ABSTRACT

An Overview of Aerospace Propulsion Research at NASA Glenn Research Center

NASA Glenn Research center is the recognized leader in aerospace propulsion research, advanced technology development and revolutionary system concepts committed to meeting the increasing demand for low noise, low emission, high performance, and light weight propulsion systems for affordable and safe aviation and space transportation needs. The technologies span a broad range of areas including air breathing, as well as rocket propulsion systems, for commercial and military aerospace applications and for space launch, as well as in-space propulsion applications. The scope of work includes fundamentals, components, processes, and system interactions. Technologies developed use both experimental and analytical approaches. The presentation provides an overview of the current research and technology development activities at NASA Glenn Research Center .

Overview of Propulsion Research at NASA Glenn

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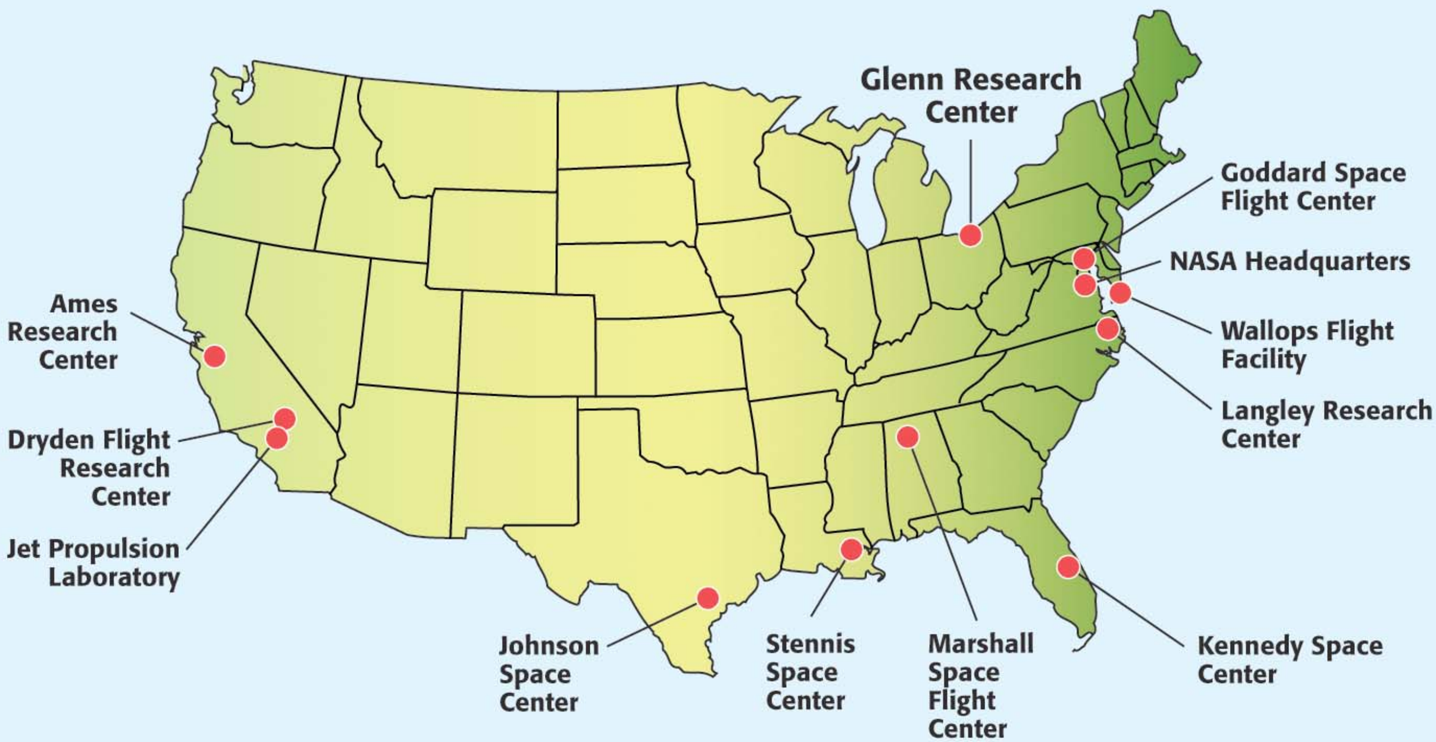
May 2007

NASA Installations



Glenn – Two Campuses Working Together to Achieve NASA's Mission

Plum Brook Station

Location: Sandusky, Ohio
Civil Service FTE: 14
On-site Contractors: 75
Total Area: 6400 Acres

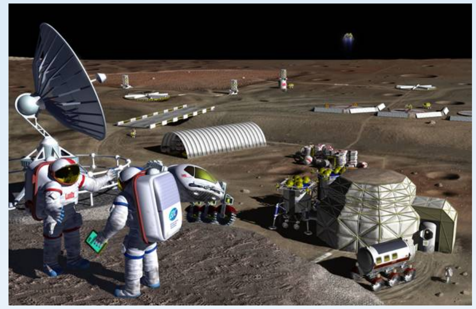
Location: Cleveland, Ohio
Civil Service FTE: 1650
On-Site Contractors: 1200
Total Area: 350 Acres

Lewis Field Main Campus

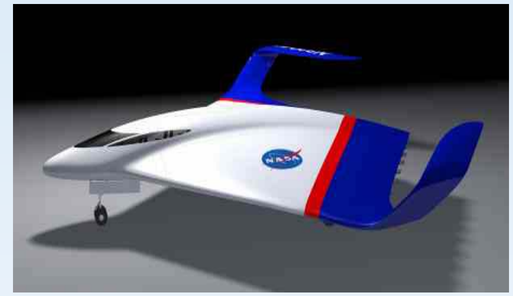
GRC Core Competencies

In-Space Propulsion including Nuclear Systems

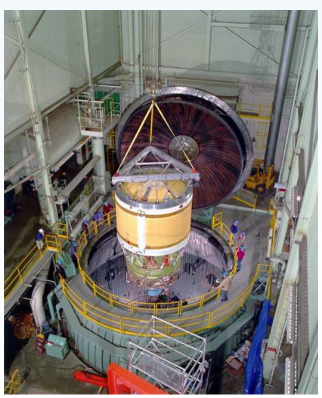
Power and Energy Conversion Systems



Aeropropulsion Systems

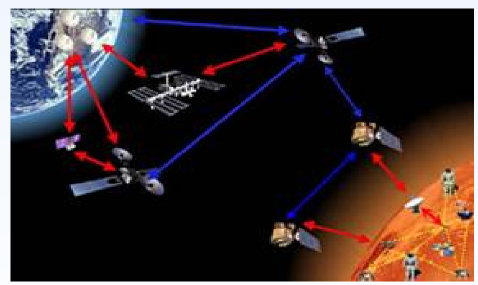


Fluids, Combustion and Reacting Systems Including Gravity Dependence



Interdisciplinary Bioengineering for Human Systems

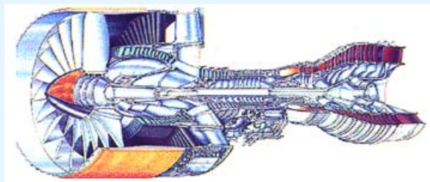
Aerospace Communications Architectures & Subsystems

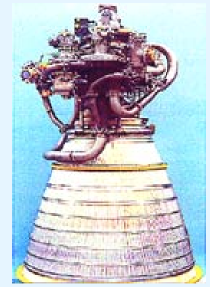


Test and Evaluation for Atmospheric, Space and Gravitational Environments

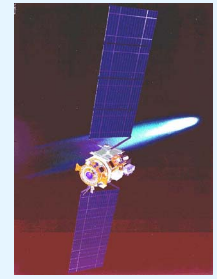
Propulsion

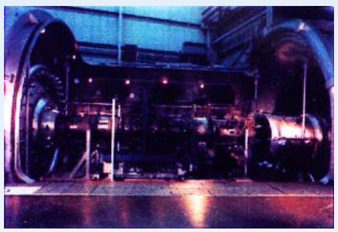
Aeronautics





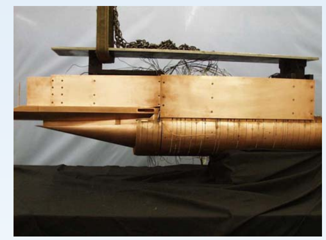
Space





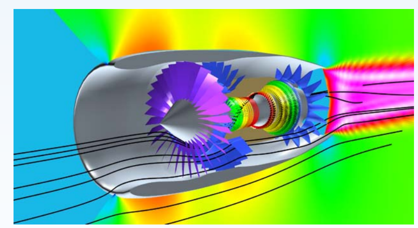
Systems

Components



Fundamental/
Applied Research

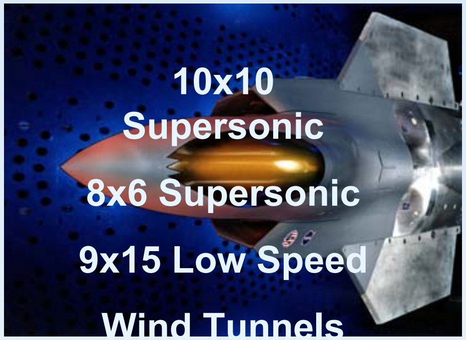
System
Simulations



Core R&D Capabilities

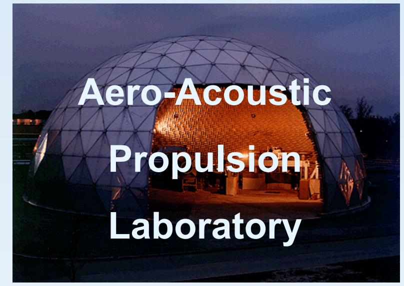
Fluid Mechanics
Heat Transfer
Simulation Models
Combustion
Cryogenics
Turbulence
Transition
Diagnostics
Plasma Physics
Ice Accretion
Acoustics
Turbulence/Chemistry

Aero Test Facilities



Eminent NASA Propulsion Subsonic, Transonic, Supersonic complex

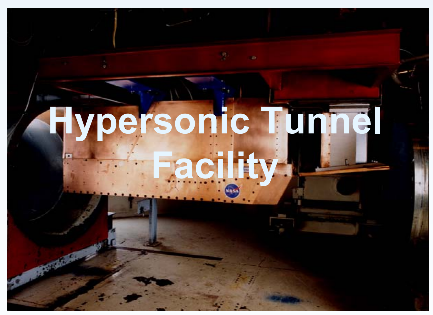
World's Largest Refrigerated Icing Tunnel



Nozzle Acoustic Test Rig

Powered Lift Rig

NASA's Only Full Scale Engine Altitude Facility



Clean Air Simulated

Thirty-six Versatile Engine Component Test Rigs

CD-99-78753

Space Simulation facilities

Space Power Facility (SPF)

World's largest space environment simulation chamber(100-ft diameter by 122-ft high).

