SP CE 2000
RANSPORTATION
AY

Risk Reduction

for the Next Generation

In-Space Agenda

♦ In Space Investment Area Overview	Les Johnson
♦ Hall Propulsion Technology	Robert Jankovsky
♦ Ion Propulsion Technology	John Brophy Mike Patterson
♦ Fission Propulsion: SAFE	Mike Houts
♦ Cryogenic Fluid Management Technologies	David Plachta
♦ Solar Thermal Propulsion Technologies	Steve Tucker
♦ Momentum Transfer Tether Technology	Kirk Sorensen
♦ Electrodynamic Tether Coatings for ProSEDS	Jason Vaughn
♦ AeroAssist Technologies	Richard Powell
♦ Solar Sail Technology	Humphrey Price
♦ Mini Magnetospheric Plasma Propulsion (M2P2)	Dennis Gallagher

SPACE 2000

TRANSPORTATION

AY

Risk Reduction
for the Next Generations

Hall Propulsion Technology Development
NASA Glenn Research Center

50 kW Thruster Technology

EXPRESS Ground/Space Correlation

Contact Info:
Robert Jankovsky, NASA Glenn Research Center
216.977.7515
Robert.Jankovsky@grc.nasa.gov

Fred Elliott, NASA Glenn Research Center
216.433.2322
Fred.Elliott@grc.nasa.gov

"ST Day 2000: Reducing Risk for the Next Generations"

- **Technology goals and objectives**

  It is the goal of this activity to develop 50 kW class Hall thruster technology in support of cost and time critical mission applications such as orbit insertion.

- **Background**

  NASA MSFC is tasked to develop technologies that enable cost and travel time reduction of interorbital transportation. Therefore, a key challenge is development of moderate specific impulse (2000-3000s), high thrust-to-power electric propulsion. NASA GRC is responsible for development of a Hall propulsion system to meet these needs.

- **Current Status**

  First-phase, sub-scale Hall engine development completed. 10 kW engine designed, fabricated, and tested. Performance demonstrated >2400 s, >500 mN thrust over 1000 hrs of operation documented.

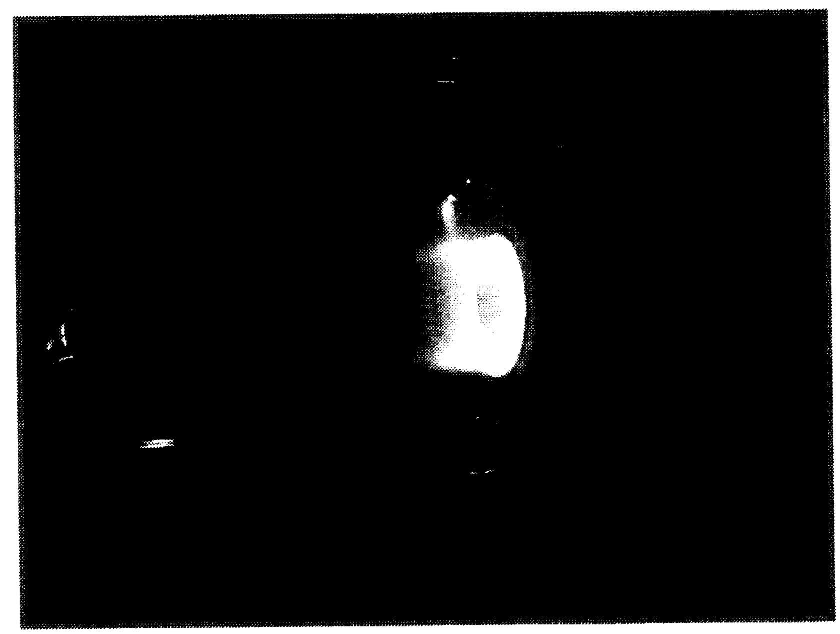
50 kW Thruster Technology

- Major accomplishments (FY00):

  The NASA T-220 10 kW Hall Effect Thruster demonstrated over 500 mN thrust at 2450 seconds specific impulse (Isp) and 59% total efficiency while demonstrating good erosion characteristics over 1000 hours of operation. This is the longest operation ever achieved on a high power Hall thruster (>5 kW). This test indicates the availability of 10 kW Hall thruster technology for future NASA, commercial, and military missions and confirms the technical approach for development of even higher power thrusters.

- Near Term Plans (FY01):

  Procure a 50 kW engine design and prepare diagnostics and test equipment.



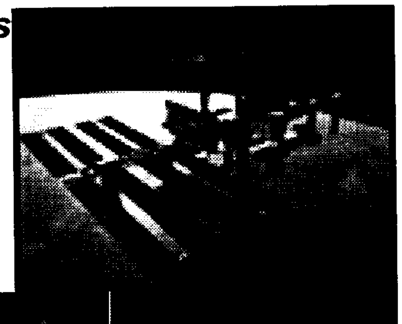
"ST Day 2000: Reducing Risk for the Next Generations" - Hall Propulsion

50 kW Thruster Technology

50 kW Thruster Applications

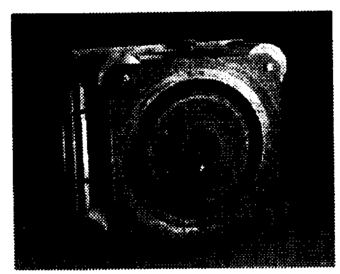
"ST Day 2000: Reducing Risk for the Next Generations" - Hall Propulsion

ISS Drag Makeup
Significantly reduces required refueling flights

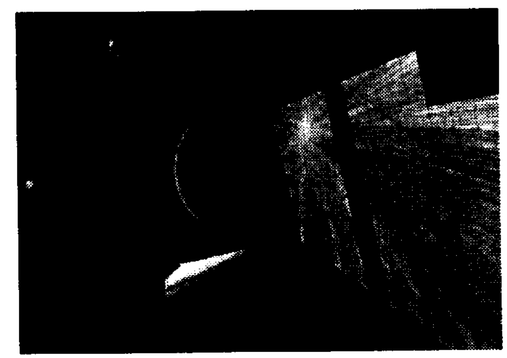


Lunar/Mars Exploration
, Reduces Launch Vehicle Fleet

LEO to GEO space transportation *Four Times the Payload of Chemical Systems In Four Weeks using next generation Power levels*



- Need Power Levels ~ 50 kW & Isps ~ 2000 sec



Space Solar Power
Reduces number of launch vehicles required by a factor of 5 ! Deliveries in few weeks to less than four months.

- Technology goals and objectives

  Compare measurements of critical plasma parameters from on-orbit with ground test data. Develop fundamental understanding of the differences enabling extrapolation to other thrusters/geometries for integration assessments.

- Background/Approach
  - Several different types of sensors integrated on two Russian Geo-Comsats (Express-A #2 & EXPRESS-A #3) utilizing 1.5 kW SPT-100 Hall thrusters.
  - Ground tests validating sensors and duplicating space measurements to be taken at NASA GRC
  - Additional GRC ground tests with alternate thrusters/geometries

EXPRESS Ground/Space Correlation

- **Sensors integrated on to Express-A, #2 and launched**
  - Data being collected
  - Data transfer and correlation with thruster operation being addressed
- **Sensors integrated on to Express-A, #3 and launched**
  - Data being collected
  - Data requirements also being addresses
- **GRC ground testing**
  - Planning stages - test details being discussed
  - S/C representative sensors being procured

Current Status

- **Major accomplishments (FY00):**

  Successful launch of sensor packages on EXPRESS-A #2, and EXPRESS-A #3

- **Near Term Plans (FY01):**

  Procure a duplicate set of EXPRESS-A #2, and EXPRESS-A #3 sensors. Plan ground test program.

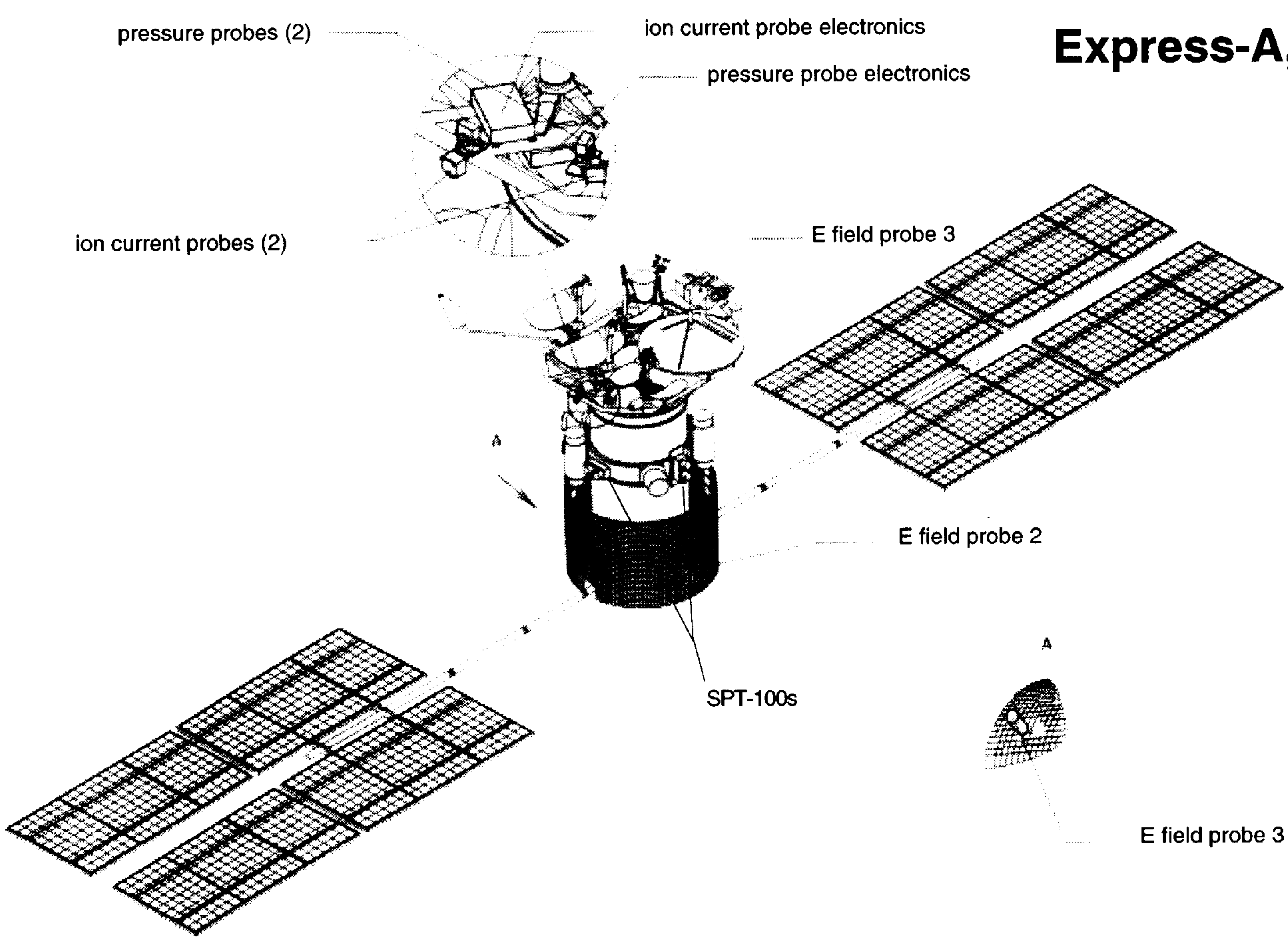
EXPRESS Ground/Space Correlation

- **Sensor Types**
  - **Pressure: Measure local density to understand how plume expands Simple measurement, previously conducted**
    - Measurement in back flow region very difficult on ground
    - Maybe important for assessing corona phenomena for payload
  - **Electric Field Strength: Measure how the plasma modifies E-field at S/C surface**
    - Less simple measurement , previously conducted
    - Gives insight into how the spacecraft couples to the ambient space plasma
    - Maybe important for assessing corona phenomena for payload

EXPRESS Ground/Space Correlation

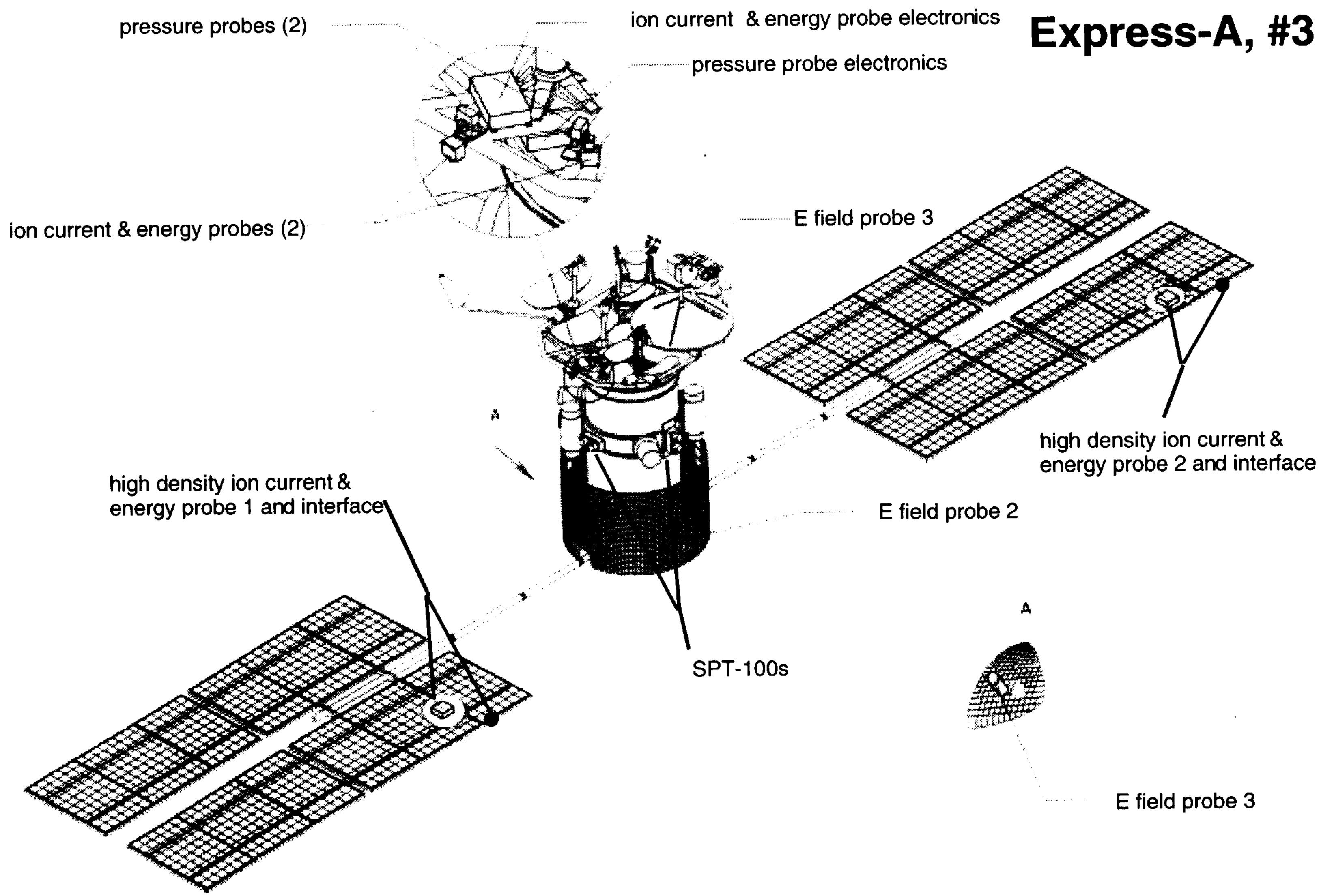
- **Sensor Types (continued)**
  - **Ion Current: Measure the flux density of the plume ions**
    - Simple measurement, not previously conducted
    - Easily compared with ground tests data and analytic predictions
    - Flux of ions needed for estimating thermal/momentum transfer to other parts of S/C
  - **Ion Current & Energy: Measure the flux density and energy of the plume ions**
    - Difficult measurement, not previously conducted
    - Provides desired information for determination of integration impacts
    - Flux and energy ions needed for determining thermal/momentum transfer and erosion of S/C

