Dan Frias
11/15/17

HONEYWELL CLEEN II

Open Discussion – November 2017

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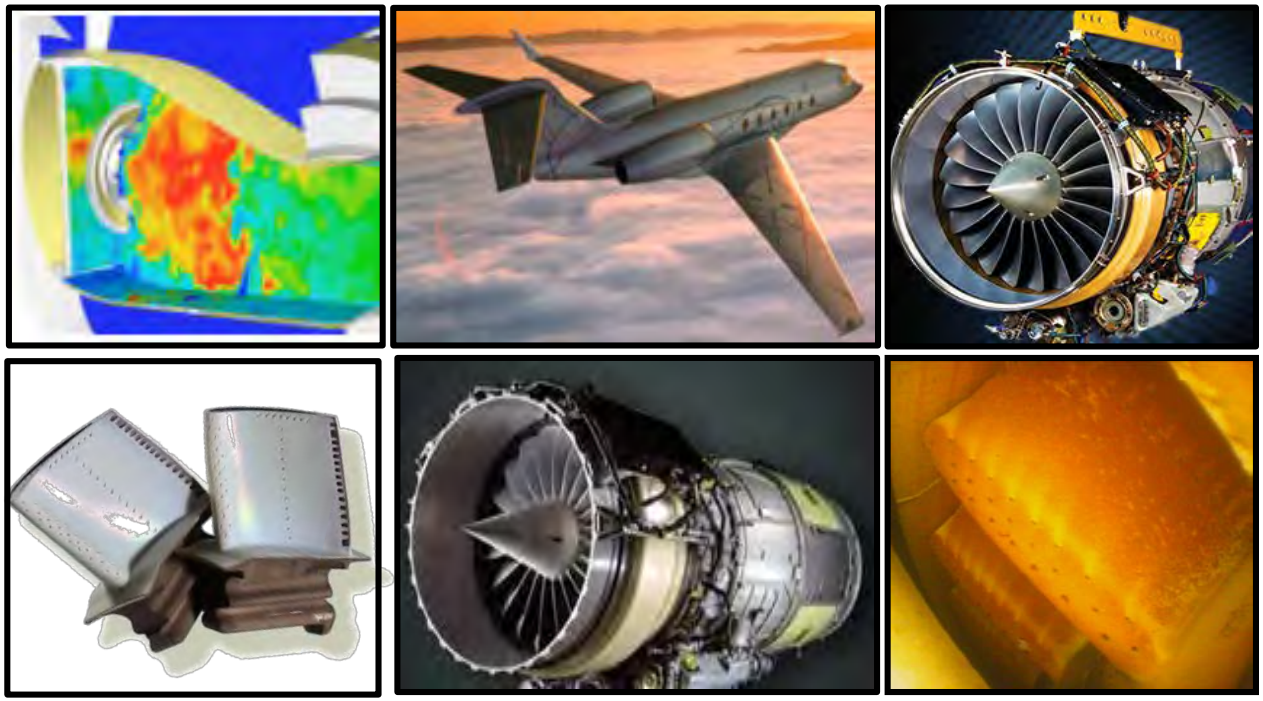
Agenda

- Elevator Speech
- Honeywell's Products and CLEEN II
- CLEEN II Technologies and Challenges
- Technology Maturation Approach
- Program Schedule Status
- Engine and Aircraft Systems Analysis Status
- Technologies Status – Compact Combustor
- Technologies Status – Blade Outer Air Seal (BOAS)
- Engine Validation Plan
- Summary

CLEEN II Elevator Speech

- Honeywell's CLEEN II program is maturing advanced combustor and turbine technologies to reduce weight, fuel burn and NOx emissions



