N93-71878

INTEGRATED TECHNOLOGY PLAN

FOR THE CIVIL SPACE PROGRAM

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SPACE R&T BASE: PROPULSION

HIGH THRUST CHEMICAL

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6/26/91

SPACE R&T BAS. PROPULSION HIGH THRUST CHEMICAL

OBJECTIVES

PROGRAMMATIC

Provide a technology base and maintain an institutional capability for continued advances in the development of advanced space propulsion systems to support launch, upper stage, orbit transfer and ascent/descent engines.

TECHNICAL

- Validated design and analytical codes for cryogenic turbopump bearings and seals.
- Full 3D codes for turbopump internal flow and heat transfer.
- Design methodologies and diagnostic capabilities for combustion stability.
- Reduced Operations cost. Increase life, safety.
- Higher energy density propellants.
- In-situ engine concepts.

MILESTONES - (BASE PROGRAM)

- FY93 - Demonstrate metallized RP-1 performanc
- FY94 - Complete 3D Pump Code Development
- FY94 - Complete H/O Stability Model
- FY94 - Complete Subscale testing of Ceramic Brush seals.
- FY95 - Complete assessment of cryogenic magnetic bearings.
- FY96 - Complete combined cycle analysis.
- FY96 - Complete atomic hydrogen engine/feed system fabrication.
- FY97 - Complete generation of tribomaterials da base for turbopump bearings.

RESOURCES ($M)

	PLANNED	3X GUIDELINE
FY91	3.5	3.5
FY92	3.5	3.5
FY93	3.6	4.8
FY94	3.8	6.1
FY95	3.9	7.4
FY96	4.1	8.2
FY97	4.3	9.2

PARTICIPANTS

LEWIS RESEARCH CENTER

- High Thrust Chemical

LUNAR AND PLANETARY PROPELLANTS

NEEDS

- Reduce cost of SEI missions
- Validate performance potential of In-situ propellants
- Demonstrate compatibility between production and propulsion systems

CHALLENGE/APPROACH

- Develop propulsion technology for engines that operate on propellants produced at the moon and Mars
- Insure engines operate with high degree of reliability and autonomy

BENEFITS

- Significantly reduce Earth launch-to-orbit mass requirements
- Increase self-sufficiency of planetary bases
- Significantly reduce trip-time for manned Mars missions

LUNAR AND PLANETARY PROPELLANTS

CURRENT PROGRAM

- Complete Carbon Monoxide/Oxygen sub-scale combustion experiments
- Identify technology issues for dual-fuel engine design
- Define Metal/oxygen monopropellant hazard classification
- Establish Metal/Oxygen monopropellant formulation

AUGMENTED PROGRAM

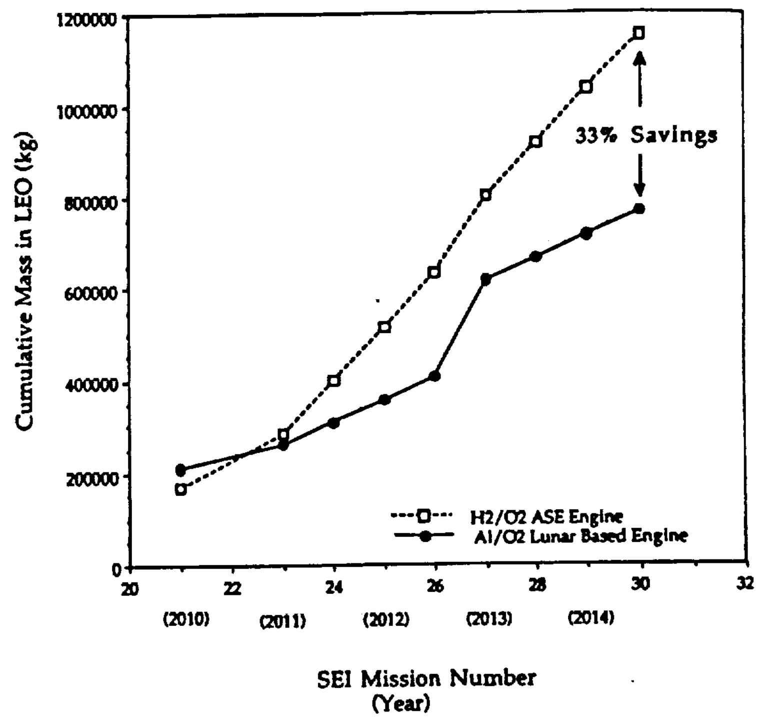
- Validate Sub-Scale Metal/Oxygen monopropellant combustion
- Demonstrate Carbon Monoxide/Oxygen engine at large scale
- Demonstrate capability for Large-batch production of Metal/Oxygen monopropellant

