

HONEYWELL CLEEN II

CONSORTIUM PRESENTATION – OPEN DISCUSSION

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PROGRAM MANAGER

October 28, 2020

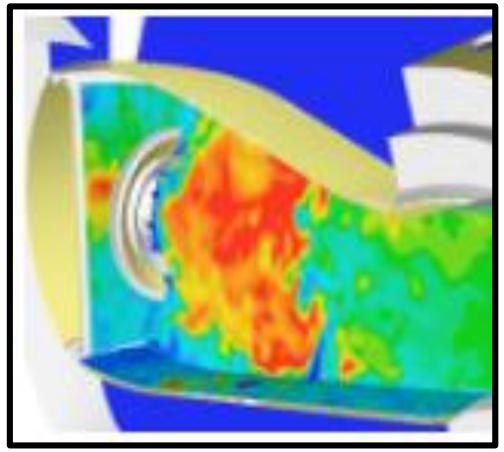
Honeywell

AGENDA

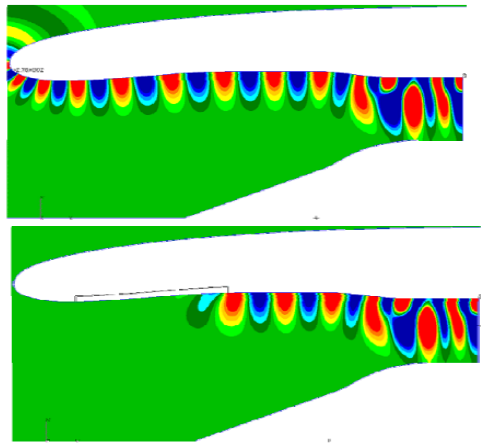
1. Elevator Speech
2. Honeywell's Products and CLEEN II
3. CLEEN II Technologies
4. Technology Maturation Approach and Program Schedule
5. Engine and Aircraft Systems Analysis Status
6. Technologies Status – Compact Combustor
7. Technologies Status – Blade Outer Air Seal (BOAS)
8. Technology Status – Advanced Acoustic Fan and Liners
9. Technology Status – Advanced High Pressure Compressor
10. Future Plans for TRL 5/6
11. Summary

CLEEN II PROGRAM TECHNOLOGIES

<u>Elevator Speech:</u> Honeywell's CLEEN II program is maturing advanced propulsion engine technologies for improved fuel burn, reduced emissions and noise.





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

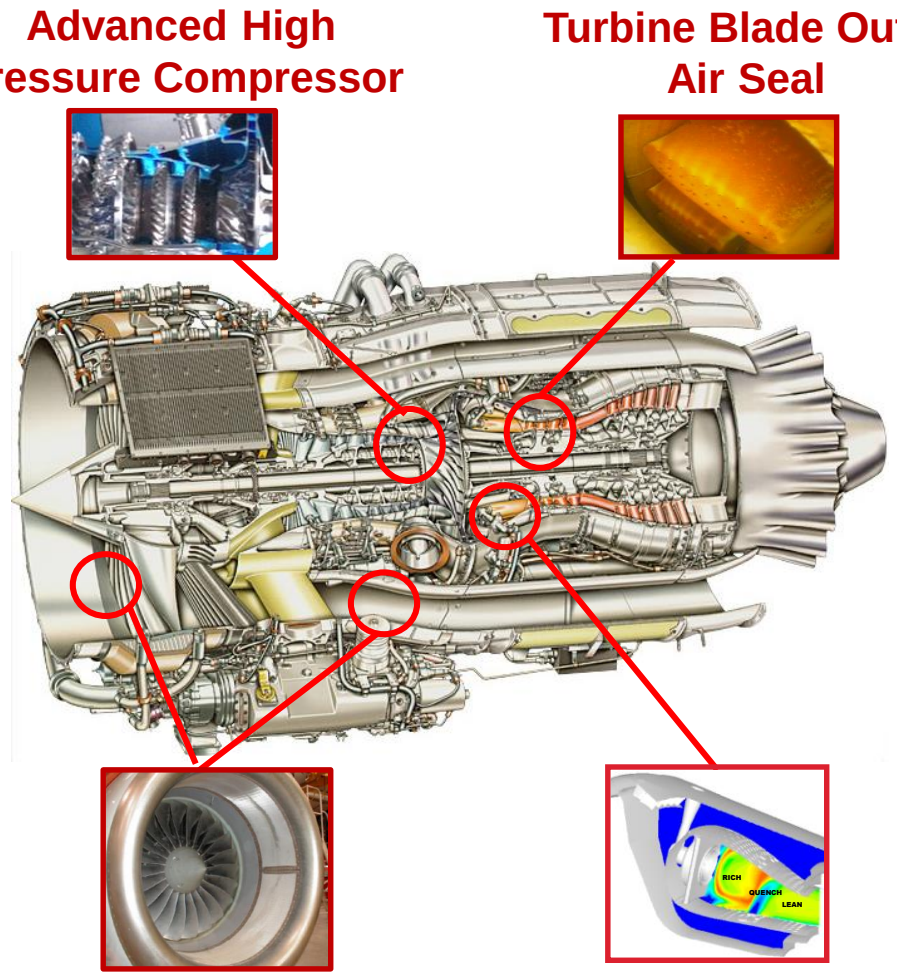
Engine	Platform
HTF7000	Bombardier Challenger 300
HTF7350B	Bombardier Challenger 350
HTF7250G	Gulfstream G280
HTF7500E	Embraer Legacy 450/500 Embraer Praetor 500/600
HTF7700L	Cessna Citation Longitude

CLEEN Technologies Enhance Future Product Capabilities

HONEYWELL CLEEN II TECHNOLOGIES

The Advanced Compact High Pressure Compressor (HPC) lowers fuel burn by increasing OPR, efficiency, and temperature capability, while reducing weight.