Spacecraft Propulsion Facility (B-2)

world's only facility capable of testing full-scale upper-stage launch vehicles and rocket engines under simulated high-altitude conditions

Unique Electric Propulsion test Capabilities

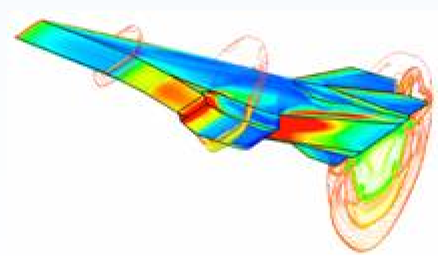
World's Highest Fidelity Space Simulation Chambers
13 Large Facilities, 12 Small
Capability from Concept to Flight

Aero Propulsion – Thrust Areas

- **Subsonic**
  - **Performance – Fuel burn & Weight reduction**
  - **Noise and Emissions (NOx and CO_2) Reduction**

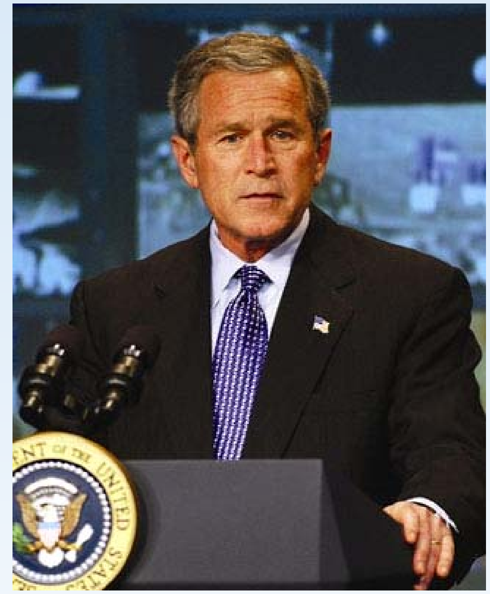
- **Supersonic**
  - **Variable Cycle (Cruise efficiency & Take-off reqmnts.)**
  - **Integration (sonic boom & performance)**
  - **High Altitude Emissions**

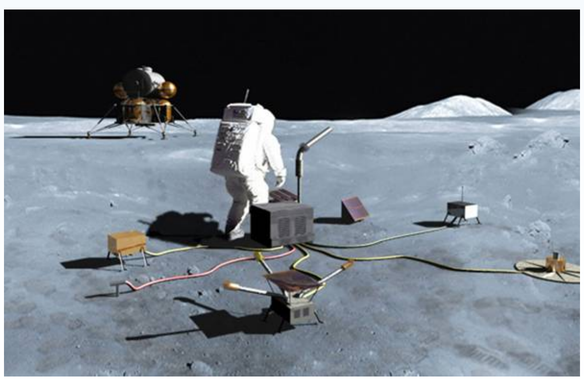
- **Hypersonic**
  - **Mode transition**
  - **Scramjet performance**
  - **Thermal Management**



A Bold Vision for Space Exploration

- Complete the International Space Station
- Safely fly the Space Shuttle until 2010
- Develop the Crew Exploration Vehicle (CEV)
- First crewed CEV flight 2014
- Return to the moon no later than 2020
- Extend human presence across the solar system and beyond
- Implement a sustained and affordable human and robotic program
- Develop supporting innovative technologies, knowledge, and infrastructures





"It is time for America to take the next steps.

Today I announce a new plan to explore space and extend a human presence across our solar system. We will begin the effort quickly, using existing programs and personnel. We'll make steady progress – one mission, one voyage, one landing at a time"

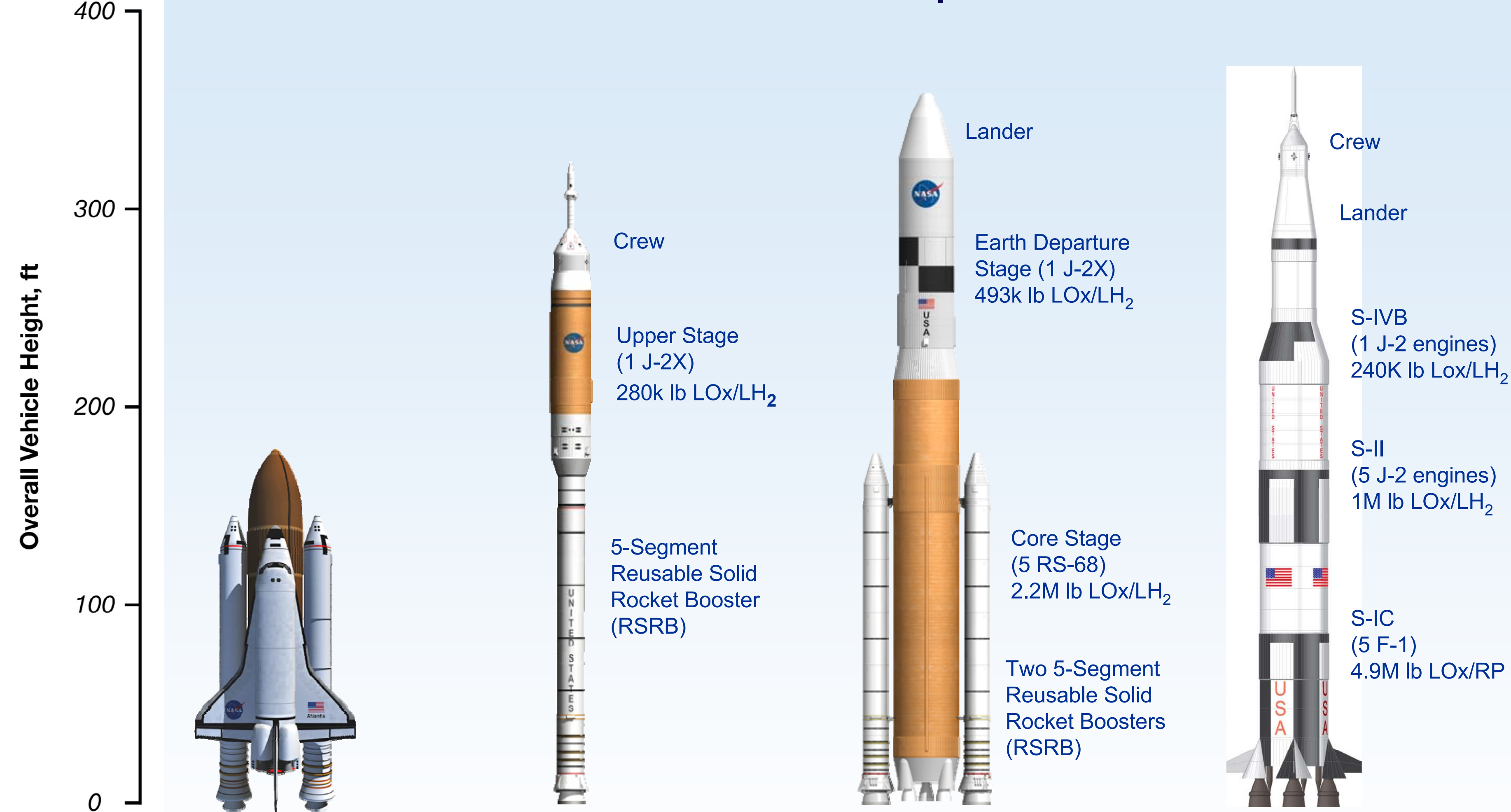
President George W. Bush – January 14, 2004

Constellation Launch Vehicle Elements

Ares I Crew Launch Vehicle

Ares V Cargo Launch Vehicle

Launch Vehicle Comparisons



Space Shuttle

Height: 184.2 ft
Gross Liftoff Mass: 4.4 M lb

55k lbm to LEO

Crew Launch Vehicle Ares I

Height: 321 ft
Gross Liftoff Mass: 2.0M lb

55k lbm to LEO

Cargo Launch Vehicle Ares V

Height: 358 ft
Gross Liftoff Mass: 7.4M lb

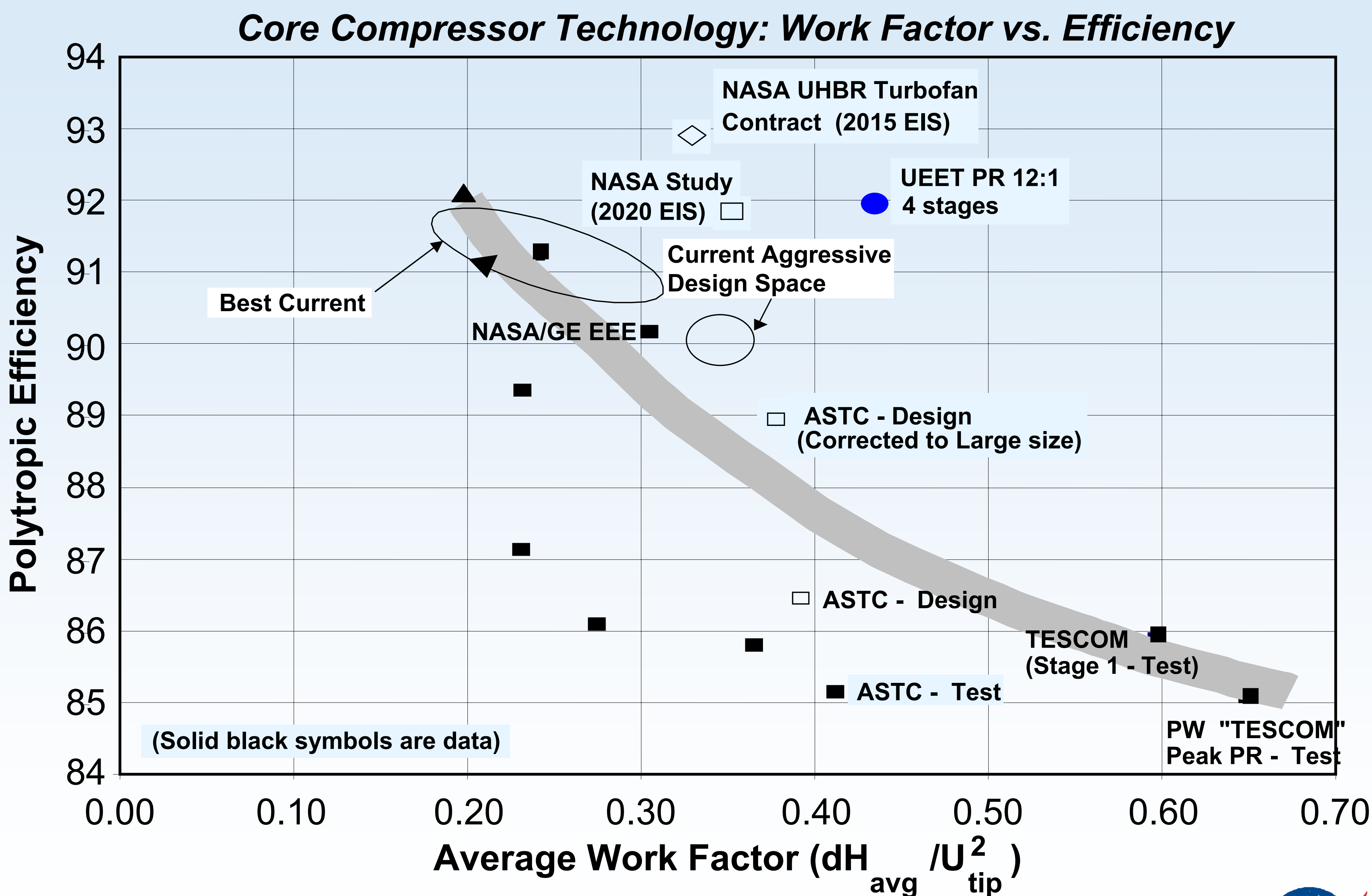
121k lbm to Trans-Lunar Injection (TLI)
147k lbm to TLI in Dual-Launch Mode with CLV

