

ADVANCES IN ANODE AND CATHODE BLOWERS

**9th Annual SECA Workshop
Pittsburgh, PA**

Sponsor: Department of Energy

**Presented by: Dr. Giri Agrawal
R&D Dynamics Corporation**

Date: August 7, 2008

Outline

1. R&D DYNAMICS OVERVIEW

2. CATHODE BLOWERS

- a. Prototype Units
- b. Development Programs
 - Low Cost Unit
 - High Temperature Recycle Blower

3. ANODE BLOWERS

- Warm Recycle Blower
- Hot Gas Recycle Blower

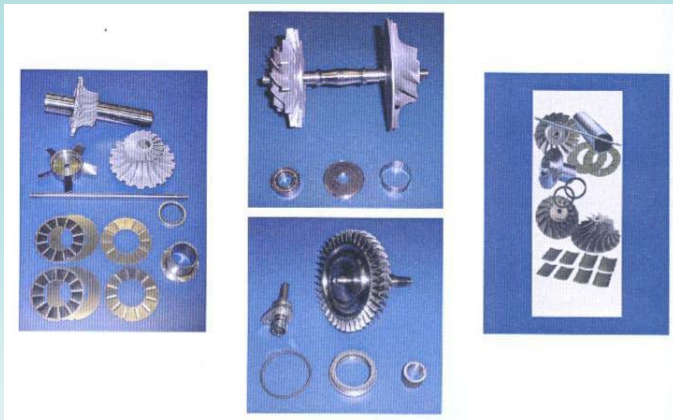


OUR BUSINESS

Design, Develop and
Production Manufacture
Oil-Free, Efficient, and
Affordable High-Speed
Turbomachinery



R&D Dynamics, Bloomfield, CT



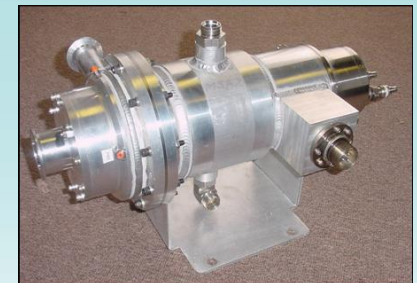
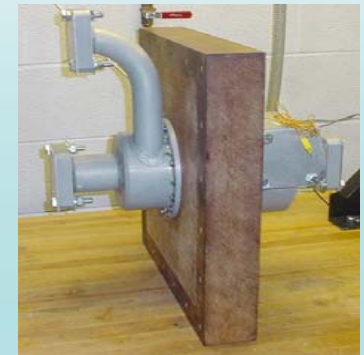
Background

- ❖ Started in 1990
- ❖ 23,000 sq. ft. space
- ❖ 47 employees
- ❖ 50% development programs
- ❖ 50% production programs
- ❖ Quality system approved by FAA
- ❖ ISO 9001:2000 / AS9100 registered
- ❖ Major facility expansion planned for 2009



Experience

- ❖ Fuel Cell Blowers
- ❖ Motor driven gas compressors
- ❖ Turboalternators
- ❖ Turboexpanders for air separation plants
- ❖ Hydrogen turboexpander
- ❖ Refrigerant centrifugal compressors
- ❖ High temperature turbochargers



Foil Air/Gas Bearings

- ❖ Advantages of Foil Air/Gas Bearings include....
 - Increased Reliability
 - No Oil/Grease Contamination
 - Higher Speed Capability
 - Smaller Size/Weight
 - Increased Performance
 - Quieter Operation
 - No Scheduled Maintenance
 - Lower Life Cycle Cost



CATHODE BLOWERS

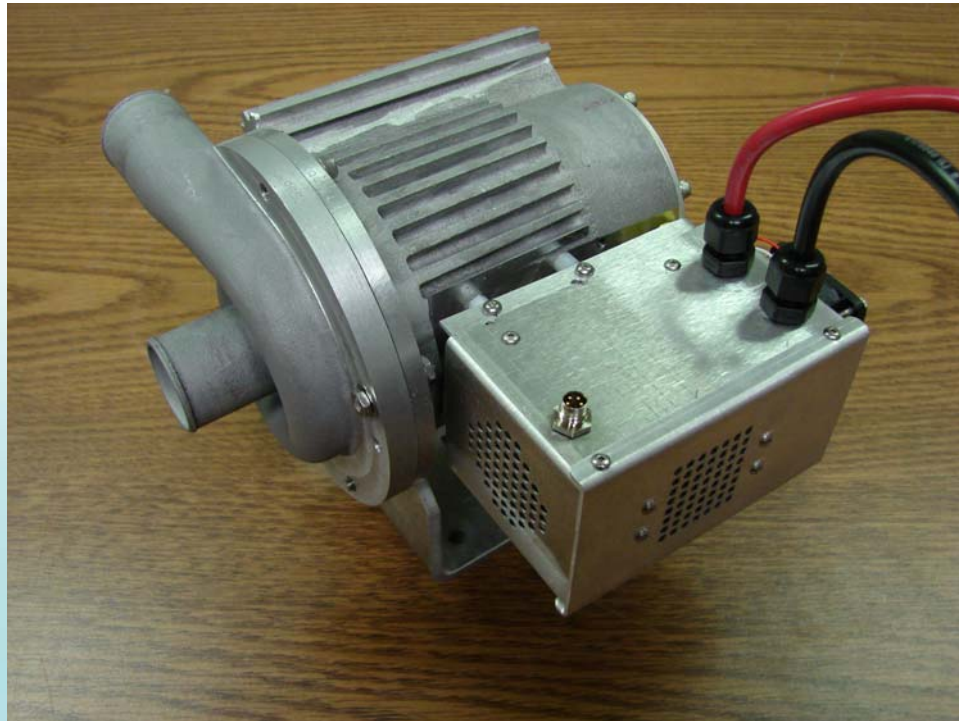
Prototype Units

Prototype Units

Accomplishments

- ✓ Blowers have been tested by various SECA members and others on 5 kW to 80 kW fuel cell systems
- ✓ Blowers have passed all major tests including...
 - Endurance > 2000 Hrs
 - Start/Stop > 10,000 Cycles
 - Vibration & Shock
 - Before and After Performance

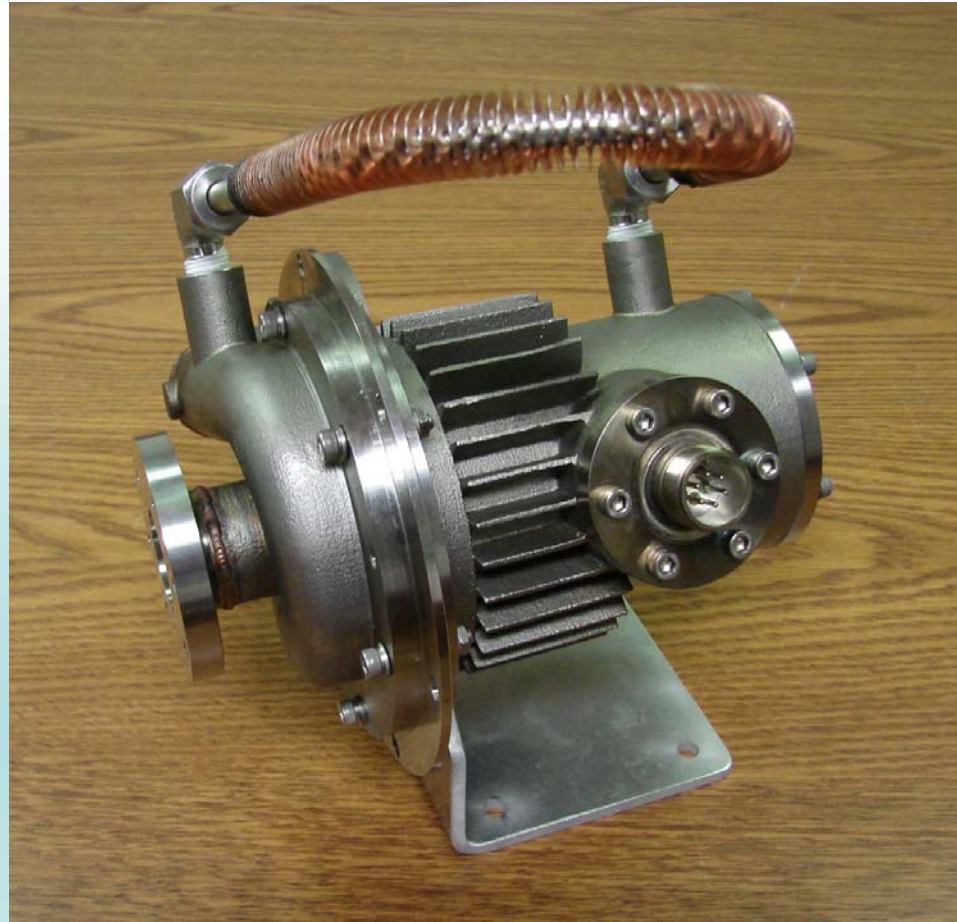
Cathode Air Blower for Automotive Application



