Turbomolecular Pumps for Harsh Environments

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Turbomolecular Pump Advantages

- Supply clean vacuum at high flow rates
- Pump all species, including noble gasses
- Low power consumption
- Small size and mass

Miniaturization Challenges

- **Tip Speeds**
  - Must be significant fraction of the mean molecular speed
  - For a 2.5 cm pump, speeds > 200,000 rpm are needed
  - This can lead to:
    - » Reduced bearing life
    - » High rotordynamic loads due to environmental vibration or shock
    - » High power consumption
- **Rotor/Stator Clearances**
  - Must be large enough to accommodate manufacturing tolerances and vibration
  - Must be small enough not to degrade pump performance

Creare Pump Projects

- **5 L/s miniature turbomolecular pump (complete)**
- **5 L/s ruggedized turbo-drag pump (ongoing)**
- **1.5 L/s extremely miniaturized turbo-drag pump (ongoing)**

Design Efforts

- **Miniaturization requires optimization of:**
  - Motor
  - Turbopump rotor and stator
  - Molecular drag stage
- **Analytical optimization efforts include:**
  - Electromagnetic analysis of motor
  - Structural analysis of pump rotors
  - Bearing life analysis
  - Random vibration and rotordynamic analyses
  - Evaluation of turbo and drag stage pumping performance at small size scales

Experiments Complement Analysis

- **Testing is necessary to complement design efforts and verify analytical models:**
  - Motor (bearing) life tests
  - Tests of alternative magnet designs for motor
  - Bench tests of individual turbo- and drag-pumping stages
  - Testing of completed pumps

5 L/s TMP

- **Power consumption: 1 W**
- **Rotational speed: 100 Krpm**
- **Discharge press: .01-.2 Torr**
- **Compression ratio (N_2): $2x10^6$**
- **Volumetric flow (air): >4 L/sec**
- **Volume: 165 cm^3**
- **Mass: <400 gm**
- **Design life: >1 year**

