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Earth-To-Orbit Turbomachinery Subsystem

N93-71882

Presented to:
Integrated Technology Plan External Review Team
Tysons Corner, McLean, Virginia

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P. 22

Overview Earth-to-Orbit Propulsion Turbomachinery Subsystem

By:
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Computational Fluid Dynamics Branch
Structures and Dynamics Laboratory

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Earth-To-Orbit Turbomachinery Subsystem

Overview

- Objectives/Focus
- MSFC/LeRC Teaming
- Determination of Needs and Deliverable Products
- Turbomachinery Technology Components and Disciplines
  - Component Specific Technologies
  - Discipline Specific Technologies
- Turbomachinery Large Scale Validation
- Accomplishments
  - Turbine Stages
  - Complex Flow Paths
- Summary

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Objectives/Focus

- Develop the Technology Related to the Turbomachinery Systems of High Performance Rocket Engines
  - Advanced Design Methodologies and Concepts
  - Develop High Performance Turbomachinery Data Bases
  - Validated Turbomachinery Design Tools
- Specific Turbomachinery Subsystems and Disciplines
  - Turbine Stages
  - Pump Stages
  - Bearings
  - Seals
  - Structural Dynamics
  - Complex Flow Paths
  - Materials
  - Manufacturability, Producibility, Inspectability
  - Rotordynamics
  - Fatigue/Fracture/Life

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Earth-To-Orbit Turbomachinery Subsystem

MSFC/LeRC Teaming

Turbomachinery Thrust Co-Managers – L. Schutzenhofer/MSFC
J. Gauntner/LeRc

Working Groups	Co-Chairmen
Bearings	F. Dolan/MSFC J. Walker/LeRC
Structural Dynamics	L. Kiefling/MSFC C. Chamis/LeRC
Fluid and Gas Dynamics	H. Struck/MSFC R. Gaugler/LeRC
Materials	S. Gentry/MSFC R. Dreshfield/LeRC
Manufacturing/Producibility/Inspection	J. Clark/MSFC T. Herbell/LeRC
Turbomachinery	L. Schutzenhofer/MSFC J. Gauntner/LeRC
Fatigue/Fracture/Life	G. Faile/MSFC M. McGraw/LeRC

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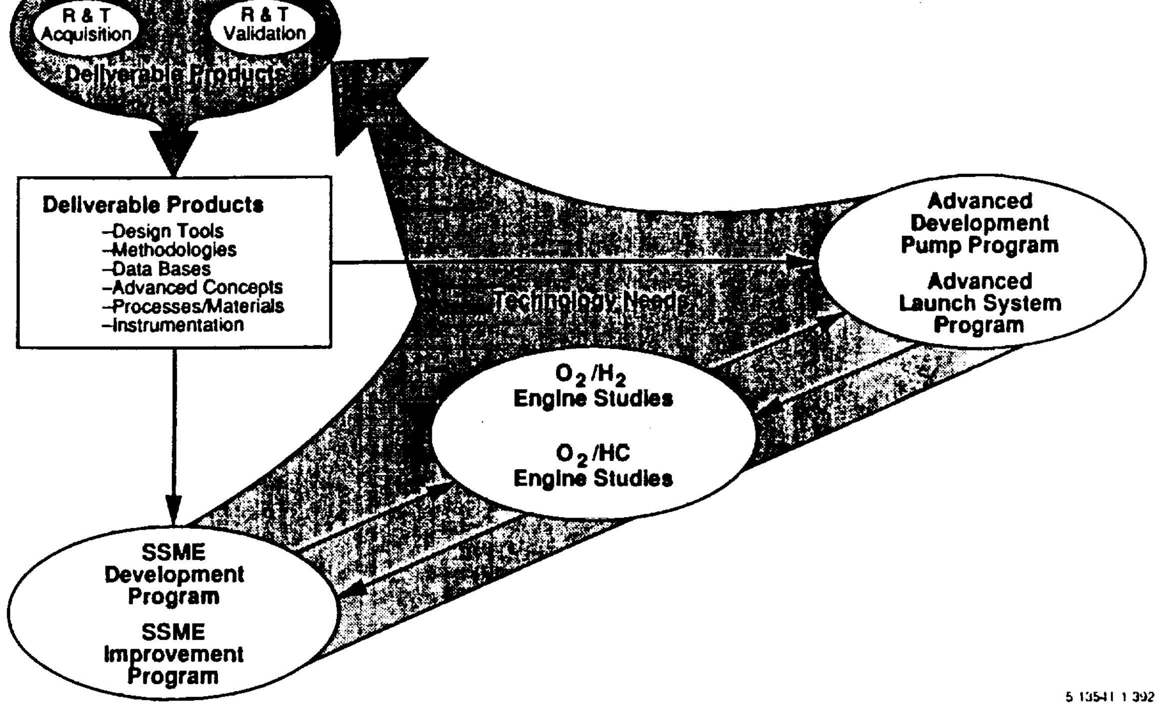
Determination of Needs and Deliverable Products



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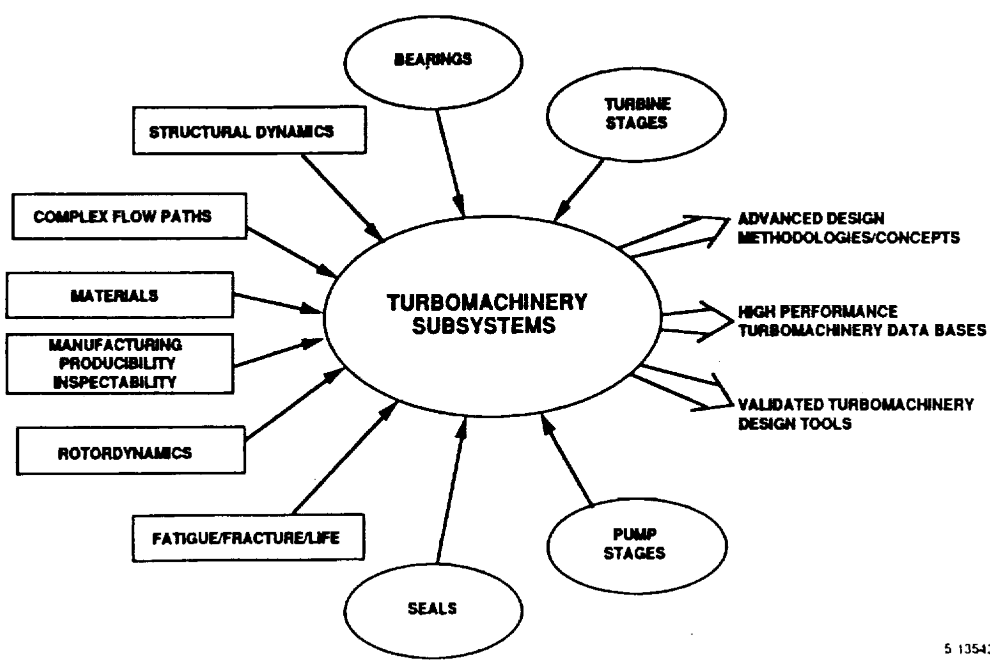
Technology Components and Disciplines



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Turbomachinery Component Specific Technologies

- **Turbine Stage Design Methods**

  Modeling of Multistage Turbines For High Efficiency, Reduced Loads, and Reduced Heat Transfer Supported By Experimental Verification

- **Pump Stage Design Methods**

  Modeling of Impellers and Inducers For High Efficiency, Reduced Loads, and Reduced Cavitation Supported by Experimental Verification

- **Bearings**

  Improvement of Life and Performance of Cryogenic Bearing Technology Through Improved Design Concepts, Design Criteria, Materials, Manufacturing Techniques, Lubrication/Cooling Techniques, Dynamic Analysis, Hybrid Suspension Systems, etc.

