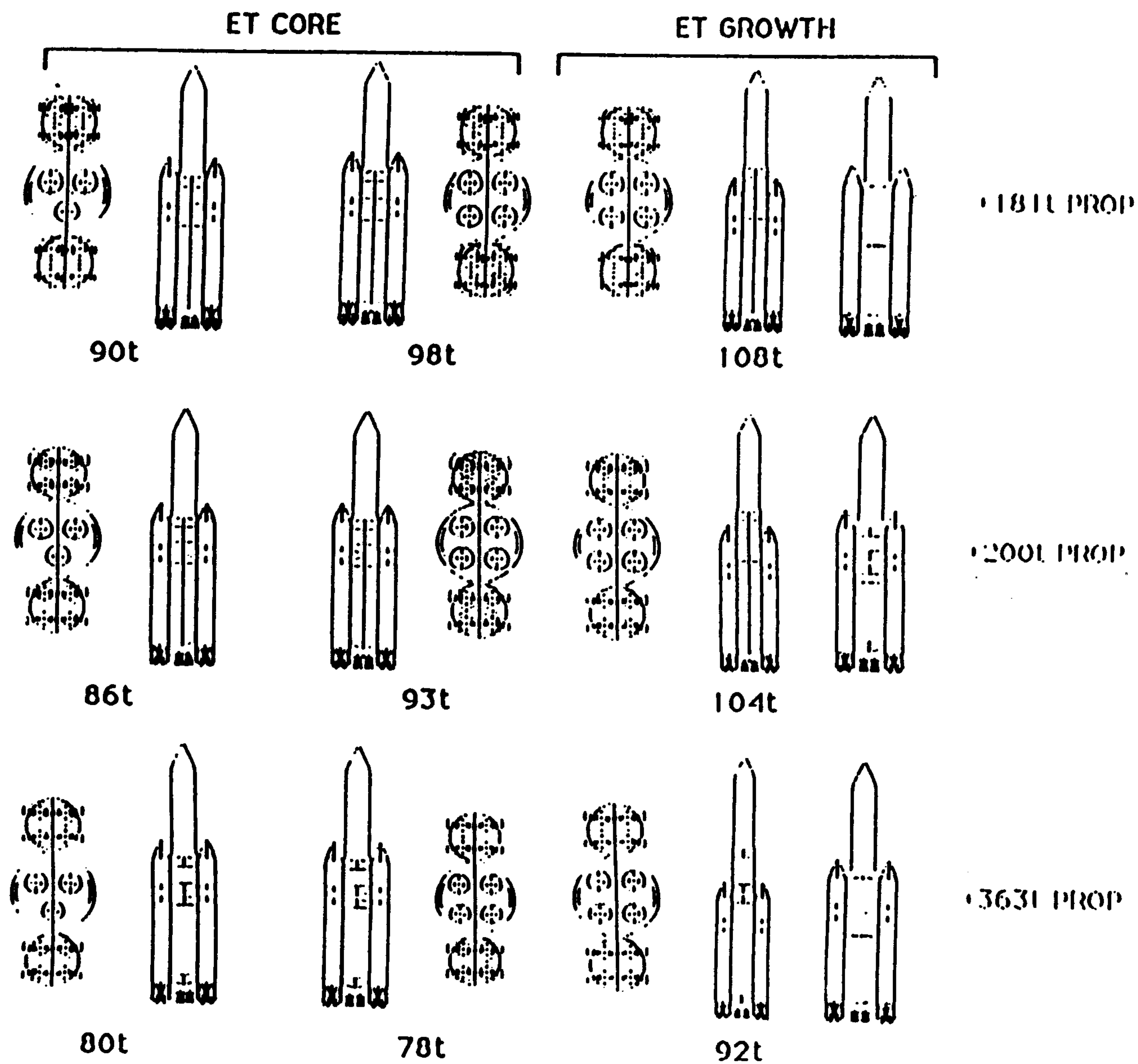
CORE
- EXP SSME

BOOSTER
- SH NOZ STE

CORE
- EXP SSME

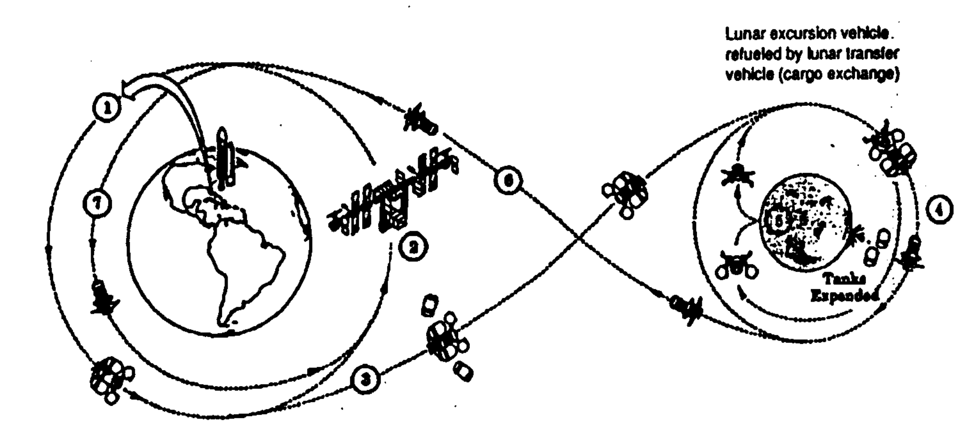
BOOSTER
- SH NOZ STE

CORE
- STE



NASA

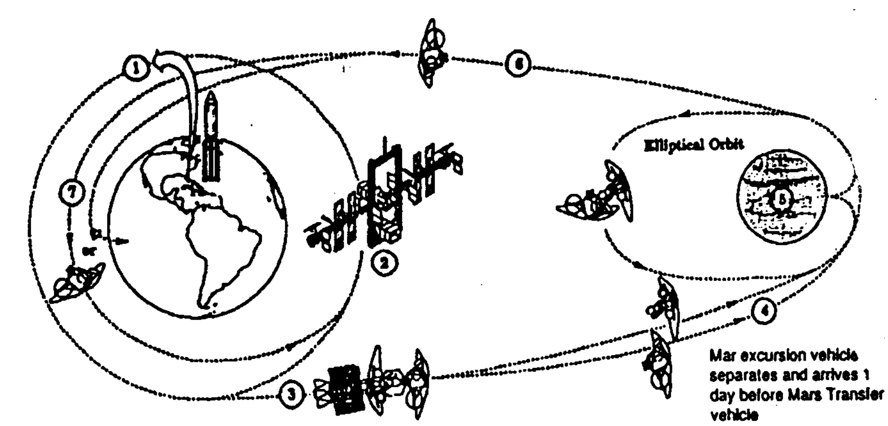
LUNAR MISSION PROFILE



1. Payload Delivered to Space Station Freedom
2. Lunar Transfer Vehicle Mated with Payload at Freedom
3. Trans-Lunar Phase with Lunar Transfer Vehicle
4. Lunar Transfer Vehicle Rendezvous with Lunar Excursion Vehicle from Moon
5. Excursion Vehicle Returns to Moon with Payload
6. Trans-Earth Phase with Transfer Vehicle
7. Transfer Vehicle Aerobrake Maneuver and Return to Freedom

NASA

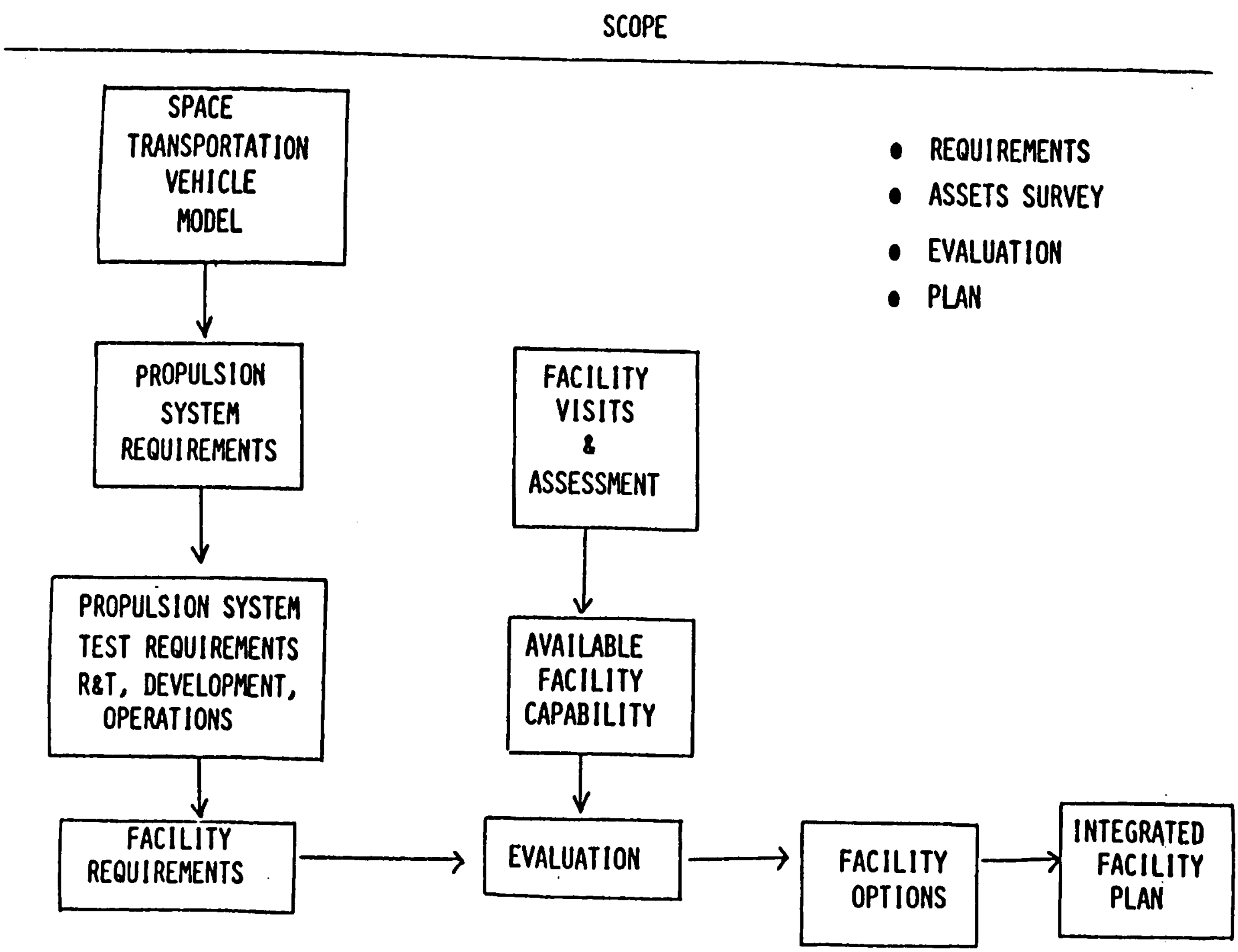
MARS MISSION PROFILE



1. Payload Delivered to Space Station Freedom
2. Mars Transfer Vehicle Mated with Payload at Freedom
3. Trans-Mars Phase with Lunar Transfer Vehicle
4. Mars Transfer Vehicle Remains in Mars Orbit; Mars Excursion Vehicle Descends to Surface
5. Excursion Vehicle to/from Mars Surface
6. Trans-Earth Phase with Transfer Vehicle
7. Transfer Vehicle Aerobrake Maneuver and Return

LIFE CYCLE COST BASED DECISIONS RATIONALE

- FACILITY ASSESSMENT TEAM CHARTER
- FUTURE PROGRAM REQUIREMENTS
- CAPITAL INVESTMENT <u>VS</u> O&M COSTS



LIFE CYCLE COST

THE TOTAL COST OF A FACILITY - INCLUDING THE INITIAL CAPITAL INVESTMENT AND ALL OPERATING AND MAINTENANCE COSTS FOR THE LIFE OF THE PROGRAM.

RECOMMENDATION

- ESTABLISH A PROPULSION TEST WORKING GROUP WITHIN NASA - SEPARATE PANEL OF PROPULSION WORKING GROUP.
- DEVELOP A FINITE MODEL FOR COST ANALYSIS OF ALTERNATE SITES FOR PROPULSION TEST
- SUBJECT ALL CANDIDATE SITES TO INDEPENDENT ANALYSIS - NASA HEADQUARTERS LEAD
- PROGRAM DECISION BASED ON INDEPENDENT ASSESSMENT

APPLICABILITY

- NEW PROGRAM STARTS
- MAJOR PROGRAMMATIC CHANGES

NASA
Stennis Space Center

N91-28249
PRESENTATION 4.2.13

SPACE TRANSPORTATION

PROPULSION SYSTEMS

SYMPOSIUM

E.G. Woods
NASA/SSC

June 25-29, 1990

NASA
Stennis Space Center

Space Transportation Propulsion Systems

SYMPOSIUM

Development, Manufacturing & Certification

PANEL

Flight Certification

TOPIC

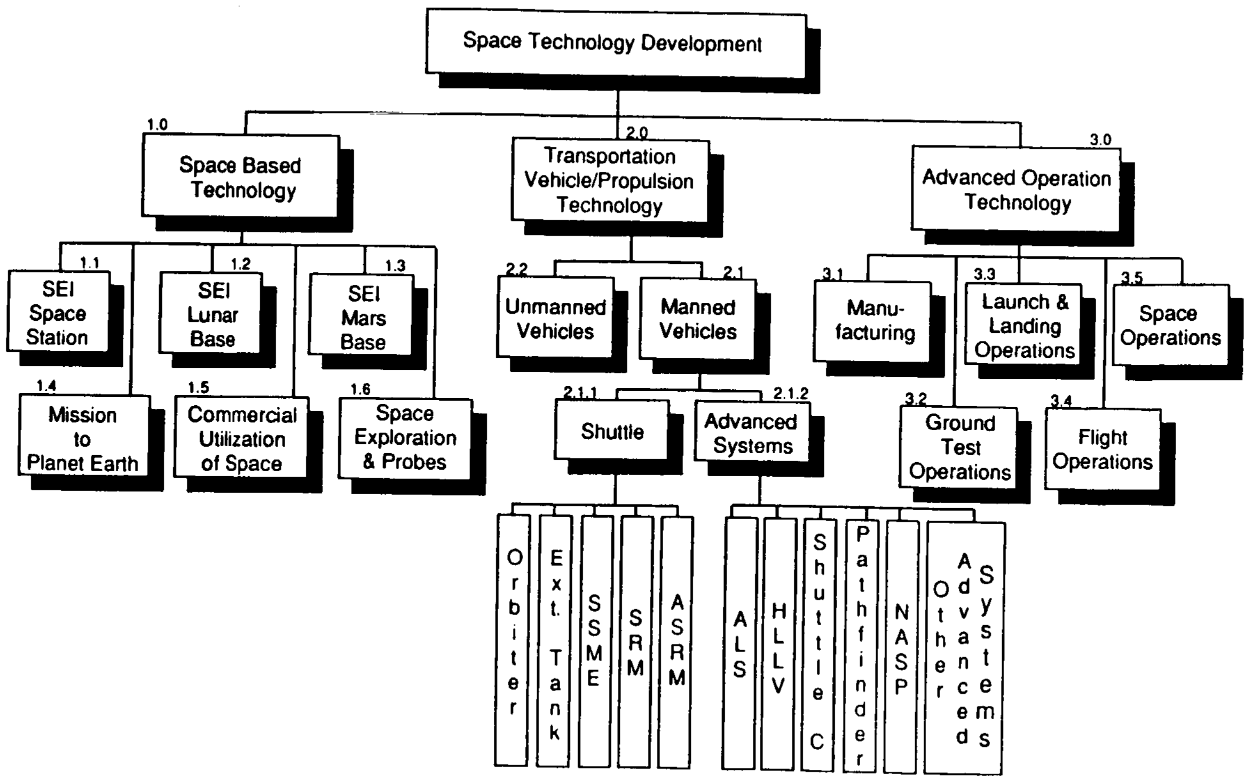
Infusion of Instrumentation Technology (Engine Plume Diagnostics)
Into Operational Test Programs

SUBJECT

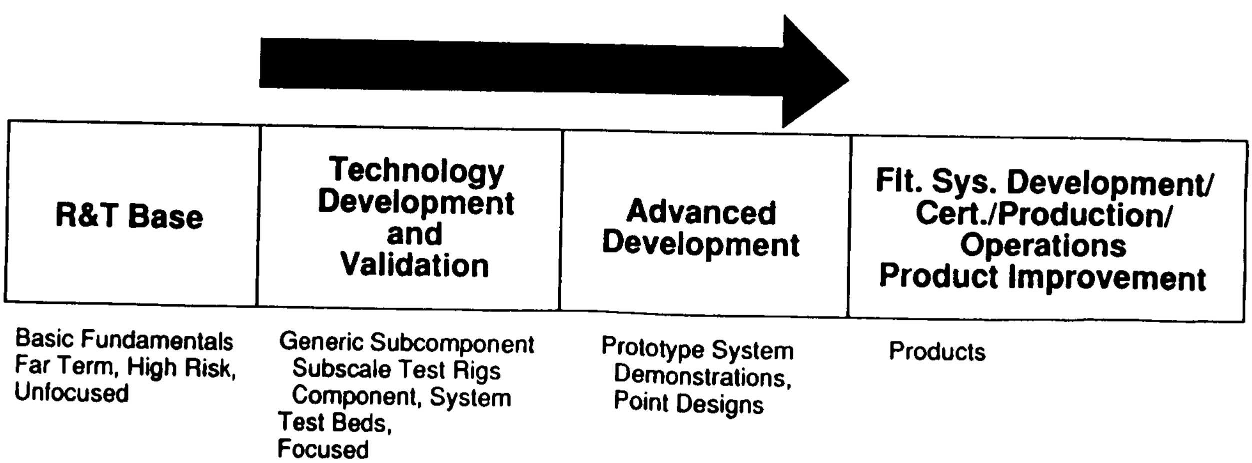
E.G. Woods
Topic Coordinator
NASA/SSC

June 25-29, 1990

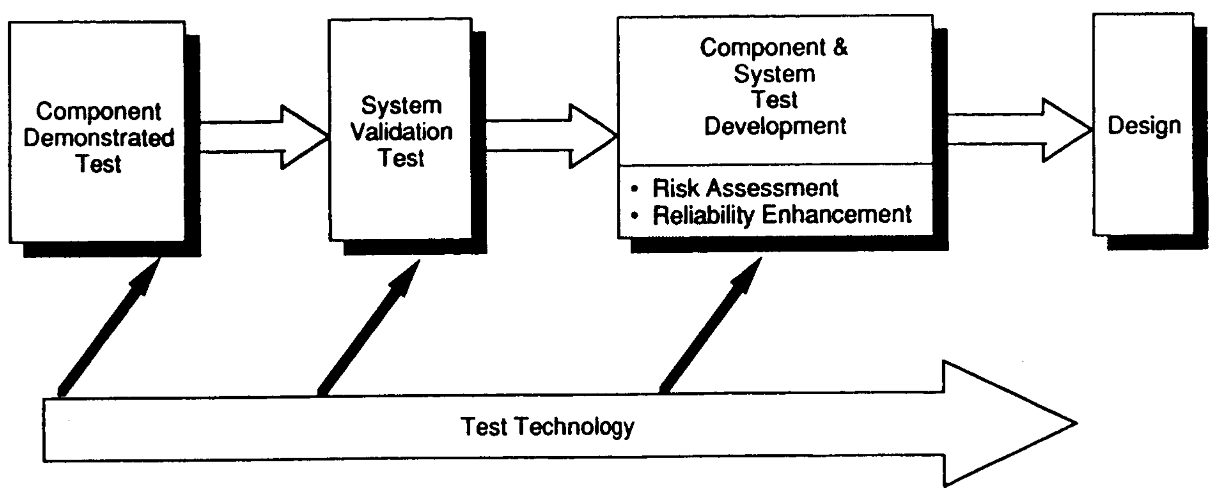
HIERARCHY OF CIVIL SPACE TECHNOLOGY PROGRAM



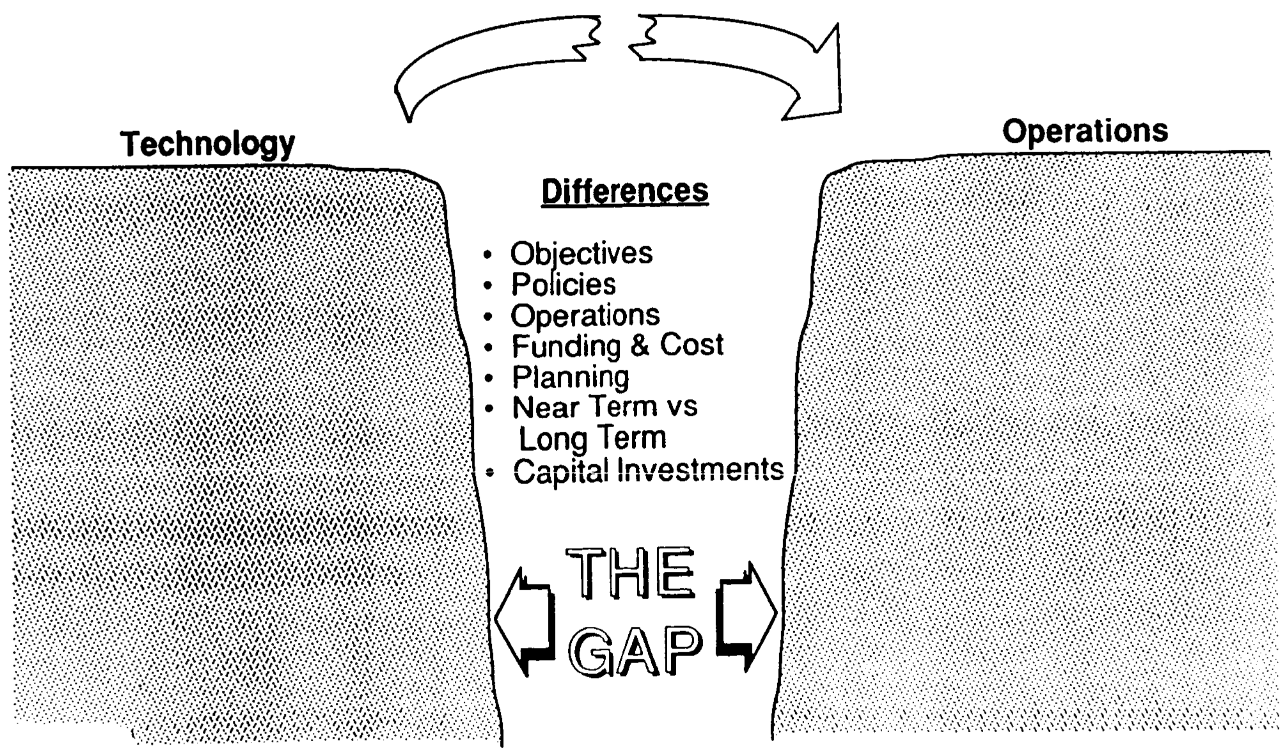
EVOLUTION OF TECHNOLOGY DEVELOPMENT



TECHNOLOGY VALIDATION PROCESS



POTENTIAL IMPACTS



IMPACTS OF TECHNOLOGY INFUSION INTO FLIGHT CERTIFICATIONS

Capability	vs	Obsolescence
Automated	vs	Labor intensive
Timely	vs	Delays
Effective	vs	Inefficiency
Synthesis	vs	Repeated duplication of efforts
Quality	vs	Poor simulation
Knowledge and confidence	vs	Loss of expertise

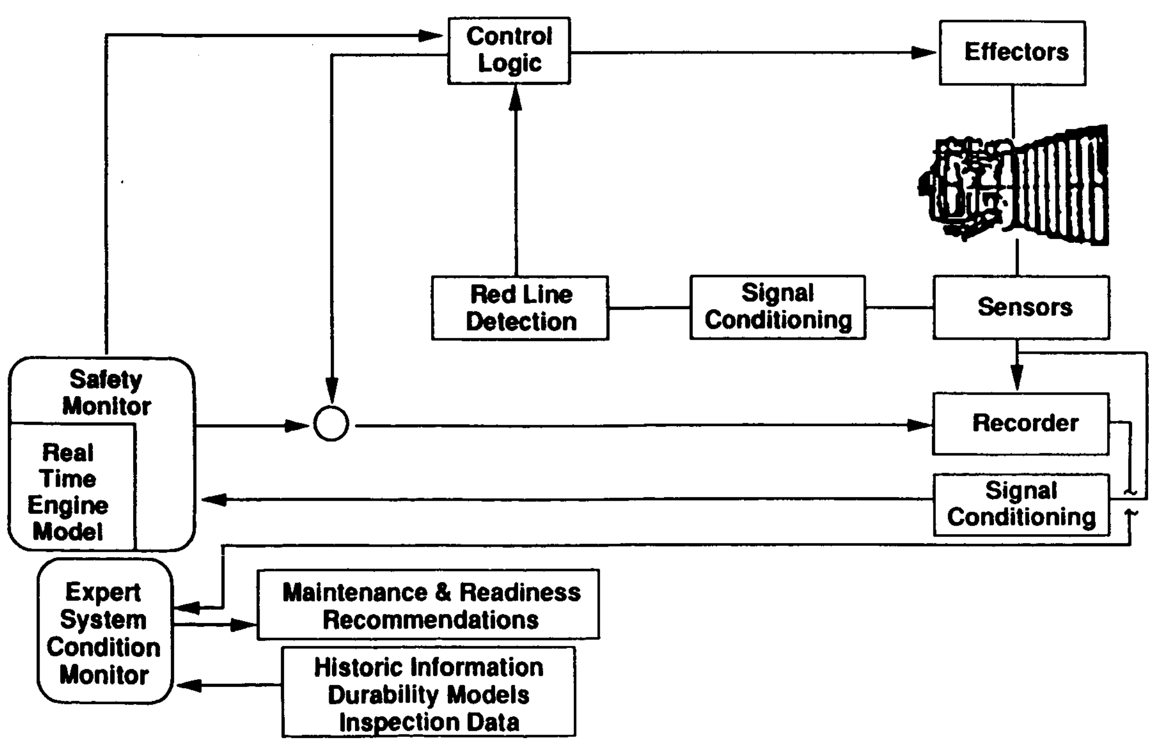
POTENTIAL SOLUTIONS

- Proceed programs with technology development and continue technology options up to critical design review
- Early and continued communications between technology and operational elements
- Adequate, stable funding of technology problems
- Schedule and plan technology demonstration "windows" into program operations
- Cross-train personnel in technology and operational policies and procedures
- Pre-planned product improvements at three year cycles
- Plan for technology improvements for Test-Launch-Landing, and Ground Support systems, as well as, vehicle transportation systems
- Identify blind spots in operations
- Establish "ownership" of technology enhancements by operations personnel

EXAMPLES OF CURRENT TECHNOLOGY INFUSION INTO FLIGHT CERTIFICATION

SHUTTLE THERMAL IMAGER & ICE DETECTION SYSTEM	→	SPACE SHUTTLE
ENGINE PLUME DIAGNOSTICS	→	SPACE SHUTTLE MAIN ENGINE TEST PROGRAM
SMART HYDROGEN SENSOR & FUGITIVE GAS DETECTION SYSTEM	→	SPACE SHUTTLE MAIN ENGINE TEST PROGRAM

OAET - CSTI HEALTH MONITORING & CONTROLS



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Stennis Space Center

CHALLENGES FOR FUTURE SPACE VEHICLE PROPULSION SYSTEM PROGRAMS

- Reduce Cost ⇩
- Improve Reliability ⇧
- Improve Safety ⇧
- Improve Performance ⇧

N91-28250

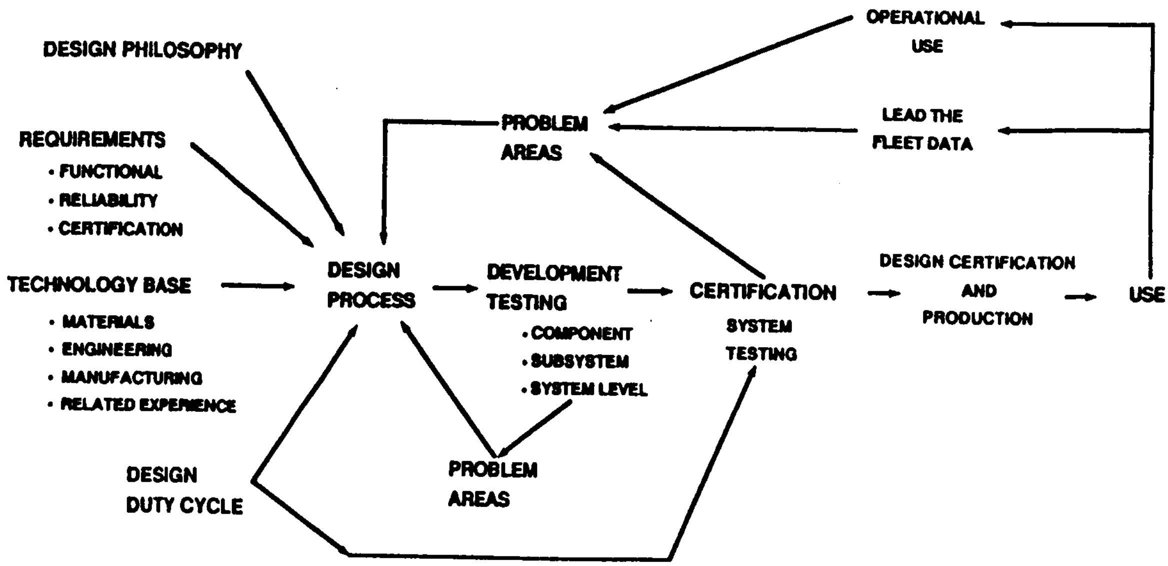
LIQUID ROCKET ENGINE FLIGHT CERTIFICATION

STEVE RICHARDS
PROPULSION LABORATORY
MARSHALL SPACE FLIGHT CENTER

FLIGHT CERTIFICATION DEFINITION

THE METHODOLOGY AND PROCESS BY WHICH WE GAIN THE CONFIDENCE TO FLY INCLUDING:

- DESIGN METHODOLOGY
- ANALYSIS
- COMPONENT TEST
- SUBSYSTEM TEST
- SYSTEM DEVELOPMENT TEST
- SYSTEM CERTIFICATION TEST



CERTIFICATION ISSUES

- NO INDUSTRY/GOVERNMENT WIDE RECOGNIZED RULES/REQUIREMENTS
  - RULES AND REQUIREMENTS SET BY INDIVIDUAL AGENCIES AND BY INDIVIDUAL PROGRAMS WITHIN AGENCIES
  - PROCESSES ARE HISTORICALLY BASED AND HEURISTIC
- HEAVILY DEPENDENT ON EXPENSIVE AND TIME CONSUMING TEST PROGRAMS
- NO QUANTIFICATION OF ENGINE RELIABILITY
- LITTLE CERTIFICATION AT COMPONENT LEVEL
- NO EXISTING "SPACE BASED" ENGINE CRITERIA

ENGINE CHARACTERISTICS

ENGINE	THRUST (LBF)	ISP (SEC)	WEIGHT (LB)	THRUST TO WEIGHT	MIXTURE RATIO (O/F)	CHAMBER PRESSURE (PSIA)	FLT REUSE	THROTTLE	O2/H2	O2/HC	AIR/HC	N2O4/HDZ	GAS GEN	EXPANDER	STAGE COM
SSME	488,800	452.9	7,004	69.79	6.026	3,126	X	X	X						X
F-1	1,748,200	304.1	18,616	93.91	2.27	982				X			X		
J-2	230,000	425.0	3,454	66.59	5.5	780		*	X				X		
RL-10	16,500	444.4	305	54.10	5.0#	465		*	X					X	
LR87	529,000	298.0	4,530	116.78	1.905	827						X	X		
LR91	103,320	314.0	1,260	82.00	1.770	827						X	X		
JET+ (TYP)	15,000	++	2,500	6.00	N/A	**400	X	X			X				

* J-2 THROTTLED MIXTURE RATIO BETWEEN 4.5 TO 5.5
RL-10 THROTTLED MIXTURE RATIO BETWEEN 4.3 TO 5.7
** BURNER PRESSURE
\# MIXTURE RATIO IS 6.0 FOR SHUTTLE CENTAUR
\+ TYPICAL FIGHTER ENGINE
++ EQUILVALENT Isp : CRUISE POWER 64 SEC AIR AND FUEL, 5100 SEC FUEL ONLY
AUGMENTOR POWER 99 SEC AIR AND FUEL, 1700 SEC FUEL ONLY

ENGINE DESIGN AND MISSION REQUIREMENTS

ENGINE	DESIGN STARTS	DESIGN LIFE	MISSIONS	MISSION STARTS	MISSION NOM TIME
SSME	55	27,000 S	55	1	520 S
F-1	20	2,250 S	1	1	165 S
J-2	30	3,750 S	1	1	380 S
				2*	150 S*
					350 S*
RL-10	20	4,500 S	1	2	700 S
LR87	12	1,980 S	1	1	165 S
LR91	12	2,700 S	1	1	225 S
JET**					
HOT PARTS	1,600	2,200 H	1,500	1	2 H
COLD PARTS	3,200	4,400 H	3,000	1	2 H

* S-IVB Stage (First Burn & Restart)
** TYPICAL FIGHTER ENGINE

STRUCTURAL DESIGN CRITERIA

DESIGN CRITERIA	SSME	F-1	J-2	JET	RL-10	LR87	LR91
<u>DESIGN</u> <u>LOADS</u>							
o WORST CASE	X	X	X	X	X	X	X
o STATIC CONTRIBUTORS	X	X	X	X	X	X	X
- 3 SIGMA LEVEL	X	X	X	X			
- 2 SIGMA LEVEL					X		
o DYNAMIC CONTRIBUTORS	X			X	X	X	X
<u>MATERIAL</u> <u>PROPERTIES</u>							
o MINIMUM	X	X	X	X	X	X	X
<u>GEOMETRY</u>							
o MINIMUM	X	X	X	X	X	X	X

STRUCTURAL DESIGN FACTORS OF SAFETY

DESIGN FACTOR	SSME	F-1	J-2	JET	RL-10	LR87	LR91
ULTIMATE STRENGTH	1.4	1.5	1.5	1.5	1.5	1.4	1.4
YIELD STRENGTH	1.1	1.1	1.1	*	*	1.0	1.0
PROOF REQUIREMENT	1.2	1.2	1.2	*	1.2	1.2	1.2
LOW CYCLE FATIGUE	4 X DSL	*	*	2 X DSL	*	*	*
HIGH CYCLE FATIGUE	10 X DSL	*	*	(1)	*	*	*

NOTES: (*) NO SPECIFICATION REQUIREMENT
DSL = DESIGN SERVICE LIFE
(1) JET DESIGNED = 10 MILLION CYCLES FOR FERROUS ALLOY PARTS
= 30 MILLION CYCLES FOR NON-FEROUS ALLOY PARTS

COMPONENT/SUBSYSTEM TESTING

TEST PERFORMED	SSME	F-1	J-2	JET	RL-10	LR87	LR91
COMPONENT STRUCTURAL TESTS	(1)	(1)		(1)	(2)	(2)	(2)
COMPONENT DYNAMIC TESTS	X	X	X	X	NI	X	X
COMPONENT DURABILITY TESTS	(2)			X	X	NI	NI
COMPONENT PROOF PRESSURE TESTS	X	(2)	(2)	X	X	X	X
COMPONENT SPIN TESTS	(2)			X			
COMPONENT TESTING DURING DEVELOPMENT	X	X	X	X	X	X	X
SUBSYSTEM OPERATIONAL VERIFICATION	X	X	X	X	X	X	X
SUBSYSTEM TESTING DURING DEVELOPMENT	X	X	X	X	X	X	X

NOTE: (1) ALL MAJOR COMPONENTS
(2) CRITICAL COMPONENTS
NI = NO INFORMATION

SYSTEM LEVEL DEVELOPMENT TESTS

TEST PERFORMED	SSME	F-1	J-2	JET	RL-10	LR87	LR91
SYSTEM LEVEL DYNAMIC TESTS		X	X	X	X	X	X
SYSTEM LEVEL DURABILITY TESTS	X	X	X	X	X	X	X
SYSTEM LEVEL THERMAL TESTS	(4)	X	X	X		X	X
SYSTEM LEVEL OPERATIONAL VERIFICATION	X	X	X	X	X	X	X
SYSTEM LEVEL MARGIN TESTS	X	X	X	X	X	X	X
OTHER SYSTEM LEVEL TESTS		(3)		(1)		(2)	(2)
SYSTEM LEVEL TESTING PRIOR TO FLIGHT	X	X	X	X	X	X	X

NOTE: (1) CAPABILITY OF ENGINE TO INJEST OBJECTS AND TO CONTAIN FAILURES ARE ALSO VERIFIED
(2) ENGINE STORAGE CAPABILITY IS EVALUATED
(3) THERMAL PROTECTION SYSTEM THERMAL TEST
(4) PART OF VEHICLE SYSTEM TESTS

CERTIFICATION/QUALIFICATION TESTS

TEST ATTRIBUTE	SSME	F-1	J-2	JET	RL-10	LR87	LR91
NUMBER OF TESTS REQUIRED	10	20	30	N/A	20	12	12
TOTAL TEST DURATION REQ.	5000 S	2250 S	3750 S	150 H	4500 S	1992 S	2532 S
NUMBER OF SAMPLES	2	1	2	1	3	1	1
HARDWARE CHANGES ALLOWED	YES	YES	YES	YES	NO	YES	YES
FLEETLEADER CONCEPT USED	YES	NO	NO	YES	NO	NO	NO
OVERSTRESS TESTING	YES	NO	NO	NO	YES	NO	NO

OBSERVATIONS

- ROCKET ENGINE AND DEVELOPMENT AND CERTIFICATION PROCESS IS "DESIGN-TEST-FAIL-FIX" UNTIL SYSTEM IS CONSIDERED MATURE ENOUGH TO FLY
- FORMAL CERTIFICATION TEST PROGRAMS ARE AIMED AT DEMONSTRATING DESIGN MATURITY AND OPERATIONAL READINESS
- CONFIDENCE TO FLY IS GAINED THROUGH:
  - APPLICATION OF HEURISTIC RULES
  - HISTORICALLY BASED FACTORS OF SAFETY IN DESIGN
  - ACCEPTED DESIGN PRACTICES
  - DEVELOPMENT TEST OF COMPONENTS, SUBSYSTEMS AND SYSTEM (NOT REQUIRED TO BE FINAL FLIGHT DESIGN)
  - AS WELL AS FINAL FLIGHT DESIGN IN CERTIFICATION TEST SERIES
- CERTIFICATION TEST SERIES TYPICALLY SUPPORTS A DEMONSTRATED RELIABILITY ON THE ORDER OF 70 TO 80% (AT LOW CONFIDENCE) FOR FLIGHT USE

WORKING LIST OF IDEAL CHARACTERISTICS FOR SPACE BASING (PRELIMINARY)

- NO LEAKAGE ALLOWED
- NO ENGINE PURGES
- NO ENGINE PRECONDITIONING
- NO EXTERNAL FLUIDS OTHER THAN PROPELLANTS
- NO MATERIAL DEGRADATION DUE TO SPACE EXPOSURE
- NO "HANDS-ON" INSPECTION OF THE HARDWARE PRE/POST FIRING
- VERIFIABLE HEALTH MONITORING CAPABILITY AND RESPONSE
- REMOVABLE AND MAINTAINABLE AT SOME LEVEL ON-ORBIT
- HIGH RELIABILITY
- NO SCHEDULED MAINTENANCE
- RECONFIGURATION STRATEGY DURING FIRING IF NECESSARY

CHALLENGE: WHAT WILL BE REQUIRED TO CERTIFY A REUSABLE, SPACE-BASED ENGINE AND PROPULSION SYSTEM FOR FLIGHT USE?

CERTIFICATION OBJECTIVES

- ESTABLISH A METHODOLOGY WHICH
  - DEFINES JUSTIFIABLE REQUIREMENTS
  - QUANTIFIES ENGINE RELIABILITY
  - MINIMIZES REQUIRED TESTING
- VERIFY THE METHODOLOGY BY EXPERIMENT
- ESTABLISH REQUIRMENTS FOR SPACE BASE ENGINE CERTIFICATION
- APPLY THE METHODOLOGY TO ENGINES FOR SEI

PROPOSED ACTIONS/PROGRAMS

- PERFORM A SURVEY OF METHODS, TOOLS, AND DATA APPLICABLE TO CERTIFICATION
- DEFINE A NEW METHODOLOGY FOR CERTIFICATION
- DEVELOP TOOLS TO SUPPORT METHODOLOGY
- VERIFY TOOLS AND METHODOLOGY BY TEST
- DEFINE REQUIREMENTS FOR SPACE BASED CERTIFICATION

DEVELOPMENT MANUFACTURING & CERTIFICATION APPLICABLE ACTIVITIES

- JET PROPULSION LABORATORY CERTIFICATION METHODOLOGY STUDIES
- LEWIS RESEARCH CENTER CERTIFICATION METHODOLOGY DEVELOPMENT
- SAE - G11 RC LIQUID ROCKET ENGINE CERTIFICATION SUBCOMMITTEE OF THE RELIABILITY, MAINTAINABILITY, AND SUPPORTABILITY COMMITTEE

PRESENTATION 4.2.15

"TEST VS. SIMULATION"

N91-28251

BY

CHARLES C. WOOD

JUNE 27, 1990

Rockwell International

Space Transportation Systems Division

Huntsville Operations

INTRODUCTION

OVERVIEW: SPACE VEHICLES REQUIRE SIMULATION CAPABILITIES

- PROPULSION
- STRUCTURES
- LOADS
- AERODYNAMICS
- CONTROL
- OTHER

PRESENTATION SCOPE: PROPULSION SIMULATION AND PROPULSION SYSTEM TESTING

PRESENTATION OBJECTIVE/APPROACH: THROUGH ASSESSMENT OF SIMULATION CAPABILITIES AND REVIEW OF CONTRIBUTIONS FROM PROPULSION SYSTEM TEST PROGRAMS ILLUSTRATE THAT BOTH SIMULATION AND PROPULSION SYSTEM TESTING EACH HAVE IMPORTANT ROLES IN SPACE VEHICLE DEVELOPMENT.

SIMULATION CAPABILITY ASSESSMENT

(NO PROPULSION SYSTEM TEST)

EVALUATION CRITERIA	VEHICLE FLIGHT CATASTROPHE RISK	MISSION LOSS RISK	LAUNCH DELAY RISK	LAUNCH COMPLEX RISK	SYSTEM TEST PROVIDES DATA	REMAINING RISK AFTER 20 SECOND FRF
"Wrong" Component Verification	Very High	Very High	High	High	Yes	Low
Instrumentation Failure	Moderate	Moderate	Very High	Very High	Yes	Minor
Hazardous Fluid Leakage	High	High	Very High	Very High	Yes	Moderate
POGO Failure	Moderate	High	Minor	Minor	Can	Moderate
Thrust Vector Control Failure	Low	Low	Low	Minor	No	Minor
Propellant Loading Procedures/Operations	No	No	Very High	High	Yes	No benefit
Clustered Engine Performance	Minor	Minor	Minor	Minor	Yes	Minor
Performance Margin Uncertainty	Minor	High	No	No	Yes	Moderate
Stored Gas Mass, Loading, Operations	Minor	Minor	Minor	Moderate	Yes	Minor

SIMULATION CAPABILITY ASSESSMENT

(NO PROPULSION SYSTEM TEST)

EVALUATION CRITERIA	VEHICLE FLIGHT CATASTROPHE RISK	MISSION LOSS RISK	LAUNCH DELAY RISK	LAUNCH COMPLEX RISK	SYSTEM TEST PROVIDES DATA	REMAINING RISK AFTER 20 SECOND FRF
Pressurization System Performance	Moderate	High	Minor	Minor	*Yes	Moderate
Propellant Mass Uncertainty	Minor	Moderate	Very High	Minor	Yes	Low
Low Level Cutoff Sensor	Minor	Minor	Moderate	No	Yes	No benefit
Engine/Feed Systems Chill	Minor	Minor	High	Minor	*Yes	Minor
Tank Insulation	Minor	Minor	High	Minor	*Yes	Minor
Hardware Thermal Control	Minor	Minor	High	Moderate	*Yes	Minor

* Mission Dependent

ADVANCED VEHICLE SIMULATION CAPABILITY ASSESSMENT

(NO PROPULSION SYSTEM TEST)

EVALUATION CRITERIA	SHUTTLE	ADVANCED VEHICLE WITH SMALLER VOLUME, COMMON BULKHEAD	
	FLIGHT CATASTROPHIC/ LAUNCH DELAY RISK	ALTITUDE START	ORBITAL START
		RISK	RISK
Pressurization Systems Performance	Moderate/ Minor	Much Higher/ Same	Significantly Higher/Higher
Propellant Mass Uncertainty	Minor/ Extremely High	Higher/Same	Much Higher/Same
Engine/Feed System Chill	Minor/High	Higher/Same	Significantly Higher/Higher
Tank Insulation	Minor/High	Higher/Same	Much Higher/Same
Hardware Thermal Control	Minor/High	Higher/Same	Significantly Higher/Higher

Note: Risk relative to shuttle.

SYSTEMS TESTS IDENTIFIED EVENTS

STAGE	CATASTROPHE		UNWORKABLE		TOTAL PER STAGE **
	FLIGHT	PREFLIGHT	FLIGHT	PREFLIGHT	
SHUTTLE	3	3	5	17	40
S-1C	4	0	3	3	13
S-II	2	0	8	8	21
S-IVB	8	0	6	3	20
S-I/IB	5	1	4	2	15
S-IV*	2	0	3	1	6

* Incomplete

** Includes Categories not included

EXAMPLE

SHUTTLE
SSME NOZZLE STERN HORN RUPTURE - H_2 DUMPED.
MARGINAL STABILITY CHARACTERISTICS - ET/ORBITER 17" O_2 DISCONNECT.

SAT V
F-1 ENGINE TO STAGE BOLTS STRUCTURAL FAILURES
S-II ENGINE THRUST CHAMBER CHILL FAULTY - ENGINE STALL POTENTIAL

MPTA TESTING EVALUATION

ATTEMPTED FIRINGS/ABORTS	INERTING PURGE USAGE	FIRE WATER USAGE (EXTERNAL)	ABORT SOURCE
21/9	5K - 12 System 30K - 3 System	6	Vehicle 2 Engine 8

SATURN V, IB, I TESTING EVALUATION

DEVELOPMENT STAGES					FLIGHT STAGES	
VEHICLE	TEST NUMBER	ABORTS	TEST INADVERTENTLY "CUT"	TEST STAGE DESTROYED	ACCEPTANCE TESTED	DESTROYED IN TEST
SIC "ALL SYSTEMS"	15	5	3		15	1
S-11 BATTLESHIP ALL SYSTEMS	54 9	29 6	1	1	15	
SIV B	21	-	-	1	27	1
SI/IB	23	6			22	

MPTA Hardware Replacement and Repair

MPTA Test Number	Pumps	Major Valves	EIU/MDMS	Other	LH2 Recirculation System, Pressurization System	Valves	Sensors	LH2 Diffuser, Feed Line Screens, Other
	←	ENGINE		→	←	VEHICLE		→
1-002				1	4	5	4	1
2							1	2
3				1		1	1	2
4							1	1
5-A	12	9		1			4	3
5			1		4	2	4	
6-01		9	1	1			2	
6-02/3	1	7		2	3		5	1
6-04			1	5			4	
7-01		1						
7-02		2			2		4	
8		2			5	1		
9-01	1						4	
9-02	4		1		1	1	2	
10		4	10	3	1		2	
11-01	2	7			4	6	2	
11-02				3	6	4		
12				3		1		
Total	**20**	**41**	**15**	**20**	**30**	**21**	**40**	**10**

Note: Hardware changes made prior to designated test number

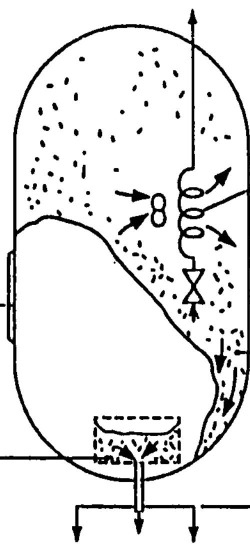
"SPECIAL" VEHICLE SIMULATION ISSUES

(PROPULSION RELATED)

SPACE ENVIRONMENT EFFECTS ON:

- PROPELLANT MANAGEMENT
- PROPELLANT THERMAL CONTROL
- TANK PRESSURE CONTROL
- PROPELLANT DYNAMICS
- PROPELLANT RESUPPLY

"SPECIAL" VEHICLE SIMULATION ISSUES



"SPECIAL" VEHICLE SIMULATION ISSUES

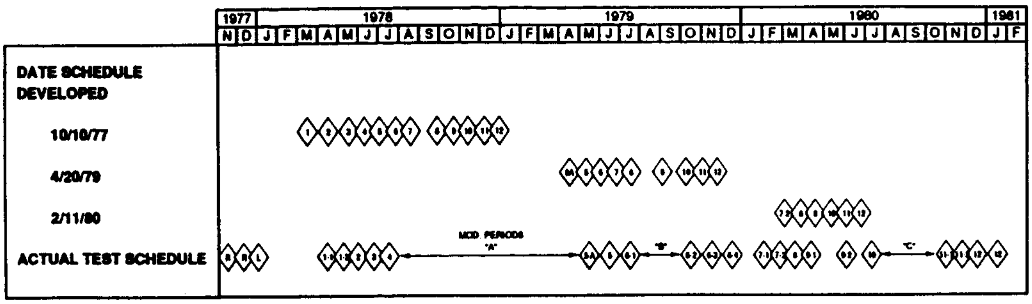
(PROPULSION RELATED)

<u>SIMULATION ASSESSMENT</u>:

FOR SOME ISSUES -

- NECESSARY TECHNOLOGY DOES NOT EXIST
- DEMONSTRATION OF TECHNOLOGY NECESSARY
- ORBITAL EXPERIMENTAL DATA NECESSARY
- DEVELOPMENT STAGE GROUND TEST POSSIBLE/DESIRABLE
- SPECIAL DEVELOPMENT GROUND FACILITIES REQUIRED

MPTA TEST SCHEDULE



NOTE: R/L - RESONANT/LOADING TESTS

CONCLUSIONS

- PROPULSION SYSTEM TESTING HAS PREVENTED CATASTROPHE AND MISSION LOSS EVENTS AND LAUNCH DELAYS.
- THE COMPLEXITY OF INTERACTIVE CHARACTERISTICS OF VARIOUS SUBSYSTEMS/ DEFIES ACCURATE SIMULATION. SYSTEM TESTING PROVIDES FOR MODEL BASING AND ENHANCES SIMULATION.
- SOME ADVANCED/"SPECIAL" VEHICLES MAY HAVE EQUAL OR GREATER REQUIREMENTS FOR PROPULSION SYSTEM TESTING AND UNUSUAL TEST FACILITIES/ METHODS MAY BE REQUIRED.
- A GROUND PROPULSION "SYSTEM TEST" PROGRAM IS THE LOGICAL APPROACH FOR PROVING DESIGN CHARACTERISTICS/METHODS WHERE FLIGHT CATASTROPHIC FAILURES OR OTHER FAILURES CAN BEST BE UNDERSTOOD AND CONTROLLED.
- ADVANCEMENT IN TECHNOLOGY AND TECHNOLOGY DEMONSTRATION IN SOME AREAS IS NECESSARY TO SATISFY FUTURE MISSION REQUIREMENTS.

N91-28252

DEVELOPMENT PROGRAM ENHANCEMENT SUGGESTIONS

(PROPULSION RELATED)

POTENTIAL INSTRUMENTATION DIFFICULTIES:

1. NASA develop standardized procedures for instrumentation installation.
2. NASA require use of existing/proven instrumentation where available.
3. NASA recognize the potential need for new instrumentation requirements early and recognizing the need for extended development, commence development activities early to engine initiation.

HAZARDOUS FLUID LEAKAGE:

1. Do technology work leading to "no leak" connection of separable connectors to avoid leakage. Impose on contractors.

PROPELLANT LOADING PROCEDURES AND OPERATIONS:

1. NASA standardize on method and procedures for this discipline.
2. Conduct supporting test as necessary.

PRESSURIZATION SYSTEM:

1. Develop a standardized pressurant gas heat source for tank pressurization. Design to operate in modular forms to account for various vehicle size, pressurant gas, etc., as may be required.
2. Review/improve on simulation capability for predicting tank pressure vs. time. Consider differing pressurant gas, propellant, tank size, volume, etc.

PROPELLANT MASS UNCERTAINTY:

1. Develop approach/procedures which standardizes this discipline.
2. Prepare specification requirement and initiate development program for simplier loading system. Prove by test.

SECTION 4.3

OPERATIONAL EFFICIENCY PANEL

N91-28253

PRESENTATION 4.3.1

GENERAL DYNAMICS
Space Systems Division

OPERATIONAL EFFICIENCY PANEL

SPACE-BASING TECHNOLOGY REQUIREMENTS

LUIS R. PEÑA

THE SPACE EXPLORATION INITIATIVE

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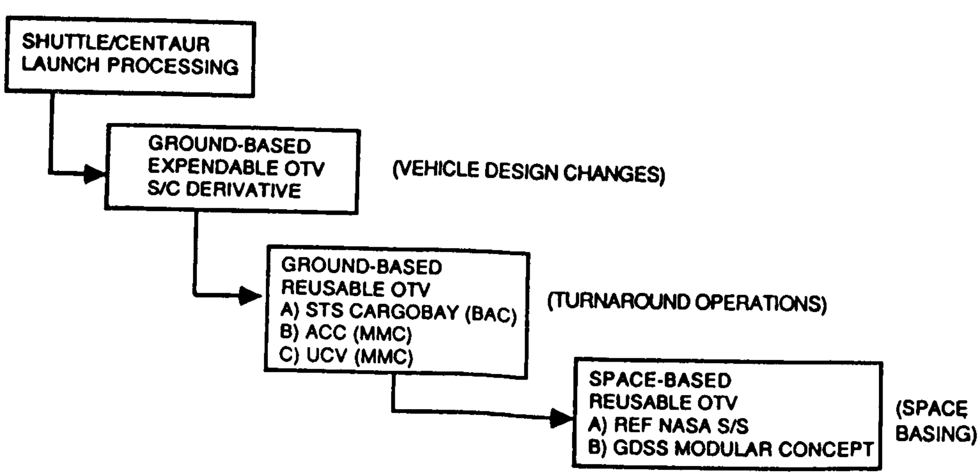
GENERAL DYNAMICS
Space Systems Division

SPACE-BASING TECHNOLOGY REQUIREMENTS SOURCES

SPACE STATION	- OTV CONCEPT DEFINITION AND SYSTEMS ANALYSIS	MSFC
	- TURNAROUND OPERATIONS ANALYSIS FOR OTV *	MSFC
	- CENTAUR OPERATIONS AT THE SPACE STATION	LeRC
	- LONG TERM CRYOGENIC STORAGE FACILITY	MSFC
LUNAR / MARS / NODES	- INFRASTRUCTURE STUDY *	MSFC
	- CENTAUR DERIVED LUNAR TRANSFER VEHICLE	LeRC
	- UP-GRADED CENTAUR	LeRC

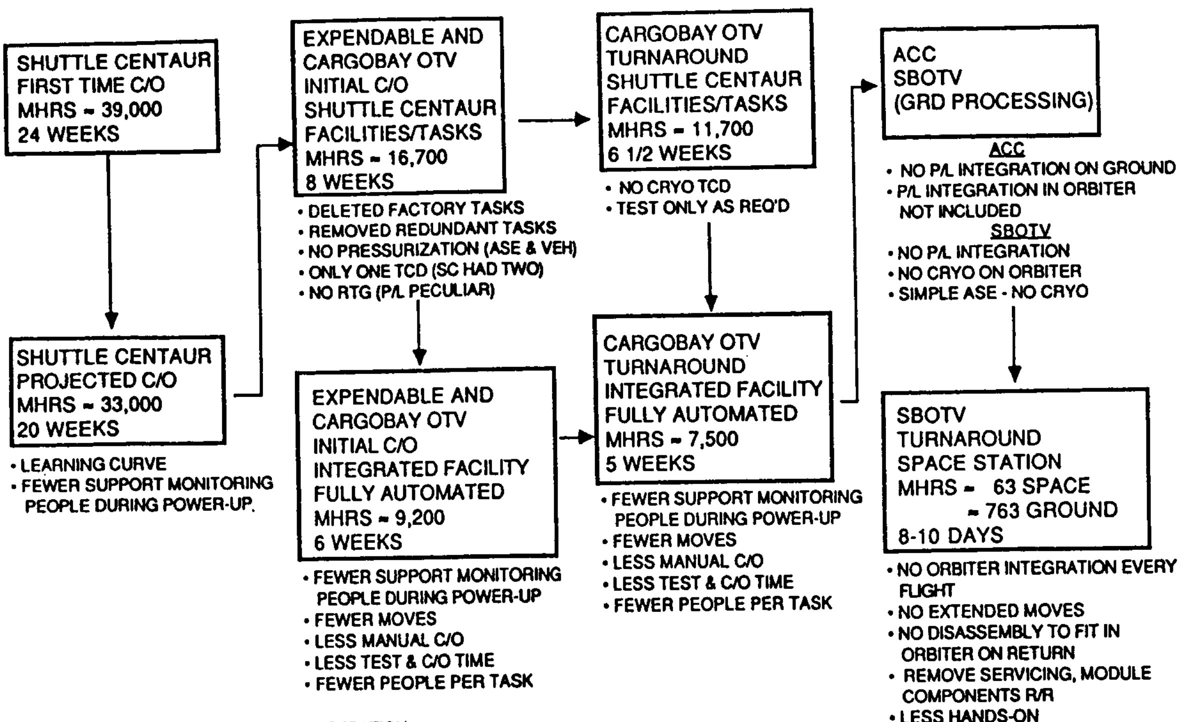
GENERAL DYNAMICS
Space Systems Division

OTV PROCESSING HERITAGE



GENERAL DYNAMICS
SPACE SYSTEMS DIVISION

GROUND PROCESSING PROGRESSION TO SPACE PROCESSING



TCD - TERMINAL COUNTDOWN DEMONSTRATION

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TECHNOLOGY REQUIREMENTS
SPACE-BASED OTV SERVICING AND MAINTENANCE

1. CRYOGENIC PROPELLANT TRANSFER, STORAGE AND RELIQUEFACTION
2. AUTOMATED FAULT DETECTION / ISOLATION AND SYSTEM CHECKOUT
3. OTV DOCKING AND BERTHING
4. OTV MAINTENANCE / SERVICING OPERATIONS AND FACILITIES / SUPPORT EQUIPMENT
   - TELEOPERATORS / ROBOTICS
   - CREW TRANSLATION EQUIPMENT
   - OTV TRANSLATING & BERTHING ROTATION EQUIPMENT
   - CONTROLS AND DISPLAYS
   - EVA OPERATIONS
5. OTV / PAYLOAD MATING AND INTERFACES

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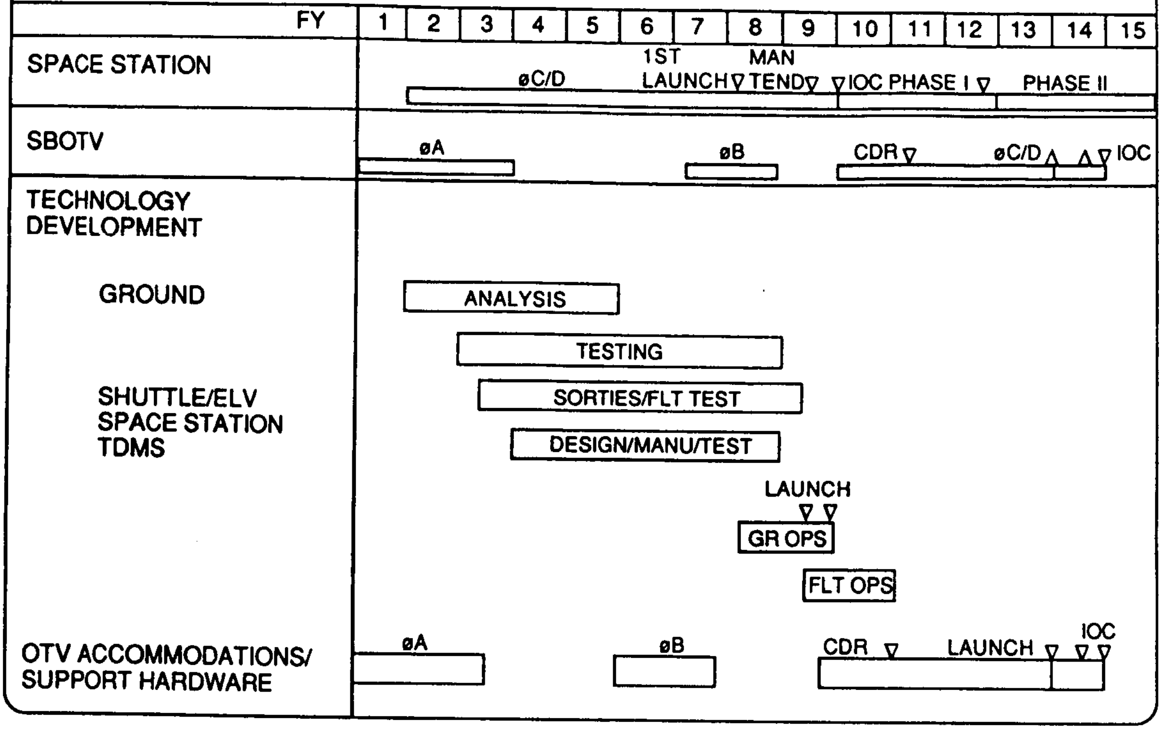
DESIGN AND DEVELOPMENT SCHEDULE FOR OTV'S AND OTV ACCOMMODATIONS/SUPPORT HARDWARE



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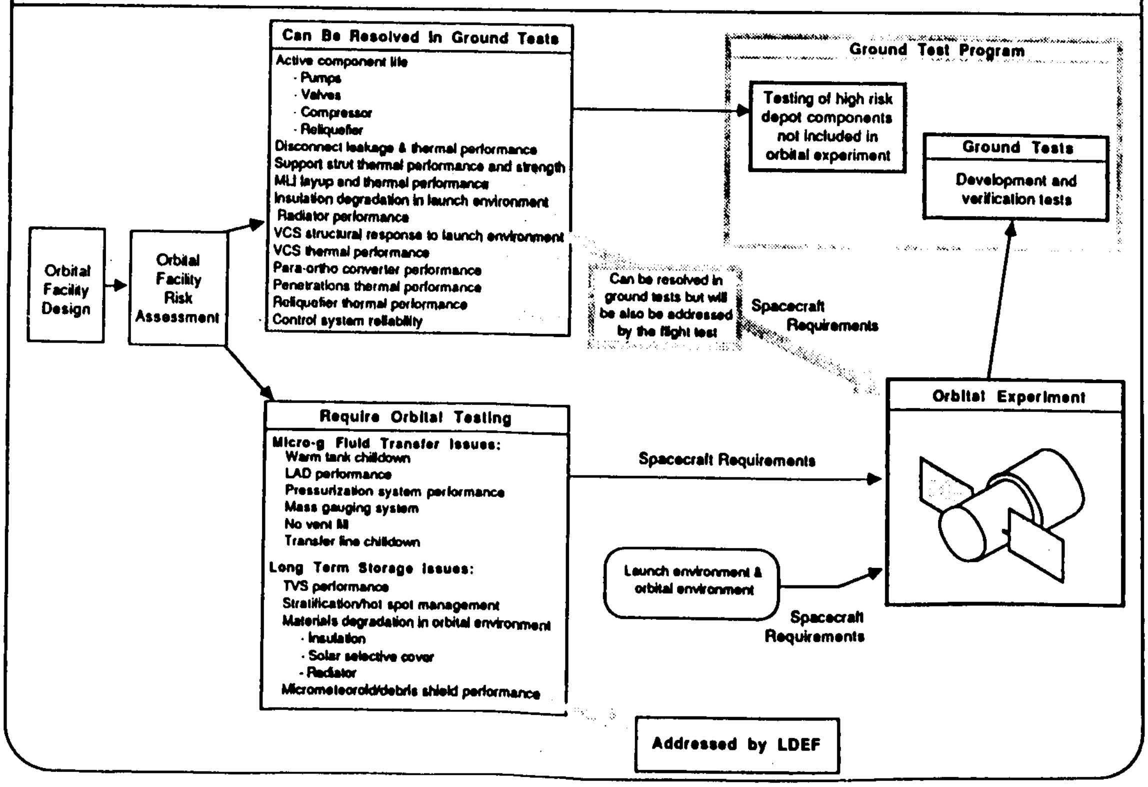
CRYOGENIC TECHNOLOGY TEST PROGRAM DEVELOPMENT



CRYOGENIC PROPELLANT TRANSFER, STORAGE AND RELIQUEFACTION MANAGEMENT SUMMARY

MANY OTV PROPELLANT STORAGE, TRANSFER, AND RELIQUEFACTION TECHNOLOGY PERFORMANCE ISSUES CAN BE RESOLVED THROUGH ANALYSIS AND GROUND TESTING

- o ACTIVE COMPONENTS (RELIQUEFIER, PUMPS, VALVES, COMPRESSORS, RADIATOR)
- o PASSIVE COMPONENTS (MLI, VCS, P-O CONVERTER)

CERTAIN TECHNOLOGY DEVELOPMENTS REQUIRE ORBITAL, LOW-G TESTING

- o TRANSFER
  - LIQUID ACQUISITION DEVICE
  - PRESSURIZATION SYSTEMS
  - MASS GAGING SYSTEMS
  - NO-VENT FILL/REFILL
  - TRANSFER LINE CHILLDOWN
- o LONG-TERM STORAGE ISSUES
  - THERMODYNAMIC VENT SYSTEM
  - STRATIFICATION AND "HOT SPOT" MANAGEMENT
  - MATERIALS DEGRADATION (MLI, SOLAR SELECTIVE COVER, RADIATOR)
- o MICROMETEOROID/DEBRIS SHIELD PERFORMANCE

PROPELLANT TRANSFER TECHNOLOGY ANALYSIS & GROUND TESTING

DESCRIPTION OF TECHNOLOGY:

- o AUTOMATIC, LEAK-FREE OPERATION OF CRYOGENIC TRANSFER LINES AND DISCONNECTS
- o CHILLDOWN BEHAVIOR OF TRANSFER LINES
- o PRECHILL ACCUMULATOR & COMPRESSOR SYSTEM TEST
- o VALVE & TRANSFER PUMP TESTING

RATIONALE & ANALYSIS:

- o SYSTEM REQUIRES FULLY AUTOMATED TRANSFER SYSTEM
- o RELIABILE, LEAK-FREE OPERATION OF DISCONNECTS, PUMPS, VALVES, AND COMPRESSORS

TECHNOLOGY OPTIONS:

- o TRANSFER LINE CONFIGURATIONS; ELV-SS DEPOT TANK, DEPOT-OTV, ET SCAVENGING
- o TRANSFER PRESSURANT SYSTEM; AUTOGENOUS, GHe, GH2, PUMP-FED
- o TRANSFER LINE INSULATION TYPES/INTERNALLY COATED VS. UNCOATED

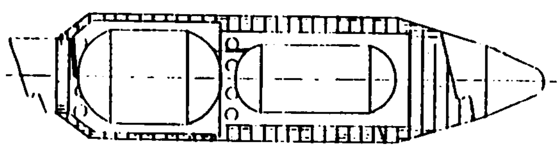
OTV PROPELLANT STORAGE DEPOT DEVELOPMENT CRITICAL SCALING RELATIONSHIPS

EXPERIMENT	SIGNIFICANT PARAMETERS
Thermodynamic venting, passive & active	TVS flowrate/direct venting flowrate, tank pressure/vapor pressure, Weber no., jet Reynolds no., mixing parameter (time), Bond no., mixer heat input / total heat input
Tank prechill	Tank pressure, volume/tank mass, temperature, Nusselt no., spray Reynolds no., mixing parameter
No-vent fill	Nusselt no., spray / jet Reynolds no., mixing parameter, peak pressure / vapor pressure, Weber no., Jacob no.
Liquid acquisition device fill / refill	Bond no., liquid volume / total volume, bulk density / liquid density, average bubble volume / total ullage volume
Slosh dynamics & control	Bond no., jet Weber no., acceleration ratios, dimensionless slosh frequency, damping factor, expulsion efficiency

FLIGHT EXPERIMENT OPTIONS

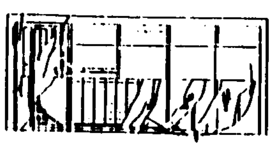
SMALL SCALE (~1/10) ORBITAL FLIGHT EXPERIMENT

Launch Vehicle: Atlas/Centaur
Experiment Size: 10.5 ft. dia. max., 24 ft. long
LH2 Capacity: 230 cu. ft., 998 lbs. (Receiver Tank)
Total Weight: ~9800 lbs. wet



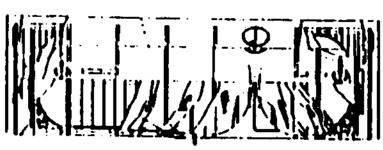
LARGE SCALE (~4/10) ORBITAL FLIGHT EXPERIMENT

Launch Vehicle: TITAN IV SS I &II
Experiment Size: 15 ft. dia. max., 47 ft. long
LH2 Capacity: 1320 cu. ft., 5728 lbs. (Receiver Tank)
Total Weight: ~25000 lbs. wet



FULL SPACE STATION LH2 TDM

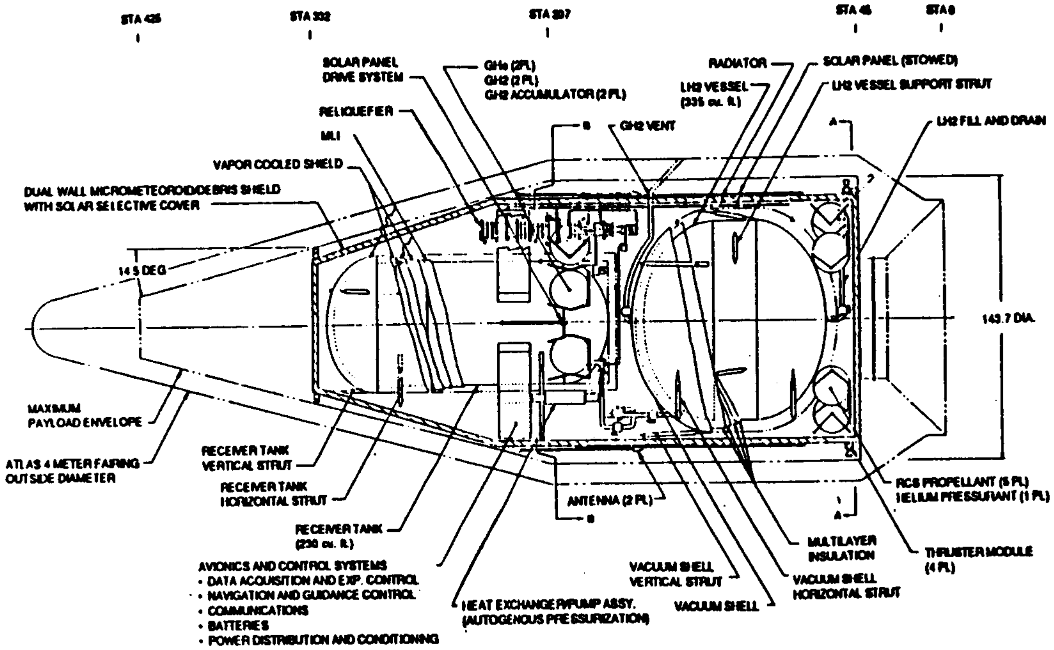
Launch Vehicle: Space Shuttle (dry), or SDV
Experiment Size: 14.5 ft. dia. x 34.5 ft. long
LH2 Capacity: 3292 cu. ft., 14286 lbs.
Total Weight: ~18000 lbs. dry



FULL SCALE LONG TERM CRYOGENIC STORAGE DEPOT

Launch Vehicle: Space Shuttle (dry), SDV or ALS
Size: 14.5 ft. dia. x 50 ft. long
Capacities: 3292 cu. ft. LH2, 1203 cu. ft. LO2
14286 lbs. LH2, 85714 lbs. LO2
Total Weight: ~30200 lbs. dry

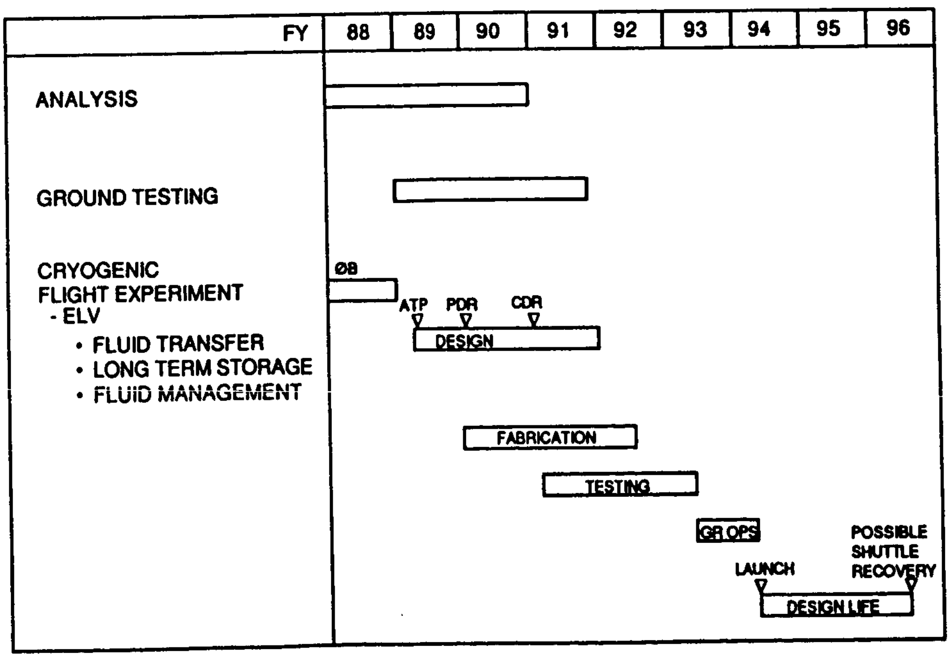
SMALL SCALE (~1/10) LTCSF FLIGHT EXPERIMENT (CONFIGURED FOR ATLAS/CENTAUR LAUNCH VEHICLE)



SIDE VIEW

ALL DIMENSIONS IN INCHES

OTV ACCOMMODATIONS/SUPPORT HARDWARE *TECHNOLOGY DEVELOPMENT - CRYOGENIC PROPELLANT ELV EXPERIMENT



*MAY REQUIRE SPACE STATION TDM

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OTV MAINTENANCE PHILOSOPHY

THREE-LEVEL MAINTENANCE
- LEVEL ONE - OTV LOCAL MAINTENANCE
- LEVEL TWO - SPACE STATION REPAIR OF REPLACEABLE UNITS
- LEVEL THREE - RETURN TO EARTH MAINTENANCE

STOCK SPARE PARTS BASED ON RELIABILITY, CRITICALITY & COST
- SPACE STATION STORAGE VS SHUTTLE DELIVERY

STRESS MODULAR CONSTRUCTION FOR ASSEMBLY & REPLACEMENT CAPABILITY
- MINIMIZE INTERFACES
- SIMPLIFY INTERFACES

PROVIDE OPERATIONAL FLIGHT INSTRUMENTATION & BUILT-IN TEST
- FAULT ISOLATE TO REPLACEABLE UNIT

MINIMIZE EVA VEHICLE MAINTENANCE OPERATIONS
- CONSIDER SAFETY IN HAZARDOUS SITUATIONS
- TRADE-OFF EVA VERSUS SUPPORT EQUIPMENT
  - TV INSPECTION
  - TELEOPERATIONS / ROBOTICS FOR COMPONENT REPLACEMENT

AUTOMATED FAULT DETECTION/ISOLATION AND SYSTEM CHECKOUT SUMMARY

THE AUTOMATED FAULT DETECTION/ISOLATION AND SYSTEM CHECKOUT REQUIRED TECHNOLOGY DEVELOPMENT FOR GROUND PROCESSING CAN BE RESOLVED THROUGH ANALYSES, SIMULATION AND GROUND TESTING.

THE REQUIRED TECHNOLOGY DEVELOPMENTS FOR SPACE PROCESSING (SAME AS ONES FOR THE GROUND) CAN FOR THE MOST PART BE RESOLVED THROUGH ANALYSES, SIMULATION AND GROUND TESTING.

- NO TESTING ON A SHUTTLE SORTIE OR ELV

- MAY WANT TO INCLUDE SOME PROTOTYPE EQUIPMENT ON MAINTENANCE/SERVICING/SUPPORT EQUIPMENT SPACE STATION TDM

MAINTENANCE/SERVICING OPERATIONS AND SUPPORT EQUIPMENT TECHNOLOGY SUMMARY

MANY MAINTENANCE/SERVICING/SUPPORT EQUIPMENT REQUIRED TECHNOLOGY DEVELOPMENTS CAN BE RESOLVED THROUGH ANALYSIS, SIMULATION AND GROUND TESTING.

- TELEOPERATIONS/ROBOTICS/TOOLS
- CREWMAN SUPPORT/WORKSTATION/TRANSLATION EQUIPMENT
- OTV TRANSLATING AND BERTHING ROTATION EQUIPMENT
- CONTROLS/DISPLAYS/COMMUNICATIONS

CERTAIN TECHNOLOGIES REQUIRE ORBITAL, LOW-G TESTING

- EVA MAINTENANCE/SERVICING OPERATIONS/CONTROLS/TOOLS
- TELEOPERATIONS/ROBOTICS/CONTROLS/TOOLS (VERIFICATION)

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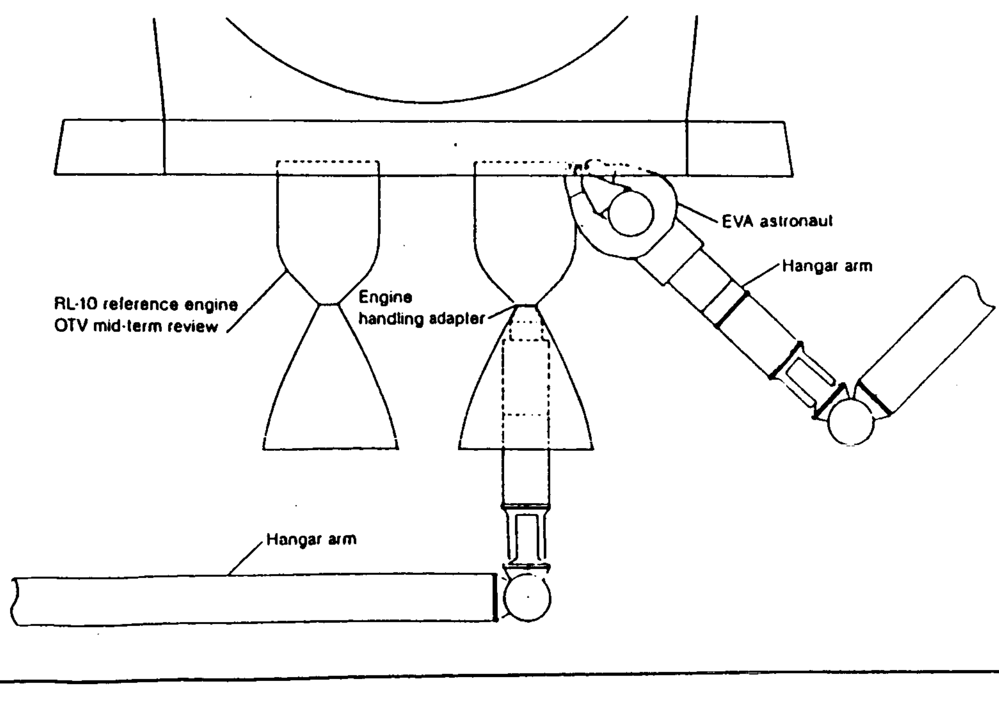
ENGINE REPLACEMENT OPERATIONS



ENGINE REPLACEMENT TRADE COMPARISON

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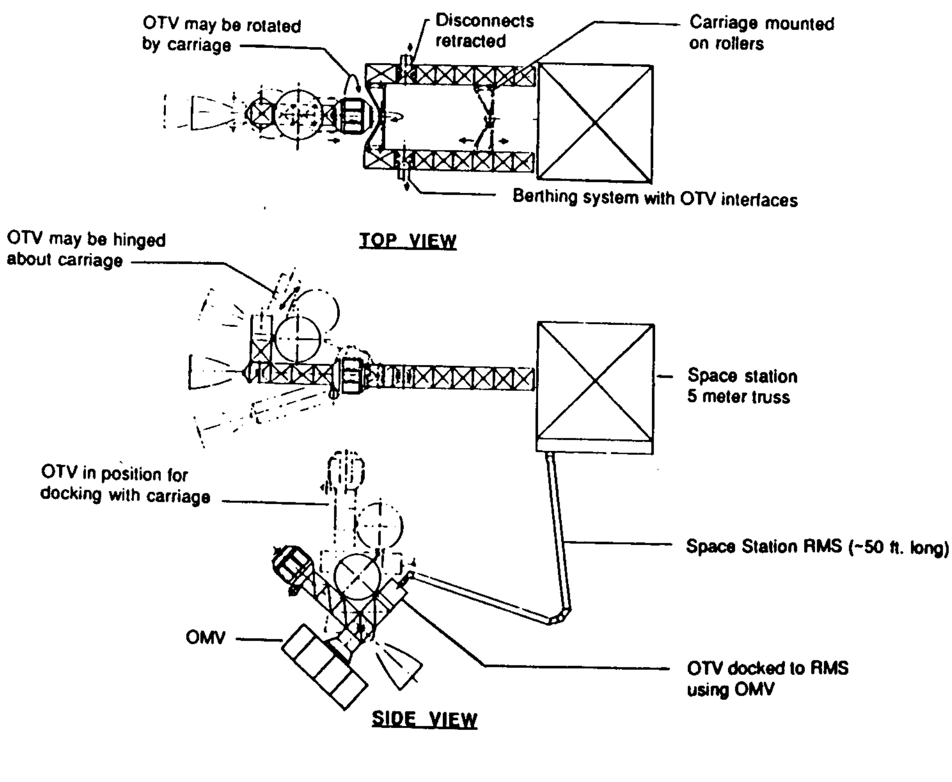
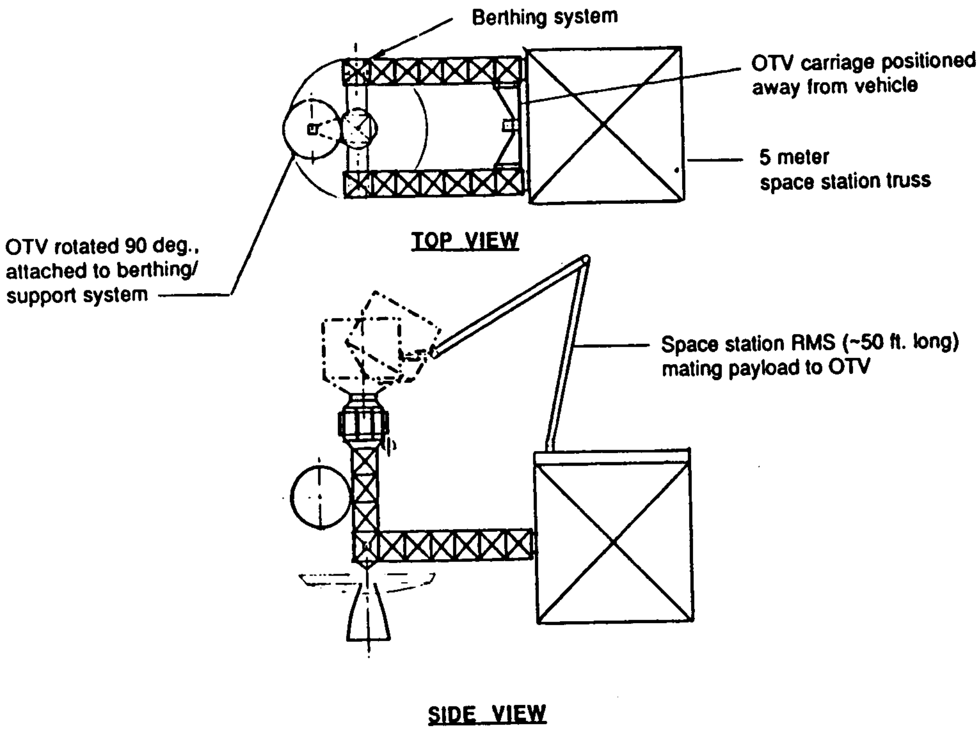
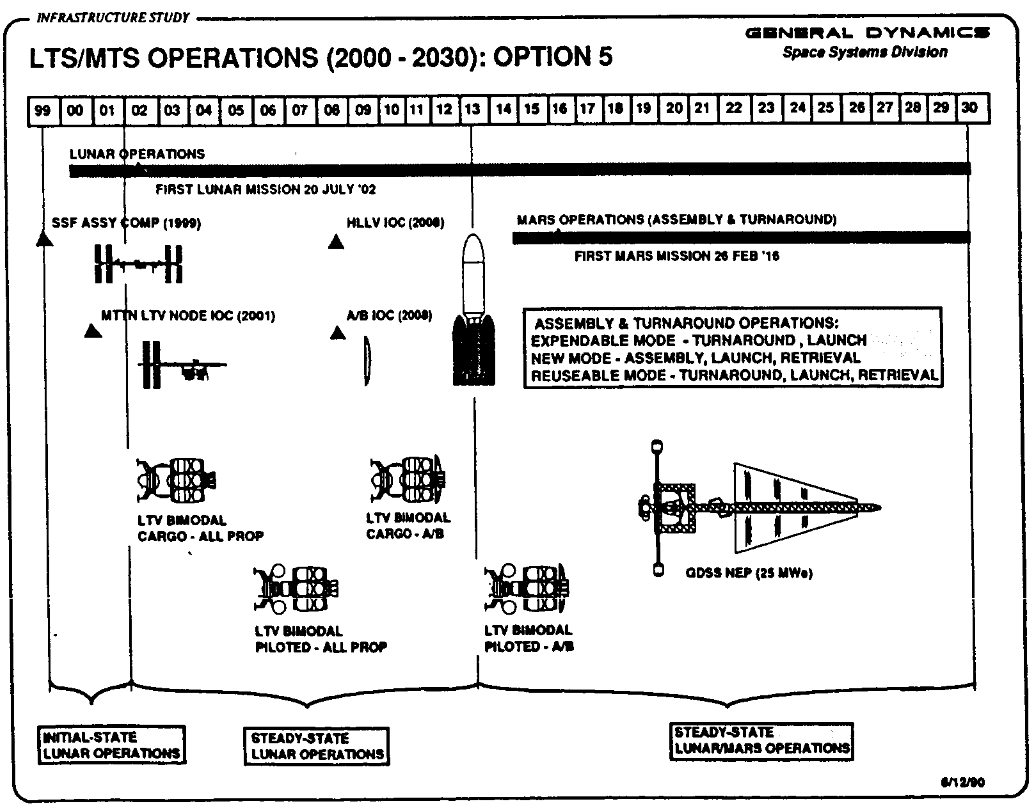
CRITERIA \ OPTION		TELEOPERATION WITH EVA	TELEOPERATION ONLY	TELEOPERATION WITH AUTOMATED LATCHES
SUPPORT EQUIPMENT REQUIREMENTS		2 RMS - 1 crew support adapter - 1 grasping adapter EVA support equipment	2 RMS - 1 servicing tool adapter - 1 grasping adapter	1 RMS - 1 grasping adapter
VEHICLE DESIGN REQUIREMENTS		OTV modular design EVA compatible disconnect	OTV modular design EVA/teleoperator compatible disconnect	OTV modular design Automated disconnect
TASK DURATION		18:10	12:50	7:15
MANHOURS	EVA	24:50	---	---
	TOTAL	53:30	20:20	13:45
MANHOUR COST(NMM)		49.5M	7.5M	2.7M
△ VEHICLE WEIGHT PER MISSION		Baseline	Same	+100lb/engine
REQUIRE TECHNICAL DEVELOPMENT		No	Minimal	Yes
ACCESSIBILITY REQUIREMENT		Aerobrake: remove Crew: 4 ft x 5 ft x 6.5 ft RMS : nossle area	Aerobrake: remove Crew: none RMS : 28 in. dia for RMS & tool, nozzle area	Aerobrake: not removed Crew: none RMS : nozzle area
VEHICLE COMPLEXITY		Baseline	Same	Increased - Hardware - Software
VEHICLE RELIABILITY		Baseline	Same	Decrease
COST (REV 8 NMM)		130M	53M	556M

ALTERNATIVE DOCKING OPERATION



CONCEPT FOR OTV/PAYLOAD INTEGRATION





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TECHNOLOGY CRITICALITY & CAPABILITY ASSESSMENT

Technology	Criticality Assessment	Mission Element		Capability	Need Date
		Lunar	Mars		
Cryogenic Fluid Management	1	X	X	Refuel/Store	1998
Nuclear Electric Power System	1		X	25 MWe	2005
Ion Thrusters	1		X	F=410n, ISP=9ks	2005
Heat Pipe Radiation	1		X		2005
Cryogenic Ascent/Descent Propulsion	2	X	X	Man-rated, Reuse, High ISP, Throttle	1998
Aerobrake (rigid or flexible)	1	Low Engy	High Engy	Flex Preferred	1998/05
Gaseous Oxygen/Hydrogen RCS	3	X	X	50-100# thrust	1998
Automated Health Monitoring	2	X	X	All systems	1998
Regenerative Fuel Cells	1	X	X	4-6kW	1998
In-Space Rendezvous & Docking	1	X	X	Lunar/Mars Orb	1998
EVA Systems Technology	2	X	X	8 psi suit	1998
In-Space Assembly, Ckout, Processing	1	X	X	Ground control	1998
Closed Loop Life Support Systems	2	X	X		1998
Radiation Protection	1	X	X	Crew Mod	1998
Artificial Gravity	2		X	Reqm't pending	2005
Upgraded OMV	1	X	X	80 Klbs P/L	1998

TRANSFER VEHICLE
TECHNOLOGY DEVELOPMENT PLAN

TECH PLANS GDSS	NASA	TECHNOLOGY DEVELOPMENT
STV	√	**HUMAN FACTORS** • MAN RATING/SAFING, PROXIMITY OPS • LIFE SUPPORT SYSTEMS AND REQ'MTS • ARTIFICIAL GRAVITY, ECLSS
STV	√	**SPACE MISSION PLANNING AND SUPPORT** • INTEGRATED MISSION DEVELOPMENT • MISSION PERFORMANCE SCENARIOS • EMERGENCY SCENARIO/ALTERNATIVES
STV NASP CDLTV	√	**AEROBRAKE / AEROSYSTEMS** • HYPERSONIC AERO THERMODYNAMICS • MATERIALS • AUTONOMOUS OPERATIONS
STV NASP ALS	√	**EXPERT SYSTEMS** • ON-BOARD INTELLIGENT SYSTEMS • DECISION-AID • GROUND AND MISSION OPS INTEGRATION
STV NASP ATLAS ALS	√	**SIMULATION MODELS - INTEGRATED** • MISSION PARAMETERS • AVIONICS & STRUCTURES DEVELOPMENT • LAUNCH AND GROUND SYSTEMS
STV	√	**IN-SPACE OPERATIONS** • RENDEZVOUS, DOCKING, MATING & ASSY • SPACE BASING, MAINTENANCE, ROBOTICS • AUTONOMOUS OPERATIONS
STV AUS NASP ATLAS ALS SPS	√	**CRYOGENIC MANAGEMENT - ADVANCED** • "0" G CRYO XFER, LIQUID ACQ DEV (LAD) • FLOW & MASS MEASUREMENT • RELIQUEFACTION, INSULATION SYSTEMS

TECH PLANS GDSS	NASA	TECHNOLOGY APPLICATIONS
STV AUS ATLAS T/C ALS	√	**AVIONICS, MPRAS, REDUNDANCY** • ADAPTIVE / EXTENDED GN & C • SOFTWARE UPDATE SYSTEMS • SPACE COMM'S HI RATE - DATA / VOICE
STV AUS NASP ATLAS T/C ALS & SPS	√	**MATERIALS / STRUCTURES AND TANKS** • COMPOSITES - STRUCTURAL SHIELDING • METAL MATRIX COMPOSITES, AL-LI • CRYO-TANK COMPOSITES / INSULATION
STV AUS NASP ATLAS T/C ALS	√	**FLUID / MECHANICAL SYSTEMS - ADVANCED** • ELECTRO / PNEU VALVES • ELECTROMECHANICAL ACTUATORS • AUTOGENOUS PRESSURIZATION / TVS
STV AUS T/C	√	**PROPULSION SYSTEMS - ADVANCED** • ALTERNATE RCS METHODS • MULTI- MISSION & MULTI-CYCLE PROP • NUCLEAR PROPULSION SYSTEMS
STV SPS	√	**ELECTRICAL POWER SYSTEMS** • BATTERIES, SOLAR CELLS, FUEL CELLS • RTG AND NUCLEAR SYSTEMS, He3 • SUPERCONDUCTIVITY, COLD FUSION
STV AUS ATLAS T/C ALS	√	**MANUFACTURING TECHNOLOGY** • CONCURRENT ENGR, COST REDUCTION • SIMPLIFIED METHODS / HIGH RELIABILITY • ROBOTIC APPLICATIONS
STV AUS ATLAS T/C ALS	√	**LAUNCH RESPONSIVENESS** • AUTO CH'KOUT, IHM, REDUNDANCY MGT • AUTO PROPELLANT LOADING • AUTOMATED / INTEGRATED TEST & GSE

N91-28254

PRESENTATION 4.3.2

SPACE TRANSFER VEHICLES

AND

SPACE BASING

FOR

1990 SPACE TRANSPORTATION PROPULSION SYSTEMS SYMPOSIUM

LOCATION: UNIVERSITY PARK, PA
DATE: 26 - 29 JUNE 1990

MARTIN MARIETTA

McDonnell Douglas

Joe Kelley

Acknowledgment

This presentation, "Space Transfer vehicles and Space Basing" represents a selection of work performed by Martin Marietta Corporation (Prime contractor) and McDonnell Douglas (subcontractor) under NASA Marshall Space Flight Center Contract "Space Transfer Vehicle Concepts and Requirements", NAS-8-37856 along with related company funded efforts and has been previously presented at Program reviews at MSFC.

