

HONEYWELL CLEEN II

CONSORTIUM PRESENTATION – OPEN DISCUSSION

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PROGRAM MANAGER

MAY 2020

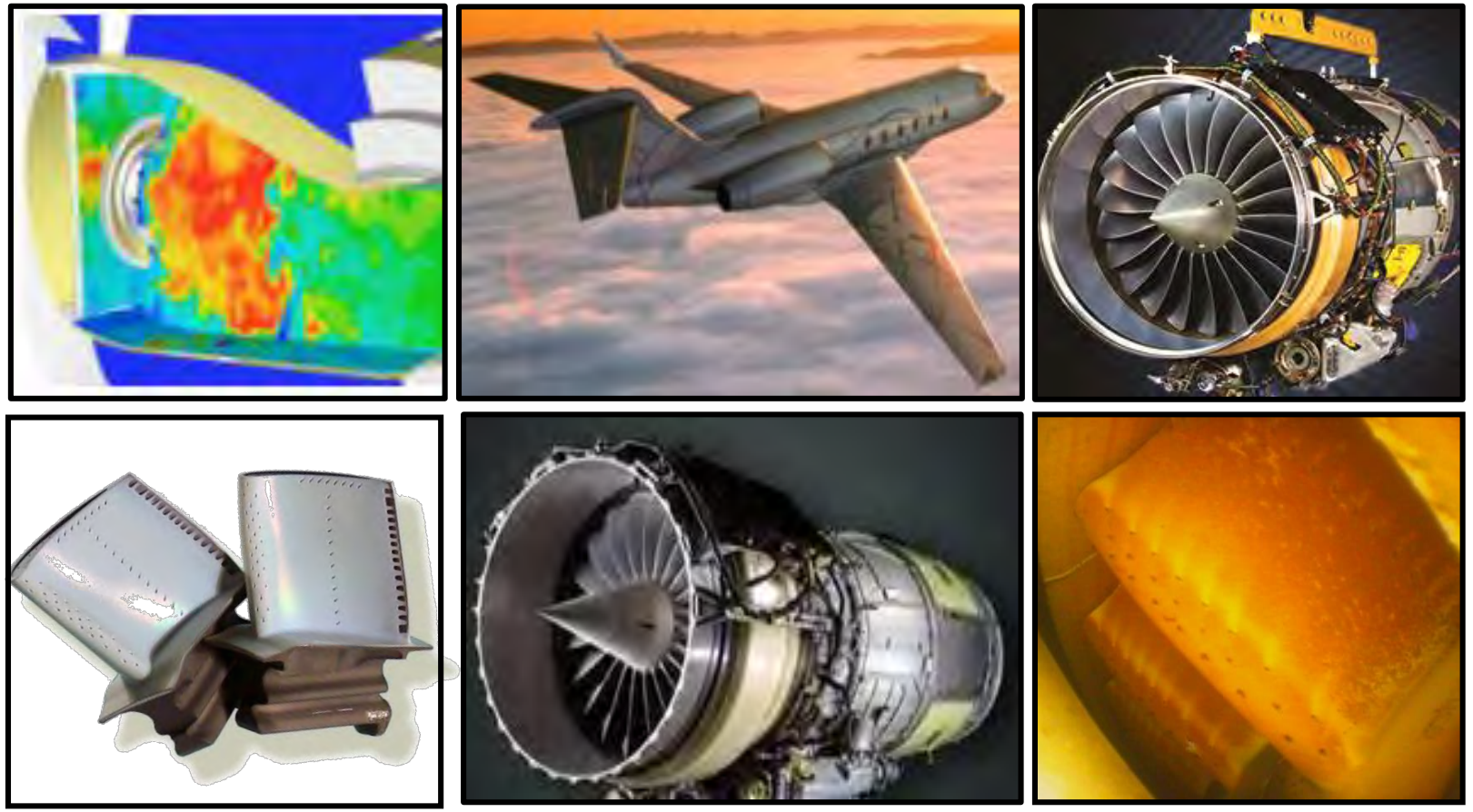
Honeywell

AGENDA

1. Elevator Speech
2. Honeywell's Products and CLEEN II
3. CLEEN II Technologies
4. Technology Maturation Approach and Program Schedule
5. Engine and Aircraft Systems Analysis Status
6. Technologies Status – Compact Combustor
7. Technologies Status – Blade Outer Air Seal (BOAS)
8. Future Plans
9. Summary

CLEEN II PROGRAM TECHNOLOGIES

Elevator Speech: Honeywell's CLEEN II program is maturing *advanced turbine and combustor technologies* to reduce weight for improved fuel burn and reduced emissions



NEXT GENERATION TURBOFAN CAN BENEFIT FROM CLEEN TECHNOLOGIES TO REDUCE FUEL BURN AND EMISSIONS

- State-of-the-art (SOA) performance
- Industry leading dispatch reliability
- Quantum leap in value: cost and durability
- Versatile technology: 7000-10000 lbs thrust
- Five aircraft applications to date
  - > 2000 engines in service
  - > 5 million flight hours

