Federal Aviation Administration

Dan Frias
11/02/16

HONEYWELL CLEEN II

Open Discussion – November 2016

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Agreement Number: DTFAWA-15-A-80017
Contractor Name: Honeywell International Inc.
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Phoenix, Arizona 85072-2181

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Agenda

- Elevator Speech
- CLEEN II Technologies
- Project Schedule
- Project Year 1 Accomplishments
- Project Year 2 Plans
- Project Technologies
- Summary

CLEEN II Elevator Speech

- The Honeywell CLEEN II program matures technologies to reduce fuel burn and NOx emissions with a SABER Compact Combustor and Advanced Turbine Blade Outer Air Seal System (BOAS).







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Broad base of Commercial & Military Turbine Products That Can Benefit From CLEEN Technologies

APUs

100 to 1400 hp for commercial and military aircraft

Turbofan Engines

3,000 to 10,000 lb thrust for commercial and military aircraft

Turboprop Engines

575 to 1,600 shp for commercial and military aircraft

Turboshaft Engines

500 to 5,000 shp for tanks, commercial and military rotorcraft

B08-147

Over 150,000 Turbine Engines Delivered – Large Installed Base

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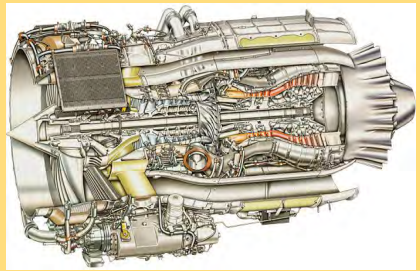
CLEEN II Technologies Summary

CLEEN Technology Name	Goal Impact	Benefits and Applications
SABER Compact Combustor	Fuel burn Emissions	• Reduce weight (fuel burn) • Reduce emissions • Super mid-sized class business jet for turbofan • Entry into service (EIS) 2025
Advanced Turbine BOAS System	Fuel burn	• Improved turbine efficiency (fuel burn) • Applicable to turbofan, turboshaft, turboprop engines, and to large auxiliary power units (APUs) • EIS 2025