The MSFC Contracting Officer Technical Representative is Mr. Don Saxton (205) 544-5035. Mr. Joe Keeley is the Martin Marietta STV Program Manager at (303) 977-8614 and the McDonnell Douglas study Manager is Mr. Steve Wasko at (714) 896-3311 x 9757.

Agenda - Space Basing

- Why Space Base?
- What is Space Basing?
- What Must We Do?
- What Solutions Are There?
- What Are SSF Impacts?
- What Technologies Do We Need?
- Conclusions

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Why Space Base?

- Cut Earth-to-Orbit (ETO) Launch Costs and No. of Flights
  - Launch Facility Buildup
  - Separate Crew / Cargo ETO Flights
- Reduce Impacts of ETO Launch Delays
- Utilize Reusable Elements Efficiently
  - Minimize Return-to-Earth-Relaunch Cycles
- Learn by Doing
  - Skylab, MIR
- Set Groundwork for Expanded Exploration
  - On-orbit Assembly, Flight Certification, Refurbishment
  - Crew / Cargo Transfer / Rendezvous

OR

- Direct Flights to Moon / Mars Only
  - Limits Potential for Near Term Exploration
  - Mandates Indigenous Resources

Why Space Base?

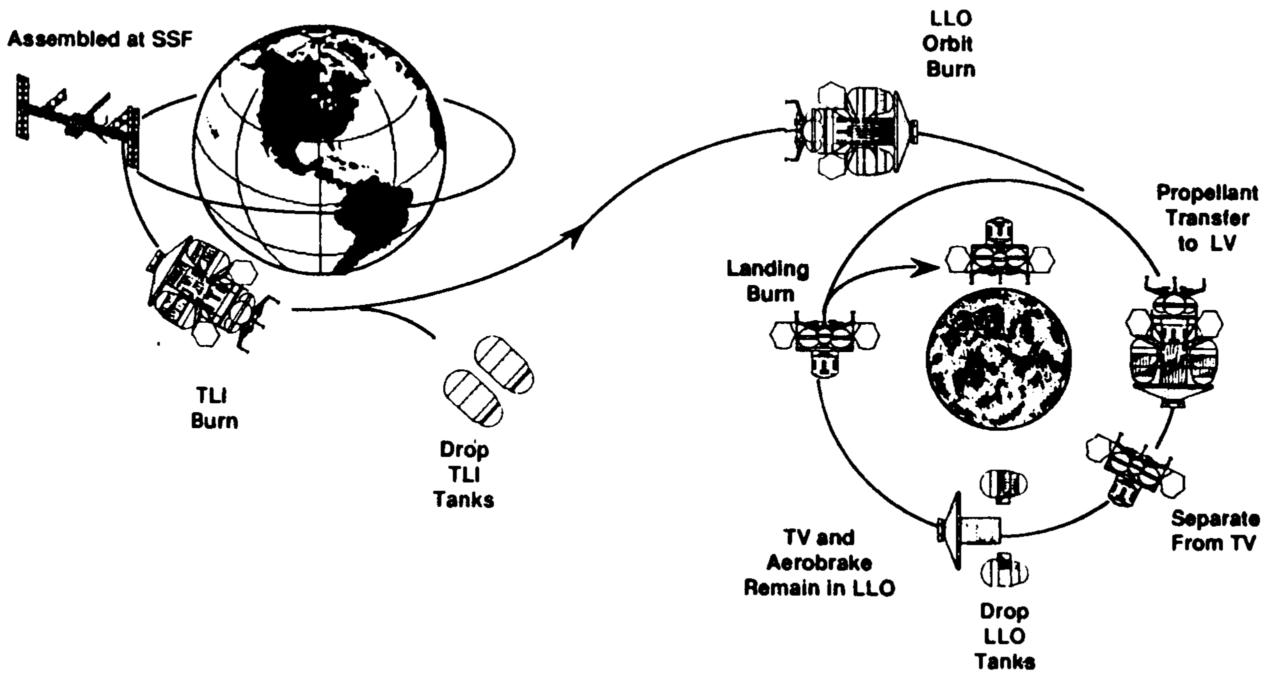
- Crew Resources
  - Life Support Modules and Components
  - Life Support Liquids and Gasses
- Cargo
  - Science Equipment
  - Habitability Equipment
  - Payload Elements
- Vehicle Systems
  - Space Transfer Vehicles (Expendable and Reusable)
  - Space Tugs
  - Manned Maneuvering Units
- Vehicle Resources
  - Propellants / Gasses
  - Water / Coolants

Mission Scenario 4E-5B Outbound Flight

Common vehicle with single crew module, single propulsion system, drop tanks and aerobrake return.

The mission begins in low earth orbit. The TLI burn is accomplished with the vehicle using propellants from a set of TLI drop tanks which are then jettisoned. The LLO insertion burn is accomplished with the vehicle with propellants from a set of LLO drop tanks which are also jettisoned. Tanks located on the underside of the aerobrake contain the propellant required for the return mission. The vehicle separates from the aerobrake and tanks which remain in lunar orbit. The vehicle then performs the landing burn.

Mission Scenario 4E-5B, Crew & LEV Delivery



Outbound Flight (Initial Flight - With LEV)

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What Must We Do?

Define and Bound:

- Crew Growth
  - Lunar; Visit, Explore, Settle
  - Mars; Visit, Explore, Settle
  - Solar System Visits

- Crew Support Systems
  - Visits; Small Quarters
  - Exploration; Work / Relaxation / Science Quarters
  - Settlements; Homes

- Space Transfer Vehicle Families
  - LEO → Lunar → Mars → Solar System

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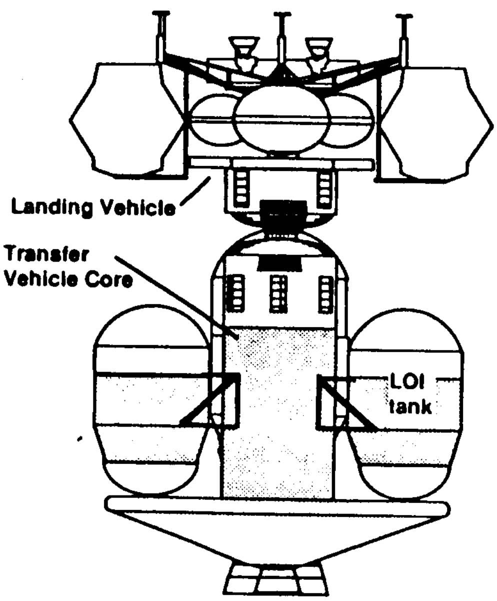
Final Concept Candidate - Crew Concept 4E-2B:

This chart provides a detailed vehicle configuration as well as identified attribute the the criteria evaluation produced. The key attributes of this configuration are:

- Lowest Development and Validation Costs
- No Crew Transfer
- Optimum support of all STV DRMs

Final Concept Candidate - Crew Concept 4E-2B



ATTRIBUTES:

- **Lowest Development & Validation Cost**
- **Simplify LEO Assembly & Checkout In Steady State Phase**
- **No Crew Module Transfer**
- **Optimum Support Of All STV DRMs**

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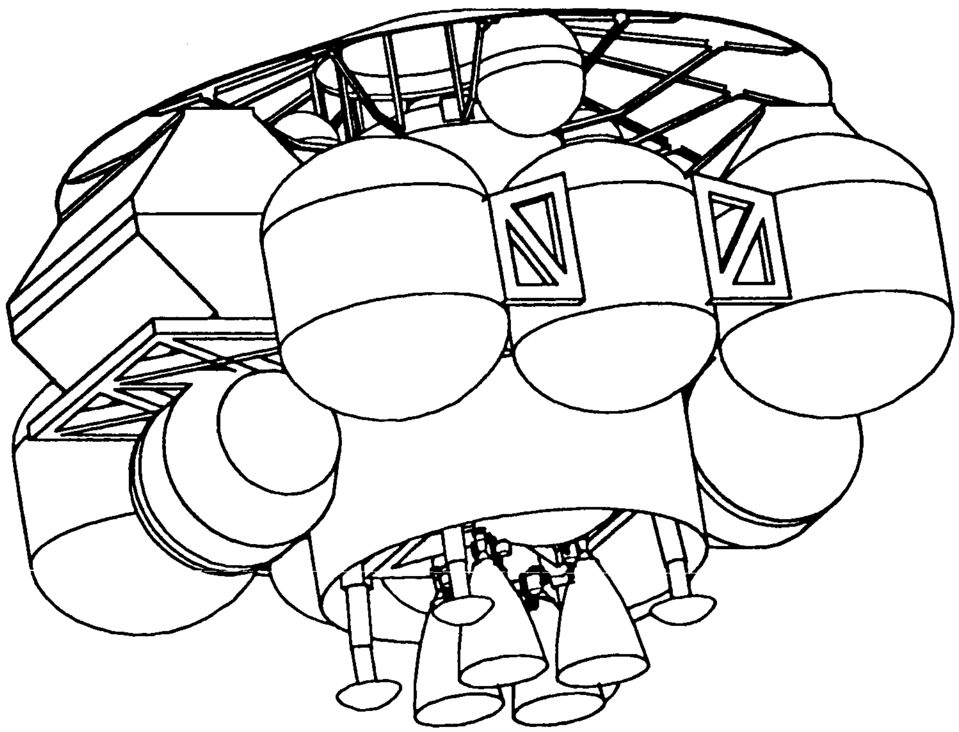
STV Concept 4E-5B

Concept 4E-5B employs a single propulsion system. It is a Transfer/Landing vehicle with drop tanks, a single crew module, 45.0' dia. aerobrake and launched from LEO to the Lunar surface. This concept requires one Shuttle-C Block 2 flight to deliver the Transfer/Lander and LOI drop tanks and two HLLV flights to deliver the TLI drop tanks to LEO for assembly. Pre-flight assembly and final verification along with flight recertification and re-certification is accomplished at LEO.

The Transfer/Landing vehicle consists of one stage with four RL-10 engines and a propellant capacity of 29.0 t., two TLI drop tanks with a propellant capacity of 133.0 t and two LOI drop tanks with a propellant capacity of 20.0 t. The single crew module is used for both the trans Earth/Lunar trip and to transport the crew to the Lunar surfaçe.

STV Concept 4E-5B



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Configuration Summary - Crew Concept 4E-5B

Crew Concept 4E-5B is a Single Propulsion Transfer/Landing Vehicle with Drop Tanks, single crew module, 45.0' dia. Aerobrake and launched from LEO to the Lunar surface. This Concept requires 1 Shuttle-C Block 2 flight to deliver the Transfer/Lander and LOI Drop Tanks and 2 HLLV flight s to deliver the TLI Drop Tanks to LEO for assembly. Pre-flight verification is accomplished at LEO.

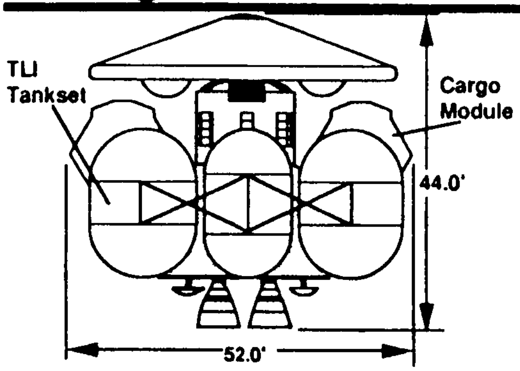
The Transfer/Landing Vehicle consist of a stage with 4 RL-10 engines and a propellant capacity of 29.0 t., 2 TLI Drop Tanks with a propellant capacity of 133.0 t and 2 LOI Drop Tanks with a propellant capacity of 20.0 t. The Transfer/Landing Vehicle with the single crew module is used to transport the crew to the Lunar surface and the trans Earth/Lunar trip.

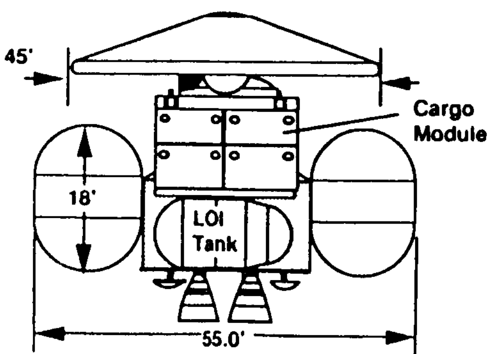
DRM adaptability for this concept is:

Transfer/Landing Vehicle	Delivers 11.8 t to GEO
Transfer/Landing Vehicle w/Drop Tanks	Planetary Propulsion Unit

The Program Cost and Mass Properties for Crew Concept 4E-5B are summarized on the chart.

Configuration Summary - Crew Concept 4E-5B





Preliminary Mass Properties

	(t)
Transfer/Vehicle Core	16.3
TLI Tank (2 @ 2.8)	5.6
LOI Tank (2 @ 1.1)	2.2
Total Mission Propellant	159.0

Key Features

- Single Propulsion Transfer/Landing Vehicle w/ Drop Tanks
- LEO to Lunar Surface Crew/CargoDelivery
  Aerobrake Return to LEO, Single Crew Cab
  Lunar Architectures 1 & 2
- Transfer/Landing Vehicle Core -
  - 29 t Propellant
  - 4 RL-10 Engines
- Drop Tanks
  - (2) TLI 66.5 t Propellant (each)
  - (2) LOI 10 t Propellant (each)
  - (2) Return Tankset 3 t Propellant (each)
- Requires 1 Sh-C Block 2 and 2 HLLV Flts for LEO Delivery
  - Transfer/Landing Vehicle & A/B Pkgd In Sh-C Block 2
  - Each TLI & Return Tankset Pkgd In HLLV - 20' Dia., 84 t
- Evolution
  - Transfer/Lander - Delivers 11.8 t to GEO
  - Transfer/Lander with Drop Tanks-Planetary Propul. Unit
- Program Cost
  - DDT&E - $10.1B
  - Production - $2.9B
  - Operations - $19.1B
  - Total LCC - $32.1B
- LEO Operations Include Delivery, Assy & Verification of Core and Drop Tanks; Refurb of Core and Crew Cab
- Cargo Height Above Lunar Surface - 24.3'
- Critical Operations
  - Outbound - 1 Crit-1, 5 Crit-2
  - Return - 4 Crit-1, 1 Crit-2

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Configuration Definition - Crew Concept 4E-5B

Crew Concept 4E-5B is a Single Propulsion Transfer/Landing Vehicle with Drop Tanks, single crew module, 45.0' diameter Aerobrake

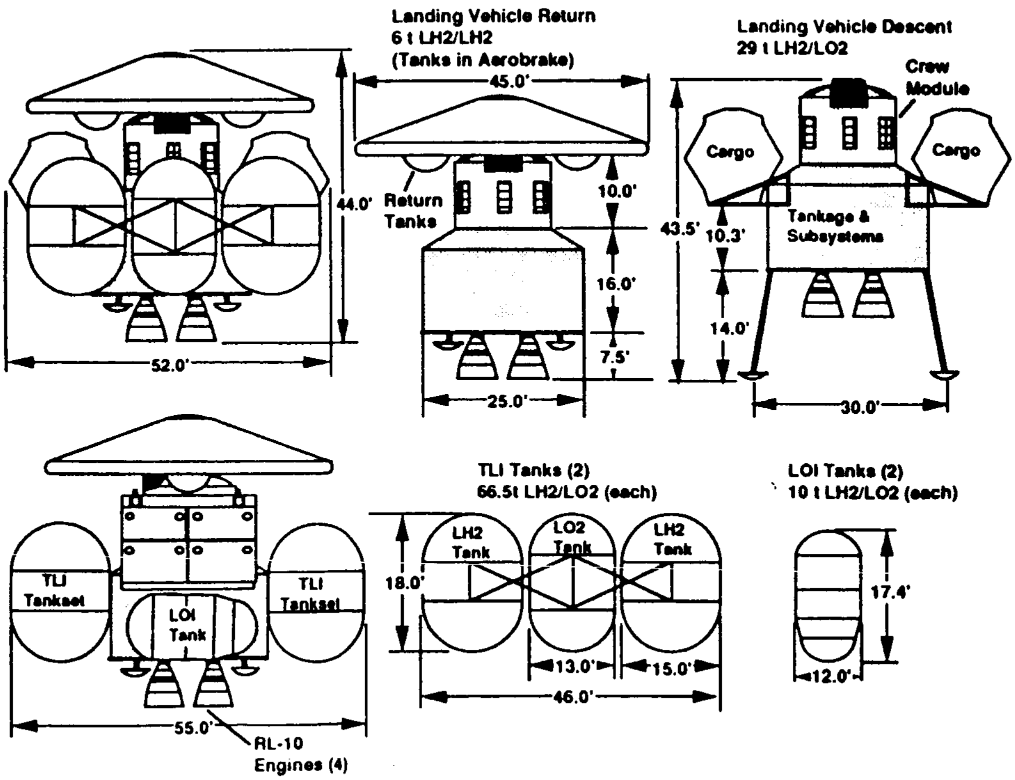
The Transfer/Landing Vehicle stage is 25.0' in Diameter with an overall height of 43.5' when the landing legs are extended. It has two LH2 tanks and two LO2 tanks surrounded by a skirt. The Propulsion System consist of 4 RL-10 Engines and a propellant capacity of 23.0 metric tons. The TLI tankset consist of two LH2 tanks and one LO2 tanks supported in an open frame work The overall length of the tankset is 46.0' and has a propellant capacity of 66.5 metric tons each. The LOI tankset has one LH2 tank, one LO2 tank, and a Intertank structure. The overall dimensions of the tankset are: 12.0' in dia. x 17.4' in length and has a propellant capacity of 10.0 metric tons each. The tanksets are mounted to the Core with struts. Umbilicals connect the TLI and LOI feed lines to the core tanks. Maximum payload capacity is 14.6 metric tons and the payloads are mounted on the sides of Landing Vehicle via payload support racks. The single Crew Module is used to transport the crew to the Lunar surface and the trans Earth/Lunar trip.

The 45.0' diameter Aerobrake is mounted to the Transfer/Landing Vehicle via a docking mechanism and is left in LLO when the Transfer/Landing Vehicle descends to the Lunar surface. The return tanks with 6.0 metric ton of propellant are mounted in the Aerobrake and are connected to the core tanks when the Transfer/Landing Vehicle rendezvous and docks with the Aerobrake for the return trip.

A Mass Properties Statement provides the weight breakout for the various elements.

Configuration Definition - Crew Concept 4E-5B

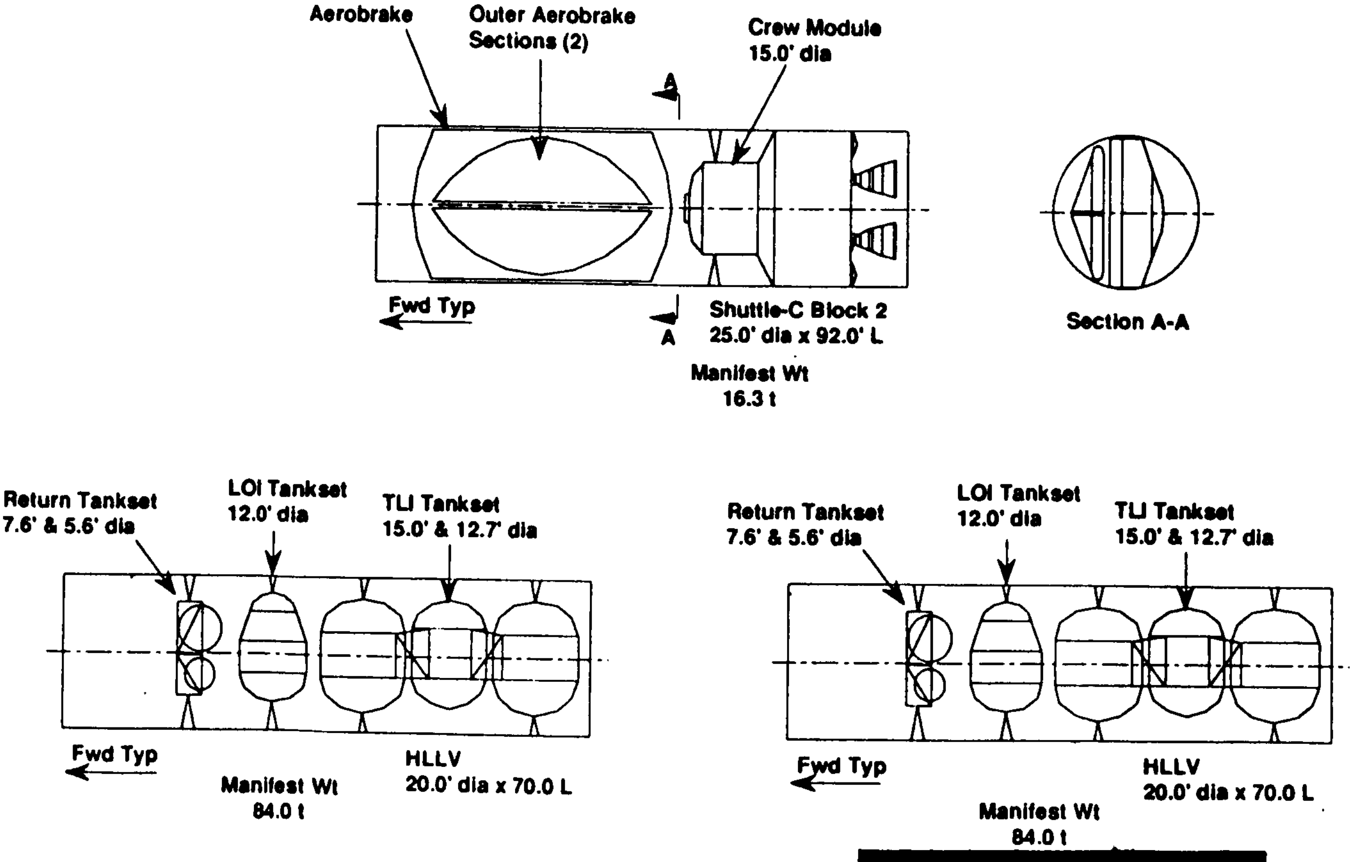
Preliminary Mass Properties (t)	
Transfer/Landing Vehicle Core	
• Tanks	.89
• Structure	1.83
• Propulsion Sys	.33
• Engines	1.24
• Other Subsystems	1.23
• Aerobrake	2.00
• Crew Module	6.62
• Contingency	2.12
• Total	16.26
TLI Tanks (each)	
• Structure	1.91
• Intertank	.19
• Prop Sys	.21
• Other Subsys	.15
• Contingency	.37
• Total	2.83
LOI Tanks (each)	
• Structure	.46
• Intertank	.18
• Prop Sys	.14
• Other Subsys	.15
• Contingency	.14
• Total	1.07
Total Mission Propellant	159.0



Manifest Layout for 4E-5B

The vugraph shows how Concept 4E-5B is packaged in the ETO launch vehicle payload bays for delivery to LEO for assembly. The Transfer/Landing Vehicle and Aerobrake are delivered in one Shuttle-C Block 2 flight . and the TLI, LOI, and Return Tankset are delivered in two HLLV flights.

Manifest Layout for 4E-5B



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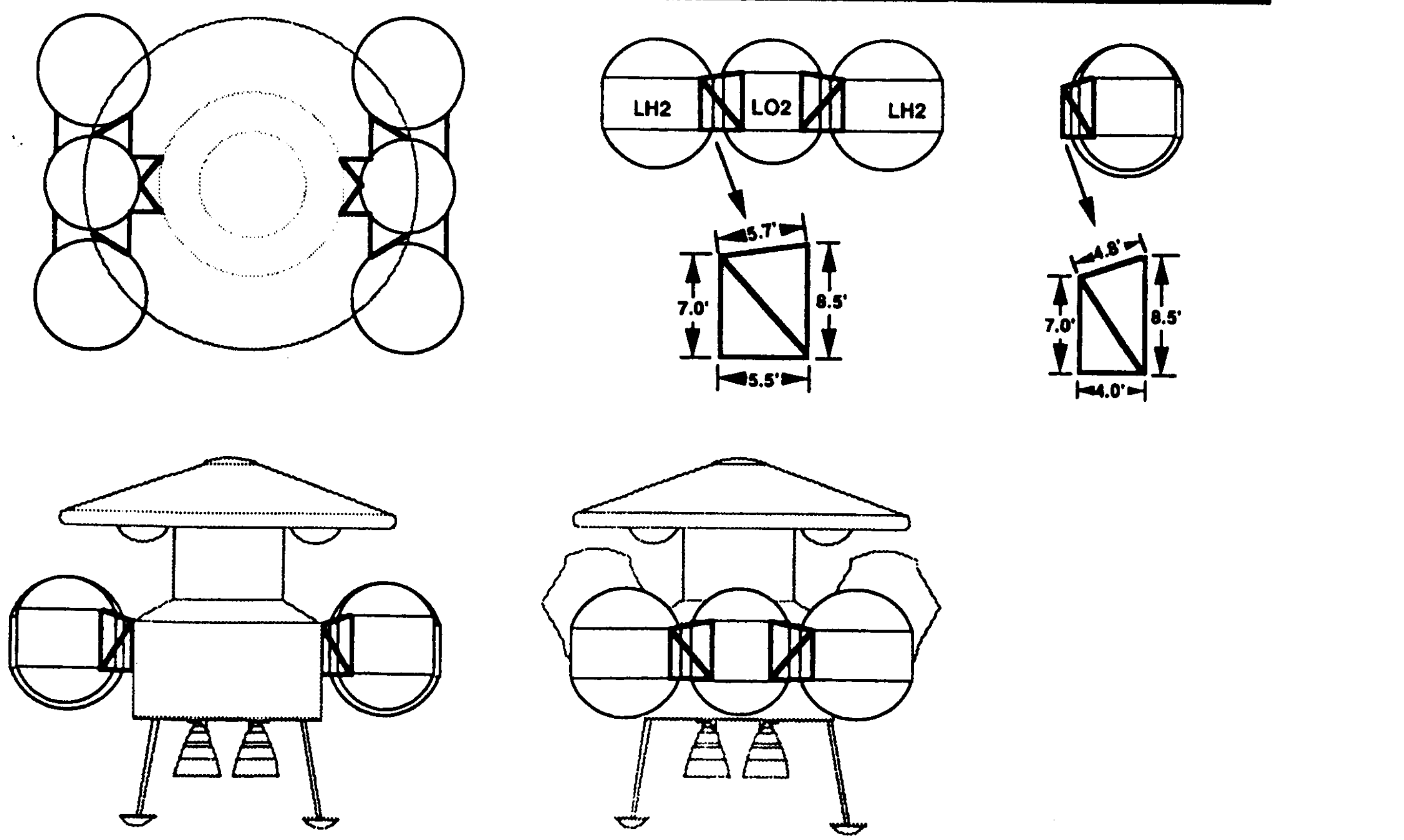
Configuration Definition - 4E-5B TLI Tank Support

The TLI Tankset is composed of two LH2 tanks and one LO2 tank and.tubular truss structure. The LO2 tank forms the backbone of the tankset and the truss work is attached to the tank at the fwd and aft ring frames. The LH2 tanks are then attached to the trusses A similar arrangement of trusses is used to attach the tankset to longerons on the Transfer/Lander Vehicle.

Configuration Definition - 4E-5B TLI Tank Support



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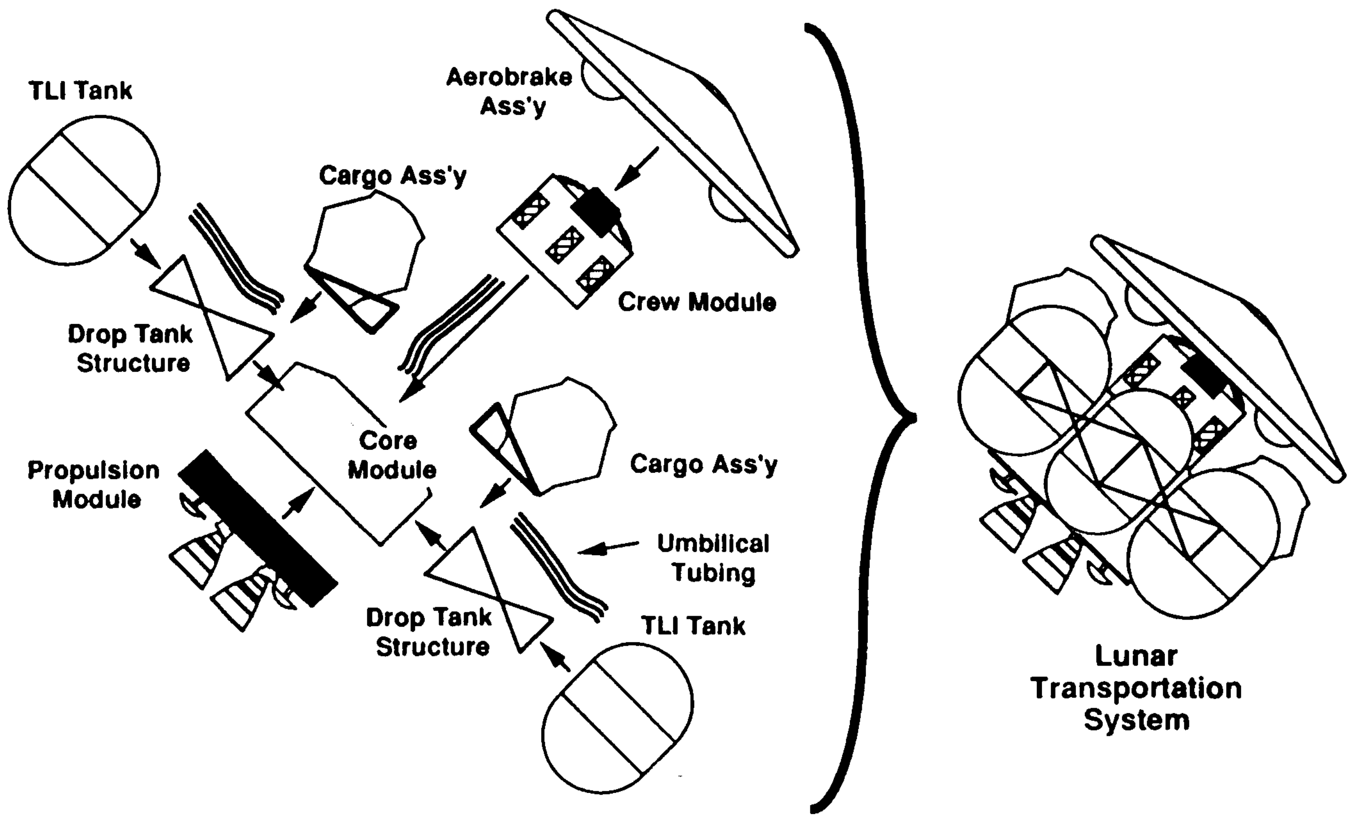
LEO Node Assembly & Checkout Operations:

This chart shows a graphical representation of the major vehicle elements that must be received, assembled, checkout, launched, and refurbish in support the next mission at the LEO Node. The LEO Node operations evaluation is based on defining the complexity of turning the segregated elements on the left, into the integrated and operational vehicle shown on the right.

LEO Node Assembly & Checkout Operations



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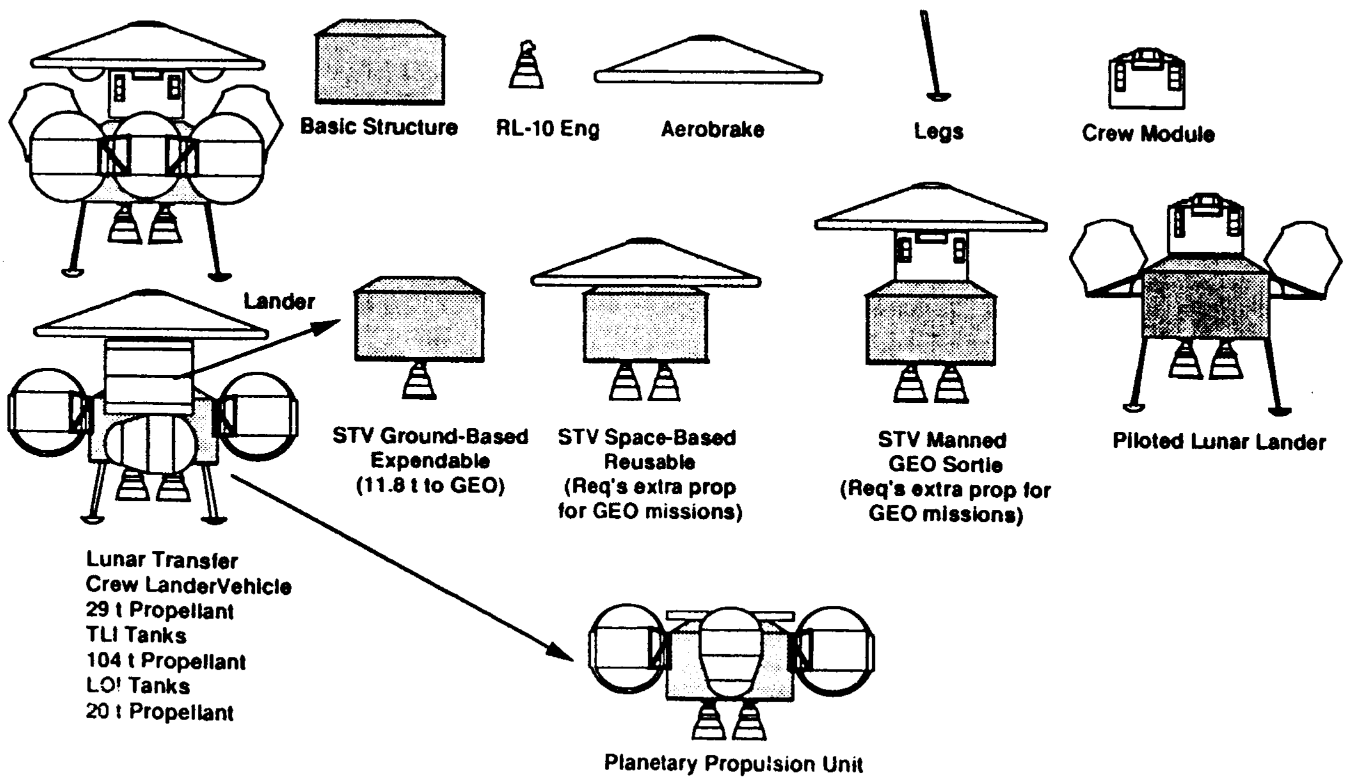
Configuration DRM Adaptability - Cargo Concept 4E-5B

The vugraph shows how the various elements of the Lunar Transfer and Landing Vehicle might be used for STV and Planetary missions. To perform some of the STV missions, additional propellant would be required.

DRM adaptability for this concept without increasing the propellants is:

Transfer/Landing Vehicle	Delivers 11.8 t to GEO
Transfer/Landing Vehicle w/Drop Tanks	Planetary Propulsion Unit

Configuration DRM Adaptability - Crew Concept 4E-5B



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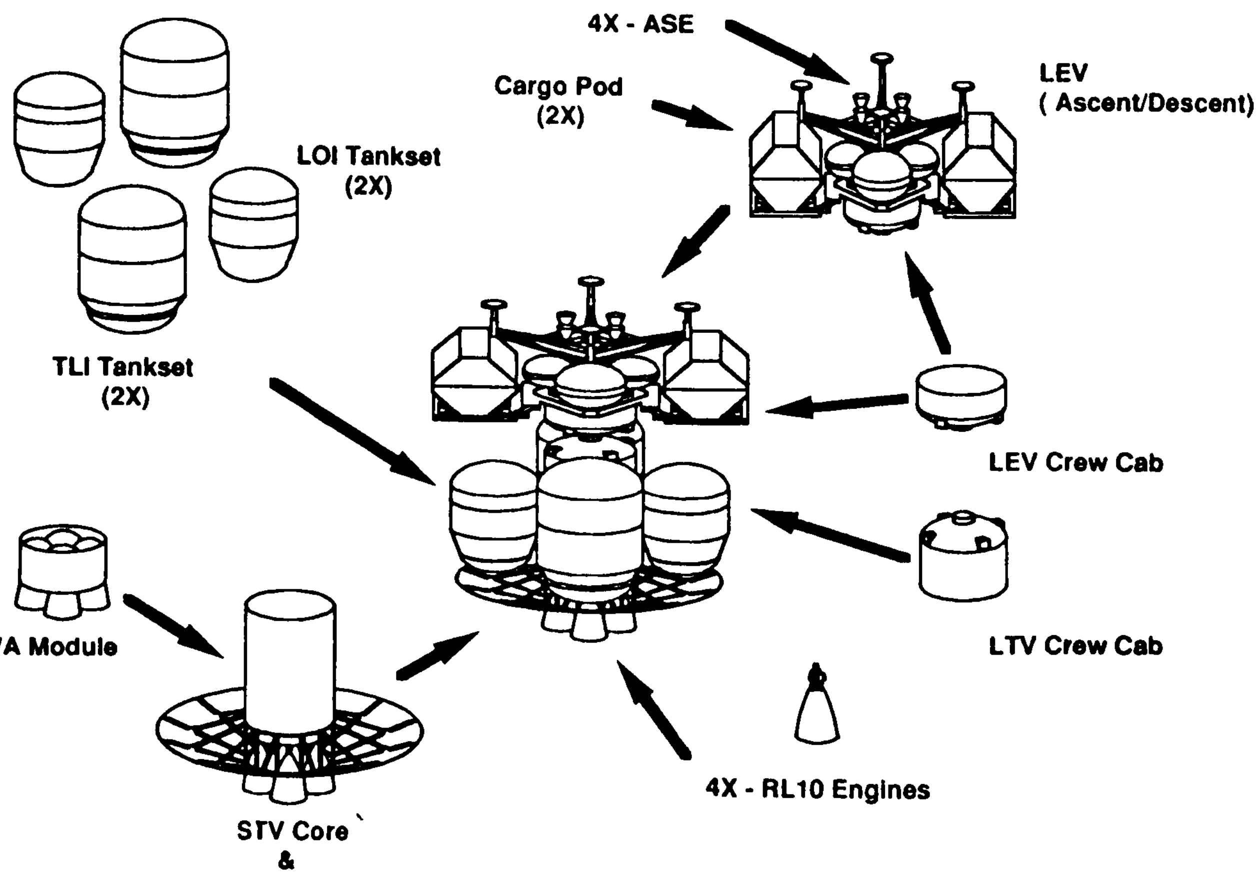
STV/LTV/LEV Commonality

Our approach to the Space Exploration Initiative vehicle selection process emphasized commonality to meet the individual mission requirements for cargo delivery to the moon and man/cargo flights for delivery and return. We formulated evolutionary paths for these systems to grow to satisfy the Mars Exploration usage. We identified alternative conceptual configurations for cargo, combined and personnel-only missions to meet the Lunar, near earth, planetary delivery, and Mars exploration requirements. The STV Core includes main engines, avionics and aerobrake which is mated with cryogenic propellant tanks into the LTS transfer vehicle at LEO. The crew cab is installed together with prepackaged cargo for transfer operations to the Moon. Modular, common avionics, propulsion, and structural components are utilized whenever possible on each vehicle. We have rated each concept with relative cost elements, operational complexity, delivery performance, and other factors and consolidated the options into a selected family of vehicles with recommendations for September approval by MSFC.

STV/LTV/LEV Commonality



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Criteria for Operational Objectives

Criteria for STV design, technological advancements, and launch site test philosophy need to be met to guarantee the turn-around assessment of the ground based STV will be achieved. Each criteria results in improved operational capabilities from current processing. These improvements are realized in reduced times and manpower, and ultimately in significantly decreased operational contributions to life cycle.

Criteria For Operational Objectives

- **Design Features**
  - GO_2/GH_2 Attitude Control Supplied by Main Propulsion Interface
  - Automated Leak Detection
  - No Post Mission Drain/Purge Requirements
  - Minimal STV/Spacecraft Interfaces
  - Minimal STV/Launch and Landing Vehicle Interfaces
  - High Accessibility and Quick Fasten/Release ORUs
- **Technologies**
  - Eliminate Ordnance
  - No Planned TPS Turn Around Refurb - Ease of Repair and Inspection
  - Fault Detection/Fault Isolation to ORU Level
  - Self-Alignment and Auto Mate/Demate Mechanical Interfaces
  - Self Monitoring Engines that Use Flight Data to Determine Health and Maintenance Requirements

Test Philosophy

- Minimal On-Line Operations
- Testing at System Level Only
- No Repetition of Tests Due to Facility Transfers

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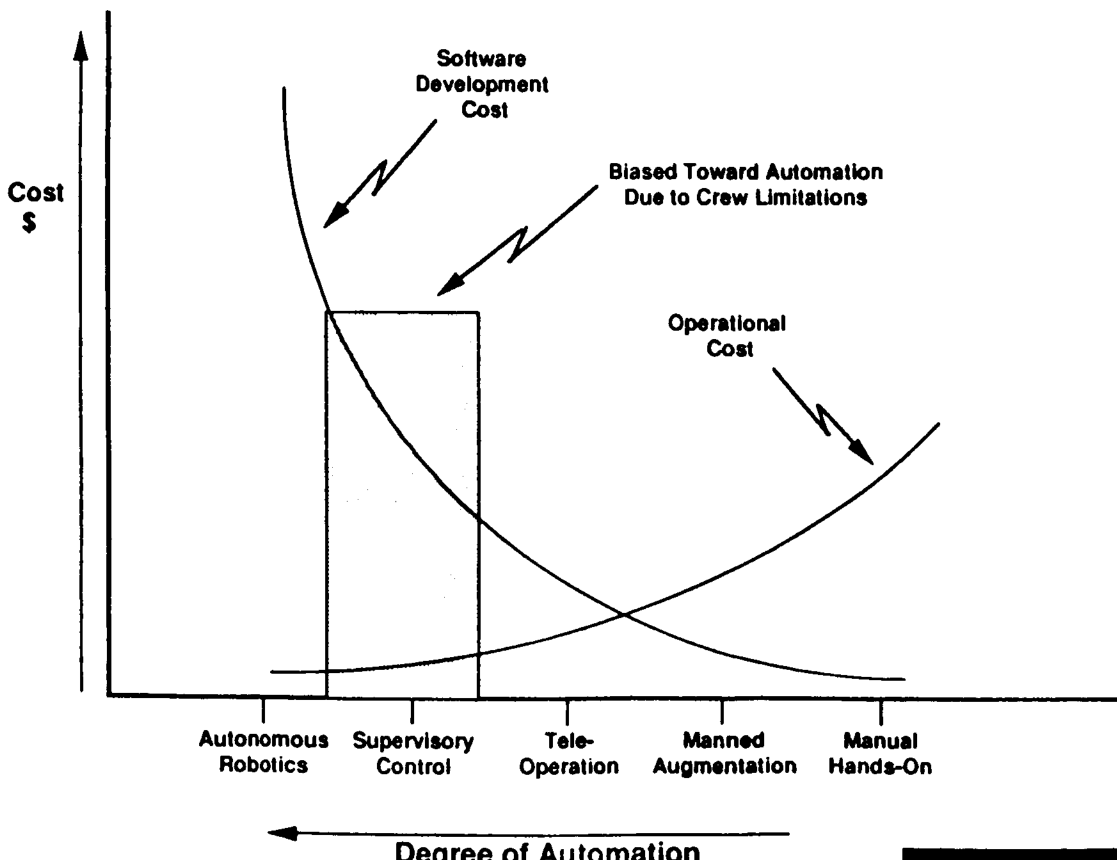
Degree of Automation

When considering whether to perform processing operations at space station by EVA or IVA, it is not just a decision between robotics and manual EVA. Automation is a continuum stretching from hands-on operations through to autonomous robotics. Level of complexity and development costs soar as operations are made completely automated. A degree of manual intervention tends to keep cost down by allowing human decision making to determine what to do next, and then have the robot do a limited set of tasks. This is normally referred to as supervisory control.

For STV processing support from the space station, we must also consider the availability of personnel at the station for STV related activities. By utilizing an IVA astronaut, supervisory control, and an RMS robotic arm, we would minimize the demands made on the astronaut and the time necessary for turn-around of an STV mission.

Degree of Automation



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EVA vs IVA Preliminary Ranking

We conducted an in-depth trade study to assess the level of automation that should be incorporated in space-based STV support operations. This assessment included evaluation of the parameters listed below. Consideration was given to performing specific operations with EVA, remote operations with an IVA crew member providing control, and fully automated robotic operation. We found that remote operations were preferable to fully automated operations in most cases, although the precise level of automation depends on the specific task. The ranking shown in the chart below is generically indicative of the preferred approach.

EVA vs IVA Preliminary Ranking

Parameter (10 is Best, 1 is Worse)	EVA	RMS (Teleop)	Auto Robotics
Operational Crew Requirements	1	5	10
Maintenance Crew Requirements	10	5	1
Development Cost	10	8	1
STV Design Drivers	10	9	8
TPS Inspection and Repair	5	4	2
Propellant Loading	1	8	10
Operational Cost	1	7	10
Payload Mating	1	10	6
Pre-Launch Testing	1	10	9
Scheduled/Uncheduled Maintenance	1	9	10
Totals	41	75	67

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EVA vs IVA Trade Study Summary

The charts shown below and on the following two pages summarize the results of the analysis performed. In addition to the evaluative notations provided against each of the parameters, a rating of 1 to 10 (10 being best) is also assigned to each of the parameters being evaluated to provide a comparative ranking.

EVA/IVA Trade Study Summary

Parameter	EVA		RMS (Teleoperator)		Autonomous Robotics	
Operational Crew Requirements	Requires Crew of Three 2 - EVA, 1 - IVA	1	Requires Crew of One	5	No Crew Required for Operation	10
Maintenance Crew Requirements	EVA suit, Support Tools & Equipment (Very Limited)	10	RMS Arm, End Effectors, Elec- tronics (Probably In Pressurezed Area) (Limited)	5	MRMS, End Effector, Support Mechanisms, Electronics (Probably Not In Pressurized Area) (Extensive)	1
Development Cost	Existing Technology (None)	10	Existing Technology Requires Application and System Clarifica- tion and Software Development (Limited)	8	Requires Development of an Autonomous System as Well as Extensive Software and Space Qualification (Extensive)	1
STV Design Drivers	Requires BITE, Accessibility, Ease of Repair & Replacement	10	Requires BITE, Accessibility, Modular Design, LRUs Indexed to Position on Cradle	9	Requires BITE, Accessibility, Modular Design, LRUs Indexed to Position on Cradle, Indexed Storage Areas, Additional Arms	8

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EVA/IVA Trade Study Summary (Continued)

Parameter	EVA		RMS (Teleoperator)		Autonomous Robotics	
TPS Inspection and Repair	Visual Inspection. Repair Could Be Possible, Albeit Very Difficult	5	CCTV Inspection Also Advanced Techniques Such as Acoustical, Optical, Radio, Graphic	4	Auto Inspection Using Advanced Techniques. Repair Probably Not Possible	2
Propellant Loading	Unsafe Utilization of EVA Manpower	1	Could Be Readily Performed Under Remote Control	8	Automated Quick Connect/Disconnect System Could Be Implemented	10
Operational Cost	Ties Up 3 Crewmen. Very Expensive	1	Only 1 Crewman Involved. No Pre- or Post-EVA Requirements. Operational Time is Less. 1/7 the Cost of EVA.	7	No Operational Crew. Some Crew Involvement in Maintenance and Servicing or Automated Equip. Less than the Cost of RMS.	10
Payload Mating	Ineffective Use of EVA Manpower	1	Easily Implemented and Effective	10	Could be Implemented, but Adds Complexity	6

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EVA/IVA Trade Study Summary (Concluded)

Parameter	EVA		RMS (Teleoperator)		Autonomous Robotics	
Pre-Launch Testing	Ineffective Use of EVA Manpower	1	Umbilical Could Be Remotely Connected and Checkout Conducted From Control Console	10	Testing Could Be Completely Automated. Adds Complexity	9
Scheduled/ Unscheduled Maintenance	Requires Transporting Work Station, LRU to Work Site, Performing R & R and Transporting Back	1	LRU Transported By RMS. R & R Readily Performed	9	LRU Transported by MRMS Precisely and Safely. R & R Easily Performed	10
Totals		41		75		67

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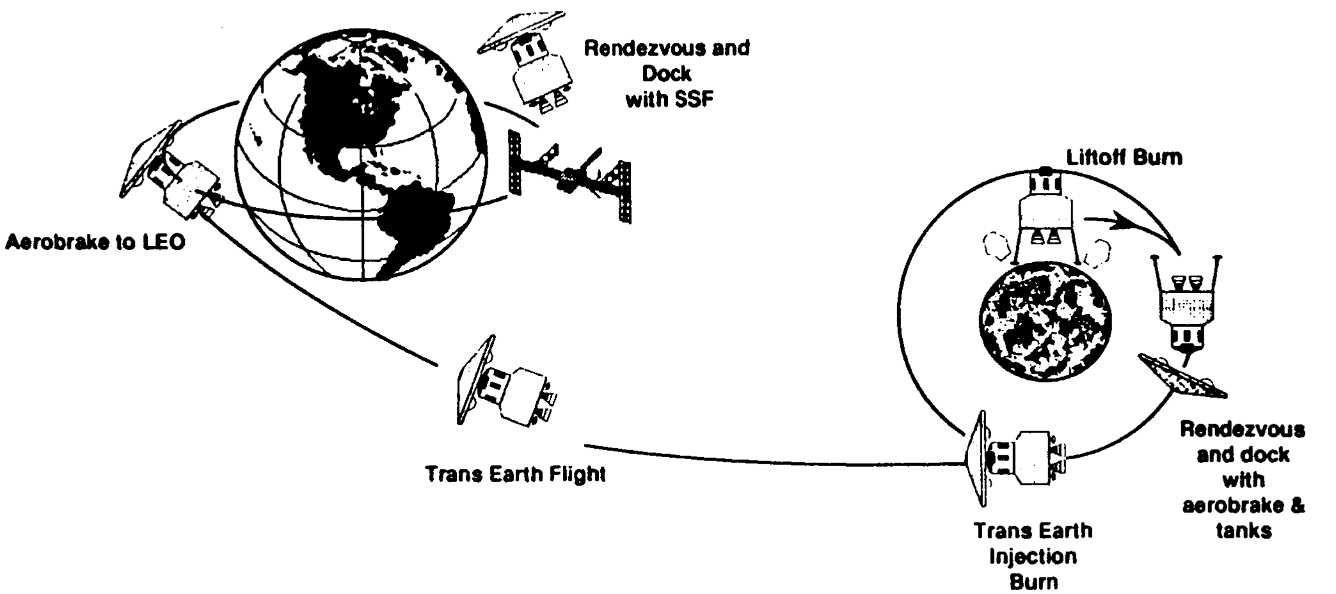
Mission Scenario 4E-5B Return Mission

The mission begins with the lift off burn. The vehicle performs a rendezvous and docking maneuver with the aerobrake and tanks which remained in orbit after the Outbound mission. The Trans Earth burn is accomplished using propellants from the aerobrake tanks. The vehicle performs an aerobrake reentry and rendezvous and docking in LEO.

Mission Scenario 4E-5B, Crew & Limited Cargo Return



Return Flight

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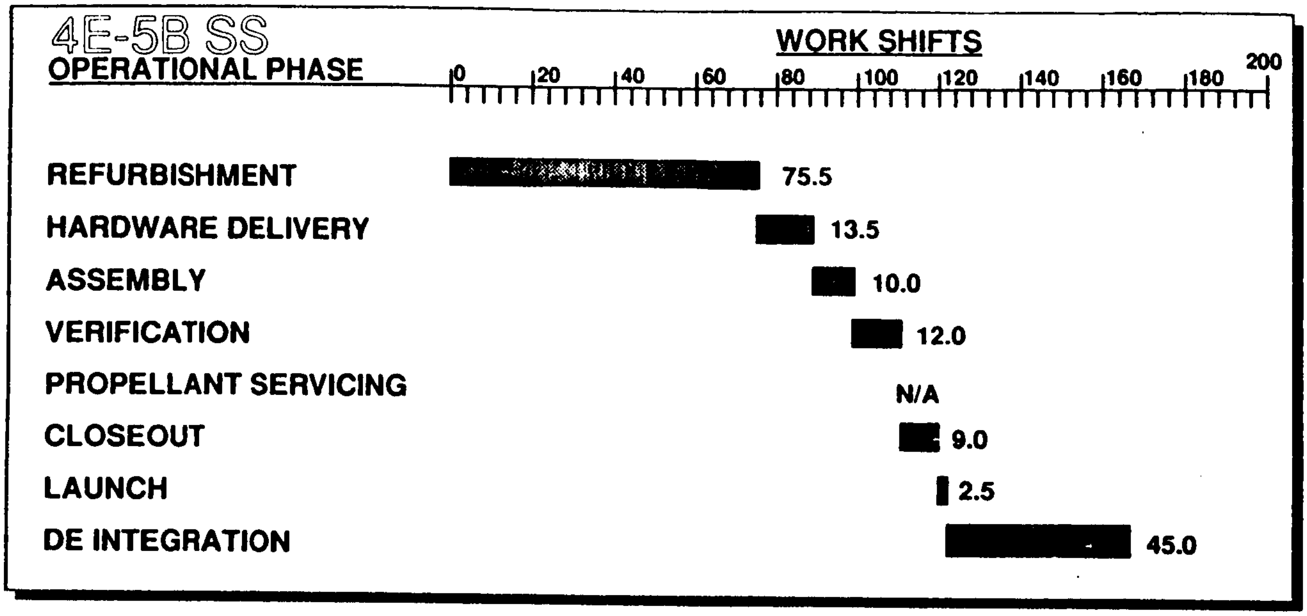
On-orbit Servicing Timelines - Steady State Operations



- Manned reflight configurations do not vary more than 3% in complexity and 5% in timelines. These differences are not significant.

STV at Work, Concept 4E-2B - 90 Day Reference

Concept 4E-2B is a single stage Transfer Vehicle with drop tanks, a separate landing vehicle and two crew modules. This Concept requires 2 Shuttle-C and 2 HLLV flights to deliver the Lander, Transfer Vehicle Core, Aerobrake, and Drop Tanks to LEO for assembly. Pre-flight assembly and final verification along with flight recertification and re-certification is accomplished at LEO.

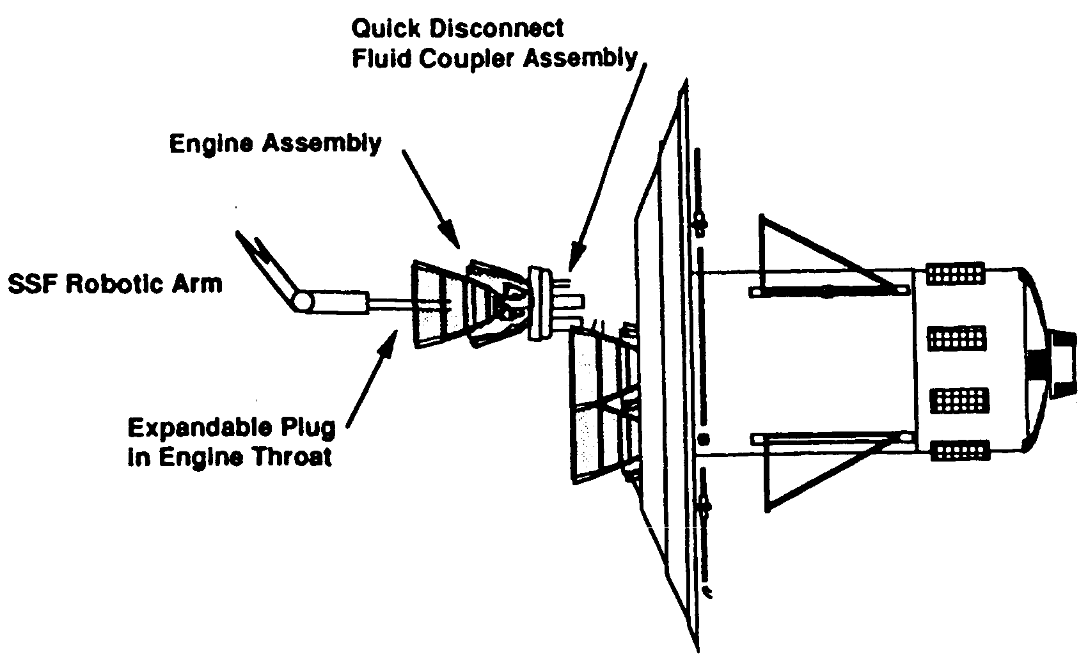
The Transfer Vehicle with a 45' dia. Aerobrake has 4 RL-10 engines with a propellant capacity of 5.7 t in the STV core tanks, 107.2 t in the TLI Drop Tanks, and 41.8 t in the LOI Drop Tanks. The Landing Vehicle has 4 ASE (Advanced Space Engines) with a propellant capacity of 22.3 t.

The picture on the left depicts the LTV with cargo performing the main engine burn to start the journey to the moon. The picture on the right shows the LTV and LEV in lunar orbit. This picture was taken after the crew and cargo transfer and the two vehicles have separated. Note that the TLI drop tanks are no longer attached to the LTV.

LTV Main Engine Changeout

Using a single robotic arm equipped with an engine handling fixturing, and an engine assembly equipped with a pneumatically actuated release plate, removal and replacement of an LTV main engine becomes a relatively normal maintenance task.

LTV Main Engine Changout



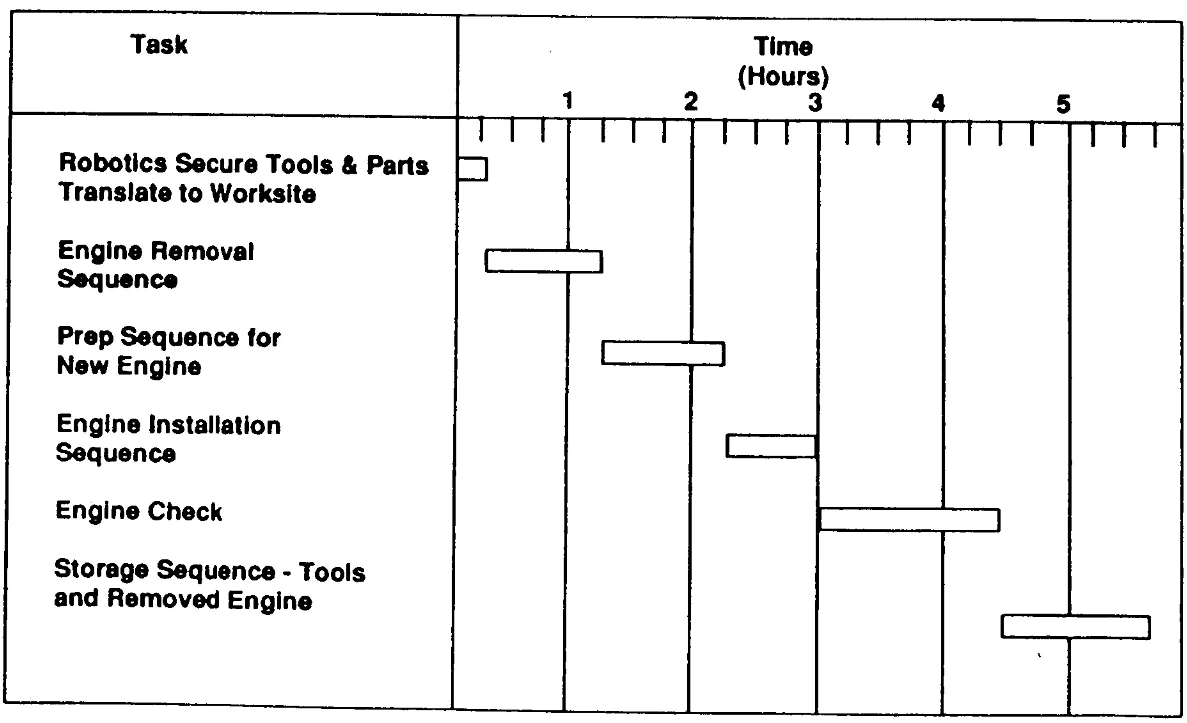
STV Main Engine Remove/Replace Timeline

On-orbit removal and replacement of the STV main engines can be accomplished through the use of automated systems if the STV and main engines are initially designed to accommodate these activities. A special tool will be required to release and support the main engine during removal and installation activities. This tool should be adaptable for either robotic or EVA operation.

Main engine replacement can be accomplished in approximately 5.5 man-hours through the use of robotics. This projected time is supported by data received from Rocketdyne and Pratt and Whitney regarding the anticipated removal and replacement of their engines on-orbit. In comparison, EVA operations to perform this activity would require approximately 13 man-hours to accomplish.

If it is determined that the on-orbit removal of the turbopumps is cost effective and desirable during engine replacement, then an additional 4.5 hours per turbopump must be added to the timeline. This will result in an expenditure of approximately 14-15 hours (two turbopumps) to complete the entire operation. Special tools for turbopump removal/installation would be required, as well as a special engine stand to withstand torque requirements.

STV Main Engine Remove / Replace Timeline



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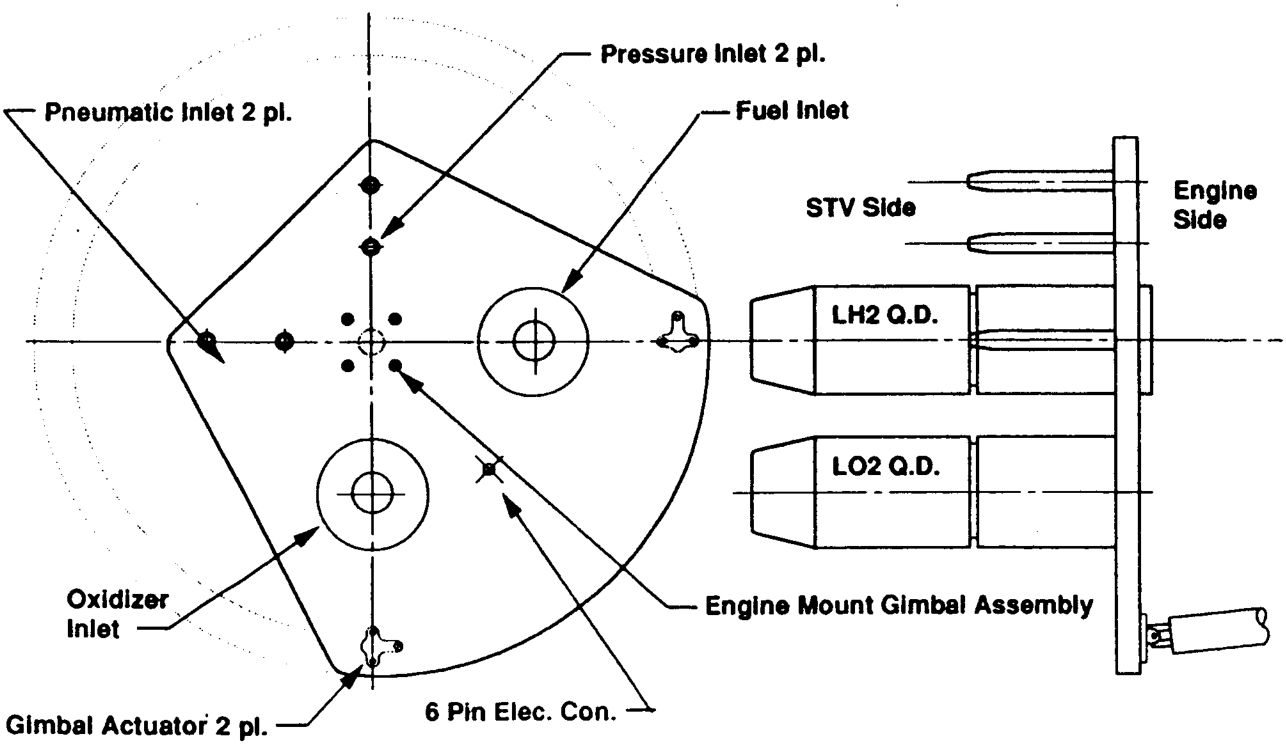
STV Main Engine Mate/Demate Mechanism

This mechanism employs an engine interface plate onto which are mounted six quick disconnect probes. On the opposite side of the interface plate to the probes are mounted the engine gimbal and its two gimbal actuators. This enables the engine to be installed just like a plug-in module.

STV Main Engine Mate/Demate Mechanism



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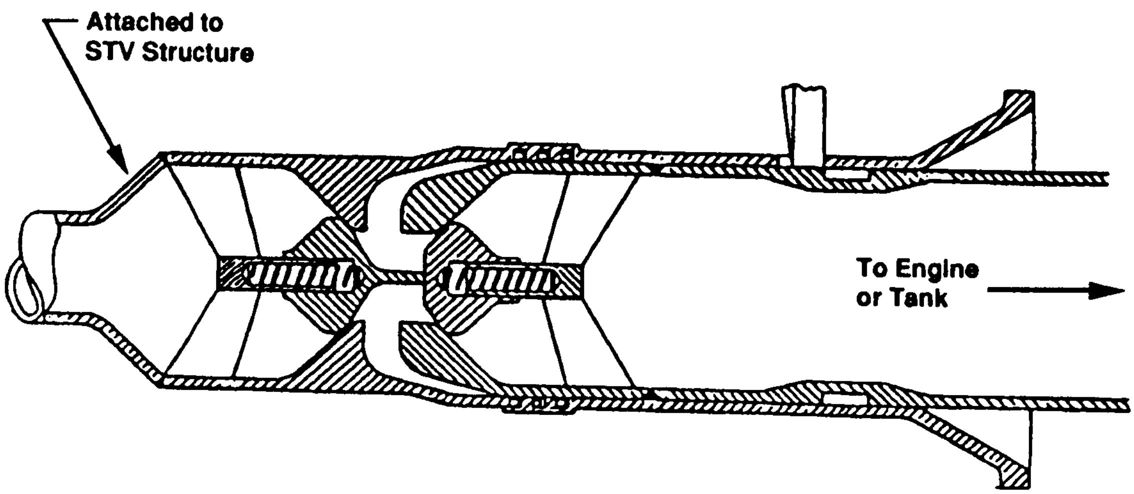
Cyrogenic Fluid Probe / Quick Disconnect.

This conceptual quick disconnect is shown not yet fully engaged. When fully engaged, both poppets fully open and the pneumatic cam latch aligns with its mating groove in the probe. When activated, the cam engages the groove in the probe and its tapered surface produces a preload into the probe engagement. The probe side structurally attaches to the engine, tank, or aerobrake (ACS system). The configuration shown would only be for propellant tanks as the engine would require no poppet valve in the probe side, while the ACS system would require no poppet valves at all. The nose of the probe is shaped to minimize the chances of any misalignment from damaging the seals Note the seals are engaged prior to the poppets opening.

Cryogenic Fluid Probe / Quick Disconnect



Open Design Issues
- Man Rating
- Thermal Isolation from Structure
- Thermal Insulation
- Seal Design
- Materials

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Alternate STV Propulsion Concept

Martin Marietta and Aerojet Tech Systems cooperated under MM IRAD D-34S to conceive, analyze and evaluate the use of an integrated propulsion/airframe configuration using modular, high performance, cryogenic liquid rocket engines arranged in an annular ring around a modified plug nozzle concept for two separate main engine functions in the Lunar Transportation System. Multiple engines provide increased reliability and improve man rating potential.

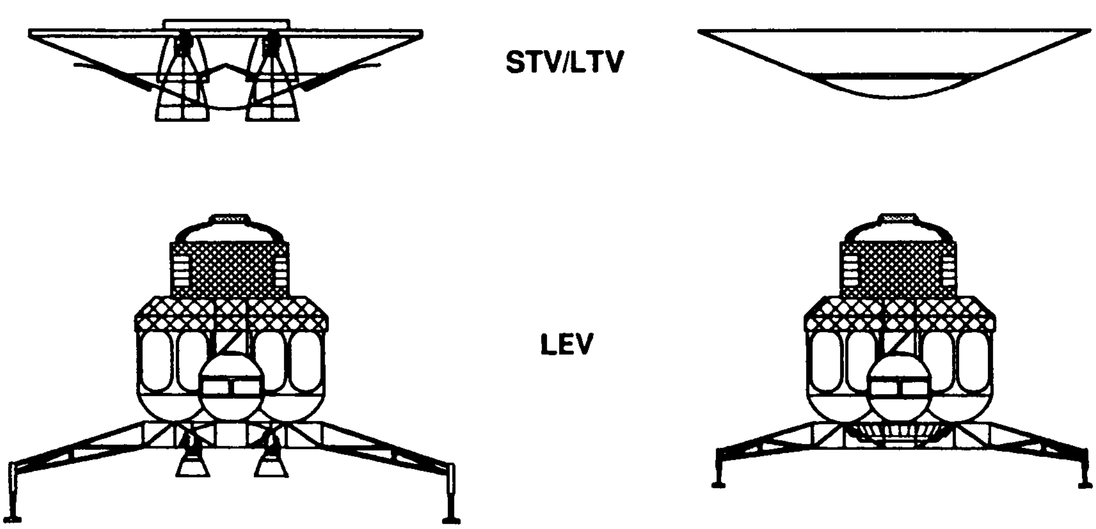
The STV/LTV configurations utilizes these engine subassemblies located on the aerobrake windward side and positioned through the aerobrake hot side during main engine burns. No aerobrake doors are required.

The Lunar landing/ascent exploration configuration substitutes an annular ring of similar engines, operated in the throttling mode, around the truncated plug central core to provide a diffused rocket plume landing similar to the multi nozzle landing propulsion on the Mars Viking Landers.

Alternate STV Propulsion Concept

IRAD D-34S

Conventional Engines | **Modular Engine Systems**



GenCorp
Aerojet TechSystems

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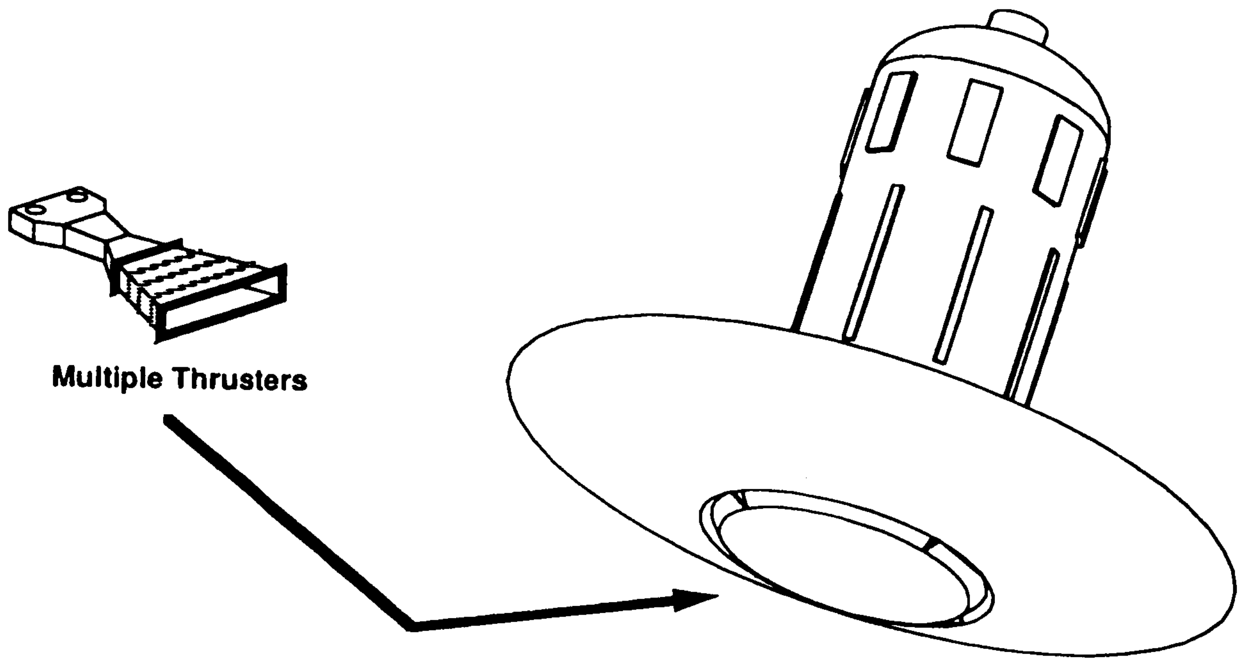
STV Core With Integral Engine/Aerobrake

The STV core is shown with the modular engine system built into the aerobrake. The engine is comprised of multiple thrusters, similar to that shown in the inset. The configuration remains intact for the engine firing phases of the mission as well as the aerobrake phases. Doors are not required to cover the engines.

STV Core With Integral Engine / Aerobrake

IRAD D-34S



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What Do We Impact? / How?

- Space Station (If Used)
  - Science; Microgravity, View Angles
  - Reboost Propellants
  - Control
- Costs (If Nodes Used)
  - Same Systems as on Space Station

Operational Drivers at Space Station Freedom

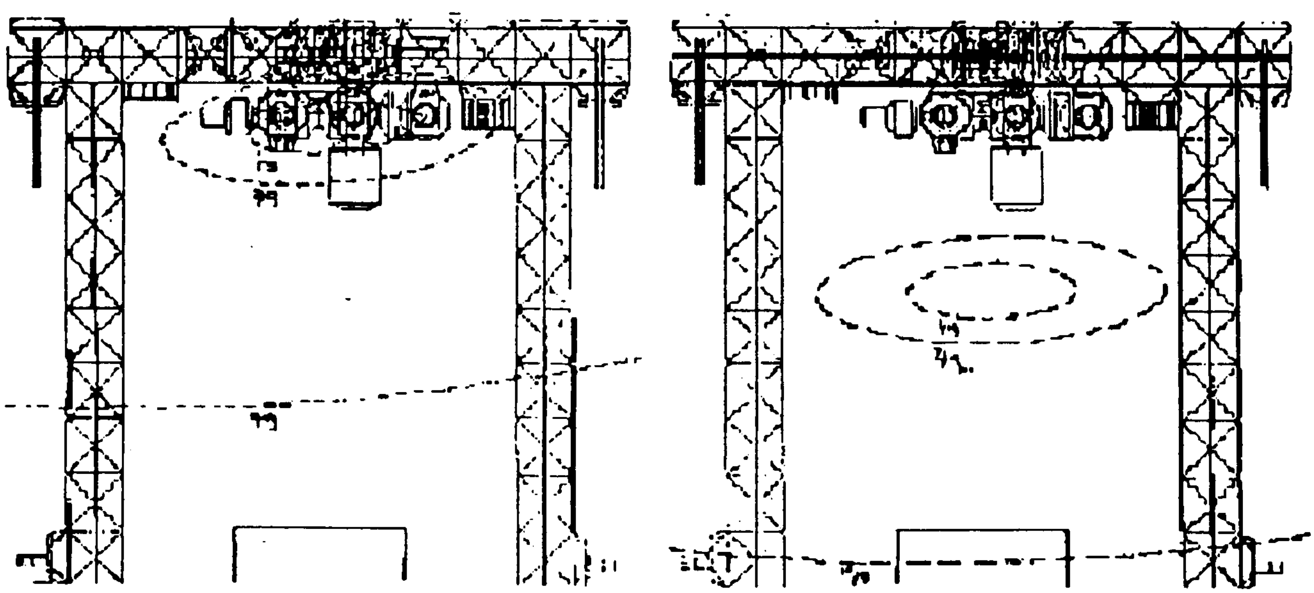
DRIVER	*IMPACT*
PROGRAM	
1. 2 vs 1 Lunar Flights Per Year	Doubles Processing Time At SSF
2. Expendable vs. Reusable Cargo Flights	Reusable Flights Requires A Node
SYSTEM	
1. Number of Elements In System	Greater Number Of Assembly Operations
2. Automated Rendezvous & Docking vs Teleoperation (Unmanned)	Crew Time Required At SSF For Teleoperation
3. Built In Test vs. SSF Checkout	Equipment/Interfaces Required At SSF
SUBSYSTEM	
1. Aerobrake Assembly vs Deployable	Greater SSF Assembly Operations
2. Propellant Transfer vs Wet Tanks	More Complex Vehicle Operations
COMPONENT	
1. Line Replaceable Units vs Integral	Less Subsystem Disassembly
2. Electro-Mechanical vs Hydraulic Actuators	Reduced Maintenance

STV Mass Sensitivity - Microgravity Environment

Station center of gravity location is shown as a function of STV mass. A Level II directive (BB000610A) has been recently issued, changing the previous requirement of 10 μg in the laboratory modules. This directive states that the Station "shall be capable of providing quasi-steady acceleration levels not to exceed 1 μg for at least 50% of the user accommodation locations in each of the pressurized laboratories (US Lab, ESA and JEM PM at AC)". As shown in the plot of % total laboratory volume within 1 and 10 microgravity levels, any appreciable mass STV supported on a lower keel will not be able to meet this directive.

STV Mass Sensitivity - Microgravity Environment

1, 2 and 10 μG Contours for 0 Mass STV and 200000 kg STV with Servicing Enclosure Supported on a Lower Keel



Empty Enclosure - No STV

200000 kg STV

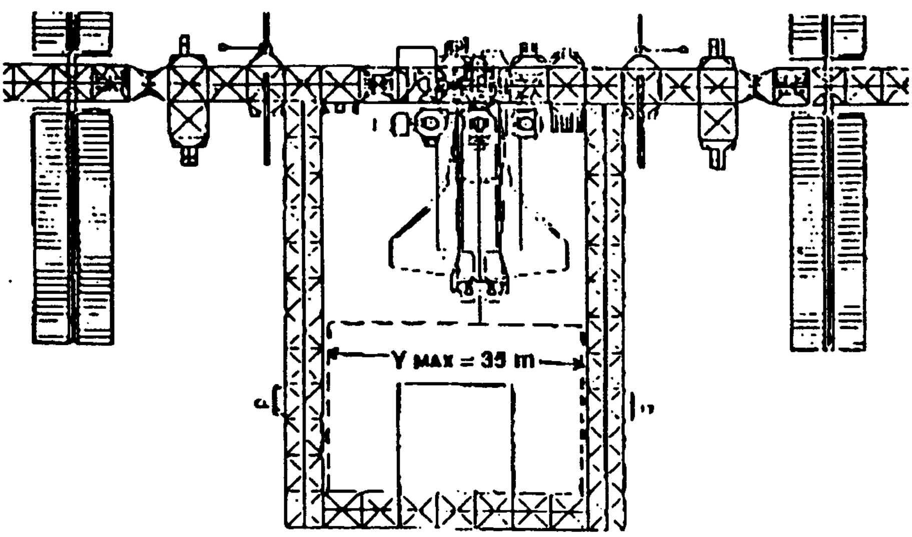
STV Mass on Lower Keel Has Severe Impact to SSF μg Environment

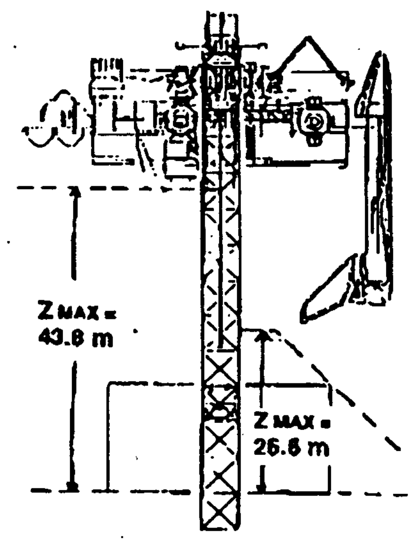
STV Size Sensitivity - Enclosure Limits

The size to which an STV can grow within the constraints of the Space Station system is governed by the limits to growth of its enclosure. The two dimensional constraints are in the Y (or latitudinal) dimension and the Z (or radial) dimension of the Station configuration. The STV enclosure is assumed to be placed in a location bounded by a "lower keel", or two downward pointing extensions of the truss structure connected by a cross boom. The boom dimensions are governed by the physical space available on the main truss structure as well as constraints in station controllability which govern the extent to which the truss can grow downward.

As depicted on the figure, the maximum dimension the enclosure can grow along the Y axis is 35 meters. Thus the maximum STV diameter within the enclosure will be 31-33 meters, depending on safety factors. In the Z dimension, the limit, as shown, has two components. Forward of the lower keel truss structure plane, the maximum enclosure growth limit is 26.6 meters. This is due to clearance requirements for STS docking to the Space Station. Aft of the truss structure plane, the limit is relaxed to 43.8 m, which is bounded by the envelope for a pressurized logistics module attached to a min-node.

STV Size Sensitivity - Enclosure Limits





STV size can grow to within 4m of enclosure growth limits

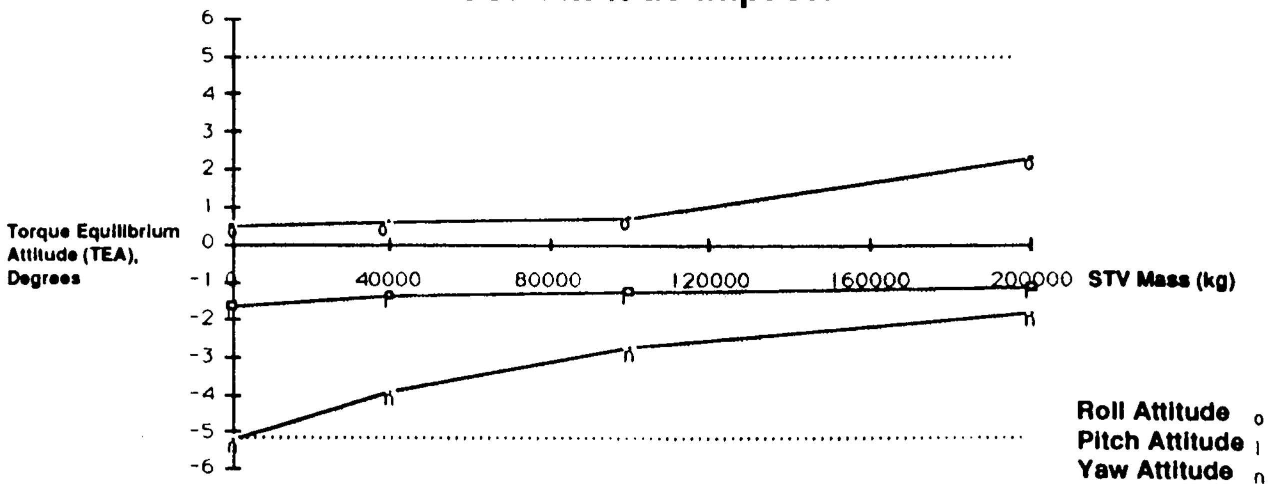
STV Mass Sensitivity - GN&C

For this analysis, it was assumed that a high-mass STV is supported in a 15.3 x15.3 m servicing enclosure positioned on a lower keel of the Space Station. This configuration is from the November 1989 NASA 90-day study on Human Exploration, which recommended the addition of a lower keel to support lunar operations.

Space Station Freedom flies at Torque Equilibrium Attitude (TEA), where aerodynamic and gravity gradient torques cancel. Current analysis indicates that the TEA of the Assembly Complete Station has a large negative pitch angle and will not meet the requirement to fly within +/- 5 degrees of LVLH. The addition of a lower keel will significantly improve the pitch attitude. As the mass of the STV is increased, pitch and yaw attitudes are further reduced toward LVLH. Roll TEA attitude increases with additional STV mass, but over the range of potential STV mass to be supported, Station TEA will remain within the +/- 5 degree requirement.