HTF7000 Series

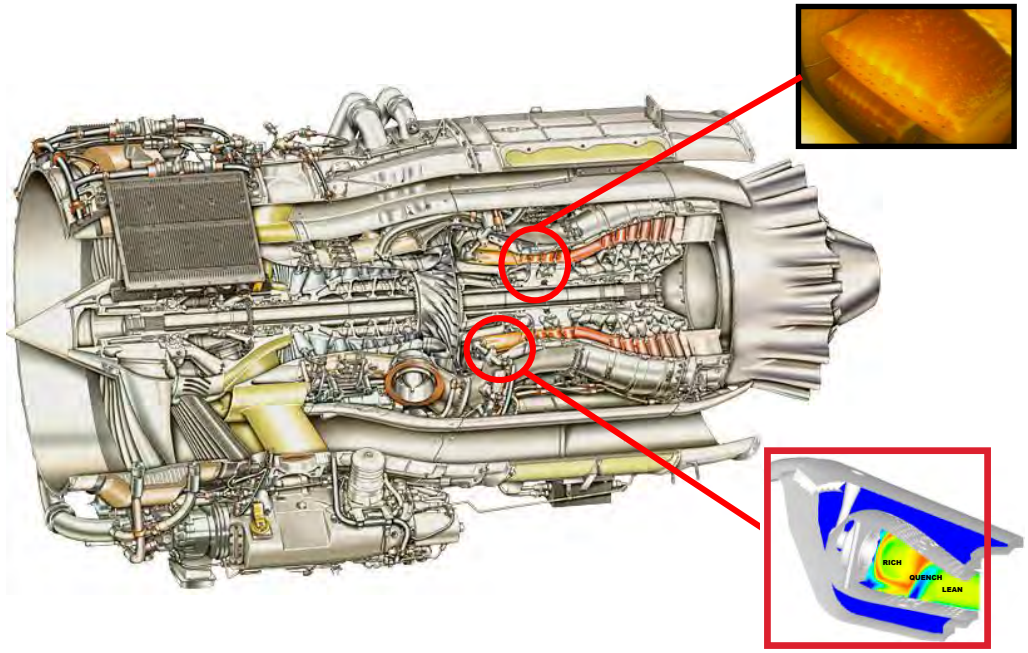
Engine	Platform
HTF7000	Bombardier Challenger 300
HTF7350B	Bombardier Challenger 350
HTF7250G	Gulfstream G280
HTF7500E	Embraer Legacy 450/500 Embraer Praetor 500/600
HTF7700L	Cessna Citation Longitude

CLEEN Technologies Enhance Future Product Capabilities

HONEYWELL CLEEN II TECHNOLOGIES

Under CLEEN II Honeywell is developing and demonstrating advanced Combustor and Turbine technologies

Blade Outer Air Seal



Compact Combustor

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

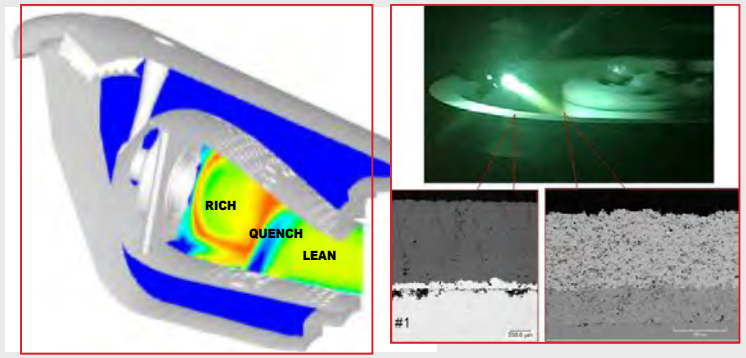
Compact Low Emissions Combustor integrates advanced aerodynamics and fuel injection technologies to reduce engine NO_X emissions and weight, contributing to reducing fuel burn.

CLEEN II TECHNOLOGY SUMMARY

CLEEN Technology Name	Goal Impact	Benefits, Applications and Collateral Benefits
Compact Combustor System	**Emissions**	• **Goal** - Reduce NOx emissions to >50% margin (CAEP/8), for next generation super mid-sized class business jet turbofan engines for 2025 entry into service (EIS)
Advanced Turbine BOAS System **Compact Combustor**	**Fuel Burn**	• **Goal** - Enable turbofan engine fuel burn reduction >22% relative to the baseline engine for next generation turbofan, turboshaft, turboprop engines for 2025 EIS **Collateral Benefits** • FAA CLEEN programs support validation of Low-k thermal barrier coating (TBC) and Alloy 10 powder metal super-alloy • Low-k TBC currently being evaluated by major aerospace and industrial engine original equipment manufacturer (OEMs) • Applied to current and future turbine propulsion and industrial engines should increase fuel efficiency and lower operating costs