Project Schedule - Technology Maturation Approach



Analysis and Development Tests

TRL3

Component Rig Tests

TRL4 **TRL5**

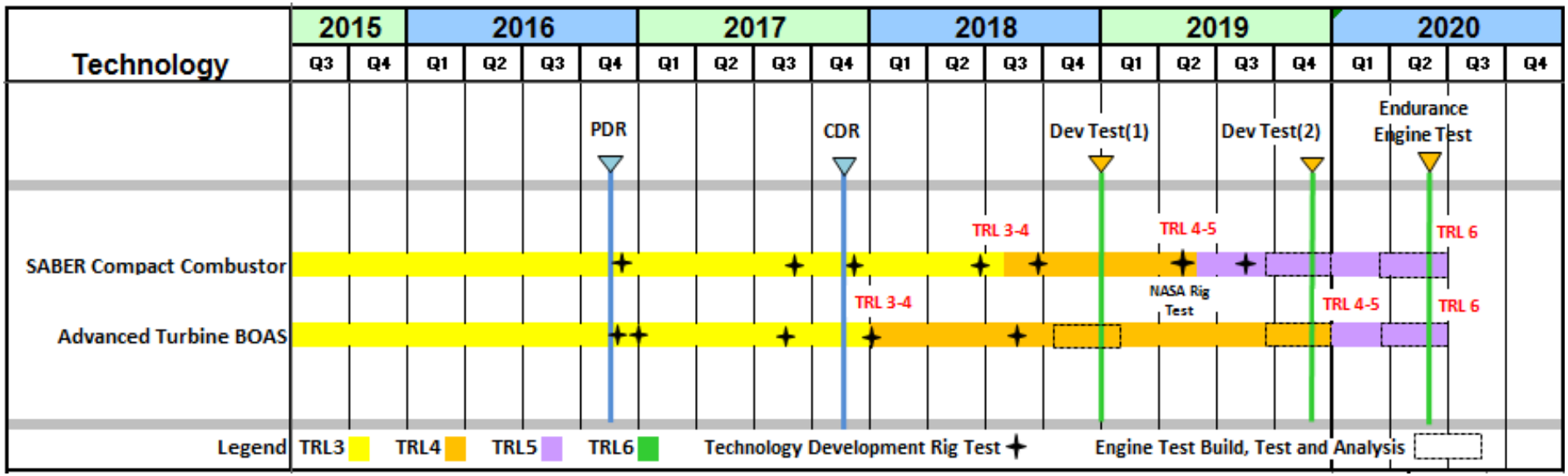
Engine Testing

TRL6

TRL = Technology Readiness Level

A Systematic Approach Toward Reducing Risk

Project Schedule



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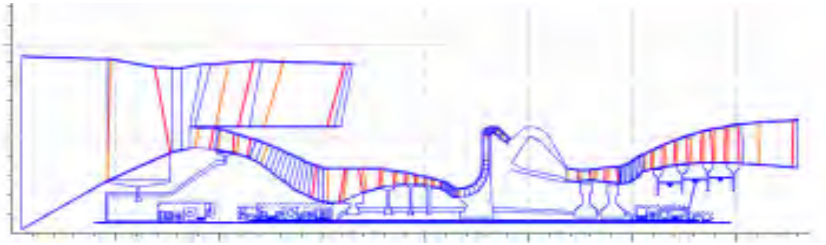
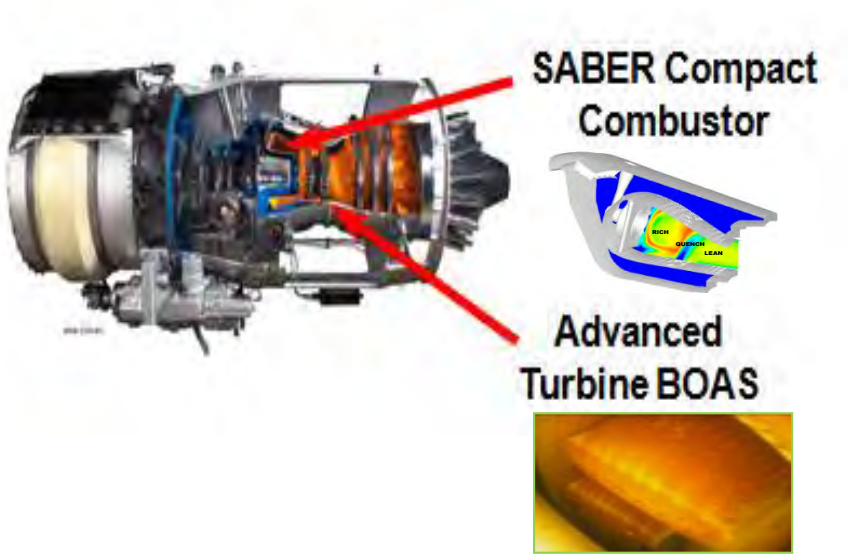
Project Year 1 Accomplishments

- **Systems Engineering**
  - Completed System Preliminary Design
- **BOAS**
  - Preliminary BOAS System Design Complete
- **SABER Compact Combustor**
  - Completed Sub-Component Rig Design
- **Program Management**
  - Submitted Program Task Plan
  - Submitted Program Risk Assessment
  - Submitted 11 Monthly Reports



Honeywell's FAST1D Software



Completed Several Technology Preliminary Designs

Project Year 2 Plans

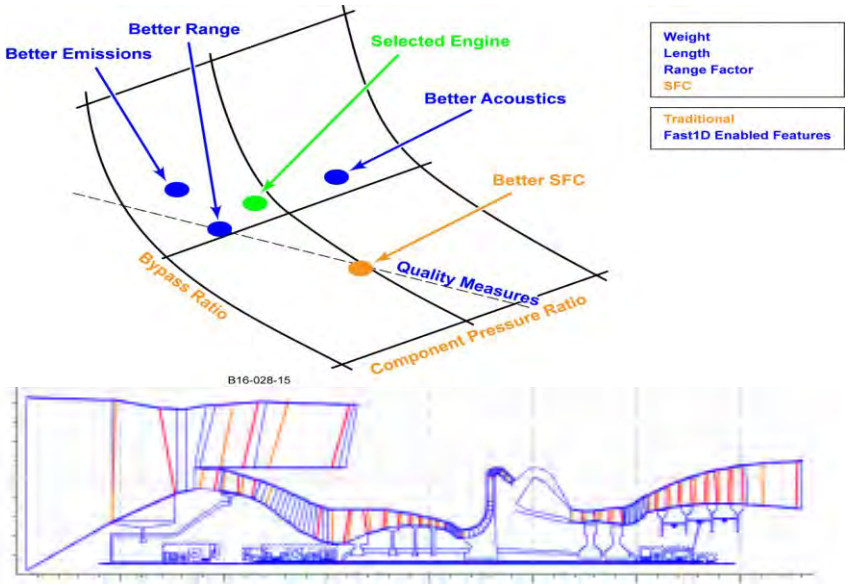
- **Systems Engineering**
  - Complete System Detailed Design
- **BOAS**
  - Complete Rig Design
  - Conduct Development Tests
  - Complete BOAS Materials Downselect
- **SABER Compact Combustor**
  - Conduct Component Rig Tests
  - Complete NASA Component Rig Hardware Design
- **Program Management**
  - Continue Monthly Reports
  - Participate in May/November Consortiums

