High Temperature Anode Recycle Blower for Solid Oxide Fuel Cell

Department of Energy Award No.

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Prepared for DOE

By Mohawk Innovative Technology, Inc.

Mohawk Innovative Technology, Inc.

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Pittsburgh, PA
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Project Team

MITI

- Hooshang Heshmat, PhD
  - Principal Investigator
- Jose Luis Cordova, PhD
  - PM/Thermal Management
- James F. Walton II
  - Rotordynamics

FCE

- Hossain Ghezel Ayagh, PhD
  - FCE Director
- Stephen Jolly
  - Systems Design Engineer
- Micah Casteel, PhD
  - Mechanical Engineer

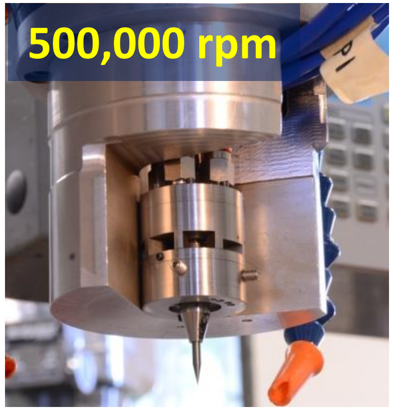
DOE Program Manager: Arun Bose, NETL

Team Background

- ***MITI*** Specializes in High-Speed, High-Temperature Oil-Free Rotating Machinery Technology
  - Blowers, Compressors, Turbo-alternators, Gas-Turbine Engines, Flywheel Energy Storage, and more.
- ***FCE*** Integrated fuel cell company that designs, manufactures, installs, operates and services stationary fuel cell power plants.

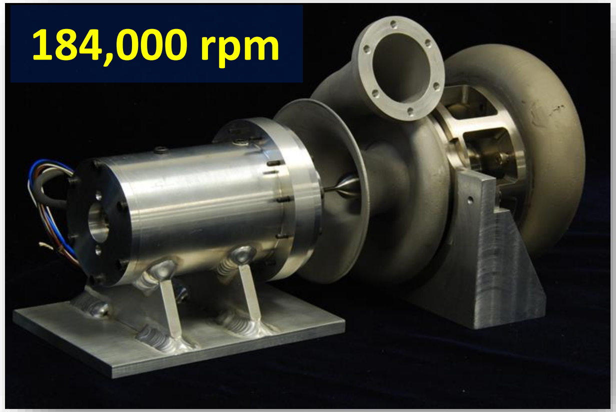
MITI's Oil-Free Turbomachinery

Micro Machining



Hydrogen Blower

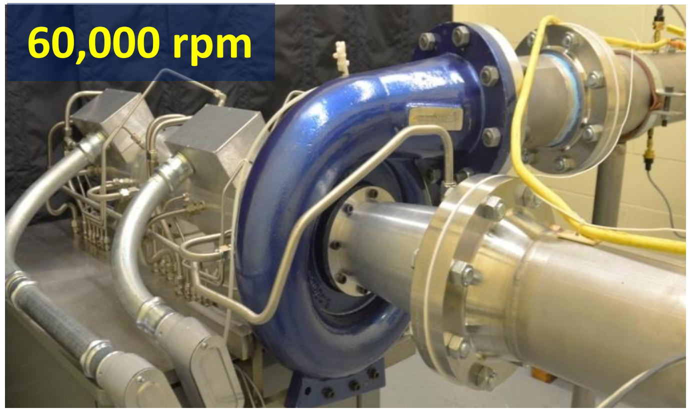
8 kW Turbogenerator



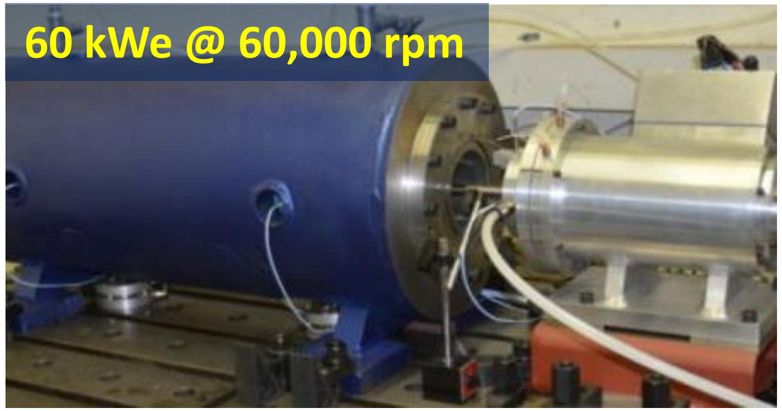
Air Cycle Machine

Fuel Cell Compressor

Hydrogen Pipeline Compressor



Flywheel Electromechanical Battery



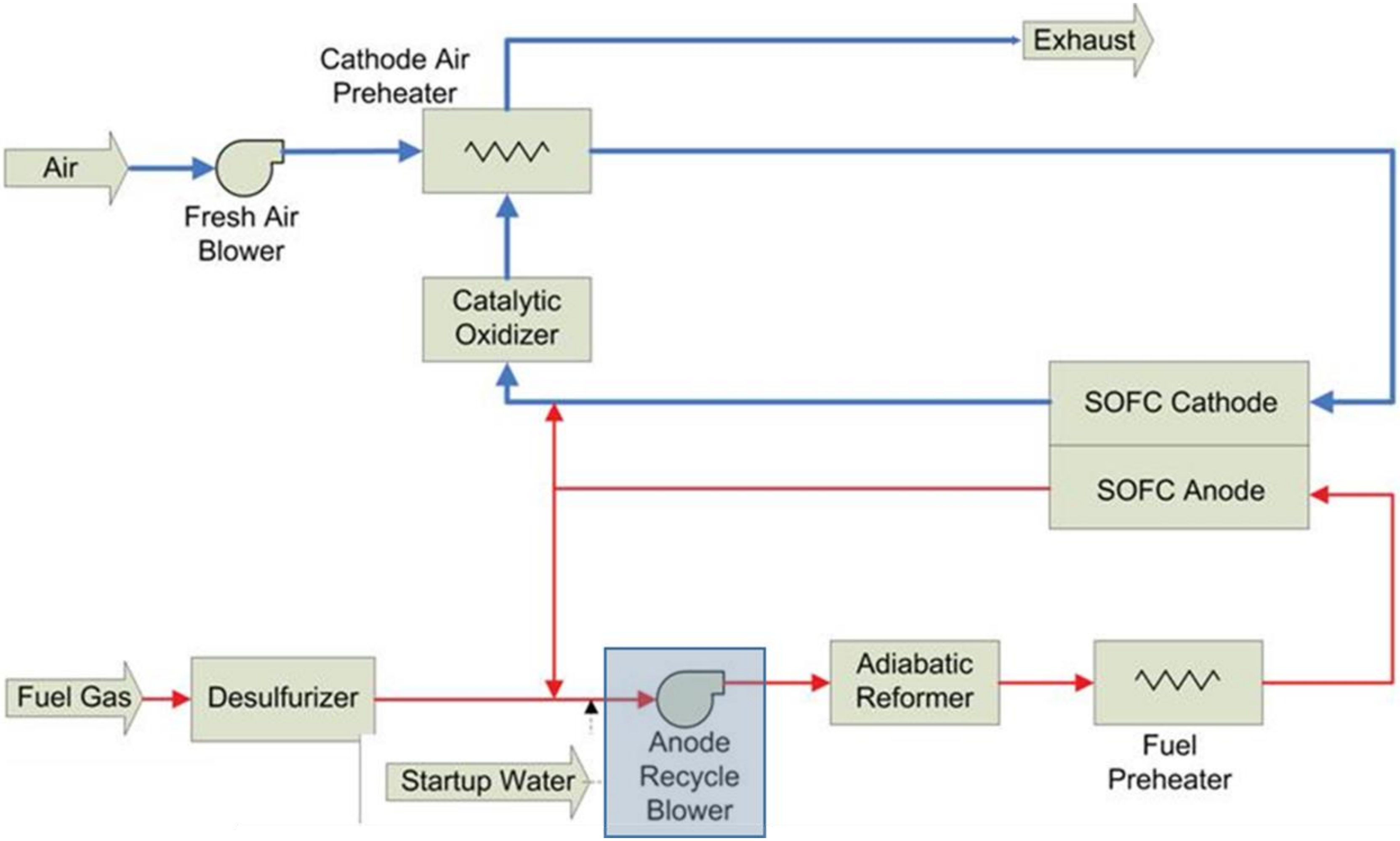
ORC Turbogenerator

Fuel Cell Energy, Inc. 200 kW SOFC

- Develops Solid Oxide Fuel Cell (SOFC) for power generation and electrolysis.
- 200 kW SOFC selected as commercialization platform.
- Thermally integrated modules enable compact and lower cost system.
- Unattended Operation with Remote Monitoring
  - >60% Electrical Efficiency
  - >5000 hours of operation
- Heat recovery capability for > 80% total thermal efficiency.