Express-A, #2



"ST Day 2000: Reducing Risk for the Next Generations" - Hall Propulsion

EXPRESS Ground/Space Correlation



"ST Day 2000: Reducing Risk for the Next Generations" - Hall Propulsion

EXPRESS Ground/Space Correlation

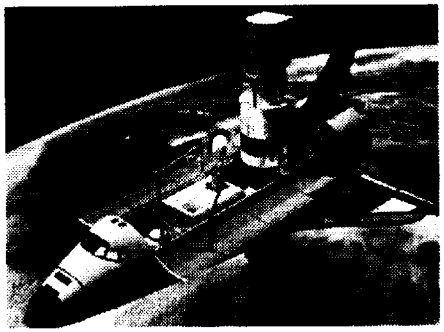
2nd Generation RLV Plans

Dan Dumbacher

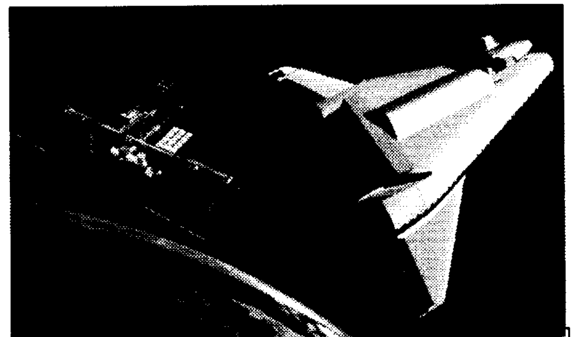
Agenda

- Heritage and Background
- Goals and Schedule
- Program Requirements and Organization
- Technology Drivers and Interfaces
- Acquisition Strategy and Planning
- Status and Summary

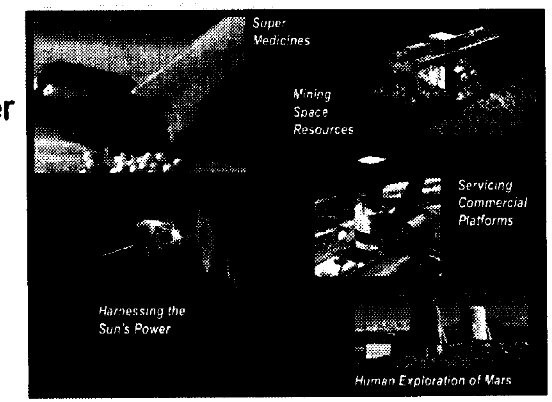
Generations of Reusable Launch Vehicles



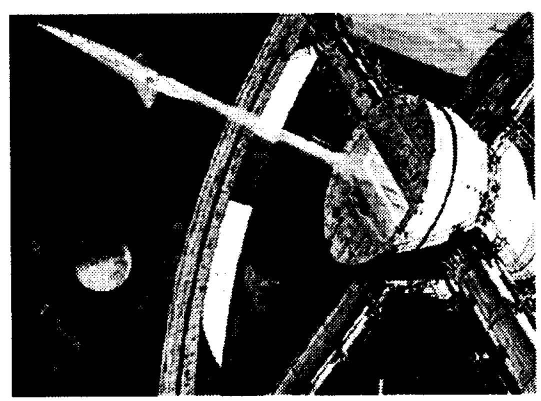
Today: Space Shuttle
1st Generation RLV
- Orbital Scientific Platform
- Satellite Retrieval and Repair
- Satellite Deployment



2010: 2nd Generation RLV
- Space Transportation
- Rendezvous, Docking, Crew Transfer
- Other on-orbit operations
- ISS, Orbital Scientific Platform
- 10x Cheaper
- 100x Safer



2025: 3rd Generation RLV
- New Markets Enabled
- Multiple Platforms / Destinations
- 100x Cheaper
- 10,000x Safer

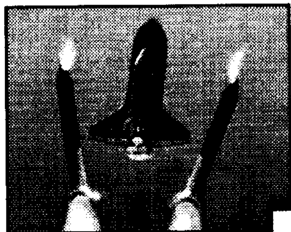


2040: 4th Generation RLV
- Routine Passenger Space Travel
- 1,000x Cheaper
- 20,000x Safer

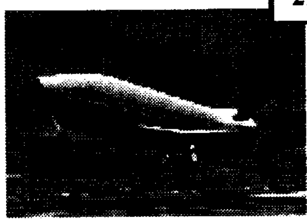
Foundation Studies and Plans

- STAS - Space Transportation Architecture Studies
  - **Focused Industry and In-House Studies of Space Transportation requirements, architecture options and preliminary risk reduction**
    - Phase I - Aug - Sept '98 - Initial requirements definition
    - Phase II - Sept '98 - Feb 99 - Initial architecture options
    - Phase III - July '99 - Dec '99 - Requirements and architecture refinement , technology prioritization
    - Phase IIIB - Dec '99 - July '00 - System engineering process definition, technical risk reduction plan
- ISTP - Integrated Space Transportation Plan
  - **Annual effort to integrate NASA plans and resource requirements for:**
    - Space Shuttle safety upgrades and on-going programs
    - Crew Transfer/Return Vehicle
    - 2nd Generation RLV and NASA Unique systems
    - Alternate Access to Space Station
    - 3rd Generation RLV and In-Space Transportation
- SLI - Space Launch Initiative ➡ 2nd Generation RLV Program
  - **Systems Engineering and Requirements Definition**
  - **2nd Generation RLV Competition and Risk Reduction**
  - **NASA Unique systems**
  - **Alternate Access to Space Station**

Integrated Space Transportation Plan



Ensure continued safe access to space through **<u>Space Shuttle Safety Upgrades</u>** until a replacement alternative has been demonstrated



2nd GEN Invest in technical and programmatic **<u>Risk Reduction</u>** activities, driven by industry needs, to enable full-scale development of commercially-competitive, privately owned and operated, Earth-to-orbit (ETO) reusable launch vehicles (RLVs) by 2005.

2nd GEN Develop an integrated architecture with systems that build on commercial ETO launch vehicles to meet **<u>NASA-Unique</u>** requirements that cannot be economically served by commercial vehicles alone.

2nd GEN Enable procurements of near-term, launch services for select International Space Station needs on **<u>Existing and Emergent Commercial Launch Vehicles.</u>**

Secure safe, reliable and cost-effective access to space in the far-term through investments in **<u>3rd-Generation RLV Technologies</u>** for ETO and in-space applications

Space Launch Initiative Goals

The goal of this Space Launch Initiative is for NASA to meet its future space flight needs, including human access to space, using commercial launch vehicles that will improve safety and reliability and reduce cost.

Safety Goal - *Improve safety to better than 1 in 10,000 Loss of Crew*
Cost Goal - *Reduce mission cost to $1000/lb*

Four principles exist:
Commercial Convergence – flying on privately owned and operated launch vehicles;

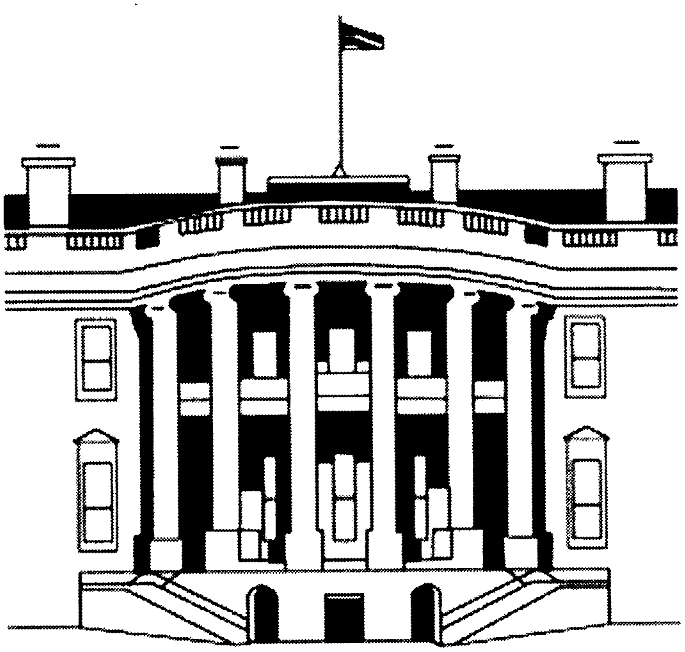
Competition – bringing innovation and new ideas to bear;

Assured Access – ensuring alternate means of getting to space despite launch mishaps;

The Ability to Evolve – adding new capabilities affordably as new mission needs emerge.

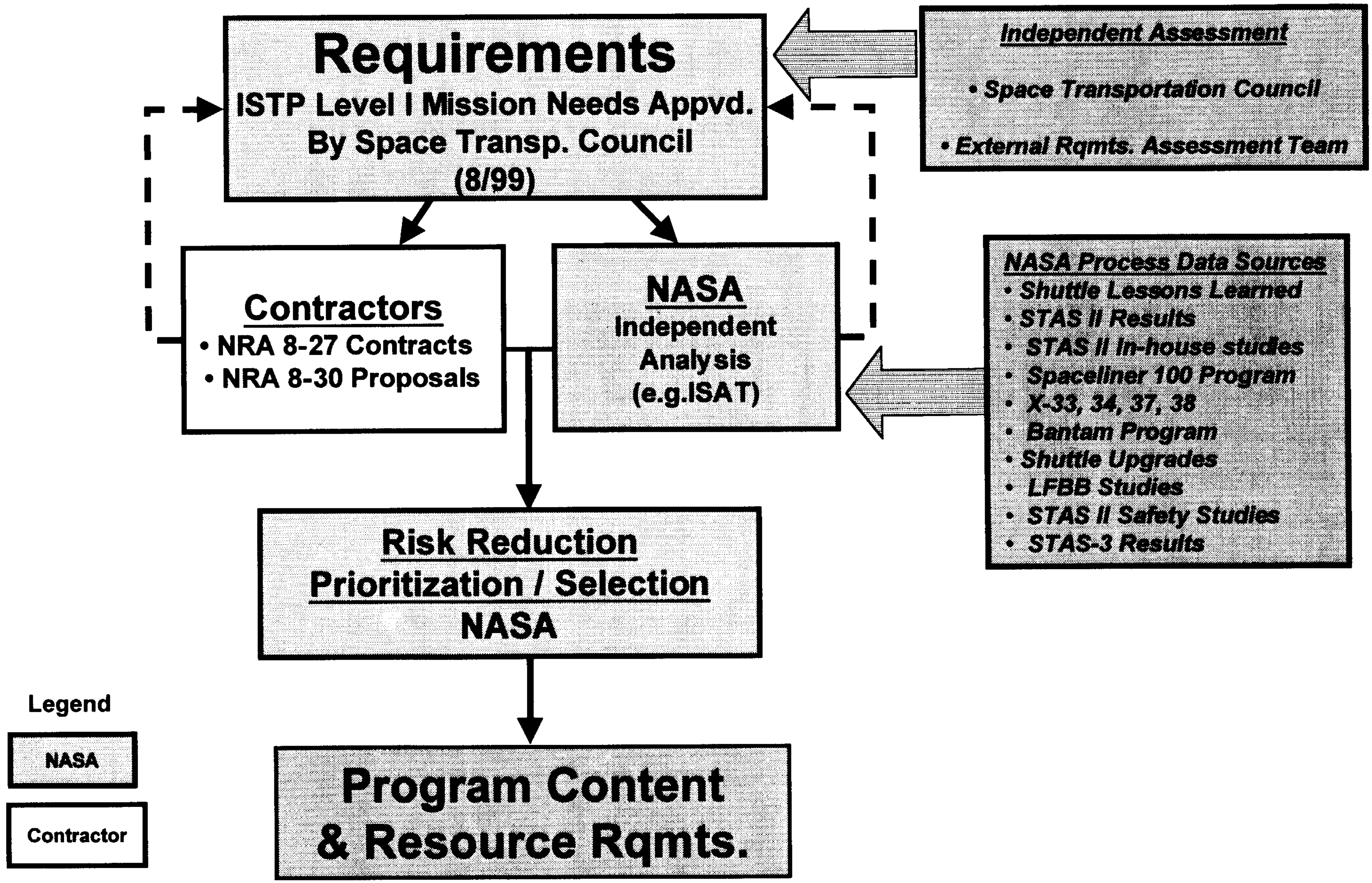
National Endeavor

"The Space Launch Initiative is an extremely ambitious undertaking. If successful – and I'm confident it will be – it will dramatically alter the economics of space launch. I believe that this Space Launch Initiative could ultimately have as profound an impact on space exploration and space commerce as anything our nation has ever attempted."

