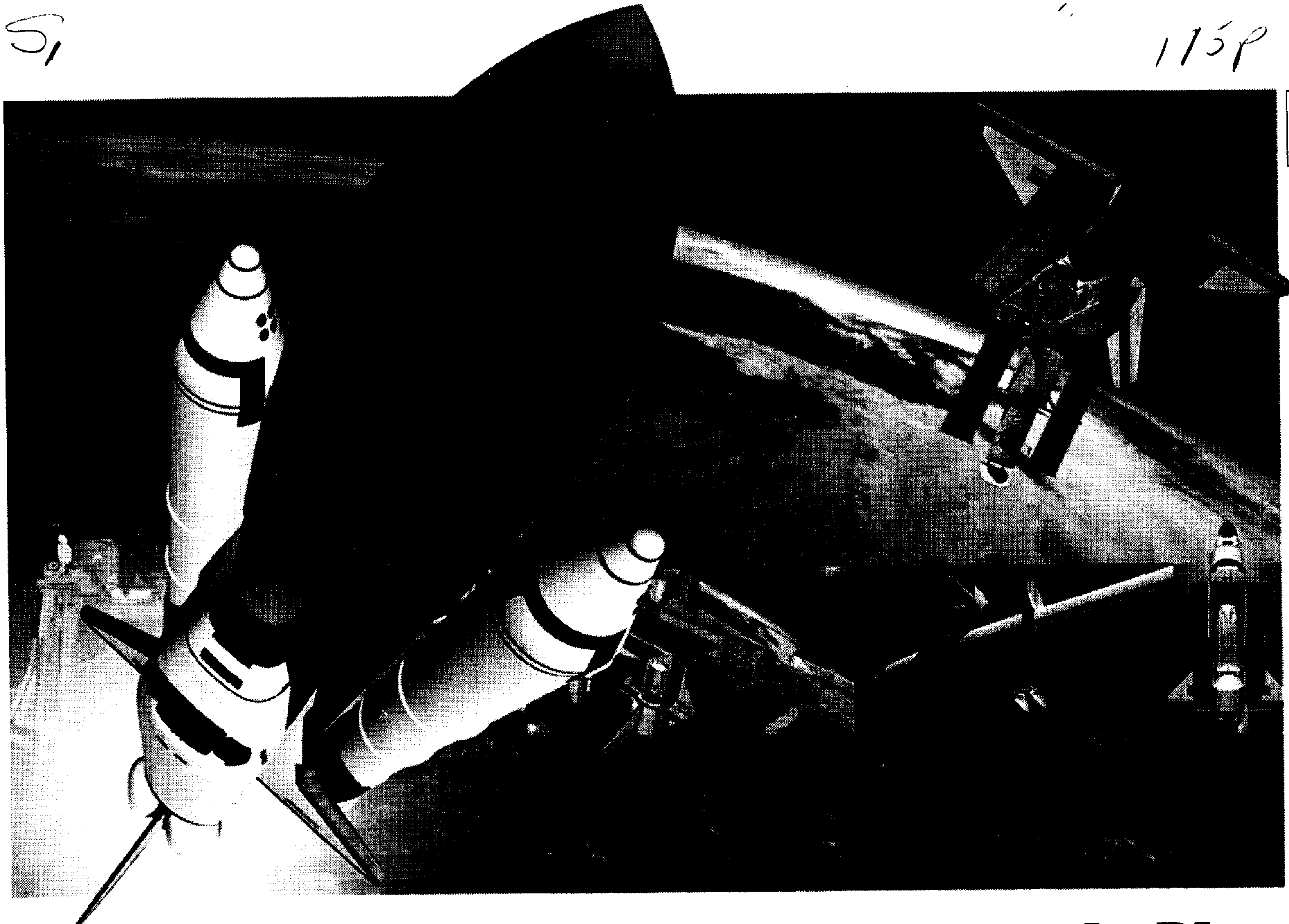
CONF PAPER 11N/16

S1

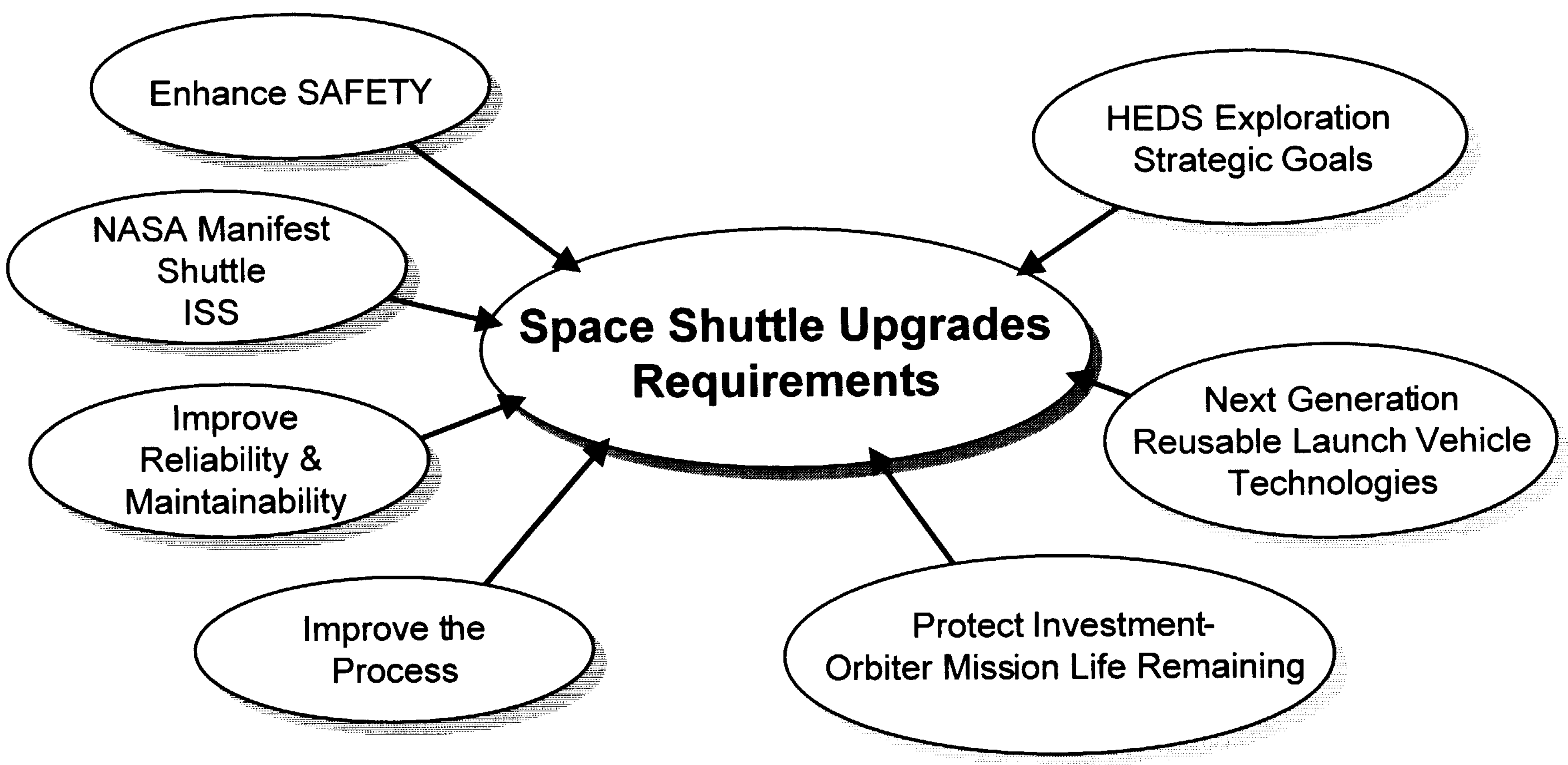
115P



Shuttle Upgrade Plan

September 11, 2000

Why Space Shuttle Upgrades?



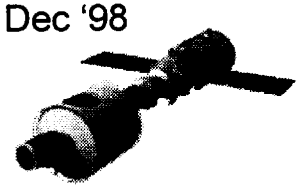
Future Shuttle Manifest

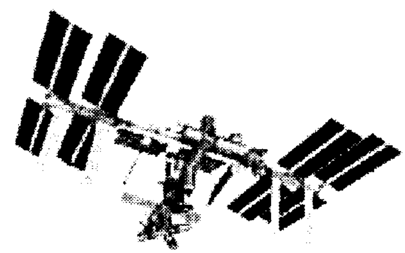
Space Shuttle Upgrades are the foundation for ISS and future HEDS Initiatives

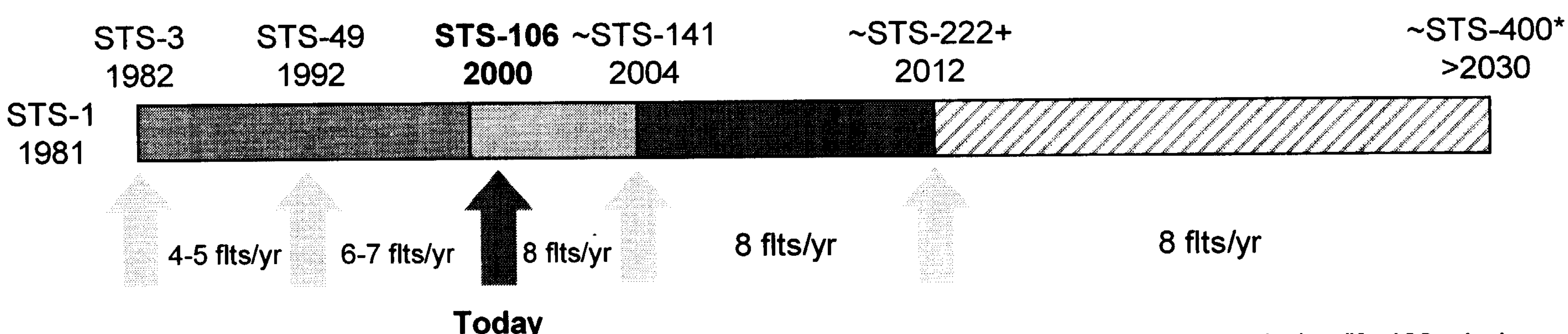
International Space Station

Assembly	Logistics and Utilization

STS-88
Dec '98



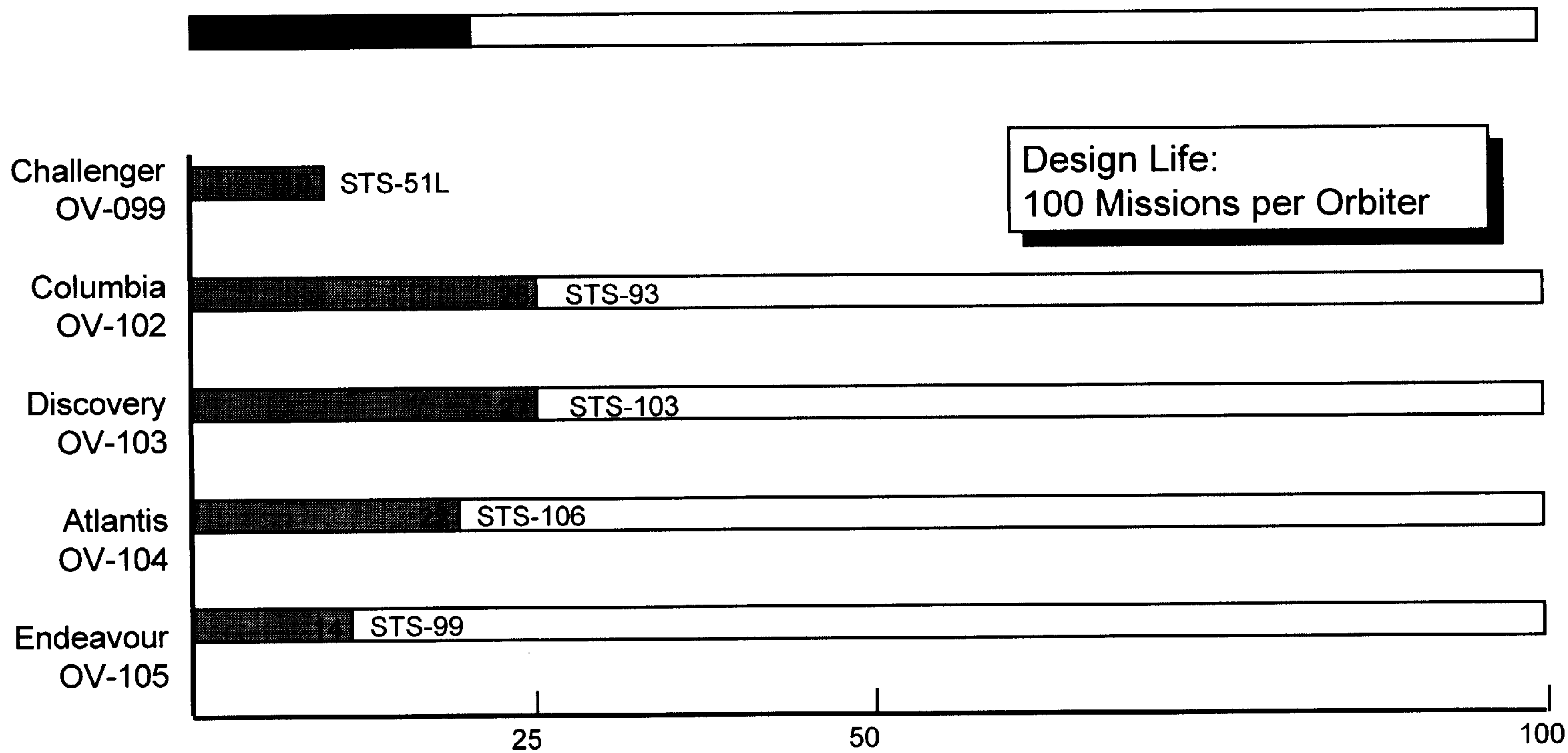




* Orbiter design life 100 missions

Orbiter Mission History

Total flights to date: 99
Orbiter lifetime Remaining: 311



Space Shuttle Program

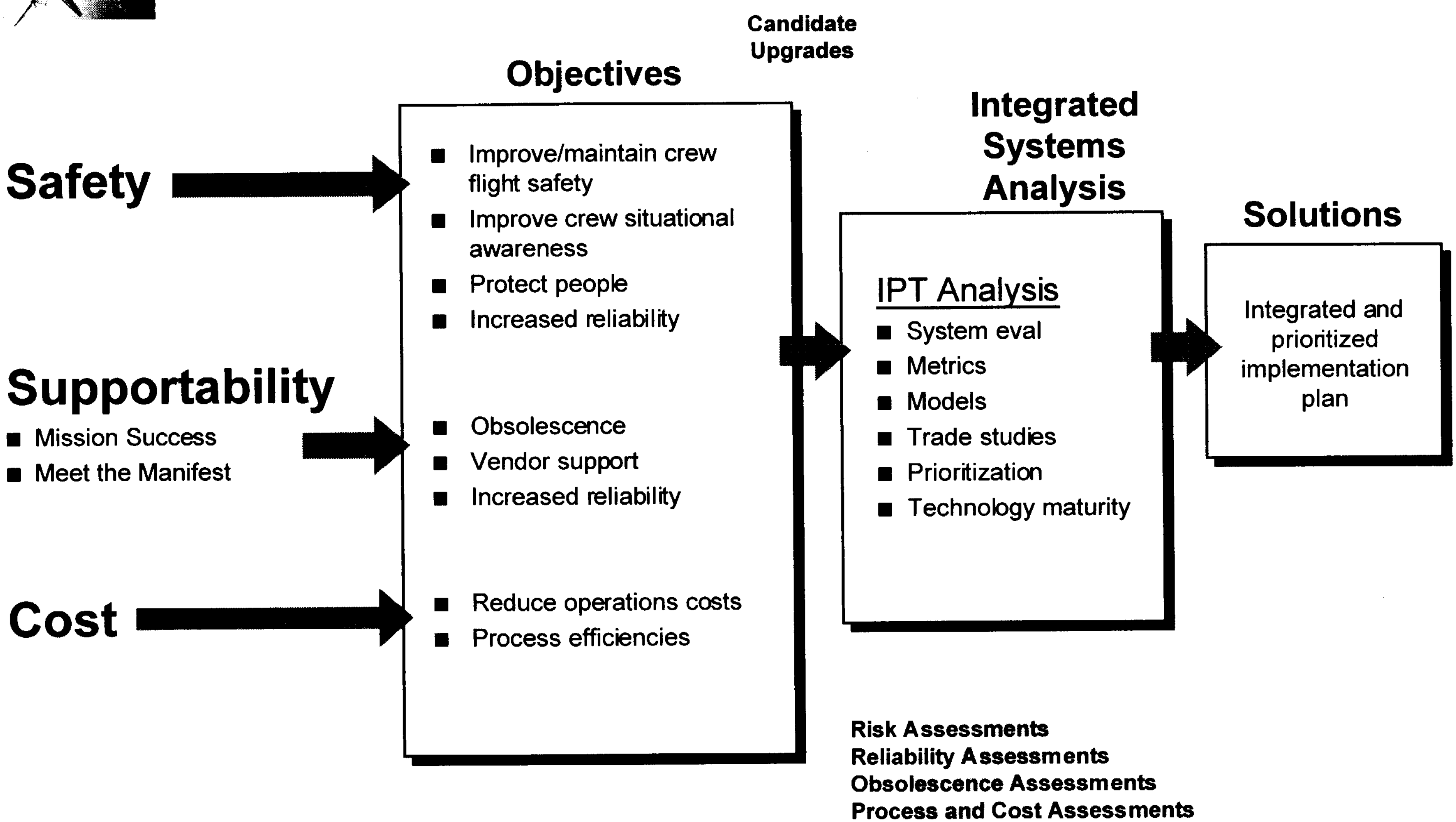
SSP GOALS

Get with the Program !

Space Shuttle Program

SSP OBJECTIVES

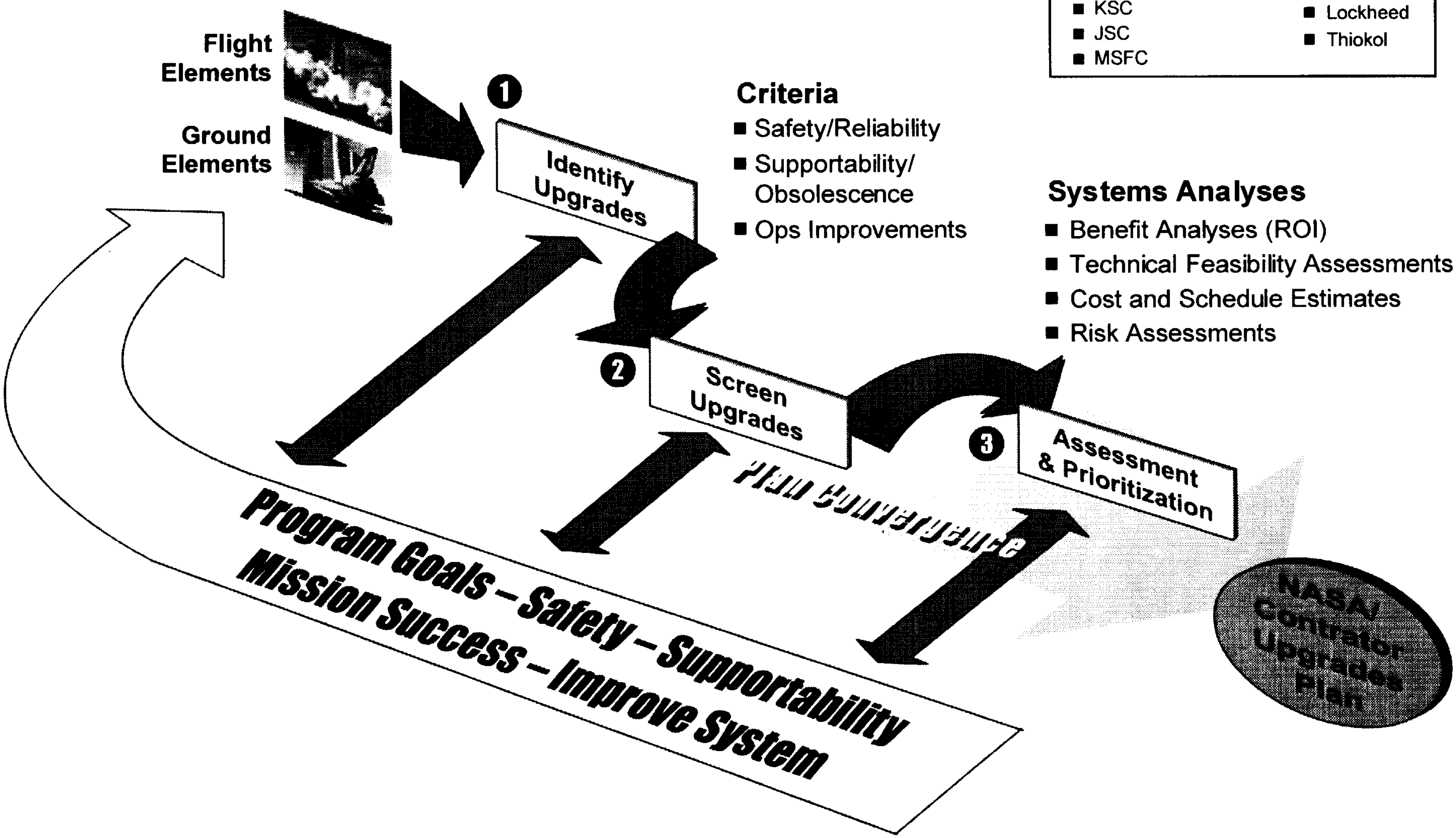
Selection Criteria Ensures System Process



An Integrated Team Process

Integrated approach to produce a unified NASA/Industry STS upgrades plan which supports NASA's goals:
Improve Shuttle Safety - Support ISS - Support Future HEDS Initiatives

NASA	Industry
■ Headquarters	■ USA
■ Space Shuttle Program	■ Boeing
■ KSC	■ Lockheed
■ JSC	■ Thiokol
■ MSFC	



Criteria
- Safety/Reliability
- Supportability/ Obsolescence
- Ops Improvements

Systems Analyses
- Benefit Analyses (ROI)
- Technical Feasibility Assessments
- Cost and Schedule Estimates
- Risk Assessments

Shuttle Upgrade Plan Background

Pro-active upgrade program to keep Shuttle flying ***safely*** and efficiently until the next generation vehicle to meet agency commitments and goals for human access to space

- ISS assembly and support
- Mission support for complex scientific payloads: e.g., HST, SRTM, etc...
- Testbed for new technology
- Human exploration and development of space

Safety Upgrades

Supportability Upgrades

Shuttle Upgrade Plan Background

Pro-active upgrade program to keep Shuttle flying ***safely*** and efficiently to 2012 and beyond to meet agency commitments and goals for human access to space

Safety Upgrades

Risk Reduction Goals

- Major reduction in ascent catastrophic risk
- Significant reduction in orbital and entry system catastrophic failure risk
- Improve crew cockpit situational awareness for managing critical operational situations

Supportability Upgrades

Flight Hardware Availability Assurance

- Obsolescence
  - Parts availability
  - Vendor support
- Failure rates
- Repair times
- Inventory attrition

Operational Improvements

- Maintainability
- Reliability
- Mission success
- Operational simplicity\
- Turn-around time improvements
- Cost reduction

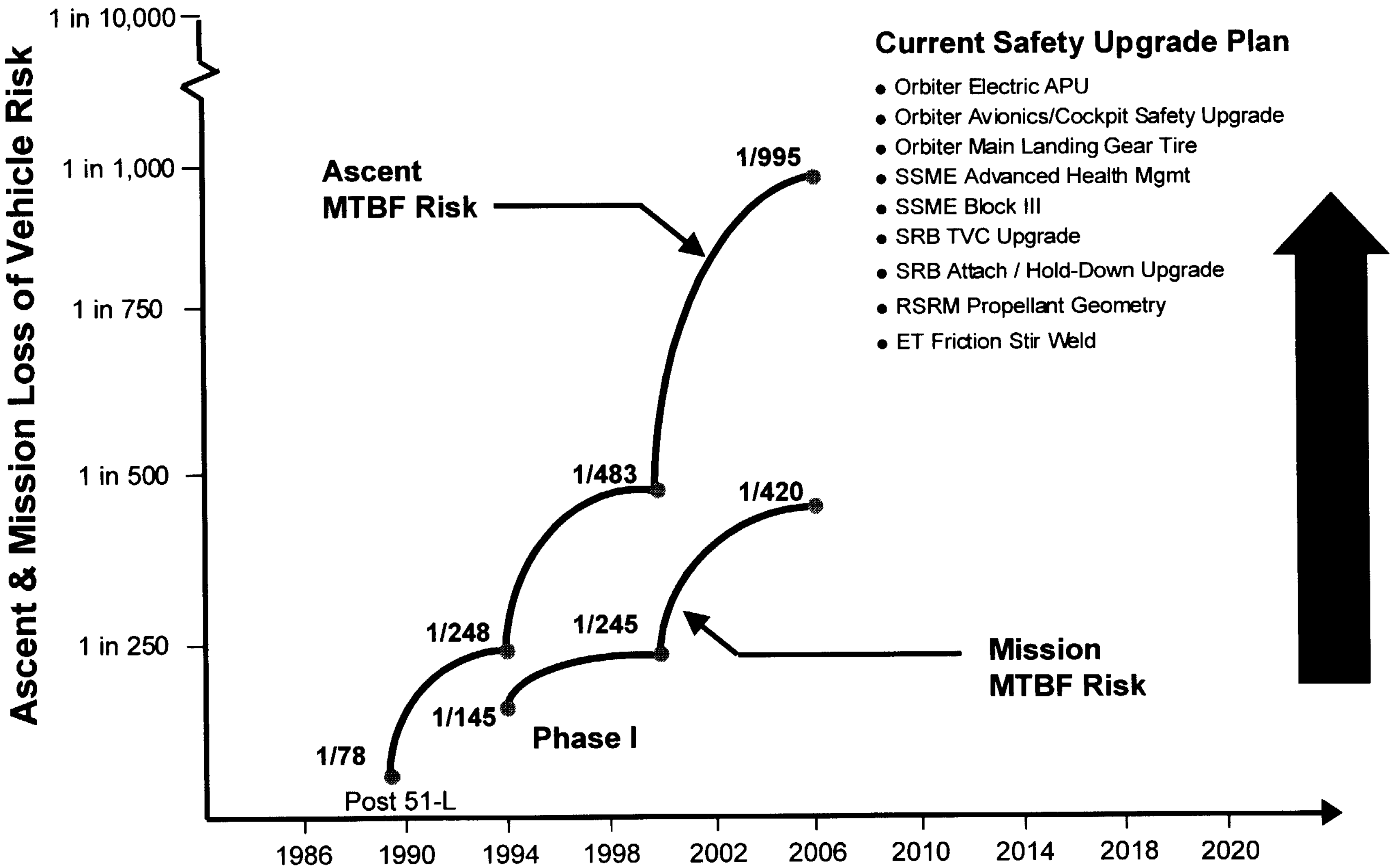
Space Shuttle *Safety* Upgrades

The Goals & The Challenges

- **Goals**
  - Major reduction in ascent catastrophic risk
  - Significant reduction in orbital and entry system catastrophic failure risk
  - Improve crew cockpit situational awareness for managing critical operational situations
- **Challenges**
  - All upgrades operational in the fleet by end of 2005
  - No impact to on-going Manifest support
  - Control costs to estimates provided in President's proposed budget

Safety Benefit of Planned Shuttle Upgrades

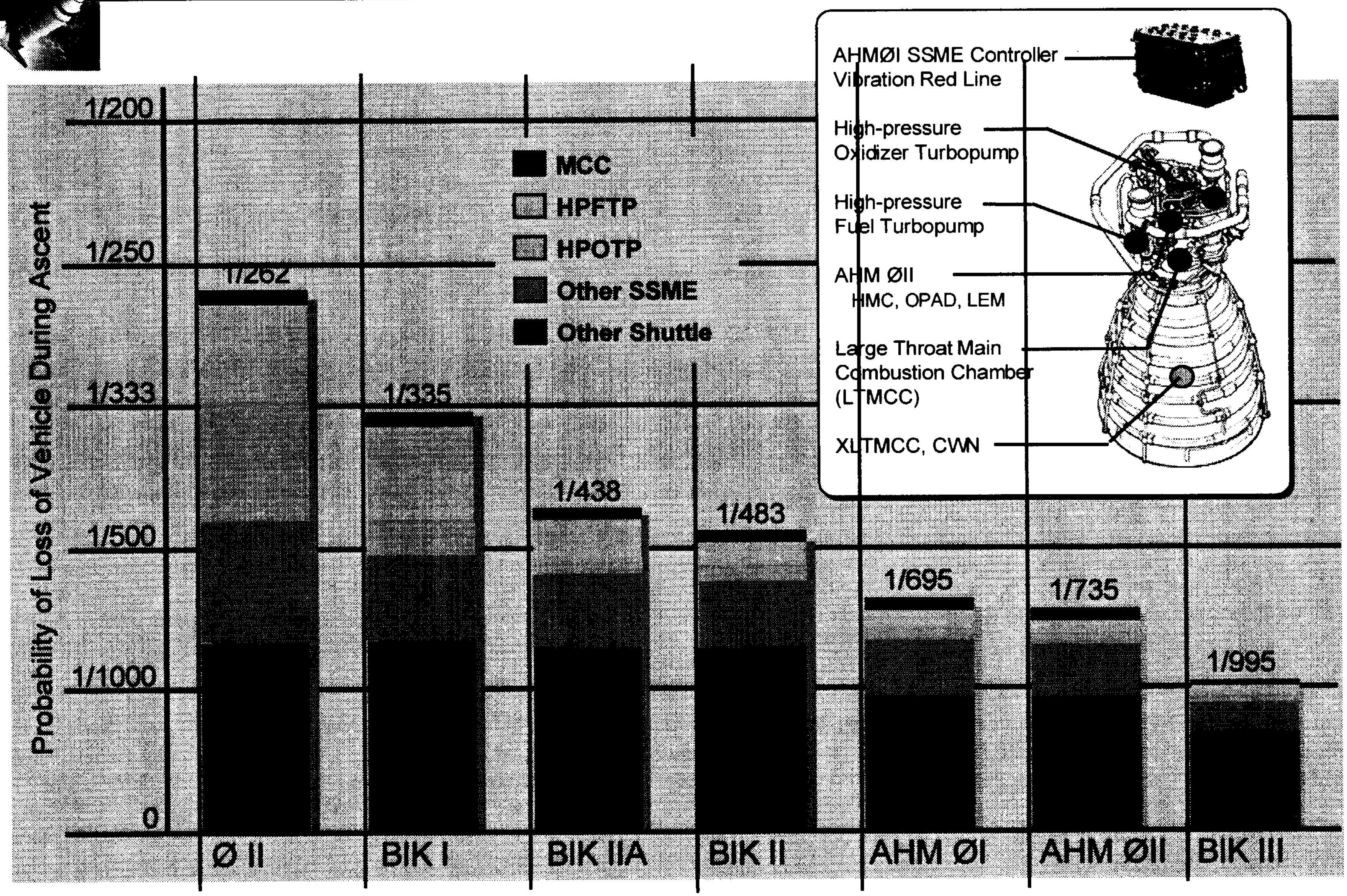
Increased Safety Through Selected Upgrades



Current Safety Upgrade Plan

- Orbiter Electric APU
- Orbiter Avionics/Cockpit Safety Upgrade
- Orbiter Main Landing Gear Tire
- SSME Advanced Health Mgmt
- SSME Block III
- SRB TVC Upgrade
- SRB Attach / Hold-Down Upgrade
- RSRM Propellant Geometry
- ET Friction Stir Weld

SSME Upgrades Reduce Ascent Risk



Space Shuttle Safety and Supportability
Safety Upgrade Candidates

Safety Upgrades | Supportability Upgrades | Approved Upgrades | Advanced Technology

Orbiter Avionics

- **Cockpit**
  - Enhanced Caution and Warning
  - Crew Situational Awareness Displays
  - AFD Switch Panel Upgrade
  - Device Driver Unit Replacement (DDU)
- **Data Processing**
  - Mission Management Computer
  - Modular Auxiliary Data System
  - Modular Memory Unit (MMU)
- **Communications**
  - Ku-Band DEA
  - PCMMU
  - S-Band FM
  - Network Signal Processor
- **Navigation**
  - Trajectory Control Sensor (TCS)
  - IMU Replacement (SIGI)
- **Power Sub-Assemblies**
  - Hybrid Drivers
- **Thermal Protection System**
  - More Durable Lower Surface Tile (Study)
- **Structures & Mechanisms**
  - Crew Escape System (Study)
  - Main Landing Gear Tire Improvements
  - Micrometeoroid/Orbital Debris Mitigation (MMOD)
- **Environmental Control & Life Support Systems**
  - Hydrogen Water Separator

SRB / RSRM / ET / SSME

- SRB Advanced TVC
- Integrated Electronics Assembly
- ABACS
- ET Robust TPS
- ET Digital Radiography
- New O-Ring Material
- Case Stiffener Segment/T-Ring
- RSRM Propellant Geometry
- SRB Attach/Hold Down Hardware
- ET Friction Stir Initial Welds
- Advanced Health Monitoring
- SSME Block III
  - XLTMCC and Robust Nozzle
- SRB TVC Upgrades / FIV
- SRB Altitude Sensor Assembly
- Nozzle/Case Joint J-Leg Insulation
- Integrated Receiver-Decoder (IRD)
- Range Safety Distributor (RSD)

Power & Propulsion

- Electric APU
- Enhanced Pyro Initiator Controller
- Improved Pilot Operated Valve
- Quad Check Valve Redesign
- Long Life Alkaline Fuel Cell

Operations

- **Ground Operations**
  - Maintainability for Safety (Study)
  - SCAPE Suit Improvements (Study)
  - CLCS
- **Flight Operations**
  - PIDAE
  - Shuttle Upgrades Design Visualization
  - Robotic Situational Awareness Display
  - Human Factors/Cockpit Engineering Study
  - Expansion of MCC Landing Sites
  - AWPS
  - EECOM STS Pressure Management Tool
  - Alternatives to Hardware Based Robotics Training
  - DM Trajectory Operations
  - Interface Redesign
- **Flight Tests**
  - Wireless Sensor
  - Laser Dynamic Range Imager HTD

