Ramgen Power Systems, Inc.

Ramgen Engine
Technology Overview Briefing

March 2002

Presented to Galveson

Introduction

The Ramgen engine is potentially a “disruptive technology” to the gas turbine industry.

Its development requires an “open minded” combination of existing industrial gas turbine and aerospace technology thinking.

The technology requires a full engine development program.

What is the Ramgen Engine?

The Ramgen engine is potentially a “disruptive technology” to the gas turbine industry.

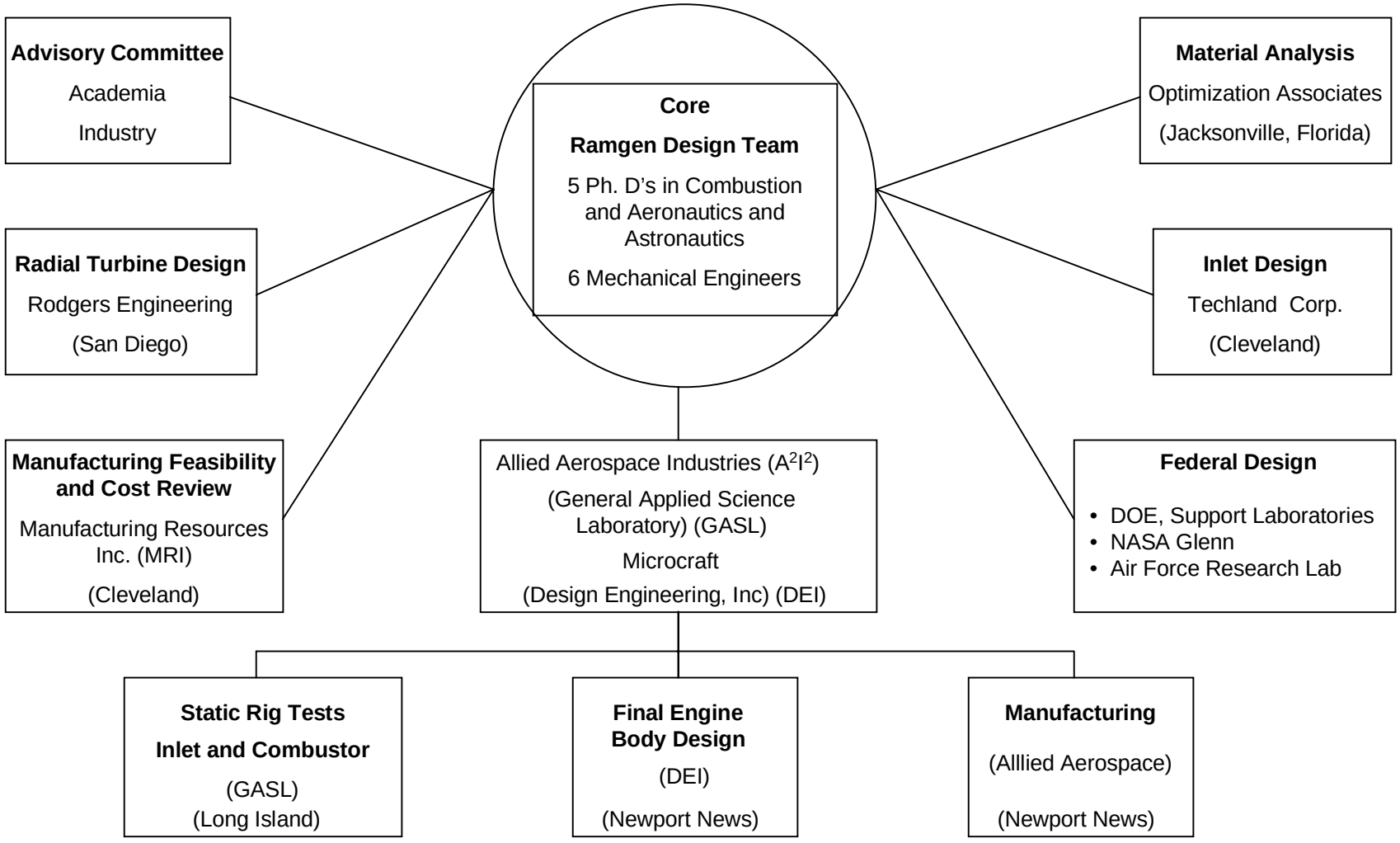
The Ramgen engine represents a unique application of well established ramjet technology to the generation of electrical power, propulsion and drive applications.

Captures the power of flight ramjets in a stationary engine.

System Performance Overview

- Performance
  - Simple Cycle 37% - 39% LHV
  - Recuperated 46%
  - Combined Cycle 51%
  - Cogeneration 79%
- Emissions
  - < 10 ppmvd NOx @ 15% O2 Base Load
  - < 35 ppmvd CO
  - UHC's <25 ppm
- Cartridge Design for Low Cost Maintenance