Benefits

In Situ Propellant Utilization

- Reduces Earth Launch Mass Requirements (see figure)
- Decreases Mars Mission Time
- Reduces Mission Complexity
- Establishes Self-Sufficiency of Lunar and Mars Bases

Lunar Ascent/Descent Vehicle Propulsion



SPACE R&T BAS PROPULSION
HIGH THRUST CHEMICAL

Metallized Propellants:

- Metallized Propellants Offer

  Higher Specific Impulse and Higher Propellant Density
  Safer Propellants (Gelled)

- Significant Performance Increases Are Possible

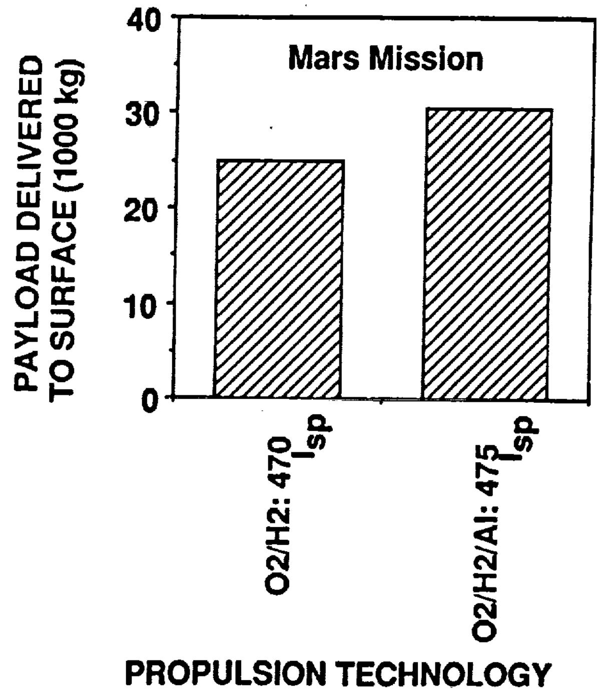
  Higher Delivered Payload
  Lower Initial Mass in LEO

Oxidizer +	Fuel +	Metal
O_2	H_2	Al
O_2	Hydrocarbon	Al
N_2O_4	MMH	Al

Metallized Propellants:
Areas of Application and Benefit

- Mars:
  - Payload To Surface Increased By 20 to 33 Percent
  - High I_{sp} Storable NTO/MMH/Al for Mars Ascent
- Lunar:
  - Payload To Surface Increased By 3 Percent
- Robotic Planetary:
  - Enables Fast Missions
- Earth to Orbit:
  - Liquid Rocket Boosters
    Added Payload
    Safety Enhanced With Gels

PAYLOAD MASSES FOR EXPEDITION MISSION



Current and Needed Technology for Metallized Propellants

Current	Needed
• Combustion /Testing: Preliminary Subscale O_2 /RP-1 /Al	Complete Characterization: O_2 /H_2 /Al, O_2 /RP-1 /Al
• Rheology: Preliminary Understanding of Rheology: RP-1 /Al	Complete Understanding: H_2 /Al Gels (60 % Al) RP-1 /Al (60 % Al)
• Formulation: Large-Batch Formulation	Large-Scale Manufacturing

