Air-Riding Seal Technology for Advanced Gas Turbine Engines

(SC0008218)

FLORIDA TURBINE TECHNOLOGIES

Neil Kant

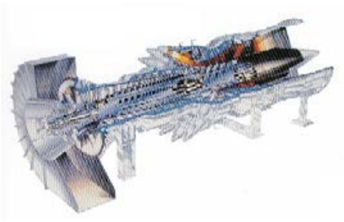
2 November 2016

Agenda

- FTT company overview
- DOE-sponsored technology development research at FTT
- Opportunities for collaboration with UTSR universities

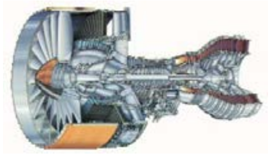
FTT is: Affordable Efficiency™

- An aerospace and energy high-technology provider – specializing in development of *next-generation turbomachinery*
- Lowest cost provider of <u>advanced</u> propulsion and power systems
  - Today's system solutions "cost too much" and "take too long"
- Employer of 200+ talented professionals
- Woman Owned Small Business
- Headquarters: Jupiter, Florida
- Incorporated: October 1998



Industrial

Utilities



Commercial

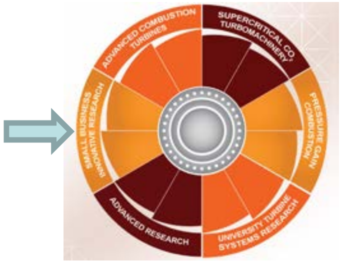
Military

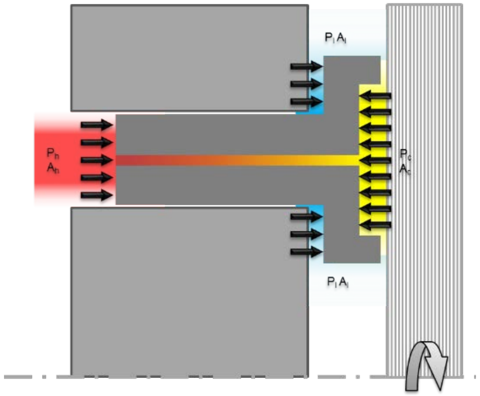
Space

Micro-Turbines

DOE-Sponsored Technology Programs

- Air Riding Seal Technologies for Gas Turbines
  SBIR (DE-SC0008218)

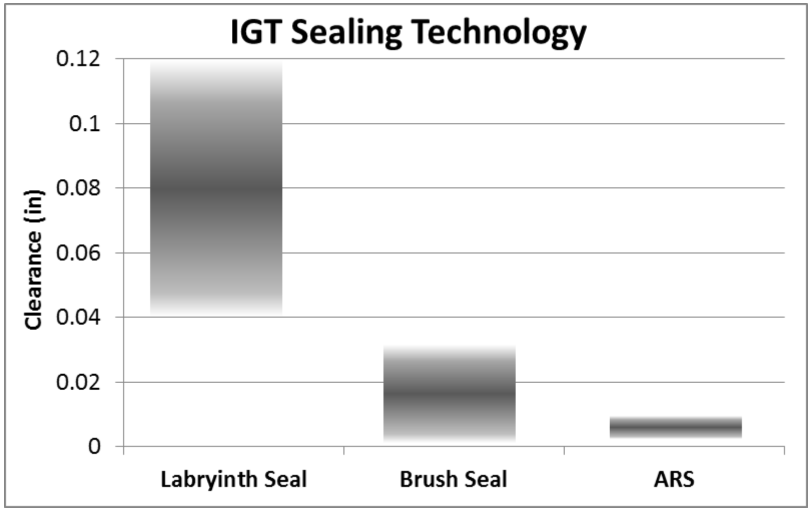




- TurboGT™ Gas Turbine with ARTICReturn™ Cooling
  Advanced Turbines Program (FE-0023975)

Air Riding Seal (ARS) Intro

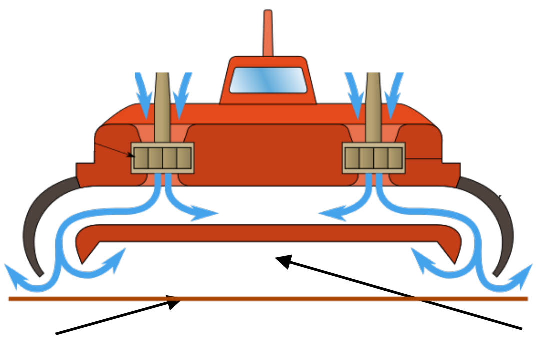
- Current Sealing Options
  - Leakage - Large gaps cause high leaks
    - High radius labyrinth seals or high Pressure Ratio
  - Wear – Initial build gaps increase due to wear
    - Brush seals

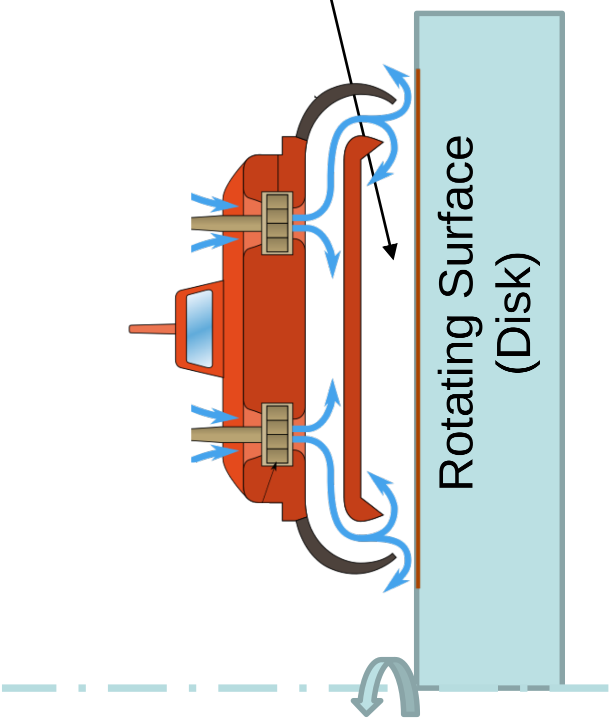


- Air Riding Seal
  - Reduce clearance/effective gaps between rotating and static components by up to 95%
  - Efficient, Effective Low Flow Seal
  - Transient and Thermal Tolerant