Project Objectives

- Develop Scalable Oil-Free High Temperature Anode Recycle Blower for SOFC Power Plants
  - Design of a scalable oil-free high temperature SOFC recycle blower
  - Experimental validation
  - Demonstrate commercial viability
- Reduce BOP and Increase Efficiency
  - Recycle anode off-gas
  - Reduce external water supply used for fuel reforming
  - Small footprint



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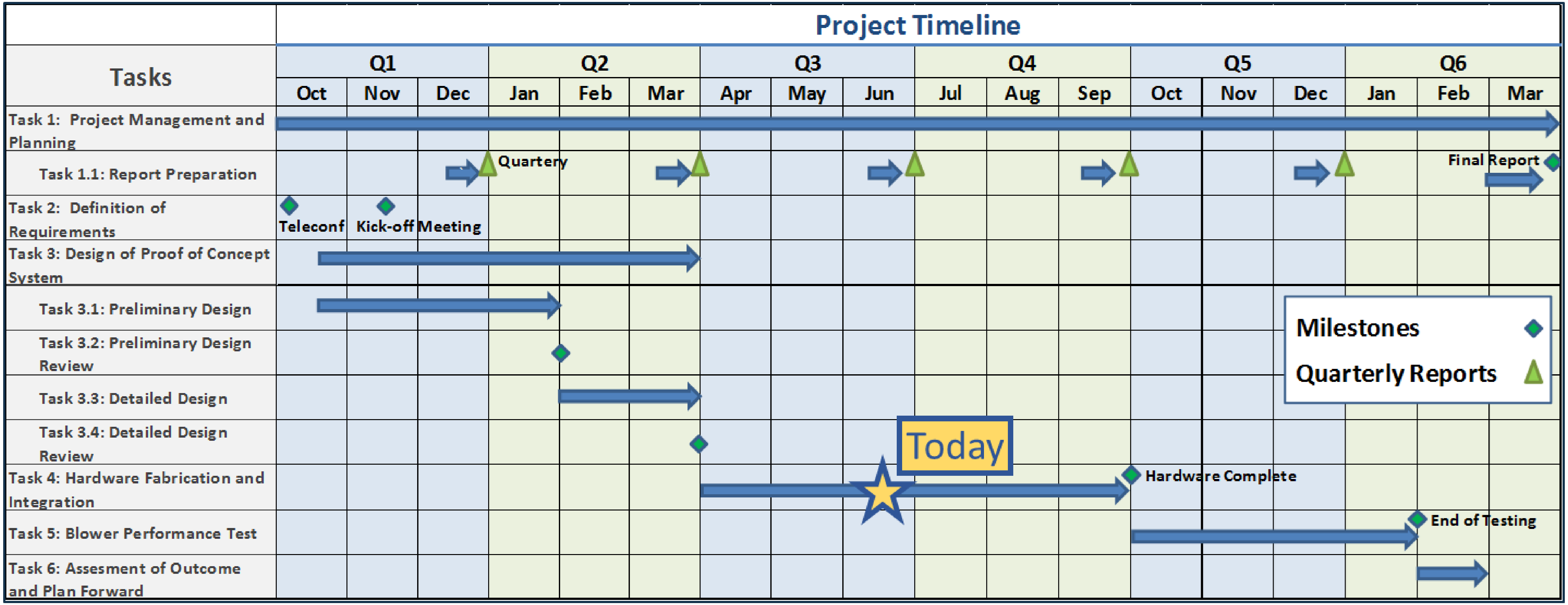
Project Structure and Timeline

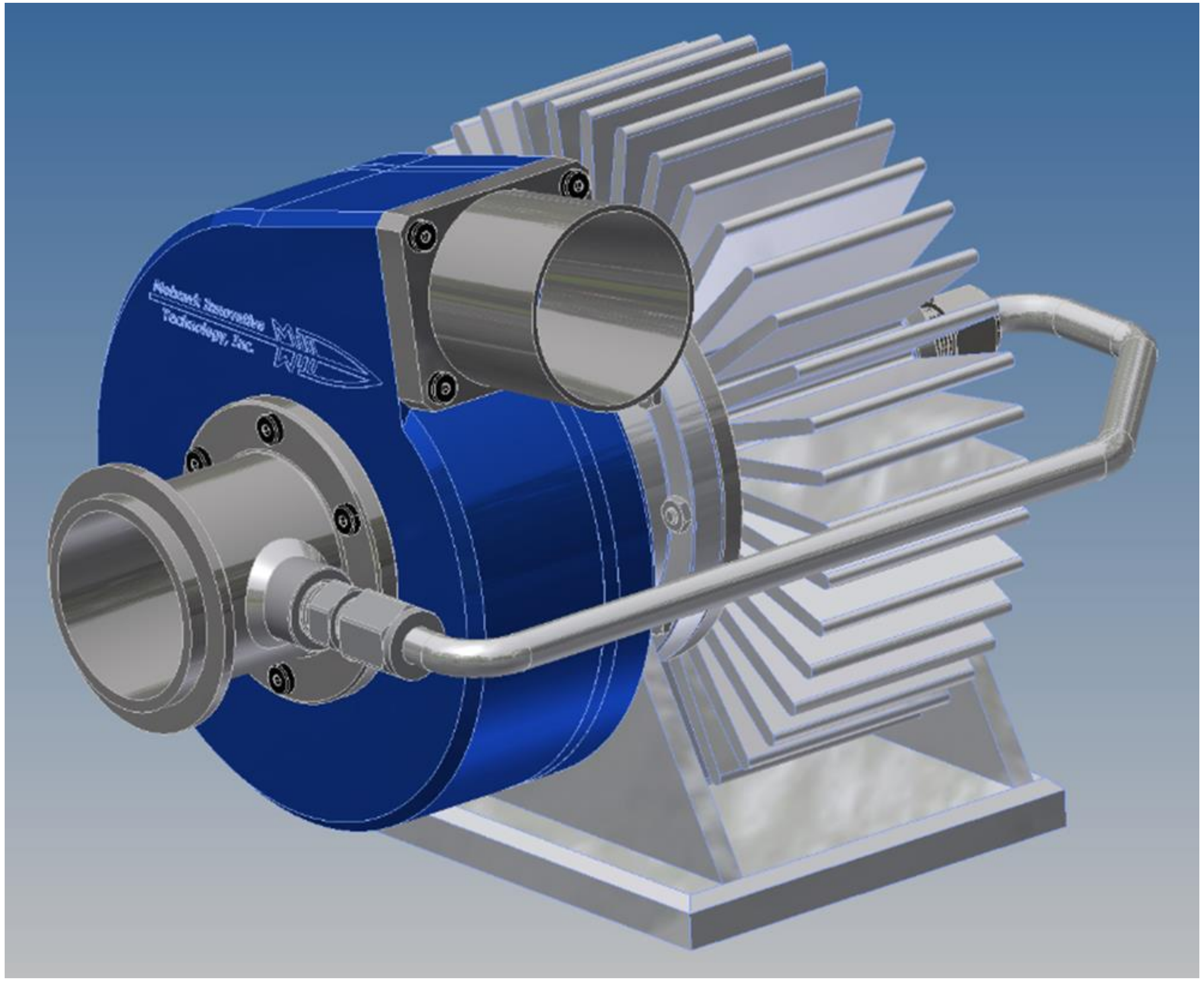


Task 2: Operating Conditions (Specs)

- Three sets of operating conditions specified with input from FCE:
  - Start-Up Transient
  - Nominal Operation
  - Rated Operation
- These require a high turn-down ratio engine
  - Temperature: Up to 180^{o}C
  - Flow Rate: 0.02 to 0.04 kg/sec
  - Pressure Increase: ~8 kPa
  - Gas composition: Varialble Mix, of Water, CO_2 and H_2 (Primarily)
- Water content requires encapsulation of magnet and stator element