Honeywell's Broad Base of Commercial & Military Turbine Products

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

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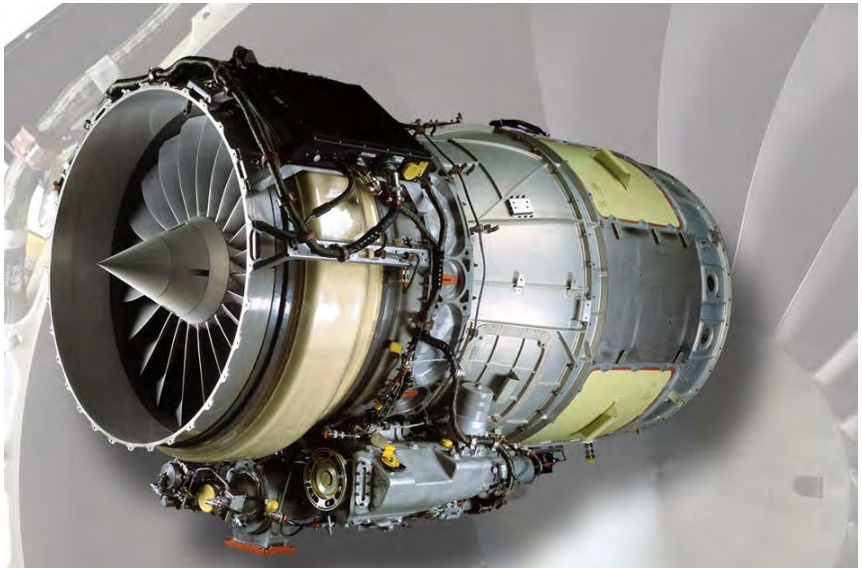
Over 150,000 Turbine Engines Delivered – Large Installed Base

Next Gen HTF Can Benefit from CLEEN Technologies to Reduce Fuel Burn and Emissions



- State-of-the-art performance
- Quantum leap in value: cost and durability
- Versatile technology: 7000-7500 lbs thrust
- Industry leading dispatch reliability
- Five aircraft applications to date
- > 1000 engines in service
- >2 million flight hours

HTF7000 Series

Engine	Platform
HTF7000	Bombardier Challenger 300
HTF7350B	Bombardier Challenger 350
HTF7250G	Gulfstream G280
HTF7500E	Embraer Legacy 450/500
HTF7700L	Citation Longitude