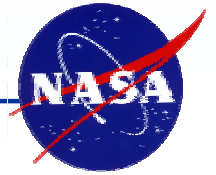
Ramgen as a Company
Technical Resources



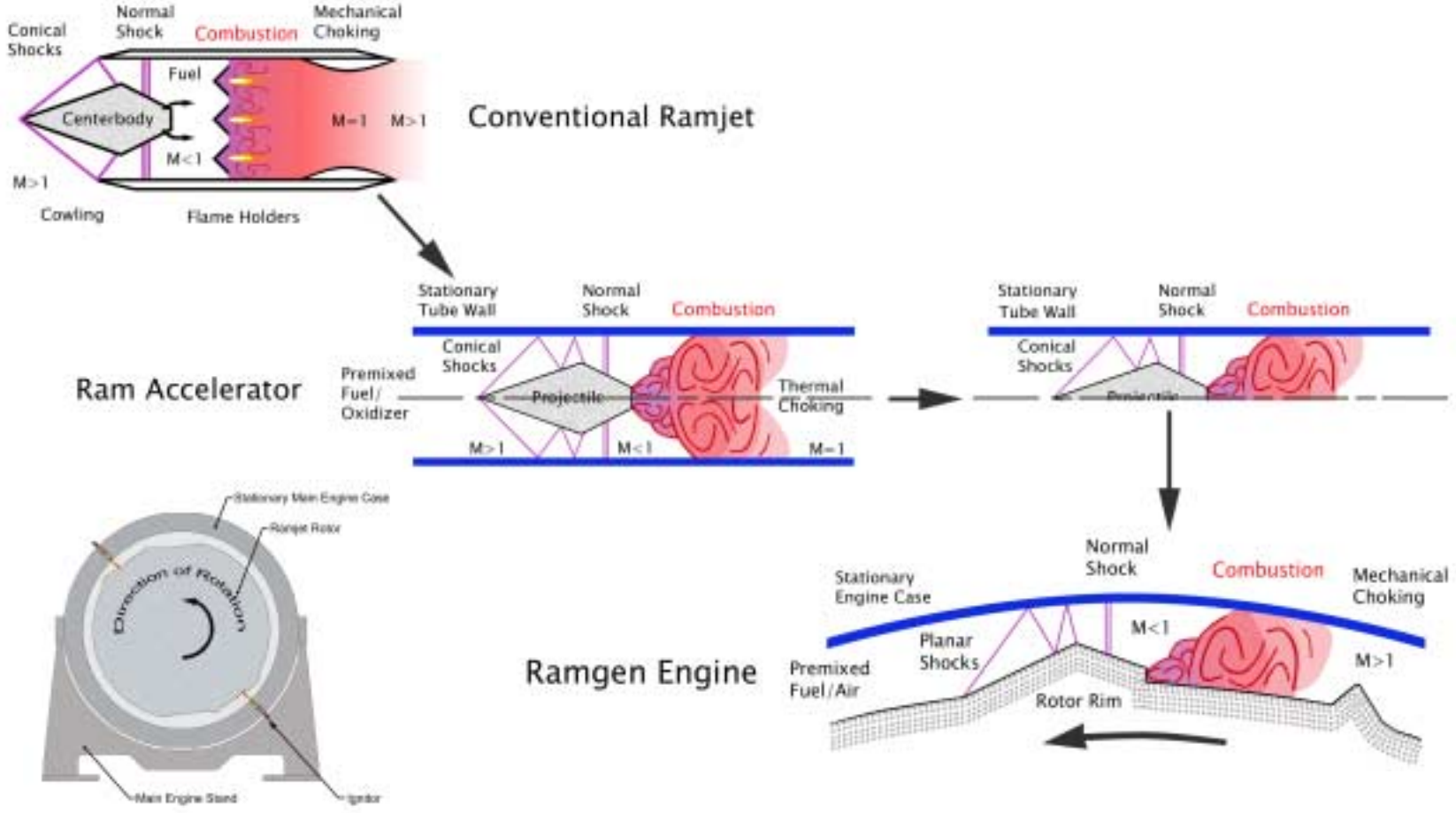
NASA/DoD/DoE Propulsion and Power Systems Alliance Vision

"Improve propulsion and power generation technology program coordination and collaboration among NASA, DOD, DOE, and Industry – leading to a greater national alliance/reliance among the program participants and stakeholders, and more effective leveraging of program funding."