Task 2: Key Design Requirements

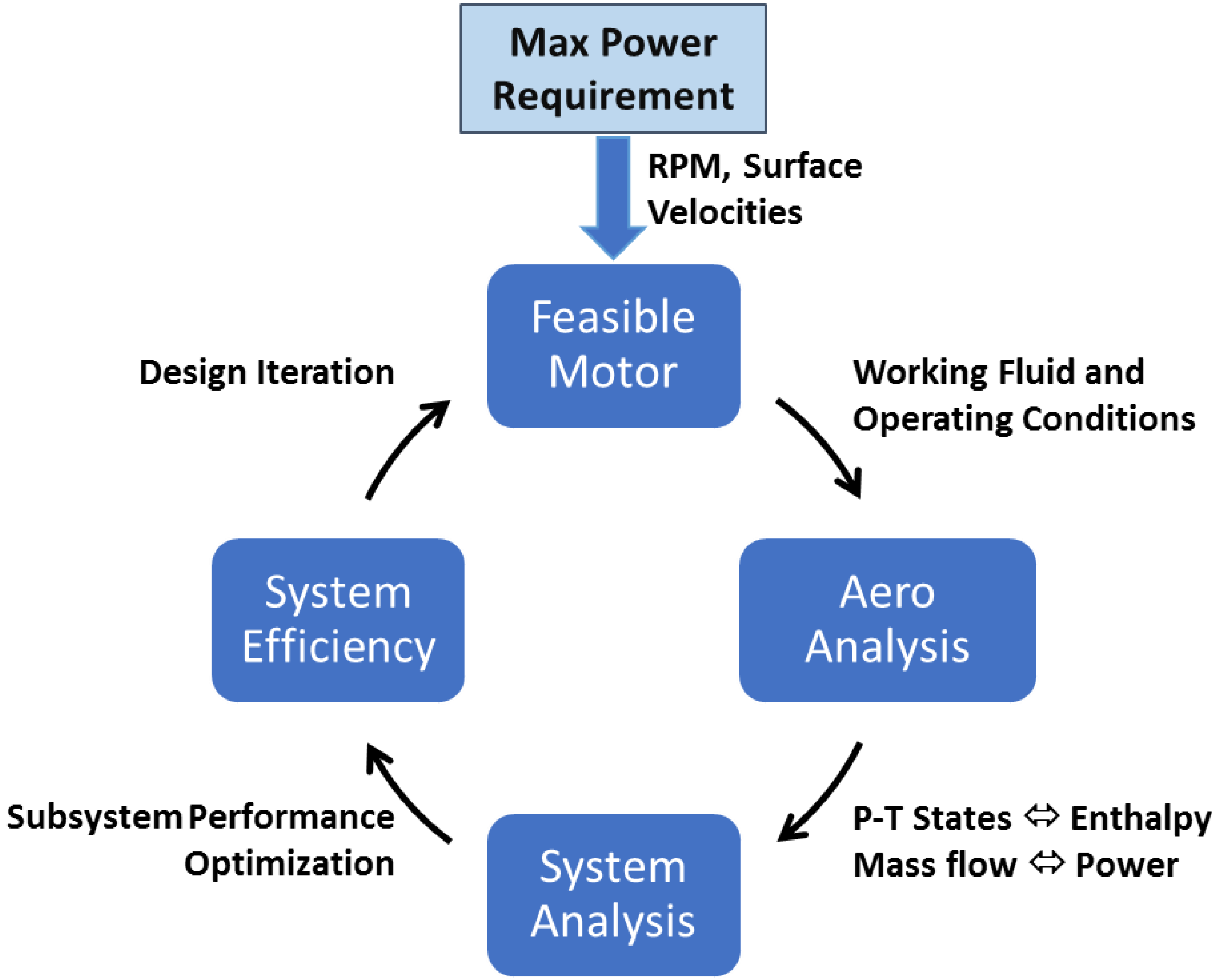
- Net Power Input < 1.5 kW
- Oil-Free Design
  - No Internal Liquid Cooling or Lubrication
  - High Efficiency
- Air Cooling
- Economical Design
  - Low Capital/Operating Cost
  - Maintenance-Free
  - Long Life



Task 3: Blower Design Process

Oil-Free System Design Elements

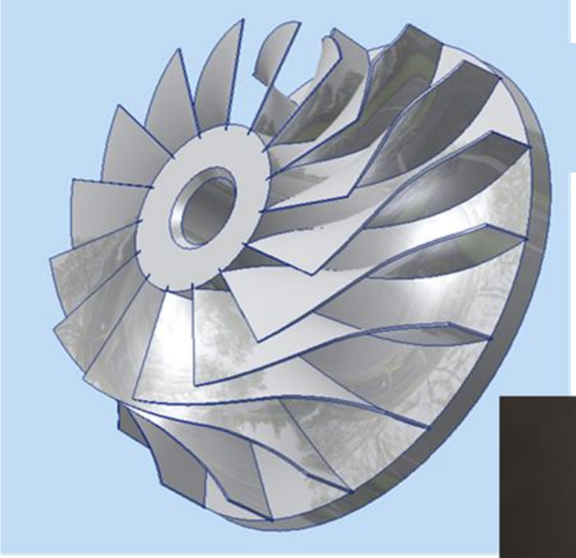
- Motor/Power Electronics
- Fluid/Thermodynamic Analysis
- Aerodynamic Design
- Rotor-Dynamic Analysis
- Foil Bearing Design
- Thermal Management



Task 3: Aerodynamic Design Summary

Chosen Design

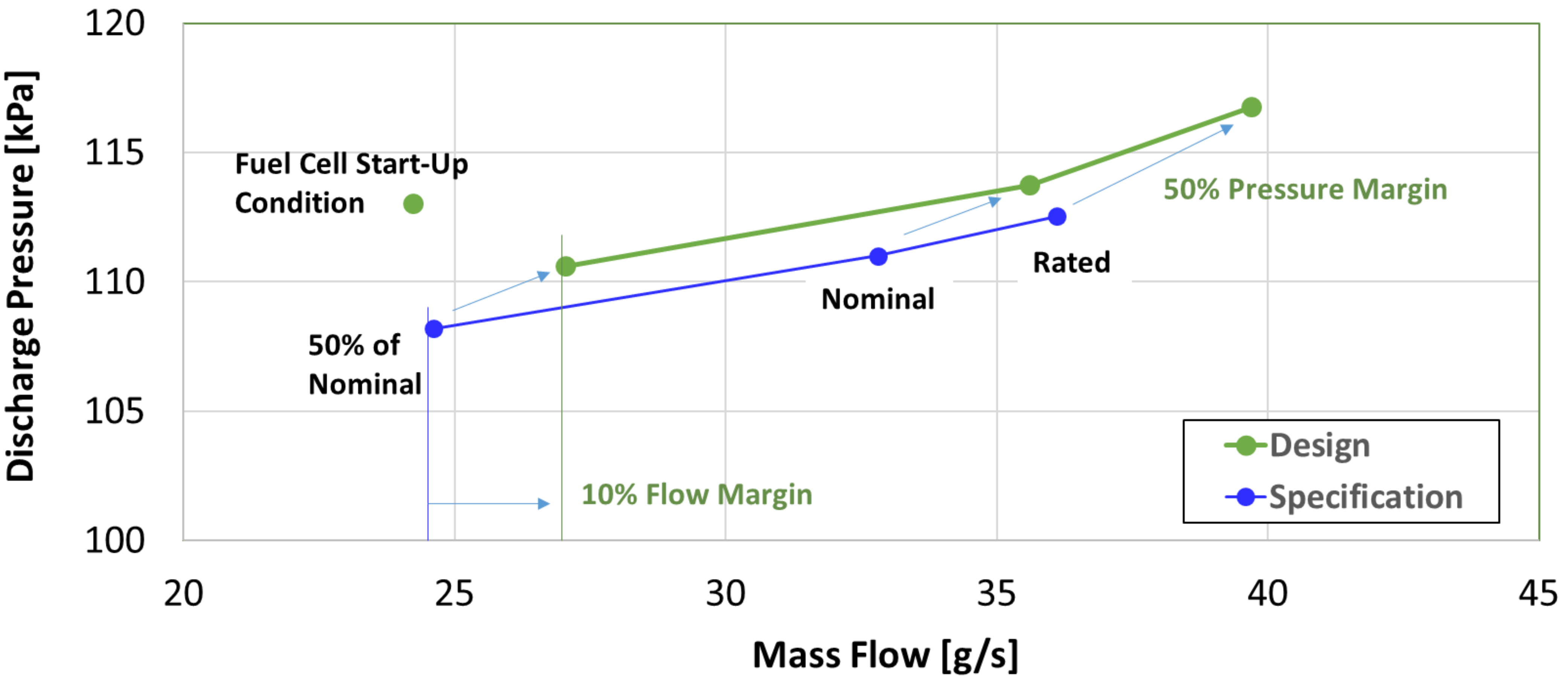
- Type = Centrifugal
- Diameter = 50 mm
- Operating Speed Range
  - 55 krpm < N < 80 krpm
  - Flow
- Efficiency > 85%
- Material Selection:
  - Aluminum 2618-T61



