Space Transportation Directorate

Technology Activities in the Aerodynamics & Hydrodynamics of Propulsion Elements at MSFC (NASA)

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Overview

- **MSFC Space Transportation Goals**
- **Fluid Dynamic Technologies under development**
  - Hardware
  - Design process
  - (Benchmark)
- **Future plans and expected trends**
- **Concluding remarks**

MSFC Space Transportation Goals

- **Integrated Space Transportation Plan role out 10/99**
  - Presented to industry at Space Transportation Day
- **Focus on Safety, Reliability, Cost, & NASA mission requirements**
- **Second generation RLV (IOC 2009-2010)**
  - Safety reliability goals:
    - Loss of crew 1/10,000, loss of vehicle 1/1,000 mission
  - Cost Goals to reduce recurring operational cost to NASA to $1,000/pound of payload
- **Additional goals defined for 3rd generation RLV (IO2 ~2025)**

MSFC Space Transportation Goals

- **Second generation goals require operable, long-life H2O2 and RP/O2 Engines**
  - SSTO further requires increased T/W " 80 - 85 for H2O2 Systems
  - Conventional rocket engine cycles
  - Rocket based, combined cycles IOC likely > 2009
- **Shuttle derived on New Design RLV will be considerable**
  - "down select" by 2005
- **Allocation's for meeting goals not yet provided to propulsion system and components**

MSFC Space Transportation Goals

- **Demonstration of technologies in ground test and/or flight tests key to technology development and maturation demonstration**
  - Provide validated technologies for operational system integration
- **Reducing design & development (D&D) cost crucial to test demonstration philosophy**
  - Current D&D cost prohibitive for ST propulsion systems
- **Fluids design & analysis expertise at MSFC focused on Space Transportation**
  - Improving the design process through better tools
  - Developing advanced hardware concepts
  - In partnership with other NASA Centers, Industry, and Academia

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Fluid Dynamics Technologies Under Dev. At MSFC

Task Title	Focus Area
Altitude compensating nozzle tech	- Engine T/W improvements, design database
Aerospike plume induced base heating	- Design environments, tool validation
Inducer testing technology development	- Cavitating Inducer flow physics, validation data
Optimization methodology development	- Design process improvement
	- Design data for pumps
Turbopump Optimization	- Increased engine T/W, Isp
Improved Hydrocarbon Physics	- Design tool improvement
Engine Performance Methodology	- Design process improvement
Performance Modeling of laser lightcraft	- Design process improvement
RBCC flowpath analyses	- Increased engine thrust, greater Isp

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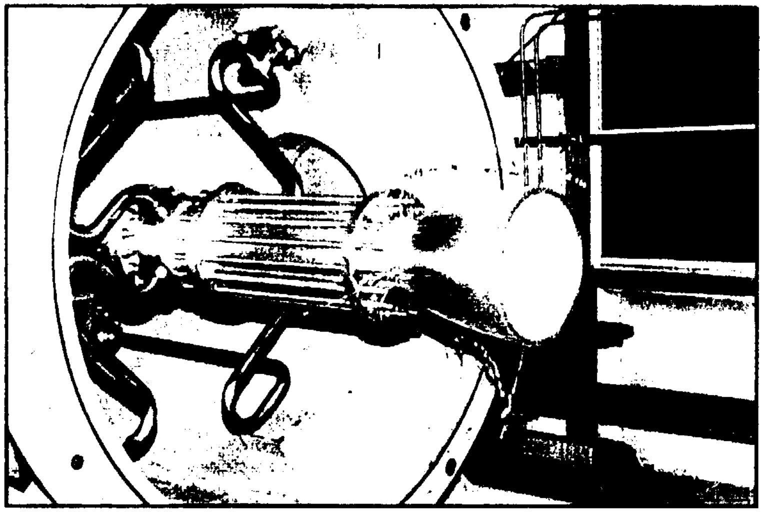
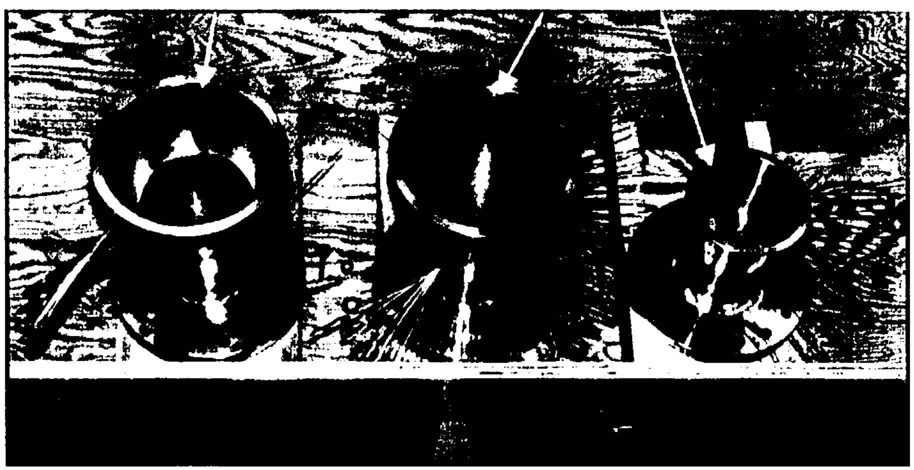
Altitude Compensating Nozzle Technology