- **Seals**

  Modeling of Seals For Incompressible/Compressible Flows to Reduce Leakage and Improve Performance; Improve Rotordynamic Characteristics

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Earth-To-Orbit
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Turbomachinery Discipline Specific Technologies

- **Structural Dynamics**

  Modeling Related to Structural Dynamic Characteristics to Increase Lifetime, Decrease Weight, Identify Insipient Failures, Decrease Costs, Assess Retrofitable Design Changes, Develop/Validate Design Tools

- **Complex Flow Paths**

  Improve Modeling of Coolant Flows and Ducts With CFD Supported By Experimental Validation

- **Materials**

  Develop and Evaluate Candidate Materials to Assess Reactivity to High Pressure/Temperature and Oxygen/Hydrogen Environments With Specific Emphasis on Turbine Blades, Bearings, and Seals

- **Manufacturability, Producibility, Inspectability**

  Develop/Evaluate Process Techniques, Improve and Optimize Producibility, Improve In-Service Nondestructive Inspection, etc.

- **Rotordynamics**

  Improve Rotordynamic Modeling, Diagnostic Procedures, Balancing Methods, Probalistic Analysis Methods Along With Experimental Validation

- **Fatigue/Fracture/Life**

  Develop, Test and Verify Analysis Tools Related Fracture Mechanics, Crack Initiation Life Prediction, Associate Materials Data Base, etc. to Improve Service Life Prediction

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Turbomachinery Large Scale Validation

Objective:

- **Provide Validation of Turbomachinery Design Methods and Hardware Concepts Through**
  - Bench Testing
  - Large Scale Subcomponent Testing
    - -- Rig Tests
    - -- Turbopump Tests
  - Engine Systems Tests (TTB)
- **Compare Data to Most Advanced Computational Methods**
  - Stress Methods to Limits
  - Parameter Sensitivity Studies
- **Develop Turbomachinery Specific End Products**
  - Validated Design Methods
  - Empirical Data Bases
  - Scaling Laws/Methods
  - Design Criteria; Life Limits, Performance,...
  - Advanced Hardware Concepts

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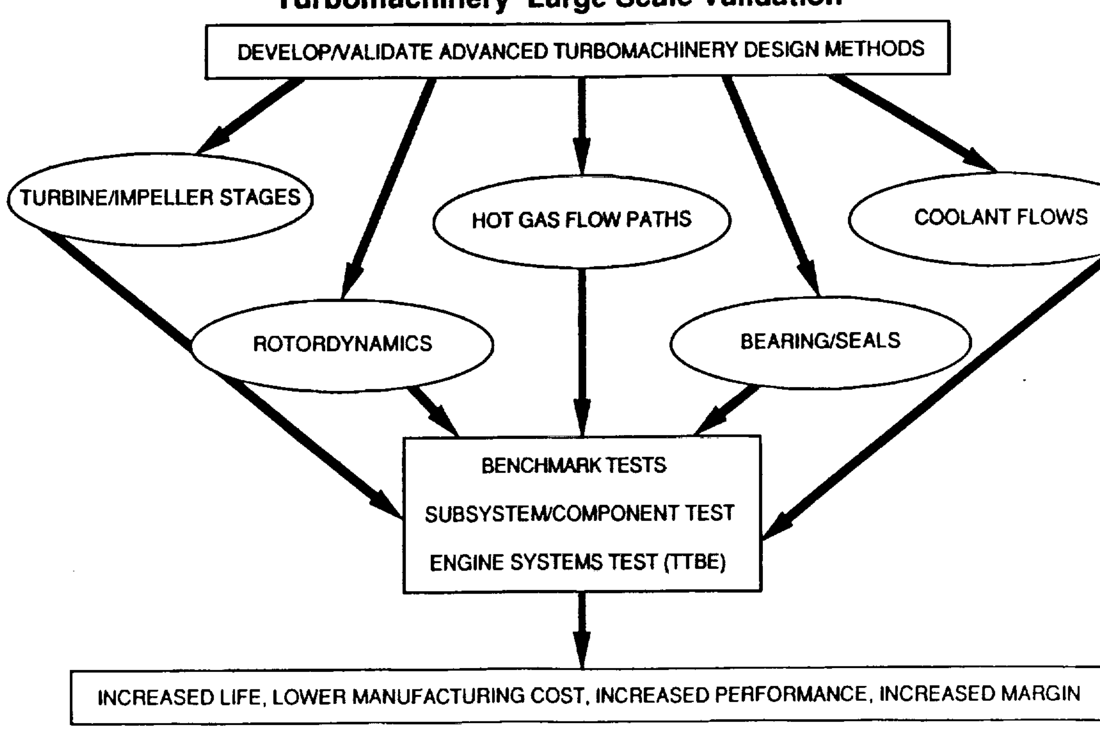
Turbomachinery Large Scale Validation



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Earth-To-Orbit Turbomachinery Subsystem

Accomplishments

- **Turbine Stage**

  Computational Fluid Dynamic Analysis and Validation Led to Decision to Implement a Single Stage Turbine Into STME Instead of Two Stages.

- **Complex Flow Paths**

  Technology Flow Testing Led to the Development of the SSME Phase II+ Hot Gas Manifold; CFD Analysis Validated In Air- and Water-Flow Facilities

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Turbine Stage

Consortium for CFD Applications in Propulsion

- **Objectives**
  - Identify needs
  - Development of CFD as a design tool through challenging applications
  - Evaluation/development of advanced hardware concepts
- **Teams in place**
  - Turbine
  - Pump
  - Combustion-driven flows
- **Participants (e.g., Turbine Team)**

NASA	Industry	Small Business	Universities
MSFC	Aerojet	Calspan	Penn. State Univ.
LeRC	General Electric	Rotodata	Miss. State Univ.
ARC	Pratt & Whitney	Sci. Res. Assoc.	Univ. of Ala. (T)
	Rocketdyne	SECA	Univ. of Ala. (Hsv.)
	United Technologies Res. Cen.		