60°C Air Inlet Temperature

Integrated Motor Drive

Fuel Blower for Stationary Fuel Cell



160°C Inlet Gas
Hermetically Sealed
Stainless Steel Construction

ATR Reformer Air Blower for Automotive Application



40°C Air Inlet Temperature

Cathode Air Blower for Automotive Application



45°C Air Inlet Temperature

Cathode Air Blower for Automotive Application



60°C Air Inlet Temperature

Liquid Cooled

CATHODE BLOWERS

Development Program

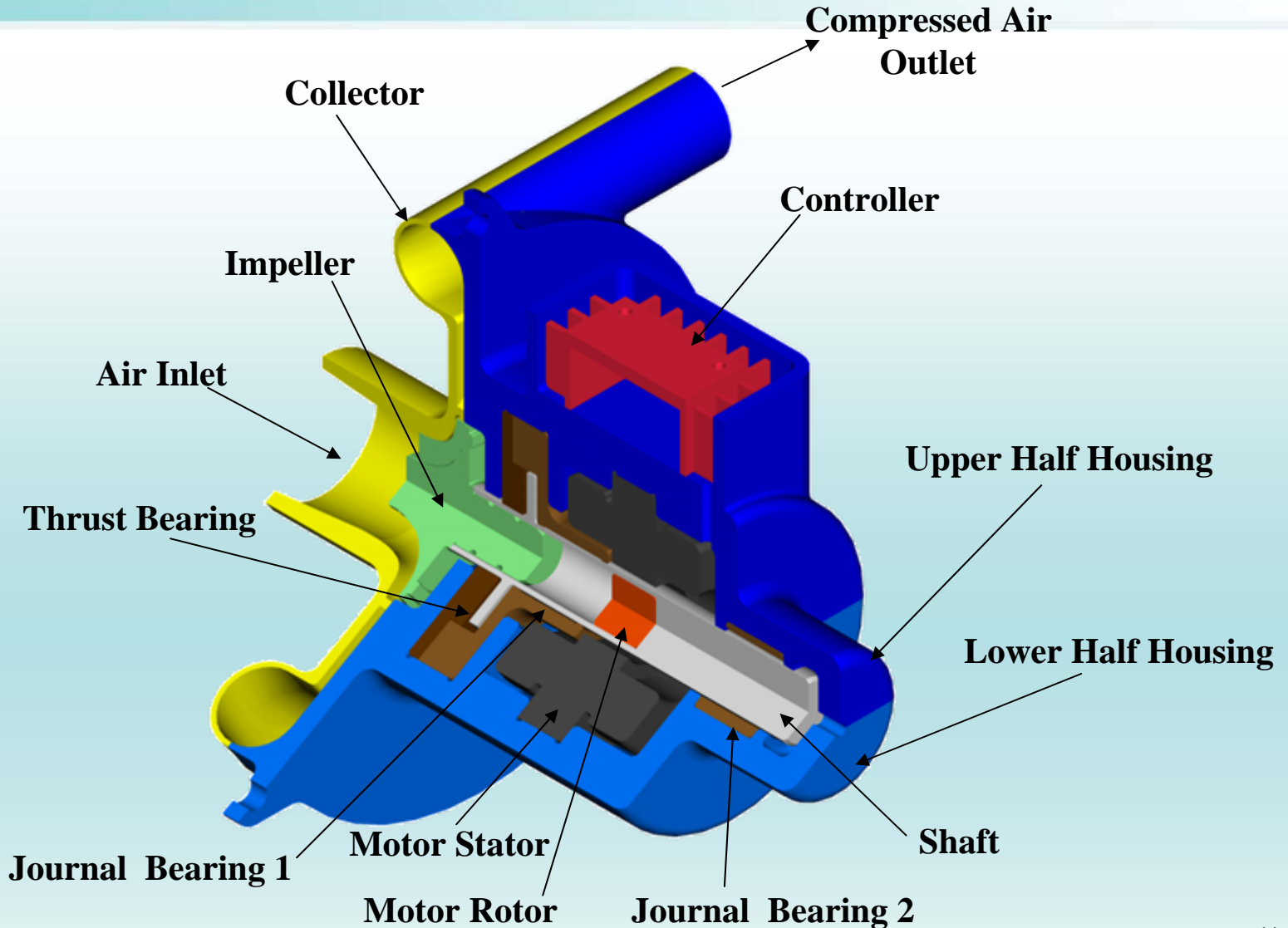
A Low Cost Unit

A Low Cost Unit Accomplishments

- ✓ Design for 5- 10 kW SOFC completed...
 - Novel design
 - DFMA techniques used
 - New materials
- ✓ Blower needs to be built and tested