SPACE R&T BASE: PROPULSION
HIGH THRUST CHEMICAL

COMBUSTION

TECHNOLOGY REQUIREMENTS
- Develop Atomization, Supercritical Vaporization, Mixing Models
- Develop Damping Device Models
- Develop Diagnostics To Make Measurements In The Combustor
- Develop Performance & Stability Database

TECHNOLOGY CHALLENGES
- Designing High Performance Stable Engines
- Reducing The Amount Of Development & Qualification Testing

BENEFITS
- Reduced Engine Weight
- Increased Engine Design Margin
- Reduced Engine Development Time

SPACE R&T BASE: PROPULSION
HIGH THRUST CHEMICAL

AUGMENTED PROGRAM

INJECTOR ATOMIZATION CHARACTERIZATION
- Develop Supercritical Spray Combustion Model

ROCKET ENGINE COMBUSTION DIAGNOSTICS
- Develop Devices To Measure Rocket Combustor Fluid Properties

NEW STABILITY RATING TECHNIQUES
- Develop High Energy Frequency Controlled Technique

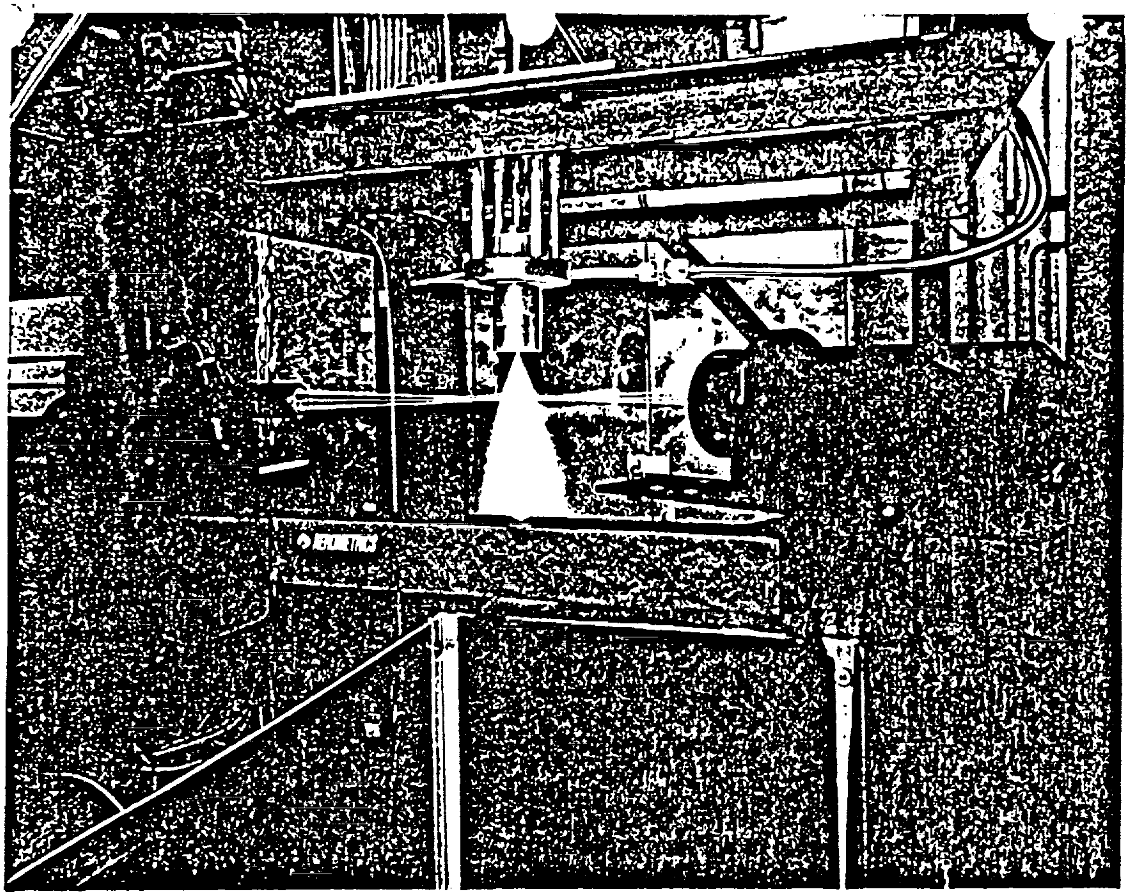
PERFORMANCE & STABILITY DATABASE
- Create Standardized Reporting Format & Database