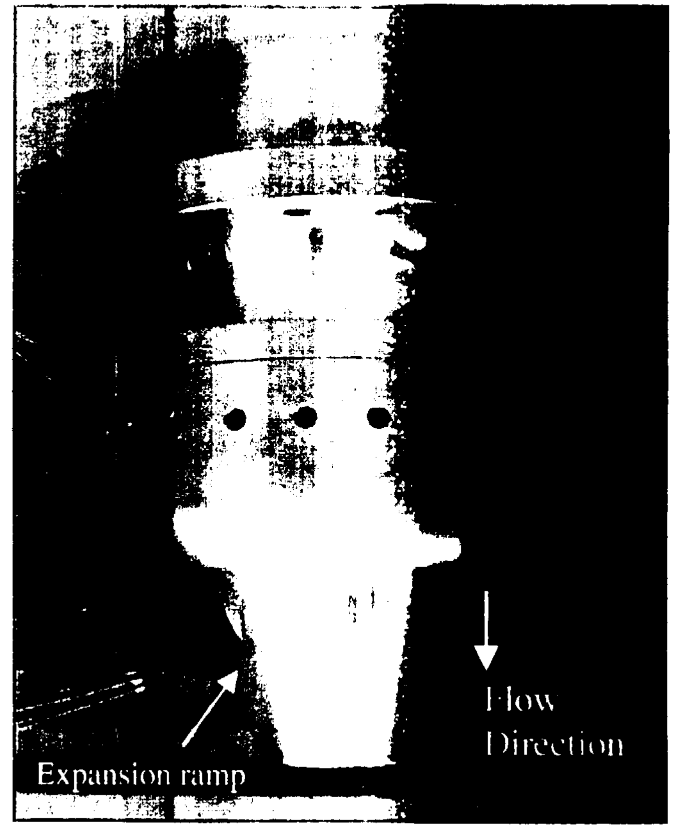
- **Technology Need**
  - Need for greater T/W engine designs, increased mission average Isp
- **Approach**
  - Perform CFD analysis of various ACN concepts designed to a common operational point
  - Verify predicted performance through airflow testing (MSFC)
- **Partner**
  - Aerojet
- **Status**
  - Designs completed & models built by Aerojet under Cooperative Agreement
  - MSFC/Aerojet jointly completed initial CFD runs
  - Funding obtained for cold flow tests; facility calibration underway
- **Estimated Completion**
  - Testing scheduled during January/February of 2000

Altitude Compensating Nozzle Technology



Reference nozzle in the MSFC Nozzle Test Facility



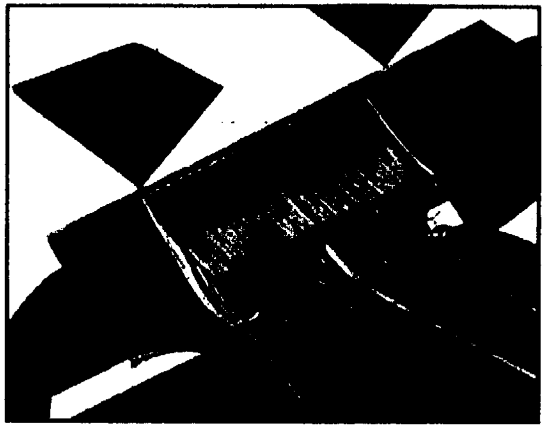


Axisymmetric plug nozzle

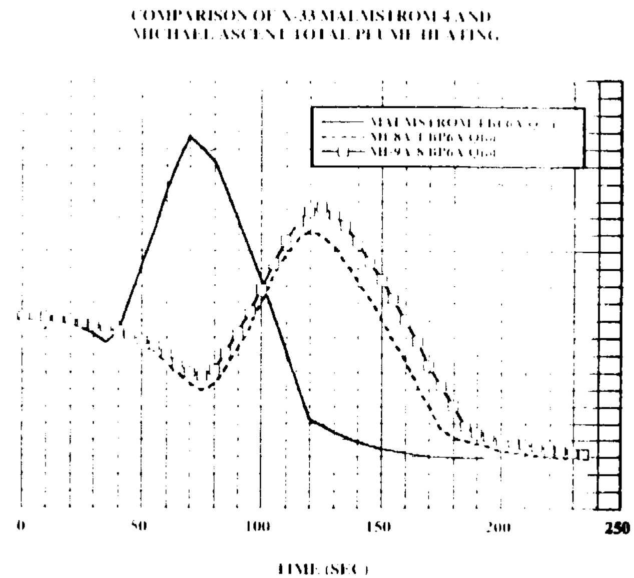
Aerospike Plume Induced Base Heating Environment