Advanced Technology

- Crew Escape
- Reusable First Stage
- Non-Tox OMS/RCS Propellants
- PEM Fuel Cell
- Electromechanical Actuators
- Water Membrane Evaporator
- Integrated Vehicle Health Mgmt
- Propellant Densifications
- Fiber Optics

Space Shuttle Safety and Supportability
Safety Upgrade Candidates

Safety Upgrades | Supportability Upgrades | Approved Upgrades | Advanced Technology

Orbiter Avionics

- **Cockpit**
  - Enhanced Caution and Warning
  - Crew Situational Awareness Displays
  - AFD Switch Panel Upgrade
  - Device Driver Unit Replacement (DDU)
- **Data Processing**
  - Mission Management Computer
  - Modular Auxiliary Data System
  - Modular Memory Unit (MMU)
- **Communications**
  - Ku-Band DEA
  - PCMMU
  - S-Band FM
  - Network Signal Processor
- **Navigation**
  - Trajectory Control Sensor (TCS)
  - IMU Replacement (SIGI)
- **Power Sub-Assemblies**
  - Hybrid Drivers
- **Thermal Protection System**
  - More Durable Lower Surface Tile (Study)
- **Structures & Mechanisms**
  - Crew Escape System (Study)
  - Main Landing Gear Tire Improvements
  - Micrometeoroid/Orbital Debris Mitigation (MMOD)
- **Environmental Control & Life Support Systems**
  - Hydrogen Water Separator

SRB / RSRM / ET / SSME

- SRB Advanced TVC
- Integrated Electronics Assembly
- ABACS
- ET Robust TPS
- ET Digital Radiography
- New O-Ring Material
- Case Stiffener Segment/T-Ring
- RSRM Propellant Geometry
- SRB Attach/Hold Down Hardware
- ET Friction Stir Initial Welds
- Advanced Health Monitoring
- SSME Block III
  - – XLTMCC and Robust Nozzle
- SRB TVC Upgrades / FIV
- SRB Altitude Sensor Assembly
- Nozzle/Case Joint J-Leg Insulation
- Integrated Receiver-Decoder (IRD)
- Range Safety Distributor (RSD)

Power & Propulsion

- Electric APU
- Enhanced Pyro Initiator Controller
- Improved Pilot Operated Valve
- Quad Check Valve Redesign
- Long Life Alkaline Fuel Cell

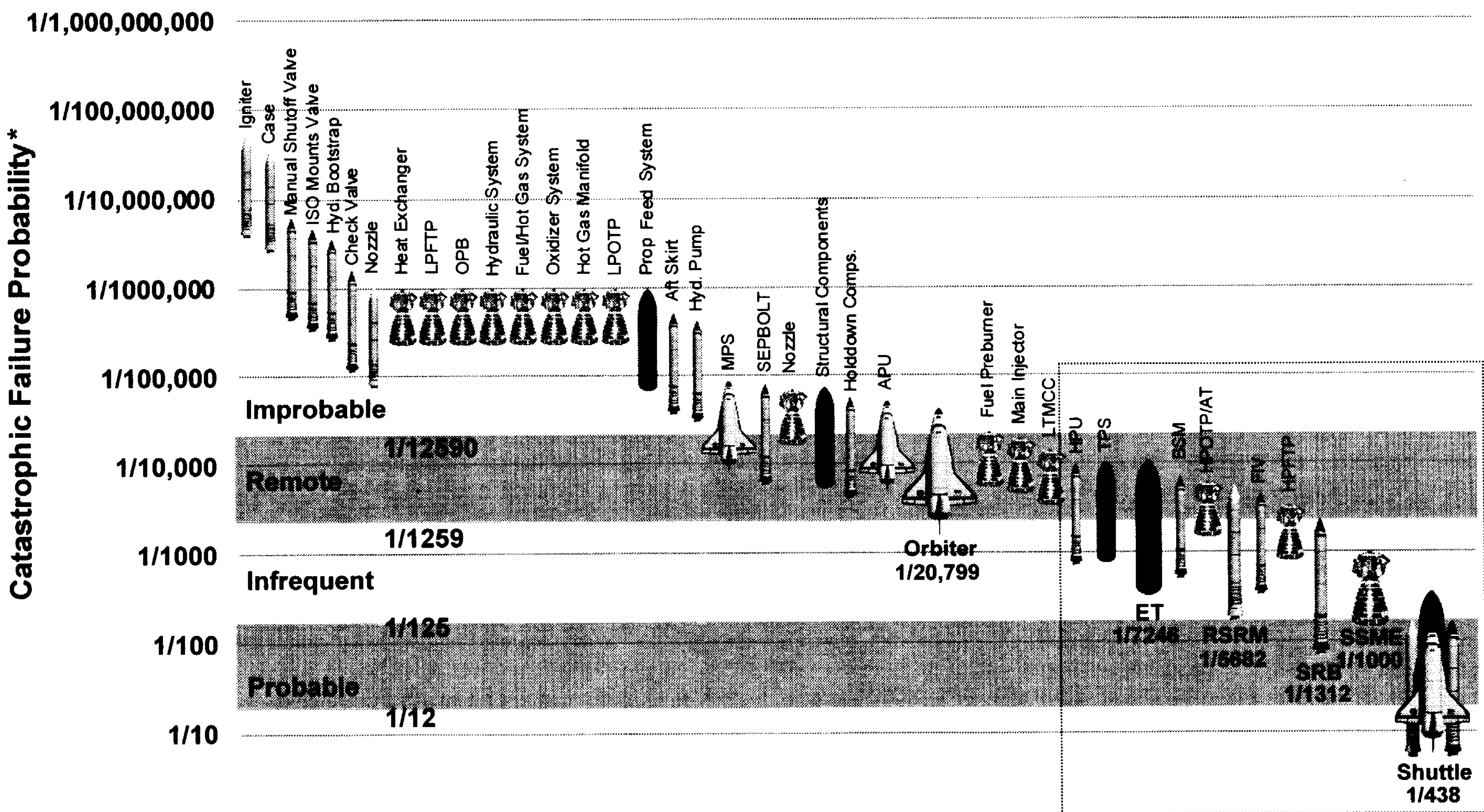
Operations

- **Ground Operations**
  - Maintainability for Safety (Study)
  - SCAPE Suit Improvements (Study)
  - CLCS
- **Flight Operations**
  - PIDAE
  - Shuttle Upgrades Design Visualization
  - Robotic Situational Awareness Display
  - Human Factors/Cockpit Engineering Study
  - Expansion of MCC Landing Sites
  - AWPS
  - EECOM STS Pressure Management Tool
  - Alternatives to Hardware Based Robotics Training
  - DM Trajectory Operations
  - Interface Redesign
- **Flight Tests**
  - Wireless Sensor
  - Laser Dynamic Range Imager HTD

Advanced Technology

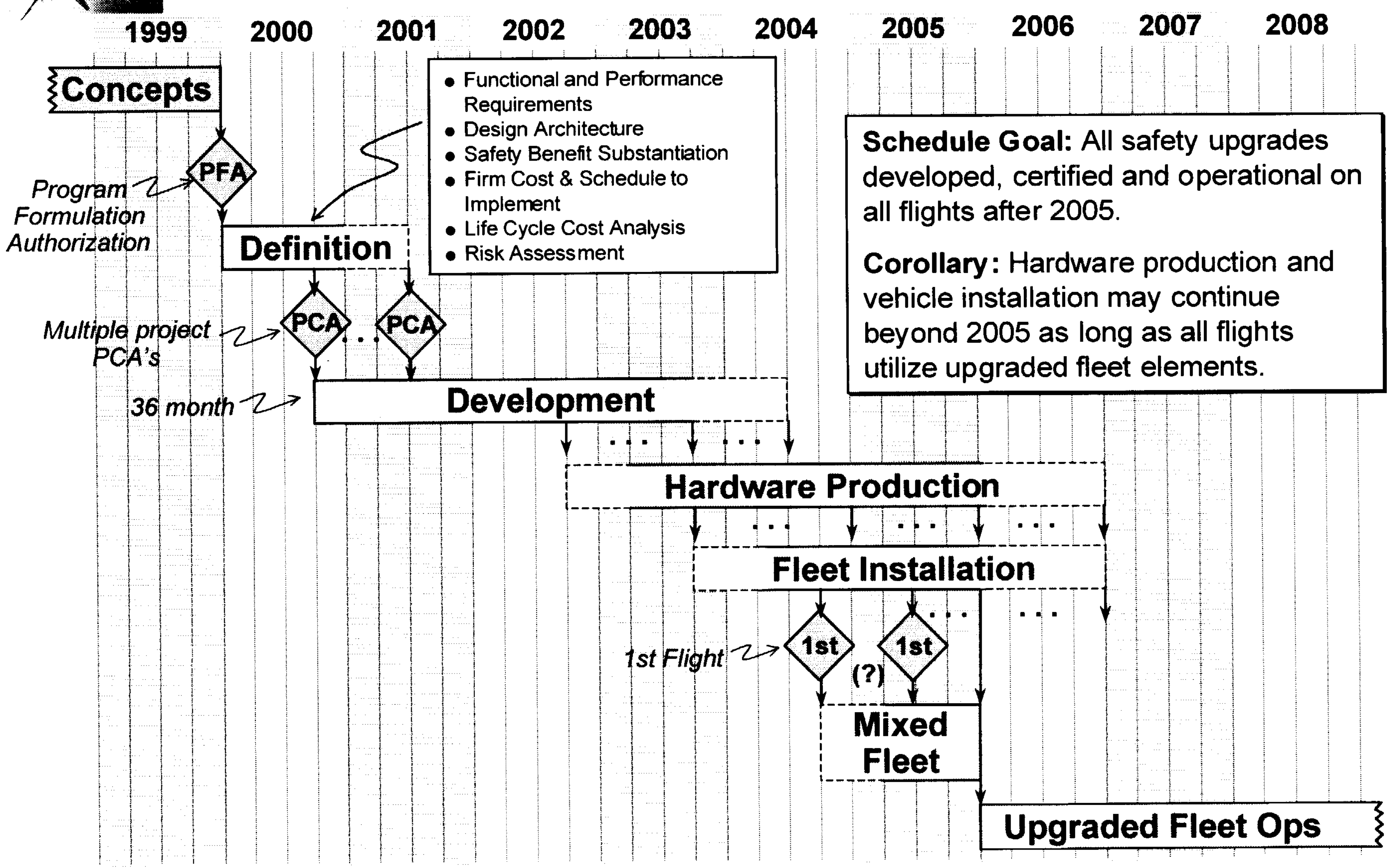
- Crew Escape
- Reusable First Stage
- Non-Tox OMS/RCS Propellants
- PEM Fuel Cell
- Electromechanical Actuators
- Water Membrane Evaporator
- Integrated Vehicle Health Mgmt
- Propellant Densifications
- Fiber Optics

Block IIA Configuration - Ascent



* Based on 1998 QRAS

Shuttle Safety Upgrade Schedule Strategy



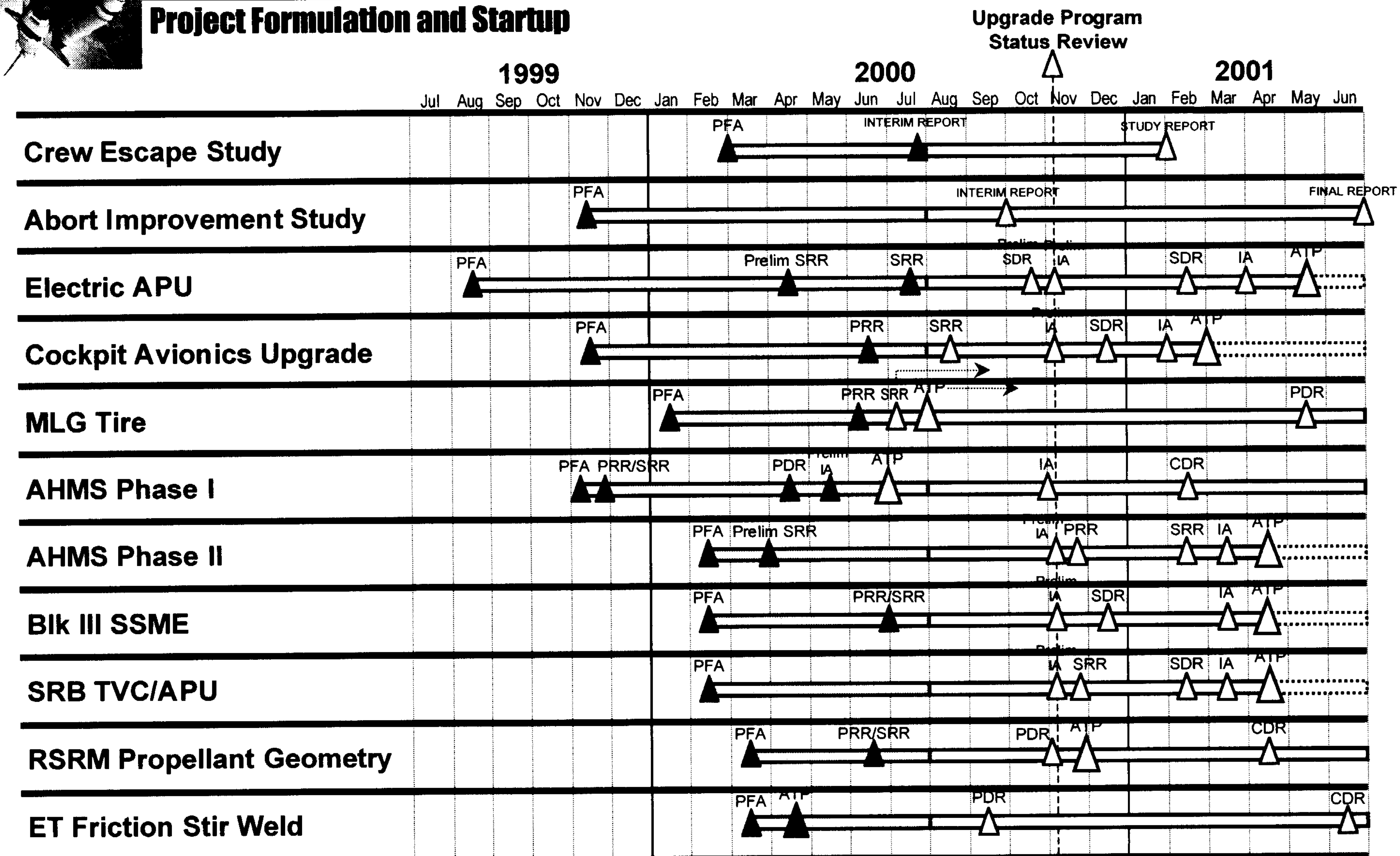
Schedule Goal: All safety upgrades developed, certified and operational on all flights after 2005.

Corollary: Hardware production and vehicle installation may continue beyond 2005 as long as all flights utilize upgraded fleet elements.

Shuttle Safety Upgrade Schedules

Project Formulation and Startup

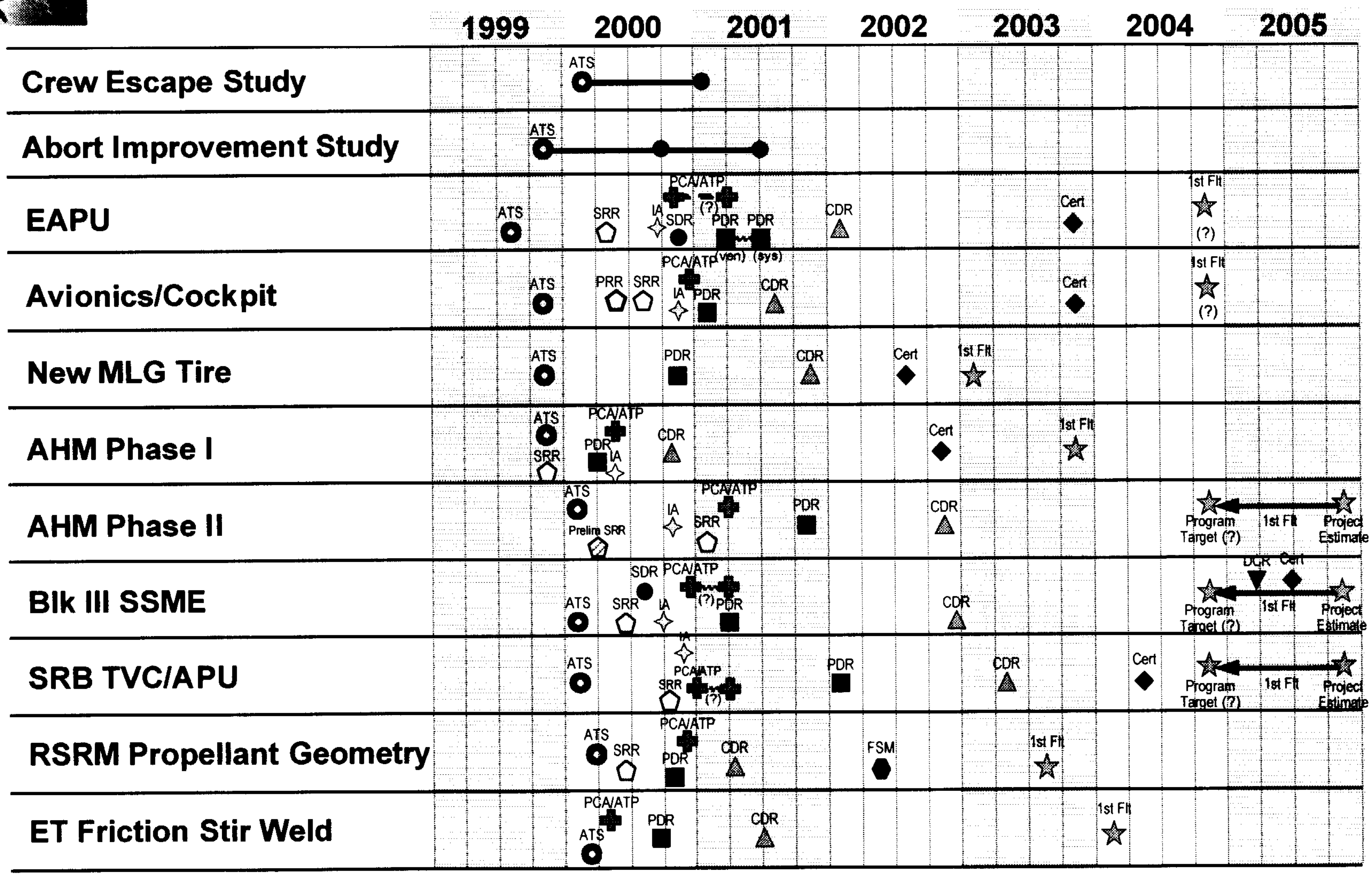
REVISION (8/1/00)



Other Studies: Maintainability for Safety, TPS, SCAPE Suit

ROM Safety Upgrade Schedules

Non-Baseline Working Schedules (Calendar Year Quarters)



Other Studies: Maintainability for Safety, TPS, SCAPE Suit

Note: SSP Program goal is to achieve 1st Flight for all safety upgrades by 2004 or early 2005, thus supporting full fleet operations of all safety upgrades by the end of 2005.

High Priority Safety Upgrades

- **Electric Auxiliary Power Unit (APU)**
  - Battery-powered electric motors replace hydrazine powered turbines to drive Orbiter hydraulic pumps
  - Eliminates hydrazine leakage/fire hazards, eliminates turbine overspeed hazards, and reduces toxic materials processing hazards
  - Simplifies APU startup/shutdown procedures and constraints
- **Avionics/Cockpit**
  - New architecture provides a symmetric cockpit, improved graphics, more data connectivity, and a new computational platform (Command Display Processor)
  - Reduces crew workload, provides enhanced caution and warning, abort/trajectory assessment, RMS workstation, flight instruments, rendezvous/proximity/docking operations thereby increasing safety
- **New Main Landing Gear Tire**
  - Redesign tire and rim to increase the low operating margins
  - Additional margin in landing speed, low temperature, and load limit

High Priority Safety Upgrades (cont'd)

- **SSME Advanced Health Monitoring Phase I**
  - Upgrade SSME Controller with real-time turbopump synchronous vibration redline capability and a new high-speed interface, fly a Health Management Computer (HMC) prototype, fly an Optical Plume Anomaly Detection (OPAD) experiment, investigate Linear Engine Model (LEM) as an MOD tool, Phase II requirements definition
  - Reduces probability of catastrophic engine failure by approx 23%, lays groundwork for Phase II
- **SSME Advanced Health Monitoring Phase II**
  - Flight HMC with advanced Real-Time Vibration Monitoring System (RTVMS), OPAD, and LEM
  - Reduces probability of catastrophic engine failure by an additional ~ 24%, increases SSME anomaly detection capabilities enhancing mission success and ground operations
- **Block III SSME**
  - New SSME Engine with an extra large throat and longer Main Combustion Chamber (MCC) and a shortened, robust, channel-wall constructed nozzle
  - Improves 3-engine catastrophic failure scenario MTBF, improves 3-engine and nozzle failure MTBF, eliminates failure modes, reduces production time and cost, and reduces nozzle maintenance

High Priority Safety Upgrades (cont'd)

- **SRB TVC/APU**
  - Develop a new SRB APU for the Thrust Vector Control system which does not use hydrazine. Downselect from three options.
  - Eliminates hydrazine leakage/fire hazards, eliminates turbine overspeed hazards, and reduces toxic materials processing hazards
- **SRB Attach/Hold Down Hardware**
  - Design more robust SRB attach/hold down hardware for use between the SRB and ET
  - Reliability improvement to 1/995 (QRAS) ascent loss of vehicle
- **RSRM Propellant Grain Geometry**
  - Modify propellant grain geometry in five locations
  - Improves structural margins of safety in the motor, reduces time spent in the hazardous motor environment, eliminates propellant trimming in areas of improvement
- **ET Friction Stir Weld**
  - Develop solid state initial weld technology to be used during ET production
  - Friction stir welding can increase weld joint strength, achieve higher weld margins, and improve fracture toughness as well as improve supportability, cost and process control

Orbiter Avionics/Cockpit Upgrades

Description

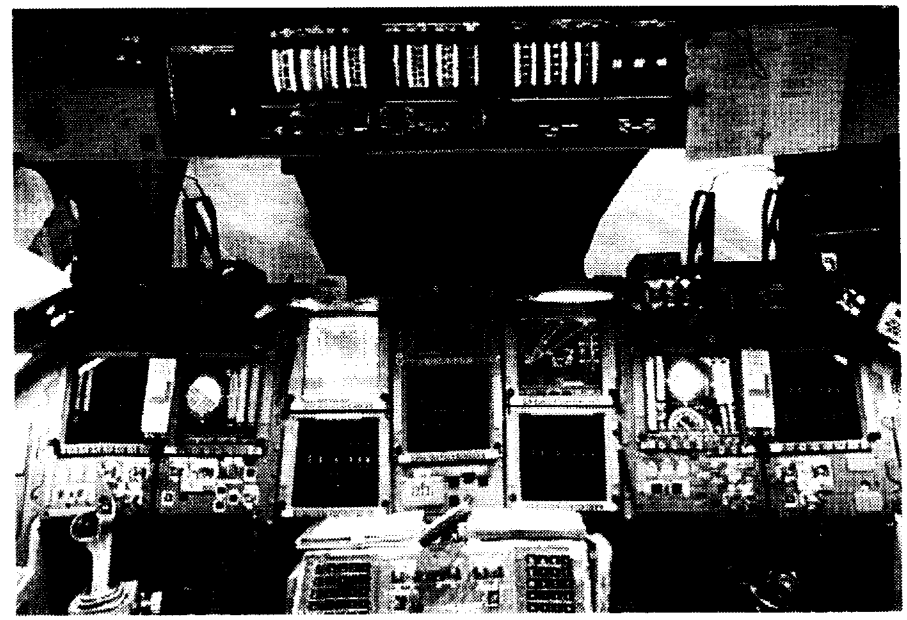
Orbiter Avionics/Cockpit safety upgrade provides

- "Smart Cockpit" … problem root cause
- A symmetric cockpit
  - Any display on any screen
  - Any keyboard commands any display
- Integrated data sources and graphics
- A new computational platform

Benefits

Flight Safety

- Enhanced caution and warning
- Improved crew situational awareness
- Improved crew workload margin during critical operations

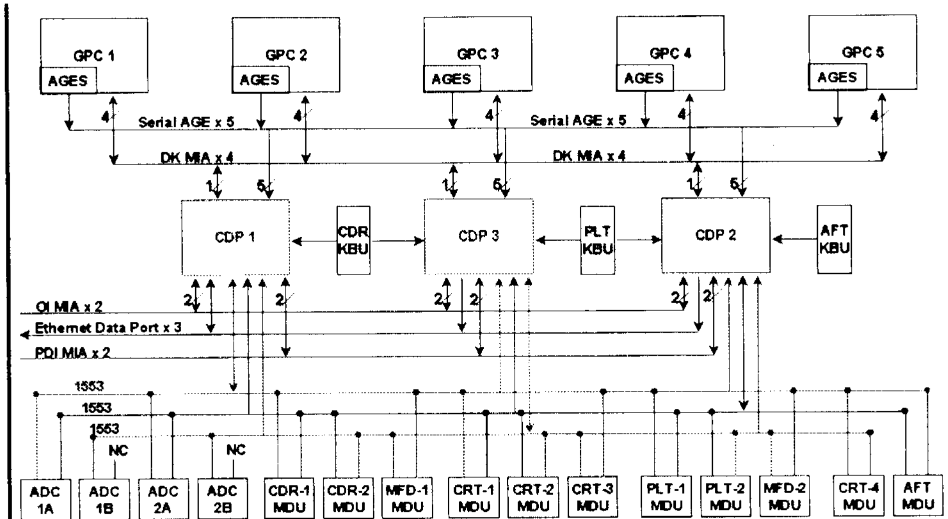


"Smart Cockpit" builds on "Glass Cockpit"

Orbiter Avionics/Cockpit Upgrades

Description

- Upgrade Orbiter Avionics/Cockpit architecture to create
  - A symmetric cockpit – any display on any MDU, any keyboard to any display
  - Connectivity to vehicle and payload data (PASS, BFS, OI, PL)
  - Integrated data sources and graphics on MDUs
  - A new computational platform (Command Display Processor) for keyboard commands, displays, enhanced caution and warning and abort/trajectory assessment
  - A low-impact implementation to allow labs to support a mixed fleet



Benefits

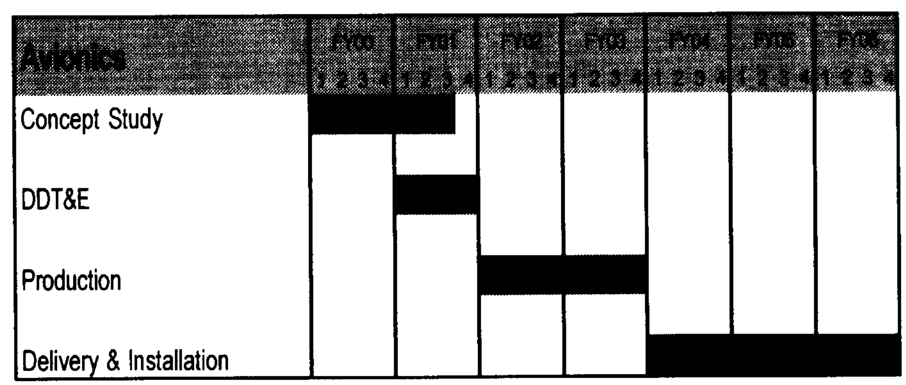
Flight Safety

- Architecture meets highest priority Cockpit Council safety objectives and provides a growth path to further cockpit workload reductions
  - Improve crew abort/trajectory situational awareness
  - Reduce crew workload
  - Provide enhanced caution and warning to find problem root cause
  - Improve capacity margin for General Purpose Computers

Mission Success

- Upgrade RMS workstation and flight instruments
  - Improved RMS/docking situational awareness
- Simplify rendezvous/proximity/docking operations
- Increased system reliability

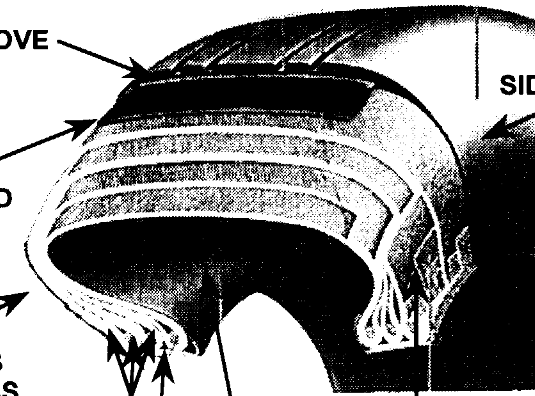
Schedule



Improved Main Landing Gear Tire

Description

- Redesign Orbiter Main Landing Gear Tire to increase load capacity for higher speed landing capability
  - Increase safety margin
  - Increase pressure rating design
- New wheel design required after tire development is finalized



Benefits

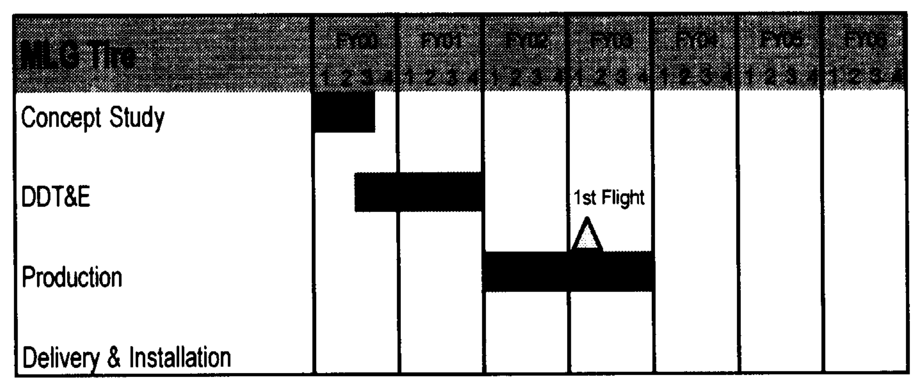
Flight Safety

- Increase load capacity safety margin on tire
- Increase landing speed safety margin

Supportability

- Replace rubber compounds to mitigate future obsolescence

Schedule

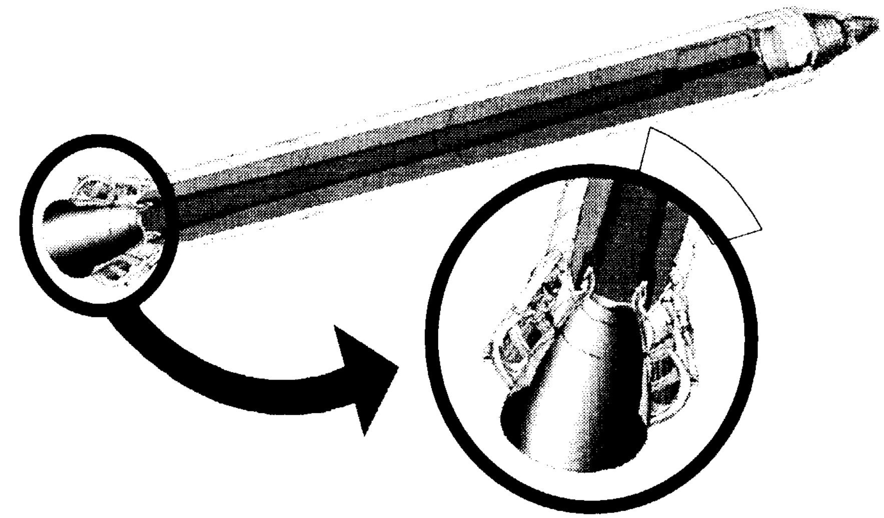


SRB Thrust Vector Control/APU Upgrades Plan

Description

SRB APU Upgrade Trade Studies

- Electric APU
- Solid Propellant Gas Generator (SSPG
- Blowdown / Reccumulation System

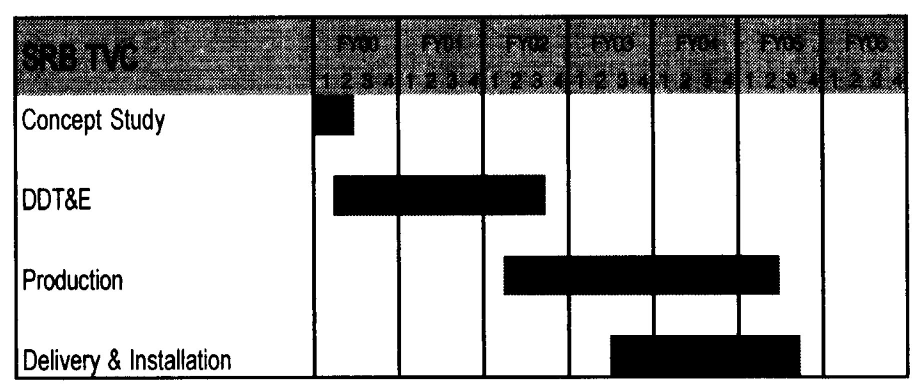


Benefits

Safety

- Flight Safety - Reduces ISRB LOV (1/X) ascent risk to 1442
- Ground Safety - Reduces toxic materials processing and handling

Schedule

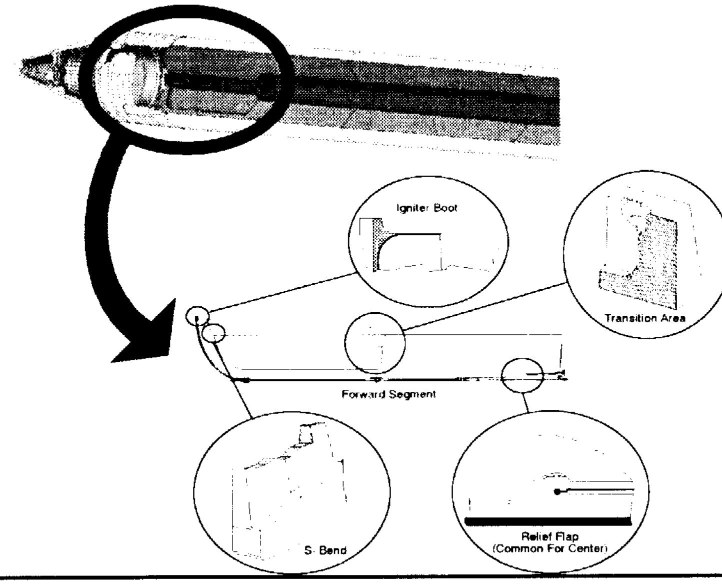


***Tentative Schedule**

RSRM - Propellant Grain Geometry Modification

Description

- Modify propellant grain geometry to improve structural margins of safety (1.4 to 2).
- Modifies propellant, liner, and insulation



