Development and Test of the Toroidal Intersecting Vane Machine (TIVM) Air Management System

Sterling Bailey, Ph.D. , P.E.

Mechanology

May 25, 2005

This presentation contains no proprietary or confidential information

Project FC28

Overview

Timeline

Project Start November 2001

Project End October 2005

Budget

Total Project Funding

DOE Share $2,000,000

Contractor Share $735,000

FY04 DOE Funding $600,000

FY05 DOE Funding $600,000

Barriers Addressed

Compressors/Expanders. Automotive-type compressors/expanders that minimize parasitic power consumption and meet packaging and cost requirements are not available. To validate functionality in laboratory testing, current systems often use off-the-shelf compressors that are not specifically designed for fuel cell applications. These result in systems that are heavy, costly, and inefficient. Automotive-type compressors/expanders that meet the FreedomCAR technical guidelines need to be engineered and integrated with the fuel cell and fuel processor so that the overall system meets packaging, cost, and performance requirements.

Partners

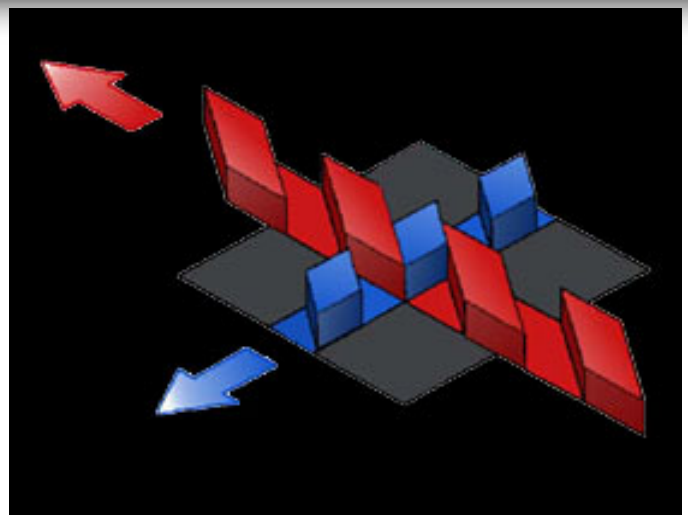
Argonne National Laboratory

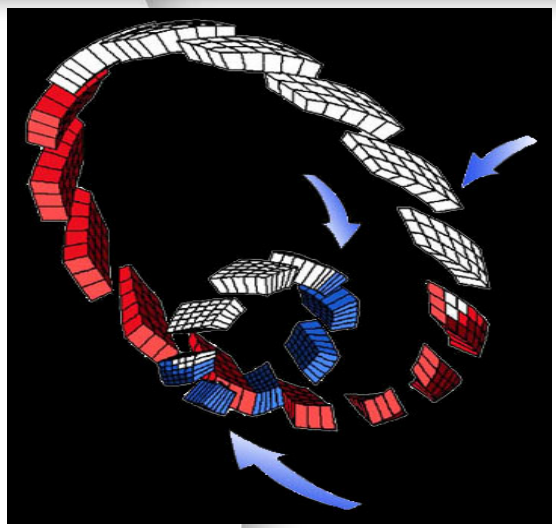
TIVM Air Management System Development Objectives