Advanced Fan Rotor light weight design and novel **Acoustic Liners** reduce tonal and broad band noise and fuel burn.



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
• **Advanced Turbine BOAS System** • **Advanced Compressor** • **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
• **Compact Combustor System**	**Emissions**	• **Goal** - Reduce NOx emissions to >50% margin relative to CAEP/8, for next generation turbofan, turboshaft, turboprop engines for 2025 EIS
• **Advanced Acoustic Fan Rotor and Acoustic Liner Technologies**	**Noise** **Fuel Burn**	• **Goal** - Enable turbofan engine noise reduction of 2.5 EPNdB (Stage 5) and enable turbofan engine fuel burn reduction >22% relative to the baseline engine for next generation turbofan, turboshaft, turboprop engines for 2025 EIS

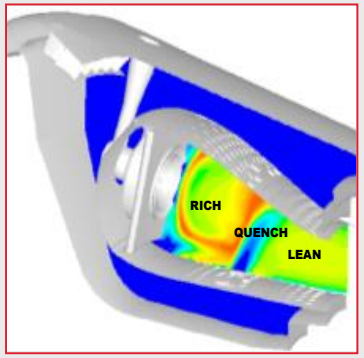
Collateral Benefits:

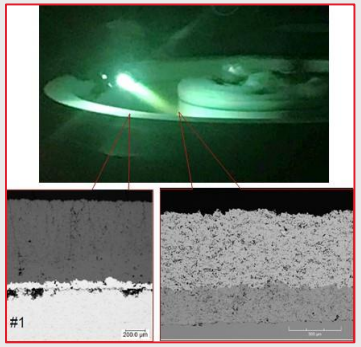
- FAA CLEEN programs support validation of Low-k thermal barrier coating (TBC) and Alloy 10 powder metal super-alloy
- Low-k TBC currently being evaluated by major aerospace and industrial engine original equipment manufacturer (OEMs)
- Applied to current and future turbine propulsion and industrial engines should increase fuel efficiency and lower operating costs

TECHNOLOGY MATURATION APPROACH

TRL 3 → TRL 4 → TRL 5 → TRL 6

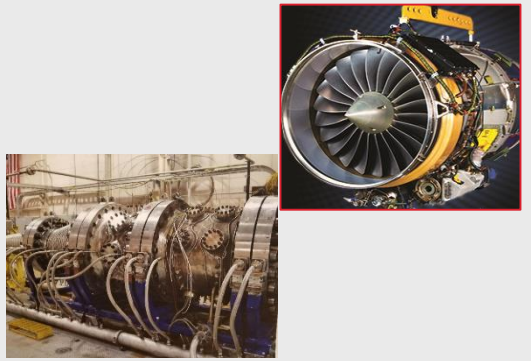
CLEEN II





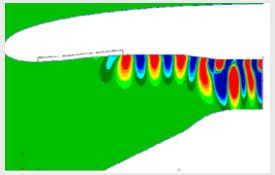
Analysis and Technology Demonstration Testing

Component / System Development Testing



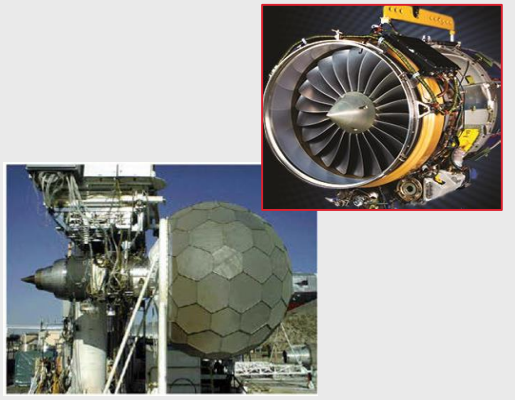
Engine Demonstration and Validation Testing

CLEEN II Add-on



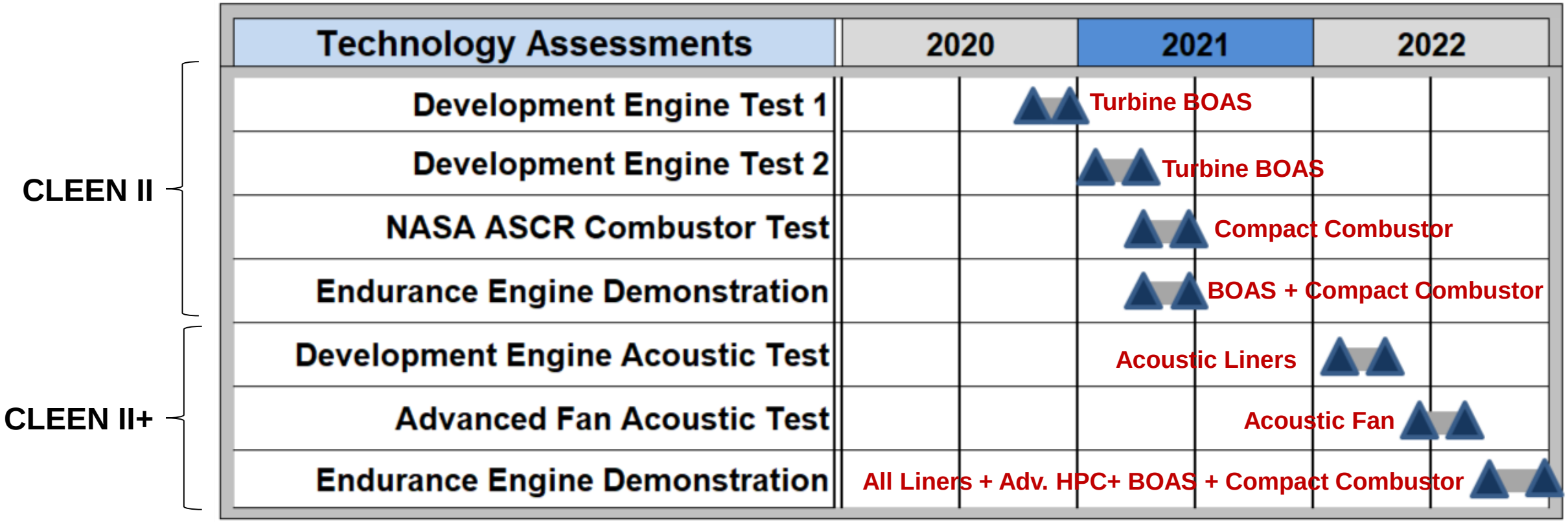
Analysis and Technology Demonstration Testing