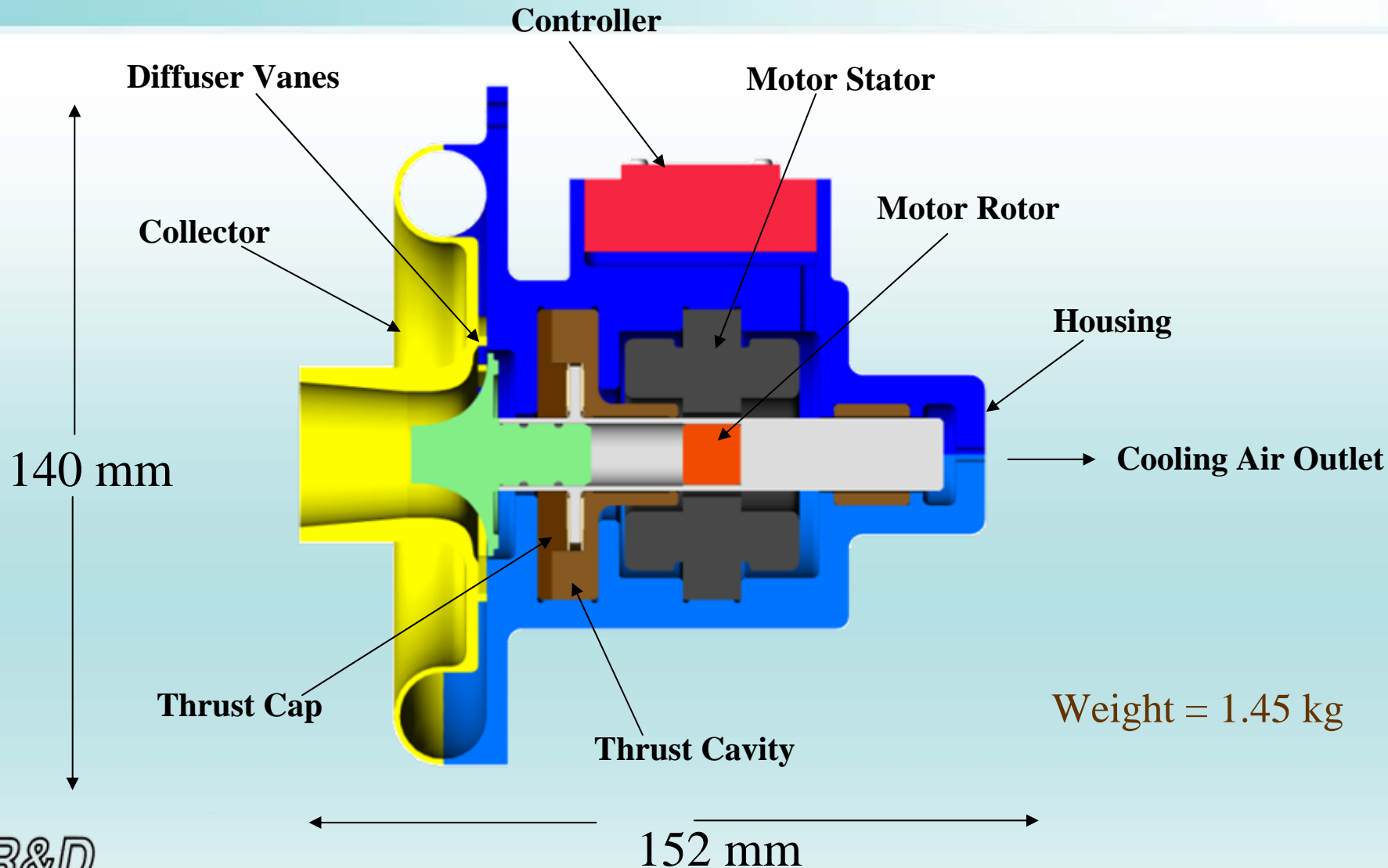
Low Cost Cathode Blower Design

Blower Cut-Section View

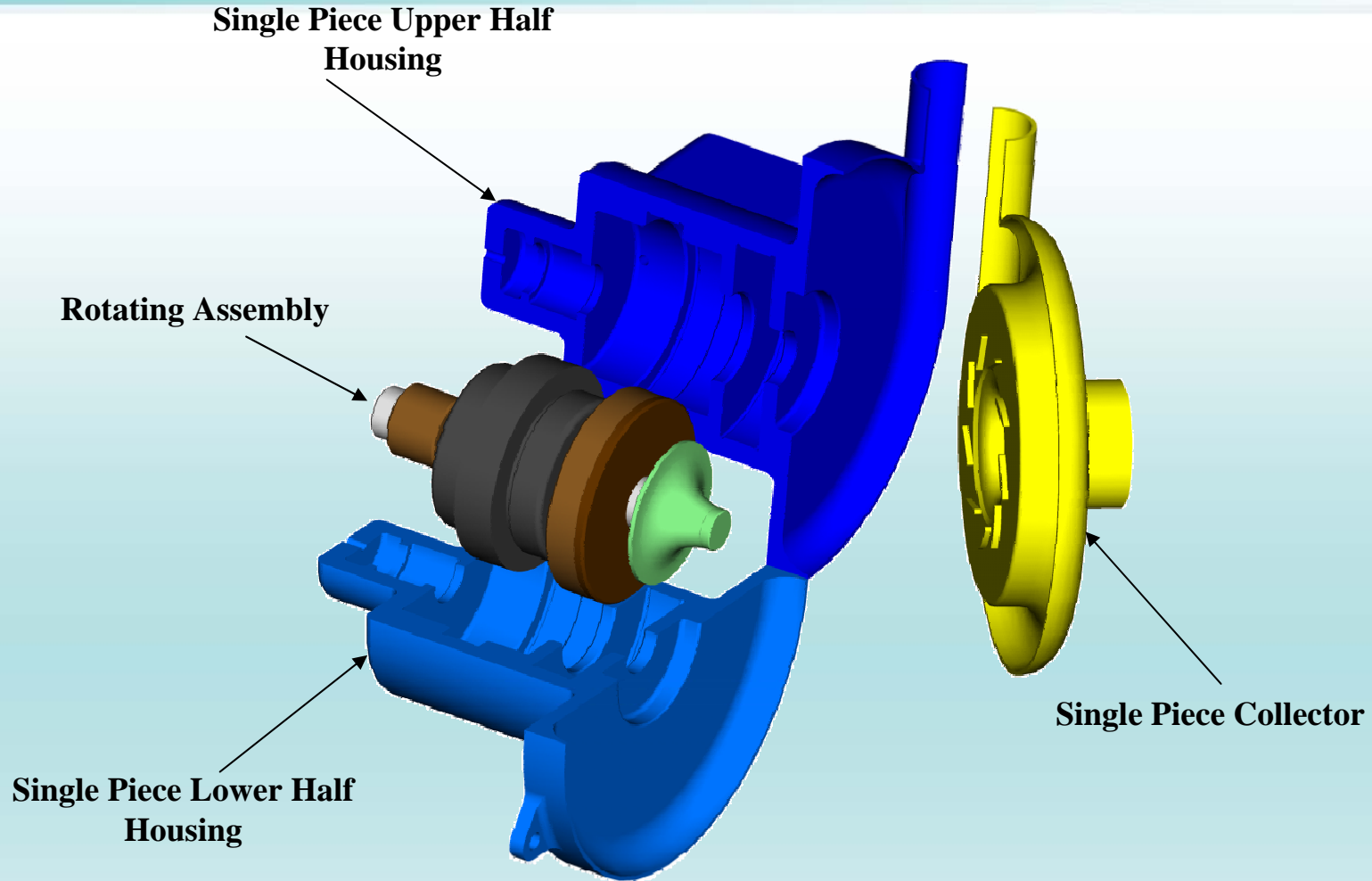


Low Cost Blower Cross-Section

Number of Parts = 16



Innovative Low Cost Split Housing Design



Technical Summary

▲ Blower Type	Centrifugal
▲ Mechanical Speed	80,500 rpm
▲ Flow	1500 SLPM
▲ Pressure Ratio	1.2
▲ Weight	1.45 kg (3.2 lbm)
▲ Bearings	Foil Gas Bearings
▲ Motor Type	Permanent Magnet Motor
▲ Controller Type	Sensorless Controller
▲ Input Electric Power	769 watt
▲ Overall Efficiency	> 62 %
▲ Total Blower Cost	\$105.11 [@ 50,000 units/year]
▲ Life	>40,000 hrs

CATHODE BLOWERS

Development Program

A High Temperature Recycle Blower

A High Temperature Recycle Blower

Accomplishments

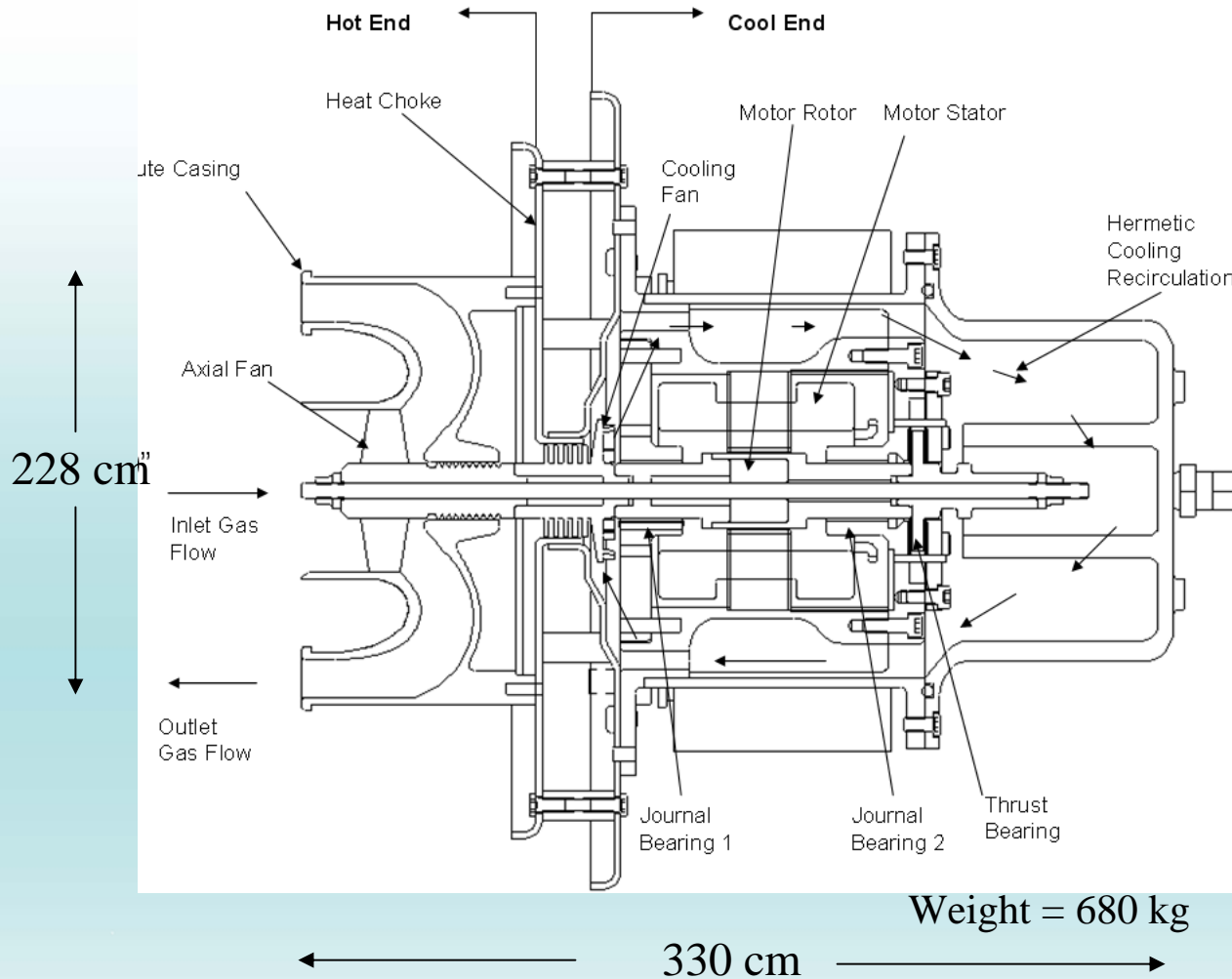
- ✓ Preliminary Design Completed
 - To improve efficiency of Fuel-Cell-based coal-fueled power generating stations
 - To be used in 5 MW POC Plant