STV Mass Sensitivity - G,N&C

SSF Attitude Impacts



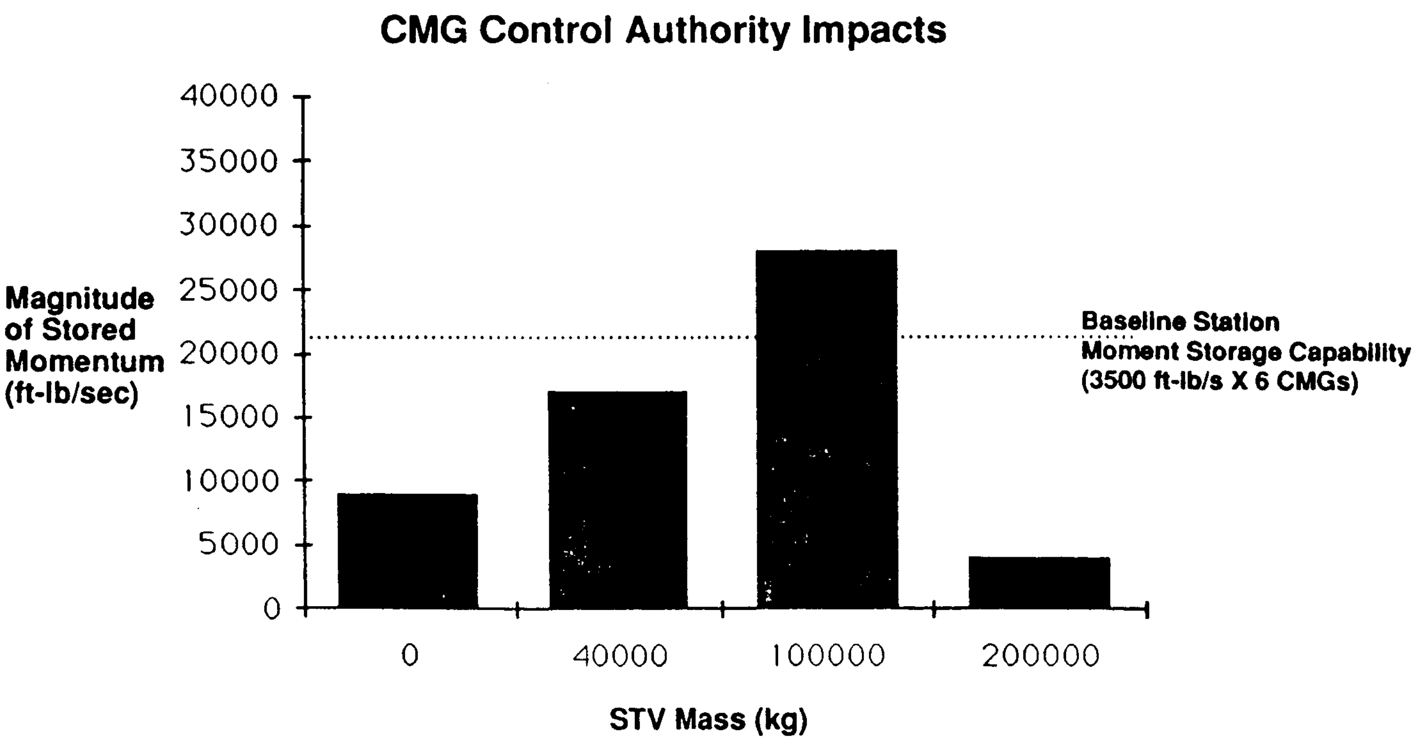
Assumptions:
- ± 5° in pitch is SSF req't (Source: SSFP Document 30426)
- Low mass STV mounted on horizontal keel
- Higher mass STV mounted on lower keel
- C.G. of high mass STV located at X=0, Y=0, Z=-50m

Increased STV Mass "Helps" Maintain SSF Pitch Attitude

STV Mass Sensitivity - GN&C

Baseline momentum storage capacity for Space Station Freedom is provided by a pallet containing 6 Control Moment Gyros (CMGs). Each CMG provides 3500 ft-lb/s of momentum storage for a total of 21000 ft-lb/s capacity at Assembly Complete. Required momentum storage capacity is a function of many variables, including specific configuration and momentum management scheme during flight. Analysis using a momentum-management simulation indicates that increased STV mass will have low impact on Station control. Required momentum storage capacity initially increases, then is reduced for higher-mass STVs, when the aerodynamic torque effects are offset by the large gravity gradient torque gains. The maximum momentum storage requirements can most likely be met by the addition of two or three CMGs over the range of STV mass to be supported on a lower keel. Location of these additional CMGs is not critical, and could be supported on or near the existing CMG pallet.

STV Mass Sensitivity - GN&C



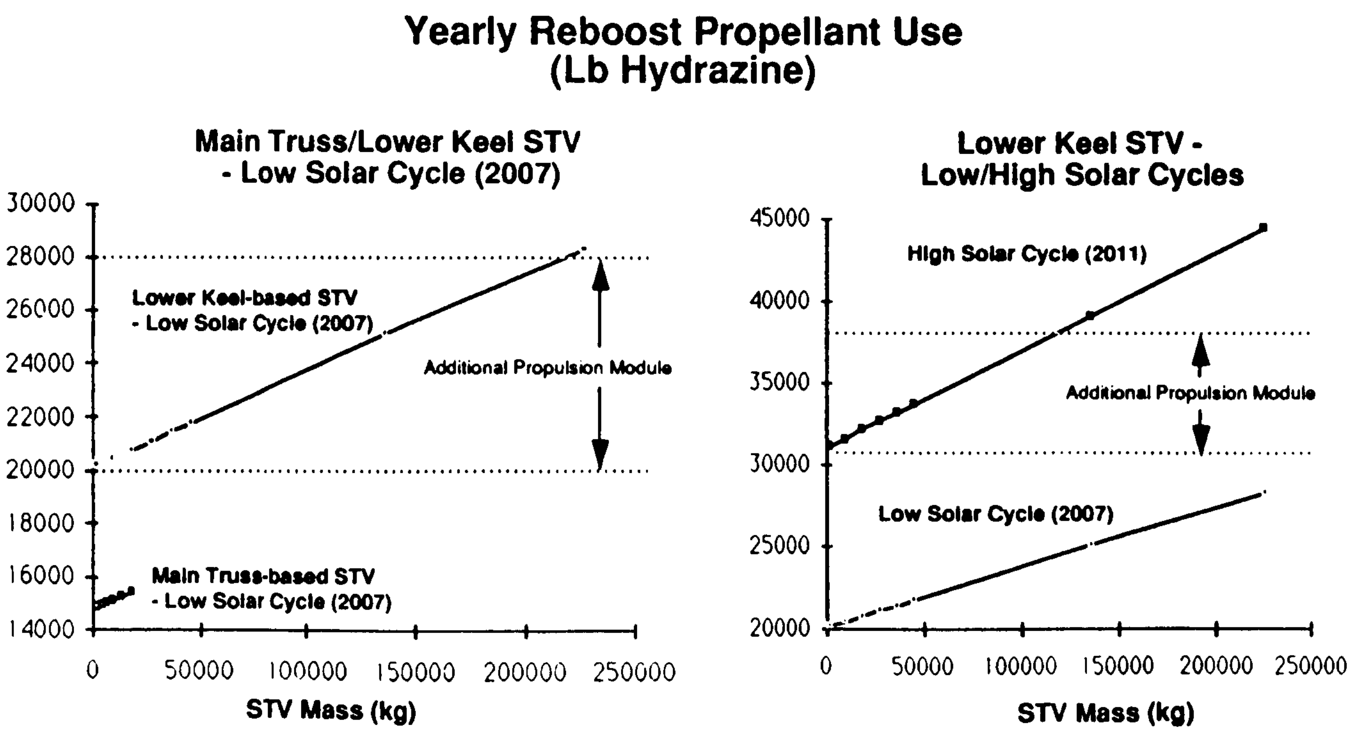
STV Mass Near 100,000 kg Requires Additional Control Moment Gyros (CMGs) to Manage Increased Station Momentum

STV Mass Sensitivity - Reboost Logistics

Reboost propellant required during a low solar cycle year is shown as a function of STV mass. This chart compares the propellant required for a low-mass STV based on the main truss as an attached payload with a large-mass STV supported on a lower keel. The addition of the lower keel and servicing enclosure increases Station propellant use by about 5000 lb Hydrazine. After this initial increase, the entire range of STV mass will not require more than one additional propulsion module (8000 lb Hydrazine) for the low solar cycle year.

Yearly required reboost Hydrazine is shown for both low and high solar cycle years over the range of STV mass on a lower keel. The high solar cycle year is the worst-case for reboost requirements and will require up to two additional propulsion modules over the STV mass range.

STV Mass Sensitivity - Reboost Logistics



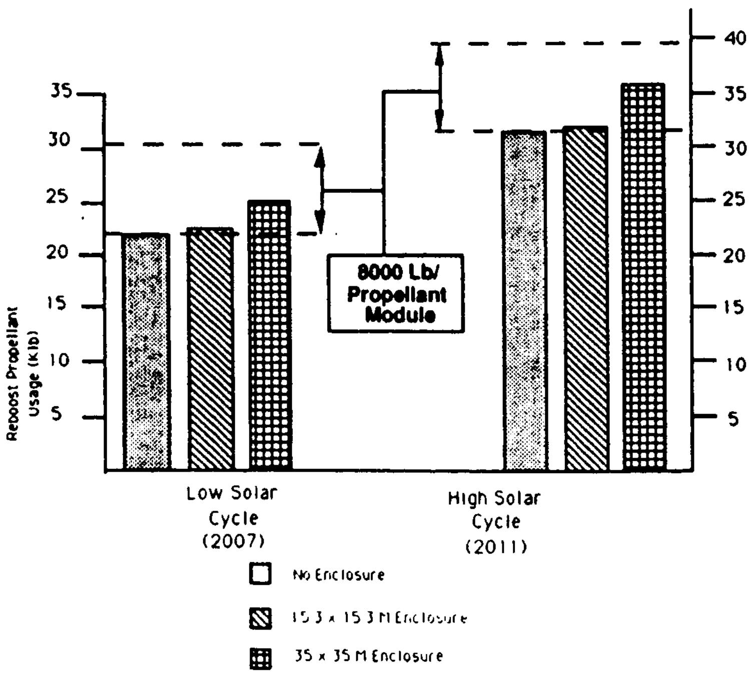
Increases in STV Mass have Moderate Impact on SSF Reboost Propellant Logistics

STV Size Sensitivity - Reboost and Microgravity

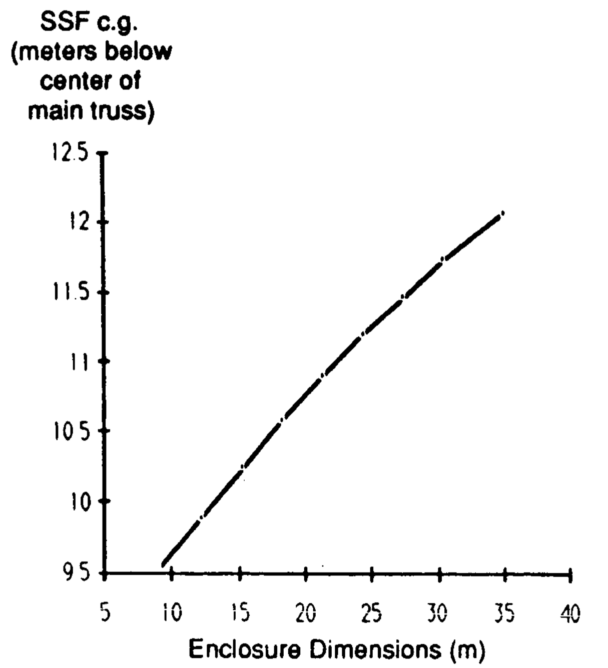
As the size of the STV enclosure increases, there are also impacts to Space Station reboost logistics planning and the Station microgravity environment. As the frontal area of the enclosure grows, the drag coefficient increases, and extra propellant must be provided to the Space Station for altitude maintenance. The Space Station Freedom reboost propulsion system is based on a monopropellant hydrazine system that is resupplied by propellant modules which contain 8000 lb each. Four of these pallets per year are planned for delivery to the Station. As can be seen on the left hand chart, even when the enclosure reaches its maximum size of 35x35 m, less than one additional propellant module would be needed in a high solar cycle yea. This is when reboost requirements are at a maximum due to atmospheric expansion.

As the enclosure size grows, added drag and mass cause the Station center of gravity (and microgravity ellipses) to move lower relative to the experiment module section. This movement, less than three meters from minimum to maximum enclosure size, can be considered of a minimum impact.

STV Size Sensitivity - Reboost and Microgravity



Station Center of Gravity Location (Along Z Axis)



Minimal SSF impacts with growth in STV and enclosure size

STV Size Sensitivity Analysis - Issues

The primary STV size growth issues which still require analysis include trading off between allowing the Z dimension growth to its maximum while moving the C.G. of the STV system back along the Station's X axis. This cantilever effect has implications to Station flight dynamics and control which cannot be predicted at this time.

A second issue involves the impacts of STS approach operations on STV size growth. There will be an uncertainty in STS position as it moves along its approach path which may lower the Z dimension growth limit below 26.6 meters. Additionally, there is a safety requirement for STS rendezvous which requires that all potential impact points be visible to the STS crew. Any size STV enclosure will violate this requirement, so operational procedures will have to be addressed. The STS RCS firing sequence for Space Station approach is being planned to avoid RCS plume impingement upon Station pressurized elements, radiators and photovoltaic arrays. This sequence may have unforeseen effects due to plume impingement, and resulting overpressure, on the STV enclosure walls. This will undoubtedly be dependent on STV enclosure size. Finally, contingency departure paths for a shuttle whose Station docking maneuver has been aborted have not been determined, but will be restricted by enclosure size growth.

Two final issues involve Space Station payload operations. Downward viewing payloads on the horizontal truss will have their field of view blocked by the presence of the enclosure. Relocating them to the truss structure below the STV enclosure is one solution, but many operational issues still remain. A payload element to be supplied by the European Space Station partners is a man-tended free flyer which will be serviced at the Station on a regular basis to be determined. Its approach path, and its docking point have yet to be determined, but lower node locations are the preferred option for this operation, and this may impact Z dimension growth limits.

STV Size Sensitivity Analysis - Issues

- X vs. Z Growth Tradeoff and Mass Cantilever Effects
- Space Shuttle Approach Paths
  - Impact on Z Dimension Growth Limit
  - STS Docking Viewing Angle Requirement
  - Plume Impingement and Overpressure on Enclosure
  - STS Abort Waveoff Paths
- Downward Looking Payload Viewing
- Man Tended Free Flyer (MTFF) Interference

STV Assembly Sensitivity Analysis - Issues

Although a number of SSF mechanical systems can be adapted for use in the STV program, there are still several mechanical systems required for the LEO servicing facility that will be unique to the STV program. These include an STV core stage handling fixture, engine removal support hardware, STV stack deployment device, and enclosure opening and closing mechanism. These devices will have to be defined more clearly so that their functions and operational complexity may be better determined.

With regards to current SSF mechanical devices that can be adapted to the STV program such as the space station remote manipulator system (SSRMS), the STS docking adapter, and the SSF capture latches, more analysis will have to be performed to determine the degree to which these satisfy the STV mission without modification, and what modifications would have to be made to completely satisfy STV operations.

For the SSRMS there is the issue of whether a dedicated unit is required for STV assembly and operations, or whether the SSF baselined unit can satisfy both STV assembly and SSF housekeeping and payload requirements and timelines. Also there is the potential impact of dynamic loads on the SSRMS due to propellant sloshing in the propellant tanks and how the SSRMS will translate into and out of the LEO servicing facility enclosure.

Other potential STV impacts on current SSF mechanical devices include if the STS docking adapter needs to be upgraded for STV operations. Coincidentally, if the STV wants to take advantage of a STS docking adapter, this feature would have to be built into the STV design. Finally, if SSF capture latches are to be used, the ETO trunnions would have to be compatible.

STV Assembly Sensitivity Analysis - Issues

- New STV Dedicated Mechanical Devices
  - Core Stage Handling Fixture
  - Engine Removal Support Hardware
  - STV Stack Deployment Device
  - Enclosure Opening and Closing Mechanisms
- Space Station Remote Manipulator System (SSRMS)
  - Need for Dedicated Unit
  - Impact of Dynamic Propellant Loads
- Use of Upgraded Unpressurized STS Docking Adapter for STV
- Compatibility of STV Component ETO Trunnions With SSF Latches

STV Sensitivity Analyses - Conclusions

The requirement to support STV assembly and servicing operations at Space Station Freedom causes many impacts to Space Station Freedom Systems. In addition to augmentation of the Integrated Truss Structure and its Utility Distribution System, an enclosure with STV servicing equipment will be provided. Additional power must be supplied to perform these servicing operations, and to operate STV systems during checkout. Additional thermal control will have to be provided for this extra power, and as is seen earlier, the provision for this growth still has to be incorporated into the Space Station design. The majority of servicing operations, such as aerobrake assembly, STV component connection and propellant tank handling will be growth impacts on the Assembly Complete Space Station.

However, once the impacts are incorporated into the Station, the growth systems show little sensitivity to variations in the STV systems. Station flight control attitude remains within baseline requirements. The original Station microgravity requirement of 10 μg is satisfied for all foreseen STV masses, while the new 1 μg requirement is never satisfied with a lower keel enclosure. Thus there is no benefit of STV mass targets. Size growth can be accommodated for all projected STV configurations, and altitude reboost logistics has only minor changes with STV size growth. The current array of Station mechanical devices will be usable for STV components, especially the Mobile Servicing Center, which is the key to Space Station operational flexibility. Finally, additional power must be provided to service the STV, but all foreseen power levels can be incorporated by adding photovoltaic <u>or</u> solar dynamic arrays.

STV Sensitivity Analyses - Conclusions

- Major Space Station Freedom Impacts to Accomodate STV
  - Added Truss Structure
  - Add Enclosure
  - Additional Power and Thermal Control
  - Servicing Operations

- Space Station Systems <u>Not</u> Sensitive to STV Variations
  - Station Control and Microgravity Environment
  - STV Size Accomodations
  - Assembly and Servicing Operations
  - Power and Thermal Control Systems

On-Orbit Operations During LTS Mission*

- **LTS Component Unloading & Inspection**
- **Storage of LTS Components**
- **LTS Assembly**
- **Pre-Flight Checkout**
- **Flight Certification Inspection**
- **Crew Transfer**
- **OMV Mate/Transport/Unmate**
- Launch From LEO
- Rectify In-Flight Malfunction (Could Occur Anytime During Mission)
- Verify Clean Tank Separation
- LTV Rendezvous & Dock With LEV
- Perform Fluids Transfer, LTV to LEV
- Perform Cargo Transfer, LTV to LEV
- Perform LEV Checkout
- Undock & Conduct Lunar Mission (Includes Operational I/F With Surface Systems)
- LEV Rendezvous & Dock With LTV
- Perform Cargo Transfer, LEV to LTV
- Perform LTV Checkout
- Undock and Perform TEI Burn
- Verify Clean Tank Separation
- Verify Engine Retraction
- Verify Aerobrake Door Closure (Conduct Aerobrake Maneuver to LEO)
- **OMV Mate/Transport/Unmate**
- **Post-Flight Inspection & Checkout**
- **Maintenance**
- **Vehicle Storage**

*Operations Listed Represent Potential EVAs.
Operations Shown In Bold Type Occur in LEO.

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Early Space Station Support to STV

During the early stages of the STV program, the space station facilities and personnel could be used effectively to prove out, demonstrate, and develop concepts to be utilized on the STV in the near future. Inspection procedures, diagnostic checkout, limited remove and replace functions, utilization of the RMS, demonstration of aerobrake reusability, and EVA/IVA timelines could all be evaluated and analyzed. Additionally, procedures, tools and techniques could be developed and evaluated and demonstrations performed of propellant transfer and storage, adequacy of meteoroid and debris shielding, traffic control, communications, and STV utilization.

Early Space Station Support to STV

- Large Cargo Vehicle Delivery to LEO
  - STV Berthing Port
  - MRMS Utilization
- STS Launch Vehicle Delivery to LEO; or Delivery By Other Launch Vehicles
  - STV Berthing Port, MRMS
  - STV/Payload Integration Area
  - Storage for Multiple Payload Adapter
  - Limited Propellant Storage & Transfer Capability
  - Diagnostics, Communications, Power
- Support Technology Growth and Development
  - STV Berthing Port, MRMS
  - Rudimentary Payload Storage & Checkout Area (Enclosed)
  - Elementary RMS for STV Servicing
  - Demonstrate Propellant Storage & Transfer Capability
  - Diagnostics, Communications, Power

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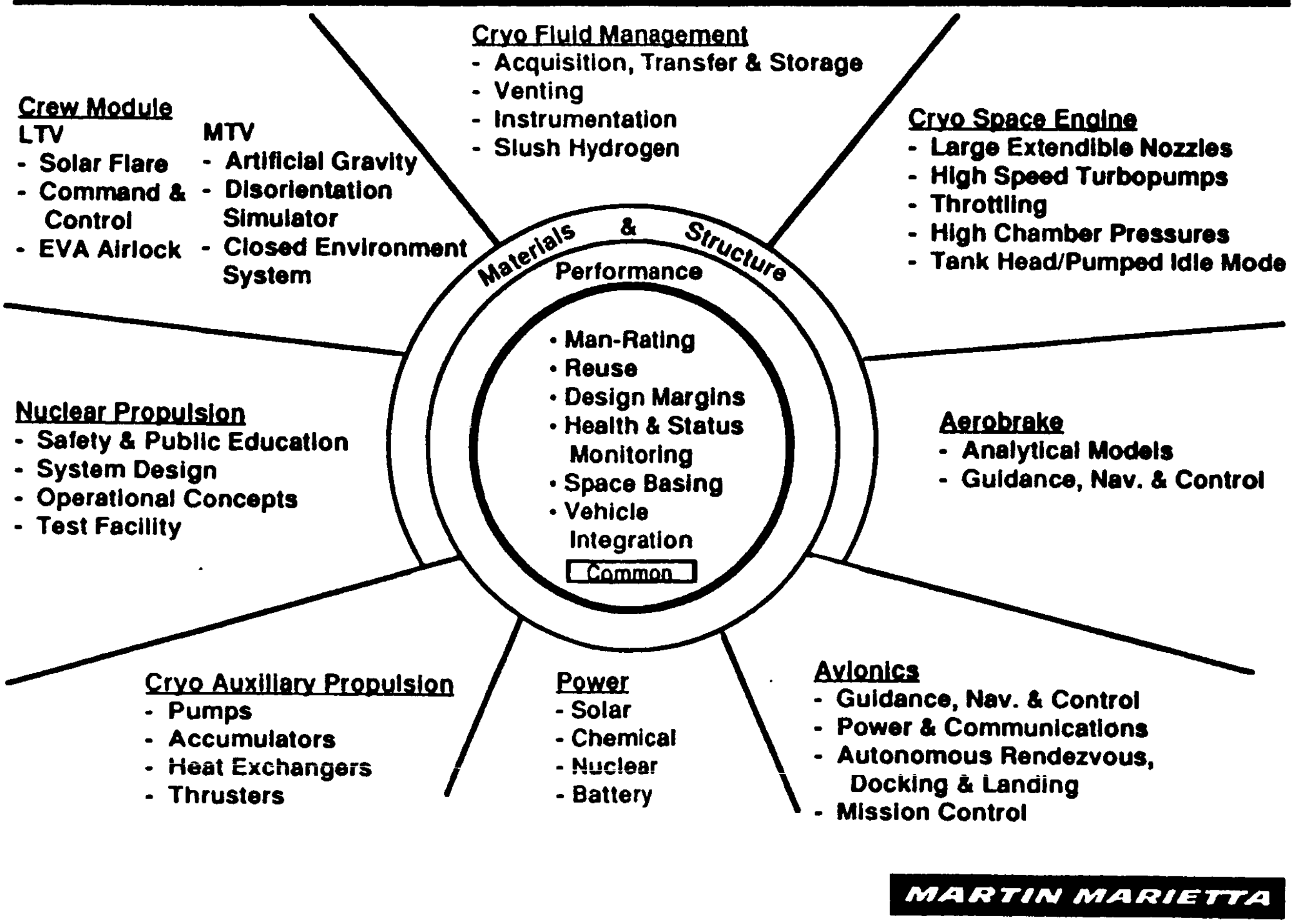
Key STV Technology Areas

Key technologies were identified which require development for eight major STV systems. Six of the enabling technology areas are common to the eight systems and are shown in the center of the figure. All eight systems require enabling technologies that affect performance, however, technologies affecting performance are generally different for each system. Five of the STV systems also have enabling technologies which affect materials and structure, while all eight have two or more technology areas that are unique to that particular system and are listed under the individual technology heading.

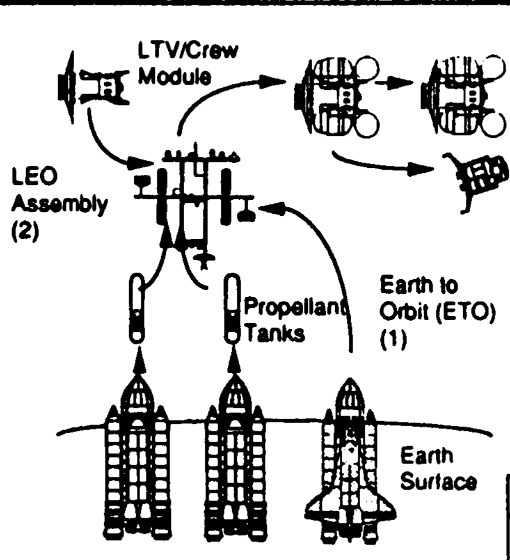
Key STV Technology Areas



STV Fluid Management Technologies

An evaluation has been made of the fluid management technologies required for a complete STV mission . The mission that was used for reference is concept 4E-2B which is similar to the 90 Day Study baseline. While some of the other architectural concepts may reduce this listing somewhat, this listing is believed to be more representative of those technologies that will cover almost all of the concepts that may be selected. The technologies are divided into groups which support each mission phase, with some duplication occurring where a single technology (such as propellant settling) spans multiple phases.

STV Fluid Management Technologies



3) TLI Phase

- Engine Feed
  - Start Basket
  - Settling
    - RCS
    - THI Mode
    - Slosh Suppression
- Tank Press. for Eng Start
  - Helium
  - Pumped Idle Mode
- Self-Sealing QDs
- Line Purging

2) LEO Assembly

- Cryogenic Couplers
- Pressure Control (Drop Tanks)
  - Mixer Pump
  - TVS/VCS
  - Thk MLI Blkts (Lnch Degrad)
  - Refrigeration
- Cryo Transfer–Drop Tanks To Refill LTV Core
  - Automated Prop Loading
  - Tank Chilldown
  - Transfer Line Chilldown
  - Transfer Pump
  - He Pressurization
  - Transfer Techniques
    - "No-Vent" Fill
    - LAD for Transfer
    - Vented Fill
      - Drag Impacts
      - Prop Venting of Boiloff
      - Settling via RCS

1) ETO Phase (Launch/Ground Operations)

- Automated Prop Loading with AI
- Lgtwgt Cryo Tanks
- Lgtwgt Insul Cncpts
  - SOFI/MLI Combo

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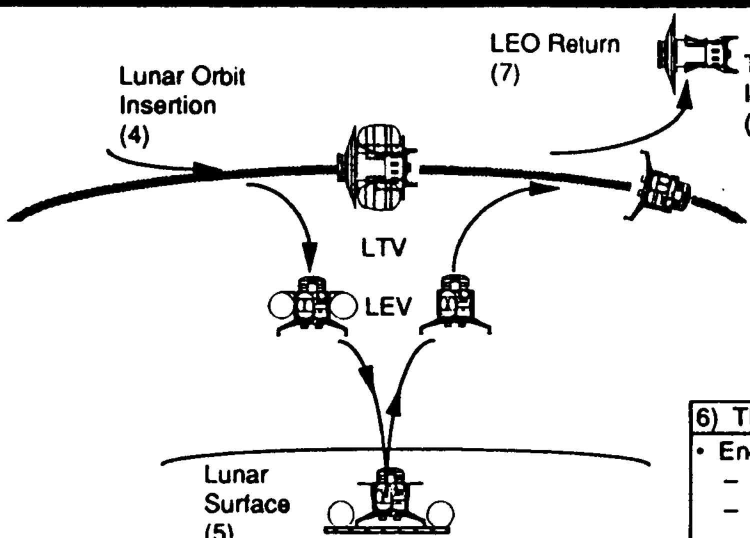
STV Technology - Cryo Fluid Management Schedule - 2

The Cryo Fluid Management technologies that are considered essential for the development of STVs are summarized in this schedule. The SEI Option 5 program milestones are defined at the top of the schedule. Individual technologies include cryogenic storage, boiloff venting, health & status monitoring, instrumentation, electromechanical vent valve and hydrogen slush technologies. All are considered low risk technologies since all except health & status monitoring are predicted to reach level 7 maturity prior to the STV program CDR based on currently planned NASA development. Although cryo fluid management health & status monitoring technology is expected to reach a level 6 maturity prior to the STV CDR, it is considered a critical technology because of the long component and subsystem level development time and criticality to the overall STV vehicle.

STV Fluid Management Technologies



Broad Base Rqmts
- Instrumentation
- Health Monitoring
  - Automated Control

7) LEO Return
- Propellant Residual Handling
- Tank Safing
- Onorbit CFM H/W Checkout/Maint

6) TEI
- Engine Feed
  - Start Basket
  - Settling
    - RCS
    - THI Mode
    - Slosh Supp
- Tank Press. for Eng Start
  - Helium
  - Pumped Idle Mode
- Self-Sealing QDs (Drop Tanks)
- Line Purging

4) Lunar Orbit Activities
- Cryo Transfer–LTV Drop Tanks To Refill LEV
  - Automated Propellant Loading
  - Tank Chilldown
  - Transfer Line Chilldown
  - Transfer Pump
  - Transfer Techniques
    - No-Vent Fill
    - Vented Fill
      - Prop Venting of Boiloff
      - Settling via RCS
      - Spinup
- Resupply of Crew Consumables
  - LN2/LO2
  - Water, etc
- Engine Feed
  - Start Basket
  - Settling via RCS
  - THI Mode
- Tank Press. for Engine Start
  - Helium
  - Pumped Idle Mode
  - Slosh Suppression
- Self-Sealing QDs
- Line Purging

5) Lunar Surface
- Pressure Control–LEV Tanks
  - Refrigeration
  - TVS/VCS
  - Thick MLI Blankets

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Space Basing - Conclusions

Space Based Operations Benefits:

- Key to Expanded Space Exploration
- Cuts ETO Launch Costs
- Minimize Ground Weather / Schedule Impacts
- Efficient Use of Reusable Space Elements
- Extends Levels of Crew Proficiency
- Oversize Payload Erection / Assembly
- Positive Control for Structural Mating
- Cargo Mission Launch on Time / Launch on Demand
- Contingency Mission Standby
- Space Operations / Scientific Evaluation
- Mission Control Alternatives

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N91-28255

PRESENTATION 4.3.3

STV ENGINE DESIGN CONSIDERATIONS

PRESENTED TO

SPACE TRANSPORTATION PROPULSION SYSTEMS SYMPOSIUM

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ENGINE DESIGN CRITERIA AND ISSUES

The engine workshop organized by MSFC resulted in agreement that the items listed were the major criteria which should be considered in developing detailed design requirements for the STV engine. Several of the items are not truly separate but are different aspects of the overall vehicle-engine system. For example, space basing requires efficient vehicle turn around operations to accomplish mission goals at reasonable cost. Similarly health monitoring tasks are affected by the system/subsystem interface architecture and and provide data to define vehicle status for continuing man rating through the next mission.

STV *ENGINE DESIGN CRITERIA AND ISSUES*

MSFC- BOEING

1. MAN RATING
2. SPACE BASING
3. OPERATIONS
4. SYSTEM/SUBSYSTEM I/F ARCHITECTURE
5. HEALTH MONITORING
6. PERFORMANCE
7. MARGINS
8. ENGINE CONFIGURATION/CHARACTERISTICS

DESIGN REQUIREMENTS FOR MAN RATING

Man rating is the most basic and possibly the only firm requirement for an engine to support the human exploration initiative. The document JSC-23211 "Guidelines for Man Rating Space Systems" provided man rating guidelines intended to be applicable to all future NASA missions. The task at hand is to convert these guidelines into mission, vehicle and engine requirements.

Safe return of the crew after any two failures has been interpreted as a requirement on the total vehicle which may result in unconventional approaches to engine interfaces and fault isolation. Trade studies must be conducted in parallel with evolution of the vehicle configuration to establish the approach to be used. For example, containment of a failed turbopump could be accomplished by the engine hardware or protective barriers could be provided between adjacent engines.

STV DESIGN REQUIREMENTS FOR MAN RATING

MSFC- BOEING

- MAN RATING IS A SYSTEM REQUIREMENT.
  - CRITICAL SYSTEMS MUST BE TWO FAILURE TOLERANT.
    - THE PROPULSION SYSTEM MUST PROVIDE SAFE CREW RETURN TO LOW EARTH ORBIT FROM ANY PART OF THE LUNAR MISSION.
    - AN INDEPENDENT CREW ESCAPE SYSTEM TO RETURN FROM THE LUNAR SURFACE IS NOT PRACTICAL FOR EARLY MISSIONS.
- ENGINE REQUIREMENTS DERIVED FROM SYSTEM REQUIREMENT.
  - ALTERNATIVES FOR A TWO FAILURE TOLERANT SYSTEM:
    - EACH ENGINE IS TWO FAILURE TOLERANT, OR
    - REDUNDANT ENGINES
  - ENGINES MUST BE ISOLATED TO PREVENT FAILURE PROPAGATION TO OTHER ENGINES OR SUBSYSTEMS.
  - VERY HIGH RELIABILITY IS REQUIRED
    - MAJOR FACTOR IN ENGINE AND COMPONENTS DESIGN
    - ENGINES RELIABILITY REQUIREMENT WILL BE ESTABLISHED AFTER CONFIGURATION SELECTION.

TEST REQUIREMENTS FOR MAN RATING

The engine development and qualification test programs must fully demonstrate all functional and performance design requirements to accomplish planned manned missions. Special tests should be conducted to validate safety related redundancies, fault isolation and containment of fragmented components. Testing with the engine mated to a simulated vehicle propellant system is required to explore engine system dynamics and and interactions. The flight test program will evaluate engine start and autogenous tank pressurization in the same low acceleration space environment as the fully operational manned missions.

STV TEST REQUIREMENTS FOR MAN RATING

MSFC- BOEING

- ENGINE TEST FIRINGS SIMULATE FULL MISSION FIRINGS
  - AT LEAST TWO ENGINES TESTED TO DEMONSTRATE LIFE.
    - POST TEST DISASSEMBLY AND INSPECTION
  - ENDURANCE TEST TO FAILURE.
    - POST TEST INSPECTION AND ANALYSES
      - DETERMINE FAILURE SEQUENCE
      - IDENTIFY FAILURE PRECURSORS
- DESTRUCTIVE TESTING TO VERIFY FAILURE ISOLATION.
- LUNAR ENVIRONMENT SIMULATION FOR ENGINE & VEHICLE LIFE
  - MISSION FIRING SEQUENCE AT END OF TEST
- GROUND TEST FIRINGS WITH VEHICLE PROPELLANT FEED SYSTEM
- UNMANNED FLIGHT TESTS DEMONSTRATE ESSENTIAL FUNCTIONS.

DESIGN REQUIREMENTS FOR SPACE BASING

Space basing of the STV will require that the engines remain operational after up to 5 years in the space vacuum environment. The two main issues for space basing are materials compatibility and design of the engine and vehicle interfaces for minimum maintenance.

STV DESIGN REQUIREMENTS FOR SPACE BASING

MSFC- BOEING

- EXPOSURE TO LOW EARTH ORBIT OR LUNAR ENVIRONMENTS FOR THREE YEARS
- SPARES STORAGE AT THE SPACE STATION IN A PROTECTED ENVIRONMENT FOR FIVE YEARS
- ACCOMMODATE ENGINE REMOVAL AND REPLACEMENT AT THE SPACE STATION AND IN LUNAR ENVIRONMENT
- ELIMINATE SPECIAL FLUIDS REQUIREMENTS FOR VALVE ACTUATION, PURGE OR OTHER PURPOSES.
- MINIMIZE PRE-MISSION CHECK OUT REQUIREMENTS AND ELIMINATE ANY LOSS OF FLUIDS IF POSSIBLE.

ENGINE OPERATIONS REQUIREMENTS

Engine related maintenance and checkout operations at the space station will incur crew costs now estimated at $123,000 per hour. The high costs emphasize the need for highly reliable systems which will require little or no maintenance over the life of the vehicle. The reliability of the functional hardware must be supported by comprehensive instrumentation to verify the status and confirm that reliability has not been degraded over the life of the vehicle. Redundant instrumentation with additional verification by cross referencing related measurements will be required to assure that health of the hardware is correctly diagnosed.

STV

ENGINE OPERATIONS REQUIREMENTS

MSFC- BOEING

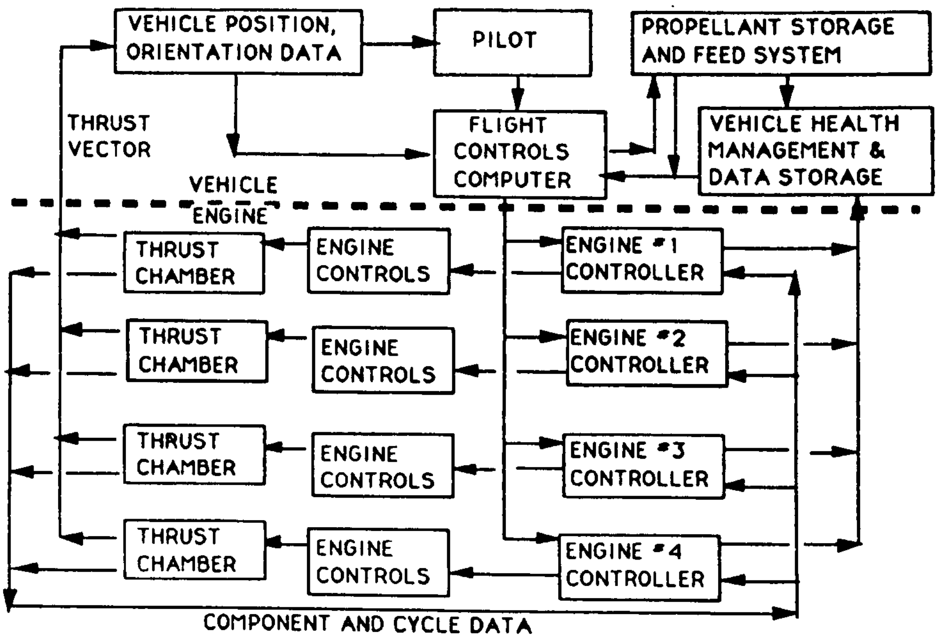
- LONG LIFE TO MINIMIZE ENGINE REPLACEMENT
- QUICK DISCONNECTS FOR FLUIDS AND ELECTRICAL INTERFACES
  - POSITIVE INDICATION OF CONNECTION
  - MAXIMUM ACCESSIBILITY
- EASILY REMOVABLE NOZZLE EXTENSION
- IMPROVED INSTRUMENTATION AND COMPUTER SYSTEM RELIABILITY
  - AUTOMATED ENGINE CHECKOUT AND INTERFACE VERIFICATION
  - INSTRUMENTATION REDUNDANCIES
- HEALTH MONITORING SYSTEM WITH CAPABILITY TO IDENTIFY FAILED COMPONENTS OR INSTRUMENTS.

HEALTH MONITORING LOGIC DIAGRAM

The propulsion system health monitoring and management functions will include the propellant system as well as the engines. It is likely that each engine will have a health monitoring capability as part of the electronic engine controller. The same data used by the engines will be evaluated and stored by the vehicle health management computer and data storage system. The vehicle system will have complete historical data records for each engine to support diagnostic functions and develop recommended engine operating strategies to satisfy vehicle propulsion requirements. Vehicle health management system recommendations will be provided to the flight controls computer where they may be overridden by the pilot if necessary during critical maneuvers.

STV HEALTH MONITORING LOGIC DIAGRAM

MSFC- BOEING



HEALTH MONITORING DATA REQUIRED

The parameters identified are general propulsion system data which are applicable to the type engines and vehicle systems expected for the STV. The health management system will use vehicle propellant system data and thrust commands as well as the engines components data to evaluate the engines status and ability to continue to function.

STV HEALTH MONITORING DATA REQUIRED

MSFC- BOEING

- DATA PROVIDED BY THE VEHICLE
  - PROPELLANTS
    - QUANTITIES REMAINING
    - INTERFACE PRESSURES
    - INTERFACE TEMPERATURES
  - COMMANDS
    - THRUST
    - MIXTURE RATIO
  - ENGINES HISTORICAL RECORD CHARACTERIZATION
- DATA PROVIDED BY THE ENGINE
  - COMPONENTS
    - VIBRATION
    - ROTATIONAL SPEED
    - TEMPERATURES
    - STATUS (VALVES OPEN/CLOSED)
  - THERMODYNAMIC CYCLE
    - MIXTURE RATIO
    - FLOW RATES
    - PRESSURES
    - TEMPERATURES
- DATA PROCESSING AND CYCLE ANALYSES IDENTIFY POTENTIAL COMPONENT MALFUNCTION

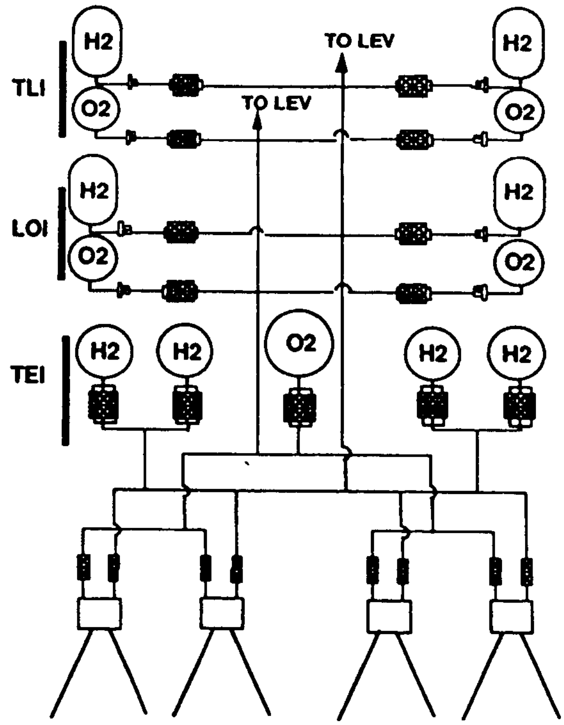
LTV PROPELLANT FEED SYSTEM

The feed system schematic of the lunar transfer vehicle (LTV) is single failure tolerant for the trans lunar injection (TLI) and lunar orbit insertion (LOI) burns. The trans earth injection (TEI) portion of the feed system is two failure tolerant to assure safe return of the crew if emergency conditions develop in lunar orbit.

Six valves at the exit of each TEI tank are arranged to provide three parallel paths for opening after any two failures. Two valves in series in each path at the tank exits provides assurance that each tank can be isolated from the system manifold after a single valve failure. The two valves in series on each propellant feed line to the engine are in series with the engine shut off valves to prevent loss of propellants with any two failures including engine failure.

STV   LTV PROPELLANT FEED SYSTEM

MSFC- BOEING



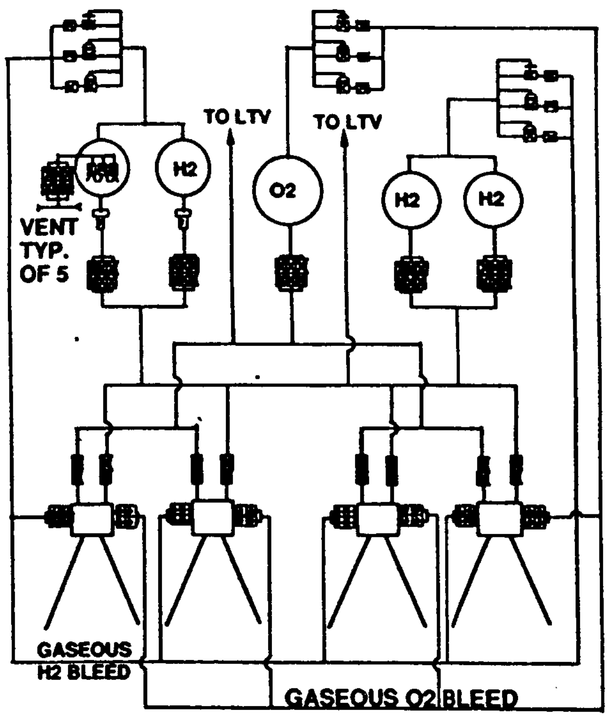
- TLI AND LOI PROPELLANT SYSTEM
  - QUAD REDUNDANT VALVES FOR TLI AND LOI BURNS SATISFY SINGLE FAILURE TOLERANT REQUIREMENTS TO PERFORM MISSION.
  - TWO FAILURE TOLERANT SYSTEM IS NOT REQUIRED FOR TLI AND LOI BECAUSE TEI SYSTEM PROVIDES SAFE RETURN.
- TEI PROPELLANT SYSTEM
  - SAFE RETURN OF THE CREW FOR MAN RATING REQUIRES A TWO FAILURE TOLERANT SYSTEM.
  - PROPELLANT TANKS CONNECT TO DISTRIBUTION MANIFOLDS THROUGH PARALLEL AND SERIES TRIPLE REDUNDANT VALVE MODULES.
  - TWO VALVES IN SERIES CONNECT MANIFOLDS TO ENGINES FOR TWO FAILURE TOLERANCE IN SERIES. FOUR ENGINES SATISFY PARALLEL REDUNDANCY REQUIREMENTS.
- TOTAL 78 FEED SYSTEM VALVES

LEV PROPELLANT SYSTEM

The lunar excursion vehicle (LEV) propellant system is two failure tolerant to any catastrophic loss of fluid failure. Quad check valve arrangements for each engine autogenous pressurization line prevent loss of pressurization flow in the event af an engine failure. Hydrogen tank pairs are pressurized from a common manifold to limit the number of regulators required.

STV LEV PROPELLANT SYSTEM

MSFC- BOEING



- FEED SYSTEM
  - 46 CRYOGENIC SHUT OFF VALVES
- VENT SYSTEM
  - 15 CRYOGENIC SHUT OFF VALVES
  - 30 GAS SHUT OFF VALVES
- PRESSURIZATION SYSTEM
  - 32 CHECK VALVES
  - 9 GAS SHUT OFF VALVES
  - 9 PRESSURE REGULATORS

FEED SYSTEM FAILURE RATES

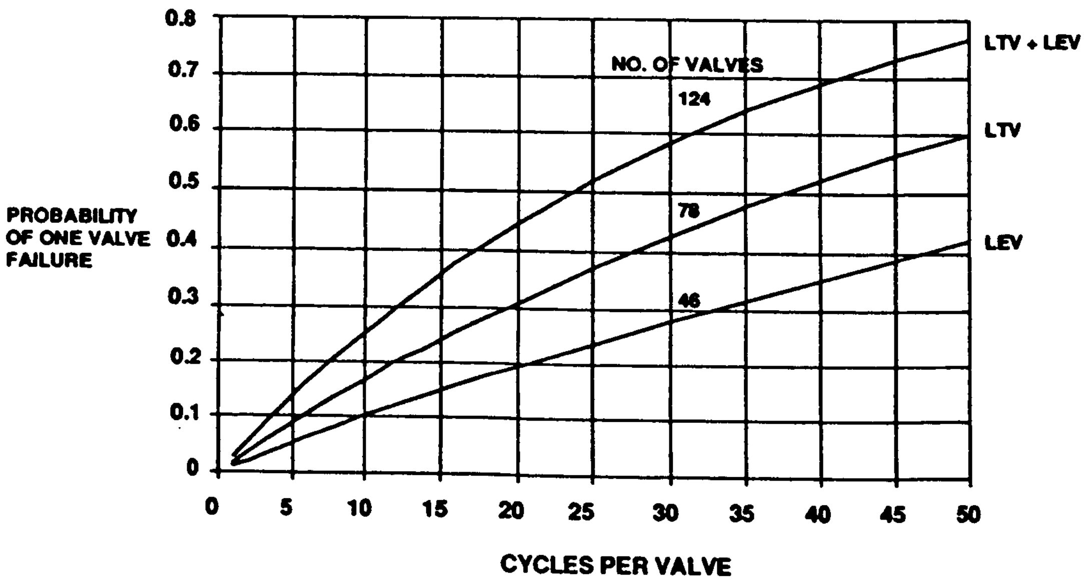
The large number of shut off valves used in the feed systems to satisfy a two failure tolerant requirement for man rating increases the probability that some valve failures will occur requiring replacement. Inlet valves of the RL10 engine were assumed to be representative of the type shut off valve applicable to the propellant feed system. Valve failure rates were estimated at 236 failures per million cycles at 50% confidence level based on 1470 RL10 firings with no failures of the two inlet valves. This failure rate results in a 50% probability of at least one valve failure after less than 25 valve cycles for the total LTV & LEV vehicle set.

The probability of valve failures occurring in less than the desired life of the vehicle establishes a need to develop proven valve reliability data and efficient techniques for valve replacement.

STV — MSFC- BOEING

FEED SYSTEMS FAILURE RATES

- VALVE RELIABILITY BASED ON RL10 INLET VALVES
  - TOTAL 1470 FIRINGS WITH NO FAILURES THROUGH MAY, 1988
  - COMBINED FUEL AND OXIDIZER VALVES DUE TO SIMILAR DESIGN

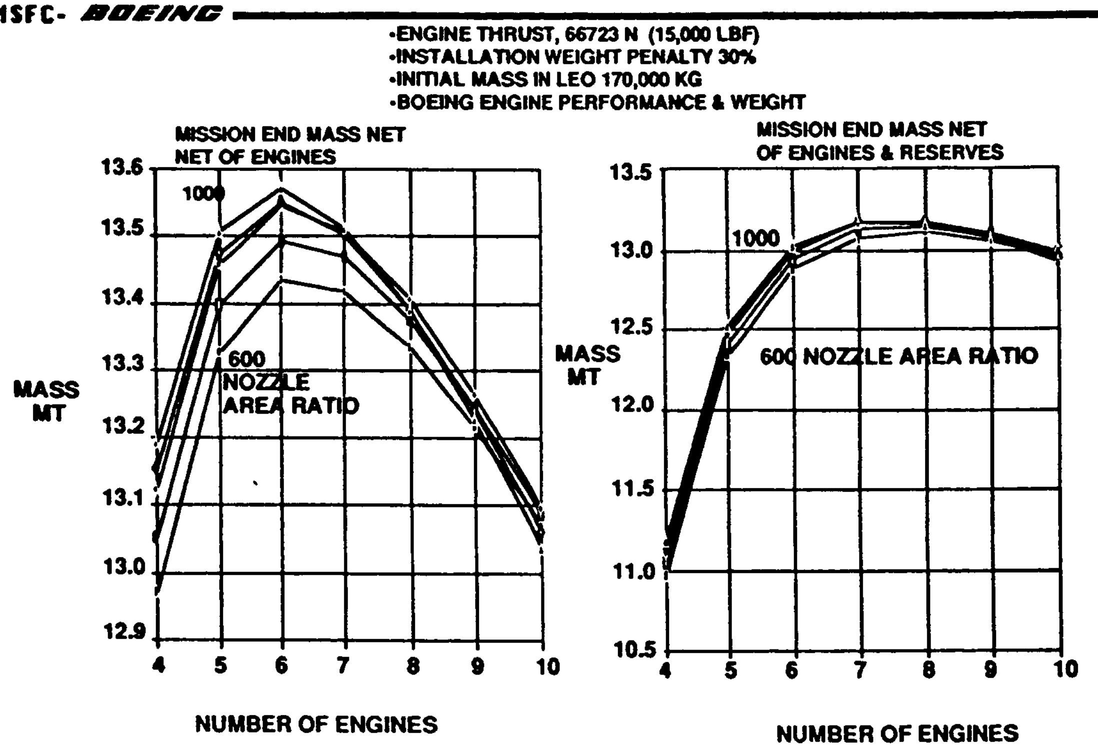


ENGINE NOZZLE TRADE FOR 98% IDEAL ISP

The equilibrium ISP trend caused the mission burnout mass net of engines and reserves to be higher for a nozzle area ratio of 1000 instead of the 600 found for the Boeing ISP trend. The burnout mass advantage of the nozzle area ratio of 1000 is small and does not appear to justify the increased engine diameter and length required.

STV ENGINE NOZZLE TRADE FOR 98% IDEAL ISP

MSFC- BOEING

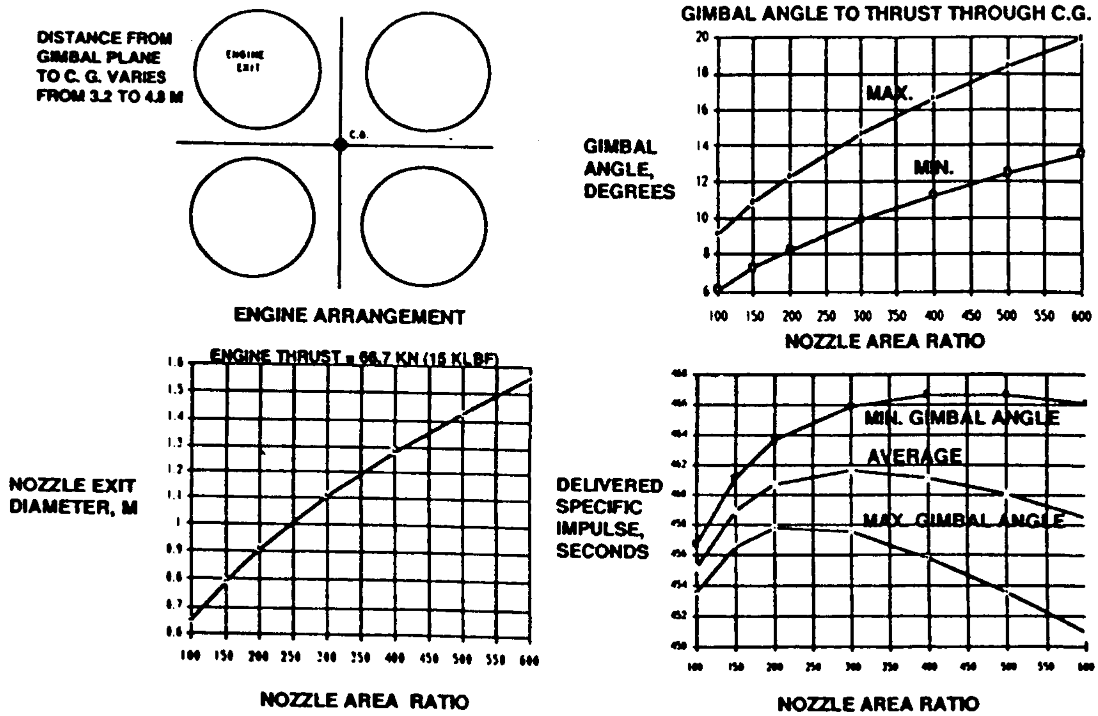


AREA RATIO GIMBAL ANGLE LIMITS

The lunar excursion vehicle engines nozzle area ratio will establish the separation required between the engines and the vehicle center line to avoid interference between the engines. A minimum separation of 15 cm between the nozzles was assumed with the engine center lines parallel to the vehicle center line to establish gimbal angle and nozzle area relationships. If the engines thrust is pointed through the vehicle center of gravity with the 600 nozzle area ratio the maximum gimbal angle of 20 degrees will be required when the center of gravity is nearest the gimbal plane. The cosine thrust losses caused by pointing thrust through the C. G. for the entire thrust time would reduce the delivered specific impulse for the total thrust vector.

STV AREA RATIO GIMBAL ANGLE LIMITS

MSFC- BOEING



REACTION CONTROL SYSTEM

An oxygen hydrogen reaction control system (RCS) has the logistic advantage of commonality with the main propulsion propellants. Development of an oxygen hydrogen thruster of the size needed for the STV would be required to realize the potential advantages. Obtaining full benefits of the oxygen hydrogen RCS will also require development of a system to use propellants from the main propulsion tankage. Thrusters will likely require gaseous propellants for satisfactory pulsing operation. An efficient, reliable method of generating gaseous hydrogen and oxygen from the stored liquids is needed. The variable flow demands inherent in the RCS application cause the design of a stable system to be extremely difficult.

STV

REACTION CONTROL SYSTEM

MSFC- BOEING

SYSTEM DESCRIPTION	ADVANTAGES	DISADVANTAGES
•MONOPROPELLANT HYDRAZINE •CURRENT TECHNOLOGY	•SIMPLEST SYSTEM •WELL CHARACTERIZED •PRESSURANT NITROGEN STORED IN PROPELLANT TANKS	•LOW PERFORMANCE •TOXIC PROPELLANTS •LIMITED THRUSTER LIFE •SEPARATE SYSTEM FOR OPERATION AT SPACE STATION
•BIPROPELLANT N2O4-MMH •CURRENT TECHNOLOGY	•GOOD PERFORMANCE •WELL CHARACTERIZED	•TOXIC PROPELLANTS •MAXIMUM NUMBER OF STATION INTERFACES •CONTAMINATING EXHAUST - MMH NITRATE
•OXYGEN HYDROGEN •SYSTEM INTEGRATED WITH FUEL CELLS •SUPERCRITICAL CRYOGENIC FLUID STORAGE	•GOOD PERFORMANCE •NO UNIQUE FLUIDS REQUIRED •NON TOXIC •POTENTIAL TO USE THRUSTERS IN SINGLE FLUID MODE FOR OPERATION NEAR STATION	•TECHNOLOGY RISK, SYSTEM DYNAMICS •THRUSTER DEVELOPMENT
•OXYGEN HYDROGEN •SYSTEM INTEGRATED WITH MAIN ENGINES •PROPELLANTS STORED AS LIQUIDS, PUMPED TO HIGH PRESSURE TANKS OR ACCUMULATORS	•GOOD PERFORMANCE •NO UNIQUE FLUIDS REQUIRED •NON TOXIC •POTENTIAL TO USE THRUSTERS IN SINGLE FLUID MODE FOR OPERATION NEAR STATION	•TECHNOLOGY RISK, SYSTEM DYNAMICS •THRUSTER DEVELOPMENT •HIGH SYSTEM RELIABILITY MAY BE DIFFICULT

ENGINE DESIGN MARGINS

Design margins for the STV engine should be higher than normally used for unmanned vehicles which have no reusability requirements. Increased design margins should provide the increased reliability and longer life needed for the human exploration program.

STV

MSFC- BOEING

ENGINE DESIGN MARGINS

STV Engine Design Considerations

- •DESIGN MARGINS ARE NEEDED TO:
  - •ASSURE HIGH RELIABILITY
  - •MAINTAIN HIGH RELIABILITY TO END OF ENGINE LIFE
- •MARGINS VERIFICATION BY COMPONENT TESTS
  - •VALVES CYCLE LIFE
  - •THRUST CHAMBER TEMPERATURE/PRESSURE CYCLES
  - •ROTATING MACHINERY
    - •ROTATIONAL SPEED
    - •PRESSURE/TEMPERATURE CYCLES
  - •THROTTLING
    - •MISSION DUTY CYCLE
  - •MIXTURE RATIO CONTROL CAPABILITY

ENGINE CONFIGURATION & CHARACTERISTICS

The STV engine is expected to be space based with a primary mission to support the human exploration program for several years. The STV engine will also be required to provide propulsion capability for a variety of commercial and military missions. High reliability is essential to achieve a man rated vehicle capable of efficient operation in a space based mode. Design for maintainability in space is also a major consideration in efficient operation of the propulsion system.

STV ENGINE CONFIGURATION & CHARACTERISTICS

MSFC- BOEING

- RELIABILITY IS A PRIMARY CONSIDERATION
  - REDUNDANT COMPONENTS WHERE FEASIBLE
  - DESIGN FOR ZERO MAINTENANCE
- ENGINE REMOVAL AND REPLACEMENT IN SPACE
  - MINIMUM NUMBER OF CONNECTORS
  - READILY ACCESSIBLE INTERFACE CONNECTORS
  - VERIFY CONNECTORS INTEGRITY WITHOUT LOSS OF FLUID
  - VERIFY ELECTRICAL SYSTEM WITHOUT HARDWARE FUNCTION
- GASEOUS OXYGEN AND HYDROGEN BLEED PRESSURIZATION
- USE HYDROGEN FOR PNEUMATIC POWER IF NEEDED
- PERFORMANCE AND CONTROLS
  - THROTTLE FROM 10% TO 100% THRUST
  - WIDE RANGE OF MIXTURE RATIO CONTROL

PRESENTATION 4.3.4

GENERAL DYNAMICS
Space Systems Division

UPPER STAGE
PROPULSION
TECHNOLOGY REQUIREMENTS

Hal Hahn

PROPULSION SYSTEM DESIRED FEATURES
Improve Launch Processing, Performance, Cost, Reliability, Safety

- Simplifed Subsystems
  - Single Engine
  - No Active Thrust Control
  - No Propellant Utilization
  - No Prelaunch Childown
  - Low NPSP, Simplified Pressurization
  - Simplified Environmental Control (No Purges)
  - Electromechanical Valve Controls
  - EMA TVC
  - All Welded System
  - Redundant Seals at Seperable Connections (i.e. lipseals)
  - Integral Heat Exchangers for Warming Pressurant Gas or
  - Autogenous H2 and O2 Pressurization Systems
- Enhanced Checkout, System Monitoring
  - IHM - Integrated Health Monitoring
  - BIT - Built in Test
  - Automatic Operations, Checkout
- Minimal/No Catastophic Failure Modes
- Robust Margins
- Fault Tolerance

BENEFITS OF SINGLE ENGINE CENTAUR/UPPER STAGE

Increases Payload Capability:	• A/C 415 lbs to GTO • T/C 1100 lbs to GEO
Reduces Cost:	• Save 1/2 Main Propulsion Hardware
Increases Reliability	• Reduces Number of Parts
Reduces Launch Processing Time and Cost	• Reduced Amount of Hardware to Checkout • Simplifies Propulsion System

INCREASED THRUST AND SPECIFIC IMPULSE NEEDED

- Today; RL10A-4 Engine on Atlas/Centaur has

  20.8K lbf thrust (each of 2 engines)
  450 sec Isp

- Single Engine Centaur on Atlas Requires

  35K lbf thrust
  Maximum possible specific impulse

- Advanced Upper Stage for HLV Requires

  > 50K lbf thrust

UPRATED RL10 ENGINE VS NEW ENGINE

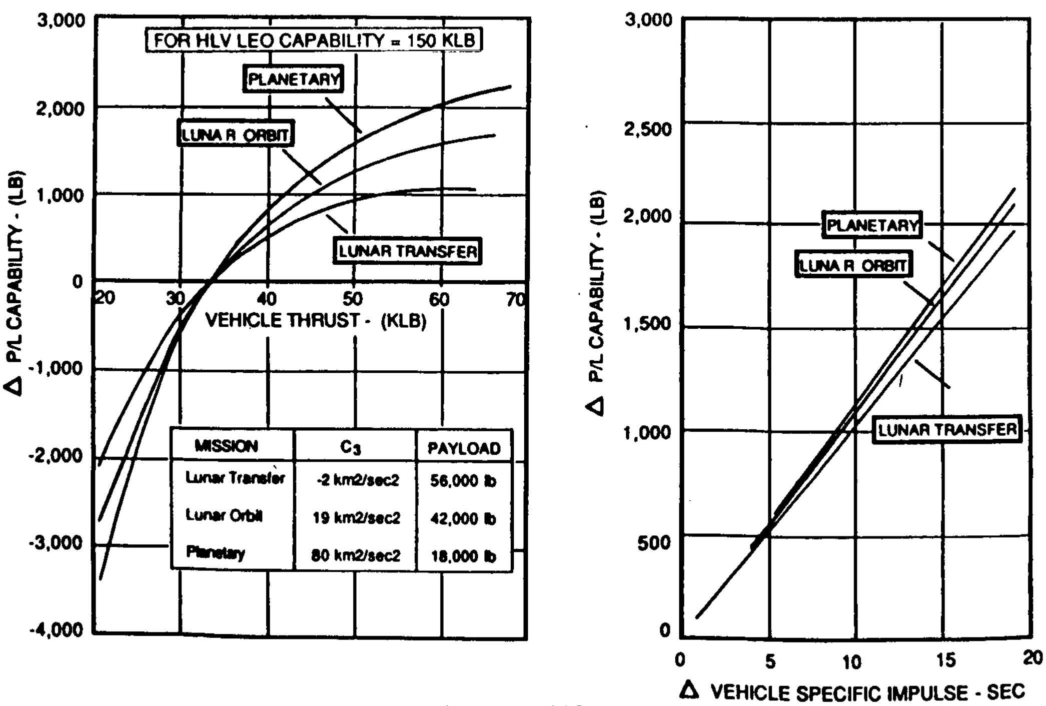
	1990	1995	2000
RL10 Derivative			
35K lb Thrust, FSD	————	————	
Advanced Engine			
Test Bed (20K)	————	————	
FSD			————

Near Term Needs
35K lbs Thrust
- Develop RL10 to Full Capability or 5 Year Time Table
- Only the RL10 Will Satisfy Near Term Needs
- Single Engine A/C ELV

Intermediate to Longer Term
> 50K lbs Thrust
- Use Two 35K RL10s
- Accelerate FSD of Advanced Engine (Size for > 50K Instead of 20K)

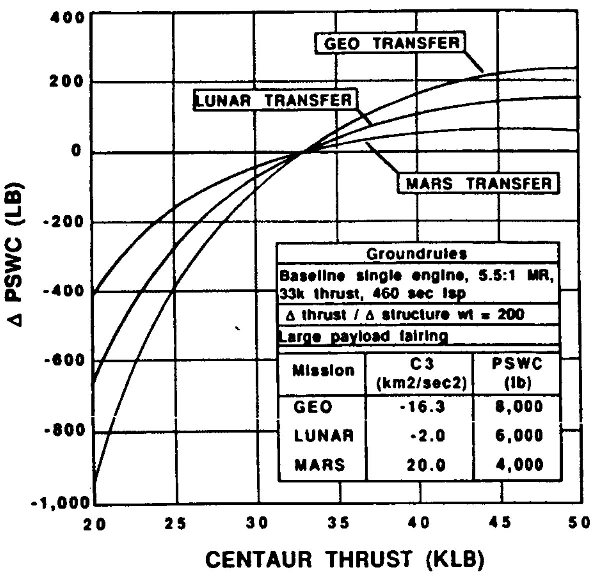
Upgraded Centaur Study

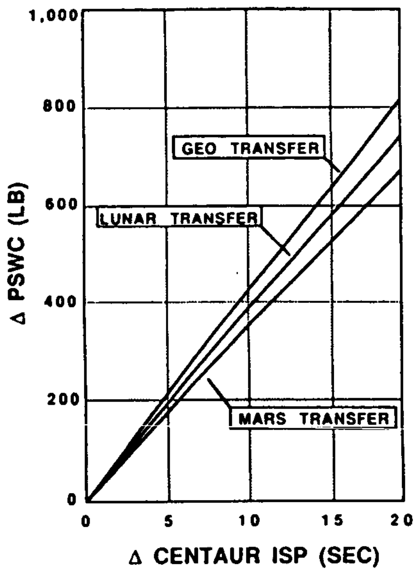
THRUST AND SPECIFIC IMPULSE EFFECT ON PERFORMANCE CAPABILITY



ATLAS IIAS - SINGLE ENGINE CENTAUR STUDY

THRUST AND SPECIFIC IMPULSE SENSITIVITIES





N91-28256

PRESENTATION 4.3.5

The Propulsion System Is The Key to Airline-Like Operation of ETO Vehicles

Charles J. O'Brien

GenCorp Aerojet Propulsion Division

Sacramento, California

Operational Efficiency Panel

NASA Space Transportation Propulsion Systems Technology Symposium

Penn State University - June 25-29, 1990

Agenda

Efficient Engine Operations

- Steps for improved operability (ALS)
- LCC/lb payload is figure of merit
- Current practice is major cost driver
- Single stage to orbit approach
- Propulsion & vehicle technologies have emerged to allow SSTO operation
- Conclusions for improved operability

ALS STME Improved Operability

OEPSS Concern	Aerojet ALS Approach
• Hydraulic & pneumatic actuation	Electrical actuation for valves & TVC
• Accessibility	Modularity access
• Lack hardware integ. & commonality	Commonality of lines, valves, bellows, seals
• Gimbal system	Gimbal system
• High maintenance TPA	Robust, low temp. turb., hydrostatic bearings
• Pressurization systems	Autogenous GOX & GH2 HEX
• Helium gas purge	Purge - He spin start & GOX inj. conditioning
• Preconditioning system	No chilldown
• Contamination	Filters & quality control

Operationally Efficient Propulsion System Steps In Progress

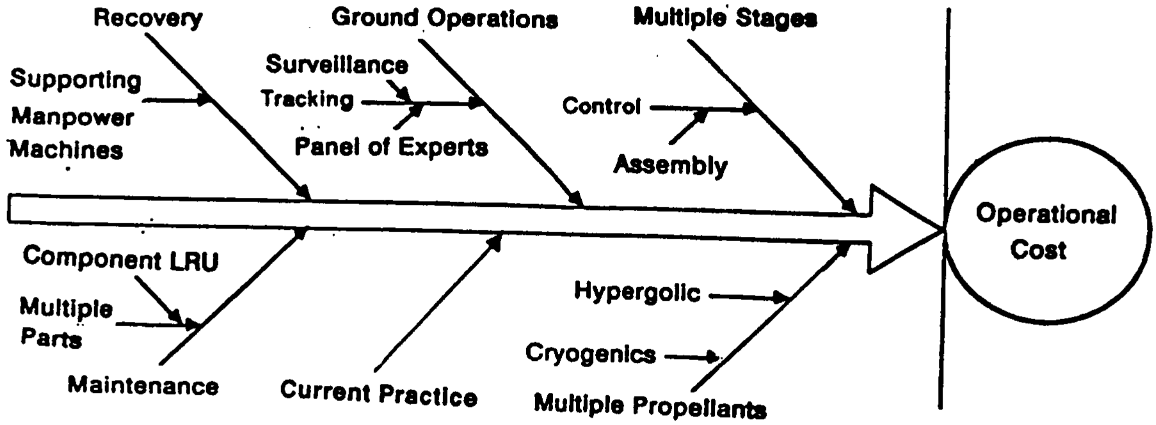
Figure of Merit Is LCC/LB Payload

- o Payload → **High Performance**
- o Life Cycle Cost
  - o Dev Cost (Non/Recur)
  - o Production (Recur)
  - o Ops Cost (Recur)
    - -- Preparation
    - -- Launch
    - -- Recovery
    - -- Refurbish
    - -- Problem Solve
    - -- Consumables

Dev Cost, Production, Ops Cost → **ALS** → **Low Cost** | Toward Manless Launch

ALS Trades Performance For Low Cost

Current Operational Cost Is Labor-Intensive



Innovate Utilizing Space Shuttle Experience

Current Practice Is Major Cost Driver

Propulsion Systems & Shuttle Vehicle

- o 1970 technology and operations
- o Schedule & cost inhibit change

ALS - One Approach To Reduce Cost

- o Trades performance for low cost
- o Applies operations advances to current practice

Multiple Stages Is Major Cost Driver

- o Cost of developing, servicing, maintaining, launching, tracking and recovery of numerous stages is high.

- o Single stage (SSTO) vehicle has highest potential for low LCC/lb payload for reusable systems.

- o For purpose of stimulating panel discussion let's examine SSTO vehicle operation goals.

  - o Examine engine requirements to identify technologies & operation goals

Goal Is Fully Automated Operations

Approach for Development

Dedicated X-Vehicle - Alt./Parallel Approach

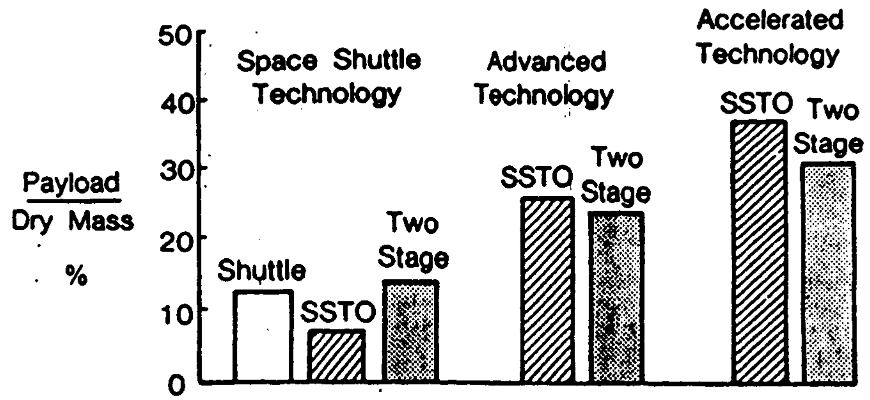
- o No payload or schedule commitment
- o Used as test bed to improve operations
  - o Propulsion & vehicle systems
  - o Incremental improvements allowed

Single Stage Vehicle Offers Airline Type Operation

- o Condition monitored
- o Idle mode checkout
- o Pilot/computer-aided control

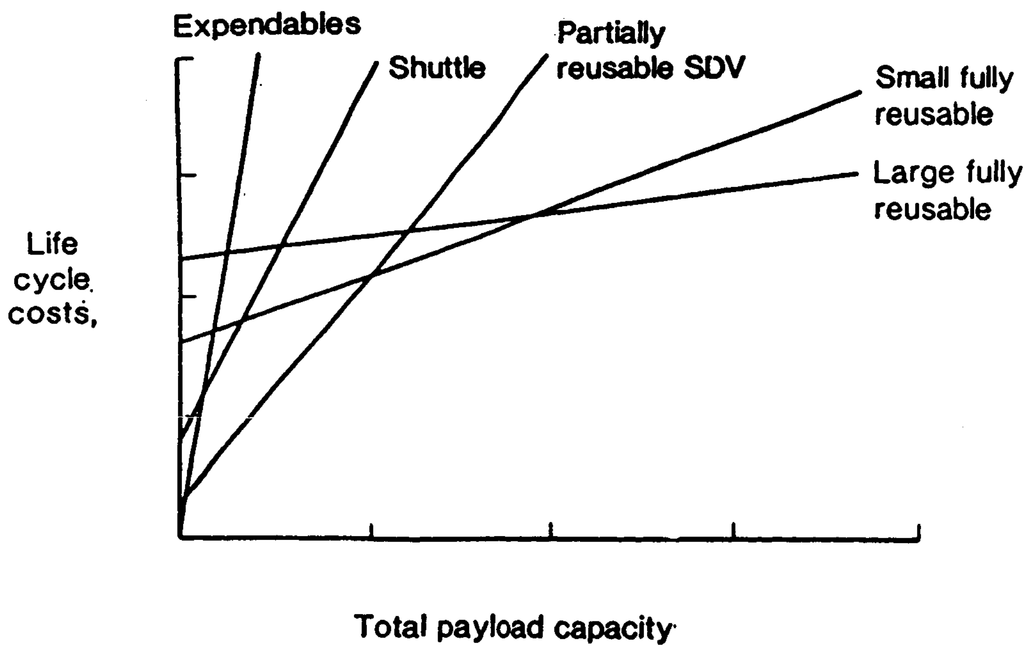
TECHNOLOGY IMPACTS ON VEHICLE DRY MASS EFFICIENCY

Payload 30 Tons

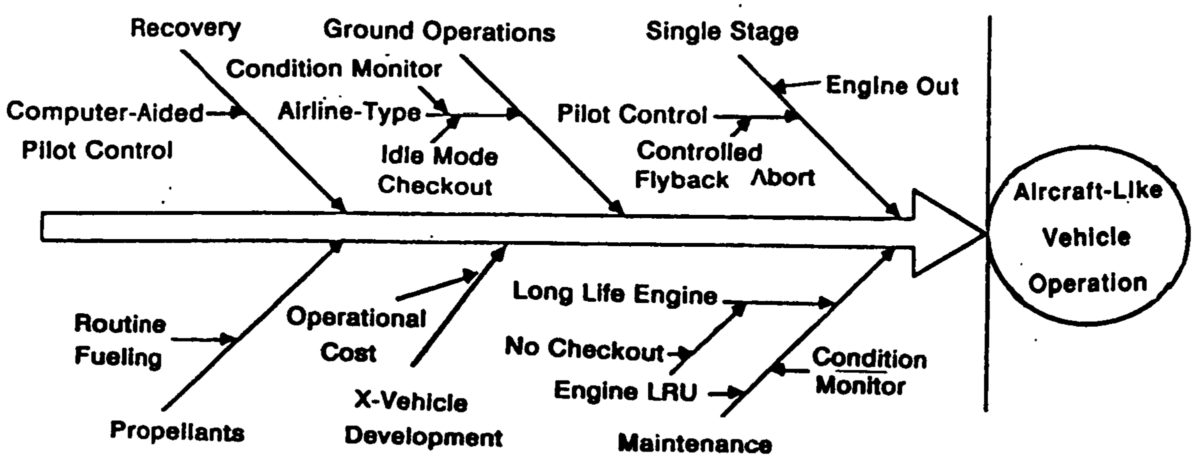


Key Technologies	SSME Al Tankage Al Structure Limited use of Composites	Dual Fuel/Separate Engines Al Tankage Warm and Cold Structure Composites	Dual Fuel/Integral Engines Al Composite Tankage Warm Structure Composites

LIFE CYCLE COST COMPARISONS



Single Stage to Orbit Approach



SSTO Approaches Aircraft - Like Operation

How Do We Make An SSTO Propulsion System Operationally Efficient?

- o Utilize STGG to increase turbine life
- o Utilize hydrostatic bearings to increase pump life
- o Optimize engine cycle to reduce turbine temperature
- o Utilize SDI thrust chamber technology
- o Use all welded joints (no leakage)
  - o self diagnostic automated condition monitor
  - o no observation points or LRU
- o No gimbal - thrust modulate engines for TVC

Technologies Have Emerged To Allow SSTO Operation

GenCorp
Aerojet
TechSystems

Efficient Propulsion System Operations

Conclusions

- Major advances are being made with ALS engine cost.
- Existing artificial interfaces do no permit improving ALS propulsion system operability.
- Must have dedicated X-ALS to continue improving operations.
- Minimum LCC/lb payload will eventually be achieved with SSTO operation.
- Must have dedicated X-SSTO to perfect engine, vehicle, and operations.

The Challenge is Here and We Must Meet It.

N91-28257

PRESENTATION 4.3.6

SPACE SHUTTLE WITH COMMON FUEL TANK FOR LIQUID ROCKET BOOSTER AND MAIN ENGINES (SUPERTANKER SPACE SHUTTLE)

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Presented to
The Space Transportation Propulsion Technology Symposium
25-29 June, 1990

The Pennsylvania State University

TABLE OF CONTENTS

ABSTRACT

An Operations and Schedule Enhancement is shown that replaces the four-body cluster (Orbiter, External Tank, two Boosters) with a simpler two-body cluster (Orbiter, Liquid Rocket Booster / External Tank). At staging velocity, the Booster Unit (liquid-fueled booster engines and vehicle support structure) is jettisoned while the remaining Orbiter and Supertank continues on to orbit, similar to the Atlas Rocket Booster. The Solid Rocket Boosters on the current U.S. Space Transportation System (STS or Shuttle) are allotted 57 days for Processing & Stack Time until Orbiter mate[1]. The simpler two-body cluster reduces this allotted time to 20 days. Liquid Booster Systems have proven superiority over Solid Rocket Boosters in the following categories: Reliability/Safety, Resiliency (ability to resume flights after an accident), Environmental Concerns, Recurring Costs, and Evolution Potential[2]. Facility impacts to Kennedy Space Center are the same as found during the Phase "A" Design Study for replacing the Shuttle's Solid Rocket Boosters with Liquid Rocket Boosters. These impacts will occur under the given guidelines for any alteration to the four-body cluster vehicle. Retaining booster engines on the Common Fueled Tank until near orbital velocity is achieved would negate the need for Space Shuttle Main Engines (SSME's) on the Cargo Carrier of an unmanned Shuttle. As a result the number of launches available per year increases while the cost of hardware decreases. Alternative and future generation vehicles are reviewed to reveal greater performance and operations enhancements with more modifications to the current methods of propulsion design philosophy, e.g., combined cycle engines, and concentric propellant tanks.

NOMENCLATURE

ET	External Tank
GLOW	Gross Lift-Off Weight
Isp	Specific Impulse
JSC	Johnson Space Center
KLbs	1000's pounds
KSC	Kennedy Space Center-NASA
LCC	Launch Control Center
LOX	Liquid Oxygen
LH2	Liquid Hydrogen
LRB	Liquid Rocket Booster
MECO	Main Engine Cut-Off
MLP	Mobile Launch Platform
NASA	National Aeronautics and Space Administration
OMS	Orbital Maneuvering System
R & PM	Research and Program Management
SEP	Separation of Booster from Space Vehicle
SSME	Space Shuttle Main Engine
SRB	Solid Rocket Booster
STS	Space Transportation System
VAB	Vehicle Assembly Building

INTRODUCTION

The following is a theoretical concept for changing the U.S. Space Transportation System (STS or Shuttle) into a total liquid fuel system by replacing the existing Solid Rocket Boosters (SRB's) and External Tank (ET) configuration with a Common Fuel Tank Booster configuration (See Figure 1, Super-Tanker Space Shuttle).

The Common Fuel Tank Booster, given the name Supertanker, is comprised of a Booster Unit (liquid fueled engines and vehicle support structure) mounted on aft end of a large propellant tank assembly. At staging velocity, the Booster Unit is jettisoned while the remaining Orbiter and Supertank continues on to orbit, similar to the Atlas Rocket Booster. The Supertank will supply Liquid Hydrogen (LH2) and Liquid Oxygen (LOX) to the Space Shuttle Main Engines (SSME's) as well as to eight booster engines mounted on its aft dome. The Supertanker-Shuttle can achieve the same launch performance as depicted in current LH2/LOX Liquid Rocket Booster Design studies.

Liquid Booster Systems have proven superiority over Solid Rocket Boosters in the following categories:

- Resiliency (ability to resume flights after an accident),
- Reliability/Safety,
- Environmental Concerns,
- Recurring Costs, and
- Evolution Potential[2].

Consequently, multiple studies were conducted to determine facility impacts at Kennedy Space Center and program-wide feasibility if SRB's were indeed replaced with Liquid Rocket Boosters (LRB's). From these studies it was concluded that a Liquid Booster System is preferable to Solid Booster Systems.

This paper proposes a propulsion design philosophy for a Common Fuel Tank Booster in which Processing, Reliability/Safety, Environmental Concerns, and Scheduling are emphasized while Performance is given secondary consideration. It is shown that Recurring Costs from Operations Check-Out and processing time are minimized when compared with four-body cluster systems.

STS-SUPERTANK EVALUATION

The Supertanker Design consists of an Orbiter (or Cargo Carrier, if used on Shuttle C), a Common Fuel Tank, given the name Supertank, of 38 Feet in diameter with a 76 foot long liquid Hydrogen Tank barrel section, and a Booster Unit made up of eight-500 Klb thrust LH2/LOX engines (See Figures 1 & 4). Since data is readily available on these LRB engines[3], they are referred to throughout this paper. At staging velocity, the Booster Unit is jettisoned while the remaining Orbiter and Supertank continues on to orbit, in a similar manner to the Atlas Rocket Booster. It may be noted that Operations would be minimized if only one liquid booster engine with one LOX and one LH2 turbopump was used[4]. However, greater reliability is realized if four[3] 1,100,000 lb thrust LH2/LOX burners with two LOX and two LH2 turbopumps were used instead, e.g., USSR Energia.

A propulsion evaluation was performed for the SUPERTANKER-SHUTTLE Vehicle using parameters from SRB-STS (see Appendix A). Gross Lift-Off Weight (GLOW) was calculated as 3838 Klbs. The total Vehicle Dry Weight at Launch was calculated as 535 Klbs, and the total Common Fuel Tank Fuel Mass as 3304 KLBs (472 LH2 / 2832 LOX). The LH2 tank barrel is limited to 76 foot length for use with existing Orbiters. The SUPERTANKER's diameter is then set at 38 Feet. (As calculated in Appendix B)

The size of the Supertanker is somewhat larger than the existing Space Shuttle External Tank (ET). Current ET's are 27.5 feet in diameter with a 76 foot long LH2 tank barrel section. The SUPERTANK will be 7.9 feet shorter due to a shorter LOX Tank and absence of the SRB Thrust Beam[5]. (See Appendix B and Figure 5).

DIMENSIONS

LENGTH OF LOX TANK 37.5 Feet
LENGTH OF LH2 TANK 104.8 Feet
TOTAL LENGTH OF SUPERTANK 146 Feet
LENGTH OF BOOSTER UNIT 13.0 Feet
TOTAL LENGTH OF SUPERTANKER 159 Feet

Unlike other Liquid Rocket Booster concepts, the Booster Unit contains all the booster engines, avionics, and controls in one compact, lightweight package. Since the Booster Unit is in a single compact package that could be adapted readily for dry (land base) recovery. A recovery attempt may prove feasible if the total price of the Booster Unit is greater than about $80 million.

An additional reason for using the 38 foot diameter LH2 tank is its potential use as a Space Station Component. Unlike the current External Tank, the Supertanker uses a 31.9 inch diameter fuel line on its aft tank dome, which would provide somewhat easy access for Hydrogen Tank entry (See Appendix C).

RELIABILITY AND SAFETY

The U.S. Space Shuttle is the first vehicle in history that uses Solid Rocket Boosters on a manned mission. NASA chose to use SRB's based on projected low development costs compared to liquid systems. The development costs were indeed held down by designing the Solid Rocket Boosters from adopted designs from the Minuteman and Titan programs[2]. However, Recurring Costs and processing time were grossly underestimated.

Liquid systems have a greater reliability than solid systems. Liquid systems' reliability is inherited due to their ability to perform a controlled shut down and their easy ability to perform many tests for flight readiness at various levels of systems complexity, i.e., component, full up engine, and static firing of the entire flight system as in a Flight Readiness Firing (FRF). An indication of this ease of testing is obtained by camparison of the number of hot fire tests that have been conducted on the Main Propulsion System and Solid Rocket Boosters, more than 1350 versus 15[2]. In addition, the severity of a failure in a solid system results in a higher probability of loss of vehicle. A liquid fueled booster system comprised of four engines that can obtain an Abort-to-Orbit with one engine out, has a calculated reliability of 0.9935[3]. This can be compared to the reliability of 0.9765 demonstrated by the 174 Titan and 50 Shuttle flights with segmented Solid Rocket Motors.

ENVIRONMENTAL CONCERNS

The Solid Rocket Boosters each contain 1,112,665 Lbs of propellant[6] which is composed of:

- 69.72% oxidizer, Ammonia Perchlorate (NH_4ClO_4),
- 16.00% fuel, Aluminum powder (Al),
- 0.28% catalyst, Iron Oxide (Fe_2O_3),
- 12.04% hydrocarbon binder/fuel ($C_{6.884} H_{10.089} O_{0.278} N_{0.264}$)
- 1.96% hydrocarbon binder/fuel ($C_{6.15} H_{6.97} O_{1.17} N_{0.03}$).

Each flight of a Solid Rocket Booster Shuttle produces:

EXHAUST PRODUCT	FORMULA	ATOM #	MOLE FRACTN %[7]	MASS FRACTN %
Aluminum Oxide	(Al_2O_3)	102.0	7.98	30.25
Carbon Monoxide	(CO)	28.0	23.16	24.10
Carbon Dioxide	(CO_2)	44.0	2.15	3.52
Chlorine atom	(Cl)	35.5	0.17	0.22
Iron Dichloride	($FeCl_2$)	126.9	0.09	0.42
Hydrogen atom	(H)	1.0	0.43	0.02
Hydrochloric acid	(HCl)	36.5	15.60	21.17
Hydrogen gas	(H_2)	2.0	27.84	2.07
Steam	(H_2O)	18.0	14.09	9.43
Nitrogen gas	(N_2)	14.0	8.42	8.76
other	average	17.0	0.07	0.04
		TOTAL	100.00	100.00

30.21% by mass of exhaust products condenses.

The above calculations were performed assuming the following conditions:

Chamber Pressure 685.0 psia,	Exhaust Pressure 14.85 psia
Chamber Temperature 6113 R,	Exhaust Temperature 4100 R
Chamber Density 0.296Lbm/ft^3,	Exhaust Density 0.00987Lbm/ft^3,
Throat Temperature 5763 R,	Exhaust Velocity Mach 2.83 or 18,103 mph

As shown above, over one half (volume) of the exhaust is combustible gas. Over one fifth (mass) of the exhaust is hydrogen chloride gas, which produces dangerous hydrochloric acid when combined with water on the ground, but more importantly, produces ozone destroying chlorine ions in the upper atmosphere when it is exposed to ultraviolet light from the sun. The Solid Rocket Boosters were designed years before first mention of deteriorating Ozone concerns. Indeed, it was through the study of SRB exhaust plumes that brought the subject to a head.[8]

Each Space Shuttle Main Engine consumes 147 lbs per sec of Liquid Hydrogen and 882 lbs per sec of Liquid Oxygen. Since the oxygen to fuel ratio is 6-to-1, each SSME will produce the following exhaust products:

EXHAUST PRODUCT	FORMULA	ATOM #	MOLE FRACTN %	MASS FRACTN %
Hydrogen gas	(H_2)	2.0	0.41	3.57
Steam	(H_2O)	18.0	99.59	96.43
other	(H, OH, O)	N/A	trace	trace
		TOTAL	100.00	100.00

SCHEDULING

Reference Figure 9[1], this chart can be used to estimate the time required to process a Supertanker for Launch. It is assumed that the Supertanker arrives at KSC with its booster unit already mated to the Supertank. Since a Supertanker is similar in many aspects to LRB's, a generic LRB Process Flow would be comparable to a Supertanker Process Flow. However, it is shown below how process flow time (barge offload to orbiter mate) for a Supertanker is reduced from 33 to 20 days when compared with Liquid Rocket Boosters.