Benefits

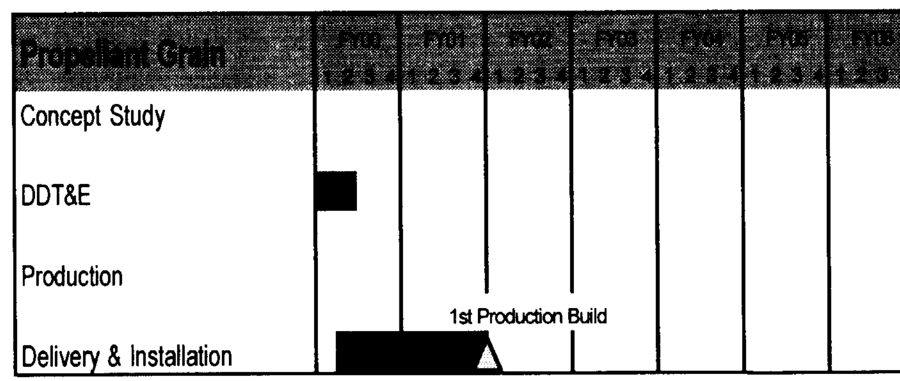
Flight Safety

- Increase safety factor in the RSRM.
- Change hazard mitigation from inspection to design.
- **Ground Safety**
- Reduce the time operators and inspectors at Utah and KSC spend in a hazardous environment inside the motor.
  - Eliminate the need for propellant trimming
  - Eliminate inspections

Improve the System

- Eliminate the re-inspection criteria at KSC after six months storage and the associated additional segment handling.
- Robust design reduces obsolete material threats

Schedule

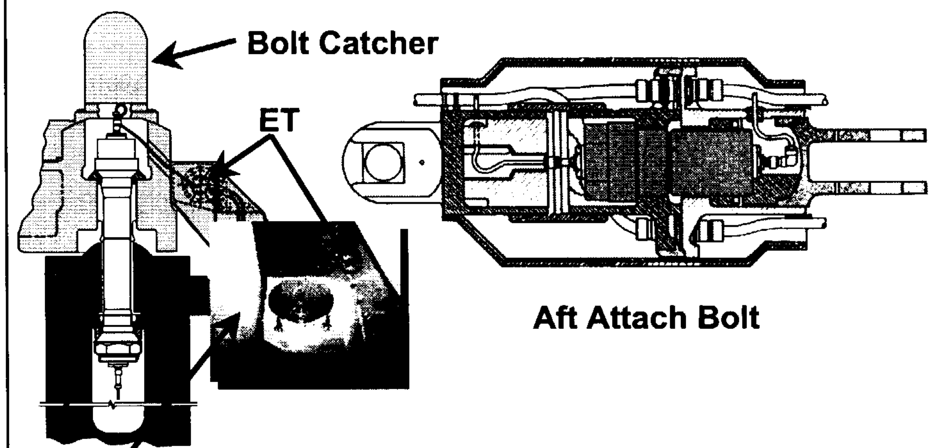


SRB Attach/Hold-down Hardware Upgrades Plan

Description

- Elements to be evaluated
  - Blast container
  - Bolt catcher
  - ET/SRB attach bolts (forward and aft)
- Performance testing to anchor analytical models
- Research of available material properties
- Process reengineering to reduce potential for human error
- Results in improved component robustness

Forward Attach Bolt



Aft Attach Bolt

Benefits

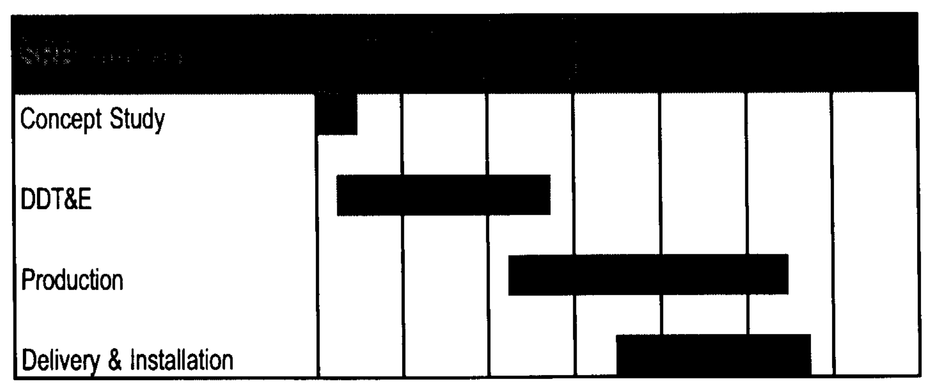
Safety

- Increased Factor of Safety (FOS) from 1.35 to minimum requirement per 07700 Vol X design factor of safety requirement
  - Current FOS is an exception to the requirement
- Improved component robustness
- Reduced potential for human error

Supportability

- Increased maintainability through reduction of human error

Schedule

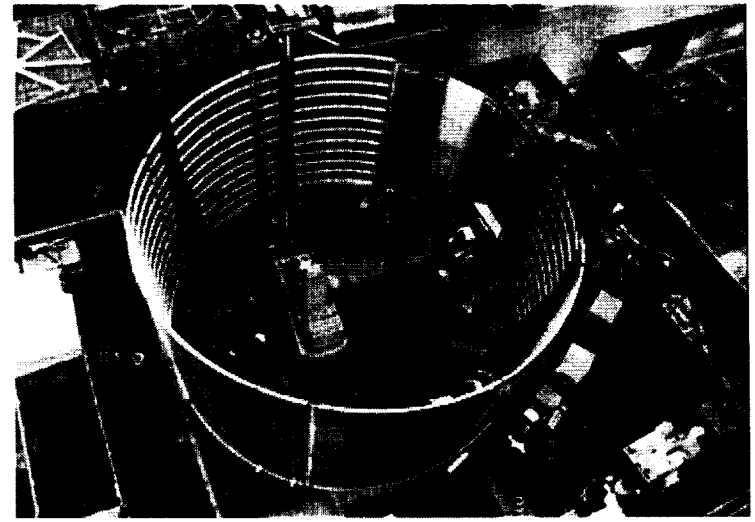


*Tentative Schedule

External Tank (ET) Upgrades - Friction Stir Weld (Barrels, Longitudinal)

Description

- Implement friction stir weld technology for External Tank longitudinal LOX and LH2 barrels
- Characterize weld process requirements and allowables
- Focus on Non-Destructive Evaluation (NDE) qualification requirements
- Develop weld process bandwidth parameters toward the goal of a 6 sigma control process



Benefits

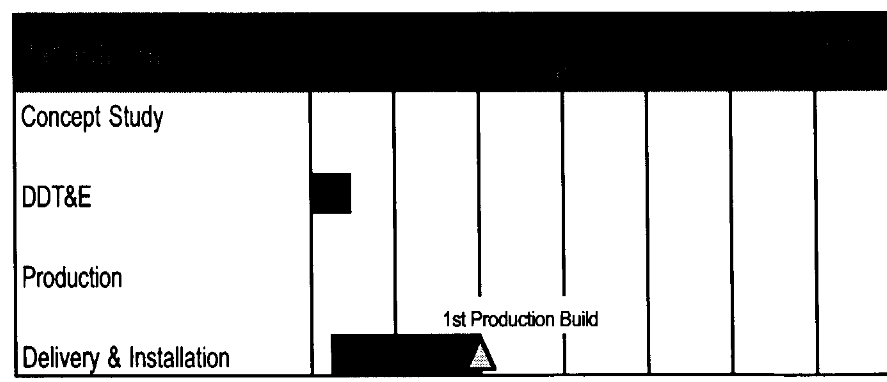
Flight Safety

- Increases barrel reliability by improving
  - Weld joint strength
  - Weld margins
  - Fracture toughness
  - Process control

Improve the System

- Decreased ET production time
- Decreased ET production cost
- Operational demonstration of important industry technology

Schedule

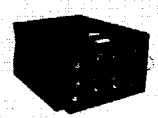


SSME Advanced Health Management System

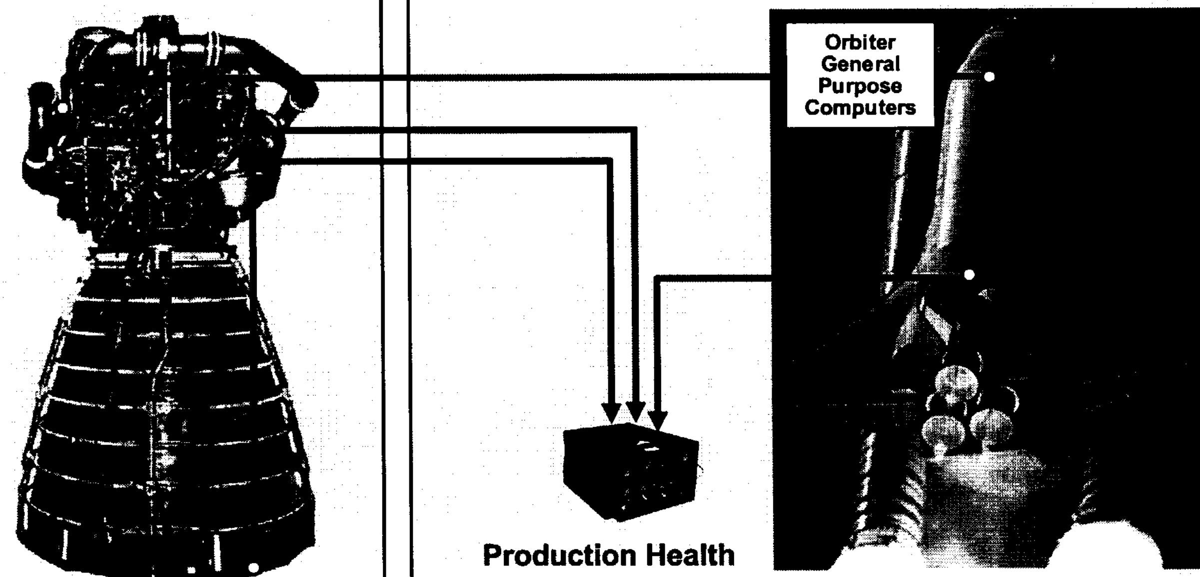
Phase I

SSME Block II Controller Upgrade
- Vibration redline
- DCU memory
- Communication bus

Phase IIA



Protoflight Health Management Computer
- Design
- Development
- Vehicle integration
- Flight demo/monitor
- RTVMS, OPAD, LED flight experiments



Catastrophic Redlines
Reside in Engine Controller

23% Reduction in Failure Probability

Phase IIB

Production Health Management Computer
- Expanded vibration monitoring
- Exhaust plume monitoring
- Engine model
- Expert systems
- Vehicle & System integration

Engine Health & Advisories Recommend Action
Resides on Orbiter

Similar Risk Reductions Calculated for Phase II

Goal: Reduce risk of SSME catastrophic failure by approximately 40%

SSME Advanced Health Management Phase I

Description

- SSME Advanced Health Monitoring Phase I – Synchronous Vibration Redline
  - Modify SSME Controller
    - Reliable real-time turbopump synchronous vibration redline capability
    - High speed serial interface for external communication
  - Develop and fly prototype Health Management Computer (HMC)
  - Fly OPAD Flight Experiment
  - Develop Linear Engine Model (LEM) as a MOD tool
  - Phase II Requirements Definition

Phase I

SSME Block II Controller Upgrade

Prototype Health Management Computer

Catastrophic Redlines
Reside in Engine Controller

Benefits

Flight Safety

- Reduces SSME catastrophic failure probability approximately 23%
- Reduces Shuttle catastrophic failure probability approximately 8%

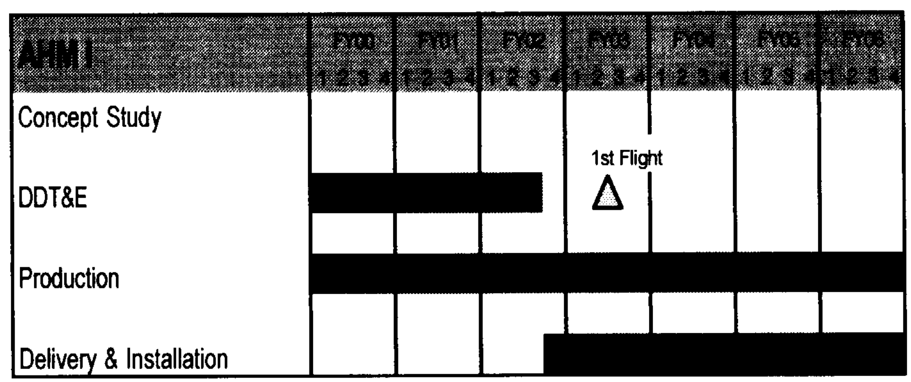
Mission Success

- Improved SSME Controller external communication
- Develops tool to be used by crew and MOD

Technology

- Develops technology needed for Phase II
- Integrated with and contributes to program and agency IVHM goals

Schedule

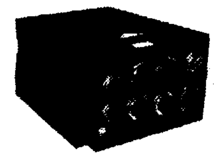


SSME Advanced Health Management Phase II

Description

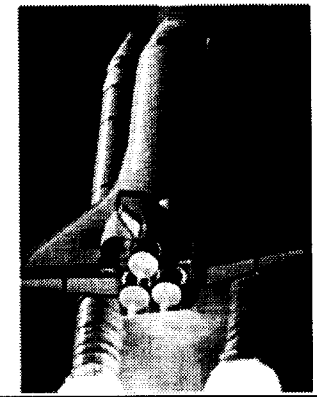
- SSME Advanced Health Monitoring Phase II – Advanced Health Management System (AHMS)
  - Health Management Computer (HMC) hosts
    - Advanced Real Time Vibration Monitoring System (RVTMS)
    - Optical Plume Anomaly Detection (OPAD)
    - Linear Engine Model (LEM)
- Phase II AHMS assesses results of RVTMS, OPAD and LEM and makes an overall SSME health recommendation

Phase II



Production Health Management Computer

- **Expanded vibration monitoring**
- **Exhaust plume monitoring**
- **Engine model**
- **Expert systems**
- **Vehicle & System integration**



Engine Health & Advisories Recommend Action

Resides on Orbiter

Benefits

Flight Safety

- Reduces SSME catastrophic failure probability approximately 24%
- Phase I and Phase II combined reduces SSME catastrophic failure probability approximately 41%

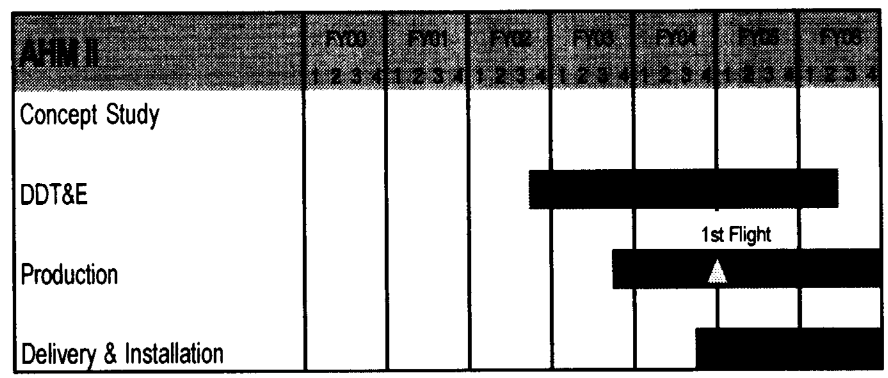
Mission Success

- Detects and isolates failures with high confidence and provides mitigation options which were previously unavailable
  - Mitigation of off mixture ratio operation
  - Enhances SSME operability due to additional data and automated engine health assessments

Technology

- Integrated with and contributes to program and agency IVHM goals

Schedule

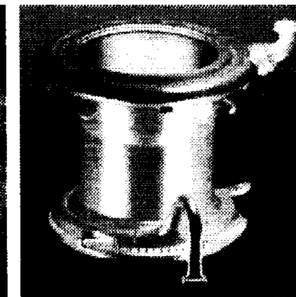


Block III SSME

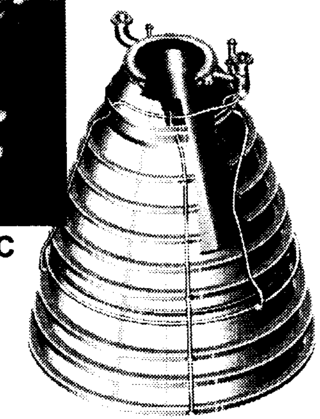
Description

- Extra-Large Throat Main Combustion Chamber (XLTMCC)
  - Reduced operating environments (pressure, temp)
  - Reduced hazards in Orbiter aft compartment
  - Reduced number of critical welds and parts
- Channel-Wall Nozzle
  - Reduces hazards of current nozzle

High Performance SSME



Larger LTMCC



Advanced Nozzle

Benefits

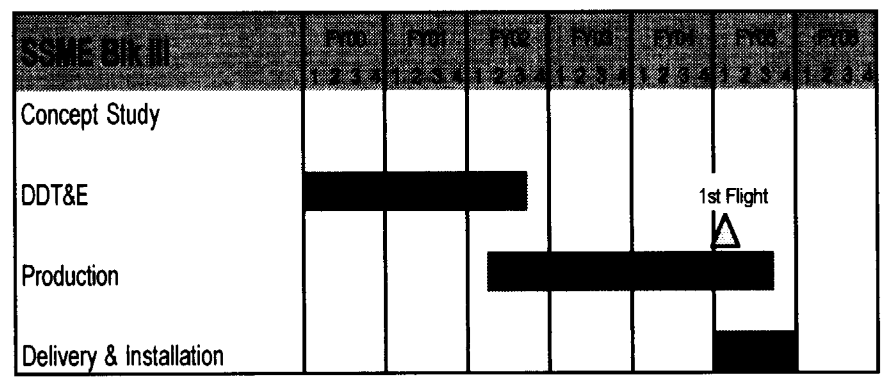
Flight Safety

- Increases SSME catastrophic failure MTBF by approximately 30-35%.
- Potential increased abort thrust capability
- Increased engine margin
- MCC/Nozzle interface is below the heat shield

Improve the System

- Decreased production time and production costs
- Increased turbine life
- Reduced inspections

Schedule

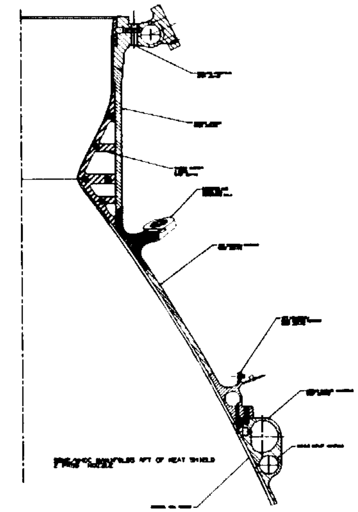


SSME Blk III X-Large Throat MCC

Description

- X-large throat MCC reduces operating environment for turbopumps and other components for increased engine reliability
- XLTMCC is ~18 inches longer to make optimum MCC/Nozzle configuration
- Has optimum RAO contour for Isp performance
- Fabricated by HIP braze process to eliminate failure modes and achieve 2X reliability improvement

- JBK-75 cast manifolds & jacket
- HIP braze close-out of channels
- Only 4 FMEA/CIL Crit 1 welds - was 23
- Only 10 parts + pins - was 20
- MCC/Nozzle interface below heat shield



Benefits

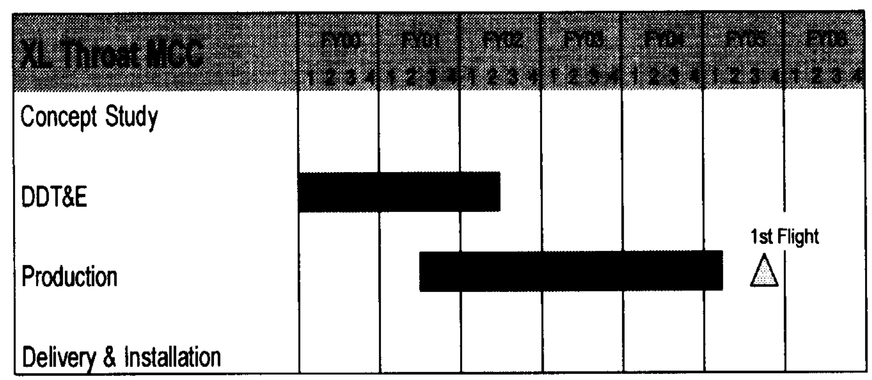
Safety & Reliability

- Improves 3-engine catastrophic MTBF from 1 in 1885 to 1/2586 with reducing the operating environment
- Doubles MCC MTBF from 1 in 8,950 to 1 in 17,901

Improve the System

- Unit production cost ~$1M lower
- Production cycle time reduced ~6-12 months

Schedule

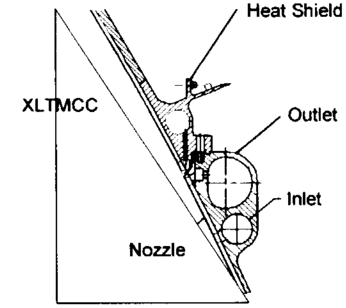


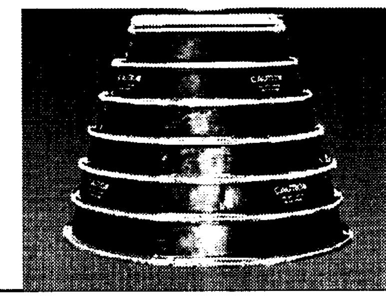
SSME Block III Channel-Wall Nozzle

Description

- Channel-wall constructed nozzle shortened by XLTMCC length increase with optimum contour
- Simplified construction - 5 major subassemblies (integral inlet / outlet casting, liner, jacket, forward end plumbing & drain lines, & TPS)
- Simple aft end flow turn-around with 1 weld -- no steerhorn feedlines
- No chamber coolant control valve/actuator
- Robust fabrication with reduced part count & welds

- Integral inlet & outlet JBK-75 cast manifolds
- JBK-75 liner & jacket
- HIP braze close-out of channels
- Eliminated ~300 welds & 5800 inches of welds
- Eliminated ~250 parts
- MCC/Nozzle interface below heat shield





Benefits

Safety & Reliability

- Improves 3-engine MTBF from 1 in 2363 to 1 in 2593 and doubles nozzle MTBF from 1 in 13,860 to 1 in 27,720
- Benign joint failures with G15 below heat shield

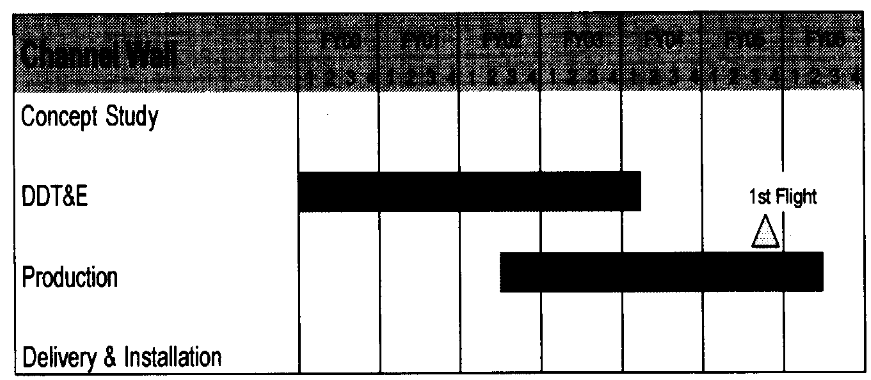
Mission Success

- Recover XLTMCC Isp loss with optimum contour and smooth wall (~1s)

Improve the System

- Reduce nozzle maintenance -- no leakage/repairs
- Reduces fabrication cycle time by 18 months
- Unit production cost ~$2M lower

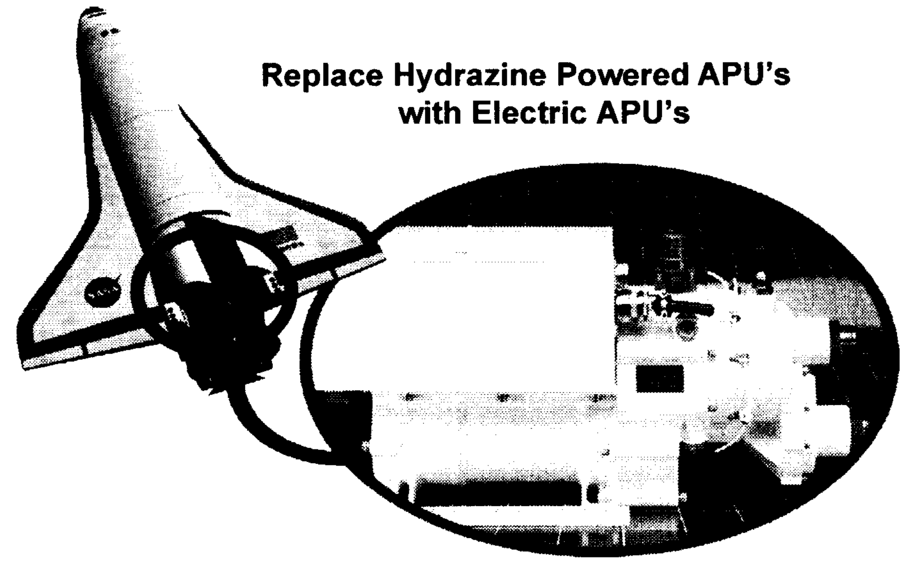
Schedule



Electric Auxiliary Power Unit (EAPU)

Description

- Upgrade three existing hydrazine system/high speed turbines with three electric motor driven, hydraulic pump systems powered by batteries
- EAPU upgrade consists of three main components
  - Electro-Hydraulic Drive Unit (EHDU) and Cooling
  - Battery system
  - Electric Power Distribution & Control (EPD&C)



Benefits

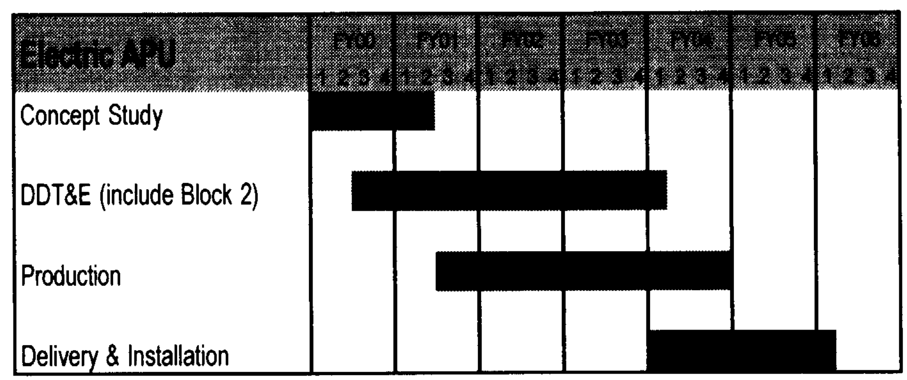
Flight Safety

- Eliminates hydrazine turbine hazards
  - Over speed
  - Hydrazine leakage
  - Re-ingestion of vented hydrazine

Ground Safety

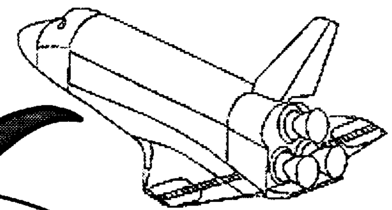
- Reduces toxic materials processing and handling

Schedule

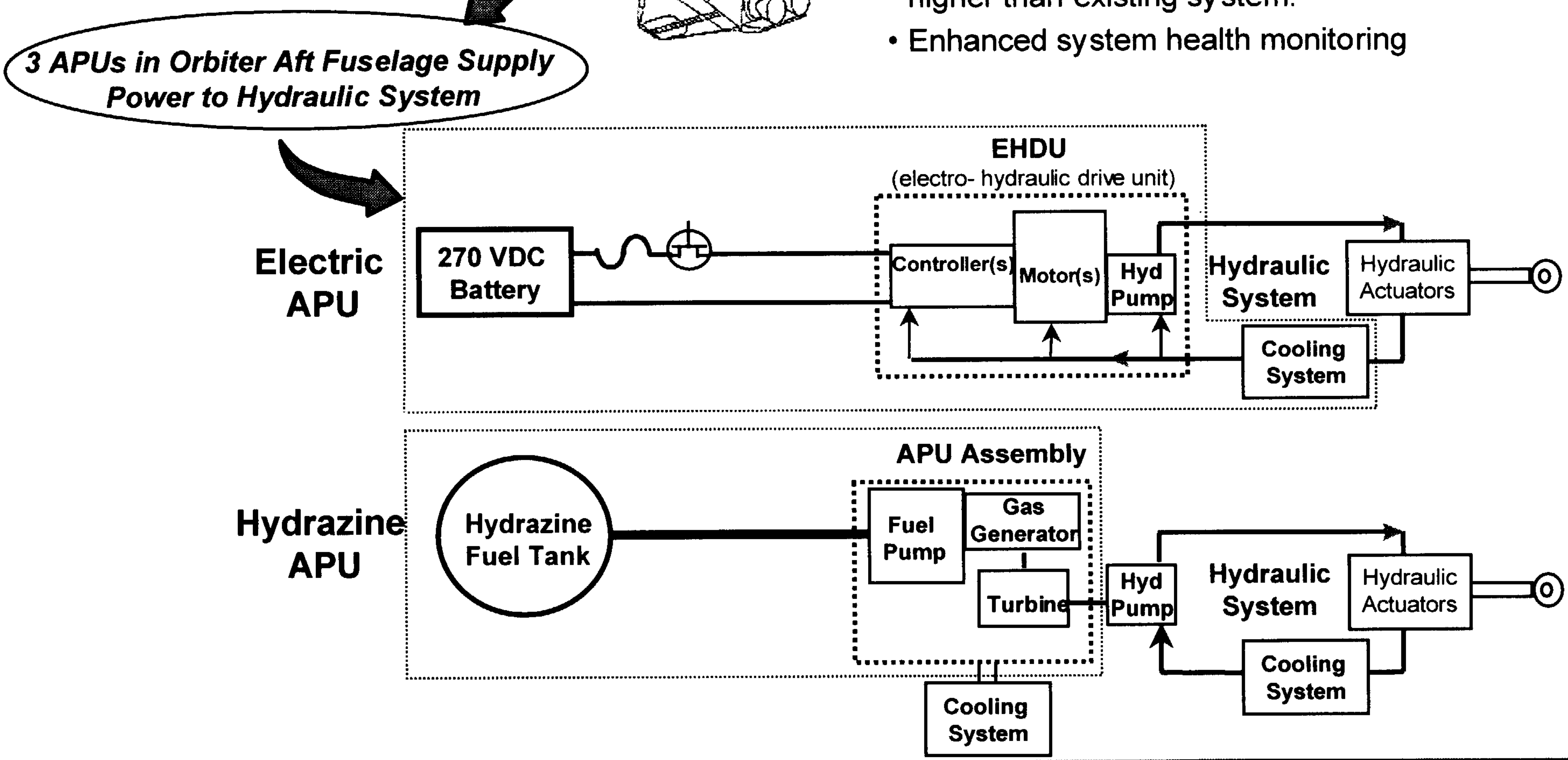


Electric Auxiliary Power Unit (EAPU)

Replace existing hydrazine and high speed turbine systems with electric motor driven, hydraulic pump systems powered by batteries



- Takes advantage of battery advancements to minimize weight impact.
- EHDU output power will be 30 percent higher than existing system.
- Enhanced system health monitoring



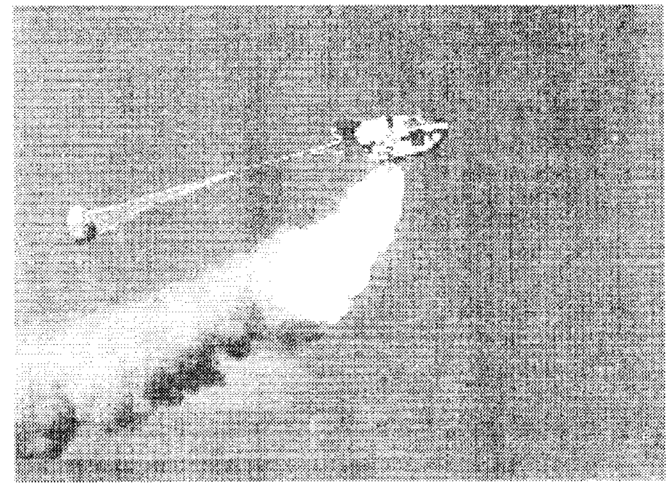
High Priority Safety Studies

- **Crew Escape Engineering Design Trade (Study)**
  - In-depth engineering study of contingency crew survival options
    - Extraction, ejection, crew module separation
  - Determine feasibility, survival utility, cost, and technical impacts
  - Increases probability of a successful crew bailout
- **TPS Lower Surface Tile (Study)**
  - Develop a more durable lower surface tile for bottom of Orbiter
  - Reduces risk of tile burn-through, reduces post-landing repair, and may provide additional MMOD protection
- **SCAPE Suit Improvement (Study)**
  - Objective is to develop a safer and more efficient SCAPE suit
    - Current suit is heavy, allows undesirable levels of CO_2, and is not efficiently cooled
  - Technical approach is to design and develop a prototype suit with decreased weight, better CO_2 scrubbing, and better cooling

High Priority Safety Studies

- **Shuttle Abort Improvements (Study)**
  - Investigate Orbiter hardware/software/procedural improvements to eliminate/decrease two engine out blackzones and other abort scenarios
  - Reduce areas of no coverage, eliminate abort scenarios, increase probability of a successful abort
  - Investigate propulsion element improvements to eliminate/decrease two engine out blackzones and other abort scenarios
  - Reduce areas of no return, eliminate abort scenarios, increase probability of a successful abort
- **Maintainability for Safety (Study)**
  - Objective is to identify maintainability improvements which can improve safety
  - Reduce potential of collateral damage during ground processing, improve personnel safety

Crew Escape System (Study)



Description

- Enhance crew escape capability in the event that the Orbiter can not return to one of the designated landing sites.
  - Expand crew escape envelope from 20,000 ft to 150,000 ft
  - Add capability to save multiple incapacitated crewmembers
  - Expand ability to use crew escape system based on flight conditions (vehicle speed, trajectory, attitude)
- Crew Escape candidates for study are:
  - Forward fuselage/crew module separation
  - Ejection seats
  - In-place extraction system

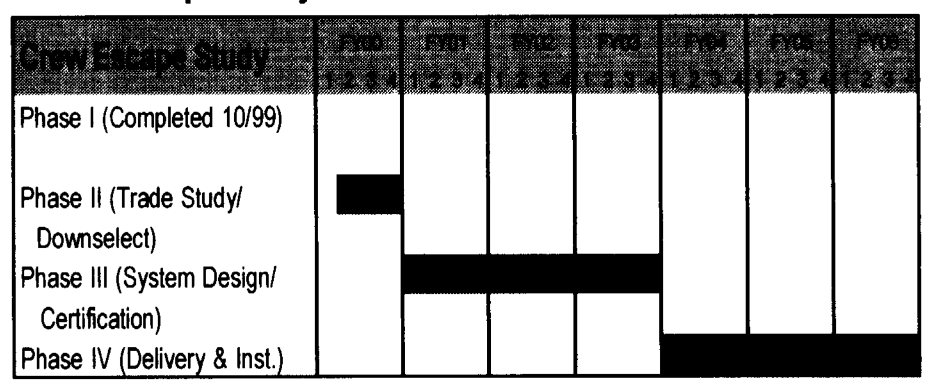
Benefits

Flight Safety

- Increase probability of crew survival during loss of vehicle scenarios
  - Probabilities for the three candidates will be estimated in the study
- Increase probability of crew survival in a rapid egress scenario on the launch pad
  - Capabilities for the three candidates will be evaluated in the study

Schedule

Crew Escape study includes Phase I and Phase II

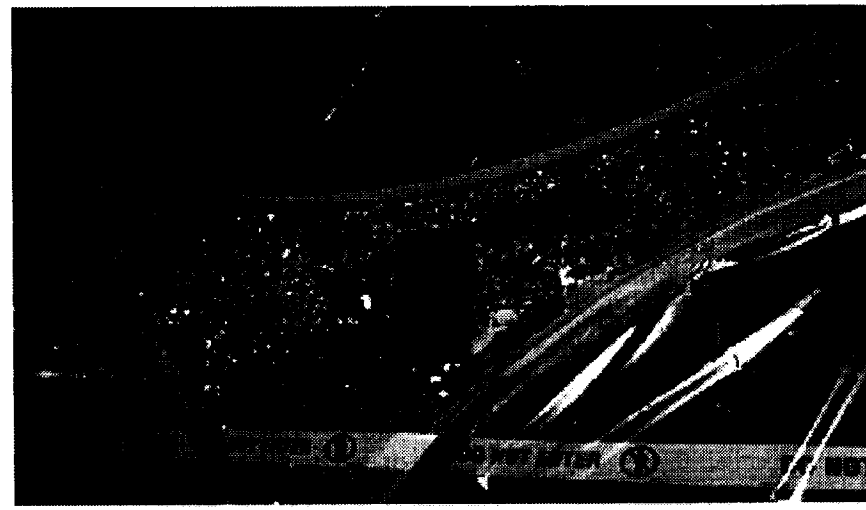


Orbiter TPS Lower Surface Tile (Study)

Description

Develop a more durable TPS tile for the orbiter vehicle's bottom fuselage region that will significantly reduce flight damage without compromising the thermal performance of the current system.