TECHNOLOGY MATURATION APPROACH

TRL 3 → TRL 4 → TRL 5 → TRL 6



Analysis and Technology Demonstration Testing

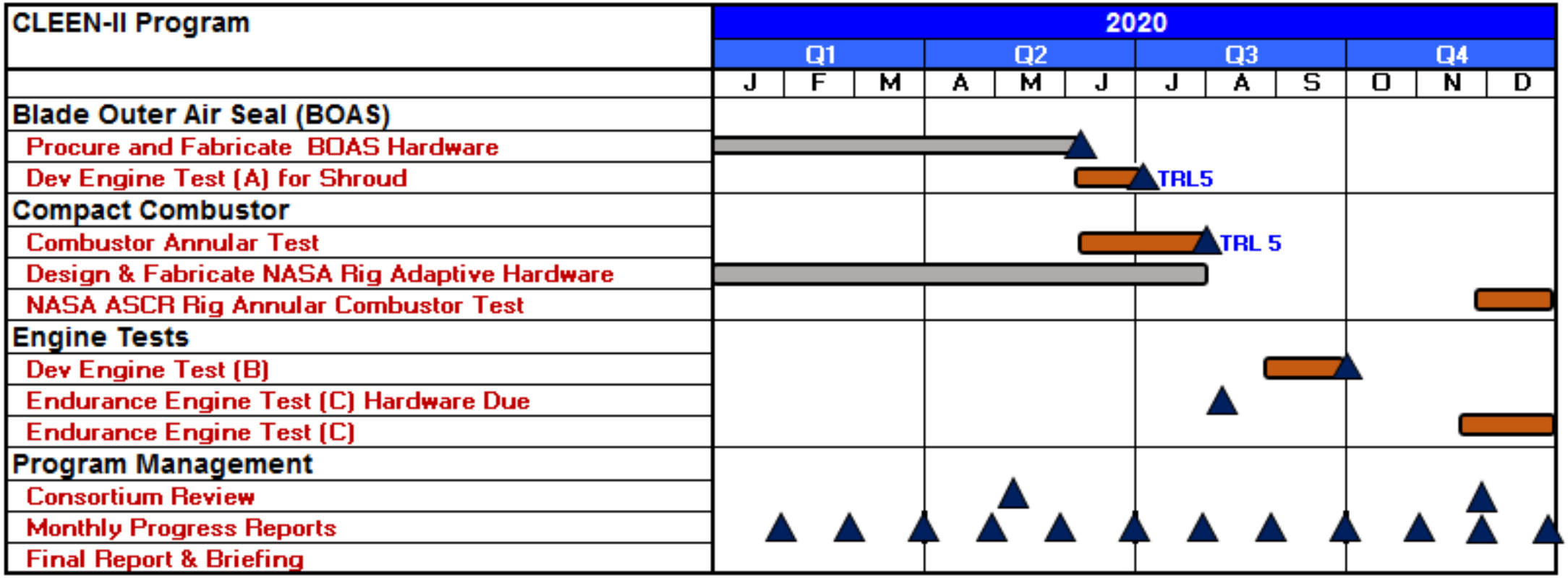
Component / System Development Testing

Engine Demonstration and Validation Testing

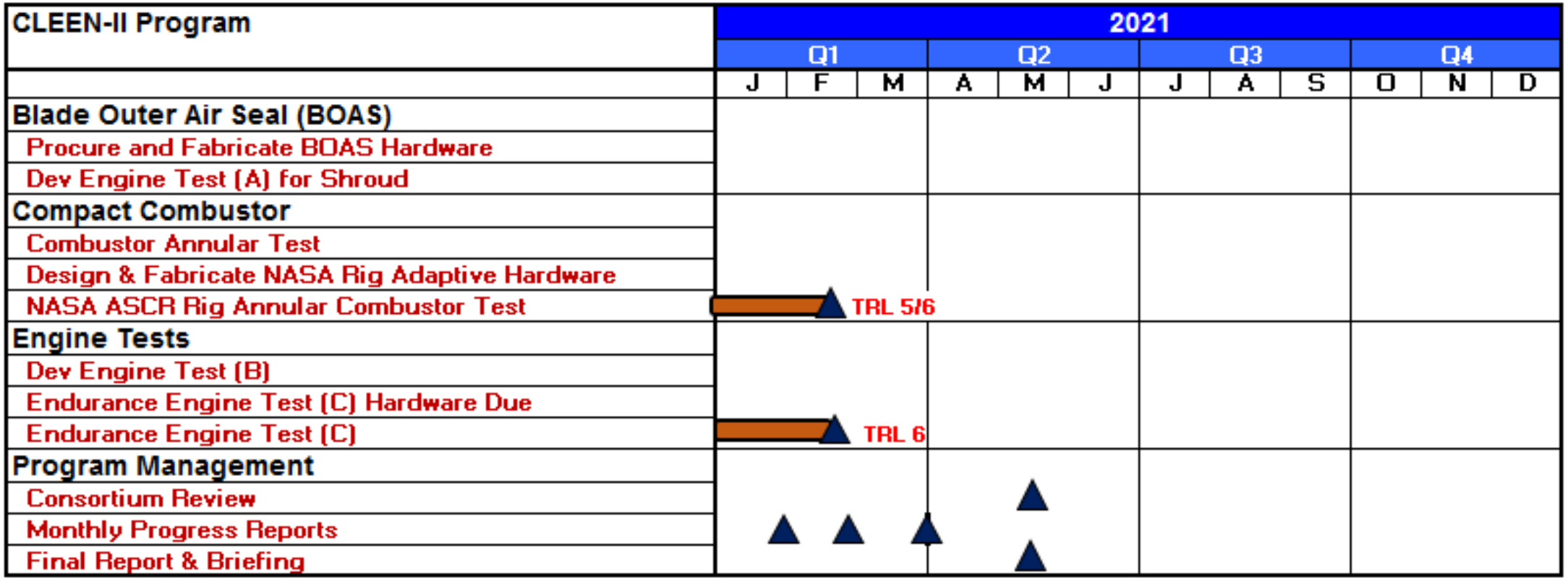