1) Standalone check-out will not change from 18 days

2) MLP Mate & Close-Outs will be halved since 1 mate is performed instead of two; A savings of 2 days.

3) If the Booster Unit is mated at the factory with the tank, then there would not be an ET mate with its associated Close-Outs for a savings of 11 days.

NOTE: No changes should occur to the 5 days allotted for Orbiter Mate and Integrated Systems Test. This test is essentially an Orbiter systems test and with respect to time, independent of the propulsion system used.

Also, 2 days will be cut off the LRB Flow at the PAD since only one fuel and one oxidizer are loaded into one tank each. The Pad Schedule for the Supertanker would then parallel the existing SRB/STS Pad Schedule.

By using a common fuel tank vehicle as described above, the 80 days allocated for barge offload, Processing & Stack Time, Orbiter mate, and launch for the SRB-STS is reduced to 45 days for the Supertanker. Since there are two integration cells, two launch pads, and assuming there will be two check-out cells and two MLP's for the Supertanker, the Supertanker could support a manned shuttle launch every 22 days or 16.2 Launches per year. However, since 20 days are required for processing until mate, 36 Supertankers could be made available each year if required.

STS SRB vs SUPERTANKER COST COMPARISON

PROCESSING COSTS

The amount of workload and cost per flight to process the SRB's at KSC can be found in Table 1 as 100,716 man-hours and $1,925,365. Similarly in Table 2 the workload and cost per flight to process the LRB's can be found as 107,701 man-hours and $1,979,000[1]. Although the workload to process engines will not vary between the LRB's and the Supertanker, since both contain eight engines per mission, the total man-hours will be less for the Supertanker because only one fuel and one oxidizer tank is processed instead of three. The processing costs for the Supertanker could actually be less than stated above since Engineering Support is a large portion of this cost and there already exists a Liquid Engine Support group at KSC for the Orbiters SSME's.

PROPELLANT COSTS

Propellant costs, $22.4 million, amount to 4% of the Total Recurring Costs[9] for the SRB-STS. Using hydrogen and oxygen as the only propulsion propellants, this cost would be reduced to $611,210 (See Figure 6[9 & 14] and Appendix D). However, the propellant cost listed in TABLE 3 is for the External Tank and Orbiter OMS Pods. SRB propellant is included in its own hardware costs.

SUPERTANKER HARDWARE COST

The average unit cost of each 16 foot diameter LRB was stated by General Dynamics as $51 million with the four engines representing 42% of this cost[3] (See Figure 7). If a 38 foot diameter LRB with eight of these same engines was built, it can be reasoned that it would cost 2.375 times (38 ft diameter curcumference is 2.375 times greater than a 16 ft diameter) more to build a 38 foot diameter tank as it would be to build a 16 foot diameter tank. However, the eight engines with an unit cost of $5,355,000 will remain the same. If it is assumed the Design, Development, Testing, and Engineering as well as the 244 planned flights remains the same, then the Basic Supertanker Unit Cost can be calculated to be $113.1 million, which means the engines now represents 37% of the total hardware costs.

It is concluded from this method that the hardware cost for the Supertanker is the same as the $110 million, as found in TABLE 3 below, for the External Tank and two SRB's it replaces. Therefore, the Total Recurring Costs (Processing, Propellant, and Hardware) for operating the Supertanker-Shuttle would amount to the same as the Total Recurring Costs for operating the Current SRB-Shuttle, if the same flight rate was maintained.

Currently, the same amount of time to process an Orbiter is required to process a set of SRB's, 180 shifts for an Orbiter versus 171 shifts for an SRB. Thus, the flight rate cannot be increased unless a new SRB Stacking facility (off-line) and new Orbiter processing bay were built. However, the Supertanker could support a flight rate of 36 launches per year (12.8 manned Shuttle launches and 23.2 unmmanned Cargo Shuttle launches). All but the first four categories listed in TABLE 3 are approximately the same regardless of the number of launches. Therefore, the result of increasing the flight rate as listed above would greatly reduce the cost per flight and cost per pound of payload to orbit. Assuming the manned Shuttle has a payload capacity of 70,000 lbs and a Cargo Shuttle has a payload capacity of 160,000 lbs, the cost per pound of payload to orbit would then be $1470. In comparison, the cost per pound to orbit for 1985 Fiscal Year was $5470.

TABLE 3[9]

(FY-85 STS TOTAL COSTS FOR 8 FLIGHTS)

SRB	$ 464.2 Mill	Flight Operations (JSC)	$ 345.3 Mill
Eternal Tank	$ 415.8 Mill	Launch Operations (KSC)	$ 347.5 Mill
Orbiter Hardware	$ 162.6 Mill	Propellants	$ 30.3 Mill
Crew Equipment	$ 36.3 Mill	SSME Testing(Stennis SC)	$ 51.6 Mill
Ground Support	$ 24.1 Mill	Contract Administration	$ 17.1 Mill
	SUBTOTAL	$1894.8 MILLION	

plus

NETWORK SUPPORT	$ 20.4 Million
R & PM (NASA)	$ 274.2 Million
FY-85 TOTAL COST	$2189.4 Million (in 1985 dollars for 8 flights) or $ 273.5 Million per flight

SUPERTANKER FACILITY IMPACTS[1]

From Lockheed's analysis in the LRB study it was determined that the following major KSC impacts would occur for any major alteration to the current Space Transportation System:

1) New Integration Cell in the VAB's High Bay 4 (cost $33.4 mil)
   To allow non-interference with ongoing manned Shuttle schedule missions.

2) New Horizontal ET/LRB Processing Building and Engine Shop (cost $124.6 mil)
   New Integration Cell would replace today's ET Processing Cell

3) Two New Mobile Launch Platforms (cost $200 mil each)

   Less expensive than modifying current MLPs and would allow non-interference with manned Shuttle missions.

4) Additional LH2 Storage Tanks at both Pads (cost $117 mil each)
   Additional Tanks would allow 24 Hour Scrub Turnaround

5) Launch Control Center modifications (cost $14 mil)
   LCC would need modifications to preform tests to the new engines.

Total first line facilities cost $825.7 million[1].

Hold-Down Post Placements Problems encountered during the LRB study would be eliminated because the weight of the vehicle is distributed about a single, centrally located structure and the exhaust plume is generated from a single concentrated source. (See Figure 8).

SUPERTANKER EVOLUTION POTENTIAL

The same propulsion design philosophy (of one oxidizer - one fuel tank and stage only propulsion) that was used to design the Supertanker-Shuttle could also be applied to smaller commercial vehicles. See Figure 11.

A Delta Class (7,600 Lbs to Low Earth Orbit) vehicle could be designed. (See Appendix E). GLOW was calculated to be 173,100 lbs and the 10 Foot diameter LH2 and LOX tanks would have a length of 72.9 Feet and 26.0 Feet respectively.

A Shuttle-Z Class (450,000 lbs to Low Earth Orbit) vehicle could be designed. (See Appendix E). GLOW was calculated to be 10,557,000 lbs and the 60 Foot diameter LH2 and LOX tanks would have a length of 123 Feet and 44.0 Feet respectively.

In similar calculations, a Titan Class (42,900 Lbs to Low Earth Orbit) could also be designed. (See Appendix E). Glow was calculated to be 990,900 Lbs. If a vehicle length of 111.5 feet is used with 16.5 feet of that length allotted for engines and propulsion system, then calculations are performed to yield a vehicle diameter of 24.9 feet. If this vehicle was "man rated" the ten crew member Personnel Launch System (PLS) could be launched with the inherited better reliability and cleaner vehicle than a PLS utilizing the current Solid Rocket/Hypergonic powered Titan vehicle.

MULTI-BOOSTER UNIT STAGES
MANNED SHUTTLE

The Thrust-to-weight ratio after booster separation on SRB-STS is simply: Thrust 3 SSME's vacuum / Vehicle Mass after Booster SEP. Both values can be found in appendix A to give 1410 Klbs/1573 Klbs which equals 0.896 : 1.

To keep this Thrust-to-Weight ratio the same on the Supertanker, fuel had to be sacrificed due to a greater dry weight to orbit (from a heavier ET). To increase vehicle performance, the six outer Booster Engines and support structure would be jettisoned (approximately 100 klbs) at Mach 4.5. This will leave two 500 Klb thrust booster engines with the SSME's to obtain 2310 Klbs / 1583 Klbs or 1.46-to-1 thrust-to-weight ratio. The two booster engines could be retained until 3 G acceleration is obtained again. For a thrust of 2310 Klbs, 3 G acceleration is achieved at a vehicle weight of 770 Klbs. This amount of fuel (813 Klbs) would be consumed in 158 Seconds after Booster Unit Separation.

SHUTTLE - C

If the two retained booster engines are kept until orbit, there would be no reason to have two or three SSME's on an unmanned payload carrier (e.g., Shuttle-C). Since there is no thrust from the SSME's, the minimum thrust-to-weight limitation of 0.896 : 1 would now require Booster Unit Separation at a velocity greater than that for the Manned Supertanker Shuttle. The current Shuttle-C concept contains two or three SSME's, valued at $35 to $55 million each when new, which have flown the designed 10 flights. However, since the Orbiter takes 60 days to process, the manned shuttle can only be launched 12.8 missions per year. As a result only six SSME's will become available to allow three Shuttle-C flights.

The Solid Rocket Boosters on the current U.S. Space Transportation System require 57 days for Processing & Stack Time until Orbiter mate. This is the same amount of time required to process an Orbiter. Unless an off-site SRB stacking facility is built, a Shuttle-C composed of the current concept would interfere with the ongoing Manned Space Operations. The proposed Advanced Solid Rocket Motor would shorten this processing time to 42 days[10] and would allow for 2.5 launches more per year than can be flown with Orbiters. Since only 20 days are required to process the Supertanker until Orbiter or Payload Carrier mate, it would be capable of not only supporting the 12.8 Manned Shuttle launches per year, but also could support 23.7 Shuttle - C launches per year. (See Table 4).

Shuttle-C has been determined to require 83 shifts (42 two-shift days or 28 three-shift days)[10] if two or three SSME's are installed at KSC. However, a Cargo Carrier requiring no Main Propulsion System Engines could be used if two or three Booster Engines were retained on the Supertanker. A Cargo Carrier without any MPS engines would reduce the 83 activities per flow for a SSME Cargo Shuttle to 43 activities. At three shifts per day, it would require:

24 days to process Cargo Carrier and install payload
4 days to integrate Cargo Carrier to Supertanker
7 days at pad

for a total of 35 days from Cargo Carrier on dock to launch[11].

TABLE 4

BOOSTER	# DAYS TO MATE	# of MANNED SHUTTLES IT COULD SUPPORT	# OF SHUTTLE-C IT COULD SUPPORT
Solid Rocket Booster	57 Days	12.8*	0.0
Advanced Solid Rocket	42 Days	12.8*	2.5
Supertanker	20 Days	12.8*	23.5**

* NOTE: Assumes only two Orbiter Processing Facilities, 180 activities per flow, and three shifts per days.

** NOTE: Assumes Shuttle-C does not interfere with Manned Shuttle Pad Operations.

COMBINED CYCLE

Another Performance Enhancement for the near-term would be replacing four Booster Engines with an Air Breathing Nozzle under the External Tank (See Figure 2). In this concept, air would be induced to flow through the nozzle by a change of momentum from the hot exhaust flumes of the remaining five booster engines (NOTE: the SSME's on the Orbiter have been eliminated). As the air passes the throat of the nozzle, hydrogen is injected and ignited, thereby creating thrust in a somewhat similar manner as a Ram Jet.

By using such a system, thrust created by the Air Breathing Nozzle has a Specific Impulse (Isp) that varies from 1600 to 3500 seconds[12 & 15]. It can be shown that after 15 seconds into flight, air is self induced through the nozzle, therefore the Booster Rocket Engines thrust could be reduced or eliminated.

If the Shuttle's Trajectory is altered so that it remains in the atmosphere for much of the initial boost phase (first 145 seconds), the Air Breathing Nozzle could provide much of the required thrust. When a performance analysis is performed using data obtained in Figure 9, and assuming the Booster Rocket Engines are shutdown after 15 seconds and not restarted until Booster Unit Separation at Mach 6, GLOW is calculated to be 1495 Klbs. (See Appendix F)

The previous performance characteristics would require an External Tank of 145 foot length x 27.5 foot diameter that would contain 282.9 Klbs of LH2 and 796.6 Klbs of LOX. In comparison to today's conventional External Tank, the ET required for the above Combined Cycle Shuttle would require the following: The LH2 tank will need to be lengthened by 22 feet; the LOX tank could be shortened by 6.3 feet; and the Intertank will be shortened by 42.957 inch (3.6 feet) because the SRB Thrust Beam could be eliminated. (See Figure 5)

SUPERTANKER II

An Operations Enhancement could be accomplished by creating a "Second Generation" Supertanker vehicle: (See Figure 3, SUPERTANKER II)

A Second Generation Supertanker would employ concentric LOX/FUEL tanks. A 19.5 foot diameter LOX tank would be placed inside a 38 foot diameter torroidal shape LH2 tank. Both insulated tanks would be thermally independent of each other by a 1 inch air gap between tanks and each tank would have a barrel section of 120 foot length.

The orbiter (or payload) would be placed forward of the propellant tanks. Loads present on the LOX tank aft end would require a much thicker tank skin than currently used on today's shuttle. The LOX tank would then become the most suitable load bearing structure. However, for pad simplicity the LOX tank would not need to be pressure stabilized, as are the Atlas Booster, and Centaur.

The forward end of the LH2 tank would need to be independent of the LOX tank forward end, because the LH2 tank is at a colder temperature. This would allow the LH2 tank to shrink more than the LOX tank. With no loads present on its forward end and only hydrostatic loads present on it aft end, the LH2 tank skin may become extremely lightweight.

Another three 500 KLB thrust Booster Engines would need to be added to the Booster Unit, since the SSME's will have been eliminated. Of course, now three booster engines must be retained until MECO.

An "active" pressurization system has been replaced by a "passive" system. In this system "hot" LH2 at 39 degree Rankine and 6 psig and LOX at 168 degrees Rankine and 6 psig[13] is loaded into the vehicle. As the vehicle ascends and consumes fuel, the liquid propellants will "flash boil." That is, the liquid near the liquid/gas surface will boil whenever the pressure tries to go below 6 psig. In doing so, it will pull energy from its surrounding liquid at 9,730 Kilowatts in the LH2 environment and 5,750 Kilowatts in the LOX environment. This increases the surrounding fluids' density, causing it to sink to the tank bottom where the fuel inlet is. Consequently, only the warmest, least dense liquid is at the surface. Any added heat from outside sources only enhances the process. (See Appendix G).

Concentric fuel tanks would eliminate the geyser and pogo concerns associated with long feedlines. The LOX tank would be located closer to the ground which, could eliminate the need for large propellant pumps during loading.

CONCLUSION

A substantial schedule and manpower savings could be realized if the United States Space Shuttle was configured with a Common Fuel Tank with aft mounted booster engines (a Supertanker). Though the hardware and processing cost for the Supertanker would parallel the existing Space Shuttle's SRB's, all costs for the Space Shuttle's External Tank would be eliminated. Furthermore, when the Supertanker is compared with proposed LRB concepts, Launch Operations are reduced considerably because only one set of oxidizer and fuel tanks are processed instead of three. The size of the fuel tank does not affect the magnitude of manpower required to process it. The most appealing benefits from the Supertanker concept are its reduction in cost per flight (more flights could be made per year), reduced environmental impacts (its only by-product is water), and greater reliability (as inherited in multi-engine liquid systems). Also, the Supertanker will make the Shuttle-C concept highly feasible since it is not restrained by the supply of used SSME'S. The same facilities impacts to KSC would occur with the Supertanker (or almost any new concept different from the current configuration) as with the Liquid Rocket Booster Program.

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APPENDIX A

To find an unknown propulsion parameter of a vehicle the following calculations are made:

EQU 1.) $Vb = G * Isp * \ln(Mini / Mfin) - k * G * t$

where

- Vb = Velocity of vehicle after fuel has been expended
- G = Gravitational constant = 32 feet per sec per sec
- Isp = Specific Impulse of total vehicle (lbf / lbm/sec)
- Mini = Mass of initial vehicle
- Mfin = Mass of vehicle after fuel has been expended
- t = Amount of time to achieve Vb after lift-off
- k = Correction Factor - derived by considering the amount of time thrust is used to overcome gravity.

Using known characteristics from SRB-STS to find unknown charateristics of Supertanker Shuttle.

SRB-STS(6)		SUPERTANKER
220,092 lbs	Orbiter Inert & OMS Prop	220,092 lbs
51,246 lbs	Payload	70,000 lbs
66,760 lbs	External Tank or Supertank	120,300 lbs
376,416 lbs	SRB (dry weight)	
	Booster Unit (Structure)	73,004 lbs
	Booster Unit (eight-engines)	54,533 lbs
714,514 lbs	Total Vehicle Inert Weight @ Launch	537,929 lbs
338,098 lbs	Mass at MECO	410,392 lbs
1542 Klbs	Mass after Booster Separation	1542 Klbs
269 (228) Sec	Booster Isp in Vac (S/L)	427 (382) Sec
2397 Klbs	AVE Booster Thrust (Boost Phase)	4205 Klbs
	Booster Thrust Vac (S/L) * 8	4508 (3902) Klb
	SSME Parameters(17)	
453.5 (361)[407]Sec	SSME Isp in Vacuum (S/L)[Ave Boost Phase]	
1413(1131)[1272]Klb	SSME Thrust in Vacuum (S/L)[Ave Boost Phase]	
6986 lbs	SSME Weight	
1590 Klbs	External Tank Fuel of SRB-STS	
4525 Klbs	Gross Lift-Off Weight (GLOW) for SRB-STS	
123.6 Seconds	Time to Booster Separation	121.3 Seconds

Average Thrust and Average Specific Impulse was derived by assuming the vehicle was reacting against a degrading air pressure during boost phase.

STS-SRB EVALUATION

Using Equation 1) a propulsion analysis of today's SRB-STS will revealed parameters which can be correlated with the Supertanker The velocity gained by the SRB-STS after Booster Separation is calculated by the following:

Using Eq 1):

Vmeco = (32 ft/sec^2) * 453.5 Sec * ln (1542/338) - 0
= 22,026 Ft/sec

Although, it was assumed that "k" was zero in the above equation, in actuality it is finite. When the above result is correlated with the Supertanker, this parameter nearly cancels out.

Because the Specific Impulse is different for the SSME's and the SRB, the Average Vehicle Isp during the boost phase is calculated by doing the following:

EQU 2) Average Vehicle Isp =

$$\{(Isp_1 * Thrust_1) + (Isp_2 * Thrust_2)\} / (Thrust_1 + Thrust_2)$$

Ave Veh Isp = 310.3 Seconds from the calculation
{(407sec * 1272Klb) + (259sec * 2397Klbs)} / (1272Klbs + 2397Klbs)

Using Eq 1):
Vboost.sep = (32 ft/sec^2) * 310.3 Sec * ln (4525/1542 + 376) -
0.9 * 32 ft/sec^2 * 123.6 Sec

Velocity at Booster Separation = 4,963 Ft/sec or Mach 4.67

"k" was assumed to be 0.9 after reviewing the flight trajectory until booster separation at 23 miles downrange and 29 miles altitude, and realizing that 90% of this boost energy was spent overcoming gravity.

Total Velocity Gained by the vehicle after launch:
22,026 Ft/sec + 4,963 Ft/sec = 26,989 FT/sec

SUPERTANKER EVALUATION

Using Equation 1) a propulsion analysis of the Supertanker will revealed its propulsion parameters. The velocity gained by the Supertanker after Booster Separation is calculated by the following:

Because the thrust of the SSME's has not changed with the Supertanker Concept, the Thrust-to-Weight after Booster Unit Separation can not change. Therefore, Vehicle Mass after Booster Unit Separation must remain at 1542 Klbs. It has been assumed that the Supertanker is 67 Klbs heavier than the ET, therefore the amount of fuel after Booster Unit Separation must be 67Klb less or 1140 Klb

Using Eq 1): Vmeco = (32 ft/sec^2) * 453.5 Sec * ln (1542/410) - 0
= 19,210 Ft/sec

"k" was again assumed to be zero as in the STS/SRB equation.
The difference between the above result for vehicle gained after Booster Unit Separation and Total Velocity Gained after Launch for STS/SRB is the amount of Velocity Gained the Supertanker Vehicle must acquire during the boost phase.

or 26,989 Ft/sec - 19,210 = 7,779 Ft/sec

Because the Specific Impulse is different for the SSME's and the Booster Unit Engines, the Average Vehicle Isp during the boost phase equation 2) is again used:

Average Vehicle Isp =
$\{(Isp_1 * Thrust_1) + (Isp_2 * Thrust_2)\} / (Thrust_1 + Thrust_2)$

Ave Veh Isp =
{(407sec * 1272Klb) + (405sec * 4205Klbs)} / (1272Klbs + 4205Klbs)
= 406 Seconds

Using Eq 1):
7,779 FT/sec = (32 ft/sec^2) * 406 Sec * ln (GLOW/1,669,537) -
0.8 * 32 ft/sec^2 * 122 Sec

GLOW = 3838 Klbs

"k" was assumed to be 0.8 because the Booster Unit Separation would take place farther downrange while altitude wouldn't necessary need to change. Therefore it was assumed that less of the vehicles energy was spent overcoming gravity.

SUPERTANK SIZE

GLOW was found in Appendix A as 3,838,000 Lbs. In addition, Vehicle Dry Weight is 535,000 Lbs. The amount of propellant (LH2 and LOX) required is 3,303,500 Lbs. Because the LOX-to-Fuel ratio is 6 : 1, the amount of LH2 and LOX loaded at atmospheric pressure onto the Supertanker is 472 KLbs and 2832 KLbs respectively. If a 3.0% ullage is included, then that amount of fuel would required tanks with a volume capacity of 110,000 Ft^3 for LH2 and 40,950 Ft^3 for LOX[13].

LH2 TANK DIAMETER

(Reference Figure 5, LH2 Tank), Because the length of the hydrogen barrel is fixed (at 76 Feet) as well as the size of the domes, the only variable is the tank diameter. This diameter is found by doing the following calculations:
Volume of LH2 tank: Volume of Tank Barrel + Volume of both Domes

Because the domes are not hemispheres, but are elliptical. Their volumes will be calculated by:
EQU 3) Vdom = (4/3 * pi * a^2 * b)
where "a" is major radius of 228 inch or 19.0 Ft (which is the radius of Supertank as derived through iteration) and "b" is minor radius of 172.8 inch or 14.4 Ft (which is the radius of curvature of dome as derived in TANK DOME DIMENSIONING).
Using Equation 3)
Vol of LH2 Domes = 21,775 Ft^3 = (4/3 * pi * 19^2 * 14.4)

Volume of Tank Barrel: 110,000 - 21,775 = 88,225 Ft^3
Cross area of Tank: Volume / Barrel Length : pi * Diameter^2 / 4
= 88,225 Ft^3 / 76 Ft = 1160.9 Ft^2

<u>Diameter of Tank Barrel: 38.2 FT</u> = {1160.9 Ft^2 * (4/pi)}^0.5

TANK DOME DIMENSIONING

The aft fuel dome was designed using a 211.855 inch radius of curvature[5]. Therefore, its radius is 1.28 times greater than the tanks barrels 165 inch (13.75 Foot) radius. If a Supertanker with a 19.0 foot (228 inch) radius tank was used, then the radius of curvature would be 292.8 inch. [(228 / 165) * 211.855 inch]
From Figure 6, it can be found that the radius of curvature is 1.70 [211.855 / 124.125] times greater than the longitudinal distance of dome ellipse to dome/barrel interface on todays External Tank. Hence, this distance on the SUPERTANKER would be 172 inch (14.4 feet). This dimension is found by 292.8 inch / 1.70. Therefore, the longitudinal distance has been increased by 47.9 inch or 4.0 feet for each dome.

LOX TANK DIMENSIONING

(Reference Figure 5, LOX Tank), The LOX Tank diameter and size of aft dome is determined by the diameter of the LH2 Tank, as found above. The only variable that can be changed due to fuel volume requirements on the LOX Tank is the major axis found using equation 3.The minor axis will initially assumed to be the radius of the tank

The major axis is found by doing the following calculations:

Volume of LOX tank: Volume of Aft Dome + Volume of Frwrd Ogive
40,950 Ft^3 = (21,775 Ft^3) / 2 + 4/3 * pi * a^2 * 19.0 Ft
a = 19.4 Ft

Length of LOX Tank is then found as:
Length of Aft Dome + Length of Forward Ogive + Length of Nose Cone
Length of Lox Tank = 14.4 Ft + 19.4 Ft + 3.65 Ft = 37.5 FT

Total Length of LH2 Tank = Length of both domes + Length of Barrel
= (14.4 * 2)Ft + 76 Ft = 104.8 Ft

Total Length of Supertank = Length of LH2 Tank + Length of LOX Tank + Length of LOX Nose Cone
= 104.8 Ft + 37.5 Ft + 3.65 Ft
= 145.9 Ft

APPENDIX C

LH2 BOOSTER UNIT FEEDLINE SIZE

LIFTOFF THRUST = 5538 KLBS (4149 from B.U. & 1153 from SSME's)
Booster Unit Thrust = 4385 KLBS
SUPERTANKER Isp = 382 SECONDS
FUEL RATIO (O/F) = 6:1

BOOSTER LH2 FLOW RATE = 1,640 LBS/SEC [(4,385,592 / 382) * (1/7)]
372.7 FT^3/SEC [(1640 LBS/SEC) / (4.4LB/FT^3)]

SSME THRUST * 3 = 1,480,000 LBS
SSME Isp = 453.5 SECONDS
SSME FUEL RATIO = 6:1
LH2 FLOW RATE = 466 LBS/SEC [(1,480,000 / 453.5) * (1/7)]
106 FT^3/SEC [(466 LBS/SEC) / (4.4 LBS/FT^3)]

ET LH2 FUEL LINE = 17 INCH DIAMETER = 1.58 FT^2 CROSS AREA
LH2 FUEL LINE VELOCITY = 67.1 FT/SEC (106 / 1.58)

AREA OF SUPERTANKER LH2 FEEDLINE = 5.55 FT^2 = 800 INCH^2
(372.7 FT^3/SEC) / (67.1 FT/SEC)
DIAMETER OF LH2 FEEDLINE = 31.9 INCH [{800 * (4/pi)}^0.5]

LOX FEEDLINE SIZE

NOMINAL THRUST = 5538 KLBS (4385 from B.U. & 1153 from SSME's)
SUPERTANKER Isp = 410.6 SECONDS
FUEL RATIO (O/F) = 6:1
LOX FLOW RATE = 11,561 LBS/SEC [(5,538,000 / 410.6) * (6/7)]
163 FT^3/SEC [(11561 LBS/SEC) / (71LBS/FT^3)]

F-1 THRUST = 1,500,000 LBS
F-1 Isp = 260 SECONDS
F-1 FUEL RATIO = 2.27:1
LOX FLOW RATE = 4005 LBS/SEC [(1,500,000 / 260) * (2.27/3.27)]
= 56.4 FT^3/SEC [(4005 LBS/SEC) / (71 LBS/FT^3)]

F-1 LOX FUEL LINE = 17 INCH DIAMETER = 1.58 FT^2 CROSS AREA
LOX FUEL LINE VELOCITY = 35.7 FT/SEC (56.4 / 1.58)

AREA OF SUPERTANKER LOX FEEDLINE = 4.56 FT^2 = 656 INCH^2
[(163 FT^3/SEC) / (35.7 FT/SEC)]
DIAMETER OF LOX FEEDLINE = 28.9 INCH [{656 * (4/pi)}^0.5]

APPENDIX D

PROPELLANT COST (9)

Liquid Hydrogen - $ 1.18 per pound
Liquid Oxygen - $ 0.04 per pound
Solid Propellant - $10.00 per pound

SRB-STS (6)

LH2 -	227,161 Lbs	*	$ 1.18/lb	=	$	268,050
LOX -	1,362,967 Lbs	*	$ 0.04/lb	=	$	54,519
SRB -	2,208,000 Lbs	*	$10.00/lb	=	$	22,080,000
	Total Cost of Propellant			=	$	22,402,569

This amounts to 4% of the total recurring cost for SRB-STS.

SUPERTANKER

LH2 -	472,000 Lbs	*	$ 1.18/lb	=	$	556,960
LOX -	2,832,000 Lbs	*	$ 0.04/lb	=	$	113,280
	Total Cost of Propellant			=	$	670,240

This would amount to 0.12% of the total recurring cost for SRB-STS.

COMBINE CYCLE

LH2 -	282,900 Lbs	*	$ 1.18/lb	=	$	333,822
LOX -	796,600 Lbs	*	$ 0.03/lb	=	$	23,900
	Total Cost of Propellant			=	$	357,720

APPENDIX E

DELTA CLASS SUPERTANKER APPLICATION

DELTA CLASS		SHUTTLE CLASS
1,520 lbs	Payload shoud or Orbiter	220,092 lbs
7,600 lbs	Payload	70,000 lbs
6,200 lbs	Supertank	120,300 lbs
3,500 lbs	Booster Unit (Structure)	73,004 lbs
3,900 lbs	Booster Unit (engines)	54,533 lbs
22,720 lbs	Total Vehicle Inert Weight @ Launch	537,929 lbs
18,145 lbs	Mass at MECO	410,392 lbs
	Ave Isp for Booster Engines (Boost Phase)	404.5 sec
	Isp Vacuum	427.0 sec
	Relative Velocity at Booster Unit Separation	7,779 Ft/sec
	Velocity Changed after Booster Unit Sep	19,210 Ft/sec

Values for mass of Delta Class vehicle was arrived by scaling the Shuttle Class Vehicle down to reflect the Mass to Orbit for the Delta Class. Two thirds of B.U. Engine mass, half of B.U. Structure mass, and the Payload shroud is jettisoned at Booster Unit Separation.

Using Equation 1) a propulsion analysis of the Delta Class Supertanker will revealed its propulsion parameters. The velocity gained by the Supertanker after Booster Unit Separation as well as the velocity at Booster Unit Separation is assumed to remain the same as the Shuttle-Supertanker.

Using Eq 1) to find Mass at Booster Unit Separation (Msep):

$$19{,}210\ \text{Ft/sec} = (32\ \text{ft/sec}^2) * 427\ \text{Sec} * \ln(\text{Msep}/18{,}145) - 0$$
$$= 68{,}730\ \text{lbs}$$

"k" was again assumed to be zero as in the Supertanker equation.

Using Eq 1) to find GLOW for the Delta Class Vehicle:

$$7{,}779\ \text{FT/sec} = (32\ \text{ft/sec}^2) * 404.5\ \text{Sec} * \ln(\text{GLOW}/74{,}580) - 0.8 * 32\ \text{ft/sec}^2 * 122\ \text{Sec}$$

GLOW = 173,177 lbs

SUPERTANK SIZE

The amount of propellant (LH2 and LOX) required is 150,450 Lbs. Because the LOX-to-Fuel ratio is 6 : 1, the amount of LH2 and LOX loaded at atmospheric pressure onto the Supertanker is 21,500 Lbs and 128,950 Lbs respectively. If a 3.0% ullage is included, then that amount of fuel would required tanks with a volume capacity of 5,250 Ft^3 for LH2 and 1,870 Ft^3 for LOX[13].

TANK DIMENSIONS

If a 10 Foot diameter core vehicle is used then calculations as performed in Appendix A will yield a LH2 tank length of 72.9 Feet. And a LOX tank with the same shape as the LH2 tank will yield a length of 26.0 Feet.

TITAN CLASS SUPERTANKER APPLICATION

TITAN CLASS		SHUTTLE CLASS
8,500 lbs	Payload shroud or Orbiter	220,092 lbs
42,900 lbs	Payload	70,000 lbs
36,500 lbs	Supertank	120,300 lbs
18,000 lbs	Booster Unit (Structure)	73,004 lbs
24,000 lbs	Booster Unit (Engines)	54,533 lbs
129,900 lbs	Total Vehicle Inert Weight @ Launch	537,929 lbs
96,400 lbs	Mass at MECO	410,392 lbs
	Ave Isp for Booster Engines (Boost Phase)	404.5 sec
	Isp Vacuum	427.0 sec
	Relative Velocity at Booster Unit Separation	7,779 Ft/sec
	Velocity Changed after Booster Unit Sep	19,210 Ft/sec

Values for mass of Titan Class vehicle was arrived by scaling the Shuttle Class Vehicle down to reflect the Mass to Orbit for the Titan Class. Two thirds of B.U. Engine mass, half of B.U. Structure mass, and the Payload shroud is jettisoned at Booster Unit Separation.

Using Equation 1) a propulsion analysis of the Titan Class Supertanker will revealed its propulsion parameters. The velocity gained by the Supertanker after Booster Unit Separation as well as the velocity at Booster Unit Separation is assumed to remain the same as the Shuttle-Supertanker.

Using Eq 1) to find Mass at Booster Unit Separation (Msep):

19,210 Ft/sec = (32 ft/sec^2) * 427 Sec * ln (Msep/96,400) - 0
= 393,220 lbs

"k" was again assumed to be zero as in the Supertanker equation.

Using Eq 1) to find GLOW for the Titan Class Vehicle:

7,779 FT/sec = (32 ft/sec^2) * 404.5 Sec * ln (GLOW/426,720) -
0.8 * 32 ft/sec^2 * 122 Sec

<u>GLOW = 990,833 lbs</u>

SUPERTANK SIZE

The amount of propellant (LH2 and LOX) required is 894,500 Lbs. Because the LOX-to-Fuel ratio is 6 : 1, the amount of LH2 and LOX loaded at atmospheric pressure onto the Supertanker is 127,750 Lbs and 766,750 Lbs respectively. If a 3.0% ullage is included, then that amount of fuel would required tanks with a volume capacity of 31,200 Ft^3 for LH2 and 11,100 Ft^3 for LOX[13].

TANK DIMENSIONS

If a vehicle length of 111.5 Foot is used with 16.5 feet allotted for engines and propulsion system, then calculations as performed in Appendix A will yield a vehicle diameter of 24.9 Feet.

SHUTTLE-Z CLASS SUPERTANKER APPLICATION

SHUTTLE-Z CLASS		SHUTTLE CLASS
90,000 lbs	Payload shroud or Orbiter	220,092 lbs
450,000 lbs	Payload	70,000 lbs
383,000 lbs	Supertank	120,300 lbs
216,000 lbs	Booster Unit (Structure)	73,004 lbs
251,800 lbs	Booster Unit (Engines)	54,533 lbs
1,390,800 lbs	Total Vehicle Inert Weight @ Launch	537,929 lbs
1,024,900 lbs	Mass at MECO	410,392 lbs
	Ave Isp for Booster Engines (Boost Phase)	404.5 sec
	Isp Vacuum	427.0 sec
	Relative Velocity at Booster Unit Separation	7,779 Ft/sec
	Velocity Changed after Booster Unit Sep	19,210 Ft/sec

Values for mass of Shuttle-Z Class vehicle was arrived by scaling the Shuttle Class Vehicle down to reflect the Mass to Orbit for the Shuttle-Z Class. Two thirds of B.U. Engine mass, half of B.U. Structure mass, and the Payload shroud is jettisoned at Booster Unit Separation.

Using Equation 1) a propulsion analysis of the Shuttle-Z Class Supertanker will revealed its propulsion parameters. The velocity gained by the Supertanker after Booster Unit Separation as well as the velocity at Booster Unit Separation is assumed to remain the same as the Shuttle-Supertanker.

Using Eq 1) to find Mass at Booster Unit Separation (Msep):

19,210 Ft/sec = (32 ft/sec^2) * 427 Sec * ln (Msep/1,024,900) - 0
= 4,180,600 lbs

"k" was again assumed to be zero as in the Supertanker equation.

Using Eq 1) to find GLOW for the Shuttle-Z Class Vehicle:

7,779 FT/sec = (32 ft/sec^2) * 404.5 Sec * ln (GLOW/4,546,500) -
0.8 * 32 ft/sec^2 * 122 Sec

GLOW = 10,556,950 lbs

SUPERTANK SIZE

The amount of propellant (LH2 and LOX) required is 9,166,150 Lbs. Because the LOX-to-Fuel ratio is 6 : 1, the amount of LH2 and LOX loaded at atmospheric pressure onto the Supertanker is 1,309,450 Lbs and 7,856,700 Lbs respectively. If a 3.0% ullage is included, then that amount of fuel would required tanks with a volume capacity of 319,400 Ft^3 for LH2 and 114,000 Ft^3 for LOX[13].

TANK DIMENSIONS

If a 60 Foot diameter core vehicle is used then calculations as performed in Appendix A will yield a LH2 tank length of 123 Feet. And a LOX tank with the same shape as the LH2 tank will yield a length of 44.0 Feet.

APPENDIX F

COMBINED CYCLE PERFORMANCE EVALUATION

VELOCITY RANGE	FUEL CONSUMED (KLBS)	INITIAL MASS	Isp (SEC)	FLIGHT TIME
0 TO 1 MACH	55 (27.5 LH2, 27.5 LOX)	1495 KLBS	1600	25.4
1 TO 2 MACH	38 (29.2 LH2, 8.8 LOX)	1440 KLBS	2200	24.7
2 TO 3 MACH	26 (23.2 LH2, 2.3 LOX)	1402 KLBS	3200	24.3
3 TO 4 MACH	23 (23.0 LH2, 0.0 LOX)	1377 KLBS	3500	23.8
4 TO 5 MACH	24 (24.0 LH2, 0.0 LOX)	1354 KLBS	3200	23.5
5 TO 6 MACH	30 (30.0 LH2, 0.0 LOX)	1330 KLBS	2600	22.9
	STAGE 80 KLBS			
6 TO 26 MACH	885 (126 LH2, 758 LOX)	1200 KLBS	440	294
	MASS AT MECO	335 KLBS		

TOTAL TIME to MECO 438.6 Sec = 7.3 Minutes

TOTAL BOOSTER FUEL 156.9 LH2 AND 38.6 LOX
TOTAL SHUTTLE FUEL 282.9 LH2 AND 796.6 LOX = 1079.5 KLBS

The following is a breakdown of the GLOW of 1495 Klbs:

Mass at MECO = 335 Klbs
Mass of External Tank is assumed to remain at 69 Klbs
Mass after Booster Seperation = 1200 Klbs
Mass of Booster Unit & Air Breather = 105 Klbs
Fuel for Air Breather(LH2) = 196 Klbs
Mass of Booster Unit Engines (5) = 25 Klbs

APPENDIX G[13]

LH2 HEAT FLUX REQUIREMENTS

As found in the 1989 Fundamentals
Pressure = 20 psia   Volume vapor = 8.95 Ft^3/lbm
Temperature = 39 Rankine   Density Liq = 4.32 lbm/Ft^3
Delta Enthalpy (across dome) = 311 - 122 = 189 BTU/lbm

Maximum drainage from tanks occurs during boost phase. As found in Appendix A:

Maximum Thrust / Isp = (4205 + 1296 Klbs) / (408 Sec)
= 13,488 lbs/sec
Since LH2 mass flow is 1/7 of this total, then:

LH2 Mass Flow: 1,887 lbs/sec = 437 FT^3/sec
[1,887 lbs/sec / 4.32 lbm/FT^3]
which is the same amount of gaseous Hydrogen at 20 psia that must be generated.

This amount of GH2 (in mass) is then:

GH2 Mass Gen: 48.8 lbm/sec = [437 FT^3/sec / 8.95 Ft^3/lbm]

Finally, to generate this amount of GH2 would require:
9,224 BTU/sec = 33.2 10^6 BTU/hr = 9,730 Kilowatts
from the calculation: [(48.8 lbm/sec) * (189 BTU/lbm)]

LOX HEAT FLUX REQUIREMENTS

As found in the 1989 Fundamentals
Pressure = 20 psia   Volume vapor = 2.67 Ft^3/lbm
Temperature = 168 Rankine   Density Liq = 70.2 lbm/Ft^3
Delta Enthalpy (across dome) = 35.1 - (-55.1) = 90.2 BTU/lbm

Again Maximum drainage from tanks is calculated to be 13,208 lb/sec. LOX to LH2 ratio is 6:1 therefore:

LOX Mass Flow: 11,322 lbs/sec = [11,322 lbs/sec / 70.2lbm/ft^3]
= 161.3 FT^3/sec
which is the same amount of gaseous Oxygen at 20 psia that must be generated.

GOX Mass Gen: 60.4 lbm/sec = [161.3 FT^3/sec / 2.67 Ft^3/lbm]

Finally, to generate this amount of GOX would require:
5,450 BTU/sec = 19.6 10^6 BTU/hr = 5,750 Kilowatts
from the calculation: [(60.4 lbm/sec) * (90.2 BTU/lbm)]

about the author

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* received B.S. in Engineering Physics from Eastern Kentucky Univ. in 1985.

* working towards receiving M.S. in Thermal-Fluids from the Mechanical Eng Dept at the University of Central Florida.

* was a part-time member of the Lockheed Advance Programs Group during the Liquid Rocket Booster Integration Accessment on Facility Impacts at NASA Kennedy Space Center during 1988.

* has been employed as a Mechanical Systems Engineer for External Tank Program for Lockheed Space Operations Company since Aug 1987.

Questions and comments can be made through the following address:

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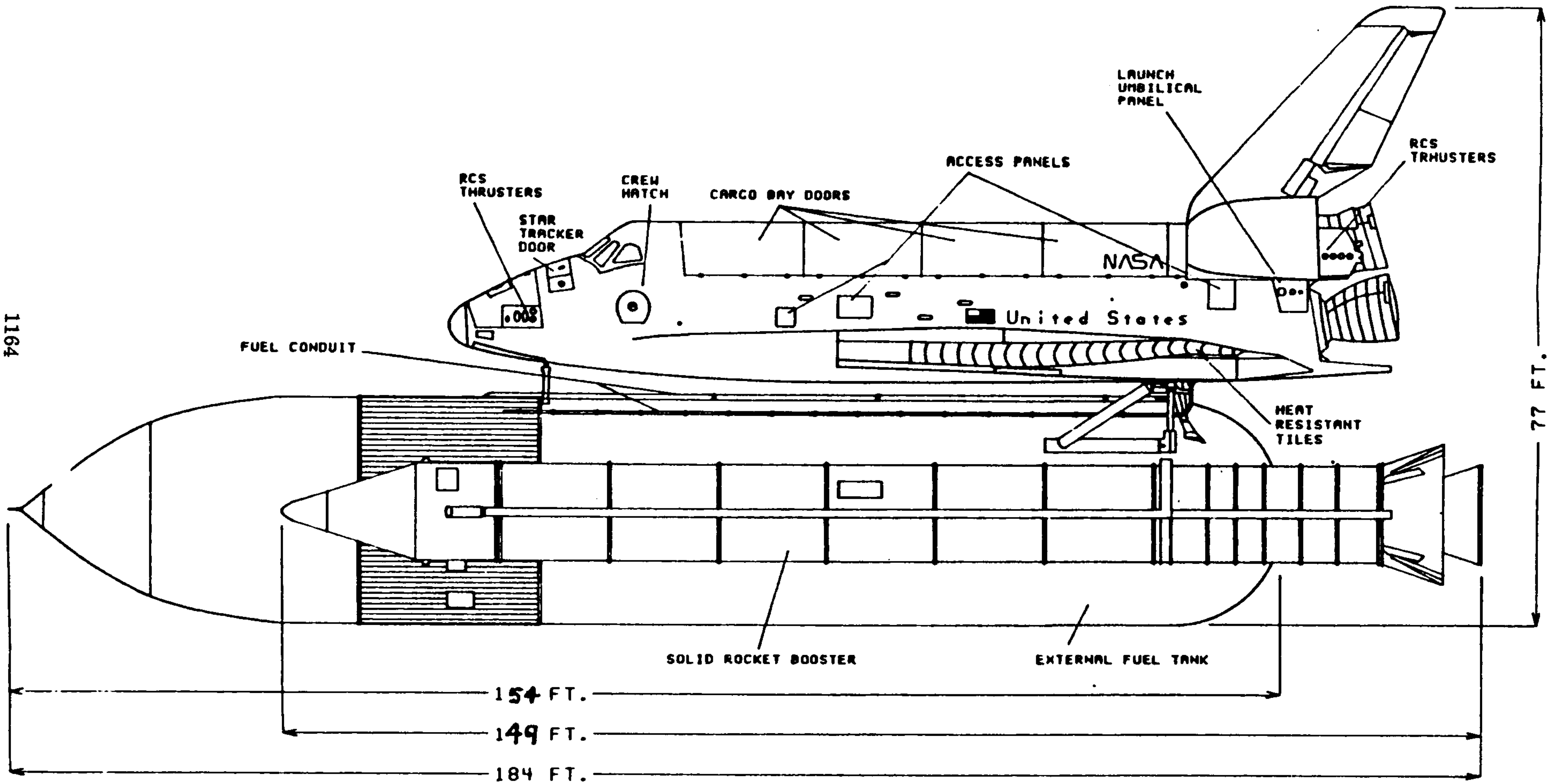
(407) 867-5835

Acknowledgement:

The author wishes to thank Russel E. Rhodes of NASA-KSC and Lockheed's Advanced Programs Group for several helpful discussions throughout the course of this work.

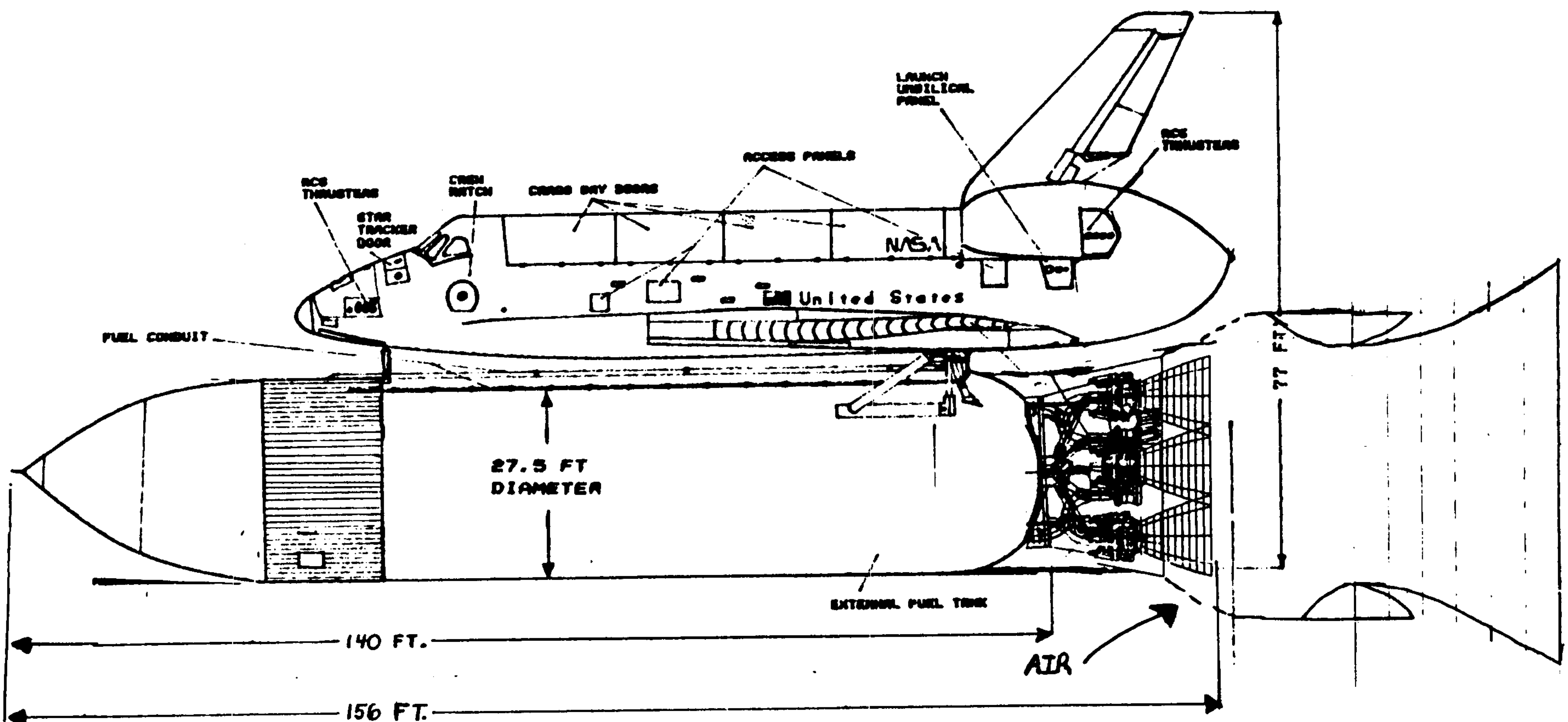
REFERENCE FIGURE



THE SPACE SHUTTLE DISCOVERY

FIGURE 2

COMBINED CYCLE



SPACE SHUTTLE DISCOVERY

FIGURE 3

SUPER-TANKER II SPACE SHUTTLE

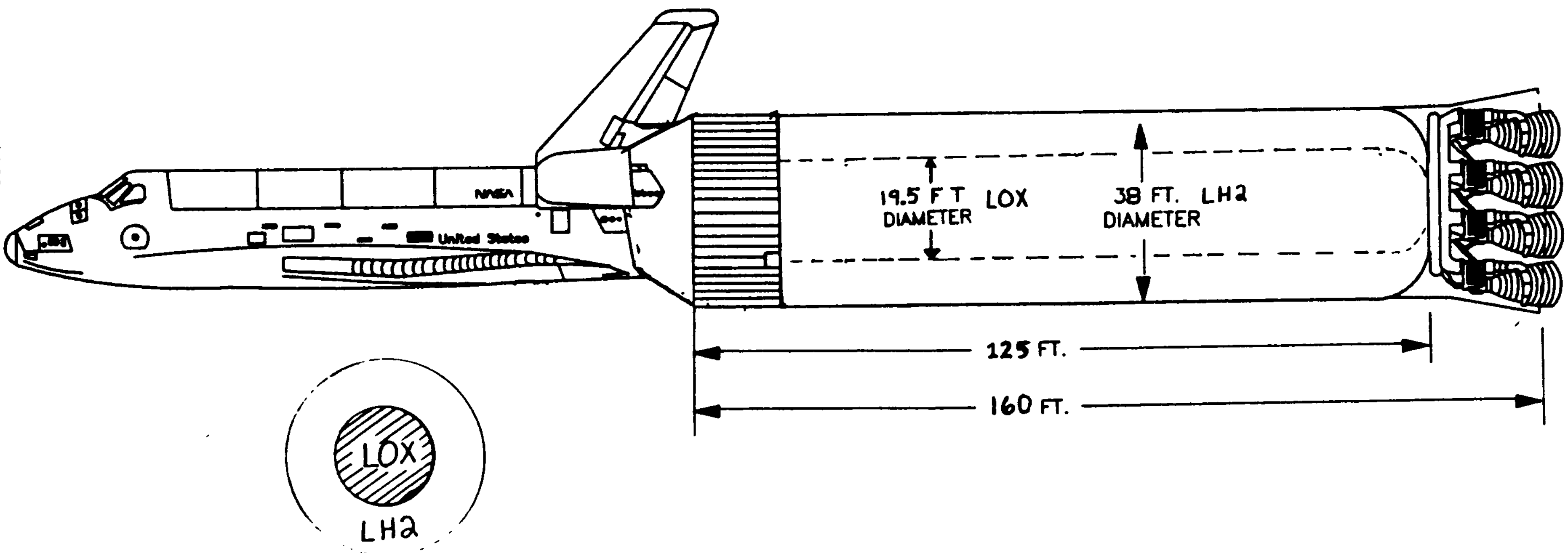
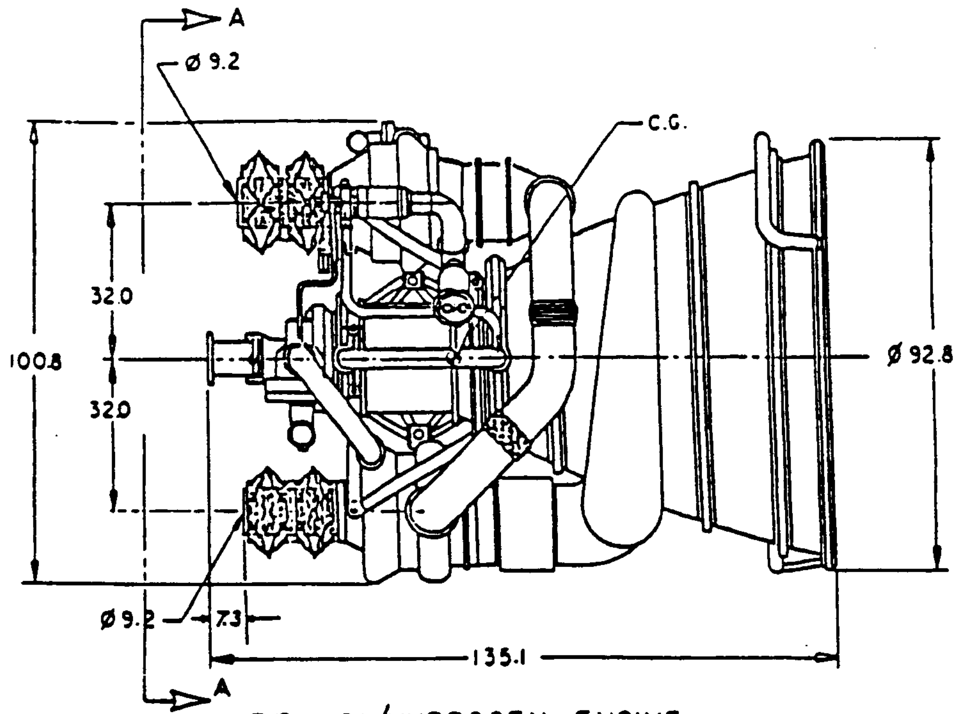


FIGURE 4

PAGE 1 OF 2



LRB LOX/HYDROGEN ENGINE
Dimensions in Inches

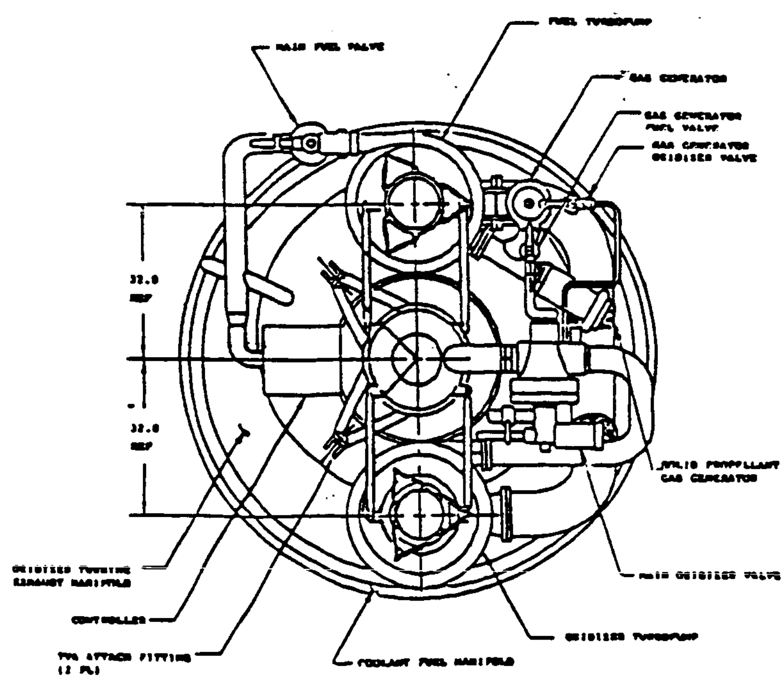


Figure 5.2.1-6 LO2/LH2 GG Engine Drawing

FIGURE 4

EXPENDABLE LOX/H_2 GAS GENERATOR ENGINE CHARACTERISTICS

GENERAL DYNAMICS
Space Systems Division

LRB

Engine Parameters	Nominal Thrust	Minimum Thrust
Throttle, (percent)	100	75.0
Vacuum Thrust (lb)	558,000	418,500
Sea Level Thrust (lb)	518,574	388,930
Chamber Pressure (psia)	2250	1701
Vacuum Isp (sec delivered)	411.4	412.3
Sea Level Isp (sec)	382.3	373.2
Mixture Ratio	6.0	6.0
Oxidizer Flow Rate (lb/sec)	1162.7	893.3
Fuel Flow Rate (lb/sec)	193.8	148.9
Nozzle Area Ratio	20	
Throat Radius (in)	6.54	
Exit Diameter (in)	58.4	
Overall Length (in)	112.9	
Inlet Pressure: LOX (psia)	65	
Inlet Pressure: LH_2 (psia)	45	
Inlet Temperature	Saturation at 16 psia	
Mission Life	1	
No. of Starts	5	
Reliability	99% @ 90% confidence level	
Dry Weight (lb)	6100	

FIGURE 5

SRB THRUST BEAM

PAGE 1 OF 3

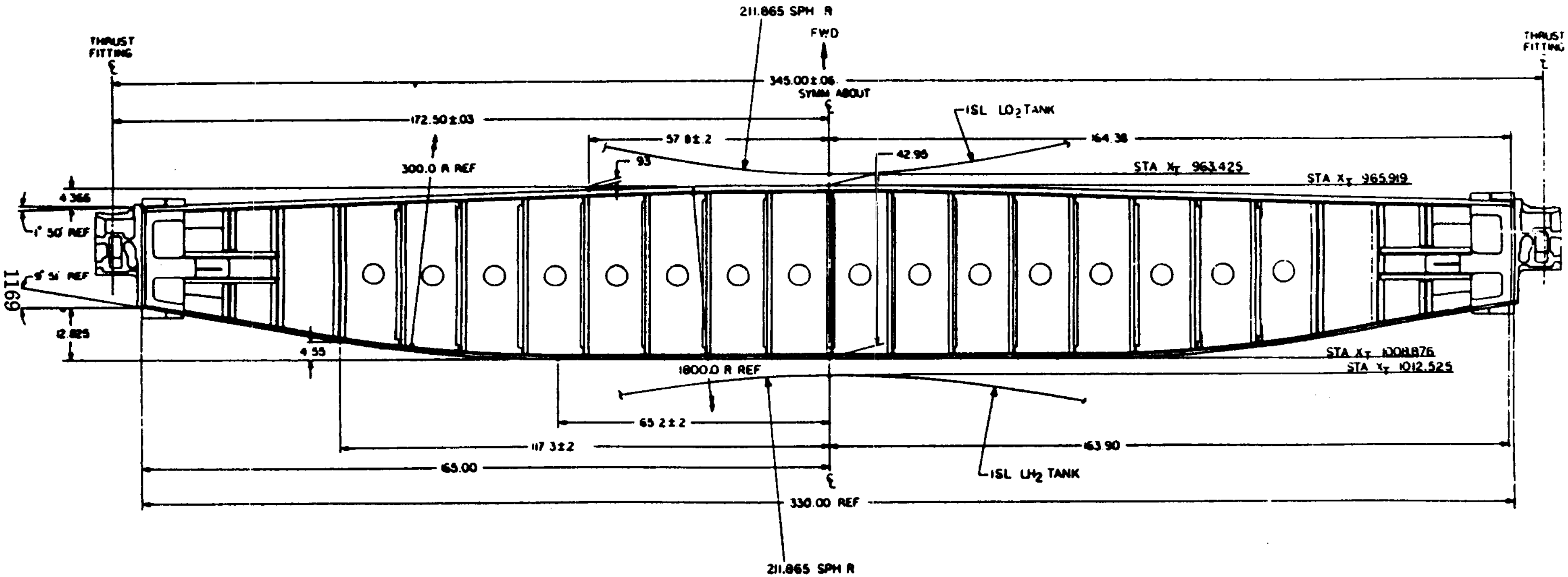


FIGURE 5

LIQUID HYDROGEN TANK

PAGE 2 OF 3

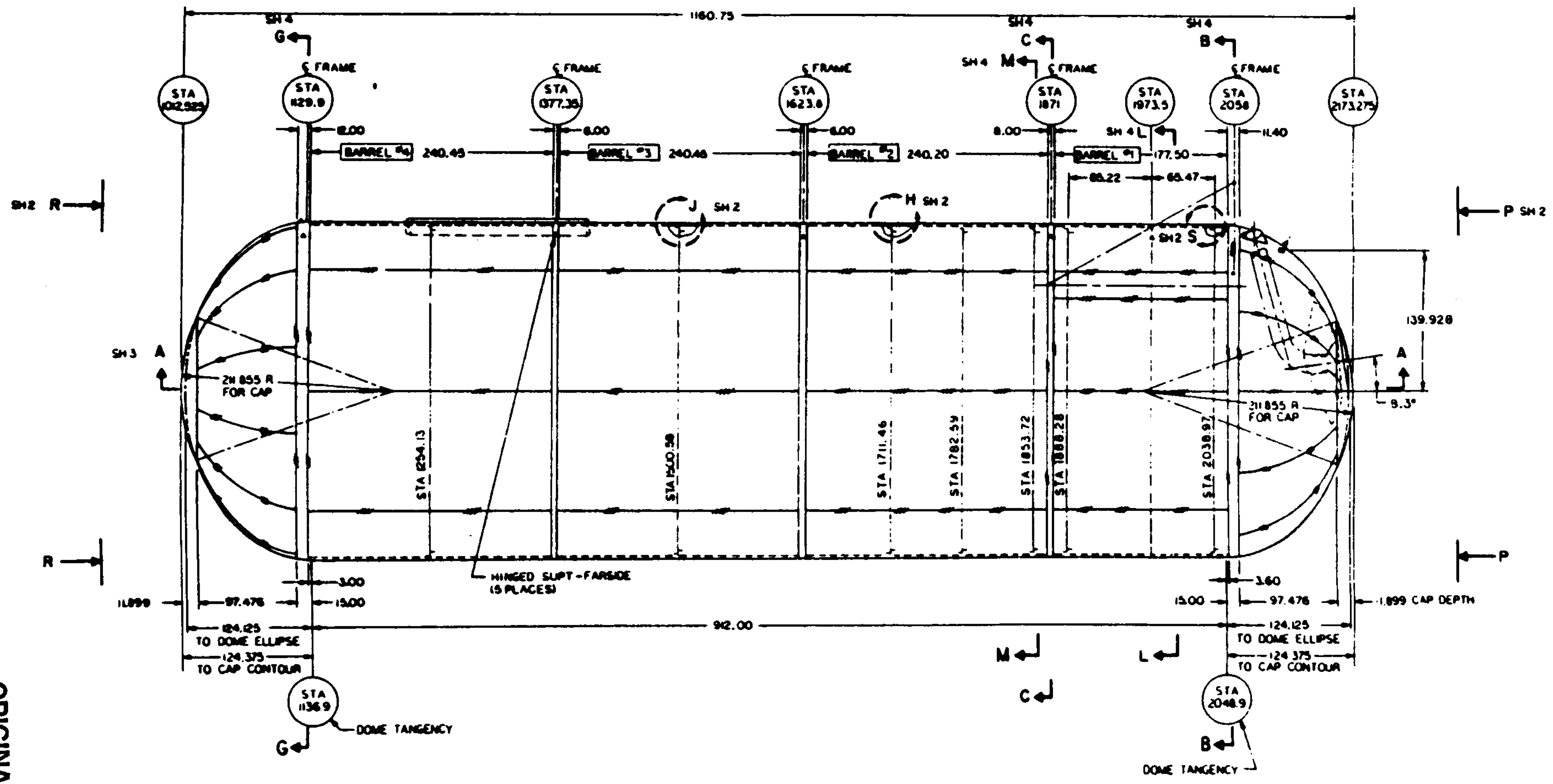


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FIGURE 5

LIQUID OXYGEN TANK

PAGE 3 OF 3

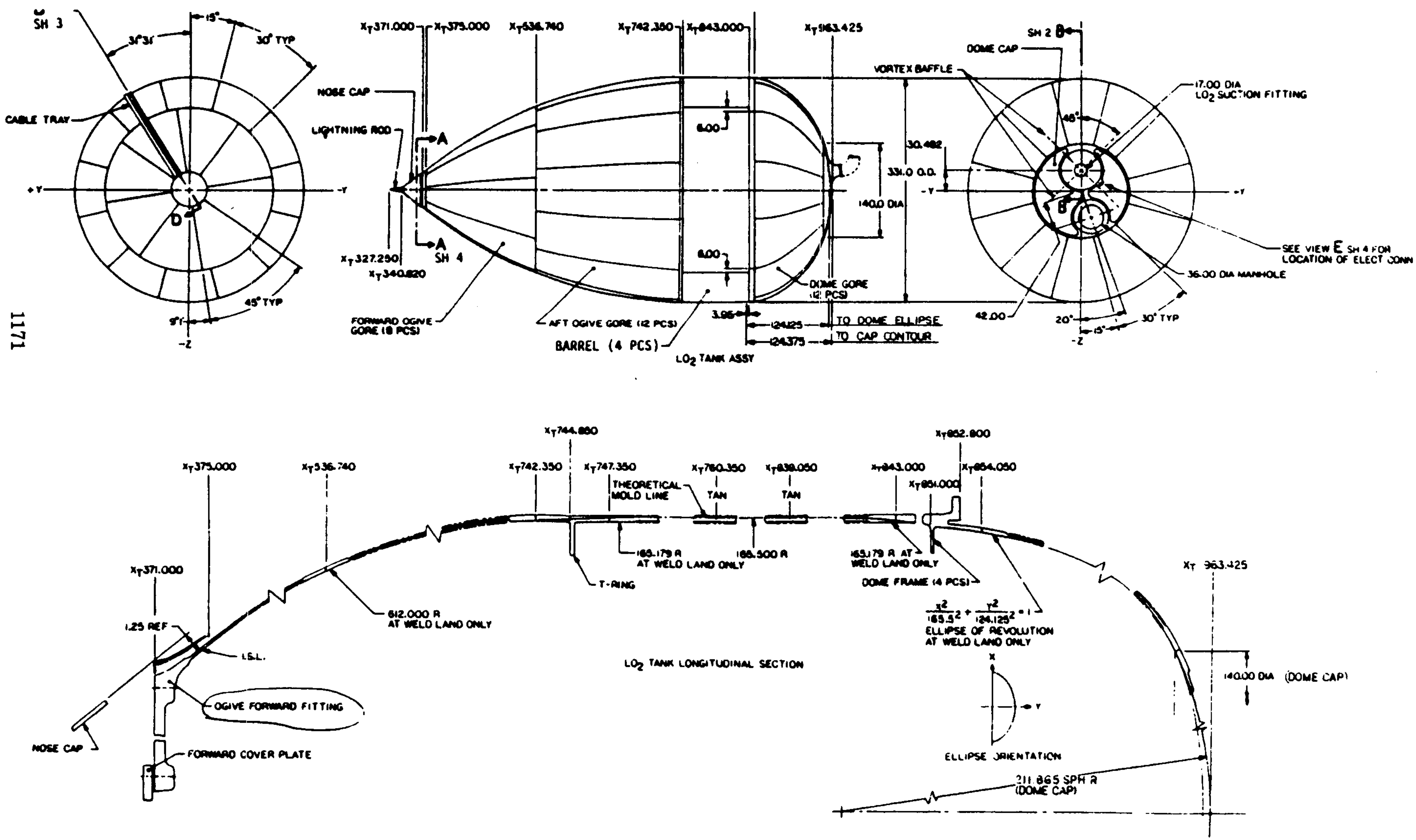

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FIGURE 6

PRES...ATION by BOEING | ASSESSMENT OF S...S CONFIGURATIONS | KSC SEPT 17, 1987

PAGE 1 OF 2

PROPELLANT SAFETY, PERFORMANCE AND COST DATA

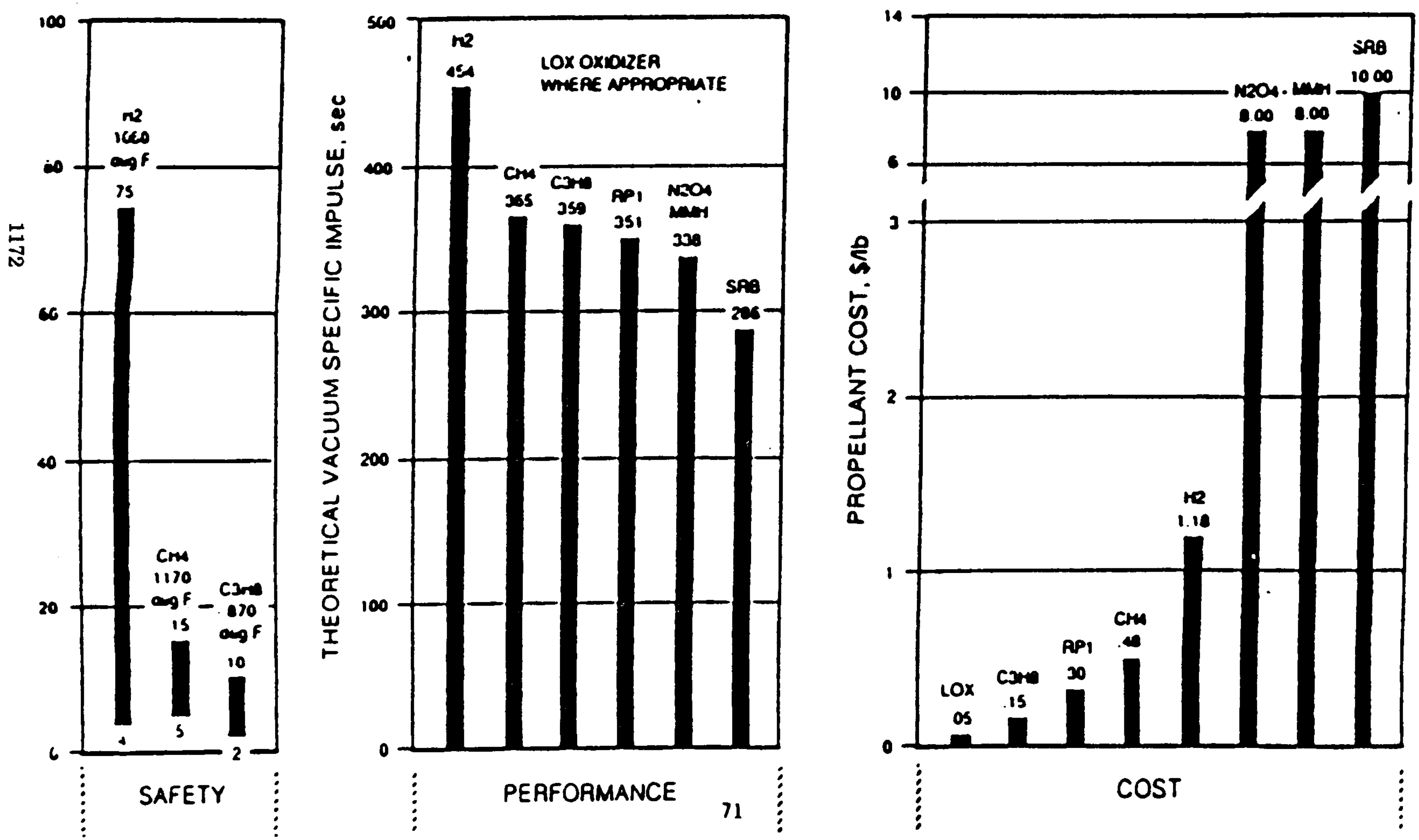


FIGURE 6

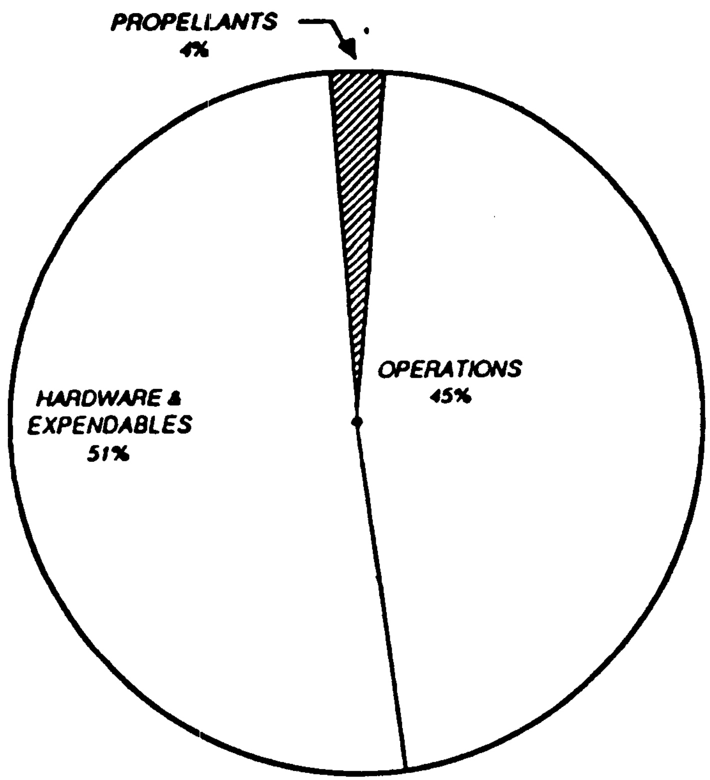
PRESENTATION by BOEING

ASSESSMENT OF STAS CONFIGURATIONS

PRESENT. AT KSC SEPT 17, 1987

RECURRING COST CONSIDERATIONS

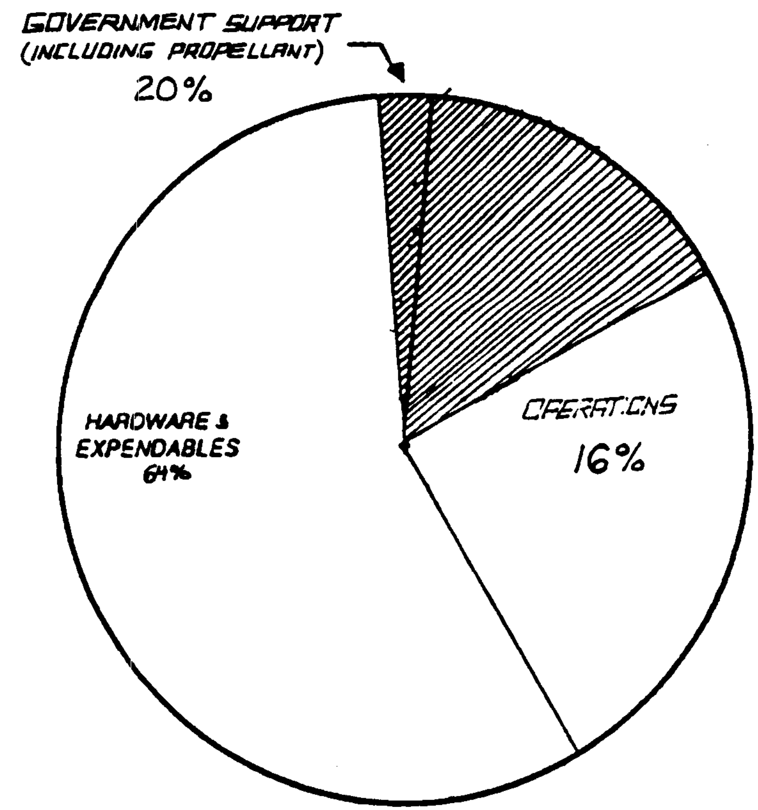
PAGE 2 OF 2



SHUTTLE STS

$273,500,000 PER FLIGHT

$5,470 PER POUND



TITAN IV

$130,000,000 PER FLIGHT

$3,333 PER POUND

FIGURE 7

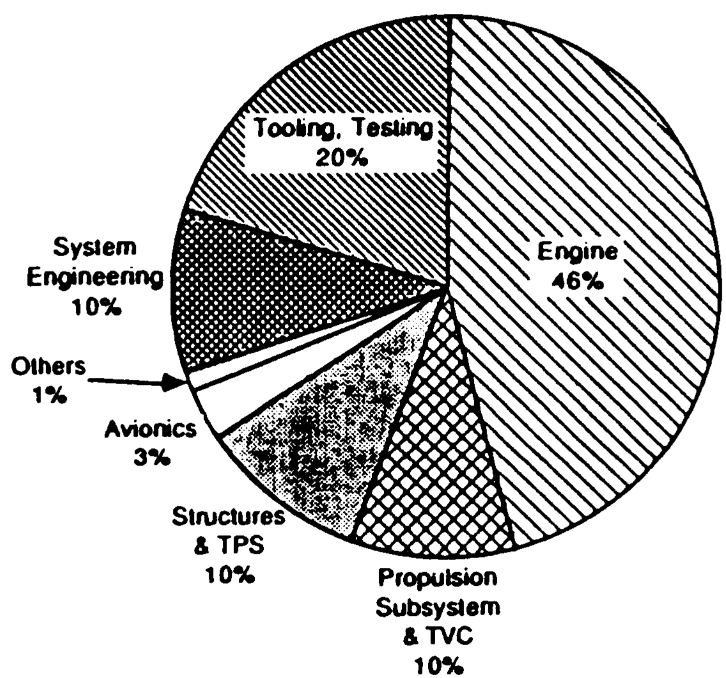
GENERAL DYNAMICS
Space Systems Division

PAGE 1 OF 2

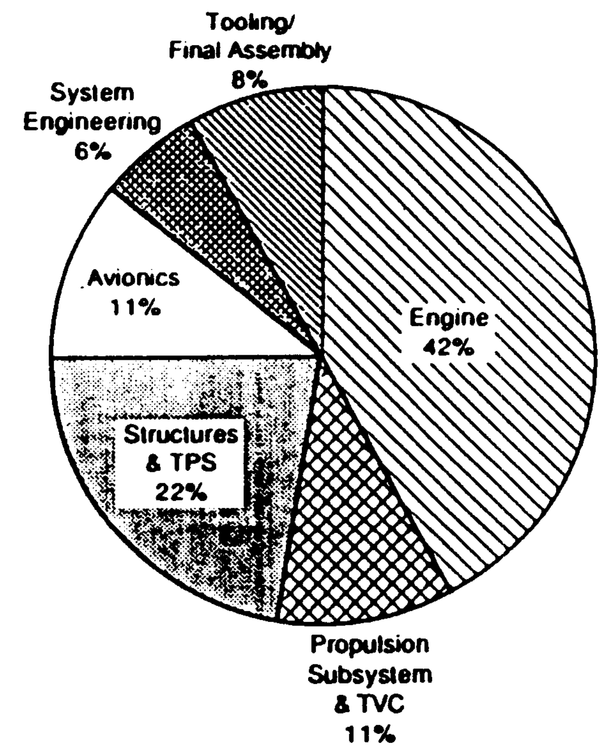
ENGINES ARE MAJOR COST CONTRIBUTOR

LRB

LO2/LH2 LRB COST BREAKDOWN



VEHICLE DDT&E = $ 3,224 M*



AVERAGE UNIT COST = $51M*

(244 BOOSTERS)

* INCLUDE 40% NASA FACTOR

FIGURE 7

HARDWARE
COST PER FLIGHT

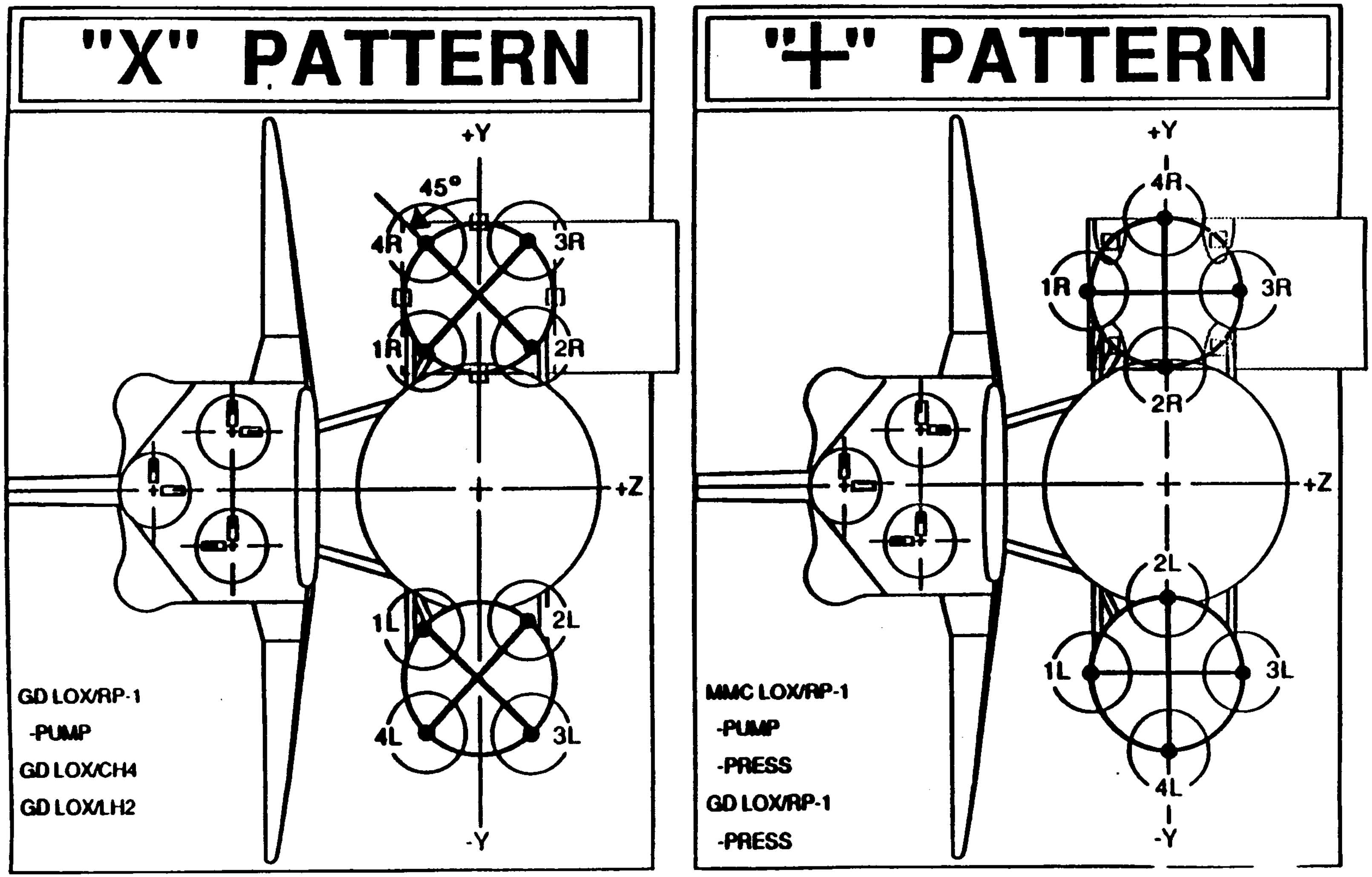
PAGE 2 OF 2

FIGURE 8

KSC ADVANCED PROJECTS & TECHNOLOGY OFFICE

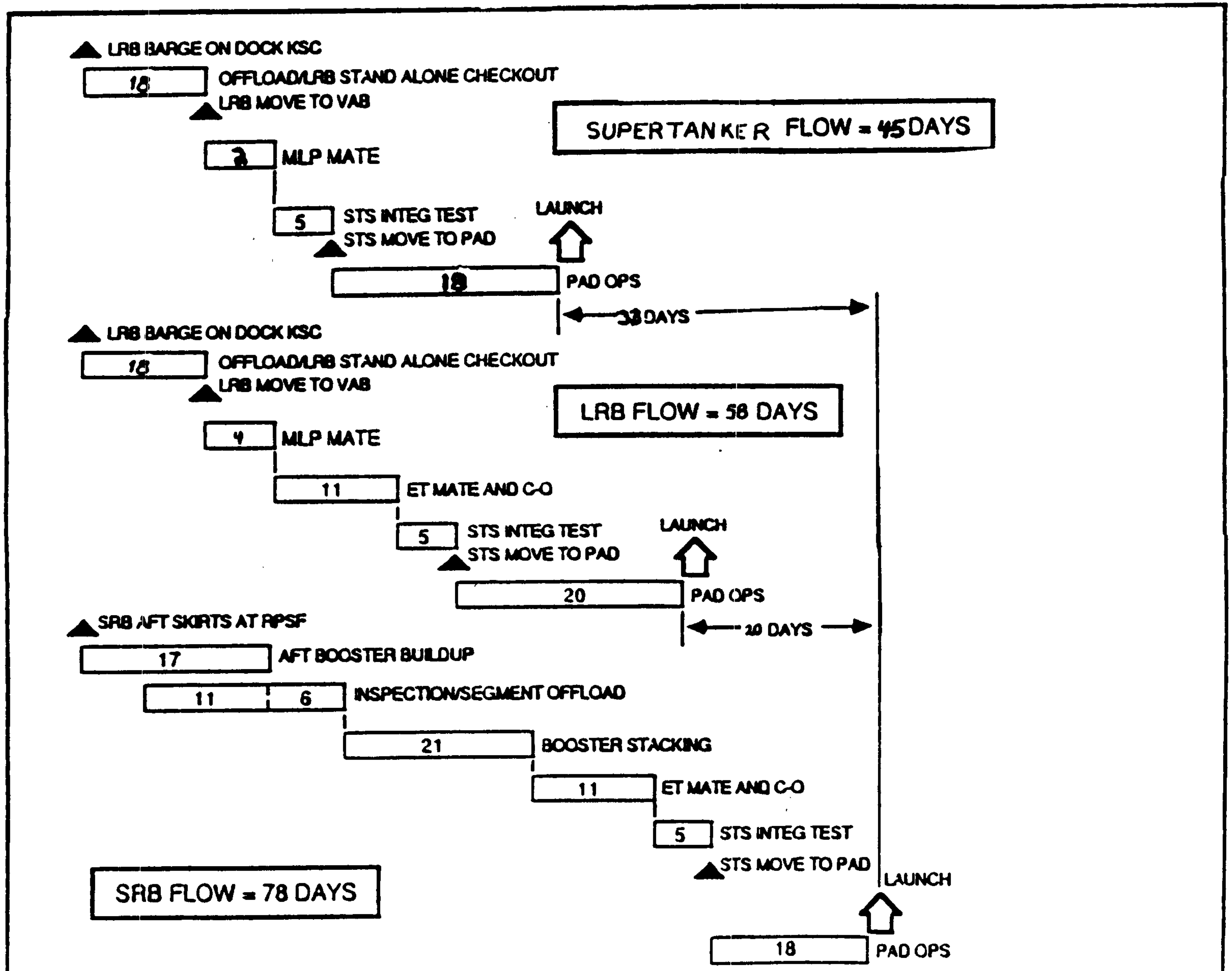
LRB PROPOSED ENGINE PROPORTIONS (VIEWS LOOKING FORWARD)

OCT 88



Lockheed Space Operations Company

FIGURE 9



NOTE: SRB RETRIEVAL, DISASSEMBLY, REFURBISHMENT AND REMANUFACTURING ARE NOT SHOWN.