- Reduce the thermal conductivity of the current RCG/TUFI/AETB-8 tile to that of the RCG/LI-900 tile.
- Modify the TUFI process to be compatible with the LI-900 tile material
- Produce a tile system of comparable weight, catalytic performance, and thermal conductivity as the current LI-900 baseline system with enhanced durability.
- Produce a tile coating applicable to the LI-900 significantly more durable than the RCG/TUFI combination, with comparable weight and catalytic performance
- Products deliverable for FY00:
- Midterm (June 2000) and Final reports (Oct 2000) for each effort
- For each of the above efforts, no less than
  - 8 square tiles (6" square, 2" thick)
  - 4 arc jet pucks (3.875" diameter, 2" thick)



Projected Benefits

Safety & Reliability

- LOV (1/X) due to On-Orbit M/OD: Current 2197; Projected ~2800
- Reduces hazardous ground operations by elimination of re-waterproofing
- Reduced risk and increased safety for components, system and personnel; 50% Reduction in tile contribution to Orbiter risk from M/OD

Mission Success

- Increased reliability of components and systems; Significant reduction in component damage

Supportability

- Maintenance free lower surface significantly decreases amount of unplanned work in OPF. Weight reduction of 200-600 pounds. Supports 30-day OPF flow

Improve the System

- Supports 30-day OPF flow

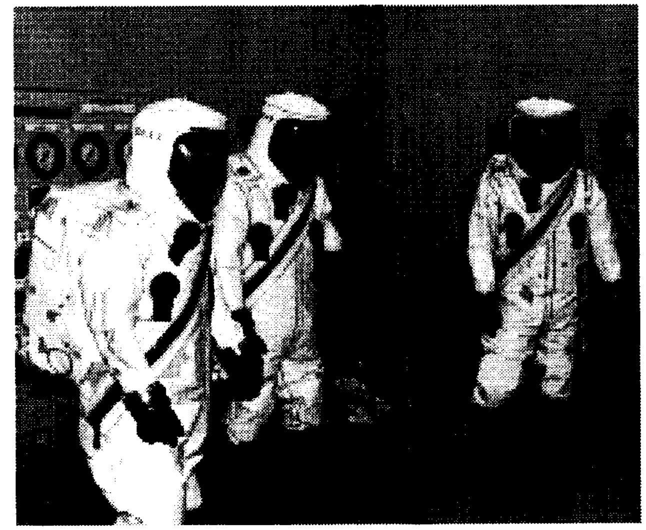
Schedule

TPS Study	FY00 1 2 3 4	FY01 1 2 3 4	FY02 1 2 3 4	FY03 1 2 3 4	FY04 1 2 3 4	FY05 1 2 3 4	FY05 1 2 3 4
Concept Study	■	■					
DDT&E							
Production							
Delivery & Installation							

Advanced Protective Suit Program (Study)

Description

- Redesign existing propellant handler's Self-Contained Atmospheric Protective Ensemble "SCAPE" suit which is used for protection during propellant loading operations
  - Phase 1 included development of a new 1 hour cooling dewar and then a 2 hour dewar
- Currently investigating teaming with part of the U.S. Army Soldier and Biological Chemical Command, "Natick Labs", for development of suit specifications and for suit production.



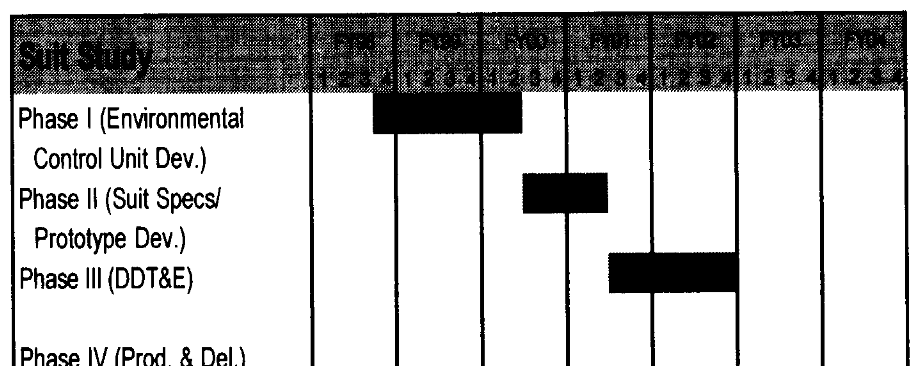
Benefits

Ground Safety

- Design goals for new suit include
  - Reduce carbon dioxide levels
  - Improve thermal characteristics
  - Improve visibility
  - Improve dexterity
  - Eliminate need to be upright to maintain adequate air flow
  - Improve communications/reduce noise
  - Improve fit
  - Decrease cost
  - Decrease weight

Schedule

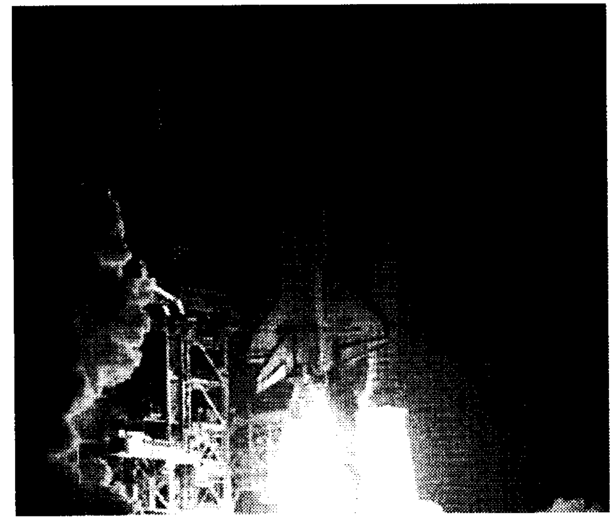
Advanced Protective Suit study includes Phase I and Phase II



Abort Improvements (Study)

Description

- Current abort capability does not include full crew and vehicle survivability coverage for some two and three engine out scenarios (black zones).
- A multidisciplinary team was formed to brainstorm possible improvements. The most promising improvements will be implemented or studied further. Study addresses
  - Vehicle capability characterization (i.e. improve vehicle models, databases, constraints or limitations that drive blackzones)
  - Improvements to software, procedures, or hardware

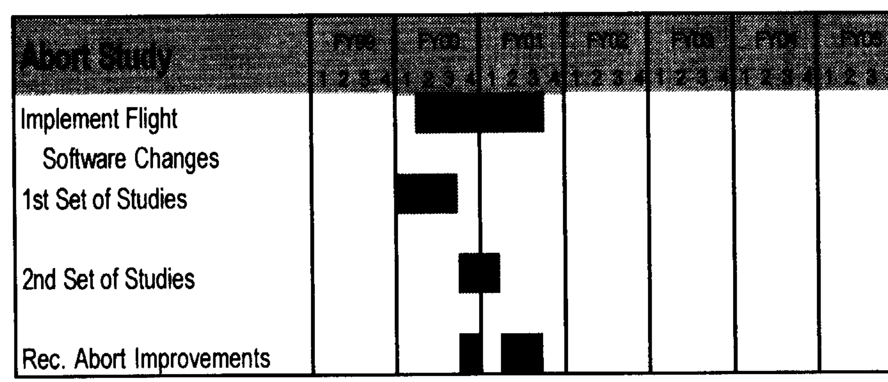


Benefits

Flight Safety

- Improve probability of a runway landing or bailout in certain loss of crew and vehicle abort scenarios
- Black zone criteria (targets for improvement)
  - ET attach structural failure for 3 SSME's out in 1st Stage (< 100 sec)
  - Loss of Control (LOC) during the pullout maneuver (qbar > 800 psf)
  - Structural failure during the pullout maneuver (Nz>3.5 g's)
  - Recontact/LOC after ET Separation near Vrel=0 on RTLS
  - Recontact/LOC for 3 SSME's out during last minute of PRTLS
  - Thermal limit and/or 3.5 g exceedance for MECO near VI=19K fps

Schedule



Space Shuttle Safety Upgrade Implementation Strategy

- Space Shuttle Program is committed to implementing the major safety upgrades by 2005.
- A SSP upgrades program plan to facilitate and manage the implementation of the upgrades.

Shuttle Upgrade Plan Background

Pro-active upgrade program to keep Shuttle flying ***safely*** and efficiently to 2012 and beyond to meet agency commitments and goals for human access to space

Safety Upgrades

Risk Reduction Goals

- Major reduction in ascent catastrophic risk
- Significant reduction in orbital and entry system catastrophic failure risk
- Improve crew cockpit situational awareness for managing critical operational situations

Supportability Upgrades

Flight Hardware Availability Assurance

- Obsolescence
  - Parts availability
  - Vendor support
- Failure rates
- Repair times
- Inventory attrition

Operational Improvements

- Maintainability
- Reliability
- Mission success
- Operational simplicity\
- Turn-around time improvements
- Cost reduction

Shuttle Supportability Upgrade Priorities

- **Key flight hardware *obsolescence* assessments**
  - Orbiter communication system
  - SRB integrated electronics assembly
- **Infrastructure refurbishment and repair**
  - Modernizing the Launch Processing System at KSC
  - Currently carrying out detailed assessment of all ground support facilities

Preliminary Supportability Study Conclusions

Key near term decisions

- Strategy for funding-limited supportability upgrade plan for 2000 & 2001 assuming no additional funds before 2002
  - Key question to be resolved is relative phasing of Orbiter major communication system upgrade and SRB major avionics upgrade
- Initiate design and acquisition effort, including vendor contracts, to implement necessary upgrades for near term supportability threats

Continue to refine supportability analyses and plans

- Independent assessment of supportability analyses and plans
- Develop more in-depth analysis and rationale
  - Reliability statistical variation analyses
  - LRU unique projections (rather than by similarity)
- Revise technical plans, proposals, costs and schedules
- Develop POP2000 budget submit for additional funding needed starting in FY02 and subsequent years

Preliminary Supportability Study Conclusions

- Only minor hardware supportability issues in fluid and mechanical subsystems
- Orbiter and SRB obsolete avionics are primary threat to assured manifest support through 2012
- Necessary additional funds to accomplish prudent supportability upgrades are under review and will be handled as part of the POP2000 budget planning for FY02 and subsequent years

Process to Identify Supportability Upgrades

Identify Issues
- Parts availability
- Failure rate
- Repair time
- Attrition
- Support equipment
- Operational complexity
- Infrastructure

→

Validate Issues and Assess Consequence
- Metric/Trend data
- Best/Worst case scenarios

→

Identify Options
- Alternate supplier
- Substitute part
- Repair facility improvement
- LRU upgrade

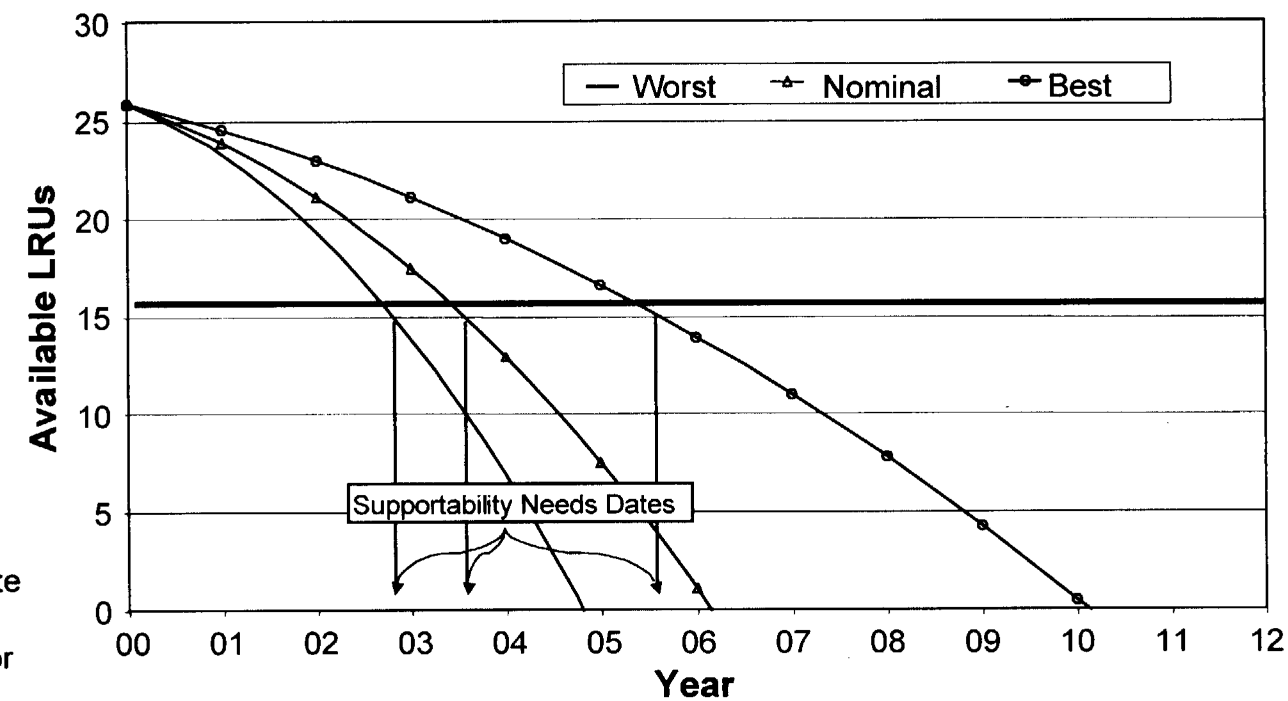
→

Evaluate Options and Choose Preferred Solution
- Feasibility of option
- Risk
- Schedule
- Life cycle cost
- Ancillary benefits
  - Performance
  - Operations simplicity
  - Inherent reliability
  - Etc.

→

Prioritize and Provide Rationale for Recommended Supportability Upgrades

Example LRU Best, Nominal and Worst Cases



Nominal

- Estimate near term demand (failures, attrition) for 8 flights per year from historical data
- Establish increasing failure rate trend from historical data or similar hardware to account for "bathtub" failure rate
- Estimate near term Repair Turn Around Time (RTAT) from NSLD assessments of historical data and mitigating circumstances
- Estimate increasing trend to account for impact of obsolete parts on RTAT
- Use historical attrition rate

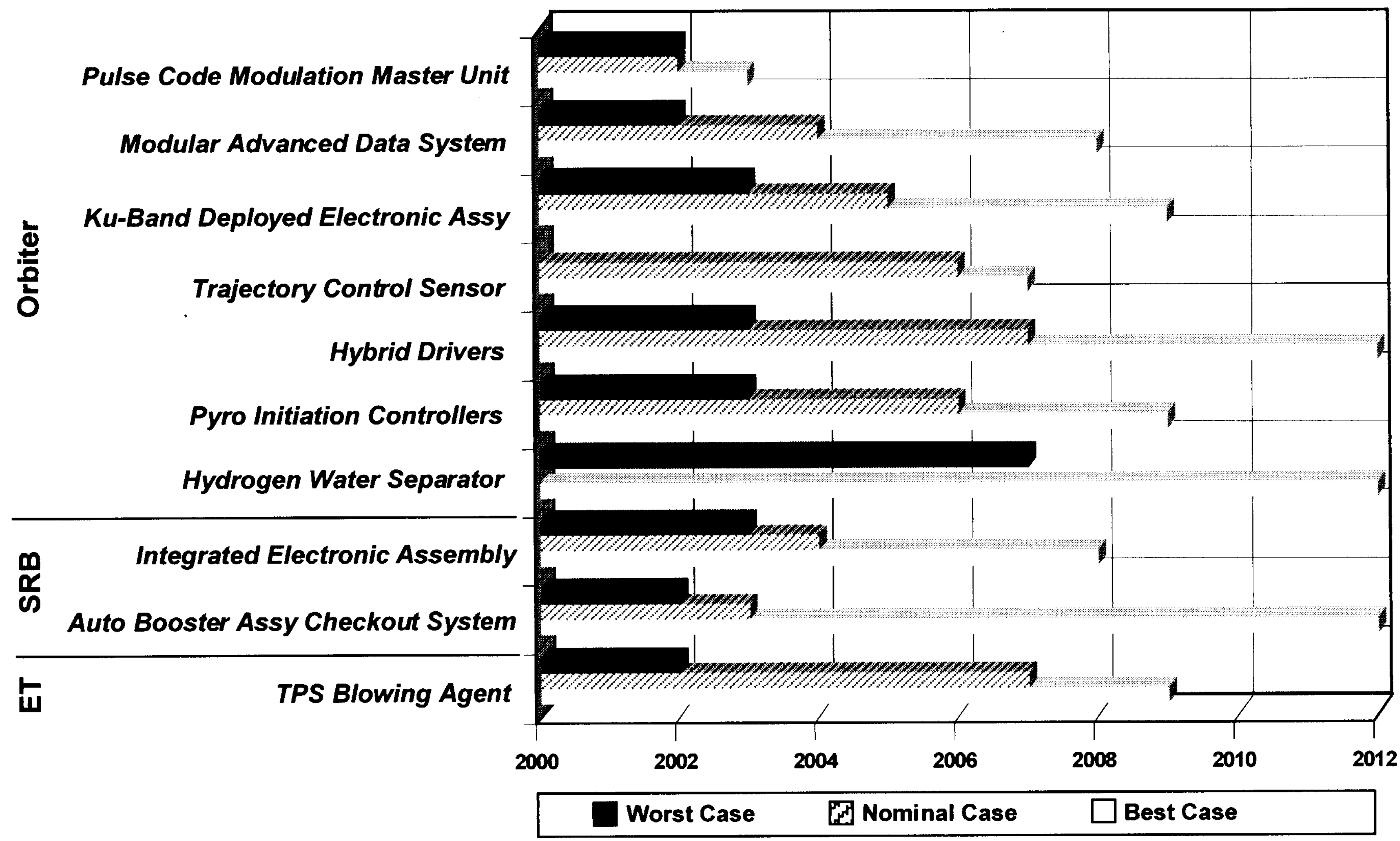
Best

- 1/2 increase in nominal failure rate
- No change in RTAT
- Historical attrition rate

Worst

- 2x increase in nominal failure rate
- 2x increase in nominal RTAT
- Historical attrition rate

Obsolescence Mitigation Need Dates



Space Shuttle Safety and Supportability Safety Upgrade Candidates

Safety Upgrades | Supportability Upgrades | Approved Upgrades | Advanced Technology

Orbiter Avionics

- **Cockpit**
  - Enhanced Caution and Warning
  - Crew Situational Awareness Displays
  - AFD Switch Panel Upgrade
  - Device Driver Unit Replacement (DDU)
- **Data Processing**
  - Mission Management Computer
  - Modular Auxiliary Data System
  - Modular Memory Unit (MMU)
- **Communications**
  - Ku-Band DEA
  - PCMMU
  - S-Band FM
  - Network Signal Processor
- **Navigation**
  - Trajectory Control Sensor (TCS)
  - IMU Replacement (SIGI)
- **Power Sub-Assemblies**
  - Hybrid Drivers
- **Thermal Protection System**
  - More Durable Lower Surface Tile (Study)
- **Structures & Mechanisms**
  - Crew Escape System (Study)
  - Main Landing Gear Tire Improvements
  - Micrometeoroid/Orbital Debris Mitigation (MMOD)
- **Environmental Control & Life Support Systems**
  - Hydrogen Water Separator

SRB / RSRM / ET / SSME

- SRB Advanced TVC
- Integrated Electronics Assembly
- ABACS
- ET Robust TPS
- ET Digital Radiography
- New O-Ring Material
- Case Stiffener Segment/T-Ring
- RSRM Propellant Geometry
- SRB Attach/Hold Down Hardware
- ET Friction Stir Initial Welds
- Advanced Health Monitoring
- SSME Block III
  - XLTMCC and Robust Nozzle
- SRB TVC Upgrades / FIV
- SRB Altitude Sensor Assembly
- Nozzle/Case Joint J-Leg Insulation
- Integrated Receiver-Decoder (IRD)
- Range Safety Distributor (RSD)

Power & Propulsion

- Electric APU
- Enhanced Pyro Initiator Controller
- Improved Pilot Operated Valve
- Quad Check Valve Redesign
- Long Life Alkaline Fuel Cell

Operations

- **Ground Operations**
  - Maintainability for Safety (Study)
  - SCAPE Suit Improvements (Study)
  - CLCS
- **Flight Operations**
  - PIDAE
  - Shuttle Upgrades Design Visualization
  - Robotic Situational Awareness Display
  - Human Factors/Cockpit Engineering Study
  - Expansion of MCC Landing Sites
  - AWPS
  - EECOM STS Pressure Management Tool
  - Alternatives to Hardware Based Robotics Training
  - DM Trajectory Operations Interface Redesign
- **Flight Tests**
  - Wireless Sensor
  - Laser Dynamic Range Imager HTD

Advanced Technology

- Crew Escape
- Reusable First Stage
- Non-Tox OMS/RCS Propellants
- PEM Fuel Cell
- Electromechanical Actuators
- Water Membrane Evaporator
- Integrated Vehicle Health Mgmt
- Propellant Densifications
- Fiber Optics

Supportability Upgrades: Requirements and Definitions

Mandatory Supportability Upgrades

- **Mandatory supportability** means "3 shipset availability" for the orbiter fleet (8 shipsets for SRB) based on 8 flights per year through 2012 and equivalent criteria for other shuttle elements
- **At the hardware LRU level** the "3 shipset *un*availability" is determined by one of the following criteria:

  1) the subject LRU contains obsolete part(s) with projected spares inventory depletion before 2012, **and** the obsolete part(s) cannot be replaced with new part(s) without redesigning the assembly or component it is used in; i.e., LRU redesign is required to keep flying after the current parts inventory is depleted. That is, we can't get the part anymore nor can we buy a "plug and play" replacement part, so we have to redesign the LRU or at least one of its subassemblies to accommodate new parts.

  2) The projected failure rates and repair times for the subject LRU cannot be handled by the maintenance depot, even with **reasonable** depot enhancements (additional staffing and equipment); that is, the maintenance workload will overload the depot and eventually lead to hardware unavailability for flight. That assumes that we do a first order trade on enhancing our repair capability before we say we have to upgrade the flight hardware.

Supportability Improvements which provide significant benefits with respect to:

- Reliability
- Mission success
- Operational processing efficiency
- Life cycle cost

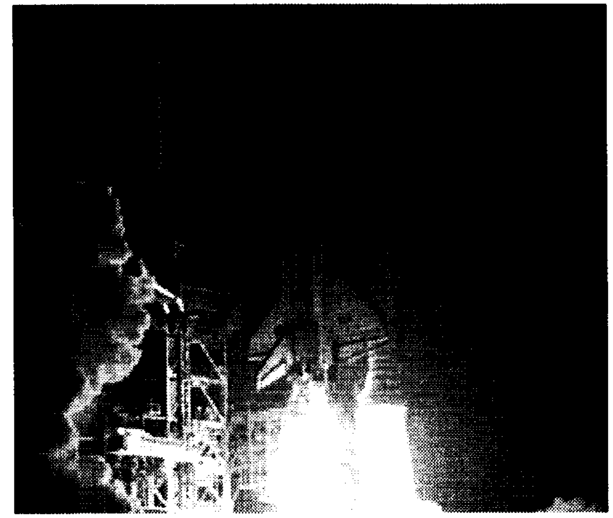
Mandatory Supportability Shuttle Upgrades

Upgrade Project	Supportability Driver
Pulse Code Modulation Master Unit	Project failure rate exceeds repair rate
Modular Advanced Data System	Failure rate is expected to exceed repair rate
Ku-Band Deployed Electronic Assembly	Projected failure rate exceeds repair rate
Trajectory Control Sensor (TCS)	Limited life item
Hybrid Drivers	Not enough hybrid drivers for approved upgrades
Enhanced PIC	Projected demand and attrition exceeds supply
Hydrogen water Separator	Increasing nickel deposits degrade performance
SRB Command Receiver Decoder	Projected failure/attrition rated impact supportability
SRB Integrated Electronics Assembly	Projected attrition rate and limited life impacts supportability
Auto Booster Assy Checkout System	Projected CPU failure/attrition rates exceed projected supply
Robust ET TPS Study	TPS foam blowing will become obsolete

Supportability Improvement Shuttle Upgrades

Upgrade Project	Supportability Driver	Payback Year 0% Discount	Payback Year 6.25% Discount
S-Band Network Signal Processor	Obsolete, wearout and degradation failures may exceed ability to repair, Opportunity for bandwidth improvement	**N/A**	**N/A**
S-Band FM Transmitter	Obsolete, wearout and degradation failures may exceed ability to repair	**N/A**	**N/A**
Improved Pilot Operated Valve	Projected reliability improvements provide return on investment	**2009**	**2011**
Quad Check Valve Redesign	Projected reliability improvements provide return on investment	**2010**	**2012**
New O-Ring Material	Projected return on investment and flow time reduction	**2006**	**2006**
Case Stiffener Segment/T-Ring	Projected reliability improvements provide return on investment	**2011**	**2013**
ET Digital Radiography	New digital process provides flow time reduction and substantial ROI	**2008**	**2010**

Modular Auxiliary Data System Recorder



Description

- Option 1: Upgrade
  - Produce new tape for both recorders for near term support
  - Replace tape function with solid state memory in the Modular Memory Unit
- Replace Pulse Code Modulators (PCMs) with high speed PCMs
- Option 2: AHM
  - Procure new tape for both recorders for near term support
  - Combine with Health Management Computer upgrade for the main engines

Benefits

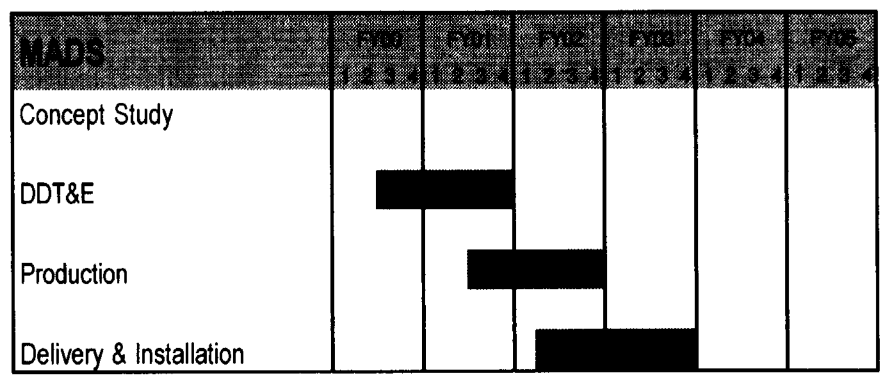
Supportability

- Tape procurement mitigates near term obsolescence need
- Option 1 mitigates technological obsolescence of recorders

Improve the System

- Both options convert from tape recording to solid state memory
- Option 1 provides for high speed PCMs
- Option 2 leverages technology of SSME AHM effort

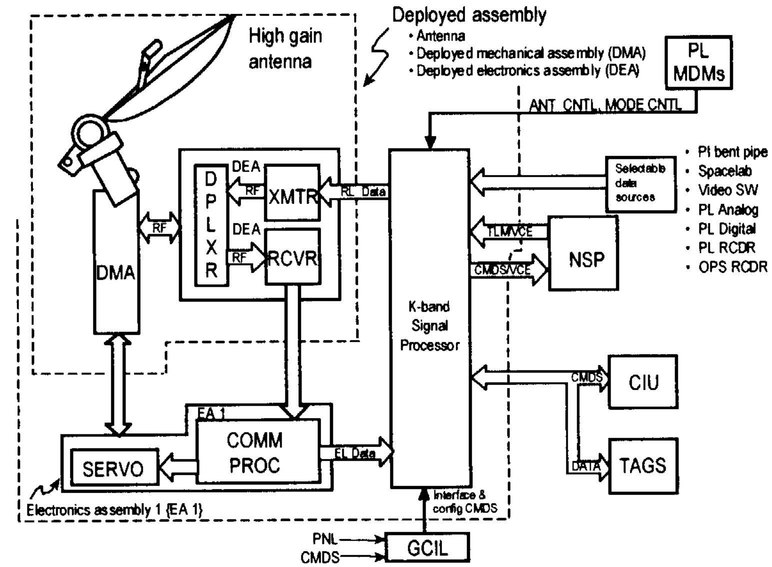
Schedule



KU-Band Deployed Electronic Assembly

Description

- Replace obsolete Ku-band communications system electronics
  - Option 1: Retrofit current hardware
    - Board-level upgrade of the DEA … I.e., drop in SRU's
    - Separate rendezvous sensor from KU-band hardware
  - Option 2: Replace current deployed parabolic dish Ku-band assembly and supporting electronics with modern phased array antenna (PAA)
    - High bandwidth PAA
    - Separate rendezvous sensor
    - Includes upgrades of communications architecture



Benefits

Safety & Reliability

- PAA option eliminates Crit 1 CIL

Supportability

- Both options mitigate obsolescence issues of the Deployed Assembly
- PAA option mitigates all other obsolescence issues in communications system

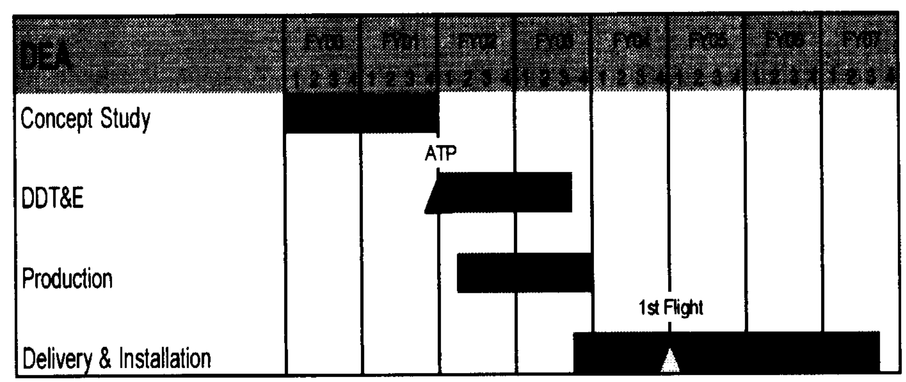
Meet the Manifest

- Provides simultaneous high bandwidth communications during rendezvous
- Improves reliability for mission success and on time launch

Improve the System

- Enables high-bandwidth communications during rendezvous operations
- PAA option is required to enable increased bandwidth capability of Network Signal Processor upgrade
- PAA option provides high-bandwidth operations without opening payload bay doors
- PAA option is an enabler for the MOD Re-invent process

Schedule



Pulse Code Modulating Master Unit

Description

- Option 1: Replace form, fit, function with new technology
  - Reduces number of subassemblies
  - Improves reliability and performance
  - Supports increased data downlink and MOD re-invention
  - May absorb Payload Data Interleaver (PDI) function
- Option 2: Integrate with mission computer as part of safety upgrades

Benefits

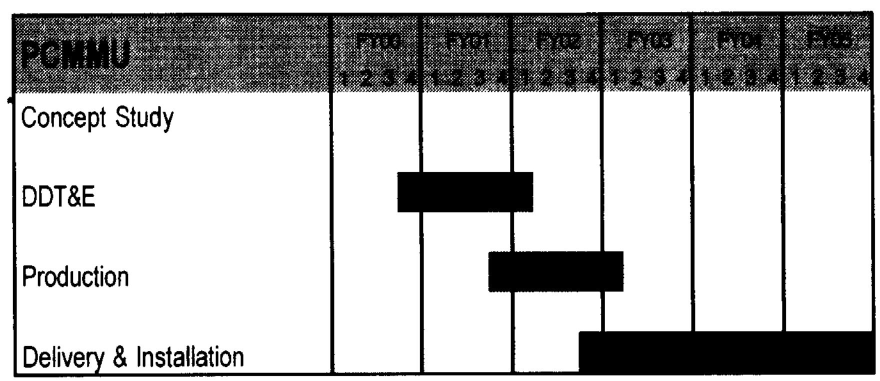
Supportability

- Mitigates obsolescence issues with current PCMMU

Improve the System

- May absorb Payload Data Interleaver (PDI) function
- Increase data downlink
- Supports MOD Re-invention