CLEEN Technologies Enhance Future Product Capabilities

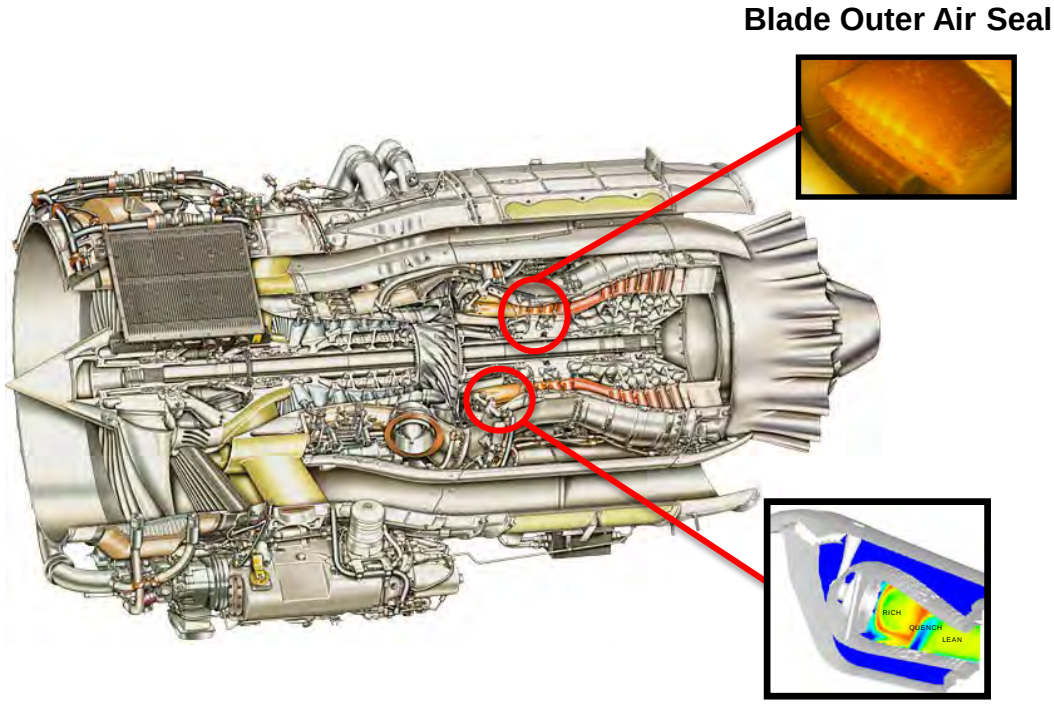
CLEEN II Technology Summary

CLEEN Technology Name	Goal Impact	Benefits and Applications Status
Compact Combustor System	Emissions	• Goal to reduce emissions >50% NOx relative to CAEP/8 • Application to Super mid-sized class business jet for turbofan for 2025 entry into service (EIS)
Advanced Turbine Blade Outer Air Seal (BOAS) System Compact Combustor	Fuel burn	• Goal to reduce overall engine fuel burn >22% relative to the Baseline Engine • Applicable to turbofan, turboshaft, turboprop engines, and to large auxiliary power units (APUs) for 2025 EIS

- **CLEEN Value:**
  - **Fuel Burn** – CLEEN enables >22% fuel burn improvement over baseline engine through an advanced engine architecture with high efficiency turbine technologies
  - **Emissions** – CLEEN enables >2x NOx margin improvement over combustor state-of-the-art through advanced combustor aerodynamic design, materials selection and fuel control

Honeywell CLEEN II Technologies

- Honeywell is developing and demonstrating two technologies under CLEEN II – Compact, low emissions combustor and an advanced turbine BOAS.



The advanced ***Turbine BOAS*** increases high pressure turbine efficiency, resulting in reduced fuel burn.

The low emission ***Compact Combustor*** uses advanced aerodynamics and fuel injection technologies to reduce engine NO_X emissions while reducing weight, and thereby reducing fuel burn.

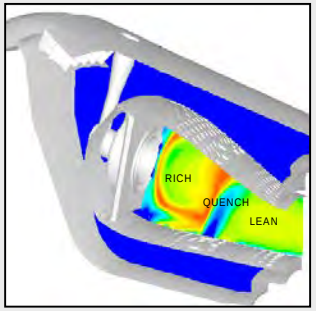
Honeywell CLEEN II Technology Challenges

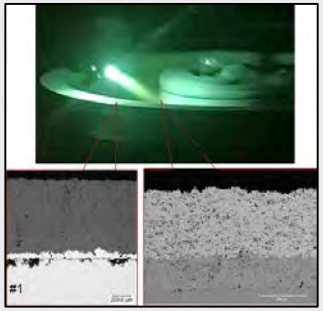
CLEEN Technology	Technical Challenge	Technical Approach
Compact Combustor System	NOx	Optimized Primary Zone Aerodynamics, fuel placement, reduced residence time. Validate at full engine conditions.
	Operability	Improved atomization and fuel placement. Validate at altitude relight conditions in test rig.
Advanced Turbine BOAS System	High Temperature and Weight	Selection of advanced light weight, high temperature materials and coatings.
	Leakage	Minimize part count in system design and advanced turbine blade tip design for improved turbine efficiency.