Component / System Development Testing



Engine Demonstration and Validation Testing

RIG + ENGINE TESTING SCHEDULE



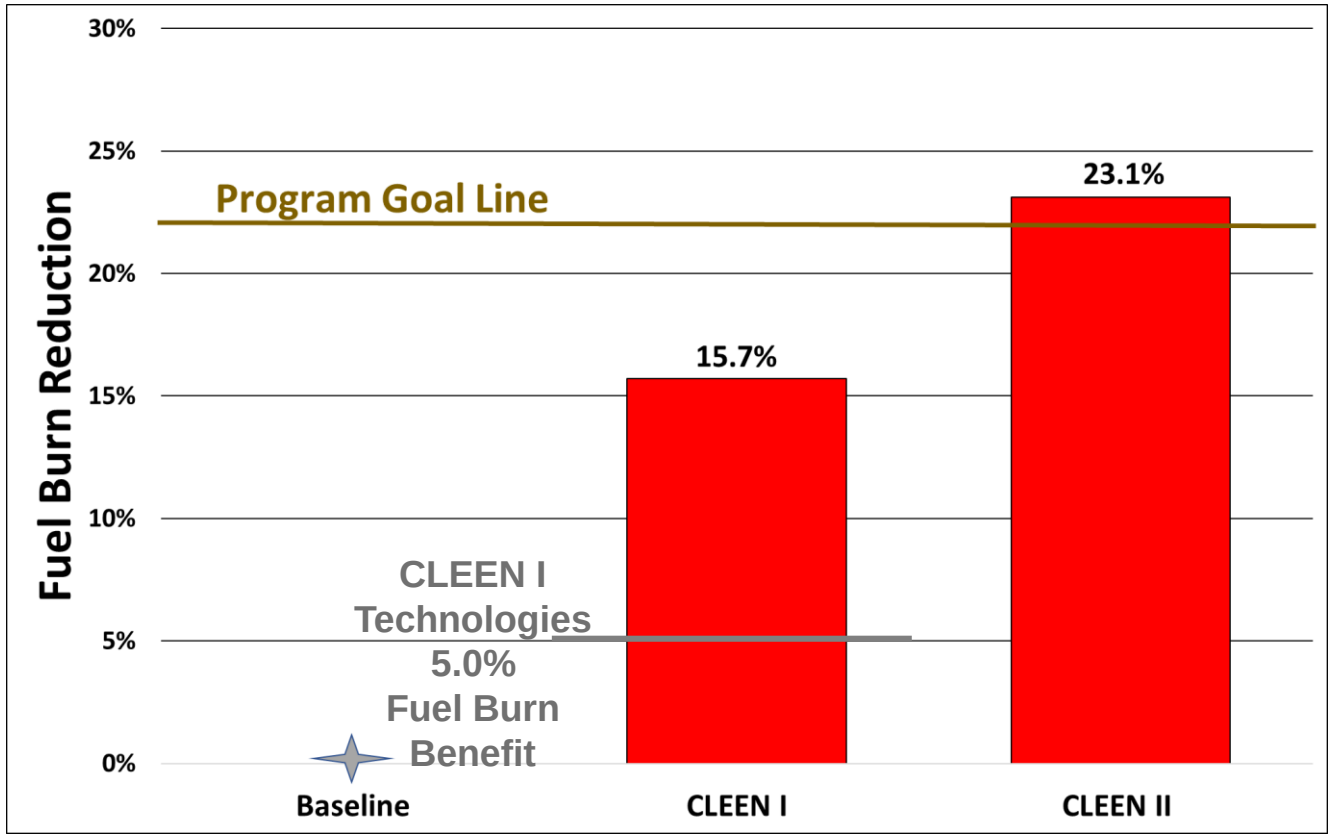
CLEEN II Technologies TRL 6 Q2 2021, CLEEN II+ Technologies TRL 6 Q4 2022