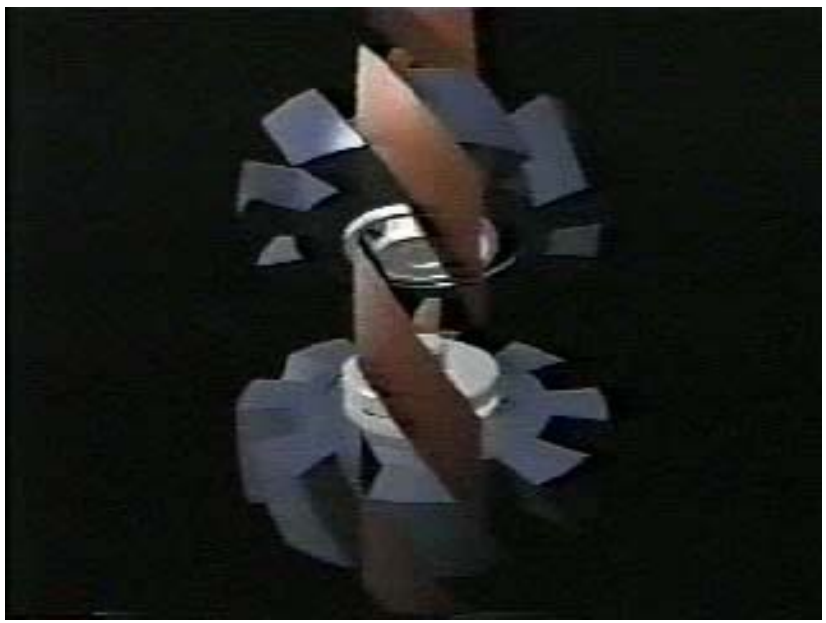
- The overall objective of this program is to develop the innovative TIVM concept into working compressor/expander/motor hardware that satisfies the DOE-FreedomCAR Guidelines – and is easily adaptable to individual car system requirements – and to measure the TIVM air management system performance

- Mechanology wants to provide the global automotive fuel cell market with a significantly improved air management product as soon as possible