Development Tests TRL 3

Component Rig Tests TRL 4/5

Several Technology Development Tests Planned for Year 2

Systems Engineering



Honeywell's FAST1D Software

Benefits

- Reduced engine thrust specific fuel consumption (TSFC)
- Improve power-to-weight ratio
- Minimize fuel burn and NOx emissions

Risks/Mitigations

- Insufficient aircraft fuel burn assessment/work with Gulfstream and Georgia Tech

Objectives

- Define a 'CLEEN II' engine with advanced technologies that enable reduction in fuel burn and reduction in NOx emissions

Work Statement

- Complete PDR (complete)
- Complete DDR (future effort)

Accomplishments/Milestones Since Program Start

- Completed PDR

Schedule

- Customer PDR Review (11-16)
- Customer DDR Review (10-17)

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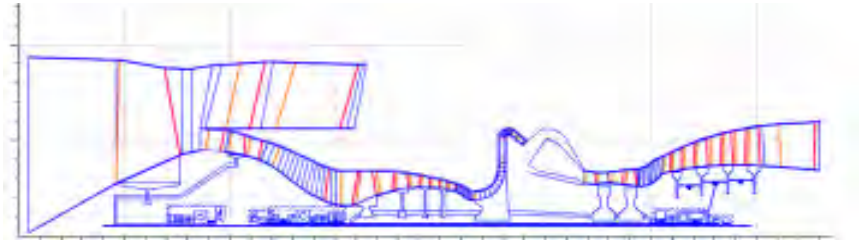
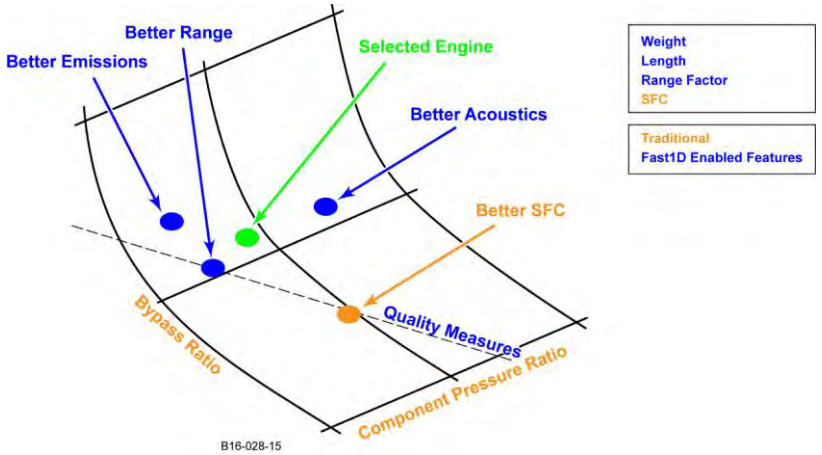
System Engineering - Preliminary Design



- **Honeywell's Fast1D thermodynamic modeling**
  - Flowpath generation
  - Component efficiency prediction
  - Disk sizing
  - Bearing compartment sizing
  - Weight trends
  - Detailed design tasks are moved forward in process
- **New component designs and system trades are evaluated throughout the engine**



- **Understanding the Design Space**
  - Parametric studies used to define viable solution design space
  - Traditional results (SFC) are captured along with other important design features
  - Fast1D provides a holistic, simultaneous look at basic engine performance PLUS mission range and fuel, acoustic, emissions, engine geometry, length, weight and quality measures