Technology Maturation Approach

2015 2016 2017 2018 2019 2020

TRL 3 TRL 4 TRL 5 TRL 6





Analysis and Technology Demonstration Testing

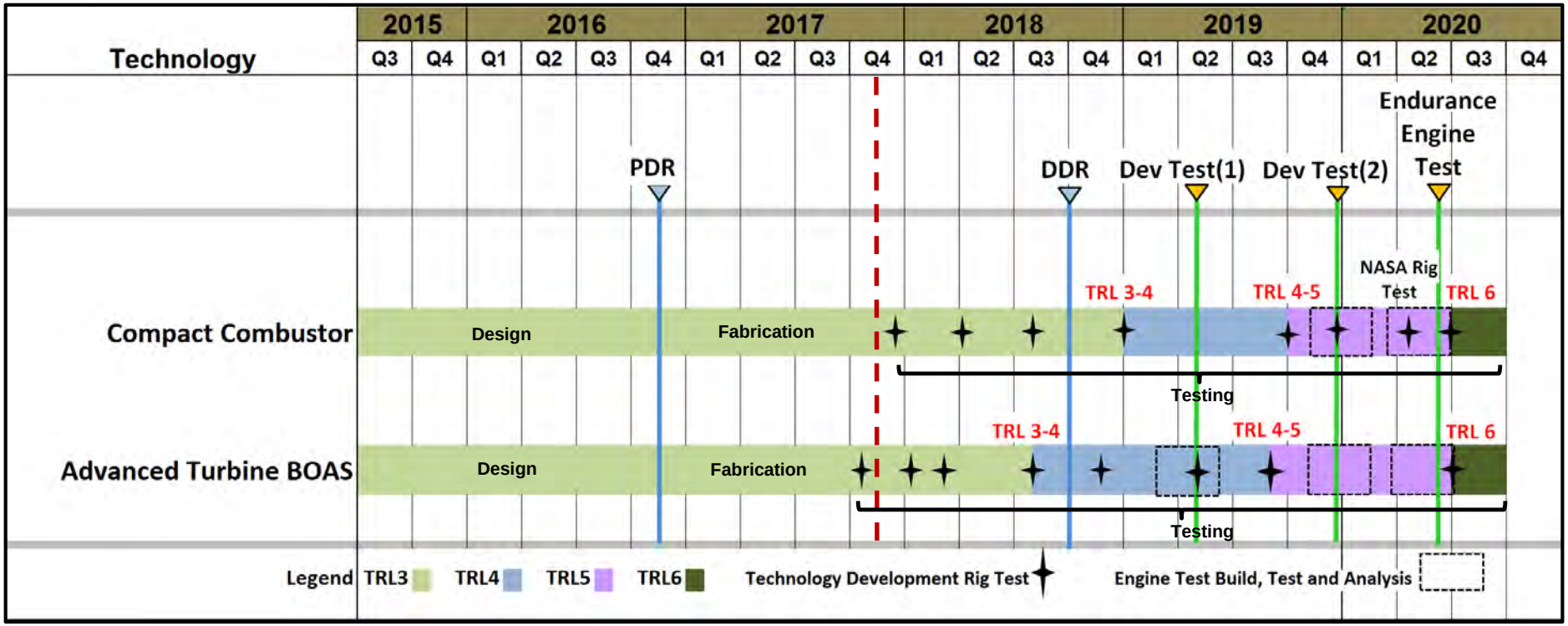
Component / System Development Testing

Engine Validation Testing

Nov 2017 Status

A Systematic Approach Toward Reducing Risk

Program Schedule



TRL = Technology Readiness Level

Program Accomplishments

- **Year 1**
  - Program Kickoff and Task Plan Complete
  - System Level Risk Assessment Complete
  - Compact Combustor, BOAS & Engine System PDRs Complete
  - Submitted all Monthly Reports and Participated in Year 1 Consortium

- **Year 2**
  - BOAS Shroud Preliminary Design Review Complete
  - BOAS Material Characterization Testing Underway
  - BOAS TBC Process Optimization Complete
  - Combustor Design Preliminary Testing Underway
  - Submitted all Monthly Reports and Participated in Year 2 Consortium

CLEEN II Preliminary Designs Complete

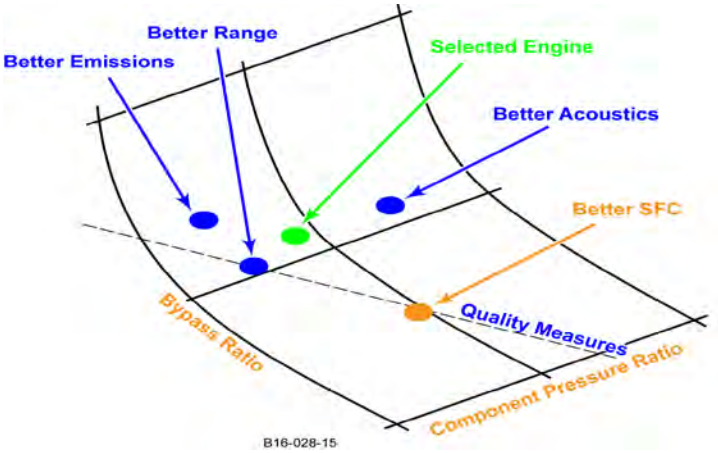
Future Plans

- **Year 3 Plans**
  - Complete Engine Concept Detailed Design Review
  - Finalize BOAS Shroud Design
  - Procure Hardware for Engine Testing
  - Complete BOAS Material Characterization Testing
  - BOAS TBC Complete TRL 4 Testing
  - Complete Combustor Tech Demo Testing
  - Complete NASA Rig Hardware Design
  - Submit all Monthly Reports and Participate in Year 3 Consortiums

CLEEN II Technologies Complete TRL 4 Testing in Year 3

Engine and Aircraft Systems Analysis Status

Engine and Aircraft Systems Analysis



Benefits

- Reduced engine thrust specific fuel consumption (TSFC)
- Improved power-to-weight ratio
- Reduced 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 NOx emissions.

