Oil-Free Centrifugal Hydrogen Compression Technology Demonstration

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Project ID #
PD_34_Heshmat

Overview

Timeline

- September 1, 2008
- Funding Authorized 2/28/09
- August 31, 2011
- 5 Percent Complete

Barriers

- Hydrogen Delivery Compressor
  - Reliability
  - System Cost
  - Efficiency of H2 Gas Compression

Budget

- Total project funding
  - $2,992,416 DOE
  - $1,149,253 MiTi®/MHI
- $1,496,208 FY08/09 Funding
- $1,496,208 FY10/11 Funding

Partners

- Lead: Mohawk Innovative Technology, Inc. (MiTi®)
- Mitsubishi Heavy Industries

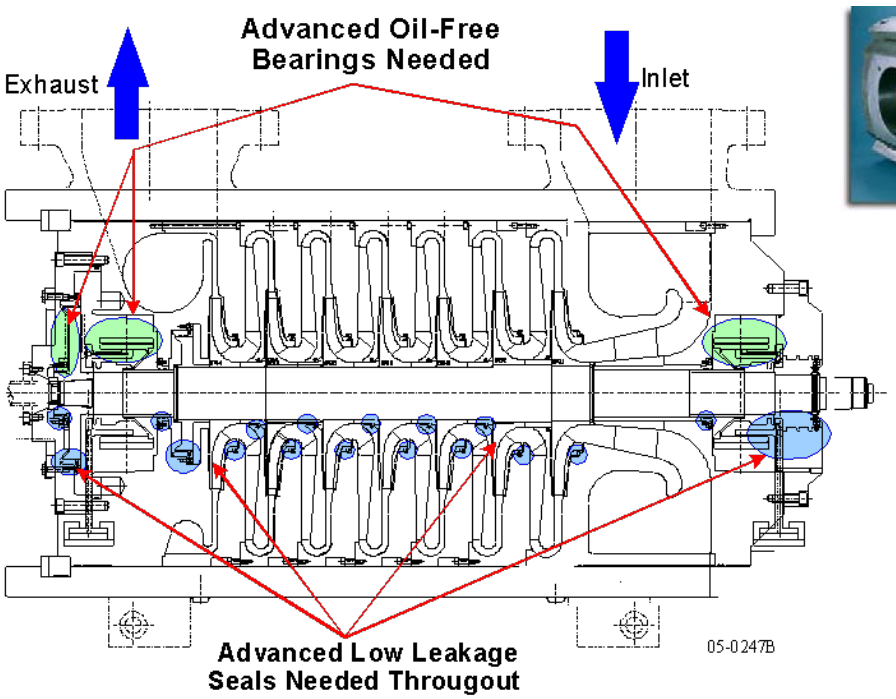
Relevance

Objective:

- **Demonstrate key technologies needed to develop reliable and cost effective centrifugal compressors for hydrogen transport & delivery**
  - **Flow 500,000 to 1,000,000 kg/day**
  - **Pressure rise to 300-500 psig**
  - **Contaminant-Free/Oil-Free Hydrogen**

Category	2005 Status	Project Target FY2012	FY2017
Reliability	Low	Improved	High
Energy Efficiency	98%	98%	>98%
Capital Investment ($M) (based on 200,000 kg of H2/day)	$15	$12	$9
Maintenance (% of Total Capital Investment)	10%	7%	3%
Contamination	Varies by Design		None

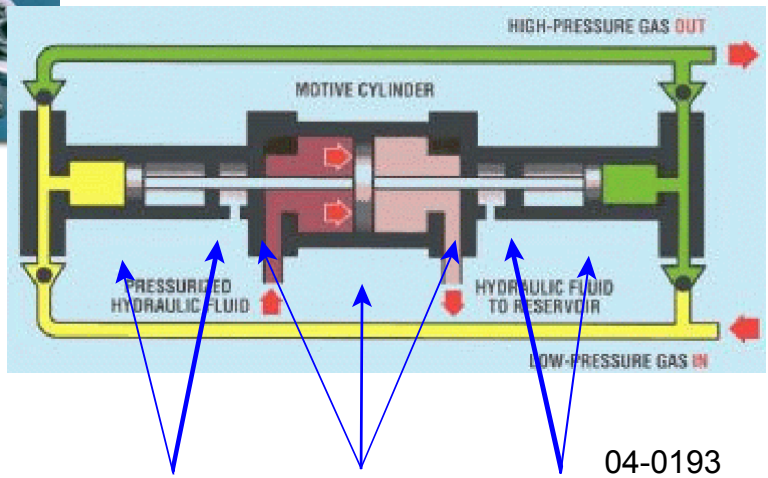
Relevance - Candidate Compressors



Centrifugal Compressor

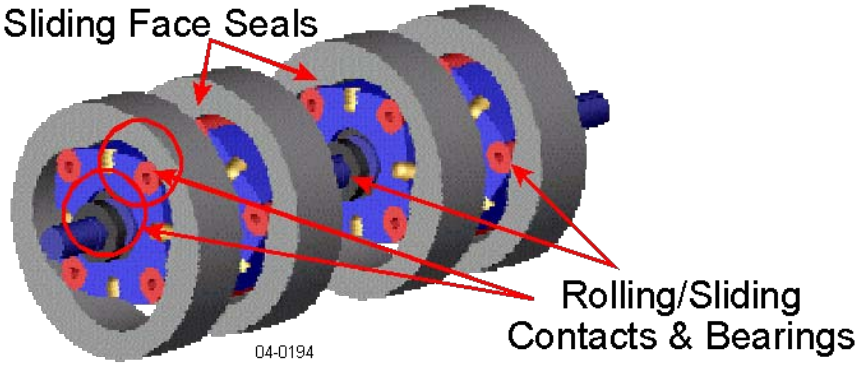
- One Moving Part
- High Reliability
- Minimal Contact/Sliding Parts
- High Efficiency and High Flow