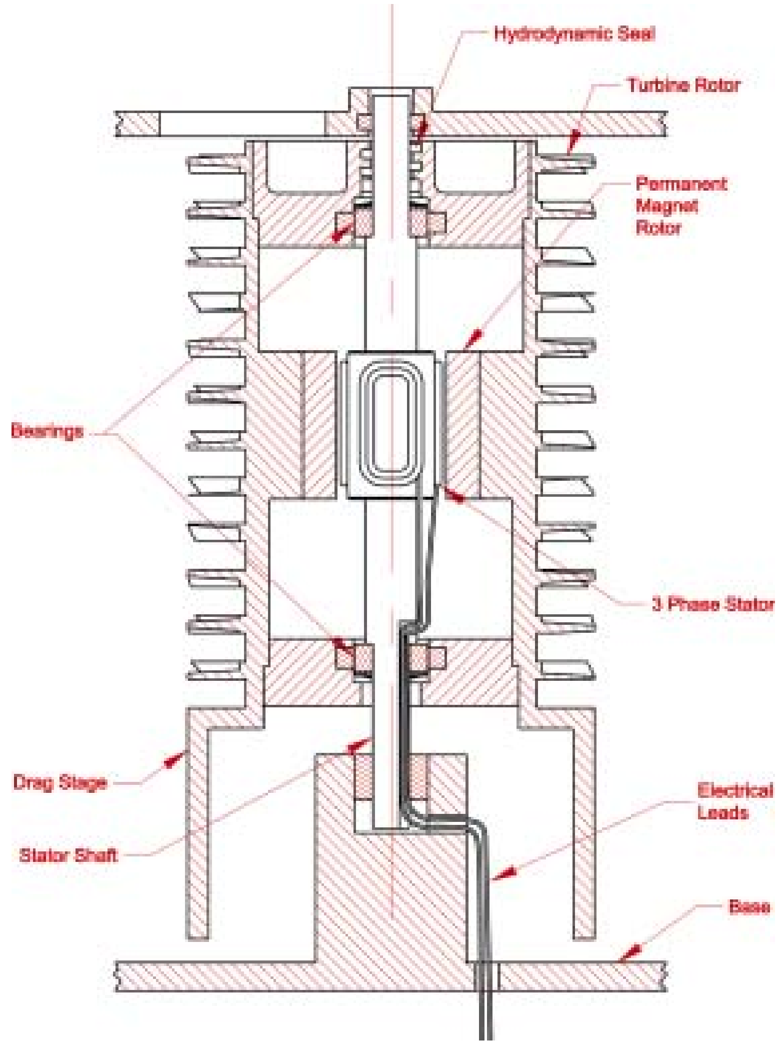
Ongoing projects

- **Ruggedized 5 L/s turbo-drag pump (NASA/KSC)**
- **“C-cell” turbo-drag pump (NASA/JPL)**

Ruggedized Pump

- **Designed to withstand vibration loads during launch of space shuttle**
  - **Will support use of MS for hazardous gas detection**
- **Utilizes "inside-out" (exterior rotor) motor**
  - **Avoids need for conventional, overhung pump rotor**
  - **Allows very stiff rotor**
    - » **critical frequencies well above exciting frequencies**
    - » **reduced possibility of rotor/stator contact**

Ruggedized Pump



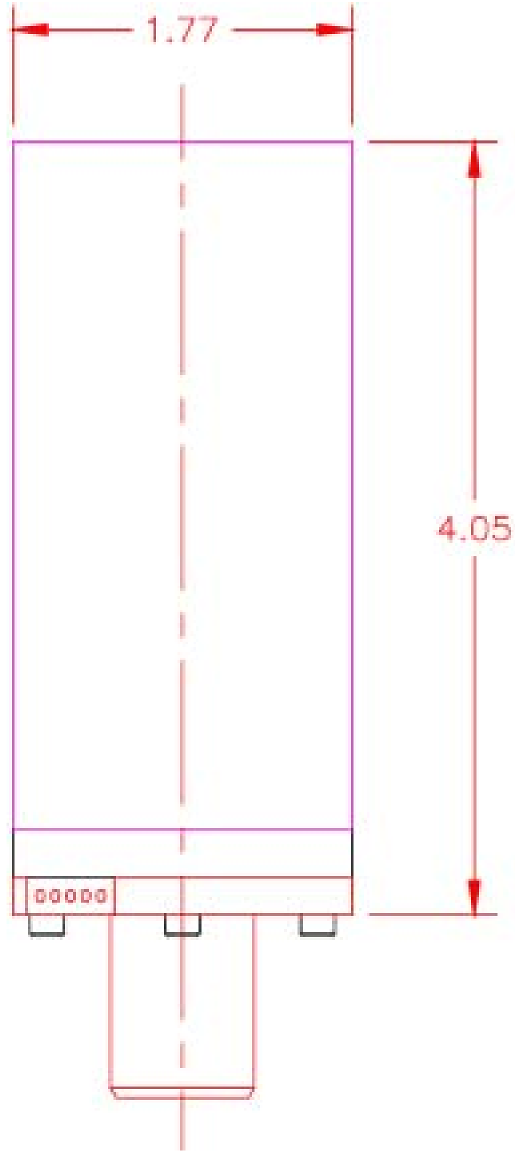
Ruggedized Pump: Status

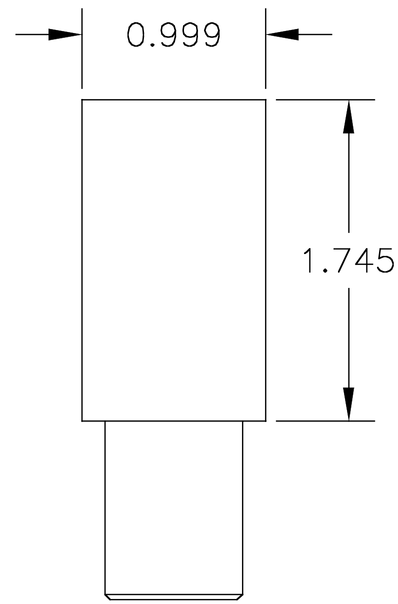
- **Project began 11/02**
- **Motor assembled and being tested**