May 2020 Status

Progressive Approach to Validate Technology and Reduce Risk

2020 PROGRAM SCHEDULE



2021 PROGRAM SCHEDULE

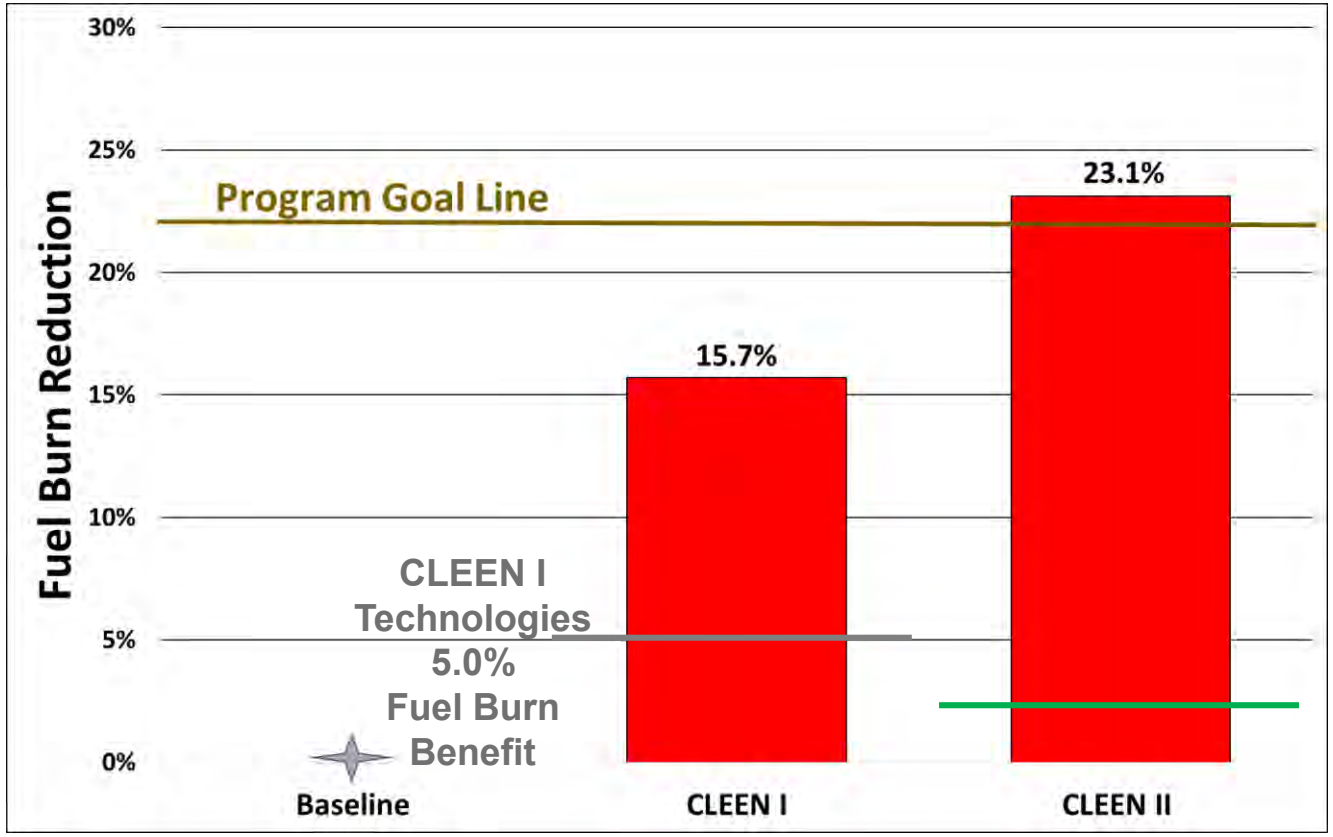


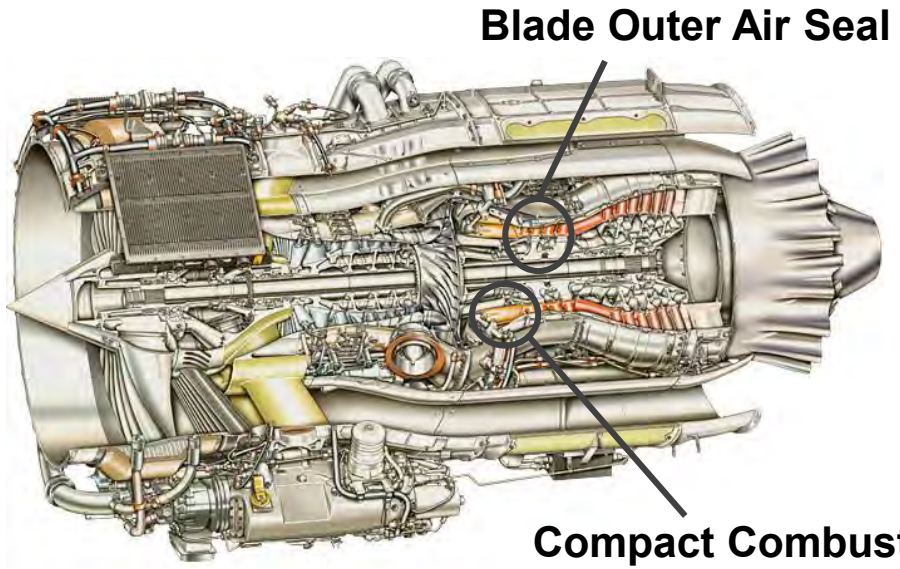
ENGINE AND AIRCRAFT SYSTEMS ANALYSIS STATUS