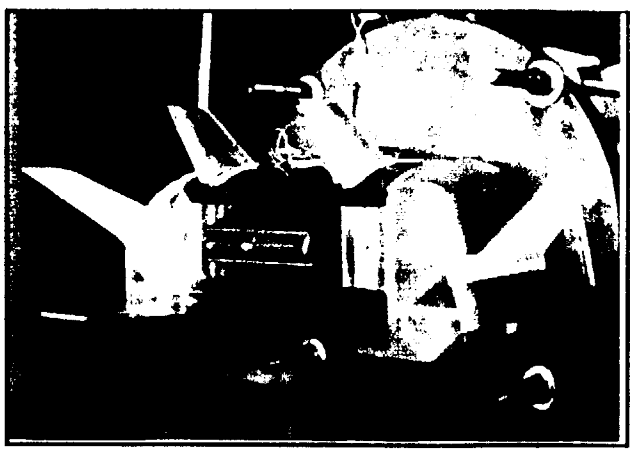
- **Technology Need**
  - Plume-induced, base environment prediction tools anchored to conventional nozzles (bell or conical)
  - Conventional methods for obtaining base heating data too expensive
- **Approach**
  - Computational tools enhanced/developed: FDNS and GRASP
  - Qualis rig development
  - Update base heating engineering code
- **Partners**
  - ESI and Qualis Inc.
- **Status**
  - CFD data used to anchor design tool (altitude, base-bleed, fences)
  - Design tool applied to X-33 and VentureStar designs
  - Qualis rig tested at MSFC, CFD predictions validated
- **Work Completed**

Aerospike Plume Induced Base Heating Environment

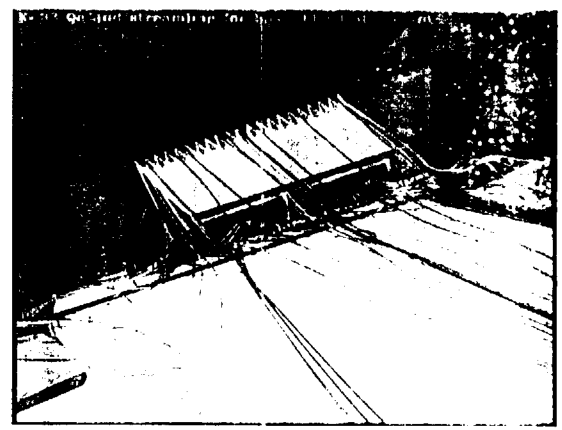


Sea level, no bleed





Short Duration hot-fire of base flows

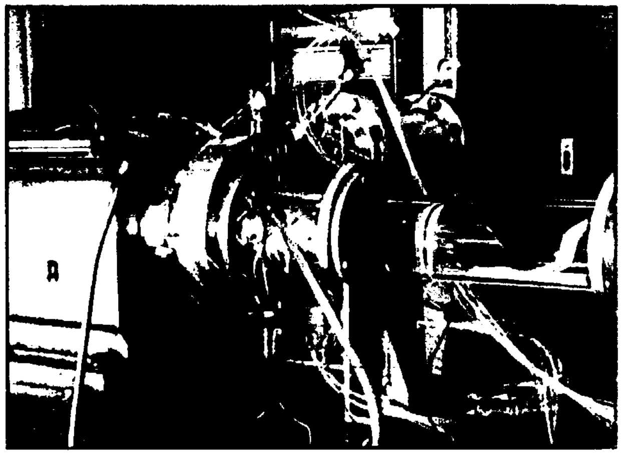


At an altitude of 3.7km w/ base bleed

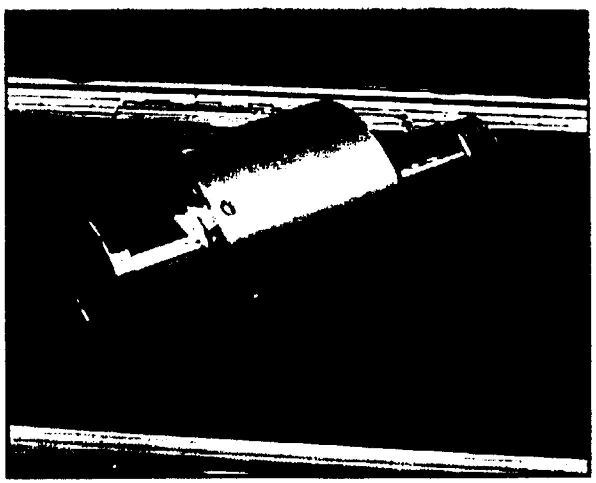
Inducer Testing Technology

- **Technology Need**
  - Cavitating inducers dynamics not well understood
  - Empirical data necessary to improve design and analysis tools
- **Approach**
  - Develop a simple, low cost means to perform flow visualization & to measure shaft loadings for cavitating inducers
  - Test various inducer designs, expand the database, develop models
- **Partners:** none
- **Status**
  - Axial inlet rig with large flow visualization windows manufacture
    - Initial tests will use the Simplex inducer
  - Rotating balance design, manufactured, and integrated into inducer test rig
    - Initial test will use well characterized P&W ATD inducer
- **Estimated Completion**
  - Flow vis. capability demo. 1/2000, Rotating balance demo. 3/2000