FIGURE 10

AIAA-87-2000
Rocket Fan—A Hybrid Air-Breathing, Hydrogen-Fueled Engine

W.B. Kerr and J. Marra, Pratt & Whitney,
West Palm Beach, FL

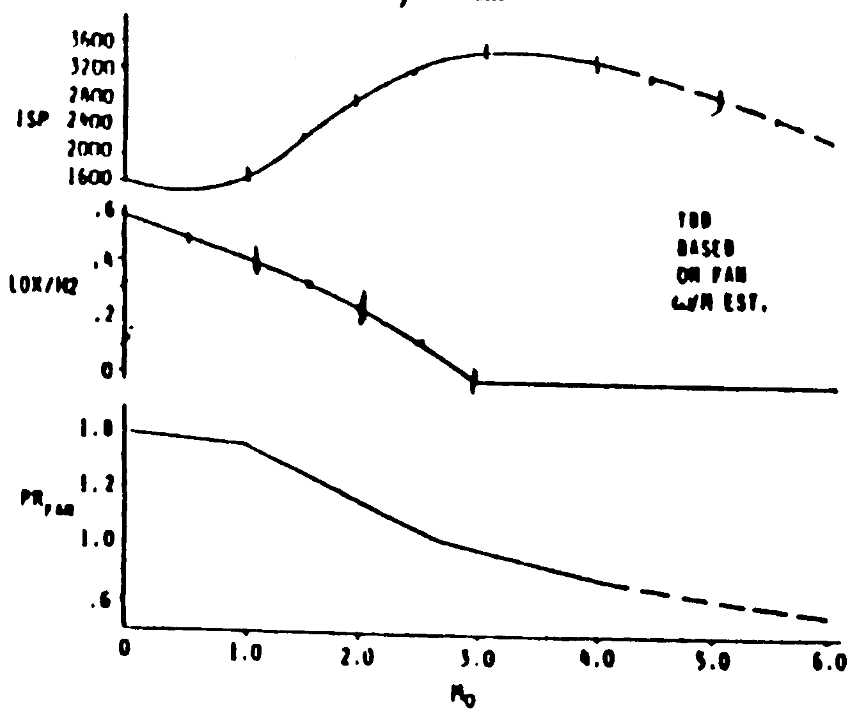


FIGURE 4.- TYPICAL RF OPERATION

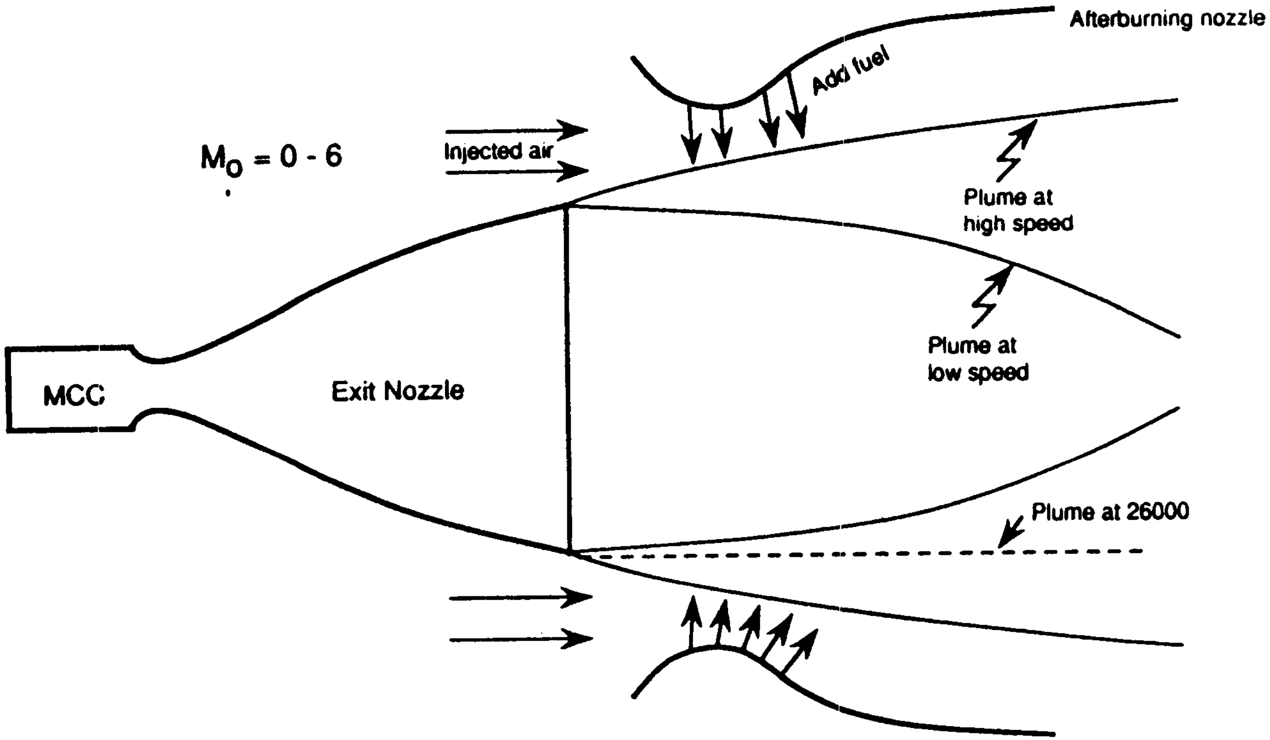
AIAA/SAE/ASME/ASEE 23rd Joint Propulsion Conference

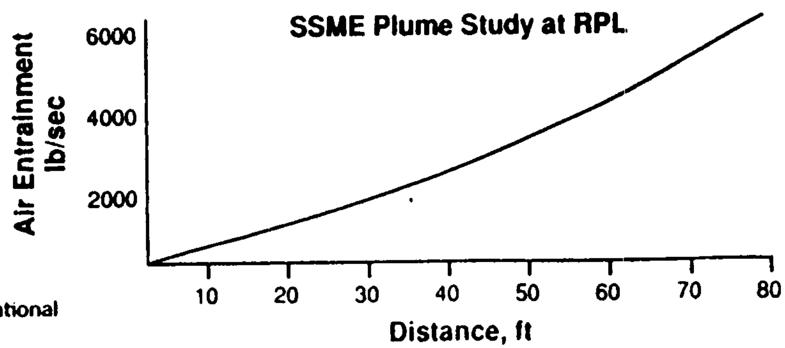
June 29-July 2, 1987/San Diego, California

FIGURE 10

COMBINED CYCLE, ROCKET ENGINE AFTERBURNING

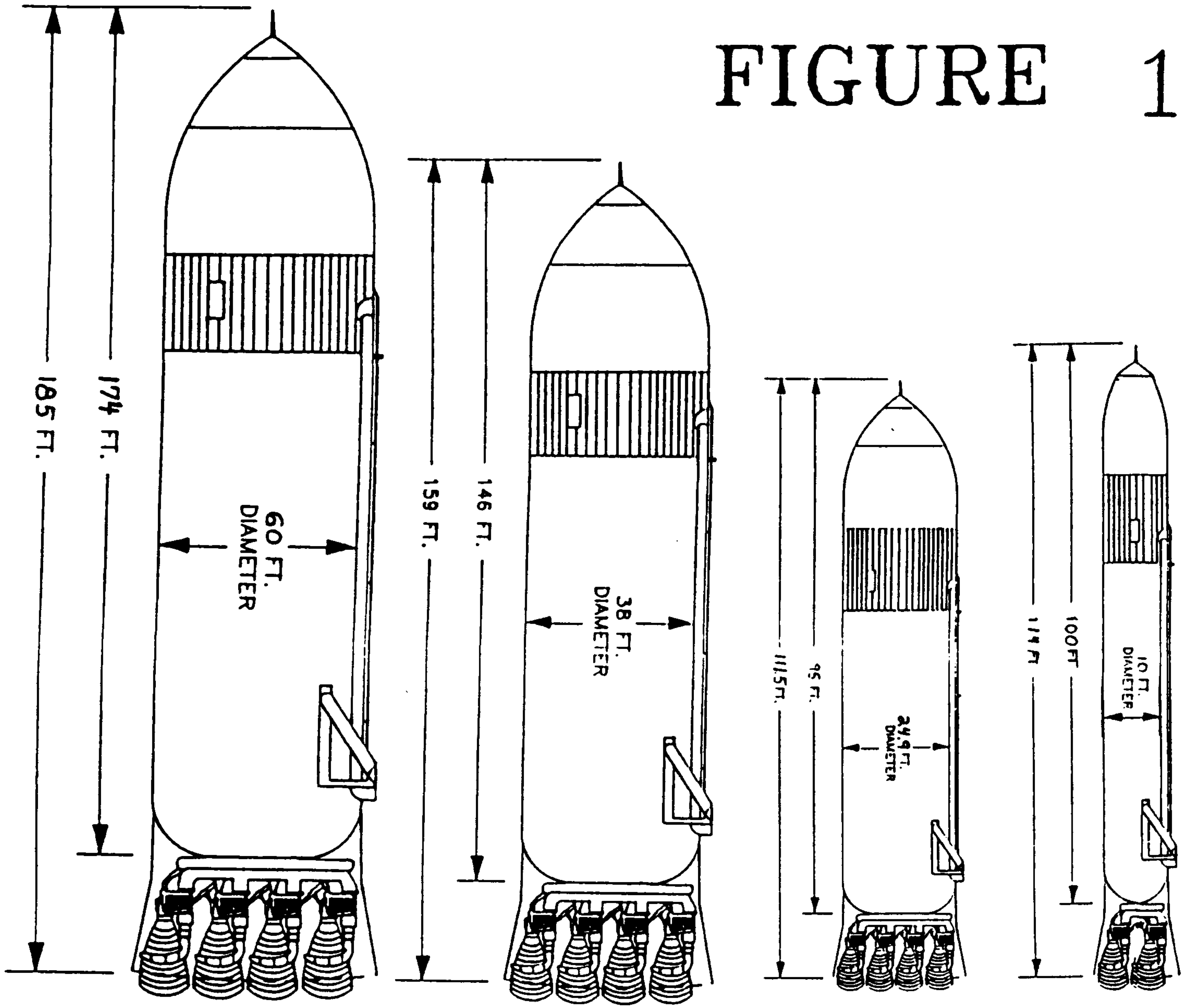
PAGE 2 OF 2





Rockwell International
Rocketdyne Division

FIGURE 11



	SHUTTLE-Z CLASS	SHUTTLE CLASS	TITAN CLASS	DELTA CLASS
GLOW	10,557,000 lbs	3,838,000 lbs	990,900 lbs	174,400 lbs
PAYLOAD	450,000 lbs	180,000 lbs	42,900 lbs	7,600 lbs

TABLE 1

KSC ADVANCED PROJECTS & TECHNOLOGY OFFICE

LIQUID ROCKET BOOSTER INTEGRATION FIRST PROGRESS REVIEW

JULY 1988

TASK 1 - SRB BASELINE DEFINITION

SRB PROCESSING MHRS AND COST (PER FLIGHT)

SRB ACTIVITY	MANHOURS	COST
SRB PROCESSING	18,603	$ 311,191
SRB STACKING	10,240	181,008
VAB INTEGRATION	5,095	88,728
PAD PROCESSING	18,575	343,842
SRB SHOPS/SE MAINT	3,378	54,264
SRB OPS SUPPORT	6,898	179,466
INTEG OPS SUPPORT	7,961	164,167
PSF - MAINT	2,818	54,488
VAB - MAINT	4,639	90,196
PAD/MLP - MAINT	276	5,661
SAFETY	5,377	114,630
OVERHEAD	4,183	90,407
SPC (LSOC) SUPPORT		
SRB PROCESSING	1,120	23,016
SRB STACKING	784	16,111
VAB INTEGRATION	254	5,220
PAD PROCESSING	5,704	109,146
OPS SUPPORT	814	14,888
GRUMMAN	3,997	78,936
	100,716	$1,925,365

Lockheed Space Operations Company

TABLE 2

KSC ADVANCED PROJECTS & TECHNOLOGY OFFICE

LIQUID ROCKET BOOSTER (LRB) KSC IMPACT

MAY 10, 1988

LRB PROCESSING MANHOURS AND COST

SKILL MIX	RATIO	MANHOURS	COST
LRB PROCESSING			
VAB OPS		11,744	
PAD OPS		3,632	
		4,680	
TOTAL TECHNICIANS	1.00	20,056	$ 355,392
ENGINEERING	0.89	17,850	366,814
FAC & GROUND SUPPORT	1.14	22,864	393,258
LOGISTICS	0.53	10,630	172,095
QUALITY	0.38	7,621	139,393
SAFETY	0.08	1,604	29,346
PP&C	0.22	4,412	78,892
OVERHEAD	0.42	8,424	162,574
GRUMMAN	0.71	14,240	281,235
SUBTOTAL		107,701	$1,979,000
BASE SUPPORT - EG&G	1.60	32,090	$513,434
NASA - CS	1.92	38,508	847,165
SUBTOTAL		70,598	$1,360,599
GRAND TOTAL		178,298	$3,339,599

COMMENTS AND ASSUMPTIONS:

1. MHRS AND COST FOR PROCESSING LRBs FROM RECEIPT THRU LAUNCH
2. ALL SKILL MIXES ARE RATIOED TO TECHNICIANS
3. MHRS AND COST ARE BASED ON THE LRB PROCESSING FLOW
4. EG&G BASE SUPPORT ASSUMES 20% SUPPORTS CARGO AND 80% SUPPORTS SHUTTLE ELEMENT PROCESSING
5. THE NASA/KSC CIVIL SERVICE VALUES HAVE THE SAME ASSUMPTIONS AS THE EG&G BASE SUPPORT ASSUMPTION IN ITEM #4
6. A NON-RECOVERABLE LRB IS ASSUMED IN THE ABOVE TABLE

Lockheed Space Operations Company

THE SUPERTANKER DESIGN PHILOSOPHY IS:

- 1 Liquid Oxidizer Tank
- 1 Liquid Fuel Tank - preferably Hydrogen

  These propellants fulfill ALL Propulsion, Power, and Cooling requirements
- Fuel and Oxidizer tanks structurally separated
- Propulsion is derived from a single engine cluster
- One or more engines are jettisoned at staging velocity along with thrust structure

SUPERTANKER DESIGN PHILOSOPHY BENEFITS:

- *Increased flight rate over 350% with reduced operations manpower and facilities*
- *Eliminates harmful exhaust products*
- *Enables commercial vehicles to be competitive on the world market*
- *Flight Safety and Reliability are greatly increased*
- *Ground Safety is greatly improved*
- *Potential for Space Station Component*
- *Unmanned Cargo Shuttle can be added to existing fleet without sacrificing Manned Shuttle Flights*
- *Increased probability of launching when planned*

RELIABILITY

SOLIDS

Demonstrated - 0.9765

2 Failures in 100 Boosters

1 Failure in 25 Missions
(2 Boosters/Mission)

15 Full-Up Hot Fire Tests

LIQUIDS

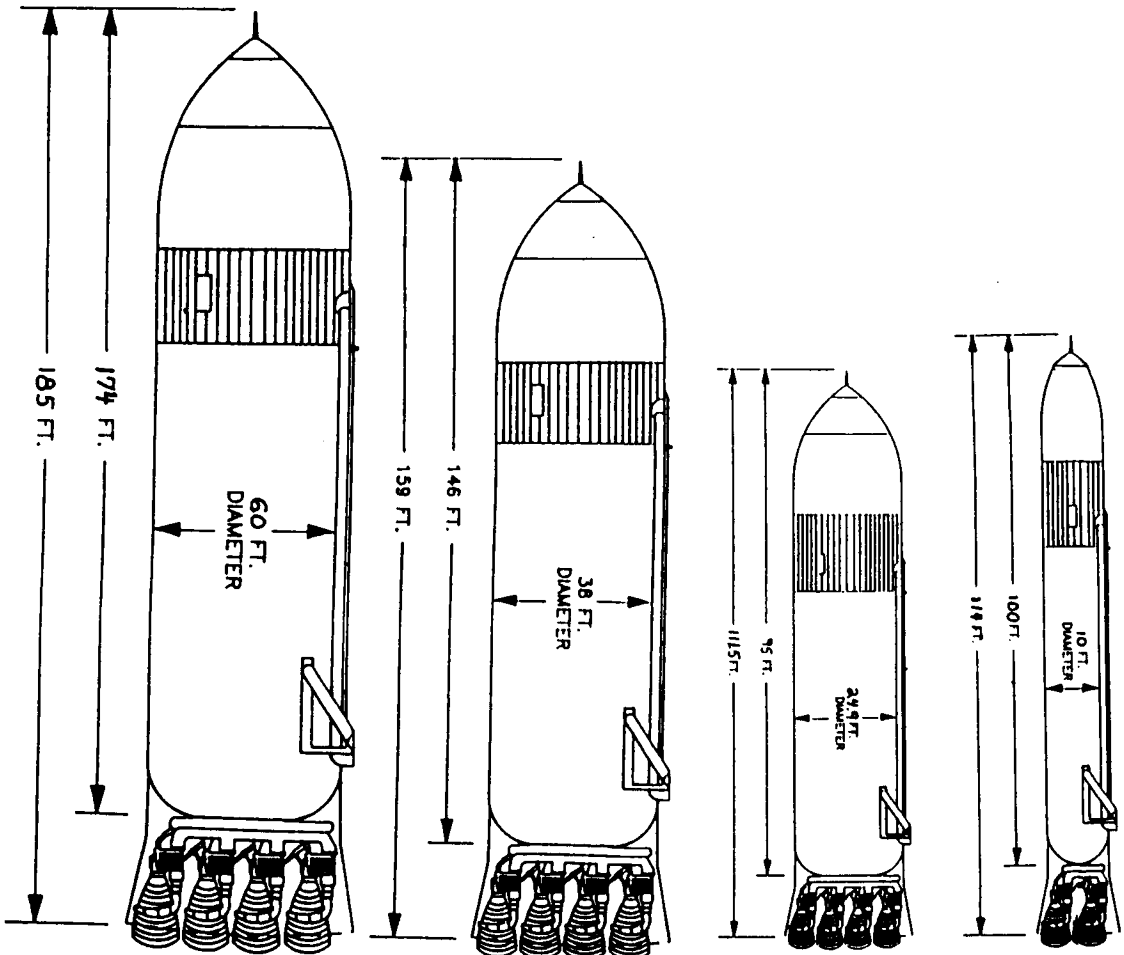
Demonstrated - 0.9935

<1 Failure in 100

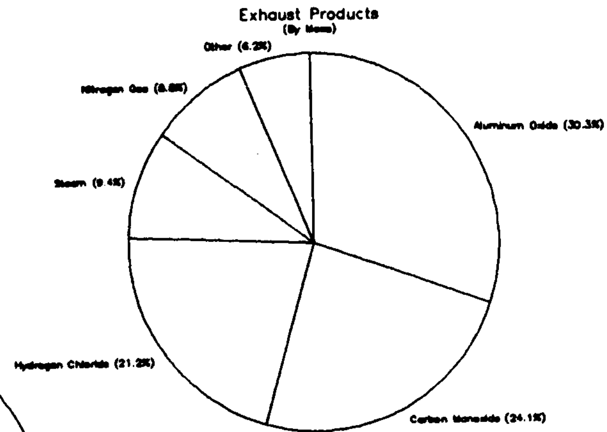
1 Engine Failure in 50 Missions
(3 Engines/Mission)

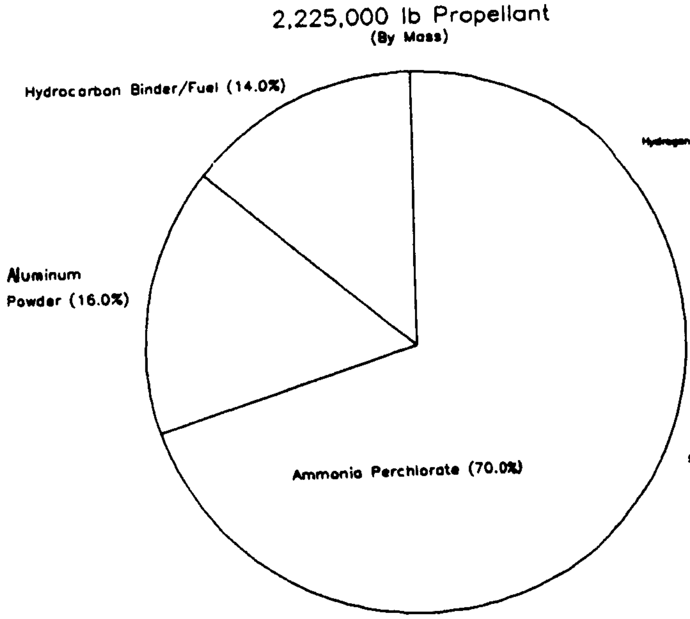
1350 Full-Up Hot Fire Tests

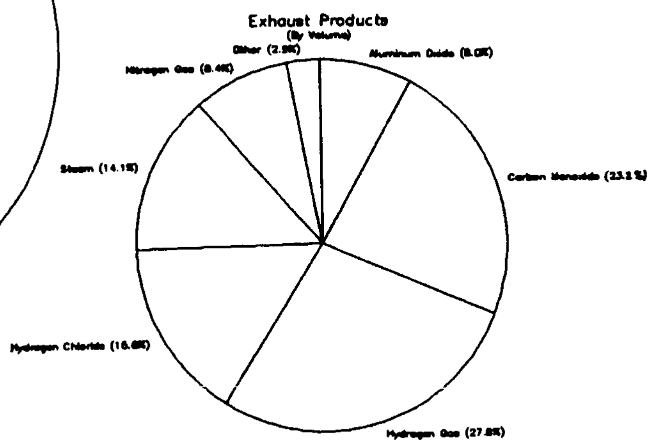
Theo. Design Reliability 0.9997



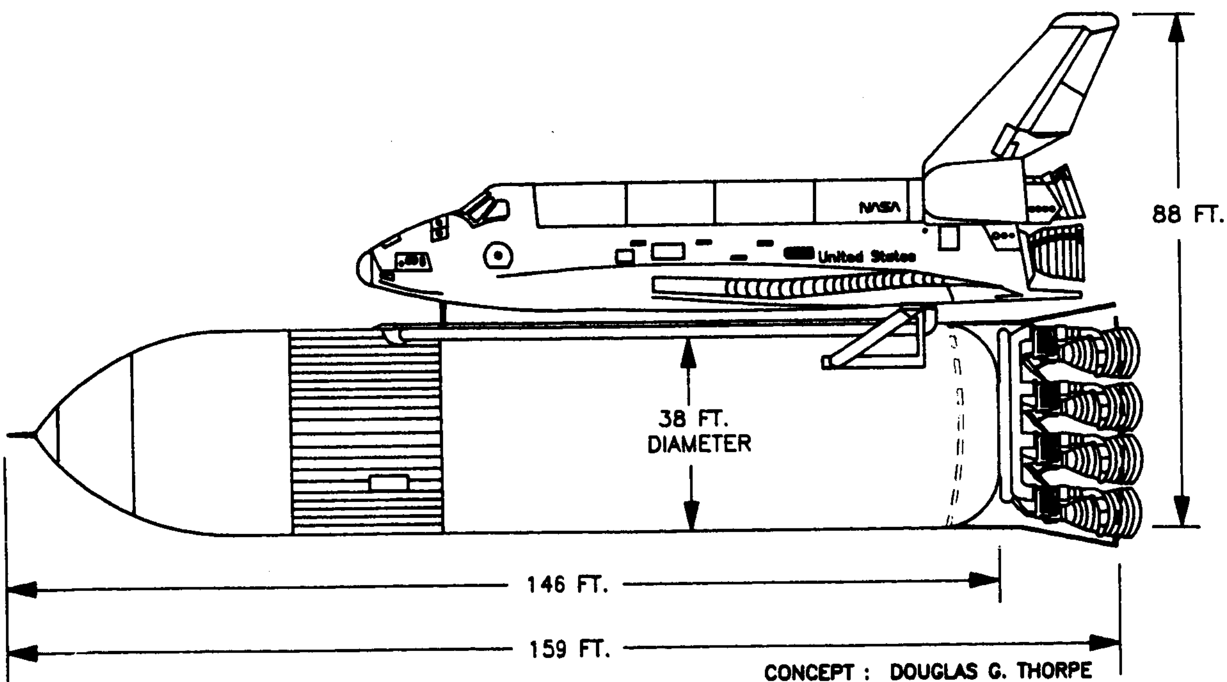
	SHUTTLE-Z CLASS	SHUTTLE CLASS	TITAN CLASS	DELTA CLASS
GLOW	10,557,000 lbs	3,838,000 lbs	990,900 lbs	1[illegible]4,400 lbs
PAYLOAD	450,000 lbs	180,000 lbs	42,900 lbs	7,600 lbs







SUPER-TANKER SPACE SHUTTLE



CONCEPT : DOUGLAS G. THORPE
CAD : JOEL E. STIEGLITZ

N91-28258

PRESENTATION 4.3.7

DETERMINING CRITERIA FOR SINGLE STAGE TO ORBIT

By
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Penn State, Pennsylvania

INTRODUCTION

The following exercise will determine the criteria for Single Stage to Orbit booster vehicles. To validate the assumptions and results several existing vehicles are examined. As a control the Manned Space Shuttle is used to calculate the equivalent orbital velocity. This velocity is then used to determine if the selected vehicle can achieve orbit and to calculate its payload capacity.

The following vehicles were chosen to determine if they could achieve orbital velocity in a single stage:

Saturn V
Second Stage (SII) w/SSME engines
Second Stage (SII) w/J2 engines
Third Stage (S4B) w/SSME engines
Third Stage (S4B) w/J2 engines

Space Shuttle
External Tank w/SSME engines
External Tank w/J2 engines

Atlas Rocket Booster(current configuration)

Note: The Space Shuttle's External Tank will be configured as a "Stage and a Half" Rocket Booster. This is accomplished by placing liquid fueled engines under its aft fuel dome. A payload pod, without engines, will be mounted in the location usually reserved for the Orbiter.

Performance is sacrificed to achieve single stage to orbit. Additional calculations will be performed using the SSME-External Tank vehicle. In this concept the vehicle will stage unneeded propulsion capability at an appropriate staging velocity. This vehicle is given the name (1.5) External Tanker - SSME. It is comprised of a Booster Unit (liquid fueled engines and vehicle support structure) mounted on the aft end of the External Tank assembly. At staging velocity, the booster engines and vehicle support structure are jettisoned while the remaining engines and vehicle continues on to orbit, similar to the Atlas Rocket Booster.

(1.5) EXTERNAL TANK-SSME EVALUATION
Staged Booster Unit

A propulsion evaluation was performed for the (1.5) External Tank - SSME Vehicle using parameters from SRB-STS (see Appendix A and B). Gross Lift-Off Weight (GLOW) was calculated as 1844.2 Klbs. The total Vehicle Dry Weight at Launch was calculated as 254,060 lbs. Of this dry weight **84,240 lbs will be usable payload.**

EXISTING VEHICLE EVALUATION
Single Stage to Orbit

A propulsion evaluation was performed for each of the existing vehicles listed below (Single Stage to Orbit configuration) using parameters from SRB-STS (see Appendix A, C, and D). All SII and all External Tank vehicle configurations could achieve orbit with a useful payload. The best configuration, the Space Shuttle's External Tank with SSME engines, could achieve orbital velocity with **52,800 lbs of usable payload.**

Saturn V
Second Stage (SII) w/SSME engines
Second Stage (SII) w/J2 engines
Third Stage (S4B) w/SSME engines
Third Stage (S4B) w/J2 engines

Space Shuttle
External Tank w/SSME engines
External Tank w/J2 engines

Atlas Rocket Booster(current configuration)

CONCLUSION

A substantial schedule and manpower savings could be realized if a Single Stage to Orbit vehicle could be produced. Several configurations were studied using existing hardware. A relationship was obtained to determine if a configuration could obtain orbital velocity. This dimensionless relationship was given by the following:

GAMMA% = (Non Payload / Gross Lift-Off Weight)% * exp (Alpha/Isp)

where Isp is the average Specific Impulse of the liquid rocket engine during the entire boost phase. Alpha, a dimensionless value which is a function of trajectory and inflight losses, was determined to be 954.65 in this exercise using only rough order magnitude assumptions. Orbital velocity is obtained in a single stage for GAMMA% less than 100%. This relationship can be applied to any vehicle, including NASP.

Since performance is sacrificed to achieve single stage to orbit, additional calculations were performed using one of the configurations as a one & one half stage vehicle. The one & one half stage vehicle offered a 59.6% increase in useful payload to orbit while the Single-Stage to Orbit vehicle would offer a reduced manpower and schedule requirements.

To find an unknown propulsion parameter of a vehicle the following calculations are made:

EQU 1.) Vb = G * Isp * ln(Mini / Mfin) - k * G * t

where

Vb	=	Velocity of vehicle after fuel has been expended
G	=	Gravitational constant = 32 feet per sec per sec
Isp	=	Specific Impulse of total vehicle (lbf / lbm/sec)
Mini	=	Mass of initial vehicle
Mfin	=	Mass of vehicle after fuel has been expended
t	=	Amount of time to achieve Vb after lift-off
k	=	Correction Factor - derived by considering the amount of time thrust is used to overcome gravity.

The following known characteristics from Solid Rocket Booster - Shuttle (SRB-STS) will be used to find unknown characteristics of the Single Stage to Orbit vehicles.

TABLE 1

Solid Rocket Booster - Shuttle (SRB-STS) Parameters

220,092 lbs	Orbiter Inert & OMS Propellant
51,246 lbs	Usable Payload
66,760 lbs	External Tank
376,416 lbs	SRB (dry weight) * 2
714,514 lbs	Total Vehicle Dry Weight @ Launch
338,098 lbs	Mass at Main Engine Cut-Off (MECO)
1,590,128 lbs	External Tank Fuel
4,525,000 lbs	Gross Lift-Off Weight (GLOW)
1,542,000 lbs	Mass after Booster Separation
269 (228) Sec	Booster Isp in Vacuum (Sea/Level)
2,397,000 lbs	Average Booster Thrust (Boost Phase)
123.6 Seconds	Time to Booster Separation

Rocketdyne SSME Parameters

453.5 (361)[407]Sec	SSME Isp in Vacuum (S/L)[Ave Boost Phase]
471(377)[424]Klb	SSME Thrust in Vacuum (S/L)[Ave Boost Phase]
6986 lbs	SSME Weight
67.4 lbf/lbm	SSME Thrust to Weight

Rocketdyne J2 Parameters

427 (341.6)[384]Sec	J2 Isp in Vacuum (S/L)[Ave Boost Phase]
230(184)[207]Klb	J2 Thrust in Vacuum (S/L)[Ave Boost Phase]
3480 lbs	J2 Weight
66.1 lbf/lbm	J2 Thrust to Weight

Average Thrust and Average Specific Impulse was derived by assuming the vehicle was reacting against a degrading air pressure during boost phase.

STS-SRB EVALUATION

Using Equation 1) a propulsion analysis of today's SRB-STS will reveal parameters which can be correlated with the Supertanker. The velocity gained by the SRB-STS after Booster Separation is calculated by the following:

Using Eq 1):

Vmeco = (32 ft/sec^2) * 453.5 Sec * ln (1542/338) - 0
= 22,026 Ft/sec

It was assumed that "k" was zero in the above equation to give a Rough Order of Magnitude value. When the above result is correlated with the Supertanker, this parameter nearly cancels out.

Because the Specific Impulse is different for the SSME's and the SRB, the Average Vehicle Isp during the boost phase is calculated by doing the following:

EQU 2) Average Vehicle Isp =
$$\{(Isp_1 * Thrust_1) + (Isp_2 * Thrust_2)\} / (Thrust_1 + Thrust_2)$$

Ave Veh Isp = 310.3 Seconds from the calculation
{(407sec * 1272Klb) + (259sec * 2397Klbs)} / (1272Klbs + 2397Klbs)

Using Eq 1):
Vboost.sep = (32 ft/sec^2) * 310.3 Sec * ln (4525/1542 + 376) -
0.9 * 32 ft/sec^2 * 123.6 Sec

Velocity at Booster Separation = 4,963 Ft/sec or Mach 4.67

"k" was assumed to be 0.9 after reviewing the flight trajectory until booster separation at 23 miles downrange and 29 miles altitude, and realizing that 90% of this boost energy was spent overcoming gravity.

Total Velocity Gained by the vehicle after launch:
22,026 Ft/sec + 4,963 Ft/sec = 26,989 FT/sec

Total Delta V at MECO = 30,550 Ft/sec

(1.5) EXTERNAL TANK-SSME EVALUATION
Staged Booster Unit

Using Equation 1) a propulsion analysis of the ET-SSME Vehicle (with stage Booster Unit) will reveal its propulsion parameters. The payload capacity of the ET-SSME Vehicle is calculated by the following:

It will be assumed for ease of calculations this vehicle will have the same performance characteristics (Staging Velocities, Thrust-to-Weight, "k" values) as the SRB-Shuttle. Also, specifics in performance of an operational vehicle (i.e., unused fuel, safety margins, increased mass of possible larger LOX feedline, primer on every other fastener) will be assumed to be included in this Rough Order of Magnitude exercise.

Using Eq 1):

22,026 Ft/sec = (32 ft/sec^2) * 453.5 Sec * ln (Msep - Mjet / Morb) - 0

result 1] Msep = 4.562 Morb + Mjet

The mass jettisoned (Mjet) at staging velocities is comprised of 4 booster engines and half of the booster unit structure mass. This would leave 3 retained SSME's and half of the booster unit structure mass to travel on to orbit.

Mjet = M(4 Boost.Eng) + 0.5 * Mboost.Unit Struct

Mjet = 28,000 lbs + 16,500 lbs = 44,500 lbs

result 2] Msep = 4.562 Morb + 44,500 lbs

The same vehicle performance as found for SRB-Shuttle is assumed for this vehicle therefore, the following calculation is performed to find the relation of Gross Lift-Off Weight and the mass of the vehicle after Booster Unit Separation (Msep):

Using Eq 1):

4,963 Ft/sec = (32 ft/sec^2) * 435.5 Sec * ln (GLOW/Msep) - 0.9 * 32 ft/sec^2 * 123.6 Sec

result 3] 1.843 Msep = GLOW

combining result 2] and result 3] to yield Mass to Orbit (Morb) in terms of GLOW

1.843 (4.562 Morb + 44,500) = GLOW

result 4] 8.409 Morb + 82,000 lbs = GLOW

(1.5) EXTERNAL TANK-SSME EVALUATION
Staged Booster Unit

A breakdown of the Gross Lift-Off Weight (GLOW) will yield another relationship for GLOW and Morb.

TABLE 2
Gross Lift-Off Weight (GLOW)

Mass Jettisoned	44,500 lbs
Mass to Orbit	Morb (unknown)
-----------------	---------------
GLOW =	1,634,628 lbs + Morb

GLOW values are substituted into result 4] to find the Mass of vehicle that achieves orbital velocity.

8.409 Morb + 82,000 lbs = 1,634,628 lbs + Morb
result 5] Morb = 209,560 lbs

A breakdown of the Mass to Orbit (Morb) will finally yield the amount of usable payload to 100 mile orbit at 28.5 degree.

TABLE 3
Mass to Orbit (Morb)

External Tank Mass	66,760 lbs
Booster Engines * 3	21,000 lbs
50% Booster Unit Structure	16,500 lbs
Mass Payload Pod	21,060 lbs
Usable Payload	**84,240 lbs**

Note: Mass of Payload Pod was assumed as 1/4 of usable payload.

Mass to Orbit	218,560 lbs
Vehicle Dry Weight @ Launch	329,765 lbs
Gross Lift-Off Weight	1,844,190 lbs
Dry Launch Mass to GLOW fraction	0.1378
Payload to GLOW fraction	0.0457

APPENDIX C

EXTERNAL TANK-SSME VEHICLE EVALUATION
(SINGLE STAGE TO ORBIT)

Using Equation 1) a propulsion analysis of the ET-SSME Vehicle will reveal its propulsion parameters. The payload capacity of the ET-SSME Vehicle with Single-Stage-To-Orbit trajectory is calculated by the following:

Since the vehicle is a Single-Stage-To-Orbit, the mass to obit will be simply the inert mass at launch. This mass to orbit can be calculated by one iteration of Equation 1) with using the Total Velocity Gained by the SRB-STS vehicle found above. Only 6 SSME's will be used instead of 7. It is assumed the lower thrust to weight at liftoff (calculated below) for the ET-SSME will be balanced by its quicker orbital insertion.

Using Eq 1):

26,989 Ft/sec = (32 ft/sec^2) * 441.2 Sec * ln (Fuel + Morb/Morb) - 0.9 * 32 ft/sec^2 * 123.6 Sec

or

Equation 3): **Morb = Fuel / {[exp(954.65/Isp)] - 1}**

Mass to Orbit = 206,387 lbs

GLOW would then simply be 206,387 + 1,590,128 lbs or 1,796,515 lbs.
NOTE: The given Isp has been averaged over the entire burn until orbit.

A breakdown of the Mass to Orbit (Morb) will finally yield the amount of usable payload to 100 mile orbit at 28.5 degree.

TABLE 5
Mass to Orbit (Morb)

External Tank Mass	66,760 lbs
Booster Unit (six-engines)	41,916 lbs
Booster Unit (Structure)	32,396 lbs
Mass Payload Pod	13,063 lbs
Usable Payload	**52,252 lbs**
Total Vehicle Dry Weight @ Launch	206,387 lbs

Note: Mass of Payload Pod was assumed as 1/4 of usable payload.

Mass to Orbit	206,387 lbs
External Tank Fuel	1,590,128 lbs
Gross Lift-Off Weight	1,796,515 lbs
Dry Launch Mass to GLOW fraction	0.1149
Payload to GLOW fraction	0.0291

APPENDIX D

EXISTING VEHICLE EVALUATION
(SINGLE STAGE TO ORBIT)

Using Equation 2) a propulsion analysis of existing vehicles using different engine performance will reveal their propulsion parameters. The payload capacity of each selected vehicle is calculated using equation 2) and assuming the trajectory will remain the same for the given thrust to weight at lift-off.

TABLE 6

VEHICLE	TANK DRY WT (LBS)	TANK FUEL	MASS TO ORBIT[1]	Bstr.Unt[3] Structure	PL POD[4] Fairing	Usable Payload	Non-P/L Dry Mas
ET-SSME	66,760	1,590,128	206,180	31,400	13,000	52,800	153,380
ET-J2	66,760	1,590,128	178,220	31,000	7,740	30,960	147,260
SII-SSME	78,750	992,700	128,700	N/A	3,920	15,680	109,100
SII-J2	78,750	992,700	111,260	N/A	1,165	4,660	106,600
S4B-SSME	24,900	238,175	30,880[2]	N/A	0	0	31,900[5]
S4B-J2	24,900	·238,175	26,700[2]	N/A	0	0	31,860[5]
ALTAS-STO	5,420	303,200	8,579[2]	N/A	0	0	9,595[5]

NOTE 1: 100 mile orbit at 28.5 degree direct insertion

NOTE 2: Mass to orbit was not greater than Inert Weight of vehicle. Orbital velocity was not achieved.

NOTE 3: Booster Unit Structure is calculated as 1.75% of GLOW for External Tank vehicles. For External Tank vehicles this structure includes the weight of avionics, manifolds, and TVC's. The Saturn Vehicles are already designed to be supported from the aft end and Booster Unit Sturture Mass is included with dry tank weight.

NOTE 4: Payload Pod is calculated as one-forth of usable payload

NOTE 5: Hypothetical weight of vehicle with no payload.

EXISTING VEHICLE EVALUATION
(SINGLE STAGE TO ORBIT)

TABLE 7

VEHICLE	# OF ENGINES	ENGINE WEIGHT	THRUST TO WT	Avg Isp	Non P/L TO GLOW%	Payload to GLOW%	Gamma%[6]
ET-SSME	6	42,000	1.259	441	8.539%	2.929%	74.39
ET-J2	12	41,760	1.250	416	8.328%	1.751%	82.64
SII-SSME	4	27,950	1.345	441	9.729%	1.340%	84.76
SII-J2	8	27,850	1.250	416	9.656%	0.422%	95.81
S4B-SSME	1	7,000	1.409	441	11.856%	0.000%	103.29
S4B-J2	2	6,960	1.258	416	12.028%	0.000%	119.35
ATLAS-STO	3	4,175	1.400	266	3.068%	0.000%	111.48

NOTE 6: **GAMMA%** is calculated by the following:

Equation 4) **GAMMA% = (Non Payload / GLOW)% * exp (954.65/Isp)**

When GAMMA% is greater than 100% then, there can be no useful payload to orbit.

The latter term in equation 4) is 8.7123 for SSME's and 9.9228 for J2's.

ATTACHMENT TO **"DETERMINING CRITERIA FOR SINGLE SINGLE STAGE TO ORBIT"**
30 October 1990

SINGLE SINGLE STAGE TO ORBIT
RATIONALE

An all LOX/LH2 Liquid Rocket Booster Space Shuttle has been proposed by a contractor (Reference 1). In this concept two 16.16 foot diameter boosters would replace the current solid rocket boosters. Each of these boosters had a LOX tank forward of the LH2 tank and was propelled by four - 565,000 lb thrust engines.

A recent study was completed which placed these same eight booster engines under a single LOX/LH2 tank (Reference 2). This tank was enlarged in diameter to contained the extra propellant for both the booster engines and Space Shuttle Main Engines. This vehicle, given the name "Supertanker", would jettison the booster engines and associated propulsion hardware at staging velocity.

If this jettisoned hardware was retained until orbital velocity is achieved (Single-Stage-To-Orbit), useful payload would be sacrificed for greater Launch Operations Efficiency (Reference 3). However, payload capacity greatly increases if vehicle performance is optimized within the bounds of Launch Operation Efficiency.

Note: The source mistakenly used a heavy weight External Tank Mass in their original design work instead of the Light Weight Tank Mass (Reference 3). This weight savings was transferred to payload capacity for the LOX/LH2 LRB Shuttle.

References

1) "Liquid Rocket Booster Study," General Dynamics Space Systems Division, NASA Marshall Space Flight Center, NAS8-37137, 18 MAY 1988

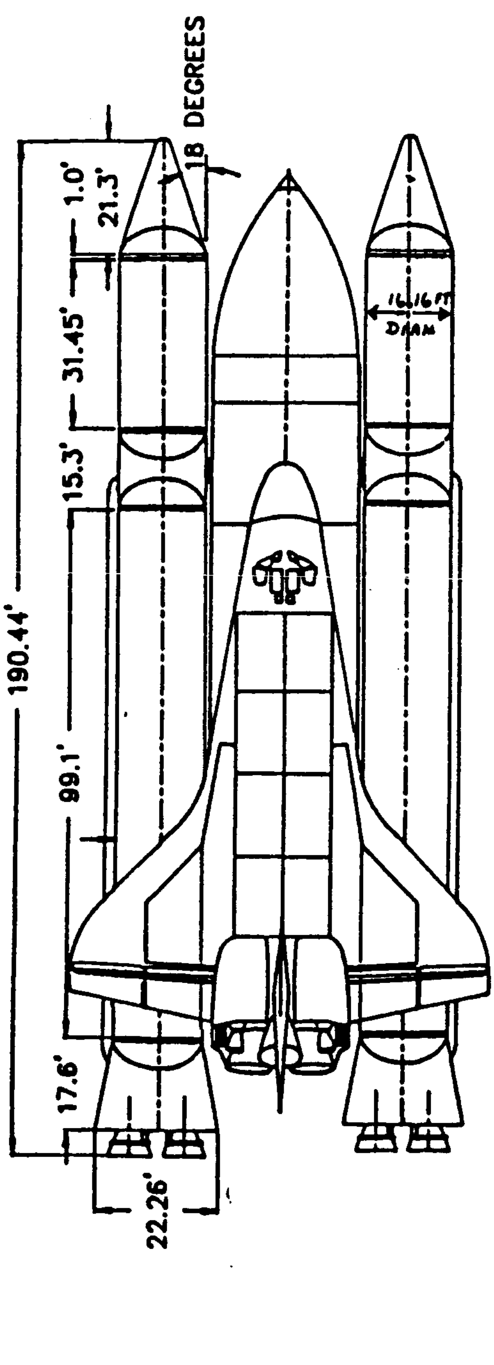
2) Douglas G. Thorpe, "Space Shuttle with Common Fuel Tank for Liquid Rocket booster and Main Engines (Supertanker Space Shuttle)" Space Transportation Propulsion Technology Symposium, June 1990

3) "Shuttle Systems Weight and Performance," NASA Lyndon B. Johnson Space Center, JSC-NSTS-09095-95, 17 October 1989

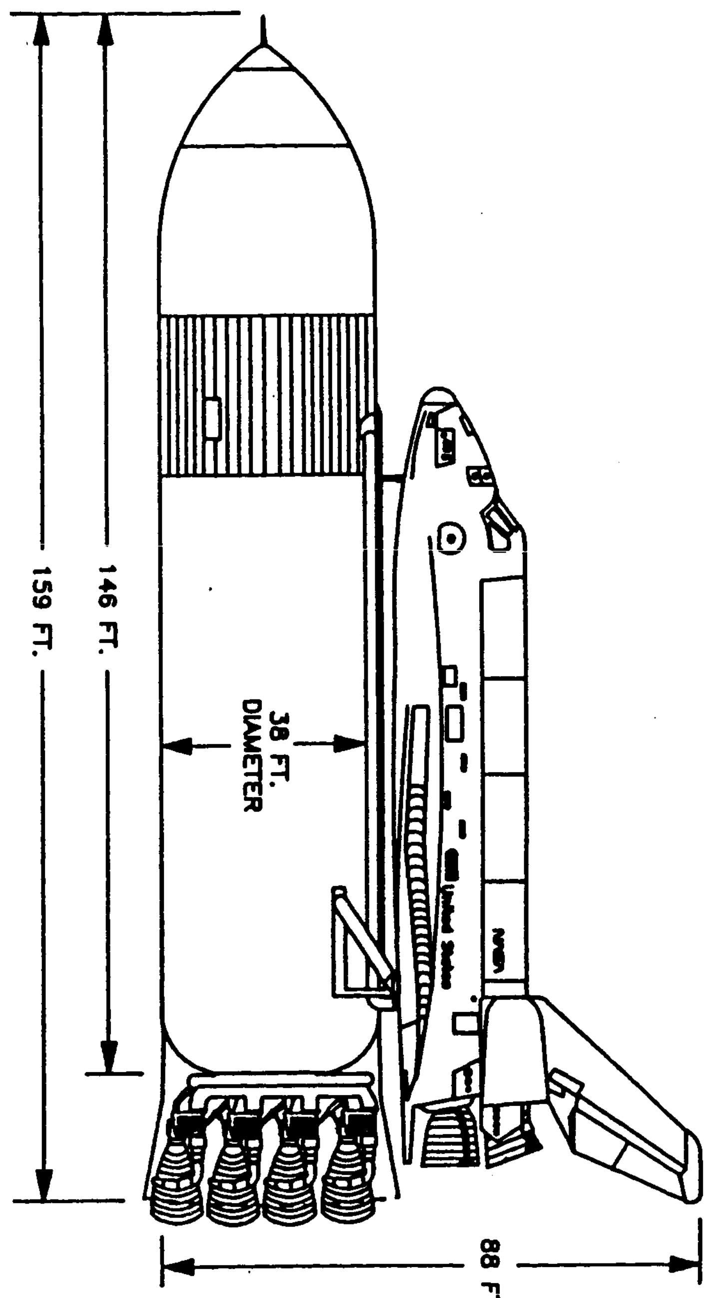
ATTACHMENT TO "DETERMINING CRITERIA FOR SINGLE SINGLE STAGE TO ORBIT"

	LH2/LOX LRB	SUPERTANKER	SINGLE STAGE TO-ORBIT
MECO CONDITIONS			
Time	497 seconds	485 seconds	344 seconds
Altitude	360,670 ft	360,670 Ft	360,670 Ft
Velocity	30,280 Ft/sec	30,280 Ft/sec	30,280 Ft/sec
Manned Orbiter Configuration			
MECO mass	357,700 lb	410,400 lb	N/A
Orbiter Inert	192,700 lb	192,700 lb	N/A
Orbiter Payload	81,400 lb	80,600 lb	N/A
Propellant Tank	66,800 lb	120,300 lb	N/A
Residual Propellant	1,500 lb	1,500 lb	N/A
OMS Propellant	15,300 lb	15,300 lb	N/A
3-engine Shuttle-C Configuration			
MECO mass	357,700 lb	410,400 lb	398,000 lb
Payload Carrier	24,500 lb	24,500 lb	24,500 lb
Propulsion Boattail	55,200 lb	55,200 lb	55,200 lb
Avionics and Cont.	11,400 lb	11,400 lb	11,400 lb
Payload	183,000 lb	182,200 lb	**32,400 lb**
Booster Engines	N/A	N/A	54,500 lb
Booster Propulsion Mass	N/A	N/A	73,000 lb
Propellant Tank	66,800 lb	120,300 lb	120,300 lb
Residual Propellant	1,500 lb	1,500 lb	1,500 lb
OMS Propellant	15,300 lb	15,300 lb	15,300 lb
STAGING CONDITIONS			
Time	121.3 sec	138.3 sec	N/A
Altitude	136,200 Ft	163,000 Ft	N/A
Mach Number	4.666	5.6	N/A
Delta V	8,909 Ft/sec	10,900 Ft/sec	N/A
Mass After Staging	1,552,400 lb	1,552,400 lb	N/A
Booster Dry Mass(ea)	119,500 lb	127,500 lb	N/A
Ascent Propellnt(ea)	610,500 lb	2,158,000 lb	N/A
ET Ascent Propellant	391,500 lb	N/A	N/A
Booster Jettisoned Mass	502,500 lb	127,500 lb	N/A
3-engine Shuttle-C Configuration (additional)			
Jettisoned mass	11,900 lb	11,900 lb	11,900 lb
LIFT-OFF CONDITIONS			
Gross Lift-Off Weight	3,416,100 lb	3,838,000 lb	3,782,400 lb
Thrust	5,085,100 lb	5,085,000 lb	5,085,000 lb
Thrust-to-Weight	1.489	1.325	1.344

LO2 / LH2 LIQUID ROCKET BOOSTER



SUPER-TANKER



Eq 1) Vb = G * Ave Isp * ln(GLOW / Morb) - k * G * t

Eq 2) Average Vehicle Isp =

[(Isp1 * Thrust1) + (Isp2 * Thrust2)] / (Thrust1 + Thrust2)

Eq 3) Mass to Orbit = Fuel / [(exp(955 / Isp)) - 1]

Eq 4) Gamma = (Non Payload / GLOW) * exp(955/Isp)

STO is achievable if GAMMA is less than 1.0

HARDWARE COST COMPARISON

ET - SSME

(6) $45 million engines + $30 million tank = $300 million for 52,000 lbs payload

($5,769 / lb payload)

ET - J2

(12) $10 million engines + $30 million tank = $150 million for 30,960 lbs payload

($4,839 / lb payload)

ET - INTEGRATION PROPULSION MODULE

(4) $3 million engines +$30 million tank = $42 million for 31,000 lbs payload

($1,350 / lb payload)

SINGLE STAGE TO ORBIT BENEFITS:

- *Extreme reduction in processing time*
  24 hours from Receiving to Launch
- *Internationally competitive launch vehicle system*
- *Reduction in Vehicle Hardware, Systems, & Manpower*
- *Reduction in Launch Site supporting Infrastructure*
- *Extremely flexible to vehicle manifest*
- *Big return in Technology Investment*
- *Good morale from readily visible accomplishments*
- *All bets are off if OEPSS Technologies are not implemented*
  - *Leakfree Joints*
  - *Total Automated Checkout of vehicle*
  - *Passive Payloads*
  - *No Artificial Interfaces*
  - *Vehicle Propulsion System is preconditioned*
  - *Structural mating of Cargo Pod requires Passive Attachment*

NASA
Stennis Space Center

N91-28259

PRESENTATION 4.3.8

SPACE TRANSPORTATION PROPULSION SYSTEMS SYMPOSIUM

D.J. Chenevert
NASA/SSC

June 25-29, 1990

NASA
Stennis Space Center

Presented to: "1990 Symposium on Space Transportation Propulsion Systems Technology"

At: Conference Center of Pennsylvania State University in University Park, Pennsylvania

For: Operational Efficiency Panel, June 25-29, 1990

By:
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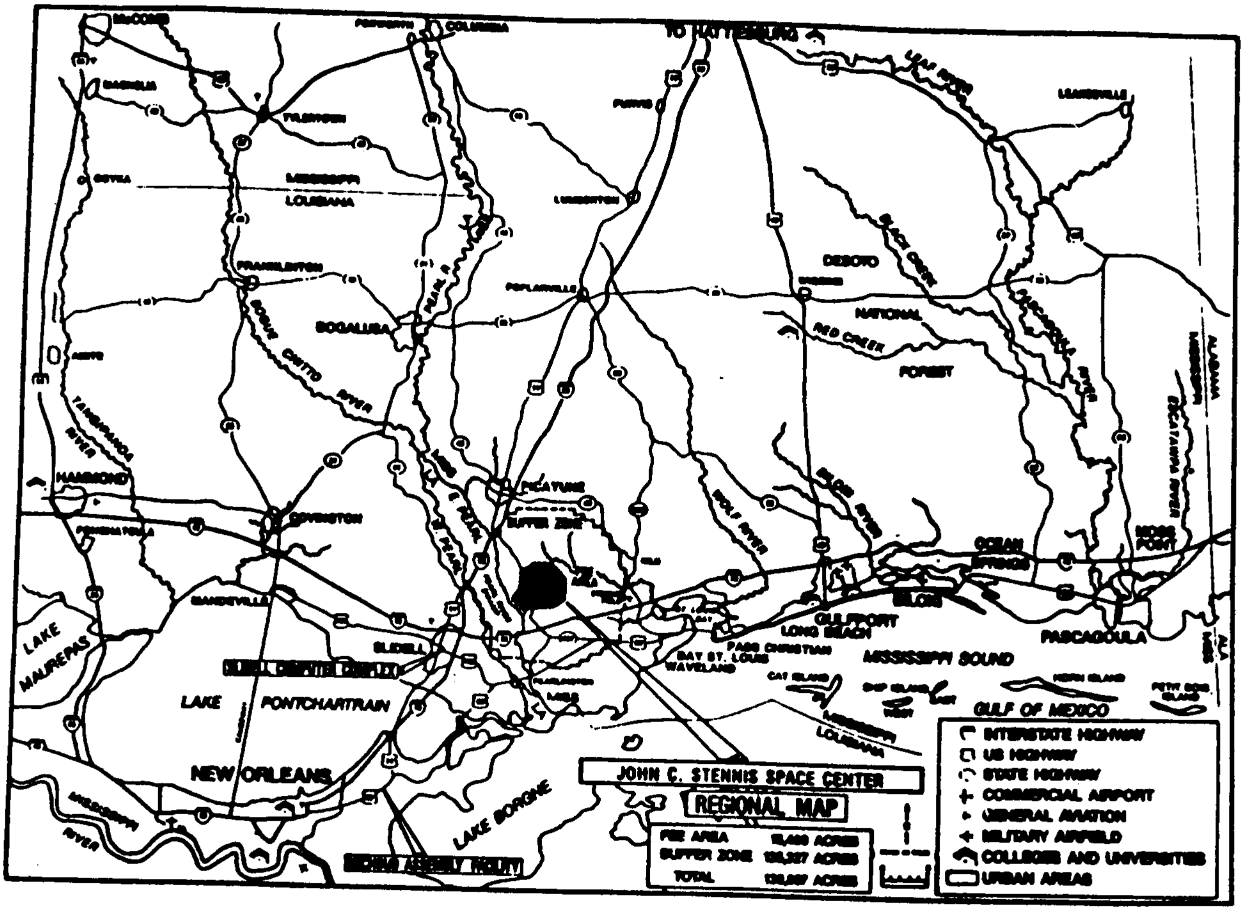


JOHN C. STENNIS SPACE CENTER ROLES AND MISSIONS

- Provide, manage, and operate facilities, laboratories, and related capabilities essential to the development testing of propulsion systems including the Space Shuttle Main Engine, the Advanced Launch System, and the Advanced Solid Rocket Motor
- Conduct research and development in propulsion test technologies including cryogenics, high-pressure gas, metrology, engine diagnostics, and safe operations
- Conduct research and technology development to support NASA goals in earth and environmental system sciences and observations, commercialization of remote sensing, and applications development
- Provide technical and institutional support services to resident agencies

MAJOR CONTRACTORS AT SSC

- Rockwell International (MPTA)
- Rocketdyne (SSME Testing)
- Martin-Marietta (External tank Support)
- Ford Aerospace-BDM Division (Support)
- Pan Am World Services, Inc. (Facilities Services)
- Sverdrup Technology, Inc. (Technical Services)
- Lockheed Engineering and Sciences Company (Remote Sensing, R&D Support)
- Quad S Company (Security Services)
- Mason Chamberlain, Inc. (Mississippi Army Ammunition Plant)
- Computer Sciences Corporation (NOAA National Data Buoy Center Support Services)

PROPULSION TEST TECHNOLOGY DEVELOPMENT AT SSC

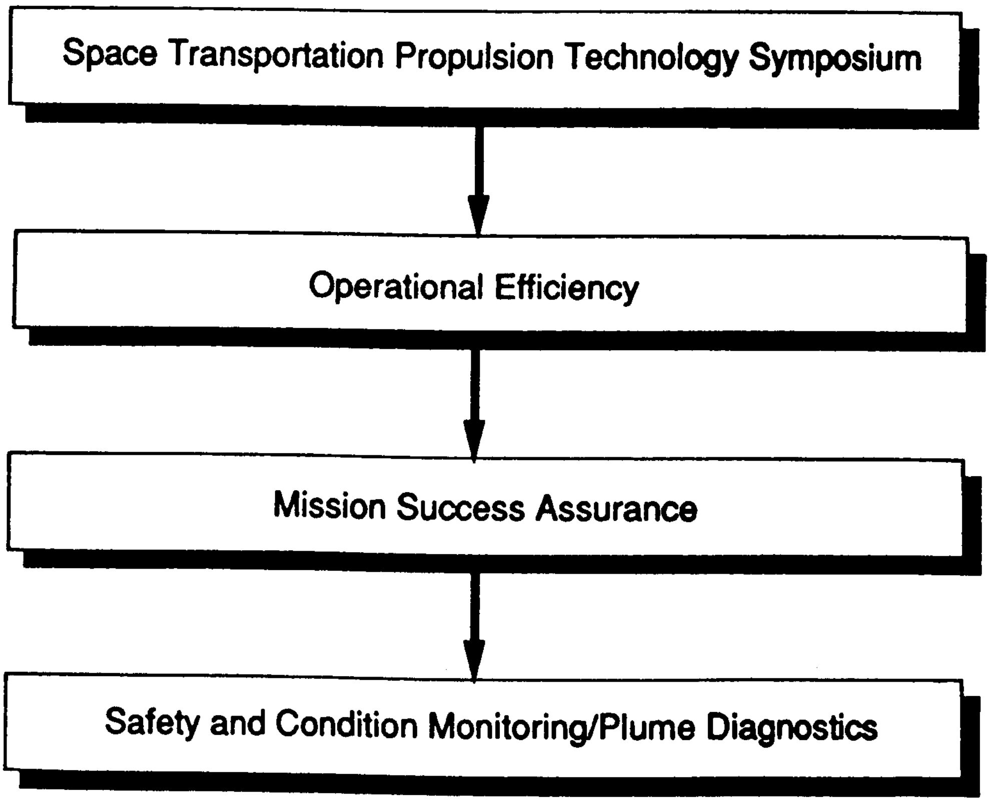
- Technology development complements test operations
- SSC has 25 years of large engine ground testing experience
- SSC has the capability for long duration static firings (2,000 seconds)
- Three active, greater than 500,000 pound thrust, test stands (one sea level and two altitude test stands)
- SSC has signficant experience in handling large quantities of liquid hydrogen, oxygen and nitrogen
- Current SSME test program and future test programs offer windows of opportunity for developing non-intrusive and diagnostic instrumentation and validating computational codes
- SSC has a very active plume diagnostic test program to develop advanced non-intrusive instrumentation systems
- Advanced ground test instrumentation/control systems and techniques can be developed economically
- SSC has extensive experience and expertise in non-intrusive remote sensing optical instrumentation sensors and systems
- Authorized by SSC charter

STENNIS SPACE CENTER

SPACE SHUTTLE MAIN ENGINE (SSME) TESTING PROGRAM

Year	No. of Tests	Seconds of Testing	Cryogens/Gases Consumption			
			Lox (Tons)	LH2 (Tons)	LN2 (Tons)	GHe (SCF)
1987	81	33,738	26,285	4,067	12,604	19,636,000
1988	89	40,414	34,873	5,020	16,166	22,523,000
1989	83	35,319	29,665	4,304	17,567	18,043,000
1990*	49	18,454	15,523	2,314	7,914	8,580,000

**Through May 1990*

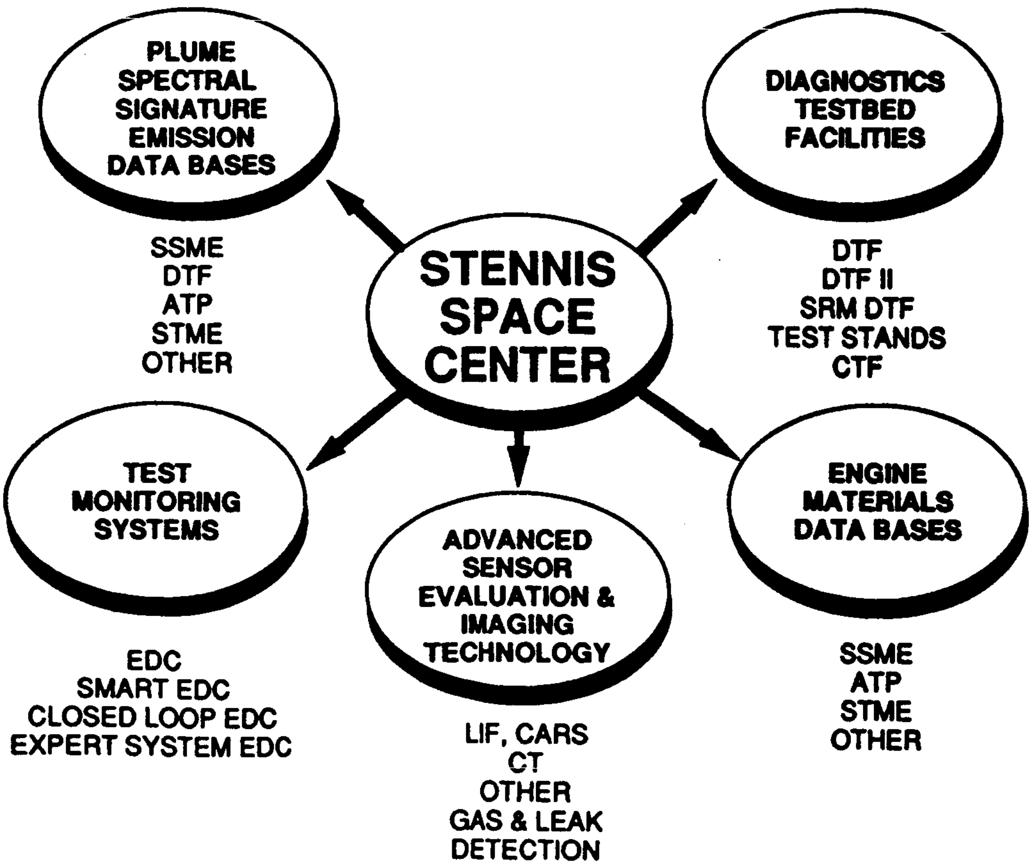


Plume Diagnostics:

- Diagnostics testbed facility (DTF) characteristics
- Engine plume diagnostics instrumentation
- DTF test/experiment results
- Applications on SSC test stands
  - A-1, Sea Level/Ambient
  - B-1, Aspirated/Diffuser

Safety and Condition Monitoring:

- Smart hydrogen sensor (SHS) and fugitive gas detection system (FGDS)
- Thermal infrared imaging technology development



STENNIS SPACE CENTER
PROPULSION TEST TECHNOLOGY
RELATED TECHNOLOGY DEVELOPMENT FACILITIES

Facility	Accomplishments	Facility Use
*Diagnostics Testbed Facility • 1200# Thruster • LOX/GH2 and Alternate fuels capability • Thrust chamber seeding capability • Small, inexpensive, accessible, flexible, quick-turnaround facilty	EDC - Engine (Plume) Diagnostics Console SHS - Smart Hydrogen Sensor	• Development of engine diagnostics sensors, instrumentation, and systems • Training of propulsion test personnel • Propulsion test control and data acquisition technology testbed • Leak detection testbed • Propulsion testing sensor and cryogenics testbed
*Electro-Optics Laboratory • Lasers • Spectrometers • Optical tables • Reference Calibration Sources • Optical Systems	STI - Shuttle Thermal Imager IDS - Ice Detection System OMA - Optical Mulichannel Analyzer	• Non-intrusive systems development, prototyping, maintenance, and calibration area
*Advanced Sensor Development Laboratory • Airborne remote sensing systems • Field remote sensing systems • Learjet Model 23 aircraft	TIMS - Thermal Infrared Multispectral Scanner CAMS - Calibrated Airborne Multispectral Scanner IRIS - Infrared Intelligent Scanner PRT5 - Precision Radiation Thermometer	• Remote sensing systems design, development, maintenance, calibration, and electro-optic systems study

DIAGNOSTICS TESTBED FACILITY CHARACTERISTICS

DIAGNOSTICS TESTBED FACILITY

EXPERIMENT PROGRAM:

Use DTF and SSME test stands to develop non-intrusive instrumentation to assist in optimizing operational testing frequency and safety.

DTF'S FUNCTION:

Allow precise exhaust plume seeding with trace levels of material specie to quantify spectral sensitivity and response time of spectrometer and advanced sensor based plume diagnostics instrumentation systems.

DIAGNOSTICS TESTBED FACILITY USAGE TO DATE

Acquisition, evaluation, and compilation of spectral database for SSME related elements and materials

Development of engine diagnostics sensors, instrumentation and systems

Training of test operations personnel

Control system proving ground

OMA/OPAD field verification

Hydrogen detection field experiments

Thermal image cryogenic leak detection experiments

Cryogenic liquid level sensor experiments

Mass flowmeter evaluation (LOX and GH2)

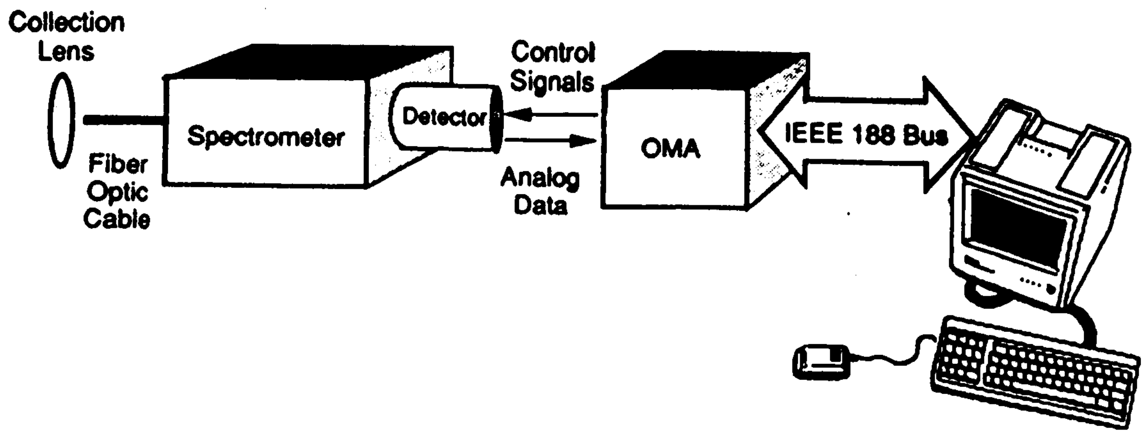
MSFC/LeRC Code R CSTI-ETO Projects

ENGINE PLUME DIAGNOSTICS INSTRUMENTATION

ENGINE PLUME DIAGNOSTICS

- Engine Plume Diagnostics System Development at SSC
  - OMA (Optical Multichannel Analyzer) on SSC test stands
  - EDC (Engine Diagnostics Console)
  - OMA & Video on Aspirated/diffuser Test Stand, B-1
  - OPAD (Optical Plume Anomaly Detector) Participant
- Bottom line - developed limited capability to look at SSME's exhaust plume to:
  - Call for engine shutdown to avoid major damage in many cases
  - Determine if a turbopump may be tested again before teardown
  - Post test anomaly resolution assistance

SYSTEM CONFIGURATION



DTF TEST/EXPERIMENT RESULTS

PLUME SEEDING TEST PLAN

Elements prioritized by:
A - Critical SSME component
B - Alloy or compound frequency of occurrence
C - Element frequency of occurrence

Group 1 Elements (High Priority)	Initial Survey Test Completed	Detection
Nickel (Ni)	X	YES
Iron (Fe)	X	YES
Chromium (Cr)	X	YES
Cobalt (Co)	X	YES
Calcium (Ca)	X	YES
Tungsten (W)	X	TBD
Manganese (Mn)	X	YES
Molybdenum (Mo)	X	TBD
Copper (Cu)	X	YES
Strontium (Sr)	X	YES

PLUME SEEDING TEST PLAN

Group 2 Elements (Intermediate Priority)	Initial Survey Test Completed	Detection
Aluminum (Al)	X	YES
Titanium (Ti)	X	YES
Silver (Ag)	X	YES
Tin (Sn)	X	TBD
Hafnium (Hf)	X	NO
Vanadium (V)	X	TBD
Yttrium (Y)	X	YES
Gold (Au)	X	TBD
Magnesium (Mg)	X	YES
Silicon (Si)	X	TBD
Tantalum (Ta)	X	TBD
Niobium (Nb)	X	NO
Zirconium (Zr)	X	TBD
Beryllium (Be)	Not to be Tested	TBD

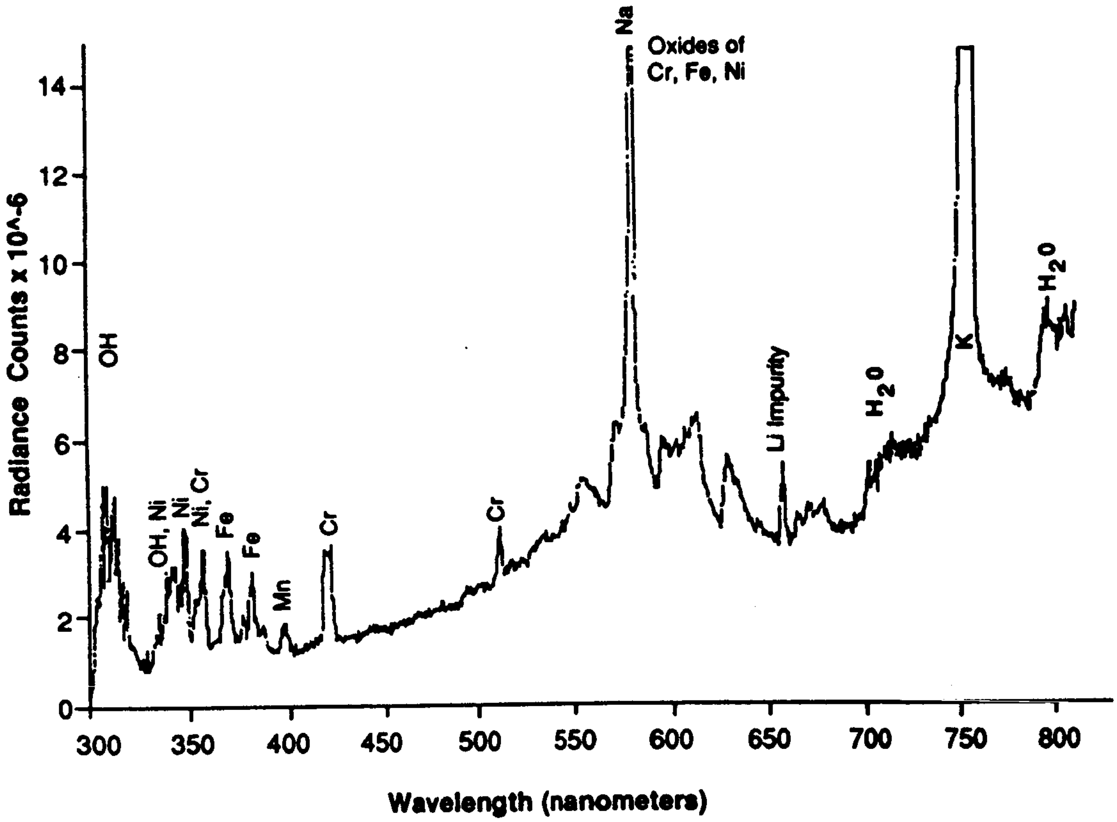
Group 3 Element (Low Priority)		
Fluorine (F)		TBD
Chlorine (Cl)	X	NO
Carbon (C)		TBD
Zinc (Zn)	X	TBD
Lithium (Li)	X	YES
Rhodium (Rl)	Not to be Tested	TBD
Palladium (Pd)	X	TBD

PLUME SEEDING TEST PLAN

Group I Materials	Initial Survey Test Completed
Inconel 718	X
Haynes 188	X
MAR-M 246+Hf	X
Waspaloy X	X
AISI 440C	X
NARloy-Z	X
MoS2	X
NiCrAlY	X
ZrO2 8% Y203	
PTFE	X
Armalon	

DTF DATA AT MACH DIAMOND LOCATION

50 ppm Inconel 718



ENGINE PLUME DIAGNOSTICS

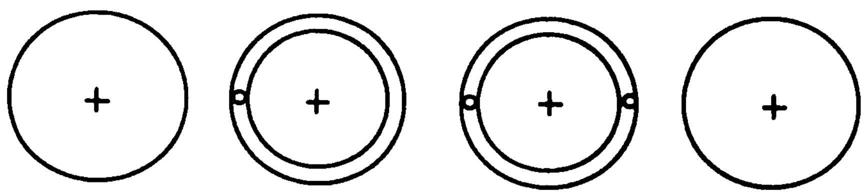
APPLICATIONS ON SSC TEST STAND

OMA Status:

Open-Ambient Test Stand: A-1

Closed Aspirated/Diffuser Test Stand: A-2, B-1

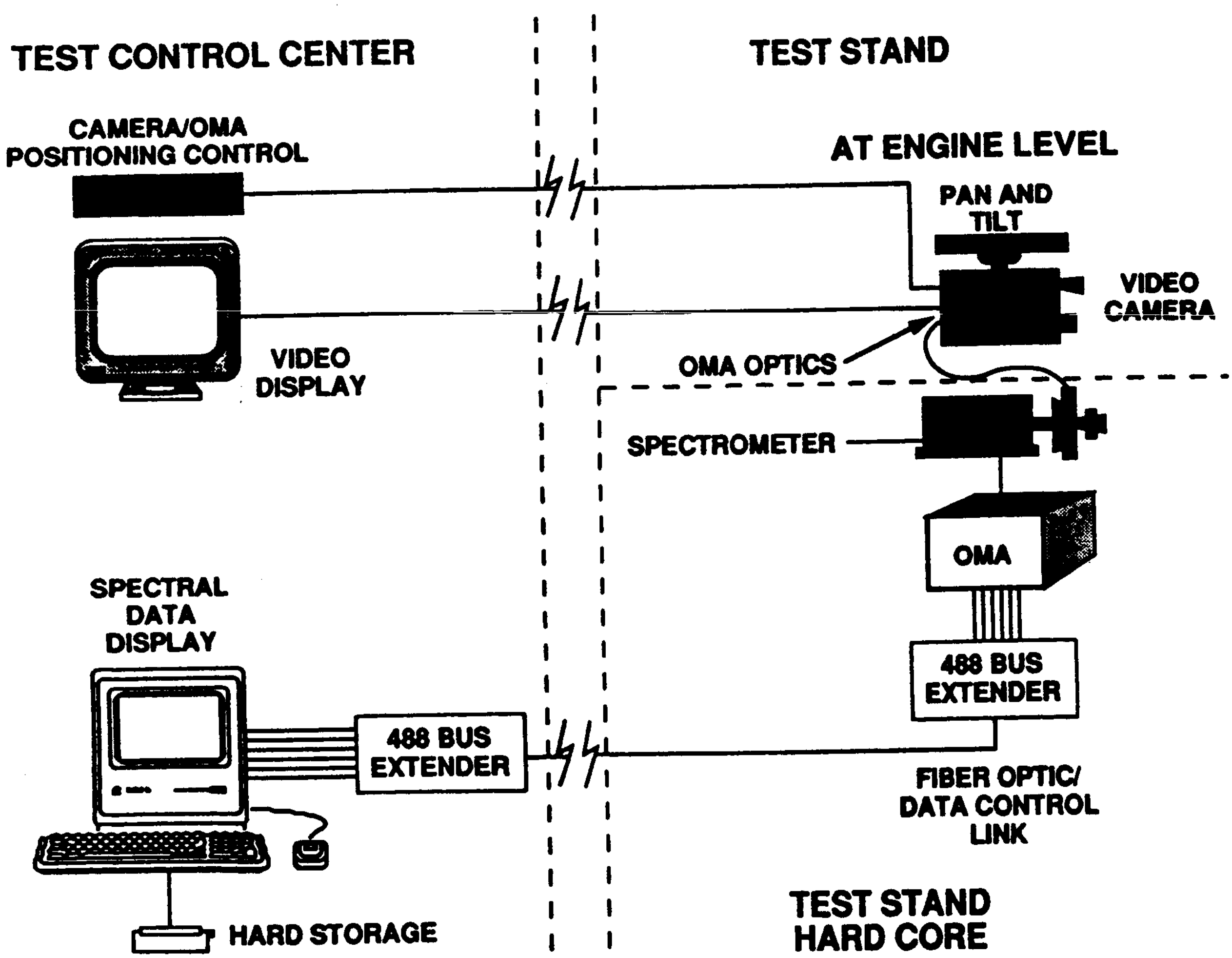
DTF



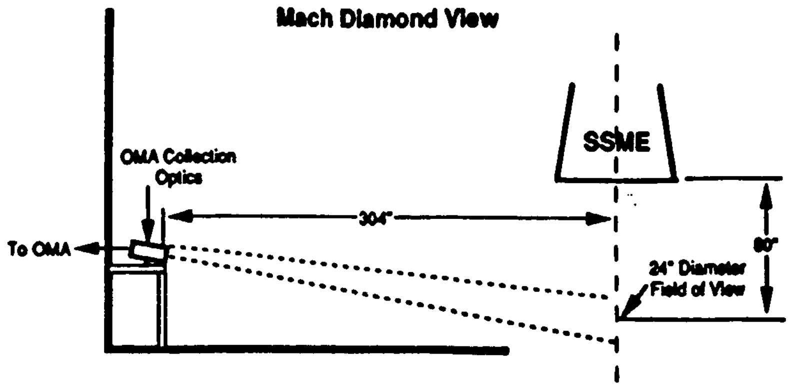
	A-1	A-2	B-1	DTF	
Planned:	3 OMAs	1 OMA	2 OMAs	1 OMA	= 7
Breakout:	2 OPS 1 EXP.	1 OPS	1 OPS 1 EXP.	1 EXP.	
Current Status:					
Under Development or Experimental	2 OMAs	Probe in Fabrication	1 OMA	1 OMA	
Operational	1 OMA	-	1 OMA	-	
Intensified array (IA)	1	1	1	1	= 4
Video	2	On-Order	On-Order	1	= 3 (2+1)

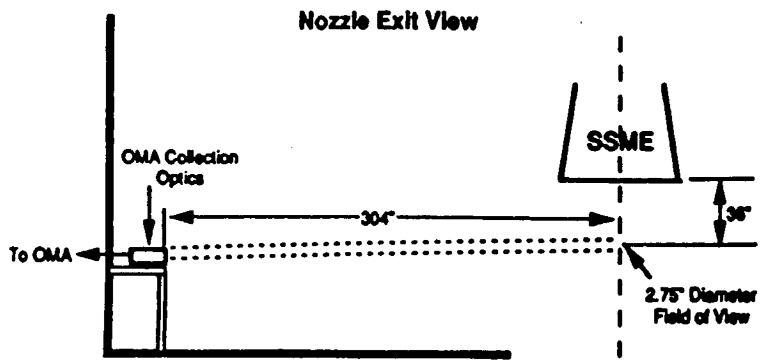
ENGINE PLUME DIAGNOSTICS

AMBIENT TEST STAND A-1



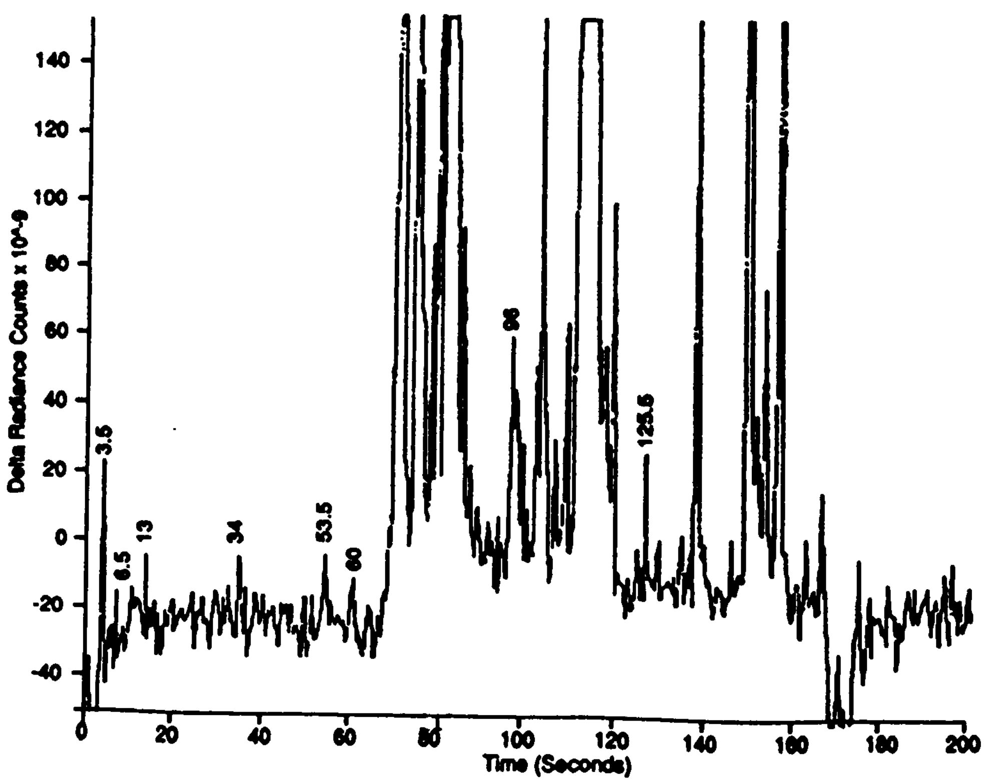
OMA CONFIGURATION



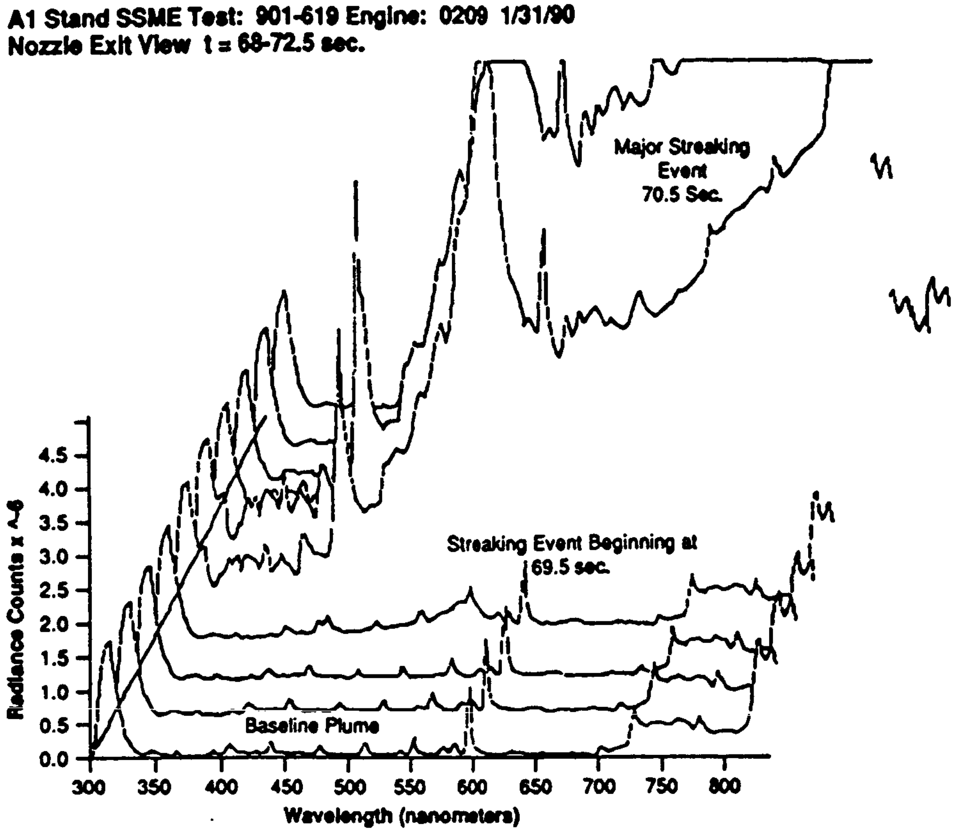


EXPANDED VIEW SHOWING MINOR FLASHES AND PRECURSORS TO MAJOR EVENTS

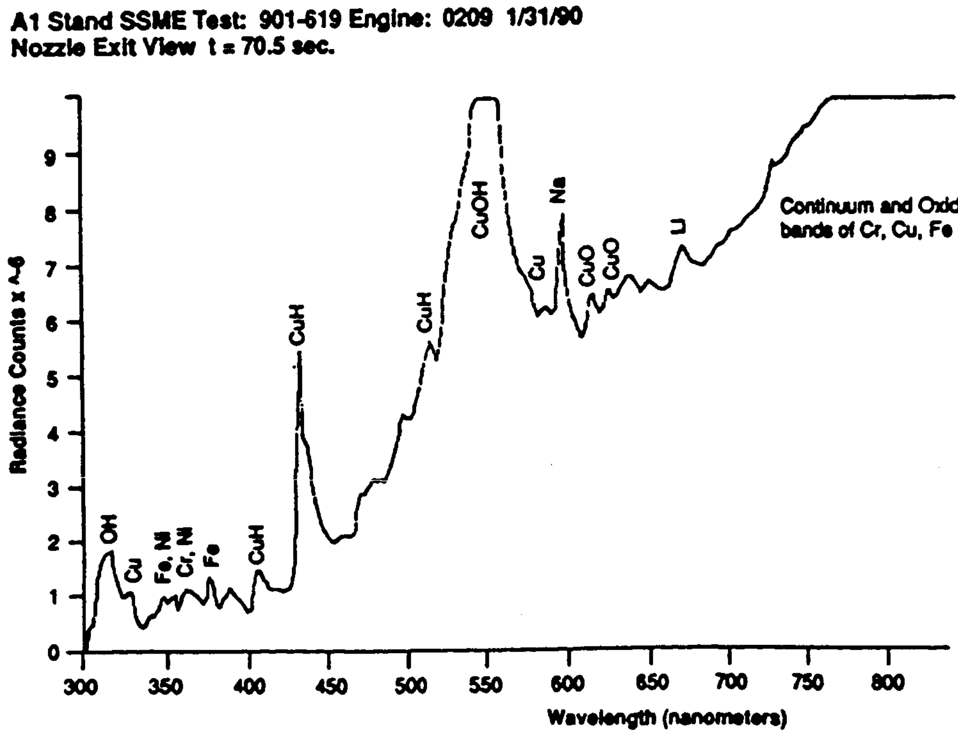
A1 Stand SSME Test: 901-619 Engine: 0209 1/31/90
CuH Peak Height (428 nm) Nozzle Exit View



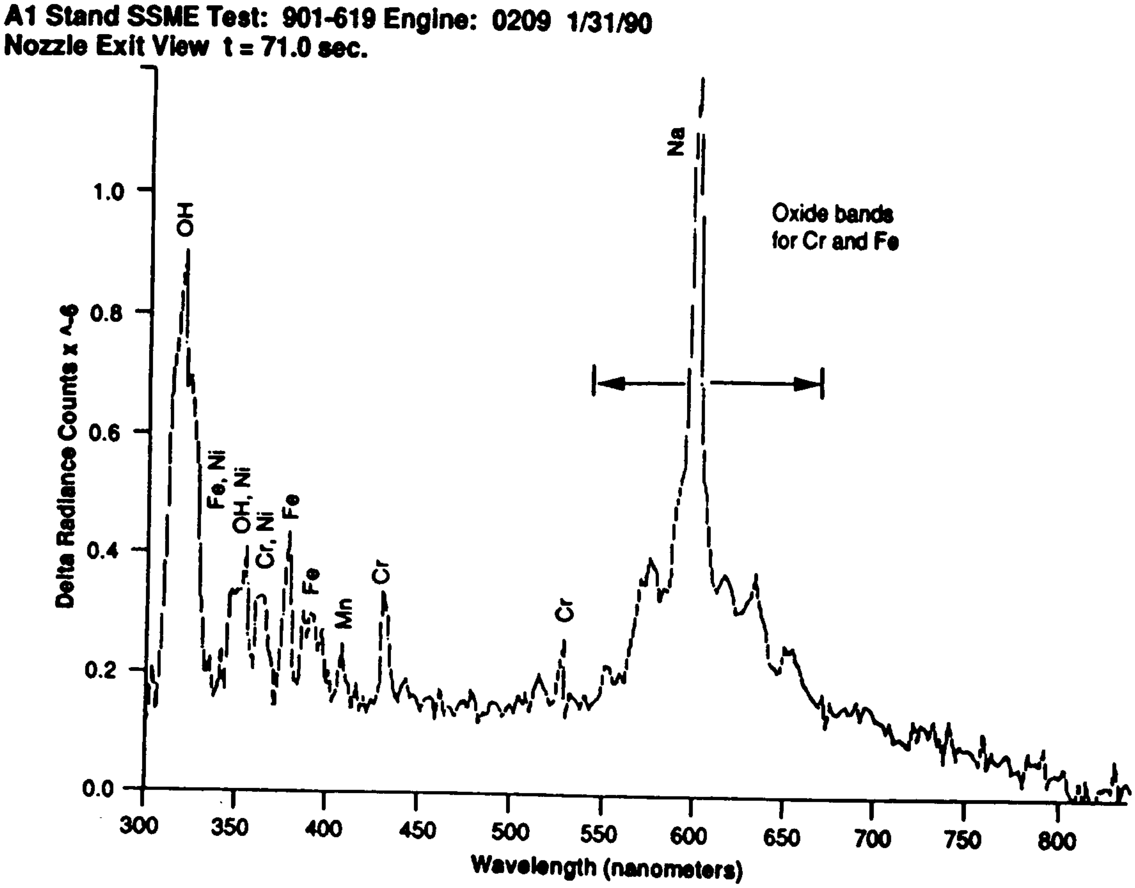
WATERFALL PLOT FROM 68 TO 72.5 SECONDS



IDENTIFICATION OF MAJOR EMISSION PEAKS DURING STREAKING EVENTS AT 70.5 SECONDS



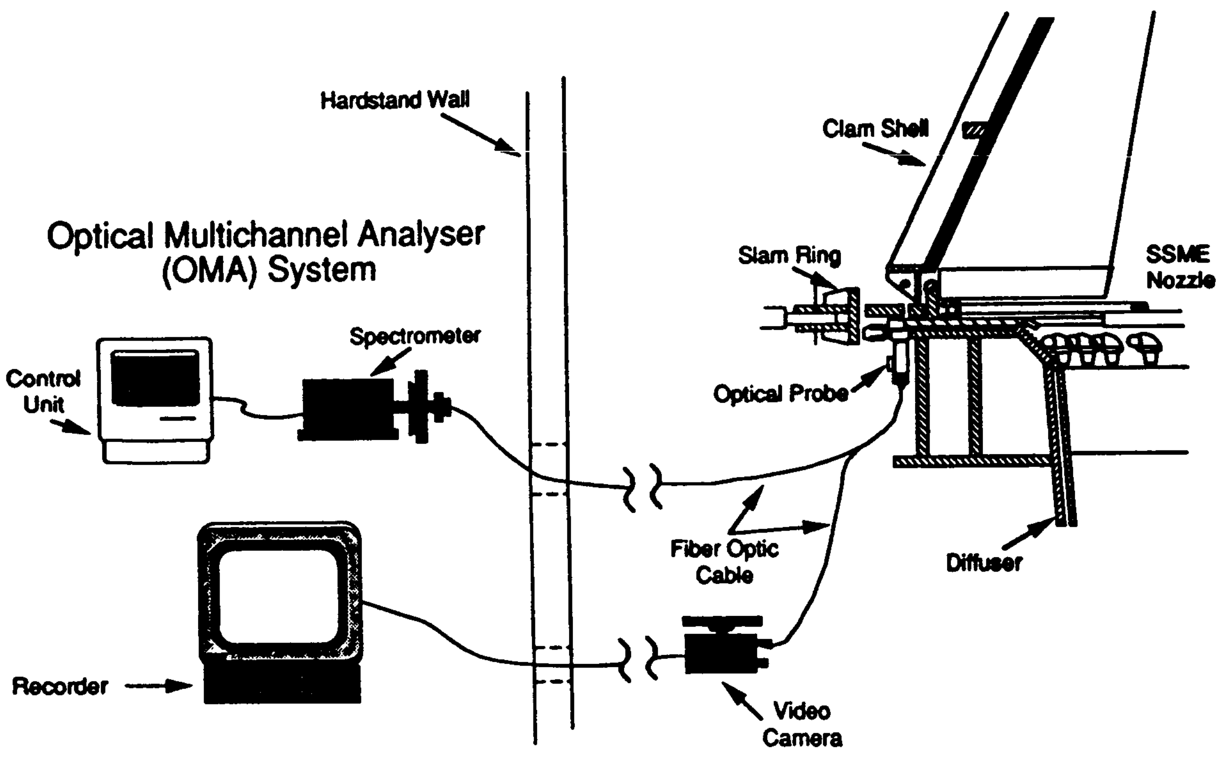
MACH DIAMOND VIEW, SPECTRAL PLOT OF HARDWARE ENHANCED PLUME AT 71.0 SEC. AFTER IGNITION