INTEGRATED BAFFLE/CAVITY MODEL
- Develop Hub Baffle & Baffle/Cavity Interaction Model

CURRENT PROGRAM

SHEAR COAXIAL INJECTOR ATOMIZATION CHARACTERIZATION
- Compare Cold Flow & Hot Fire Atomization Measurements
- Verify Existing Models & Develop New Model If Appropriate

INJECTOR/CHAMBER FREQUENCY COUPLING INVESTIGATION
- Investigate LOX Tube Resonance Coupling Instability
- Create Validation Database For Model & CFD Code Development



SPACE R&T BASE PROPULSION
HIGH THRUST CHEMICAL

TURBOMACHINERY CODES/TOOLS

NEEDS

- Model secondary flows in the turbomachinery of liquid propellant rocket engines.
- Integrate these models into current design techniques

CHALLENGE/APPROACH

- Reduce the prohibitive CPU time of numerical simulation
- Use approximation techniques until the availability of massively parallel processing

BENEFITS

- Improved turbomachinery reliability, performance and life
- Decreased time and cost of development

TURBOMACHINERY CODES/TOOLS

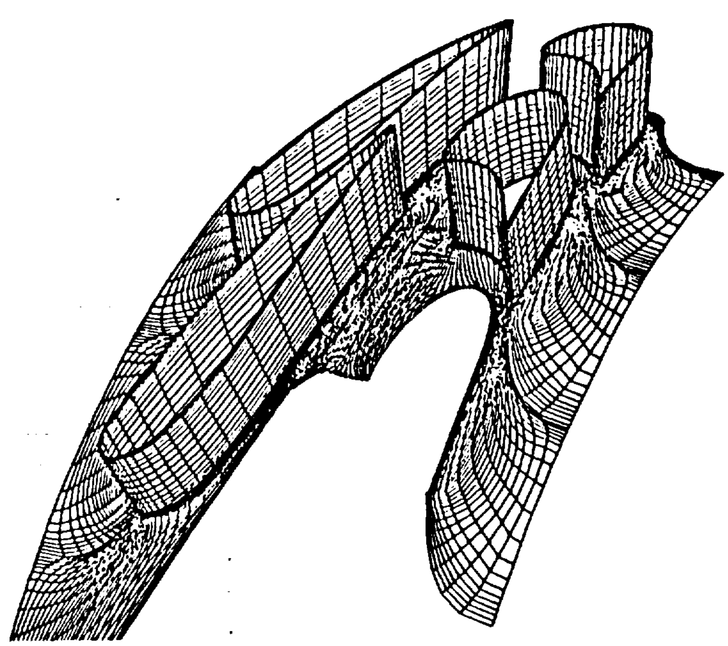
CURRENT PROGRAM

- Develop alternative approaches to numerically simulate 3D, unsteady viscous flow in space turbopumps to better predict aerothermal loads and component efficiencies