CLEEN II AIRCRAFT FUEL BENEFITS

CLEEN II aircraft mission fuel burn reduction goal of 22% from baseline engine

Fuel burn reduction includes CLEEN and Honeywell technologies

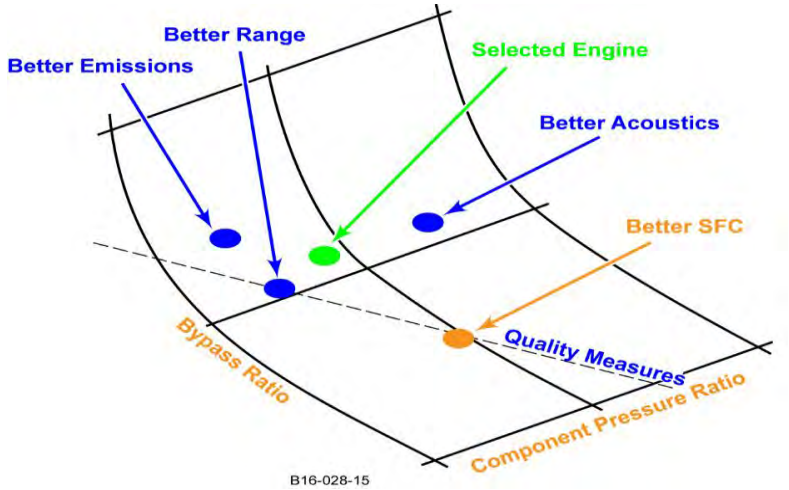




CLEEN II - Technologies
2.1% Fuel Burn Benefit

CLEEN II Continues to Contribute to Fuel Burn Reduction

ENGINE AND AIRCRAFT SYSTEMS ANALYSIS



Benefits

- Improved power-to-weight ratio
- Reduced engine thrust specific fuel consumption (TSFC)
- Reduced fuel burn

Risks/Mitigations

- Insufficient aircraft fuel burn assessment/risk mitigation BOAS design in place

Objectives

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

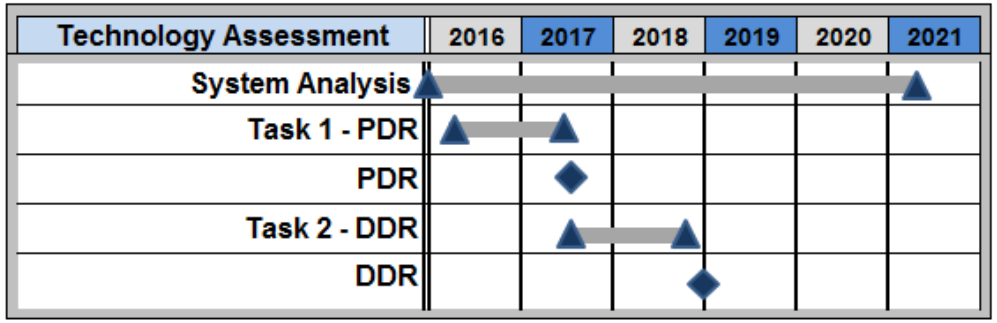
Work Statement

- Perform engine preliminary and detail engine concept reviews along with independent assessments of the technology benefits

Accomplishments/Milestones

- Engine Detail Design Review complete
- Gulfstream assessment complete
- Georgia Tech Technology Assessment in 2020/2021

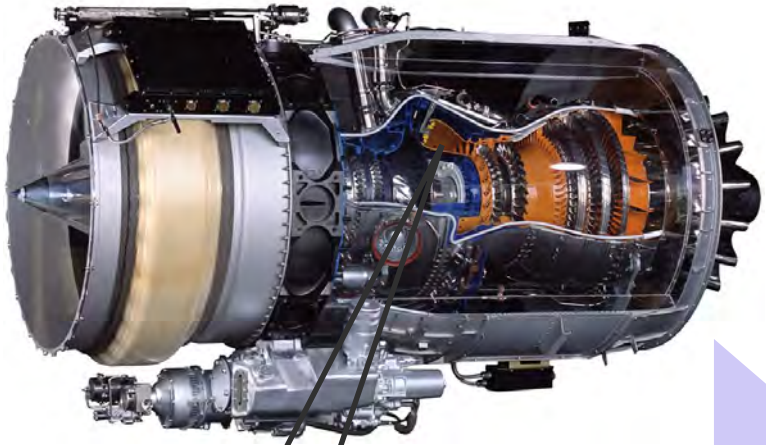
Technology Schedule

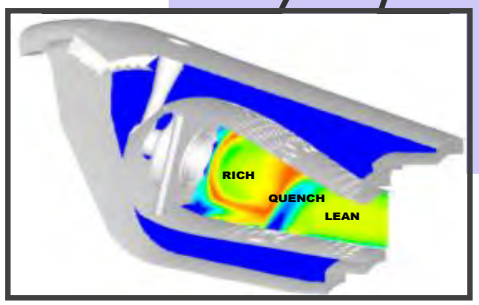


CLEEN II TECHNOLOGIES STATUS
COMPACT COMBUSTOR

Honeywell

COMPACT COMBUSTOR TECHNOLOGY



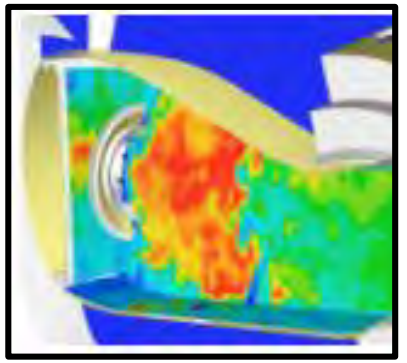


Compact Combustor

is an advanced combustor design that integrates SOA aerodynamic design, advanced material selection and coatings and improved fuel control.