The Toroidal Intersecting Vane Machine Concept







Toroidal Intersecting Vane Machine Characteristics

Positive Displacement

- Compressor/Expander
- Compressor/Compressor
- Blower

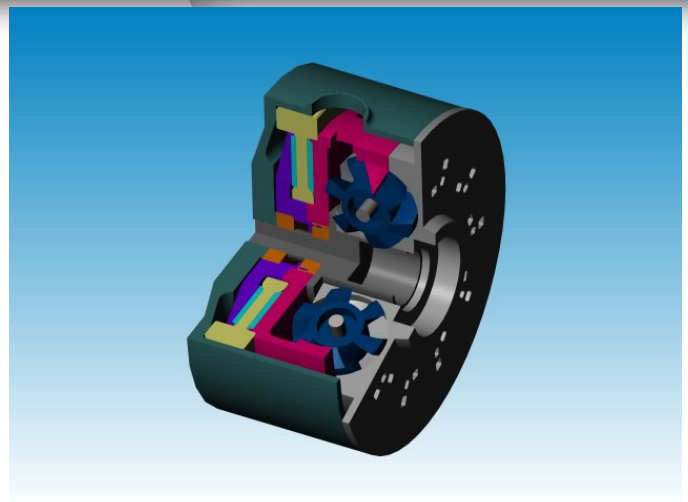
High Flow

High or Low Pressure

Small Volume

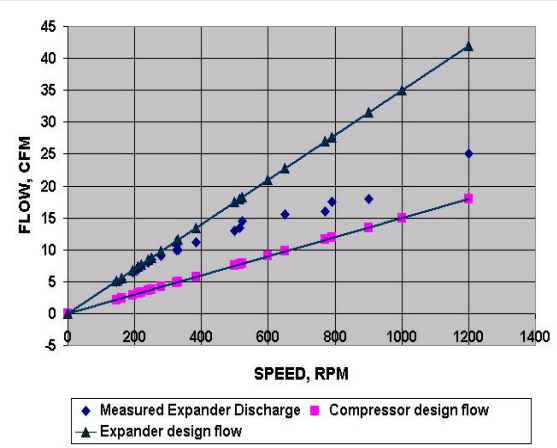
Low Production Cost

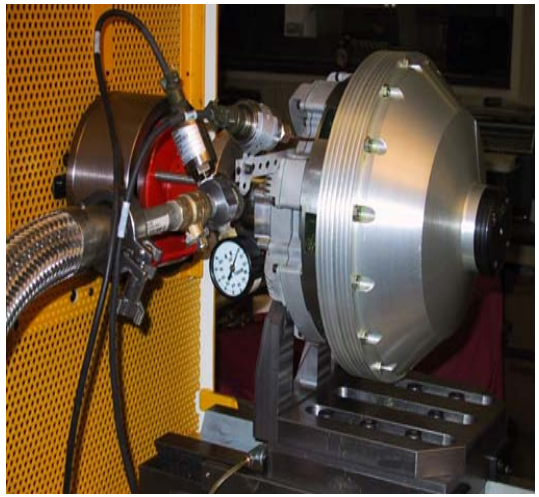
Many Spin-off Products

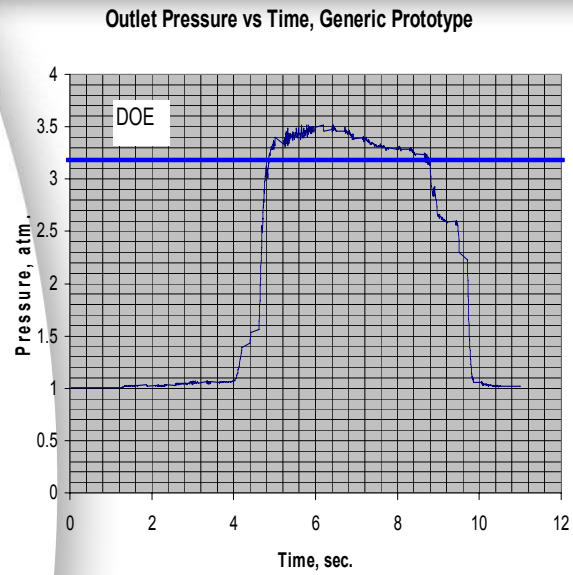


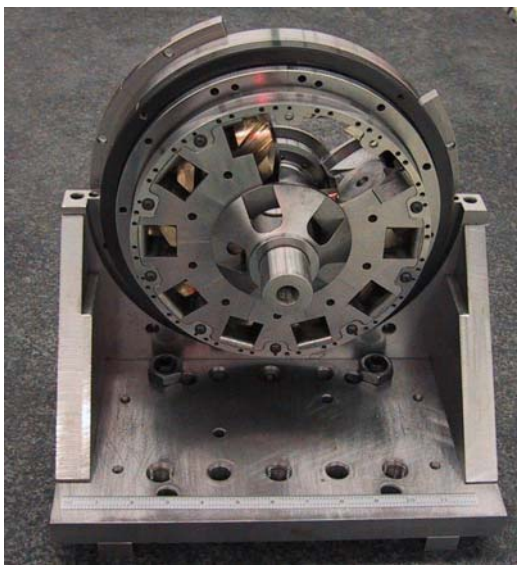
TIVM Attributes Provide Efficient Operation as an Integral Compressor/Expander for Automotive Fuel Cell Applications With Very Good Performance at High Turndown Ratios

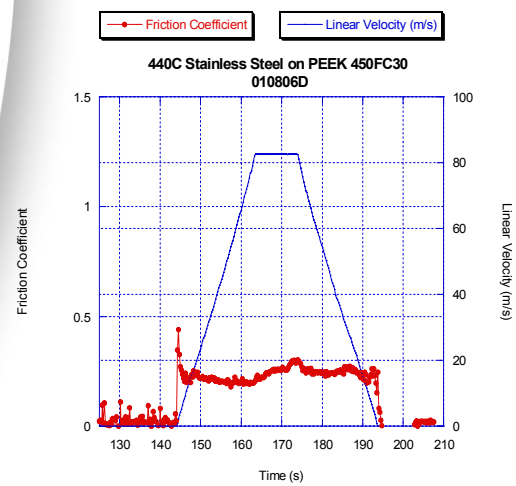
The Basic Viability of the TIVM Has Been Proven Through Hardware and Tests











MECHANOLOGY, LLC

Three Key Performance Issues Needed to Satisfy the Power Requirement

- Seals to limit air leakage without adding excessive friction
- Porting to assure low pressure drop, and power loss, across the compressor and expander inlet and discharge paths
- Confirmation of coefficient of friction for meshing vane interface – including high humidity environment

These are not unusual engineering tasks. Solid, disciplined engineering development will provide the required solutions

New TIVM Design Concept and Patents

TIVM New Architecture (TIVM DV) Uses Basic TIVM Configuration with Secondary Rotors Acting as Dynamic Valves Rather Than as Compression Chambers

Primary Rotors and Vanes Now Perform Both Compression and Expansion

Eliminates Transfer of Significant Work Through the Sliding Vane Interface, and Thus the Major Source of Friction.