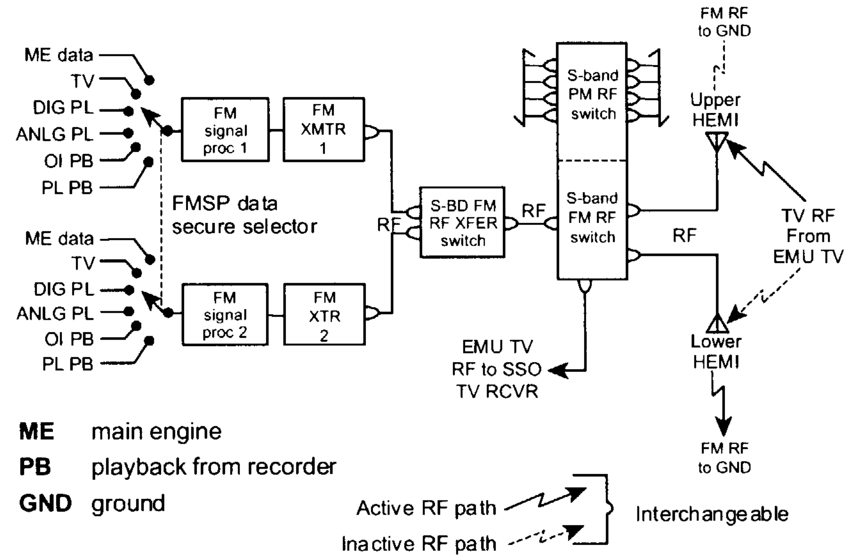
Schedule



S-Band FM

Description

- New FM system (transmitter and signal processor)

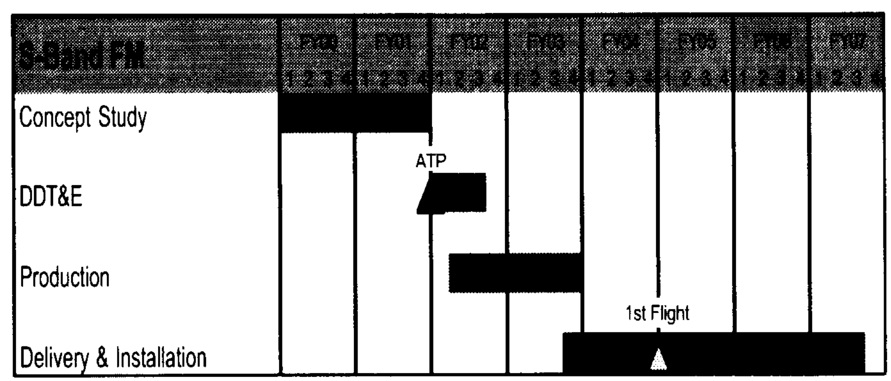


Benefits

Supportability

- Mitigate obsolescence issues of the S-Band FM System

Schedule



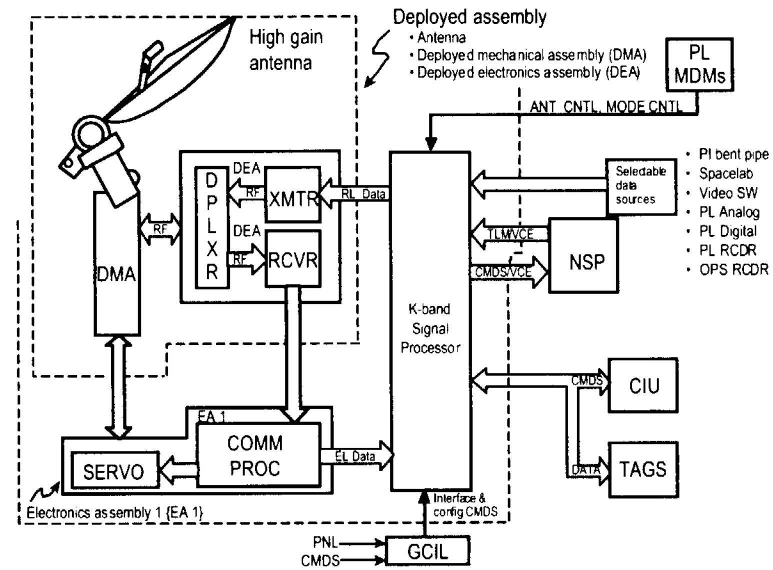
S-Band Network Signal Processor

Description

Combine signal processing and Communications Security (COMSEC) in one new LRU

Employ new voice encoding to increase data bandwidth by up to 32 Kbps

- Supports need for new telemetry without continuous scrubbing of telemetry format loads (TFLs)



Benefits

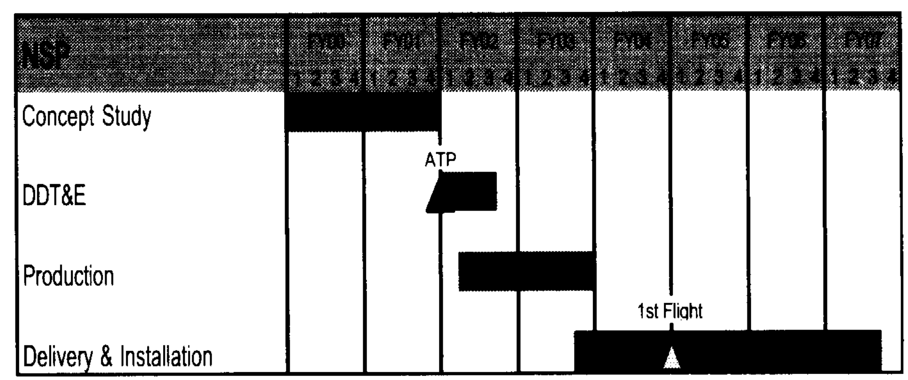
Supportability

- Mitigate obsolescence issues of the Network Signal Processor

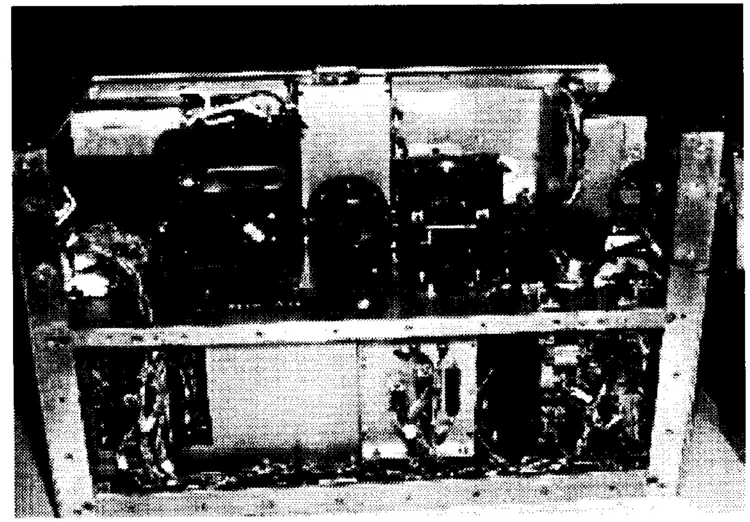
Improve the System

- Combines COMSEC with signal processing for more efficient LRU
- Increased bandwidth during all phases of flight
  - Requires PAA option upgrade of Deployed Electronic Assembly
- Enabler for MOD Re-invention

Schedule



Trajectory Control Sensor (TCS)



Description

TCS is a GFE rendezvous and docking sensor used inside 5000 foot range to target

Upgrade

- Replace galvanometer shaft with new solid shaft
- Purchase 1 new unit to certify all units to 30 flights

Benefits

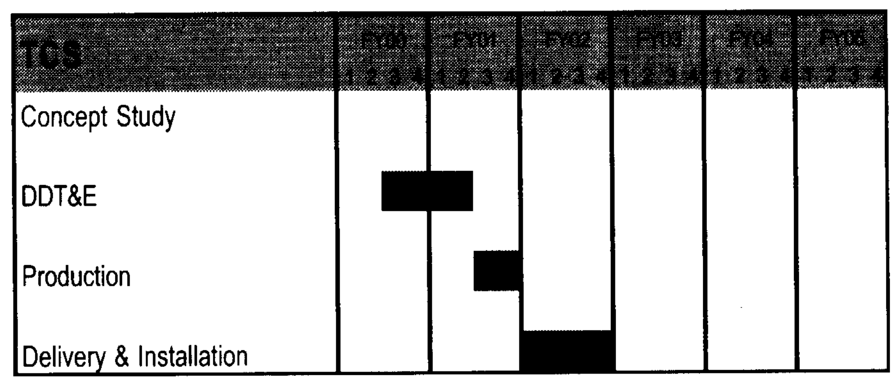
Supportability

- Mitigates obsolescence needs of current Trajectory Control System

Improve the System

- Improved reliability with new solid galvanometer shaft

Schedule



Hybrid Drivers

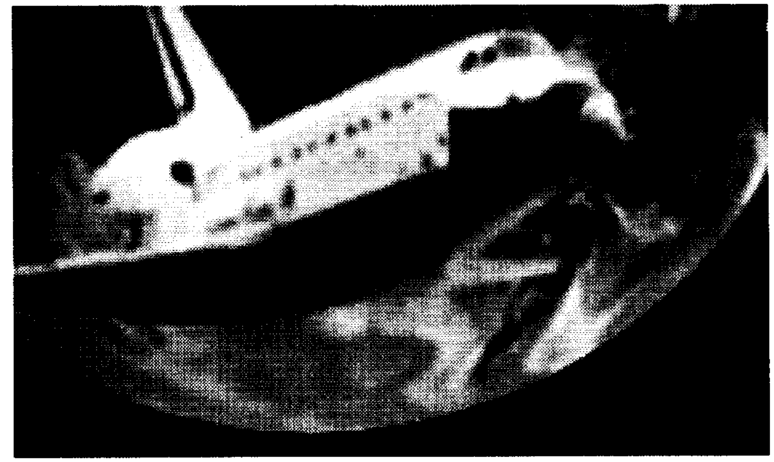
Description

Hybrid driver controllers/assemblies are solid state switching devices used to control and distribute power to Orbiter subsystems

Single programmable device which can support all requirements

Options:

- Drop in replacements for four type of Hybrid Drivers
- Four functionally equivalent types of Hybrid Drivers
- Non-preferred substitute (e.g. electromechanical relay)

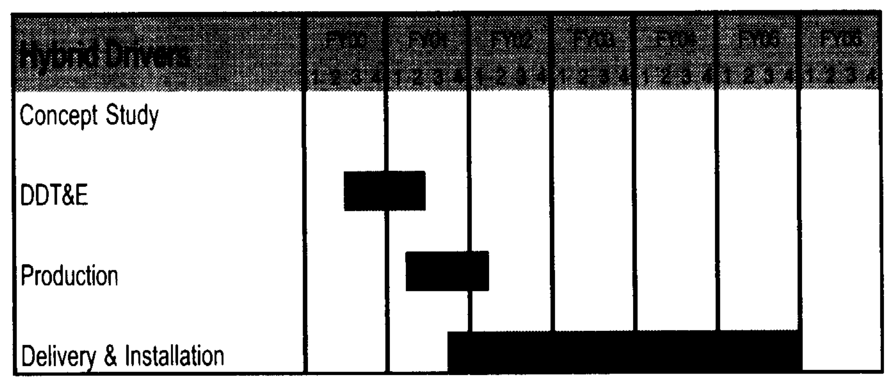


Benefits

Supportability

- Provides for Hybrid Driver needs through the course of the avionics upgrades process, other Orbiter modifications, and typical logistics demands

Schedule



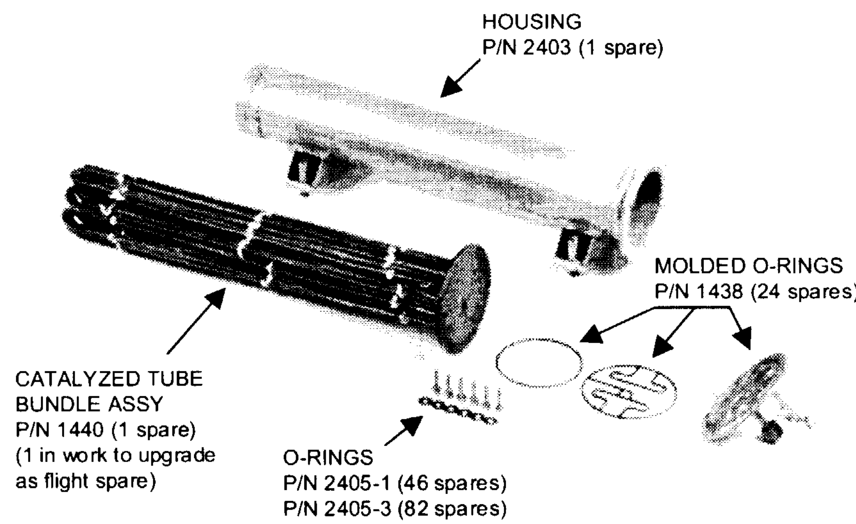
Hydrogen Water (H_2/H_2O) Separator

Description

H_2/H_20 Separator removes hydrogen gas from the potable water generated by fuel cells

Drop in replacement based upon same technology

- Water flows on the inside of tubes while space vacuum is applied to the outside of tube surfaces causing the hydrogen to pass through the solid tube wall into space vacuum

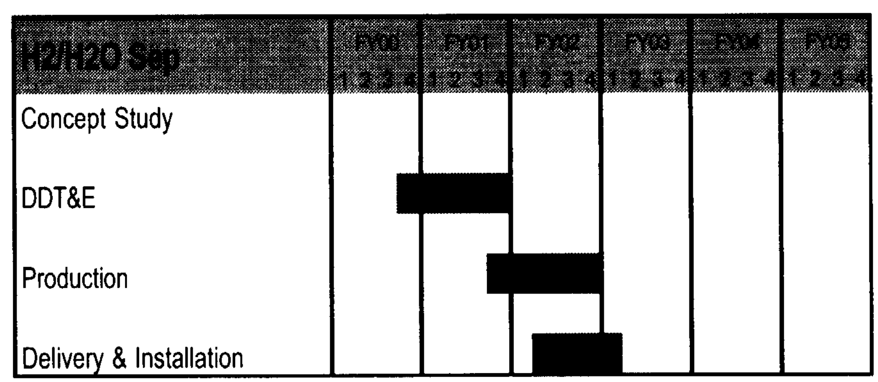


Benefits

Supportability

- Mitigates obsolescence issues with current Hydrogen Water Separators
    - Efficiency degradation (acceptable efficiency: 95%)
    - Anomalous Nickel deposits
    - Spares issues (currently only 2 spares for fleet)

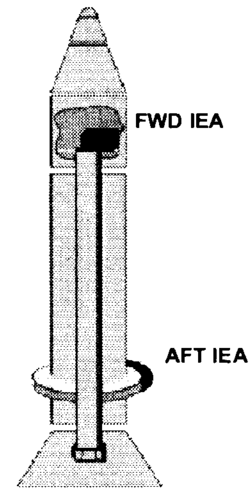
Schedule



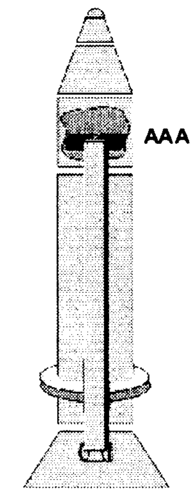
SRB Integrated Electronic Assemble Upgrades Plan

Description

- Replace obsolete 1970's vintage electronics with state-of-the-art
- Add redundancy to LCC instrumentation
- Two option in evaluation
  - IEA retrofit (interchangable with existing IEA)
  - Advance Avionics Assembly (new design to minimize life cycle cost)
- 2nd quarter FY 2000 down select



IEA Retrofit



Advanced Avionics Assembly (AAA)

Benefits

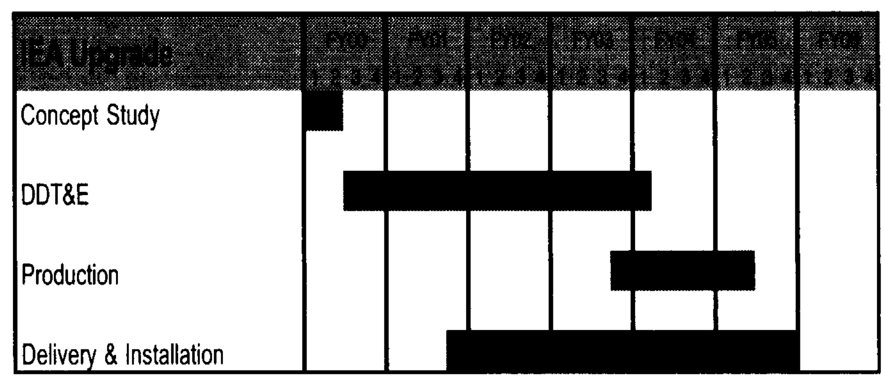
Safety

- Improved reliability and robustness
- Reduced potential for on-pad scrubs/aborts

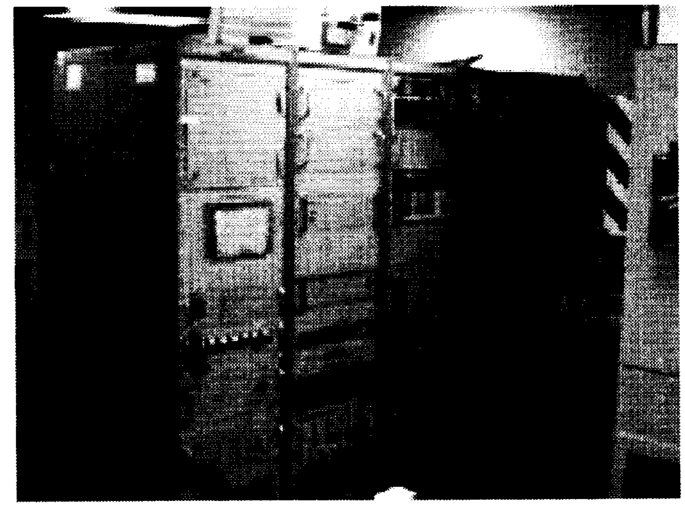
Supportability

- Obsolescence, increasing failure rates, and lack of spares pose risk to SSP manifest
- No spare APU controller cards
- Onset of age-related failures risks lowering reliability
  - 20+ year old EEE parts
  - Consensus of MSFC, DoD, and industry technical communities

Schedule



SRB Automated Booster Assembly Checkout System (ABACS)



Description

- The Automated Booster Assembly Checkout System (ABACS) is used to test SRB Flight Avionics and Thrust Vector Control Systems prior to each flight
  - Replace with new technology, commercially based assemblies
  - Incremental development to preclude impact to launch processing
  - Will consider CLCS architecture as base for ABACS
- Upgrade replaces key systems affected by obsolescence
  - ABACS Controller and Emulator
  - IEEE-488 Instruments
  - Test Station Hardware

Benefits

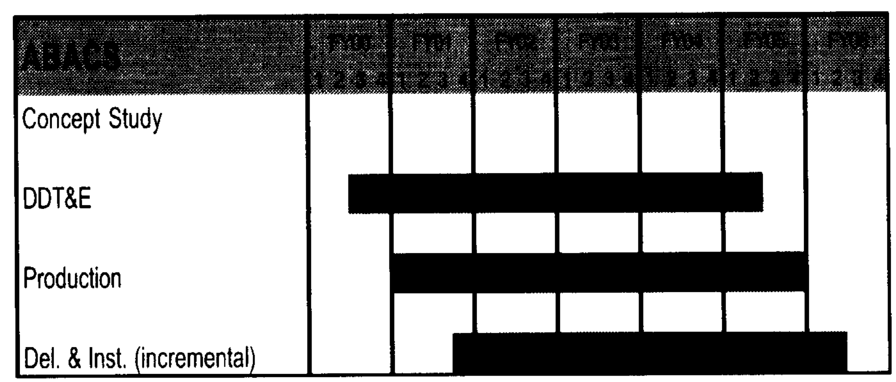
Supportability

- Increases likelihood of having a required ground processing system available to support KSC operations
- Mitigates obsolescence of key components such as 8086, 8186 and 8286 CPU's

Improve the System

- Enhances ABACS maintainability

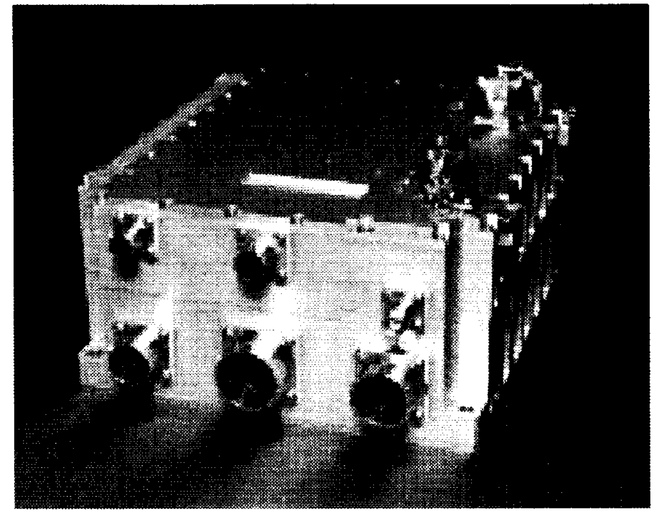
Schedule



SRB Command Receiver/Decoder (CRD)

Description

- Integrated Receiver-Decoder (IRD) and Range Safety Distributor (RSD) provide reception and command of range safety instructions
  - If needed for range safety, initiates SRB self-destruct
  - DDT&E is funded and underway and 1st engineering units are in test
- Combine IRD and RSD into one unit with new design
  - New unit is the Command Receiver Decoder (CRD)
    - Achieves full EMT compliance
    - Replace PIC with direct current firing circuit



Benefits

Flight Safety

- Eliminates a criticality 1 failure mode
- Decreased destruct reaction time

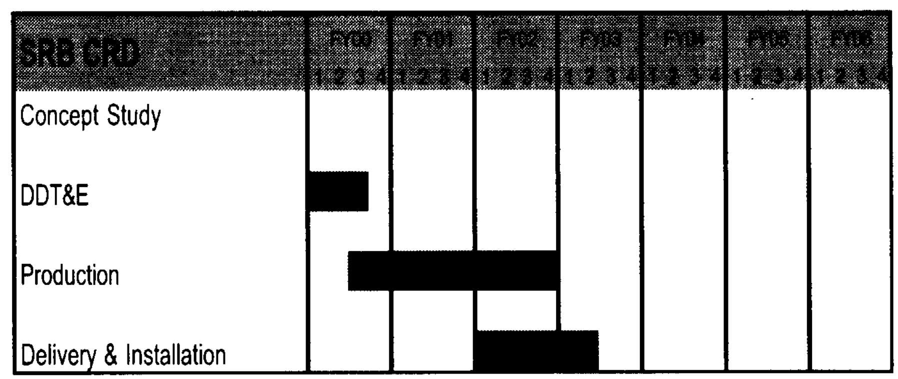
Supportability

- Mitigates obsolescence of key components
  - RSD and IRD have 39 obsolete EEE parts
  - RSD Programmable Automated Test Set requires upgrade/replacement

Improve the System

- Enhances maintainability

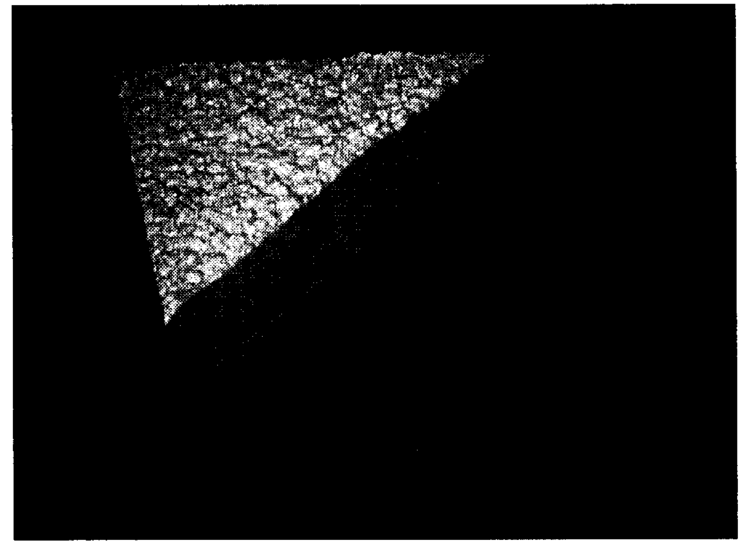
Schedule



ET Robust TPS (Study)

Description

- External Tank (ET) Thermal Protection System (TPS) is sprayed on as a foam and provides thermal protection to the tank
- Research how to formulate and manufacture TPS spray foam systems that are more damage resistant and have higher tensile strength
  - New TPS blowing agent will be environmentally compliant (eliminate HCFC's)
    - Manufacturers will phase out production of blowing agent (HCFC's) due to worldwide environmental agreements.
    - A waiver is being pursued to allow import of HCFC's beyond December of 2002.
    - A separate waiver may be needed to allow use of blowing agent beyond December of 2003.



Benefits

Flight Safety

- Reduces likelihood of damage to orbiter tiles during ascent
- Resolves flight performance issues
  - Intertank foam loss
  - Popcorning on liquid oxygen ogive

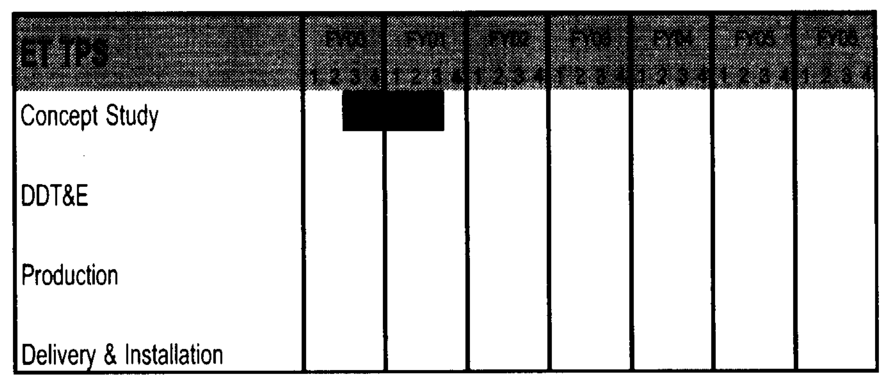
Meet the Manifest

- Reduces likelihood of TPS damage by weather at the launch pad
- Eliminates risk to ET production rate due to the unavailability of an EPA compliant blowing agent

Improve the System

- Resolves foam production issues
  - Internal lacquering in spray gun
  - Problems in Cells "K" and "B/C" with low strength and blisters

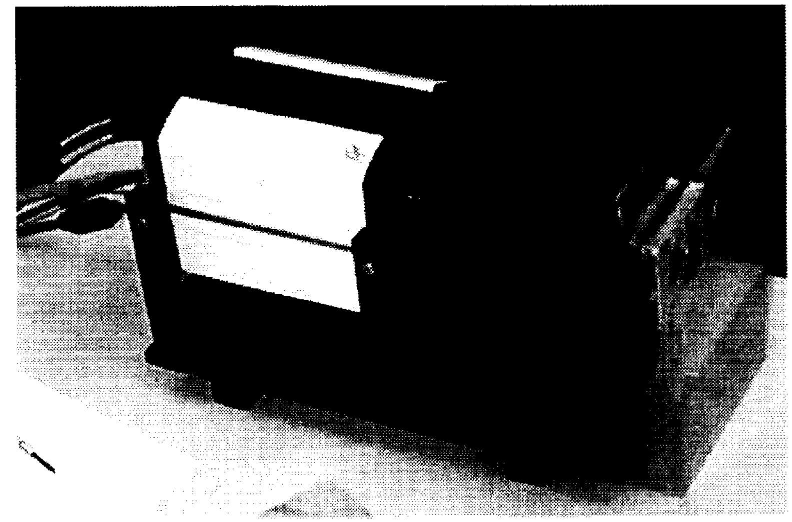
Schedule



ET Digital Radiography

Description

- All ET welds are inspected using a film x-ray process.
  - Process is manual and time consuming.
  - Film must be developed before it is known if welds pass inspection.
- Replace the current film x-ray inspection process with digital x-ray inspection process for acceptance of ET welds
  - Integrate into 20 existing ET tooling stations
  - Automated weld history and defect tracking
  - Improved user interface
  - Database development and archival capabilities



Benefits

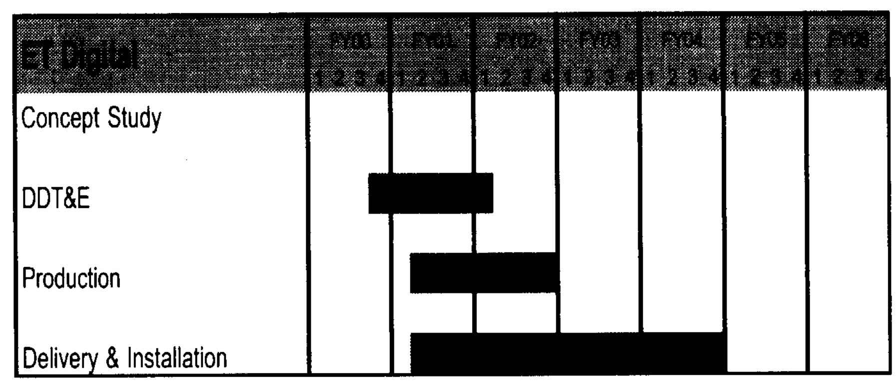
Meet the Manifest

- Reduces at least 10 days of ET production critical flow time (out of 22 months)

Improve the System

- $1.8M in recurring labor and material cost savings per year, based on 8 flights per year.
- Digital images can be quickly shared electronically with engineers at other sites to aid in problem resolution.
- Improved film density range
- Eliminates potential of data loss due to degradation of archived film
- 1.9:1 Return on Investment thru 2012 ($17.2M savings on $9.0M investment)
- Cost payback is estimated to be in 2008.

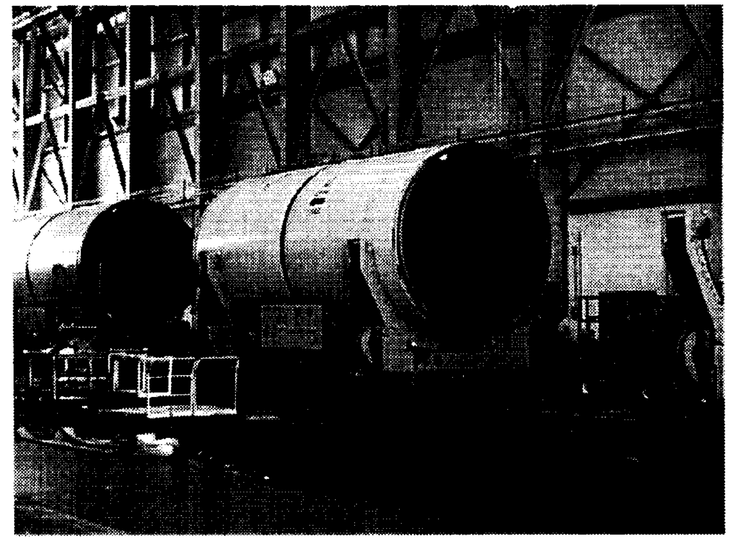
Schedule



New O-Ring Material/Joint Heater Elimination

Description

- The RSRM O-ring/joint heater system provides a seal between RSRM segments.
- Heater system is required to maintain O-ring temperature for cold weather launches
- Replace the current RSRM O-ring material with a new generation of polymers that allow for formulation of O-Ring materials with better physical properties, particularly low temperature resiliency
  - Joint heater system can be eliminated

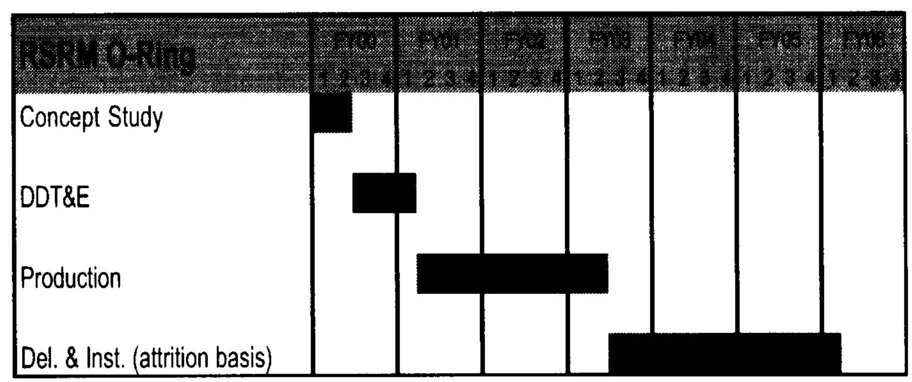


Benefits

Improve the System

- $1.6M savings in recurring costs per year by eliminating heater system build-up time and checkout.
  - 7:1 Return on Investment thru 2012
- Reduces one day of critical flow time during stacking in VAB at KSC (VAB operations no longer prevent further critical path reductions in KSC stacking operations)
- Eliminates hazards related to electrical heaters and associated power cables. May eliminate seal related launch commit criteria constraints due to current seal/heater system
- Saves 400 lbs. of SRB weight per mission
- Cost payback is estimated to be in 2006.