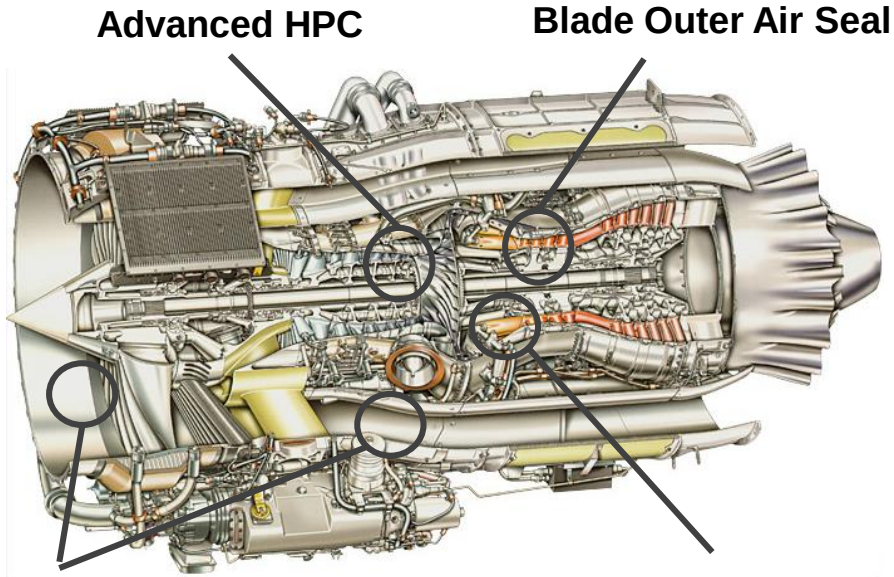
ENGINE AND AIRCRAFT SYSTEMS ANALYSIS STATUS

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

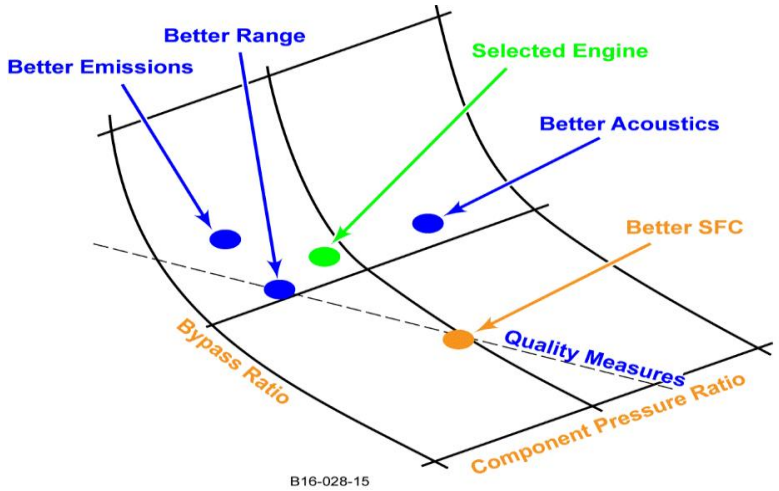




CLEEN II and CLEEN II Add-On - Technologies
~4.6% Fuel Burn Benefit (2.1% CII, ~2.5% CII+)

CLEEN II and Add On CLEEN II Continue to Contribute to Fuel Burn Reduction

ENGINE AND AIRCRAFT FUEL BURN 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

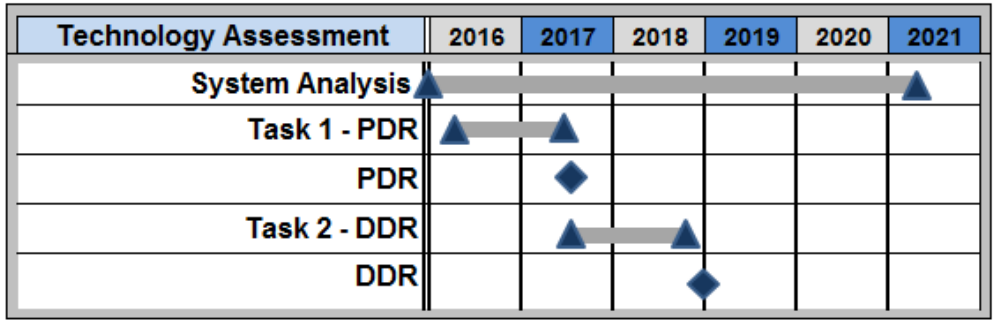
Work Statement

- 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

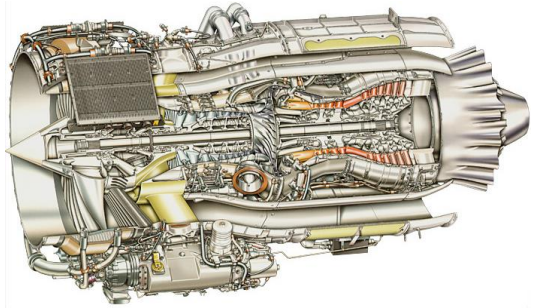
Technology Schedule (Completed Tasks)



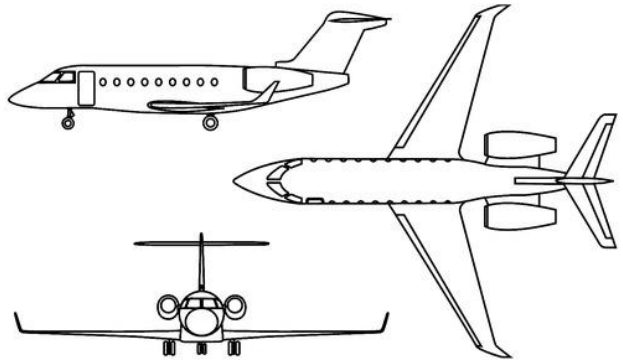
AIRCRAFT NOISE ASESSMENTS

Estimate benefits of noise technologies for a representative aircraft

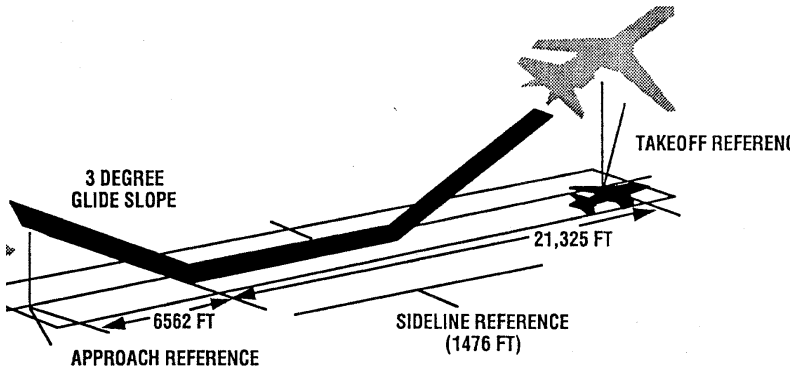
Engine Noise Prediction + Measured Technology Benefits