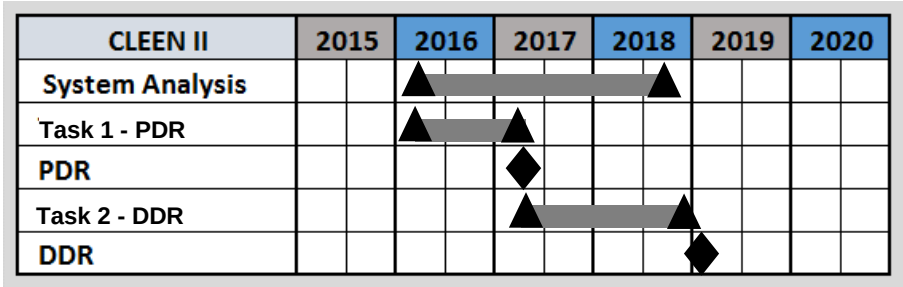
Work Statement

- Perform Engine Preliminary and Detail Engine Concept Reviews along with independent assessments of the technology benefits.

Accomplishments/Milestones

- Preliminary Engine Concept Design Review Complete
- Preliminary Gulfstream Assessment Complete

Technology Schedule



Engine and Aircraft Systems Analysis Accomplishments and Next Steps

Accomplishments

- Completed first iteration of Gulfstream quantitative assessment of fuel burn for engine/aircraft integration
- Continuing work with Georgia Tech to perform independent assessment of fleet-wide impact

Next Steps

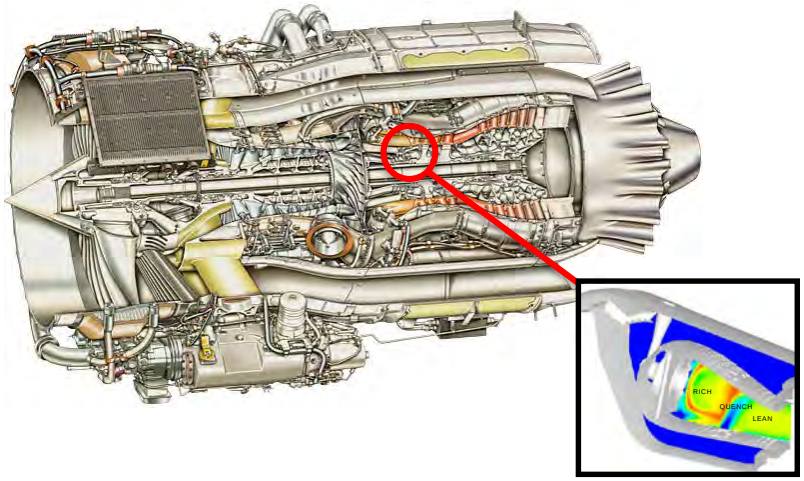
- Continue Concept Engine Detailed Design Effort
- Work with Gulfstream on second iteration assessment
- Finalize assessment plan with Georgia Tech

Systems Analysis Progressing Well to DDR in 2018

CLEEN II Technologies Status

Compact Combustor

Combustor System Technology



Benefits

- Reduction in fuel burn
- Lower engine emissions

Risks/Mitigations

- Operability - Rig test validation at Altitude cond.
- Emissions - Test validation at full engine cycle operating conditions in NASA facility
- Combustor Durability - Demo Engine cyclic test

Objectives

- Reduce NOx emissions
- Reduce combustor weight

Work Statement

- Develop and demonstrate a low emission compact combustor for improved NOx and fuel burn in a an engine.