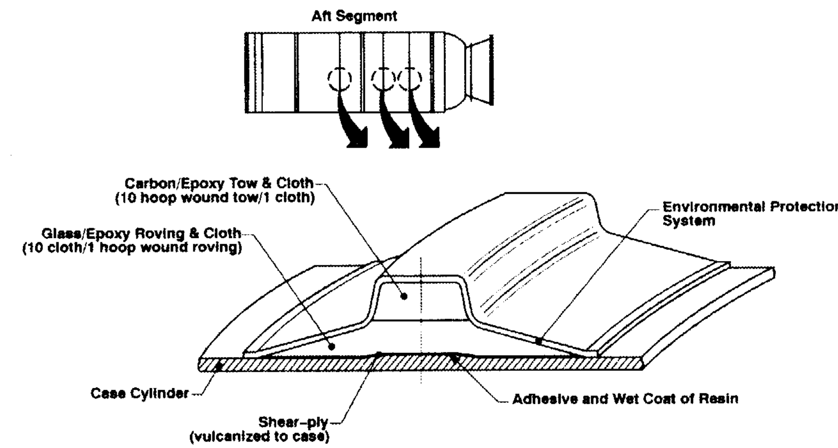
Schedule



Case Stiffener Segment/T-ring Redesign

Description

- Redesign case stiffener segment and T-rings to reduce damage to the hardware during water impact and increase proof-test demonstrated factor of safety on forward stub from 1.24 to 1.40
  - Stiffener stubs are damaged (cracked) due to cavity collapse loads during water impact



Benefits

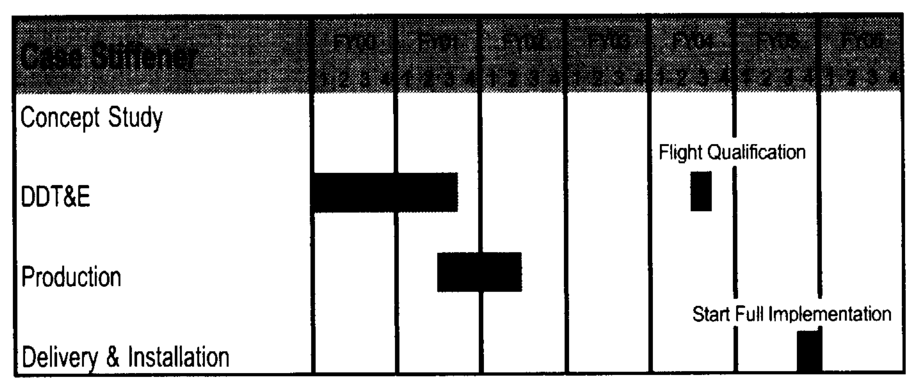
Safety/Reliability

- Increase demonstrated factor of safety on forward stub from 1.24 to 1.40
- Removing stubs eliminates stub cracks during water impact and need for subsequent inspections

Supportability

- Reduce Utah refurb/repair time and KSC flow time
- Return five currently unusable segments to flight inventory
- Reduce attrition of stiffener segments

Schedule



Pyrotechnic Initiation Controllers (PICs)

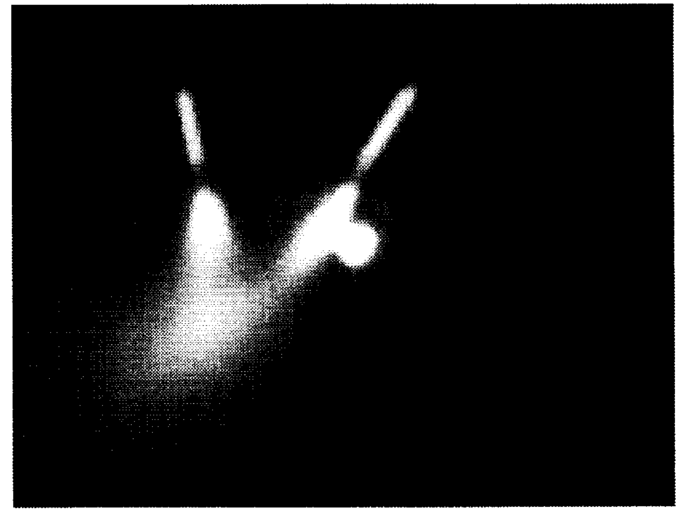
Description

PICs are capacitive discharge devices used to ignite NASA Standard Initiators for separation maneuvers

New design with same form, fit, function

- New technology & improved reliability
- 1000 units

Interdependency - Each SRB forward and aft IEA pair uses 17 PICs



Benefits

Safety & Reliability

- Improved reliability of new devices

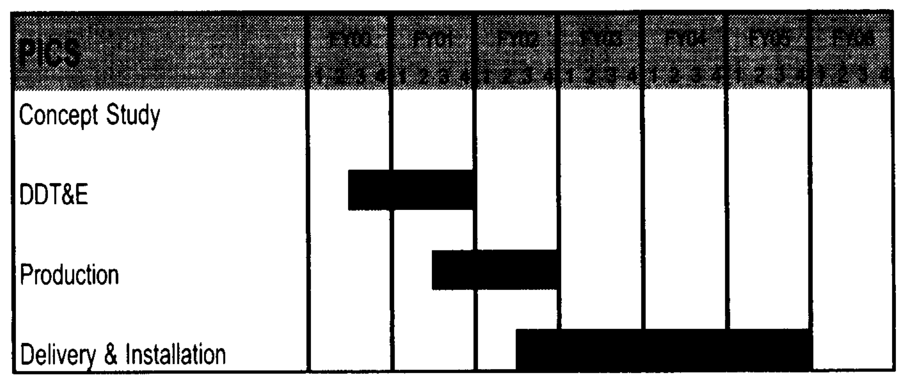
Supportability

- Mitigates obsolescence need for current PICs

Improve the System

- Weight savings with new technology
  - 30 lbs per Orbiter
  - 25 lbs per SRB
- $500k annual savings

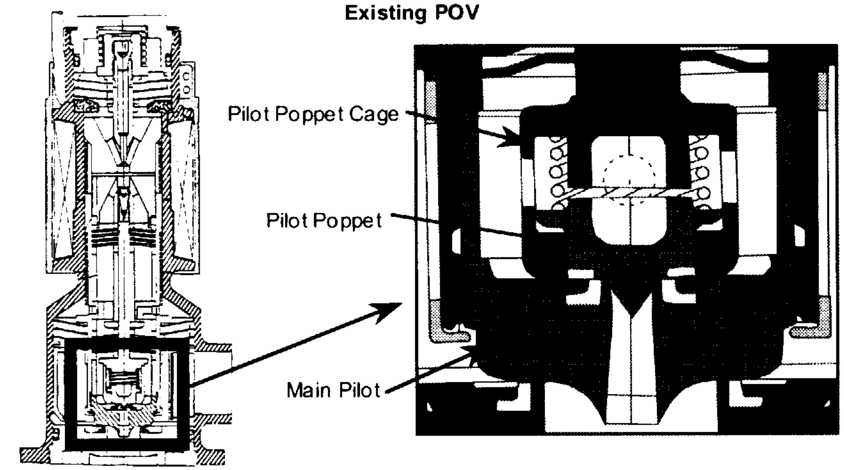
Schedule



RCS Improved Pilot Operated Valve (POV)

Description

- The POV controls the flow of fuel and oxidizer for the Reaction Control System primary thrusters
  - Failure modes include fail off and fail leak
  - A failure can lead to the loss of an ISS docking mission due to contamination (continued leakage) or loss of translation control
- Upgrade redesigns the POV seat and poppet to eliminate leakage and sticking
  - Significant effort will be spent to optimize the design



Benefits

Flight Safety

- Reduces likelihood of fuel or oxidizer leakage that could contaminate sensitive payload or ISS components

Meet the Manifest

- Reduces likelihood of shortening a mission due to a continuously leaking POV or a combination of failed POVs.

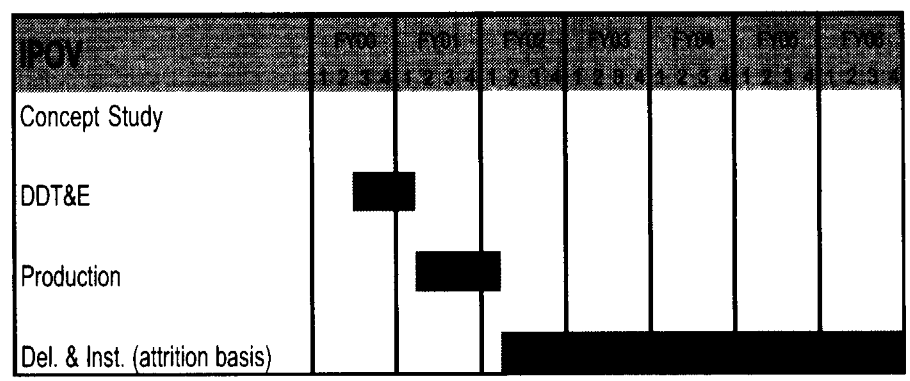
Supportability

- Reduces likelihood of time-consuming POV changeout

Improve the System

- Reduces yearly maintenance cost by approximately 50%
  - 23 new valves required per year
  - 5.5 unscheduled removals per year
- Cost payback is estimated to be in 2009.

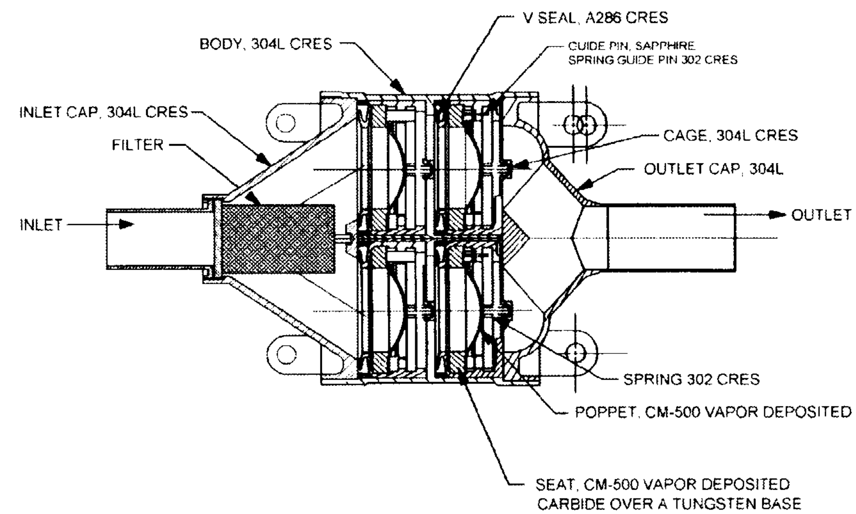
Schedule



OMS/RCS Quad Check Valve

Description

- The OMS/RCS Quad Check Valve (QCV) prevents the back flow of propellant in the helium pressurization system.
- Upgrade redesigns QCV assembly to eliminate internal leakage and stuck-open poppets
  - Phase A study
    - Study and development testing of QCV modification and new check valve design
  - Phase B qualification test/implementation
    - Replace sapphire guide pin with diamond pin and/or increase poppet spring force

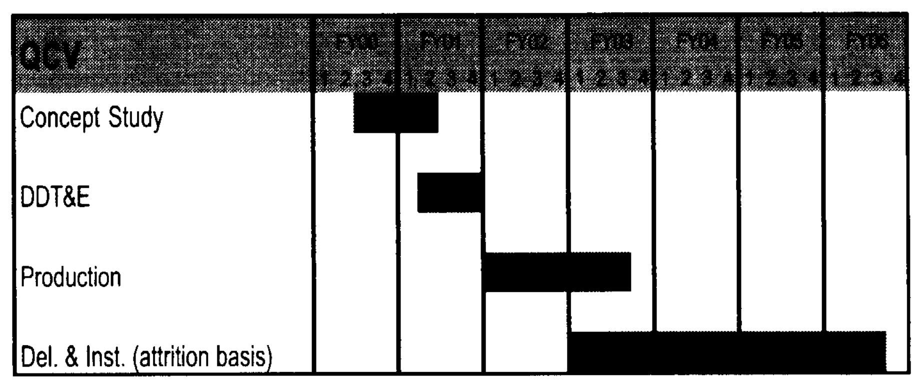


Benefits

Improve the System

- Failed QCV requires FRCS or Pod removal. These removals are time consuming and are hazardous operations.
- Since Return to Flight there have been 27 failures requiring remove and replace.
- OMRS failures require increased ground time to troubleshoot problems.
- New design estimated to have (estimate only - savings will be better quantified after Phase A study)
  - 50% maintenance savings due to decreased troubleshooting (estimated at $100K/year)
  - 50% reduction in failures requiring R&R (estimated at $300K/failure)
- Cost payback is estimated to be in 2010.

Schedule



Space Shuttle Safety and Supportability
Safety Upgrade Candidates

Safety Upgrades | Supportability Upgrades | Approved Upgrades | Advanced Technology

Orbiter Avionics

- **Cockpit**
  - Enhanced Caution and Warning
  - Crew Situational Awareness Displays
  - AFD Switch Panel Upgrade
  - Device Driver Unit Replacement (DDU)
- **Data Processing**
  - Mission Management Computer
  - Modular Auxiliary Data System
  - Modular Memory Unit (MMU)
- **Communications**
  - Ku-Band DEA
  - PCMMU
  - S-Band FM
  - Network Signal Processor
- **Navigation**
  - Trajectory Control Sensor (TCS)
  - IMU Replacement (SIGI)
- **Power Sub-Assemblies**
  - Hybrid Drivers
- **Thermal Protection System**
  - More Durable Lower Surface Tile (Study)
- **Structures & Mechanisms**
  - Crew Escape System (Study)
  - Main Landing Gear Tire Improvements
  - Micrometeoroid/Orbital Debris Mitigation (MMOD)
- **Environmental Control & Life Support Systems**
  - Hydrogen Water Separator

SRB / RSRM / ET / SSME

- SRB Advanced TVC
- Integrated Electronics Assembly
- ABACS
- ET Robust TPS
- ET Digital Radiography
- New O-Ring Material
- Case Stiffener Segment/T-Ring
- RSRM Propellant Geometry
- SRB Attach/Hold Down Hardware
- ET Friction Stir Initial Welds
- Advanced Health Monitoring
- SSME Block III
  - XLTMCC and Robust Nozzle
- SRB TVC Upgrades / FIV
- SRB Altitude Sensor Assembly
- Nozzle/Case Joint J-Leg Insulation
- Integrated Receiver-Decoder (IRD)
- Range Safety Distributor (RSD)

Power & Propulsion

- Electric APU
- Enhanced Pyro Initiator Controller
- Improved Pilot Operated Valve
- Quad Check Valve Redesign
- Long Life Alkaline Fuel Cell

Operations

- **Ground Operations**
  - Maintainability for Safety (Study)
  - SCAPE Suit Improvements (Study)
  - CLCS
- **Flight Operations**
  - PIDAE
  - Shuttle Upgrades Design Visualization
  - Robotic Situational Awareness Display
  - Human Factors/Cockpit Engineering Study
  - Expansion of MCC Landing Sites
  - AWIPS
  - EECOM STS Pressure Management Tool
  - Alternatives to Hardware Based Robotics Training
  - DM Trajectory Operations Interface Redesign
- **Flight Tests**
  - Wireless Sensor
  - Laser Dynamic Range Imager HTD

Advanced Technology

- Crew Escape
- Reusable First Stage
- Non-Tox OMS/RCS Propellants
- PEM Fuel Cell
- Electromechanical Actuators
- Water Membrane Evaporator
- Integrated Vehicle Health Mgmt
- Propellant Densifications
- Fiber Optics

Device Driver Unit (DDU)

Description

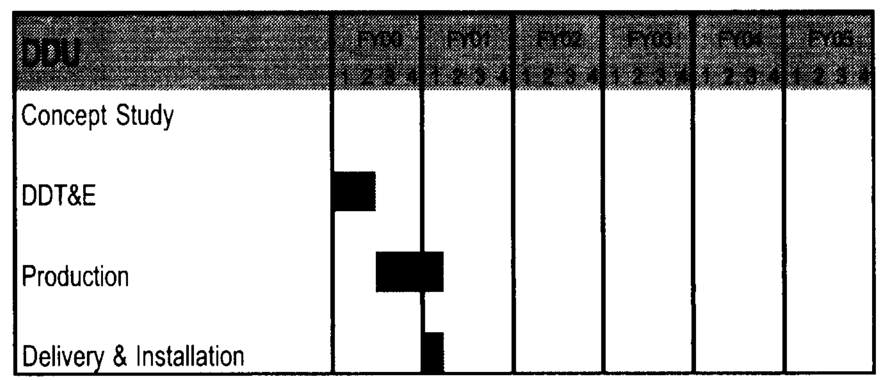
Device Driver Unit takes the place of the current Dispay Driver Unit

- Current DDU's integrated with MEDS
- Device control functionality removed from existing DDU's

Benefits

- Integrated display drivers with MEDS
- Separate device control from displays and MEDS
- Increased reliability

Schedule

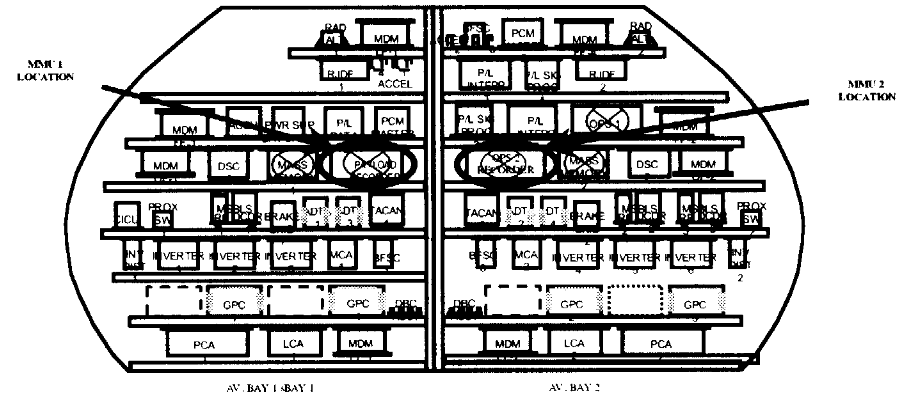


Modular Memory Unit (MMU)

Description

MMU Functions

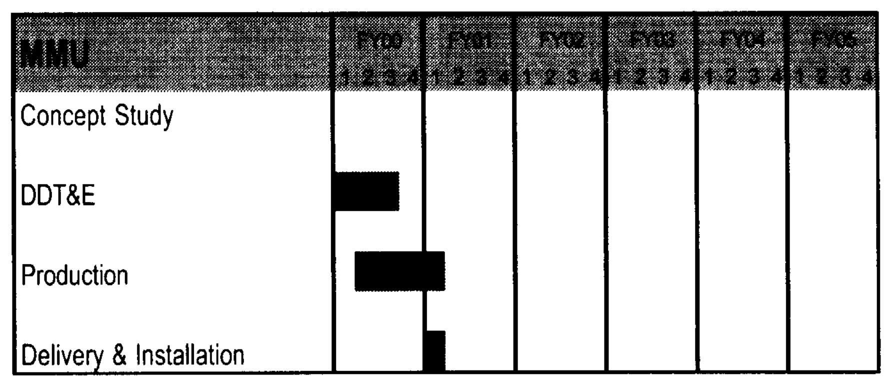
- Solid state recorder (SSR) – 425 Mbytes requirement (uses 46 Bytes card)
  - Replaces ops/payload recorder
- Solid state mass memory (SSMM) – 16 MBytes
  - Replaces Mass Memory Unit



Benefits

- Replaces old tape units with solid state technology (greater storage, faster dump)
- Weight savings: 195 lbs current – 104 lbs upgraded
- Power savings (peak): 272 w current – 84 w upgraded
- 10 Spare slots in chassis and spare power capacity for future growth

Schedule

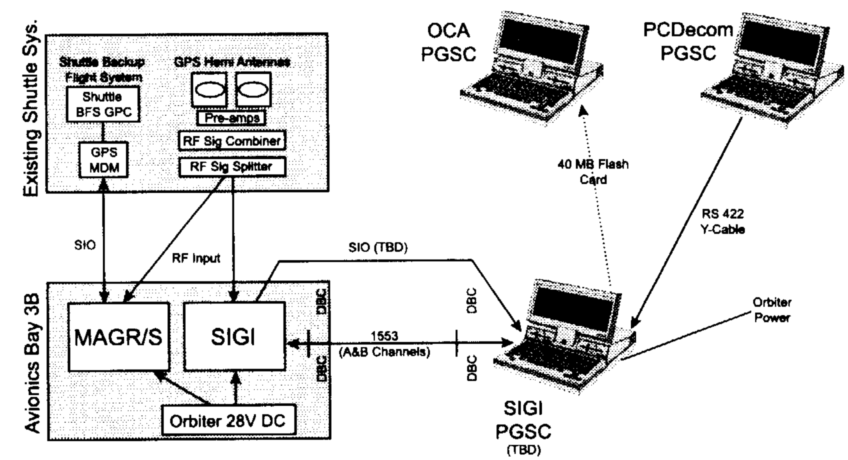


Space Integrated GPS/INS (SIGI)

Description

SIGI: Combined GPS and INS capability

- Combine functionality of global positioning and inertial navigation
- Enables replacement of TACAN and elimination of MSBLS
- Replaces HAINS



Benefits

- Provides highly reliable GPS and INS capability
- Enables elimination of high cost maintenance for MSBLS grounds systems
- Advanced technology benefit for future space vehicles

Schedule

SIGI	FY00	FY01	FY02	FY03	FY04	FY05
	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Concept Study						
DDT&E						
Production						
Delivery & Installation						

Orbiter Phase II Upgrades
Micrometeoroid/Orbital Debris Mitigation

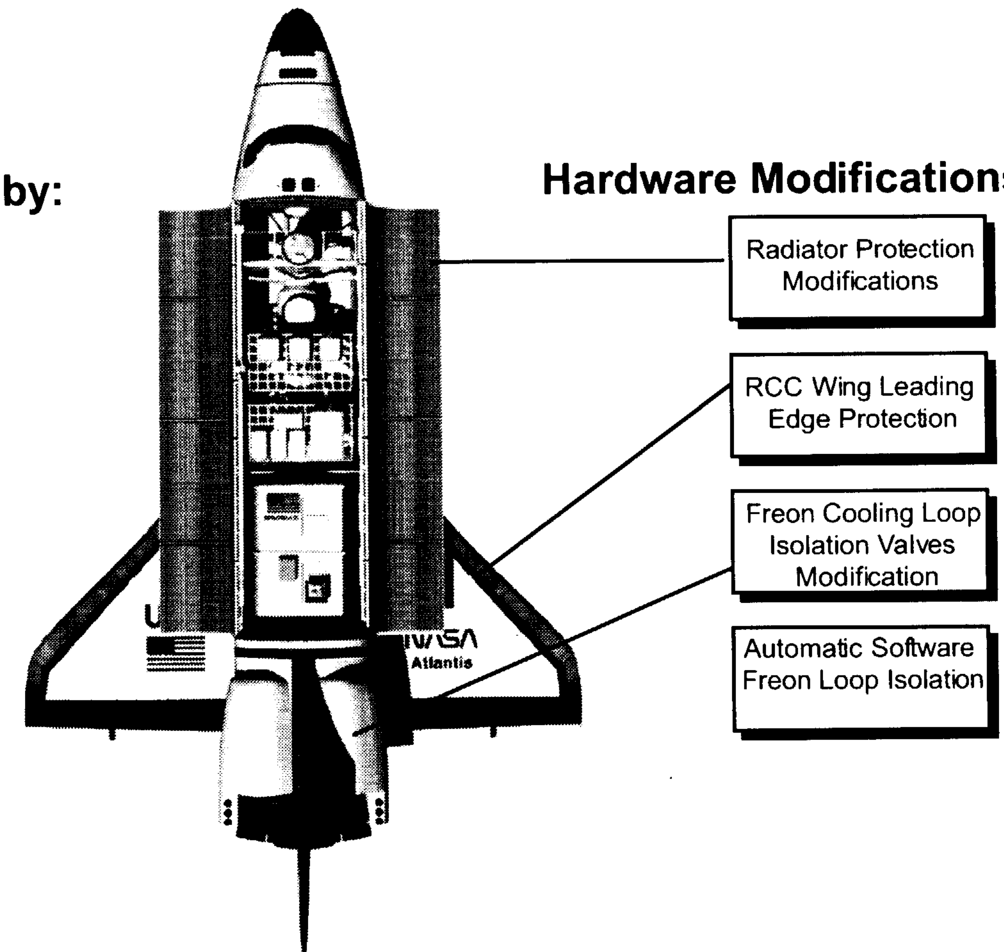
Reduce Risk of MMOD by:

- Operational Workarounds
- Attitude Timeline Modifications
- Compromises Mission Objectives
- Not always possible

MMOD Modifications will Improve:

- Safety & Mission Success
- 1/60 to 1/1190 to 1/4000
- Supportability
- Reduce Cost
- Fewer Repairs Required

Hardware Modifications



ID	Task Name	1997–2001 (May 1997 – Sep 2001)
1	MMOD 1st Flights	OV-105 Rad Shield (1/2 Mod); OV-103 Rad Isolation/W LE (phased); OV-104 Radiator and WL; OV-105 Rad Isol and WLE; OV-103 Rad Shield; OV-102 Radiator/ W LE

SRB Thrust Vector Control System Upgrades

SRB TVC System Upgrades

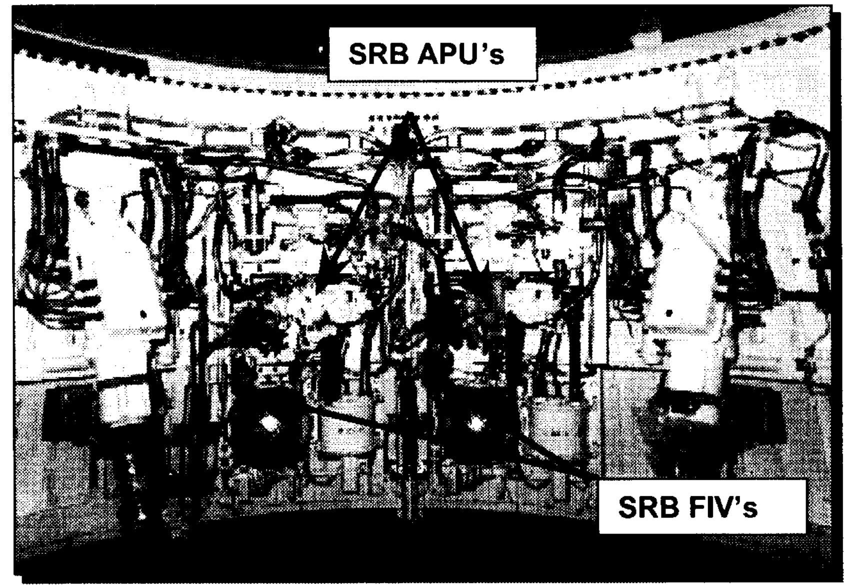
Auxiliary Power Unit (APU) Carbon Seal
- Current design susceptable to carbon fracture which can result in detonation from metal to metal contact - new design eliminates this

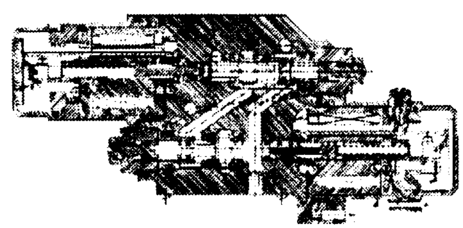
Single Mission Fuel Isolation Valve (FIV)
- Controls Hydrazine flow to the APU for the SRB TVC System
- Replaces an aging, 1970's design, reusable FIV
- Reduces leakage and improves isolation of fuel from electrical cavity
- Based on proven Orbiter FIV design

APU Gas Generator Valve Module Index Pin Modification
- Eliminates the possibility of index pin back-out, which can (and has in 2 cases) result in the failure of the PCV or SOV

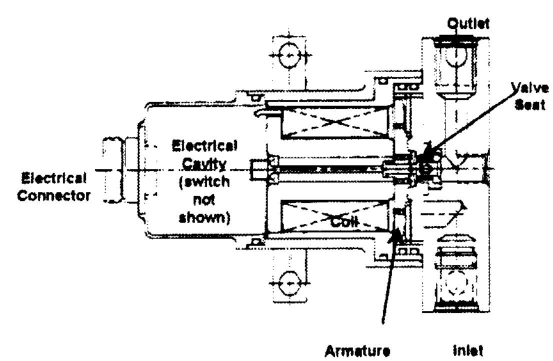
APU Turbine Wheel
- Current turbine wheel susceptible to blades cracking, new design eliminates this with a thicker blade profile
- Qualified for use on Orbiter, SRB qualification in work

TVC In-line Filter
- Adds an in-line filter to the SRB TVC Fuel system "Flush & Purge In" line (Only unfiltered TVC Fuel system line)





APU GGVM



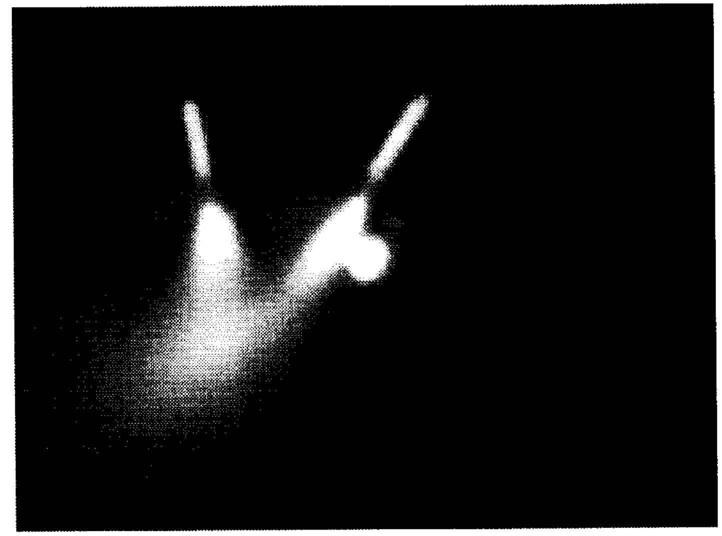
FIV

Altitude Switch Assembly (ASA)

Description

ASA: Pressure sensing device to initiate SRB recovery sequence (one unit per SRB)

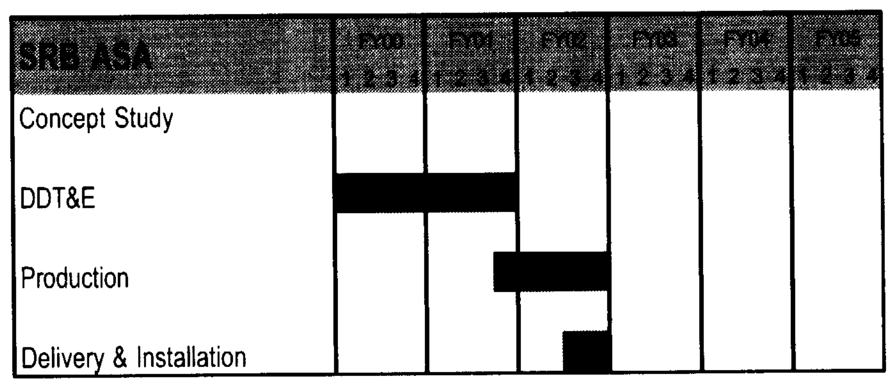
- Nose cap ejection – pilot/drogue parachute deployment
- Frustrum separation – main parachute deployment



Benefits

- Improve fault tolerance and reliability
- Improve supportability
  - Eliminate welded case, enable internal repair
  - Relax limitations on flight rate and program duration
- Improve BITE and power protection
- Eliminate impact of obsolescence

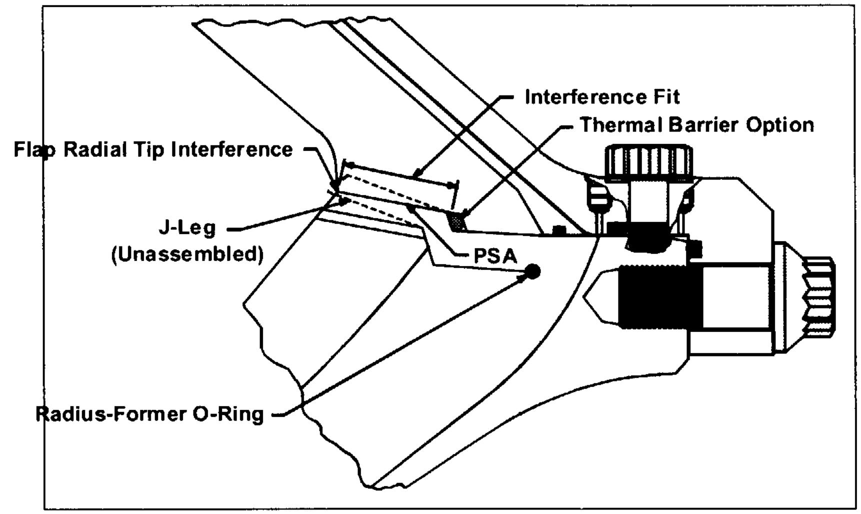
Schedule



RSRM Nozzle-to-Case Joint J-leg Insulation Design

Description

- The Reusable Solid Rocket Motor nozzle-to-case joint experiences gas paths through the polysulfide insulation to the wiper O-ring in approximately one out of seven motors.
  - Existing design is tolerant of this condition.
- Upgrade redesigns the nozzle-to-case joint insulation using proven technology adapted from the field joint and igniter-to-case joint J-leg designs to eliminate the potential for hot gas intrusion into the joint.
  - Uses a pressure actuated insulation joint.



Benefits

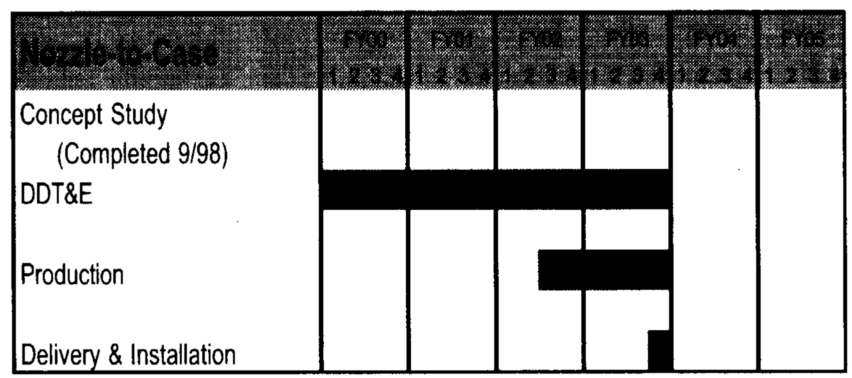
Flight Safety

- Eliminates the potential of hot gas intrusion in the nozzle-to-case joint.
  - Improves the reliability of joint.

Supportability

- Eliminates significant time and effort expended evaluating the hot gas pass throughs.