Aircraft Noise Prediction



Benefits Assessments



Schedule of 2021-2022 System Assessments

CLEEN II
(Fuel Burn and Emissions)

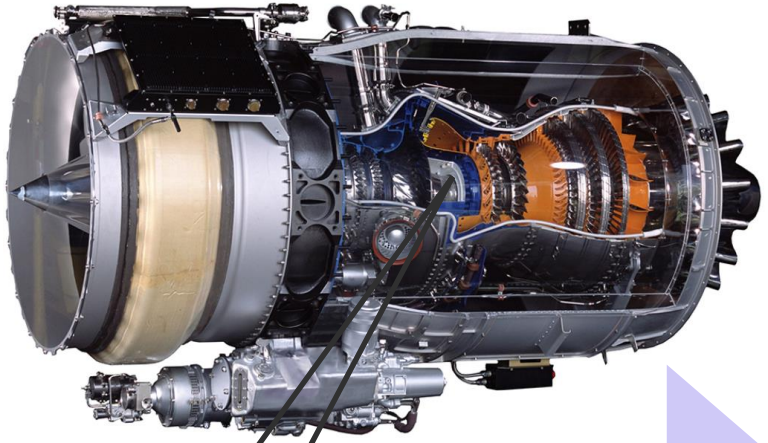
CLEEN II+
(Fuel Burn and Noise)

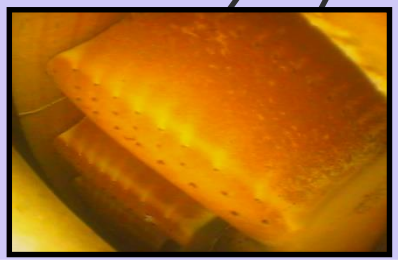
Technology Assessment	2020	2021				2022			
	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
CLEEN II Technologies Assessment									
Georgia Tech Assessment									
Cycle-based engine noise predictions									
Predict aircraft flyover noise levels									
Compute EPNL Noise benefits									
Georgia Tech Assessments									

CLEEN II TECHNOLOGIES STATUS
BLADE OUTER AIR SEAL (BOAS)