AUGMENTED PROGRAM

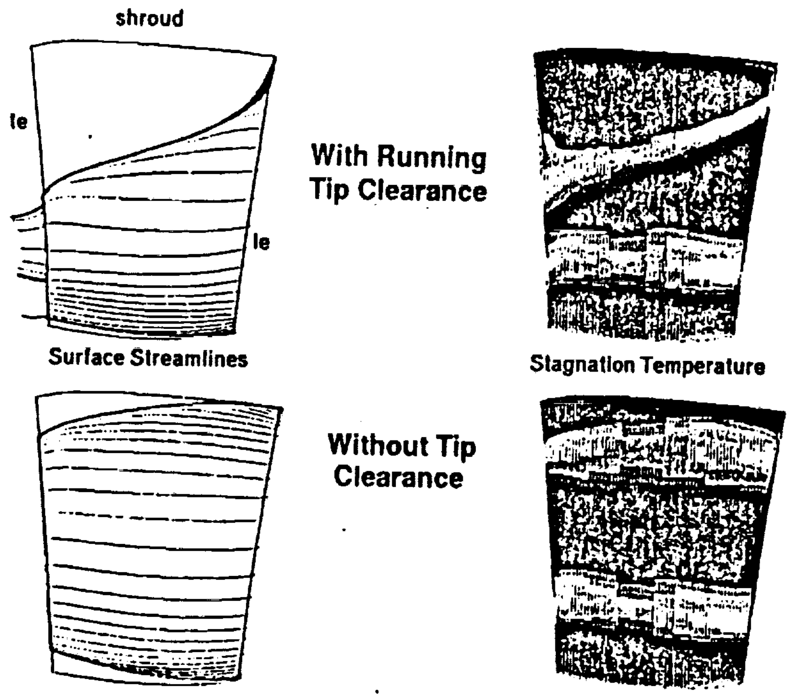
- Develop parallel processing capability for turbine design
- Develop deep throttling capability for space turbopumps
- Complete unsteady model for analysis of complete pump stage
- Verify aerodynamic performance for unique, space propulsion turbine blades

SPACE CHEMICAL PROPULSION PROGRAM
Advanced Expander Test Bed (AETB)
Hydrogen Turbine (First Stage)



Pratt & Whitney SSME HPFTP Second Vane Suction Side

Effect of First Blade Leakage Vortex on Second Vane Flow



BEARINGS

TECHNOLOGY NEEDS:

- Validated design codes and methodologies
- Advanced materials and coatings
- Improved bearing and bearing damper design
- Improved thermohydrodynamic models

TECHNOLOGY CHALLENGES:

- Measure complete bearing fluid mechanic and thermal properties to thoroughly validate codes
- Standardize measurement techniques to determine bearing dynamic coefficients
- Identify propellant compatible and wear resistant materials
- Develop bearing designs tolerant to wide operating ranges and pump transients

TECHNOLOGY BENEFITS:

- Longer Life: Increased reliability, improved maintainability, multi-mission capability
- Improved Performance: Higher speeds, greater stiffness & damping, improved stability