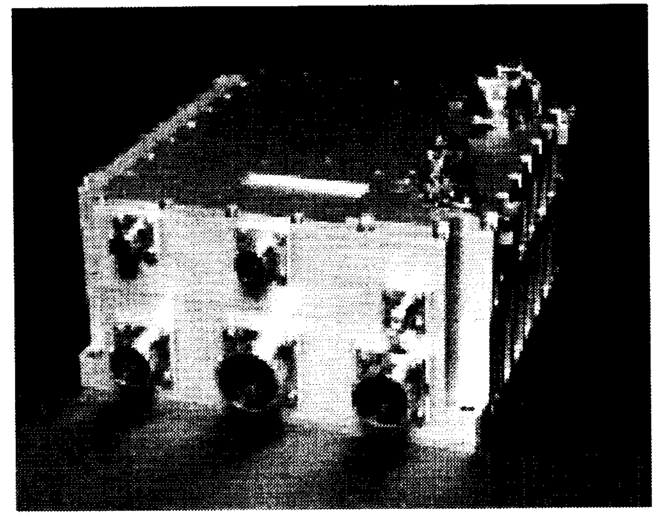
Schedule



SRB Command Receiver/Decoder (CRD)

Description

- Integrated Receiver-Decoder (IRD) and Range Safety Distributor (RSD) provide reception and command of range safety instructions
  - If needed for range safety, initiates SRB self-destruct
  - DDT&E is funded and underway and 1st engineering units are in test
- Combine IRD and RSD into one unit with new design
  - New unit is the Command Receiver Decoder (CRD)
    - Achieves full EMT compliance
    - Replace PIC with direct current firing circuit



Benefits

Flight Safety

- Eliminates a criticality 1 failure mode
- Decreased destruct reaction time

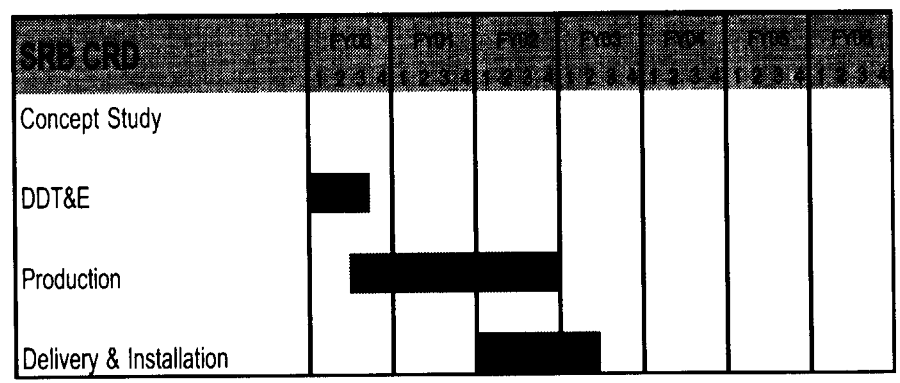
Supportability

- Mitigates obsolescence of key components
  - RSD and IRD have 39 obsolete EEE parts
  - RSD Programmable Automated Test Set requires upgrade/replacement

Improve the System

- Enhances maintainability

Schedule

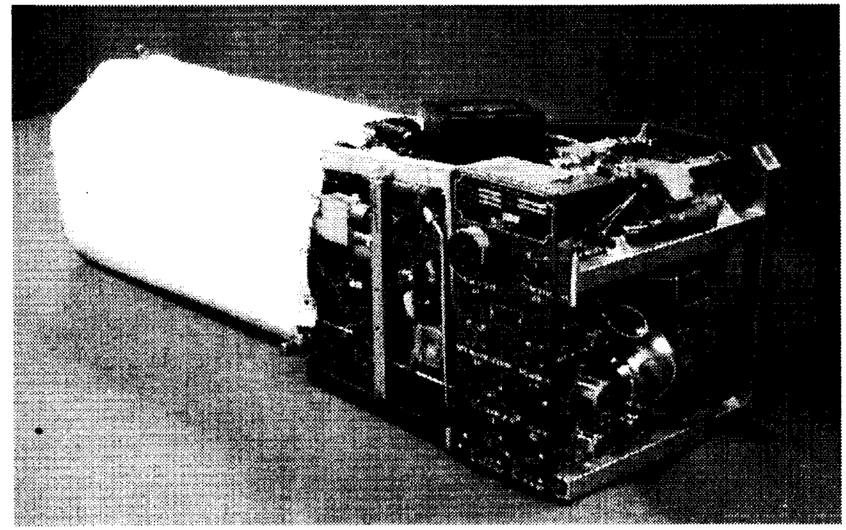


Long Life Alkaline Fuel Cell

Description

Current Alkaline Fuel Cell Modification to Long Life Alkaline

- Modify cells of existing stack to lengthen corrosion path
- Reduce reactant temperatures
- Upgrade external seals and insulator plate
- Resize reactant preheaters
- Modify regulator housing to stainless steel to eliminate aluminum corrosion
- Modification can be done during regular overhaul periods on attrition basis

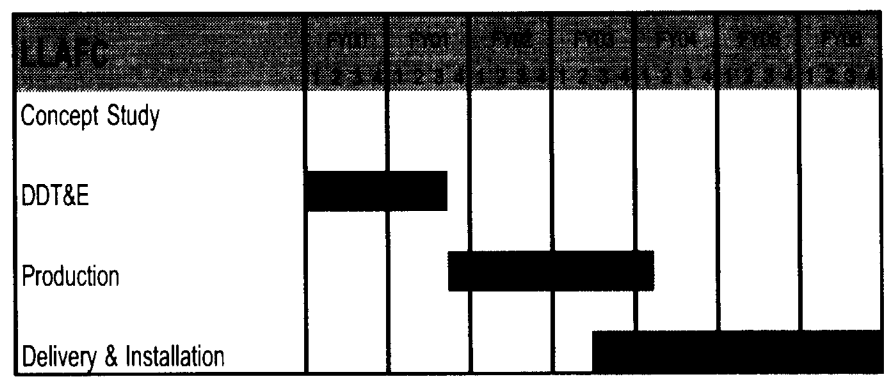


Benefits

Supportability

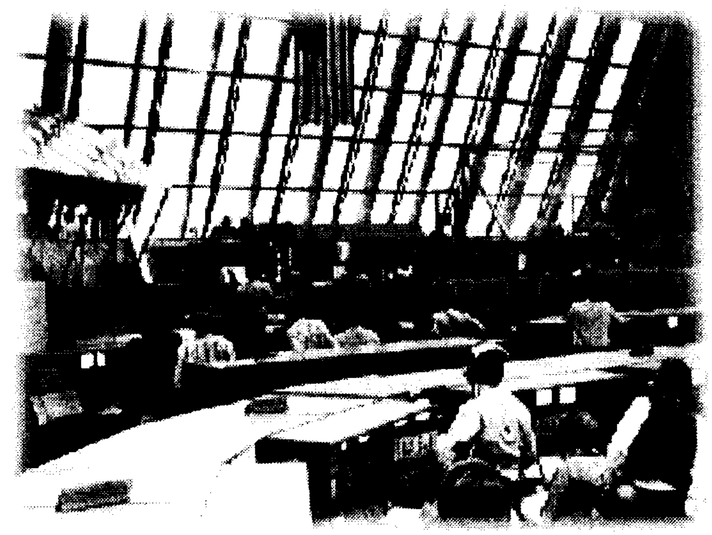
- Mitigates supportability issues of high failure and overhaul rates
  - Extended cell life
  - Reduced anode cycle voltage losses
  - Reduced operating temperatures

Schedule



Checkout & Launch Control System

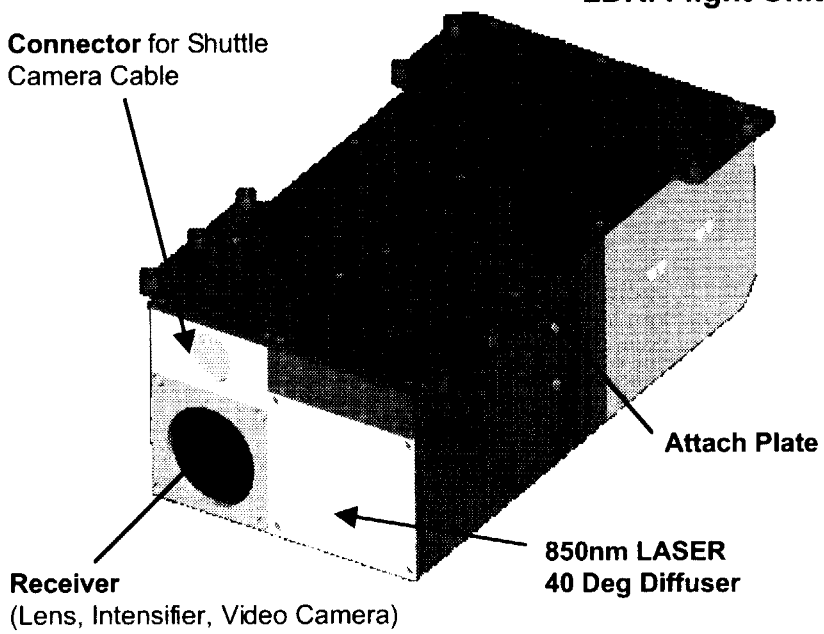
- The CLCS replaces the current Space Shuttle Firing Room with a state of the art control center featuring custom and commercial-of-the-shelf systems
- The CLCS Has Redefined the Shuttle Processing Environment in Several Key Areas Which Will Improve Checkout Efficiencies
  - Command and Monitor Data have Been Separated
  - Multi-Discipline Testing
  - Multi-Orbiter Control
  - Consolidated Data
  - Integrated Complex/Facility Control
  - Local Commanding Operations
  - Program Compatible Data



Checkout & Launch Control Systems Goals

- Reduce operations and maintenance costs by at least 50%
- Reduce the number of engineers required on console for daily power up operations by at least 50%
- Reduce the amount of paper in the control rooms by at least 50%
- Provide building blocks to support future control system requirements (e.g. Shuttle Upgrades, RLV, etc.)

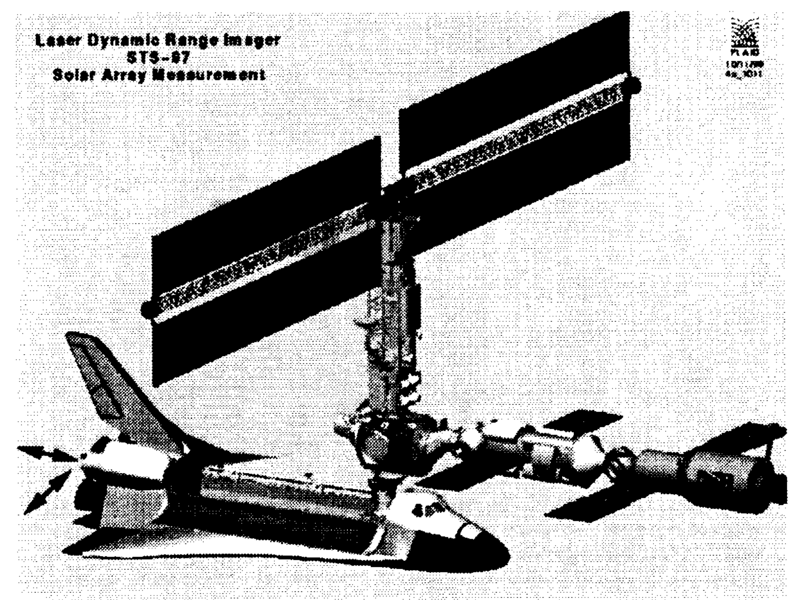
Human Exploration and Development of Space (HEDS) Technology Demonstrations



LASER Dynamic Range Imager

Description

- Range for every pixel at video rates to obtain structural-dynamics
- Real-time range video for depth perception and target info (range, range-rate and orientation)
- 3-D model building for slowly moving and stationary objects
- Eye-safe LASER - no pre-positioned targets required



Flight Operations Upgrades

- **Platform Independent Downrange Abort Evaluator (PIDAE)**
  - Develop a platform independent ascent situational awareness tool for use in multiple facilities/computational environments
  - Yields enhanced flight crew/MCC situational awareness for TAL/ECAL capability assessment and range safety limit line avoidance.
- **Shuttle Upgrades Design Visualization**
- **Robotic Situational Awareness Display**
  - Provide RMS Operator tools for onboard STS Operations.
  - Improves RMS Operator situational awareness to off-set existing system limitations
    - Visual feedback
    - Position feedback
    - Unwanted manipulator positions
    - Single Joint Operations

Flight Operations Upgrades (cont'd)

- **Human Factors/Cockpit Engineering Study**
  - This study provides an extensive review of the SSP cockpit and analysis of flight information to the crew.
  - Rapid prototyping techniques will provide integrated solutions, information on crew situational awareness, and reductions in training. Advanced concepts of operations will be evaluated in prototypes to validate implementation. Results will be incorporated into the proposed Shuttle Cockpit Upgrades.
- **Expansion of MCC Landing Sites**
  - Provides a complete set of world-wide runway data in the MCC for utilization during emergency operations as a supplement to official landing sites and existing landing site tables.
  - Expands the 42 approved sites and 150 Emergency Landing Sites to approximately 3000 sites for emergency operations.
    - Objective is to integrate with PIDAE

Flight Operations Upgrades (cont'd)

Advanced Weather Interactive Processing System (AWIPS)

- AWIPS is the meteorological analysis and forecasting tool that the National Weather Service (NWS) is installing in its forecast offices nationwide to replace legacy forecast systems. AWIPS will replace two obsolete NWS systems at JSC.
- This new System will provide capabilities not currently available with older systems. AWIPS will improve safety by providing improved capability to analyze and display meteorological data at the CONUS shuttle landing facilities.

EECOM STS Pressure Management Tool

- Provide Pressure Management tools to support EECOM operations
- Streamlines EECOM STS/ISS pressure management function by eliminating many steps performed manually by flight control personnel. This capability will greatly improve EECOM's ability to respond quickly to real-time mission impacts/re-plans and mission planning and reassessments.

Flight Operations Upgrades (cont'd)

- **Alternatives to Hardware Based Robotics Training (AHBRT)**
  - Investigates and develops technologies needed to allow software based training systems to replace hardware trainers for robotics.
  - AHBRT improves software robotics simulations, develops camera models for camera and vision system design, and develops contact models for force/torque system design.
- **DM Trajectory Operations Interface Redesign**
  - Pathfinding effort to implement findings from FDO work analysis by Ames Human Centered Computing group via a new user interface for ephemeris operations.
  - Designed to decrease unnecessary operational complexity inherent in 20 yr old architecture as well as replace several old displays/tools in the MCC.

Independent Program Analysis

Description

Perform independent assessment of upgrade projects

- Assess project maturity
- Identify project risks
- Identify potential cost increases and delays
- Identify risk mitigation strategies
- Provide independent cost assessment

Benefits

Provide SSPDO insight to project status and activity

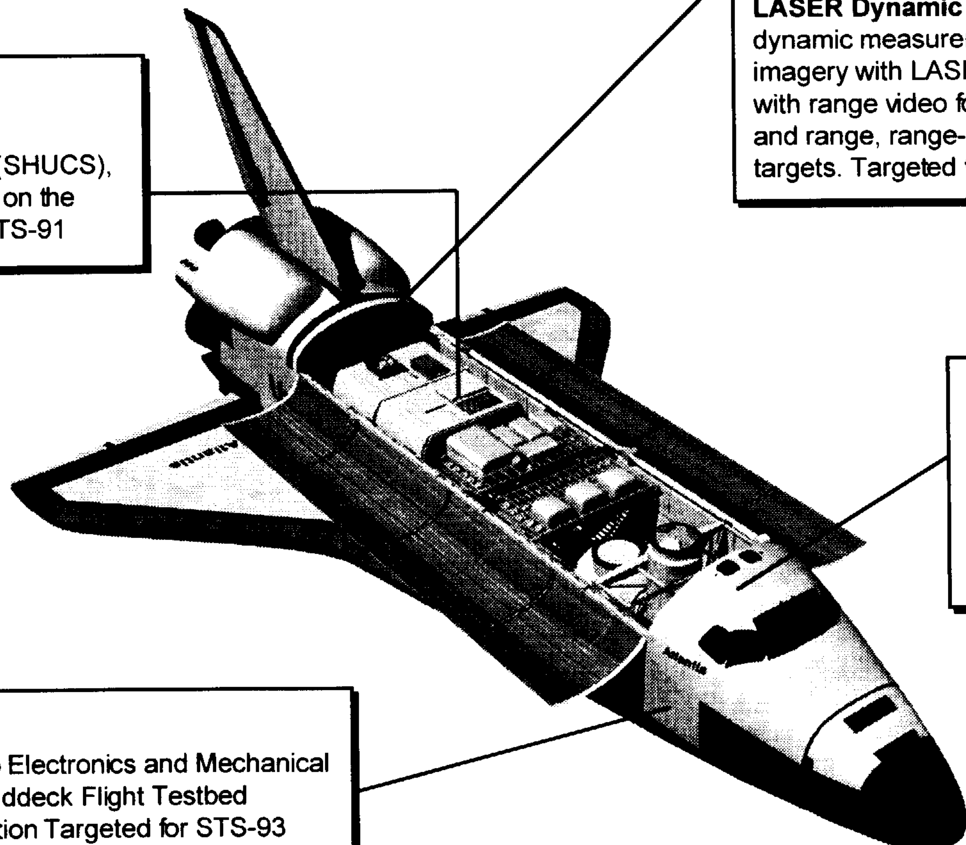
- Strategize upgrades budget through the end of program
- Help determine optimal solutions

Schedule

Ongoing activity with deliveries coincident with project milestones

Human Exploration and Development of Space (HEDS) Technology Demonstrations

Approved HTDs



HTD 1401

SpaceHab Universal Communications System (SHUCS), L-Band Antenna Mounted on the SpaceHab Targeted for STS-91

HTD 1404

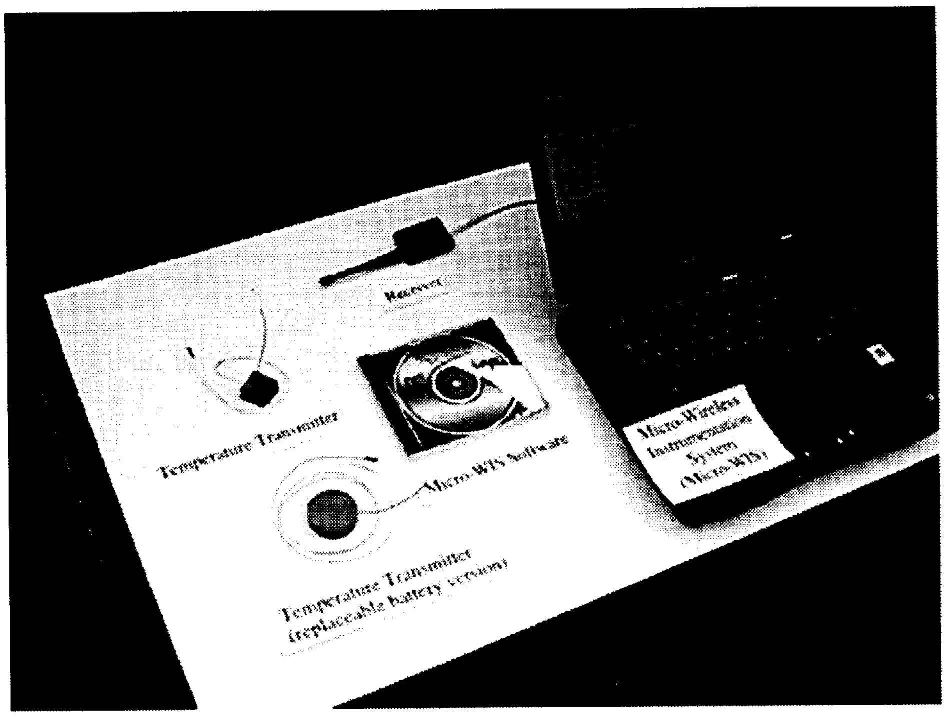
LASER Dynamic Range Imager; Structural-dynamic measurements for loads models, night imagery with LASER illumination, depth perception with range video for EVA,robotics, and fly-around, and range, range-rate and orientation for various targets. Targeted for STS-97.

HTD 1403

Micro-Wireless Instrumentation System; includes autonomous, micro-sized temperature sensor/transceivers and a data acquisition system for space and ground applications.

HTD 1404

Nano/micro Electronics and Mechanical Systems Middeck Flight Testbed Demonstration Targeted for STS-93



Micro-Wireless Instrumentation System

Description

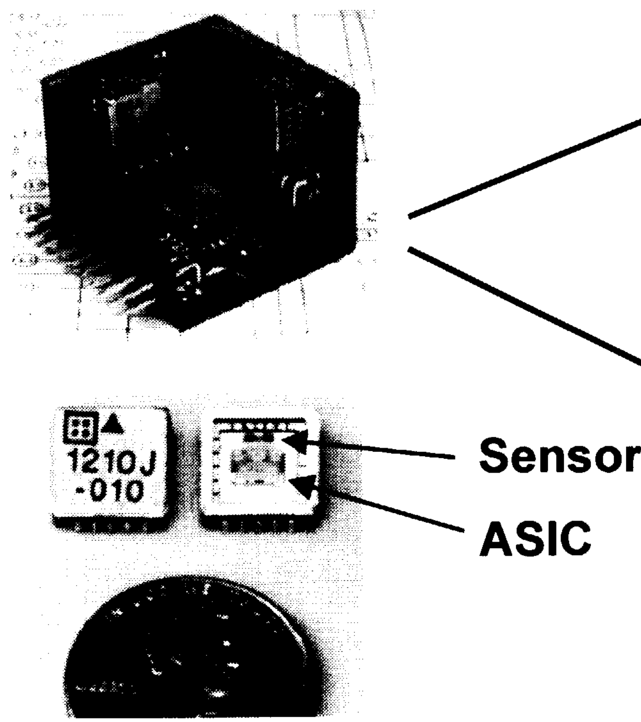
The Micro-Wireless Instrumentation System (Micro-WS) includes autonomous, micro-sized temperature sensor/transceivers and a data acquisition system for space and ground applications.

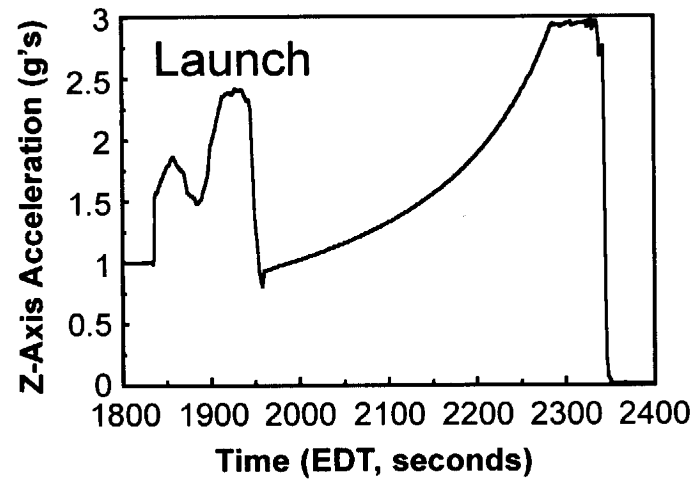
Program Supported Goals

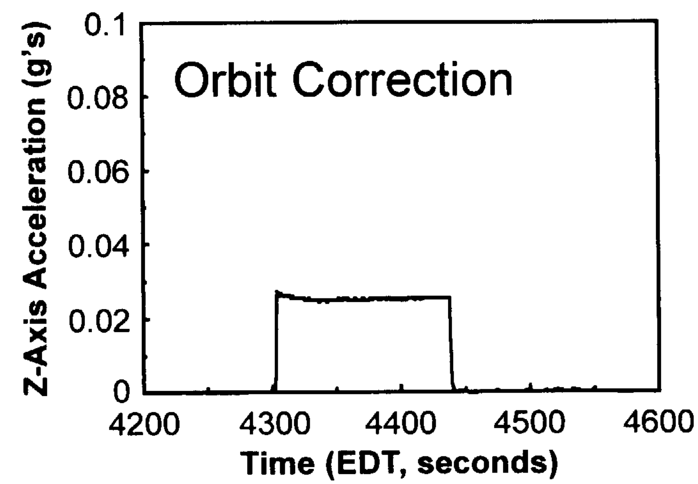
- Significant cost, weight and power savings to current operational space vehicles, ground test facilities and future spacecraft
- Revolutionary capability in systems design for future space vehicles

MEMS Accelerometers Monitored STS-93 Flight

Silicon Designs 1010J & 1210J Capacitive MEMS Accelerometers







Space Shuttle Safety and Supportability
Safety Upgrade Candidates

Safety Upgrades — Supportability Upgrades — Approved Upgrades — Advanced Technology

Orbiter Avionics

- **Cockpit**
  - Enhanced Caution and Warning
  - Crew Situational Awareness Displays
  - AFD Switch Panel Upgrade
  - Device Driver Unit Replacement (DDU)
- **Data Processing**
  - Mission Management Computer
  - Modular Auxiliary Data System
  - Modular Memory Unit (MMU)
- **Communications**
  - Ku-Band DEA
  - PCMMU
  - S-Band FM
  - Network Signal Processor
- **Navigation**
  - Trajectory Control Sensor (TCS)
  - IMU Replacement (SIGI)
- **Power Sub-Assemblies**
  - Hybrid Drivers
- **Thermal Protection System**
  - More Durable Lower Surface Tile (Study)
- **Structures & Mechanisms**
  - Crew Escape System (Study)
  - Main Landing Gear Tire Improvements
  - Micrometeoroid/Orbital Debris Mitigation (MMOD)
- **Environmental Control & Life Support Systems**
  - Hydrogen Water Separator

SRB / RSRM / ET / SSME

- SRB Advanced TVC
- Integrated Electronics Assembly
- ABACS
- ET Robust TPS
- ET Digital Radiography
- New O-Ring Material
- Case Stiffener Segment/T-Ring
- RSRM Propellant Geometry
- SRB Attach/Hold Down Hardware
- ET Friction Stir Initial Welds
- Advanced Health Monitoring
- SSME Block III
  - XLTMCC and Robust Nozzle
- SRB TVC Upgrades / FIV
- SRB Altitude Sensor Assembly
- Nozzle/Case Joint J-Leg Insulation
- Integrated Receiver-Decoder (IRD)
- Range Safety Distributor (RSD)

Power & Propulsion

- Electric APU
- Enhanced Pyro Initiator Controller
- Improved Pilot Operated Valve
- Quad Check Valve Redesign
- Long Life Alkaline Fuel Cell

Operations

- **Ground Operations**
  - Maintainability for Safety (Study)
  - SCAPE Suit Improvements (Study)
  - CLCS
- **Flight Operations**
  - PIDAE
  - Shuttle Upgrades Design Visualization
  - Robotic Situational Awareness Display
  - Human Factors/Cockpit Engineering Study
  - Expansion of MCC Landing Sites
  - AWPS
  - EECOM STS Pressure Management Tool
  - Alternatives to Hardware Based Robotics Training
  - DM Trajectory Operations Interface Redesign
- **Flight Tests**
  - Wireless Sensor
  - Laser Dynamic Range Imager HTD

Advanced Technology

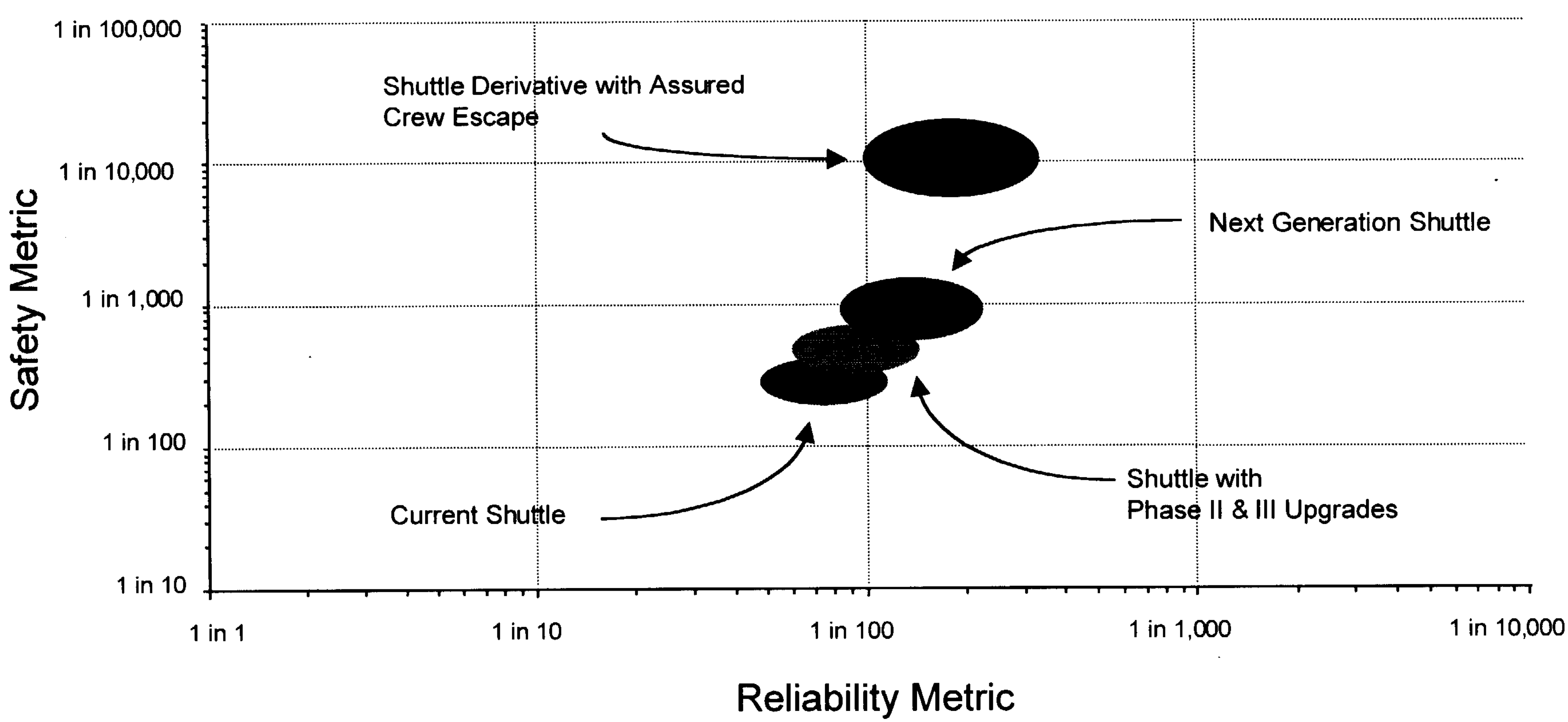
- Crew Escape
- Reusable First Stage
- Non-Tox OMS/RCS Propellants
- PEM Fuel Cell
- Electromechanical Actuators
- Water Membrane Evaporator
- Integrated Vehicle Health Mgmt
- Propellant Densifications
- Fiber Optics

Shuttle Upgrade & Evolution Future

- **Near Term Shuttle Development Priorities are:**
  1. Implementing the approved safety upgrades into the fleet by 2005.
  2. Keeping the infrastructure and the flight hardware available to support the manifest until the next generation RLV is operational (no earlier than 2012).
  3. Improving the system by implementing operational efficiencies and simplifying processes will reduce preparation risks and save cost.
  4. Supporting development of the ISTP technologies applicable to next generation RLV's and to shuttle evolution.
  5. Utilizing the shuttle as a test platform to demonstrate new capabilities and technologies that could mitigate risks for a new or shuttle derived RLV while improving the shuttle.
- **Options Post-2005**
  - No "next generation" replacement… implement evolutionary Shuttle upgrades to improve safety, reliability, supportability, and ops cost
  - Shuttle-derived RLV replacement developed… operate and sustain Shuttle until replacement is ready
  - New Design replacement developed… operate and sustain Shuttle until replacement is ready

Safety/Reliability with Uncertainties

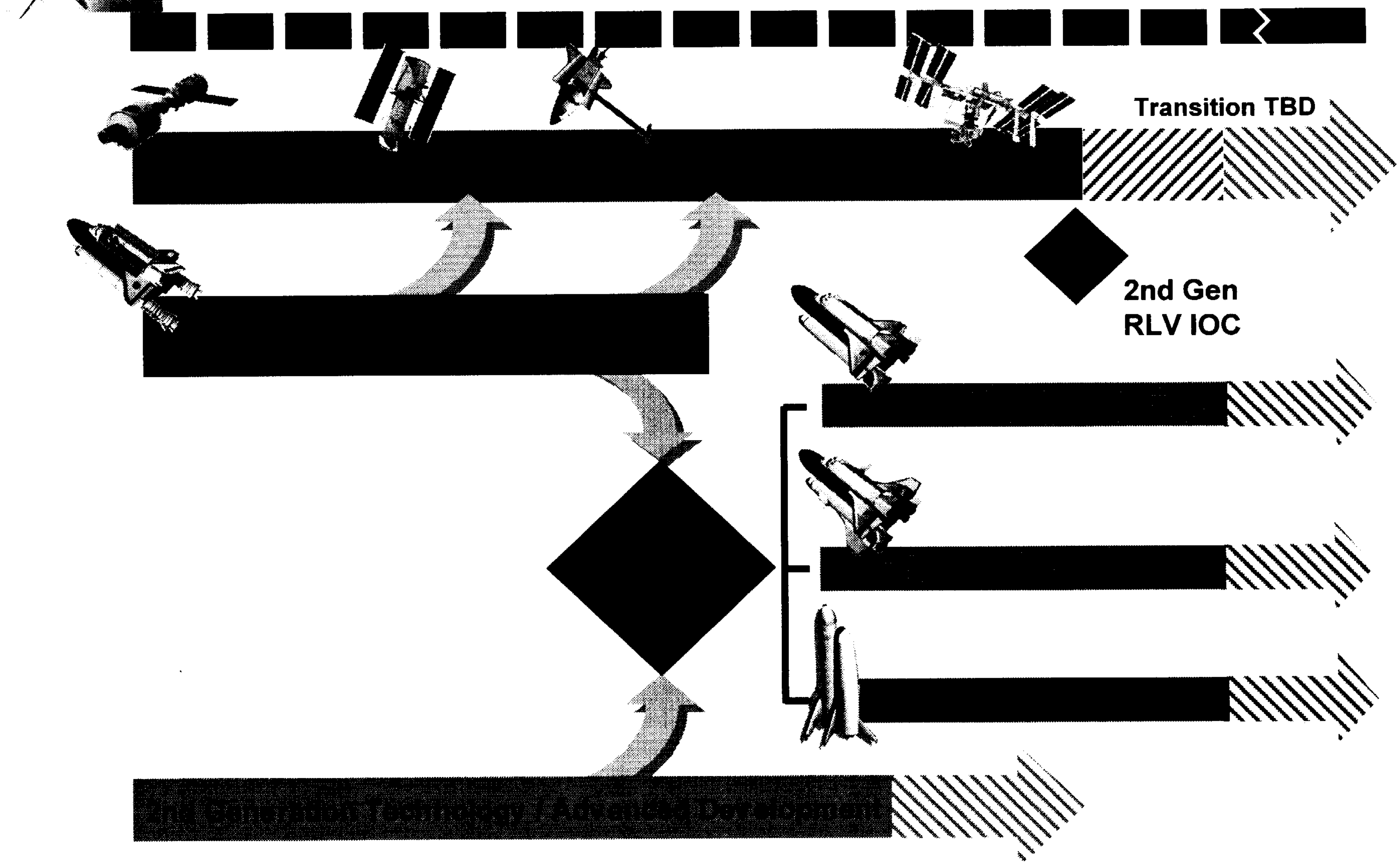
50th Percentile Probability



Next-Generation Shuttle Vision

- Improve safety and increase reliability by an order of magnitude
- Eliminate complex, expensive systems and drastically reduce vehicle operations cost
- Provide flexible and routine access to space
- Maintain capabilities for humans to work in space
- Enable advancing technologies for HEDS and future generation RLV's
- Increase ascent performance to provide abort-to-orbit capability and to allow next-generation vehicle enhancements