Alliance Leadership Team



Ramjet to Ramgen



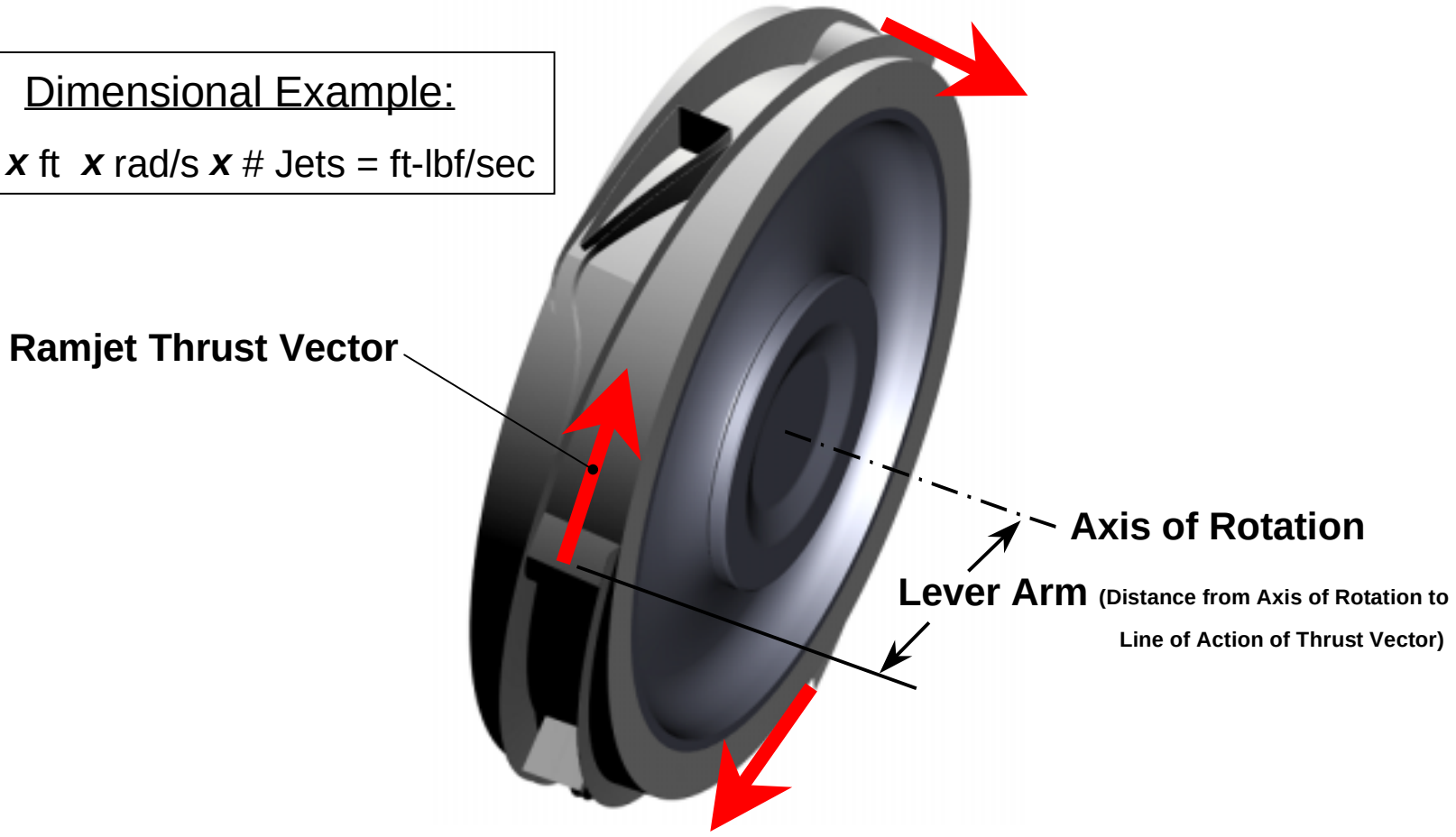
Ramgen Engine

Ramjet Thrust => Shaft Power

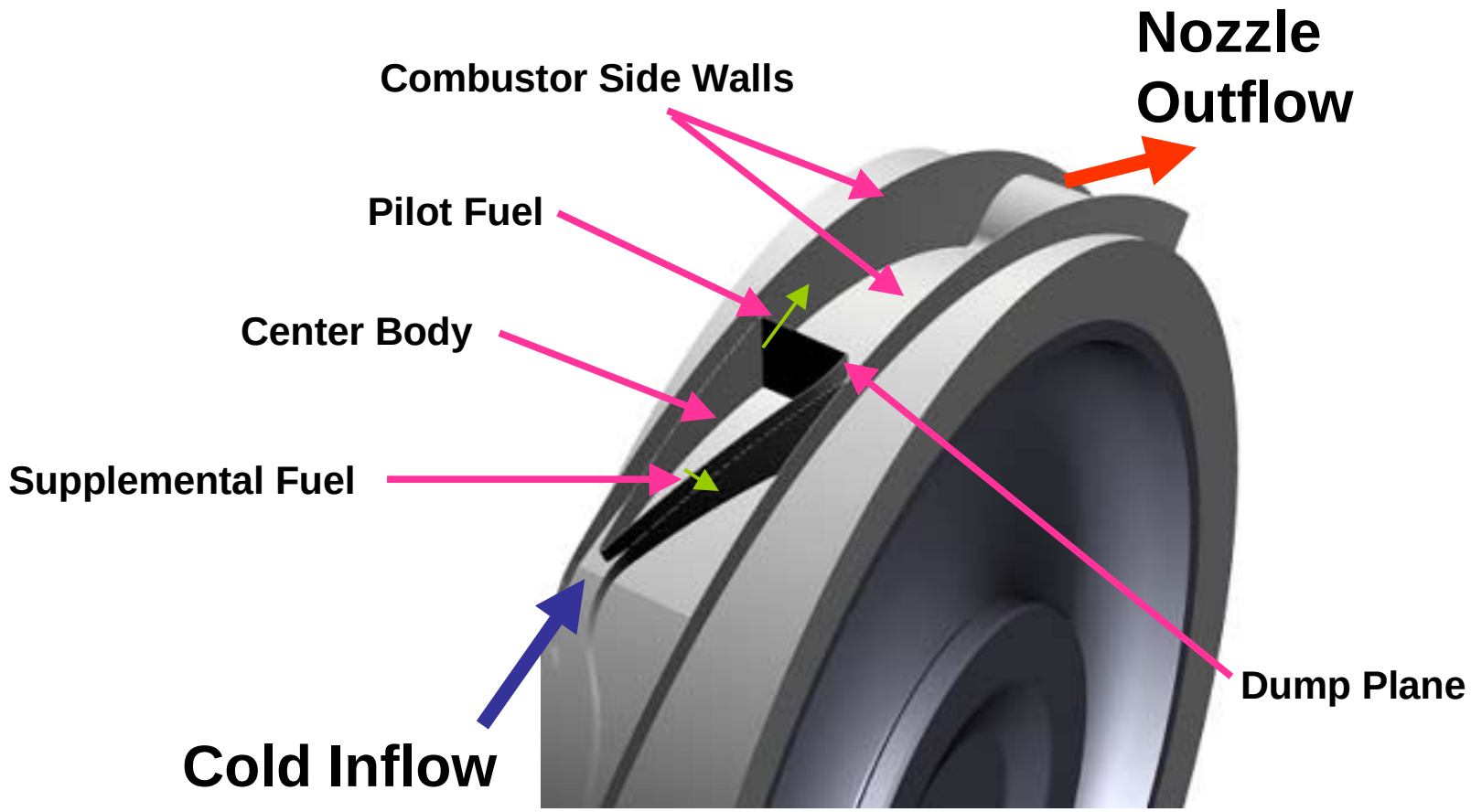
- **Ramjet Power = Thrust *x* Lever Arm *x* Rotation Rate *x* No. Ramjets**

Dimensional Example:

lbf ***x*** ft ***x*** rad/s ***x*** # Jets = ft-lbf/sec

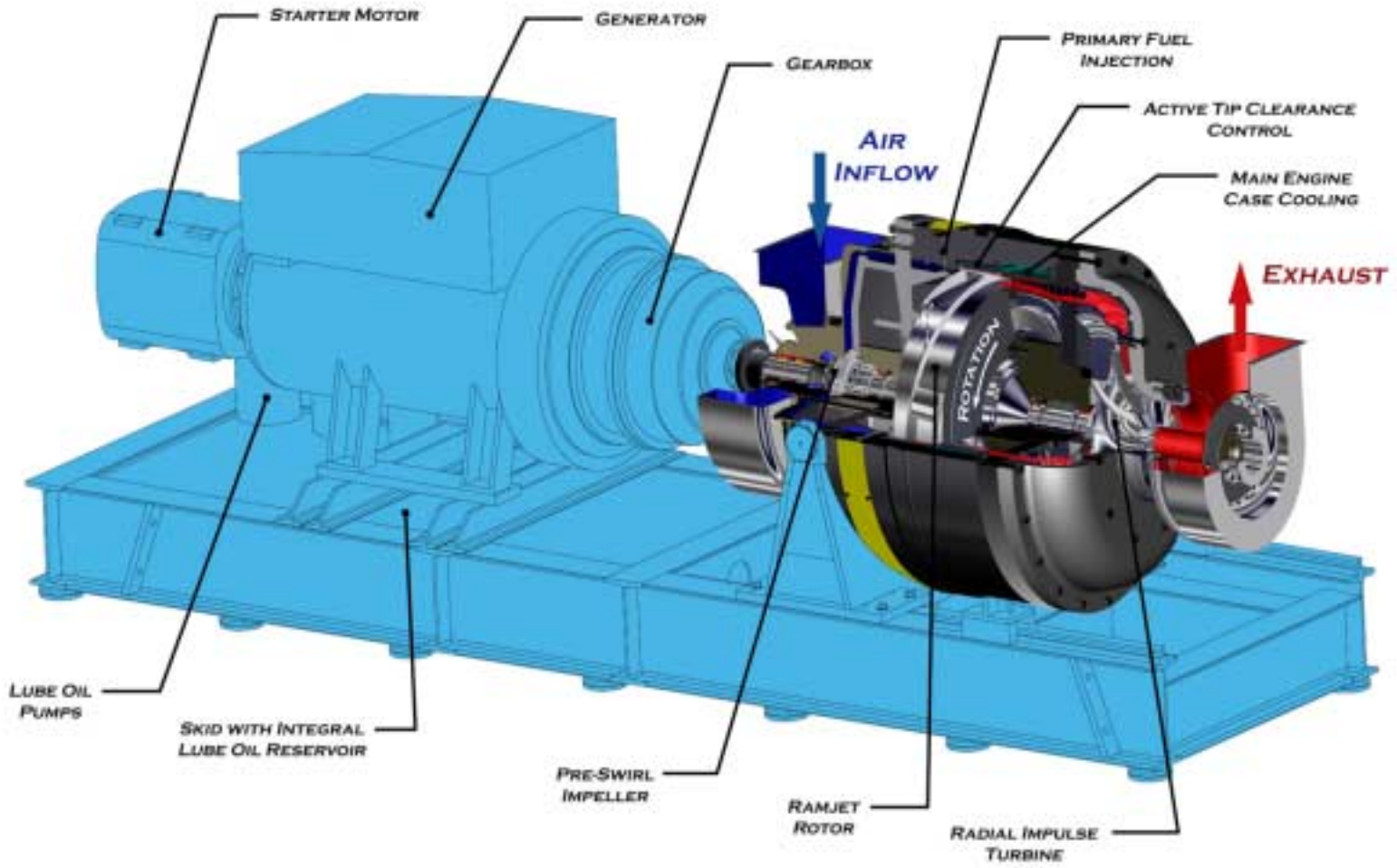


Combustor Details



2.8 MW Engine/Generator Detail

RAMGEN POWER SYSTEMS



Key Design Features

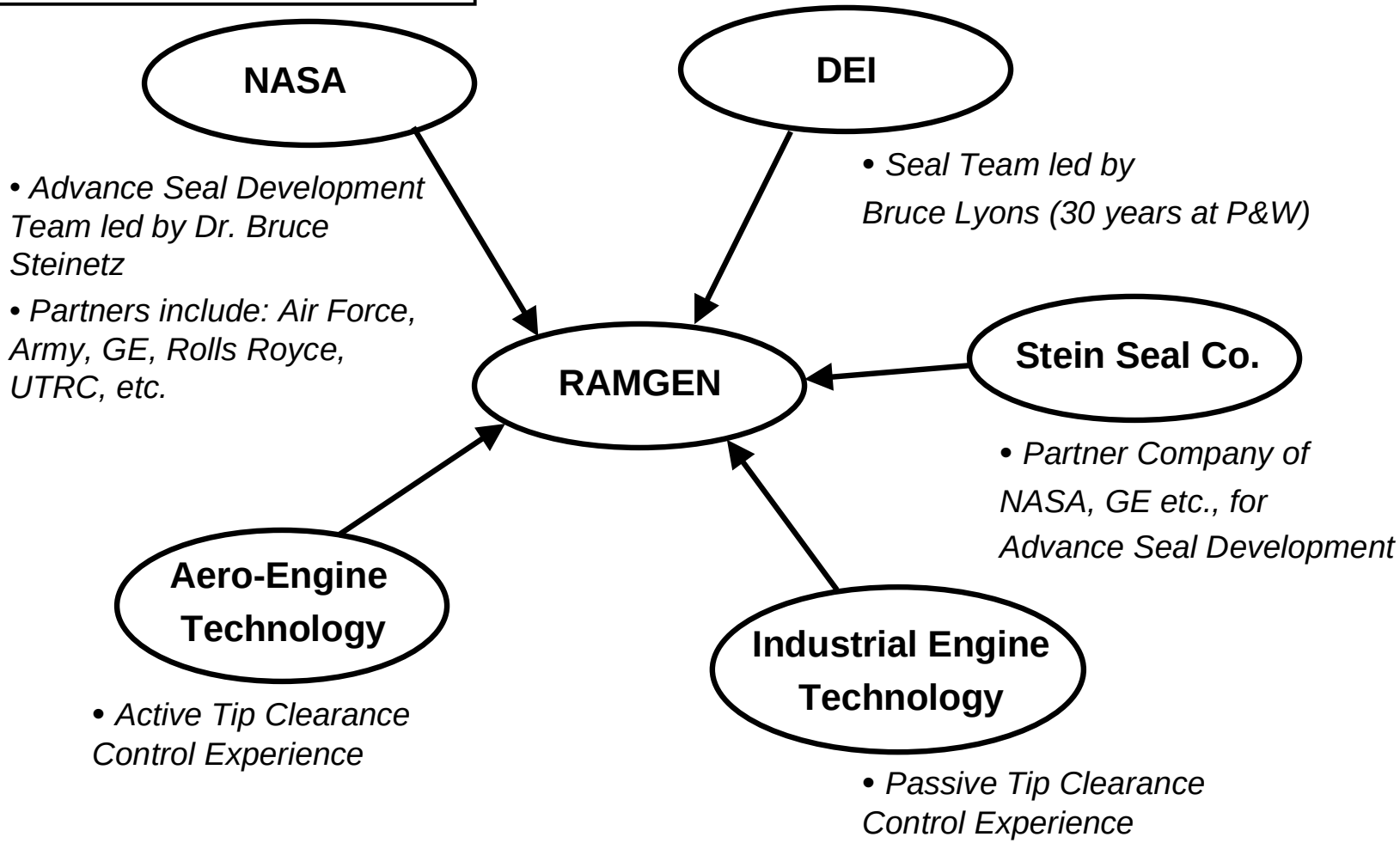
- Power – 2 to 5 MW
- First Engine – Not Optimized for Production
- Ore-Swirl Impeller and Inlet Guide Vanes
- Cooling Air and Pilor Fuel – Slinger System
- Trapped Vortex Concepts – Combustor
- Active Tip Gap Control in Engine Case
- Exhaust Guide Vanes and Transition Duct
- Radial or Axial Single Stage Turbine