Big benefit comes from a system solution optimization

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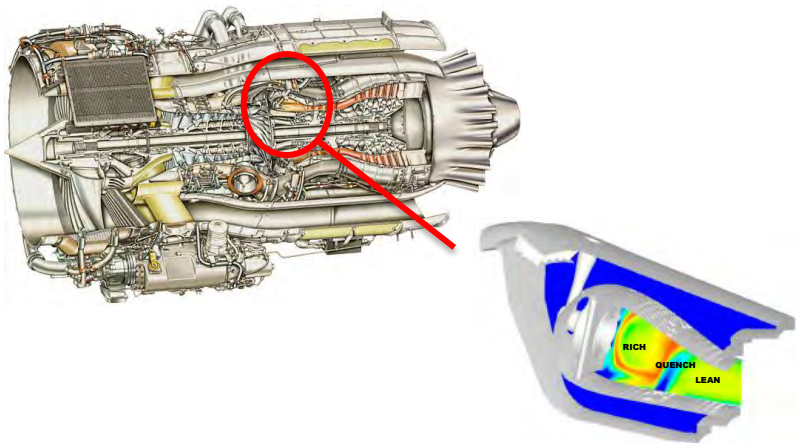
Systems Engineering – Technology Assessments

- **Gulfstream Aerospace Corporation**
  - Perform Quantitative assessment of fuel burn for engine/aircraft integration
  - Perform assessment updates as program technologies mature in CLEEN II
- **Georgia Institute of Technology**
  - Provide independent assessment
  - Perform Fleet-wide impact assessment

SABER Compact Combustor



Benefits

- Fuel burn reduction
- NOx emissions reduction

Risks/Mitigations

• Operability	Rig altitude relight tests
• Achieving NOx goal	NASA rig test
• Combustor life	Rig and engine tests

Objectives

- NOx emissions reduction
- Reduce weight through innovative design

Work Statement

• Complete Design	(in process)
• Complete Fabrication	(in process)
• NASA Rig test	(future effort)
• Complete Dev Engine Test	(future effort)
• Complete TRL 6 Engine Test	(future effort)

Accomplishments/Milestones Since Program Start

- Completed preliminary rig test design

Schedule

• Complete Design	(5-18)
• Complete Fabrication	(8-19)
• NASA Rig Test	(8-19)
• Complete Dev Engine Test	(10-18)
• Complete TRL 6 Engine Test	(12-19)

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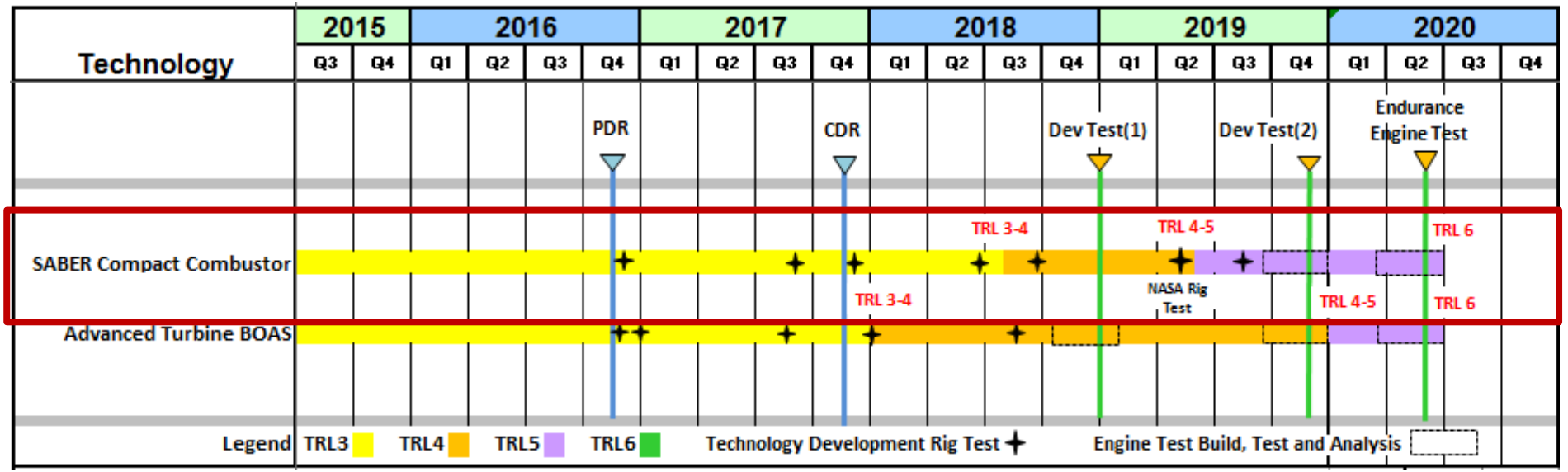
Program Testing – SABER Compact Combustor