BEARINGS

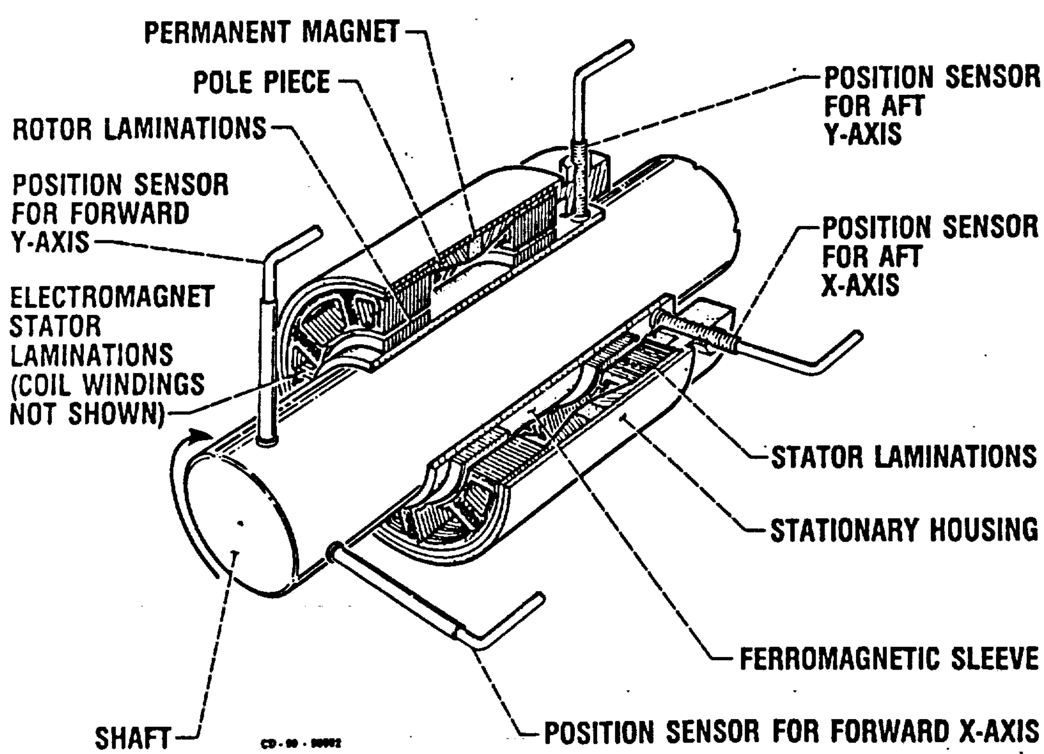
CURRENT PROGRAM

- Experimental testing of LH2 Foil Bearings
- Development of Foil Bearing design and performance prediction code
- Development of dynamic coefficients measurement technique
- Development of hydrostatic bearing steady state and dynamic characteristics code
- Flow visualization experiments of fluid film bearings for code validation
- Experimental testing of a hybrid magnetic bearing to identify technical issues

AUGMENTED PROGRAM

- Demonstration testing of foil bearings in a turbopump
- Experimental testing of LOX foil bearings
- Development of advanced hydrodynamic, hydrostatic and hybrid bearing concepts
- Experimental testing of fluid film bearings to validate codes
- Development of magnetic and superconducting magnetic bearing technology
- Demonstration of magnetic bearings in a turbopump
- Advancement of cryogenic fluid flow and thermal fundamentals to model bearing thermohydrodynamics (turbulence modeling, two-phase flow, cavitation, inertia)
- Establishment of tribomaterials design data base and methodology

HYBRID MAGNETIC BEARING



FOIL BEARING PERFORMANCE IN LH2

OBJECTIVE:

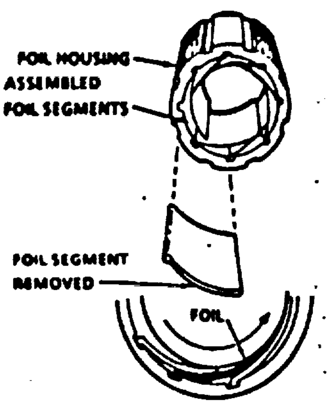
- CHARACTERIZE FOIL BEARING LOAD CAPACITY AND TORQUE IN LH_2

APPROACH:

- COOPERATIVE AGREEMENT WITH AIRESEARCH UNDER 1958 SPACE ACT
- AIRESEARCH PROVIDES ANALYSES CODES AND FIOL BEARING TESTER
- LERC PROVIDES LH_2 TEST FACILITY

JUSTIFICATION

- LONG-LIFE, HIGH LOAD CAPACITY BEARING IS NEEDED FOR CRYOGENIC TURBOPUMPS
- AIRESEARCH HAS DEMONSTRATED LOAD CAPACITY OF 200 + psi IN GN2



PROGRAM HIGHLIGHTS:

- ACHIEVED 240 PSI LOAD CAPACITY IN LH_2
- RAN STABLY AT ALL SPEEDS (10-97 KPRM)
- OVER 150 START/CYCLES WITH NO NOTICEABLE BEARING WEAR
- ACHIEVED 300 PSI LOAD CAPACITY IN LN_2
- ACCUMULATED RUN TIME: 4 HRS IN LH_2 AND 5 HRS IN LN_2