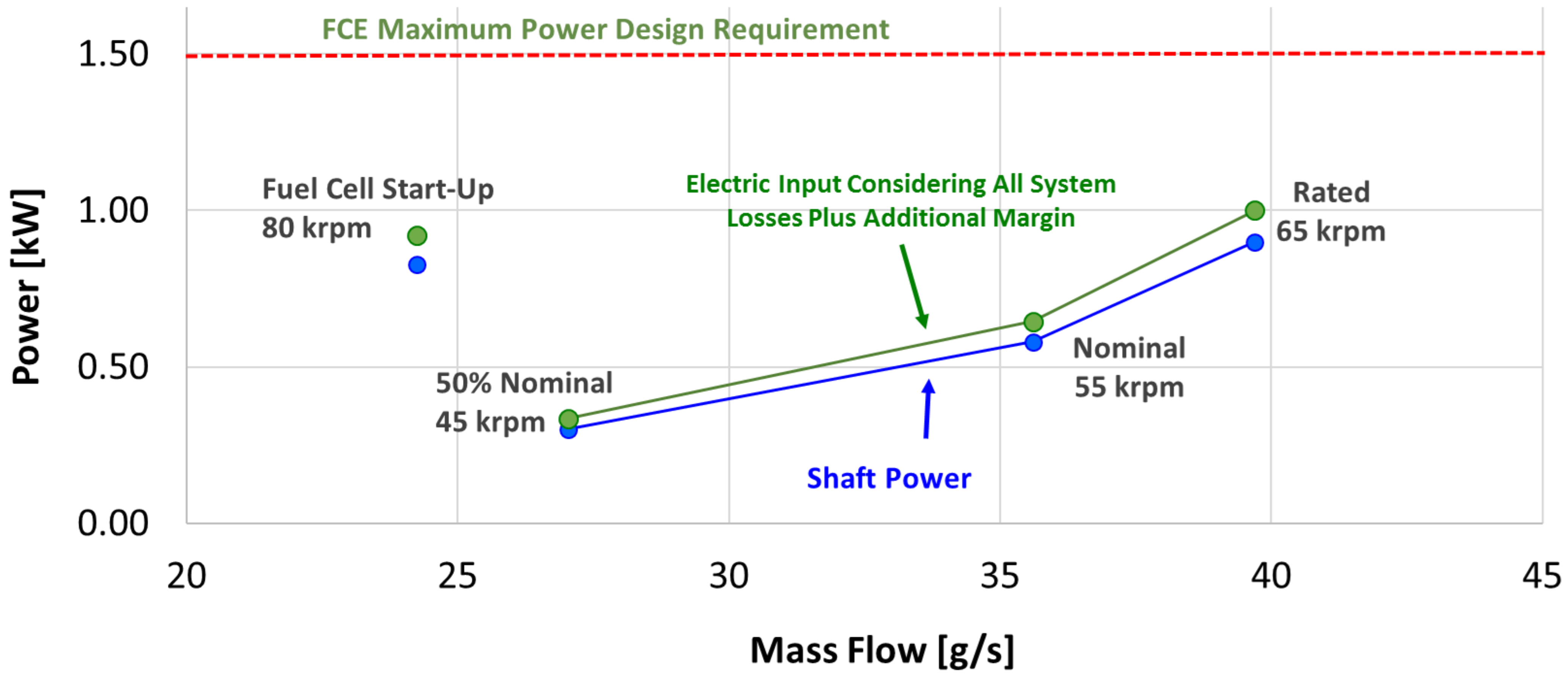
Solid CAD/CAM Model

Actual Manufactured Part

Task 3: Centrifugal Wheel Performance



Task 3: Blower Performance



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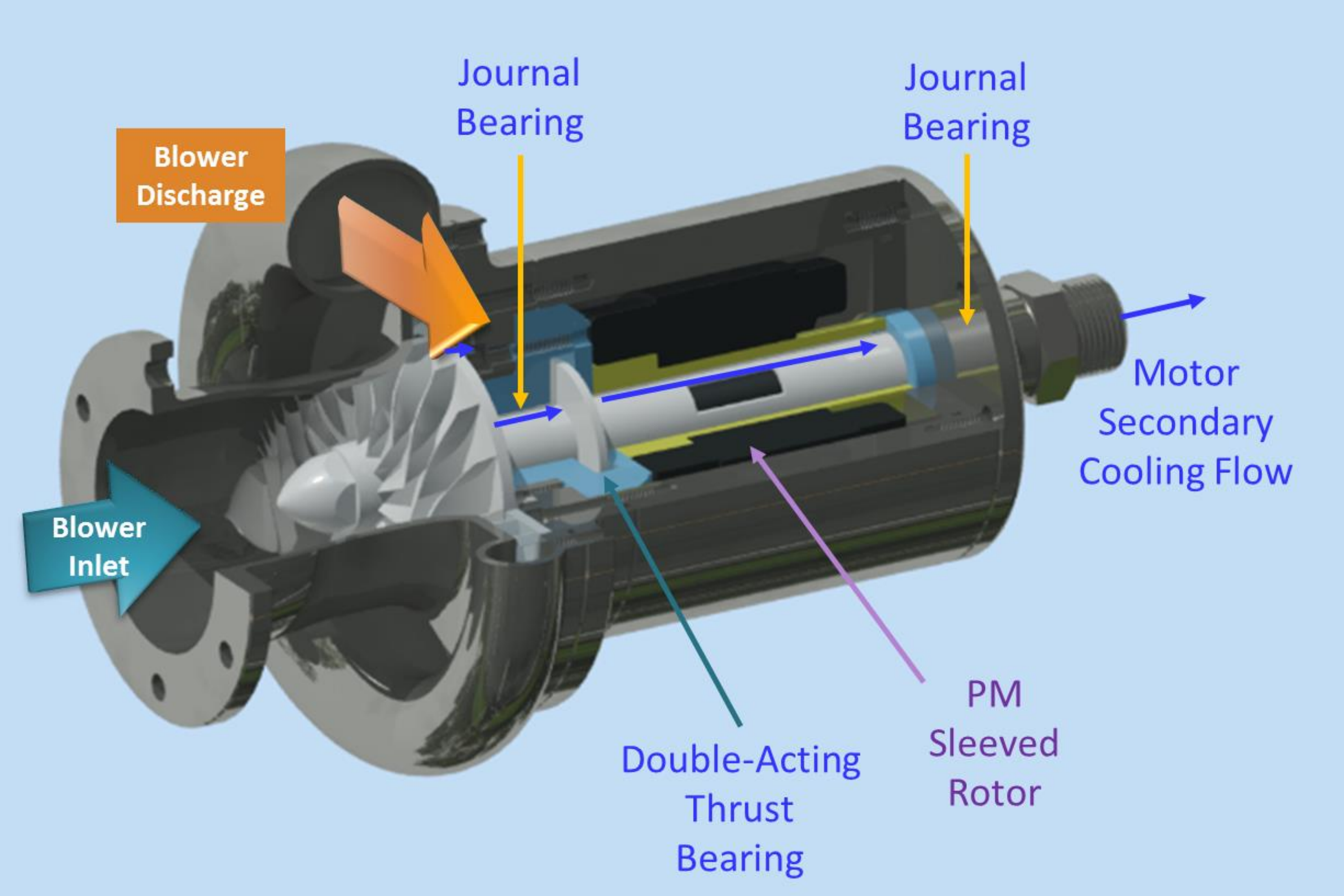
Task 3: Anode Recycle Blower Layout