Honeywell

BLADE OUTER AIR SEAL (BOAS) TECHNOLOGY



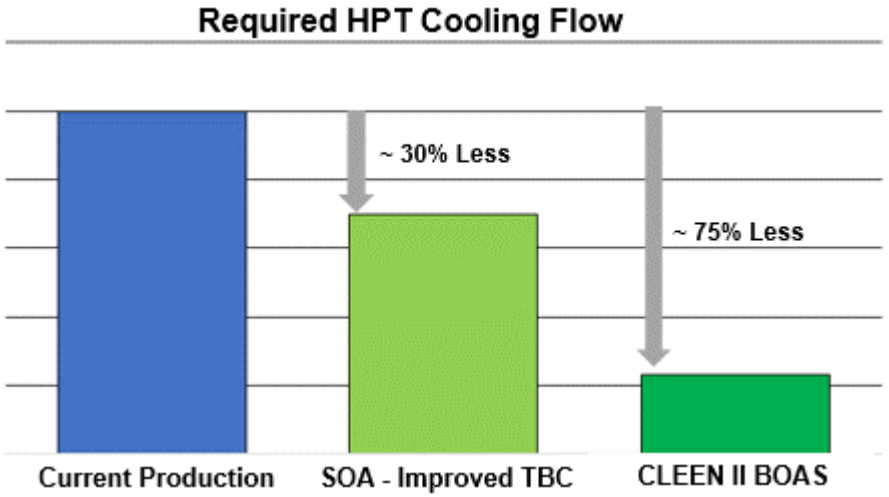


Blade Outer Air Seal

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

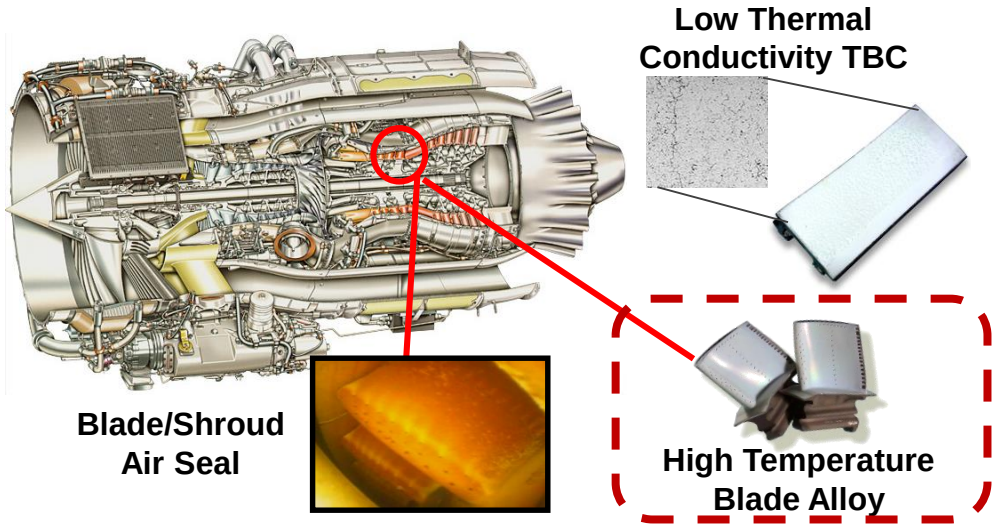
BOAS Attributes

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



BOAS Technology to Reduce Turbofan Engine Fuel Burn 2.1%

ADVANCED 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

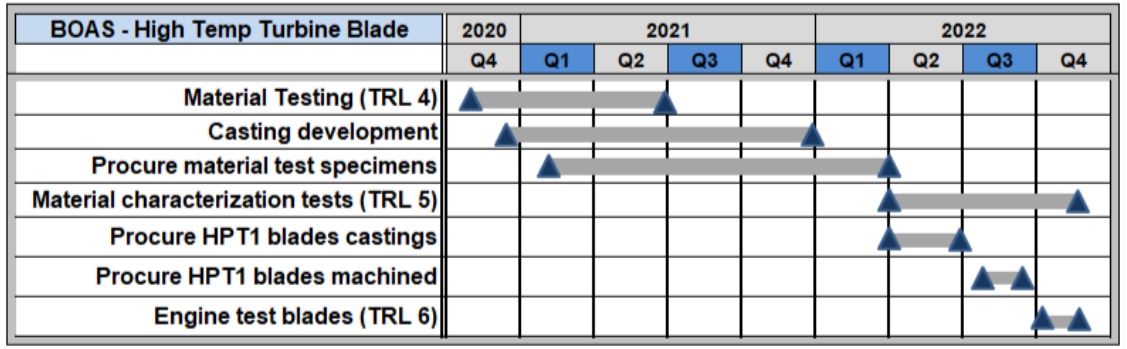
- Blade Outer Air Seal with HPT Shroud Technology
- High Temperature Capable Blade Alloy

Accomplishments/Milestones

HPT shroud design complete and hardware received for 2020/2021 engine testing

Final APS Low-k TBC shows good results, engine hardware received for 2020/2021 engine testing

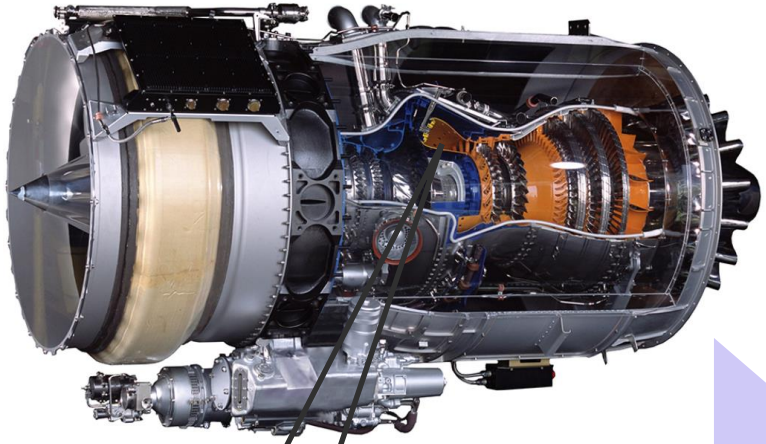
2021-2022 Project Schedule (High Temp Blade Alloy)

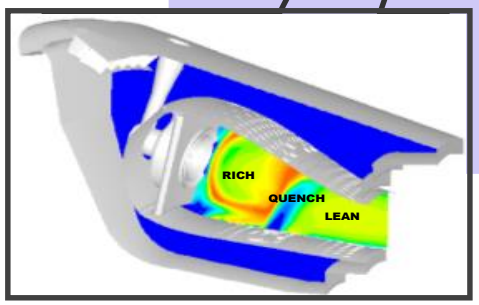


CLEEN II TECHNOLOGIES STATUS
COMPACT COMBUSTOR

Honeywell

COMPACT COMBUSTOR TECHNOLOGY



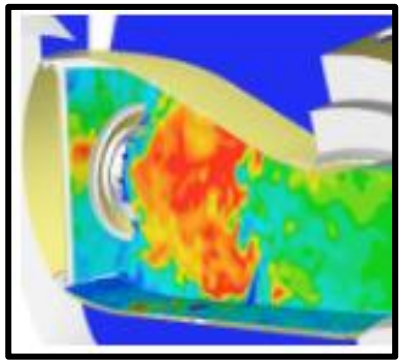


Compact Combustor

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

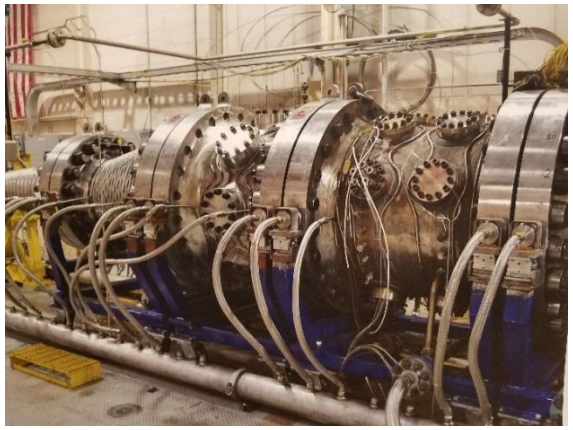
Integration of new combustor technologies developed under CLEEN II has achieved significant reduction in NOx and nvPM emissions while also meeting operability and durability requirements.

Final demonstrations and TRL 6 validations of the CLEEN II Combustor System are in progress as part of a Honeywell engine endurance test.