Piston Compressor



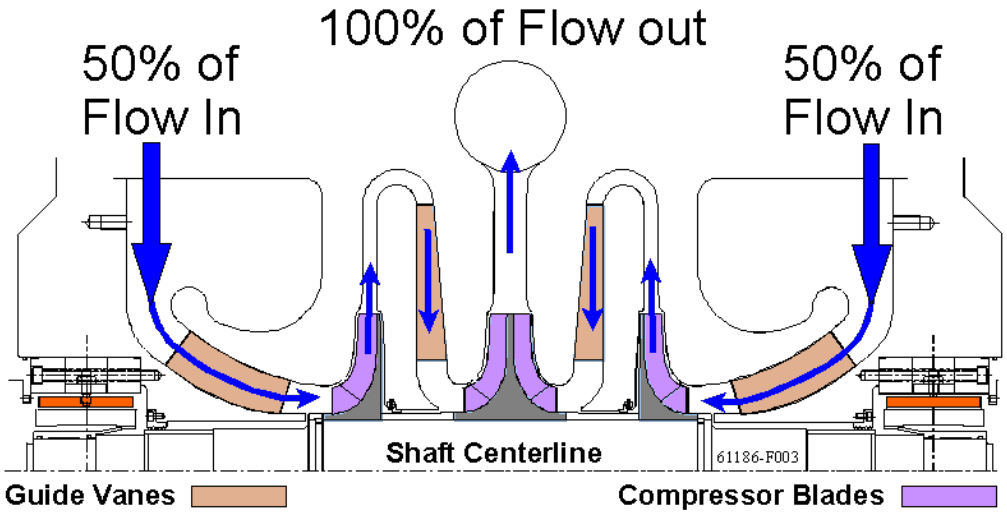
Sliding Contacts

Guided Rotor Compressor



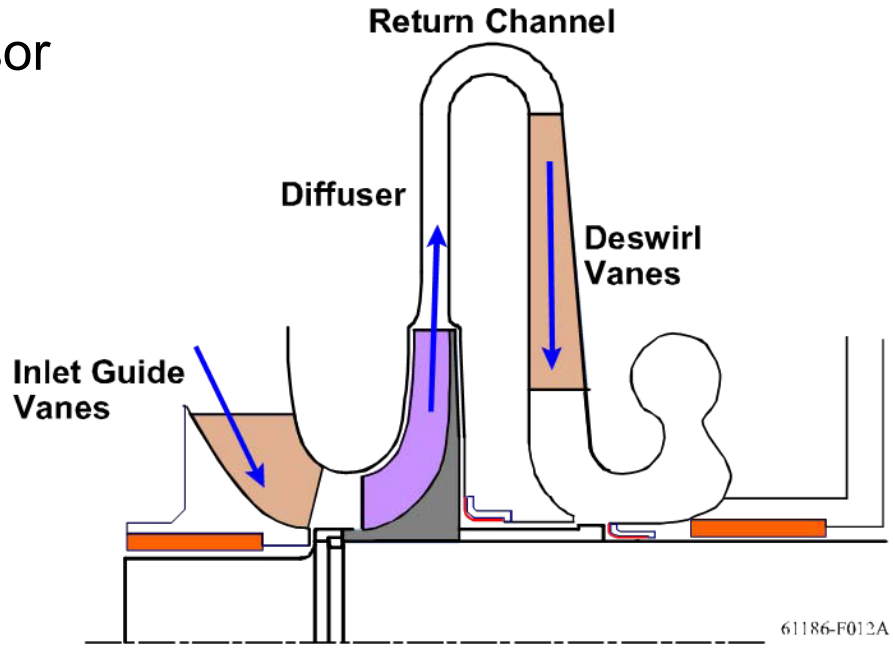
Approach/Project Plan

- Review Design Requirements
  - 500,000 kg/day of H2
  - Output Pressure 1200-1500 Psig
  - 100-200 Mile Range
- Verify High-Speed Design
  - Double Entry Design
  - Seven Compressor Stages
  - Multiple Machine Frames
- Select Stage & Speed
- Size Bearings and Seals



Approach/Project Plan

- Design Single Centrifugal Compressor Stage
  - Inlet & Impeller
  - Diffuser & Return
  - Vane and Exhaust
- Compressor Design Analysis
  - Computational Fluid Dynamics
  - Finite Element Structural Analysis
- Oil-Free Bearings and Seals
- Fabricate and Test to Characterize Pressure & Flow
- Scale System Design
  - Use Test Data & CFD Analysis Results
  - Update Multi-Stage, Multi-Frame Compressor System Design
  - Predict Full Compressor System Performance



Stage Pressure From CFD

Demonstrate feasibility of very high speed hydrogen centrifugal compressor through test .

Project Milestones

Month/Year	Milestone or Go/No-Go Decision
July-09	**Project Milestone:** Complete preliminary modular centrifugal compressor frame design to achieve pressure and flow. Select stage for detailed design, fabrication and test.
April-10	**Project Milestone:** Complete single stage compressor design including inlet, impeller, diffuser, return channel. Complete oil-free bearing and seal mechanical component system designs

FY10 DOE Milestone: Down select novel compression technology for hydrogen delivery.

Related SBIR Technical Accomplishments:

Compressor Assessment

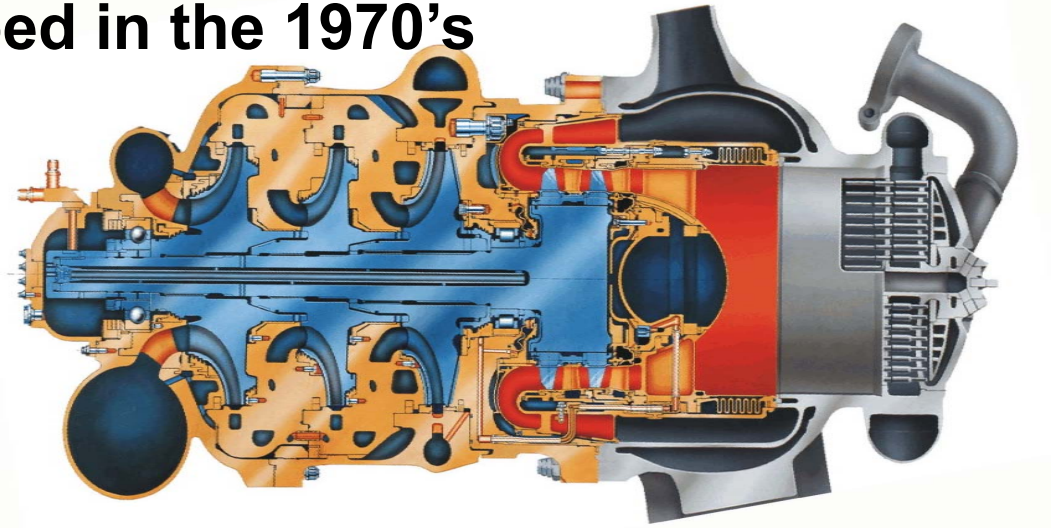
Compressor Type	Efficiency		Reliability	Costs		Contaminants
				Acquisition	O & M	
Piston	Low	Friction & Inertia	Low - Wear & Vibrations	High - Multiple Units	High - Overhauls, Outages, Efficiency	Yes - Oil
Guided Rotor	Low	Friction & Inertia	Low - Wear of Seals & Rollers	Medium -High	High - Efficiency, Bearing Life	Yes - Oil
Centrifugal	High		High	Medium	Low	No

