

Pratt & Whitney

A United Technologies Company

P&W FAA CLEEN Update

November 2014

AGENDA



PW CLEEN Program Highlights

Alternative Fuel Evaluation

PW FAA CLEEN Program Status

PRATT & WHITNEY PROGRAM HIGHLIGHTS

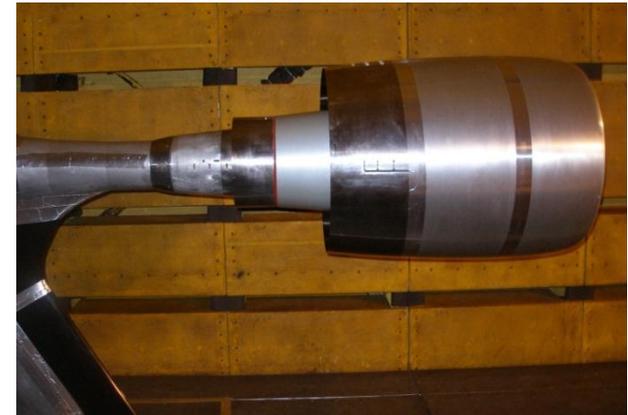
P&W'S PROGRAM HIGHLIGHTS



Rig and Engine Demonstrator Progress

400+ hrs of UHB Fan Rig Testing

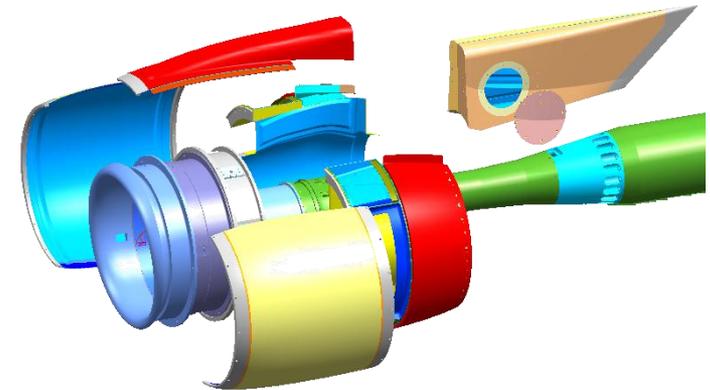
- Fan efficiency confirmed
- Aero-mechanical response consistent with advanced CFD predictions
- Acoustic behavior consistent with advanced CFD predictions



UHB Scaled Fan Rig Installed At NASA Glenn 9x15 Tunnel

Scaled CLEEN Engine Fan Rig Poised for Assembly

- Simulates installation configuration
- Rig to engine acoustic / performance scalability



Scaled CLEEN Engine Fan Rig

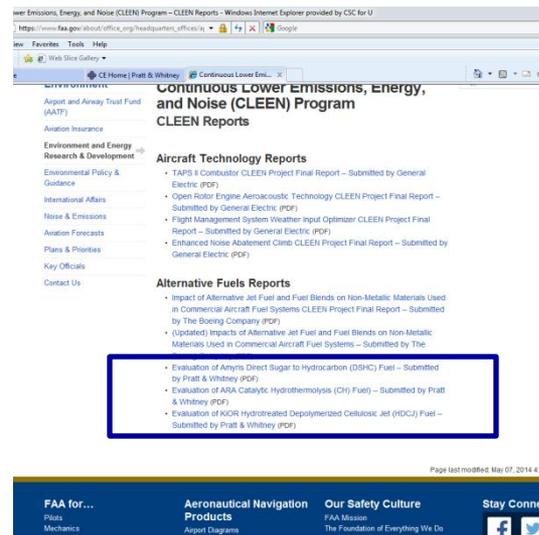
CLEEN Engine UHB Hardware in Fabrication

- All nacelle hardware received
- Engine assembly planned Q4 2015

ALTERNATIVE FUEL EVALUATION

ALTERNATIVE FUEL TASKS

- Three Alternative Fuel Test Program– **Completed**
- Hyperlink to reports:
- https://www.faa.gov/about/office_org/headquarters_offices/apl/research/aircraft_technology/clean/reports/



- PWAP APU Test on Swedish Alcohol-to-Jet – **New Task**
- OEM D4054 Support of Alternative Fuels– **New Task**

THREE ALTERNATIVE FUEL TEST PROGRAM



Alternative fuel blends tested

Baseline Jet A (or Jet A-1) conforming to ASTM D1655

- 30/70 Kior HDCJ/Jet A
- 50/50 Kior HDCJ/HEFA
- 50/50 ARA CH/Jet A
- 100% ARA CH
- 20% Amyris Farnesane

Fuel blends were from three different processes

Kior Hydroprocessed Depolymerized Cellulosic Jet (HDCJ)
Containing 50% by volume synthetic aromatics

Applied Research Associates (ARA) Catalytic Hydrothermolysis (CH)
Containing 16 to 24% by volume synthetic aromatics