Hydrostatic Example

- HydroDynamic – Gas cushion created by relative motion.
- HydroStatic – Gas cushion created by pressurized gas

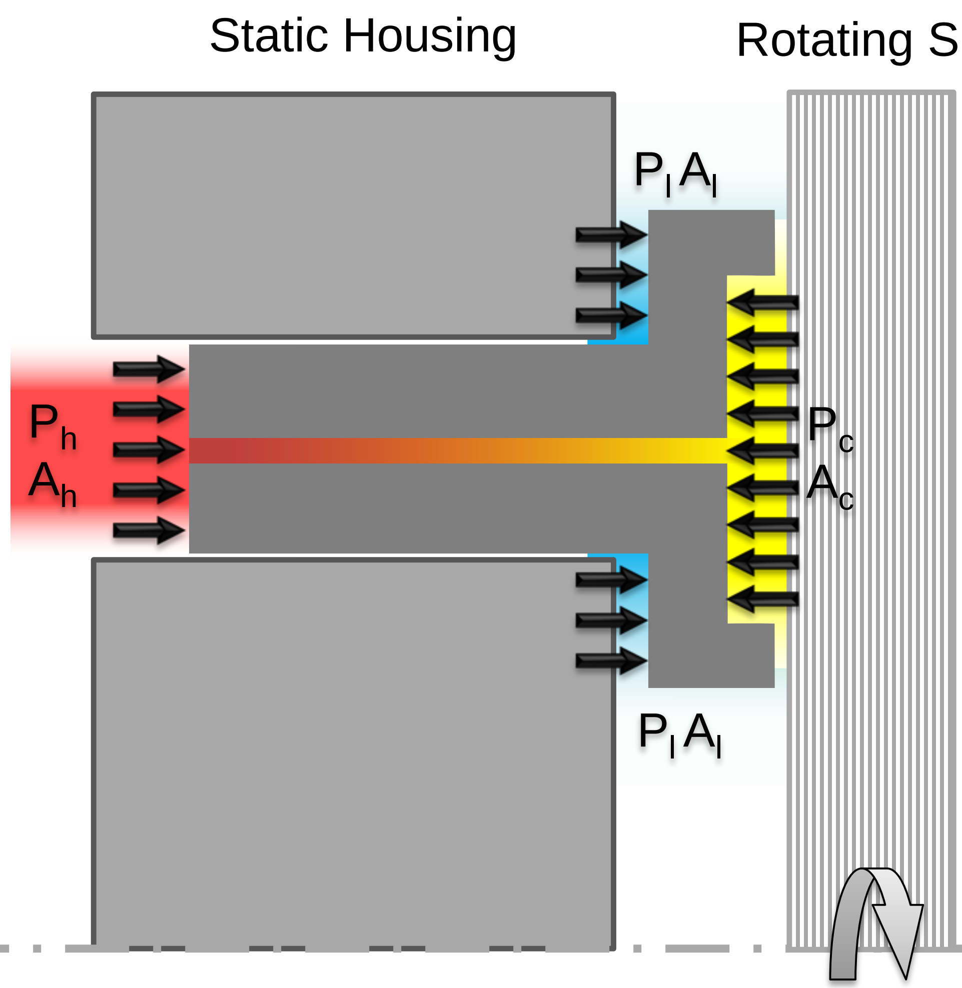




Hovercraft Image By MesserWoland - Own work, CC BY-SA 3.0,
https://commons.wikimedia.org/w/index.php?curid=1905531

Advanced Leakage Control Tech.