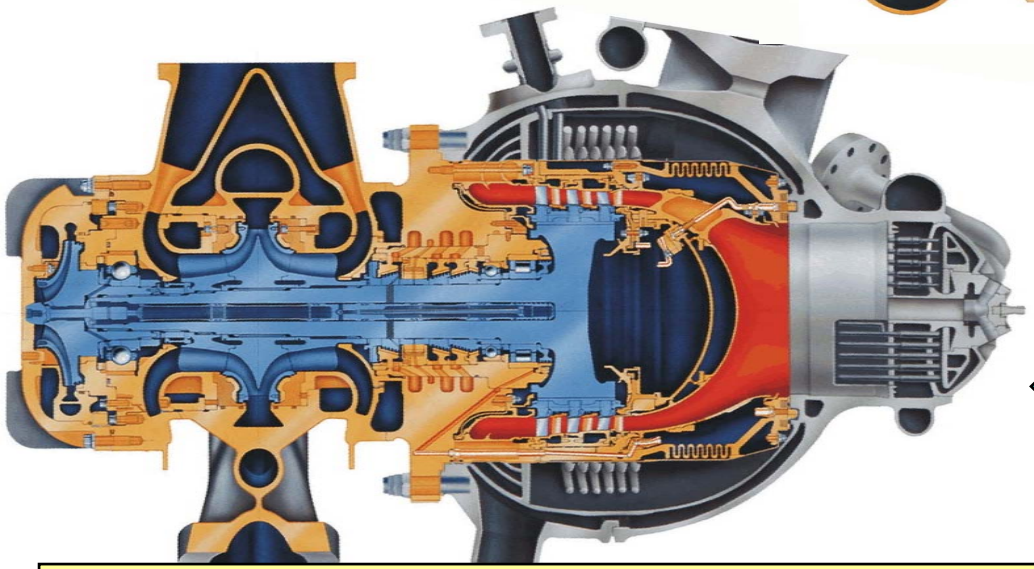
SSME Turbopump Configurations

Developed in the 1970's

Liquid Hydrogen:

Series Design
6,500 psig
4,500 kg/min
76,000 HP
36,000 rpm





Liquid Oxygen:

Double Flow Impeller
7,500 Psig
32,200 kg/min
26,000 HP
24,000 rpm

Plagued with Bearing Life Issues I.e., 10 Missions

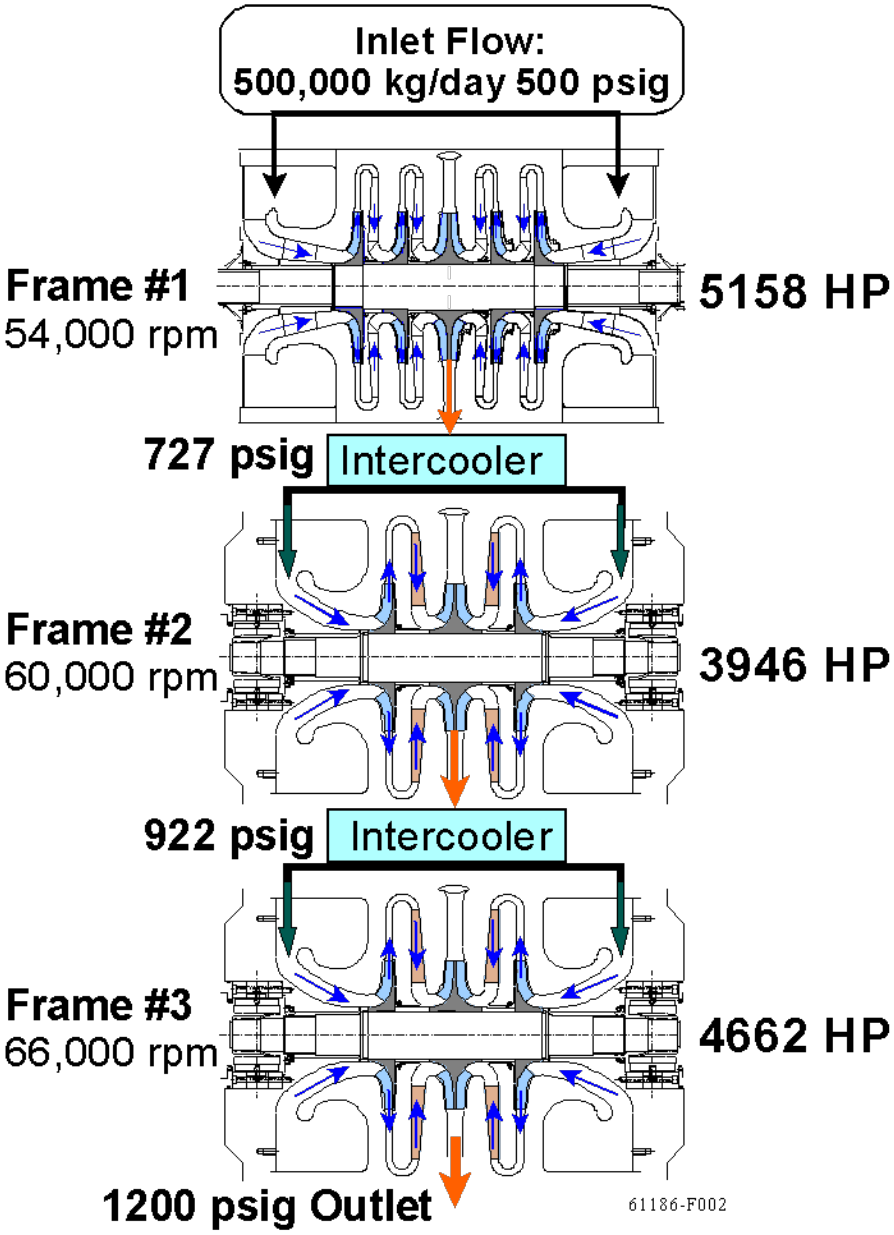
Related SBIR Technical Accomplishments:

Compressor Preliminary Design

Final Summary							
Maximum Head = 60,000 ft			Maximum Discharge Temp = 300F			Interstage Temperature = 200F	
Compressor Stage	Power (hp)	Pressure (psig)	Suction Flow (Cu-ft/min)	Speed (rpm)	Specific Diameter	Diameter (Inches)	Tip Speed (ft/sec)
Inlet		**500**	**3616**				
1	1626	573	3616		1.50	6.45	1521
2	1718	645	3400		1.56	6.42	1513
3	1814	727	3194		1.63	6.41	1511
Outlet #1	**5158**	**727**		**54000**			
Inlet #2		**712**					
4	1918	817	2960		1.55	5.92	1550
5	2028	922	2776		1.62	5.91	1548
Outlet #2	**3946**	**922**		**60000**			
Inlet #3		**912**					
6	2262	1054	2570		1.54	5.48	1578
7	2400	1200	2400		1.62	5.48	1578
Outlet #3	**4662**			**66000**			

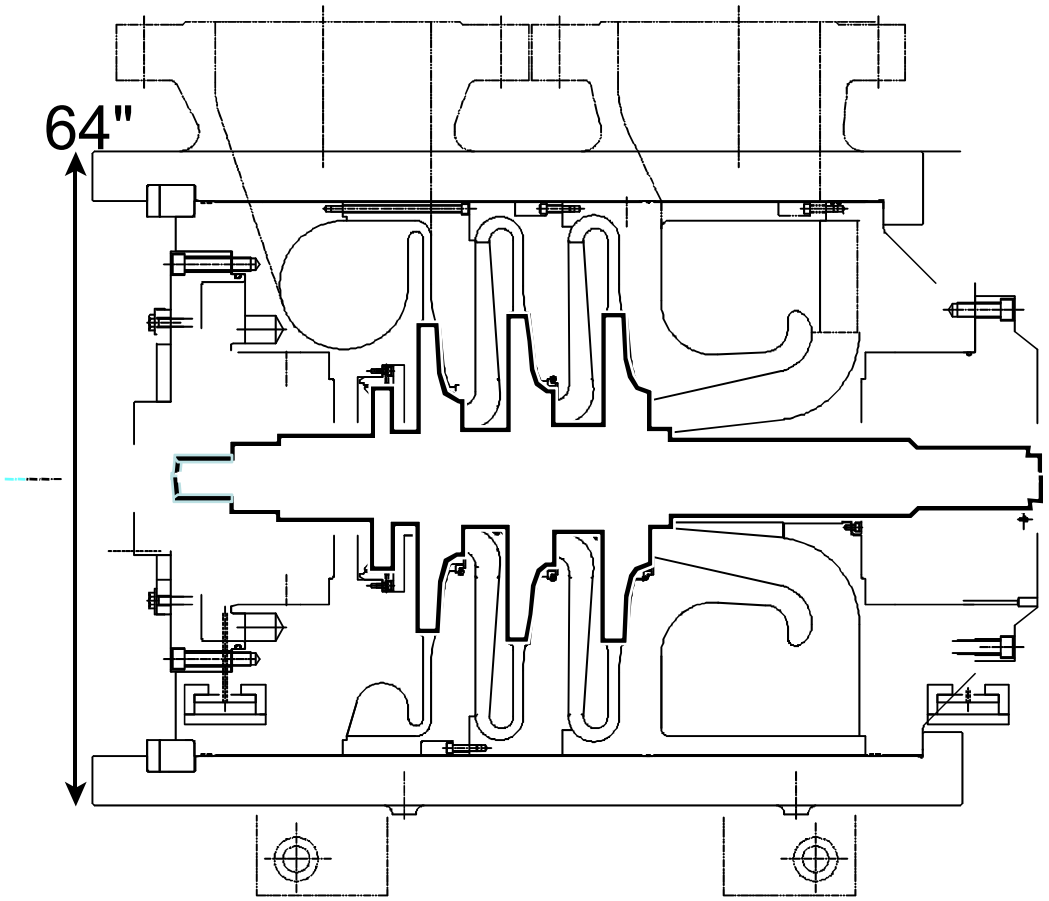
Progress

- Previous Efforts Identified Centrifugal Compressor Configuration Feasibility and Technology Needs
  - Internal MiTi® & MHI Company Funding
  - DOE SBIR
- Preliminary Compressor Design Completed
  - 500,000 Kg/day @ 1200 psig
  - Total No. of Stages Needed (7 Stages)
  - Impeller Diameters and Operating Speed Ranges Established (up to 66,000 rpm)
  - Total Driving Power < 14,000 HP

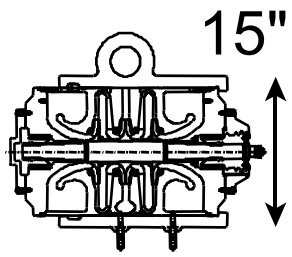


Related SBIR Technical Accomplishments:

High-Speed Compressor Benefit



Machine Size Reduced
More Than 4 Times



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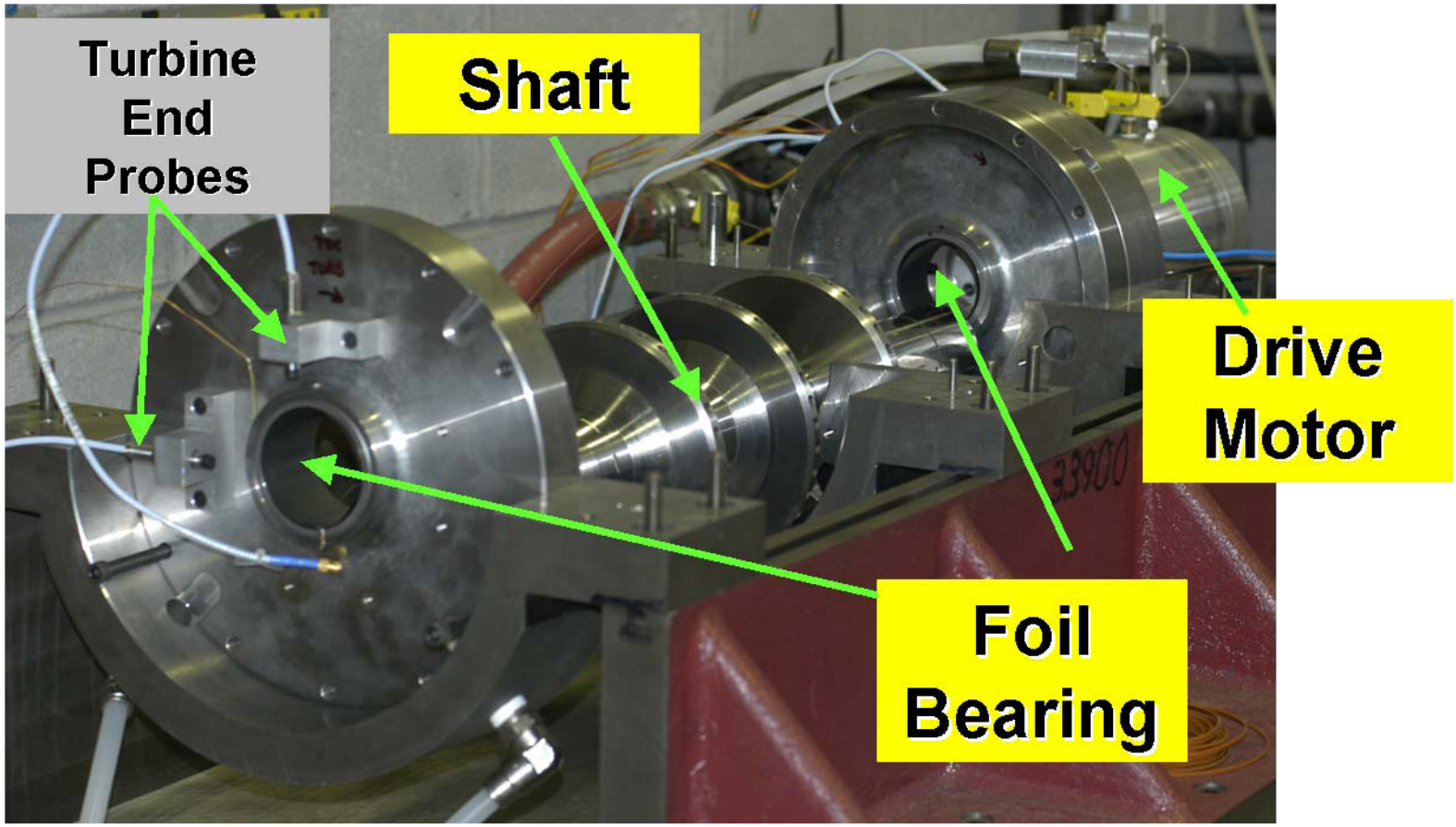
Related SBIR Technical Accomplishments:

Foil Bearings for H_2 Compressor

- Foil Bearings Sized
  - Journal Bearings
    - Diameter = 2.5” (63 mm)
    - Length = 2.0” (50 mm)
    - Projected Area = 5 in^2
- Bearing Coating Selected
  - MiTi® Korolon™ 900
  - 25 lb load capacity @ Start Up (N=0)
- Bearing Stiffness Designed
  - 20-30k lb/in/in
- Theoretical Load Capacity
  - 500 lb @ 800 fps

Related SBIR Technical Accomplishments:

Dynamic Simulator Designed & Built



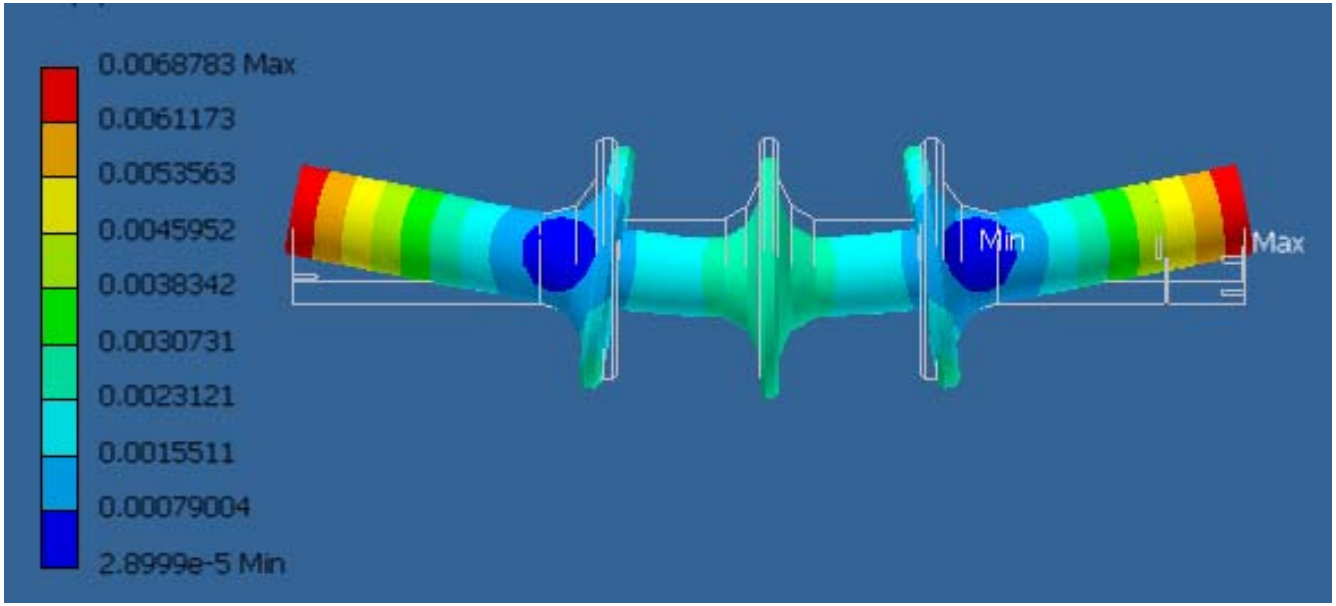
Related SBIR Technical Accomplishments:

Simulator FE Model

FEA rotor model analysis and experiment compared.