← Technology Transfer →

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Turbine Stage – Generic Gas Generator

- **Objectives**
  - Enhance and Validate Turbine Design Tools
  - Transfer Advanced Technology to Turbine Design Process
- **Approach**
  - Develop and Implement Plan Cognisant of STME Program Goals
  - Focus Activity Around STME Turbines but Ensure End Products are Generic
  - Establish a Focused Team of Committed Turbine Experts to Drive Technology Transfer and Focus Deliverable Products toward Design Tools
  - Benchmark Codes With Air-Flow Data
  - Establish and Evaluate Advanced Baseline Turbine Stage
  - Fine Tune Baseline and Validate In Air-Flow Test
- **Results**
  - Code Validated for STME – Type Turbine Stage
  - High Turning (160°) Blade Designed/Evaluated
  - Efficiency Increased by 9.8 Percent
  - Single-Stage Turbine Instead of Two
  - Projected Life-Cycle Cost Savings of $71M

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Turbine Stage – Validation

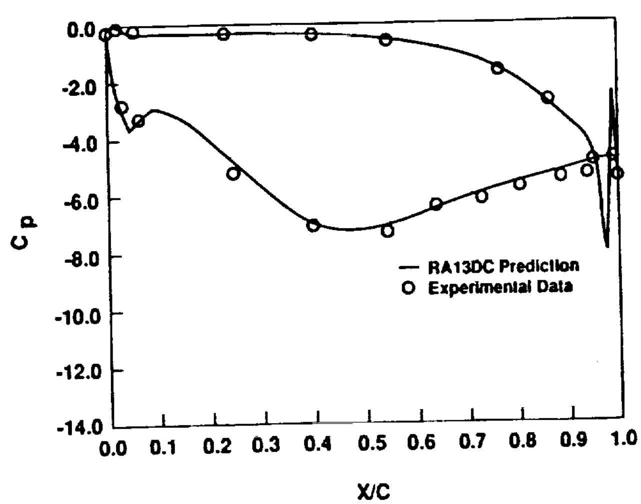

Figure 3b. Pressure Distributions for the Stator at the 50% Spanwise Location

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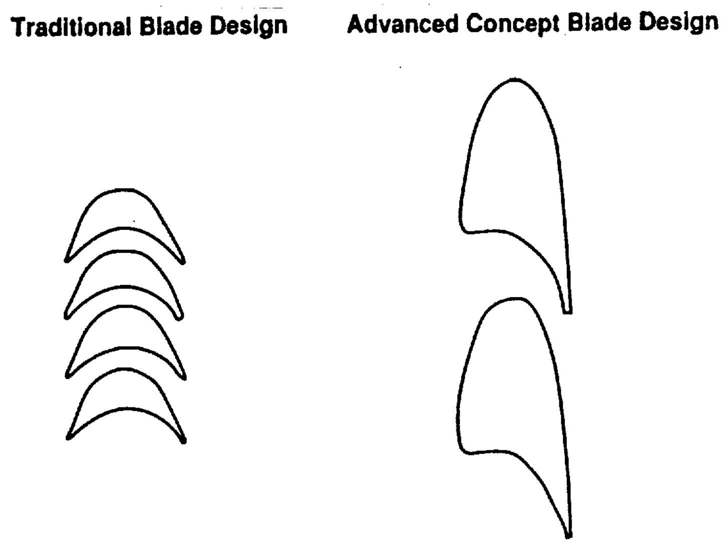
Turbine Stage – Blade Comparison



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Turbine Stage – Flow Parameter Comparison

	Previous State-of-the-Art GG Experience	Advanced G^{3}T Design Concept
General Description	70/30 Work Split Nominal Annulus Height	50/50 Work Split Increased Annulus Height
Blade turning	135°	160°
Fluid acceleration	0.9	1.6
Max blade Mach number	1.32	0.87
Efficiency	Base	+9.8 percent
Airfoil count	Base	-55 percent

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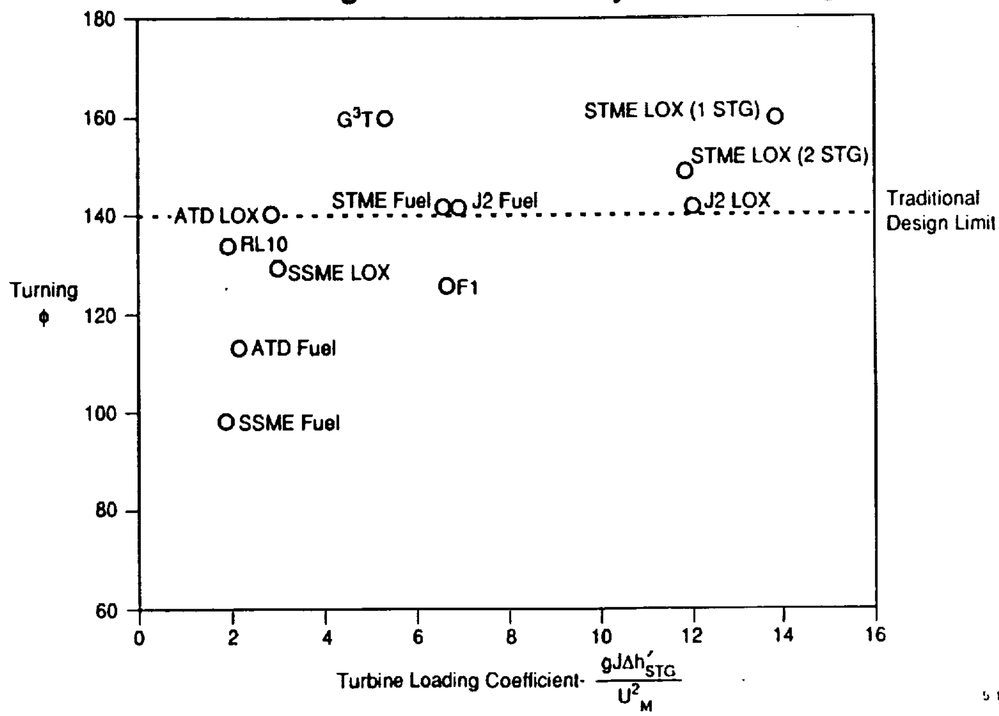
Turbine Stage – Turbine Aerodynamic Loading



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Turbine Stage – Key Milestones

