Integrated Powerhead Demonstration (IPD)

IHPRPT Phase I Cryoboost Demo

Nov 2004

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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **OCT 2004**	
2. REPORT TYPE	
3. DATES COVERED **-**	
4. TITLE AND SUBTITLE **Technology Investment Agreement (TIA) Integrated Powerhead Demonstration**	
5a. CONTRACT NUMBER	
5b. GRANT NUMBER	
5c. PROGRAM ELEMENT NUMBER	
5d. PROJECT NUMBER **4922**	
6. AUTHOR(S) **Stephen Hanna**	
5e. TASK NUMBER **02RT**	
5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Air Force Research Laboratory (AFMC),AFRL/PRSE,4 Draco Drive,Edwards AFB,CA,93524-7160**	
8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	
10. SPONSOR/MONITOR'S ACRONYM(S)	
11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**	
13. SUPPLEMENTARY NOTES	
14. ABSTRACT **N/A**	
15. SUBJECT TERMS	

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**		**14**	

Overview

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  - Rocketdyne FTP
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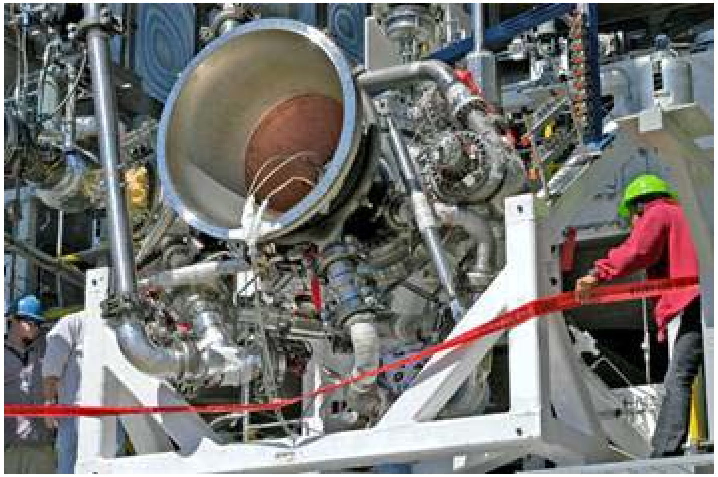
Integrated Powerhead Demonstration Engine

- Objectives
  - Demonstrate Feasibility and Benefits of Full Flow Cycle, which enables 10 times the engine life and reliability when compared to the Space Shuttle Main Engine
  - Provide Key Component Technology Validation for Boost & Upper Stage Rocket Engines
    - Hydrostatic Bearings
    - Single Piece Turbine Blisk
    - HIP bonded high Pc Main Combustion Chamber
    - Channel Wall Nozzle
    - Gas-Gas Main Injector
    - LOX rich Material development
    - Platelet Injector design
  - Provide Validation of Tools and Materials being used by prime contractors
- Mission Success Criteria
  - The IPD Project will be successful after demonstrating the feasibility and benefits of the full flow engine cycle via hot fire testing