"C-cell" Turbo-Drag Pump

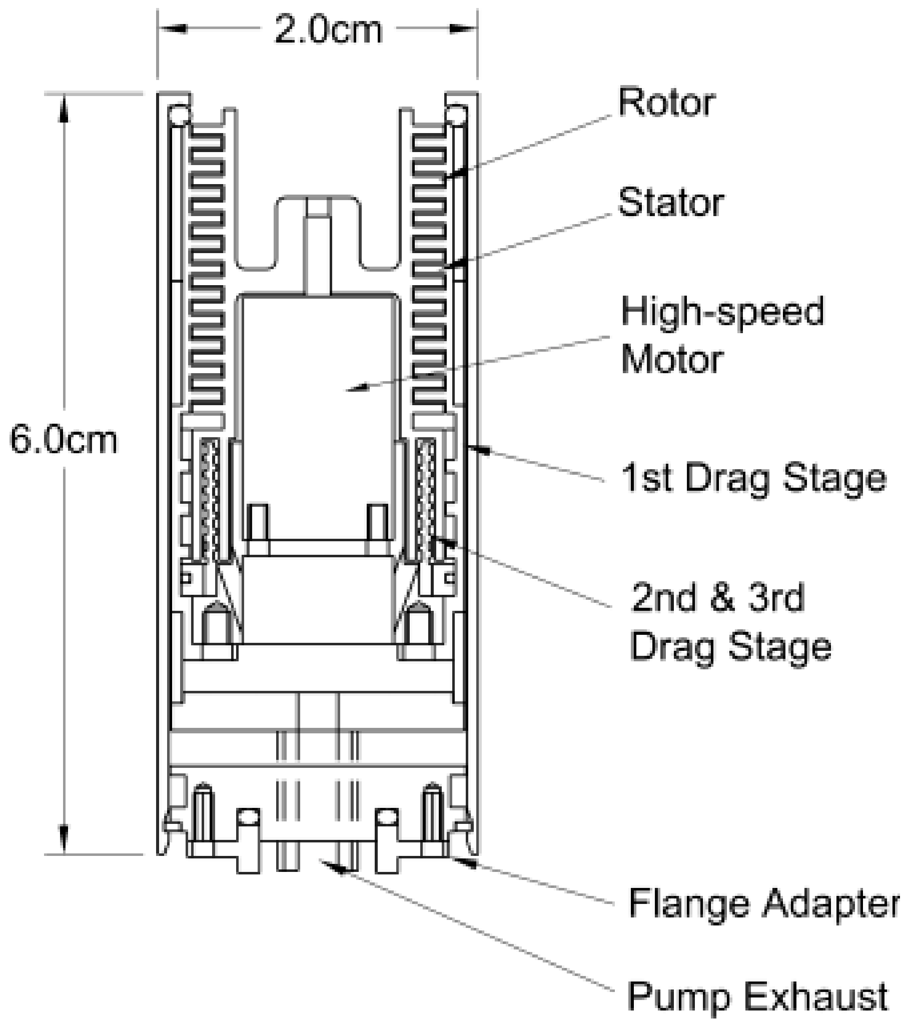
- **Scaled down version of 5 L/s pump**
  - Factor of 2 reduction in all dimensions
  - Pumping speed ~1.5 L/s
  - Design compression ratio for nitrogen > 10^9
- **Operates at twice the rotational speed of the 5 L/s pump**
  - 200,000 rpm
  - Hybrid ceramic bearings
- **Includes drag stage to allow discharge to Mars atmosphere (10 Torr)**