High Temperature Cathode Recycle Blower

➤ Design Summary

- Flow 11.2 kg/sec
- Inlet temperature 802 °C
- Pressure Rise 3.0 KPa
- Axial flow fan
- Speed 9,244 rpm
- Input power 131 kW
- Overall Efficiency 72 %

High Temperature Cathode Recycle Blower



ANODE BLOWERS

Warm Recycle Blower

Warm Anode Recycle Blower

Accomplishments

- ✓ Successfully field tested
- ✓ Suitable for 10 kW SOFC
- ✓ Rated inlet temperature 250 °C
- ✓ Flow 14 g/sec (corr.)
- ✓ PR 1.15
- ✓ Turndown 10:1
- ✓ Prototype blowers are being manufactured for various SECA members and others

Warm Fuel Recycle Blower for Automotive Application



250°C Inlet Gas
Hermetically Sealed
Stainless Steel Construction

ANODE BLOWERS

Hot Anode Gas Recycle Blower (ARGB)

Hot Anode Gas Recycle Blower

Accomplishments

- ✓ Lab tested up to 718 °C inlet temperature
- ✓ Successfully field tested by U.S. Navy
- ✓ Design improvement in progress ~ 850 °C inlet
- ✓ Design is scalable

Anode Gas Recycle Blower for SECA Program



850°C Inlet Gas
Hermetically Sealed
Scalable to Larger Sizes

Technical Requirements

- ❖ Low Cost
- ❖ High Temperature Capability ($\sim 850^{\circ}\text{C}$)
- ❖ High Efficiency
- ❖ High Reliability
- ❖ Compact
- ❖ Maintenance Free

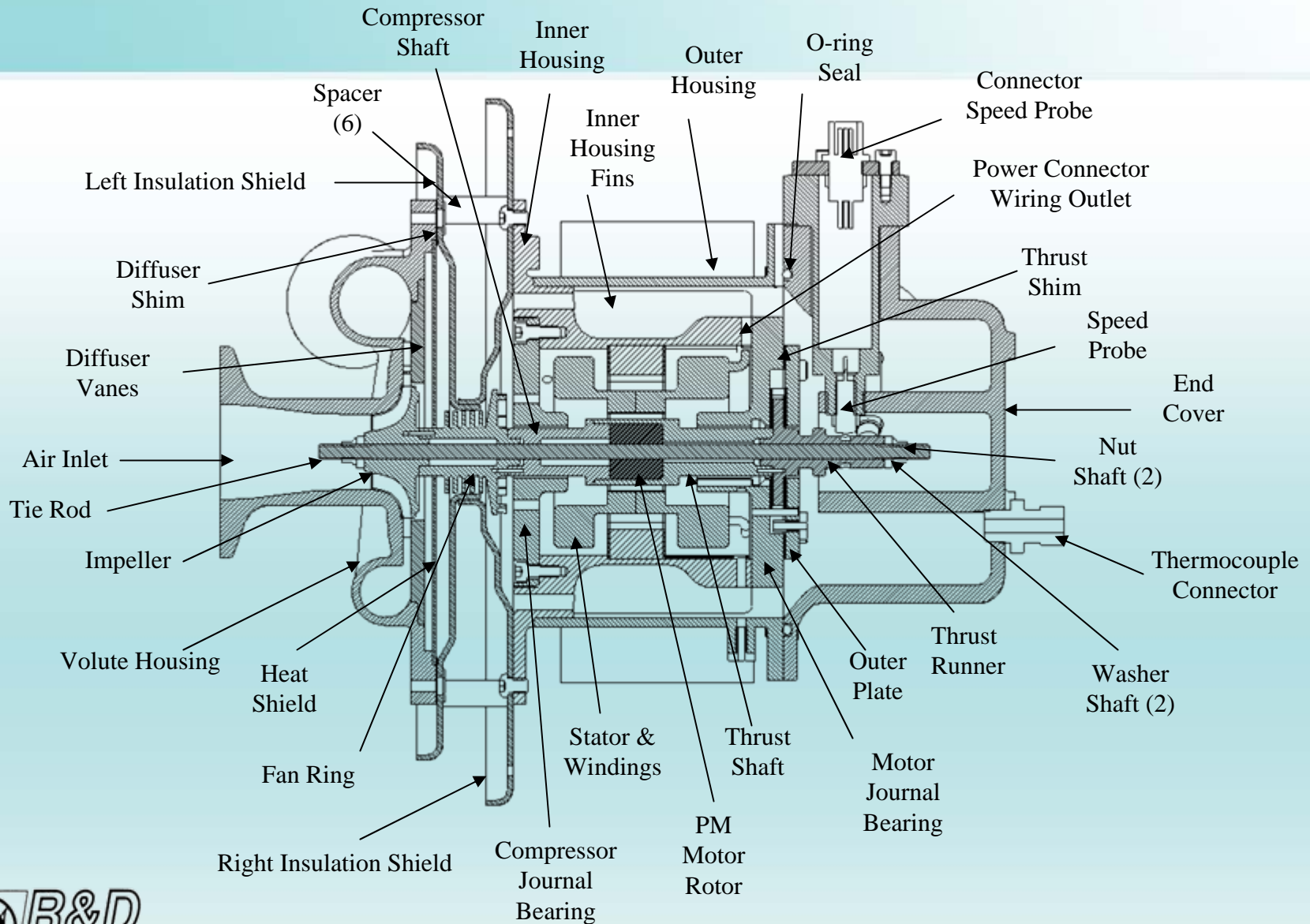
Additional Requirements by SECA Members

- ❖ Design for scalability.
- ❖ No gas leakage.
- ❖ No sulfur leak into fuel stream.
- ❖ No free silica exposure into fuel stream.
- ❖ No heavy metal leakage into fuel stream.
- ❖ Prefer DC voltage operation flexibility below 150 VDC.
- ❖ Design for 40,000 hour lifetime (flexible on maintenance interval).