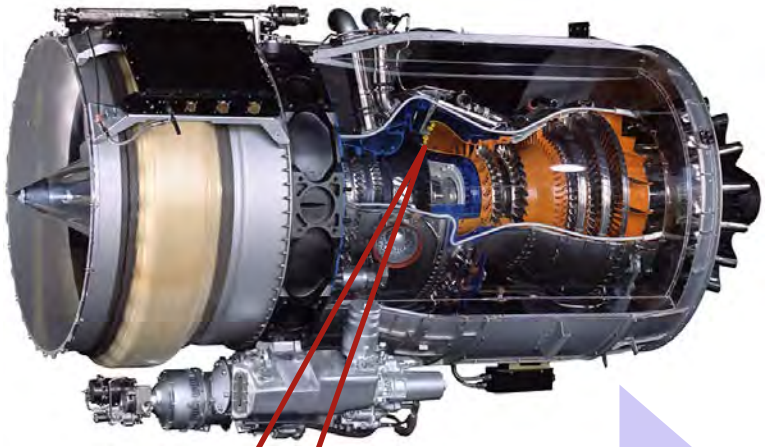
Accomplishments/Milestones

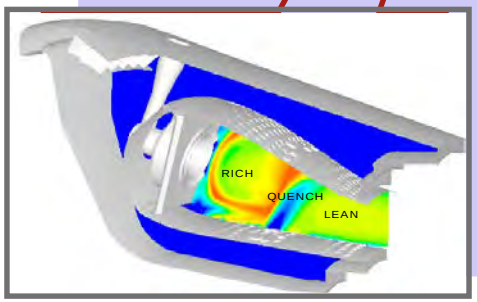
- Completed Preliminary Rig Design
- Tech Demo Combustor Rig Testing is underway

Technology Schedule

Compact Combustor	2015	2016	2017	2018	2019	2020
Technology Demo		▲		▲		
Comb System Devel			▲		▲	
Dev Engine Tests				▲		▲
NASA Rig Testing						◆
Engine Test (TRL 6)						◆

Compact Combustor Technology



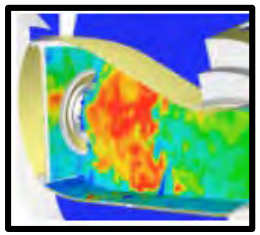


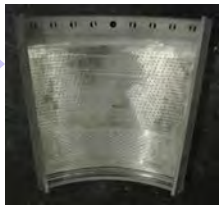
Compact Combustor

is an advanced combustor design that integrates state-of-the art aerodynamic design, advanced material selection & coatings and improved fuel control

Compact Combustor Attributes

- Improved aerodynamic design
- Advanced cooling and materials
- Improved durability enabling higher temp cycle to reduce fuel burn
- Reduced weight





Combustor Technology Progressing to TRL 4 in 2018

Compact Combustor Accomplishments

Accomplishments

- Applied advanced computational fluid dynamics (CFD) large eddy simulation (LES) and Honeywell sub-models to design and predict CLEEN II combustor aero-thermal performance, emissions and durability

- Initiated Technology Demonstration testing to refine designs
  - Technology demonstration testing will evaluate fuel ignitor and aerodynamic design features to optimize performance, emissions and wall cooling

- Completed concept definition for Demo Engine combustor system

Preliminary Designs Complete, Testing Underway

Compact Combustor Next Steps

- Complete Technology Demo testing
- Refine design based on learning from analysis and test results

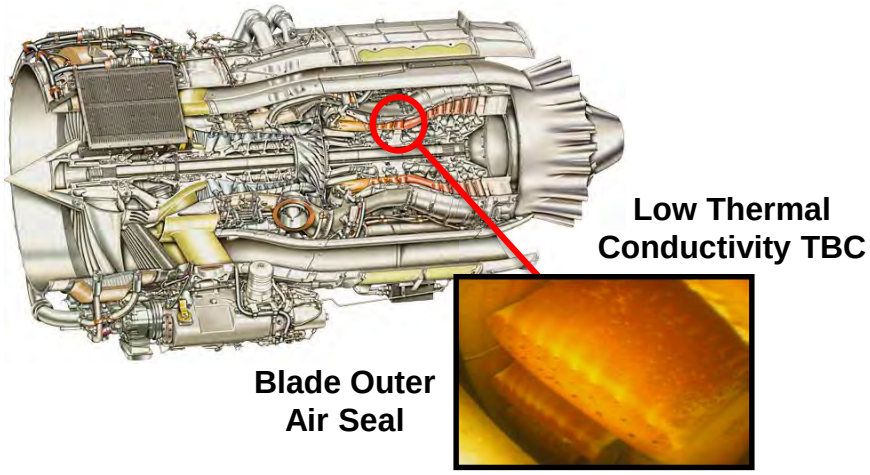
- Complete preliminary design of adaptive rig hardware to support validation testing at NASA test facility