ENGINE PLUME DIAGNOSTICS

ASPIRATED TEST STAND B-1

EDC OPTICAL PROBE SCHEMATIC FOR ASPIRATED TEST STAND



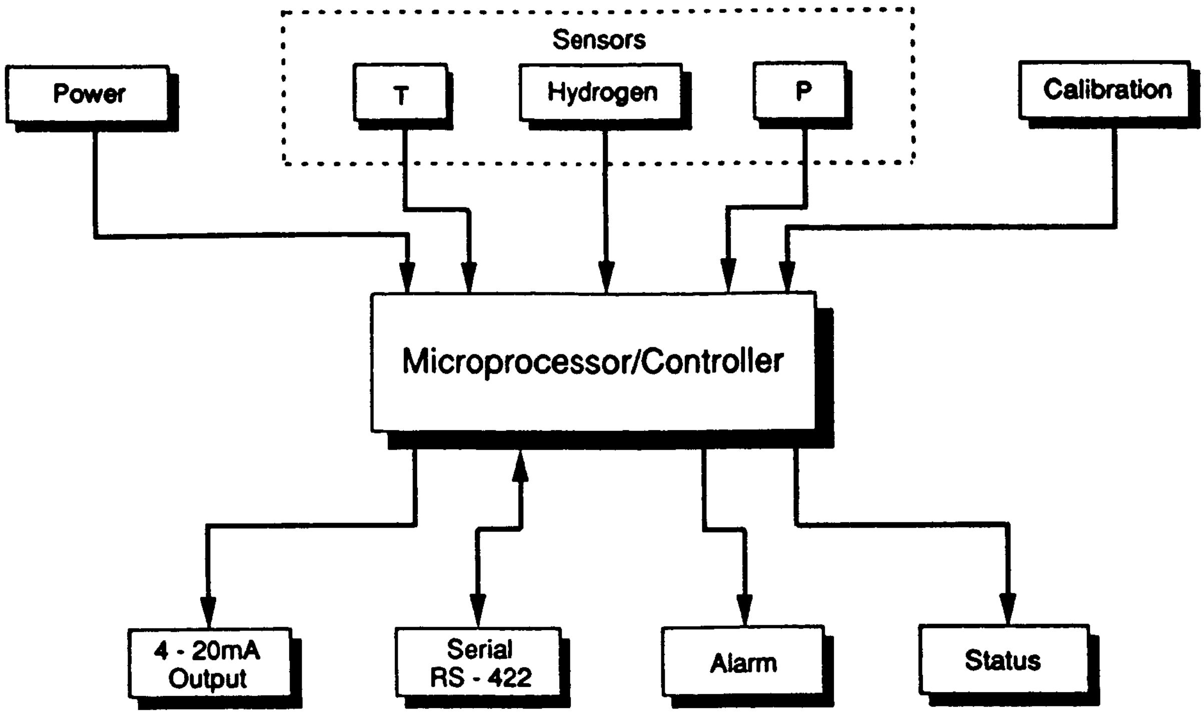
SMART HYDROGEN SENSOR AND FUGITIVE GAS DETECTION SYSTEM

SMART HYDROGEN SENSOR DESIGN GOALS

Project Goal: "Develop a reliable GH_2 sensor for Inert and Air Environments"

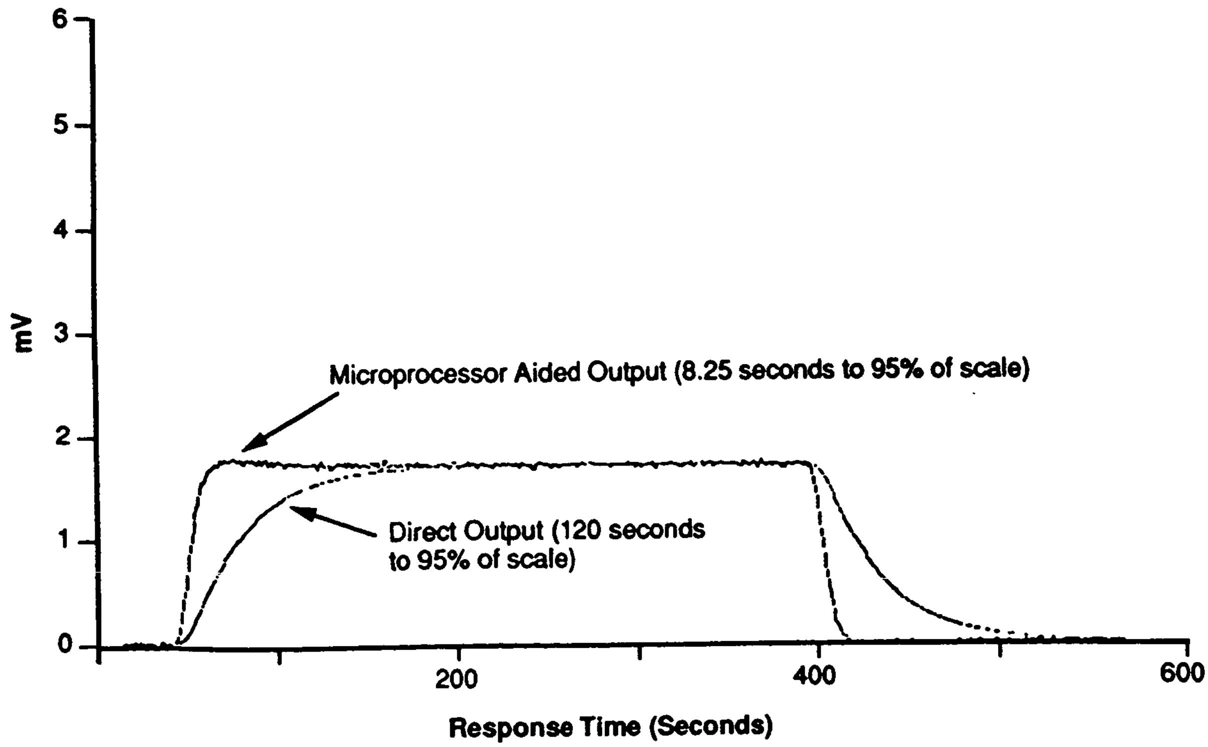
- Main Characteristics:
  - Background Gases
    - Air
    - Nitrogen
    - Helium
  - Range
    - 0-4 percent GH_2 by Volume

SMART HYDROGEN SENSOR



SENSOR RESPONSE TO 1.0% GH_2 BY VOLUME

Direct Analog vs. Microprocessor Aided Output in Nitrogen



SMART HYDROGEN SENSOR

Specifications

Temperature	Pressure	Humidity	Selectivity	Hydrogen
0 to 50 C*	0.5 - 1.5 atm	0 - 100% RH	Hydrogen Only	0 - 8% Vol 0 - 200% LeL 0 - 5,300 ppm (m) 0 - 80,000 ppm (vol)

Response Time < 10 Seconds

Estimated Values, Actual TBD → Accuracy: 0.5 - 2.0% of scale

Calibration: Built in menu driven software
90 day calibration interval

Maintenance and Reliability: Rugged Construction/Built-in self-diagnostics

---

Outputs: 4 - 20 Milliamps/serial RS-422

Power: 24 - 28 VDC/800 Milliamps

**Current test results indicate that this specification could be widened significantly in the final production units*

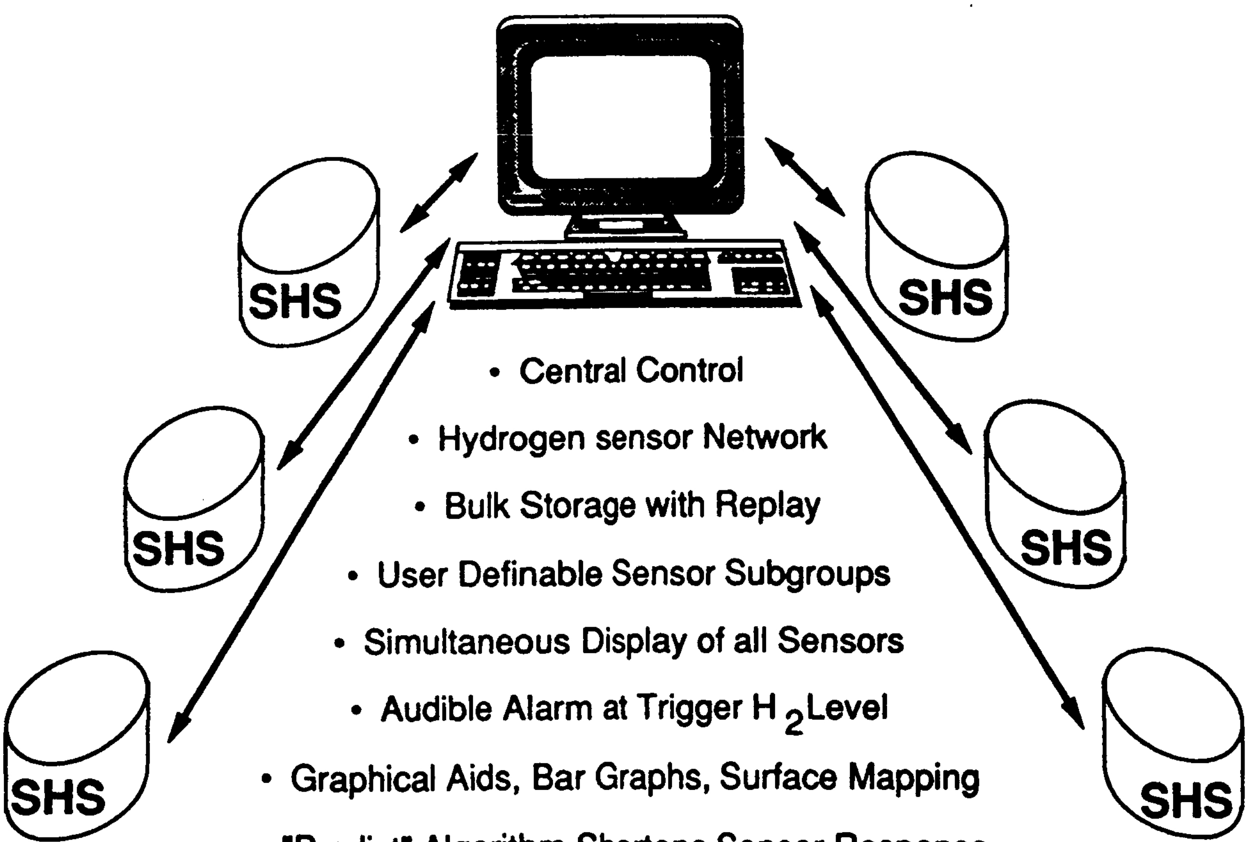
SMART HYDROGEN SENSOR PROGRAM STATUS AND PLANS

- Prototype - testbed
- Field testing first pre-production prototype
  - One year in engine test environment with exposure to high acoustic loads, overpressure, temperatures, cryo-soak to LN_2 temperature and deluge spray—still functioning
- Patent Application submitted to Patent Office
- Fugitive Gas Detection System Spin-Off
- Qualification Testing by KSC - FY90-91
- Technology Utilization Office Commercialization Initiated

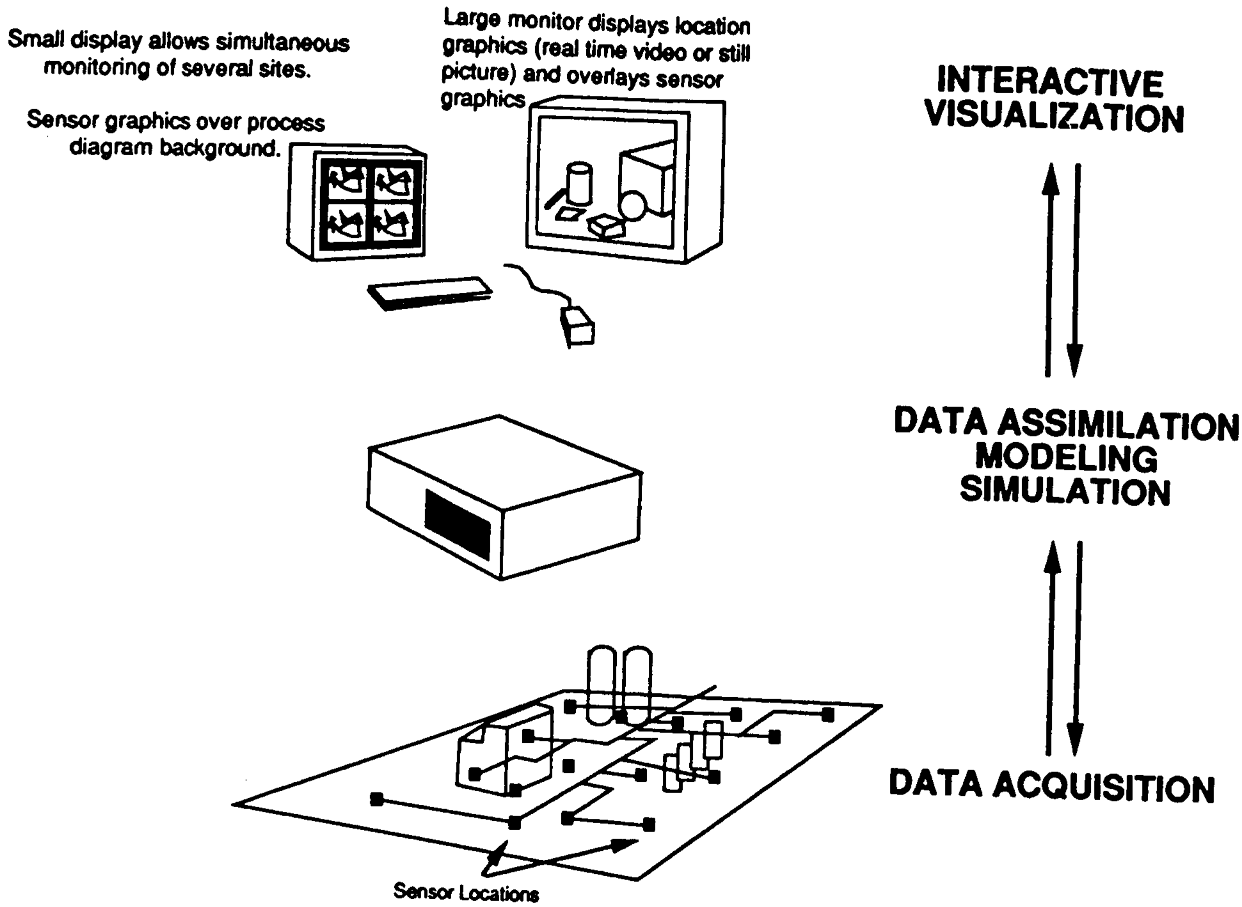
FUTURE PLANS

SSC	- LH_2 Barges - High Pressure Gas Facility - All Engine/Component Test Stands
KSC	- Launch OPS - Flight Orbiter AFT Fuselage ET Intertank
RTOP	- Fugitive Gas Detection System

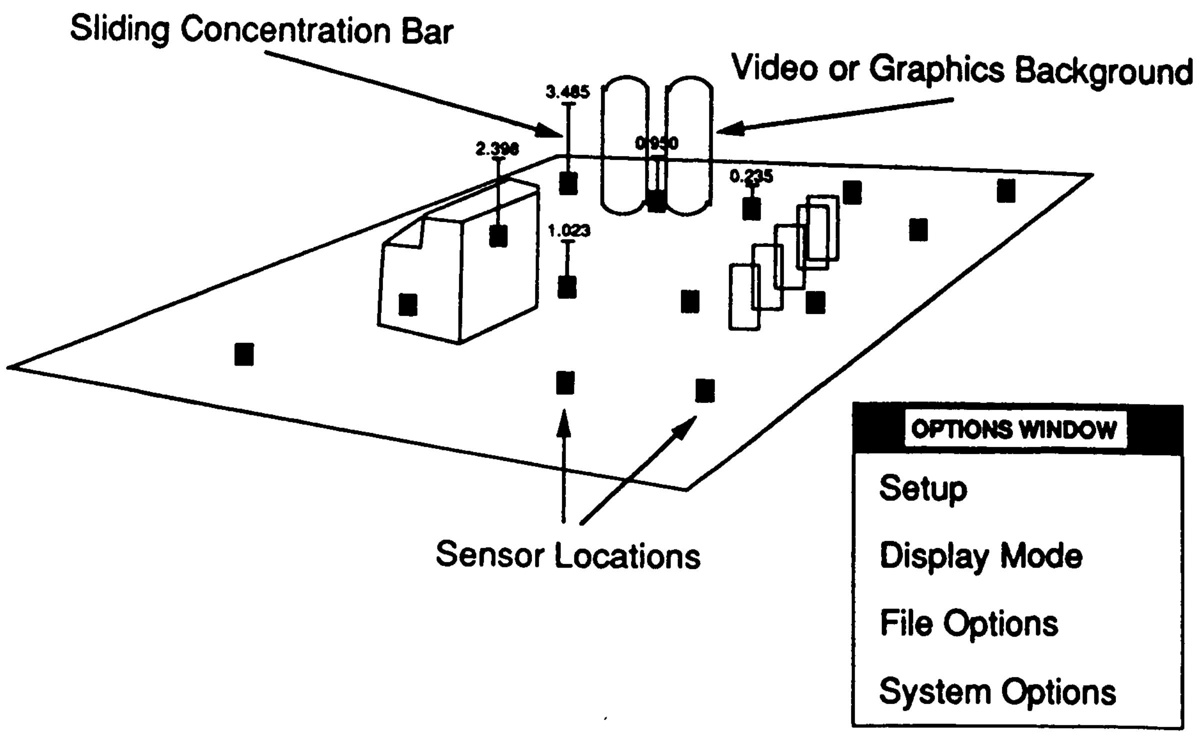
FUGITIVE GAS DETECTION SYSTEM



- Central Control
- Hydrogen sensor Network
- Bulk Storage with Replay
- User Definable Sensor Subgroups
- Simultaneous Display of all Sensors
- Audible Alarm at Trigger H_2 Level
- Graphical Aids, Bar Graphs, Surface Mapping
- "Predict" Algorithm Shortens Sensor Response

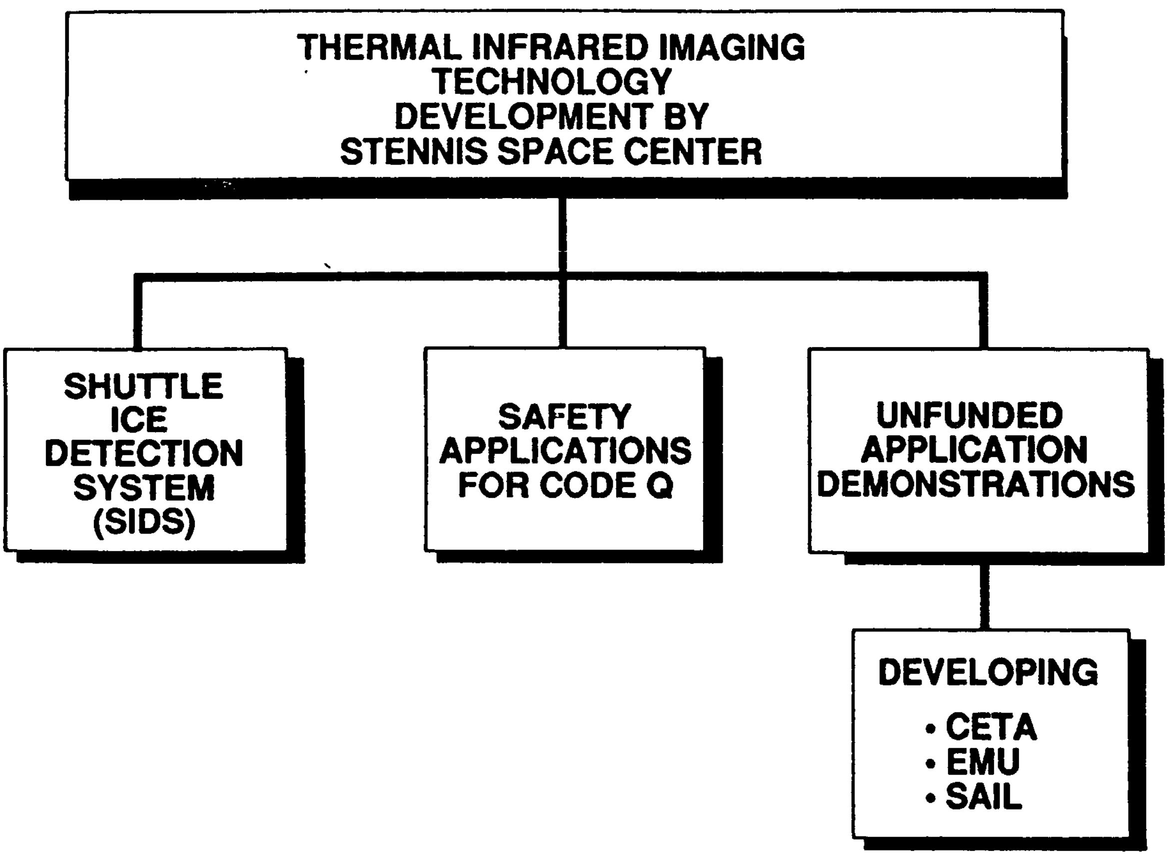


SLIDING BAR SENSOR GRID VISUALIZATION



THERMAL INFRARED IMAGING

TECHNOLOGY DEVELOPMENT



SHUTTLE ICE DETECTION SYSTEM
(SIDS)

- <u>Shuttle Thermal Imager (STI)</u>

  Provide real-time capability to remotely monitor/measure the launch stack temperatures.

  - 7 units operational at KSC
  - Upgrades and additional units ongoing

- <u>Ice Detection System (IDS)</u>

  Differentiate between Dry TPS Surfaces, Water/ Condensate, and Ice/Frost Formations/Accumulations.

  - Plan to test/evaluate prototype

THERMAL INFRARED IMAGING TECHNOLOGY
SAFETY APPLICATION

PHASE I

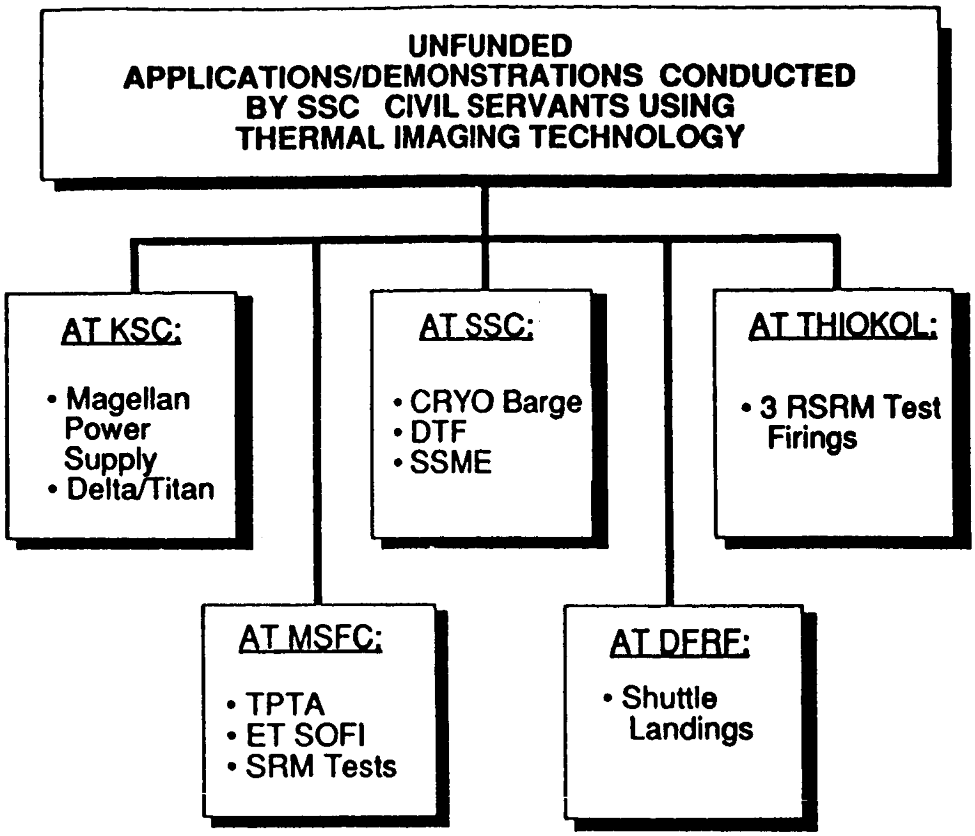
- LOX LEAKS
- REPORT IN REVIEW
- NOT A PROMISING METHOD TO DETECT LOX LEAKS

PHASE II

- FIRE DETECTION
- VARIOUS FLAMMABLE MATERIALS

PHASE III

- RESEARCH EMPHASIS TBD FROM PHASE II



OPERATIONAL APPLICATIONS OF STENNIS SPACE CENTER THERMAL INFRARED IMAGING TECHNOLOGY

- Real-time precision temperature measurement and monitoring
  - Fire detection/monitoring
  - SRB case temperature mapping
  - GOX vent hood seal
  - Cryogenic leak detection
  - Thermal modeling of launch stack
  - ET/SRB attach strut thermal isolation
  - Operations verification
  - Post-launch MLP damage assessment
  - Landing operations support
    - Tire & brake temperatures
    - Nose cone temperature
    - Leading edges temperatures
    - APU operation & shutdown
    - Missing/damaged tile/FRSI assessment
    - Fire detection
    - Night vision

DEVELOPING APPLICATIONS/DEMONSTRATION ACTIVITIES IN WHICH FUTURE SSC DEVELOPMENT IS LIKELY

JSC CREW AND THERMAL SYSTEMS DIVISION
SHUTTLE SUPPORT BRANCH (CODE EC6)

- Crew equipment translational aid (CETA) potential for other hardware testing in the 24 foot chamber (e.g. PDAS)
- Extravehicular Mobility Unit (EMU) suit component testing, 11 foot chamber
- Shuttle Avionics Integration Lab (SAIL) Cold Plate verification on OV105

N91-28260

PRESENTATION 4.3.9

OSF | WEATHER SUPPORT OFFICE

EFFECTIVITY OF ATMOSPHERIC ELECTRICITY ON LAUNCH AVAILABILITY

SPACE TRANSPORTATION PROPULSION TECHNOLOGY SYMPOSIUM AT PENNSYLVANIA STATE UNIVERSITY

Dr. JOHN A. ERNST
Director, WSO
June 28, 1990

Table 1: Number of Thunderstorm Days at KSC

SUMMARY OF THUNDERSTORMS BY MONTH FOR EACH YEAR

YEAR	MONTHS 1	2	3	4	5	6	7	8	9	10	11	12	YRSUM
1957	0	0	3	1	12	9	16	15	10	2	1	2	71
1958	1	2	4	3	5	10	8	14	9	2	1	0	59
1959	1	1	2	5	9	11	10	10	11	5	0	0	65
1960	0	2	4	3	6	17	21	11	9	4	0	0	77
1961	0	0	4	3	6	13	8	14	7	2	0	1	58
1962	0	3	3	3	4	17	19	22	10	3	1	0	85
1963	1	1	2	2	8	11	13	14	3	3	1	0	59
1964	0	0	1	4	2	7	9	17	6	0	3	2	51
1965	1	1	5	2	3	13	21	11	2	2	1	0	62
1966	0	1	1	1	14	9	10	11	17	1	0	0	65
1967	0	1	1	0	2	21	23	9	7	1	0	2	67
1968	1	1	2	3	7	12	10	11	6	11	0	0	64
1969	0	1	3	5	8	10	19	18	9	3	1	1	78
1970	0	2	4	1	1	9	15	11	9	2	0	1	55
1971	0	4	4	1	5	20	19	11	6	13	3	1	87
1972	4	3	5	3	10	8	11	17	1	5	3	1	71
1973	1	0	4	4	7	9	13	11	10	1	1	1	62
1974	0	0	3	3	10	16	21	15	12	3	1	1	85
1975	0	0	2	2	10	21	15	18	15	5	0	0	88
1976	0	0	4	0	17	10	19	10	14	1	0	2	77
1977	2	1	1	1	10	13	17	15	12	3	2	3	80
1978	2	0	1	2	8	12	24	6	8	3	1	1	68
1979	1	2	2	1	11	13	16	15	10	2	1	0	74
1980	2	1	0	4	8	13	13	7	9	4	1	0	62
1981	0	2	1	1	5	7	14	14	8	2	0	3	57
1982	1	2	3	6	7	14	17	16	8	1	3	3	81
1983	2	4	4	3	4	13	13	17	8	7	1	6	82
1984	2	3	1	4	6	9	11	10	5	0	3	1	55
1985	0	0	1	4	9	14	13	19	11	10	1	1	83
1986	2	2	4	0	5	16	15	16	7	4	2	1	74
1987	1	3	7	2	5	10	15	10	13	0	5	0	71
1988	1	0	2	2	5	6	13	15	5	2	1	1	53
1989	1	2	3	6	7	17	15	11	9	5	1	0	77
NOBS	1013	924	1009	990	1023	990	1023	1023	990	1023	990	1023	12021
N TSTRMS	27	45	91	85	236	410	496	441	286	112	39	35	2303
PER CENT	2.7	4.9	9.0	8.6	23.1	41.4	48.5	43.1	28.9	10.9	3.9	3.4	19.2

Table 2: Percentage Frequency of Thunderstorms at KSC From 33 Year Period of Record (1957 - 1989)

SUMMARY OF THUNDERSTORMS BY HOUR/MONTH

HOUR (EST)	MONTHS 1	2	3	4	5	6	7	8	9	10	11	12
0	0.0	0.1	0.5	0.6	0.7	0.9	1.2	2.2	2.6	0.8	0.2	0.1
1	0.1	0.2	0.6	0.4	0.7	0.6	1.1	1.4	2.4	1.4	0.1	0.0
2	0.4	0.0	0.8	0.3	0.7	0.9	0.7	0.7	1.6	1.[illegible]	0.3	0.0
3	0.1	0.2	1.0	0.1	0.4	0.9	0.2	0.9	1.3	0.9	0.4	0.1
4	0.3	0.3	0.8	0.2	0.7	1.0	0.6	0.9	1.6	1.1	0.3	0.3
5	0.3	0.3	1.2	0.2	0.4	0.5	0.9	0.5	1.0	0.8	0.2	0.1
6	0.0	0.3	0.7	0.1	0.3	0.8	0.4	1.2	1.3	0.5	0.2	0.1
7	0.0	0.1	0.8	0.3	0.3	0.5	1.4	1.0	1.2	0.5	0.3	0.0
8	0.1	0.1	0.6	0.4	0.3	0.5	1.3	0.8	0.8	0.7	0.2	0.0
9	0.3	0.2	0.6	0.2	0.5	0.5	0.9	1.3	1.2	0.4	0.3	0.2
10	0.2	0.3	0.8	0.5	1.0	1.0	1.0	1.2	2.4	0.3	0.3	0.3
11	0.2	0.5	0.8	0.8	1.8	2.9	2.5	4.1	2.4	0.4	0.2	0.0
12	0.2	0.4	1.2	1.2	3.2	5.0	6.6	5.8	2.2	1.2	0.4	0.5
13	0.1	0.8	1.1	1.7	3.7	9.1	11.7	8.5	4.9	1.1	0.6	0.6
14	0.1	0.3	1.2	1.9	5.3	12.8	17.0	14.0	7.0	1.2	0.5	0.3
15	0.2	0.8	0.8	1.9	5.8	14.0	19.1	16.8	7.6	1.9	0.6	0.7
16	0.3	0.5	1.0	1.8	6.3	14.9	19.5	16.2	6.9	2.2	0.6	0.5
17	0.1	0.6	0.8	1.8	7.4	13.6	18.8	14.0	7.4	1.8	0.6	0.9
18	0.2	0.2	1.3	1.2	7.1	11.4	15.5	12.0	6.4	2.3	0.8	0.5
19	0.4	0.4	1.6	1.4	5.3	8.6	10.7	6.3	6.1	2.5	0.3	0.2
20	0.4	0.6	1.2	1.0	4.6	6.4	6.5	5.6	4.8	1.9	0.5	0.1
21	0.0	0.6	1.1	0.8	3.3	4.3	4.9	3.6	3.8	1.1	0.6	0.1
22	0.1	0.4	0.9	0.9	1.6	2.6	2.6	2.2	3.0	0.9	0.4	0.2
23	0.2	0.4	0.7	0.6	1.4	1.6	2.2	1.9	1.9	0.8	0.3	0.0
NOBS	24265	22175	24190	23756	24548	23758	24550	24548	23758	24550	23756	24539
NTSTRMS	43	84	221	203	640	1144	1504	1255	812	281	92	58
PCT	0.2	0.4	0.9	0.9	2.6	4.8	6.1	5.1	3.4	1.1	0.4	0.2

RTLP EFFECT OF LIGHTNING ADVISORY ON GROUND OPERATIONS

- STOPS ACTIVITIES INVOLVING PERSONNEL WHO ARE NOT WITHIN A SHIELDED ENVIRONMENT
- STOPS EXPLOSIVE/ORDINANCE OPERATIONS
- STOPS SRM GRAIN INSPECTION
- STOPS SYSTEM MAINTENANCE AND REPAIR ON OUTSIDE COMMUNICATIONS AND POWER LINES
- FORCES CLOSURE OF VAB, OPF, AND OMRF HIGHBAY DOORS
- CABLES CAN NOT BE CONNECTED/DISCONNECTED TO CT AND MLP INTERFACES
- STOPS ORDINANCE INSPECTION OPERATIONS
- STOPS ORDINANCE DELIVERY
- STOPS OPERATIONS REQUIRING CROSSING OF PCR/ORBITER INTERFACE

RTLP EFFECT OF LIGHTNING ADVISORY ON GROUND OPERATIONS

- STOPS AIRCAFT OPERATIONS (STA; T-38) AT THE SLF
- CREW CAN STOP SHUTTLE ROLL-OUT
- STOPS VPF HYPERGOLIC OPERATIONS
- SRM SEGMENTS, ORBITER, ET, PAYLOADS, IN CANISTER AND SHUTTLE MOVEMENT CAN NOT BEGIN
- STOPS OUTSIDE LOGISTICS OPERATIONS
- PREVENTS USAGE OF OIS HEADSETS ON PAD APRON

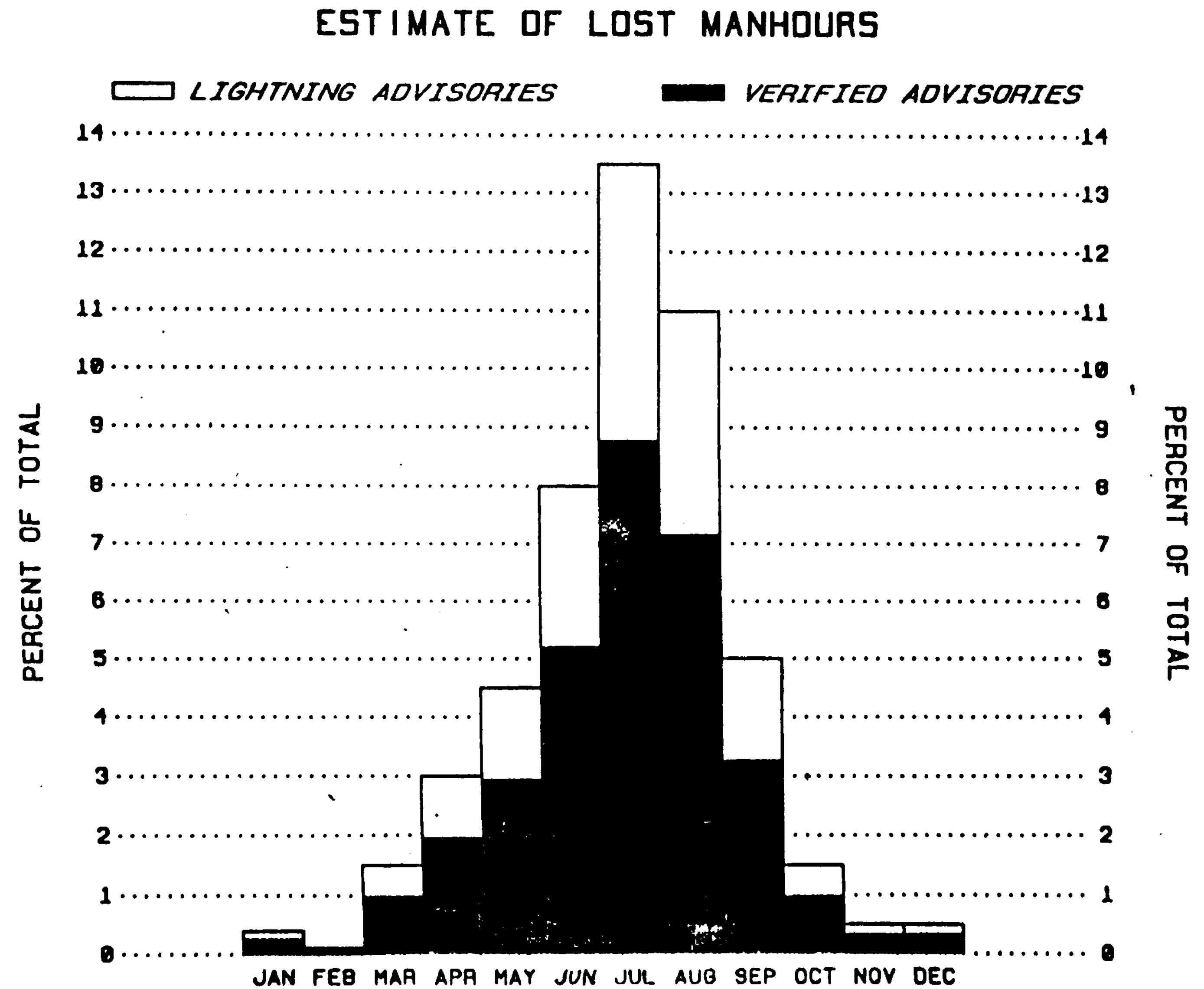
15

LIGHTNING AFFECTS TO FACILITIES, EQUIPMENT & PERSONNEL SAFETY

FACILITY/GROUP	ADVERSE WEATHER WARNING	VULNERABLE TO LIGHTING STRIKE		POSSIBLE IMPACT			PERSONNEL SAFETY
		DIRECT	INDIRECT	LAUNCH	SCHED.	COST	
COMPLEXES A & B	WORK CONT. EXC. LL						
RSS / FSS	HIGH WINDS ONLY	NO	NO	NO	NO	NONE	ON TOP
PCR	YES	NO	YES	NO	YES	YES	YES
FUEL/OXIDER HYPERGOL	NO	NO	NO	NO	NO	NONE	NO
SCAPE REST AREA	YES	NO	NO	NO	NO	NONE	NO
ORD. RECEIVE/INSP	YES	YES	YES	NO	YES	YES	YES
PAYLOAD CANISTER	YES	YES	YES	NO	YES	YES	YES
CT	YES	YES	YES	NO	YES	YES	YES
CRAWLERWAY	WNDS ONLY NO	NO	NO	NO	YES	YES	YES
VAB	EXC ORD NO	NO	YES	NO	YES	YES	ON TOP
ROOF	YES	NO	YES	NO	YES	YES	ON TOP
LCC	NO	NO	YES	NO	YES	YES	ON TOP
OPF	YES	NO	YES	NO	YES	YES	OUTSIDE
HYPER SCRUBBER	YES	YES	YES	NO	YES	YES	OUTSIDE
SRB CARRIER & RR	YES	NO	NO	NO	YES	YES	OUTSIDE
SRB REC & REFURB	YES	NO	YES	NO	YES	YES	YES
HMF	YES	NO	YES	NO	YES	YES	YES
CDSC	NO	NO	NO	NO	NO	NO	NO
OUTSIDE COMM CABLE PLNT	NO	YES	YES	NO	YES	YES	YES
PROG SUPT COMM NET	YES	NO	YES	NO	NO	YES	YES
SPIF/SMAB	YES	NO	YES	NO	YES	YES	YES
COMPLEX 40	YES	NO	YES	YES	YES	YES	YES
COMPLEX 41	YES	NO	YES	YES	YES	YES	YES
COMPLEX 36 A & B	YES	NO	YES	YES	YES	YES	YES
ESA-60	YES	YES	YES	NO	YES	YES	YES
SPIN TEST FAC	YES	YES	YES	NO	YES	YES	YES
HANGAR AO	YES	NO	NO	NO	NO	NO	ON TOP
FACS CRITICAL TO LAUNCH	YES		YES	YES	YES	YES	YES
AC POWER DISTRIBUTION	NO	YES	YES	NO	YES	YES	YES
GUARD SHACK	YES	YES	YES	NO	NO	NO	YES

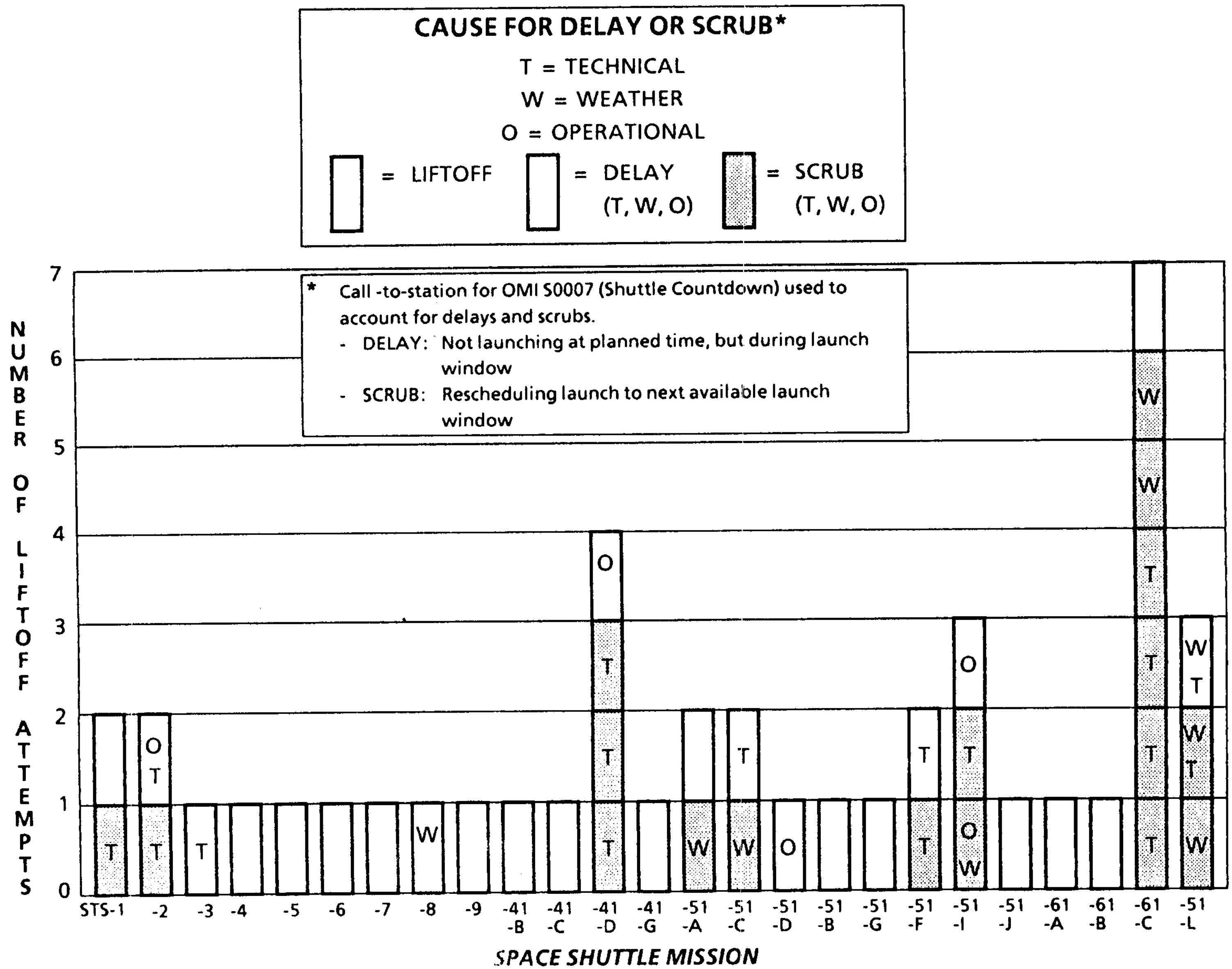
NASA

TE-CID-3/INSTRUMENTATION AND MEASUREMENTS BRANCH



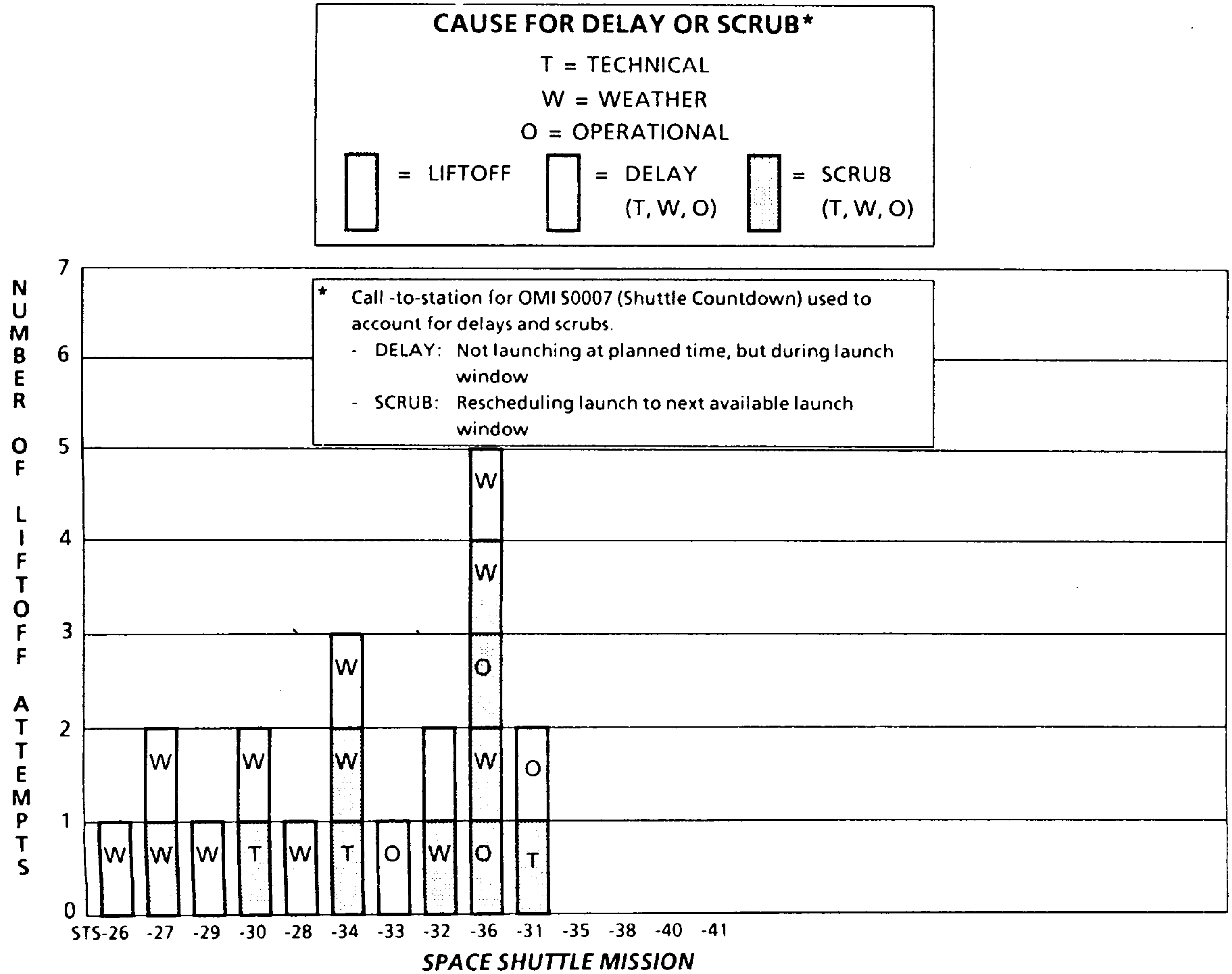
SHUTTLE LAUNCH HISTORY

Chart #1



SHUTTLE LAUNCH HISTORY

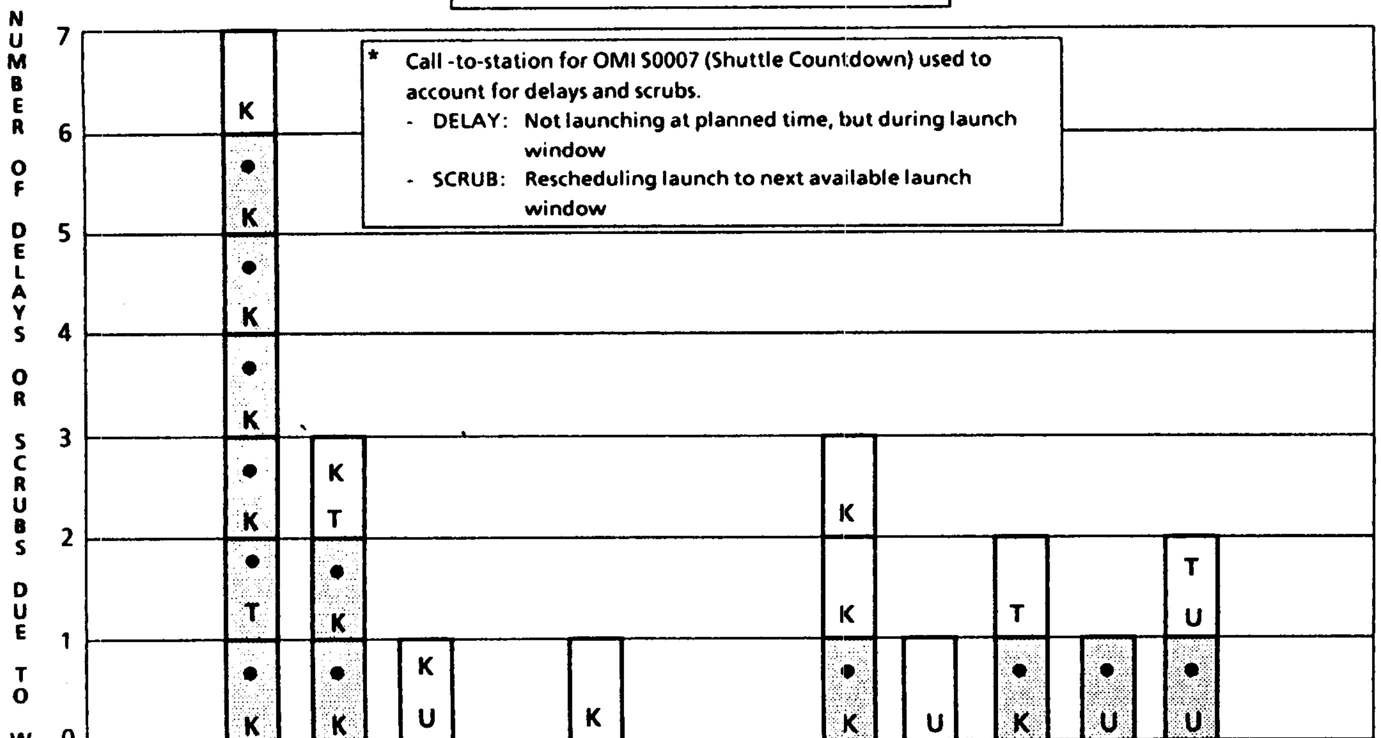
Chart #2



SHUTTLE LAUNCH WEATHER HISTORY

CAUSE FOR DELAY OR SCRUB *

K = KSC WX/WINDS
T = TAL WX/WINDS
U = UPPER LEVEL WINDS
[ ] = WX DELAY
[•] = WX SCRUB



LAUNCH ATTEMPTS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
	13	6	2	9	1	5	2	7	1	6	8	3	63

* Call-to-station for OMI S0007 (Shuttle Countdown) used to account for delays and scrubs.
- DELAY: Not launching at planned time, but during launch window
- SCRUB: Rescheduling launch to next available launch window

WSO	APPLIED METEOROLOGY UNIT

Synopsis

- **Definition** - A proposed facility in Cape area that would:
  - support a dialogue between Research and Operations focused on solving weather problems.
  - develop and test new technology, techniques, and processes.
  - provides support to the SSP operational forecast facilities at JSC/SMG and KSC/CCFF.

- **Goal** - Statement
  - AMU will provide a focused environment conducive to advancing the reliability and accuracy of weather support to space flight operations.

JOINT NASA/USAF AIRBORNE FIELD MILL PROGRAM

OBJECTIVES

- o USE NEW MEXICO TECH FLIGHT EXPERIENCE GAINED IN THE SUMMER 1988 AND 1989 FLIGHT CAMPAIGNS AT KENNEDY SPACE CENTER.
- o BUILD AN AIRBORNE FIELD MILL DATA BASE AND ANALYZE WITH METEOROLOGICAL DATA IN ORDER TO RECOMMEND CHANGES TO THE WEATHER LAUNCH COMMIT CRITERIA.
- o RECOMMEND, OR NOT, THE NEED FOR AN AIRBORNE FIELD MILL MEASUREMENT CAPABILITY ON DAY-OF-LAUNCH.

GOAL

- o INCREASE LAUNCH AVAILABILITY AND REDUCE THE CHANCE FOR WEATHER HOLDS/DELAYS

RTLP GOALS/OPERATIONAL BENEFITS

OPERATIONAL BENEFITS OF JOINT PROGRAM:

- MINIMIZE IMPACT OF ADVERSE WEATHER ON:
  - GROUND SYSTEMS AND OPERATIONS
    - REDUCE FALSE ALARMS IN LIGHTNING WARNINGS
    - IMPROVE LIGHTNING HARDENING OF GROUND EQUIPMENT
    - VERIFY RELIABILITY OF LIGHTNING PROTECTION SYSTEMS
  - FLIGHT SYSTEMS AND OPERATIONS (ULV/ELV; ALS; NSTS)
    - REFINE LAUNCH CONSTRAINTS DUE TO TRIGGERED LIGHTNING
    - POSSIBLY WIDEN LAUNCH WINDOWS IN MARGINAL CONDITIONS

N91-28261

PRESENTATION 4.3.10

"PROPULSION SYSTEM GROUND TESTING"

BY

CHARLES C. WOOD

JUNE 27, 1990

OBJECTIVE

TO PROVIDE MANAGEMENT VISIBILITY RELATIVE TO THE ROLES OF SIMULATION AND PROPULSION SYSTEM TESTING FOR FUTURE DEVELOPMENT PROGRAMS THROUGH ASSESSMENT OF CURRENT PROPULSION RELATED SIMULATION CAPABILITIES AND REVIEW OF CONTRIBUTIONS FROM PROPULSION SYSTEM TEST PROGRAMS.

BASIS FOR PRESENTED DATA

CONTENT	SOURCE
• DEVELOPMENT STATIC FIRING DATA	SPACE SHUTTLE MAIN PROPULSION SATURN STAGES
• ANALYTICAL CAPABILITY	JUDGEMENT
• PROGRAMATICS DATA (ROCKWELL)	ORBITER SATURN S-11 APOLLO CSM GEMINI
• PROPULSION SPECIALISTIC SURVEY	RESPONSE TO SURVEY

REPORT

"ADVANCED NSTS PROPULSION SYSTEM VERIFICATION STUDY FINAL REPORT" - JULY 31, 1989

SIMULATION CAPABILITY ASSESSMENT

(NO PROPULSION SYSTEM TEST)

EVALUATION CRITERIA	VEHICLE FLIGHT CATASTROPHE RISK	MISSION LOSS RISK	LAUNCH DELAY RISK	LAUNCH COMPLEX RISK	SYSTEM TEST PROVIDES DATA	REMAINING RISK AFTER 20 SECOND FRF
"Wrong" Component Verification	Very High	Very High	High	High	Yes	Low
Instrumentation Failure	Moderate	Moderate	Very High	Very High	Yes	Minor
Hazardous Fluid Leakage	High	High	Very High	Very High	Yes	Moderate
POGO Failure	Moderate	High	Minor	Minor	Can	Moderate
Thrust Vector Control Failure	Low	Low	Low	Minor	No	Minor
Propellant Loading Procedures/Operations	No	No	Very High	High	Yes	No benefit
Clustered Engine Performance	Minor	Minor	Minor	Minor	Yes	Minor
Performance Margin Uncertainty	Minor	High	No	No	Yes	Moderate
Stored Gas Mass, Loading, Operations	Minor	Minor	Minor	Moderate	Yes	Minor

SIMULATION CAPABILITY ASSESSMENT
(NO PROPULSION SYSTEM TEST)

EVALUATION CRITERIA	VEHICLE FLIGHT CATASTROPHE RISK	MISSION LOSS RISK	LAUNCH DELAY RISK	LAUNCH COMPLEX RISK	SYSTEM TEST PROVIDES DATA	REMAINING RISK AFTER 20 SECOND FRF
Pressurization System Performance	Moderate	High	Minor	Minor	*Yes	Moderate
Propellant Mass Uncertainty	Minor	Moderate	Very High	Minor	Yes	Low
Low Level Cutoff Sensor	Minor	Minor	Moderate	No	Yes	No benefit
Engine/Feed Systems Chill	Minor	Minor	High	Minor	*Yes	Minor
Tank Insulation	Minor	Minor	High	Minor	*Yes	Minor
Hardware Thermal Control	Minor	Minor	High	Moderate	*Yes	Minor

* Mission Dependent

SIMULATION CAPABILITY ASSESSMENT SUMMARY
(NO PROPULSION SYSTEM TEST)

	RISK CATEGORY				
RISK, DEGREE	VEHICLE FLIGHT CATASTROPHE RISK	MISSION LOSS RISK	LAUNCH COMPLEX RISK	LAUNCH DELAY RISK	REMAINING RISK AFTER 20 SEC
VERY HIGH	1	1	0	4	0
HIGH	1	4	2	4	0
MODERATE	3	2	2	1	4
LOW $\overline{<}$	10	8	11	6	11

Remaining risk after 20 sec, moderate (4):
- HAZARDOUS FLUID LEAKAGE
- POGO
- PRESSURIZATION SYSTEM PERFORMANCE
- PERFORMANCE MODEL UNCERTAINTY

ADVANCED VEHICLE SIMULATION CAPABILITY ASSESSMENT

(NO PROPULSION SYSTEM TEST)

EVALUATION CRITERIA	SHUTTLE: FLIGHT CATASTROPHIC/ LAUNCH DELAY RISK	ADVANCED VEHICLE WITH SMALLER VOLUME, COMMON BULKHEAD: ALTITUDE START RISK	ADVANCED VEHICLE WITH SMALLER VOLUME, COMMON BULKHEAD: ORBITAL START RISK
Pressurization Systems Performance	Moderate/ Minor	Much Higher/ Same	Significantly Higher/Higher
Propellant Mass Uncertainty	Minor/ Extremely High	Higher/Same	Much Higher/Same
Engine/Feed System Chill	Minor/High	Higher/Same	Significantly Higher/Higher
Tank Insulation	Minor/High	Higher/Same	Much Higher/Same
Hardware Thermal Control	Minor/High	Higher/Same	Significantly Higher/Higher

Note: Risk relative to shuttle.

SIMULATION ASSESSMENT

CONCLUSIONS

- SIMULATION WITHOUT PROPULSION SYSTEM TESTING RESULTS IN A HIGH RISK PROGRAM.
- WITHOUT PROPULSION SYSTEM TESTING:
  - FLIGHT CATASTROPHE/LAUNCH DELAY AND OTHER RISKS ARE UNACCEPTABLY HIGH.
  - 20 SECOND FRF REDUCES RISK.
  - ORBITAL/ALTITUDE ENGINE START REQUIREMENT INCREASES RISK SIGNIFICANTLY RELATIVE TO SHUTTLE TYPE PROPULSION SYSTEM.
- THE COMPLEXITY OF INTERACTIVE CHARACTERISTICS OF VARIOUS SUBSYSTEMS DEFIES ACCURATE SIMULATION. SYSTEM TESTING PROVIDES FOR MODEL BASING AND ENHANCES SIMULATION.

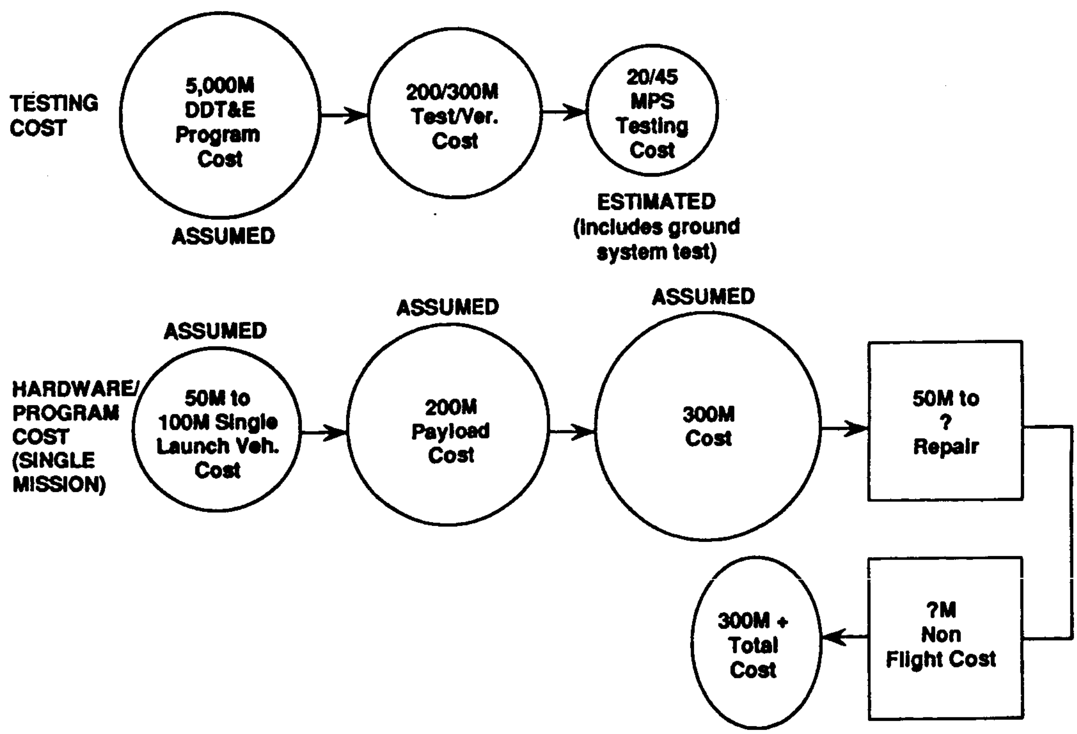
EMPIRICAL COSTING RELATIONSHIPS

RELATIONSHIPS		SOURCE
AVERAGE TEST/VERIFICATION COST / NON RECURRING DDT and E Cost (ALL DISCIPLINES)	→ Approximately 4.9 Percent	(4.2%) Gemini S-II Apollo CSM (5.2%) STS Orbiter
MPS TEST COST / MPS DDT and E Cost	→ Approximately 8.3 Percent	STS Orbiter Excluding SSMEs
MPS TEST COST / Average Test and Verification Cost (All Disciplines)	→ ~10 to 15 Percent	Deduction

NOTE: Excludes Government Furnished

- Facilities
- Equipment
- Other

ECONOMICS OF TESTING



CONCLUSION: ONE VEHICLE LOSS PREVENTED BY MPS TESTING IS COST EFFECTIVE.

SYSTEMS TESTS IDENTIFIED EVENTS

STAGE	CATASTROPHE		UNWORKABLE		** TOTAL PER STAGE
	FLIGHT	PREFLIGHT	FLIGHT	PREFLIGHT	
SHUTTLE	3	3	5	17	40
S-1C	4	0	3	3	13
S-II	2	0	8	8	21
S-IVB	8	0	6	3	20
S-I/IB	5	1	4	2	15
S-IV*	2	0	3	1	6

* Incomplete

** Includes Categories not included

EXAMPLE

SHUTTLE

SSME NOZZLE STERN HORN RUPTURE - H_2 DUMPED.
MARGINAL STABILITY CHARACTERISTICS - ET/ORBITER 17" O_2 DISCONNECT.

SAT V

F-I ENGINE TO STAGE BOLTS STRUCTURAL FAILURES
S-II ENGINE THRUST CHAMBER CHILL FAULTY - ENGINE STALL POTENTIAL

MPTA Hardware Replacement and Repair

MPTA Test Number	Pumps	Major Valves	EIU/MDMS	Other	LH2 Recirculation System, Pressurization System	Valves	Sensors	LH2 Diffuser, Feed Line Screens, Other
	← ENGINE			→	← VEHICLE			→
1-002				1	4	5	4	1
2							1	2
3				1		1	1	2
4							1	1
5-A	12	9		1			4	3
5			1		4	2	4	
6-01		9	1	1			2	
6-02/3	1	7		2	3		5	1
6-04			1	5			4	
7-01		1						
7-02		2			2		4	
8		2			5	1		
9-01	1						4	
9-02	4		1		1	1	2	
10		4	10	3	1		2	
11-01	2	7			4	6	2	
11-02				3	6	4		
12				3		1		
Total	**20**	**41**	**15**	**20**	**30**	**21**	**40**	**10**

Note: Hardware changes made prior to designated test number

Rockwell International

MPTA TESTING EVALUATION

ATTEMPTED FIRINGS/ABORTS	INERTING PURGE USAGE	FIRE WATER USAGE (EXTERNAL)	ABORT SOURCE
21/9	5K System - 12 30K System - 3	6	Vehicle 2 Engine 8

MPTA TESTING EVALUATION

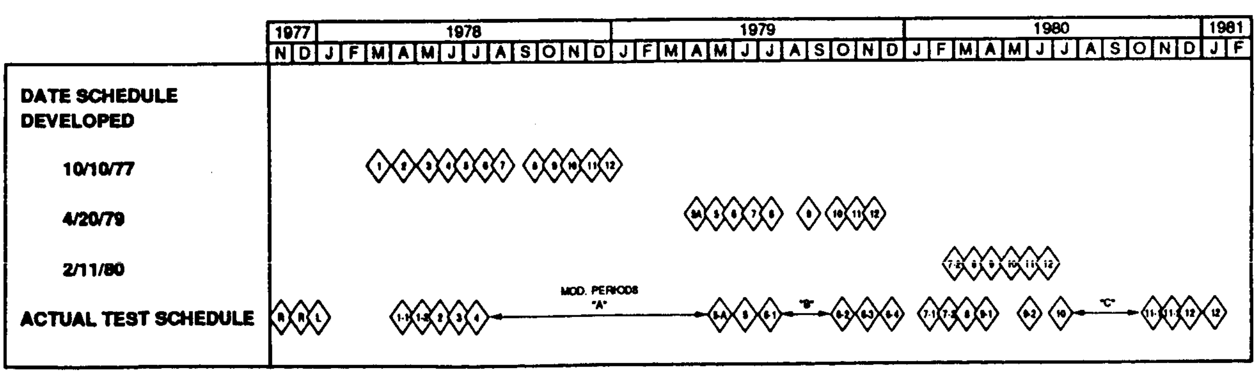
CONTINUED

ABORT CAUSE			
FAULTY INSTRUMENTATION	ENGINE REDLINE VIOLATION	ENGINE HARDWARE FAILURE	EXTENDED PROGRAM DELAYS
3	3	3	2

SATURN V, IB, I TESTING EVALUATION

DEVELOPMENT STAGES					FLIGHT STAGES	
VEHICLE	TEST NUMBER	ABORTS	TEST INADVERTENTLY "CUT"	TEST STAGE DESTROYED	ACCEPTANCE TESTED	DESTROYED IN TEST
SIC "ALL SYSTEMS"	15	5	3		15	1
S-11 BATTLESHIP ALL SYSTEMS	54 9	29 6	1	1	15	
SIV B	21	-	-	1	27	1
SI/IB	23	6			22	

MPTA TEST SCHEDULE



NOTE: R/L - RESONANT/LOADING TESTS

CONCLUSIONS

- PROPULSION SYSTEM TESTING IDENTIFIED MANY ISSUES HAVING THE POTENTIAL FOR THE FOLLOWING CONSEQUENCES:
  - CATASTROPHE; BOTH FLIGHT AND PREFLIGHT
  - MISSION LOSS
  - SIGNIFICANT LAUNCH DELAY
  - SIGNIFICANT LAUNCH COMPLEX DAMAGE
- SHUTTLE PROPULSION SYSTEM TESTING WAS REDUCED VS. SATURN AND CAN BE FURTHER REDUCED FOR SIMILAR FUTURE PROGRAMS.
- ELAPSED TIME SPAN FOR MPTA TESTING WAS EXCESSIVE AND CAN BE REDUCED.

PROPULSION SPECIALIST "SURVEY"

REQUEST: SUMMARIZE YOUR OPINION OF THE ROLE OF "ALL-UP" SYSTEMS TESTING IN VERIFICATION OF A NEW PROPULSION SYSTEM PRIOR TO FIRST LAUNCH.

REQUEST RESPONDENTS: SIXTY SIX ROCKET/SPACE VEHICLE DESIGNERS AND MANAGERS.

RESULTS: OVERWHELMINGLY SUPPORT PROPULSION SYSTEM TESTING.

RESPONSE EXAMPLES: "WERE I SCHEDULED TO RIDE ON A NEW LAUNCH VEHICLE, SYSTEM TESTING WOULD BE A PRIMARY REQUIREMENT."

"IF ANY ITEM IS GOING TO FAIL, HAVE IT FAIL ON THE GROUND WHERE IT CAN BE DIAGNOSED AND FIXED BEFORE FLIGHT."

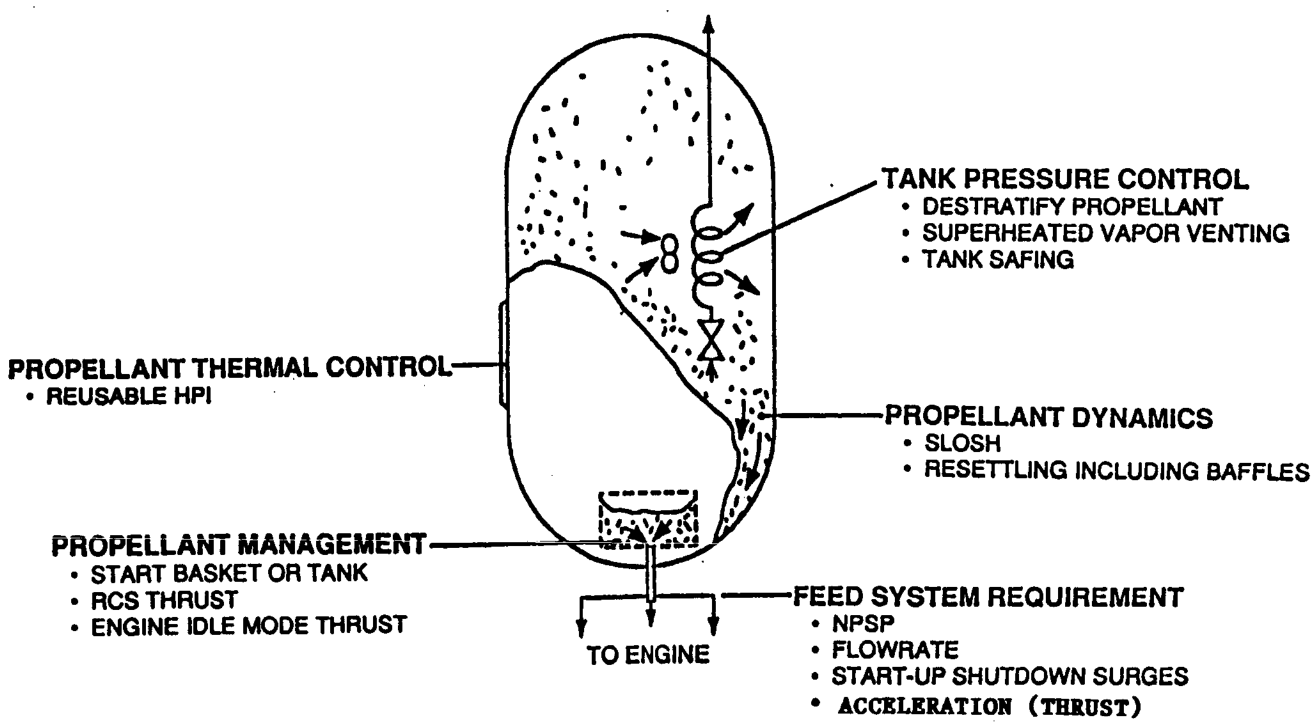
"SPECIAL" VEHICLE SIMULATION ISSUES

(PROPULSION RELATED)

VEHICLES IN THE SPACE ENVIRONMENT HAVE ADDITIONAL DESIGN/ OPERATIONAL REQUIREMENTS:

- PROPELLANT MANAGEMENT
- PROPELLANT THERMAL CONTROL
- TANK PRESSURE CONTROL
- PROPELLANT DYNAMICS
- PROPELLANT RESUPPLY

"SPECIAL" VEHICLE ISSUES



"SPECIAL" VEHICLE ISSUES

(PROPULSION RELATED)

SIMULATION ASSESSMENT:

FOR SOME ISSUES -

- NECESSARY TECHNOLOGY DOES NOT EXIST
- DEMONSTRATION OF TECHNOLOGY NECESSARY
- ORBITAL EXPERIMENTAL DATA NECESSARY
- DEVELOPMENT STAGE GROUND TEST POSSIBLE/DESIRABLE
- SPECIAL DEVELOPMENT GROUND FACILITIES REQUIRED

SUMMARY

- THE COMPLEXITY OF INTERACTIVE CHARACTERISTICS OF VARIOUS SUBSYSTEMS/DISCIPLINES DEFILES ACCURATE ANALYTICAL REPRESENTATION. SYSTEM TESTING PROVIDES DATA FOR MODEL BASING AND ENHANCES ANALYSIS.
- HISTORICALLY SYSTEM TESTING HAS PREVENTED CATASTROPHE AND MISSION LOSS FAILURES, LAUNCH DELAYS AND LAUNCH COMPLEX DAMAGE.
- PROPULSION SYSTEM TESTING IS COST EFFECTIVE IF ONE VEHICLE LOSS IS PREVENTED.
- ADVANCED/"SPECIAL" VEHICLES HAVE AN EQUAL/GREATER REQUIREMENT FOR PROPULSION SYSTEM TESTING.
- PROPULSION SYSTEM TESTING IS A SIGNIFICANT CONTRIBUTOR TO MISSION SUCCESS ASSURANCE.

N91-28262

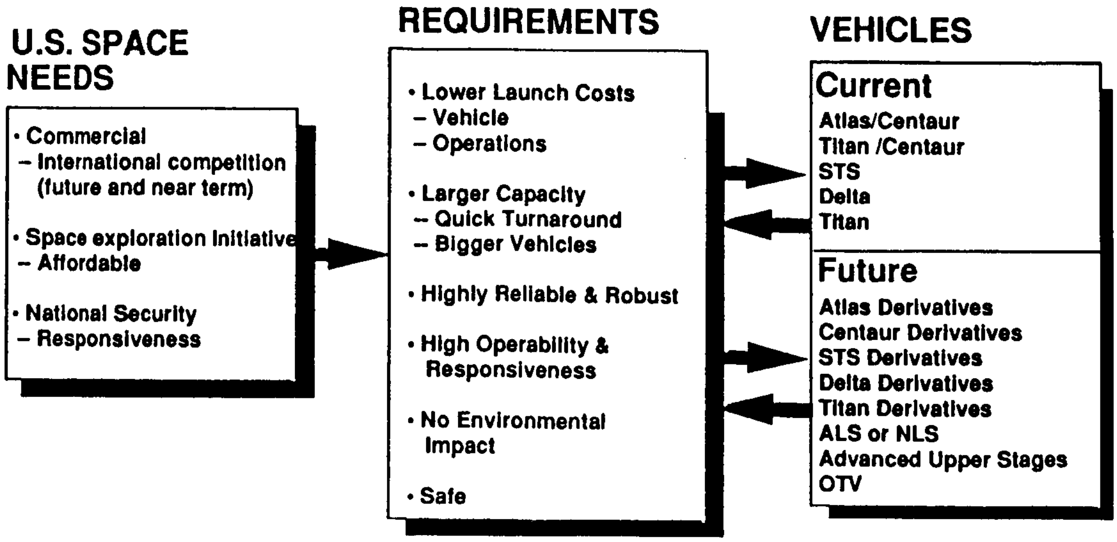
PRESENTATION 4.3.11

GENERAL DYNAMICS
Space Systems Division

PROPULSION TECHNOLOGIES
FOR NEAR TERM

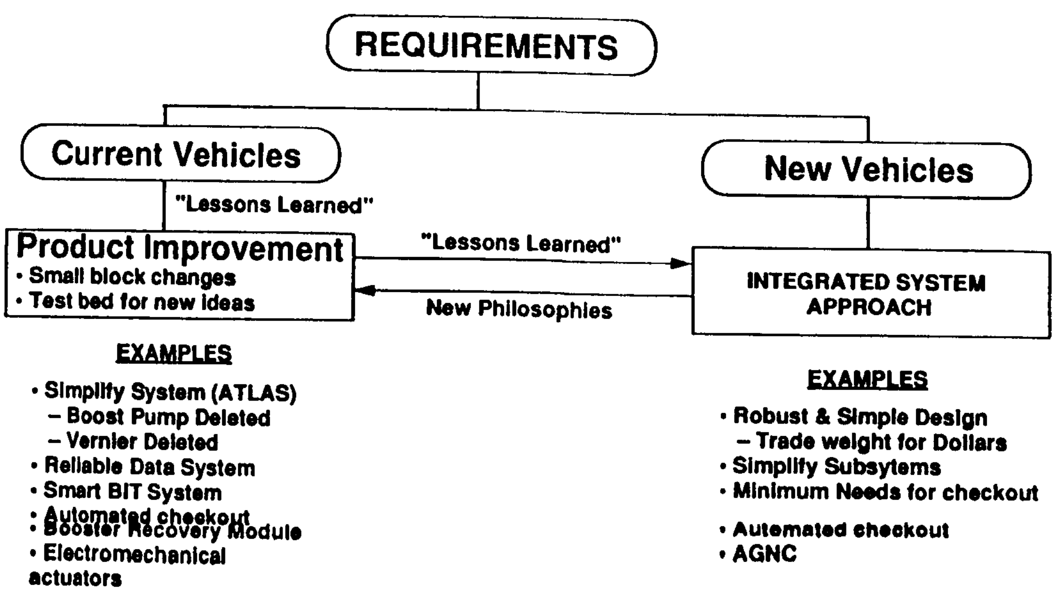
GOPAL MEHTA

PROPULSION SYSTEM REQUIREMENTS AND CONSIDERATIONS



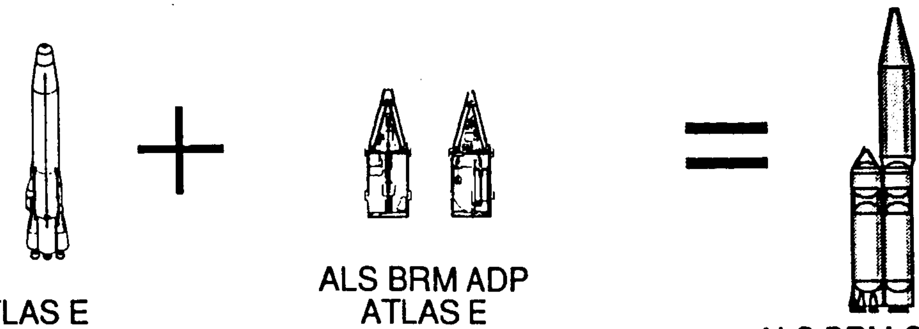
There Are Similar Requirements For Short Term And Long Term, Commercial And National Needs

COST EFFECTIVE APPROACH



Current Vehicles Are Prime Candidates For Development Of New Technologies Which Benefit Near TermCommercial As Well As Far Term National Needs

EXAMPLE: BOOSTER RECOVERY MODULE
Simple Recovery/Partial and Limited Reuse



ATLAS E
STAGE & HALF
VEHICLE

ALS BRM ADP
ATLAS E
THRUST SECTION
RECOVERY SYSTEM PODS

ALS BRM CONCEPT

- Atlas E Vehicle/Flight Demonstration
  - Vehicle Design Similar to ALS BRM
  - Near Identical Environments
  - Similar Type Recovery System
  - Similar Corrosion Prevention Operations
- ALS BRM ADP Objectives
  - Assess BRM Cost Feasibility
  - Define Engine Reuse Requirements
  - Define Engine Test Conditions
  - Evaluate Refurbishment Goals
  - Identify Reuse Operations/Facilities

The Atlas E flight experiment provides a technically sound, cost effective approach to simulate real-life conditions and provides a sanity check for the ALS BRM concept.

COMMERCIAL VEHICLES -- NEAR TERM NEEDS-- EVOLUTIONARY APPROACH

- **Use Current Vehicles To Demonstrate New Technologies & Upgrade To Make Them Competitive**

  EXAMPLES

  - **Electromechanical Actuation**
  - **Integrated Health Monitoring**
  - **Booster Recovery System**
  - **AGNC**
  - **Expert System**
  - **Smart BIT**
  - **Electromechanical Pressure Control**
  - **Critical Failure Detection**

- **Provide New Facilities To Test Uprated Systems**
- **Higher Thrust H2/O2 Engines For Boosters And Upper Stages**
- **Clean Burning Solid Motors**

Evolution of Current Vehicles Lowers Risk Of Flight Failures For New System

CONCLUSIONS

- Similar Basic And Applied Technology Needs Exist For Current And Future Vehicles

- More Emphasis Needed On Evolution Through Demonstration Of New Technologies On Existing Vehicles

  - Improves U.S. ELV Competitiveness
  - Provides Flight Experience And Reduces Risk Of Flight Failures For Future Vehicles

PROGRAM DEVELOPMANET AND

CULTURAL ISSUES

PANEL

N91-28263

PRESENTATION 4.4.1

LESSONS LEARNED AND THEIR APPLICATION TO PROGRAM DEVELOPMENT AND CULTURAL ISSUES

BY

GILBERT L. ROTH
STAFF DIRECTOR
AEROSPACE SAFETY ADVISORY PANEL
NASA HEADQUARTERS

SPACE TRANSPORTATION PROPULSION TECHNOLOGY SYMPOSIUM

PENNSYLVANIA STATE UNIVERSITY

JUNE 27, 1990

LESSONS LEARNED
AND THEIR APPLICATION TO
PROGRAM DEVELOPMENT AND CULTURAL ISSUES

"POINT ONE"

The knowledge we use today is contained in an untold number of technical and managerial handbooks. This knowledge is derived from the known strengths and weaknesses experienced during the execution of programs and projects that are being used today. Tomorrow's handbooks will define many additional lessons that designers, test operators, management, and operational personnel will apply on such programs as the National AeroSpace Plane (NASP), the Space Station Freedom (SSF), and future launch vehicles. Before placing specific lessons learned and cultural issues before you, I believe a few introductory remarks are appropriate so that we all start off from a common reference point. Let us begin with a few well-known and generally accepted concepts: (Not everyone will agree or be happy with these!)

- The greatest lesson we seem to learn is that we seldom learn from lessons learned! What this indicates is our inability to present them in an appropriate way or .....

- The "Over and Under 40 Syndrome." That is, if you are under 40, it is difficult to believe that those over 40 have been through what "YOU" are going through; whereas those over 40 find it difficult to believe that everyone else may not already know of their weaknesses and more importantly of their successes! Lessons learned are in effect the history, the evolution of technical, scientific, and managerial advancement.

- The genesis of a useful safety tool is often a tragedy. In the aftermath of the Apollo Command Module Spacecraft fire of January 1967, the Congress of the United States, along with NASA, took a number of steps to resolve the many issues raised by that accident. One such step was the creation of the Aerospace Safety Advisory Panel (ASAP) by Congress. The Panel is charged with reviewing and assessing all NASA programs and projects with an emphasis on safety, reliability, and quality assurance. An excellent explanation of this was given by Alan Lovelace Acting NASA Administrator in May 1978:

  "Where do the Panel's interests lie? A safety review usually tends to concentrate on the engineering design and quality control aspects of safety. While these are important factors, they do not represent the total necessary for safe and reliable programs. Just as important are the manufacturing practices, organizational structure, and human attitudes. Management approaches--and particularly management's ability to balance schedule, cost, design, development, and testing--often are the most important factors in the total success and safety of a program."

It is easy to see that the genesis of many of the design, test, operational, and management tools are derived from near-misses as well as tragedies.

"POINT TWO"

Although it may be somewhat difficult to separate program development and cultural issues, it is worthwhile to at least think of them separately in the beginning to understand their synergism in the end. First, let us consider cultural issues as they affect the thinking and actions of technical management and engineering.

Just as the American public was awed by the early flights made by the Wright Brothers in the first decade of the 20th century, they exhibited the same degree of amazement at the Russian's launching and orbiting the first Sputnik in October 1957. With the passage of time, the public takes for granted the continuation of these truly fantastic steps in the aerospace sciences and their implementation and application to our daily lives. Transmission of live real-time TV pictures are accepted; and if you ask one thousand viewers how it is accomplished, the answer is "I really am not sure, but it is there!" Airline transportation is accepted in the same way, and few people can remember taking a prop-driven plane from New York to Los Angeles or to London and all that it entailed. Now apply this to current and projected aerospace programs where the public expects...actually demands...that complex, beyond the state-of-the-art activities be conducted without mistakes, on-time at low cost, and provide useable and profitable spin-offs to earth-bound activities. What does this lead to?

- Horror when the Challenger accident occurred and a sweeping indictment against management and technical capability;
- How can we spend billions to put men and experiments in space when people are hungry and homeless here on earth?
- Additional oversight by outside agencies, including the Congress. What about Senator Gore's reasonable statement that "only through an annual authorization can Congress play a continuous oversight role effectively."
- The continuing argument over the appropriate mix of manned versus unmanned, reusable Shuttle versus Expendable Launch Vehicles, and government versus civilian space roles.

All of these affect the environment within which the current and future aeronautical and space ventures will have to operate. These affect resource availability to conduct every facet of the program and leads to another problem that has become a part of our lives.