Saturn V

Height: 364 ft
Gross Liftoff Mass: 6.4M lb

121k lbm to LEO

Compressor Technology State of the Art



World-Class Turbomachinery

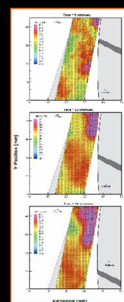
Compressors

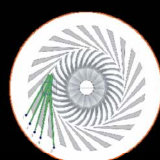
✧ Measurements ✧ Analysis ✧ Simulations ✧

Small High-Speed Compressor Test Facility

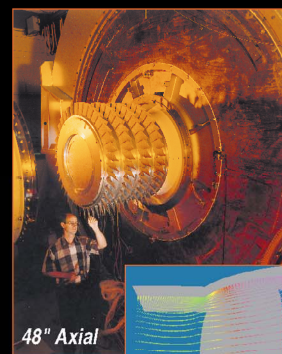
High-speed impeller for turboshaft engine

Particle Image Velocimetry measurements of unsteady impeller diffuser interaction

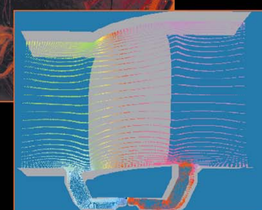




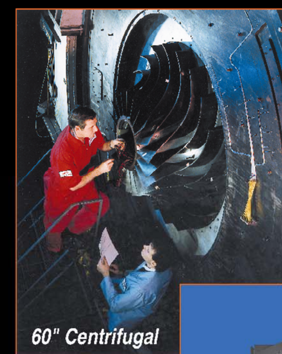
Low Speed Research Facility



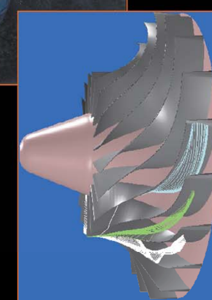
48" Axial



CFD Simulation of stator flowfield including under-platform seal cavity

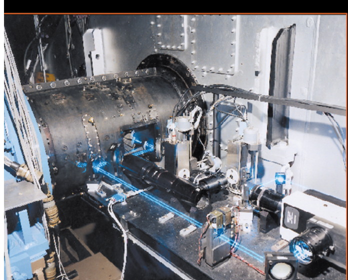


60" Centrifugal

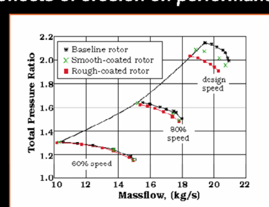


CFD Simulation Calculated Particle Traces

Transonic Compressor Facility Laser Measurement System

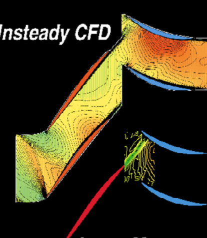


Use of rough coatings to simulate effects of erosion on performance



Wake-Blade Interaction

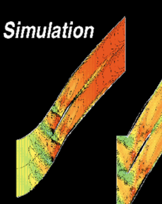
3D Unsteady CFD



Laser Measurements

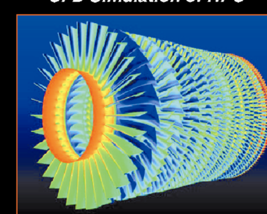
Transonic Rotor Flowfields Axial Velocity Near the Tip

CFD Simulation



Laser Measurements

CFD Simulation of HPC



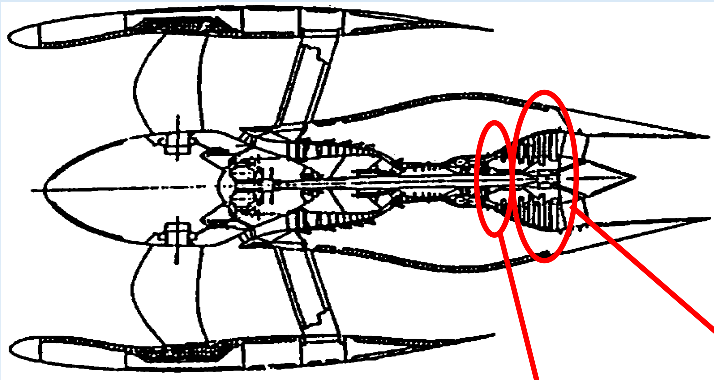
Turbine Research (Aerodynamics & Heat Transfer)

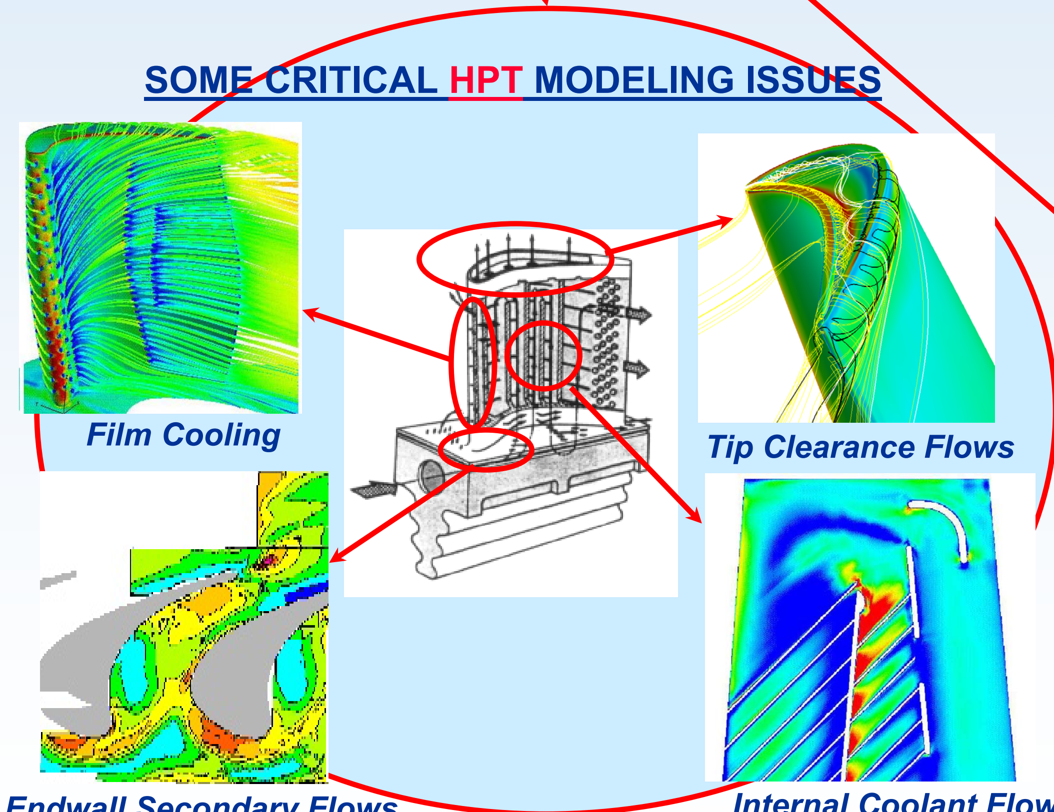
Experimental and Numerical Research for:

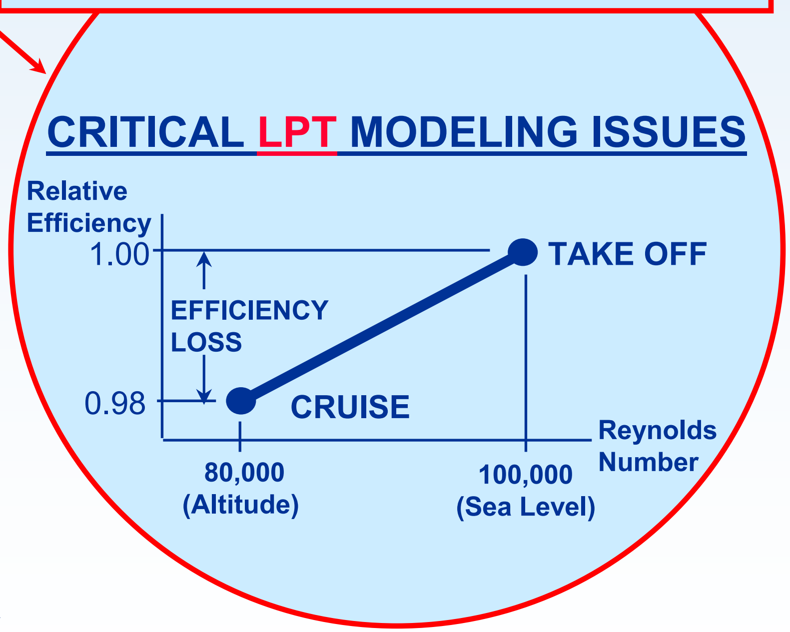
- **High-Pressure Turbine (HPT) -**
  Improved computational models for losses, heat transfer, and coolant flow.
- **Low-Pressure Turbine (LPT) -**
  Understand, model, and control the physical mechanisms responsible for high loss variations

OUTCOME:

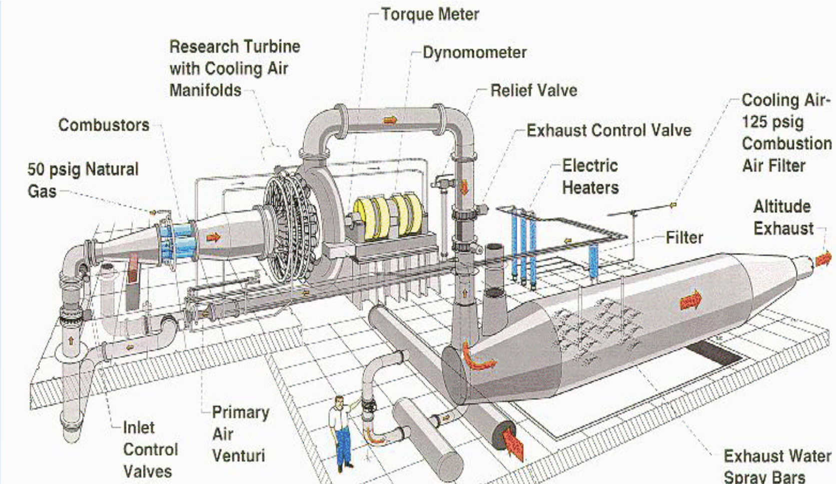
- **Reduced design cycle time & cost**
- **Improved component robustness & efficiency**



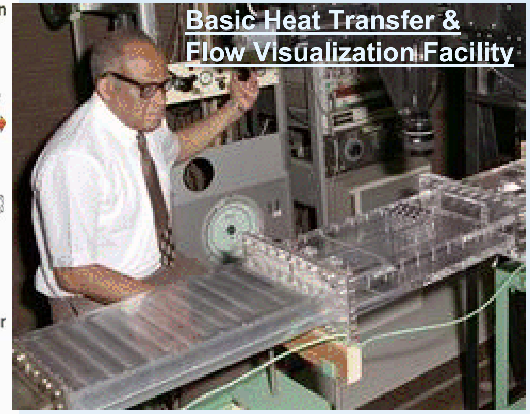




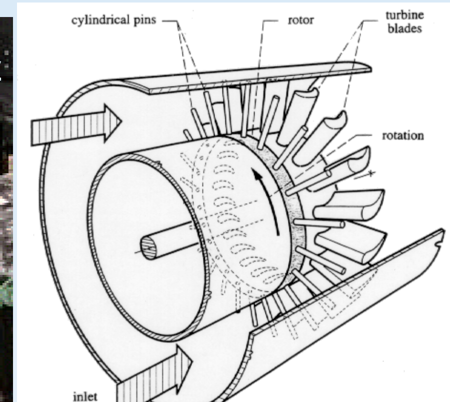
EXPERIMENTAL FACILITIES



W6A Warm Core Turbine Facility



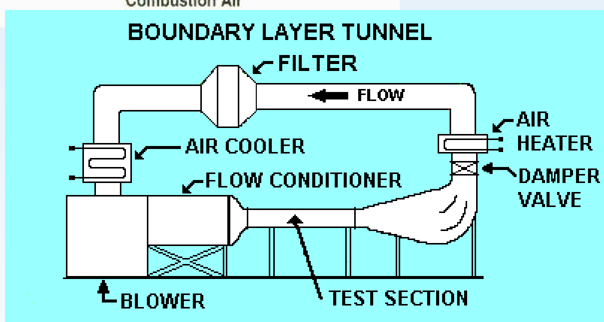
Basic Heat Transfer & Flow Visualization Facility



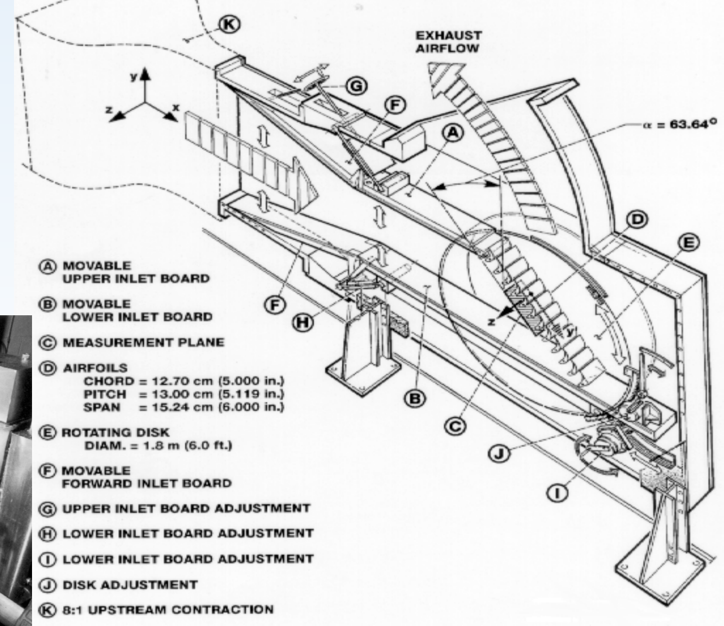
Rotor Wake Rig

CD-94-69912

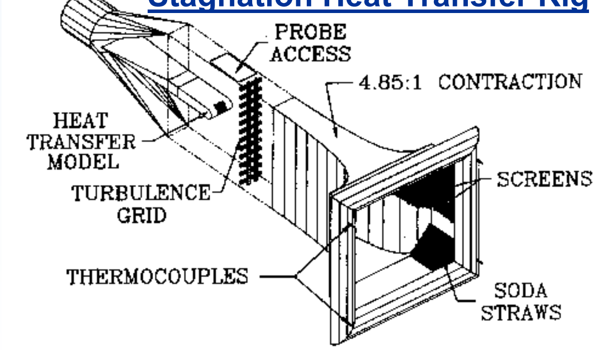
Annular Cascade, Laser Measurements

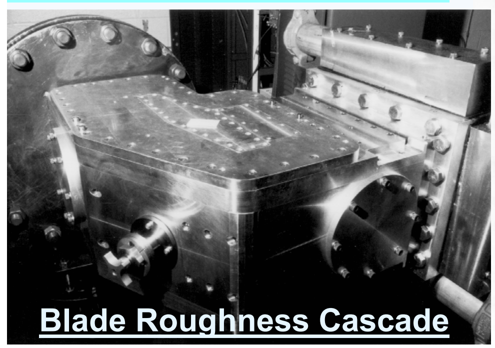


Linear Transonic Cascade



Stagnation Heat Transfer Rig



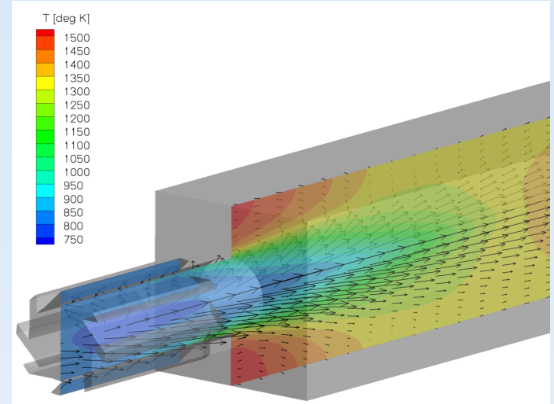


Blade Roughness Cascade

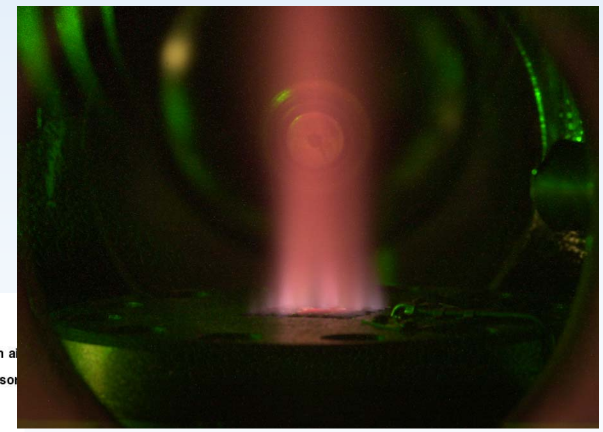
Combustion Branch

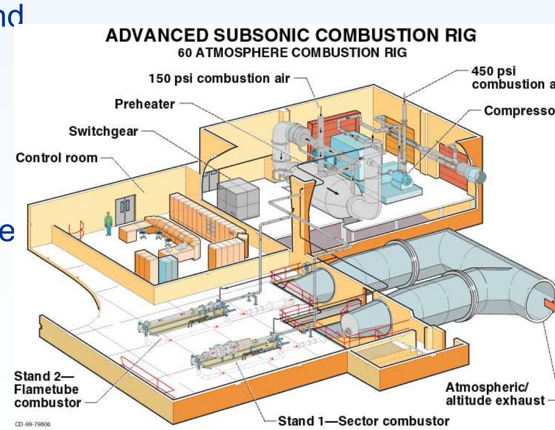
Current Research Areas

- Low Emissions Combustor Development and Testing
- Laser Diagnostics Measurements in Combustion Environments
- Fuel Reforming for Fuel Cells
- In-Situ Fuel Utilization for Planetary Missions
- Ceramic Materials Characterization in Rocket Exhaust
- Constant Volume Combustion Cycle Engine
- Active Combustion Control
- Minimum Ignition Energy Measurement for Fire-Safe Fuels
- National Combustion Code Development and Application
- Combustion Generated Particulate Measurement
- Low NOx Hydrogen Combustion
- Chemical Equilibrium with Applications Code and Thermodynamic Database