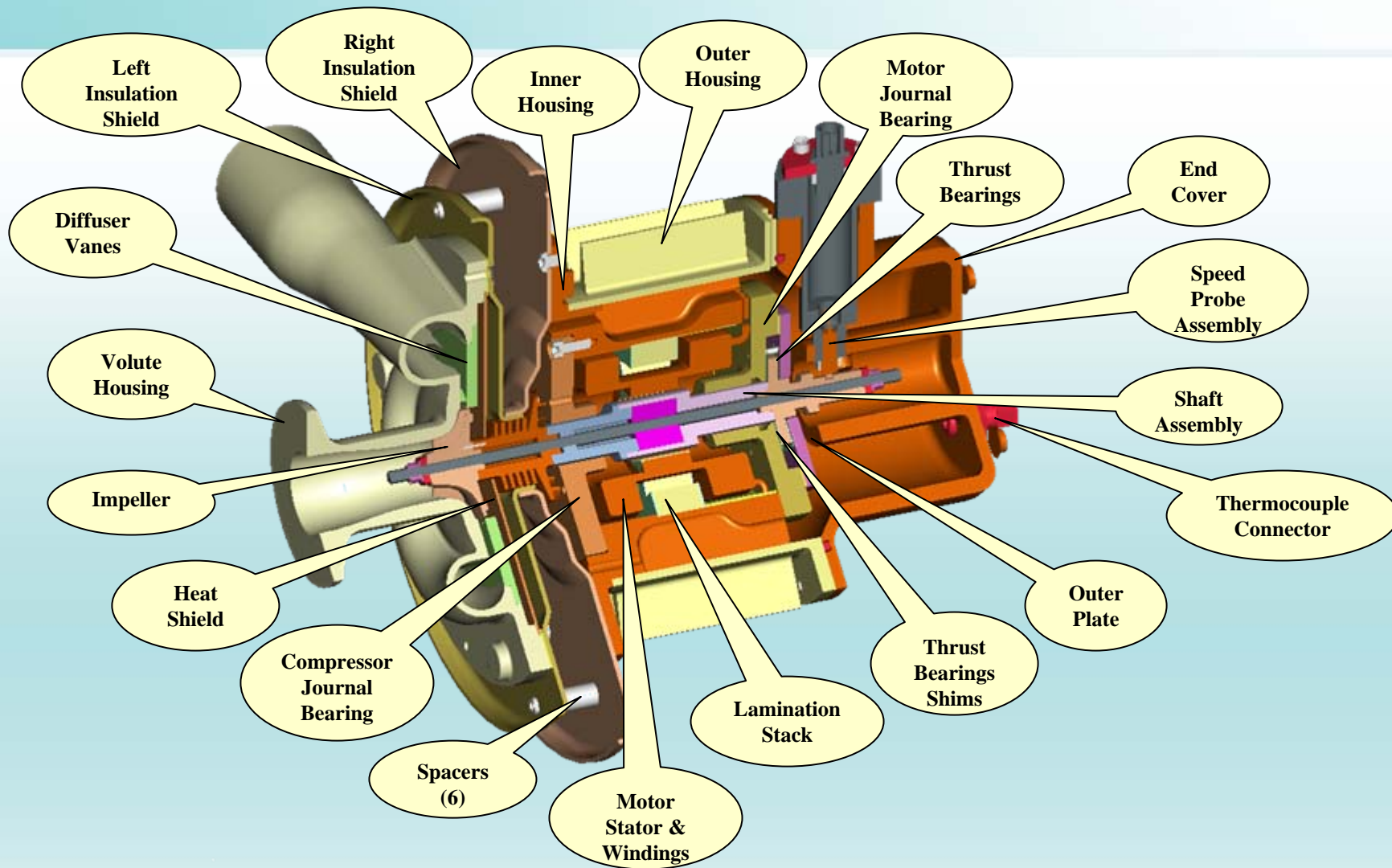
Additional Requirements (Cont'd)

- ❖ No cooling available from system other than from process fluid (air).
- ❖ All power consumption needs to include cooling.
- ❖ Purge gas is undesirable.
- ❖ Mechanical type seals do not last.
- ❖ Hydrogen around motor may be safety concern.
- ❖ Corrosion/carbon deposition issues with high temperatures.
- ❖ Metal out gassing at high temperatures with certain metals e.g. chrome.

AGRB Cross-Section Cut Vertically



AGRB Cut Away View

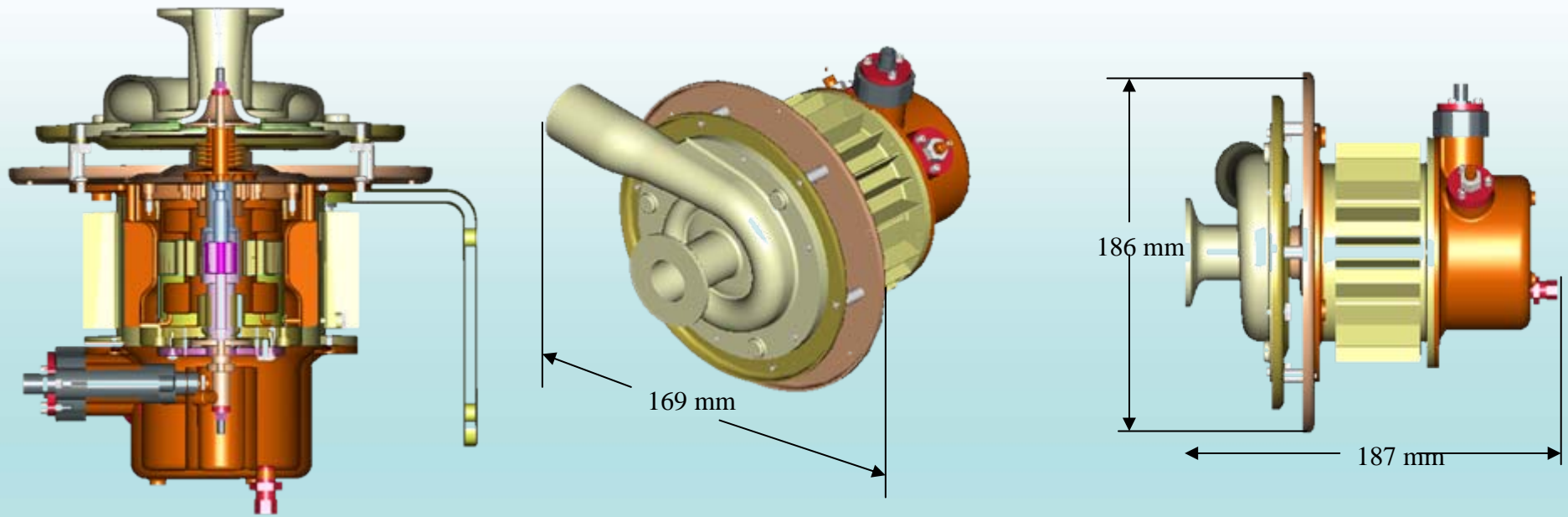


Technical Summary

▶ Blower Type	Centrifugal
▶ Mechanical Speed	98,600 rpm
▶ Pressure Ratio	1.025
▶ Weight	4.26 kg (9.38 lbs)
▶ Volume	0.565 liter (34.5 cu. in.)
▶ Bearings	Foil Gas Bearings
▶ Motor Type	Permanent Magnet Motor
▶ Controller	Sensorless
▶ Operating Temperature	850° C (1562° F)
▶ Overall Efficiency	45%