Air Riding Seal (ARS) Fundamentals



Equilibrium $\Sigma F_x = 0$

$P_h A_h + P_l A_l = P_c A_c$

Increased Clearance $\Sigma F_x = \rightarrow$

$P_h A_h + P_l A_l > P_c A_c$

Reduced Clearance $\Sigma F_x = \leftarrow$

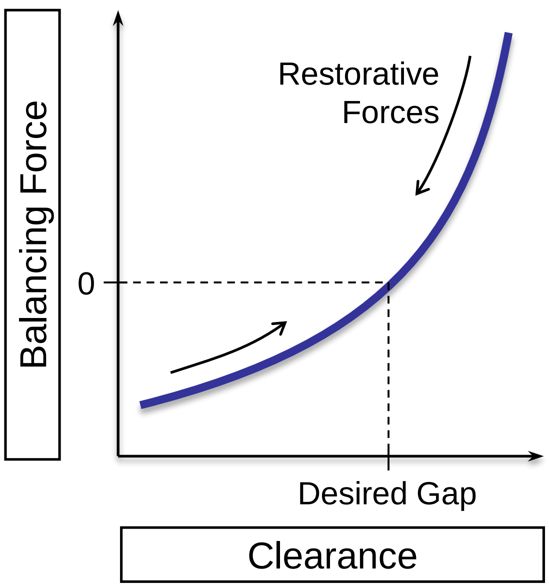
$P_h A_h + P_l A_l < \mathbf{P_c A_c}$

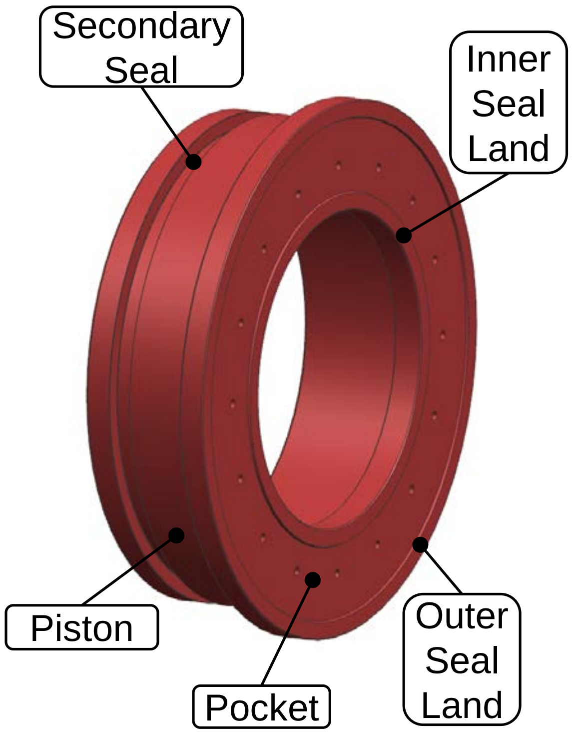
Air Riding Seal

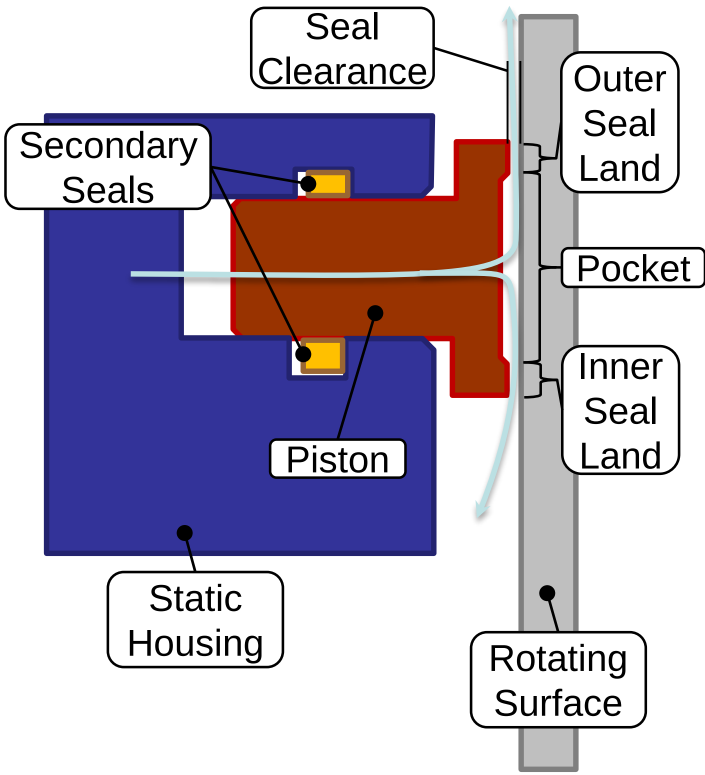
General Description

- Non-contacting static-to-rotating seal
- Hydrostatic balance of forces
- Ability to follow rotor to maintain close clearances