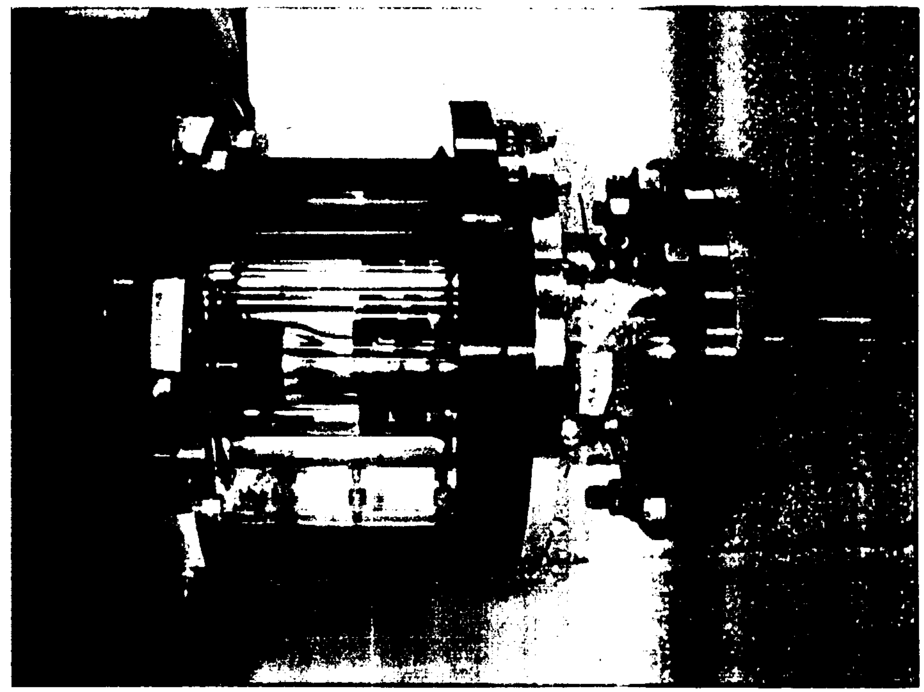
Inducer Testing Technology



Inducer test loop
Fastrac configuration



Rotating balance assembly



Axial inlet inducer test rig with Simplex inducer

Methodology for Optimizing Design of Injector

- **Technology Need**
  - Design tool that allows consideration of large design variables early in the design process
    - Provide designer with efficient, objective means for assessing design variables

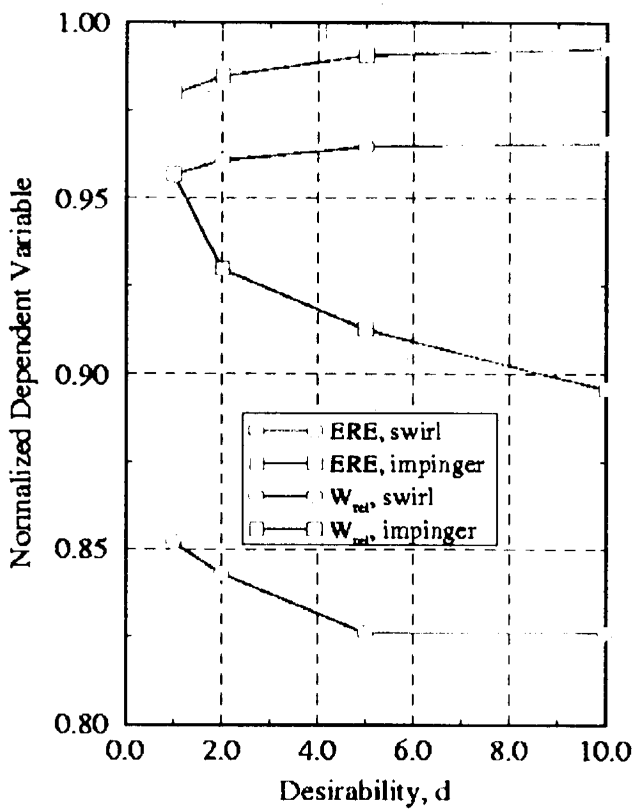
- **Approach**
  - Develop an optimization technique / process that can
    - Use empirical correlations, experimental data, or CFD results
    - Generate response surface or neural network
    - Accurately locates optimum design points subject to designer constraint
  - Use whatever elements already available and build on them
  - Select GH2/GO2 injector for methodology development and demonstration
    - Empirical models, and test data available, CFD capability available

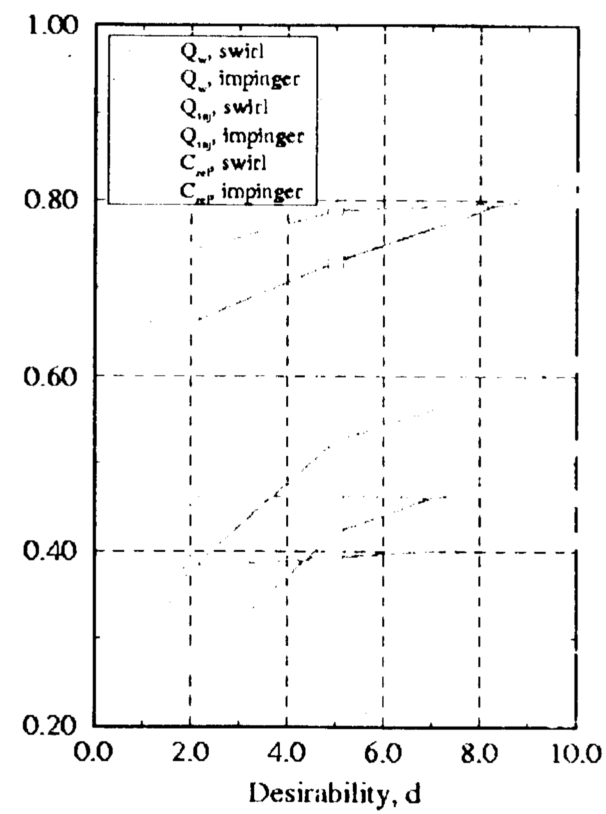
Methodology for Optimizing Design of Injector