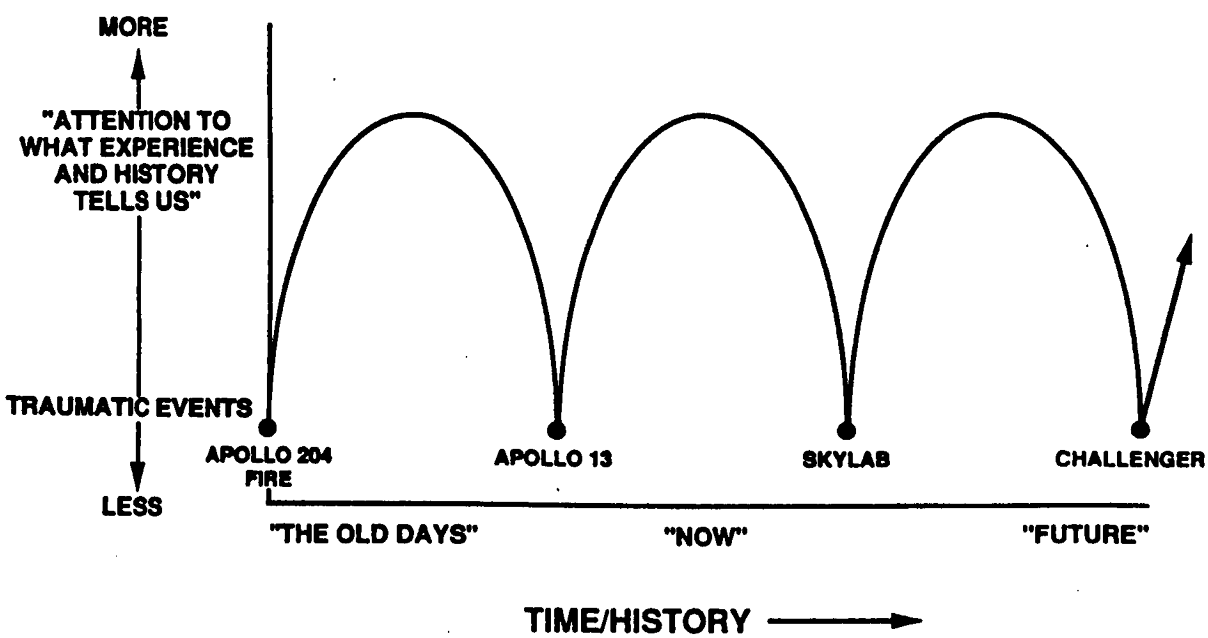
Environmental concerns are no longer taken lightly. The impact of propulsion system effluents are emerging as a major determinant in the selection of propellants. Solid rocket motors are now viewed with some apprehension because of the acids and chlorine derivatives that are discharged from launch point to stratospheric altitudes as well as the other particulates. Cleaner burning propellants and oxidizers are being developed, and the use of hybrid rockets as well as more extensive use of liquid rockets are in the offering. Even the burning of waste propellants is now a controlled activity. The use of hydrazines and other sophisticated but toxic propulsion systems require additional care and feeding. In the coming years, the "environmental movement" will be having an ever greater impact. The public's view of the world and man's affecting it is not confined to the United States, but is a world-wide concern.

In a totally different arena, look at the difference between the early spacecraft put into orbit by the United States and the USSR. The Apollo-Soyuz combined Russian-American missions conducted in the period July 15-24, 1975, showed some distinct differences:

- The androgynous USSR docking system versus the Apollo probe and drogue system;
- The use of solar panels rather than fuel cells;
- The use of 14.7-psia atmosphere versus 5-psia oxygen rich, and so on.

In effect, our spacecraft were somewhat more sophisticated and even, to a degree, chrome plated. Today, the Russian and American space vehicles are tending toward a more center-of-the-road in "chrome-plating." None-the-less, both of them do the job. In today's fiscal environment, any so-called excess in chrome-plating is not acceptable.

CULTURAL HISTORY SHOWS - - -



"POINT THREE"

Some typical lessons learned that deal with the four areas of interest:

- Requirements
- Technology/Performance/Operations
- Reliability/Safety
- Procurement/Contracting

are given here. They are, of course, only representative of so many others that each and everyone involved in aerospace design, development, test, and operations has perhaps experienced.

Requirements

Requirements come in many forms; for our purposes we will use a broad brush and look at technical specifications as well as technical management requirements at the start of a program. The reason? A lesson learned is: The future of a program is determined to a great extent by how it is started.

1. Initial system definition either was not accomplished by an orderly analysis process or effort, and was incomplete and inadequate. There were no continuing requirements to perform system analysis on selective basis during the acquisition phase. Critical evaluations should be made by the government and contractors in the early design stages concerning the specification requirements. They should be evaluated from both viewpoints--too tight, too loose. ("A Summary of Lessons Learned from Air Force Management Surveys," 1 June 1963).

2. Technical and management requirements must take into account the "Resource Conservation and Recovery Act" (RCRA was established in 1976 with amendments added in the 1980s). The development of advanced weapons systems and new aerospace technologies will be accompanied by new fuels, hybrid structural materials, and other unique chemicals as well as new processes, many of which have the potential for creating unacceptable health hazards. This continuous influx of new and exotic materials from the research, development, and acquisition pipeline brings attention to the first point in the process at which decisions need to be made to procure or not procure a specific material. (JANNAF Safety and Environmental Protection Subcommittee Workshop, 3 April 1989).

3. From a "Report to the Committee on Science and Technology, House of Representatives On Centaur Cost, Schedule and Performance Review," 1986:

The most significant reason for the problems experienced in the Centaur/Shuttle integration process was that, while we have two centers with considerable space flight experience, the prime center responsible for development of the Centaur had previously been involved in unmanned vehicle systems and now was responsible for providing complex vehicle systems that would fly within a manned vehicle. Significant philosophical differences exist between a manned and unmanned vehicle regarding safety requirements and issues. The level of fault tolerance, fault isolation and system design, including increased redundancy, are considerably greater for manned missions.

More critically, the planning and design requirements associated with the Shuttle off-nominal and abort modes were not properly assessed at the start of the program. Program requirements that should have been designed into the vehicle system to prevent loss of life or loss of an Orbiter were developed after the flight hardware design was well under way.

Lessons Learned included:

For future systems, the safety process must be understood and considered in the basic design effort of the specific flight hardware commensurate with the philosophy that exists for our manned flight programs. Responsibility of the prime hardware contractor for safety should also be emphasized. Some of the other lessons learned items mentioned in this report are also a significant contributor to the safety process problem, i.e., getting all organizations involved in the program design process very early so that their requirements can be incorporated in the most effective manner. More manpower and resources should be allotted to complex, first-time payloads, posing unique safety hazards to the NSTS and crew early enough to support major program milestones such as a critical design review and phase II safety review.

Technology/Performance/Operations

Although propulsion systems and their components are but one of a number of independent yet integrated, members of a complete aerospace flight vehicle, propulsion systems are more often the focus of concern because:

- They are active,
- They have potential for fire, detonation, toxicity, and corrosion;
- They are often life limited and temperature sensitive; and
- They provide and are a major contributor to ascent capability, attitude control, and trajectory modification.

Typical propulsion interests are centered upon such items as:

- Solid Rockets - Propellant integrity, ignitor reliability, nozzle durability, safe handling, reuse, safe/arm systems, case insulation, ballistics.
- Liquid Rockets - Turbomachinery design and certification, red-lines for test and flight, leakage, sensors, reuse, engine controllers.
- Hybrids - all of the above

- Auxiliary Power Units - Reliability, maintainability, speed control, heat dissipation, restart, leakage.

Typical lessons learned are as follows:

1. A simple design change that lost an engine

Figure 1 shows a "straight forward" design change made to the SSME High Pressure Fuel Turbopump that was the cause of SSME Engine #2013 to fail and caused the loss of the engine. This occurred April 7, 1982. It is only a small part of the whole pump assembly, but the change to the "Kaiser Hat" nut assembly configuration was pinpointed as the cause of the failure.

2. Figure 2 shows the culprit in the April 1980, spacesuit backpack fire. Ignition took place in a V-shaped passage that served to restrict the flow of oxygen between a shut-off valve and a chamber in the backpack's high pressure regulator module. The failure resulted in autoignition of the metal at the end of the drilled passage due to compression and/or shock heating of the high pressure gaseous oxygen.

3. Figure 3 indicates the erosion concerns on the solid rocket motor composite nozzle in the early days of Shuttle missions. The degree of char or erosion was ascertained to be greatly dependent upon composite ply angle, nozzle manufacturing process temperature-time-pressure parameters, material controls for volatiles, and ash. The current nozzle has predictable final characteristics and is performing as specified.

4. To meet the needs of designers, the NASA Chief Engineer's office initiated a series of "Experienced Bulletins" providing design and operational lessons learned. An example of this, shown in Figure 4, deals with a rocket motor case problem occurring on a scout launch vehicle.

5. The point of view that the SEASAT spacecraft Agena "bus" (launched in 1978) used flight proven equipment that was also standard on other spacecraft and did not need tender loving care had far reaching consequences. The SEASAT Failure Review Board noted: "It became program policy to minimize testing and documentation, to qualify components by similarity wherever possible, and to minimize the penetration into the Agena spacecraft or "bus" by the government. It led to a concentration by project management on the sensors (experiments), sensor integration, and the data management system to the near exclusion of the "bus" subsystems. Important component failures were not reported to project management, a test was waived without proper approval, and compliance with specifications was weak." The component that failed--the slip ring assembly--was never mentioned in the briefing charts. The power subsystem design had the adjacent brush assemblies of opposite electrical polarity. This wiring arrangement, together with the congested nature of the design itself, made the slip ring assembly actually unique and very prone to shorting--which it did.

6. Just a very brief word on ground facilities. The KSC "uninterruptable power supply" system has been interrupted several times during the past 10 years. There would appear to be some difference between system names and system performance.

Reliability/Safety

In a memo from the astronaut senior member discussing the proper perspective to put on corrections to eliminate or reduce possible failure modes we have this:

> "...for every failure mode someone can envision, someone else must provide a solution. These solutions come in the form of hardware and software changes, complication of ground and flight procedures, new or modified facilities, manufacturing and inspection requirements. The proven costs of such solutions are money, schedule delays, and additional unknowns. I believe that many of our solutions to problems create more serious problems through added complication, dilution of effort, and increased time compression on already over-stressed work loads. There is an infinite supply of possible failures to support these hypotheses, as evidenced by continual and sometimes increasing hardware and software change board traffic. Unless management and program personnel develop a sense of proportion, we will forever be trying to chase things to the last decimal point, frittering away limited resources on insignificant issues."

It is for this reason that the Aerospace Safety Advisory Panel is strongly supportive of the framework for risk assessment described in NASA's Management Instruction NMI 8070.4, "Risk Management Policy for Manned Flight Programs." I might add that much of this NMI would certainly apply to unmanned space flight programs and certain aeronautical R&D programs as well. The qualitative prioritization of mishaps, which are only identified by Fault Tree Analysis (FTAs) and Event Tree Analysis (ETAs), is a good first step in focusing on what could possibly be the most significant possible risks. However, where the risk level may be significant, a more quantitative risk assessment methodology may be required such as that used to determine the possibility and severity of failures during missions using nuclear power devices such as RTGs (radioisotope thermoelectric generators/Galileo and Ulysses missions). This has many other names such as Probabilistic Risk Assessment (PRA) and others. If used judiciously it can show relative values of risks (not absolute) and support effective use of program and project resources.

Some other points that can be made include the following:

1. There is obviously a close tie between requirements and safety/reliability. The safety process, including system safety, must be a part of the original program requirements so that the old saw of "Reliability should be designed into the hardware and software, not tried to be inspected into it." This also applies to safety and, to some degree, the quality control aspects of design and manufacturing. To use a current term that is receiving a great deal of attention, this means Total Quality Management (TQM), or any of another half-dozen terms meaning the same thing.

2. There is danger in placing undue reliance upon an elaborate structure of review and oversight groups in that it can become a justification for sometimes not doing the job correctly in the first place. This stems from the "Not To Worry" attitude in which the manager and the engineers say to themselves: "The reliability and quality assurance guys down the line will catch any problems, so why worry!"

3. Although this is placed under safety and reliability, it really applies across the board to everyone connected with an aerospace program...engineers, technicians, middle and higher management. The following conversation might have occurred in any company or at any government agency:

Engineer: "Why don't I get any respect from my managers?"

Supervisor: "Partly because of the way you dress. They often rely solely on shallow, initial first impressions! It's true! Most managers and executives rarely take the effort to delve beneath surface features."

Engineer: "But that's absurd. It is like saying they read reports just by glancing at the title page!"

Supervisor: "Hey, I've got some bad news about that as well....."

4. Safety also encompasses communications and the fostering of interplay between various groups and individuals working on a program. Noncommunications can certainly result in failures. The Skylab launched on May 14, 1973, had suffered a complete loss of the meteoroid shield around the orbital workshop. This was followed by the loss of one of the two solar array systems on the workshop and a failure of the interstage adapter to separate from the S-II stage of the Saturn V vehicle. The investigation identified the most probable cause of this flight anomaly to be the breakup and loss of the meteoroid shield due to aerodynamic loads that were not accounted for in its design. The Skylab report noted: The venting analysis for the auxiliary tunnel was predicated on a completely sealed aft end; the openings in the tunnel thus resulted from a failure of communications among aerodynamics, structural design, and manufacturing personnel. The failure to recognize the design deficiencies of the meteoroid shield through six years of analysis, design, and test was due, in part, to a presumption that the shield would be "tight to the tank" and "structurally integral with the S-IVB tank" as set forth in the design criteria. In practice, the meteoroid shield, as a large, flexible, limp system that proved difficult to rig to the tank and to obtain the close fit that was presumed by the design. These design deficiencies of the meteoroid shield as well as the failure to communicate within the project the critical nature of its proper venting, must therefore be attributed to an absence of sound engineering judgement and alert engineering leadership concerning this particular system over a considerable period of time."

Procurement/Contracting

In its 1963 report, the Air Force singled out the following as Program and Contract Functions that needed attention:

1. Decentralized Program Management Lacked Essential Controls

In contractor organizations that were structured according to functional line department conventions, top management did not take action to ensure that internal policies, procedures, authority, and responsibilities were clearly defined for integrated program control. To alleviate the concerns, it was recommended that clear-cut management interfaces be established between the government and their contractors with well-defined reporting procedures.

2. Late Definitization of Letter Contracts

Delays in definitizing letter contracts result in creation of work forces without positive direction, handicap progress evaluation, stimulation of continued program redirection, and expenditure of funds on tasks that do not contribute fully to the achievement of program objectives. Two points were made here: (1) program definition activities should keep two or more competitors active until definitive contract is singed with one; and (2) emphasize alternatives to letter contracts and definization milestones when letter contracts are unavoidable.

3. Make-Or-Buy Policies Not Enforced

Make-or-buy decisions were not made or evaluated in accordance with government policy or intent, thereby permitting poor utilization of industrial resources, contributing to late deliveries, poor performance, and increased costs. The action recommended was to have more fixed-price and incentive contracts that obviate government concern with contractor's make-or-buy decisions (unless use of a government-owned facility is involved).

In NASA's report to Congress on Centaur cost, schedule, and performance the following was stated regarding a "Procurement System:"

1. NASA has established a unique system for Headquarters review of selected major procurements above specified dollar thresholds. This "Master Buy Plan System" provides visibility into major procurements and allows Headquarters' review of key procurement documents to endure the quality of individual procurements as well as to identify trends that may require adjustments to the procurement system.

2. Regular and special procurement management surveys determine compliance with applicable policies et al. Included is a system for regular follow-up to ensure timely accomplishment of the recommendations included in the survey reports.

3. NASA has in place a procurement data system that provides integrated statistical reporting and trend analysis to manage effectively the NASA procurement system.

4. NASA has a procurement career development program that develops and monitors the training and skills of the procurement work force.

There are many others, but this appears as a typical list.

"SUMMARY"

This is obviously a brief, very brief, look into the lessons learned world. The purpose was to stir up your thinking, not with regard to the specific items noted here, but how to implement those lessons you have learned and will be learning to the next generation of aerospace programs. As we all know, what good is an education if we don't put it to some constructive use, and that applies to lessons learned.

FIGURE 1

HPFTP THERMAL SHIELD NUT

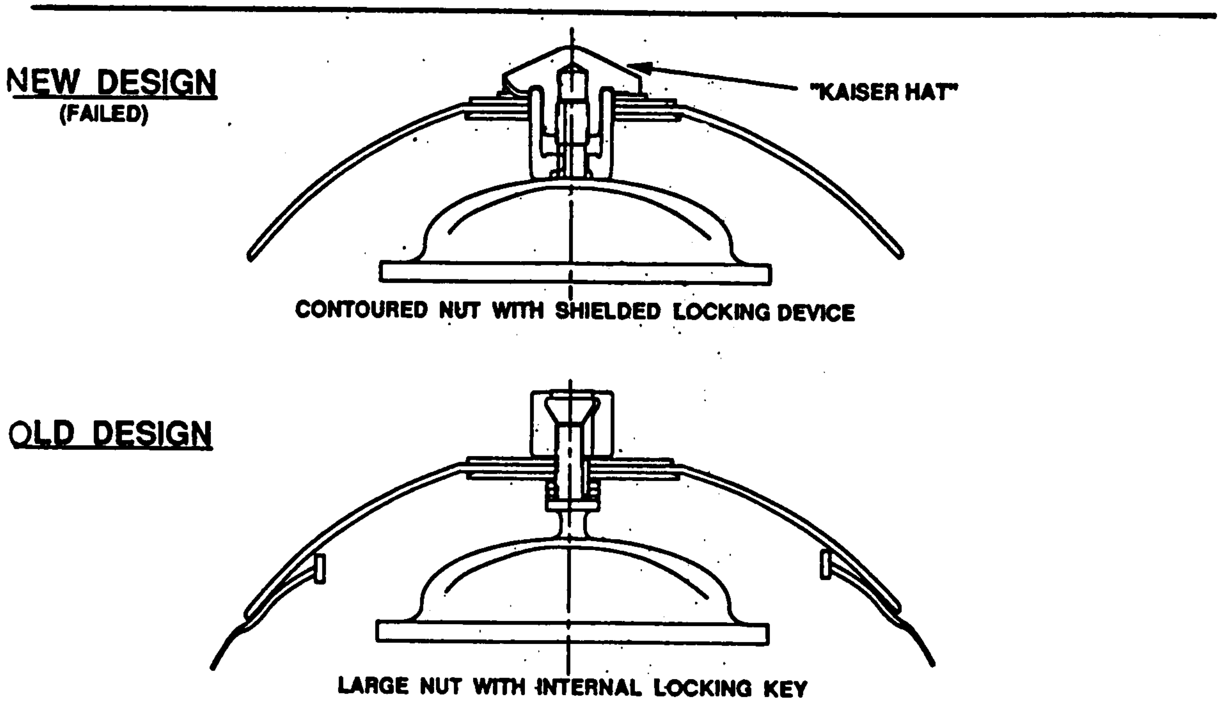


FIGURE 2A

NOMINAL INTERSECTION

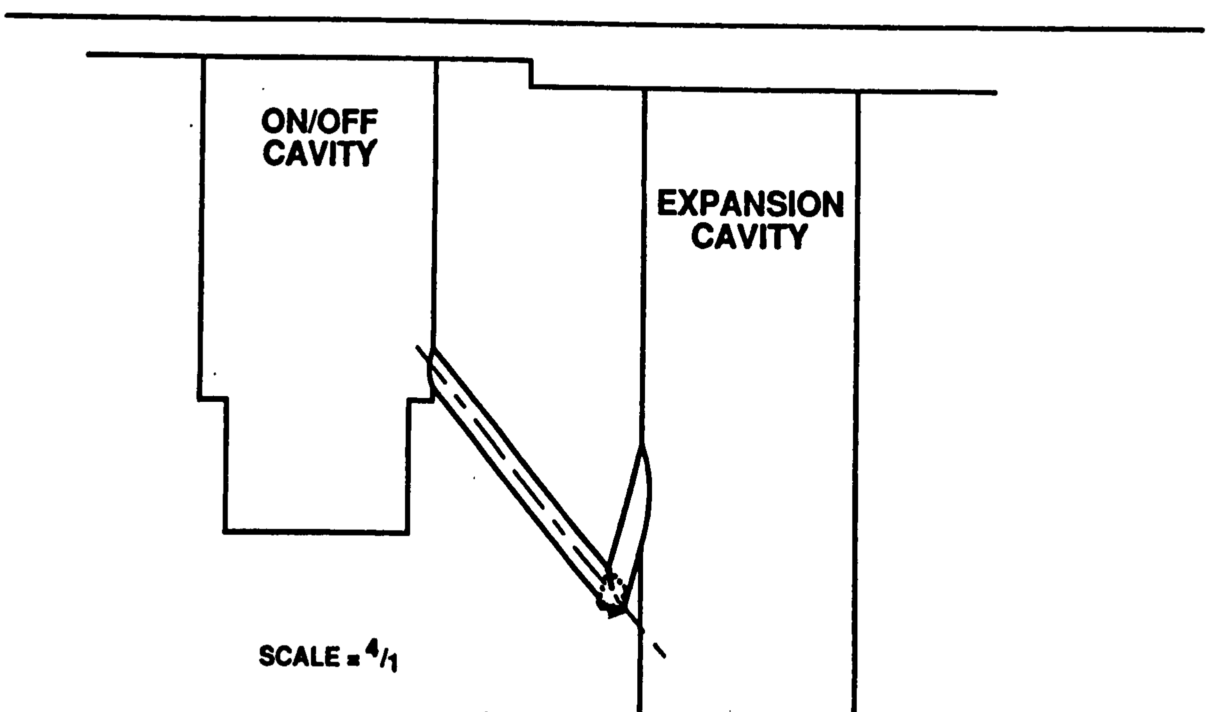


FIGURE 2B

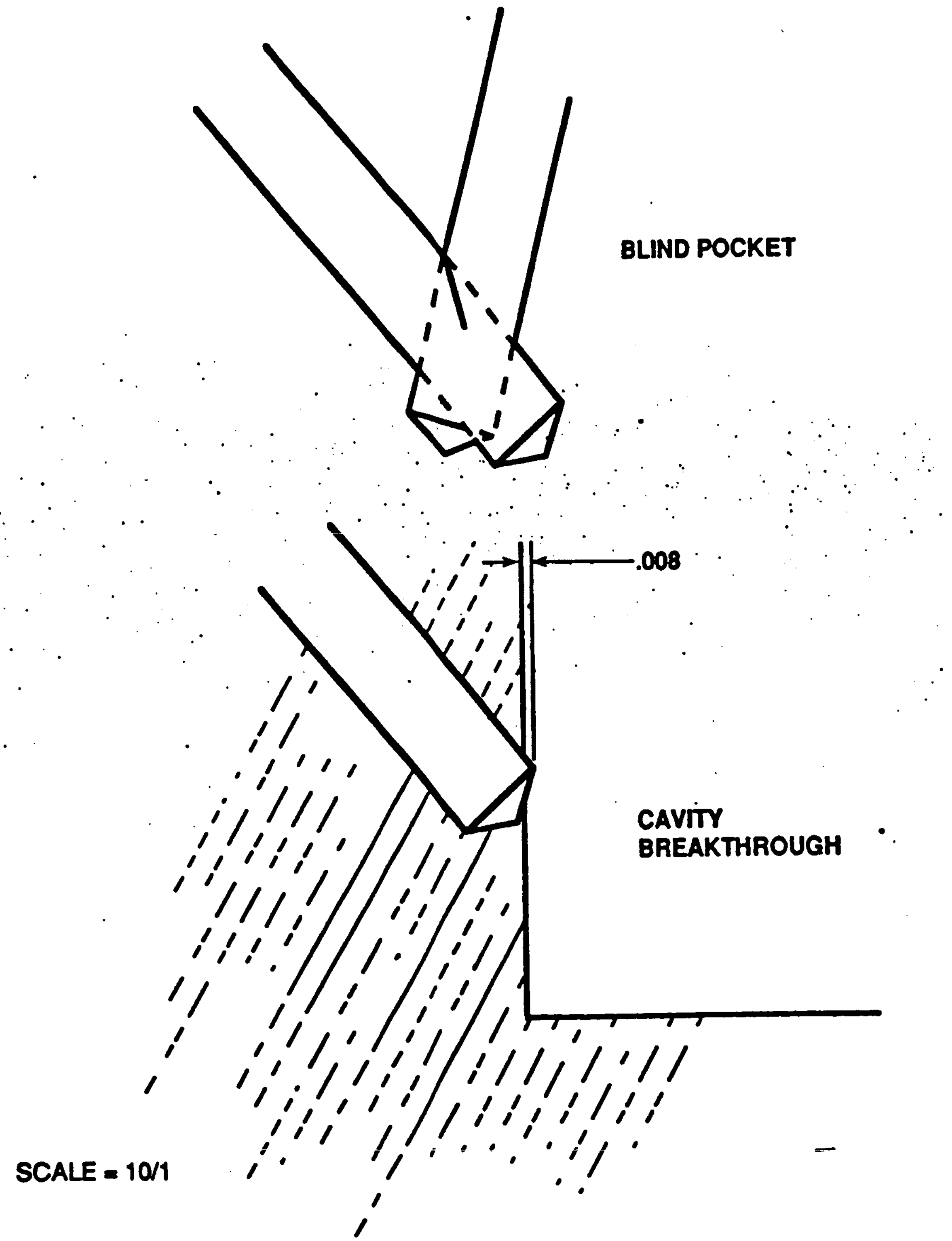


FIGURE 3A

NOZZLE ASSEMBLY

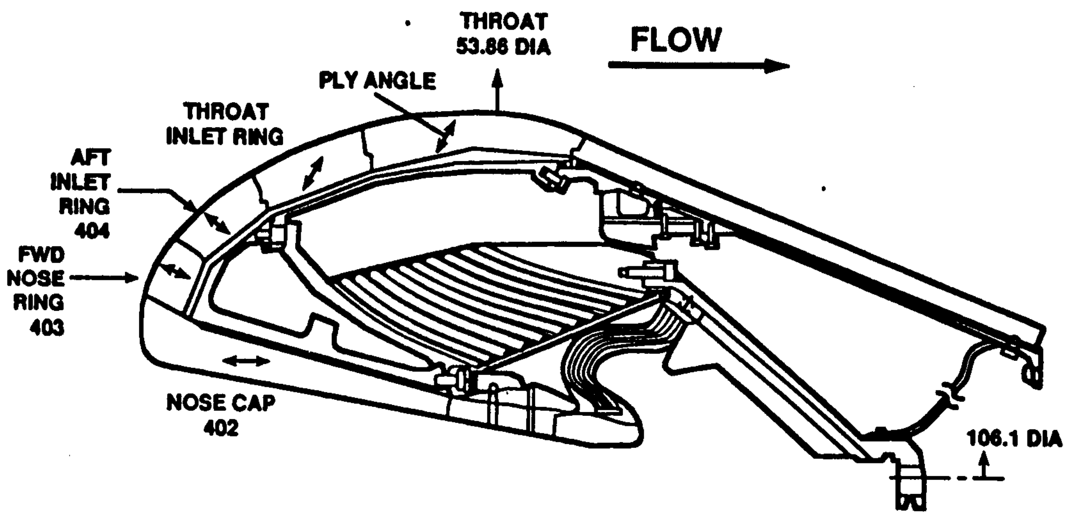


FIGURE 3B

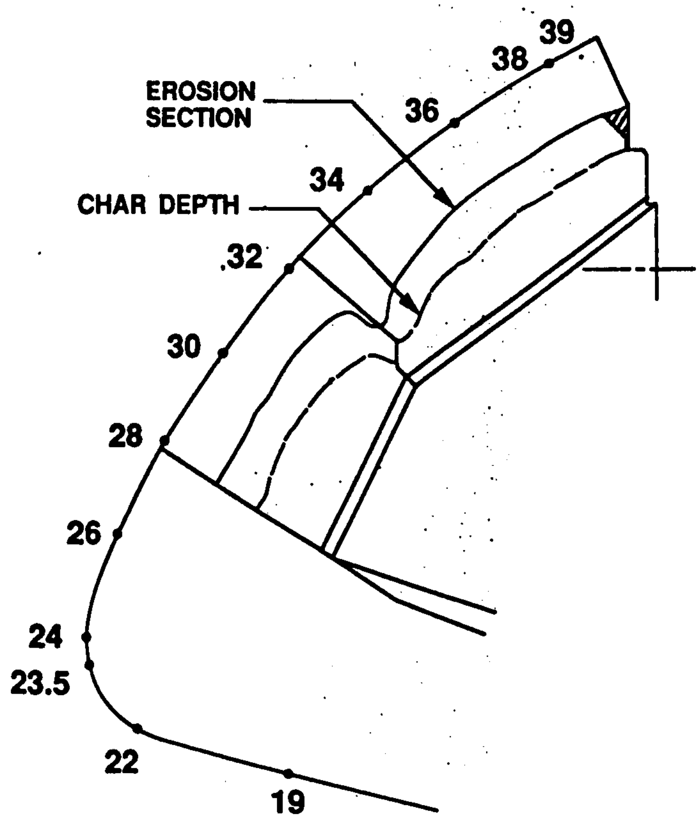
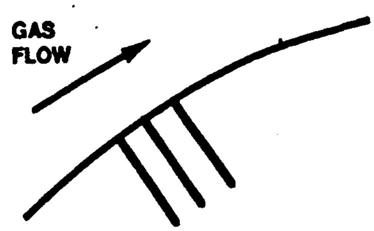


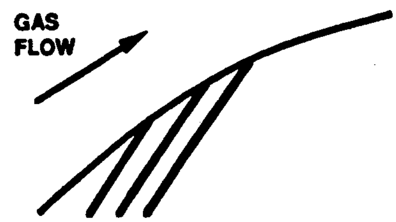
FIGURE 3C

PLY ANGLE EFFECTS



PLY PERPENDICULAR
TO NOZZLE WALL

- CONDUCTION DOWN CARBON FIBERS GETS HEAT IN DEPTH MORE QUICKLY
- THERMAL EXPANSION RETARDS OPENING BETWEEN PLIES



PLY AT ANGLE
TO NOZZLE WALL

- CARBON FIBERS REQUIRE CONDUCTING HEAT ALONG LONGER LENGTH TO REACH IN-DEPTH REGIONS
- PLIES CAN OPEN IF HIGH PRESSURES ARE GENERATED IN DEPTH

FIGURE 4

NASA
National Aeronautics and Space Administration

OFFICE OF THE CHIEF ENGINEER

Experience Bulletin No. 42 JUNE 1, 1982

ROCKET MOTOR CASE PROBLEM

INCIDENT

A Kevlar Motor Case, used on the Scout launch vehicle, was delivered to the contractor's machine shop to have aluminum skirt rings installed on the case. When a machinist attempted to remove the forward drill jig, it fell off causing the motor case to drop approximately 5 inches. The unit subsequently failed proof testing.

PROBABLE CAUSES AND CONTRIBUTING FACTORS

Visual and radiographic evaluation of the case for drop impact damage did not reveal any evidence that the structural integrity of the case had been compromised. It was decided to conditionally accept the case pending the results of hydroproof testing using strain gages and deflectometers. The results of the hydrotest were more startling than expected. Not only did the case catastrophically fail at 5% over the mean effective operating pressure of 1000 psi, but it showed positive signs of failure beginning to occur at 100 psi.

Post test visual inspection and strain gag data indicated that failure originated in one of the two drop-impact areas on the aft dome. Visual examination revealed two crack-like indications on the aft dome and evidence of interlaminar separations emanating from the ends of the crack-like indications. A 10X visual examination showed the indications to be ridges of Kevlar fibers rather than cracks, and there were no broken fibers. It is postulated that compressive loads induced in the outer layers of Kevlar by the deflection of the aft dome caused local buckling and resin crazing in the area of maximum deflection.

LESSONS TO BE LEARNED

Kevlar rocket motor cases may fail catastrophically well below anticipated operating pressures after apparent superficial damage is sustained. This finding was corroborated by other similar "drop" incidents. Two kinds of damage can occur from rough handling: (1) the case can sustain broken fibers; and/or, (2) there can be interlaminar shear failure between Kevlar winding layers. Interlaminar failures/defects are more critical in the domes than in cylindrical sections of the case. It is imperative that operating crews be warned to exercise extreme caution in handling Kevlar motor cases in order to prevent catastrophic failures due to drop damage. If Kevlar cases are damaged, even if only superficially, it is recommended that they be re-proof tested prior to use.

N91-28264

PRESENTATION 4.4.2

SPACE SHUTTLE REQUIREMENTS / CONFIGURATION EVOLUTION

E. P. Andrews
Lockheed Space Operations Company

June 27, 1990

SPACE SHUTTLE

REPEATED VOYAGES INTO SPACE, RETURN AND REUSE

SPACE SHUTTLE

- **1940's, 1950's, EARLY 1960's: TECHNOLOGY NOT AVAILABLE**
  - EMPHASIS ON CONVENTIONAL ROCKETRY
  - EXCEPTIONS: DYNASOAR & FRONT END STEERING

- **MID 1960's: NO WAY TO DESIGN A COMBINED, SINGLE STAGE AIRCRAFT/SPACECRAFT**

  PROBLEMS: WEIGHT
PROPULSION
THERMAL PROTECTION

- **TWO VEHICLES REQUIRED**
  1) REUSABLE CARGO/PEOPLE CARRIER
  2) BOOSTER (REUSABLE OR EXPENDABLE)

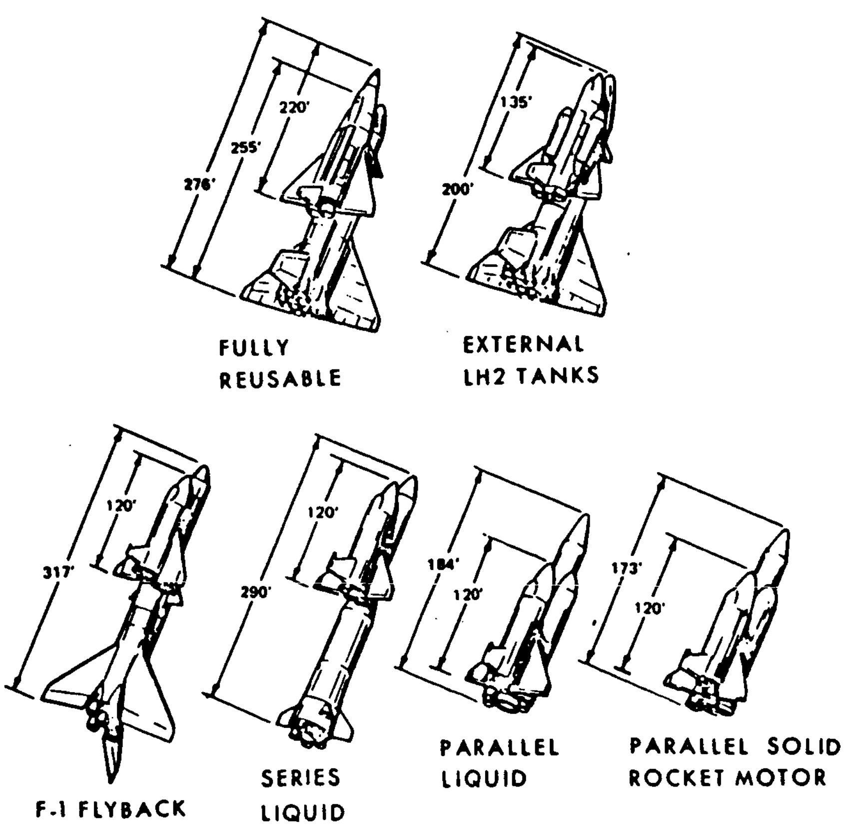
- **DECISION TO PROCEED AND DESIGN ASSISTED BY AEROSPACE TECHNOLOGY ADVANCES**
  - X-15
  - LIFTING BODIES
  - MERCURY, GEMINI, APOLLO
  - SUPERSONIC MILITARY & AIR TRANSPORT AIRCRAFT

- **FALL 1969: REUSABLE SPACE TRANSPORTATION SYSTEM**
  - TECHNICALLY FEASIBLE
  - ECONOMICALLY JUSTIFIED

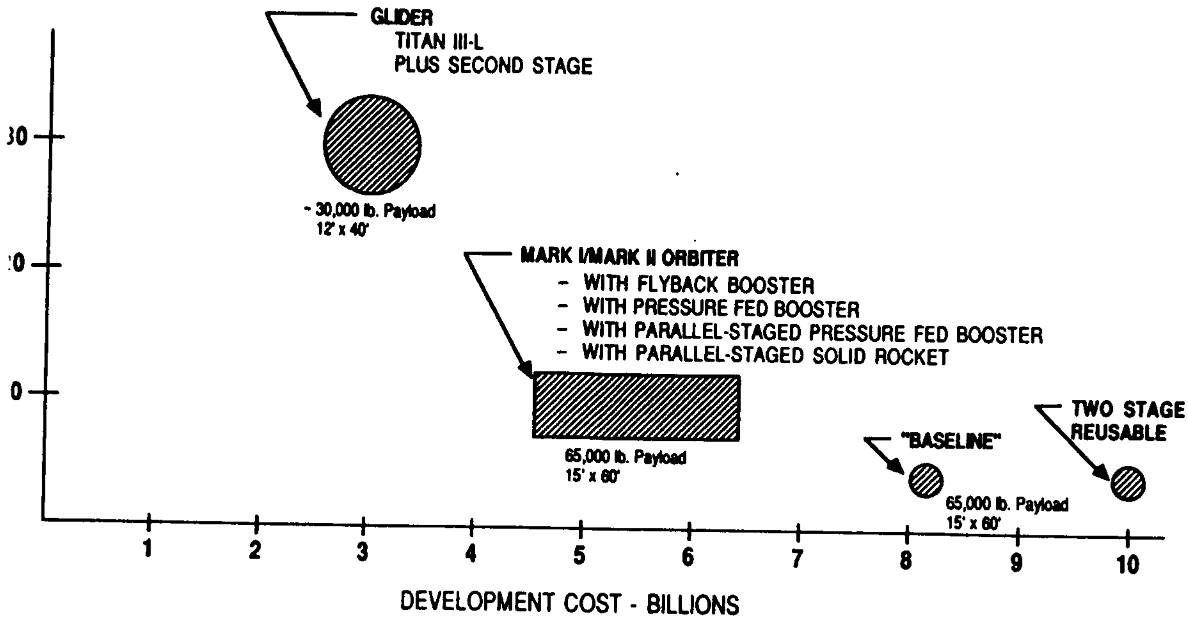
SPACE SHUTTLE CHRONOLOGY

• NASA DOD JOINT REPORT TO THE SPACE TASK FORCE	JUNE 1969
• FEASIBILITY STUDIES WITH INDUSTRY (PHASE A)	FEB. - NOV. 1969
• SPACE SHUTTLE SYMPOSIUM - SMITHSONIAN INST.	OCTOBER 1969
• DEFINITION STUDIES WITH INDUSTRY (PHASE B)	JUN. 1970 - MAR. 1972
• REVIEW BY PRESIDENT'S SCIENCE ADVISOR	AUG. 1971 - JAN. 1972
• MATHEMATICA REPORT ON SHUTTLE ECONOMICS	JANUARY 1972
• PRESIDENT NIXON'S SHUTTLE ANNOUNCEMENT	JANUARY 1972
• NASA DECISION ON SHUTTLE CONFIGURATION	MARCH 1972

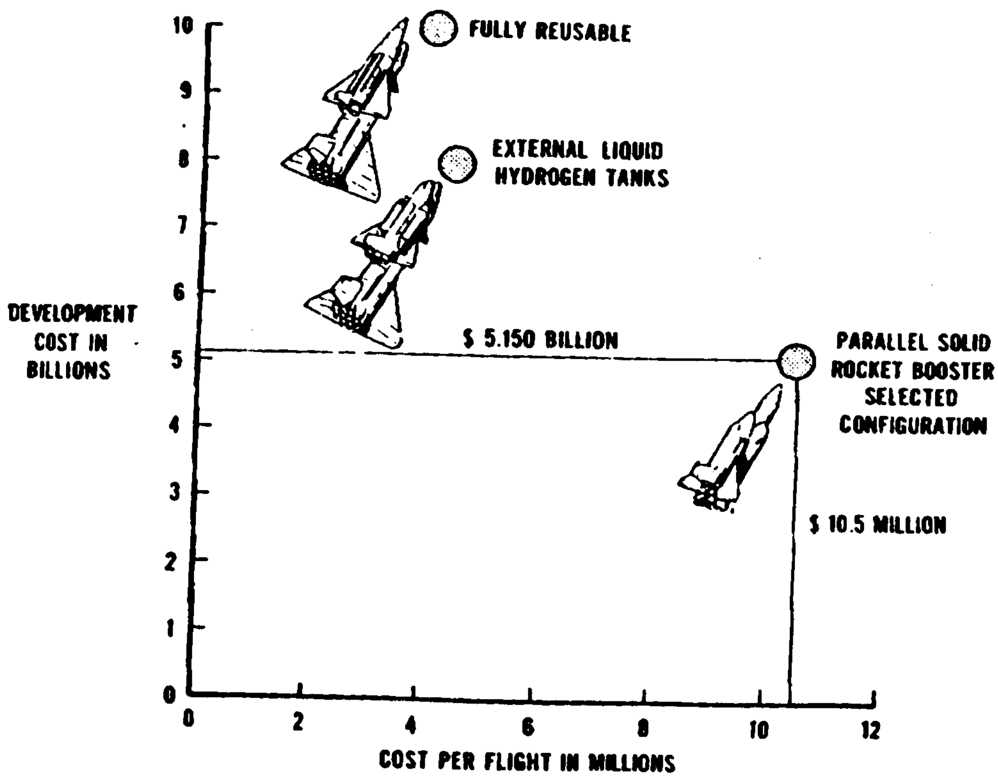
SPACE SHUTTLE COMPARISON



SPACE SHUTTLE COST COMPARISON
(1971)



SPACE SHUTTLE COST COMPARISON
(1971 Dollars)



PROGRAM GROUND RULES

- **MINIMIZE DEVELOPMENT COSTS**
  - DDT&E - $5.15B (1971$)
- **MINIMIZE COST PER FLIGHT**
  - CPF - $10.5M (1971$)
- **MAXIMIZE PAYLOAD ACCOMMODATIONS TO SATISFY USERS**

SPACE SHUTTLE PERFORMANCE

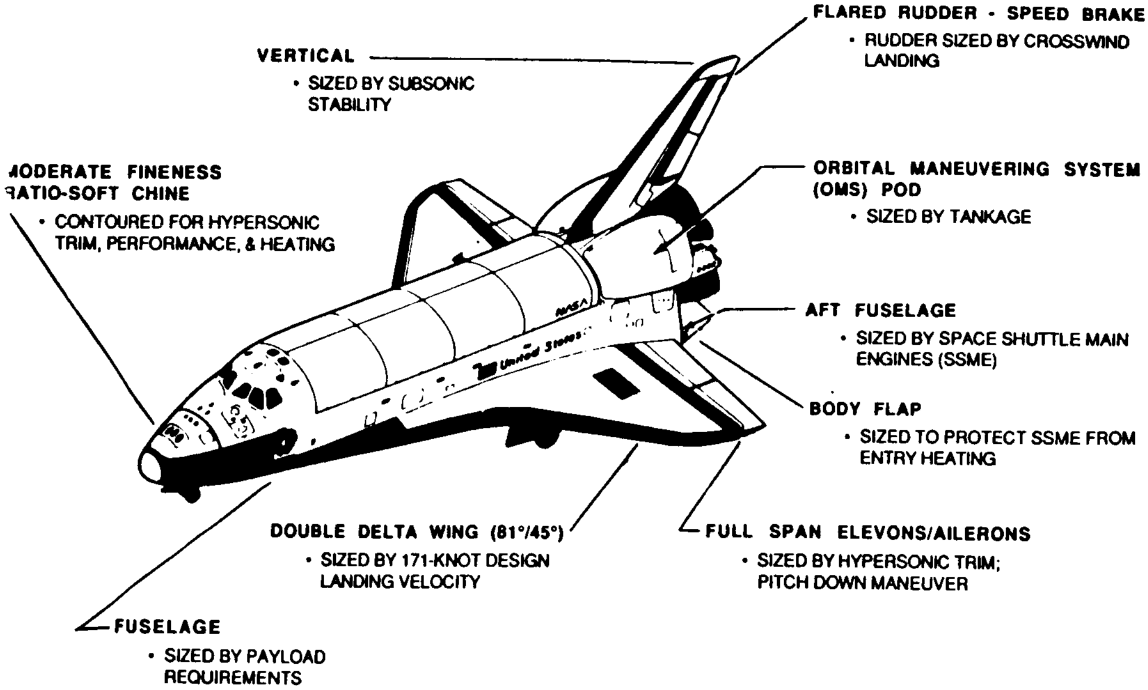
BASELINE

- 7 DAYS MISSION DURATION WITH CREW OF FOUR
- 65,000 LBS TO 100 x 100 MI DUE EAST ORBIT/32,000 LBS TO 100 x 100 MI 104° INCLINATION ORBIT
- 32,000 LBS DOWN PAYLOAD

EXTENSION KITS

- UP TO 30 DAYS DURATION WITH CREW UP TO SEVEN (ELECTRICAL POWER/LIFE SUPPORT/CREW PROVISIONS/PROPELLANTS)
- ORBIT ALTITUDES UP TO ~ 650 MI WITH VARYING PAYLOAD WEIGHTS AT VARIOUS INCLINATIONS (ORBITAL MANUEVERING SYSTEM PROPELLANT KITS)

ORBITER SIZING CRITERIA



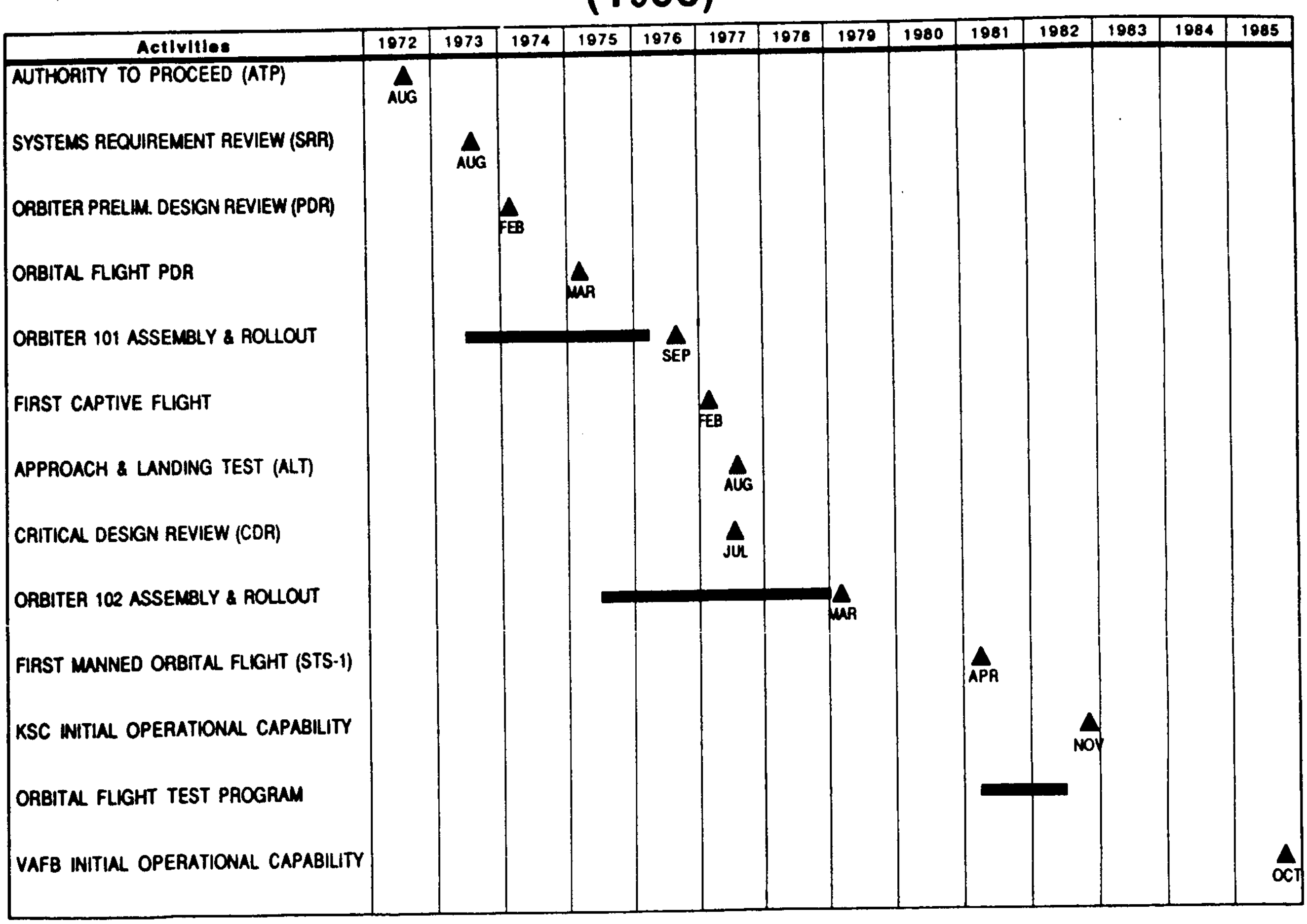
CREW/PASSENGER PROVISIONS

- **EARTH-LIKE ENVIRONMENT**
  - CABIN ATMOSPHERE IS OXYGEN-NITROGEN AT 14.7 PSI
  - TEMPERATURE REGULATED 65 - 80°F (+/- 2.0°F)
  - HUMIDITY CONTROL
  - CARBON DIOXIDE CONTROL
- **HOT AND COLD FOOD**
- **PROTECTED SLEEP STATIONS**
- **MALE AND FEMALE HYGIENE PROVISIONS**
- **MAXIMUM ACCELERATION IS 3 G's**

SPACE SHUTTLE MAIN ENGINE CHARACTERISTICS

- **THRUST**
  - SEA LEVEL 375 KLBS (1,668,080 N)
  - VACUUM 470 KLBS (2,090,660 N)
- **CHAMBER PRESSURE** 2970 PSIA ($2048\ N/CM^2$)
- **LIFE** 7.5 HOURS
  55 STARTS

SPACE SHUTTLE PROGRAM MILESTONES (1983)



SPACE SHUTTLE REQUIREMENTS

- RETURNABLE, REUSABLE SPACE HARDWARE
- PAYLOAD WEIGHT, VOLUME & ALTITUDES
  - Down Payload
- SUPPORTING SYSTEMS FOR PAYLOADS
  - Pointing & Stability
- CROSS RANGE
- CROSS WIND LANDINGS
- ORBITAL INCLINATIONS: 29° TO 104°
- CREW ACCOMMODATIONS
- EVA
- CONTINUOUS ABORT PATHS
- ELECTRICAL POWER
- ENVIRONMENTAL CONTROL
- COMMUNICATIONS, TRACKING & DATA MANAGEMENT
- GN&C
- MISSION KITS
- COSTS: DEVELOPMENT & PER FLIGHT

DROPPED IN EARLY 1970's: Separate Solid-Fuel Rockets For Abort From The Launch Pad and Jet Engines For Orbiter Flyback

N91-28265

PRESENTATION 4.4.3

CULTURAL CHANGES IN AEROSPACE

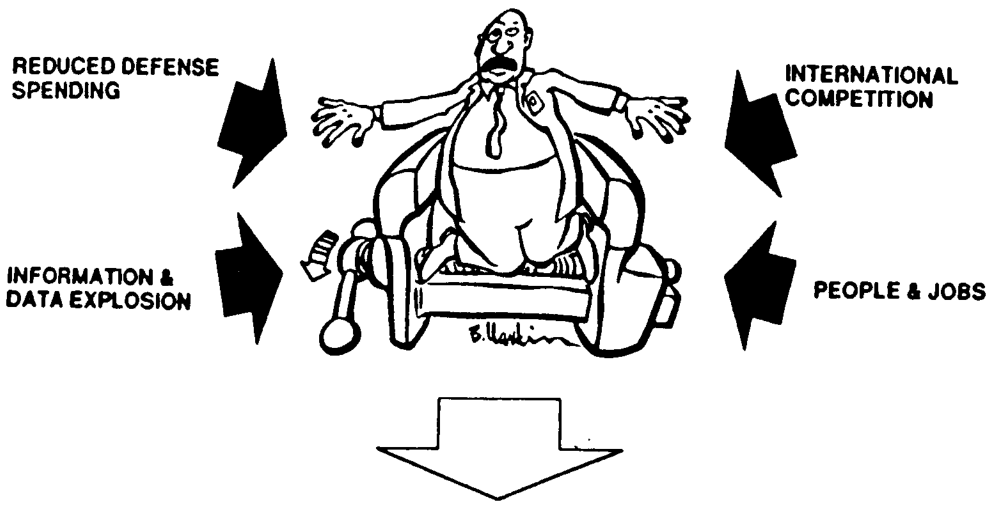
BILL STROBL

JUNE 1990

GENERAL DYNAMICS
Space Systems Division

WHAT'S HAPPENING

THE SQUEEZE IS ON AEROSPACE



- TOTAL QUALITY MANAGEMENT
- ELECTRONIC MEDIA

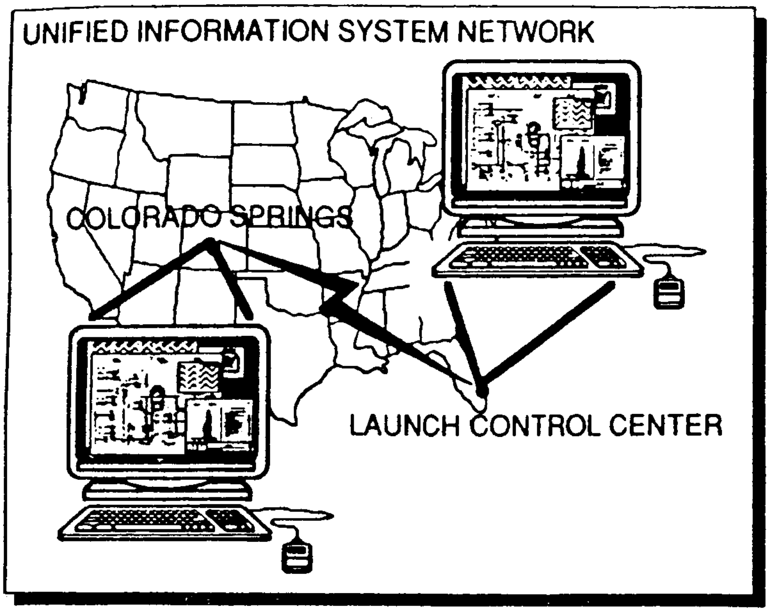
CULTURAL CHANGES ARE A WAY TO BREAK THE VISE

WHERE IS IT LEADING?

- Computers/Computer access for everyone
- Multi-Discipline Teams
  - Opportunity to be heard and contribute
  - Emphasis on processes and reducing variability
- Intercompany and International cooperation
  - Consortium/Teams/Cooperative ventures
- Younger Management
- Emphasis on listening to the "Voice of the Customer"
  - Exceed customer expectations, both external and internal
- Continuous improvement

WE ARE WITNESSING AN ERA OF CULTURAL CHANGE

COMMUNICATIONS
A New Generation of Systems



TOTAL ELECTRONIC ENVIRONMENT

- PAPERLESS SYSTEMS
- INFORMATION TRANSFER NETWORKS
- DATA STORAGE & RETRIEVAL
- EXPERT SYSTEMS
- AND MORE

A CULTURE SHOCK

PEOPLE AND JOBS

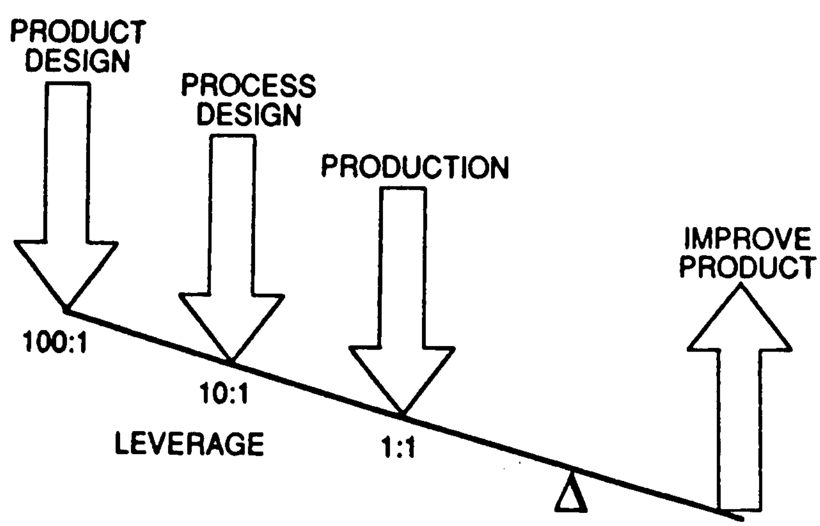
- Need to transfer our corporate knowledge to young people
  - Many of today's aerospace managers started in 1955 - 65 and are nearing retirement
  - Aerospace hiring was severely curtailed in 1969 -75
  - Many of our new managers will have less than 15 years experience
- Ambition and enthusiasm of our young people
- Motivation of employees and the opportunity to be heard
- Gain sharing

EXAMPLES OF CULTURAL CHANGES REQUIRED (Continued)

CATEGORY	PREVIOUS STATE	FUTURE STATE
Problem-Solving	Unstructured individualistic problem-solving and decision-making	Predominantly participative and interdisciplininary problem-solving and decision-making based on substantive data
Jobs and People	Functional, narrow scope management-controlled	Management and employee involvement; workteams; integrated functions
Management Style	Management style with uncertain objectives that instills fear of failure	Open style with clear and consistent objectives, which encourages group-derived continuous improvement
Role of Manager	Plan, organize, assign, control, and enforce	Communicate, consult, coach, mentor, remove barriers, and establish trust
Rewards and recognition	Pay by job. Few team incentives	Individual and group recognition and rewards, negotiated criteria
Measurement	Orientation toward data-gathering for problem identification	Data used to understand and continually improve processes

SOURCE: DoD 5000.51-G Final Draft

WHERE IS THE PAYOFF ?



ALS PHILOSOPHY

- Take some of the mystique out of the aerospace business
  - Emphasize the creative part at all levels
  - Make the rest easy and routine
- Make the system simple and robust
  - So it is more reliable and dependable
  - So it doesn't require rocket scientists to operate and maintain
  - To attract nationwide participation by both traditional aerospace and non-aerospace manufacturing companies

ROUTINE, RELIABLE, AFFORDABLE

ALS OPERABILITY CAPABILITIES ARE ANALOGOUS TO THOSE OF MILITARY TRANSPORT AIRCRAFT

"YOU CALL, WE HAUL"
- 95% Probability of Launch with 90% Confidence
- Broad Spacecraft Requirement Envelopes & Interface Standards

" END OF THE RUNWAY"
- Clean Pad - Rise-Off Umbilicals Mated/Checked Out in Factory
- All Ground Support Provided Through Launch Platform - No Towers

" FLY THROUGH FAILURE"
- Recoverable On-board Recorders
- Built-in-test & Automated Test
- Facilities Designed for 35%Surge

" OPERATIONAL ECONOMIES"
- Base Level Maintenance & Logistics
- Engine/Avionics Modularity & Ease of Removal/Replacement
- Commonality
- Technician Transparency

ADVANCED LAUNCH SYSTEM

NASA
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

OPERABILITY IN DESIGN

ASK THE MILITARY AIRLIFT COMMAND WHAT CONSTITUTES OPERABILITY:

- HIGH AVAILABILTY & RELIABILITY
- HIGH THROUGHPUT AND ON-TIME PERFORMANCE (DEPENDABILITY)
- STANDARD VEHICLE-CARGO OPS (SIMPLE INTERFACES)
- BLUE SUIT OWNED & OPERATED

N91-28266

PRESENTATION 4.4.4

BUSINESS NOT AS USUAL

Presented to
Program Development and
Cultural Issues Panel
at the
Space Transportation Propulsion
Systems Symposium

June 27, 1990

UNITED TECHNOLOGIES PRATT & WHITNEY

Rockwell International

GENCORP AEROJET

Pratt & Whitney

Don Connell

CONCLUSION

Manage the problems together (Government/Contractors)

Don't resist cultural change

TYPICAL DESIGN SIMPLIFICATION IDEAS WHICH REDUCE COSTS

ELIMINATE BOOST PUMPS

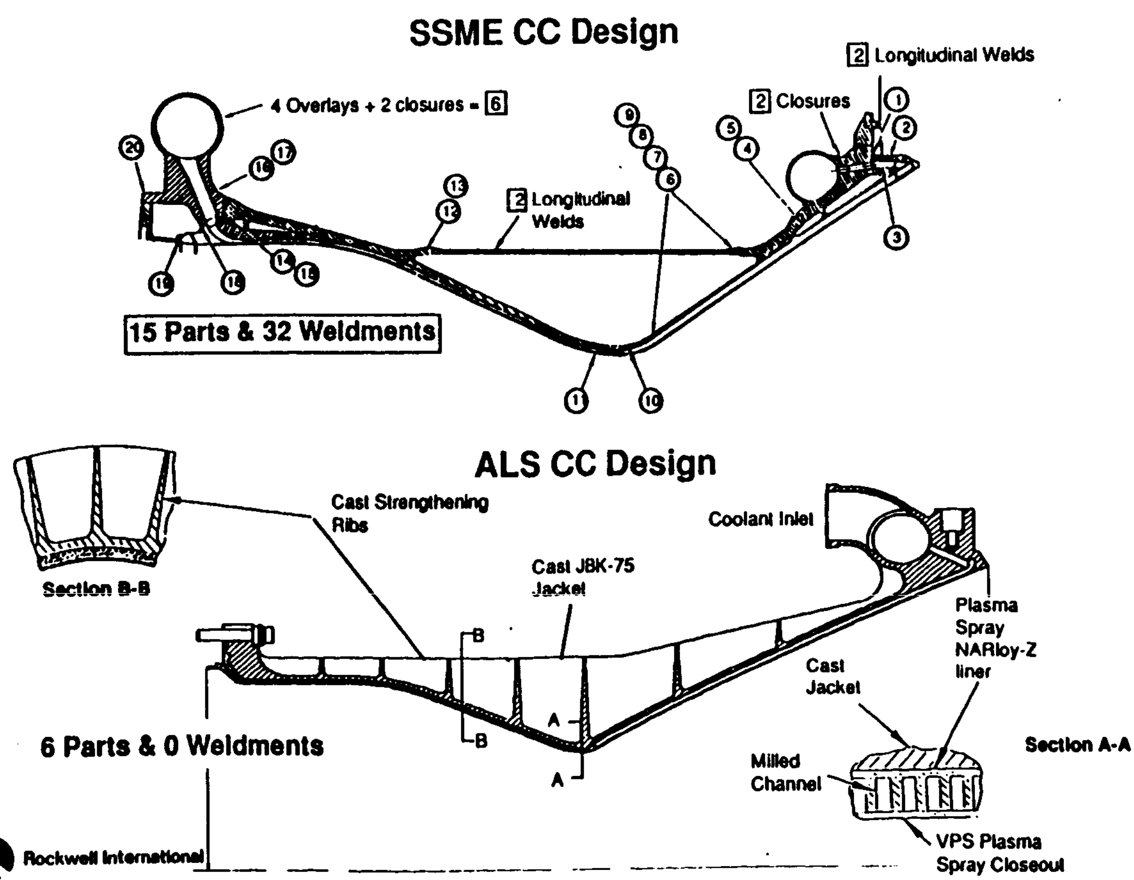
ELIMINATE FAIL-OP IN CONTROL SYSTEM

ELIMINATE THROTTLING AND CLOSED LOOP CONTROL

LOWER CHAMBER PRESSURE

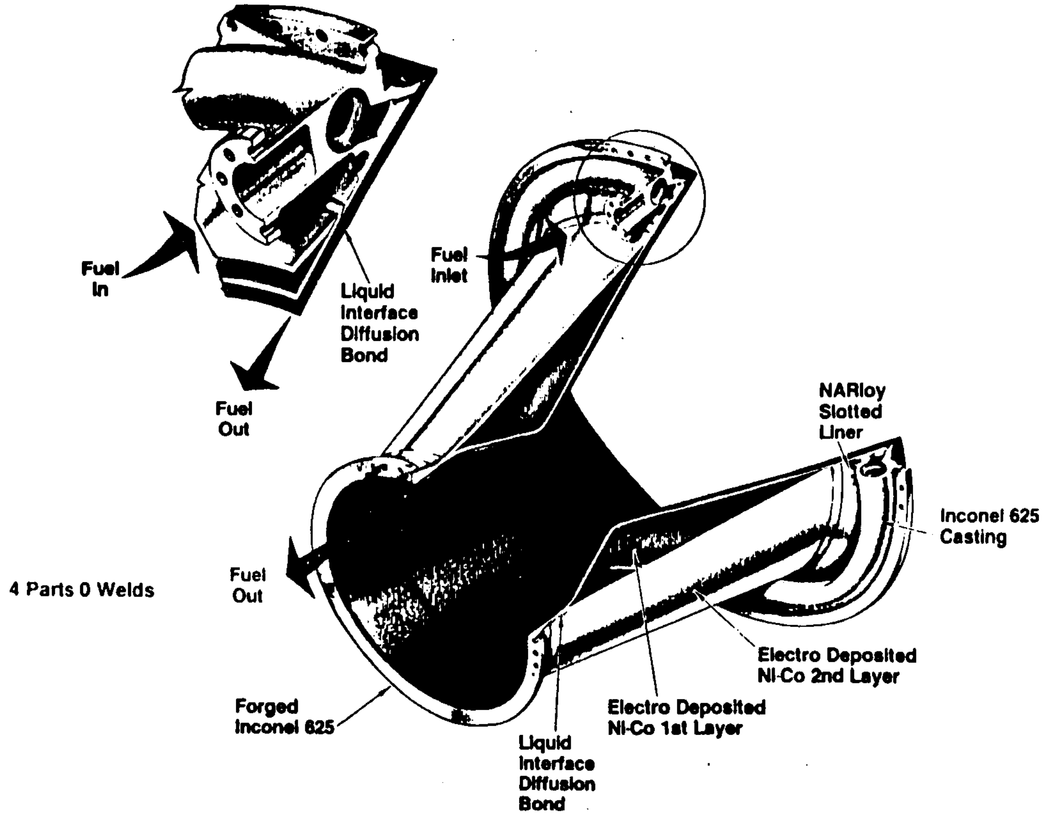
ELIMINATE POWER HEAD/DUAL PREBURNERS (GG CYCLE)

COMBUSTION CHAMBER DESIGN SIMPLIFICATION

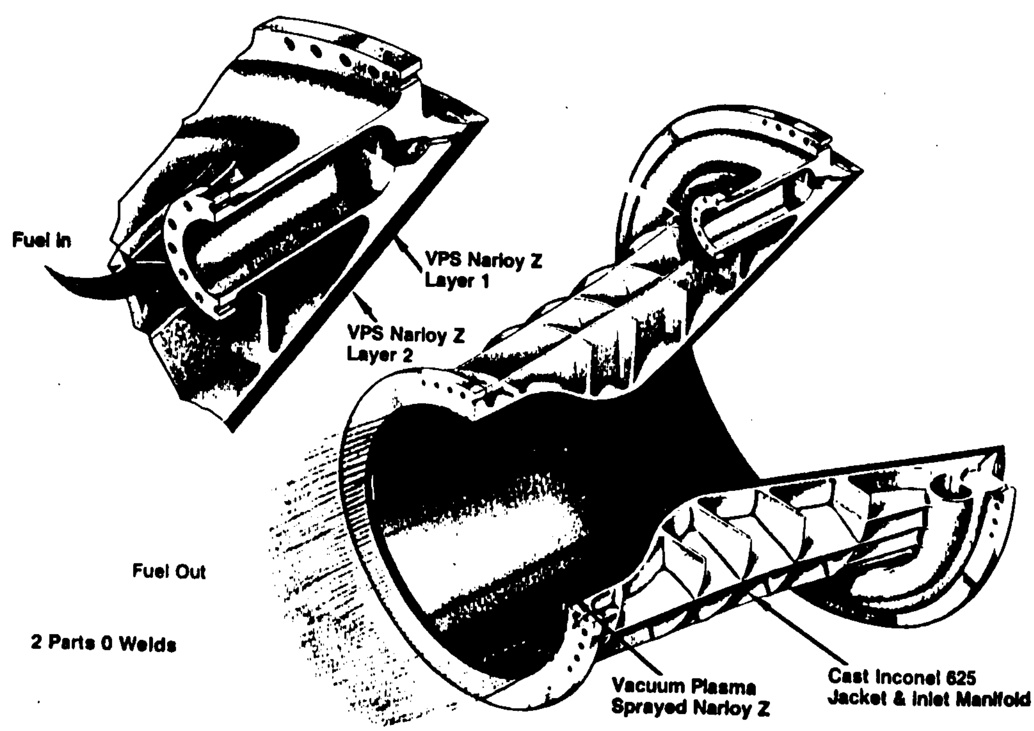


Rockwell International
Rocketdyne Division

BASELINE - 1A COMBUSTION CHAMBER

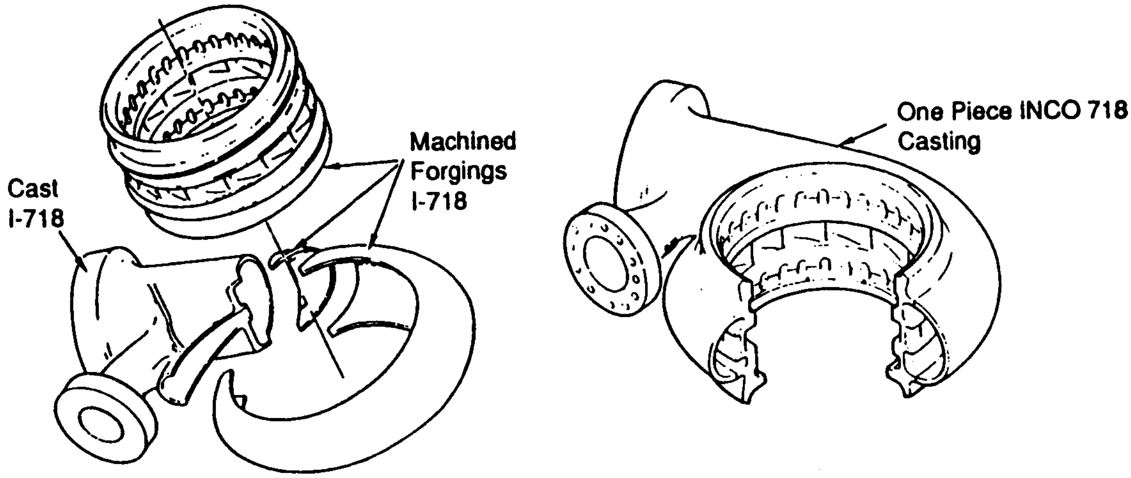


BASELINE - 1B COMBUSTION CHAMBER



Rockwell International

CASTINGS VS. MACHINED AND WELDED FORGINGS

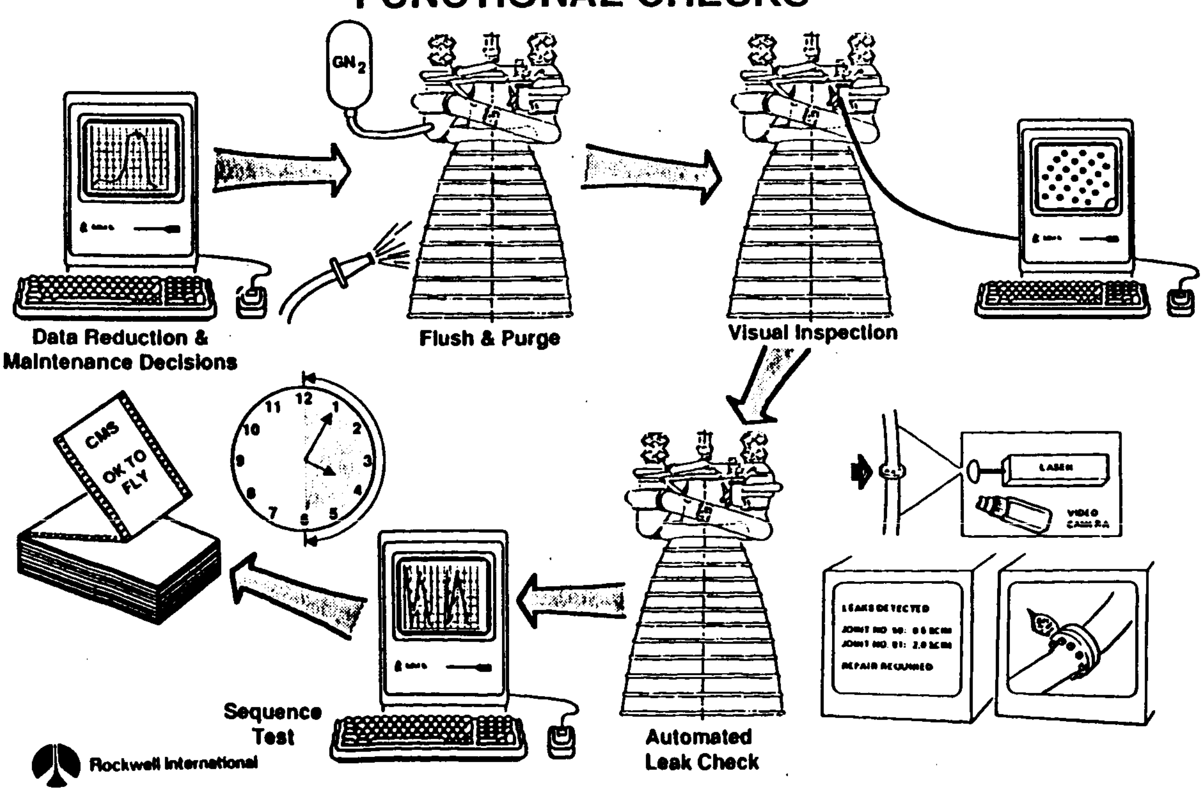


SSME Turbopump Volute

IR&D Cast Volute

Cost Savings of >10:1

AUTOMATED INSPECTIONS AND FUNCTIONAL CHECKS



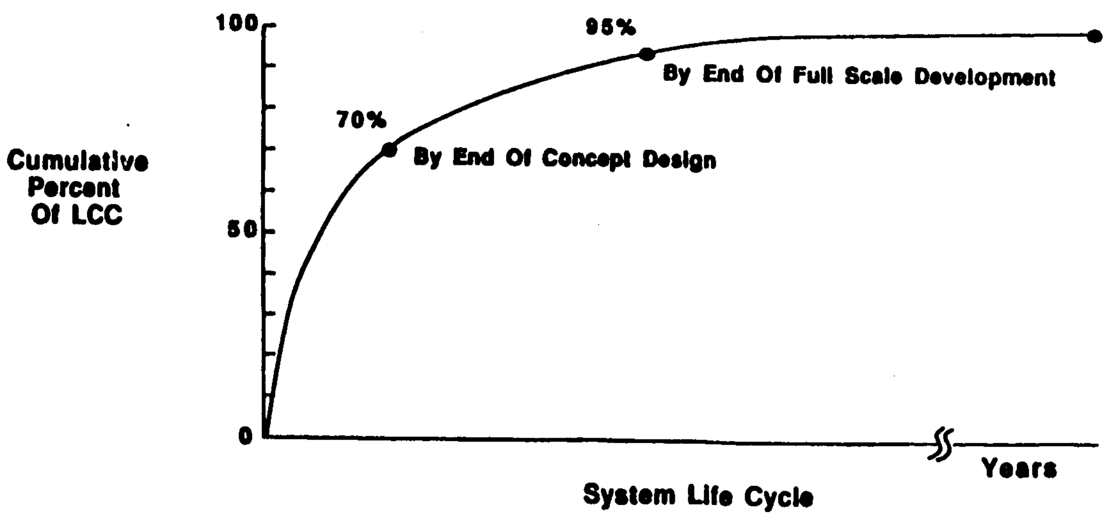
Rockwell International

Aerojet Propulsion Division

Roy Michel

Propulsion Division

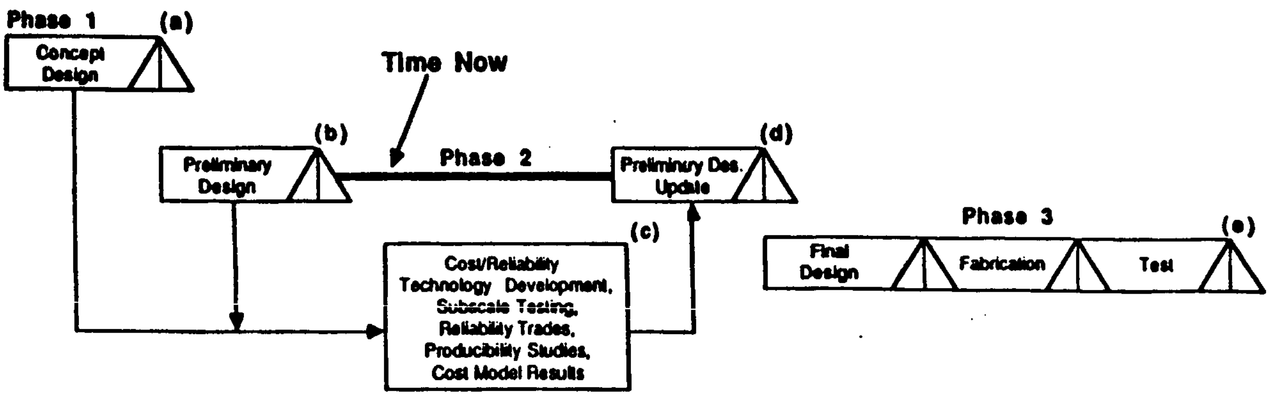
Two Thirds Of Total Life Cycle Cost Is Determined By The End Of Concept Design*



* Richman Associates, Design To Cost Seminar, Aerojet 1977

Our Approach To The TCA: Maintain Flexibility

- Establish A Point Of Departure Design (a)
- Evaluate Competing Low Cost Designs/Approaches (b)
- Examine Technical And Process Issues And Alternatives (c)
- Select Final Approach Based On Rigorous Cost Comparisons (d)
- Demonstrate The Final Concept At MSFC (e)



Our Cost Model Embodies TQM

QFD	Respond To Customer's Desire For: • Low Cost Design • Understanding Of Factors Affecting Cost
Juran	Identify Avoidable And Unavoidable Costs
	Evaluate, Early In The Design Process:
TQM	Form: Touch Labor And Material Costs To Manufacture The Hardware
SPC	Fit: Manufacturing Process Yields
Taguchi	Function: "Warranty" Costs - Reliability And Spares

Summary

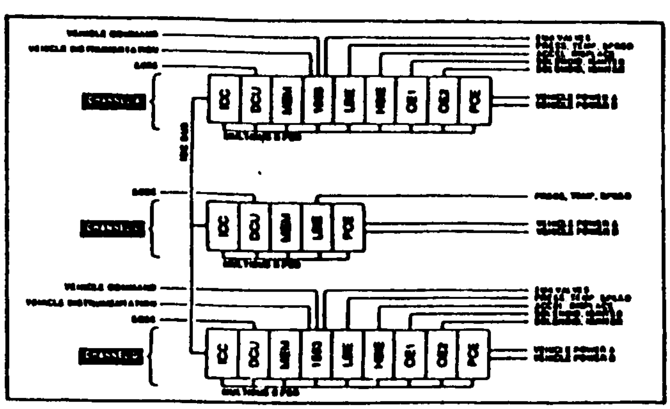
- High Reliability And Low Cost Are Obtainable
  - Inherent In Design And Manufacturing Processes:

Fewer Parts	Advanced Processes
Low Cost Materials	Reduced Inspection
Wider Margins	Efficient Manufacturing

- Contractors Are Committed
- TQM Is In
- Consortium + Government + Prime Contractors = Partnership
- Government Role Is Key
  - Fix The Requirements
  - Avoid Gold Plating
  - Limit Specifications
  - Maintain Funding And Schedule

Low Cost Approaches To Engine Controller

- Modular, Flexible Architecture Results In 70% Decrease In Controller Life Cycle Cost
- Standard Modules, Interfaces, Software
- Adaptable To Various Engine Requirements



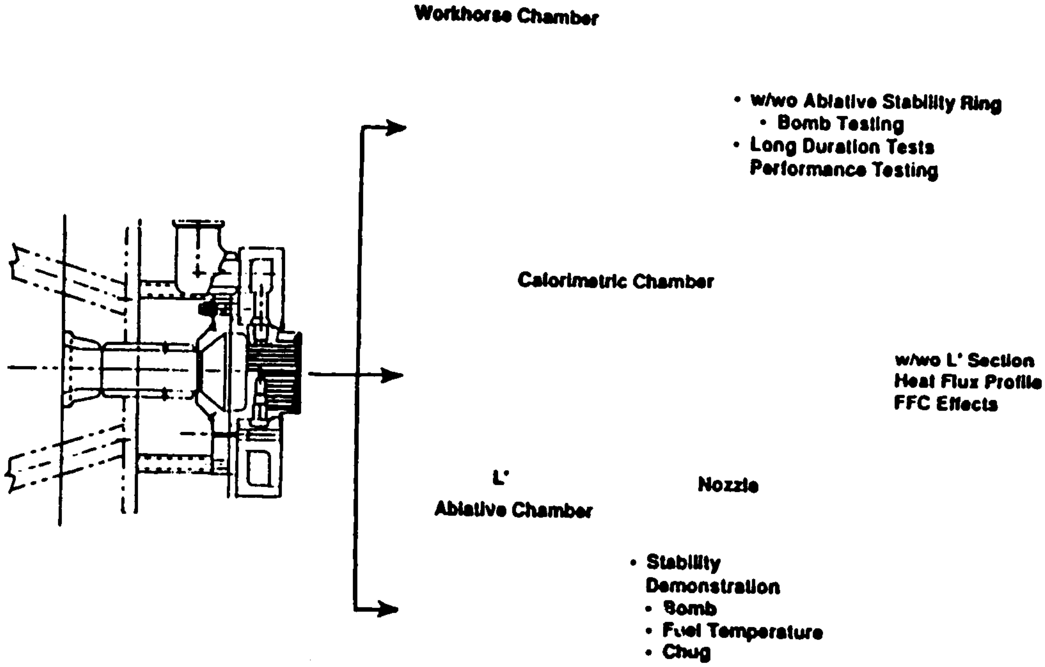
Low Cost Approaches To Propellant Control Effector

- Electromechanical Activation
- Ox And Fuel Valve Commonality
- Integral Electronics
- Digital Control And Interface
- Integral Valve Position Resolver

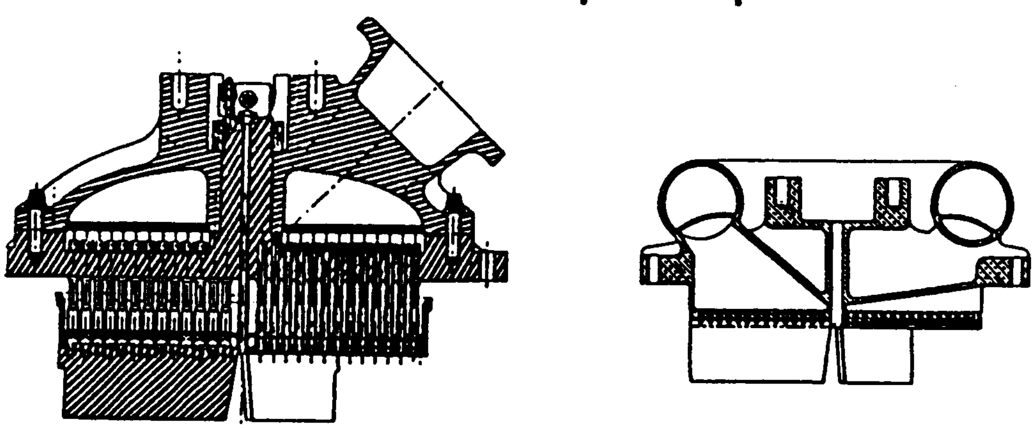
Low Cost Approaches To Turbopump Design

- Two-Stage Pump
- Self-Compensating Hydrostatic Bearings
- Cast Turbine Manifold
- Cast Pressure Vessel
- Integrally Machined Turbine Hub And Blades (Blisk)
- LCF And HEE-Resistant Turbines
  - No Coatings Or Platings
- Cast Impellers
- Reusable With Minimum Inspection And Refurb

Injector Assembly and Subscale Chambers Will Provide the Data Base for the 3-D Subscale Impinging Injector



Impinging Element Injector Offers Lower Cost and Acceptable Isp



Parameter		Baseline Swirl Coax Element	Alternative Impinging Element
# Parts		2200	15
# Operations		133	67
Injection ΔP_{FUEL}	(Psi)	340	340
Injection ΔP_{OXID}	(Psi)	515	340
Predicted Isp	(sec)	441.7	438.5

Concurrent Engineering Design Approach Addresses All Major Design Objectives

- Downstream Functions Actively Participated In The Design Process

Suppliers	Reliability
Producibility	Safety
QA	ILS

- Approach To High Reliability Formulated
- Approach To Low Cost Formulated
- Cost Model Constructed

Ongoing Advanced Development Programs Are Focused On High Reliability And Low Cost

- Combustion Devices
  - Thrust Chamber Assembly
  - Gas Generator Assembly
- Hydrogen Turbopump Assembly
- Propellant Control Effector (GGA Valve)
- Engine Controller

N91-28267

PRESENTATION 4.4.5

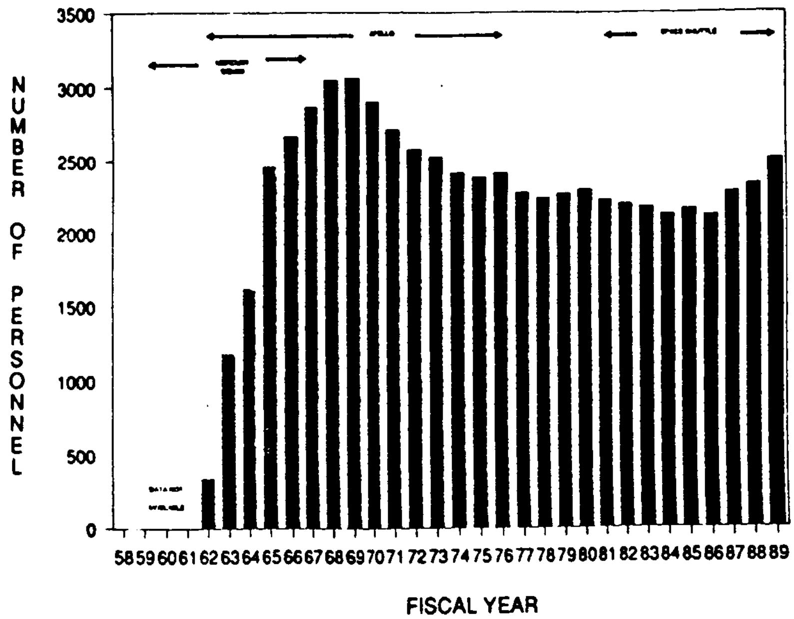
LAUNCH OPERATIONS MANPOWER YESTERDAY, TODAY AND TOMORROW

GEORGE OJALEHTO
VITRO CORPORATION
JUNE 27, 1990

SOURCES OF INFORMATION

- NASA POCKET STATISTIC - JAN 1990
- KSC GROUND OPERATIONS COST MODEL - JUN 1990
- KSC MANPOWER REPORT - NOV 1968
- SHUTTLE PROCESSING CONTRACTOR MANPOWER TREND ANALYSIS STUDIES - MAR 1990
- AVIATION WEEK "AEROSPACE FORUM" BY LT. GEN (RET.) RICHARD D. HENRY - NOV 27, 1989
- WHITE PAPER ENTITLED "IN SEARCH OF SPACE ACCESSIBILITY" BY C. ELDRED, AIR FORCE SPACE SYSTEMS DIVISION - DEC. 1989
- OPERATIONALLY EFFICIENT PROPULSION SYSTEM STUDY (OEPSS) REVIEW BY SRS TECHNOLOGIES - FEB 1990
- SHUTTLE GROUND OPERATIONS EFFICIENCIES/TECHNOLOGY STUDY (SGOE/T) BRIEFING BY BOEING - JULY 1988
- SAE TECHNICAL PAPER ENTITLED "RELIABLE LOW COST LAUNCH SERVICES" BY PETER ARMITAGE, SPACE SERVICES, INC. SEP 1989
  DISCUSSIONS WITH PETER ARMITAGE - JUN 1990
- PEGASUS BRIEFING CHARTS/TAURUS BRIEFING CHARTS FROM BILL SAAVEDRZ, ORBITAL SCIENCES CORP. - JUN 1990
  DISCUSSIONS WITH BILL SAAVEDRA - JUN 1990
- ALS COMPARATIVE ANALYSIS REPORT BY GENERAL DYNAMICS - DEC 1989

Kennedy Space Center Civil Service Level



PERSPECTIVES ON PAST AND CURRENT LAUNCH SITE MANPOWER

- IN THE 1958 - 1962 (REDSTONE, MERCURY, GEMINI) ERA WE HANDLED UP TO 27 LAUNCHES PER YEAR WITH ABOUT 350 GOVERNMENT PEOPLE PLUS SUPPORTING CONTRACTORS

- IN THE 1962 - 1975 (APOLLO) ERA WE HANDLED UP TO 30 LAUNCHES PER YEAR WITH ABOUT 3,000 GOVERNMENT PEOPLE PLUS 18,000 CONTRACTORS

- IN THE 1981 - 1989 (SPACE SHUTTLE) ERA WE HANDLE UP TO 15 LAUNCHES PER YEAR WITH ABOUT 2,500 GOVERNMENT PEOPLE PLUS 15,000 CONTRACTORS