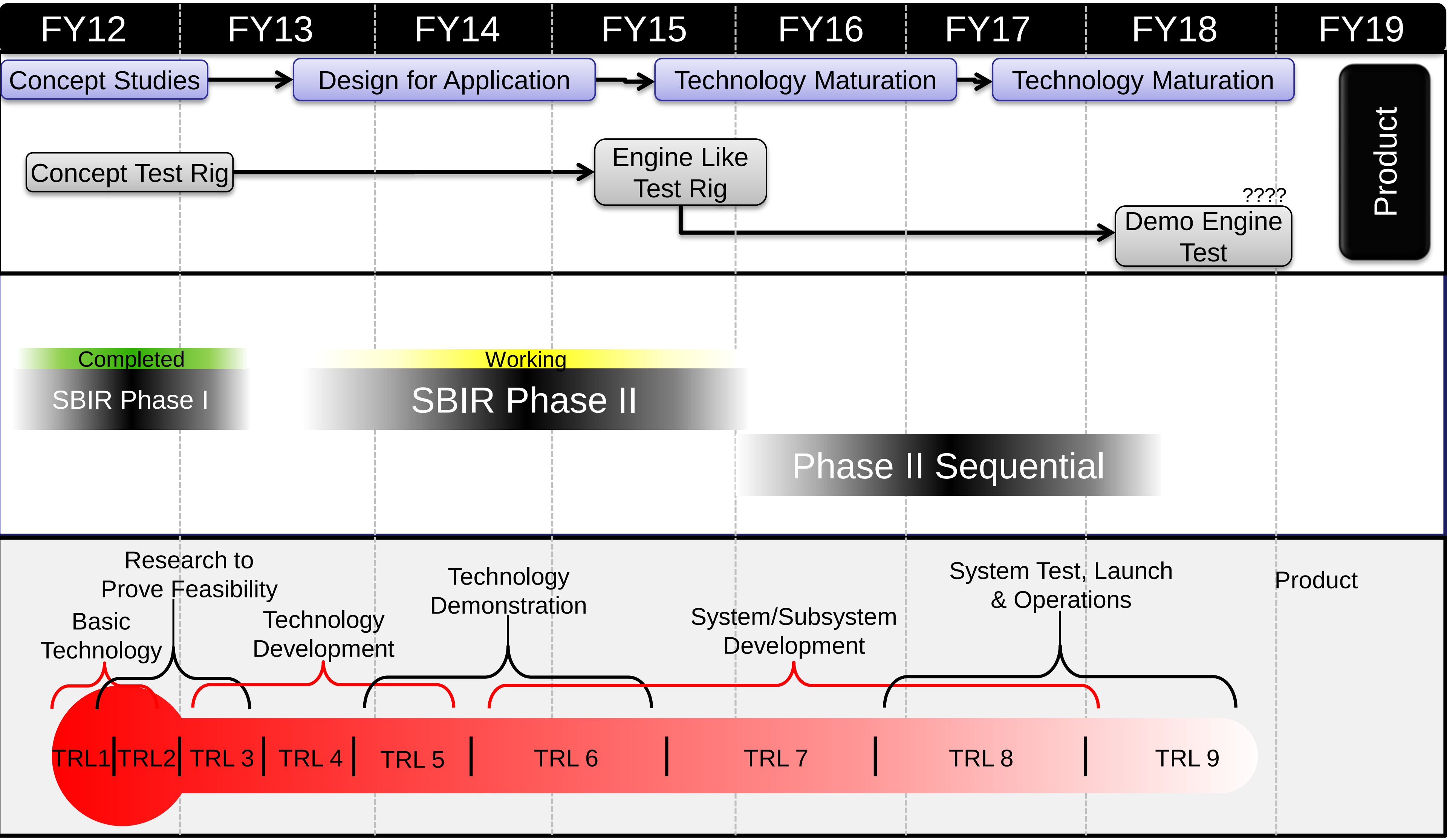
Large Transient Capability





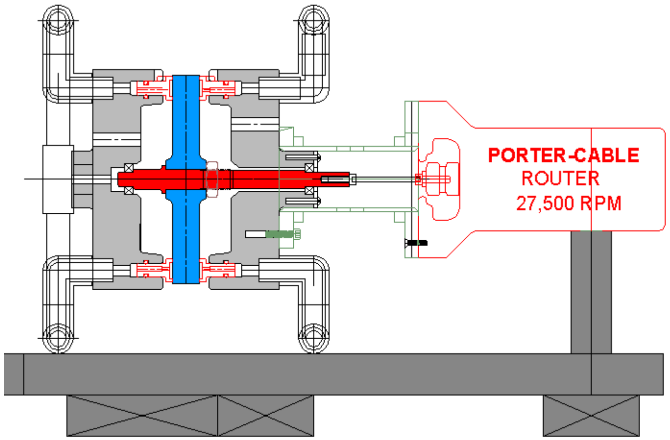


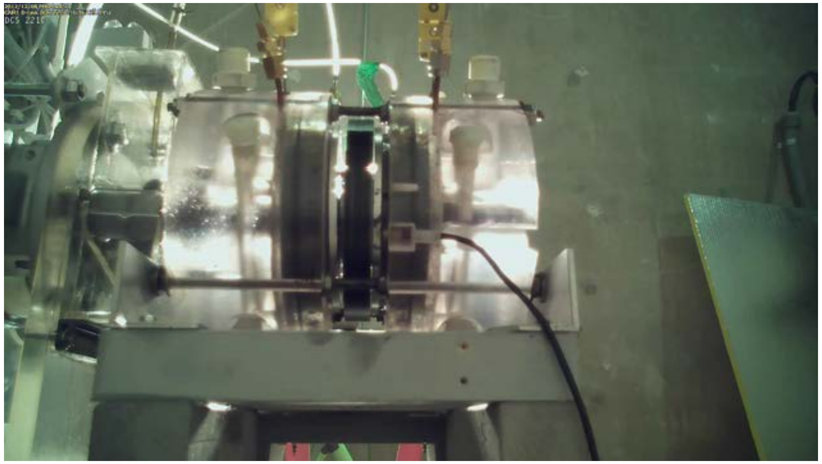
ARS Tech, Development Roadmap



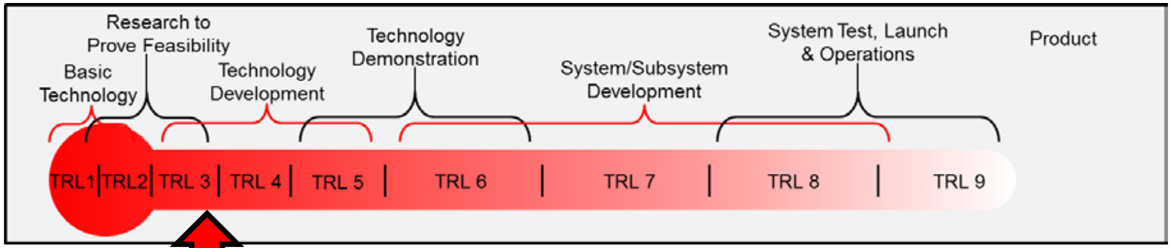
PH I: Feasibility Demonstrated

Phase 1 Air Riding Seal



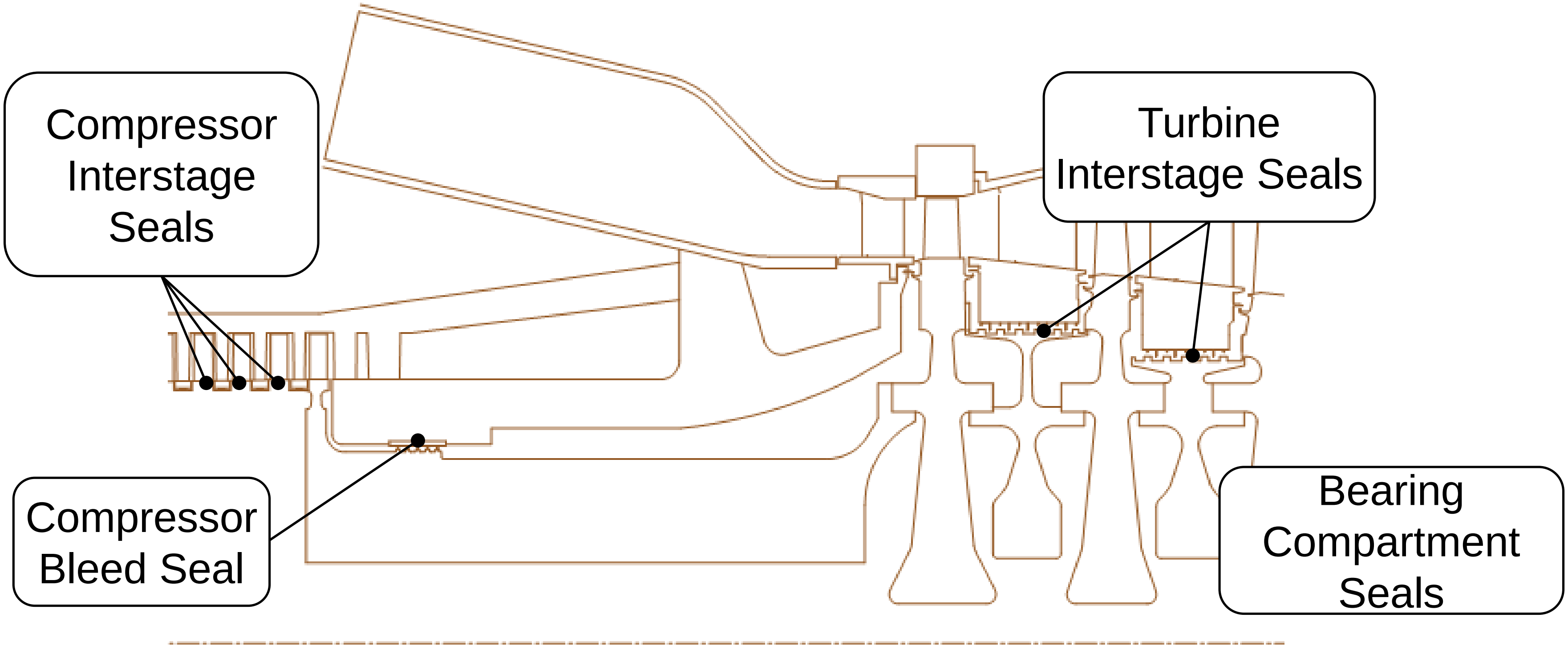


1. Cold
2. Low Pressure
3. Testing Success Showed Air Riding at Surface Speeds.



Achieved TRL 3 in Phase I

ARS Applicable to Many Locations



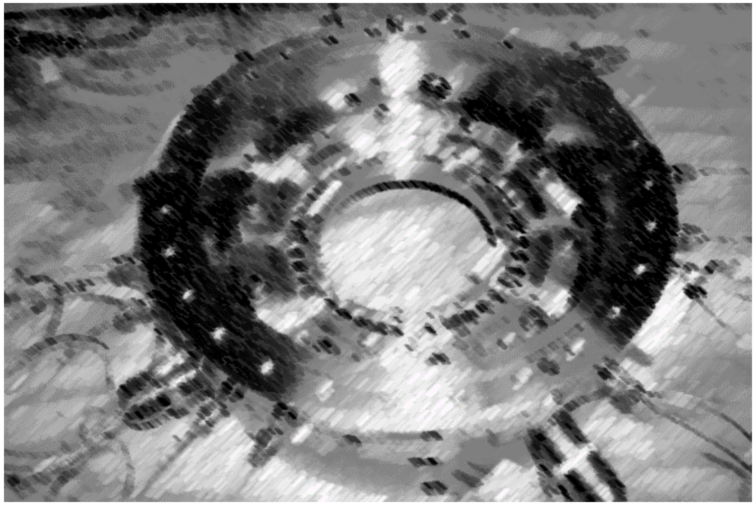
ARS technology applicable to a variety of rotating to static seals

Future ARS Engine Testing

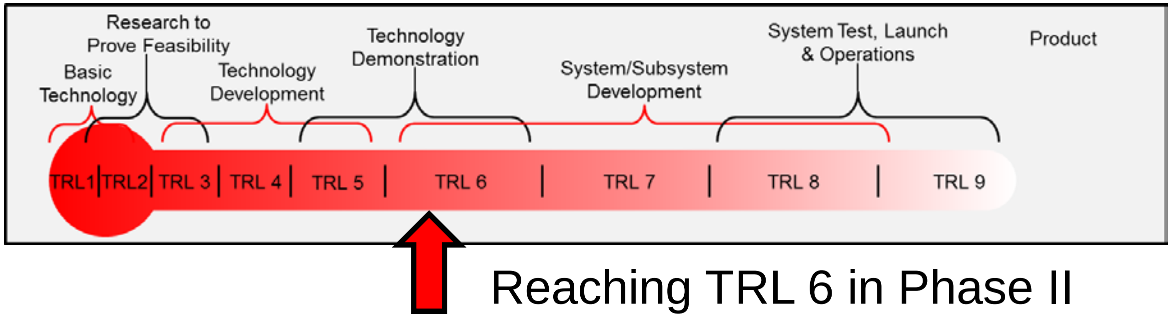
- To reduce cost and risk for future engine testing, the initial application of the ARS has been designed for the 501K
  - The ARS will be tested in a rig at engine conditions under the Phase II contract
  - Rig hardware has been designed to integrate into the engine
- ARS replaces the ‘thrust balance seal’ upstream of the first stage turbine

PH II: Capable and Adaptable Rig

Phase II Air Riding Seal



1. Phase II seal assembly sized to install an existing engine with no hardware modification.
2. High pressure and high temperature testing (Engine Conditions).
3. Seal design retracts at low pressure conditions.
4. Capability to evaluate misalignments.