- **Partner**
  - University of Florida
- **Status**
  - Methodology developed and demonstrated for single elements
    - Uses JMP software and Excel
    - Demonstrated for shear coaxial, impinging, and swirl injector elements
    - Response Surface & Neural Networks Capability demonstrated
  - Methodology being applied in turbopump optimization test
- **Estimated Completion**
  - Demonstration on RLV aerospike engine aerodynamic flowpath optimization by May, 2000

Methodology for Optimizing Design of Injector

Thrust to Weight Trends for Swirl and Impinging Elements





Turbopump Optimization

- **Technology Need**
  - SSTO RLV requires high T/W (80-85) and high Isp (445 - 450)
  - Increased hydrodynamic and aerodynamic performance turbopumps and/or higher strength materials required to meet req. engine performance
- **Approach**
  - Select the Rkdn. RS-2200 engine design point
  - Develop unshrouded impeller technology
    - Reduce turbopump weight by 50%
  - Develop an optimized turbine design
    - Increase turbine efficiency by 8 points over the baseline
    - Increase payload or allow use of available metals in turbine design
  - Use team approach to design, analyze, and test the resulting component designs
  - Generate an RLV turbopump conceptual layout that incorporates resulting pump and turbine designs

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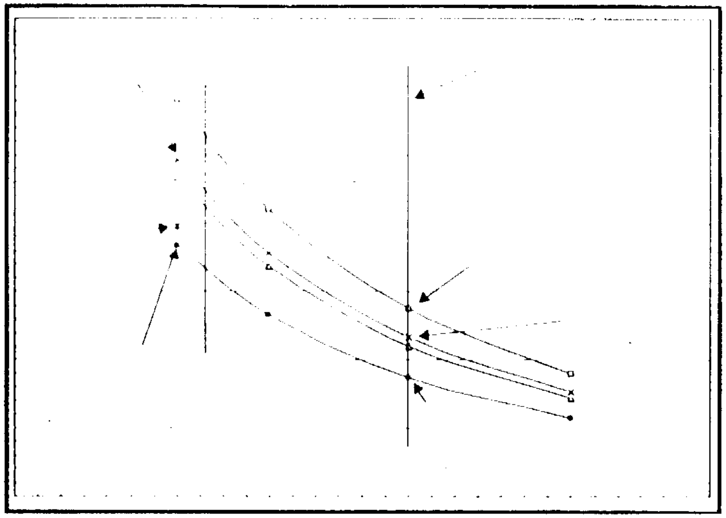
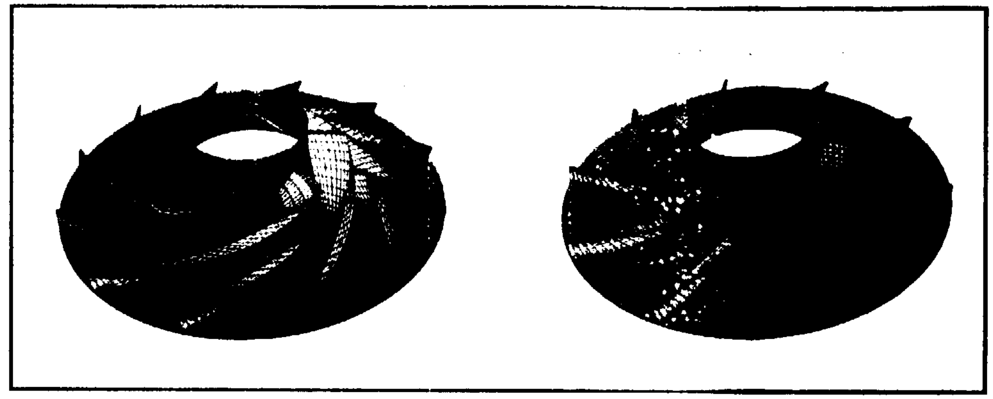
Turbopump Optimization (continued)

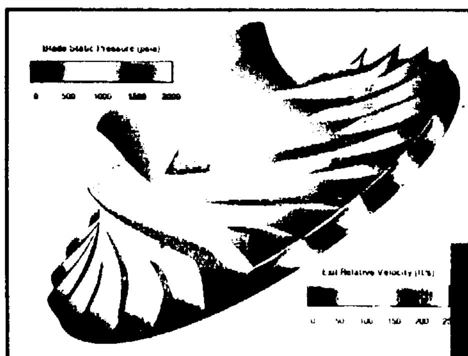
- **Partners**
  - MSFC: task management, flow path design, lead for CFD, optimization parametrics, testing
  - Rkdn: lead for design, system analysis, CFD, structural analysis, conceptual layout
  - VPI: CFD code improvements, CFD demonstrations
  - U.F.: development of optimization techniques
  - Riverbend Design Services: adv. turbine design method, consultation
- **Status**
  - Unshrouded impeller baseline rig designed, built, and installed in facility
    - Incorporates impeller design targeted at a tw0 stage SSME HPFTP
    - Rig to provide validation data for performance sensitivity to tip gap clearance
  - Initial impeller design for 2-stage RLV turbopump selected
    - Potential payload increase of 700 lb/turbopump for the baseline RLV
    - Final selection pending baseline rig test results and completion of parametrics