Compact Combustor Attributes

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



Combustor Technology Goal is to Reduce both NOx and nvPM Emissions

COMPACT COMBUSTOR ACCOMPLISHMENTS

Combustor technology has demonstrated progress in reducing NOx and nvPM emissions while meeting operability and durability requirements

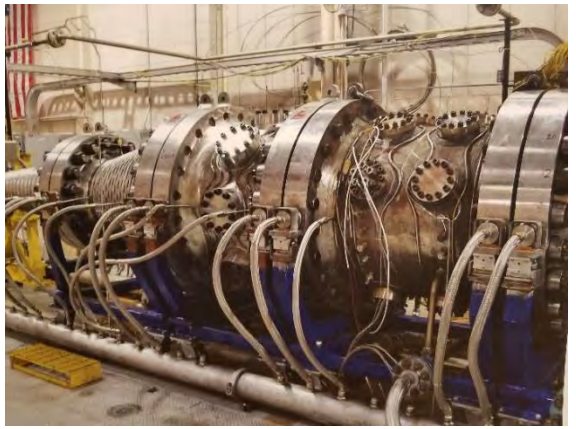
Refined CLEEN II combustor system design through analytical analysis and annular combustor rig testing in the Phoenix Combustor Test Laboratory. Preparing to run final combustor rig test in Q2/Q3-2020.

The CLEEN-II combustor system will be demonstrated in a Honeywell engine endurance test.

In parallel an identical CLEEN-II annular combustor will be tested in the NASA Glenn Advanced Subsonic Combustor Rig (ASCR) at relevant high pressure and temperature engine conditions to validate emissions and other key combustor performance parameters.

COMPACT COMBUSTOR NEXT STEPS

- Complete technology demonstration rig testing
- Complete fabrication and build of NASA test rig
- Complete Honeywell engine validation testing
- Complete NASA ASCR rig test