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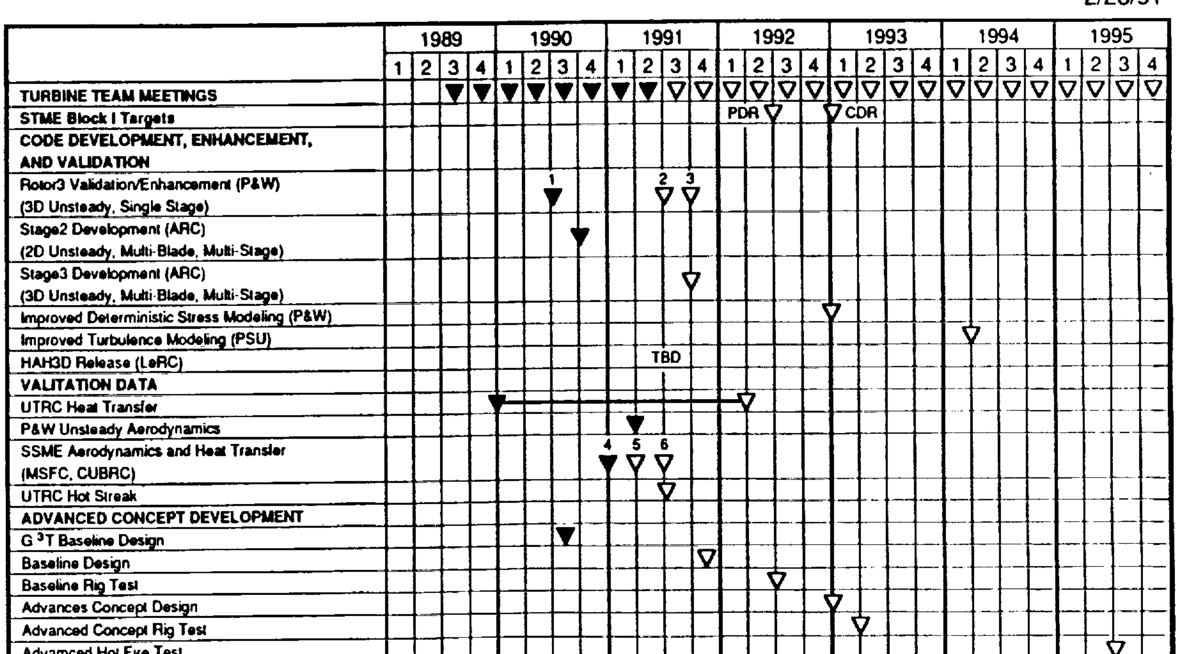

Key
1. Validation against steady aerodynamic and heat transfer data
2. Improved turbulence modeling
3. Validation against aerodynamic data
4. Steady aerodynamic data
5. Unsteady aerodynamic and heat transfer data
6. ATD steady aerodynamic data

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Turbine Stage – Technology Transfer

- **STME LOX turbine design decision: one vs. two stage turbine**
  - LCC - favors one stage (reduction in LCC of 71 million dollars)
  - Risk - comparable
  - Rotordynamic - comparable, slightly favoring one stage
  - Hardware simplicity - favors one stage
  - Turbine stage technology team support available for one stage

By concensus of Aerojet, Pratt and Whitney, and Rocketdyne on Novermber 15, 1990, a one stage oxygen turbopump turbine was recommended and subsequently implemented into the STME design.

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Complex Flow Path – SSME Phase II +

- **Objectives**
  - Validate CFD analysis using air- and water-flow data
  - Evaluate 2-duct versus 3-duct HGM design
- **Approach**
  - Compare CFD results to air- and water-flow tests
  - Apply CFD codes and test rigs to 2-duct and 3-duct HGM designs
- **Results**
  - Good agreement between CFD predicted and measured wall pressures
  - 2-duct manifold results in
    - Lower side loads on turbine end
    - Lower turbine temperatures
    - More benign internal flow environment

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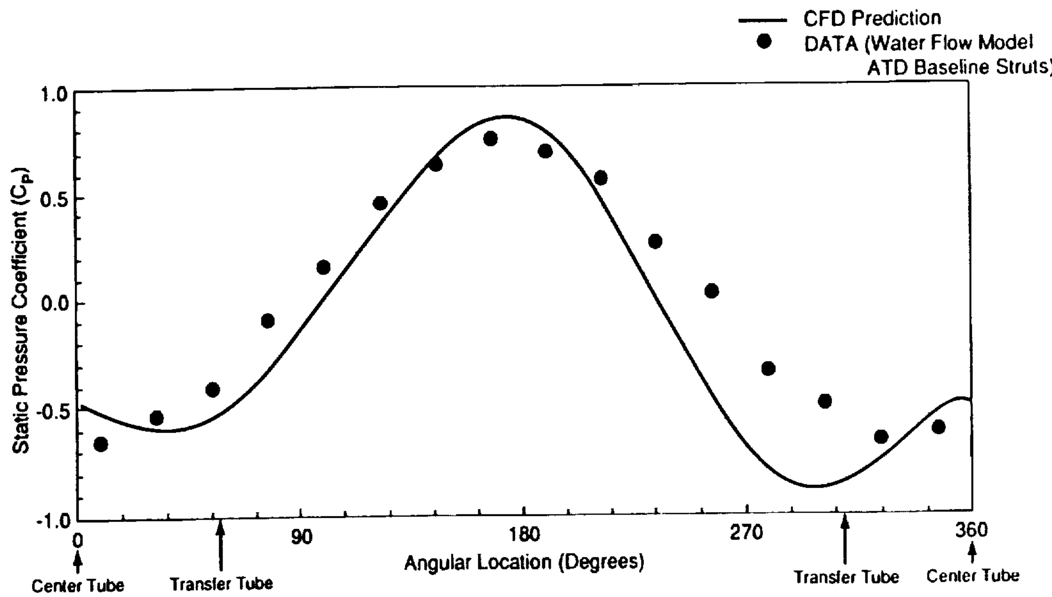
Complex Flow Path - Static Pressure Distribution at Turbine Exit Plane



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Complex Flow Path – Technology Transfer

- **SSME Program Made Key Decision to Develop Two Duct HGM**
  - Developmental Hot Fire Testing In Progress
  - Program Plans Indicate First Flight 1996

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Potential Augmented Work

- Flow Model of Entire Rocket Engine
- Advanced Turbopump
- Casting Technology
- Advanced Materials

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Earth-To-Orbit Turbomachinery Subsystem

Summary

- **Focused Management Milestone Plan In Place Via Cooperative Efforts Between MSFC and LeRC with ARC Participation.**
- **Technology Being Developed That has Potential to Flow Into Ongoing Main Stream Programs.**
- **NLS Distinguishable Technology Products Being Evolved That Also Have Generic Payoffs**
- **Technology Transfer Being Accomplish and Accelerated Via Consortium for CFD Application In Propulsion Technology**

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INTEGRATED TECHNOLOGY PLAN

FOR THE CIVIL SPACE PROGRAM

TRANSPORTATION TECHNOLOGY

EARTH-TO-ORBIT TRANSPORTATION

HEALTH MONITORING & DIAGNOSTICS

AND CONTROLS

S. Gorland

6/26/91

INSTRUMENTATION

TECHNOLOGY NEEDS

- o IMPROVED SENSORS AND MEASUREMENT SYSTEMS FOR BOTH CURRENT AND FUTURE SPACE PROPULSION SYSTEMS IN ORDER TO PROVIDE:
  - o DETAILED MEASUREMENTS FOR CODE VALIDATION IN:
    - o SUBCOMPONENT TESTS IN LABORATORIES.
    - o COMPONENT TESTS IN FACILITIES.
    - o TEST BED ENGINE.
  - o IMPROVED TEST AND LAUNCH STAND INSTRUMENTATION.
  - o IMPROVED SENSORS AND SYSTEMS FOR OPERATIONAL ENGINES FOR BOTH:
    - o CONTROL PARAMETERS.
    - o HEALTH MONITORING.