Turbopump Optimization (continued)

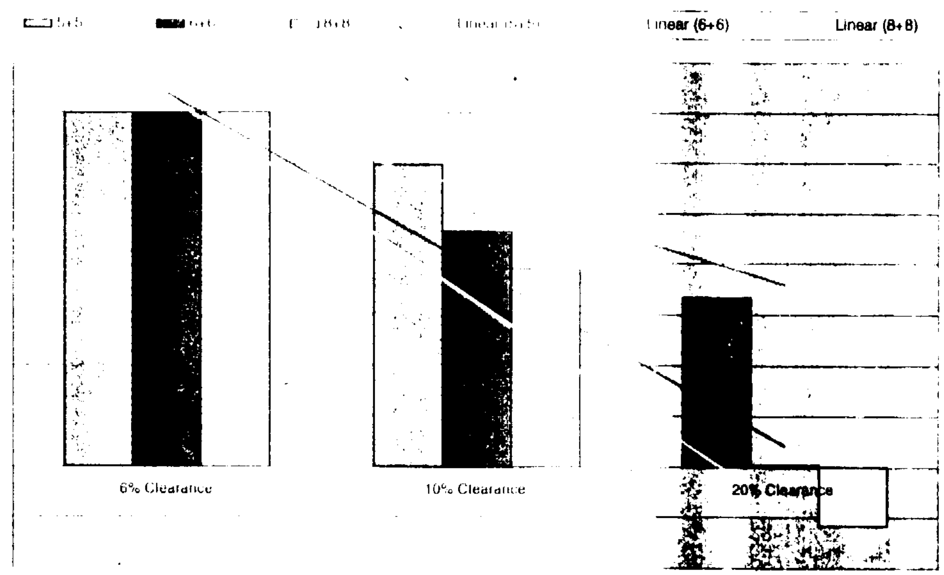




RLV design point
impeller parametrics



SSME HPFTP
design point impeller
CFD and test sample



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Turbopump Optimization (continued)

- **Status (continued)**
  - Turbine layout optimization underway
    - Optimization completed for 1, 2, and 3 axial-stage designs
      - **Radial and counter-rotating turbine concepts also considered**
    - Approximately 10-point efficiency gain through stage optimization
      - **Selected design is of a 2 stage, supersonic configuration**
      - **3D flow path optimization to follow**
  - Potential gain in payload of 590 lb per turbopump for the baseline **RLV**
  - CFD evaluation tip clearance and of various nozzle configurations underway
- **Estimated Completion**
  - Initial impeller water tests in 1/2000, final design tests in 10/2000
  - Final turbine design airflow tests completed by 2/2001