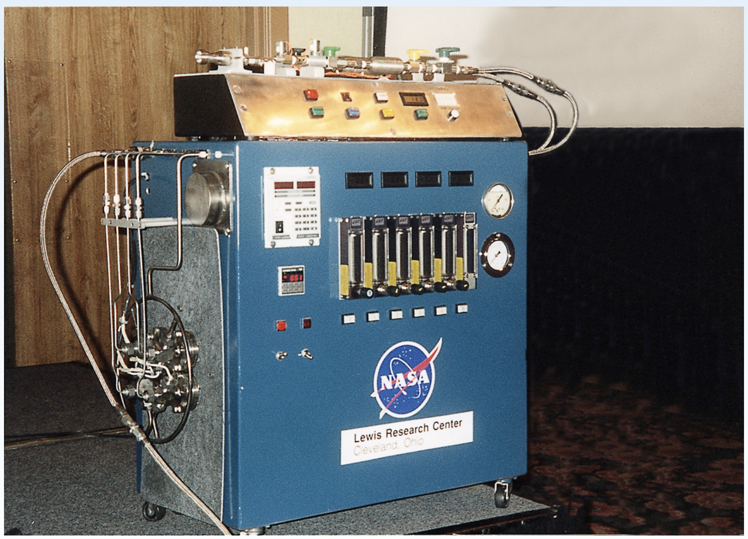
Reacting Flow CFD Predictions


Spontaneous Raman Scattering Laser Diagnostic Development

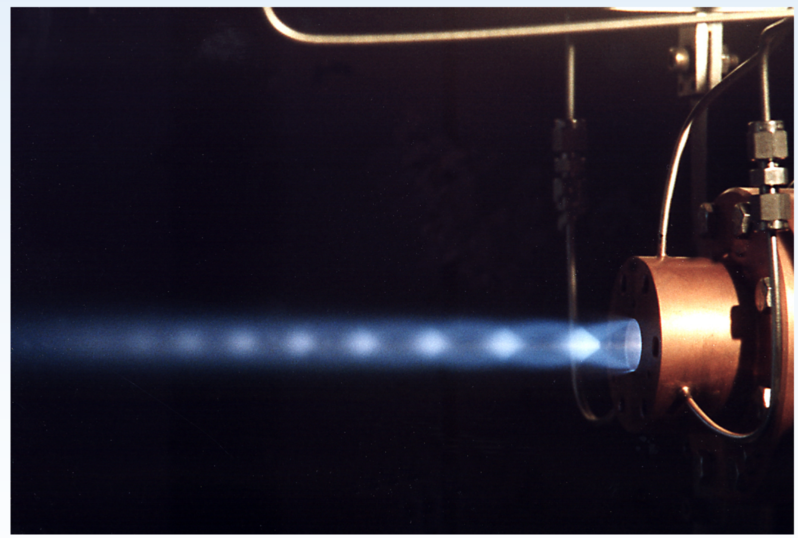


60 atm combustor test facility with laser diagnostics

- Mars In-Situ Propulsion
  - –In-situ propellant production demonstration
  - –Sub-scale combustion and ignition hot-fire testing.

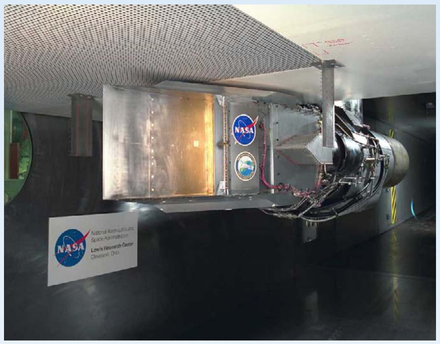


Carbon Monoxide In-situ Production Demonstrator

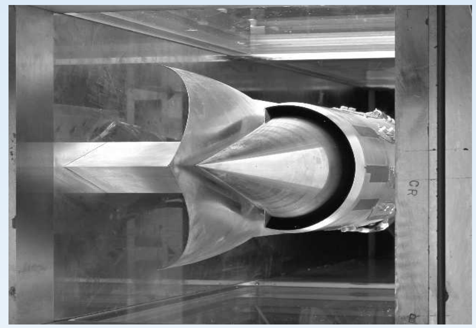


Carbon Monoxide / Oxygen Engine Demonstrator

INLET & NOZZLE RESEARCH



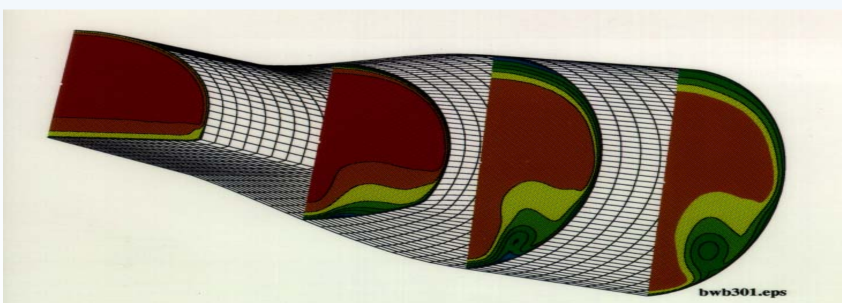
10x10 SWT



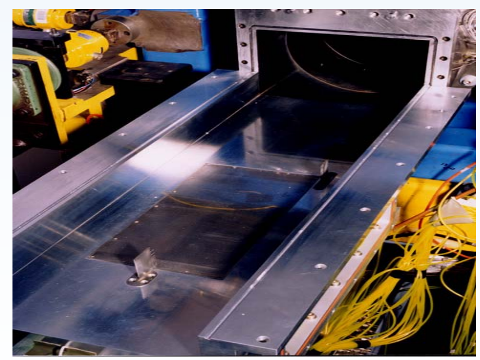
1x1 SWT

FLIGHT

LARGE-SCALE APPLICATIONS

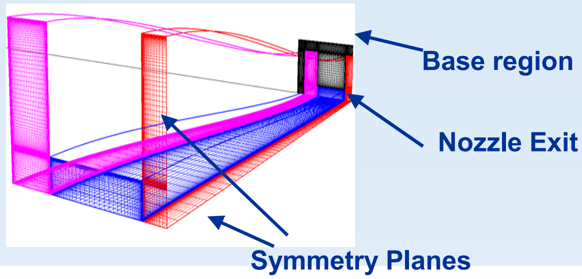


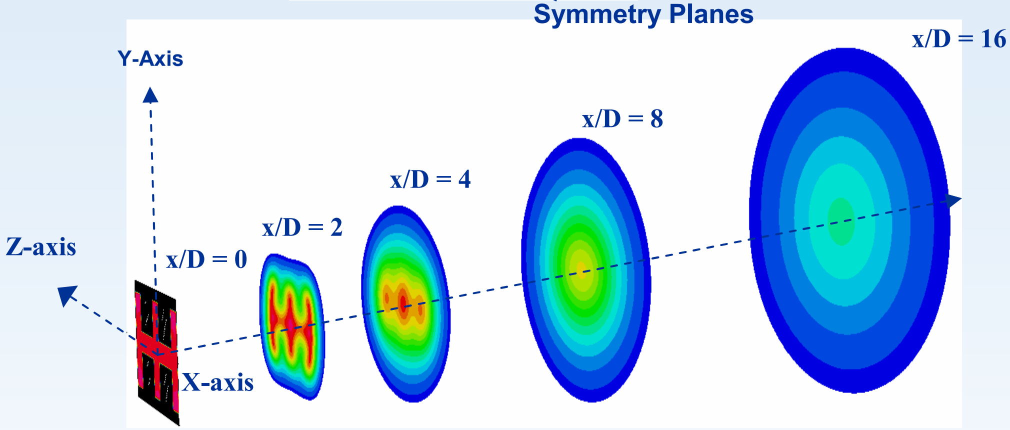
COMPUTATIONAL ANALYSES



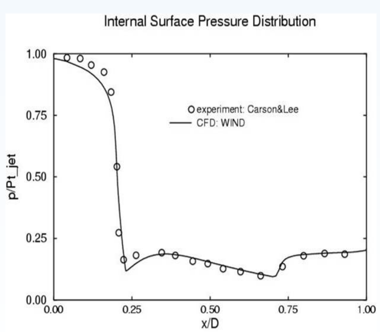
FUNDAMENTAL RESEARCH

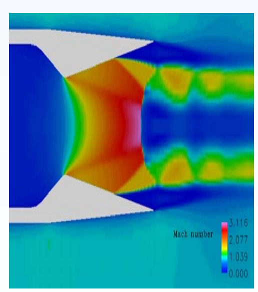
Inlet and Nozzle Research



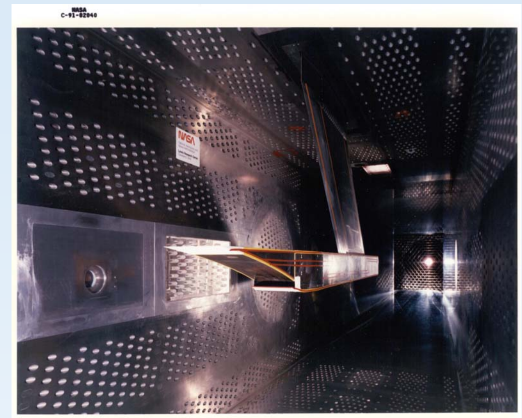


Axial Velocity Contours For 6 Lobe Nozzle (Mach 0.94 Exit)





Off-Design Computational Analysis of a Supersonic Cruise Nozzle

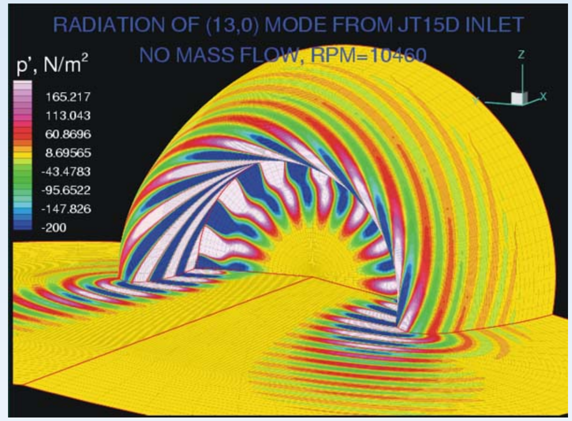


NASP Hot-Flow Single Expansion Ramp Nozzle (SERN)
8’ x 6’ Supersonic Wind Tunnel Nozzle Test

Schlieren Photograph NASP Cold-Flow Single Expansion Ramp Nozzle (SERN) 10’ x 10’ Supersonic Wind Tunnel Test, M≈2.0, NPR≈3.0