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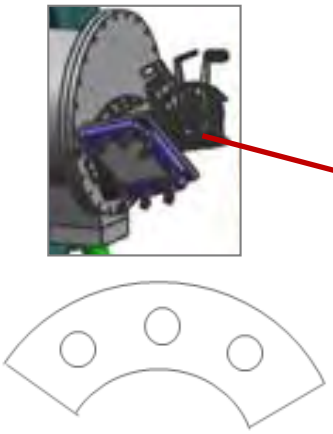
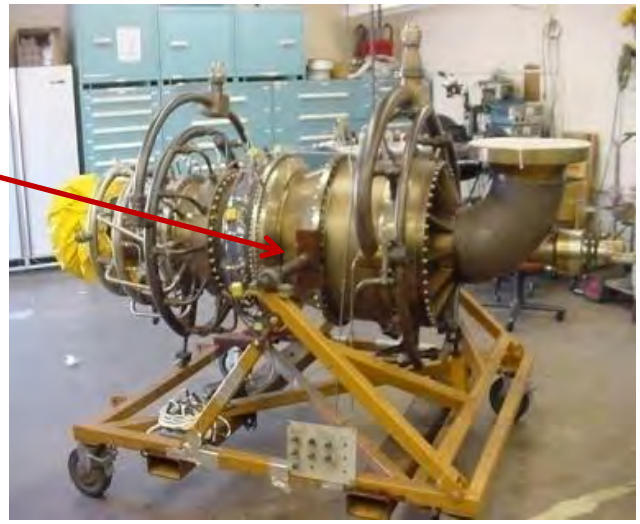
SABER Combustor – Honeywell Rig Tests



Sector Rig



- **Obtain data to correlate predicted results and select sub-system design**
  - CFD analysis and Mechanical design complete
  - Completed selection of initial combustor sub-components to be tested
  - Testing planned for late Q4 2016

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SABER Compact Combustor – NASA Rig Test

QUICK FACTS

Description
The ASCR is a high-pressure, high temperature combustion rig which simulates engine test conditions up to a pressure of 900 PSIG and a temperature of 1300°F non-vitiated (no combustibles) at 50 lb/sec air flow. The facility supports research on multiple fuel injector test hardware for large aircraft engine development, and full scale annular combustor development for regional aircraft engine development.

Name:	Advanced Subsonic Combustion Rig
Inlet Pressure:	150-900 psig
Inlet Temperature:	250° to 1300°F (non-vitiated)
Inlet Airflow:	5 to 50 lb/sec
Exhaust:	atmospheric or altitude
Facility Manager (Acting):	Gwynn.A.Severt@nasa.gov

Source: *http://facilities.grc.nasa.gov/ascr/quick.html*

- Honeywell to test the CLEEN II annular combustor system in the NASA Advanced Subsonic Combustion Rig (ASCR)
- ASCR provides data at relevant combustor engine operating conditions for the CLEEN II cycle.
  - **Validate Combustor Emissions**
  - **Combustor Performance**
  - **Liner Metal temperatures**
- Test planned for Q2 2019

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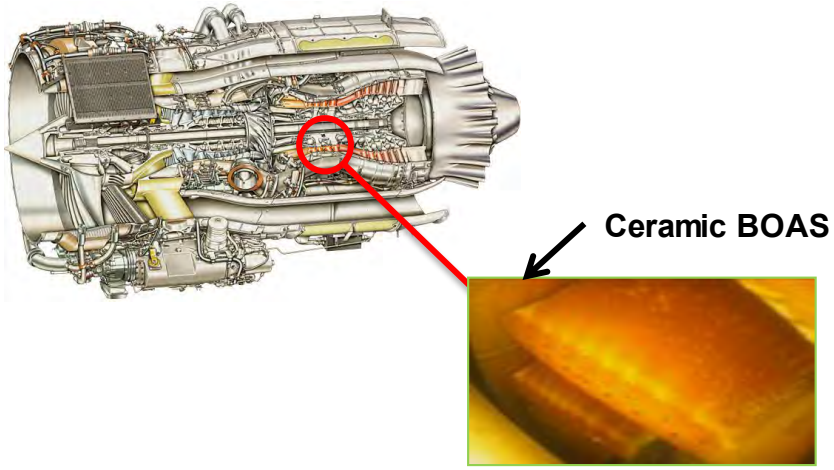
Advanced Turbine BOAS System