INSTRUMENTATION

CHALLENGES

- o THE ENVIRONMENTAL REQUIREMENTS UNDER WHICH THE SENSORS MUST FUNCTION AND THE PARAMETERS TO BE SENSED ARE FREQUENTLY BEYOND CURRENT STATE-OF-THE-ART.
- o MEASUREMENT SYSTEMS FOR CODE VALIDATION MUST BE NON INTRUSIVE (E.G. OPTICAL) OR AT LEAST MINIMALLY INTRUSIVE (E.G. THIN FILM) BECAUSE THE CODES DO NOT ALLOW FOR THE PRESENCE OF A SENSOR.
- o MEASUREMENT SYSTEMS FOR CODE VALIDATION MUST ALSO PROVIDE HIGH TEMPORAL AND SPATIAL RESOLUTION BECAUSE THE CODES ARE USUALLY FINE MESH SOLUTIONS.
- o SENSORS FOR OPERATIONAL ENGINES MUST BE HIGHLY RELIABLE PARTICULARLY WHEN FUTURE LONG TERM MISSIONS ARE CONSIDERED.
- o MEASUREMENT SYSTEMS FOR TEST AND LAUNCH PAD OPERATION MUST REQUIRE MINIMUM MANPOWER AND/OR MAINTENANCE WHILE SURVIVING THE EXTREME ACOUSTIC, VIBRATION, AND THERMAL ENVIRONMENTS DURING LAUNCH.

INSTRUMENTATION

APPROACH

- o MAXIMIZE THE USE OF OPTICAL SYSTEMS AND FIBER OPTICS.
- o DEVELOP THIN, SPUTTER DEPOSITED FILM SENSORS.
- o CAPITALIZE ON DEVELOPMENTS IN THE COMPUTER, MICROELECTRONIC, AND LASER TECHNOLOGY FIELDS.
- o BALANCE THE PROGRAM AMONG IN-HOUSE, GRANT, AND CONTRACT WORK.
- o COORDINATE CLOSELY WITH THE OTHER TECHNOLOGY GROUPS, PARTICULARLY CONTROLS.

INSTRUMENTATION

BENEFITS

- RELIABLE SENSORS FOR:
  - CONTROL AND HEALTH MONITORING.
  - INCREASED CREDIBILITY OF COMPUTER CODES.
- MORE DIRECT SENSING OF THE PARAMETER REQUIRED RATHER THAN INDIRECT INFERENCE FROM OTHER MEASUREMENTS.
- MORE EFFICIENT AND SAFER STAND AND PAD OPERATIONS.
- GENERIC TECHNOLOGY APPLICABLE NOT ONLY TO EARTH-TO-ORBIT PROPULSION SYSTEMS BUT ALSO TO SPACE BASED PROPULSION SYSTEMS INCLUDING NUCLEAR.

INSTRUMENTATION

CURRENT PROGRAM

- DETAILED MEASUREMENTS FOR CODE VALIDATION IN LABORATORIES, RESEARCH FACILITIES, AND THE TEST BED ENGINE.
  - THIN FILM THERMOCOUPLES AND HEAT FLUX SENSORS FOR THE TURBINE ENVIRONMENT.
  - PLUG TYPE HEAT FLUX SENSORS FOR TURBINE TRANSIENTS.
  - OPTICAL SYSTEMS FOR:
    - PREBURNER GAS TEMPERATURE.
    - TURBINE REGION FLOW MEASUREMENT.
    - 2D STRAIN MEASUREMENTS IN HIGH TEMPERATURE MATERIALS TEST FACILITIES.
    - HOLOGRAPHIC STRUCTURAL FLAW DETECTION.
    - OPTICAL SYSTEM ALIGNMENT IN HARSH ENVIRONMENTS USING NEURAL NETWORKS.

INSTRUMENTATION

CURRENT PROGRAM (CONT)

- o IMPROVED TEST AND LAUNCH STAND INSTRUMENTATION.
  - o OPTICAL PLUME ANOMALY DETECTION SYSTEM.
  - o GASEOUS (H2) LEAK DETECTION USING:
    - o SOLID STATE POINT SENSORS.
    - o REMOTE OPTICAL SYSTEMS.

Transportation Technology
Earth-To-Orbit Transportation

INSTRUMENTATION

CURRENT PROGRAM (CONT)

- o IMPROVED SENSORS AND SYSTEMS FOR OPERATIONAL ENGINES FOR BOTH CONTROL AND HEALTH MONITORING.
  - o OPTICAL COMBUSTION CHAMBER GAS SPECIES MEASUREMENT.
  - o FLOWMETERS:
    - o VORTEX SHEDDING.
    - o ULTRASONIC.
    - o TRIBOELECTRIC.
  - o NON-INTRUSIVE SPEED SENSOR FOR TURBOPUMPS.
  - o BEARING DEFLECTOMETER.
  - o TURBINE BLADE PYROMETER.
  - o BRUSHLESS TORQUEMETER.
  - o PRESSURE SENSOR.