Reaching TRL 6 in Phase II

Path to Validation Test

- ✓ Development of Test Plan
- ✓ Competed design of ARS
- ✓ Competed design of Test Rig
- ✓ Designed Controls and Specified Data Acquisition System
- ✓ Manufactured Hardware
- ✓ Assembled and Instrumented
- ✓ Cell Commissioning and Shakeout

Significant Endeavour to Perform the Necessary Validation (TRL 6)

ARS Technology Phase II Demo

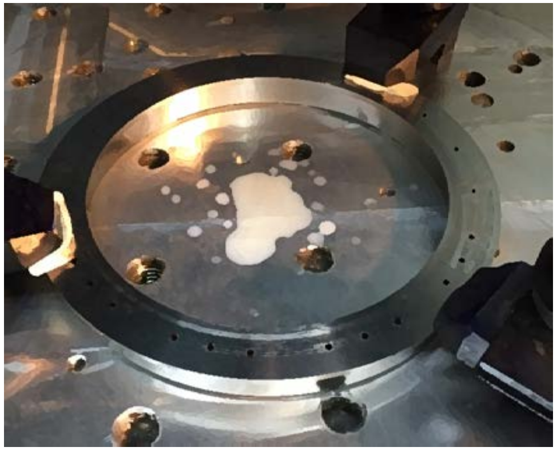
- Facility and Components Designed and Procured.
- ARS Testing Underway at FTT Facility.

ARS Rig with Instrumentation

Nitrogen Trailer for High Pressure Testing

Rig is designed to simulate full engine conditions with respect to Pressure, Temperature, and Speed with engine ready hardware.

ARS Technology Phase II Rig

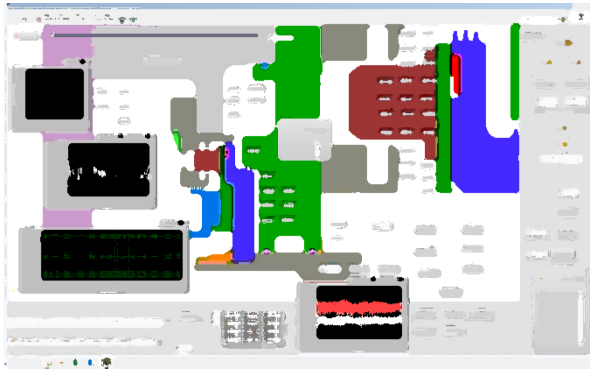


ARS Instrumentation Summary

<u>Instrumentation includes:</u>

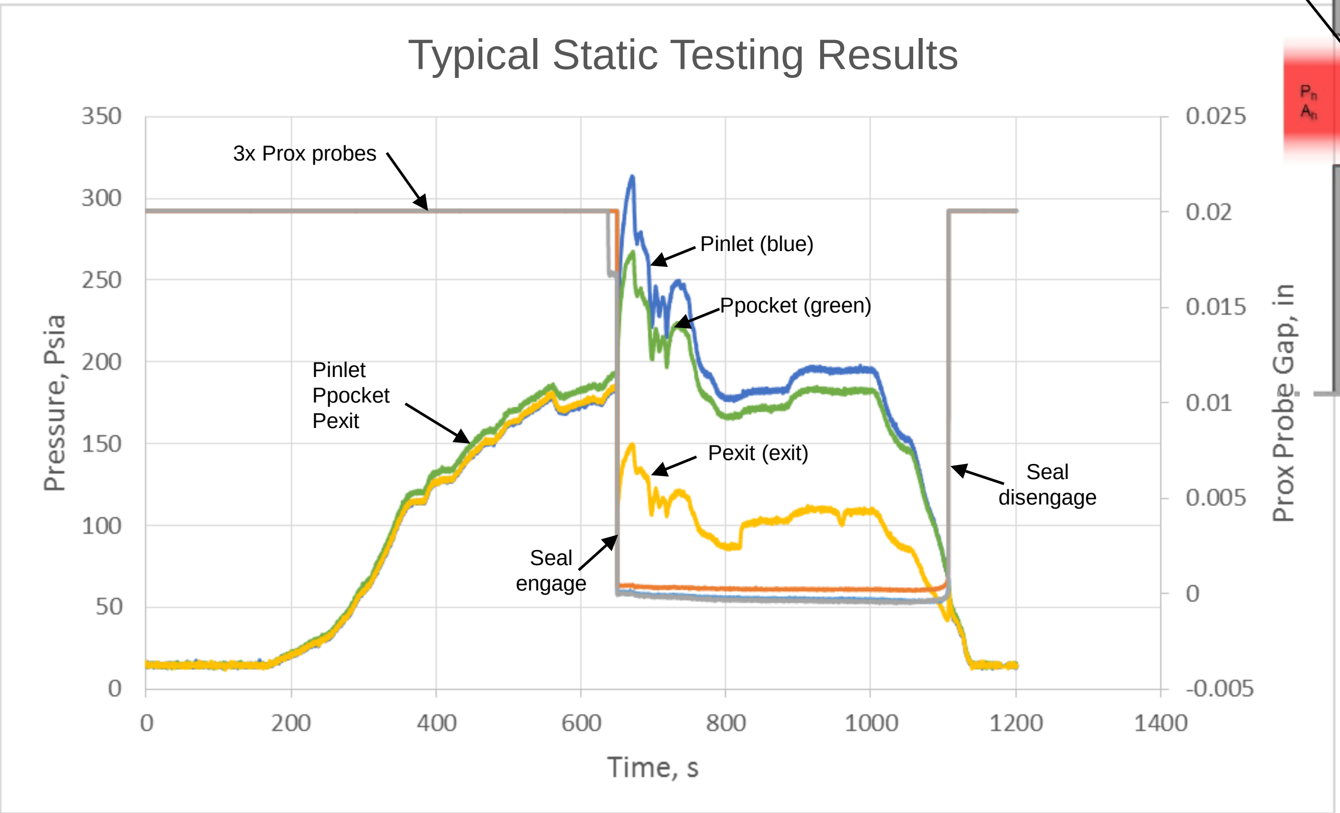
- Displacement proximity probes
- Static Pressures (up, down, and pocket)
- Cavity Temperatures
- Rotor Speeds
- Facility Health Monitoring