Innovative High Temperature AGRB

Design Packaging

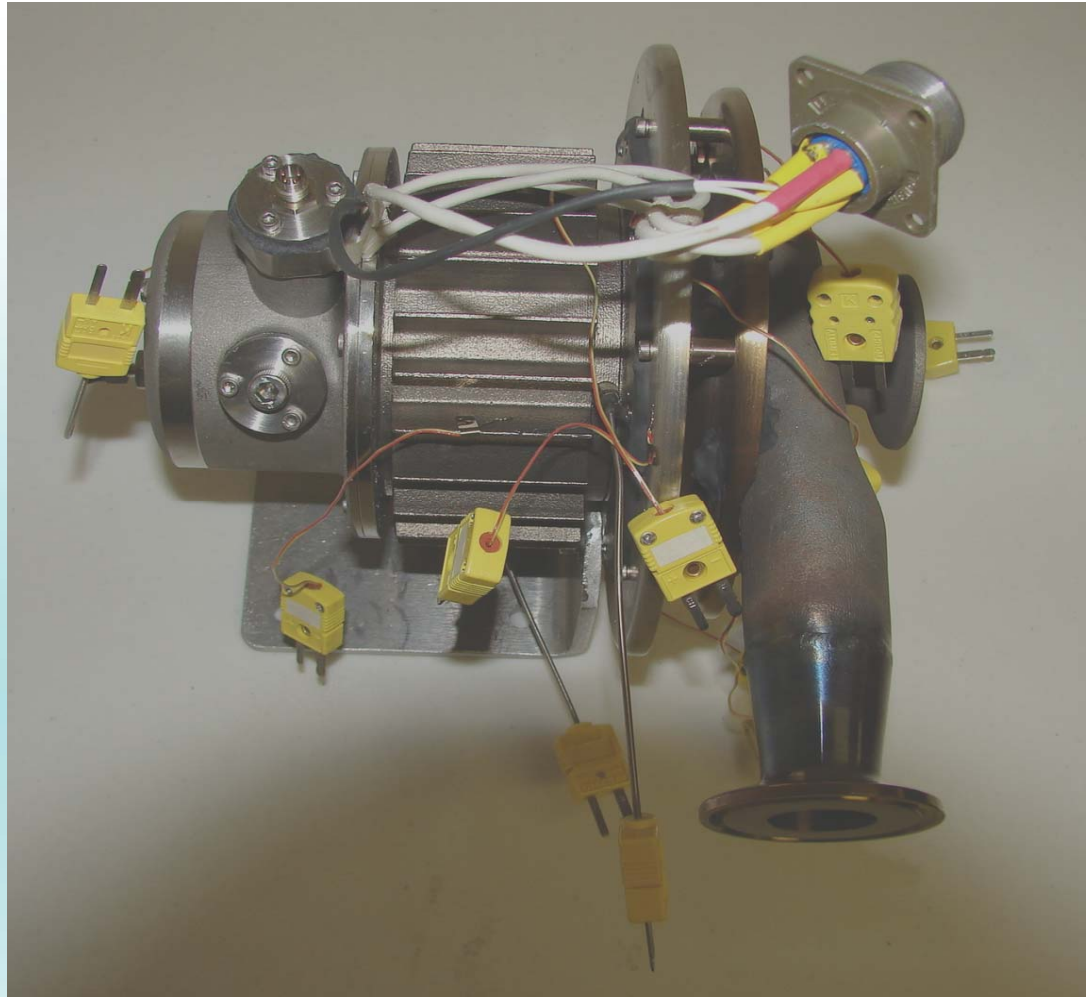


Total Assembly Weight = 4.26 kg

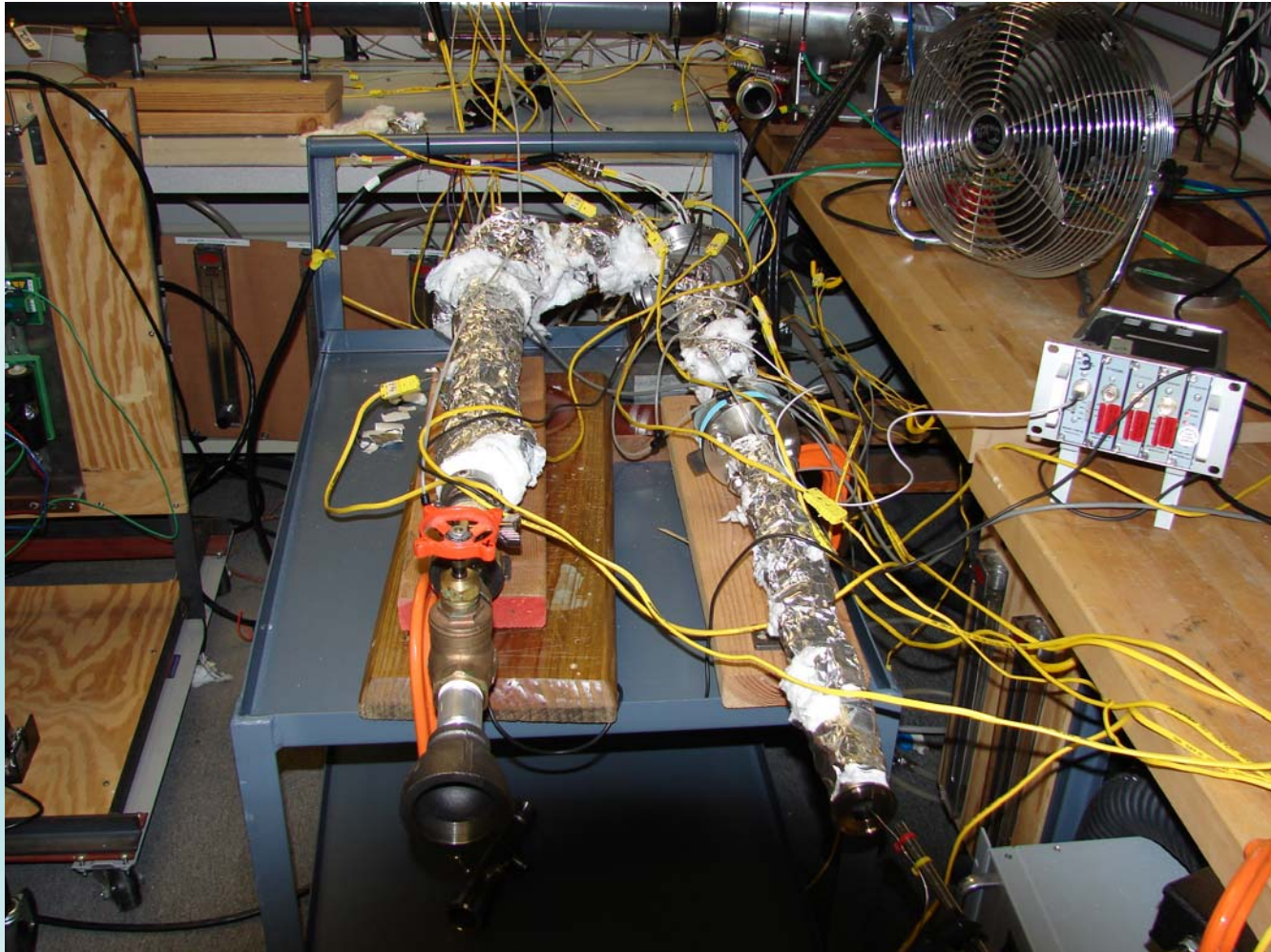
AGRB Tested in 3 Different Arrangements

1. Testing at ambient conditions
2. Testing at moderate (~ 430 °C) using heat gun as heat source
3. High temperature testing using heat furnace