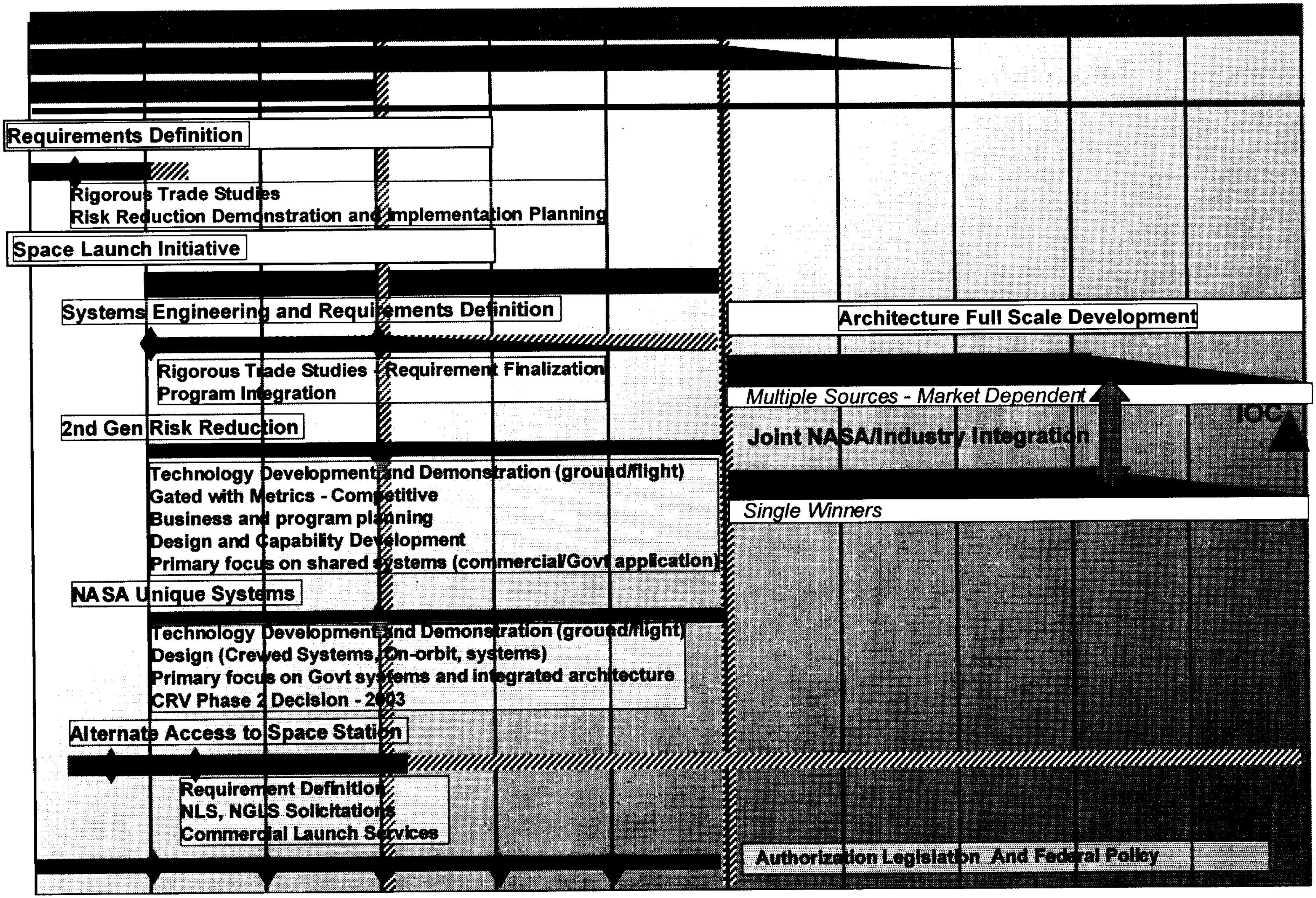


Dr. Neal Lane
Assistant to the President
for Science and Technology

2nd Gen Program Planning Process



2nd Generation Program Plan

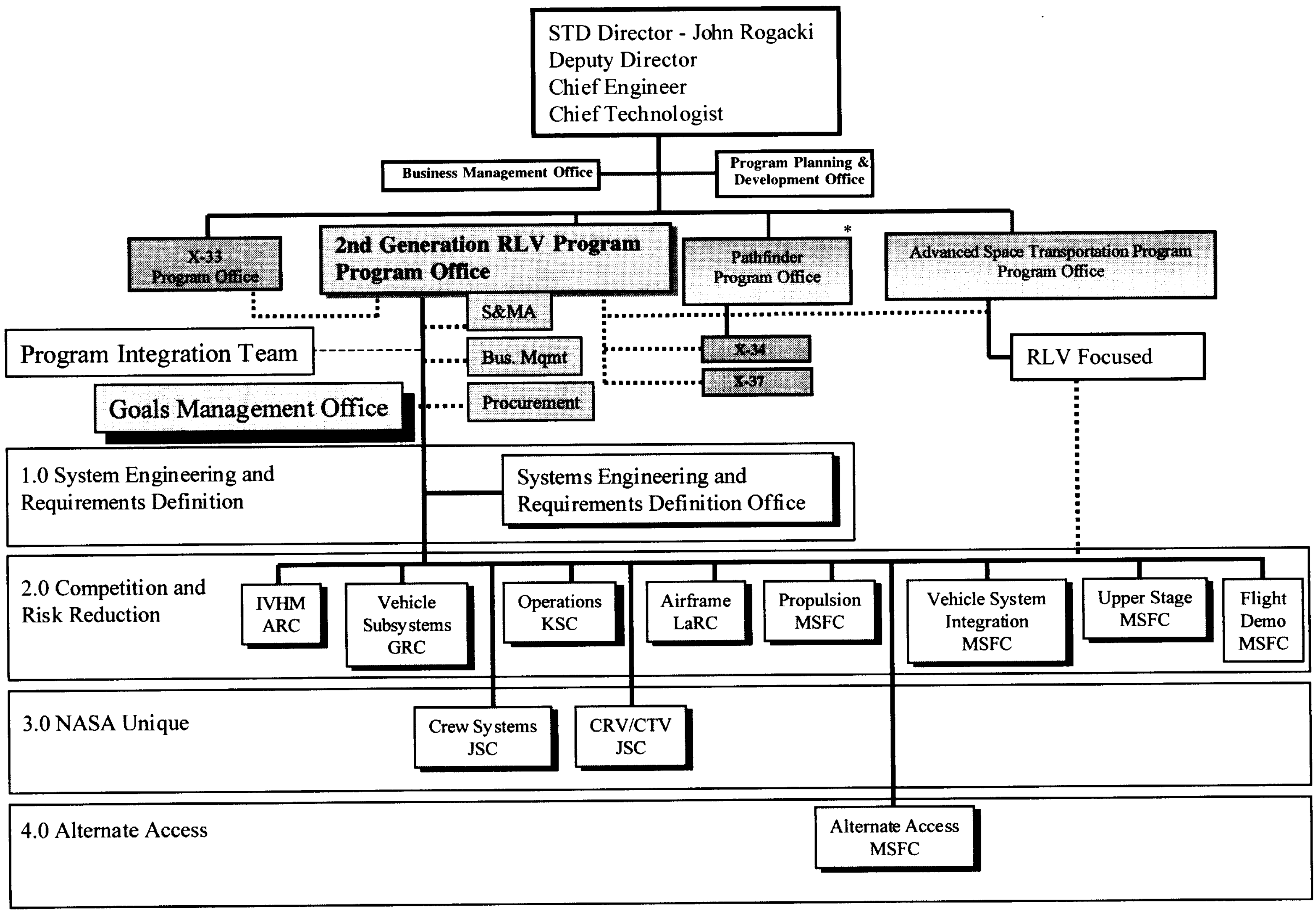


2nd Generation RLV Objectives

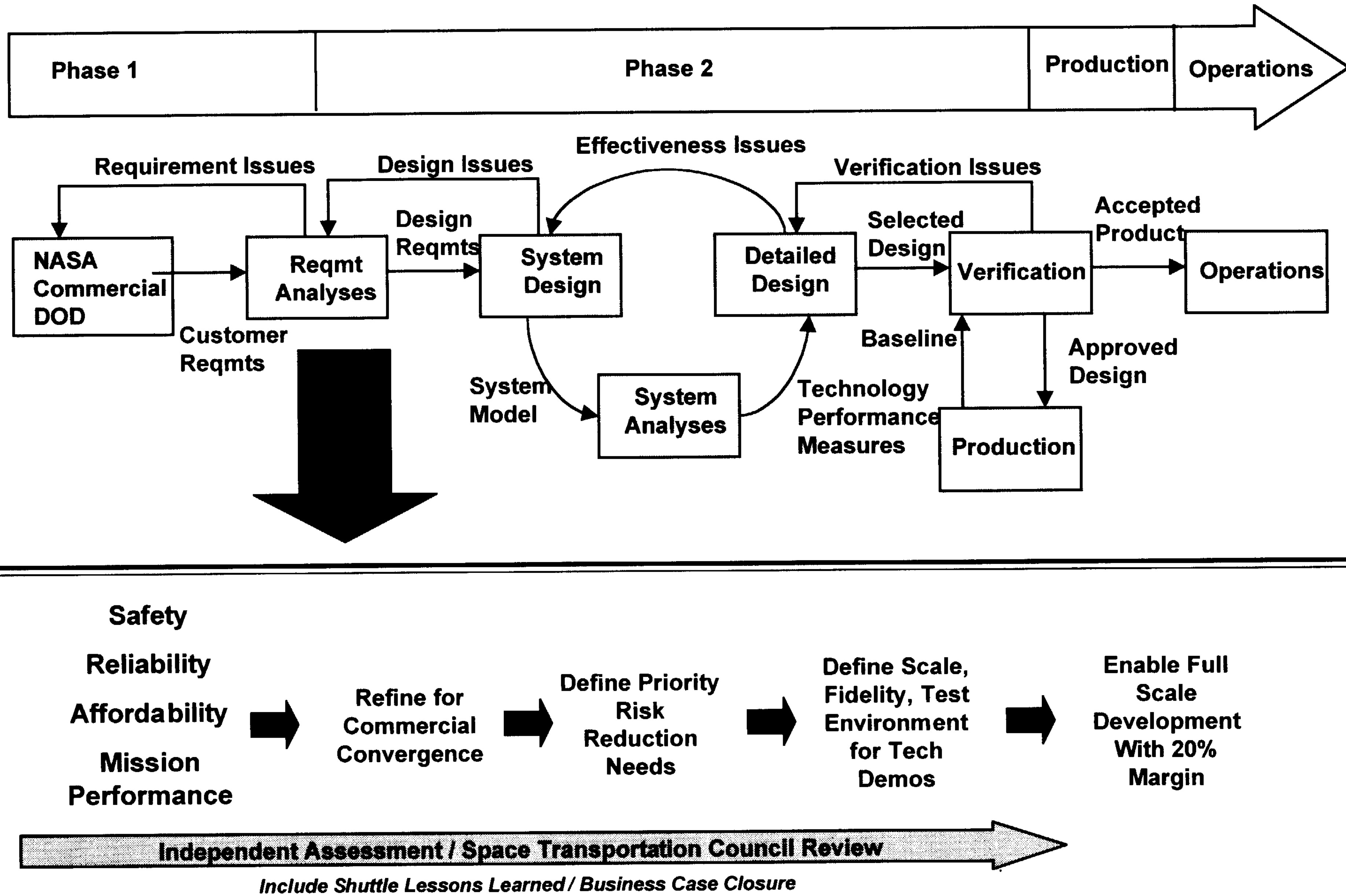
What 2nd Gen RLV must accomplish to meet our Goals

Objectives	Success Criteria	Date	Approach
A. Converge National Needs – Industry, NASA, and DOD	U.S. Transportation Needs Document Approved by Space Transportation Council	Baseline is August 1999 and updated annually	Initiated for ISTP with annual updates from systems engineering process
B. Provide an architecture requirement set derived from converged needs for industry competition	2nd Generation RLV System Requirements Database Approved by Space Transportation Council	Preliminary in August 2000 and updated annually	Initiated for ISTP with annual updates from systems engineering process
C. Develop systems engineering processes and tools, and connect goals to risk reduction Investments	Risk Reduction Investment Strategies documented in project plans Tools developed and validated. Knowledge base developed.	Initial - August 2000 with periodic updates 2002 2005	Implement rigorous systems engineering process (Utilizing tools developed by ISE, Design for Safety Initiative, etc) Initiated with NRA 8-27
D. Abate business and technical risks through defined risk reduction activities	Architecture definition at a minimum of a PDR level. Government / Industry full-scale development contracts initiated.	2005	In-house/ contractor led advanced development and technology demonstrations, including ground and flight, complete
E. Architectural decision made to safely meet unique NASA needs	CRV/CCTV Decision complete. NASA unique architecture elements identified and in development	2002 2005	NASA unique requiremen ts identified in Obj. A & B, risk reduction investments from Obj. D
F. Enable alternative Space Station re-supply	Launch service agreement(s) in place and enabling activities complete	2002-2005	Perform initial studies to define activities. Develop and implement activities jointly between Code M and Code R

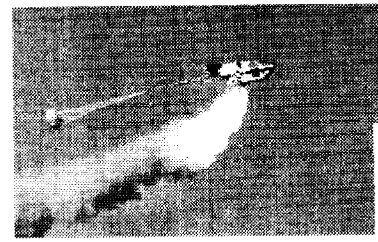
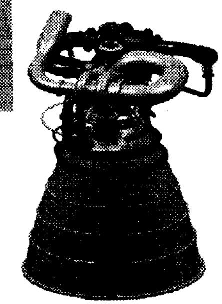
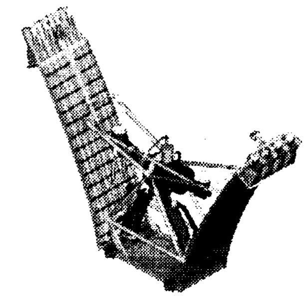
2nd Generation RLV Program Office Structure



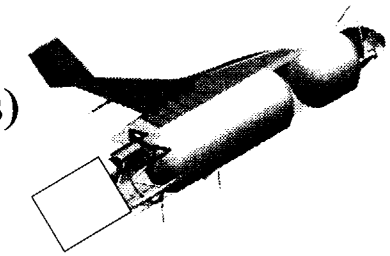
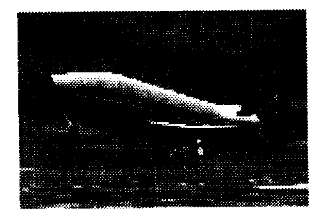
Requirements Drives the Process



Significant 2nd Technology Drivers

- **Crew Escape and Survival**
  - Detection, separation, ascent/descent
- **Operable, Long-life H_2/O_2 and RP/O_2 Engines**
  - 100 mission life, 50 missions to overhaul
- **Long life, lightweight integrated airframe**
  - Critical integrated cycle testing (500 missions)

- **Advanced TPS, IVHM, and Operations**
  - Quick turn vehicle with intelligent data analysis


- **Ejector Ramjet**
  - Improved performance margin
- **SHARP Leading Edges**
  - Global crossrange from orbit

Cutting Edge for 2nd Generation

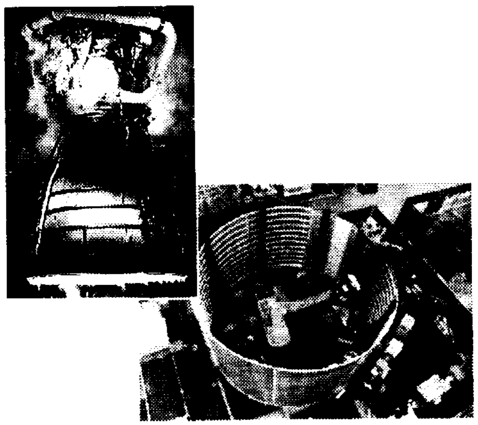
2nd Gen RLV Relation to Other Programs

2nd Generation RLV coordinates investments with:
Shuttle
X-Vehicles
ASTP
Air Force

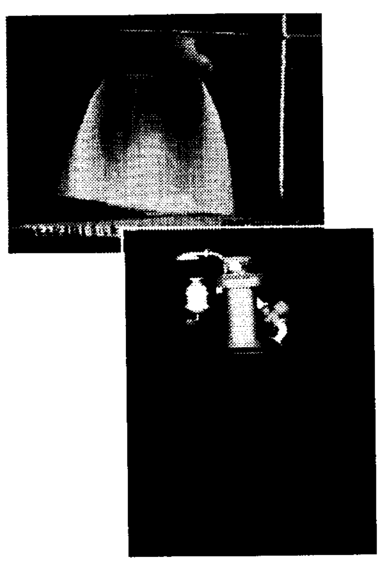
Background - Space Transportation Definitions

Integrated Space Transportation Plan (ISTP)

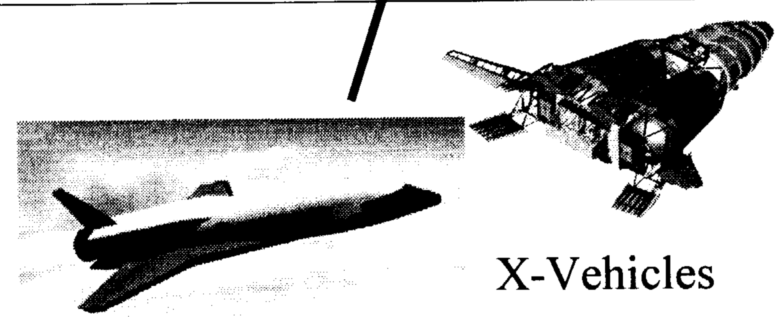
- Shuttle Safety
  - Supportability and Safety upgrades
- Crew Return Vehicle
  - X-38
- Space Launch Initiative
  - 2nd Gen RLV Program
    - Systems Eng. and Requirements Definition
    - Competition and Risk Reduction
    - NASA Unique Systems
    - Alternative Access
  - Use of on-going Flight Demonstrators (X-33, X-34, X-37 and Exp) to meet 2nd Gen Objectives
- Aero-Space Base
  - Information Technology
  - Vehicle Systems Technology
  - Propulsion and Power
  - Flight Research
  - Space Transfer and Launch Technology