Benefits

- Fuel burn reduction

Risks/Mitigations

- Insufficient material durability/rig and engine test
- Insufficient performance/alternate BOAS design

Objectives

- Improve HP turbine efficiency

Work Statement

- Complete Design (in process)
- Complete Fabrication (in process)
- Complete Dev Engine Test (future effort)
- Complete TRL 6 Engine Test (future effort)

Accomplishments/Milestones Since Program Start

- Preliminary sub-element testing underway

Schedule

- Complete Design (9-18)
- Complete Fabrication (12-18)
- Complete Dev Engine Test (10-18)
- Complete TRL 6 Engine Test (12-19)

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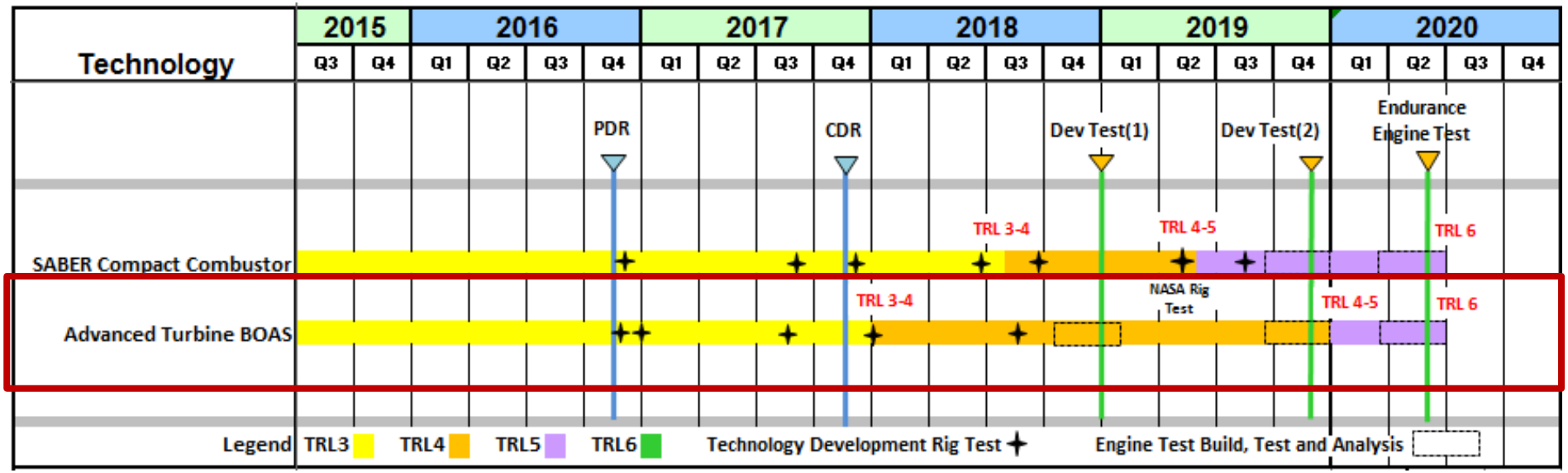
Program Testing – Advanced Turbine BOAS System