SPACE R&T BAS PROPULSION
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TURBOPUMP SEALS TECHNOLOGY

TECHNOLOGY NEEDS:

- Longer life
- Lower leakage - especially over wide throttling ranges in small turbopumps
- Higher pressure capability
- Dynamic stability, high shaft speed
- Compatible materials

TECHNOLOGY CHALLENGES:

- Low density, wear-resistant materials or material combinations
- Low leakage, non-contacting seals
- High dynamic response of seals to shaft excursions
- Oxygen compatible materials
- Actively controlling clearance

TECHNOLOGY BENEFITS:

- Space Basing capability due to improved reliability and maintainability
- Increased payload by reducing purge gases needed
- Increased component efficiency
- Improved reliability and maintainability

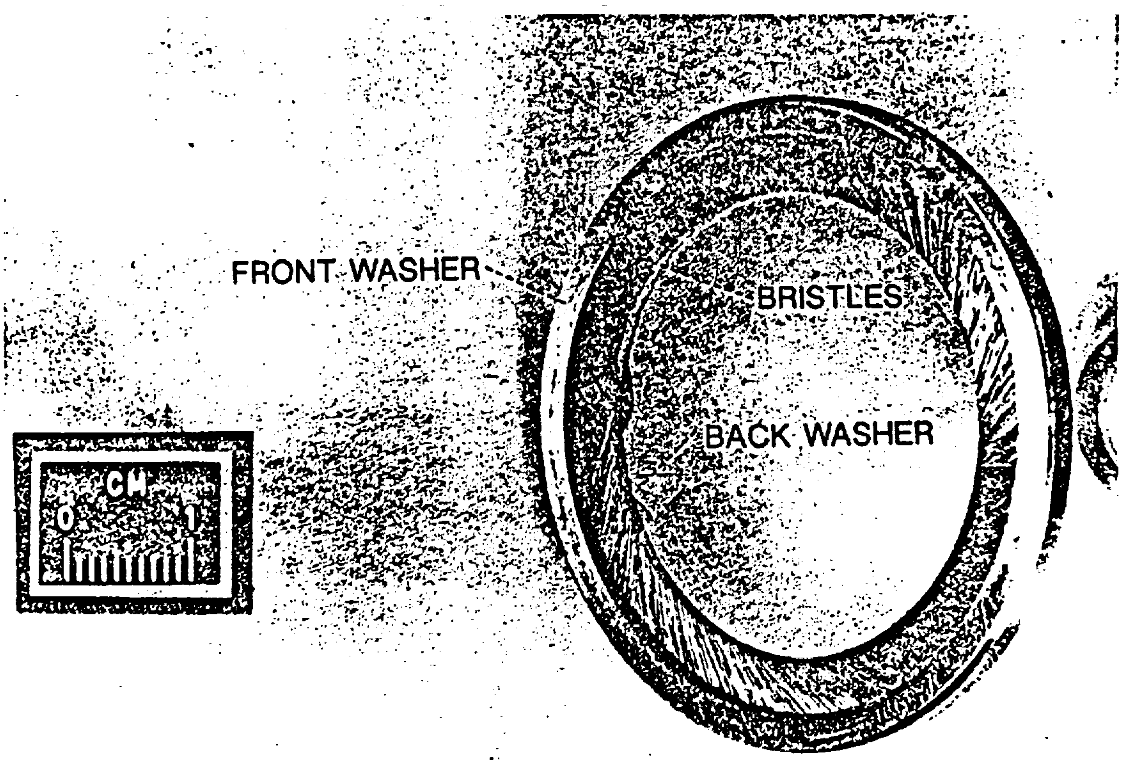
TURBOPUMP SEALS TECHNOLOGY

CURRENT PROGRAM

- BRUSH SEALS FOR CRYOGENIC APPLICATIONS (IN-HOUSE)
  FABRICATION INITIATED FOR TESTER MODS.
- BRUSH SEALS FOR HIGH TEMPERATURE APPLICATIONS (IN-HOUSE)
  ACQUIRED TEST RIG FROM THE AIR FORCE.
- NUMERICAL, ANALYTICAL, EXPERIMENTAL STUDY OF FLUID DYNAMIC FORCES IN SEALS (MECHANICAL TECHNOLOGY, INC.)
  THREE INDUSTRIAL CODES READY FOR USER EVALUATION