In parallel, Honeywell will also be testing the annular CLEEN II Combustor System in the NASA Glenn Advanced Subsonic Combustor Rig facility at relevant high pressure and temperature engine conditions to support TRL 6 performance, emissions and durability assessments.

COMPACT COMBUSTOR NEXT STEPS

- **Complete CLEEN II combustor component rig testing in Phoenix in Q4-2020**
- **Complete CLEEN II combustor engine endurance testing with the in Q2-2021**
- **Complete NASA combustor rig test section assembly, and demonstrate the annular CLEEN II Combustor System in the NASA ASCR facility at relevant engine operating condition in Q2-2021**

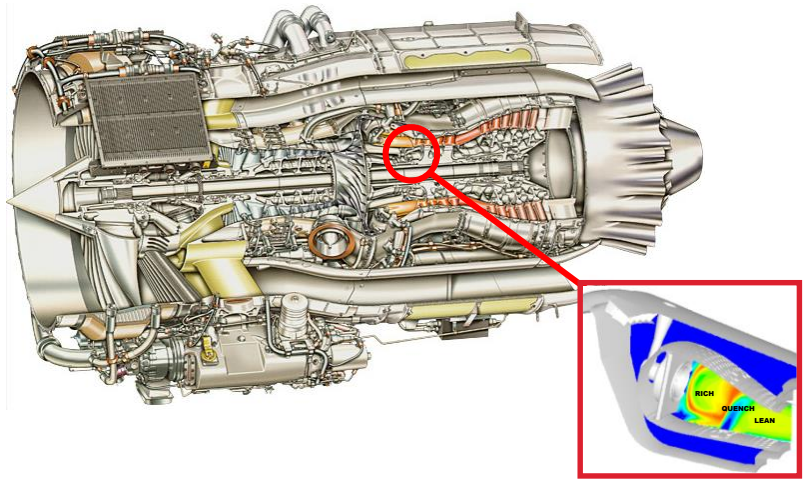


NASA ASCR Facility

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

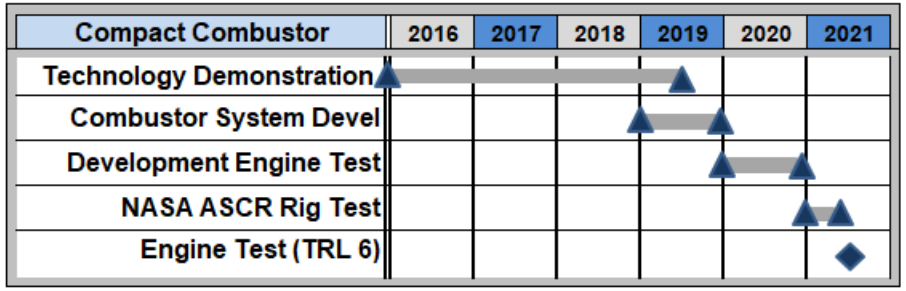
Work Statement

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

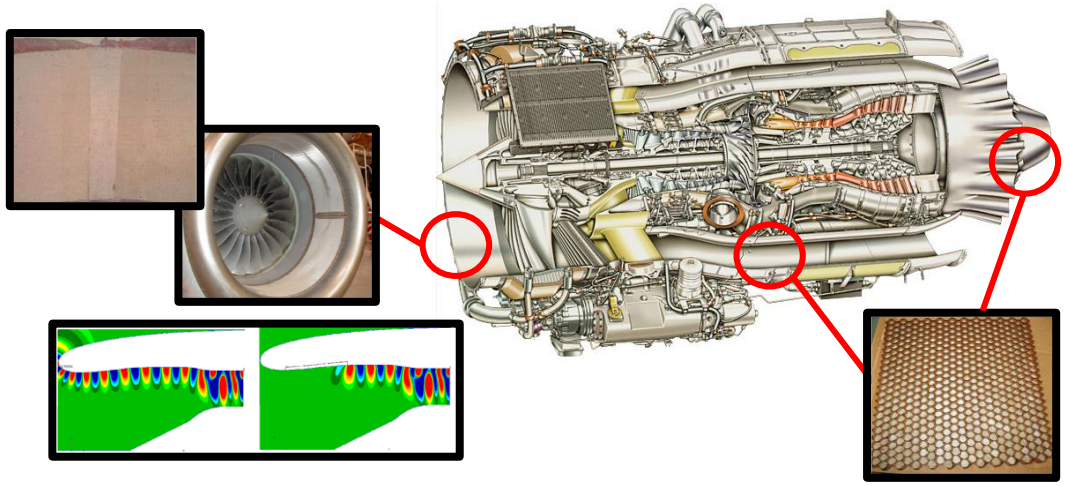
Technology Schedule



CLEEN II TECHNOLOGIES STATUS
ACOUSTIC FAN AND LINER TECHNOLOGIES

Honeywell

CLEEN II ADVANCED ACOUSTIC FAN AND LINER



Benefits

- Reduce noise by 2.5 EPNdB
- Reduce fuel burn by 1.5%

Risks/Mitigations

- Fan Noise Improvement – Fan Rig Test to validate noise generating mechanisms
- Acoustic Liner Acoustic Benefit – Manufacturing trials and acoustic test
- Acoustic Liner Durability – Endurance Engine Test

Objectives

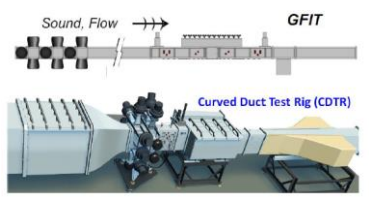
- Design a light-weight fan that reduces rotor noise
- Design acoustic liners that reduce tonal and broad band noise.
- Design bypass/center-body acoustic liners to reduce tonal and broadband noise