Configuration	1st Bending Mode (krpm)	
	Measured	Predicted
Test Simulator Rotor System	31.80	31.80
Rotating Critical Speeds	34.35	34.32

❖ Correlation achieved within < 0.1%.

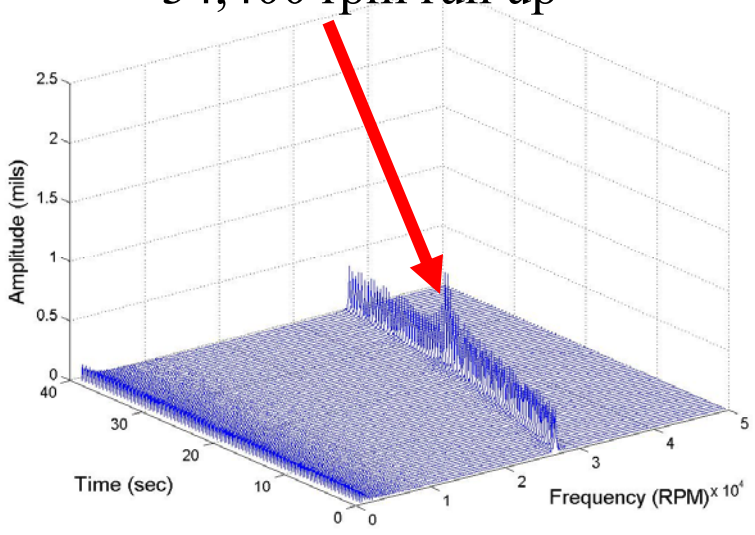


Related SBIR Technical Accomplishments:

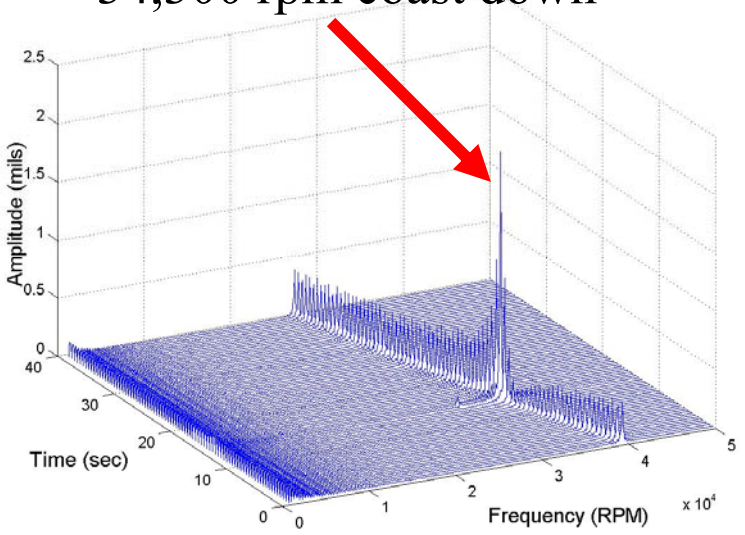
Supercritical Operation

- Experimental plots of rotor run-up and coastdown through bending critical speed.

34,400 rpm run up



34,300 rpm coast down

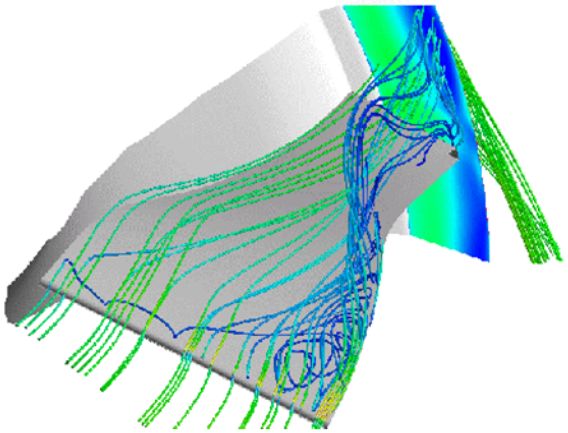


Drive End Vertical Sensor
(X1V) – T3R21

- Excellent correlation with experimental results and system stable as expected

Collaborations

- **Partner/Subcontractor**
  - **Mitsubishi Heavy Industries (Industry)**
    - **Centrifugal Compressor Stage Design**
      - **CFD**
      - **FEA**
    - **Single Stage Compressor Test**



Identified Technology Needs

- **Required High Speeds Dictate**
  - **Advanced Centrifugal Compressor Aerodynamic and Structural Design**
    - **High Stresses**
    - **Efficient and Effective Flow Path**
  - **High-Speed, Oil-Free Foil Bearings**
- **Hydrogen Requires**
  - **Novel Low Loss Seals**
  - **Low Friction and Long Wear Life Foil Bearing and Foil Seal Hydrogen Compatible Coatings**
  - **Hydrogen Compatible Materials**

Future Work for FY09-FY10

- Refine Multi-Stage/Multi-Frame Compressor Concept
  - Establish Stage Pressure Ratios and Flows
  - Define and Select Optimum Operating Speeds
  - Select One Stage for Detailed Design and Test
- Preliminary Design Review with DOE
- Conduct Detailed Design
  - Establish Flow Path Including Inlet, Impeller, Diffuser and Return Channel Designs Using Established Design Analysis and Computational Fluid Dynamics
  - Design Foil Bearings and Seals Using Coupled Elasto-Hydrodynamic Analysis
  - Design Test Shafting Using Finite Element Rotor-Bearing System Analysis

Project Summary

- This project proposes to demonstrate that advanced and very high-speed, oil-free centrifugal compressors can meet hydrogen delivery needs
- MiTi® and MHI have shown analytically that multiple multi-stage very high speed centrifugal compressors operating in series are necessary and feasible.
- A key compressor stage will be designed, fabricated and tested to validate the concept and demonstrate overall system feasibility based upon advanced 3-D aerodynamic designs combined with oil-free compliant foil bearings and close clearance compliant foil seals
- Under this effort, compressor blade tip speeds, and bearing and seal surface velocities exceeding state-of-art will be designed, built and evaluated