Design Challenges

- Maintain Acceptable Metal Temperatures on Rotor Assembly
- Develop Tip Clearance System
- Manage Supersonic Wheelspace Drag and Heating
- Utilize Slinger Technology
- Develop LPM Combustor at High G-Loads and Supersonic Boundary Conditions

Ramgen Approach to Tip Leakage Control

Tip Leakage Control Team



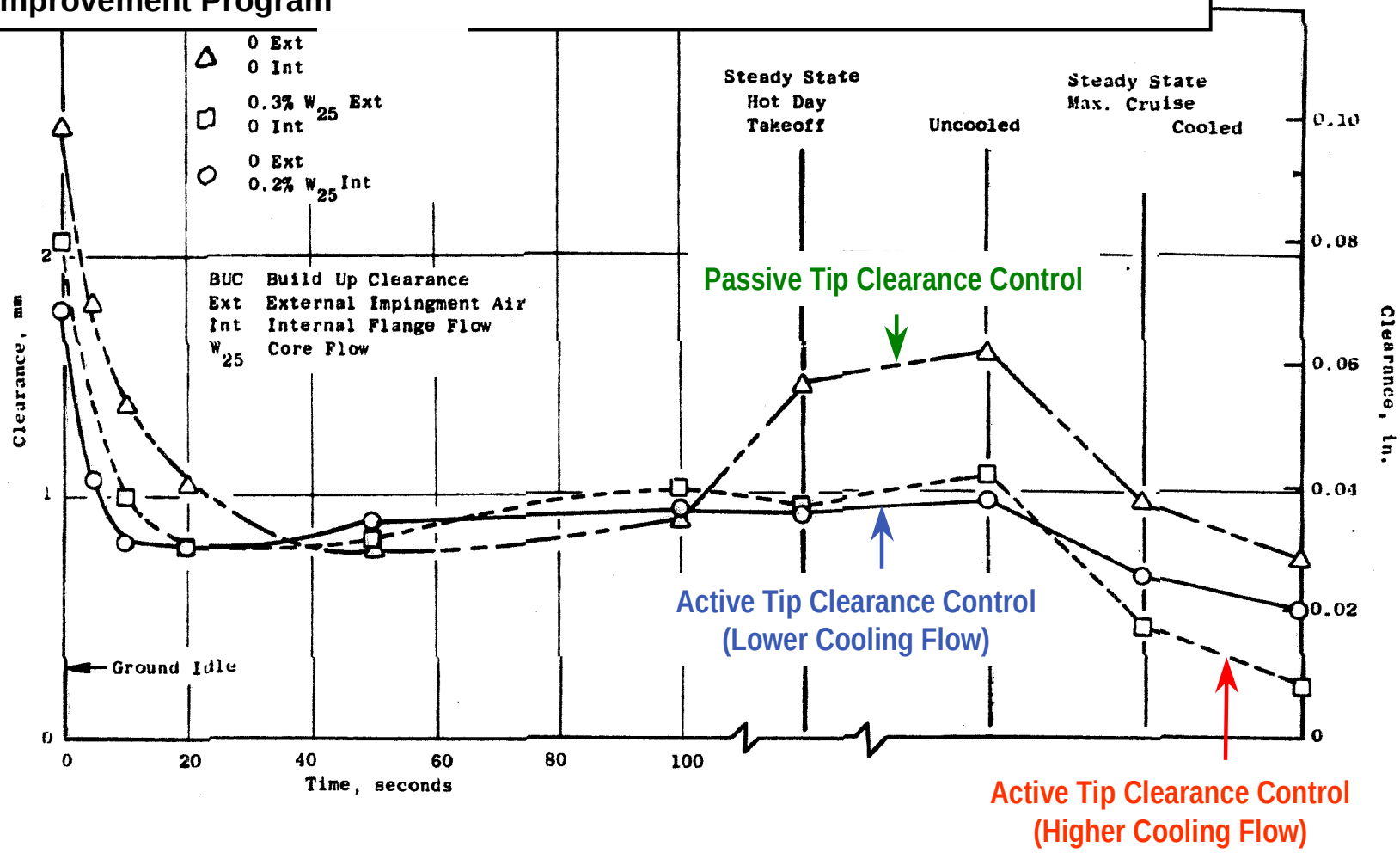
Ramgen Approach to Tip Leakage Control

Tip Clearance Control Experience

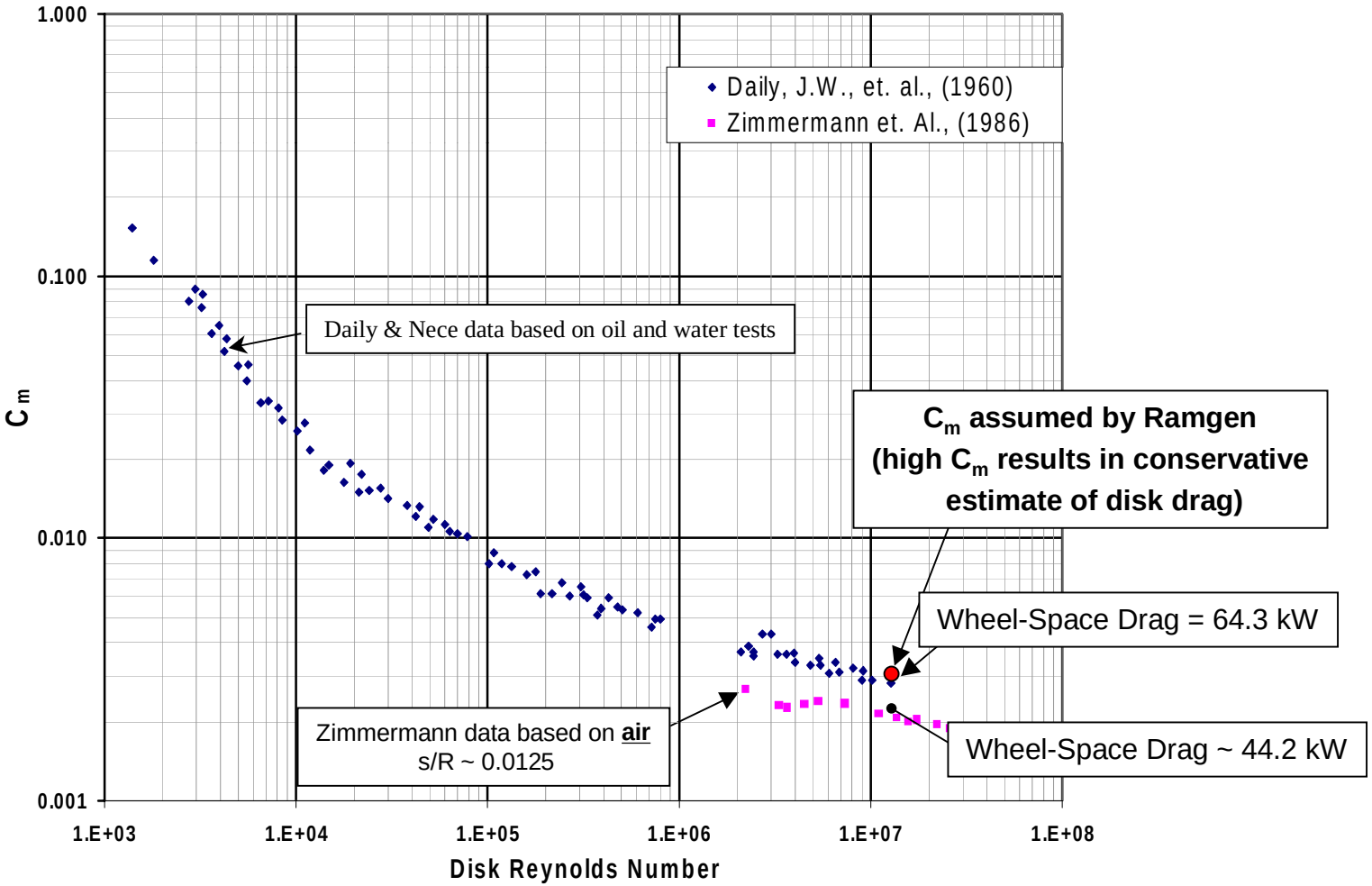
- Industrial Engines
  - › Passive