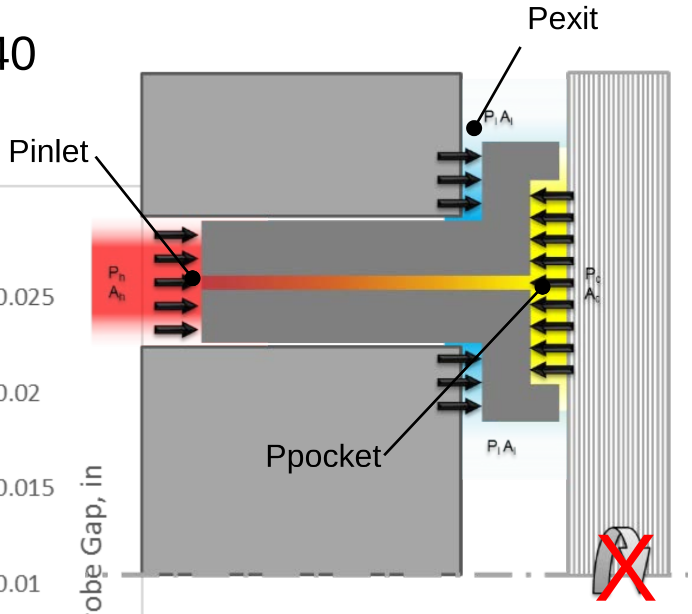
- LabView Virtual Instrument (VI) Captures real time data and presents calculations.



Air Riding Seal Rig Typical Test Results - Static

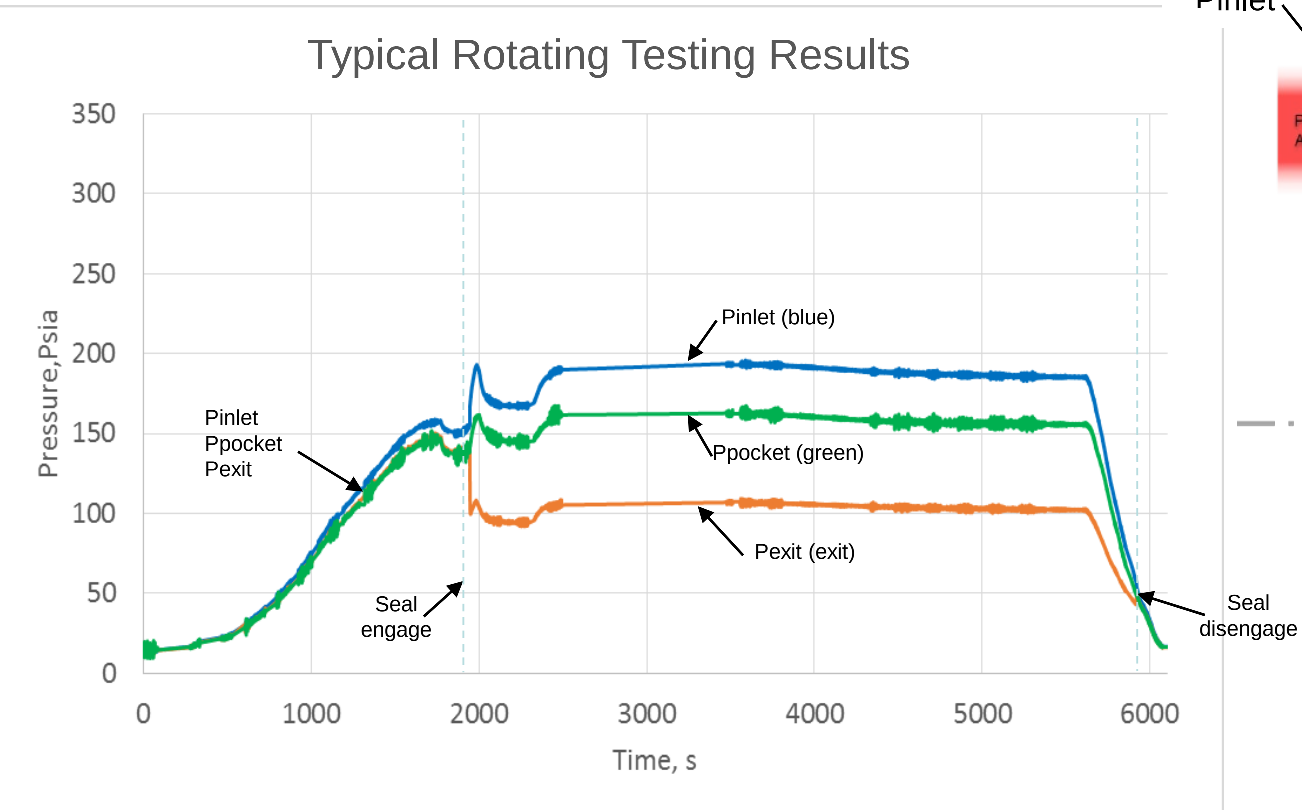
Initial testing began in May 2016. Air riding seal engages at Pinlet =~170 psia. Disengages at Pinlet=~40 psia.

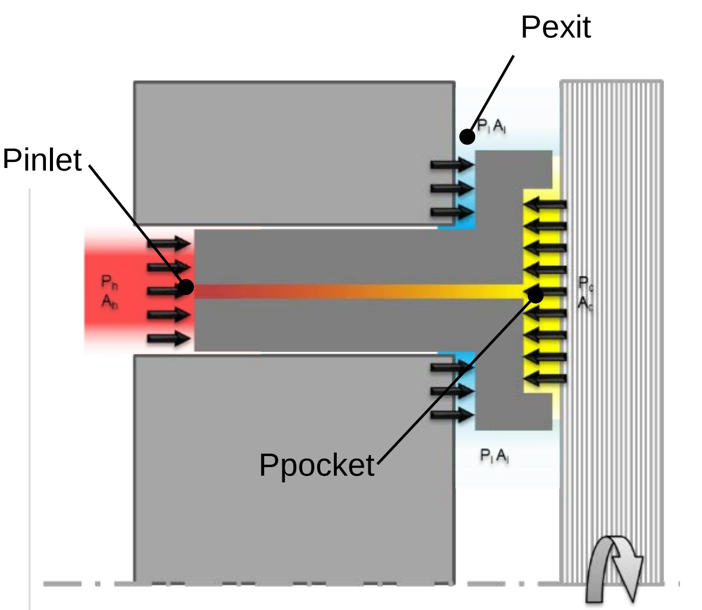




Air Riding Seal Rig Typical Test Results - Rotating

Cold rotating test in June 2016. Air riding seal engages at Pinlet =~160 psia. Disengages at Pinlet=~40 psia.