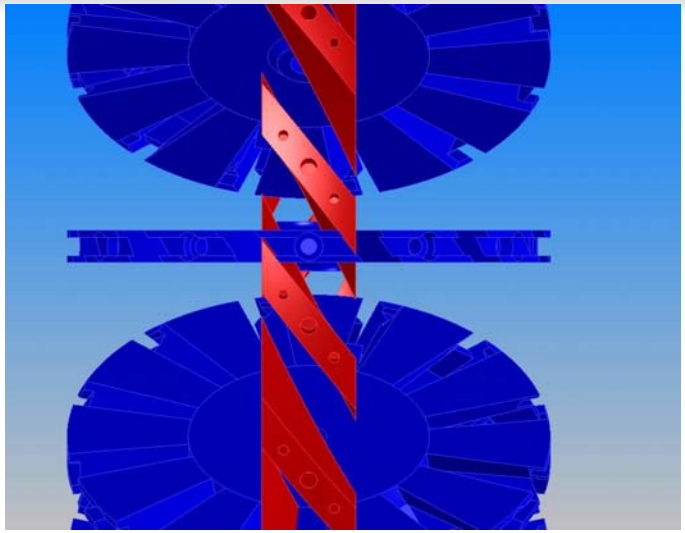
Significantly Reduces Pressure Differential Across Air Leakage Paths – Eases Sealing Challenge

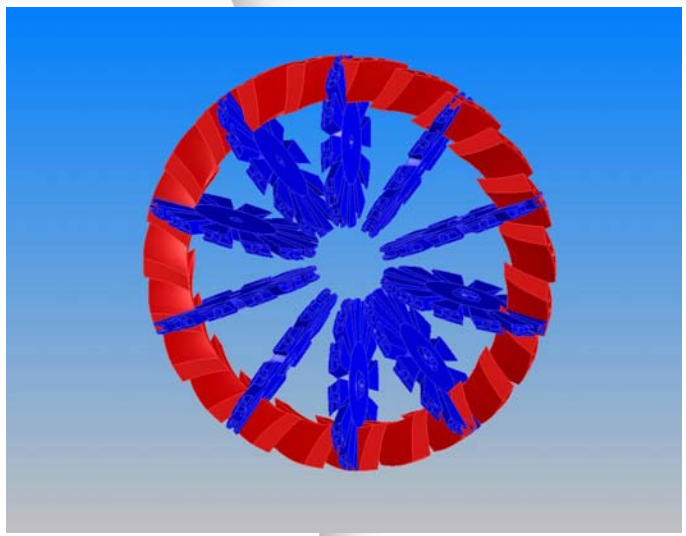
Simplifies Porting Design – Provides Generous Flow Area

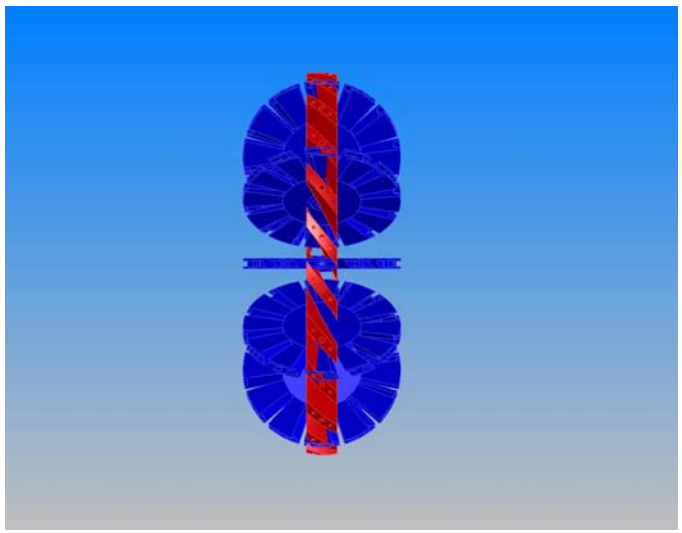
Simplifies Thermal Management

Simplifies Fabrication – Reduces Cost Challenge

New TIVM Design Concept and Patents







Patent Applications Submitted:

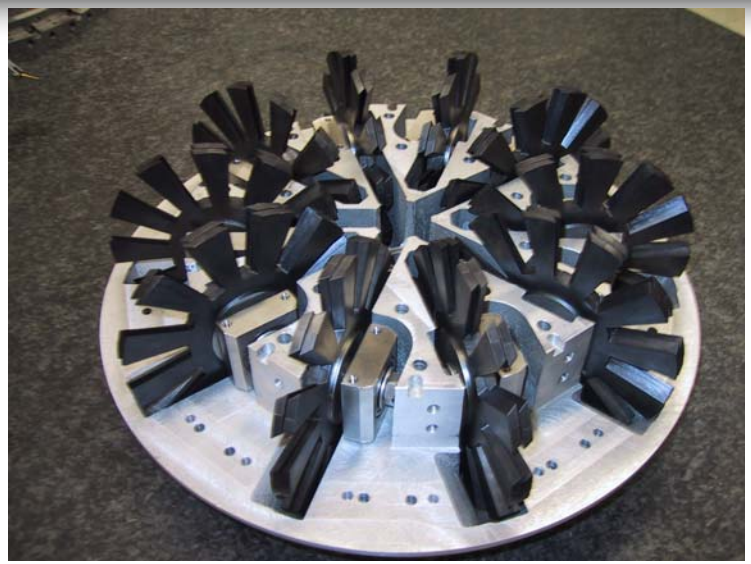
10/744230 and 10/744229

On December 22, 2003

Features Incorporated in New Design

- Injection molded PEEK secondary rotors
- “Layer cake” architecture rather than “pie pieces”
- Internal manifolding
- One piece primary ring rather than split primary ring
- Doohovskoy surfaces
- Rotor and port arrangement to balance local pressures
- Clearance seals
- Abradable seal inserts
- Segmented track inserts for seals