    - – Time Constant Matching
    - – Clearances Typically 15 mils to 30 mils
  - › Semi-active (no feed back)
- Aero Engines
  - › Active Tip Clearance Control
    - – Substantial Improvements In Tip Clearances (over passive system)
    - – Clearances Typically 5 mils to 12 mils
  - › Allison 250-C30, PW 4000 Series, GE CF6 etc.

Active Tip Clearance Control Experience

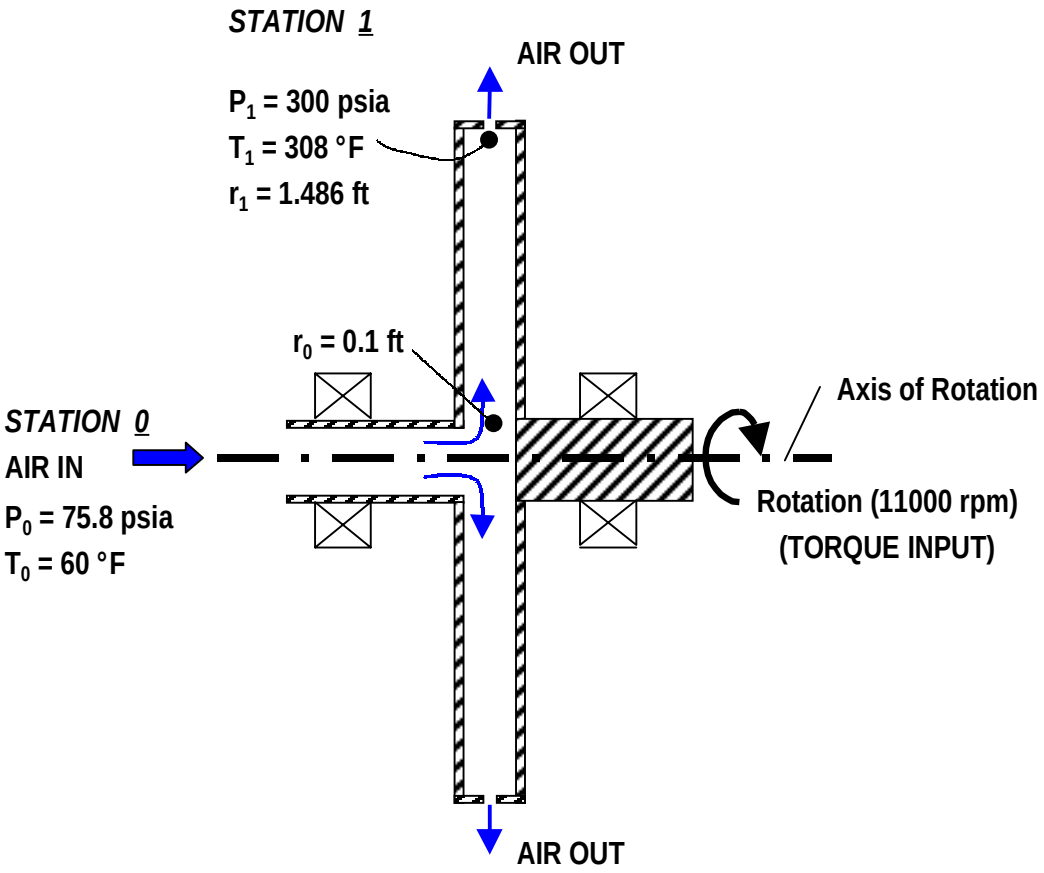
Data from CF6-6 HP Turbine, circa 1981, NASA Sponsored Engine Component Improvement Program