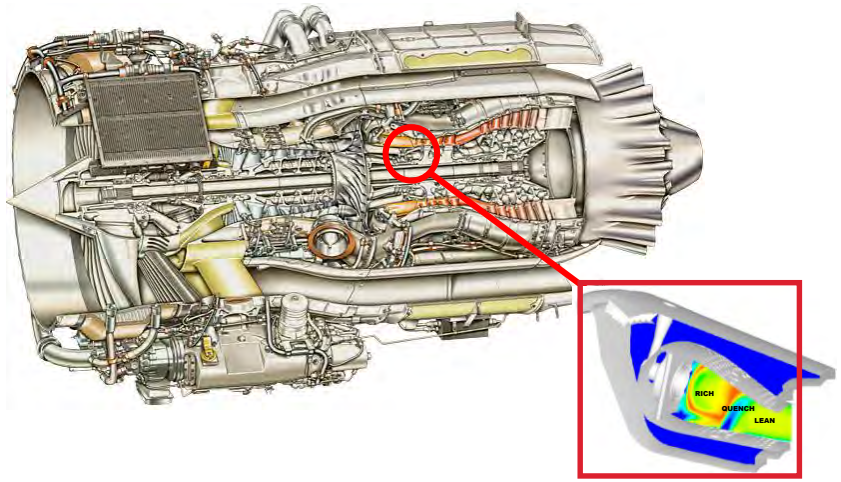


NASA ASCR Facility

Honeywell Engine Testing

Technology Maturation Plan to Demonstrate TRL 6

COMBUSTOR SYSTEM TECHNOLOGY



Benefits

- Lower engine emissions
- Reduction in fuel burn

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

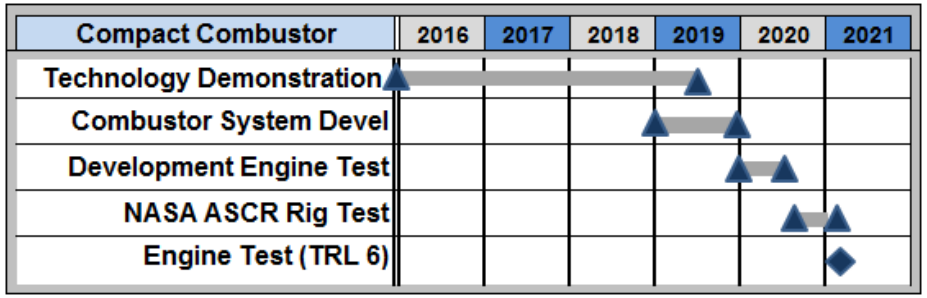
Work Statement

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

Accomplishments/Milestones

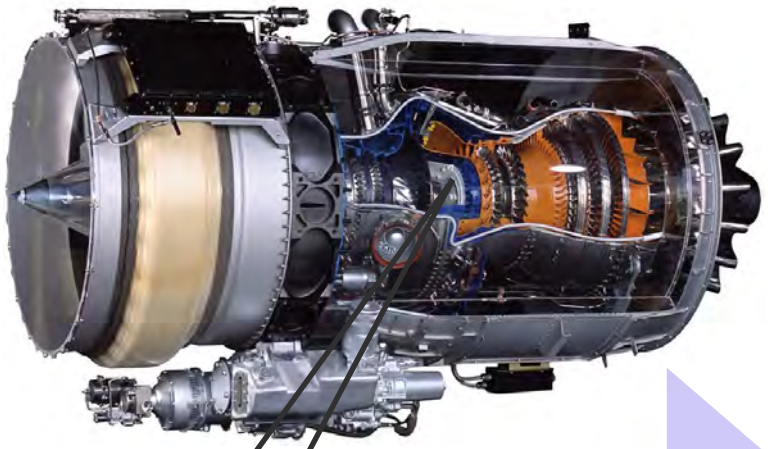
- Completed Compact Combustor design iteration
- Rig testing annular combustor technologies and full system
- Fabricating CLEEN-II NASA combustor rig hardware for testing in NASA ASCR facility in late 2020

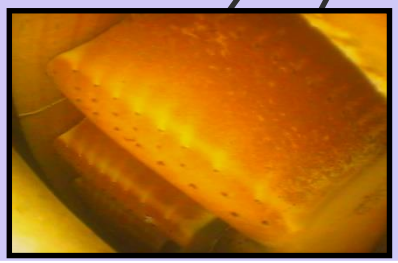
Technology Schedule



CLEEN II TECHNOLOGIES STATUS
BLADE OUTER AIR SEAL (BOAS)

BLADE OUTER AIR SEAL (BOAS) TECHNOLOGY



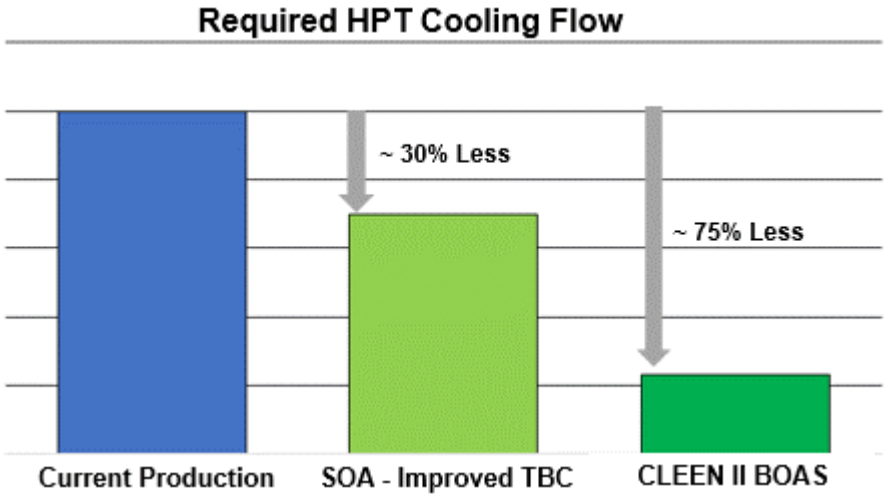


Blade Outer Air Seal

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

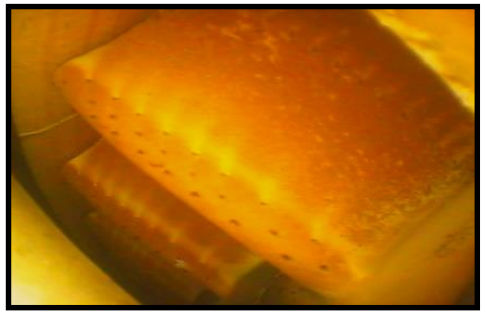


BOAS Technology to Reduce Turbofan Engine Fuel Burn 2.1%

ADVANCED BOAS SYSTEM ACCOMPLISHMENTS

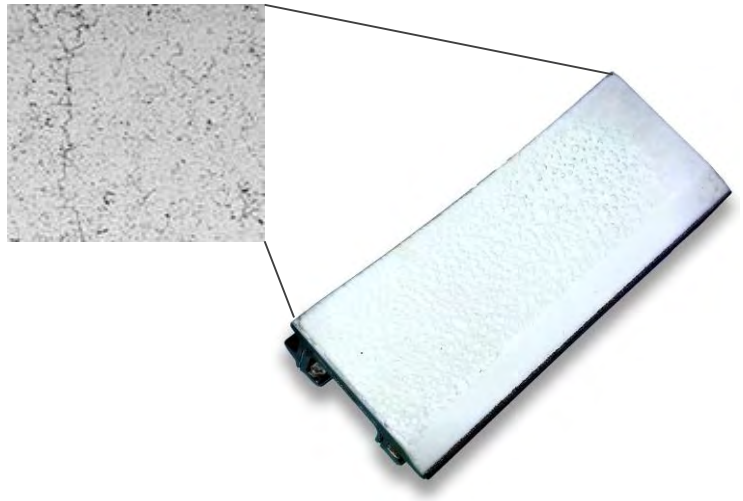
CLEEN II BOAS

- Engine Test Hardware Received, engine processing underway for Engine Testing
- Advanced Blade processing trials complete