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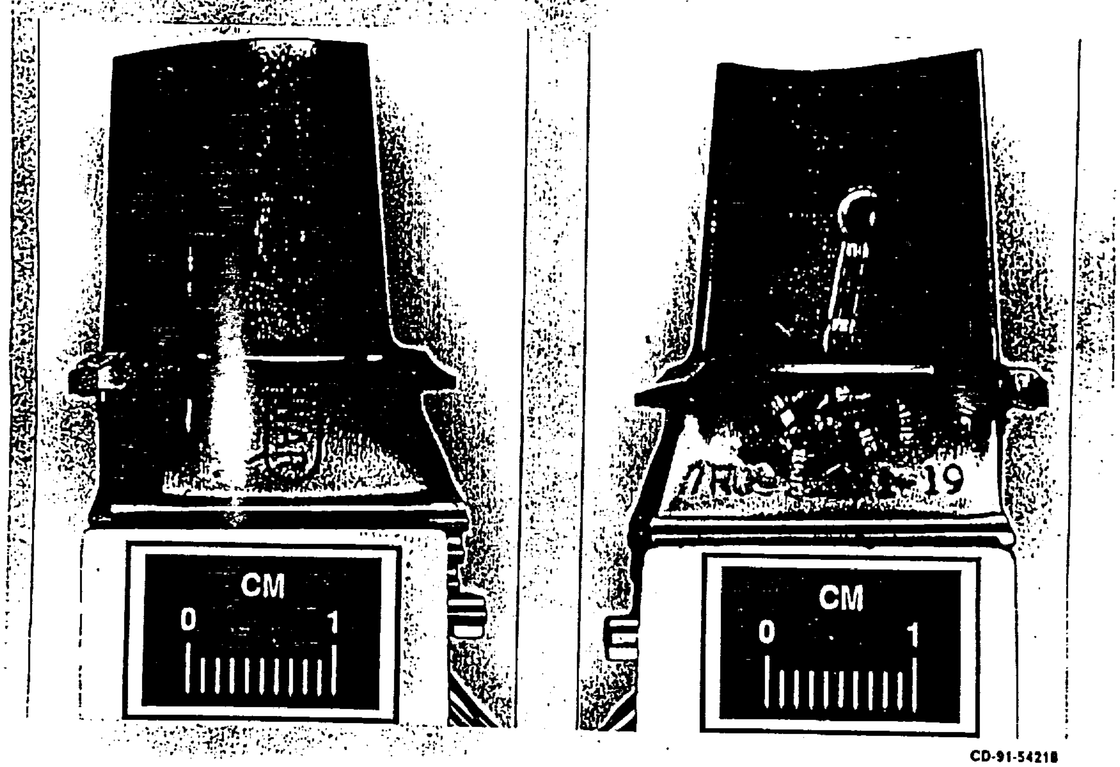
Plug-Type Heat Flux Gage



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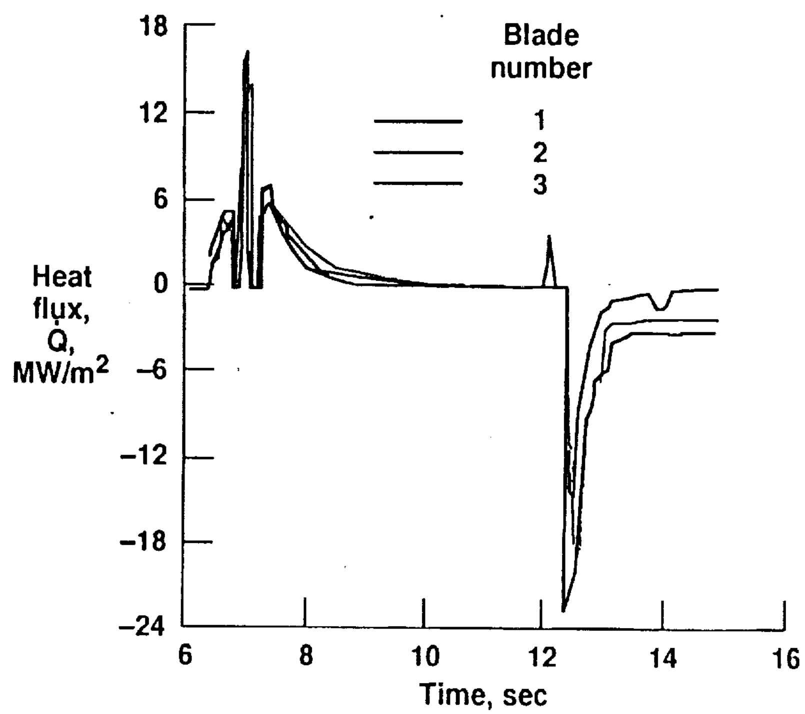
Heat Flux Measured in SSME Turbine Blade Tester



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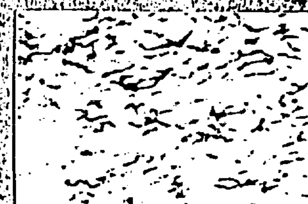
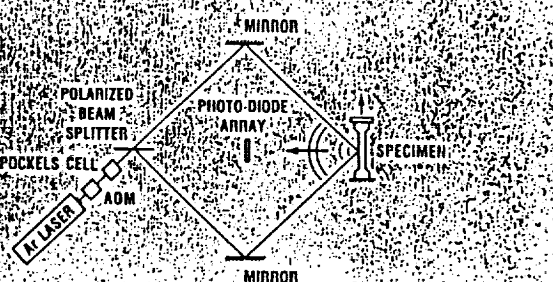
REMOTE STRAIN MEASUREMENTS

GOAL
- RELIABLE MATERIAL AND STRUCTURE TESTING

FEATURES
- NONCONTACT, NONINTRUSIVE
- INDEPENDENT OF TEST MATERIAL
- HIGH TEMPERATURE
- FULL FIELD POTENTIAL
- RIGID BODY MOTION CORRECTING



SPECKLE PATTERN



LASER SPECKLE STRAIN MEASUREMENT SYSTEM

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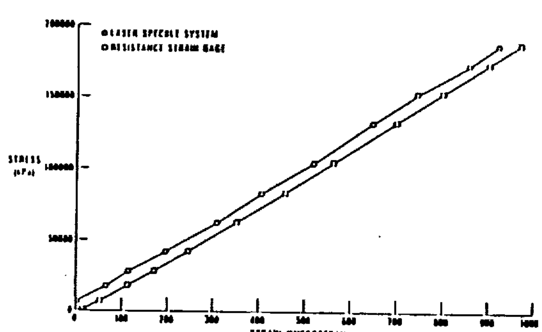
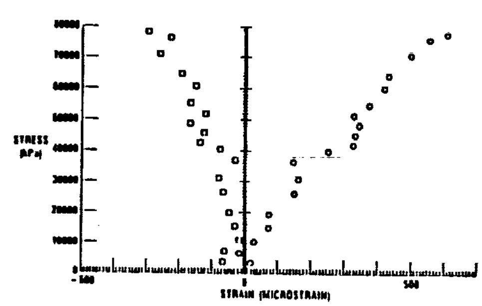
LASER SPECKLE STRAIN MEASUREMENT SYSTEM