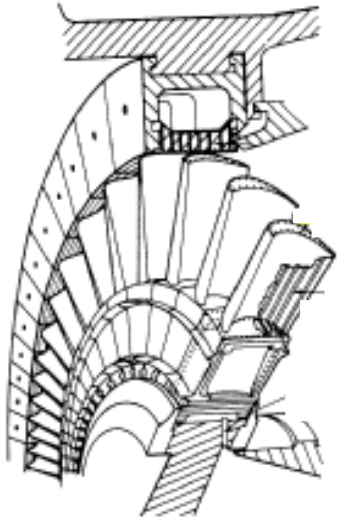


Moment Coefficients for Disks in Housings



Centrifugal Pumping in the Slinger

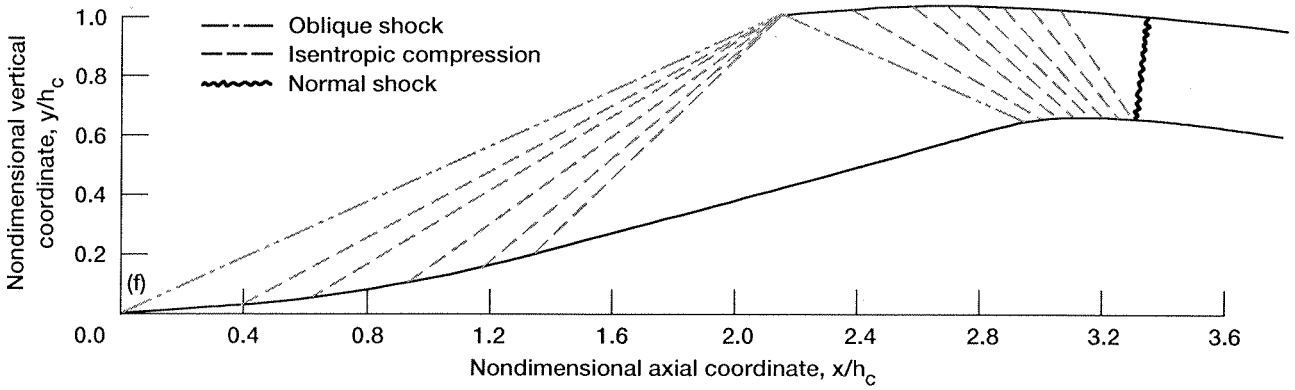




Slinger Flow Concept is Similar to Turbine Blade Cooling Passages

Comparable Inlet Tested at NASA Lewis

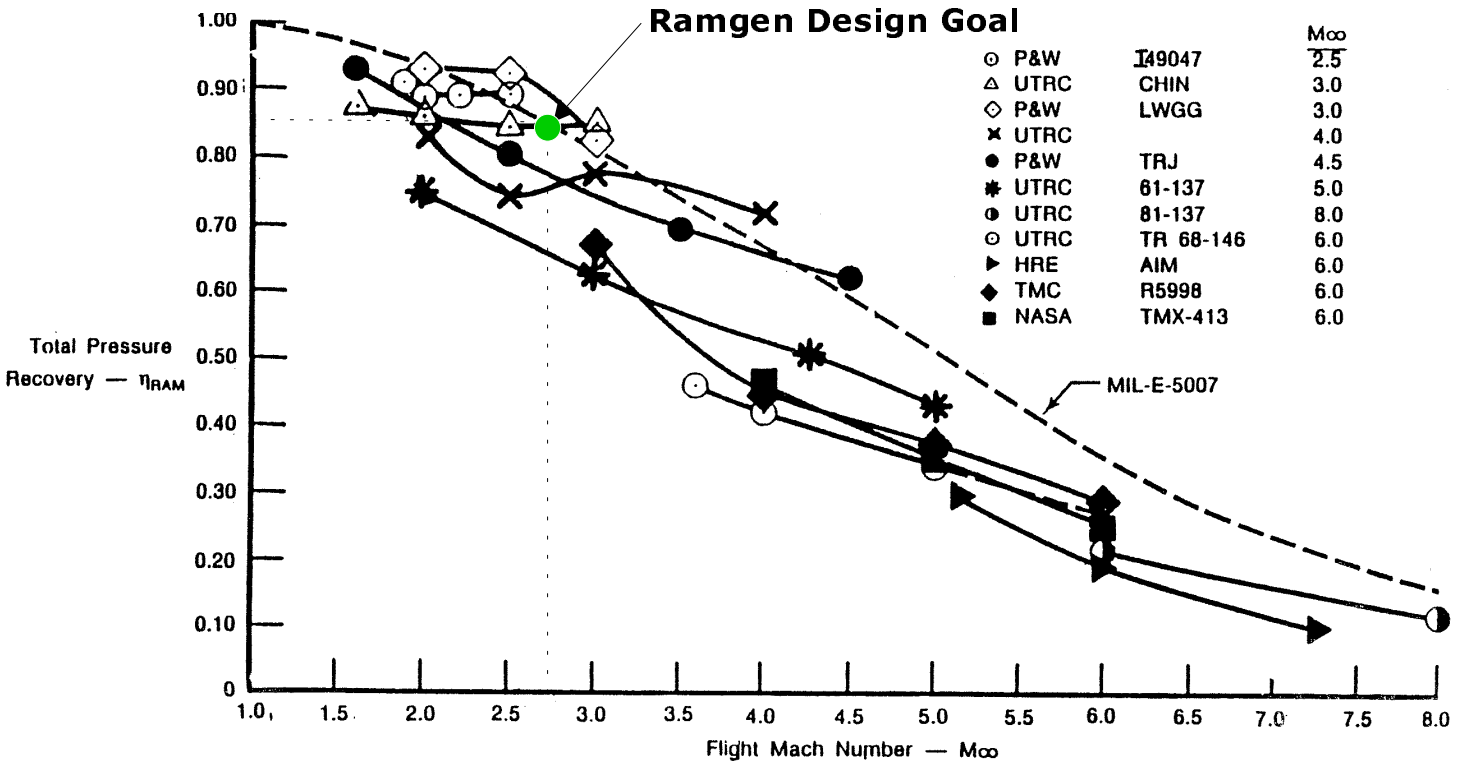
- Inlet Comparable to F-2 Tested At NASA Lewis
  - Design Mach Number = 2.7
  - Total Pressure Recovery = 0.89
  - Bleed Flow/Inlet Captured Flow ≈ 0.07