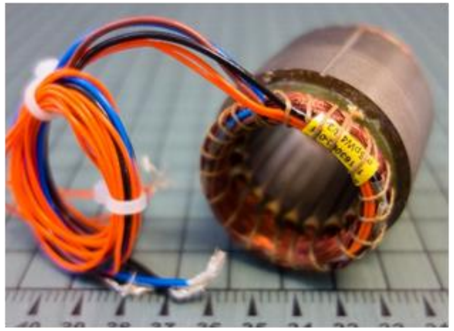
Design Features

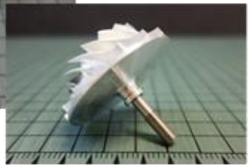
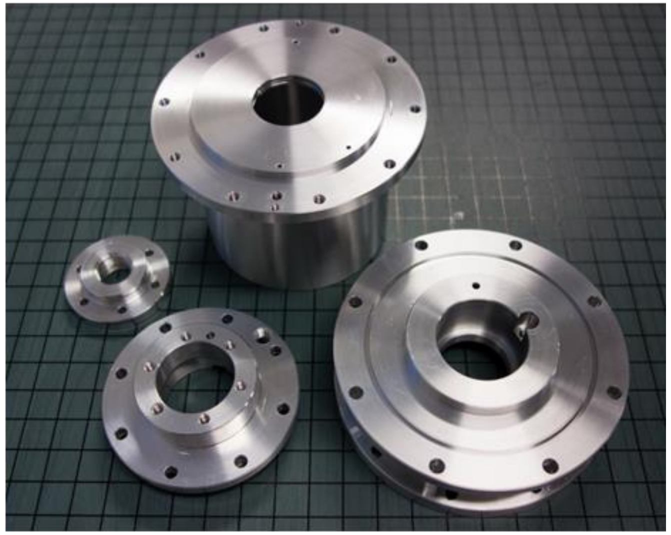
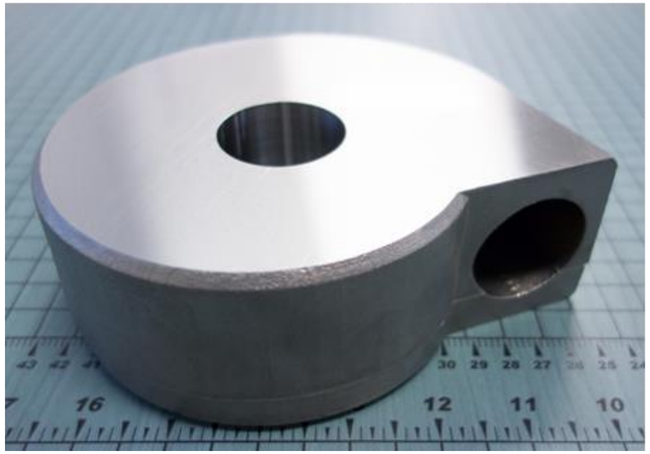
- Hermetically sealed
- One moving part
- Radial outflow
- Encapsulated permanent magnet/stator
- Process fluid lubricated and cooled system



Task 4: Hardware Fabrication and Integration

- Fabricate Parts and Assemble Prototype Blower
- Instrument Prototype
  - Temp/Pressure/Flow/Power
  - Monitor Rotor Motions
- Preliminary Tests
  - Verify Instrumentation Operation
  - Verify Motor/Drive Operation
  - Confirm Rotor Smooth Operation