Comparison of Turbo-Pump Envelopes

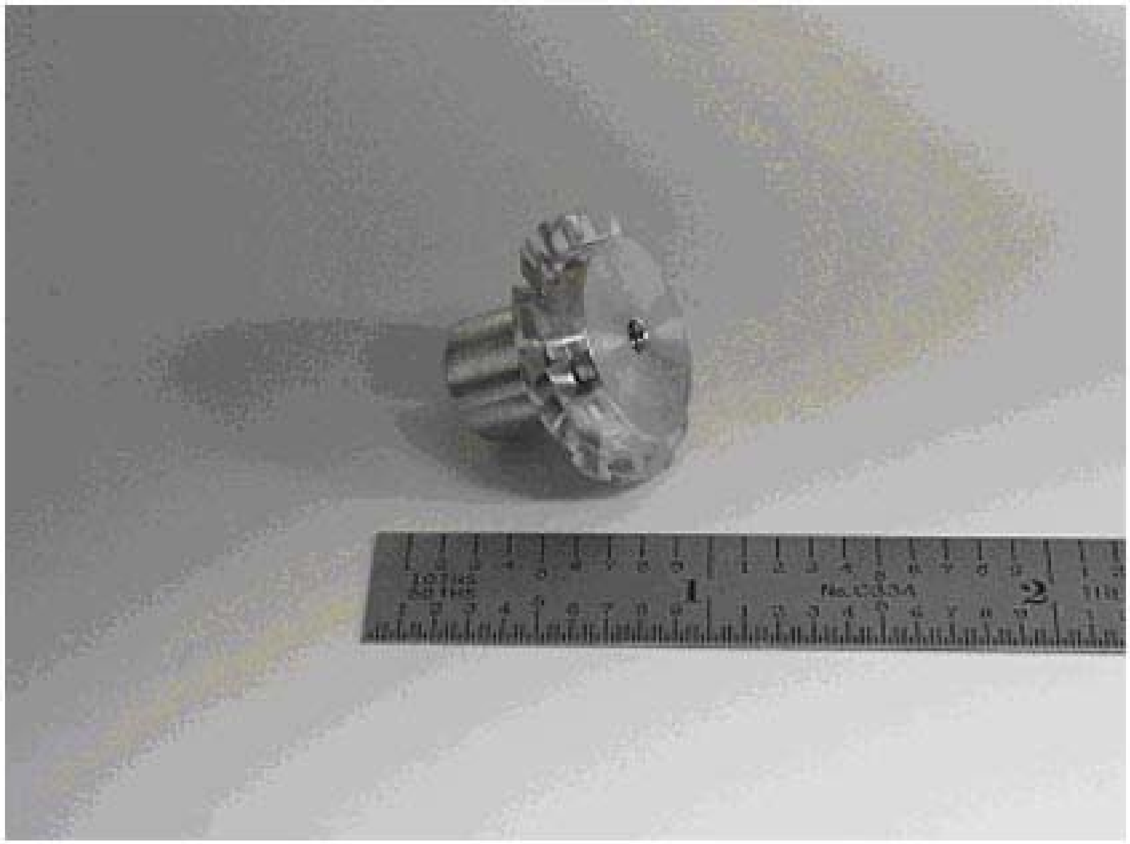




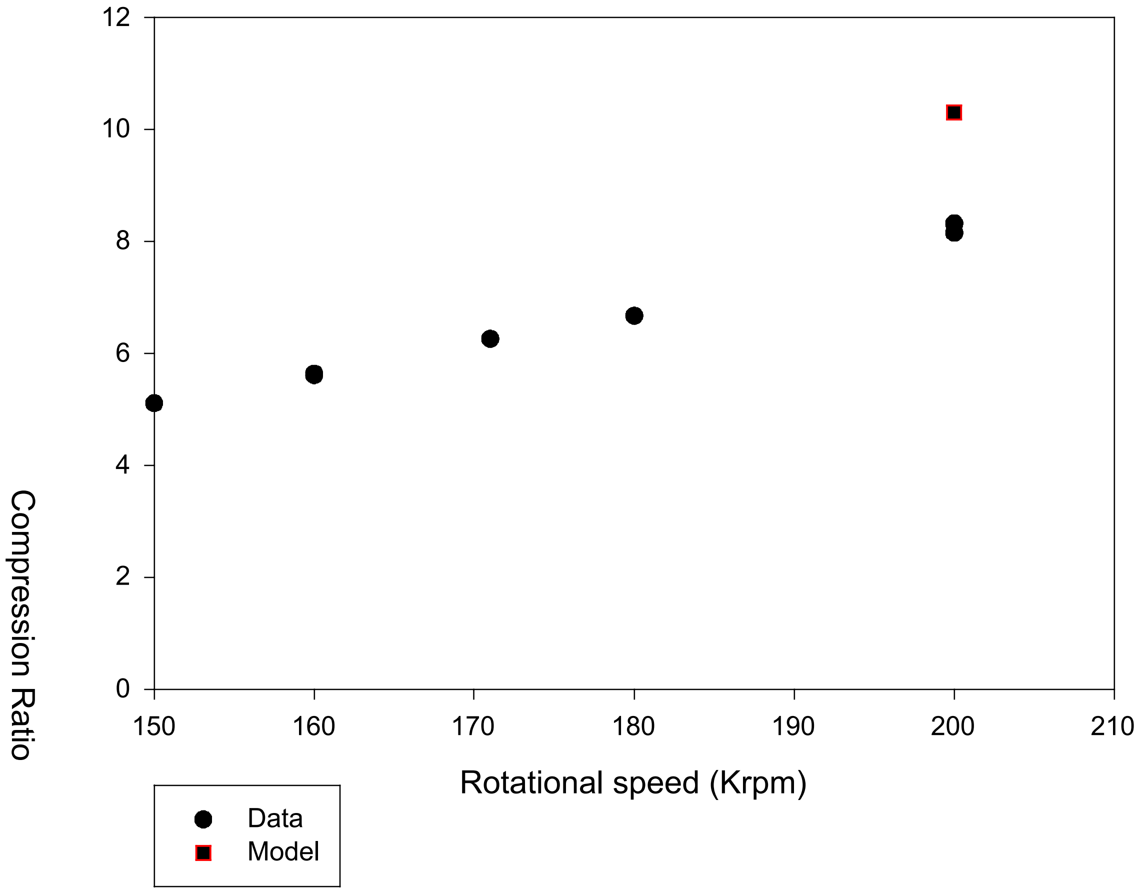
Turbo-Drag Version



Rotor/Stator/Rotor Test Article



Rotor/Stator/Rotor Compression Ratio



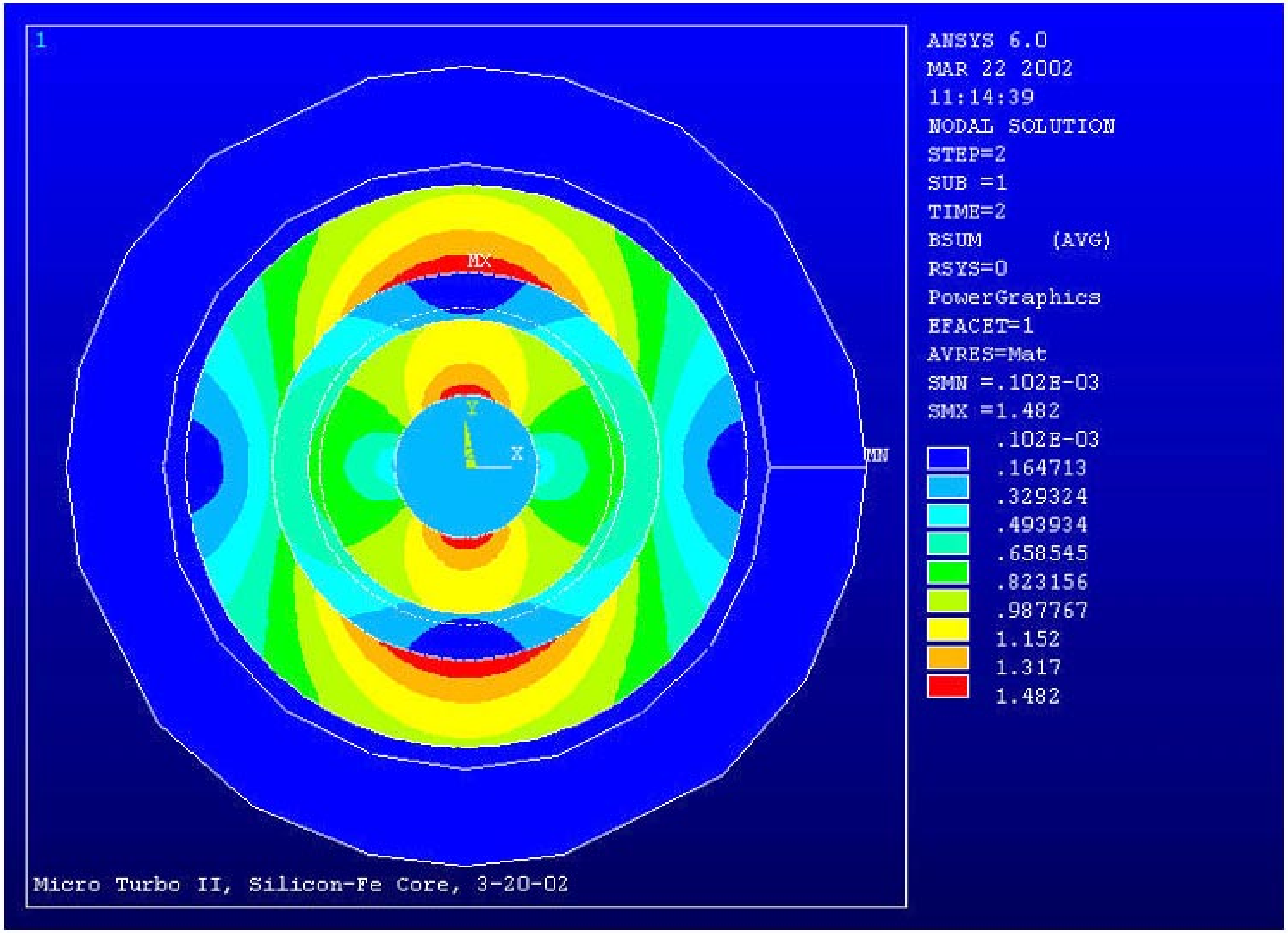
Reducing Power Consumption

- A key challenge of the miniature pump is achieving low power consumption
- This requires careful attention to:
  - Motor magnetic design
  - Drag stage design

Motor Design for Low Power

- As motor size reduced, magnetic flux density in stator substrate increases
- This motivates use of materials having high saturation flux
- Unfortunately, such materials can have high core losses
- Power consumption of initial design is too high (9 W) at 200 krpm
- Careful magnetic redesign is key to reducing power consumption