h_c = 10.45 in

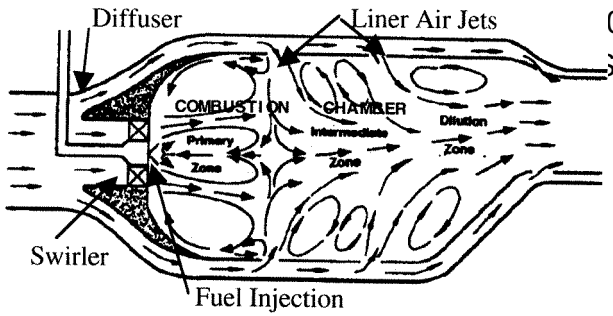
Flight Inlet Performance Experience

- Ramgen Design Goal: P_{t4}/P_{t0}= 0.86



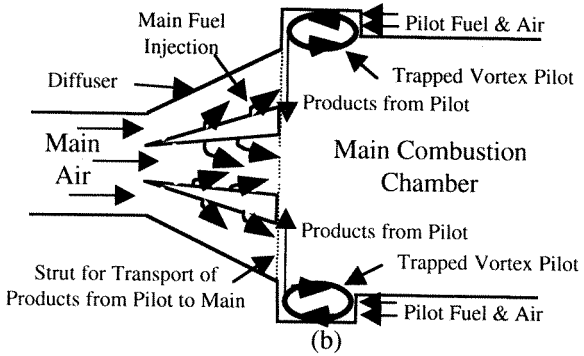
Trapped Vortex Combustor (TVC)

TVC combustors have seen wide exposure at WPAFB (GE) and DOE (NETL)

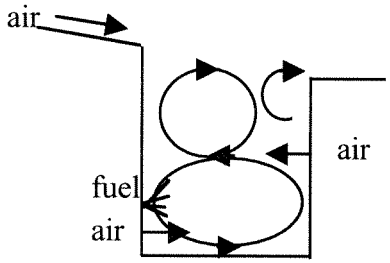


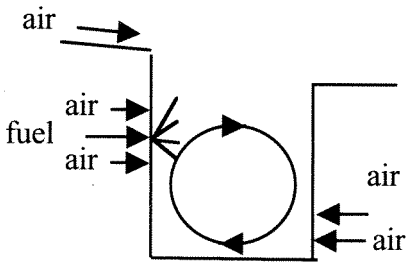
00-GT-0087, AIAA 200
Symposium, 2000)

Typical Burner



TVC Burner

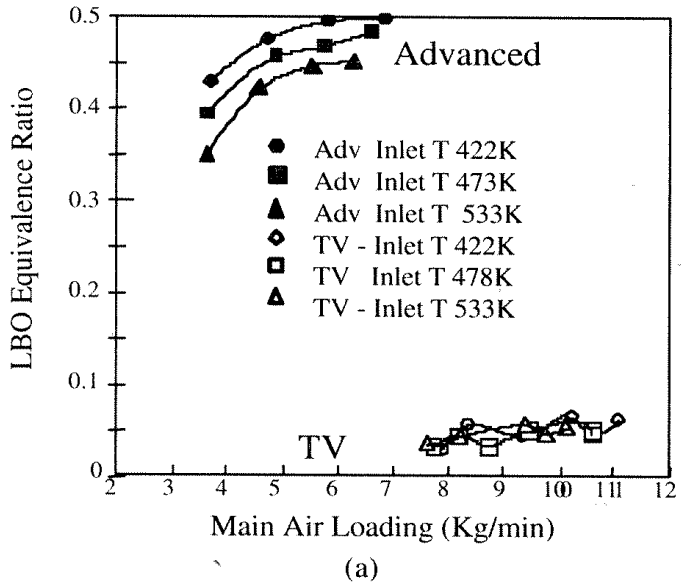


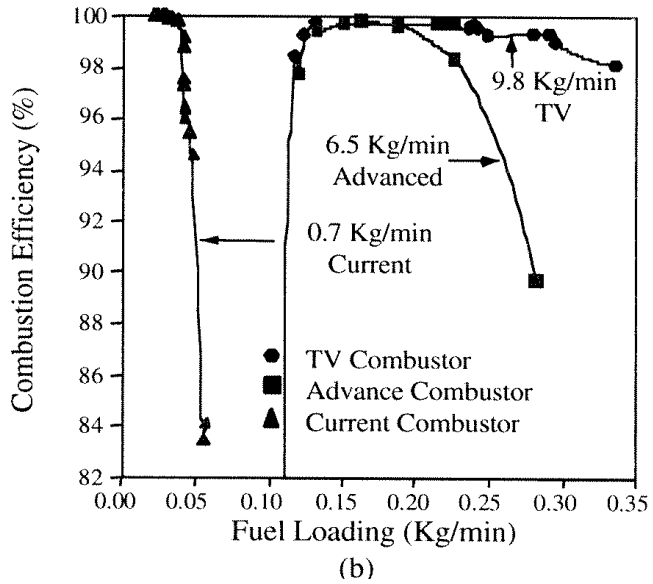


Trapped Vortex Combustor (TVC)

RAMGEN POWER SYSTEMS

TVC burners exhibit much leaner LBO limits than conventional systems while maintaining high combustion efficiencies





Predicted Performance Characteristics