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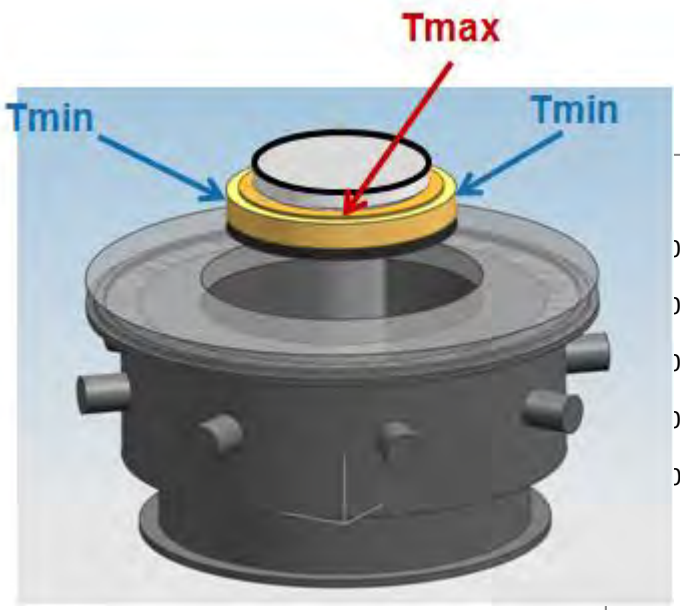
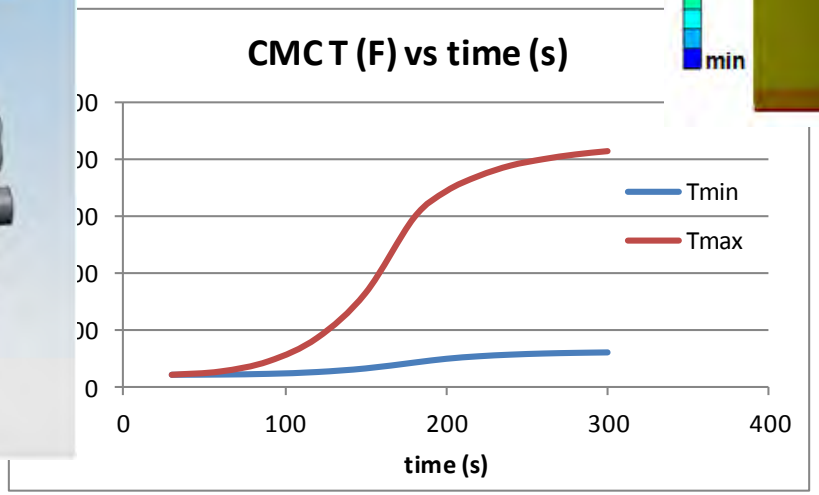
BOAS - Thermal Gradient Rig





Shroud Surface Temperature

- **Obtain data to understand the characteristics and failure modes of CMC under stress induced by a thermal gradient.**
  - Use existing mechanical research rig that was repurposed for thermal mechanical testing.
  - Rig operating conditions and requirements defined
  - Design and analyses complete
  - Test plan complete and Instrumentation requirements defined
  - Initial testing planned for Q4 2016

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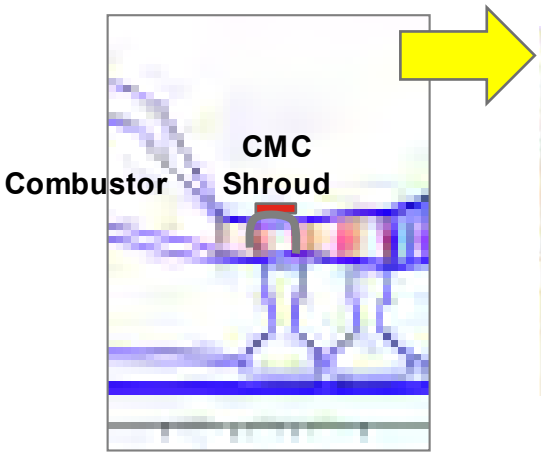
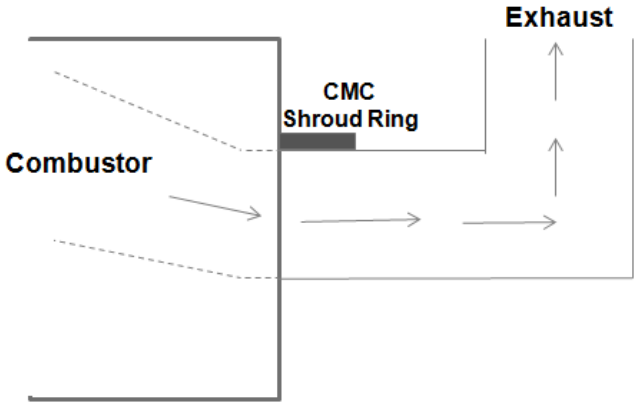
BOAS – CMC/Combustor Rig Test



Engine Configuration

Honeywell Combustor Rig



CMC Shroud / Combustor Rig

- **Obtain data to correlate predicted results for CMC shroud design**
  - Analysis and Mechanical design complete for CMC Shroud
  - Test Rig Concept Design in progress for CLEEN II combustor annular rig tests.
  - Testing planned for Q4 2017