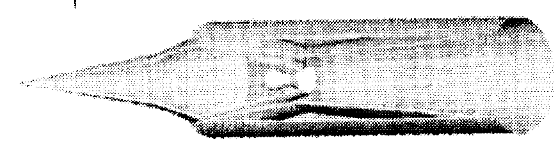
Shuttle Up-Grades

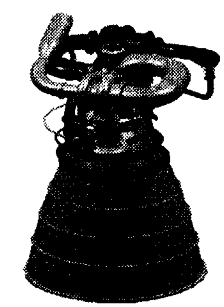


DOD Technologies



X-Vehicles

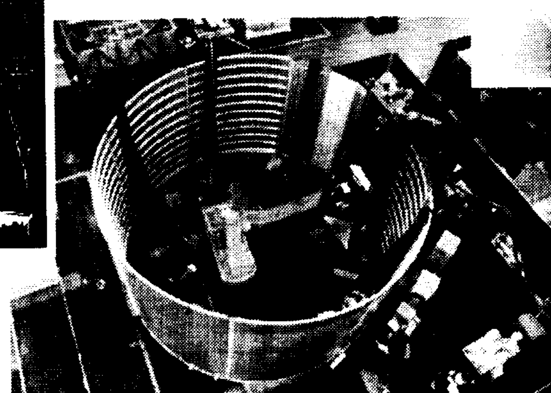


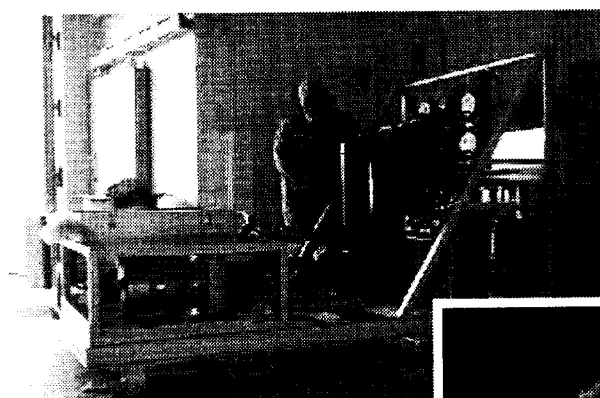


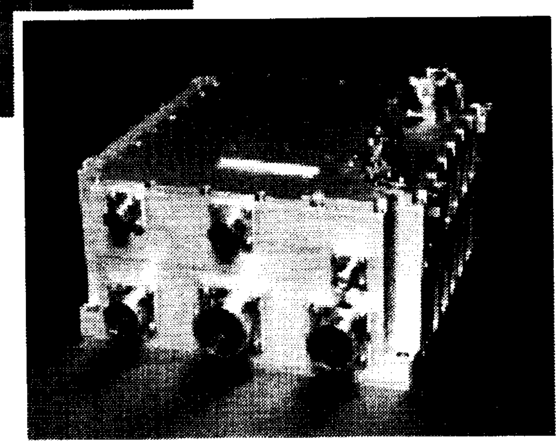
3rd Generation Technology

Space Shuttle Upgrades

- **Cooperation with the Space Shuttle Upgrades program is required to:**
  - Coordinate technology activities
  - Avoid duplication of effort
  - Consider application of Second Generation technologies to future Space Shuttle upgrades and the evolved Space Shuttle

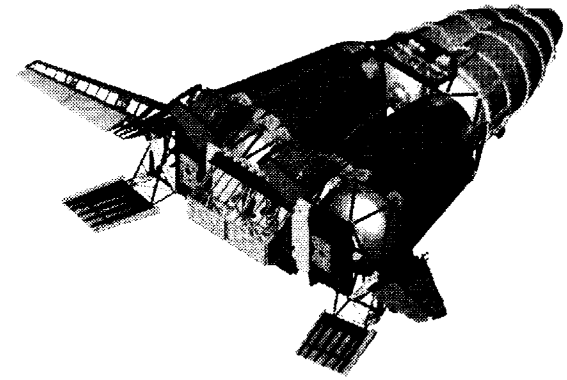


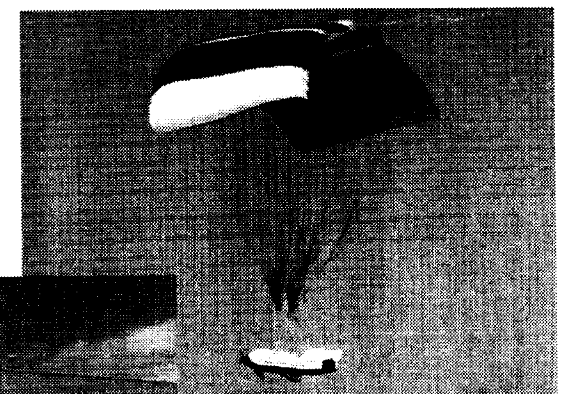


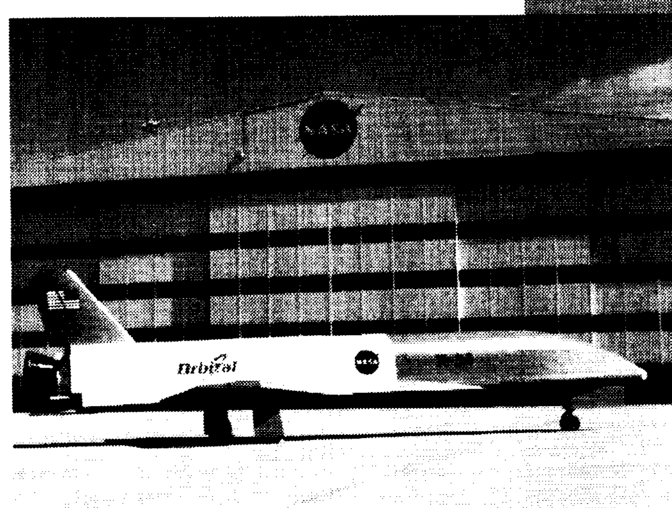


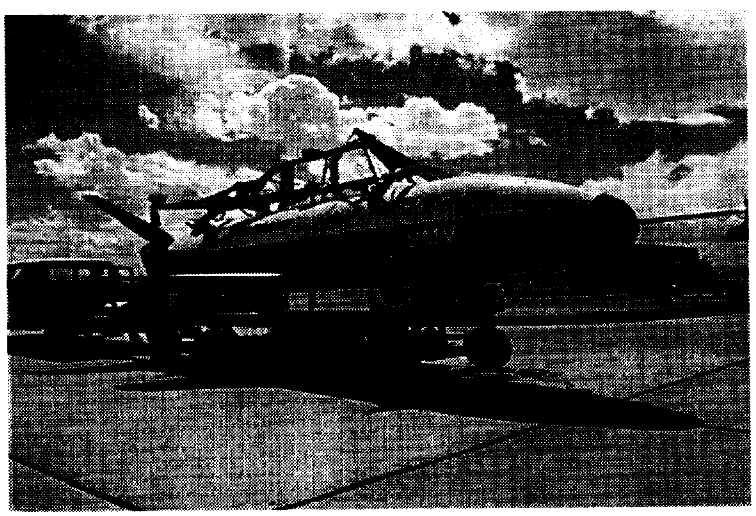
X - Vehicles

- The 2nd Generation Program is linked to the success of the current X-Vehicle programs
- The current investment in X vehicles offers a unique opportunity to reduce risk through flight test
- The future use of the current X-vehicles and other flight vehicles is dependent upon selection within the competitive process

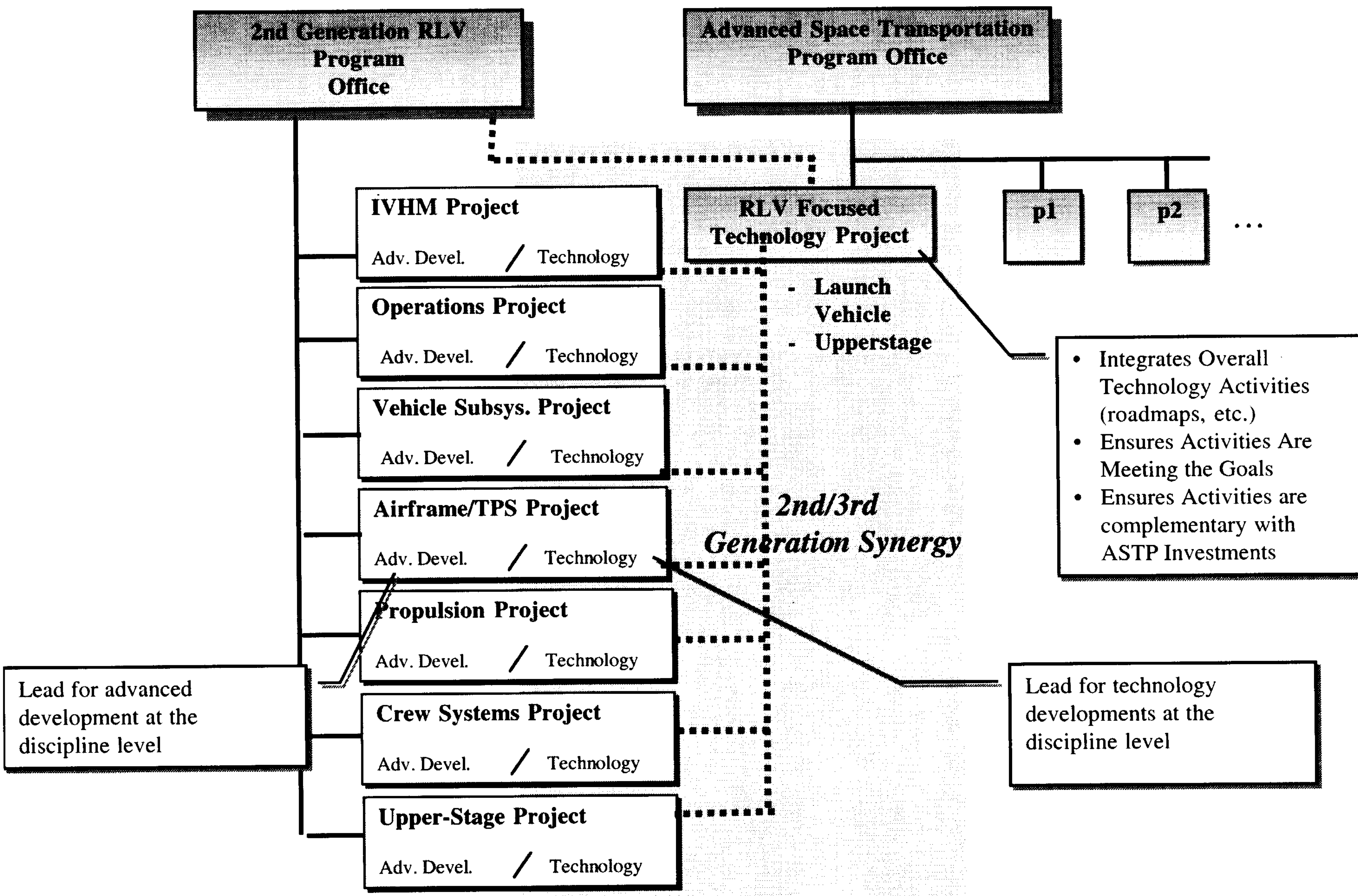






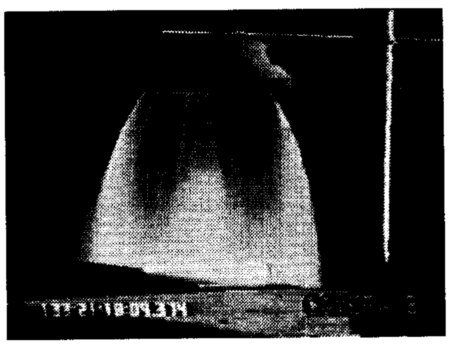


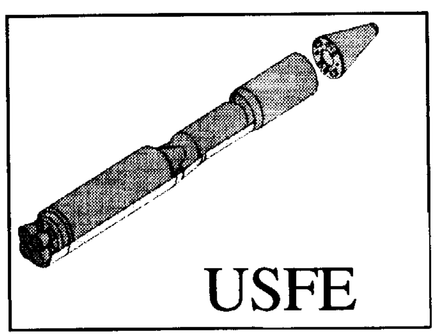
2nd/3rd Synergy Management Structure

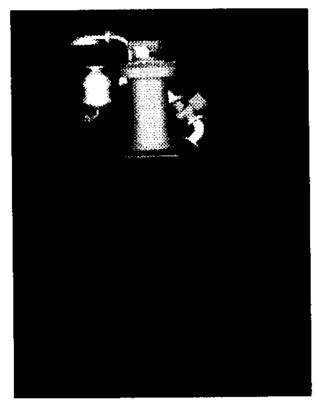


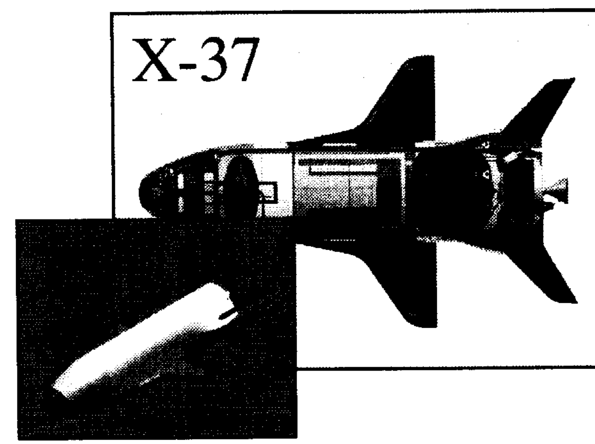
Joint Air Force/NASA Efforts

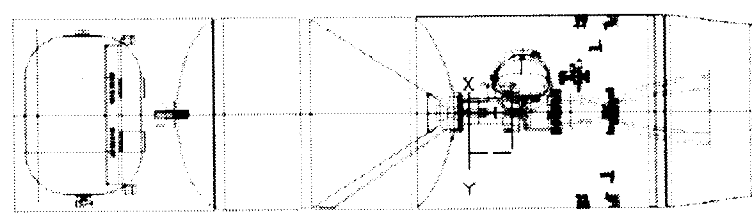
- 2nd Generation Program is coordinating its risk reduction investments with ongoing Air Force Space Transportation investments.
- 2nd Generation Program will leverage/continue already initiated joint AF/NASA efforts including IPD, X-37, USFE, Advanced Peroxide Propulsion and MWG.











Total Program Acquisition Strategy

- Overall acquisition strategy will be in 2 major competitive phases
  - **Phase I (FY00 - 02)** develops architectures through System Requirements Definition and initiates risk reduction activities.
    - NRA8-27 converges and refines top level requirements, develops process and tools and defines risk reduction priorities.
    - NRA8-30, a single NASA Research Announcement seeking competitive systems engineering and risk reduction activities conceived by the offerors, in multiple areas of program interest (e.g. propulsion, airframe)
  - **Phase II (FY03 - 05)** focuses on architecture design and advanced technology development
    - Anticipate RFP(s) for the focused architecture design and Advanced Technology development activities
  - **Phases have decision gates** for program / project updates based on systems engineering results and Agency management milestones (e.g. Space Transportation Council, Non-advocate Review)
- In-House Risk Reduction Task
  - Cross cutting risk reduction - available to all concepts with no proprietary issues
  - Develops in-house "Smart Buyers".
  - A second cycle will be implemented to fill risk reduction gaps.
- Alternate Access will be addressed separately based on study results from current contracts

Total Program Acquisition Needs

- Support a **decision for commitment to full scale development** of the RLV architecture that meets NASA's goals (target date is 2005)
  - Industry teams to define an RLV architecture life cycle implementation with emphasis on Full Scale Development (FSD) technical and business metrics.
  - Rigorous system engineering, detailed trade studies, and risk reduction activity leading to concept design with acceptable technical and investment risks.
  - Business analysis must be supported with appropriate parameter identification and metric evaluation and show closure.
- **Maintain competition** and encourage solicitation of all good ideas.
  - Established Aerospace Companies
  - Emerging Aerospace Companies
  - Stand-alone Technologies from Companies not providing a system level architecture
- Resulting awards will provide appropriate Government insight to ensure successful development of the 2nd Gen RLV.
- Resulting awards will provide appropriate options to facilitate adjustments after major program **"Decision Gates"**.
  - NAR recommendations
  - Systems Requirement Review
  - Commitment to Full Scale Development (FSD)

In-House Led Activities

High Priority / Schedule Critical Activities

Activities required for 2nd Gen based on STAS 3B / ISTP

Activities best performed by NASA / Gov't (expertise, data sharing, etc.)