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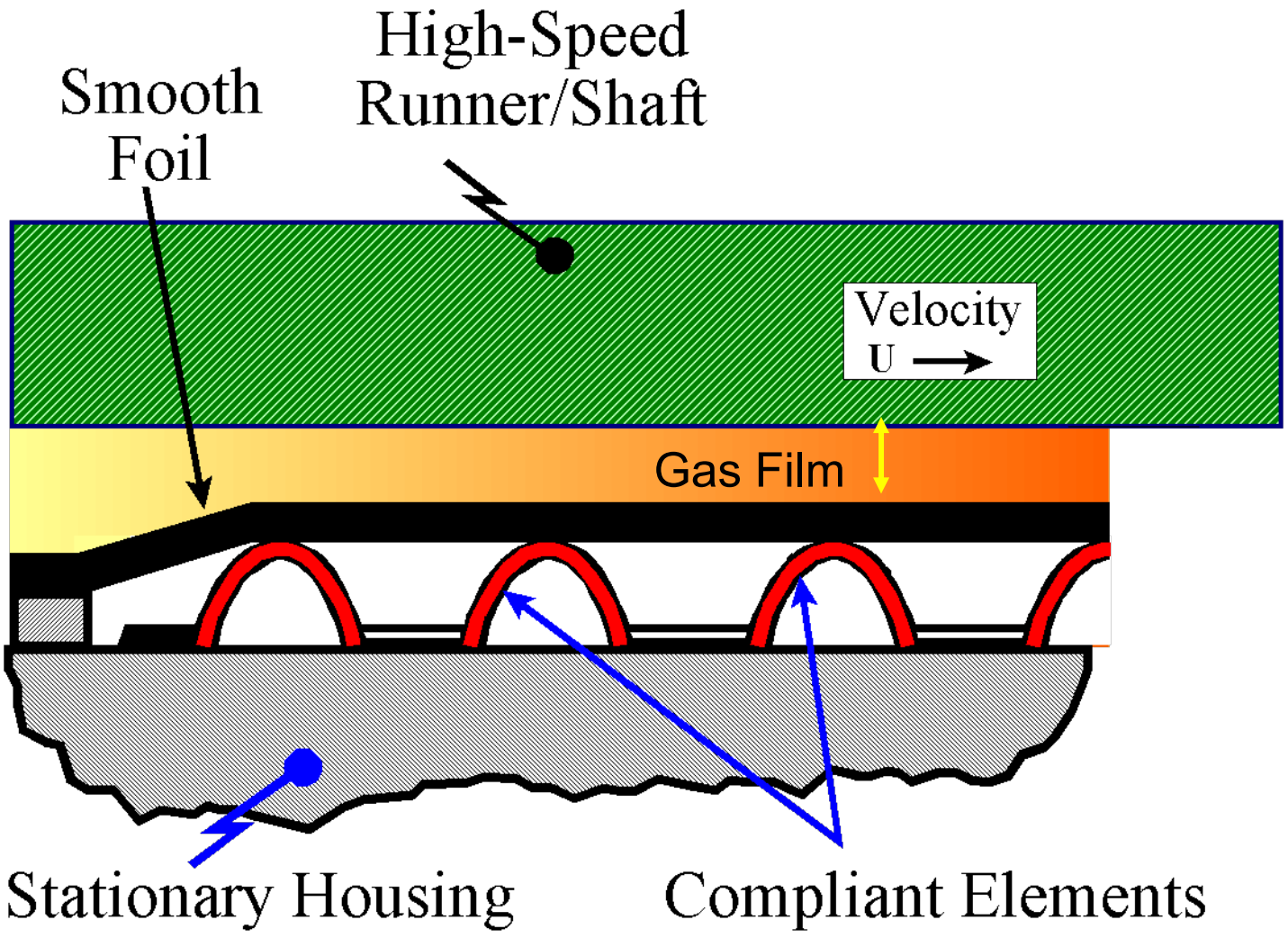
Supplementary Slide