RTA/ Acoustics Branch

Propulsion Systems Noise Research



Noise Reduction

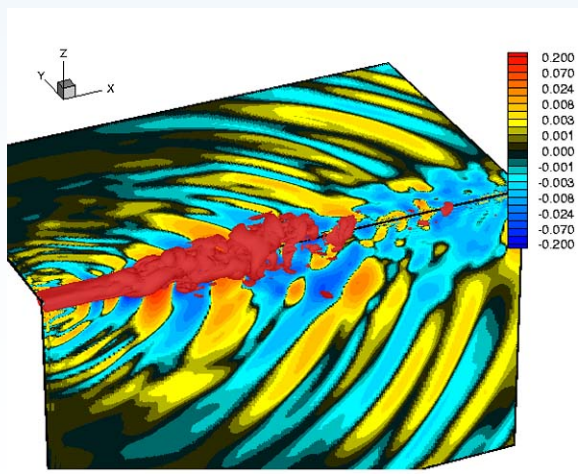
- Concept development

Experiments

- Engine noise source identification
- Concept evaluation

Numerical Methods

- Model development
- Noise Prediction

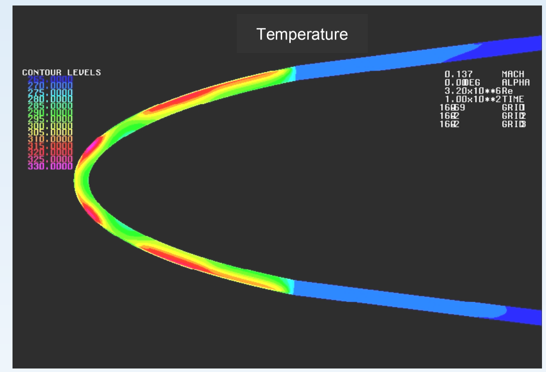


Icing Branch
Aircraft Icing Research

Icing Tunnel Research

Experimental Methods & Databases

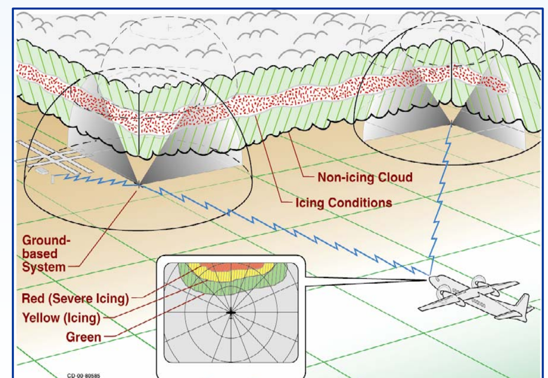
Computational Tools



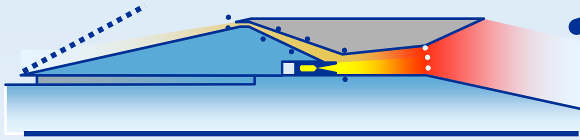
Flight Research

Education & Training Tools

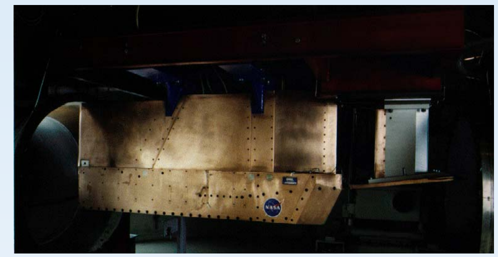
Aircraft Ice Protection



Engine Systems Branch



- •Engine System Concepts
  - •RBCC, TBCC
- •Component Interactions

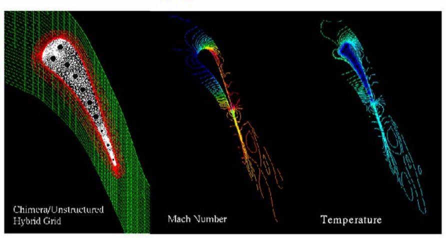


- •Engine System Testing
- •Testing Techniques

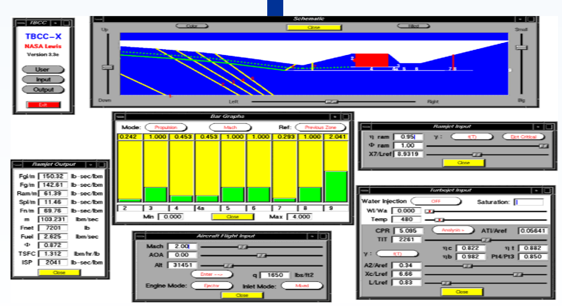
Advanced Propulsion Systems and Technology

- •New concepts
- •Improved Propulsion System:
  - – Efficiency
  - – Affordability
  - – Performance
  - – Environment

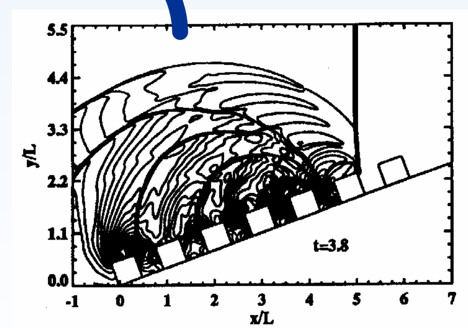
Hybrid Chimera/Unstructured Grids
for
C3X Cooled Turbine Cascade
with
Conjugate Heat Transfer



•Multidisciplinary Methods

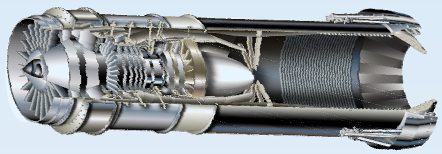


•Propulsion System Simulation



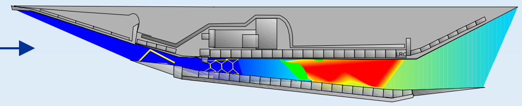
- •Advanced Numerical Methods
- •Parallel Processing

Composition of a Hypersonic TBCC Propulsion System

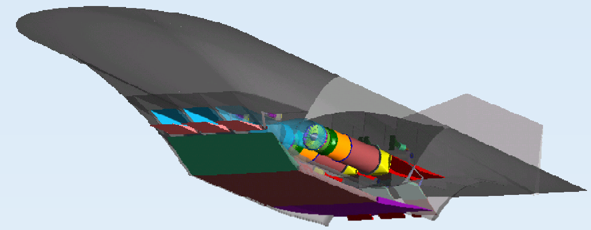


Low-Speed
Supersonic RTA propulsion
Mach 0-4+

+



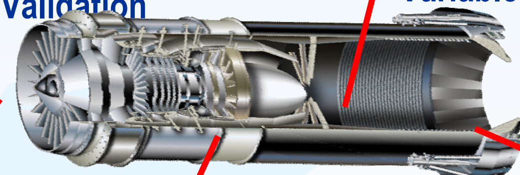
High-Speed
Hypersonic Scramjet propulsion
Mach 4-15



Hypersonic TBCC propulsion
Mach 0-15

Fan Technology Challenges Addressed by RTA:
- Supersonic inlet + fan stability & performance
- High turbomachinery loading for reduced weight
- Operability across wide flight Mach range
- Optimized Thrust / Frontal Area – No IGV, Wide Range
- Design Capability Enhancements & Validation

Mixer/Augmentor Challenges Addressed by RTA:
- Variable cycle performance & operability across wide flight Mach range
- Reduced augmentor/nozzle weight per durability
- Expanded combustion stability envelope w/ high heat release
- Trapped Vortex Combustor
- Variable Area Bypass Injector System for Multiple Design Point Optimization



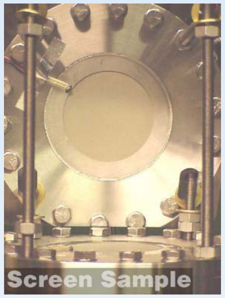
Integration Technology:
- INLET / Engine Matching over wide range of operation / distortions
- PAI
- Thermal Management

Turbine Technology Developments:
- Advanced Materials Applications
- High Temperature Bearings
- Thermal Management

Nozzle Technology Developments:
- CMC Materials Applications
- Highly Integrated Exhaust Nozzle Development
- Thermal Management

Advanced Technology Requirements are Similar for both High Mach Cruise & Accelerator Applications.
These technology requirements are significantly beyond today's State of the Art.
Variable Cycle Engine Enabling to Supersonic / High Speed Aircraft

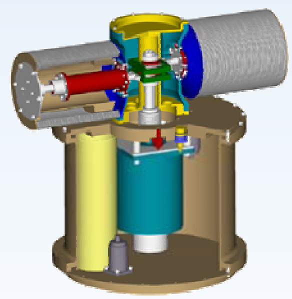
Propellant Systems Technology Branch



Liquid Acquisition
Devices for
Low-Gravity
Fluid Supply

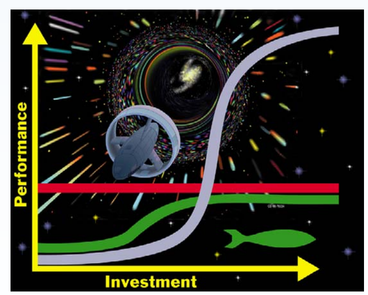
Thermal Control
Technology for Long Term
In-Space and Planetary
Cryogenic Storage

Advanced Cryogenic Propellants
High Energy Density Materials



Fluid Mass Gauging
For Low-Gravity
Tankage Systems

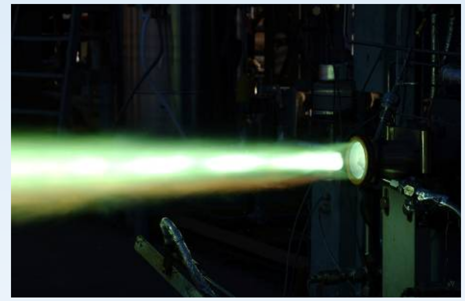
High Density Propellants
For Reusable and Expendable
Launch Vehicles



Breakthrough Propulsion
Physics for Interstellar Space
Transportation Systems

- **Risk: Cryogenic Ignition – Reliability**
- **Objective: Robust ignition of LOx/LCH4 propellants over range from cold gas to liquid conditions**
- **Approach: Build on successful GOx/methane ignition work and cryogenic LOx/Ethanol ignition work. Leverage past experience for current testing.**

Aerojet 870 lbf LOx/Ethanol Engine Hot-Fire Test (WSTF-3/06)



LOx/CH4 2" Engine Hot-Fire Test (MSFC – 12/05)

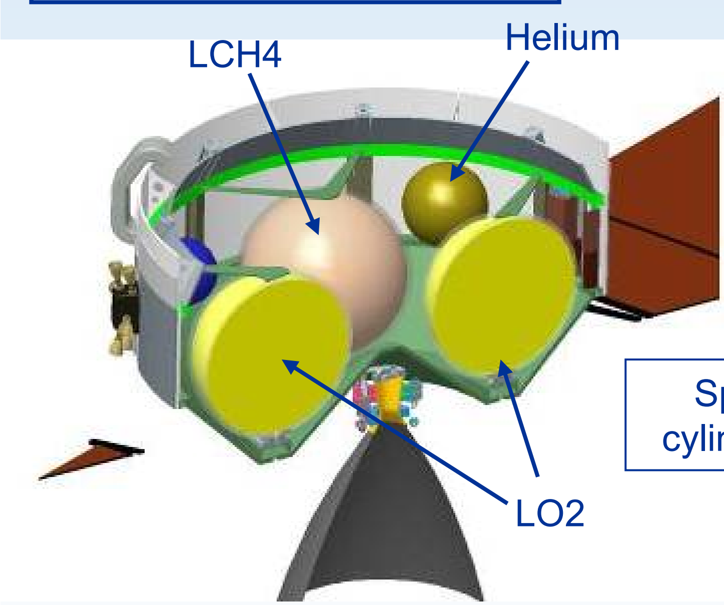
RCS Workhorse Igniter test at GRC (6/06)