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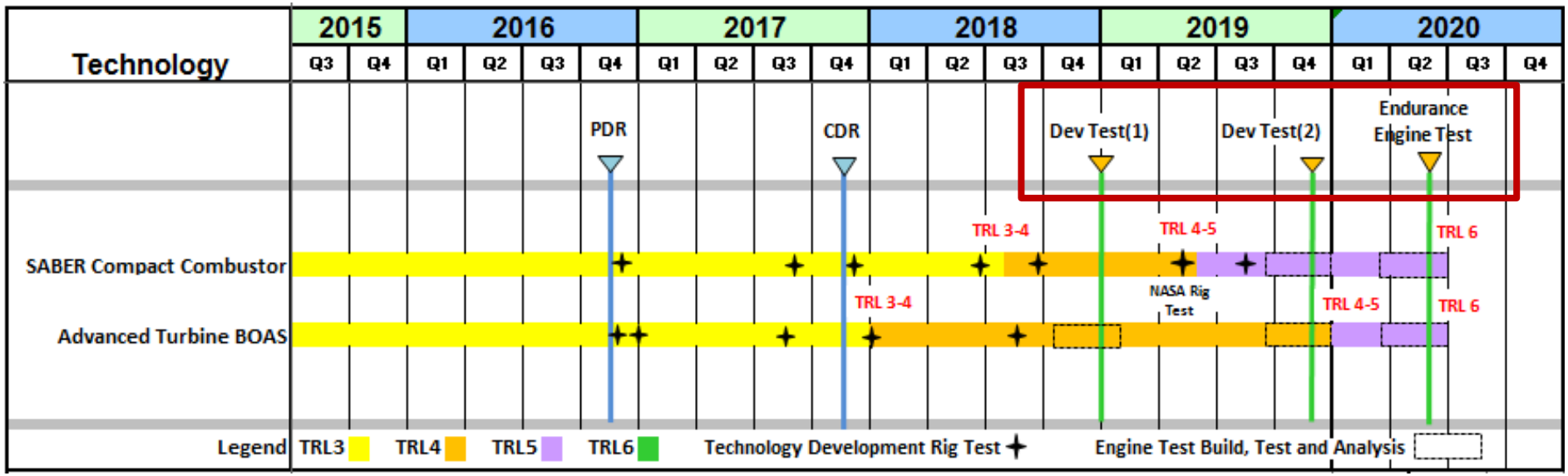
Program Testing – Engine Testing



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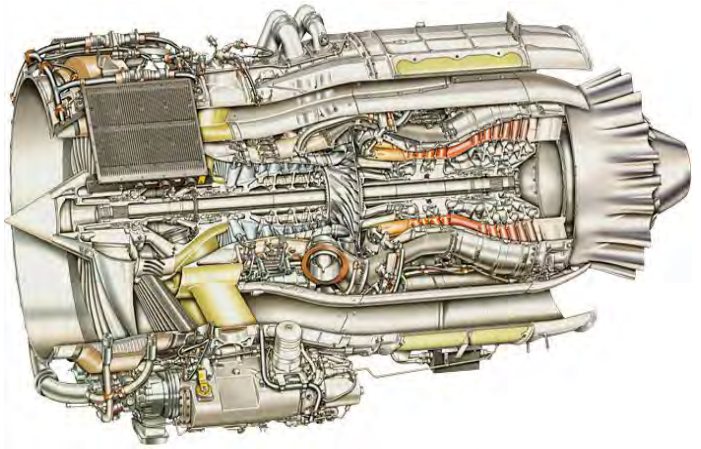
Program Testing – Engine Testing

- **Development Test(1) – Q4 2018**
  - HPT BOAS Technology assessment
- **Development Test(2) - Q4 2019**
  - SABER Compact Combustor liner wall temperature assessment
- **Endurance Engine Test – Q2 2020**
  - Engine Emissions assessment
  - Endurance Engine test to support TRL 6 validation of SABER Compact Combustor and BOAS Technologies



TRL 6
Engine Testing

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Summary

- **The Honeywell CLEEN II program is progressing well to mature the SABER Compact Combustor and the Advanced Turbine BOAS to reduce fuel burn and NOx emissions**
  - **Systems Engineering**
    - Program completed the system PDR and look forward to completing the system DDR in Year 2
  - **BOAS**
    - Preliminary BOAS System Design complete
    - Planning to complete Rig Design, conduct several development tests and down-select the BOAS Material configuration in Year 2
  - **SABER Compact Combustor**
    - Completed Sub-Component Rig Design leading to component rig tests in Year 2
    - Plan to complete NASA Component Rig Hardware Design in Year 2

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