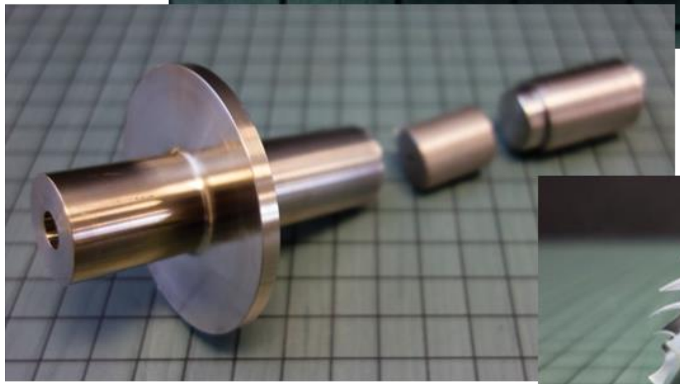



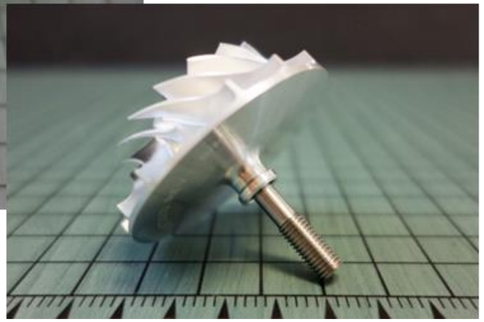




Task 4: Rotating Elements

100% of rotating components fabricated

- Integrated shaft/permanent magnet assembly
- Blower impeller

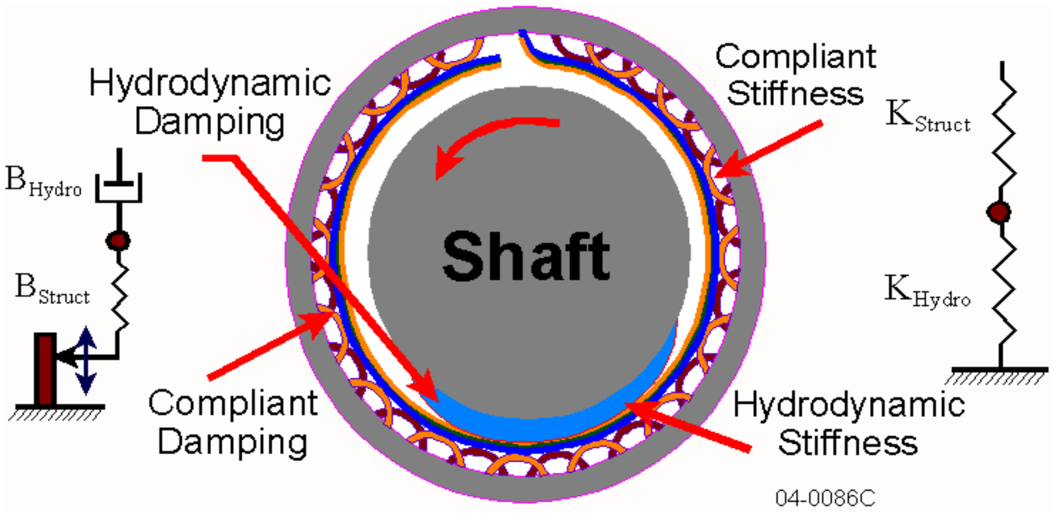




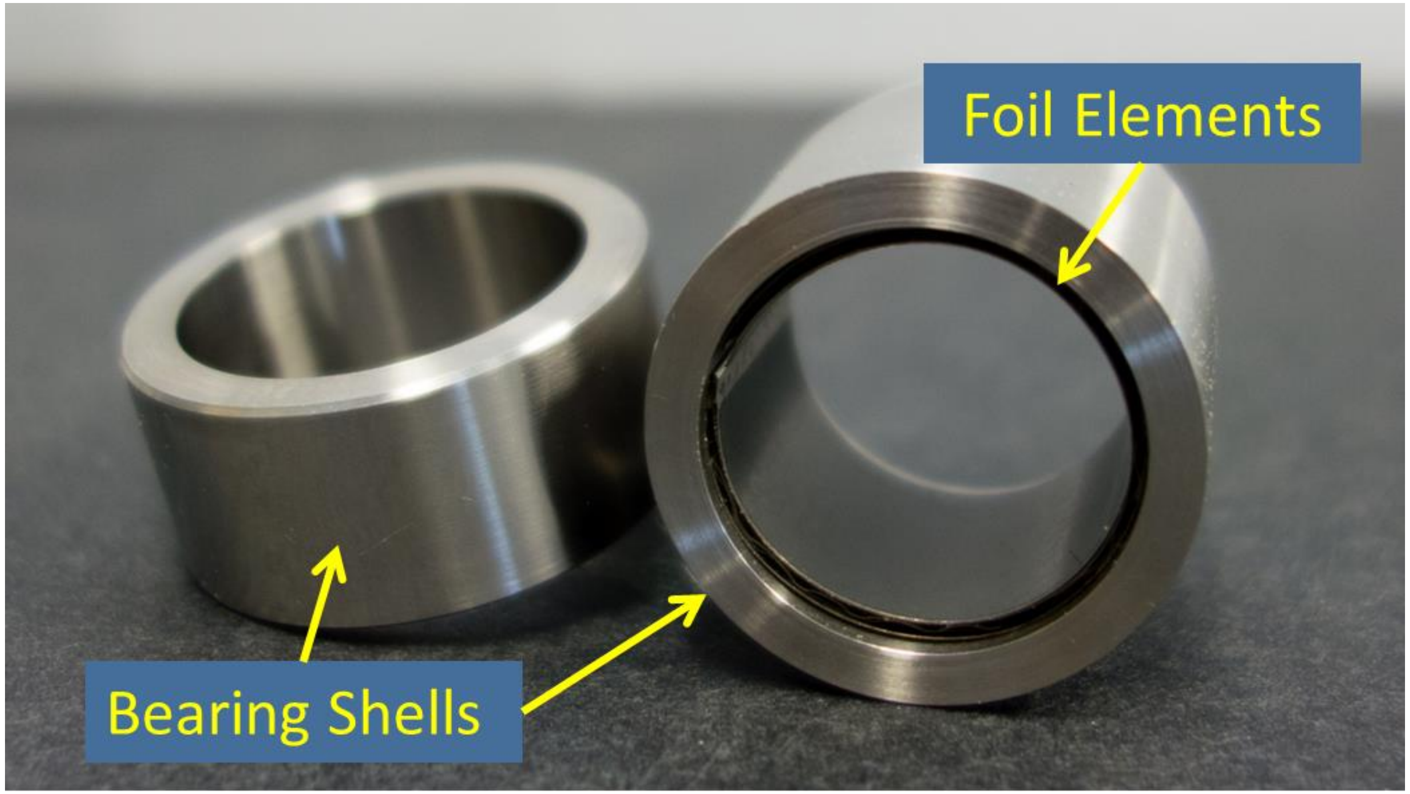
Task 4: Oil-Free Foil Bearings

Bearing Components Fabricated

- Bearing Housings
- Bearing Shells/Plates
- Foil Components

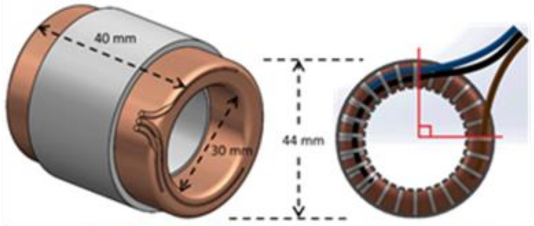


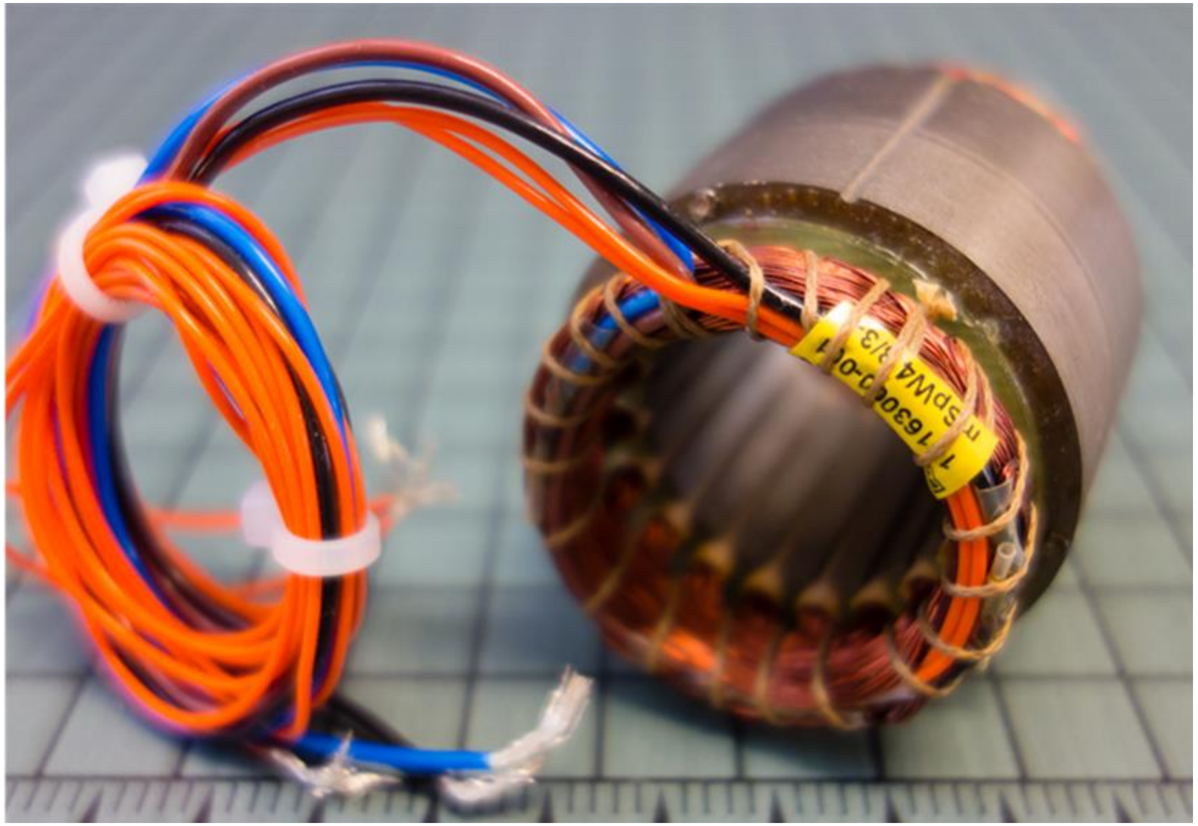
Fabricated Journal Bearings



Task 4: Motor Stator and Drive

Stator and drive/power electronics have been built.





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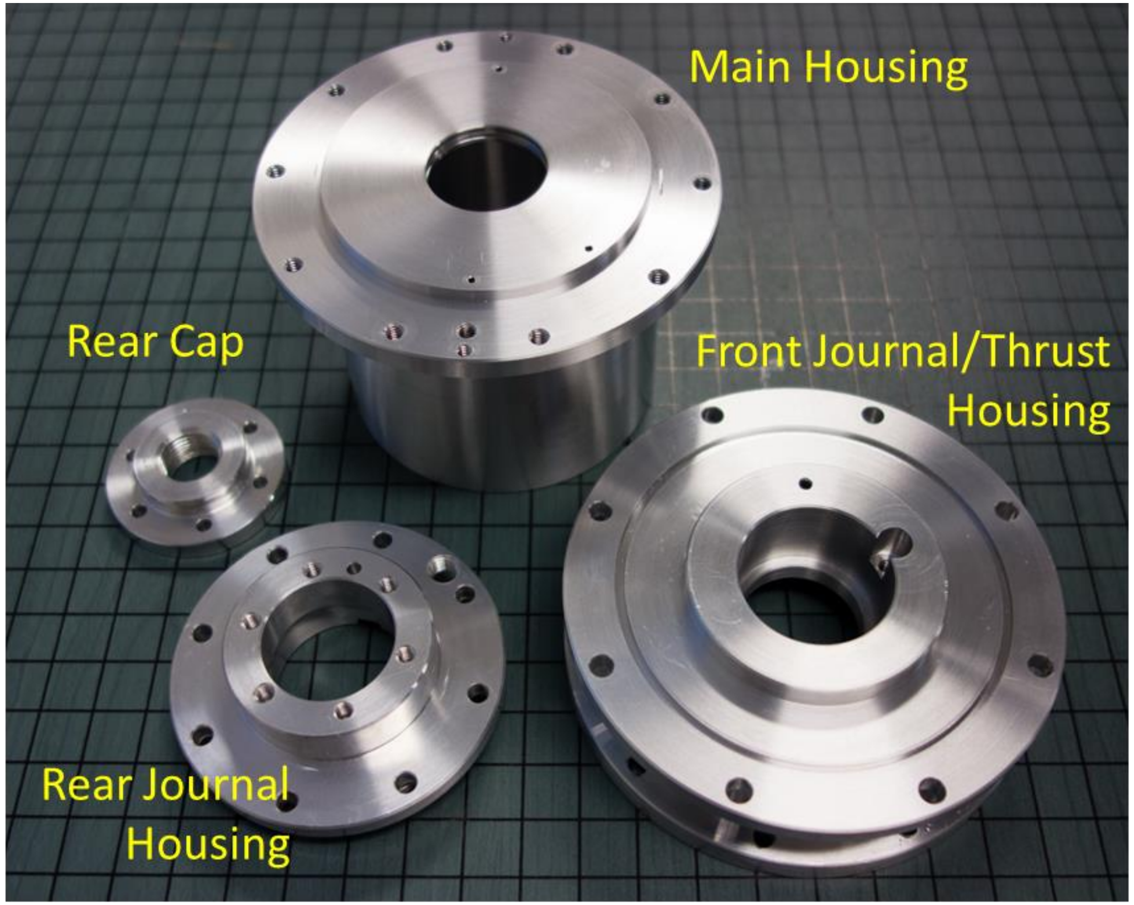
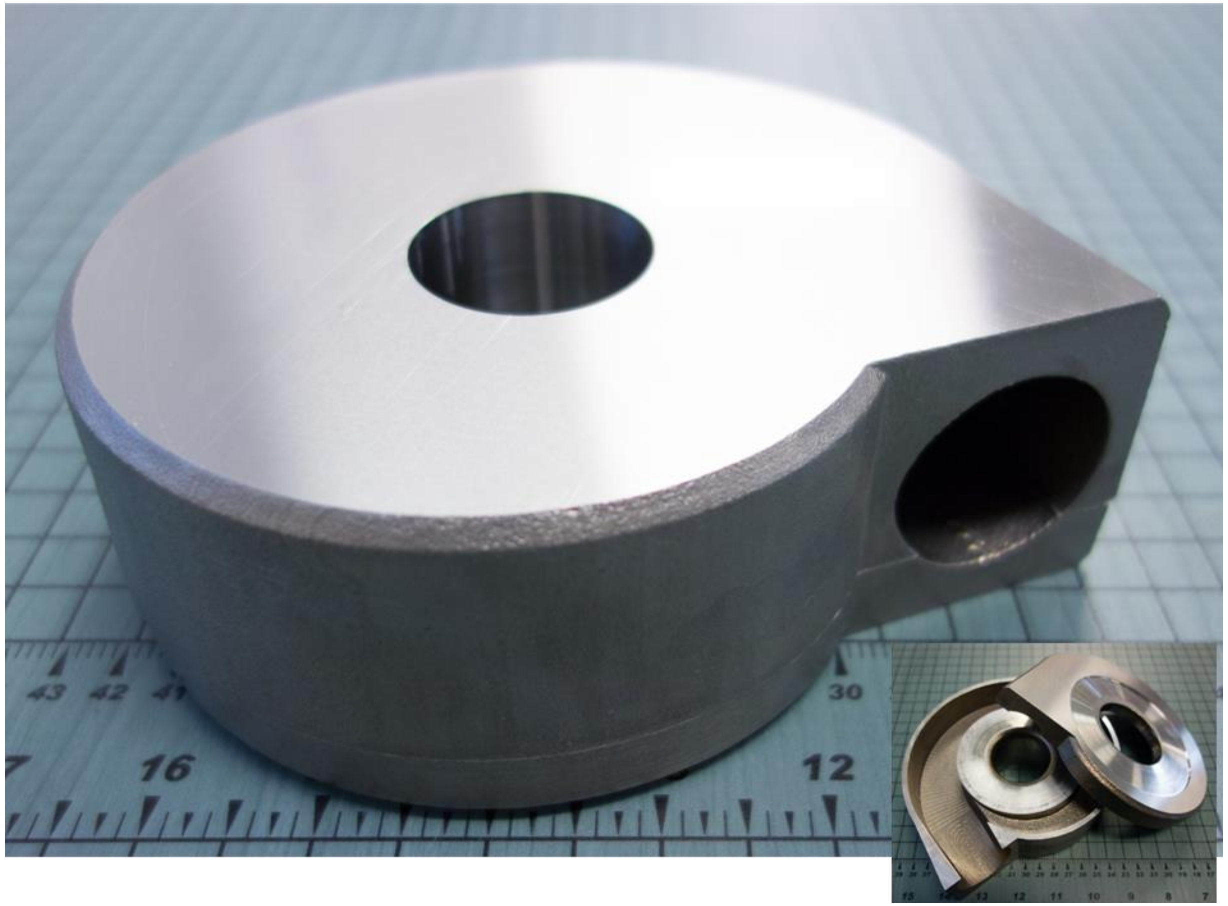
Task 4: Housings and Volute