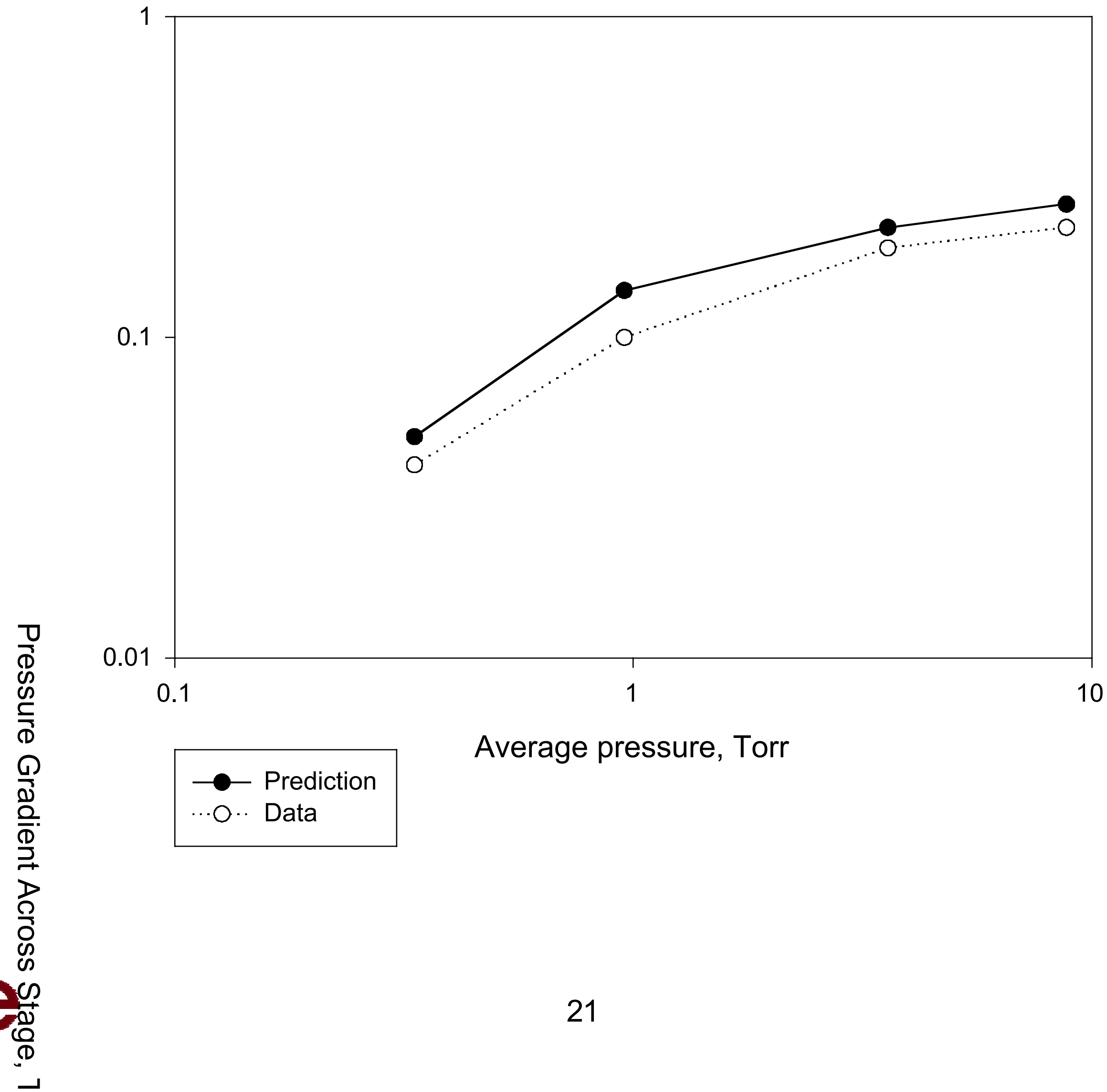
Prototype Motor Magnetic Flux Density



Drag Stage Design for Low Power

- Turbo-stages operate in molecular flow and require negligible power
- Drag stage viscous losses will dominate power consumption if motor is well-designed
- Optimizing drag stage design requires careful trade-offs among ridge width between pumping channels and required pump length
- Developed a flexible design tool based on models in literature to support trade studies

Drag Stage Test Data



Current Status of “C-cell” Pump

- **Designing motor for reduced power consumption using amorphous metal alloy ribbon stator materials**
- **Constructed breadboard prototype for motor controller**
- **Testing individual drag stages designed for low viscous heating to qualify analytical model**

Conclusions

- **While turbomolecular pumps have highly desirable features, miniaturizing them raises a host of problems**
- **These problems can be overcome with a highly multi-disciplinary approach that combines analytical efforts and experimentation**