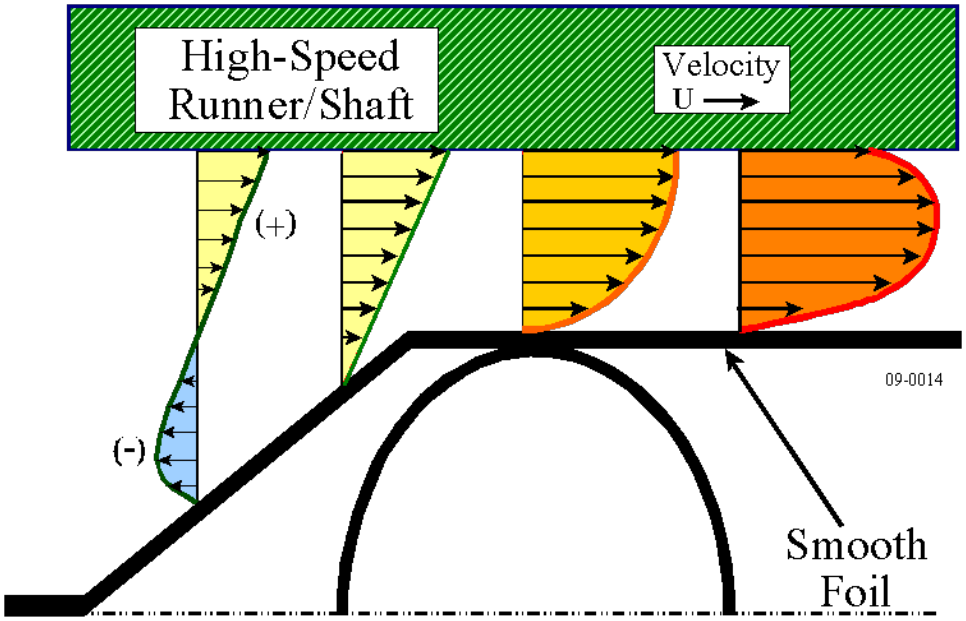
Oil-Free Bearing Technology



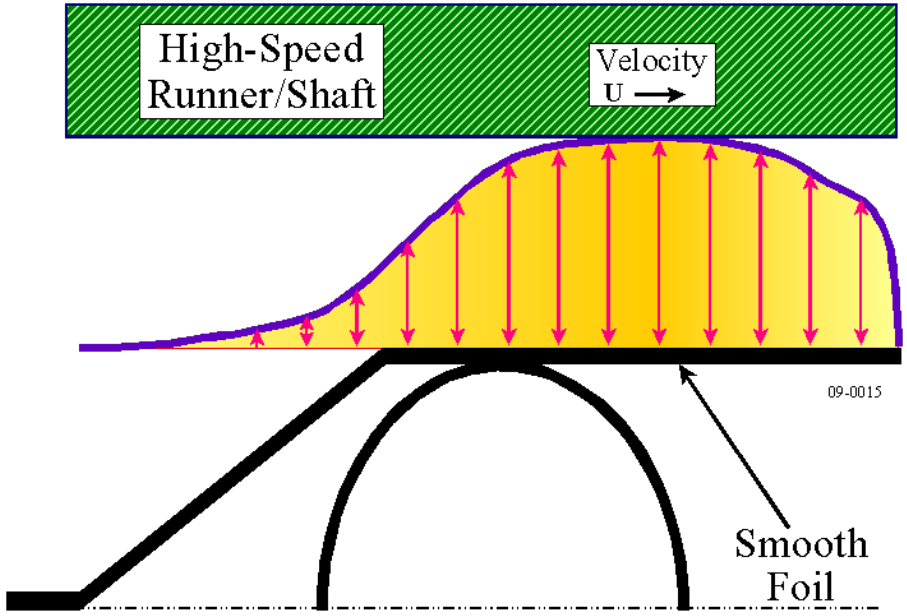
Supplementary Slide

Oil-Free Bearing Technology

Velocity Profile

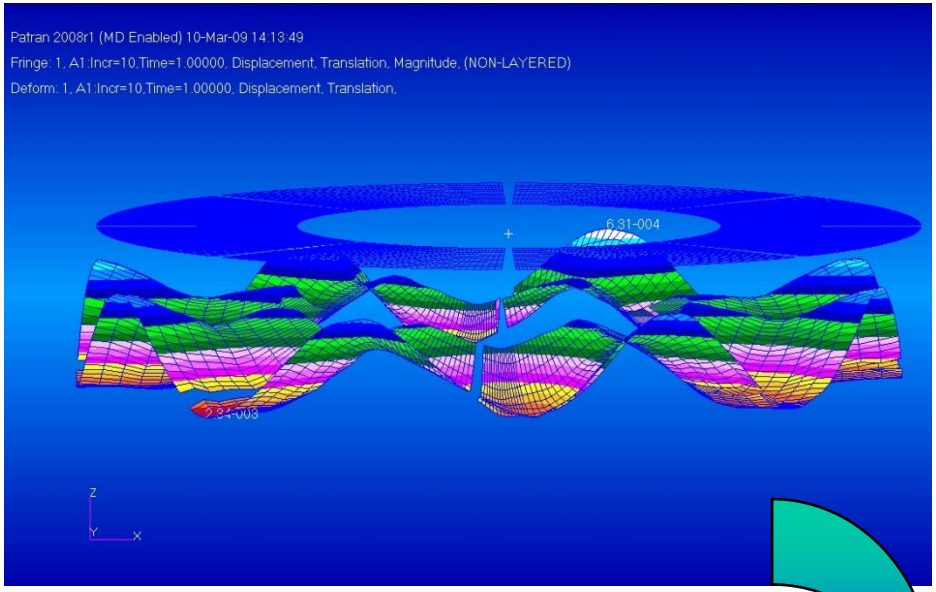


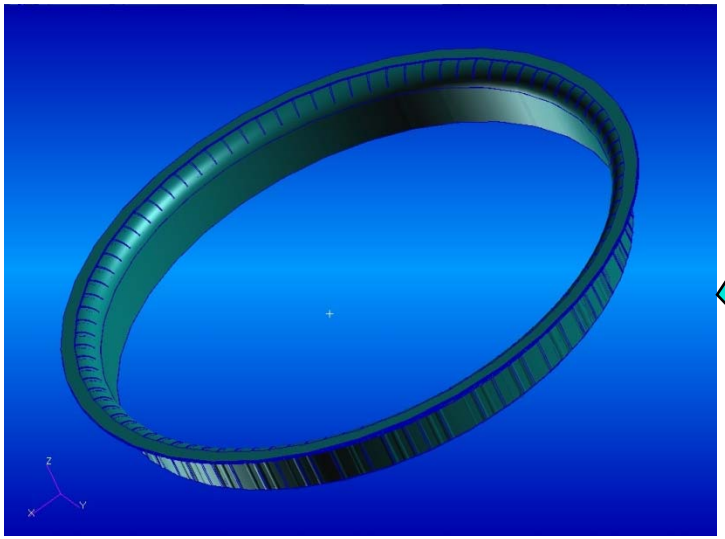
Pressure Profile



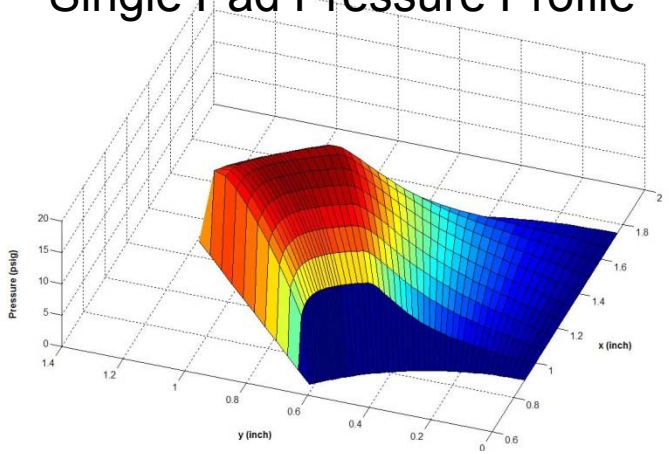
Supplementary Slide

Coupled Elasto-Hydrodynamic Seal Analysis





Single Pad Pressure Profile



Single Pad Stiffness Profile