All housings fabricated

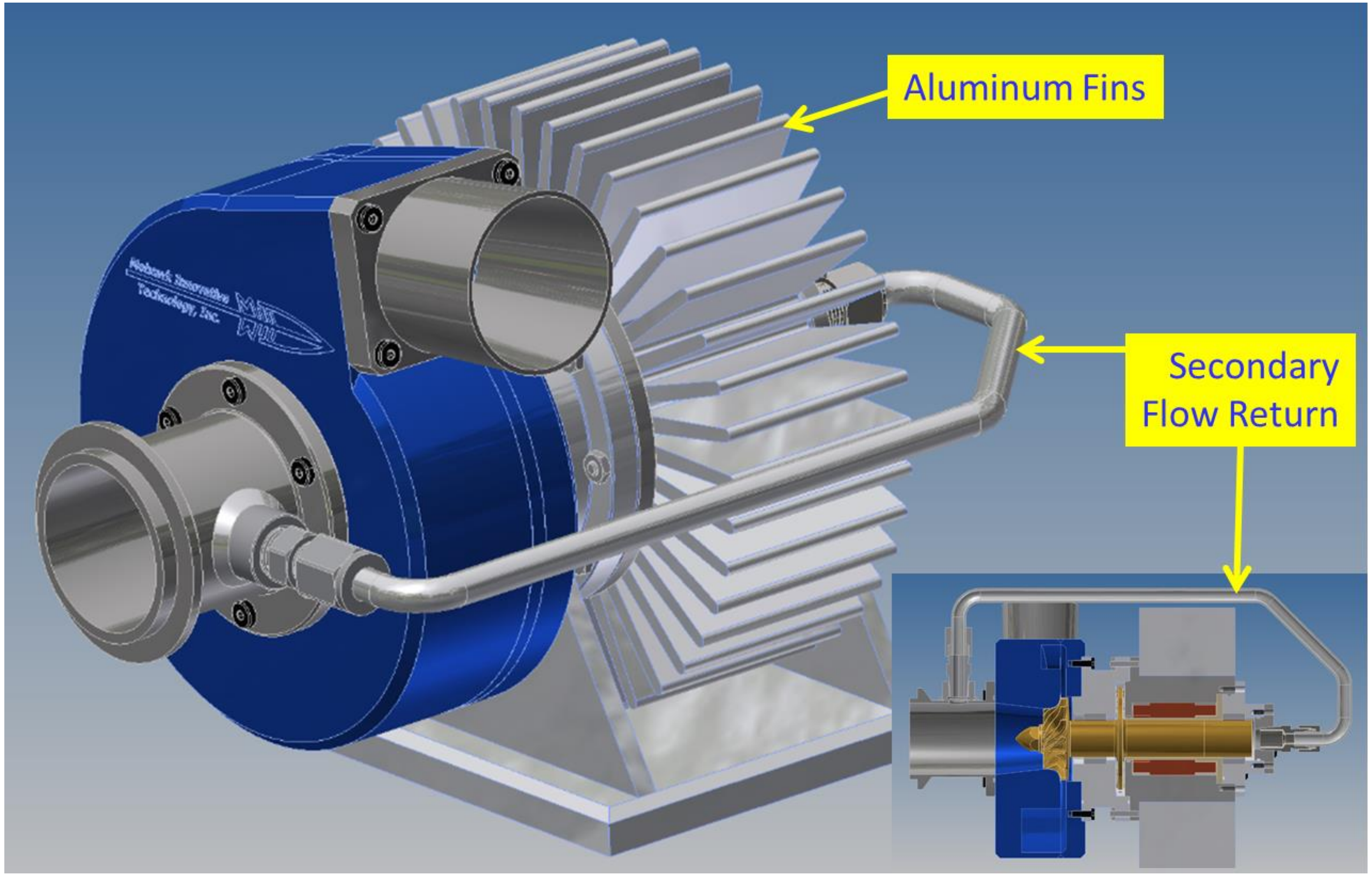


Volute parts fabricated—to be welded



Task 4: Thermal Management

- Natural Convection Based Blower Cooling
- Cooling Fins Under Fabrication (Casting)
- Secondary Flow for Cooling/Lubricating Bearings