Activities industry may not propose & must be initiated ASAP to support 2005

- Systems Engineering and requirements
  - **Systems Analysis Tool Development**
  - **Probabilistic Risk Assessment**
  - **ORM & S/C Database Enhancements**
  - **Uncertainty Analysis and Design**
  - **Commercial Cargo System Modeling Task**
- Propulsion
  - **Full-flow staged combustion injectors**
  - **Lox / H2 Combustion devices test bed**
  - **Turbomachinery technology demonstrator**
- Airframe
  - **Integrated Aerothermal and Structural-Thermal Analysis**
  - **Stage Separation and Ascent Aerothermodynamics**
  - **Materials and Advanced Manufacturing: Permeability Resistance**
  - **Lightweight, Informed, Micrometeoroid Resistant Ceramic TPS for Leading Edge and Acreage Applications**
- Crew Systems
  - **Cockpit Architecture Roadmap Team**
- Operations
  - **Advanced mission planning / ops w/ MOD**
  - **Future Launch vehicle Umbilical Development**
  - **Satellite Telemetry Acquisition and Range Study (STARS) and Space-Based Range Safety System**
- Vehicle Subsystems
  - **Proton Exchange Membrane Fuel Cell (PEMFC) Power Plant Development**
- Integrated Vehicle Health Management
  - **IVHM Architecture Roadmap Team**
- Flight Mechanics
  - **Robust Integration Technology and test bed for RLV Navigation Systems**
  - **Natural Atmospheric Environment Technology Development**

Recent Accomplishments

- Successfully completed Program Readiness Review (May 17, 2000)
  - **First major milestone required by 7120.5A**
  - **"Program Formulation" until Non-advocate Review in June 2001**
- Systems Engineering
  - **Completed STAS 3B Final Reviews**
    - **Top level rqmts. input provided to NASA**
    - **All potential vehicle concepts are being assessed (e.g. Shuttle derived, new design) to meet NASA rqmts.**
    - **Industry top priorities remain main propulsion, airframe / cryotanks, TPS**
  - **Initiated further mission needs refinement and trade studies via NRA 8-27 contracts**
    - **Mid-term reports conducted week of Sept. 26-28, 2000**
    - **Final reports - Jan 31, 2001**
  - **CTV / CRV Planning on-going w/ JSC, LaRC, ARC, MSFC**
- Acquisition strategy developed
  - **Alternate Access study contracts in place**
  - **NASA led technology development tasks reviewed and selected, downstream selections will be based on contractor input via NRA 8-30**
  - **NRA 8-30**
    - **Pre-meeting w/ HQ Code H, G,R, & M held August 25, 2000**
    - **Acquisition strategy meeting held at HQ Sept. 11, 2000**
    - **Draft NRA released on September 21, Final to be released October 10**
- External requirements assessment team formulated
  - **Required skill areas (Shuttle / RLV experience, investment experience) identified, potential team members in work**

Summary

- Systems Engineering in work based on Space Transportation Council approved mission needs.

- Program Planning and Implementation continuing w/ broad Agency and Industry Participation

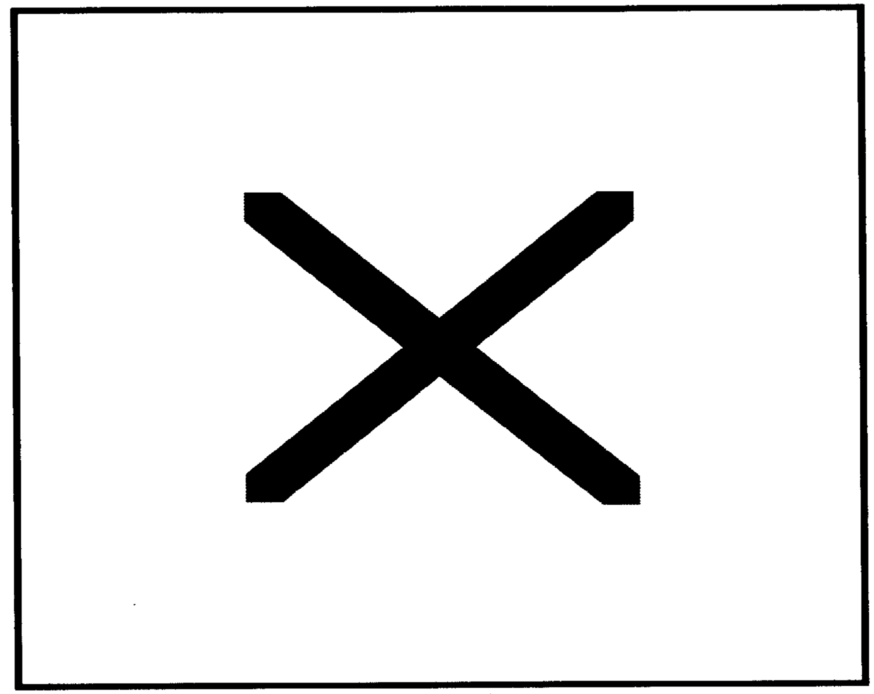
  - NRA 8-27 for requirements and tools development on-going
  - NASA In-House Development Tasks selected and set to begin
  - Draft NRA 8-30 for systems engineering and risk reduction activities on street with bidders conference planned for 10/13

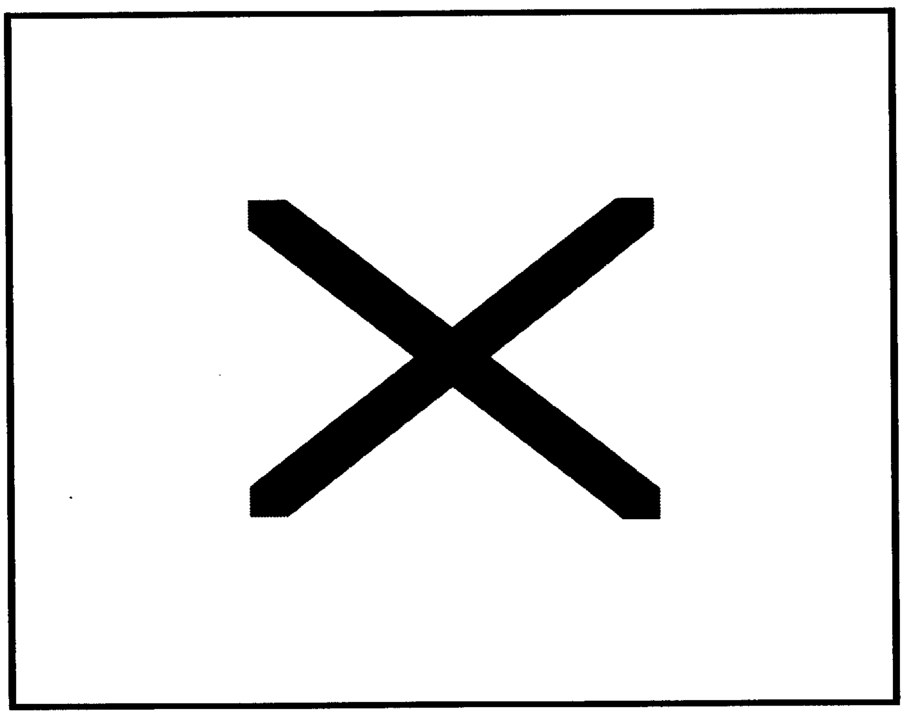
- Alternate Access study contracts to develop concepts and requirements for emerging launch systems to support ISS are in place

- Looking forward to continuing to work with Industry to achieve the Nation's goal of developing the next generation Reusable Launch Vehicle

The X-33 Program Update

Charlie Dill, X-33 Assistant Program Manager



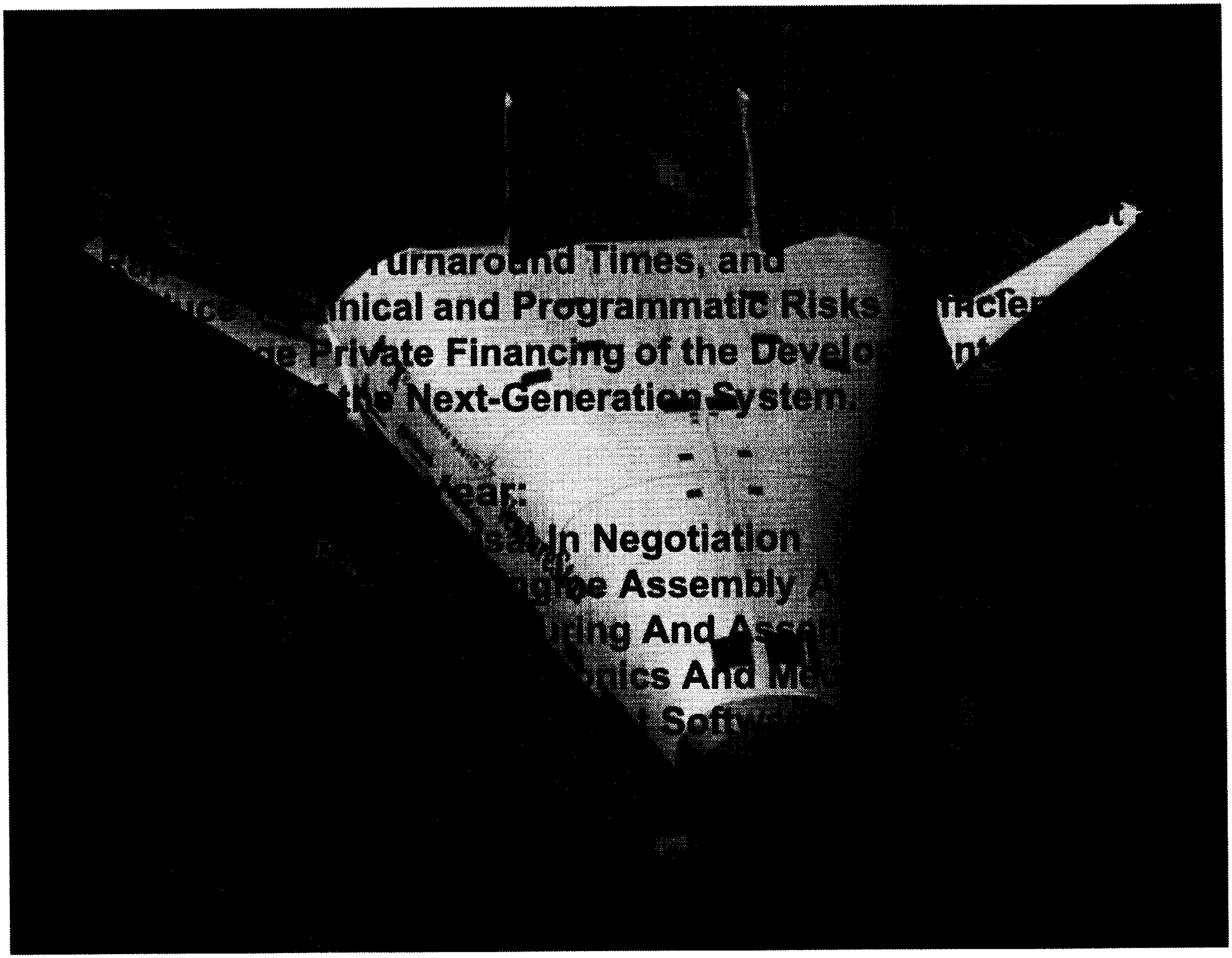


**ST Day 2000:
Risk Reduction
for the
Next Generations**

Oct. 11 - 12, 2000

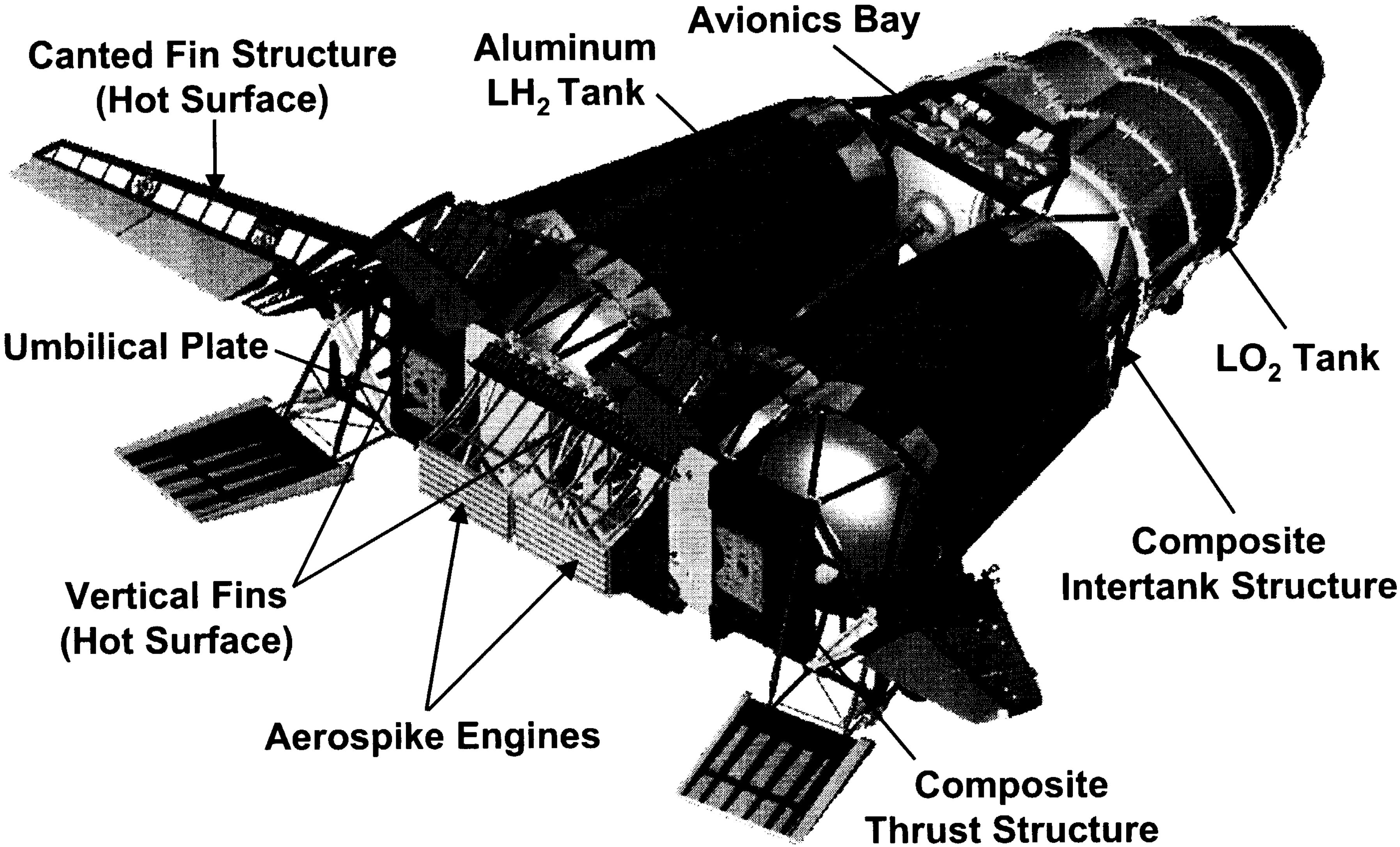
- Program Objectives and Plans
- X-33 Configuration
- Technologies
- X-33 Assembly and Test Status