Work Statement

- Design fan rotor (In process)
- Fan rig test
- Design acoustic liners (In process)
- Acoustic rig test
- Acoustic engine test

Accomplishments/Milestones

- Fan rotor design Q1 2021
- Inlet Liner design Q1 2021
- Bypass duct liner Q2 2021



Advanced Acoustic Fan Module	2020	2021				2022			
	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Fan Rotor Technology Design									
Inlet Liner Technology Design									
Bypass Duct Technology Design									
Hardware Fabrication									
NASA Acoustic Test (TRL 4)									
Acoustic Liners Engine Test (TRL 5)									
Advanced Fan Rotor Test (TRL 6)									
Acoustic Liners Endurance Test (TRL 6)									

CLEEN II TECHNOLOGIES STATUS
ADVANCED HIGH PRESSURE COMPRESSOR

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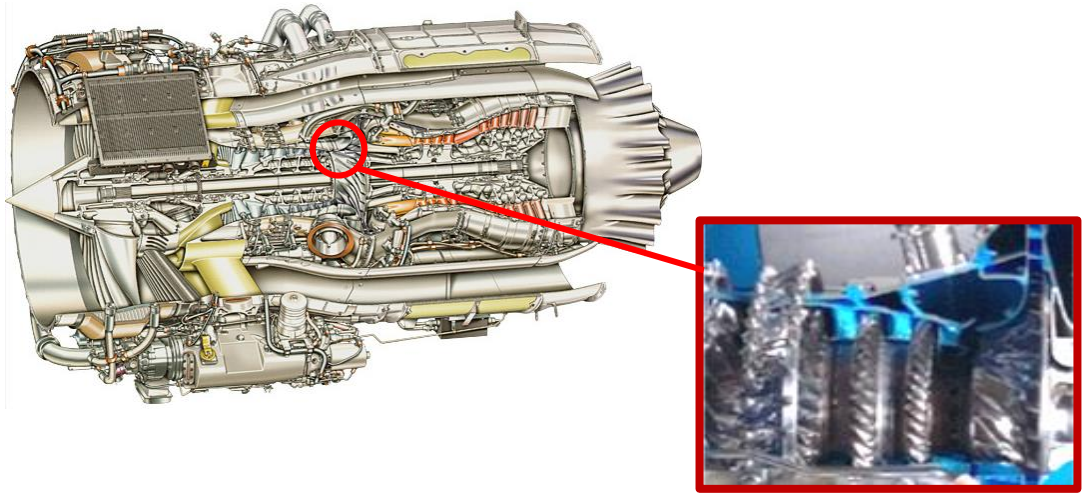
CLEEN II ADVANCED HPC



Benefits

- Axial Stage: High Efficiency Design
- Centrifugal Stage: High Temperature Capability
- Adv. HPC: 1% Fuel Burn Reduction

Risks/Mitigations

- Challenges with stall margin and operability – TRL 5 axial test (Honeywell Funded)
- Temperature Capability of Impeller – TRL 4 Material Testing (Honeywell Funded)

Objectives

- Integrate advanced HPC technologies into an HTF7000 engine to mature Advanced HPC technology to TRL 6

Work Statement

- Design of HPC static hardware (in process)
- Fabricate HPC static hardware
- Endurance engine test

Accomplishments/Milestones

- HPC Rig Test for TRL 5
- Design assessment complete in Q4 2020

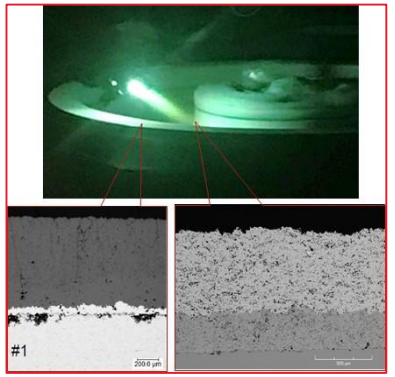
Advanced Fan HPC	2020	2021				2022			
	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
HiPR II TRL 5 test (IR&D)									
HPC design assessment						TRL 5			
HPC hardware fabrication									TRL 6
Endurance engine test									

TECHNOLOGY READINESS LEVEL (TRL) MATURATION AND SUMMARY

FUTURE PLANS – TRL 5/6 MATURATION

TRL 5 – 2020-2021

- **Development Test(1) – Q4 2020**
  - **HPT Shroud Technology** assessment underway
- **Development Test(2) – Q1 2021**
  - **HPT BOAS Technology** assessment



TRL 6 – 2021

- **NASA Combustor System Testing – Q2 2021**
- **Endurance Engine Test – Q2 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 maturing advanced propulsion engine technologies to reduce weight for improved fuel burn, reduced NOx emissions and noise.

- **Engines and Aircraft Systems Analysis**
  - Engine DDR complete. To be updated with new CLEEN II Add-on technologies
  - Gulfstream aircraft/engine assessment complete
  - Assessments to be updated upon TRL 6 demonstrations of all technologies
- **Compact Combustor**
  - Rig testing of annular combustor technologies and full system nearing completion
  - Fabrication nearing completion for NASA ASCR combustor testing in Q2 2021
  - Endurance engine testing planned Q2 2021
- **Turbine BOAS**
  - HPT shroud design complete and hardware received for engine testing
  - APS Low-k TBC ready for engine testing
  - Endurance engine testing planned for Q1-Q2 2021
- **CLEEN II Add-On Technologies**
  - Kick-Off meeting held in September
  - Design efforts underway with acoustic technologies, advanced HPC and BOAS high temperature turbine blade material