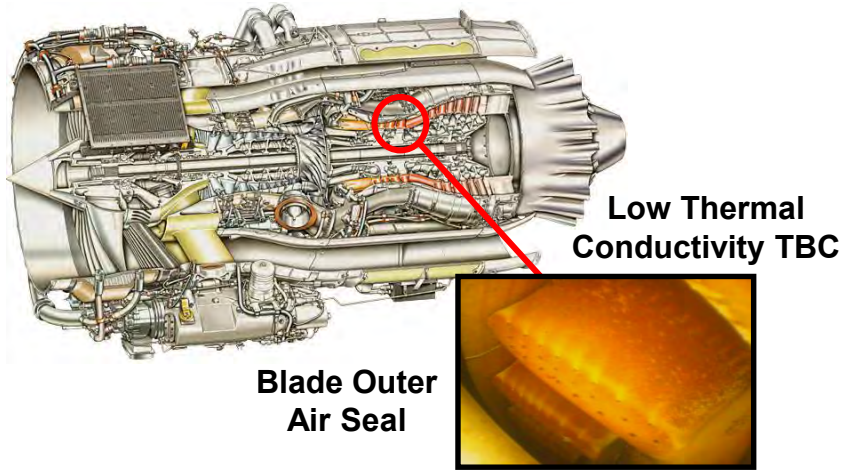
SOA-Improved TBC Configuration

- APS Low-k TBC Oxidation Testing Complete
- Engine Hardware Received, engine processing underway for Engine Testing



BOAS to Achieve System TRL 5 in Q3 2020

ADVANCED TURBINE BOAS SYSTEM TECHNOLOGY



Benefits

Fuel burn reduction

Improved power-to-weight ratio

Risks/Mitigations

Insufficient material durability/rig and engine test

Insufficient performance/alternate BOAS design in place

Objectives

Improve high pressure turbine (HPT) efficiency

Work Statement

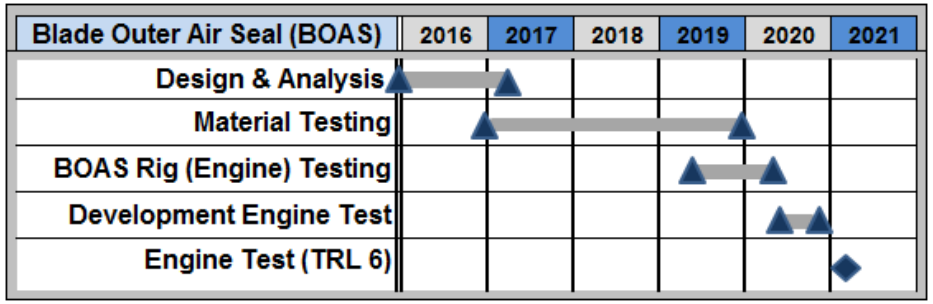
Develop and demonstrate a BOAS system that improves HPT efficiency in an engine

Accomplishments/Milestones

HPT shroud design complete and hardware received for 2020 development engine testing

Final APS Low-k TBC shows good results, engine hardware received for 2020 engine test

Project Schedule



TECHNOLOGY READINESS LEVEL (TRL) MATURATION AND SUMMARY

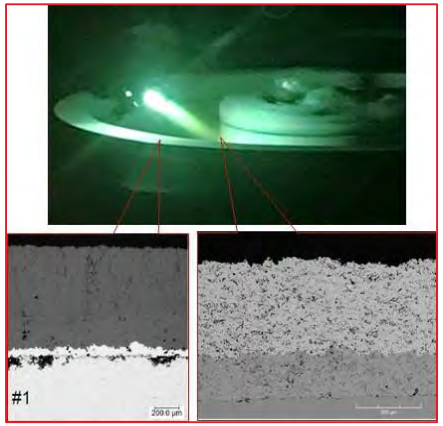
FUTURE PLANS – TRL MATURATION

TRL 5 – 2020

- **Development Test(1) – Q2 2020**
  - **HPT Shroud Technology** Assessment
- **Development Test(2) – Q3 2020**
  - **HPT BOAS Technology** assessment

TRL 6 – 2020/21

- **NASA Combustor System Testing – Q4 2020 – Q1 2021**
- **Endurance Engine Test – Q4 2020 – Q1 2021**
  - Engine emissions assessment
  - Endurance engine test to support TRL 6 validation of **Compact Combustor and BOAS Technologies**



SUMMARY

Honeywell CLEEN II program progressing well to mature the compact combustor and advanced turbine BOAS to reduce fuel burn and NOx emissions

- **Engines and Aircraft Systems Analysis**
  - Engine DDR complete
  - Gulfstream aircraft/engine assessment complete
  - Assessments to be updated upon TRL 6 demonstrations
- **Compact Combustor**
  - Compact combustor design iterations complete
  - Rig testing of annular combustor technologies and full system nearing completion
  - Fabrication well underway for NASA ASCR combustor testing in Q4 2020 - Q1 2021
  - Endurance engine testing planned for Q4 2020 - Q1 2021
- **Turbine BOAS**
  - HPT shroud design complete and hardware received for 2020 development engine testing
  - APS Low-k TBC ready for 2020 engine testing
  - Endurance engine testing planned for Q4 2020 - Q1 2021