Prototype Compressor/Expander Currently Being Tested and Refined



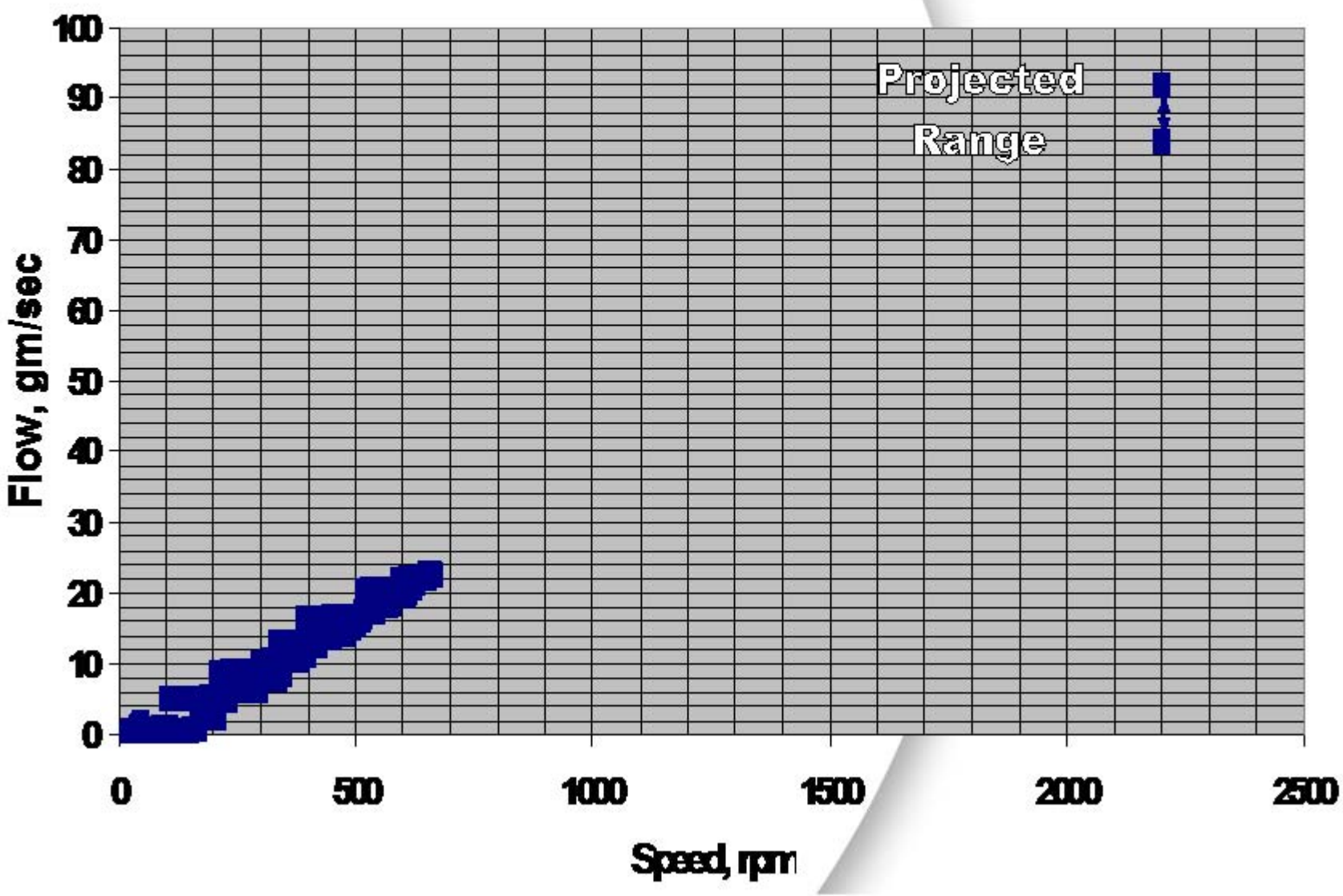
Feature Development Experience

- PEEK molded secondary rotors
  - Minor design changes needed, e.g. adjust root fillet dimension
  - Flatness not as expected, causes intersecting surface distortion and leakage. Working with molder and material producer to fine tune molding process – step-by-step progress in meeting our specifications
  - Guides added to design to support secondary rotors
  - Axial compliance observed to cause seal wear, design modified to restrain axial movement, as in generic prototype
  - Design modified to hybrid with features of “layer cake” and “pie” configurations to assist secondary rotor flatness and positioning