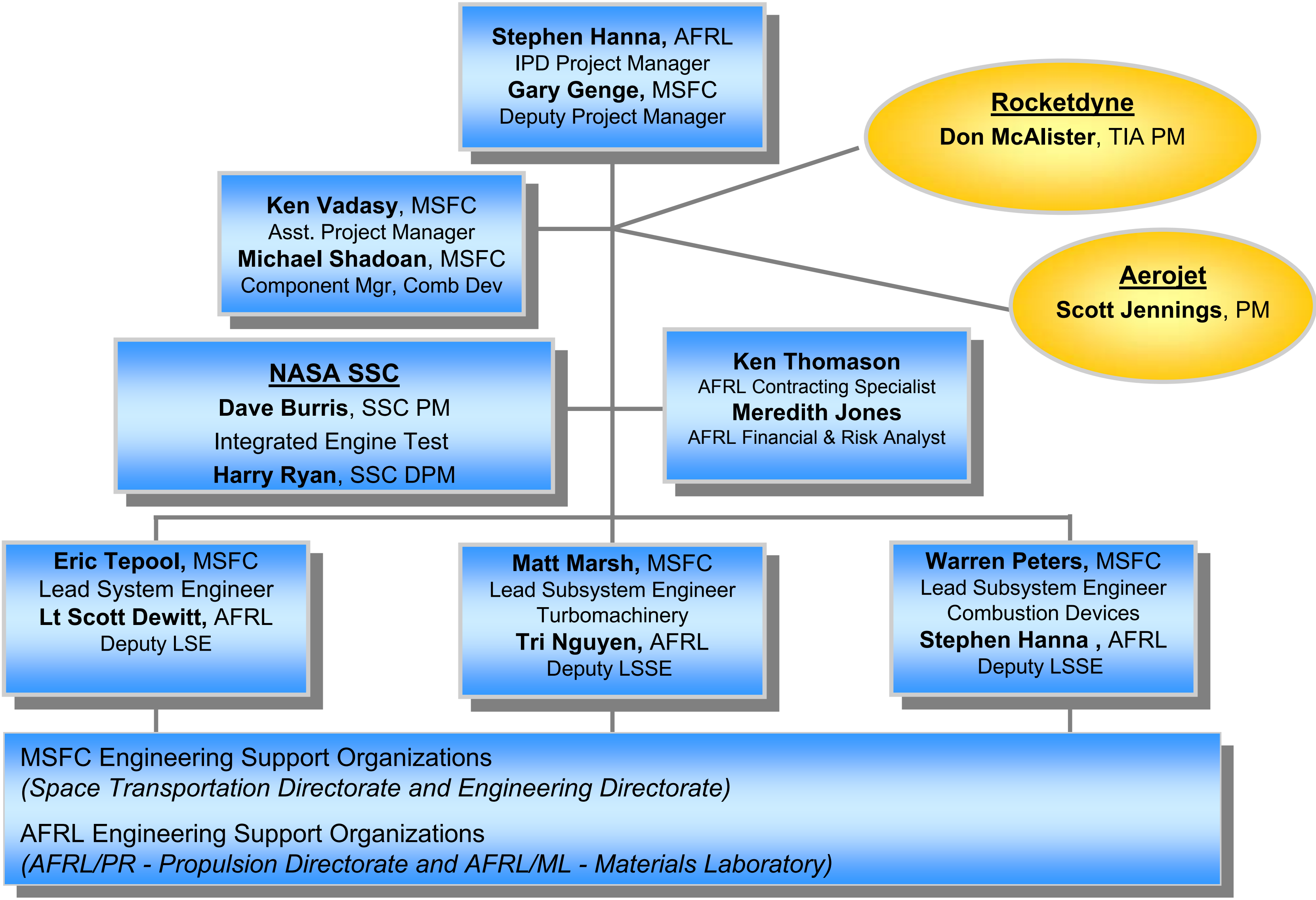
IPD Ground Demonstrator with Thrust Mount