Main Engine Igniter test at MSFC (8/06)

Main Engine Workhorse Igniter test at GRC (9/06)

CEV Cryogenic Propellant Storage and Distribution

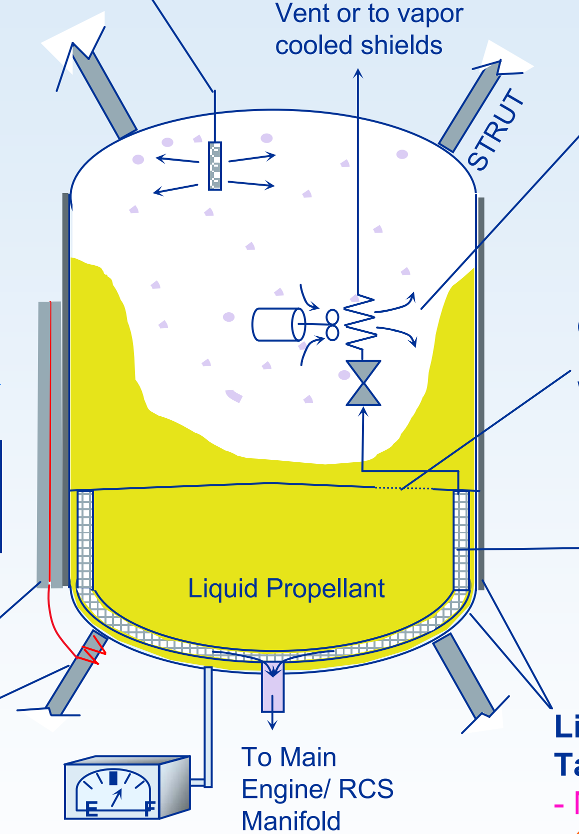
Conceptual SM Tank Configuration



Spherical or cylindrical tanks

Pressurization
- Cold helium

SM Cryogenic Tank Details



Pressure Control
- Zero-g venting (thermodynamic vent and heat exchanger)

Liquid Acquisition
- Capillary retention devices for OMS/RCS

Lightweight Cryogenic Tank
- Metallic (Al-Li)
- Composite overwrap (pressure fed system)

Thermal Control
- Insulation (launch environments and in-space)
- Vapor cooled shields
- Low conductivity/ cooled support structure

Propellant Gauging
- Settled propellant
- Inventory (Bookkeeping)
- Pressure-volume-temperature (PVT)
- High accuracy zero-g techniques

Color Code for Text

Pink - flight or extensive ground demonstration
Blue - key components ground tested
Orange - technology development required

Plasma Propulsion - Deep Space Applications

$$\frac{Mass_{final}}{Mass_{initial}} = e^{-\Delta v / velocity_{exhaust}}$$

High specific impulse (exhaust velocity) yields low propellant mass requirement and high delivered payload.

In-Space Propulsion - Technology Thrusts

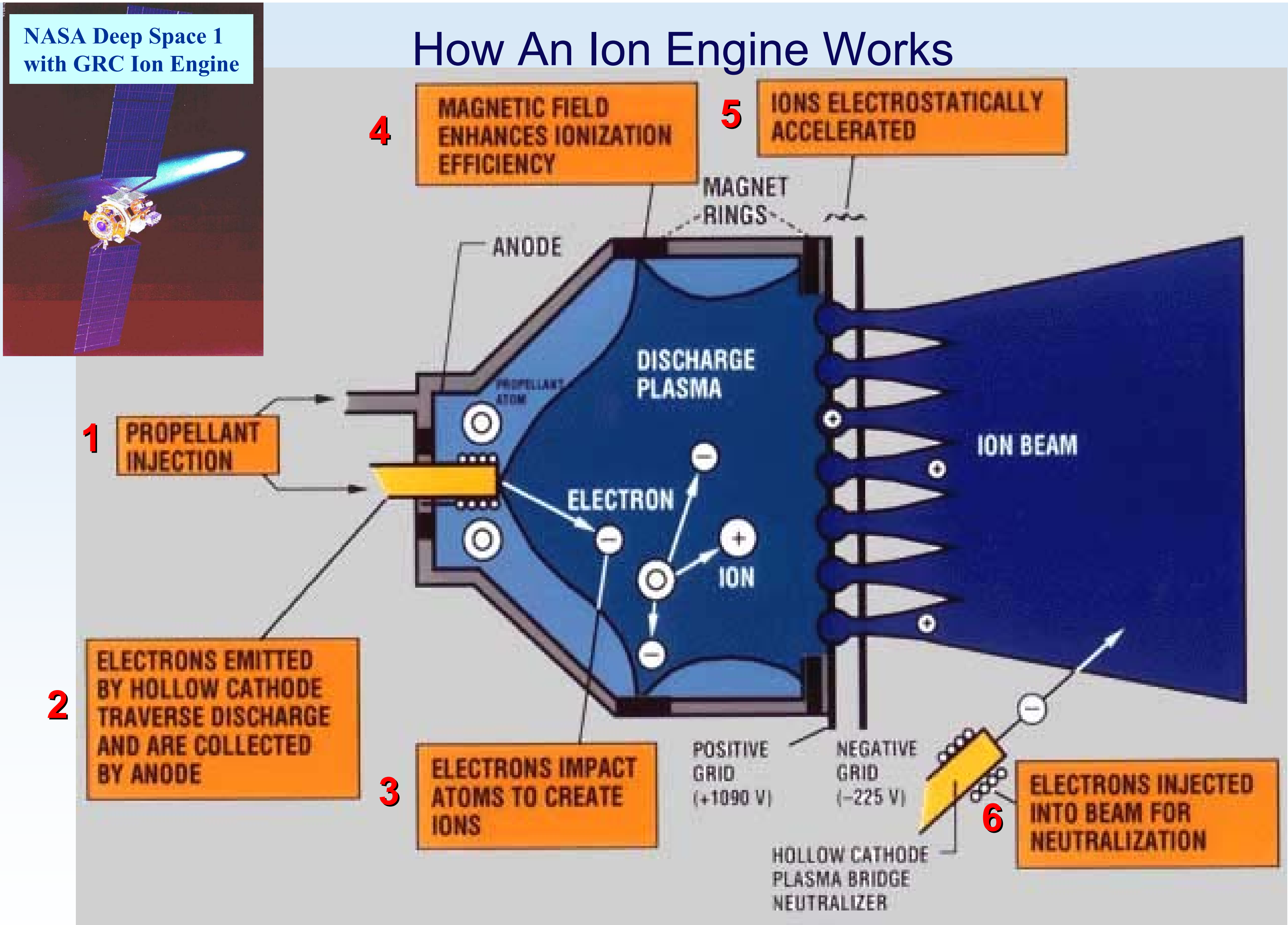
Electrostatic Propulsion

- Ion Propulsion
- Hall Thrusters

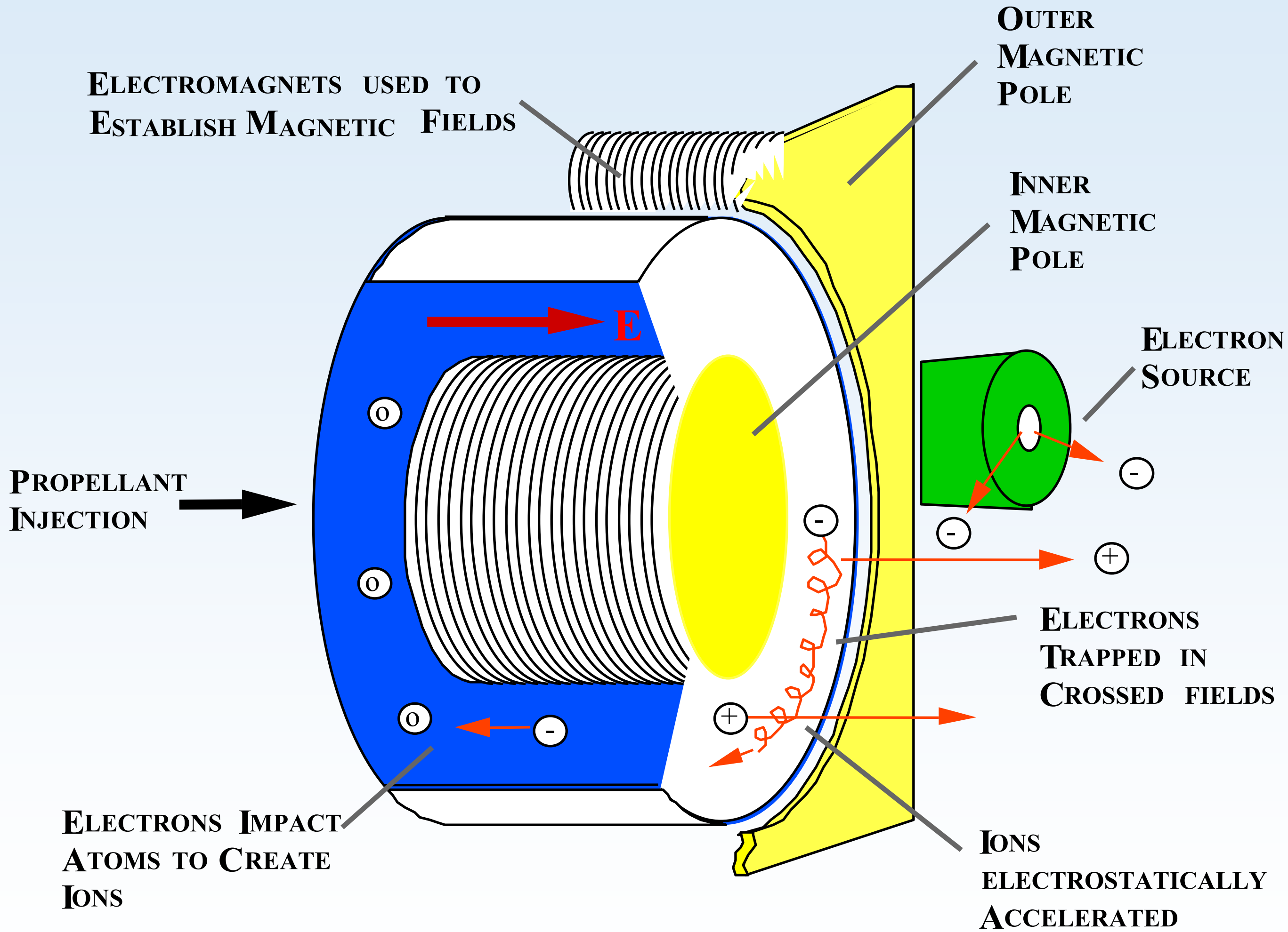
Electromagnetic Propulsion

- Magneto Plasma Dyn. (MPD) Thrusters
- Pulsed Inductive Thrusters (PIT)
- Pulsed Plasma Thrusters (PPT)
- Adv. Plasma Concepts