Space Shuttle Development Strategy



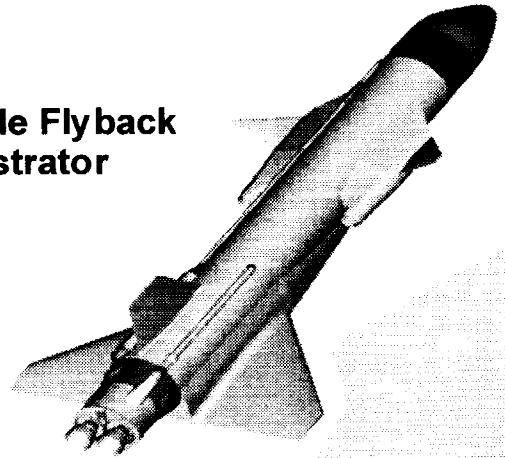
Shuttle-Derived 2nd Generation RLV

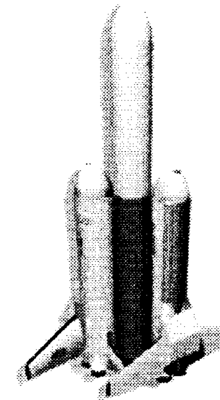
High Priority Technology / Advanced Development Needs

- Crew escape and survival technologies
- Highly reliable, long life LOx/Hydrocarbon booster engine
- Reusable first stage demonstrator
- Highly reliable, long life LOx/LH_2 main engine
- Highly reliable, inexpensive expendable LOx/LH_2 main engine (alternative)
- Inexpensive external tank (manufacturability)
- Non-toxic OMS/RCS
- Advanced, more durable and reliable TPS
- Integrated Vehicle Health Management
- Electro-mechanical actuation
- Flyback jet engines

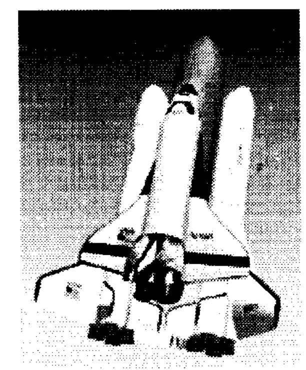
Leveraged Technologies by Partnering

Reusable Flyback Demonstrator

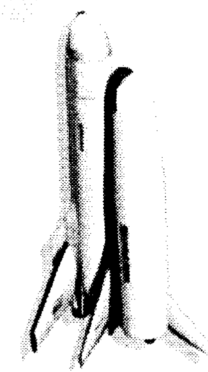




Reusable First Stage



Shuttle Upgrades



Two Stage To Orbit

LFBB Enabling Technologies

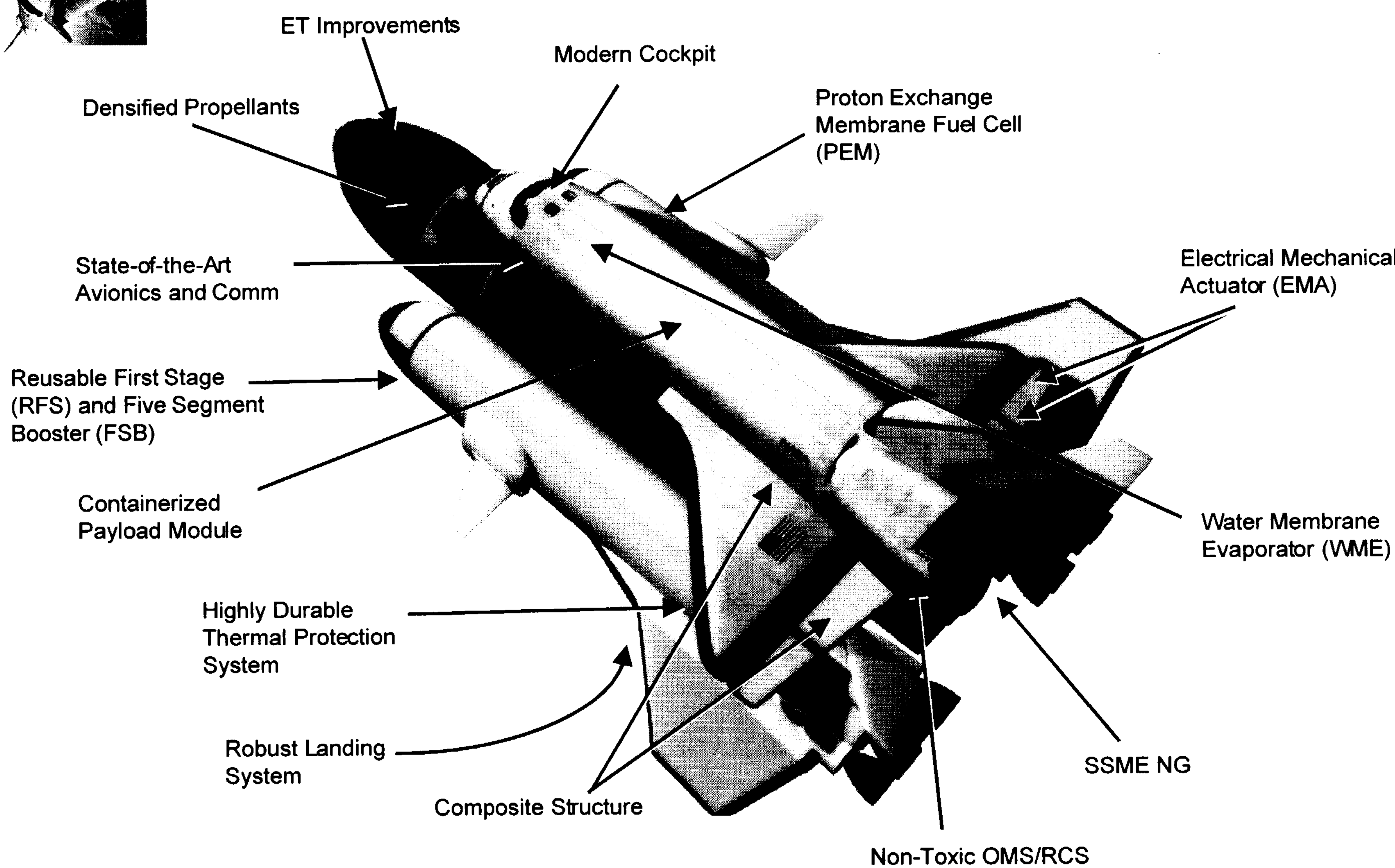
- Reusable, Reliable, Low Cost, Throttleable Booster Main Engine
- Jet Engine Integration and Exposure to LFBB Flight Environment
  - Vibro-Acoustic Environment , Air-Start, Cruise Performance
- Reusable TPS/ Cyro Insulation
  - Propellant Conditioning, High Mach No., Environmental Exposure
- Capability to Successfully Complete Mission With One Engine Out
- Integrated Vehicle Health Monitoring (IVHM)
- Serviceability and Rapid Turn Around
- Autonomous Powered Landing
- Flight Qualities
  - Aerodynamics / Aerothermodynamics
- Non-Toxic OMS/RCS
- PEM Fuel Cells

Evolved Space Shuttle Option

Potential Shuttle evolutionary improvements beyond 2005

- **Key *safety* improvement goals of evolved Shuttle**
  - Ascent "abort-to-orbit" from the pad → advanced 1st stage boosters
  - Increases main engine reliability
  - Advanced crew escape capabilities
- **Potential *advanced technology* infusion into evolved Shuttle, as demonstration *testbed* for future vehicles**
  - Phased array communication system
  - Non-toxic on-orbit propulsion & attitude control
  - More durable thermal protection system (TPS)
  - Electro-mechanical actuation
- **Advanced space transportation investments in those capabilities support *future vehicle* options as well as the evolved Shuttle option**

Evolved Space Shuttle



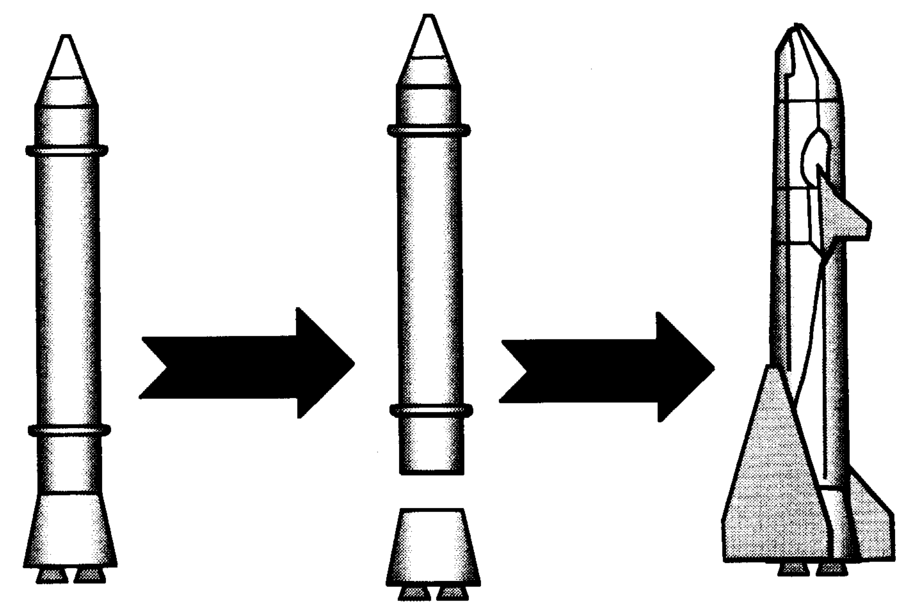
Evolvable Liquid Rocket Booster (ELRB)

Can Be Logical Building Block for Reusable First Stage

Description

- Enables most RFS safety features at less DDT&E cost
- Potentially Cuts development cost of RFS
  - Tooling for ELRB available to manufacture RFS
  - Main propulsion Test Article for ELRB is usable for RFS
  - Development test data for ELRB is applicable to RFS
  - Brings in earlier launch facility infrastructure for LOX/RP-1
- Builds experience to existing infrastructure
- Reduces impact of existing infrastructure
- Incremental Cost from ELRB to RFS is ~$TBD

Potential ELRB Evolution Path



Initially Expendable

Add Recoverable PA Module

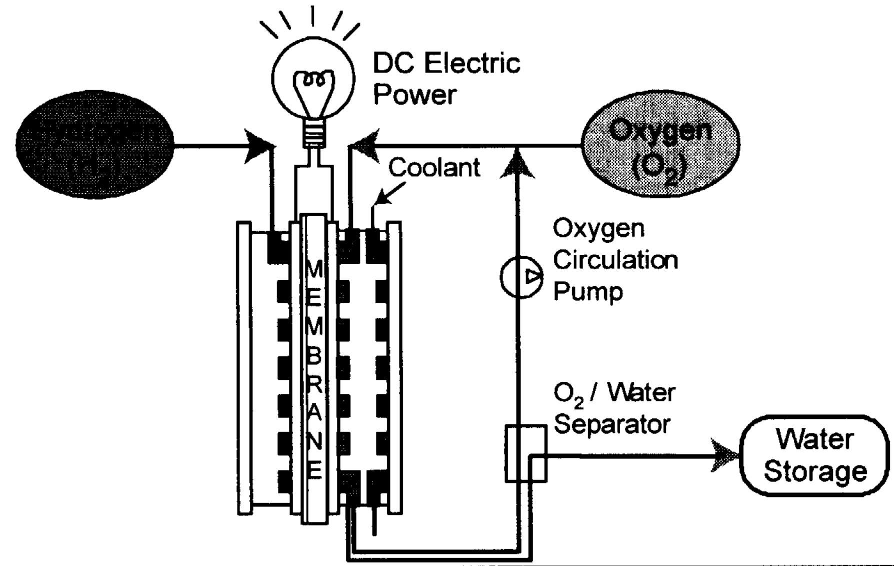
Add Wings and Flyback Systems

Proton Exchange Membrane (PEM) Fuel Cell

Description

Proton Exchange Membrane (PEM) Fuel Cell produces electricity

- Uses hydrogen as fuel and oxygen as oxidizer
- Split hydrogen protons pass through the thin electrolyte membrane and the hydrogen electrons produce electricity
- Byproduct is water
- Operates at relatively low temperatures
- High power density



Benefits

Replaces alkaline fuel cell currently used for producing vehicle and payload power

- Potential to supply greater power
  - Normal mission with only 2 (of 3) powerplants
  - Landing with one powerplant
- Supports and increased flight rate with fewer powerplants
- Lower maintenance costs
  - Increased time between overhauls
- KOH electrolyte and asbestos matrix are eliminated
- May eliminate a criticality 1R or 2 hazard
- Fuel cell flooding is reversible, with no hardware damage
- Leverage off of industry development

- HEDS applications include
  - Future launch vehicle power systems
  - Lunar/Mars transport and surface-based power systems
  - Fuel-cells for spacesuits
  - Recharge/backup power

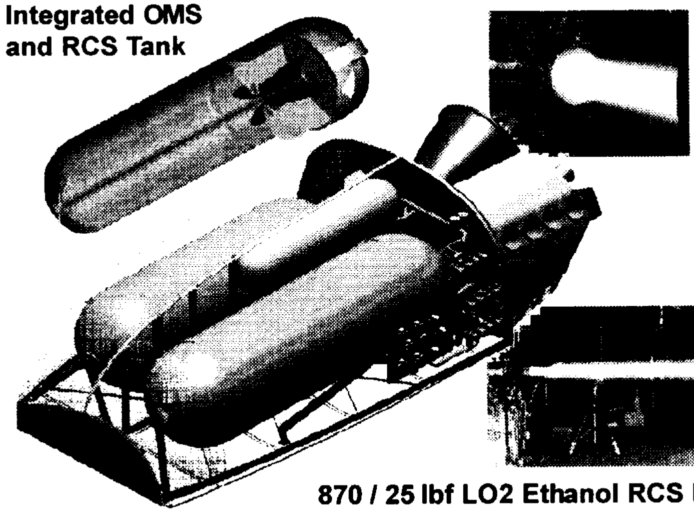
Non-Toxic OMS/RCS System

Description

Replace current toxic Hydrazine based OMS/RCS system with Liquid O_2 – Ethanol system

- Non-Toxic fuels

Implement modified pod with integrated OMS and RCS tanks



Benefits

Significant cost savings

- Eliminates SCAPE operations through the complete elimination of Hydrazine handling
- Increased ease of maintainability with ergonomically designed pod
  - All maintenance in pods within "arm's reach"
- Reduced maintenance
- Requires EAPU upgrade

Increased system reliability

- Eliminates valve failure due to propellant 'gumming' or contamination of the valves

Benefits (continued)

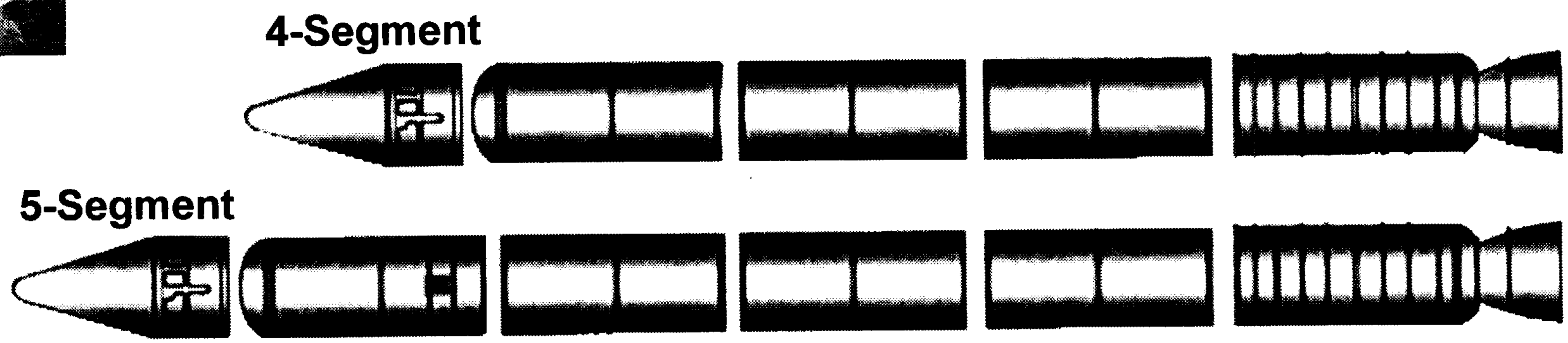
Decreased risk of mission failure for ISS docking operations

- Adds Redundant Vernier thrusters by using the Primary RCS engine torch igniter as the vernier
- Increased docking flexibility due to redundancy and improved translation capability
- Eliminates risk due to Hydrazine contamination on ISS

Improved Safety

- Eliminates auto-ignition fire hazards of hydrazine
- Eliminates risks of EVA crew exposure

5 Segment Booster



- Same forward skirt assembly and frustrum
- New attach case segments
- Grain modification
- Insulation modification
- Added center segment
- Inhibitor modification
- Insulation modification
- Standard weight stiffeners
- Added stiffener ring
- Modified nozzle
- Insulation modification

Benefits

Significant safety enhancement
- Leverages flight-proven success of existing RSRB
  - Incorporates all RSRB enhancements
- Enables engine-out from liftoff
  - Eliminates RTLS or TAL
- Demonstrated low probability of catastrophic failure

Significant cost savings
- Low life-cycle cost
  - Minimize developmental time and risk
  - Minimal facilitation
- Reduced $ / lbm to ISS

Huge increase in lift capability
- ISS payload potential increased 24 klbm
- Polar orbits from KSC

Building block for emerging programs
- Boost propulsion for HEDS missions
- Boost stage for low-cost ELV concepts

New Shuttle Ku Band PAA Communications System

Description

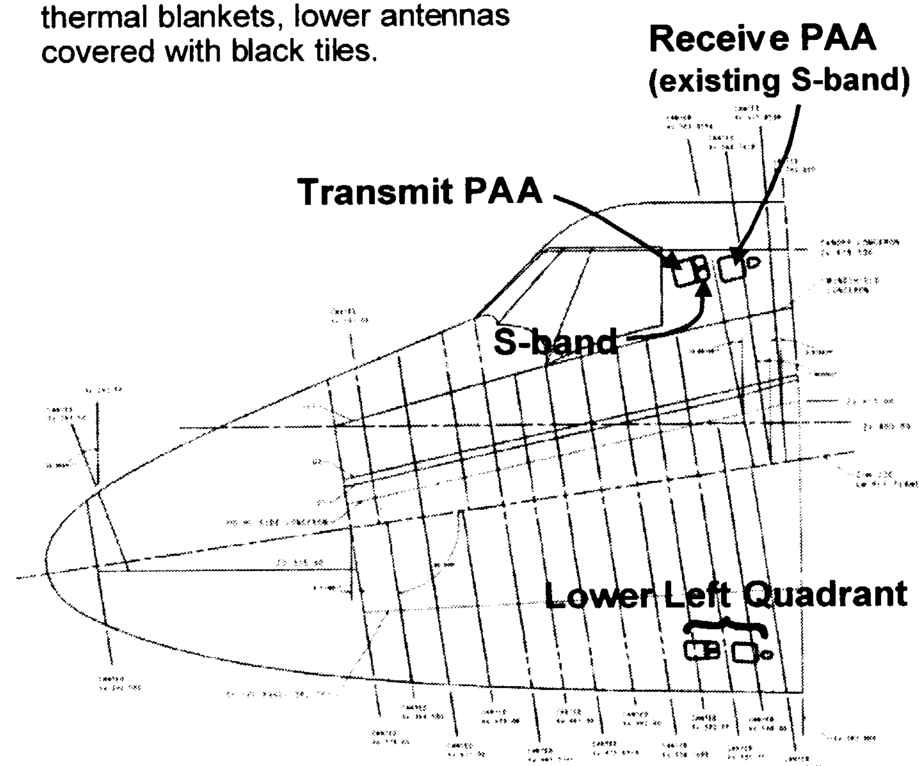
Replaces current Ku-band deployed antenna, Ku-band electronics, and the S-band FM system with four PAA transmit/receive antenna pairs and electronics

Benefits

- System has potential to transmit 75 Mbps and receive 1.5 Mbps
  - Can accommodate transmission and reception of digital TV
  - Shuttle PAA elements could be used on ISS or other future space applications
  - Current Ku-band system only transmits 50 Mbps and receives 216 kbps
  - System not dependent on payload bay doors, resulting in increased system availability
- Eliminates Criticality 1 failure modes of existing deployed antenna
- New system will have increased reliability and lower maintenance

Approximate sizes
Transmit PAA - 8" X 13" X 2.5"
Receive PAA - 10" X 13" X 2.5"

Upper antennas covered with white thermal blankets, lower antennas covered with black tiles.



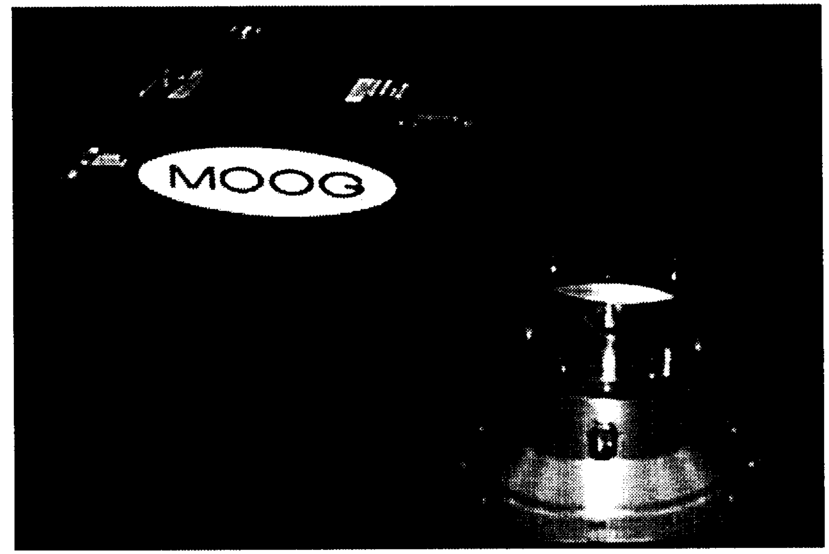
System electronics will be located in forward avionics bays.

ElectroMechanical Actuators (EMA)

Description

ElectroMechanical Actuators can be used as an actuator to move mechanical assemblies (landing gears, body flaps, valves, elevons etc.)

- Integrates into extend/retract control system
- Powered by AC or DC electricity
- May use a machine screw, ball screw drive, or gearbox
- Precision movement
- Broad variety of low to medium capacity applications



Benefits

- Replaces pneumatic and hydraulic technologies
  - Eliminates the need for hydraulic fluids and associated servicing
  - Greater reliability and fault tolerance
  - Lower maintenance costs
  - Longer service life
  - Built-in health monitoring
  - Runs smoothly
  - Many applications for future vehicles

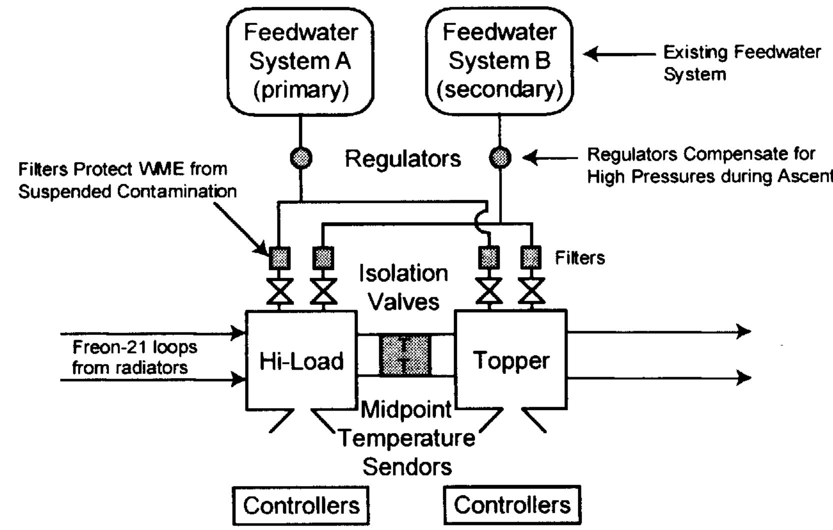
- Shuttle applications include
  - Landing gear actuators
    - Nose landing gear uplock actuator
    - Nose wheel steering actuator
    - Main landing gear strut actuator
  - ET Umbilical retract actuator
  - Aerodynamic control surface actuators
  - Body Flap actuator
  - Elevon servoactuator
  - Rudder/speedbrake hydraulic motor/servo valves
  - SSME cryogenic propellant valves
  - Thrust vector control actuators
  - Various Reusable First Stage (RFS) applications

Water Membrane Evaporator (WME)

Description

Water Membrane Evaporator provides cooling

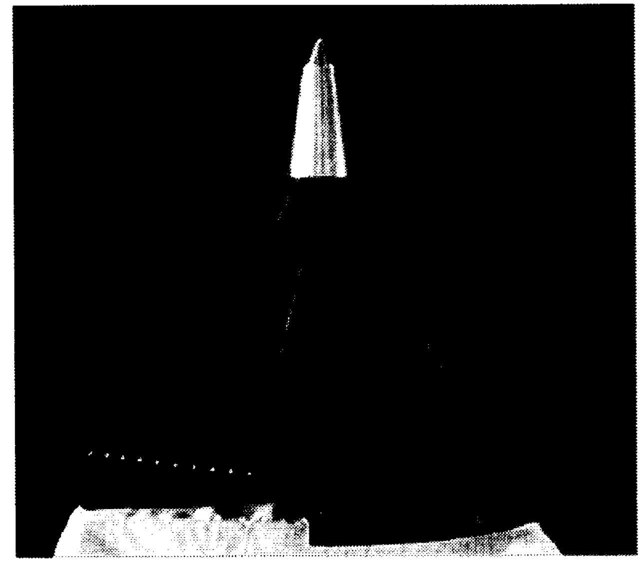
- Uses a hydrophobic micropore membrane that releases water vapor as water is heated
- Hydrophobic membrane passively controls water inventory
- Hydrophilic membrane allows cool water to replace the evaporated water
- Takes advantage of recent developments in hydrophobic micropore membrane technology



Benefits

- Replaces Flash Evaporator System (FES) which provides active cooling during ascent and entry and supplemental cooling on-orbit
  - Lower maintenance costs
    - Higher reliability (less moving parts)
      - Increased time between repairs/refurbishment
      - Longer life
    - FES has problems with clogged filters and nozzle freeze-ups
  - Leverage off of industry development
  - Synergy with advanced spacesuit (EMU) cooling system development
  - Decreased sensitivity to contaminants in the feed water

Composite Structure



Description

Incorporate composite structures into evolved or next generation shuttle

- Composites are composed of continuous fibers suspended in a resin
  - Laminates provide high stiffness and strength
- Types of composites include
  - Carbon Fiber Reinforced Composites (CFRC)
  - Ceramic based
  - Carbon/Polyamide

Benefits

- Lightweight
  - As much as 5 times lighter than steel
- High Stiffness
  - As much as 2.5 times the strength of steel
- Part Consolidation
  - Eliminate critical failures
- Extended life cycle
  - No fatigue, corrosion
- Vibration damping
- Can be optimized to fit design needs
- Dimensional stability under changing temperatures
- Can incorporate structures health monitoring into design

- Application include designs that need
  - Light weight, strength, and stiffness
    - Wings
    - Body flaps
    - Various weight-saving components/structure
  - Heat resistance
    - Carbon-carbon brakes
    - Leading edge applications (wing, rudder, nosecone)
      - Eliminates or reduces TPS
  - Inert chemical properties
    - Fuel tanks
  - Fatigue resistance
  - Insulating properties

Containerized Payload Module

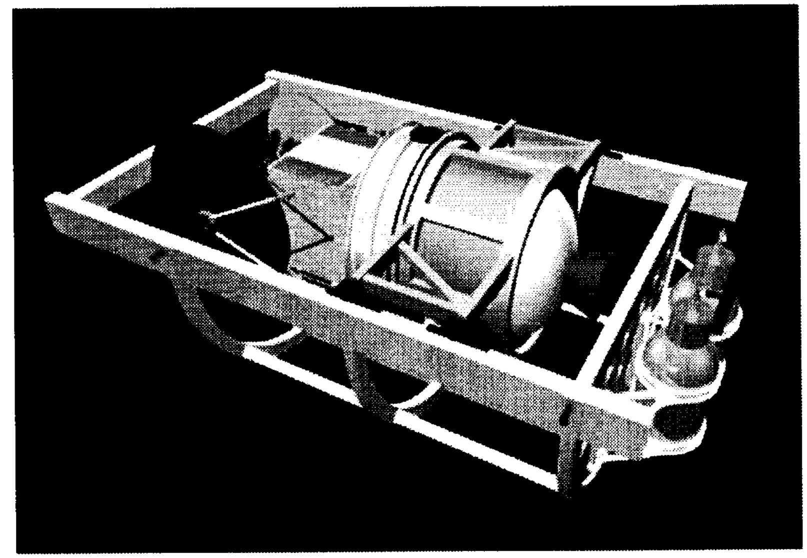
Description

Design and build a containerized payload module to standardize orbiter to payload interfaces

- Install with the payload as a completed assembly
- Uses standardized interfaces

Streamline orbiter-to-payload support services and interfaces

- Orbiter and mission kit avionics, power, distribution and control hardware support upgraded to standardized support system



Benefits

Safety and Reliability

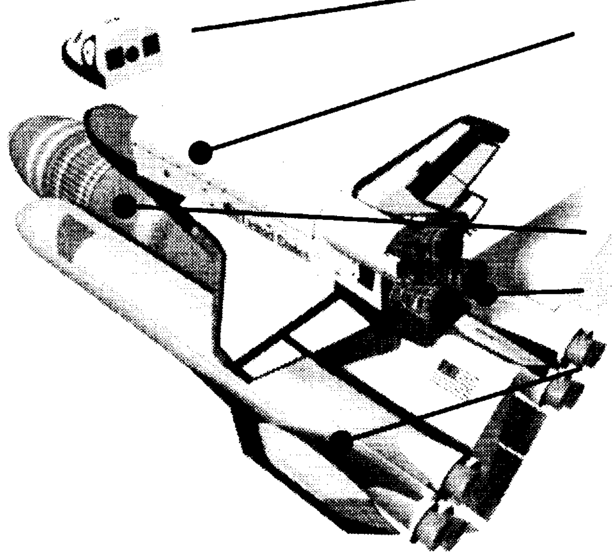
- Reduces on-orbit mission complexity

Supportability

- Significant reduction in Payload Integration and KSC reconfiguration costs
  - 36% reduction in operations and maintenance costs between
    - KSC Orbiter reconfiguration
    - Payload Integration (ICD, Engineering, Mission Kit Hardware, Requirements)
  - Additional savings due to using the standardized carrier
  - Allows for payload processing at commercial facilities
  - Allows integrated testing off-line
  - Economically accommodates future payloads
- Significant reduction in templates
  - Supports flight rates of at least 15 per year
  - Reduce template by 4 to 6 months
  - Supports 30 day OPF flow
- Takes advantage of other avionics and communications upgrades
- Note – Legacy payloads would have to be recertified. Would need to be implemented after ISS assembly complete.

Representative Shuttle-Derived 2nd Generation RLV Options

Boeing / NASA In-House



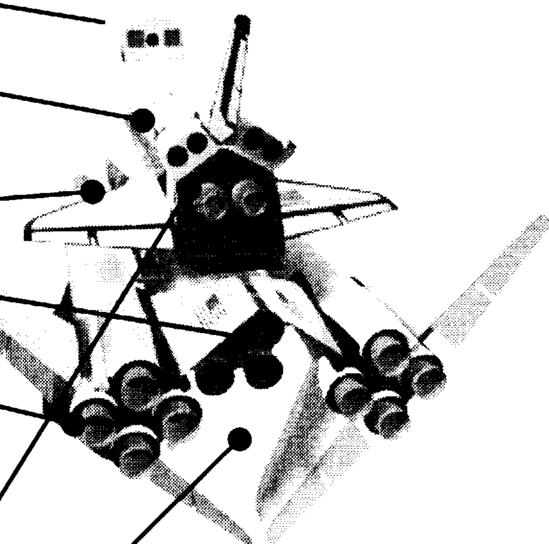
Common Features

- Crew escape pod
- Subsystem improvements: non-toxic OMS/RCS, electro-mechanical actuation, improved TPS, improved landing systems
- Retain external tank
- Improved highly reliable main engines
- Reusable first stage (with capability to make orbit with one booster engine out)

Variations

- Air breathing jet engines on orbiter for range extension and landing "wave off/go around" capability
- Main engines (expendable or recoverable) moved from orbiter to external tank
- 3 "Super" SSME or 4 SSME Engines for engine out to orbit from the pad

Lockheed / NASA In-House



Shuttle Upgrades Enabling Technologies for the Future

Near Term
- Long-Life Fuel Cells
- Avionics Cockpit Upgrades
- Elec [redacted]
- MLG T [redacted]
- AHM
- BLK III SSME

Advanced Technology
- Crew Escape
- Reusable First Stage
- Non-Tox OMS/RCS Propellants
- PEM Fuel Cell
- Electromechanical Act [redacted]
- Water Membrane E [redacted]
- Integrated Veh [redacted] Mgmt
- Propellant [redacted] ons
- [redacted] iber C [redacted]

The Vision . . .