IPD Ground Demonstrator Engine installed in E1 Complex Cell 1

IPD Management

IPD is a Joint USAF/NASA Rocket Engine Program



Benefits of IPD Full Flow Cycle

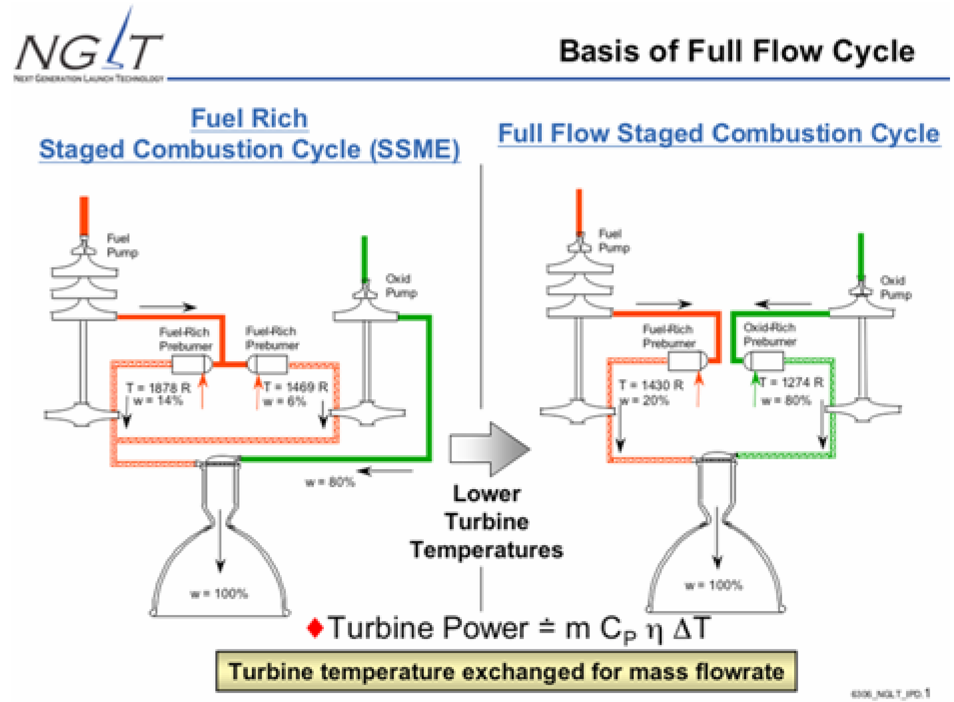
- **Importance of Benefit**

  The Full Flow Engine Cycle provides benefits for the next generation engine systems

  – Reduced Turbine temperatures to improve turbine life and increase reliability

  – Elimination of two Criticality 1 failure modes by elimination of turbopump interpropellent seal and need for heat exchanger to pressurize propellant tanks.

  – Start Sequence which is thermally more gentle on the turbine to increase life



- **Breadth of Benefit**

  The Full Flow Staged Combustion Cycle is most applicable to booster stage main engines for a variety of expendable and reusable systems for reliability, life, and reusability

  – These technologies support boost engine, second stages if utilizing high Pc designs

- **Current SOA**

  – Current State of the Art for high chamber pressure staged combustion rocket engines is the Space Shuttle Main Engine.

IPD Oxygen Turbopump

- **Importance of Benefit**

  The IPD Oxygen turbopump technologies provide many benefits for the next generation turbomachinery.

  – Hydrostatic bearings technology aids designers by easing assembly, rotordynamic, and rotational speed limitations. Additionally, once operating, the bearings do not wear -- very important on missions requiring long duration operations.

  – New Turbine materials which are inherently resistant to ignition in high pressure Gox - Removes ignition concerns without using coatings.

  – New turbine design techniques increase manufacturability, reliability and life by lowering part count, reducing operating temperature, and adding unique blade damping techniques.

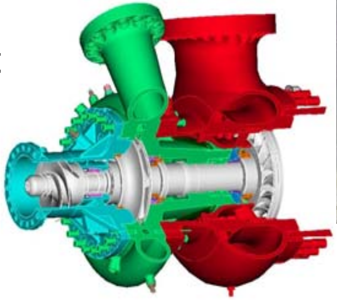
- **Breadth of Benefit**

  The technology and functionality can be applied to a variety of expendable and reusable systems for reliability, life, and reusability

  – These technologies support boost engine, second stage, and upper stage liquid engine development for hydrogen and hydrocarbon engine concepts

  – Hydrostatic bearings are applicable to any non-pressure fed rocket engine using oxygen.

IPD Oxygen Pump in Hot Fire Testing



IPD Oxygen TP (Boeing)

- **Current SOA**

  – Current State of the Art for rocket turbomachinery is the Space Shuttle Main Engine turbopumps. The key issues with the SSME Oxygen turbopump were the drivers for the technology used in this turbopump

IPD Hydrogen Turbopump

- Importance of Benefit

  The IPD Fuel turbopump technologies can provide many benefits for the next generation turbomachinery.

  – Hydrostatic bearings technology aids designers by easing assembly, rotordynamic, and rotational speed limitations. Additionally, once operating, the bearings do not wear -- possibly very important on missions requiring long duration operations.

  – New turbine design techniques increase manufacturability, reliability and life by lowering part count, reducing operating temperature, and adding unique blade damping techniques.

  – New Turbine material is resistant to hydrogen embrittlement - allowing longer operation without loss of material properties in hydrogen rich steam.