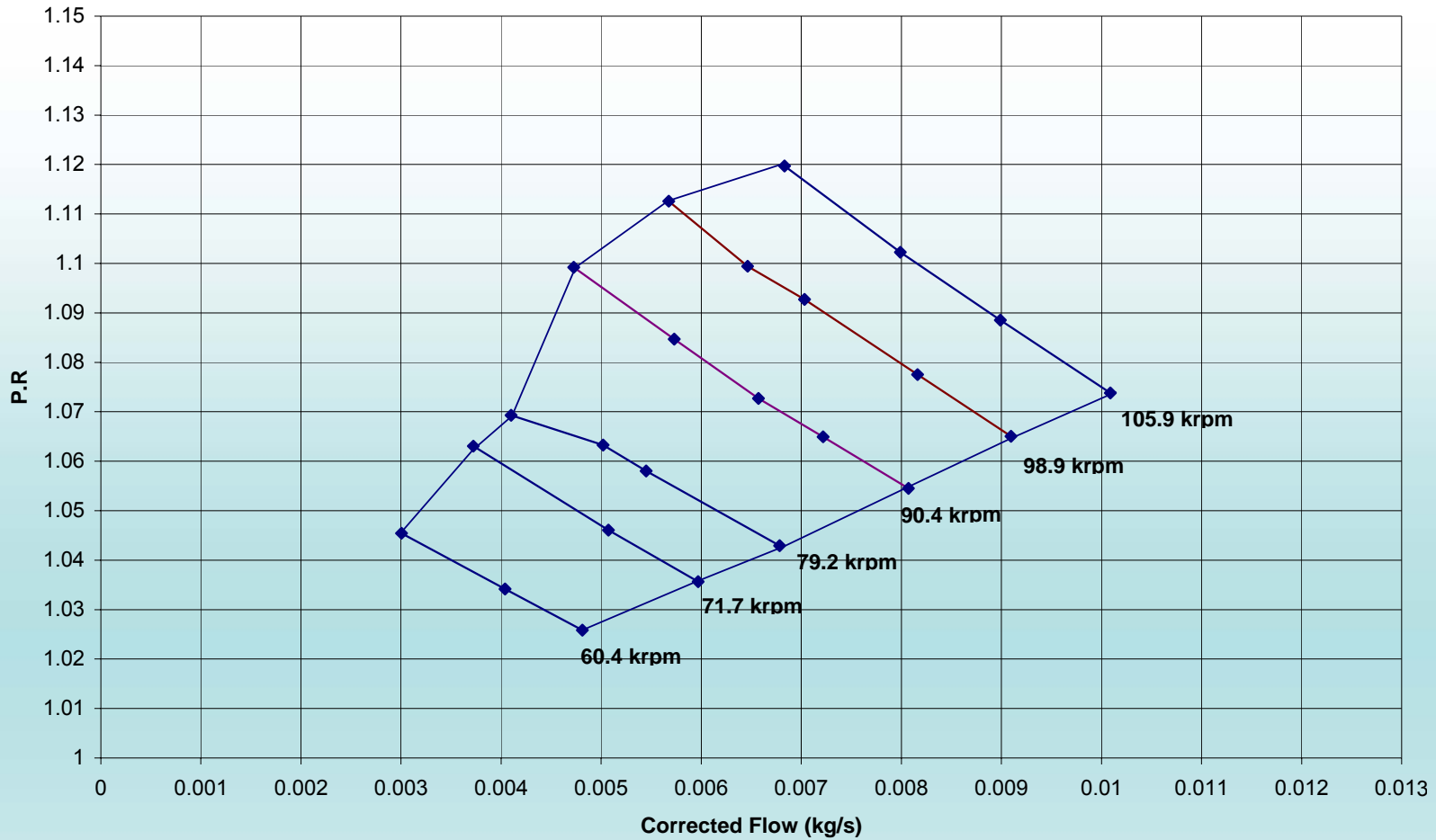
AGRB Instrumented



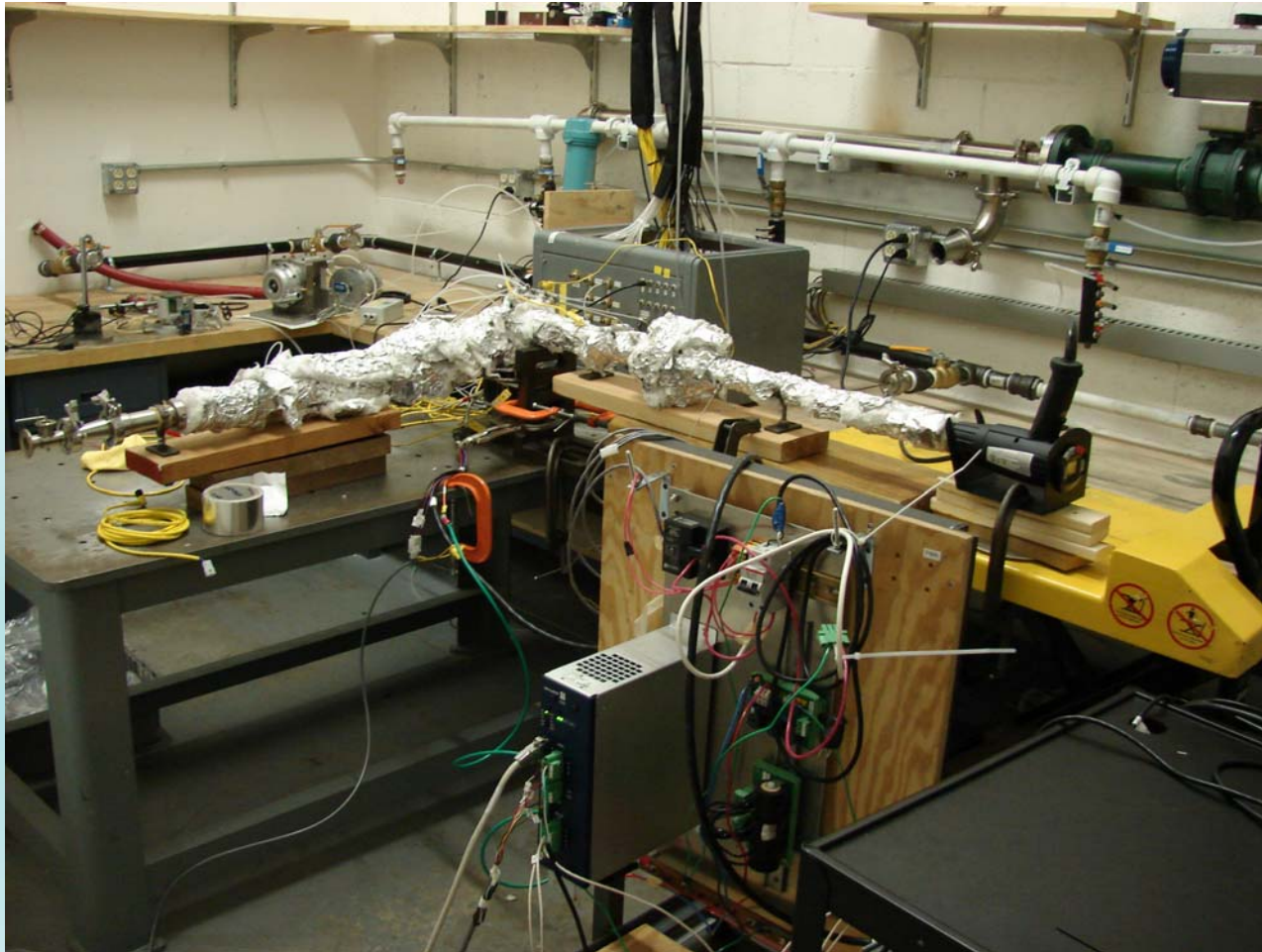
AGRB Test Rig Setup at Ambient Conditions (Arrangement #1)



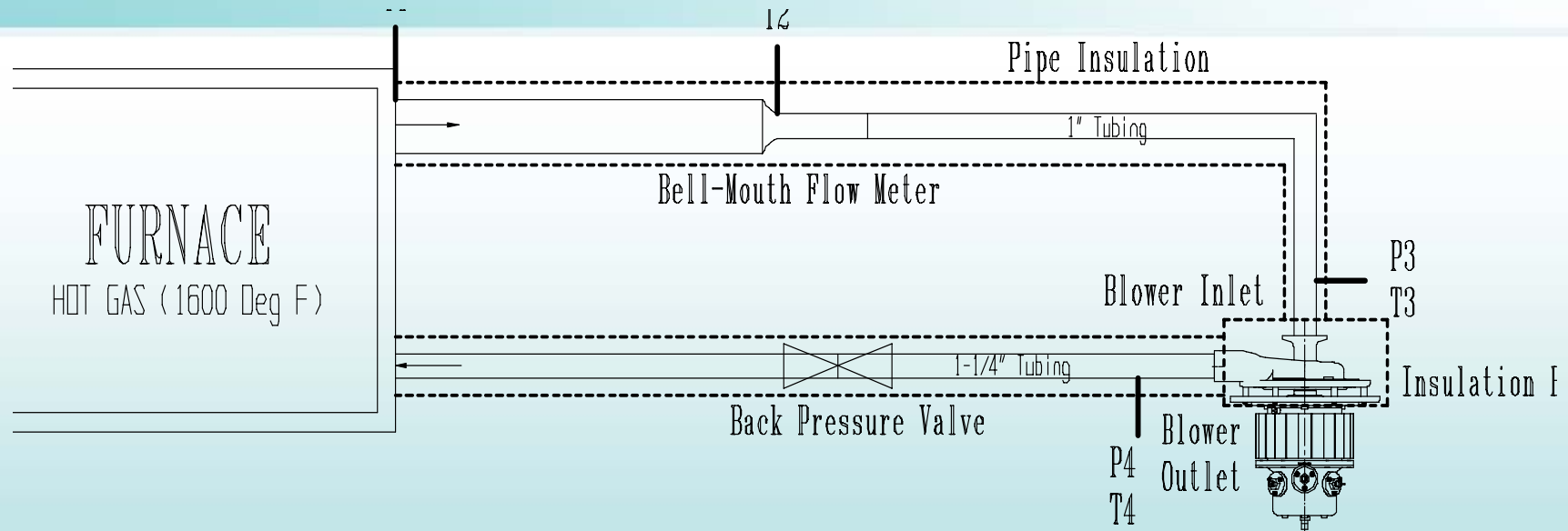
AGRB Map at Ambient Conditions (Arrangement #1)