Facility & Controls improvements to controls reduced over shoot.

ARS Rig Current Status

Accomplishments:

- Cold static testing. Seal demonstrated ‘floating’ condition.
- Cold rotating testing. RPM 11,000 RPM. (Goal 14,600 RPM)
- Hot static testing. Max temperature 650F. (Goal 820F)

Current Status:

- Teardown and inspection revealed nonconforming hardware.
- Rotor inspection showed some rubbing of surfaces.
- Rig is currently being reassembled.

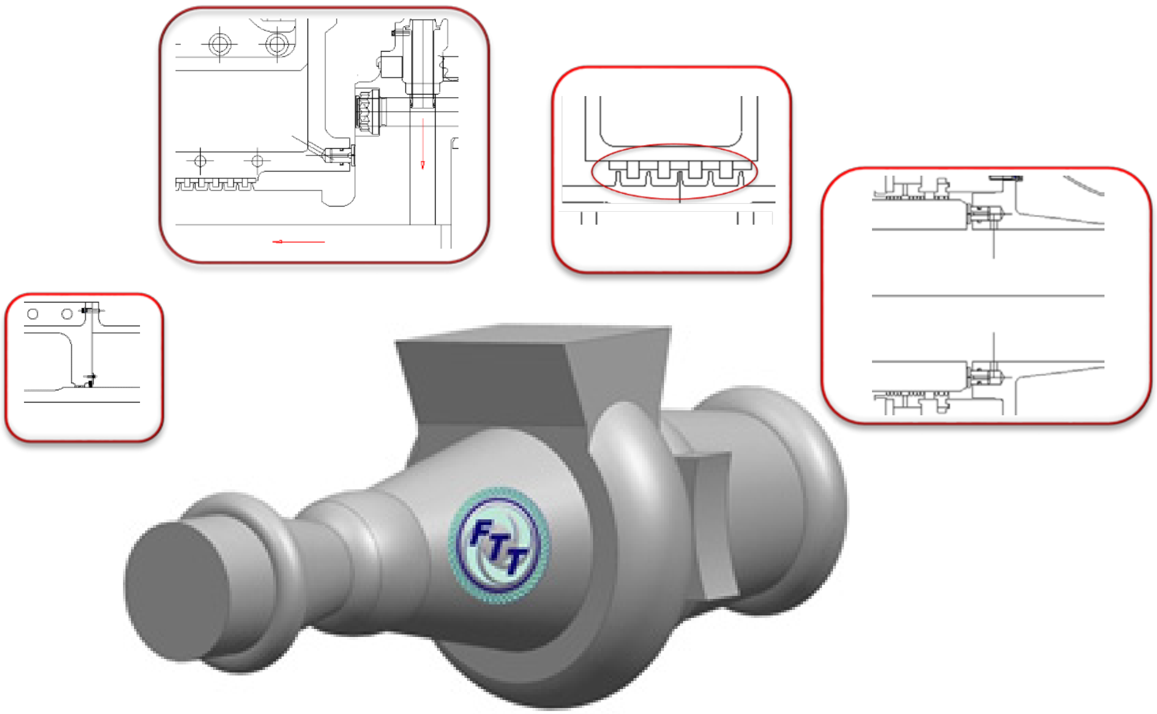
Next Steps

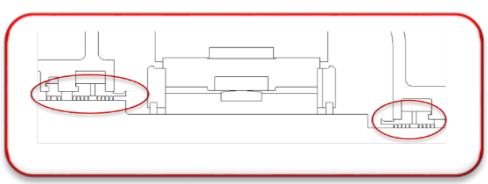
- Hot rotating testing to begin November 2016.

Benefits of ARS in High Efficiency Systems

ARS In High Efficiency Systems

ARS's Used in TurboGT™ = Reduced Leakage





Location	ARS % Eff. Area Red.
LPC Feed – Brush Seal	50%
Return Cooling - LS	>75%
Outer Bearing Compartments -LS	Up to 95%*
HPT Feed - LS	Up to 95%*
Under Vane LS	Up to 95%*

*based on radius

- Replacing all potential standard seals with ARS saves a total **1.38%** of total engine inlet airflow

ARS Performance in TurboGT™

Technology Level	Efficiency (Eta CC)	Δ Efficiency
1990s Material Systems Airfoil Technology *	64.0%	
2015 Material Systems Airfoil Technology **	64.7%	+ 0.7
Air Riding Seals (ARS)	64.9%	+ 0.2

- FTT continues development with internal funding and independent reviews.
- October 2016 Status: 64.9% with a 1600^{o}C Class Combustor Exit Temp Using 2015 Material Systems Airfoil Technology

* Status as of the Phase I Final Report
**Updated based on Incorporating the Independent Reviewer's feedback.

Opportunities for UTSR Collaboration

- Partner with University to continue testing/development
- Internship of UTSR Fellow to contribute to these technologies
- FTT industry support of University programs (via UTSR)

Summary

- Existing Programs Successfully Leverage Prior FTT/DOE Component Development Experience
- ARS testing Proved the Feasibility of the Concept and Positions the Technology for an Engine Test
- The TurboGT™ System is a Potential Platform for Realization of ARS Benefits.
  - Development Continuing at FTT
- Many Opportunities for Collaboration with UTSR Universities

Acknowledgements

Department of Energy

National Energy Technology Laboratory

Rich Dennis, Technology Manager

Steven Richardson, Project Manager

Thank You & Questions?