Outline



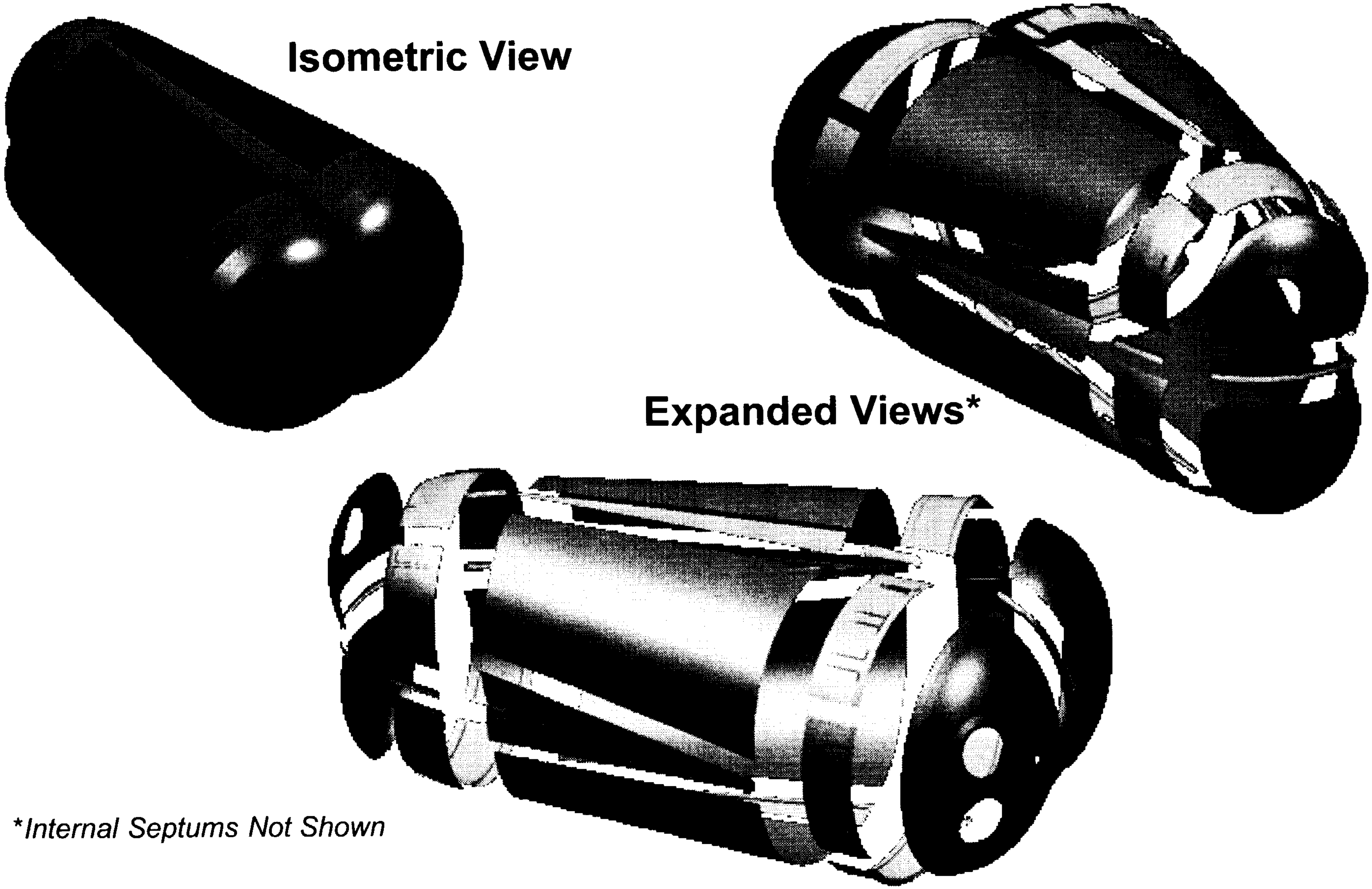
"ST Day 2000: Reducing Risk for the Next Generations" - X33 Update

Program Overview



"ST Day 2000: Reducing Risk for the Next Generations" - X33 Update

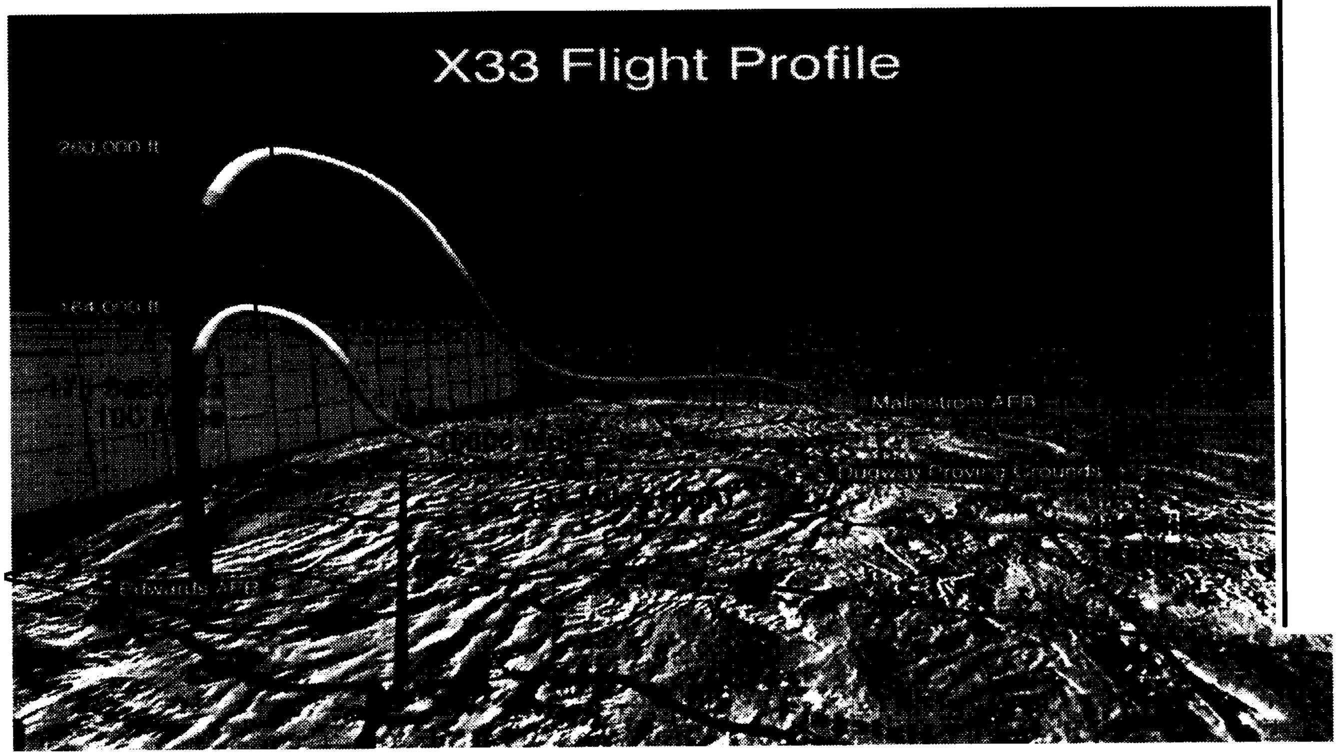
X-33 Elements

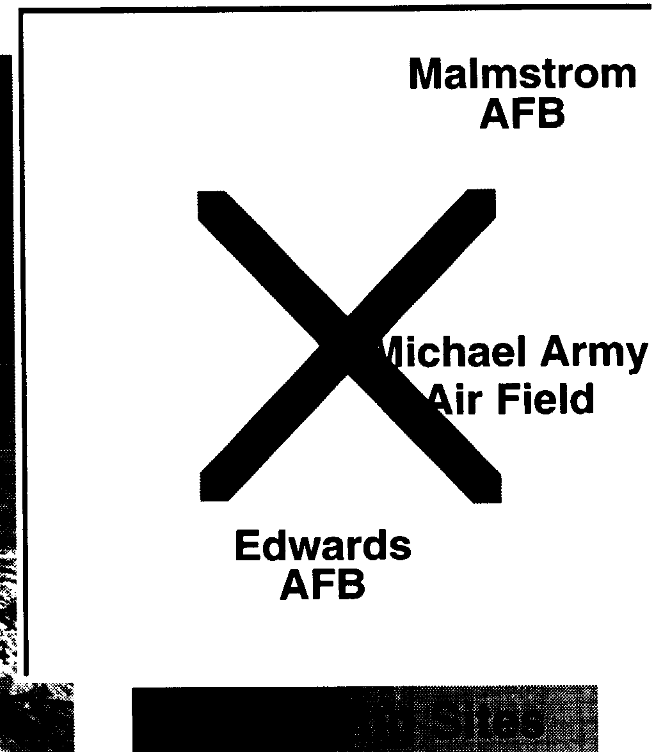


*Internal Septums Not Shown

Al LH_2 Tank Design

Aircraft-like Operations: Two Seven-Day Turnarounds
and One Two-Day Turnaround During Flight Test Series





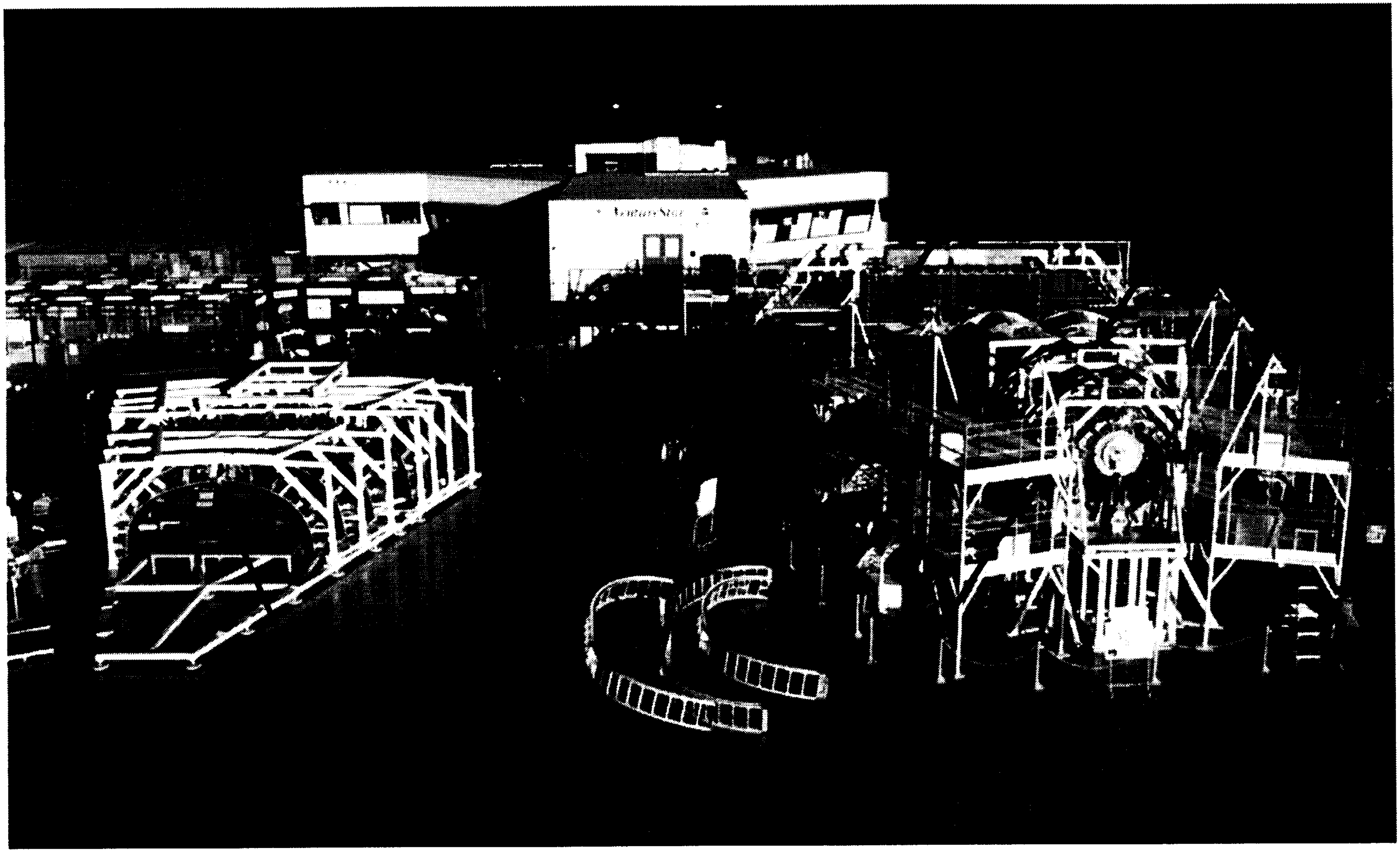
Flight 1	**Benign Thermal and Structural Loads**
Flight 2	**Intermediate**
Flight 3	**Real Gas Effects**
Flight 4	**Transition From Laminar to Turbulent Flow**
Flight 5	**Max Speed**
Flight 6	**Additional Increment of Real Gas Effects**
Flight 7	**Same Additional Increment**
Flights 8-15	**Margin to Repeat Specific Flight Profiles, Data Points**

"ST Day 2000: Reducing Risk for the Next Generations" - X33 Update

Expanding The X-33 Envelope

- **Demonstrate Aircraft-like Reusability, Maintenance and Scheduling**
  - Flying One (1) Two-day Turnaround Flight.
  - Flying Two (2) Consecutive Seven-day Turnaround Flights.
- **Robust Metallic TPS System**
  - Achieve Thermal Protection System Multi-use Operating Limits.
  - Panel Seal Designs
  - Attachment System/Replaceability
- **Composite Liquid Hydrogen Tank Mfg Processes/Assembly Techniques**
- **Linear Aerospike Engine**
  - Performance
  - Plume/Vehicle Flowfield Interaction
- **Vehicle Health Monitoring System**
  - Fiber Optic Strain & Temperature Sensors
  - Fiber Optic Hydrogen Leak Detection Sensors
- **Aerothermal Environment Prediction Verification**
  - Measure Surface Catalysis Caused by Atomic Oxygen
  - Measure Boundary Layer Transition