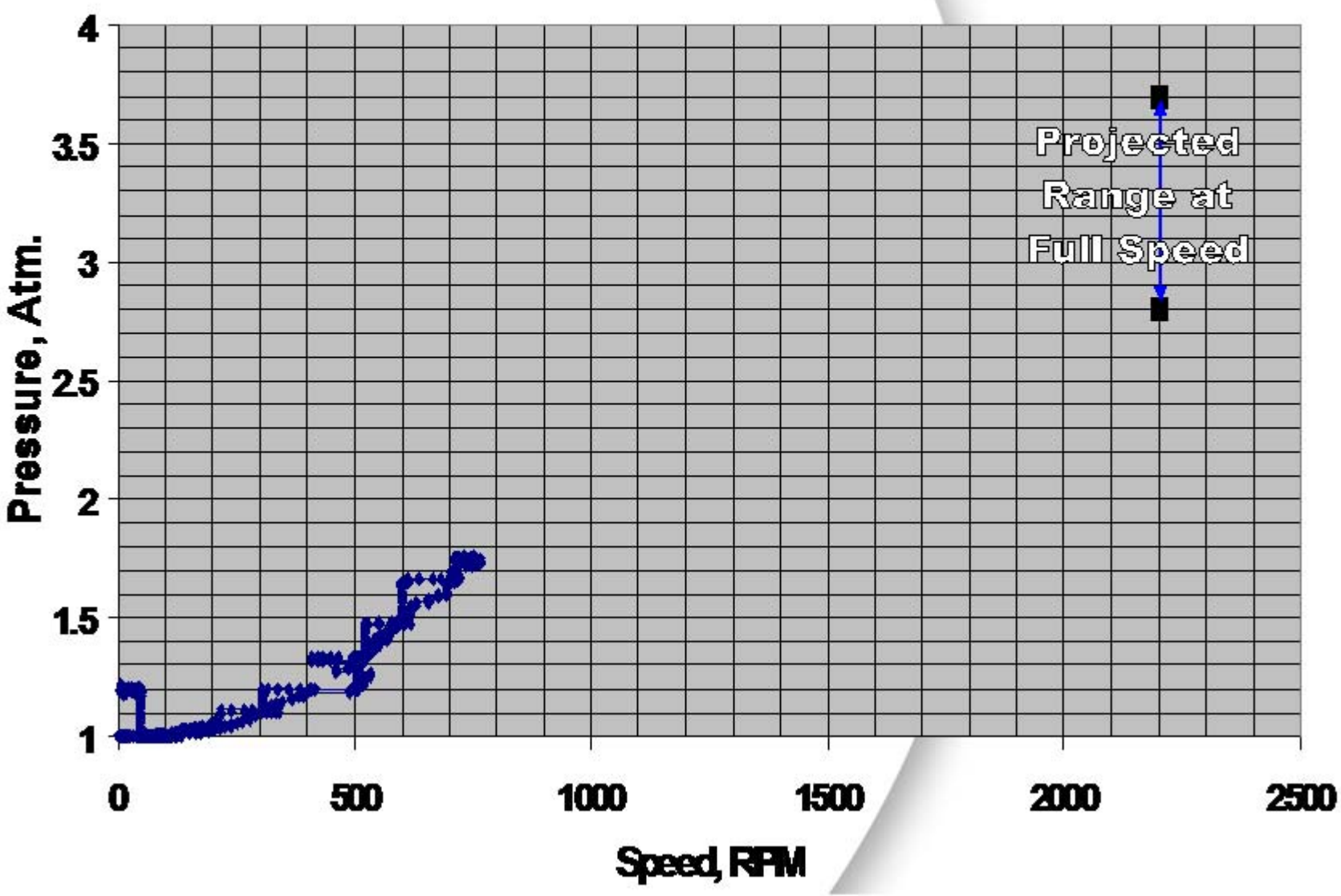
Feature Development Experience

- "Layer Cake" architecture
  - Replaces 10 precision parts and 3 piece manifold with 3 casting that require minimal secondary machining
  - However, requires individual seals with many joints
  - Teflon seals exhibited distortion, high thermal expansion
  - Further detailed testing and analysis of thermal expansion in process, design refinements being developed