AGRB Fully Insulated Open Loop Rig Setup using Heat Gun (Arrangement #2)

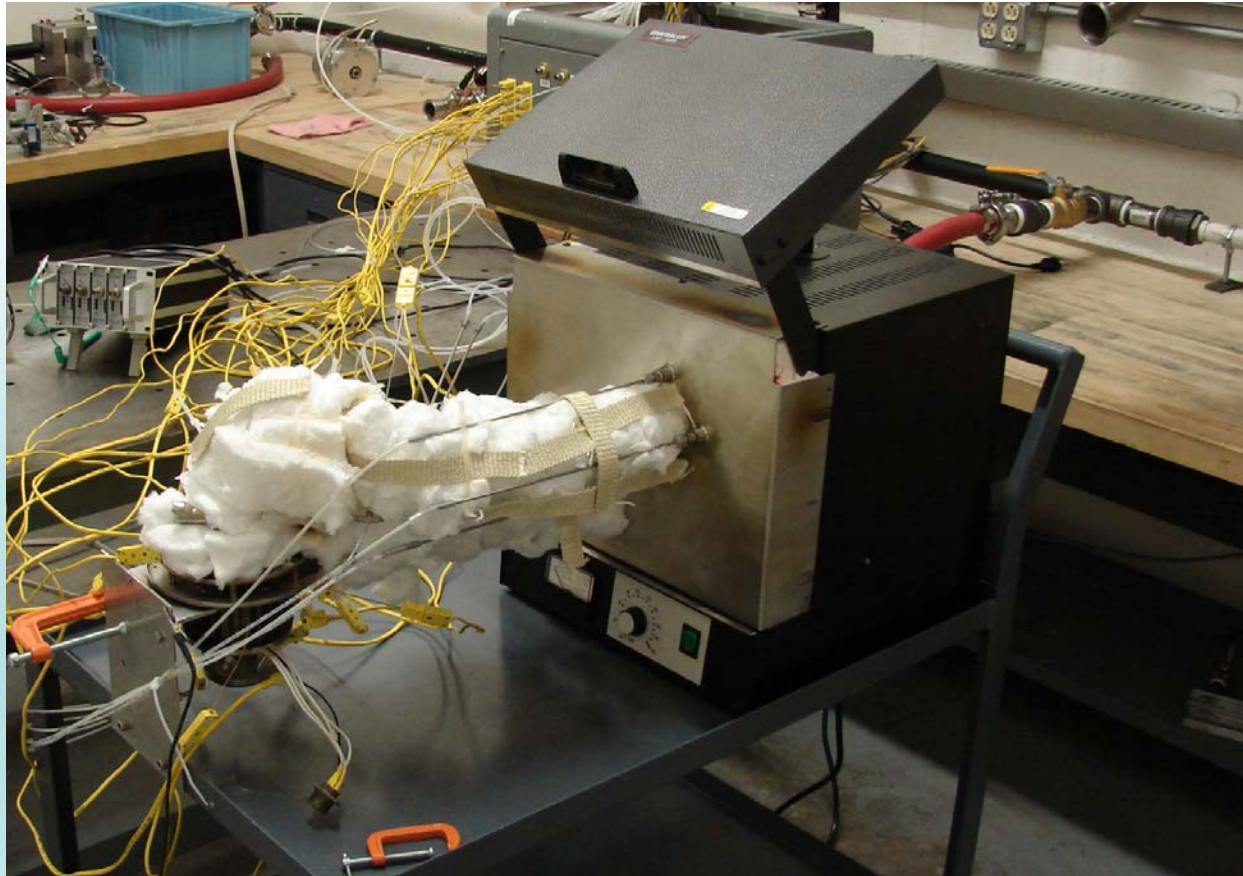


AGRB Closed Loop High Temperature System (Arrangement #3)

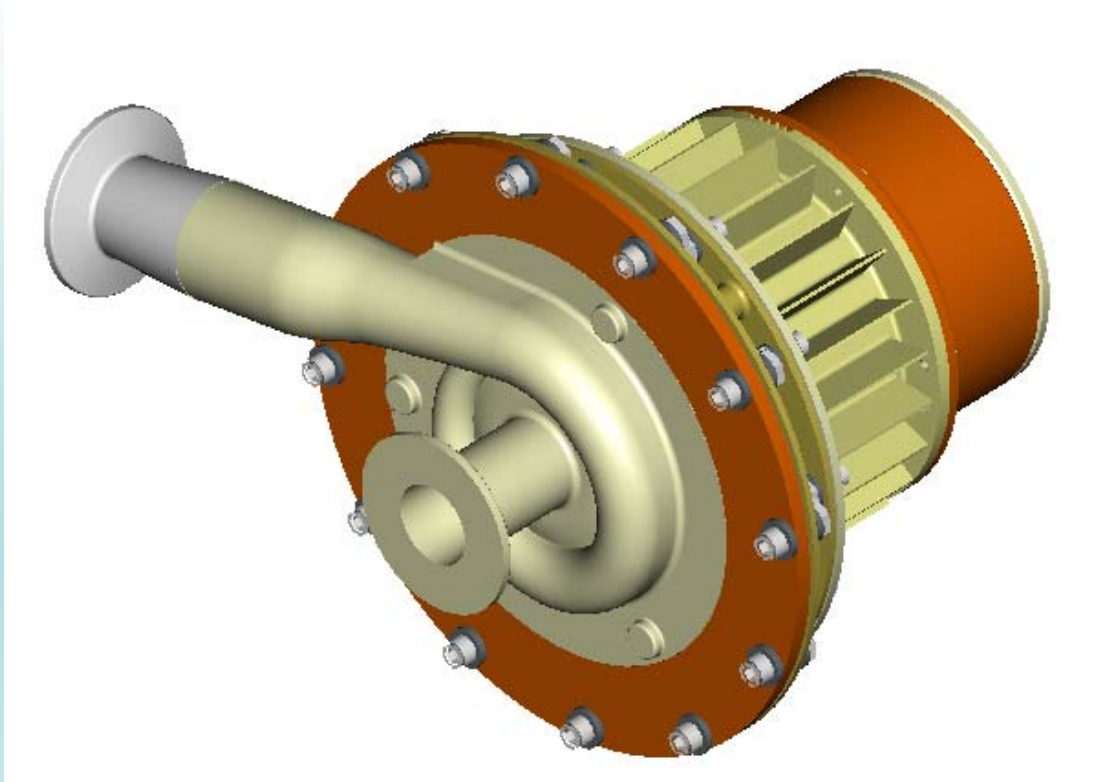


- ▲ The test cycle is based on closed loop system.
- ▲ Hot air is circulated via Furnace heated up to 850 °C.
- ▲ Flow to the compressor measured through bell mouth flow meter.
- ▲ Back pressure valve is used to back pressure the compressor to generate compressor map.
- ▲ All the plumbing connections and pipings are fully insulated for a minimal heat loss.
- ▲ The blower hot side is enclosed in an insulation box for minimal heat loss.

AGRB Fully Insulated High Temperature Rig Setup (Arrangement #3)



AGRB Cost Reduced Design



Work in Progress

- ✓ Upgrade of materials and design in progress to run AGRB at 850 °C
- ✓ Cost reduction is being worked on in parallel

Conclusions

- ✓ Component and SECA member system testing have shown that foil bearing supported blowers will meet...
 - High efficiency
 - Low volume/weight
 - High reliability
 - Oil free operation
 - Maintenance free operation

Conclusions (cont'd)

- ✓ DFMA analysis have shown that production cost target of SECA members will be met
- ✓ Pricing of limited production units will require partnership among...
 - ❖ R&D Dynamics
 - ❖ SECA Members
 - ❖ Department of Energy

Acknowledgement

*R&D Dynamics would like to thank DOE
and SECA members for their support*