Technologies Demonstrated

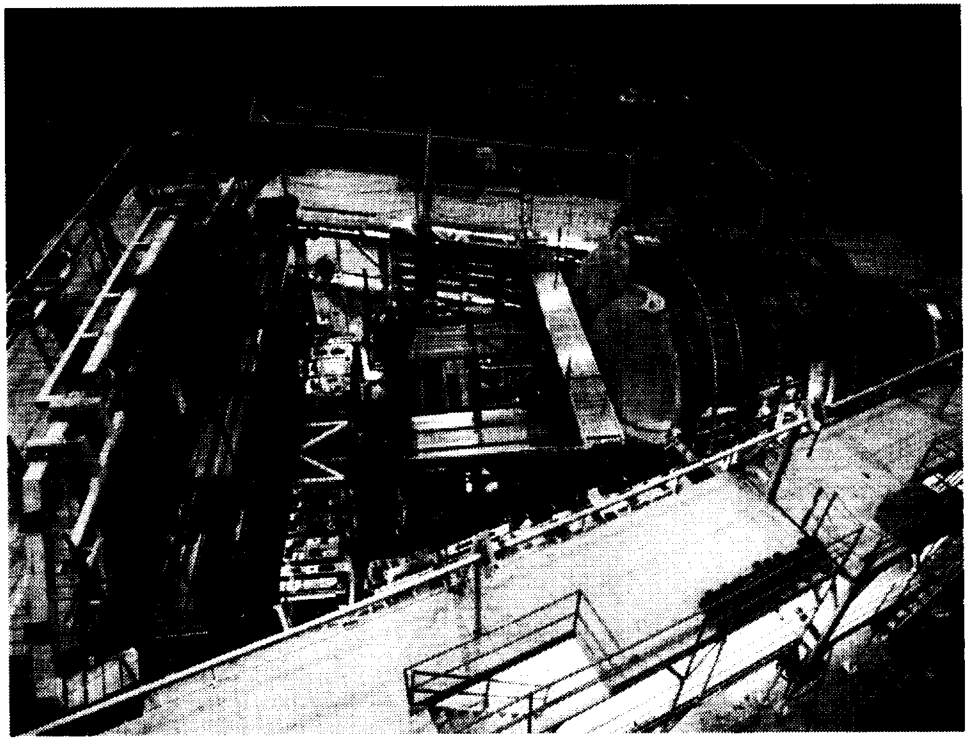


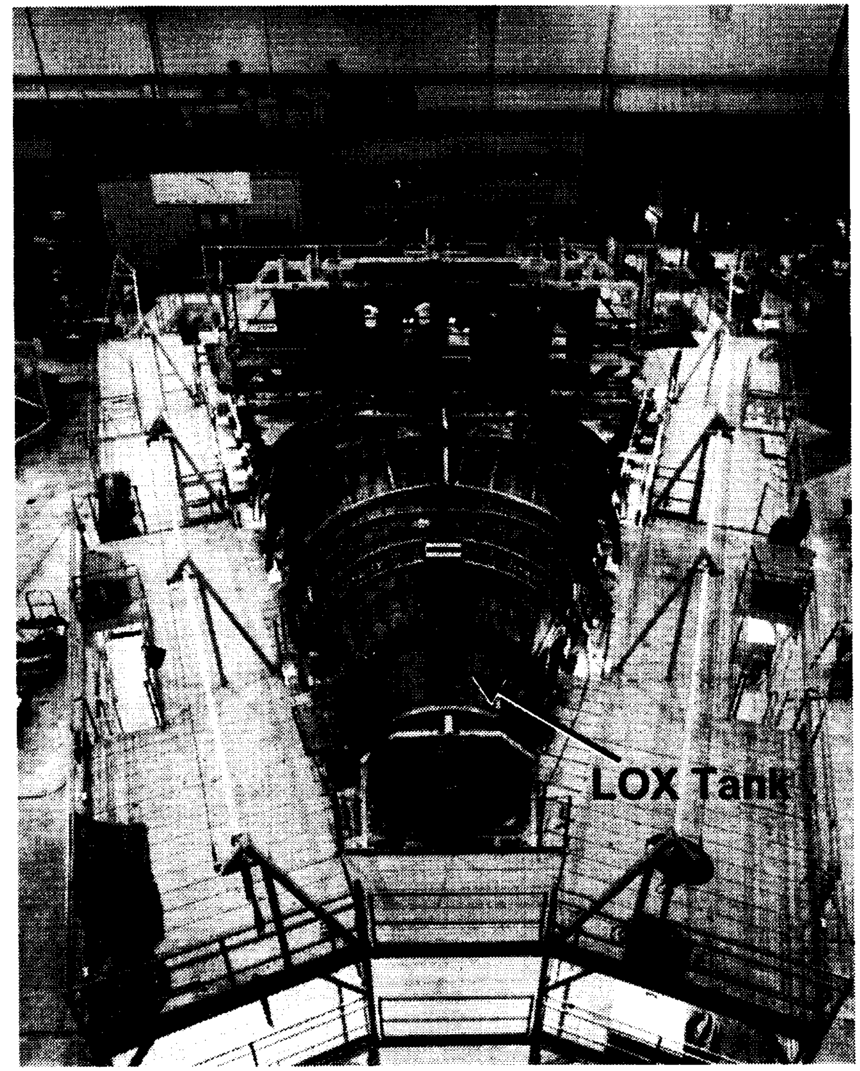
Overall Assembly 75% Complete

"ST Day 2000: Reducing Risk for the Next Generations" - X33 Update

Vehicle Assembly in Palmdale

Overall Assembly 75% Complete



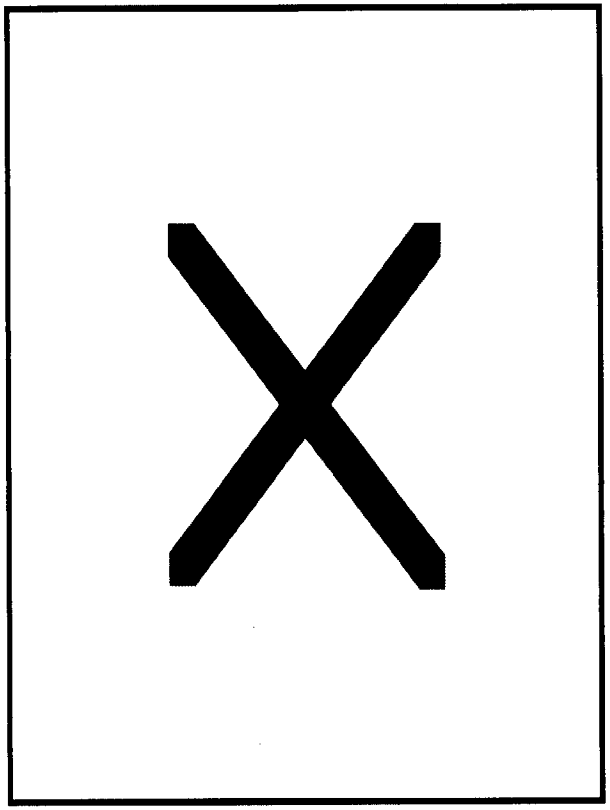


Websites On X-33: **www.x33.msfc.nasa.gov**
www.venturestar.com

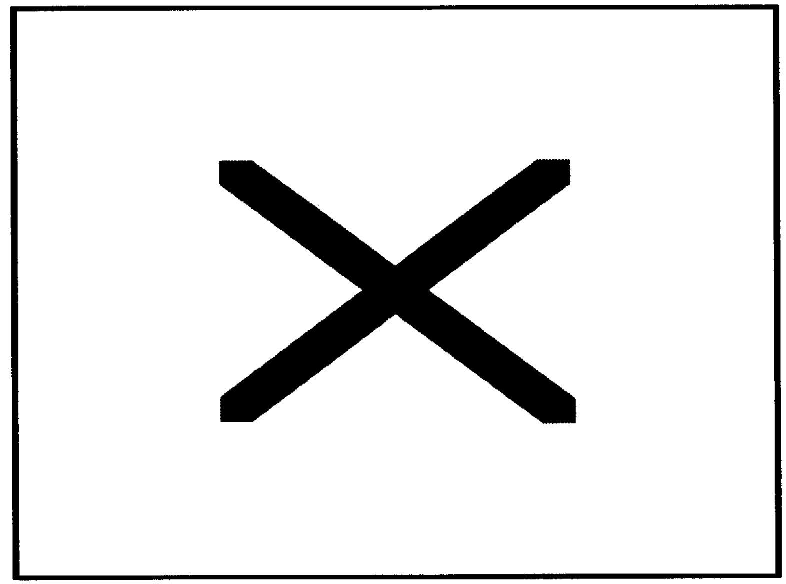
X-33 Assembly Floor

Crews Wiring X-33's Avionics Bay Within Primary Assembly Structure

X-33 Assembly Floor



View Looking Aft

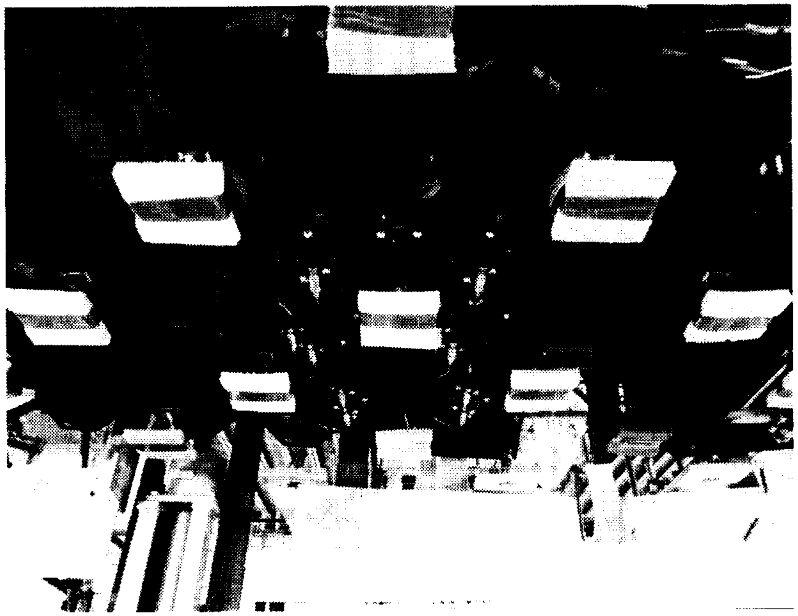


View Left to Right

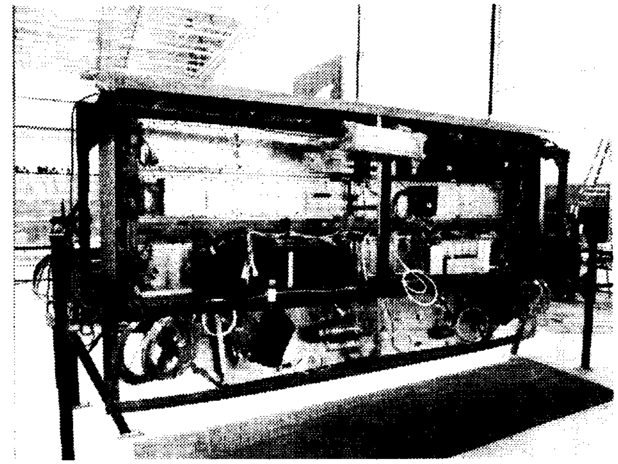
Modified F-15E Strut / F-16 Tire/Wheel

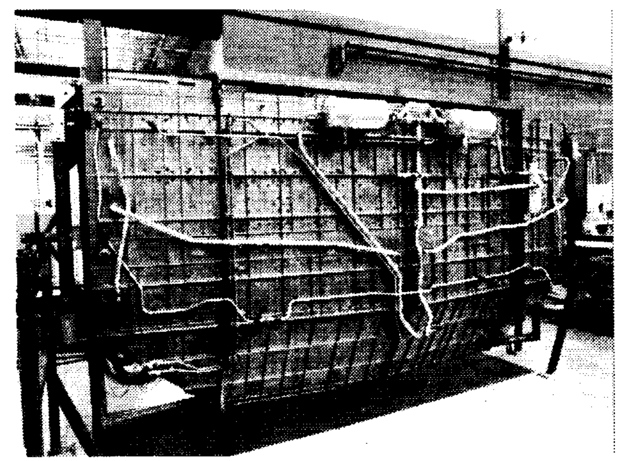
"ST Day 2000: Reducing Risk for the Next Generations" - X33 Update

Nose Landing Gear



RCS Auxiliary Propellant Tank and Control Valve Pallets

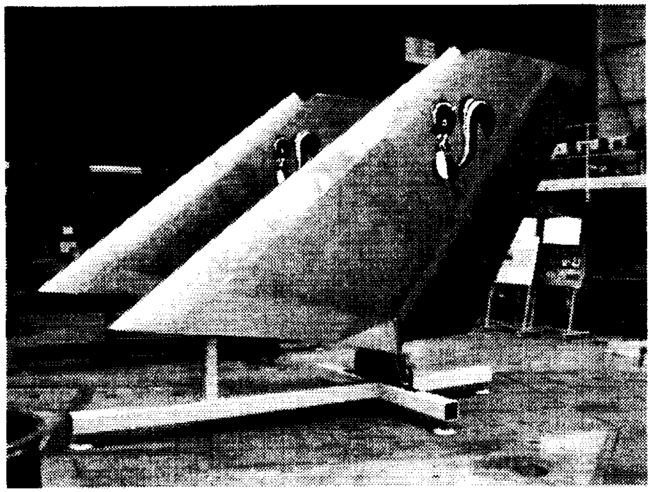




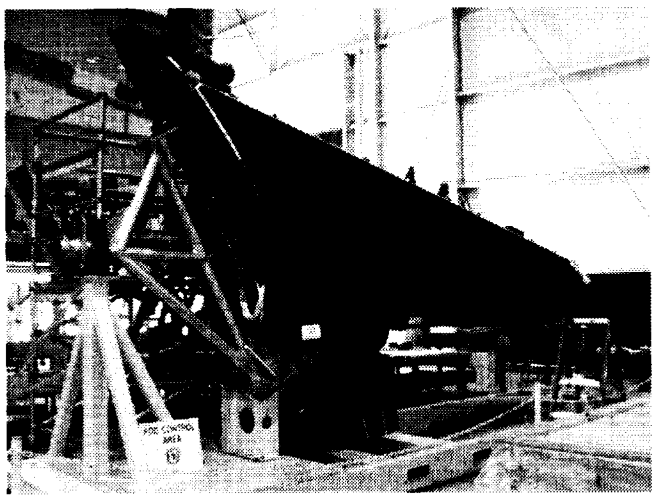
Avionics Bay

"ST Day 2000: Reducing Risk for the Next Generations" - X33 Update

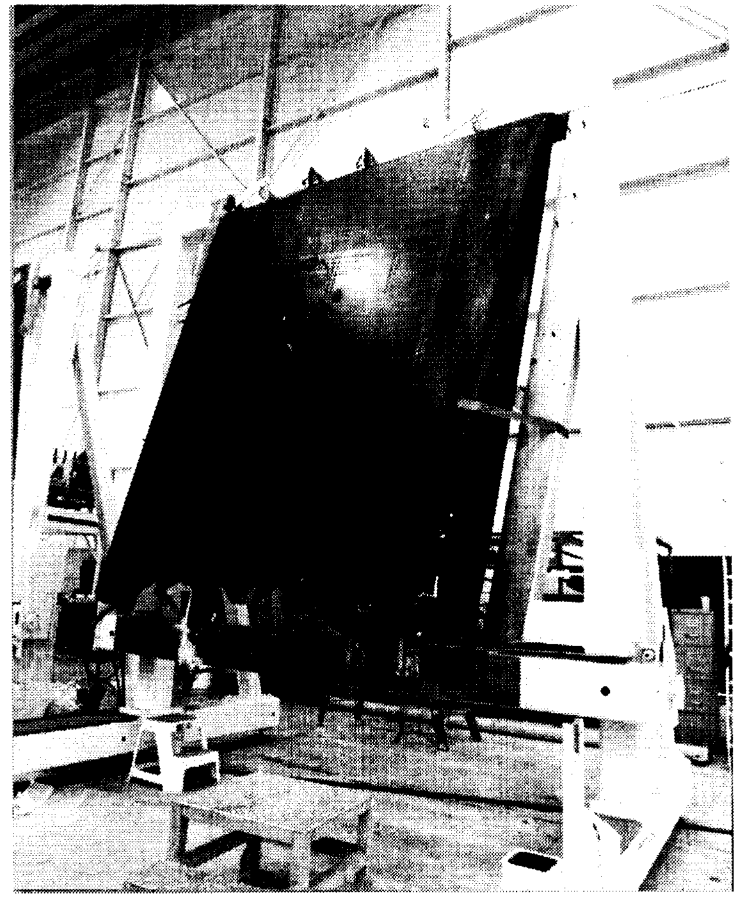
Systems Installations



Tails



Canted Fins



Body Flaps

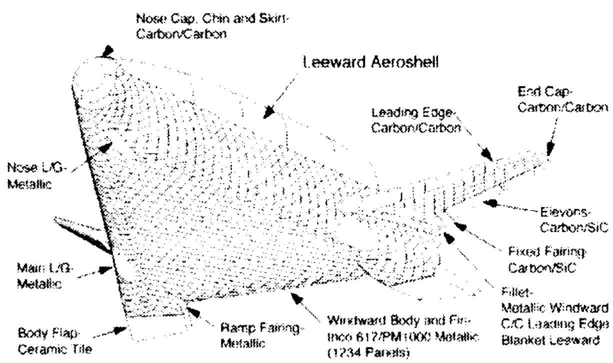
"ST Day 2000: Reducing Risk for the Next Generations" - X33 Update

Canted Fins and Tails

Upper Surface TPS
AFRSI/FRSI Blankets

Metallic TPS Fit Test

Metallic TPS Panel Layout



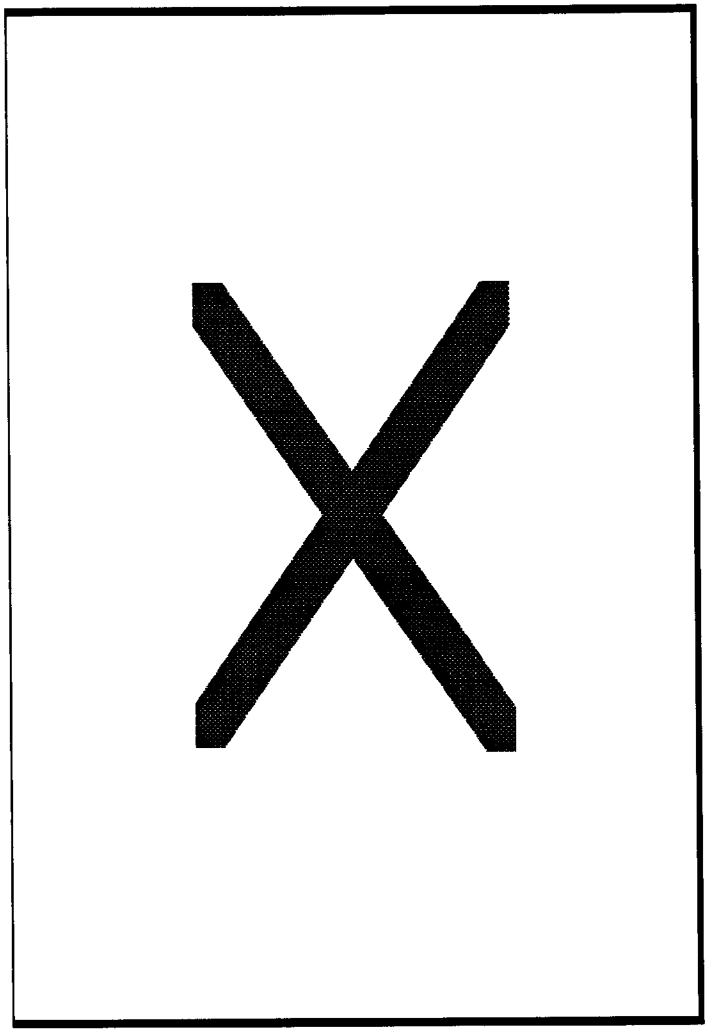
"ST Day 2000: Reducing Risk for the Next Generations" - X33 Update