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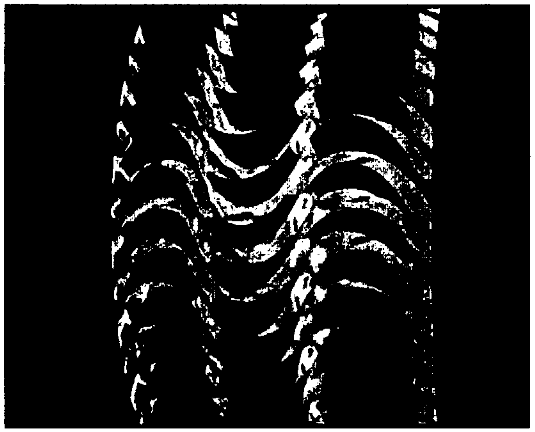
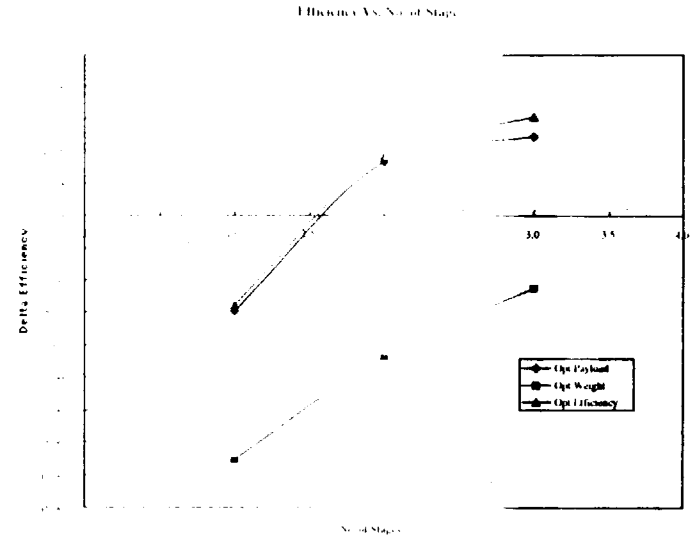
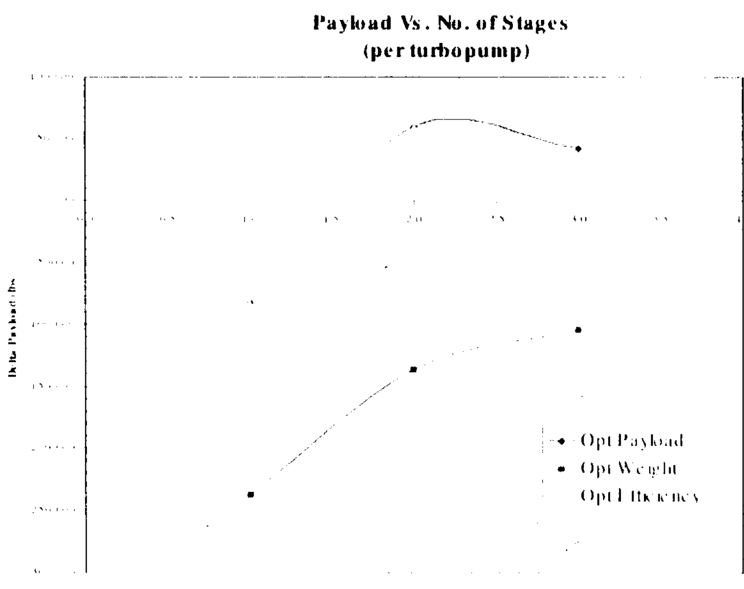
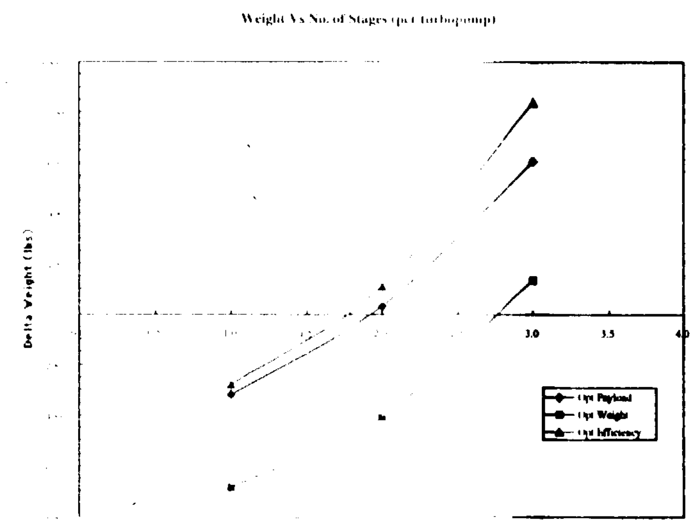
Turbopump Optimization (continued)



Turbine analysis with rectangular first stage nozzle







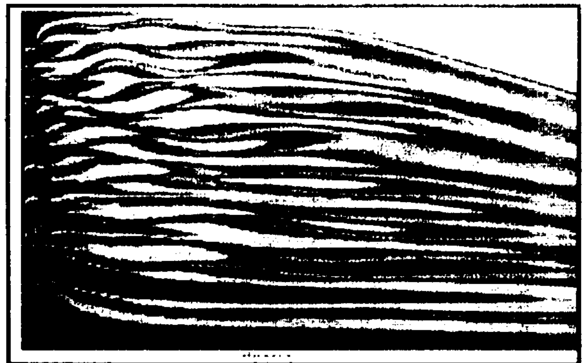
Engine Performance Methodology Improvement

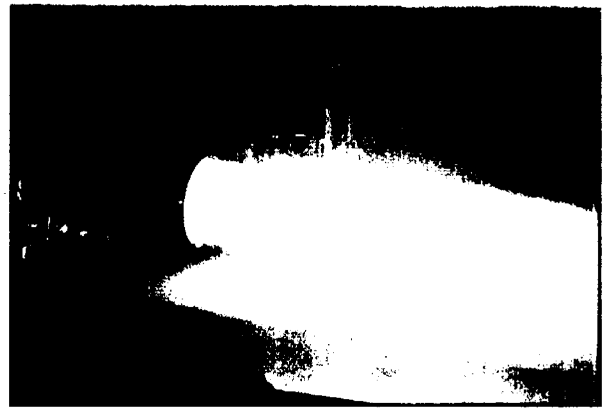
- **Technology Need**
  - Standard engine performance methods (TDK) do not account for injector performance directly
    - Required for accurate C*, thrush, and plume constituent definition

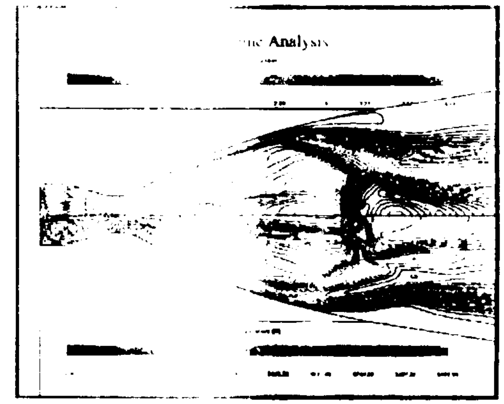
- **Approach**
  - Focus on RP / Kerosene fueled engines
  - Develop finite-rate kinetics (including soot formation) for RP combustion
  - Perform CFD analyses of axisymmetric chemically reactive flow
    - Simulate liquid-liquid injection with pseudo-gases
    - Vary impingement angle to match chamber pressure