Honeywell Rig Testing

NASA ASCR Testing

Several Compact Combustor Tests Planned in Year 3

Advanced Turbine BOAS System Technology



Benefits

- Fuel burn reduction

Risks/Mitigations

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

Objectives

- Improve High Pressure Turbine (HPT) efficiency

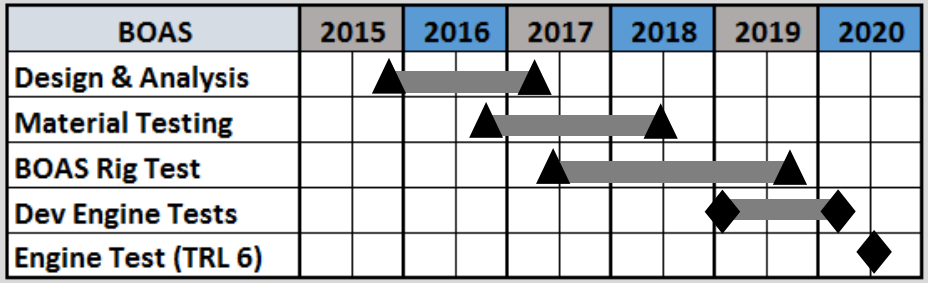
Work Statement

- Develop and demonstrate a BOAS System that improves HPT efficiency in an engine.

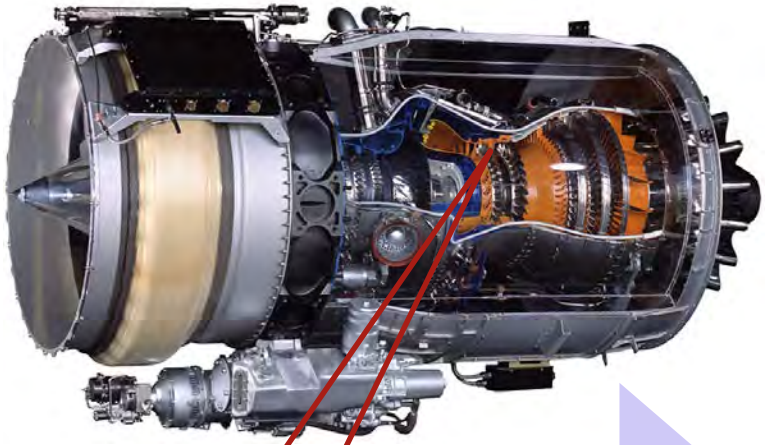
Accomplishments/Milestones

- Preliminary shroud design concepts complete
- Low-k TBC Processing down-selected

Project Schedule



BOAS Technology

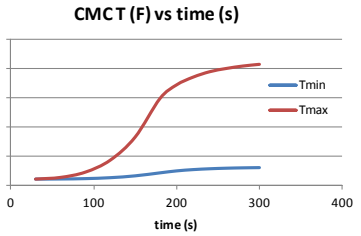


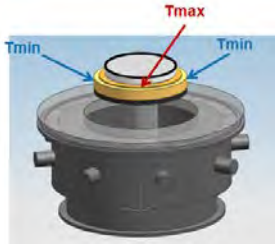
Blade Outer Air Seal

is an advanced turbine system design that addresses blade-to-shroud interaction, high temperature capability and durability.