Thermal Protection System

- Test Conducted on Structural Test Article (STA) - Identical to X-33 Flight Tank
- Successfully Completed LO_2 Flight Tank Structural Verification
- STA Tank currently at Glenn Research Center for Propellant Densification Tests

"ST Day 2000: Reducing Risk for the Next Generations" - *X33 Update*

LO_2 Tank Testing at MSFC



- **Technology**
  - **Graphite/epoxy Composite Material**
  - **Primary Load Structure**
  - **Complex Lifting Body Geometry**
  - **Unique Stand-off Structure Thermal Shield Internally Cooled**

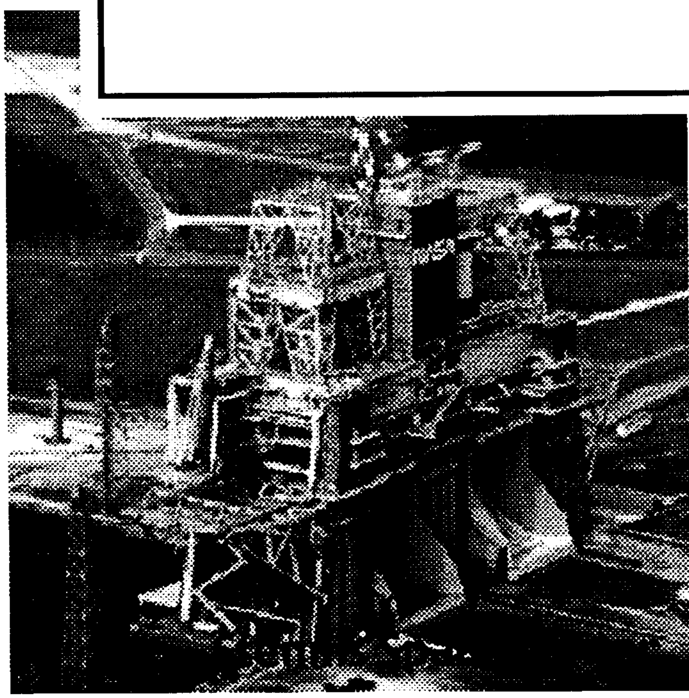
- **Status**
  - **First Test Tank Suffered Lobe Skin Delamination Following Simulated Launch Loads With Full Load of LH_2**
  - **Subscale Testing Was Successful**
  - **Joint NASA/Lockheed Martin Team Conducted Complete Failure Investigation**
  - **Further Development Required for Large Scale Cryogenic Tanks Serving As Primary Structure**

"ST Day 2000: Reducing Risk for the Next Generations" - X33 Update

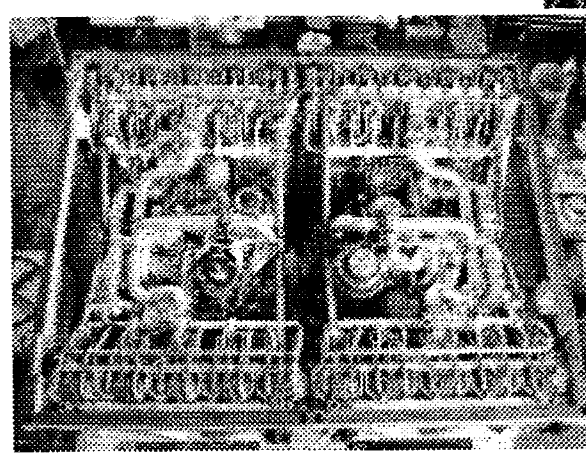
LH2 Composite Tank Test at MSFC

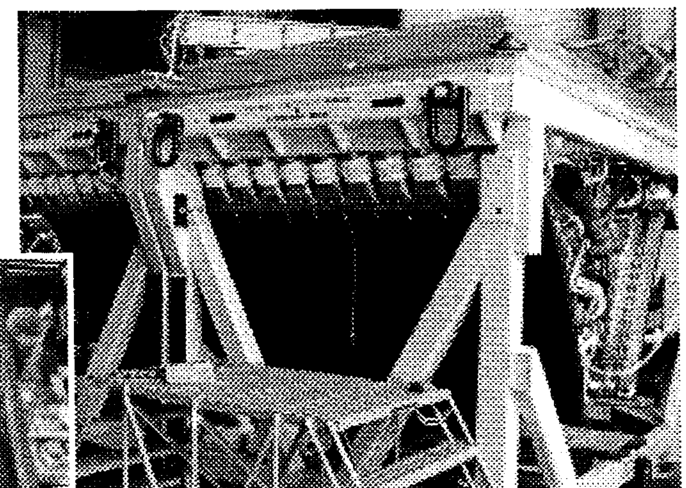
Single Engine

~~Replace with Quick Time Movie~~



- Unprecedented Success With Extensive Test Program
  - Single Thruster: 13 Tests, 985 Seconds
  - Multi Cell: 10 Tests, 49 Seconds
  - Powerpack: 17 Tests, 1506 Seconds
  - Single Engine: 14 Tests, 1563 Seconds
- No Test Cutoffs Due to Hardware Malfunction
- Achieved Full Power Level on 6th Test
- Dual Engine Testing to Begin in October(Flt. Engines)



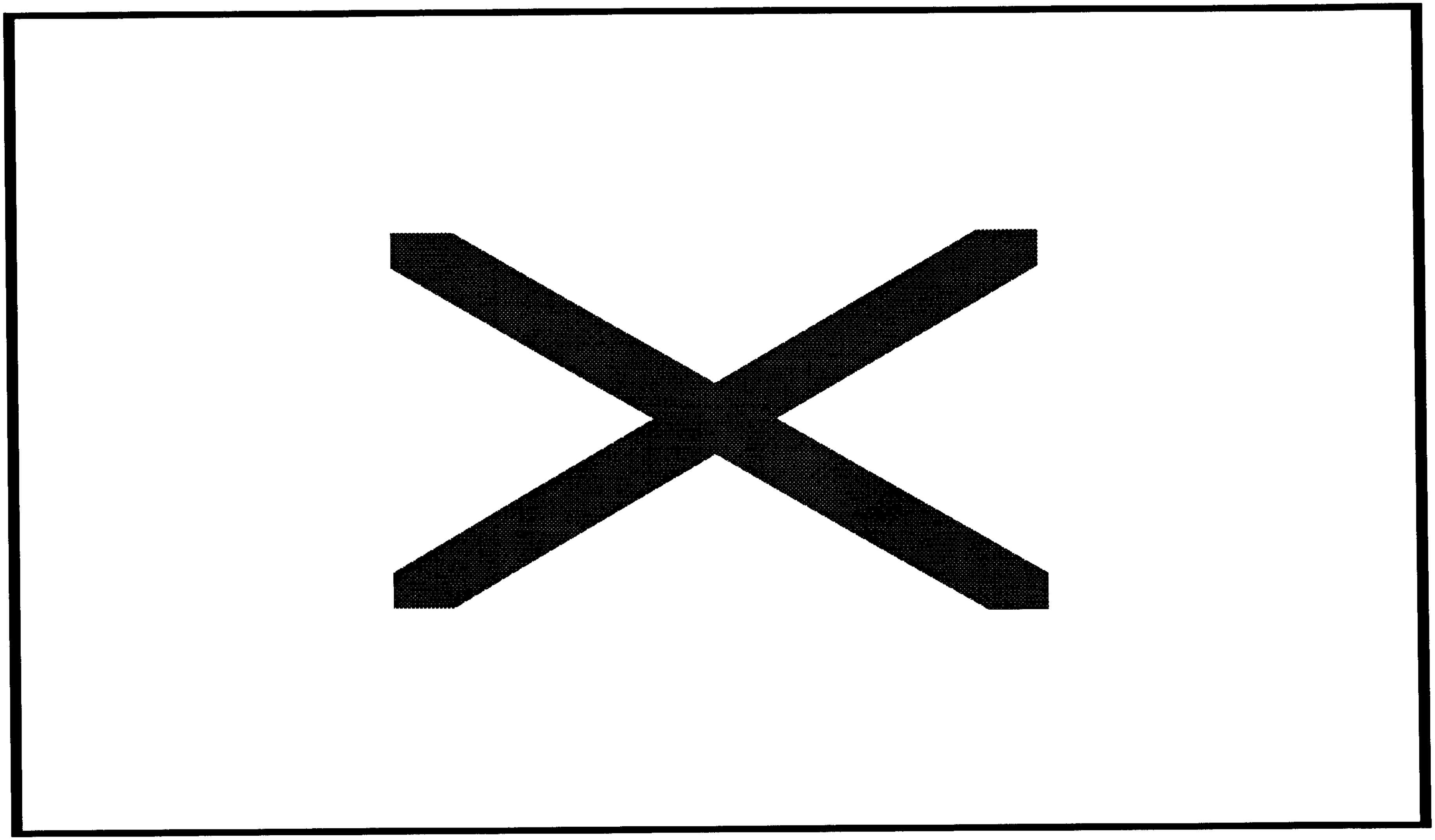


Dual Engine Assembly

"ST Day 2000: Reducing Risk for the Next Generations" - X33 Update

Aerospike Engine, XRS-2200

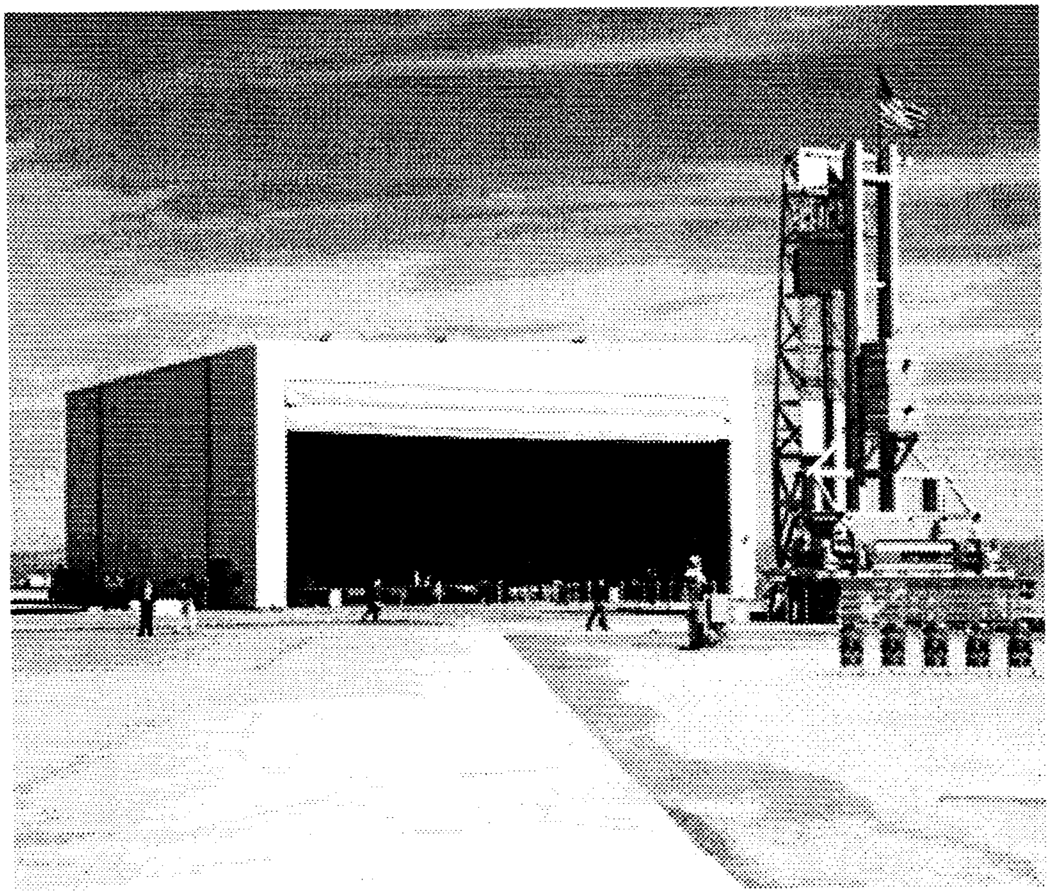
Completed 25 - Acre, $32 Million X-33 Flight Operations Center on Edwards Air Force Base, Calif.



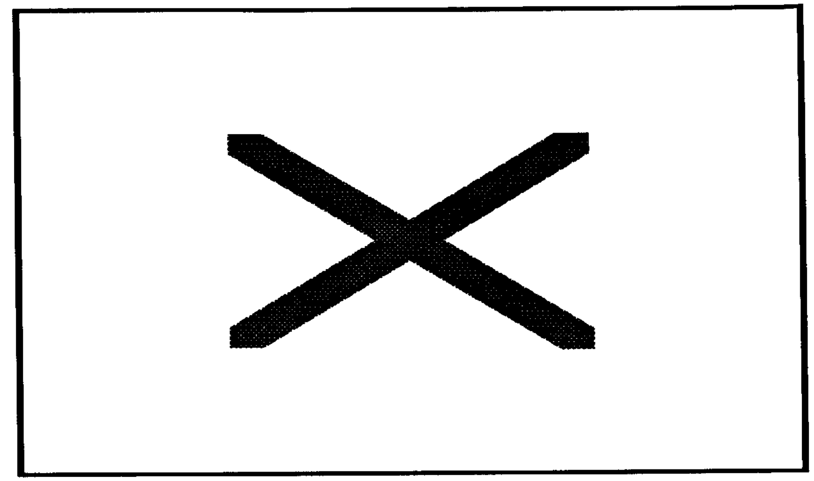
"ST Day 2000: Reducing Risk for the Next Generations" - X33 Update

Flight Operations Center

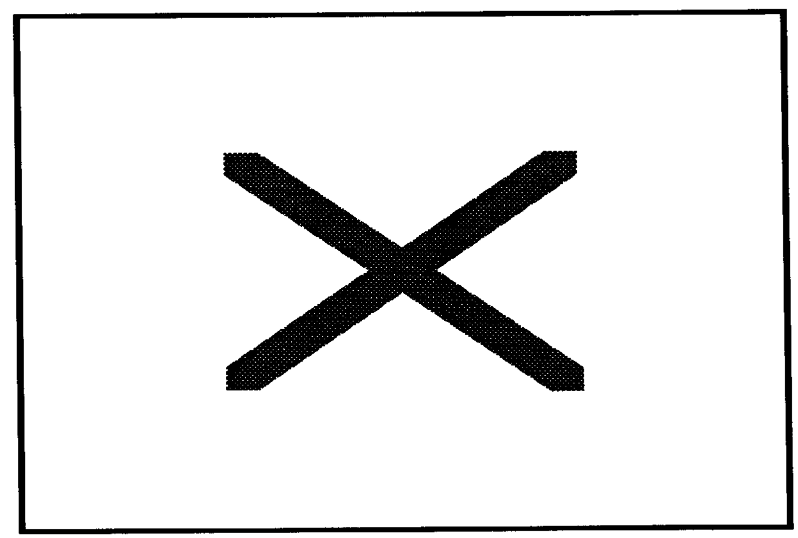
Flight Operations Center



Translating Shelter and Strong Back with Weight Simulator



Eight-Person Control Room



Strong Back with Weight Simulator

"ST Day 2000: Reducing Risk for the Next Generations" - X33 Update