Initial Development Test Results



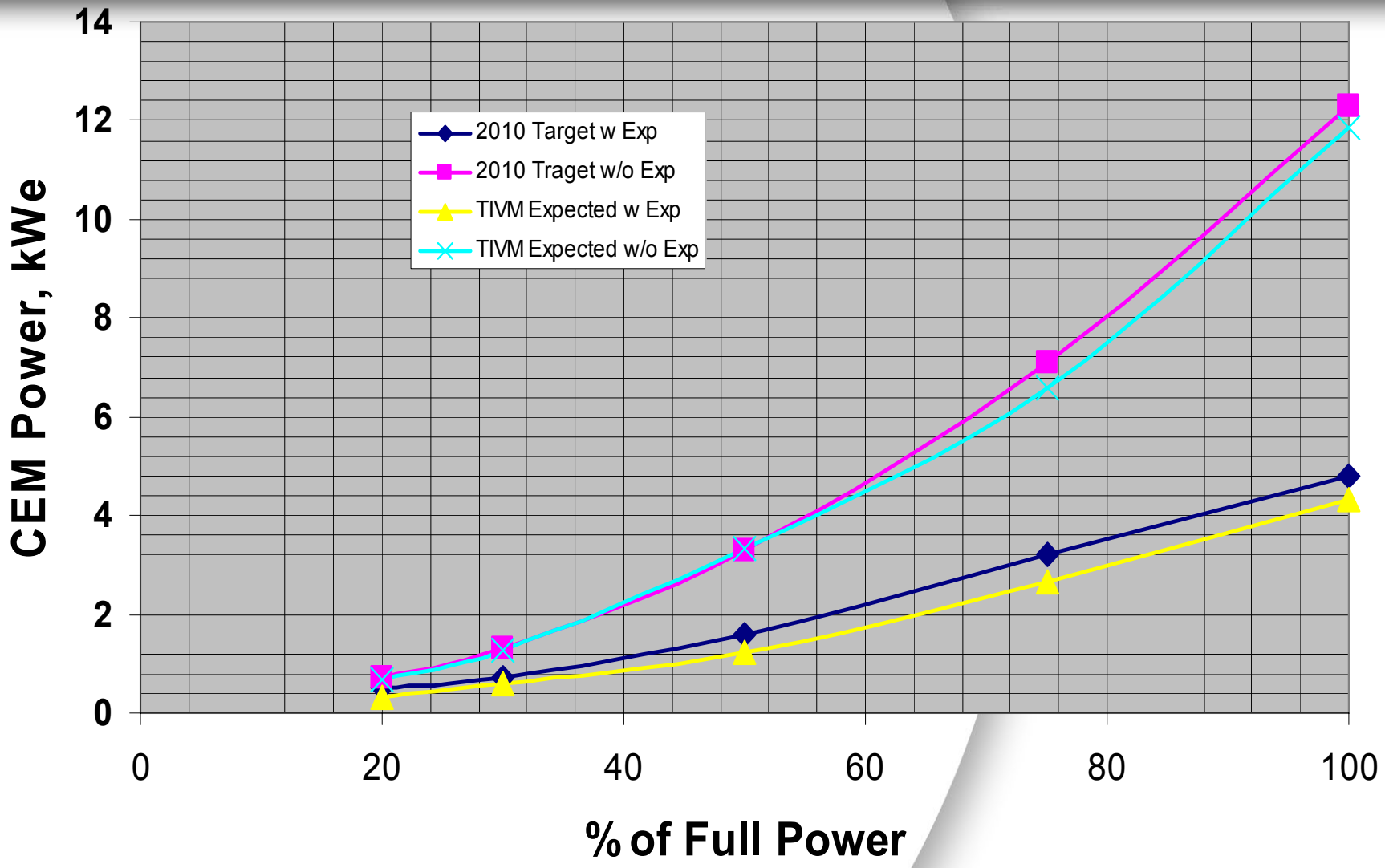
Initial Development Test Results



Testing to Full Speed/Power

- Test data for current prototype extends to 800 rpm, full speed is 2200 rpm
- Thermal expansion caused high torque above ~800 rpm in prototype
- Extensive thermal/mechanical analyses and test diagnostics used to characterize thermal expansion behavior
- Design modifications have been made to provide required thermal management, modified prototype ready for testing
- Additional tests to full speed delayed by facility fire

Expected 80 kW Unit Hydrogen CEM Power vs % Power



Expected Performance Matrix for TIVM Compressor/Expander

Requirement	Value	Comment	Expected
Flow	91g/s For 80 kWe	Flow consistent with design flow demonstrated with temporary seals - as expected for positive displacement device	Designing for 100 g/s
Pressure	2.5 atm	3.5 atm pressure demonstrated with temporary seals - as expected for positive displacement device	Capability Beyond Requirement
Power	5.8 kW	Key remaining performance issue – requires low friction effective seals	<5.5 kW - Remains to be Demonstrated
Size	15 liters	Acceptable to car makers and OEMs	20-25 liters Acceptable
Weight	15 kg	Acceptable to car makers and OEMs	20-25 kg Acceptable
Noise	<65 db	Use of polymer parts and compliant seals will mitigate	To Be Demonstrated
Cost	$400	Cost estimates based on vendor quotes Give several $100's in high volume	Expected to be acceptable

Future Work and Schedule

- Modified parts for next iteration of testing fabricated and assembled, now ready for testing
- Expect to perform next series of integral tests in May-June time frame
- Schedule allows additional 2-3 iterations prior to end of Government fiscal year
- Prototype air management system to be delivered to DOE in October 2005 for independent testing

Contract Milestones and Product Schedule

- Contract milestone to deliver a prototype compressor/expander/motor to DOE for independent testing by October 31, 2005
- Expect completion of TIVM compressor/expander prototype on schedule
- Mechanology anticipates having prototype compressor/expanders available for automobile manufacturers to test in late 2005

Publications and Presentations

Technical Accomplishments and Program Status Presentation to the FreedomCAR Technical Team on February 23, 2005

Hydrogen Safety

The TIVM Air Management System Processes Air Entering and Exiting From the Fuel Cell and Does Not Process Hydrogen. Therefore There Is No Hydrogen Hazard Associated With It.