BOAS Attributes

- Increased Temperature Capability
- Reduced Leakage
- Effective Tip Clearance
- Improved Durability
- Reduced Weight





BOAS Technology Progressing to TRL 4 in 2018

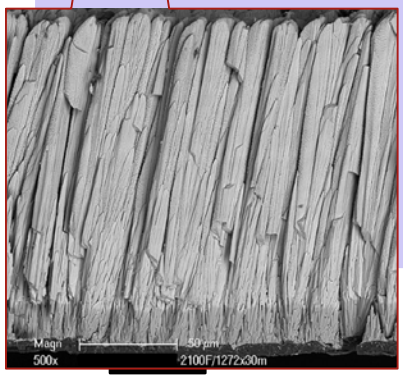
Honeywell's Next Gen EB-PVD TBC Technology

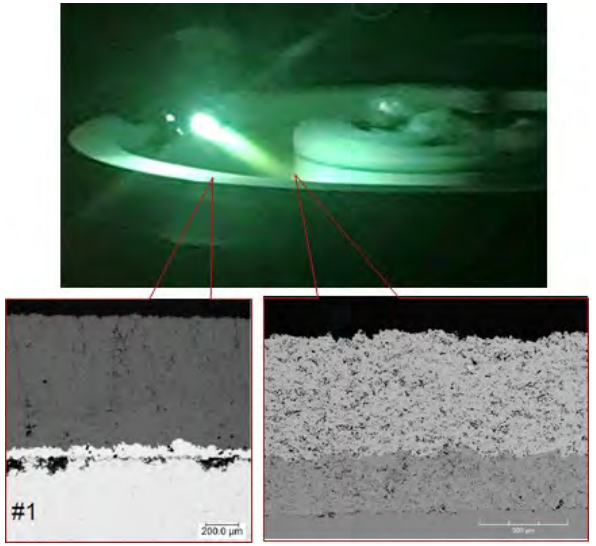
Low-K Thermal Barrier Coating (TBC) Attributes

- 33% Lower conductivity
  - > 2x component rupture life
  - > 4x TBC spallation life
- 3x Higher toughness
- 4x Sintering resistance
- Phase stable above 2,800°F
- EB-PVD validated in CLEEN I
- Air plasma spray (APS) validation in CLEEN II

Lower Thermal Conductivity TBC

is a protective ceramic coating applied to the external surface of an air-cooled turbine airfoils insulate the component, and inhibit oxidation and hot corrosion





Air Plasma Spray Technology Progressing to TRL 4 in 2017

Advanced BOAS System Accomplishments

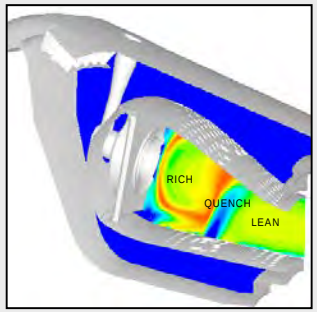
- **Shroud**
  - Material Mechanical Testing is nearing completion
  - Shroud concept progressing well based on initial analyses and preliminary material characterization data
  - Material Thermal Characterization testing well underway

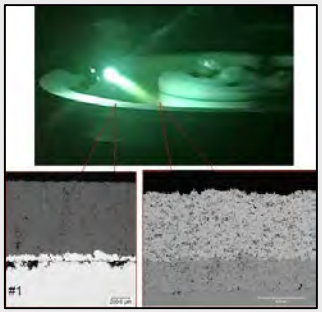
- **Low-K TBC**
  - Identified most promising processing route for low-K TBC
  - Developed viable coating systems
  - Preliminary durability testing to down-select coating system underway

BOAS to Achieve TRL 4 in Q2 2018

Technology Maturation Approach to Engine Validation

TRL 3





Analysis and Technology Demonstration Testing

TRL 4

Component/System Development Testing

TRL 5

TRL 6

Engine Validation Testing

A Systematic Approach Toward Reducing Risk

Program Testing – Planned Engine Testing

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

TRL 6
Engine Testing

Summary

- **Honeywell CLEEN II program is progressing well to mature the Compact Combustor and the Advanced Turbine BOAS to reduce fuel burn and NOx emissions**
  - **Engines and Aircraft Systems Analysis**
    - Completed Preliminary Engine Concept Design Review
    - Preliminary Gulfstream Assessment Complete
  - **Compact Combustor**
    - Completed Preliminary Rig Design
    - Preliminary Combustor Rig Testing is underway
    - Continue design of NASA combustor rig test configuration
  - **Turbine BOAS**
    - Preliminary shroud design concepts complete
    - Low-k TBC processing down-selected

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