PROPOSED AUGMENTATION

- DEFINE AND EXPERIMENTALLY VALIDATE CERAMIC BRUSH SEALS
- EXPERIMENTALLY VALIDATE ANALYSIS AND DESIGN CODE FOR 2-PHASE CRYOGENIC SEALS
- DESIGN AND DEMONSTRATE ACTIVELY-CONTROLLED OR "SMART" SEALS FOR AEROSPACE APPLICATIONS AND DEVELOP THE NECESSARY ANALYSIS AND DESIGN TOOLS



A TYPICAL BRUSH SEAL

Space R & T Base: Propulsion
High Thrust Chemical

Systems Analysis and Engine Cycles

- ***Technical Needs***
  - Higher Performance
    - Combined Cycle
    - Altitude-Compensating Nozzles
    - Full-Flow Staged-Combustion Cycle
    - High-Mixture-Ratio Operation
  - Optimization of Coolant-Side Heat Transfer

- ***Technical Challenges***
  - Higher Gas-Gas Injector Performance
  - Combined-Cycle System Integration
  - High-Aspect-Ratio Cooling Channel Database
  - Mixture Ratio Control

- ***Technical Benefits***
  - Higher Performance
  - Simpler Subsystems
  - Less Severe Operating Conditions
  - Enhanced Heat Transfer

Space R & T Base: Propulsion
High Thrust Chemical

Systems Analysis and Engine Cycles

- ***Current Program***
  - Altitude-Compensating Nozzles
    ⇒ Database on most promising concepts
  - High-Mixture-Ratio Operation
    ⇒ Capability to Operate at High Mixture Ratio Reliably
  - High-Aspect-Ratio Cooling Channels
    ⇒ Database for Future Designs

- ***Augmented Program***
  - Combined-Cycle Engine
    ⇒ Engine Concept That Uses Both Air and Oxygen as Oxidizer
  - Full-Flow Staged-Combustion Cycle
    ⇒ Development of Technology for Gas-Gas Injection and Ox-Rich Preburner
  - Liquid-Air Rocket
    ⇒ Technology to use Liquefied Air as a Propellant
  - CFD Modelling of Coolant Flow in Coolant Passages
    ⇒ CFD Model

SUMMARY

TECHNICAL CHALLENGE
- Long life turbopump components.
- Improved stability and performance of combustion devices.
- Reduced launch mass and cost, enabling SEI missions.

APPROACH
- Validated models, codes and algorithms for component design and analysis.
- Develop benchmark data for supercritical spray dynamics.
- Evaluate advanced turbomachinery sub-components (seals and bearings) design concepts.
- System and cycle analysis for design optimization.
- Fundamental combustion research and material characterization.

PAYOFF
- Improved life, durability, performance and safety in the evolution of high thrust chemical propulsion systems, e.g., SSME and liquid rocket boosters, through advanced concepts and methodologies.
- Reduce SEI costs.

RELATIONSHIP TO FOCUSED ACTIVITIES AND OTHER PROGRAMS

Develop fundamental technologies in direct support of earth-to-orbit, orbit transfer and upper stage propulsion programs. Efforts are coordinated with other Centers and DOD as appropriate.

TECHNOLOGY CONTRIBUTIONS
- Expertise and technology in turbomachinery code development utilized by ATD and NLS designers.
- Combustion stability methodology applied to MSFC TTB and RCS thrusters at JSC.