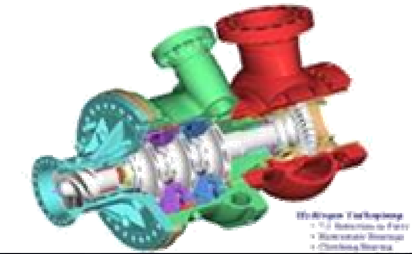
- Breadth of Benefit

  The technology and functionality can be applied to a variety of expendable and reusable systems for reliability, life, and reusability

  – These technologies support boost engine, second stage, upper stage, and transfer stages using liquid engine development for hydrogen and hydrocarbon engine concepts

  – Hydrostatic bearings are applicable to any non-pressure fed rocket engine.

IPD Fuel TP (Boeing)



IPD Hydrogen Pump ‘Green’ Testing

- **Current SOA**

  – Current State of the Art for rocket turbomachinery is the Space Shuttle Main Engine turbopumps. The key issues with the SSME hydrogen turbopump were the drivers for the technology used in this turbopump

IPD Oxygen Preburner

- **Importance of Benefit**

  Long Life High Performance Oxygen Rich Preburner for Highly Reliable and Reusable Applications

  - **Enables oxygen rich combustion to drive full flow hydrogen engine cycle as well as hydrocarbon engine cycles.**
  - **Rapid prototyping and manufacturing through the use of Aerojet's Platelet Processing**
  - **Provides oxygen pump turbine with a more benign environment than SSME**
  - **Enables life ranges up to and above 100 missions with extreme temperature uniformity**

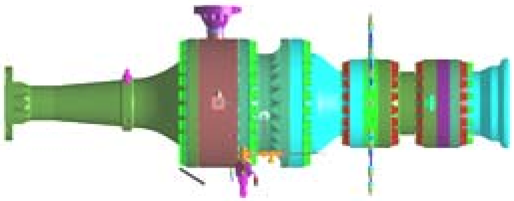
- **Breadth of Benefit**

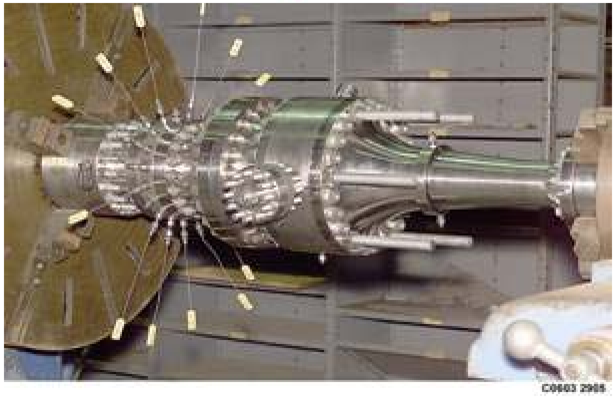
  The technology and functionality can be applied to a variety of expendable and reusable systems for reliability, life, and reusability

  - **Cross cutting technology supports boost engine, second stage, and upper stage liquid engine development for hydrogen and hydrocarbon engine concepts**

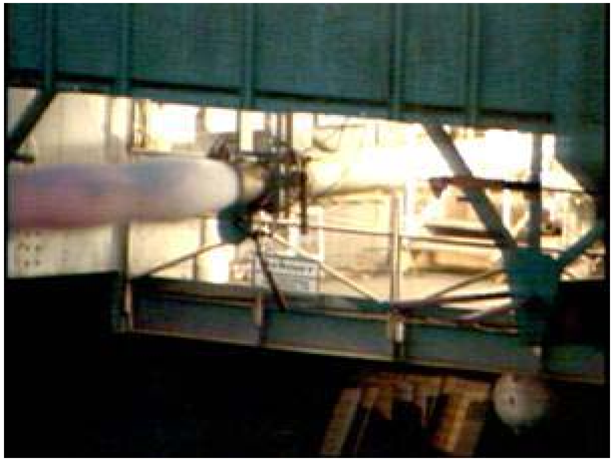
- **Current SOA**

  - **This component is the current US SOA. This is the first U.S. flight type oxygen rich preburner! Russian designs have utilized ox-rich combustion in their rocket engines.**





IPD Oxygen Preburner (Aerojet)



IPD OPB In Hot- Fire Testing

IPD Fuel Preburner

- **Importance of Benefit**

  Long Life High Performance Fuel Rich Preburner for Highly Reliable and Reusable Applications