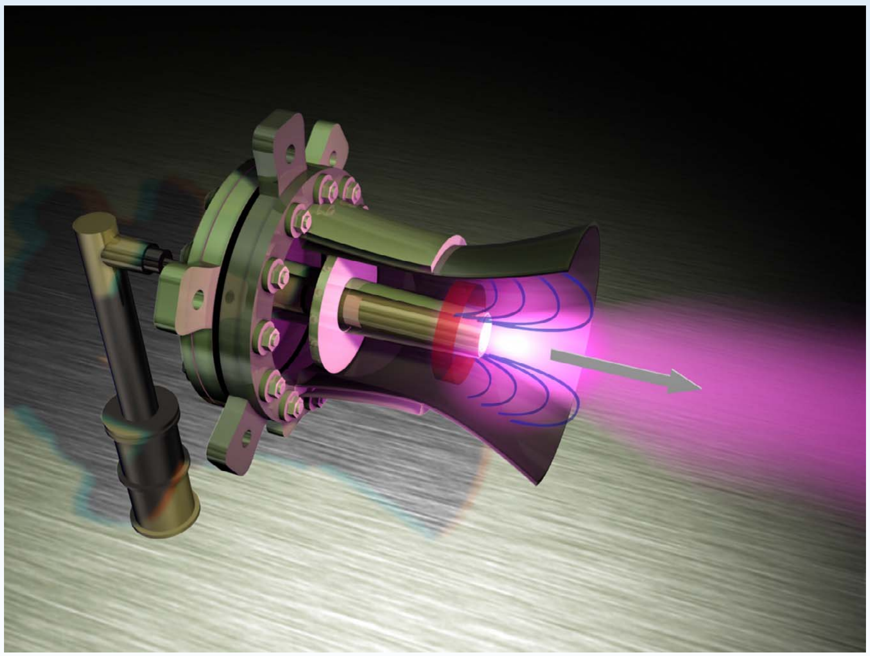
How An Ion Engine Works



Hall Thruster Technology



MAGNETOPLASMADYNAMIC (MPD) THRUSTER

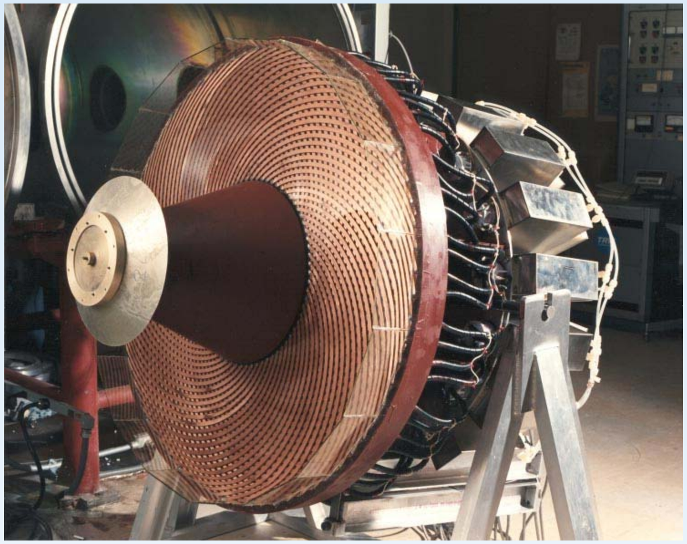


- INTERACTION OF RADIAL DISCHARGE CURRENT WITH SELF-INDUCED AZIMUTHAL MAGNETIC FIELD CREATES AXIAL J×B BODY FORCE

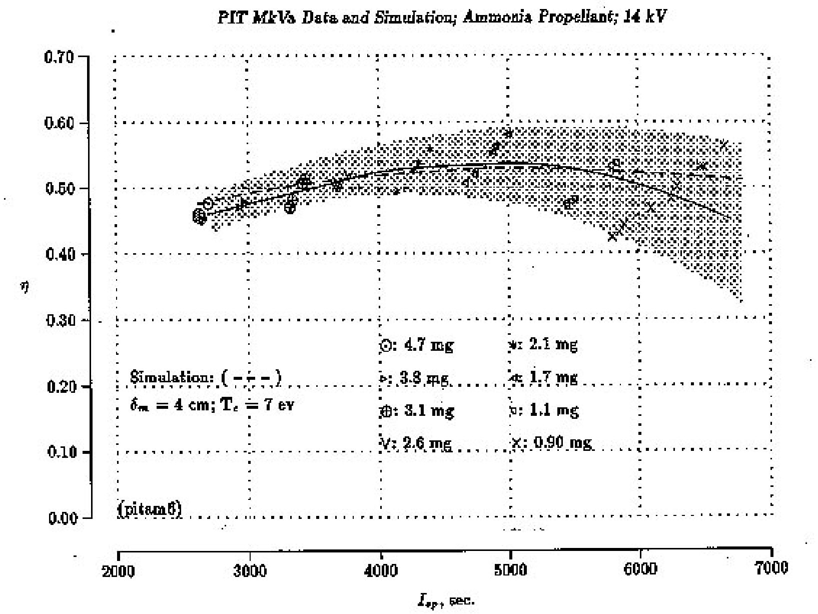
- APPLIED MAGNETIC FIELDS MAY IMPROVE THRUSTER EFFICIENCY, MITIGATE ONSET OF THRUSTER INSTABILITIES

- INVESTIGATE PERFORMANCE AT MW POWER LEVELS

PULSED INDUCTIVE THRUSTER



- SINGLE-SHOT PERFORMANCE DEMONSTRATED AT TRW OVER A WIDE RANGE OF Isp VALUES



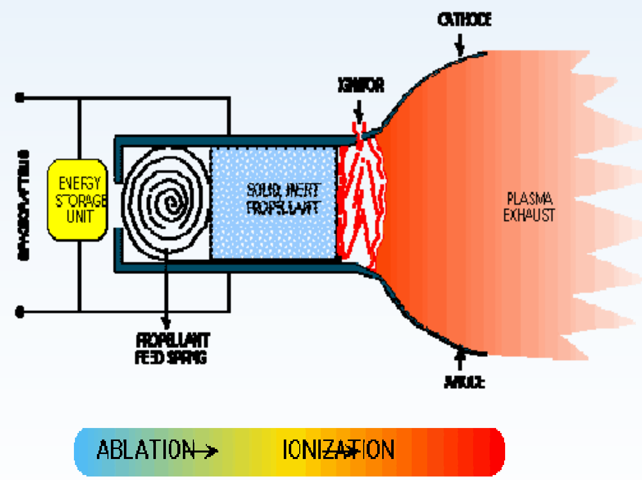
- EFFICIENT OPERATION WITH SPACE-STORABLE PROPELLANTS

- Pulsed discharge current generates a transient magnetic field (dB/dt)
- The changing magnetic field produces an electric field above the coil
- The electric field ionizes the gas propellant and generates a plasma current
- Thrust is produced by the repulsive force generated between the plasma current and the primary discharge current remaining in the induction coil

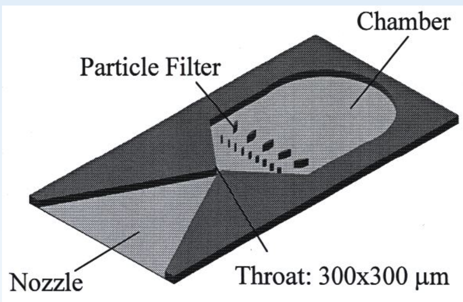
Electromagnetic Propulsion - Low Power
Pulsed Plasma Thrusters (PPTs)

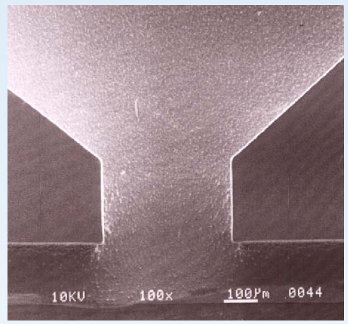
NASA EO-1 with GRC PPT Engine

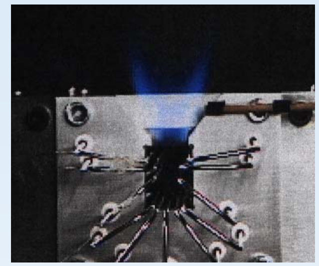
- Unique features of PPTs
  - Only propulsion option which operates at low power (< 100W), high specific impulse (> 1000s), to meet low impulse bit mission applications.
  - Simple Design
    - Solid fuel, no slow-acting, leaky valves or pressurized vessels
    - One moving mechanical part: fuel feed spring
  - Ease of Handling/Storage
    - Solid fuel installed during PPT assembly
    - Safe handling during integration, test and launch operations
    - LES 8/9 PPT successfully fired after >10 years in storage



Small Chemical Propulsion Technology
Micropropulsion







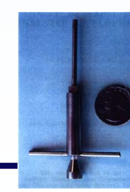
Cold Gas N2
- **Isp = 70 sec**

High-Density, High-Performance System

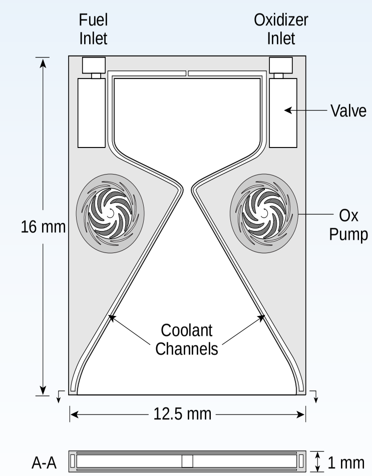
Gas Generator Solids
- **Isp > 230 sec**
- **Solid Storage**
- **Diode Laser Ignition**
- **Valveless System**
- **Modular**

High-Performance Gas System

Warm Gas (N2/H2/O2)
- **Isp = 130 sec**
- **Minimal Added Complexity (Catalyst)**



MEMS Bipropellant
- **Isp $\geq$ 300 sec**
- **Pump-Fed Biprop**
- **3-lbf Thrust**
- **T/W = 2000:1**
- **Modular**



In Closing

GRC is aligned and focused on achieving NASA mission success.

Unique combination of talented people and unique facilities & tools, well aligned to our interdisciplinary core competencies.

Our core competencies have positioned us to strategically encourage and accommodate partnerships with industry, academia and other govt. agencies – Recognized Leader in technology development & transfer