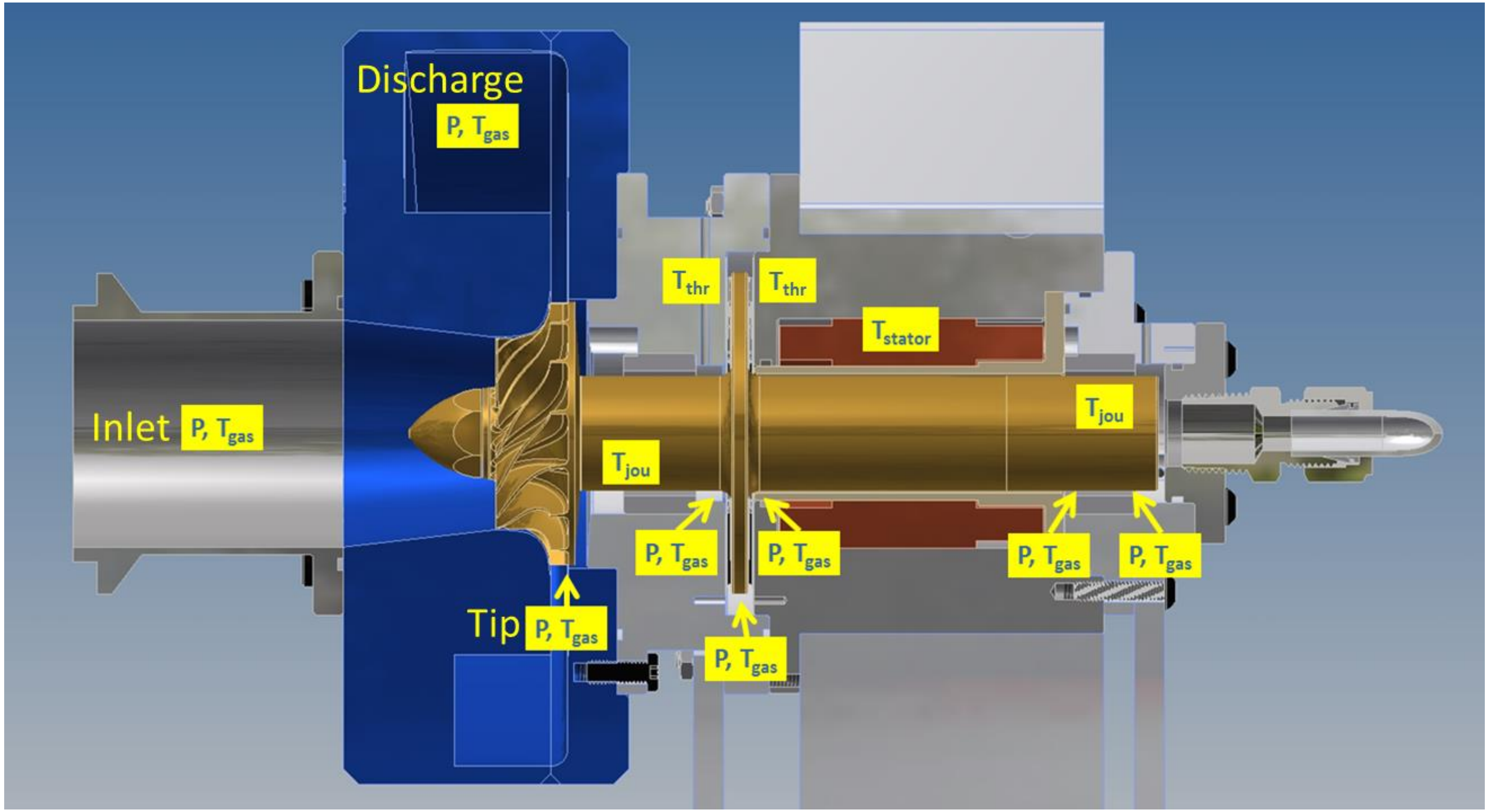


Task 4: Instrumentation

LabView-based continuous monitoring

Transducer List:

- 8 pressure transducers
- 13 thermocouples
- 4 or 5 shaft displacement probes



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Task 5: Test and Evaluate

- Demonstrate full speed operation
  - Rotordynamic stability
  - Thermal stability
- Measure flow/pressure/temperature with similitude gas
- Map performance
- Compare measured and design performance
- Identify possible improvements

Task 6: Assessment and Plan Forward

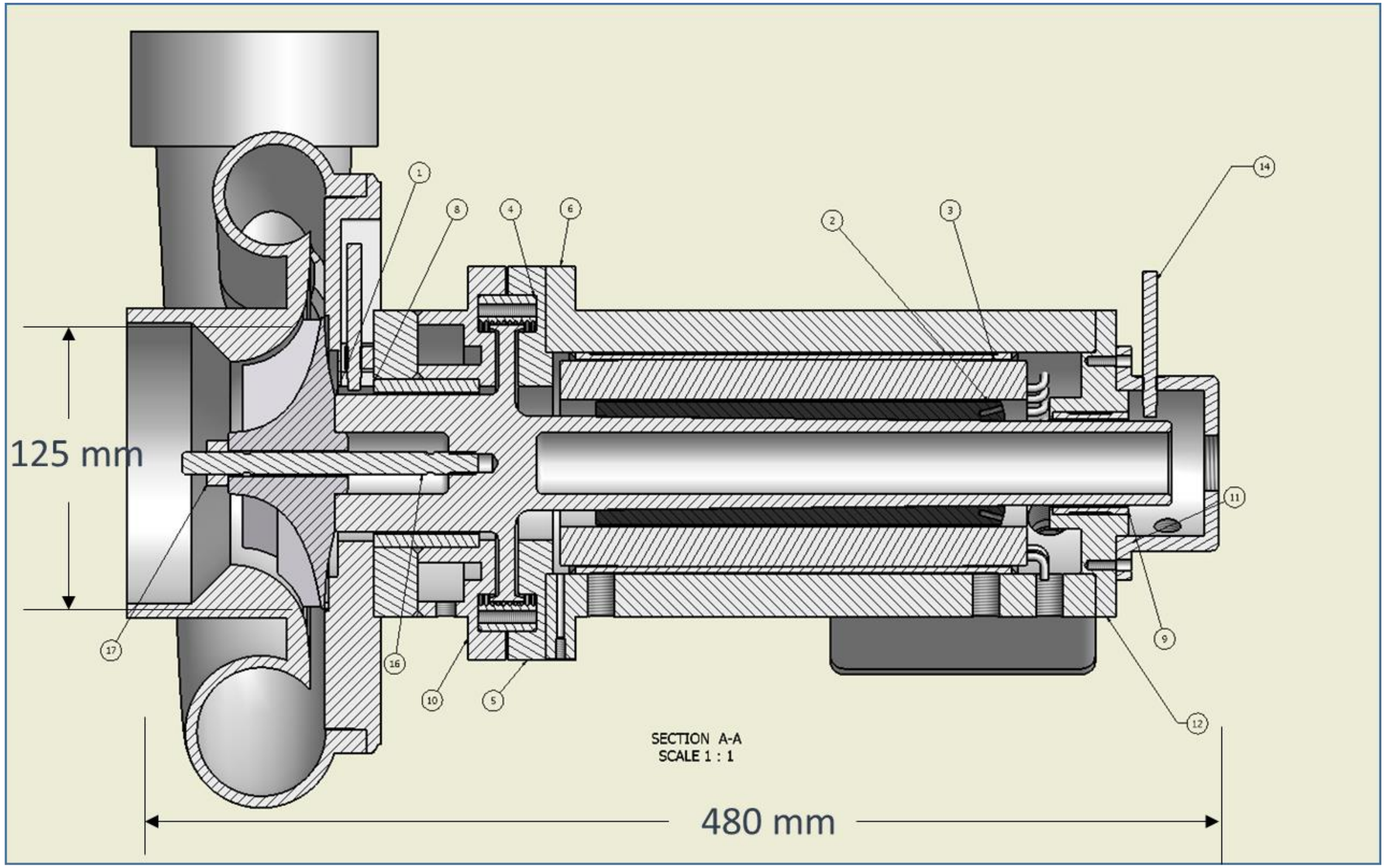
Scalability for higher capacity SOFC applications assessed

- MiTi Design Capability Demonstrated for 100 kW to Multi-Megawatt Systems
- MiTi has Demonstrated Oil-Free Blowers from 1 to 200 kW

Task 6: Notional 50 kW Blower—10 MW SOFC

High Efficiency Centrifugal Impeller

- Speed: 50 kRPM
- Diameter: 125 mm
- $\dot{m}$ = 3.5 kg/s
- CDP = 18 psia



Task 6: 100x Scalability Assessment

100 kW *Present* Design

- Type = Centrifugal
- Diameter = 50 mm
- Operating Speed Range
  - 55 krpm < N < 80 krpm
  - $\dot{m}$ ~ 35 g/sec
  - CDP ~ 100 kPa
  - Power < 1.5 kW
- Efficiency > 85%
- Material Selection
  - Aluminum 2618

10 MW Scaled Design

- Type = Centrifugal
- Diameter = 125 mm
- Operating Speed Range
  - N ~ 50 krpm
  - $\dot{m}$ ~ 3.5 kg/s
  - CDP ~ 126 kPa
  - Power ~ 50 kW
- Efficiency > 87%
- Material Selection
  - Stainless Steel

Task 6: Cost Considerations

- Total Program Cost: $758,855.00
  - Government Share: $598,855.00
  - MiTi's Cost Share: $ 160,000.00
- Estimated Cost ***After Development*** for First 10 Units
  - 1.5 kW: $10k - $15k / unit
  - 50 kW: $40k - $60k / unit

Risk Management

Main Risks Identified (R) and Planned Mitigation Strategies (M):

- **R: Thermal management: External natural air cooling may be insufficient at *SOFC* startup operating condition**
  - *M: Introduce auxiliary forced convection*
  - *M: Closed loop water/glycol*
- **R: Schedule of long lead items: Motor Magnet procurement may cause prototype fabrication delay**
  - *M: Risk Managed. MAGNET ASSEMBLED INTO SHAFT*
- **R: Prototype Fabrication Cost: Initial prototype low-volume cost may be high.**
  - *M: Reduce motor size from 1.5 to ~1 kW*
  - *M: Minimize part count*
  - *M: Casting of as many parts as possible*
  - *M: Material substitution*

Technology Readiness Level

- Prototype will be a high TRL 5 at end of Phase I
- Will achieve TRL 6 at end of Phase II

Progress Summary and Program Status

- Design Requirement Review: Completed ✓
- Preliminary/Detailed Design: Completed ✓
- **Manufacturing/Assembly Currently Underway**
  - **90% of parts fabricated**
- Testing to commence late September 2017
- **Program is on budget and on time**

Questions and Discussion

Thank you for your support and attention!