WHAT DID WE KNOW 30 YEARS AGO THAT WE MAY HAVE FORGOTTEN

NASA LAUNCH ATTEMPTS PER YEAR VS PERSONNEL ON HAND

Year	Manned Launches	S	U	Total Launch Attempts	KSC Personnel
1958		2	2	4	--
1959	1	9	5	14	--
1960	1	11	6	17	--
1961	4	19	5	24	--
1962	3	26	1	27	339
1963	1	15		15	1181
1964	1	29	1	30	1625
1965	5	28	2	30	2464
1966	5	30	1	31	2669
1967		27	1	28	2867
1968	2	21	2	23	3044
1969	4	21	1	22	3058
1970	1	13	1	14	2895
1971	2	17	1	18	2704
1972	2	18		18	2568
1973	3	13	1	14	2516
1974		16	1	17	2408
1975	1	19	2	21	2377
1976		16		16	2404
1977		14	2	16	2270
1978		20		20	2234
1979		9		9	2264
1980		7		7	2291
1981	2	13		13	2224
1982	3	12		12	2199
1983	4	15		15	2180
1984	5	12		12	2131
1985	9	14		14	2165
1986	2	5	2	7	2120
1987		3	1	4	2278
1988	2	8		8	2330
1989	5	7		7	2504

S-Successful
U-Unsuccessful

ESTIMATES OF CURRENT LAUNCH OPERATIONS MANPOWER

VEHICLE	LAUNCH RATE	NUMBER OF PEOPLE PER LAUNCH
TITAN	4/YR	300 WSMC 550 ESMC
ATLAS	4/YR	200 - 300 ESMC
DELTA	10/YR	150 WSMC 215 - 280 ESMC
SCOUT	2/YR	40 - 60
SPACE SHUTTLE	8/YR	900 CONTRACTOR ___ GOVERNMENT

OPERATIONAL CONCERNS

- OPERATIONS IS A MAJOR COST DRIVER ACCOUNTING FOR 25 TO 40% OF TOTAL COST PER FLIGHT FOR SOME ELVs
- SPACE SHUTTLE AVERAGE COST PER FLIGHT IS $219.2M OF WHICH $52M (23.7%) IS LAUNCH OPERATIONS COSTS
- SHUTTLE TURNAROUND TIME NOT NEAR ORIGINAL GOALS
  - ORIGINAL DESIGN GOAL 160 HRS
  - PRE 51L GOAL 680 HRS
  - 51L ACTUAL 1358 HRS
  - POST 51L ACTUALS 2000-3000 HRS

HIGH OPERATIONS COSTS ARE LARGELY THE RESULT OF COMPLEX VEHICLE/PROPULSION SYSTEM DESIGNS

PLANNED ELV TIMELINE REDUCTIONS

ATLAS FROM 55 DAYS TO 12 DAYS BY 1994

• AUTOMATION AND NEW HARDWARE	MINUS 10 DAYS
• OFF LINE PROCESSING AND NEW CENTAUR ENGINE	MINUS 15 DAYS
• NEW DESIGN HARDWARE, AVIONICS, LASER ORDNANCE	MINUS 18 DAYS

TITAN FROM 80 DAYS TO 27 DAYS BY 1994

• SRM ASSEMBLY FACILITY AND DOUBLE SHIFTS	MINUS 20 DAYS
• AGE MODERNIZATION	MINUS 4 DAYS
• OFF-LINE PAYLOAD PROCESSING	MINUS 26 DAYS
• LASER ORDNANCE	MINUS 3 DAYS

TODAY'S SMALL LAUNCH VEHICLE LAUNCH MANNING EXPECTATIONS

- ORBITAL SCIENCES CORPORATION
  - PEGASUS
    - ONE ENGINEER ON BOARD B-52 WITH AIRCRAFT CREW OF 3 (4 TOTAL)
    - SIX ENGINEERS FOR INTEGRATION SUPPORT
    - SIX ENGINEERS FOR FLIGHT CONTROL

    TOTAL OF 13 PEOPLE SUPPORTING LAUNCH
    (AIRFORCE RANGE PERSONNEL NOT COUNTED)
  - TAURUS
    - EXPECT 15 TO 18 PEOPLE TO SUPPORT LAUNCH (PAD, ASSEMBLY, INTEGRATION)
    - EXPECT 6 FOR BLOCKHOUSE (LAUNCH CONTROL)
    - LAUNCH SEQUENCE HAS 5 DAYS TO SETUP AND ACTIVATE AND THEN LAUNCH WITHIN 72 HOURS
- SPACE SERVICES, INC
  - CONSORT (SUBORBITAL)
    - 4 SSI ENGINEERS PLUS 4-6 INTEGRATION SUBCONTRACTOR ENGINEERS (8 TO 10 TOTAL PER LAUNCH)
  - CONESTOGA (ORBITAL)
    - ABOUT 18 PEOPLE FOR LAUNCH SUPPORT EXPECTED

TODAY'S SMALL LAUNCH VEHICLE DESIGN/OPERATIONS PHILOSOPHY

- MAXIMUM SYSTEM RELIABILITY
  - SIMPLE DESIGN
  - CONSERVATIVE DESIGN PRACTICES
  - QUALITY COMPONENT SELECTION
  - PROVEN MODERN ELECTRONIC COMPONENTS
- SIMPLE LAUNCH INTEGRATION AND PRE-FLIGHT CHECKOUT
  - MAXIMUM USE OF PREASSEMBLY AND PRETEST CHECKOUT AT MANUFACTURING PLANTS
  - MINIMUM FIELD GROUND SUPPORT EQUIPMENT AND FACILITIES
  - HORIZONTAL ASSEMBLY/INTEGRATION PRIOR TO ERECTION
  - PRE-CHECKED CORE/PAYLOAD FLIGHT-CONFIGURED PRIOR TO TRANSPORTING TO PAD
  - TRANSPORTING TO PAD BY SPECIAL VANS/HANDLING DOLLIES
  - LIMITED OR NO FIXED STRUCTURES AT LAUNCH SITE EXCEPT FOR SIMPLE LAUNCH STAND/STOOL
- MINIMUM RANGE SUPPORT REQUIREMENTS

FIXED PRICE LAUNCHES FORCES ONE TO CUT COSTS

PERSPECTIVES ON FUTURE LAUNCH OPERATIONS

- AS COMPLEXITY OF FLIGHT AND GROUND SYSTEMS INCREASES, SO DOES COST
  - FLIGHT/GROUND SYSTEMS MUST BE SIMPLIFIED
- MAINTAINABILITY/EASE OF ACCESS MUST BE DESIGNED IN
- OPERATIONAL REQUIREMENTS MUST BE A PART OF THE CONCEPTUAL DESIGN PHASE
- OVERALL VEHICLE INTEGRATION MUST BE EMPHASIZED EARLY
- LARGE COMPLEX LAUNCH CONTROL CENTERS MUST BE ELIMINATED
- MASSIVE GROUND/LAUNCH VEHICLE DATA AND CONTROL LINKS MUST GO AWAY
- PAYLOADS MUST BE PREPACKAGED, HAVE MINIMAL INTERFACES, AND BE PROCESSED OFF-LINE

PERSPECTIVES ON FUTURE LAUNCH OPERATIONS
(CONTINUED)

- MUST MOVE BEYOND RESEARCH AND DEVELOPMENT ENVIRONMENT TO AN OPERATIONAL ENVIRONMENT
  - PAST VEHICLES DESIGNED FOR PERFORMANCE FIRST; RELIABILITY SECOND, AND COST EFFECTIVENESS LAST
  - IT IS TIME TO CHANGE
- MUST EMPHASIZE RELIABILITY THROUGH SIMPLICITY, DESIGN MARGINS AND SELECTIVE REDUNDANCY
  - SIMPLICITY ALLOWS CONCENTRATION OF EFFORT
  - DESIGN MARGINS CAN REDUCE REDUNDANCY REQUIREMENTS
  - SELECTIVE REDUNDANCY GIVES ADDED ASSURANCE

Back-Up

NASA LAUNCHES PRIOR TO 1962

YEAR	LAUNCH VEHICLE	PAYLOAD	*STATUS	DATE
1958				
	Thor Able	Pioneer I	S	Oct 11
	Jupiter-C	Beacon 1	U	Oct 23
	Thor Able	Pioneer II	U	Nov 8
	Juno II	Pioneer III	S	Dec 7
1959				
	Vanguard	Vanguard II	S	Feb 17
	Juno II	Pioneer IV	S	Mar 3
	Vanguard	Vanguard	U	Apr 13
	Vanguard	Vanguard	U	Jun 22
	Juno II	Explorer	U	Jul 16
	Thor Able	Explorer 6	S	Aug 7
	Juno II	Beacon II	U	Aug 14
	Atlas	Big Joe-Mercury	S	Sep 9
	Vanguard	Vanguard III	S	Sep 18
	Little Joe	Little Joe I	S	Oct 4
	Juno II	Explorer 7	S	Oct 13
	Little Joe	Little Joe 2	S	Nov 4
	Atlas Able	Pioneer P-3	U	Nov 26
	Little Joe	Little Joe 3	S	Dec 4
1960				
	Little Joe	Little Joe 4	S	Jan 21
	Thor Able IV	Pioneer V	S	Mar 11
	Juno II	Explorer	U	Mar 23
	Thor Able	Tiros I	S	Apr 1
	Scout	Scout X	S	Apr 18
	Thor Delta	Echo A-10	U	May 13
	Scout	Scout I	S	Jul 1
	Atlas	Mercury MA-1	U	Jul 29
	Thor Delta	Echo I	S	Aug 12
	Atlas Able	Pioneer P-30	U	Sep 25
	Scout	Scout II	S	Oct 4
	Juno II	Explorer 8	S	Nov 3
	Little Joe	Little Joe 5	S	Nov 8
	Thor Delta	Tiros II	S	Nov 23
	Scout	Explorer S-56	U	Dec 4
	Atlas Able	Pioneer P-31	U	Dec 15
	Redstone	Mercury MR-1A	S	Dec 19

*S-Successful
U-Unsuccessful

YEAR	LAUNCH VEHICLE	PAYLOAD	*STATUS	DATE
1961				
	Redstone	Mercury MR-2	S	Jan 31
	Scout	Explorer 9	S	Feb 16
	Atlas	Mercury MA-2	S	Feb 21
	Juno II	Explorer S-45	U	Feb 24
	Little Joe	Little Joe 5A	S	Mar 18
	Redstone	Mercury MR-BD	S	Mar 24
	Thor Delta	Explorer 10	S	Mar 25
	Atlas	Mercury MA-3	U	Apr 25
	Juno II	Explorer 11	S	Apr 27
	Little Joe	Little Joe 5B	S	Apr 28
	Redstone	Mercury (Freedom 7)	S	May 5
	Juno II	Explorer S-45a	U	May 24
	Scout	Explorer S-55	U	Jun 30
	Thor Delta	Tiros III	S	Jul 12
	Redstone 4	Mercury (Liberty Bell 7)	S	Jul 21
	Thor Delta	Explorer 12	S	Aug 16
	Atlas Agena	Ranger I	S	Aug 23
	Scout	Explorer 13	S	Aug 25
	Atlas	Mercury MA-4	S	Sep 13
	Scout	Probe A	S	Oct 19
	Saturn I	Saturn Test	S	Oct 27
	Blue Scout	Mercury MS-1	U	Nov 1
	Atlas Agena	Ranger II	S	Nov 18
	Atlas	Mercury MA-5	S	Nov 29

*S-Successful
U-Unsuccessful

N91-28268

C. Saric
NASA Headquarters

PRESENTATION 4.4.6

MAJOR SYSTEM ACQUISITIONS PROCESS

(A-109)

MAJOR SYSTEM - COMBINATION OF ELEMENTS (HARDWARE, SOFTWARE, FACILITIES, AND SERVICES) THAT FUNCTION TOGETHER TO PRODUCE CAPABILITIES REQUIRED TO FULFILL A MISSION NEED

SYSTEM ACQUISITION PROCESS - SEQUENCE OF ACTIVITIES BEGINNING WITH DOCUMENTATION OF MISSION NEED AND ENDING WITH INTRODUCTION OF MAJOR SYSTEM INTO OPERATIONAL USE OR OTHERWISE SUCCESSFUL ACHIEVEMENT OF PROGRAM OBJECTIVES

A-109

- RECOGNIZED MAJOR SYSTEM ACQUISITION
  - IS A CRITICAL AND EXPENSIVE ACTIVITY
  - IMPACTS TECHNOLOGY, NATION'S ECONOMIC/FISCAL POLICIES, ACCOMPLISHMENT OF AGENCY MISSION
- ESTABLISHED POLICIES AND OBJECTIVES FOR PLANNING AND MANAGEMENT OF MAJOR SYSTEM ACQUISITIONS
- CHARACTERIZED BY
  - TIME-PHASED PROCESS
  - SYSTEMATIC AND DISCIPLINED APPROACH

A-109 GENERAL POLICIES

- EXPRESS NEEDS IN MISSION TERMS TO ENCOURAGE INNOVATION AND COMPETITION OF ALTERNATE SYSTEM DESIGN CONCEPTS
- PLACE EMPHASIS ON INITIAL ACTIVITIES OF ACQUISITION PROCESS TO ALLOW COMPETITIVE EXPLORATION OF ALTERNATIVE CONCEPTS
- COMMUNICATE WITH CONGRESS EARLY IN THE ACQUISITION PROCESS
- ESTABLISH CLEAR LINES OF AUTHORITY, RESPONSIBILITY, ACCOUNTABILITY
- ENSURE APPROPRIATE MANAGEMENT-LEVEL INVOLVEMENT IN DECISIONS/AGENCY HEAD APPROVAL AT KEY DECISION POINTS
- RELY ON PRIVATE INDUSTRY

A-109 OBJECTIVES

- ENSURE MAJOR SYSTEM FULFILLS MISSION NEED, OPERATES EFFECTIVELY, JUSTIFIES ALLOCATION OF LIMITED AGENCY RESOURCES
- ESTABLISH INTEGRATED APPROACH FOR BUDGETING, CONTRACTING, MANAGING PROGRAMS
- ENSURE PROCEDURES EMPLOYED PROVIDE APPROPRIATE TRADE-OFFS
- MAINTAIN COMPETITION THROUGHOUT ACQUISITION PROCESS WHEREVER ECONOMICALLY FEASIBLE AND BENEFICIAL

NMI 7100.14B

- IMPLEMENTS POLICIES AND OBJECTIVES OF A-109
- APPLIES TO ALL PROGRAMS DESIGNATED AS MAJOR SYSTEM ACQUISITIONS
    - ESTIMATED CUMULATIVE ACQUISITION COST OF $100M
    - SIGNIFICANTLY NEW OR IMPROVED CAPABILITY DIRECTED AT/CRITICAL TO FULFILLING AGENCY MISSION
    - ACQUISITION WARRANTING SPECIAL MANAGEMENT ATTENTION

NMI 7100.14B

- o RECOGNIZES 2 TYPES OF SYSTEM DESIGN CONCEPT COMPETITION

  - o CLASS 1 - ALTERNATIVE SYSTEM DESIGN CONCEPT (PREFERRED)
    COMPETITION SEEKING ALTERNATIVE METHODS OF ACHIEVING REQUIRED CAPABILITY

  - o CLASS 2 - SINGLE SYSTEM DESIGN CONCEPT
    COMPETITION SEEKING PROPOSALS FOR PREDETERMINED SINGLE DESIGN CONCEPT TO ACHIEVE REQUIRED CAPABILITY

- o BOTH TYPES ACCOMPLISHED UNDER FULL AND OPEN COMPETITION UNLESS APPROPRIATELY JUSTIFIED

MAJOR SYSTEM ACQUISITION PROGRAM PHASES

PHASE A - PRELIMINARY ANALYSIS

PHASE B - DEFINITION

PHASE C/D - DESIGN, FULL-SCALE DEVELOPMENT, OPERATION

PHASE A - PRELIMINARY ANALYSIS

- PRIMARILY AN IN-HOUSE EFFORT
- INVOLVES ANALYSIS OF ALTERNATIVE OVERALL PROJECT CONCEPTS FOR ACCOMPLISHING MISSION
- RESULTS IN STUDY DOCUMENTATION DETAILING FEASIBLE CONCEPT(S) SUITABLE FOR DETAILED STUDY IN PHASE B

PHASE B - DEFINITION

- MAJORITY OF EFFORT CONTRACTED
- INVOLVES DETAILED STUDY/COMPARATIVE ANALYSIS OF PHASE A CONCEPTS
- TECHNOLOGY, DEVELOPMENT SUPPORT REQUIREMENTS DEVELOPED
- TRADE-OFF ANALYSES ACCOMPLISHED
- RESULTS IN PRELIMINARY DESIGNS AND SPECS

PHASE C/D - DESIGN, FULL-SCALE DEVELOPMENT, OPERATION

- o EFFORT ACCOMPLISHED BY CONTRACT
- o INVOLVES DETAILED DEFINITION, HARDWARE DESIGN/DEVELOPMENT
- o RESULTS IN ACTUAL MANUFACTURE, CHECKOUT, OPERATION, EVALUATION OF MAJOR SYSTEM

ADMINISTRATOR APPROVAL OF KEY DECISIONS

(1) MISSION NEED STATEMENT (MNS)

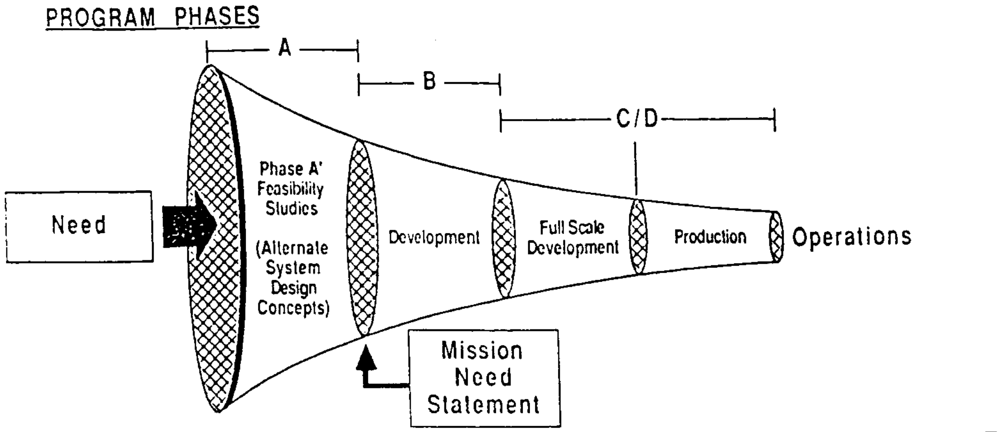
(2) SELECTION OF DESIGN CONCEPTS

RESULT IN
APPROVAL TO PROCEED WITH PHASE B

(3) REAFFIRMATION OF MNS

RESULT IN
COMMITMENT OF AGENCY TO FULL-SCALE DEVELOPMENT

NASA NMI 7100.14B ACQUISITION PROCESS (OMB Circular A-109)



Administrator's Approvals	When	Rationale
• Mission Need Statement	Prior to Phase B	• Identify Need, Priority, and Resources
• Approves Selection of System Design Concepts	Prior to Phase B	• Selects System Design Concepts to be Pursued in Phase B
• Approval to Proceed/Reaffirm Mission Need Statement	• Prior to Phase C/D and Prior to Separate Phase D, if Applicable	• Reverify Mission Need and Value to Agency

PROCUREMENT PROCESS

o PHASE B AND PHASE C/D CONDUCTED UNDER FULL AND OPEN COMPETITION UNLESS JUSTIFIED

o PROCUREMENTS CONDUCTED IN ACCORDANCE WITH SOURCE EVALUATION BOARD HANDBOOK

SOLICITATION FOR PHASE B - CLASS 1 TYPE

- OUTLINES BROAD ALTERNATIVE SYSTEM DESIGN CONCEPTS SELECTED
- DEFINED IN TERMS OF MISSION NEEDS, SCHEDULE OBJECTIVES, COST OBJECTIVES, OPERATING CONSTRAINTS
- UNCONSTRAINED BY PREDETERMINED CONFIGURATIONS, SPECS, OR EQUIPMENT APPROACHES TO
- GAIN BENEFITS OF INDUSTRY INNOVATION AND COMPETITION

SOLICITATION FOR PHASE B - CLASS 2 TYPE

- SPECIFIES SINGLE CONCEPT TO BE PURSUED
- NO ALTERNATIVE CONCEPTS REQUESTED/REQUIRED
- NEED EXPLAINED WITHIN MISSION TERMS, SCHEDULE OBJECTIVES, AND OPERATING CONSTRAINTS

(CONSIDERED ONLY WHEN JUSTIFIED BY URGENCY OF NEED OR PHYSICAL/FINANCIAL IMPRACTICALITY OF DEMONSTRATING ALTERNATIVES)

PHASE B SOLICITATIONS (CLASS 1 AND CLASS 2)

- o SOLICIT BROAD BASE OF QUALIFIED SOURCES
- o INFORM OFFERORS FOLLOW-ON RFP'S WILL BE SENT
  - O WITHOUT REQUEST TO OFFERORS SELECTED FOR PHASE B WHO SUCCESSFULLY PROVE THEIR DESIGN CONCEPTS
  - o UPON REQUEST TO OTHER POTENTIAL OFFERORS
- o NOTIFY OFFERORS OF POSSIBILITY THAT ALL PHASE B CONCEPT STUDY RESULTS (MINUS PROPRIETARY DATA) MAY BE MADE AVAILABLE FOR OPEN COMPETITION FOR CONTINUED CONCEPT STUDIES OR FOR PHASE C/D

  IF

  NASA DETERMINES CONCEPTS PROPOSED UNDER PHASE B CONTRACTS DO NOT ADEQUATELY FULFILL MISSION NEED OBJECTIVES
- o PROVIDE, TO EXTENT KNOWN, OPERATIONAL TEST CONDITIONS, MISSION PERFORMANCE CRITERIA, LIFE CYCLE COST FACTORS TO BE USED IN EVALUATION AND SELECTION OF SYSTEMS FOR PHASE C/D
- o SOLICITATION RESULTS IN PARALLEL, SHORT-TERM, FIXED-PRICE CONTRACTS

DISSEMINATION/EXCHANGE OF INFO UNDER PHASE B

- RESULTS OF PRIOR STUDIES MADE AVAILABLE TO POTENTIAL OFFERORS
- DISCLOSURE/CORRECTION OF WEAKNESSES AFTER SELECTION OF A PHASE B CONTRACTOR PERMITTED (BUT AVOID TECHNICAL LEVELING)
- TECHNICAL TRANSFUSION/CROSS-FERTILIZATION NORMALLY PROHIBITED

SOLICITATIONS FOR PHASE C/D

STRUCTURED TO ELICIT FOR SEB'S EVALUATION AND SSO'S CONSIDERATION DATA SUCH AS:

- SYSTEM CONCEPT PERFORMANCE MEASURED AGAINST NEED AND OBJECTIVES
- RISKS AND POTENTIAL RESOLUTION
- ESTIMATED ACQUISITION AND OWNERSHIP COSTS
- CONTRACTOR'S DEMONSTRATED MANAGEMENT, FINANCIAL, AND TECHNICAL CAPABILITIES TO MEET PROGRAM OBJECTIVES

SUMMARY

- o COMPETITIVE A-109 PROCESS MAKES SENSE
- o PROVIDES
  - o SYSTEMATIC, INTEGRATED MANAGEMENT APPROACH
  - o APPROPRIATE MANAGEMENT-LEVEL INVOLVEMENT
  - o INNOVATION AND "BEST IDEAS" FROM PRIVATE SECTOR IN SATISFYING MISSION NEEDS

N91-28269

PRESENTATION 4.4.7

ADVANCED LAUNCH SYSTEM

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THE CASE FOR TEAMING ON THE ALS-STME PROGRAM

PREPARED BY S.F.MOREA 6/20/90

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AGENDA

- BACKGROUND
- VIABILITY OF INDUSTRY COMPETITIVENESS
- POLICY
- ACQUISITION STRATEGY
  - PROCUREMENT OBJECTIVES
  - TEAMING BENEFITS
- CONCLUSION/SUMMARY

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BACKGROUND

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ALS & STME SITUATION

- DOD BUDGET UNCERTAINTIES AND CUTS
  - PRECLUDES FY 92 ALS VEHICLE AND ENGINE FSD START
  - MAJOR CUTS TO VEHICLE STUDIES & NON PROP. ADP'S
- DOD & NASA HAVE AGREED TO PROCEED WITH A PROTOTYPE ENGINE PROGRAM IN FY-92
  - CONSISTENT WITH NASA ADV COMMITTEE RECOMMENDATIONS
  - CONSISTENT WITH DSB RECOMMENDATIONS
  - ENDORSED BY ALS SYSTEM CONTRACTORS
  - NASA CONSIDERING SIGNIFICANT BUDGET SUPPORT

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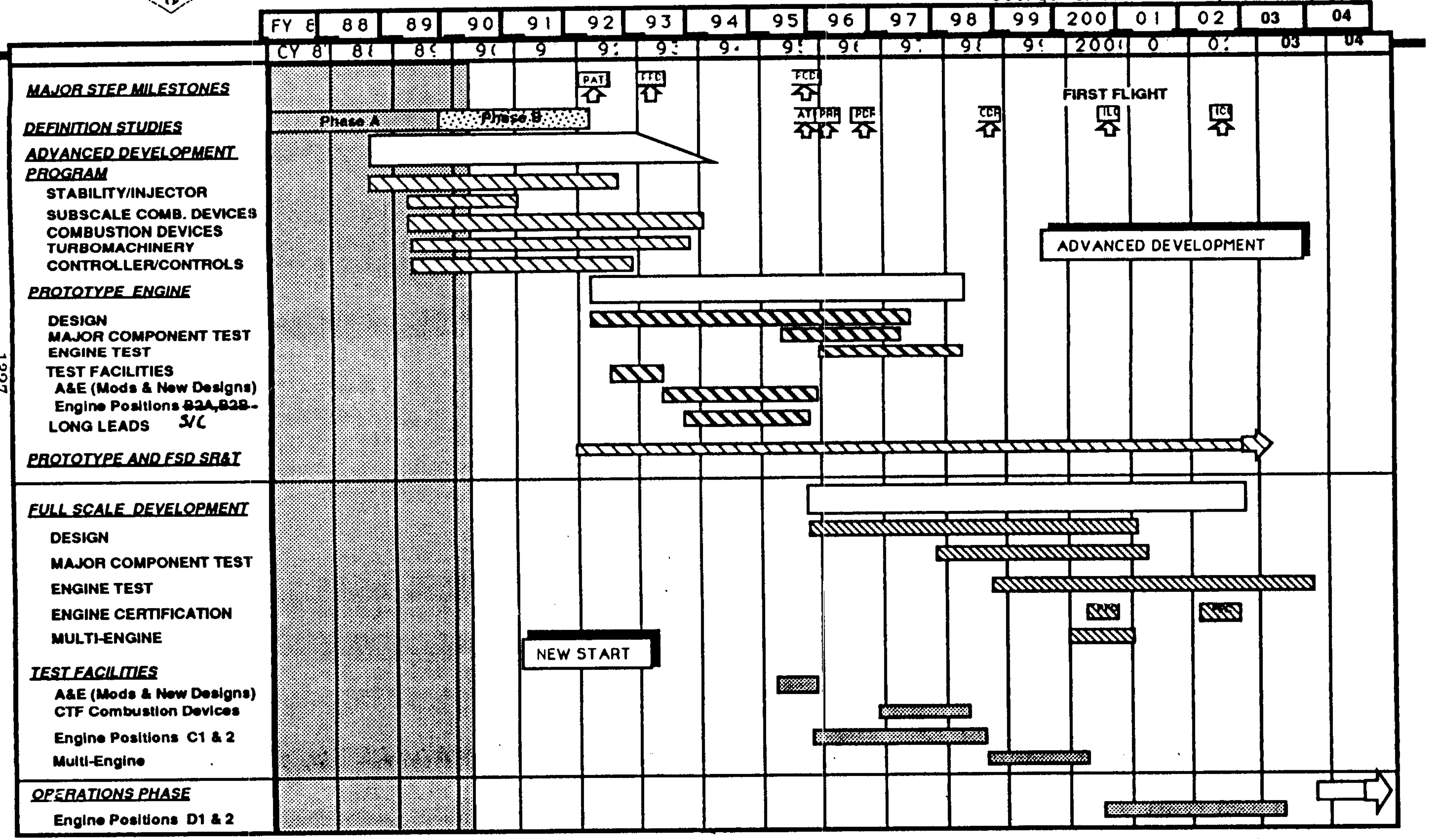

VIABILITY OF THE ROCKET ENGINE INDUSTRY COMPETITIVENESS

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CONCERN

- USA COMPETITIVENESS IN LARGE LIQUID ROCKET ENGINES IN SERIOUS JEOPARDY
  - THIS NATION NO LONGER LEADS THE WORLD IN ROCKET ENGINE DEVELOPMENT
    - NEW LOX/LH2 ENGINES ARE UNDER DEVELOPMENT IN :
      - EUROPE (1st FLIGHT EXPECTED IN 1995)
      - JAPAN (1st FLIGHT EXPECTED IN 1995)
      - USSR (UNDER DEVELOPMENT SINCE MID 1980'S)
  - NO NEW LARGE ROCKET ENGINE DEV INITIATED IN USA SINCE 1970

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LARGE LIQUID ROCKET ENGINE DEVELOPMENT PROGRAMS IN THE USA

ENGINE	THRUST	PROPELLANT	CONTRACTOR	APPLICATION	STATUS
S-3 (S-3D/E/F)	150K	LOX/KEROSENE	ROCKETDYNE	JUPITER THOR	DEV & PROD. COMP.1960
H-1	188K	LOX/RP-1	ROCKETDYNE	SATURN 1/1B	DEV & PROD. COMP.1961
F-1	1,500K	LOX/RP-1	ROCKETDYNE	SATURN V	DEV & PROD. COMP.1967
RL-10	15K	LOK/LH2	PRATT & WHITNEY	CENTAUR	D & P COMP 1963
RL-10-A3	16.5K			S-IV	D & P COMP 1964
RL-10-A3/3A	16.5K			ATLAS/TITAN	D & P COMP 1965
RL-10-A4	20.8K			ATLAS C	QUAL. COMP 1990
J-2	205K	LOX/LH2	ROCKETDYNE	S-II/S-IVB	D & P COMP 1966

* NOTE: THIS A STRICTLY COMMERCIAL ENGINE DEVELOPED FOR GENERAL DYNAMICS COMMERCIAL ATLAS/CENTAUR PROGRAM.

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LARGE LIQUID ROCKET ENGINE DEVELOPMENT PROGRAMS IN THE USA

ENGINE	THRUST	PROPELLANT	CONTRACTOR	APPLICATION	STATUS
M-1	1,500K	LOX/LH2	AEROJET	NOVA	DEV CANCELED 1967
LR-87	548K	STORABLES	AEROJET	TITAN (1ST STG)	PRODUCTION
LR-91	105K	STORABLES	AEROJET	TITAN (2ND STG)	PRODUCTION
SSME	470K	LOX/LH2	ROCKETDYNE	SHUTTLE	IN PRODUCT MPROVEMENT PHASE

CONCLUSION: COMPETITIVENESS OF THE THREE (3) LARGE LIQUID ENGINE CONTRACTORS IN THE USA SERIOUSLY ERODED SINCE THE 1960'S.

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CONCERN

- COMPETITION WITHIN USA ON LARGE LIQUID ROCKET ENGINES IN SERIOUS JEOPARDY
  - OF THE THREE RECOGNIZED ENGINE PRIME CONTRACTORS...
    - ONLY TWO HAVE RECENT LOX/LH2 ENGINE DEV EXPERIENCE
    - ONLY ONE HAS LARGE LOX/LH2 SYSTEM LEVEL EXPERIENCE
  - OPPORTUNITIES FOR NEW ENGINE DEVELOPMENTS IN THE NEAR FUTURE ARE VERY LIMITED.

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CONCERN

- OPEN COMPETITION CAN BE DETRIMENTAL TO THE BEST INTERESTS OF THE GOVERNMENT UNDER CERTAIN CIRCUMSTANCES
  - WHERE BUDGETS DO NOT ALLOW FOR THE DEVELOPMENT OF MULTIPLE SOURCES AND ALTERNATE COMPETING DESIGNS , AND.........
  - WHERE VERY SMALL MARKETS EXISTS, AND.....
  - WHERE LIMITED QUALIFIED COMPETITORS EXIST.......
  - A SOLE SOURCE WILL RESULT !!!

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POLICY

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POLICY

- **SUPPORT AND PROVIDE FOR THE LARGE LIQUID ROCKET ENGINE NEEDS OF THIS NATION**
  - MAINTAIN A VIGOROUS ROCKET ENGINE INDUSTRY IN THE USA FOR LARGE SIZE , LATEST TECHNOLOGY LIQUID ROCKET ENGINES.
    - KEEP USA FROM RELINQUISHING ITS PREEMINENCE IN LARGE LIQUID ROCKET ENGINES.
    - ALLOW USA TO BETTER COMPETE IN THE INTERNATIONAL COMMERCIAL ARENA.
    - AVOID POTENTIAL DEPENDENCY ON OTHER NATIONS FOR OUR NEXT GENERATION OF LARGE LIQUID ROCKET ENGINES.

POLICY SPECIFIC

- **CONDUCT AN STME PROTOTYPE ENGINE PROGRAM THAT:**
  - PROVIDES FOR THE LARGE LIQUID ROCKET ENGINE NEEDS OF THE NATION
  - MINIMIZES FULL SCALE DEVELOPMENT COST AND SCHEDULE OF NEXT GENERATION LARGE LIQUID ROCKET ENGINE
    - SIMILAR DOD/AF PROTOTYPE APPROACHES HIGHLY SUCCESSFUL (ie. F-16)
  - FACILITATES SYNERGISM BETWEEN THE PARTICIPATING CONTRACTORS TO OBTAIN THE BEST AND UNIQUE IDEAS, CAPABILITIES, AND TECHNOLOGIES LEADING TO THE BEST OVERALL DESIGN.
  - PRECLUDES A SINGLE CONTRACTOR FROM BECOMING A FUTURE "SOLE SOURCE".
    - AVOID A "WINNER TAKE ALL" PROCUREMENT APPROACH.

ACQUISITION STRATEGY

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PROCUREMENT OBJECTIVE

- **IMPLEMENT TEAMING NOW ON THE EXISTING ARRAY OF PHASE B, AND ADP CONTRACTS.**
  - TEAM AEROJET, PRATT & WHITNEY, AND ROCKETDYNE
  - USE TEAM TO FACILITATE ENGINE CYCLE DECISION
  - USE TEAM TO HELP RESTRUCTURE TOTAL PROGRAM TO ARRIVE AT AN INTEGRATED PLAN CONVERGING TO A PROTOTYPE ENGINE DESIGN.
- **CONDUCT THE PROTOTYPE PROGRAM WITH TEAM OF THE 3 STME PRIME CONTRACTORS.**
  - AWARD CONTRACT IN FY-92 TO TEAM OF AEROJET, PRATT & WHITNEY, AND ROCKETDYNE
  - PROTOTYPE PROVIDES PROOF OF CONCEPT

BENEFITS OF TEAMING

- MAINTAINS A VIGOROUS INDUSTRY FOR LARGE LIQUID ROCKET ENGINES IN THE USA.
  - RETAINS USA'S PREEMINENCE AND LEADERSHIP IN THE FIELD
  - MAKES USA MORE COMPETITIVE IN THE INTERNATIONAL ARENA
  - AVOIDS SINGLE CONTRACTOR FROM BECOMING A SOLE SOURCE FOR LARGE LIQUID ROCKET ENGINES
- ENHANCES COMPETITION FOR THE FUTURE

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BENEFITS OF TEAMING (cont'd)

- WITHIN THE BUDGET CONSTRAINTS, TEAMING HAS THE POTENTIAL FOR THE <u>BEST PRODUCT</u> AT <u>REDUCED DEVELOPMENT COSTS</u>
  - <u>SYNERGISM</u> OF THE PRIME COMPANIES AND GOV'T WORK
  - <u>AVOIDS CONTRACTORS WITHHOLDING BEST IDEAS</u> AND TECHNOLOGIES BECAUSE OF THE COMPETITIVE ENVIRONMENT
    - ALLOWS BEST COMPONENT DESIGNS TO EMERGE WITHIN BEST ENGINE SYSTEM DESIGN
    - CONSISTENT WITH ALS TOTAL QUALITY MANAGEMENT REQ'T
    - ALLOWS EARLY CONVERGENCE TO A SINGLE ENGINE DESIGN
  - <u>ELIMINATES DUPLICATION</u> OF EFFORTS AT THE 3 CONTRACTORS

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CONCLUSION/SUMMARY

ADVANCED LAUNCH SYSTEM

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CONCLUSION/SUMMARY

- THE NATION NEEDS TO PROCEED WITH A NEW LOX/LH2 ROCKET ENGINE PROGRAM NOW !
- OPEN COMPETITION NOW WILL HAVE DELETERIOUS IMPACTS ON THE COMPETITIVE VIABILITY OF THE LIQUID ROCKET ENGINE INDUSTRY
- TEAMING PROVIDES A WAY TO SOLVE TODAYS CONCERNS WHILE ENHANCING THE OPTION FOR OPEN COMPETITION IN THE FUTURE

N91-28270

PRESENTATION 4.4.8

SPACE SHUTTLE MAIN ENGINE

CERTIFICATION

FOR

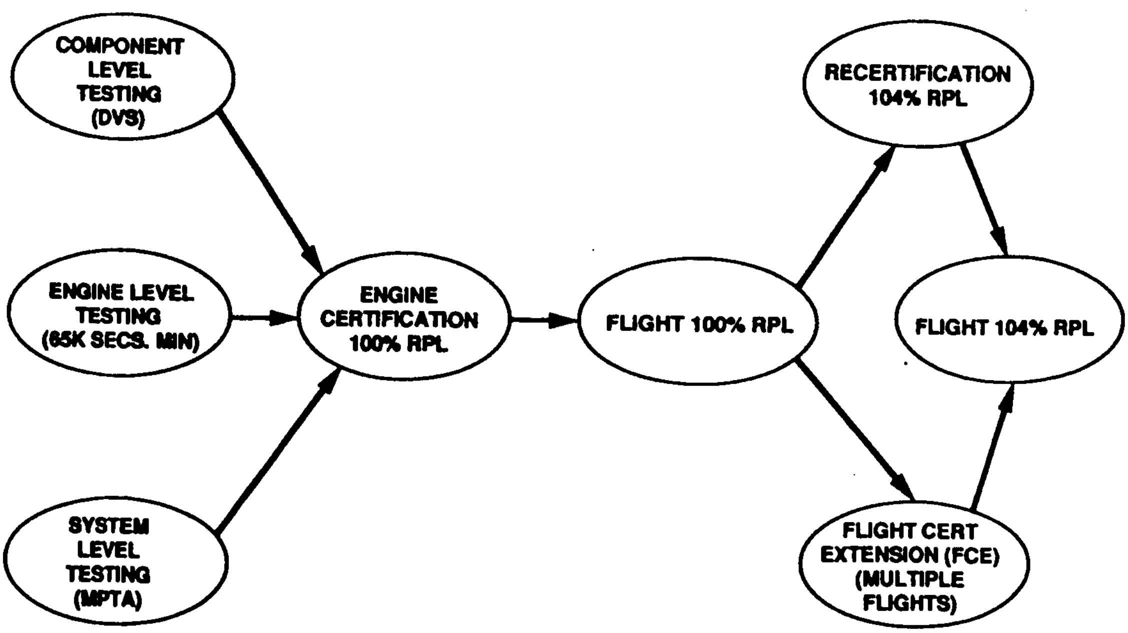
MANNED SPACE FLIGHT

RONALD G. WEESNER
PENN STATE PROP. SYMPOSIUM
JUNE, 1990

SSME IS FIRST REUSABLE LARGE LIQUID ROCKET ENGINE

• FULL POWER LEVEL (FPL) 109%	512,300 LBS
• RATED POWER LEVEL (RPL) 100%	470,000 LBS
• CHAMBER PRESSURE	3200 PSIA
• SPECIFIC IMPULSE AT ALTITUDE	435.5 SECONDS
• THROTTLE RANGE	65 TO 109%
• PROPELLANTS	OXYGEN/HYDROGEN
• WEIGHT	7000 LBS
• DESIGN LIFE	27,00 SECONDS 55 STARTS
• AT FULL POWER LEVEL	14,000 SECONDS

SSME CERTIFICATION PROCESS



SSME DEVELOPMENT/CERTIFICATION

- SSME REQUIREMENTS IDENTIFIED IN NASA APPROVED DOCUMENTS
- DESIGN VERIFICATION SPECIFICATIONS (DVS) USED TO DEFINE REQUIREMENTS AND METHOD OF VERIFICATION
- DETAILED AND COMPLETE PLANS PROVIDE FOR VERIFICATION OF EACH REQUIREMENT
  - LABORATORY TESTS, COMPONENT TESTS AND ENGINE TESTS
- TESTS PLANNED TO EXPOSE PROBLEMS EARLY
  - OFF LIMITS TESTING/MALFUNCTION TESTING/MARGIN TESTS
- ENGINE CERTIFICATION (CULMINATION OF DEVELOPMENT PROCESS)
  - TWO CERTIFICATION CYCLES ON EACH OF TWO ENGINES
  - CERTIFICATION CYCLE - 10 TESTS AND 5000 SECONDS

DESIGN VERIFICATION SPECIFICATIONS (DVS)

- ESSENTIALLY 25 LEVEL IV CEI'S CATEGORIZED BY MAJOR COMPONENT AND/OR SUBSYSTEM
- PROVIDES ALL DESIGN AND VERIFICATION REQUIREMENTS AT COMPONENT LEVEL
- PROVIDES TRACEABILITY TO THE CEI/ICD

DOCUMENT	TITLE
DVS-SSME-101	SPACE SHUTTLE MAIN ENGINE
DVS-SSME-102	GIMBAL BEARING ASSEMBLY
DVS-SSME-106	POGO SUPPRESSION SYSTEM
DVS-SSME-201	CONTROLLER - VOLUME 1
DVS-SSME-201	CONTROLLER SOFTWARE - VOLUME 2
DVS-SSME-202	ELECTRICAL HARNESS ASSEMBLY
DVS-SSME-203	INSTRUMENTATION SYSTEM
DVS-SSME-204	FLOWMETERS FOR LH2 AND LO2 SERVICE
DVS-SSME-205	IGNITION SYSTEM
DVS-SSME-206	FASCOS CONTROLLER
DVS-SSME-303	THRUST CHAMBER ASSEMBLY
DVS-SSME-304	HOT GAS MANIFOLD
DVS-SSME-305	FUEL AND OXIDIZER PREBURNER ASSEMBLIES
DVS-SSME-401	LPOTP ASSEMBLY

DOCUMENT	TITLE
DVS-SSME-402	LPFTP ASSEMBLY
DVS-SSME-403	HPOTP ASSEMBLY
DVS-SSME-404	HPFTP ASSEMBLY
DVS-SSME-508	CHECK VALVES
DVS-SSME-510	PNEUMATIC CONTROL ASSEMBLY
DVS-SSME-511	FLEXIBLE AND HARD DUCTS AND LINE ASSEMBLIES
DVS-SSME-512	HYDRAULIC ACTUATION SYSTEM
DVS-SSME-513	HEAT EXCHANGER
DVS-SSME-514	STATIC SEALS
DVS-SSME-515	PROPELLANT VALVES
DVS-SSME-516	FUEL AND OXIDIZER BLEED VALVE ASSEMBLIES
DVS-SSME-517	POGO SUPPRESSION SYSTEM VALVE ASSEMBLIES

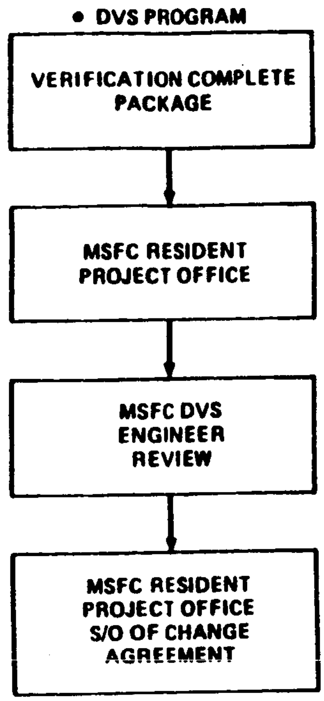
TOTAL LABORATORY DVS TEST SUMMARY
ALL COMPONENTS

THRUST CHAMBER	131	PNEUMATIC CONTROL ASSY	303
PREBURNERS	70	INSTRUMENTATION SYSTEM	70
CONTROLLER	192	CHECK VALVES	173
HIGH-PRESSURE FUEL T/P	365	HEAT EXCHANGER	22
HIGH-PRESSURE LOX T/P	830	STATIC SEALS	100
LOW-PRESSURE FUEL T/P	100	GINBAL BEARING	2
LOW-PRESSURE LOX T/P	96	DUCTS AND LINES	528
IGNITION SYSTEM	789	FLOWMETER	7
HYDRAULIC ACTUATION SYS	228	ENGINE SYSTEM	12
ELECTRICAL HARNESSES	85	POGO SYSTEM	125
HOT GAS MANIFOLD	40	POGO VALVES	276
PROPELLANT VALVES	38	FASCOS	16
BLEED VALVE	29	TOTAL	4627

COMPONENT HOT-FIRE TEST SUMMARY

TEST	NUMBER OF TESTS
SUBSCALE THRUST CHAMBER AND MAIN COMBUSTION CHAMBER AUGMENTED SPARK IGNITER	236
IGNITION SYSTEMS AND PREBURNERS	918
THRUST CHAMBERS	94
OXIDIZER TURBOPUMPS	70
FUEL TURBOPUMPS	100
TOTAL	1418

VERIFICATION COMPLETE APPROVAL FLOW
VERIFICATION COMPLETE PACKAGE



- **ENGINE LEVEL TESTING**
  - **PROGRAM REQUIREMENT OF 65,000 SECONDS TO DEMONSTRATE FLIGHT WORTHINESS**
  - **619 STARTS/79,235 SECONDS ACCUMULATED PRIOR TO STS-1**
- **SYSTEM LEVEL TESTING (MPTA)**
  - **SYSTEMS LEVEL TESTING TO VERIFY MPS COMPATIBILITY AND PERFORMANCE**
  - **TEST ARTICLE CONSISTED OF 3 SSME'S, ET, ORBITER SIMULATOR, ETC.**
  - **TEST PROGRAM INCLUDED STRUCTURAL RESONANT SURVEYS, PROPELLANT LOADING TESTS, AND 12 HOT FIRINGS**
  - **54 STARTS / 11,326 SECONDS ACCUMULATED PRIOR TO STS-1**

- FLIGHT CERTIFICATION PROGRAM
  - CERTIFICATION DEMONSTRATION TEST PROGRAM
  - TWO CERT CYCLES ON EACH OF TWO FLIGHT CONFIGURATION ENGINES
  - EACH CERT CYCLE CONSISTED OF 10 STARTS/5000 SECONDS
  - INCLUDED OVERSTRESS TESTING AND ABORT SIMULATION
  - SSME CERTIFIED FOR 100% RPL OPERATION
  - 109% RPL ABORT CAPABILITY DEMONSTRATED
  - 51 STARTS/19,858 CERT SECONDS ACCUMULATED PRIOR TO STS-1
- TOTAL HOT-FIRE TEST EXPERIENCE PRIOR TO STS-1:

  >110,000 SECONDS
  >720 STARTS
- STS-1 THROUGH STS-5 FLOWN AT 100% RPL

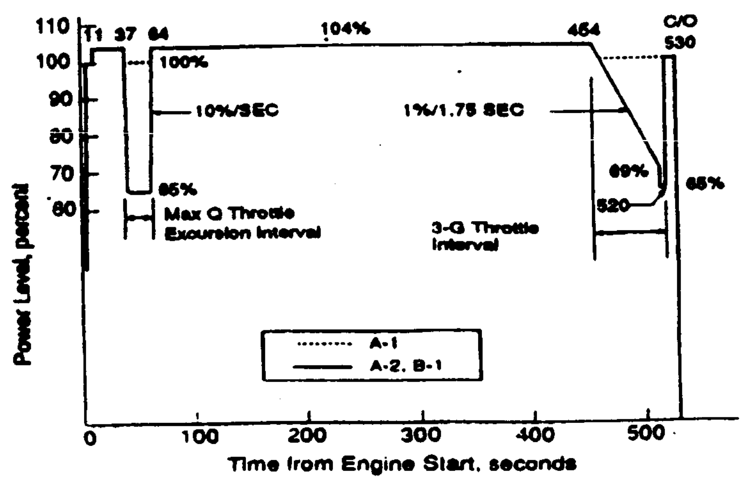
CERTIFICATION EXPERIENCE PRIOR TO STS-6 104% POWER LEVEL

- RE-CERTIFICATION (104% RPL)
  - FOUR CERT CYCLES COMPLETED (52 STARTS/20,710 SECONDS)
  - ENGINE CERTIFIED FOR 104% RPL OPERATION
- ENGINE DEVELOPMENT TESTING
  - 812 STARTS/117,514 SECONDS CUMULATIVE TOTAL PRIOR TO STS-6
- STS-6 AND SUBS WERE FLOWN AT 100% OR 104% RPL

10-TEST CERTIFICATION CYCLE/TYPICAL PROFILE

Table 1A. Certification Test Requirements
Sample No. 1

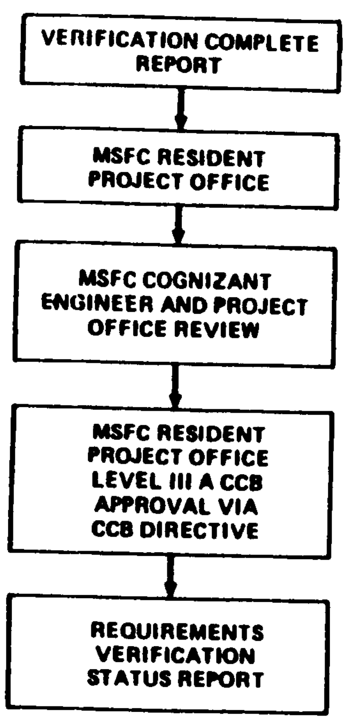
Test	Thrust Profile	Objective	Mainstage Duration, sec				
			Total	109%	104%	100%	Other
1	1	104% Nominal Mission	520		416		104
2	1	104% Nominal Mission	520		416		104
3	1	104% Nominal Mission	520		416		104
4	2	109% Nominal Mission	503	381			122
5	2	109% Nominal Mission	503	381			122
6	1	104% Nominal Mission	520		416		104
7	4B	104% Abort - AOA	623		581		42
8	3A	109% Abort - RTLS	761	518		194	49
9	1	104% Nominal Mission	520		416		104
10	1	104% Nominal Mission	520		416		104
		Minimum Cum	5510	1280	3077	194	959



CERTIFICATION EXPERIENCE POST-51L (RETURN TO FLIGHT)

- 39 CHANGES CERTIFIED AND INCORPORATED PRIOR TO STS-26R
  - CUMULATIVE TESTING DURING PERIOD - 234 STARTS/89,384 SECONDS
- PRIMARILY CHANGES TO IMPROVE LIFE OF PUMPS AT FPL
  - REDUCED FUEL TURBINE TEMPERATURE
  - IMPROVED TURBINE BLADES
  - IMPROVE DYNAMIC STABILITY OF HPOTP
  - INCREASED HPOTP BEARING LIFE
- TWO 5000-SECOND CERTIFICATIONS REQUIRED FOR MODIFICATIONS

VERIFICATION COMPLETE APPROVAL FLOW
VERIFICATION COMPLETE REPORT



CERTIFICATION REQUIREMENTS (CONT'D)

- FLIGHT CERTIFICATION EXTENSION (FCE) RSS-8503-2E
  - VERIFY SSME CAPABILITY FOR EXTENDED LIFE
  - MAINTAIN A FACTOR OF TWO ON STARTS/DURATION ON TWO SAMPLES WITH A LEAD TIME OF TWO YEARS OVER FLIGHT PROGRAM (2X2X2 RULE)
- FLEET LEADER CRITERIA (RF005-009)
  - CERTIFIED HARDWARE IS RESTRICTED FOR FLIGHT USE TO 50% OF THE FLEET LEADER EXPOSURE
  - LOWER LIFE LIMITS (RESULTING FROM PART FAILURE, ANALYSIS OR EMPIRICAL DATA) CAN BE IMPOSED BY DEVIATION APPROVAL REQUESTS (DAR)

IN RETROSPECT...

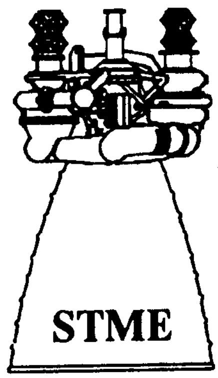
- STRUCTURED COMPONENT DEVELOPMENT YIELDED HIGH RETURN ON INVESTMENT - SHOULD HAVE BEEN EXPANDED
- EXTENSIVE GROUND TEST PROGRAM WHICH BRACKETED FLIGHT OPERATIONS ASSURED SAFE FLIGHTS
- SYSTEM LEVEL TEST PROVIDED NECESSARY VALIDATION OF ELEMENT INTERACTIONS
- SOPHISTICATED HIGH POWER/DENSITY RATIO DESIGNS COMPROMISE RELIABILITY, MANUFACTURING AND COST. ROBUST DESIGNS RECOMMENDED
- HARDWARE UNDERSUPPORT FOR FAB., ASSEMBLY AND TEST REQUIRES COMPROMISE AND CONCESSION IN EVERY ASPECT OF THE PROGRAM AND SHOULD BE VIGOROUSLY AVOIDED
- MATERIAL CHARACTERIZATION, WELD ASSESSMENT AND STRUCTURAL AUDIT SHOULD BE EARLY IN THE PROGRAM AND VERY THOROUGH
- PROGRAM COULD HAVE GREATLY BENEFITED FROM TODAY'S CFD TECHNOLOGY - ALSO CAD/CAM, TQM
- AVIONICS SIMULATION LAB FOR SOFTWARE VALIDATION PROVED TO BE MAJOR PROGRAM ASSET
- MAINTAINABILITY AND CONDITION MONITORING FEATURES WERE EXCELLENT AND SHOULD HAVE BEEN MORE EXTENSIVE
- EFFORT TO MINIMIZE CRITICALITY 1 FAILURES SHOULD HAVE BEEN MORE INTENSIVE IN THE INITIAL DESIGN PHASE
- COMPUTER CONTROLLED ENGINE OFFERS GREAT FLEXIBILITY AND WAS A DEFINITE PLUS

N91-28271

PRESENTATION 4.4.9

SPACE TRANSPORTATION MAIN ENGINE

RELIABILITY AND SAFETY



SPACE TRANSPORTATION PROPULSION TECHNOLOGY SYMPOSIUM
PENNSYLVANIA STATE UNIVERSITY

JAN C. MONK
GEORGE C. MARSHALL SPACE FLIGHT CENTER

June 27, 1990

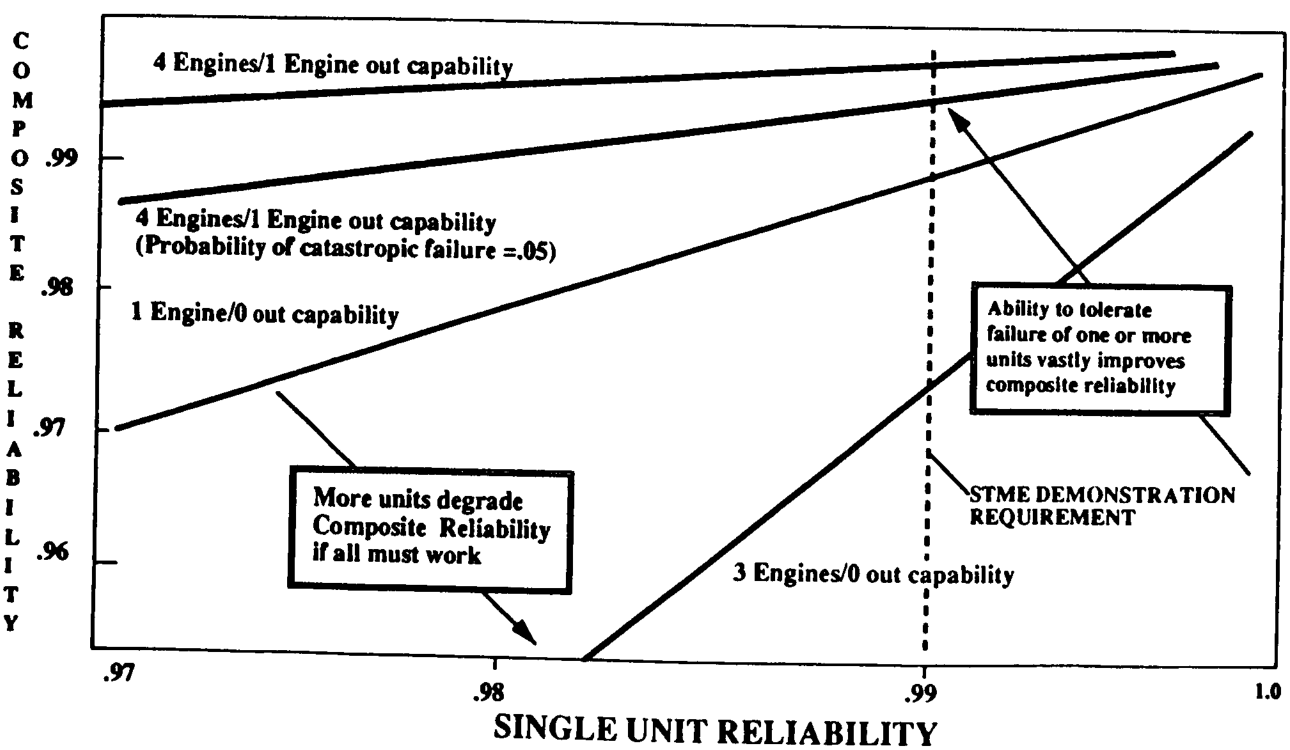
STME RELIABILITY AND SAFETY

ALS/STME APPROACH

- VEHICLE ENGINE-OUT CAPABILITY/HOLD DOWN
- EMPLOY TOTAL QUALITY MANAGEMENT
- SIMPLE, ROBUST DESIGN
- KNOWN CHARACTERISTICS

STME RELIABILITY AND SAFETY

Vehicle Engine Out Capability Provides A Significant Improvement In System Reliability



STME RELIABILITY AND SAFETY

TOTAL QUALITY MANAGEMENT (TQM)

STME RELIABILITY AND SAFETY

THE GOAL IS TO DEVELOP A ROBUST DESIGN

STME QUALITY APPROACH

DESIGN IT RIGHT

CONCURRENT ENGINEERING
VARIABILITY REDUCTION
QUALITY FUNCTION DEPLOYMENT
QUALITY ENGINEERING

BUILD IT RIGHT

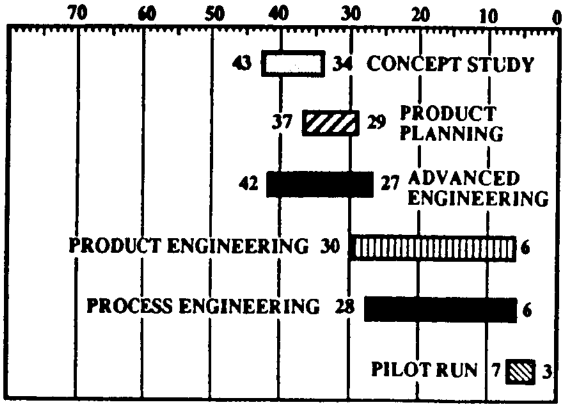
IN-PROCESS MONITORING
STATISTICAL PROCESS CONTROL
CONTINOUS PROCESS IMPROVEMENT

STME RELIABILITY AND SAFETY

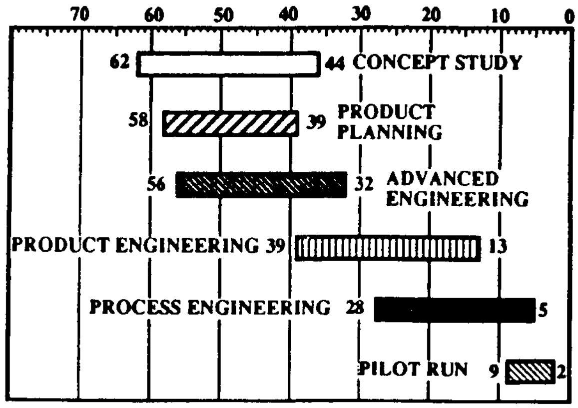
CONCURRENT ENGINEERING (Cont'd)

- **CAN SHORTEN PRODUCT DEVELOPMENT LEAD TIME**
  - OVERLAPPING PROBLEM-SOLVING INSTEAD OF SEQUENTIAL PHASES
  - AVERAGE PRODUCT LEAD TIME FOR JAPANESE AUTO MAKERS IS 43 MONTHS, COMPARED TO 62 MONTHS IN U.S.
  - RESULT IS BETTER PRODUCT AT LOWER COST

DEVELOPMENT LEAD TIME (months before market introduction)
JAPAN: 12 SAMPLES



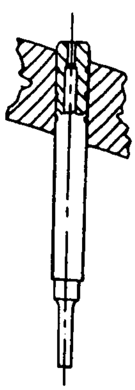
DEVELOPMENT LEAD TIME (months before market introduction)
U.S.: SAMPLES



REFERENCE: PROFESSOR K. CLARK, HARVARD BUSINESS SCHOOL, 1987

STME RELIABILITY AND SAFETY

IMPACT OF CONCURRENT ENGINEERING ON ROCKETDYNE STME MAIN INJECTOR ELEMENTS

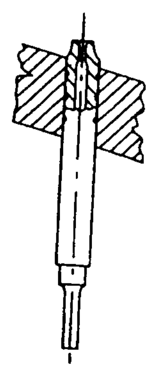


- Drilled from solid bar
- All surfaces require machining

Estimate for 600 elements

400 Hours

Original Concept



- Made from heavy wall tubing
- Swage one end to achieve entrance diameter
- Bulk of tube requires no I.D. Machining

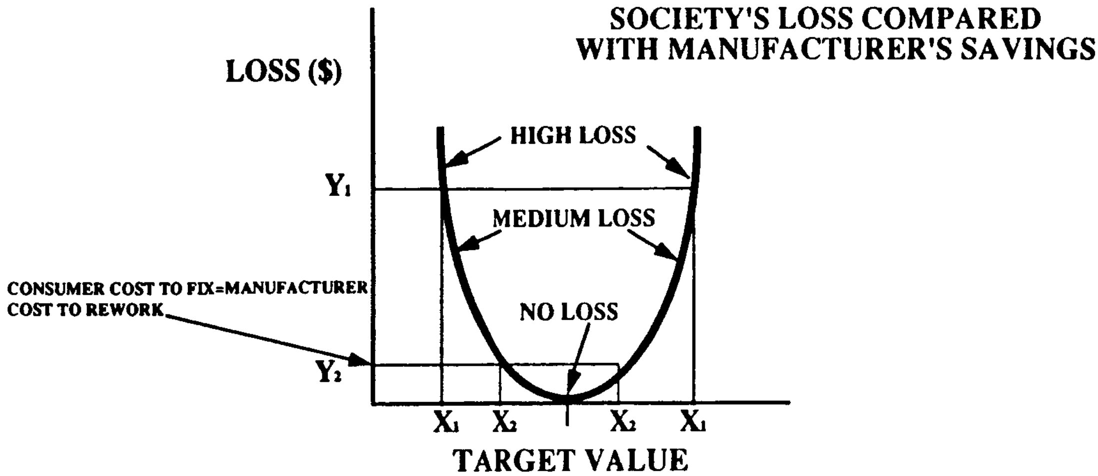
Estimate for 600 elements

204 Hours

After Concurrent Engineering

**FEWER OPERATIONS =
LESS CHANCE OF ERROR =
IMPROVED RELIABILITY**

TAGUCHI LOSS FUNCTION



THE PHRASE" GOOD ENOUGH FOR GOVERNMENT WORK" ISN'T GOOD ENOUGH ANYMORE

STME RELIABILITY AND SAFETY

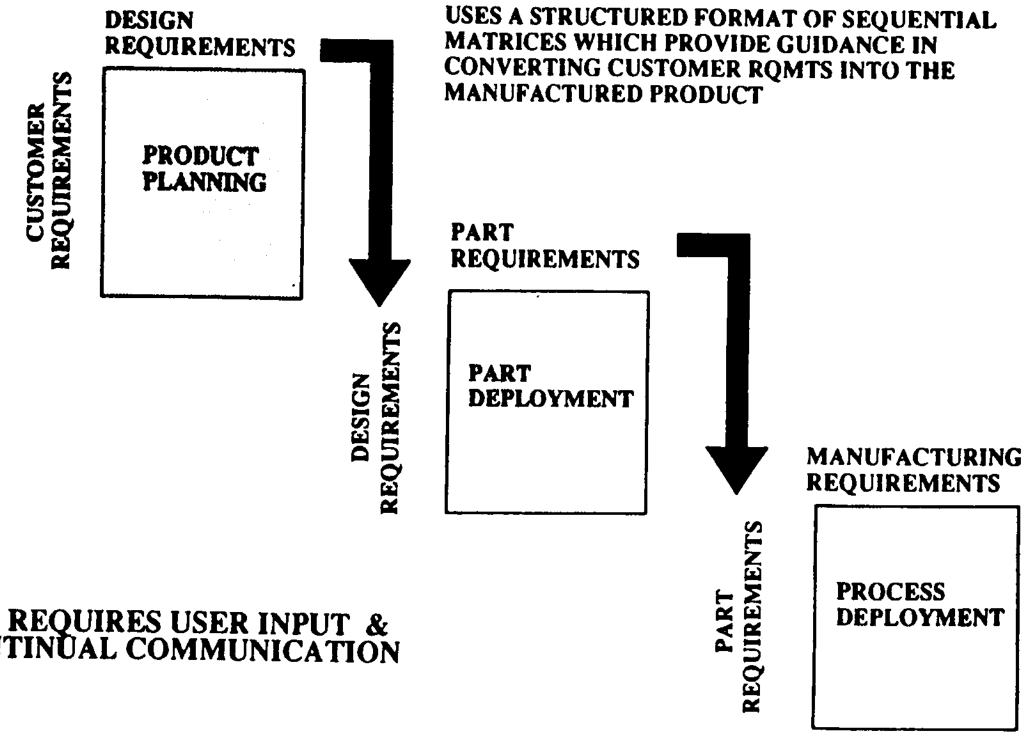
REDUCING PROCESS VARIABILITY PRODUCES A PRODUCT WITH IMPROVED RELIABILITY AND SAFETY

REDUCED PROCESS VARIABILITY = IMPROVED RELIABILITY AND SAFETY

STME RELIABILITY AND SAFETY

QFD MATRICES

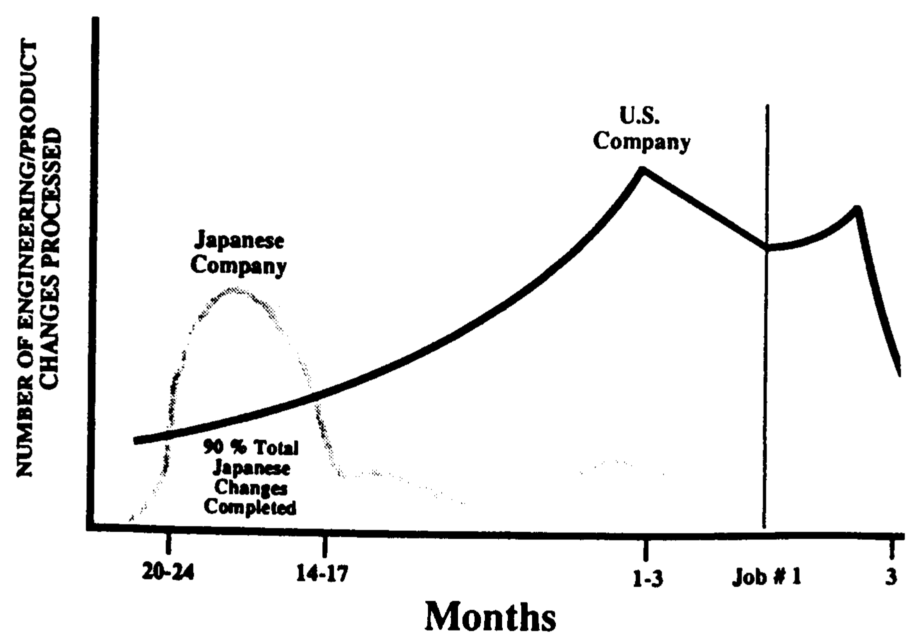
USES A STRUCTURED FORMAT OF SEQUENTIAL MATRICES WHICH PROVIDE GUIDANCE IN CONVERTING CUSTOMER RQMTS INTO THE MANUFACTURED PRODUCT



QFD REQUIRES USER INPUT & CONTINUAL COMMUNICATION

STME RELIABILITY AND SAFETY

IMPACT OF EARLY DEFINITION AND ENGINEERING



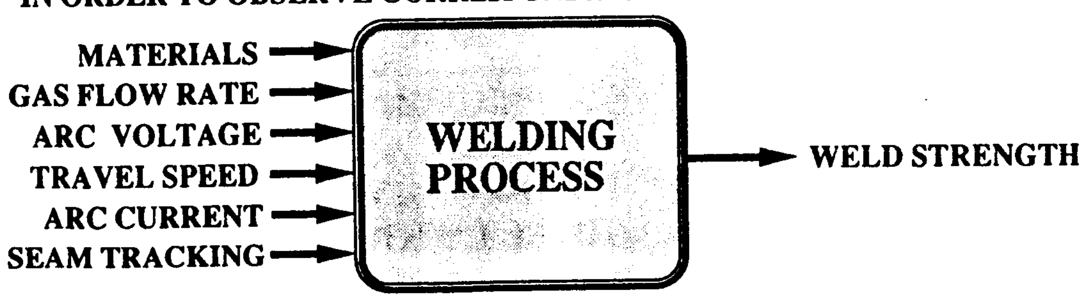
STME RELIABILITY AND SAFETY

QUALITY ENGINEERING

STME RELIABILITY AND SAFETY

DESIGNED EXPERIMENTS

DEFINITION: THE PURPOSEFUL CHANGES TO THE INPUTS OF A PROCESS IN ORDER TO OBSERVE CORRESPONDING CHANGES IN THE OUTPUT.



USING DOE, YOU CAN:

1. OBTAIN THE MAXIMUM AMOUNT OF INFORMATION USING THE MINIMUM AMOUNT OF RESOURCES
2. DETERMINE WHICH FACTORS SHIFT THE AVERAGE RESPONSE , WHICH SHIFT THE VARIABILITY, & WHICH HAVE NO EFFECT
3. *FIND FACTOR SETTINGS THAT OPTIMIZE THE RESPONSE AND* ***MINIMIZE THE COST***

STME RELIABILITY AND SAFETY

STME QUALITY APPROACH

DESIGN IT RIGHT

CONCURRENT ENGINEERING
VARIABILITY REDUCTION
QUALITY FUNCTION DEPLOYMENT
QUALITY ENGINEERING

BUILD IT RIGHT

IN-PROCESS MONITORING
STATISTICAL PROCESS CONTROL
CONTINOUS PROCESS IMPROVEMENT

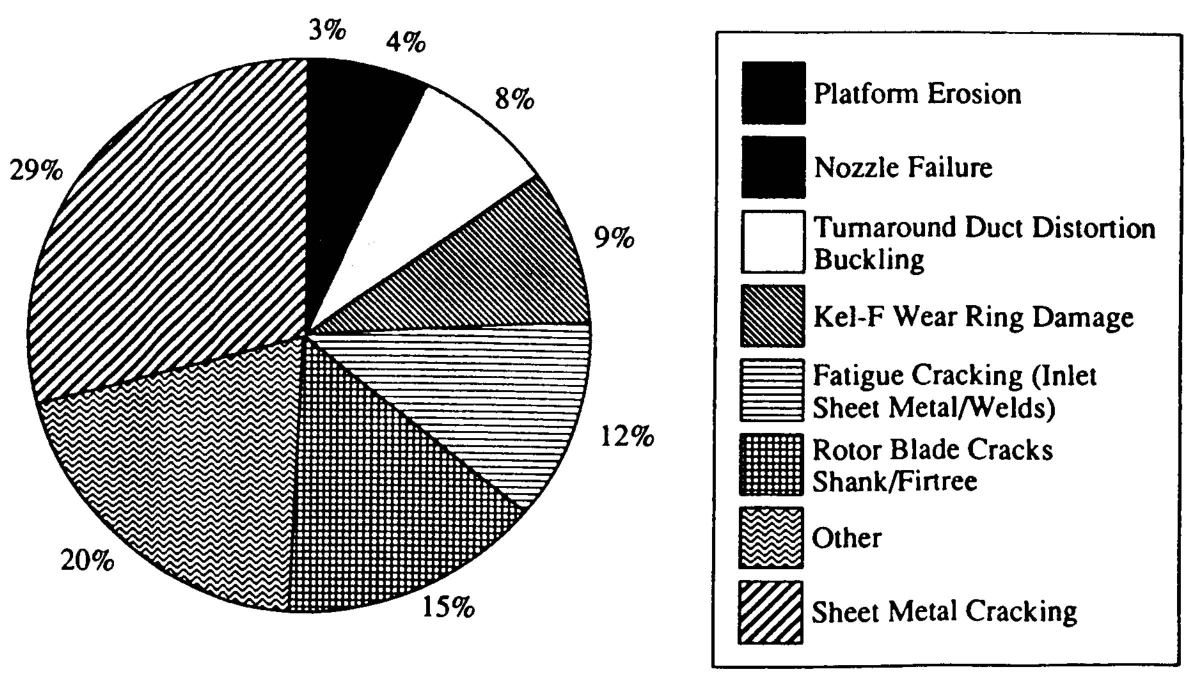
RESULTS

DECREASED LEAD TIME
FEWER ENGINEERING CHANGES
LESS REWORK AND SCRAP
FEWER DELAYS
REDUCED INSPECTION
LESS VARIABILITY
FEWER MAINTENANCE PROBLEMS
IMPROVED OPERABIL8ITY
INCREASED CUSTOMER SATISFACTION

QUALITY ENGINEERING = IMPROVED RELIABILITY

STME RELIABILITY AND SAFETY

SSME HPFTP PREDOMINANT FAILURE MODES



STME RELIABILITY AND SAFETY

SIMPLIFIED DESIGNS - P & W FUEL TURBOPUMP

FUEL TURBOPUMP COMPARISON TO SSME

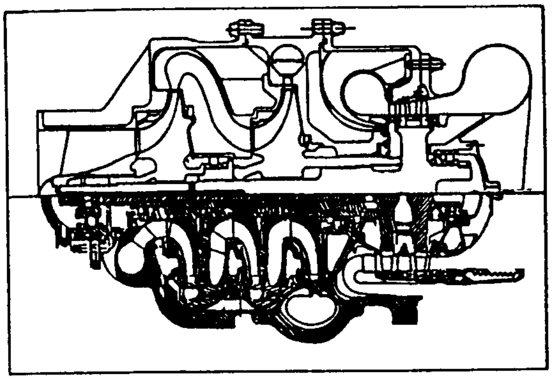
STME
- PART NOS. - 48
- PARTS COUNT - 374
- WELD COUNT - 0
- PROTECTIVE COATINGS - NO
- DISK GOLD PLATING - NO
- WELD OVERLAYS - NO

2 STAGE PUMP
CAST IMPELLERS
2 BEARINGS - SIMPLE ROTOR SUPPORT
SYSTEM COMMON FASTNERS & SEALS

1447 HOLLOW BLADES
SIMPLE TURBINE OD WALL
NO SHEET METAL LINERS
NO INTERNAL BELLOWS LINER

AXIAL INLET

VOLUTE INLET



6 BEARINGS - COMPLEX ROTOR SUPPORT
3 STAGE PUMP
MACHINED IMPELLERS
UNIQUE SEALS & FASTNERS

SSME
- PART NOS. - 169
- PARTS COUNT - 1041
- WELD COUNT - 169
- PROTECTIVE COATINGS - YES
- DISK GOLD PLATING - YES
- WELD OVERLAYS - YES

SOLID BLADES
BELLOWS LINER
WELDED SHEET METAL LINERS
COMPLEX TURBINE OD WALL

STME RELIABILITY AND SAFETY

ENGINE SYSTEM DESIGN CHARACTERISTICS THAT IMPROVE RELIABILITY

- SERIES TURBINES
- MECHANICALLY LINKED GG VALVES
- OPEN LOOP CONTROL
- DESIGN MARGINS
- LOW TURBINE TEMPERATURES
- NO BLEED SYSTEM
- FIXED OR DUAL THRUST MODE
- NOT WEIGHT CRITICAL

STME RELIABILITY AND SAFETY

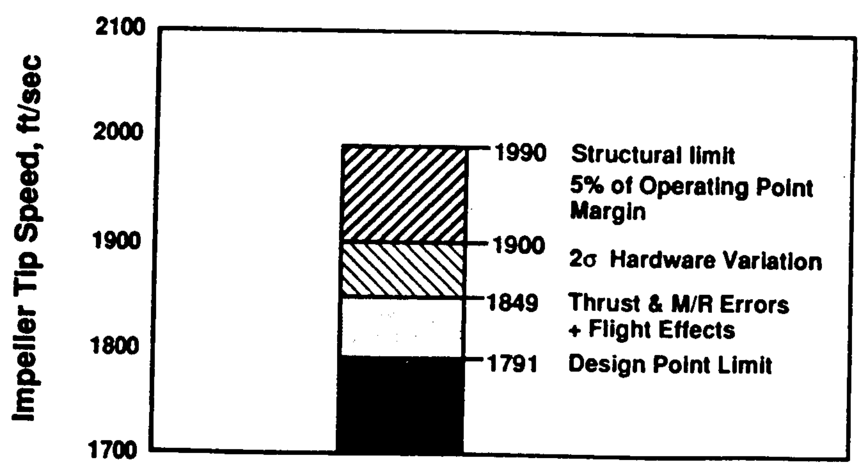
ALL CANDIDATE ENGINE CYCLES UTILIZE SERIES TURBINE ARRANGEMENT

- SIGNIFICANT RELIABILITY IMPROVEMENT OVER PARALLEL TURBINE ARRANGEMENT
  - FUEL TURBINE BLOCKAGE REDUCES LOX TURBINE AVAILABLE HORSEPOWER
  - LOX TURBINE CANNOT POWER UP INDEPENDENT OF FUEL TURBINE

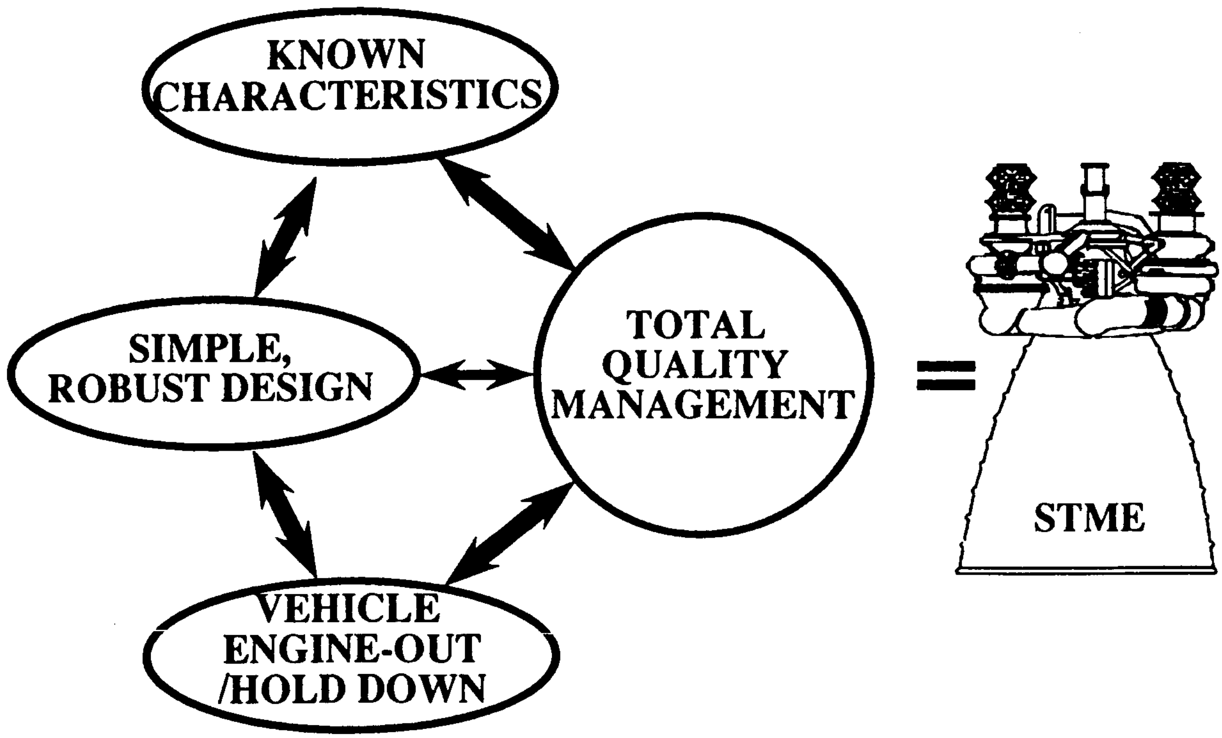
STME RELIABILITY AND SAFETY

MDC PARAMETER DERIVATION EXAMPLE

FTP Impeller Tip Speed



STME RELIABILITY AND SAFETY



N91-28272

T. F. Davidson

PRESENTATION 4.4.10

POSSIBLE FUNDING STRATEGIES

- Government alone
- Industry alone
- Universities alone
- GOVERNMENT . . . INDUSTRY . . . ACADEMIA: the *triad*

AIA *ROCKET PROPULSION STRATEGIC PLAN* IMPLEMENTATION REQUIRES:

- Rocket community (*triad*) Cooperation
- Decision maker participation
- Organization Plan inclusion
- National coordination mechanism

Thiokol CORPORATION
SPACE OPERATIONS

DECISION MAKER CONTACT MATRIX

Washington Area

Laboratories/Centers

NASA
- Johnson*
- Langley*
- Lewis*
- Marshall*
- Stennis*

Army
- Strategic Defense Command*
- Missile Command*

Navy
- NWC/China Lake
- NSWC/White Oak*
- NOS/Indian Head*

Air Force
- Astronautics Laboratory*
- Aeropropulsion Laboratory*
- Materials Laboratory*
- Space Technology Center*
- Space Command*

Government

NASA Headquarters*
Space Council
OMB*
OSTP
DoD
- Joint Chiefs*
- DARPA*
- ODDR&E
- SDIO

Army Headquarters
- AMC

Navy Headquarters
- NAVAIR
- NAVSEA

Air Force Headquarters
- AFSC

Commerce Department
Energy Department
Transportation Department

Congressional

House Committees
- Appropriations*
- Authorization
- Armed Services
- Science, Space, and Technology*

Senate Committees
- Appropriations
- Authorizations*
- Armed Services
- Commerce, Science, and Transportation

*Accomplished as of 25 Jun 1990

ORGANIZATION PLAN INCLUSION (GOVERNMENT, INDUSTRY, AND ACADEMIA)

- Use AIA *Strategic Plan* as baseline*
- Identify counterpart programs and budget
- Identify nonbudgeted counterpart programs
- Identify *other* programs

*Will be updated on a biannual basis

Thiokol CORPORATION
SPACE OPERATIONS

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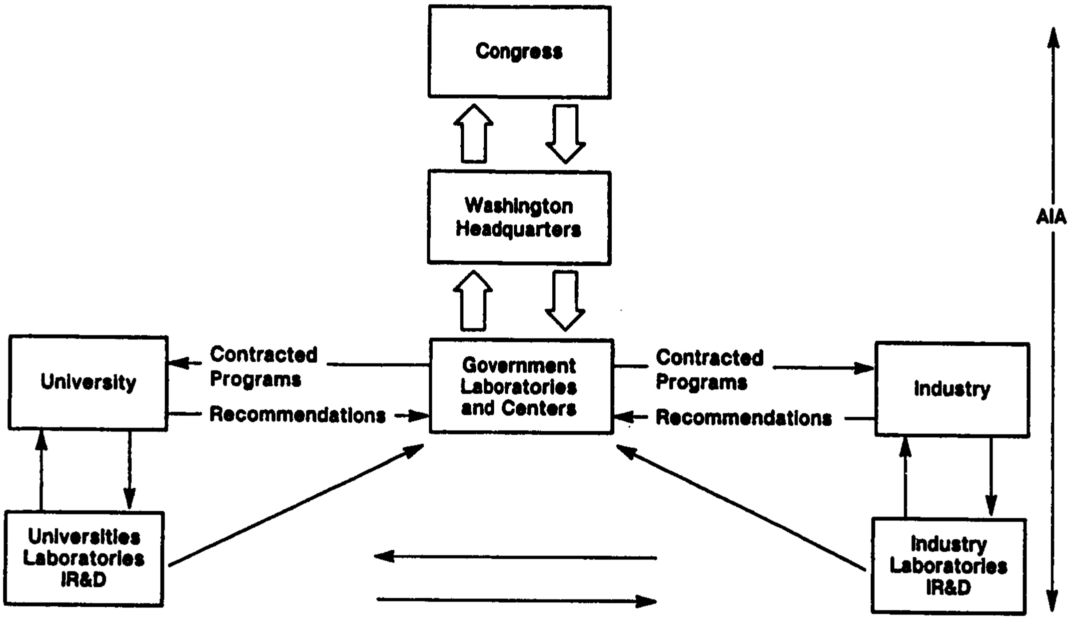
SIMPLIFIED BUDGET FLOW PROGRAM



A NATIONAL COORDINATION MECHANISM

USE

JANNAF Interagency Propulsion Committee*
(executive committee)

Current Chairman— R. J. Richmond, MSFC

NASA— 2 members
Air Force— 2 members
Navy— 2 members
Army— 2 members

Ex Officio— DTIC, OSD

***Established in late 1950s**

Thiokol CORPORATION
SPACE OPERATIONS

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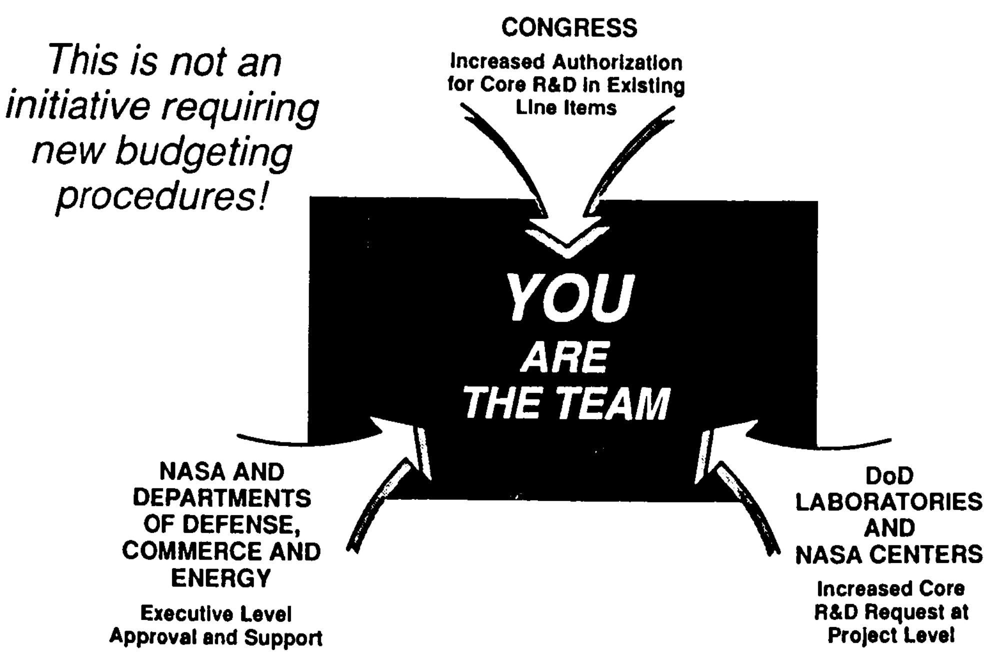
ANNUAL REVIEW AND COORDINATION APPROACH (AGAINST AIA *ROCKET PROPULSION STRATEGIC PLAN*)

JANNAF Executive Committee*

N Year	N + 1	N + 2
• Ongoing	• Budget request	• Planned
• Not funded	• Not requested	• Not planned
• Other	• Other	• Other

*With AIA Rocket Committee participation.
Annual report to the rocket community

MAINTAINING AMERICA'S LEADERSHIP IN ROCKET PROPULSION: A TEAM EFFORT



SYMPOSIUM PARTICIPANTS

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16. Abstract

The Space Transportation Propulsion Technology Symposium was held at the Pennsylvania State University in State College, PA, June 25-29, 1990. The Symposium was held to provide a forum for communication within the propulsion technology developer and user communities. Emphasis was placed on propulsion requirements and initiatives to support current, next generation and future space transportation systems, with the primary objectives of discerning whether proposed designs truly meet future transportation needs and identifying possible technology gaps, overlaps and other programmatic deficiencies. Key space transportation propulsion issues were addressed through four panels with government, industry and academia membership. The panels focused on systems engineering and integration; development, manufacturing and certification; operational efficiency; and program development and cultural issues.

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