Engine Performance Methodology Improvement (continued)

- **Partners:** None
- **Status:**
  - Methodology demonstrated on Fastrac engine
    - Performed parametric analyses to assess impact of modeling assumptions
    - Compared kinetics model to PSU uni-element test
    - Compared plume soot levels and nozzle separation point
- **Initial activity completed**
- **Extension planed for CY 2000:**
  - Extend method to multiple elements (demonstrate)
  - Improve fidelity of liquid injection model
  - Ultimate goal is to model complete droplet formation, vaporization, and combustion

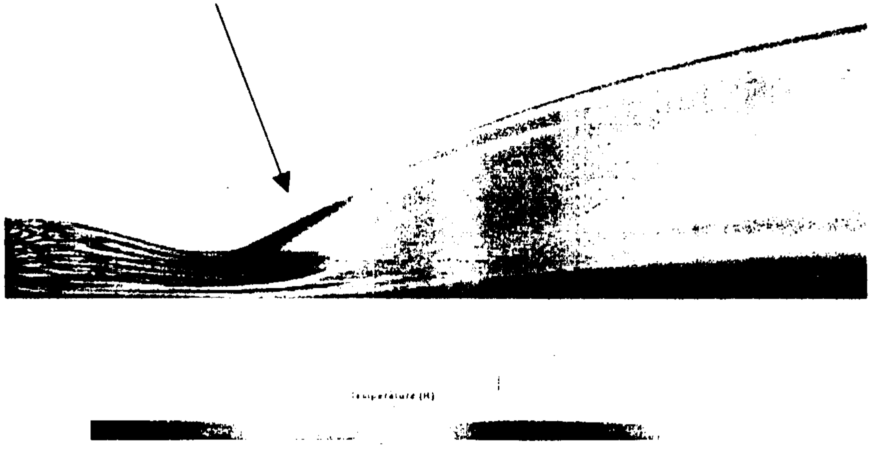




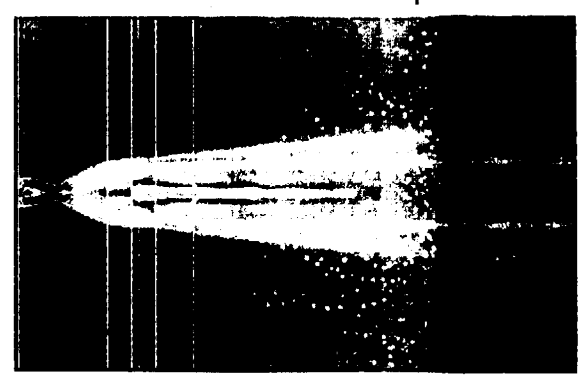


Fastrac TCA performance prediction with 30:1 nozzle

2D Injector pattern affects
on engine performance



Updated kinetics model benchmarked
PSU data and Fastrac plume



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Expected Trends & Future Plans

- **Expect continued need for high Pc engine systems**
  - Demand for higher T/W, (~100), ISP > 450
- **Materials development to begin to pay-off in next 2-4 years for stationary elements**
- **Elimination of boost pumps for weight reduction**
  - Requirement for higher suction specific speeds induced
  - Invest in Inducer design technology
- **Greater engine (and turbopump) throttling requirement (20% to 120%) for operability**
  - Invest in pump throttling technology, concept development
- **Compact, high area ratio engine designs for upper stages**
  - Invest in nozzle concepts development
  - Invest in injector / chamber concept development

Expected Trends & Future Plans (continued)

- **Greater Emphasis on Mission safety, flat NASA funding levels**
  - Increased pressure to reduce D & D cost
  - Increased value for accurate / higher fidelity design tools
- **Invest in design process improvement (fluids tools)**
  - Invest in automation of analysis (focus on pre- & post-processing)
  - Optimize tools for PC-cluster environment
  - Invest in integration of design tools across disciplines
  - Combustion physics models improvement
  - Invest in pump rotor-stator interaction analysis improvements
  - Invest in pump cavitation modeling advancements
- **Greater need for collaboration with other government groups**
  - Make maximum use of civil service "overhead"
  - Building on existing relationships
  - Initiating new relationships where none existed

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Concluding Remarks

- **NASA has developed an Integrated Space Transportation Plan**
  - 2nd, 3rd, and 4th generation goals defined
- **Fluid Dynamics groups at MSFC engaged in technology development**
  - Hardware concepts and design process improvements
  - Partnering with Industry, other Centers, and Academia
- **Second generation systems likely to emphasize same performance parameters as current systems**
  - T/W, Isp, development cost, operations cost
  - 3rd generation concepts may change relative importance of parameters
- **Development of design process tools key to meeting ISTP goals**
- **Greater coordination among government / industry sponsored activities will benefit all**