  – Enables life ranges up to and above 100 missions with extreme temperature uniformity

  – Rapid prototyping and manufacturing through the use of Aerojet's Platelet Processing

  – Provides hydrogen pump turbine with a more benign thermal environment than current SOA - SSME turbines

- **Breadth of Benefit**

  The technology and functionality can be applied to a variety of expendable and reusable systems for rapid fabrication processes, reliability, life, and reusability

  – Cross cutting technology supports boost engine, second stage, and upper stage liquid engine development for hydrogen engine concepts

- **Current SOA**

  – The current SOA is the SSME fuel preburner, which cannot provide the reliability, thermal uniformity, reusability, and engine life benefits that the IPD Fuel Preburner enables

IPD Fuel Preburner (Aerojet)

IPD Fuel Preburner Hot-fire Test

IPD HIP Bonded MCC

- **Importance of Benefit**

  The HIP Bonded Main Combustion Chamber significantly reduces fabrication time and cost while improving reliability

  – The RS68 HIP bonded MCC is currently flying, but the IPD MCC will be the first successful HIP bonded MCC capable of high Chamber Pressure (Equivalent to SSME).

  – The IPD MCC was designed and fabricated in approx 6 months less time than the average time required to fabricate an SSME chamber.

  – Processes utilized in the HIP bonded MCC are more controllable than currently used in making the structural plating style MCC.

- **Breadth of Benefit**

  The technology is expected to be applied to any expendable or reusable systems for decreased cost and fabrication time.

  – These technologies are scaleable to support boost engine, second stage, upper stage, and even small thruster liquid engine development for hydrogen and hydrocarbon engine concepts

IPD HIP Bonded MCC (Boeing)

- **Current SOA**

  – Current State of the Art is the HIP bonded RS68. The SSME fabrication difficulties in the structural plated nickel has caused the HIP bonded process to become favored.

IPD Channel Wall Nozzle

- **Importance of Benefit**

  Lower Cost and More Rapid Production times than current US tube nozzle technology

  – Channel Wall Technology developed at Aerojet for highly reliable, low maintenance, long life nozzles

  – Rapid and low cost manufacturing through the use of milled channel liner, and Aerojet's brazing process for the liner to jacket interface.

  – Enables life ranges up to and above 100 missions with little to no maintenance when compared to SSME

- **Breadth of Benefit**

  The technology and functionality can be applied to a variety of expendable and reusable systems for reliability, life, and reusability

  – Cross cutting technology supports boost engine, second stage, upper stage, and transfer stage liquid engine development for hydrogen and hydrocarbon engine concepts

  – SSME is examining IPD's Channel Wall technology for potential upgrade programs

IPD Channel Wall Nozzle (Aerojet)

- **Current SOA**

  – Current State of the Art in US is tube wall nozzle technology as utilized on the Space Shuttle Main Engine and RL10 flight engines.

IPD Testing Accomplishments

Unprecedented Achievement in the Past 20 years of Booster Engine Research & Development

- ✓ **IPD Hydrogen Preburner – October 2002, Jul 2004**
  - ✓ Demonstrated Platelet High Performance Injector
  - ✓ Demonstrated Temperature Uniformity Needed for Long Life Turbine Technology
  - ✓ Re Verification Testing Demonstrated LH2 Preburner redesign success
- ✓ **IPD Oxygen Turbopump – June 2003**
  - ✓ First U.S. FFSC Oxygen Driven Pump
  - ✓ Demonstrated Feasibility of Oxygen Rich Combustion
  - ✓ Proved New Oxygen Rich Materials for Reusability
  - ✓ Demonstrated Hydrostatic Bearings & Clutching Bearing
  - ✓ Demonstrated Electrostatic Discharge Mitigation Device
- ✓ **IPD Oxygen Preburner – October 2003**
  - ✓ Demonstrated First U.S. Flight Type Oxygen Rich Preburner
  - ✓ Demonstrated Temperature Uniformity Needed for Long Life Turbine Technology
- ✓ **IPD Hydrogen Turbopump – October 2003**
  - ✓ First U.S. Hydrogen Pump Supported by Hydrostatic Bearings
  - ✓ Demonstrated Hydrostatic Bearings & Clutching Bearing