ROOM TEMPERATURE COMPARISON
WITH RESISTANCE STRAIN GAGE



MEASUREMENT AT 1300 °F

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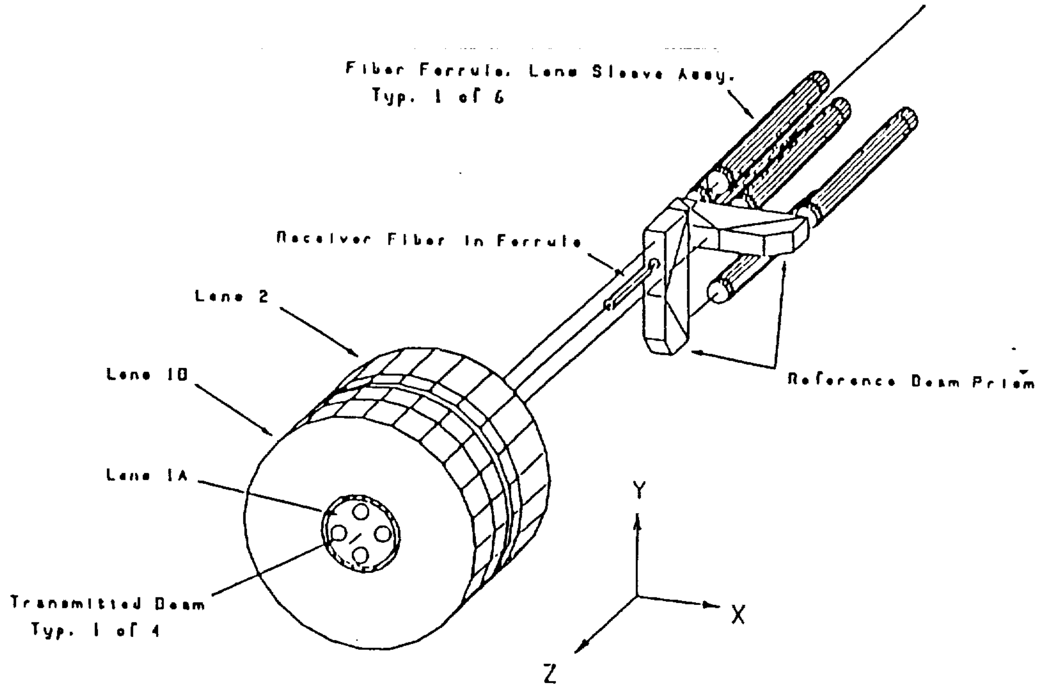
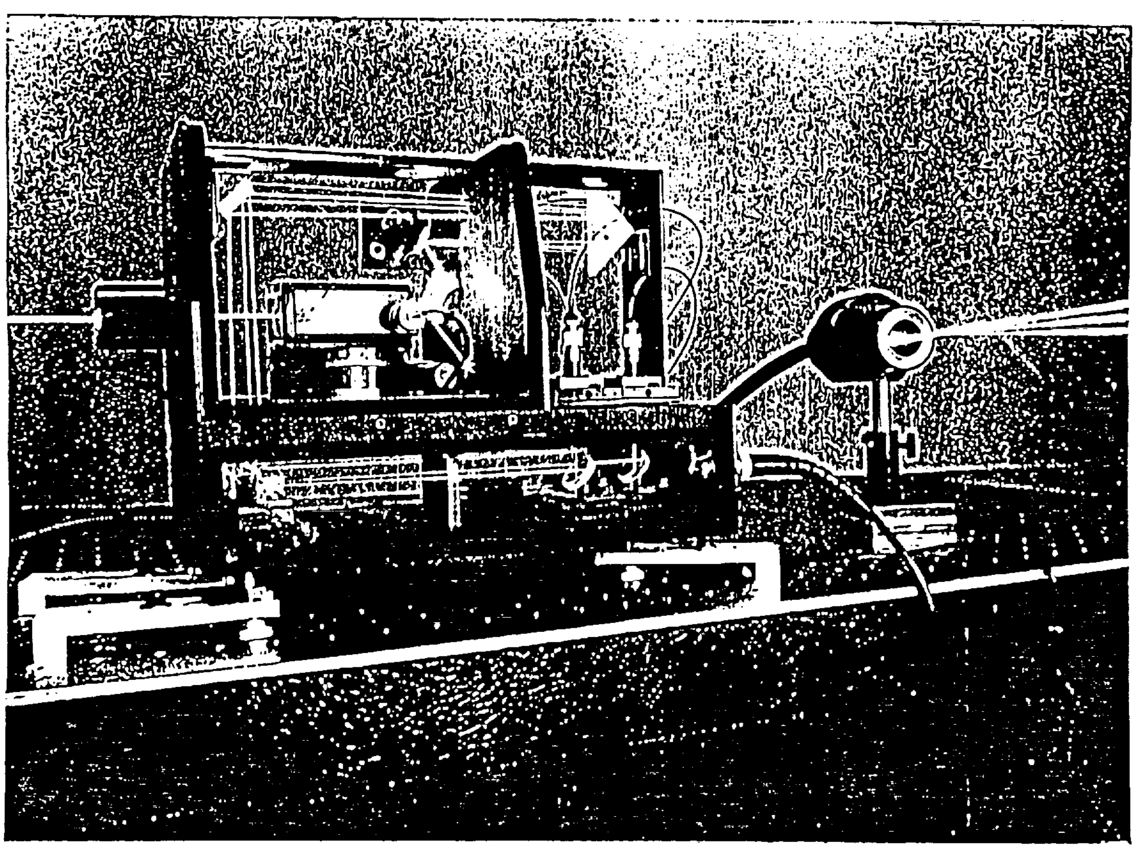


LASER ANEMOMETER PROBE
FOR TURBINE ENVIRONMENT



LASER ANEMOMETER PROBE
FOR TURBINE ENVIRONMENT

Leak Detection

Technology Needs:

- Develop sensors that detect propellant leakage from cryogenic liquid fueled rocket engines.

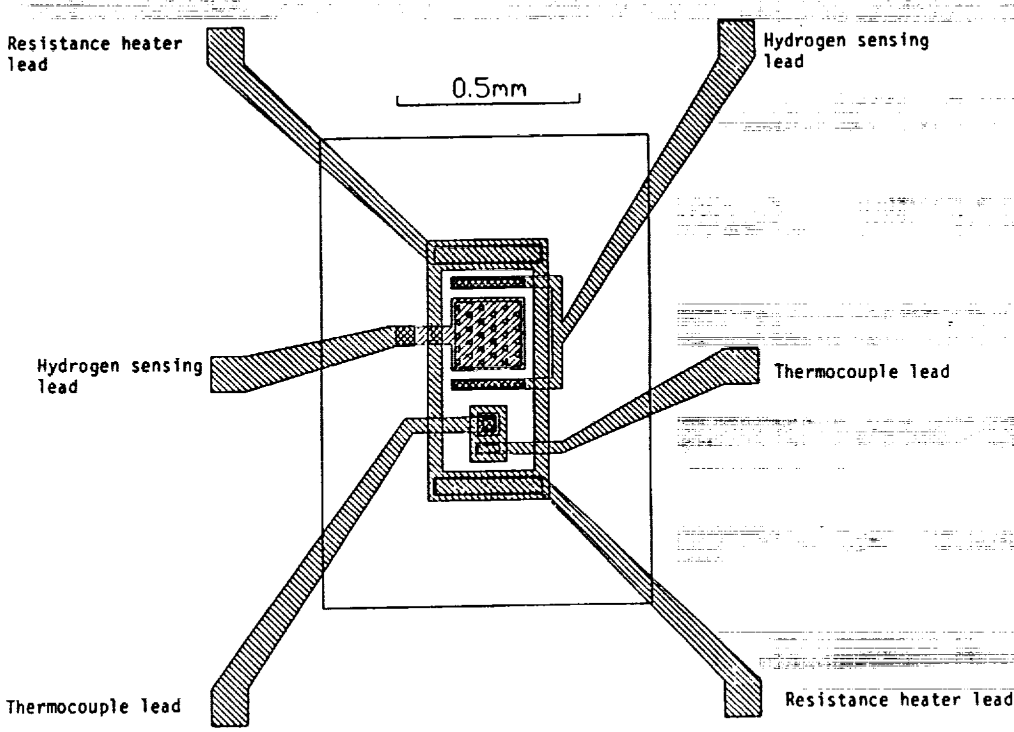
Technology Challenge:

- Develop hydrogen and oxygen sensors exhibitting:
  - Fast response
  - High sensitivity
  - High spatial resolution
- Harden and package sensors for engine environment.

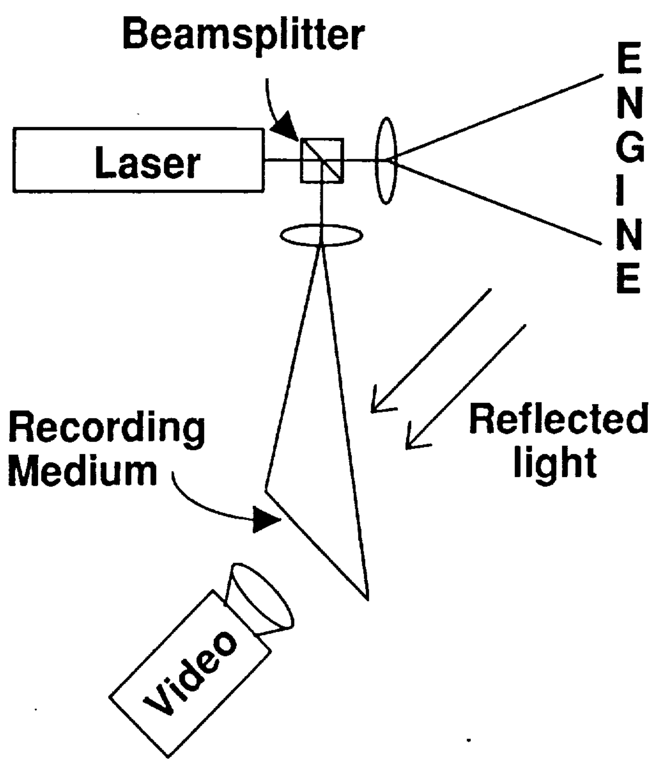
Benefits:

- Enables real time leak detection of propellants.
- Increases engine/mission safety.

Mask for Hydrogen Sensor



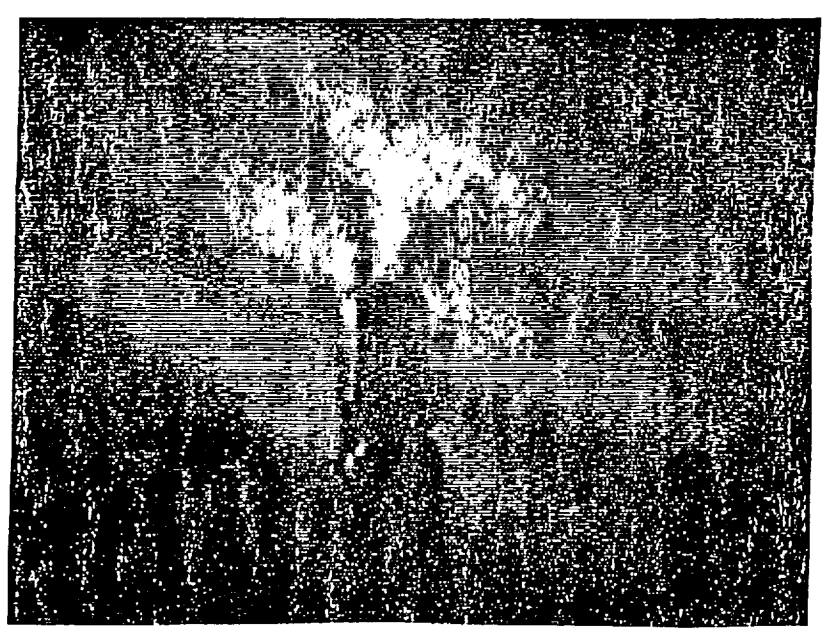
HOLOGRAPHIC INTERFEROMETRIC CONFIGURATION FOR LEAK DETECTION



SPACE PROPULSION TECHNOLOGY DIVISION

NASA Lewis Research Center

HOLOGRAPHIC INTERFEROMETRY LEAK DETECTION



HOLOGRAPHIC INTERFEROGRAM OF A LEAKY PIPE FITTING

INSTRUMENTATION

AUGMENTED PROGRAM

- ACCELERATE THE RATE AT WHICH ADVANCED INSTRUMENTATION IS APPLIED.
  - CURRENT PROGRAM IS FOCUSSED ON DEVELOPING AND VALIDATING NEW MEASUREMENT CONCEPTS IN THE LABORATORY.
  - CURRENT FUNDING LEVELS PERMIT THE DEVELOPMENT OF ONE (OR A FEW) PROTOTYPE MEASUREMENT SYSTEMS FOR FIELD APPLICATIONS.
  - AUGMENTED FUNDING WOULD ALLOW MORE RAPID APPLICATION OF NEW MEASUREMENT TECHNOLOGY.
  - SPECIFIC EXAMPLES INCLUDE:
    - HYDROGEN LEAK DETECTION SYSTEMS.
    - THIN FILM SENSORS.
    - ADVANCED FLOW, TEMPERATURE, AND TORQUE SENSORS.
    - OPTICAL DIAGNOSTIC SYSTEMS.

INSTRUMENTATION

AUGMENTED PROGRAM (CONT)

- DEVELOP NEW AND UPGRADE EXISTING INSTRUMENTATION TEST FACILITIES TO ENHANCE RESEARCH PRODUCTIVITY.
  - NEW FACILITY FOR HYDROGEN LEAK DETECTION SYSTEM TEST AND CALIBRATION.
  - NEW FACILITY FOR THE EXPOSURE OF SENSORS, MATERIALS SAMPLES, COATINGS, AND OTHER SMALL ITEMS TO HOT (BURNING) HYDROGEN AT ELEVATED PRESSURES AND UNDER TRANSIENT FLOW AND TEMPERATURE CONDITIONS.
  - UPGRADE THE EXISTING LeRC HEAT FLUX CALIBRATION FACILITY.