IPD Technical Team Has Received Multiple Awards

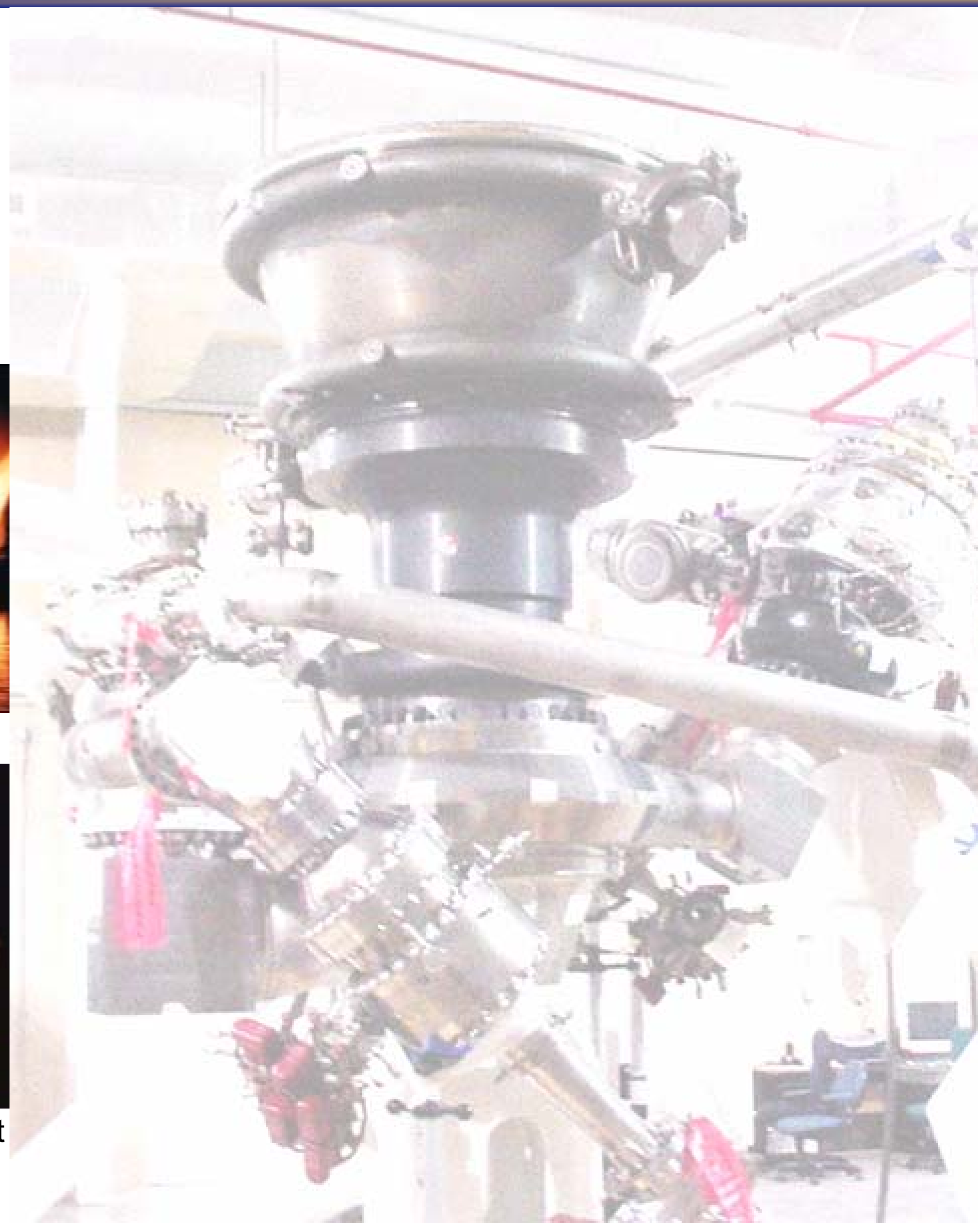
IPD Hydrogen Preburner Test

IPD Oxygen Pump Test

IPD Oxygen Preburner Test

IPD Hydrogen Pump Test

IPD Summary



IPD Hydrogen Pump Test

IPD Hydrogen Preburner Test

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