Amyris Farnesane
C-15 molecules

THREE ALTERNATIVE FUEL TEST PROGRAM



Test vehicles used

P&WC Turbofan Engine Model PW615F

1460lbs thrust, 2-spool turbofan engine



Engine Test Plan

Engine operability

Engine performance

Engine exhaust emissions & smoke

Single Nozzle Can Combustor Rig

Cold start capability

Altitude relight capability

Combustor Test Plan

Cold start mapping

Altitude relight mapping



THREE ALTERNATIVE FUEL TEST PROGRAM



Engine operability

Evaluated during a series of maneuvers

Engine Starts

Time to light

Time to idle

Inter turbine temperature

Slam Accelerations & Decelerations

Evaluated between GI and takeoff power



Operability tests showed no significant differences between fuels

THREE ALTERNATIVE FUEL TEST PROGRAM



Engine performance

Performance Test Main Parameters at a Takeoff Thrust of 1,460lbf

<i>Engine/Build</i>	6157B12	6157B12	6157B12
<i>Description</i>	Baseline JET-A	Amyris Farnesane/ Jet-A (20/80%)	Repeat 100% JET-A
<i>Test Date</i>	11 May 2013	11 May 2013	11 June 2013
<i>Parameters</i>	<i>Units</i>		
<i>SFC</i>	-	1,000	1,002
<i>WF</i>	-	1,000	1,001
<i>N1</i>	-	1,000	0,999
<i>N2</i>	-	1,000	1,000

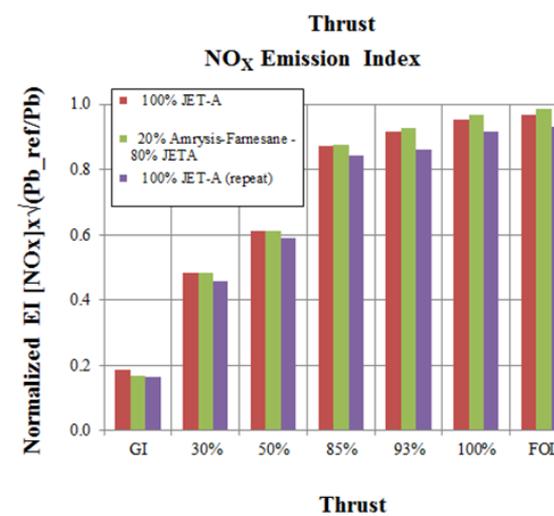
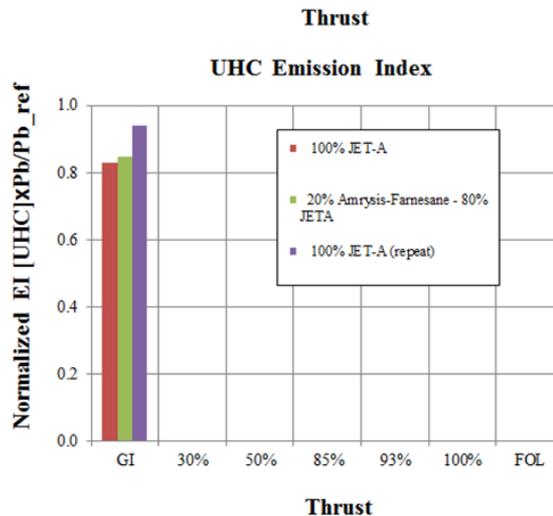
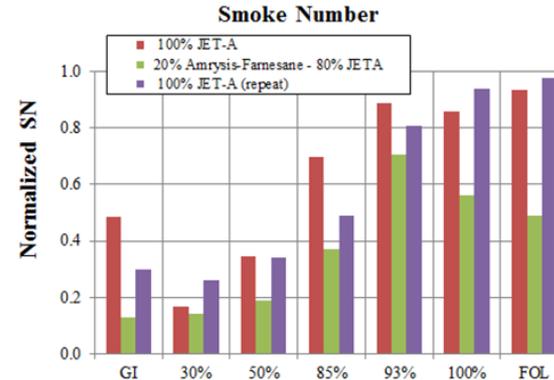
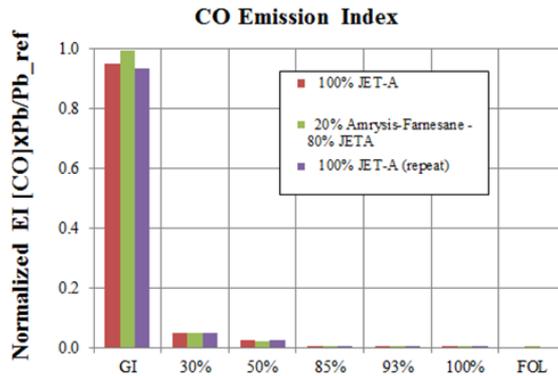
Reference: FAA Report Number DOT/FAA/AEE/2014-07

No significant impact on SFC, low rotor speed (N1) or high rotor speed (N2)

THREE ALTERNATIVE FUEL TEST PROGRAM



Engine emissions and smoke

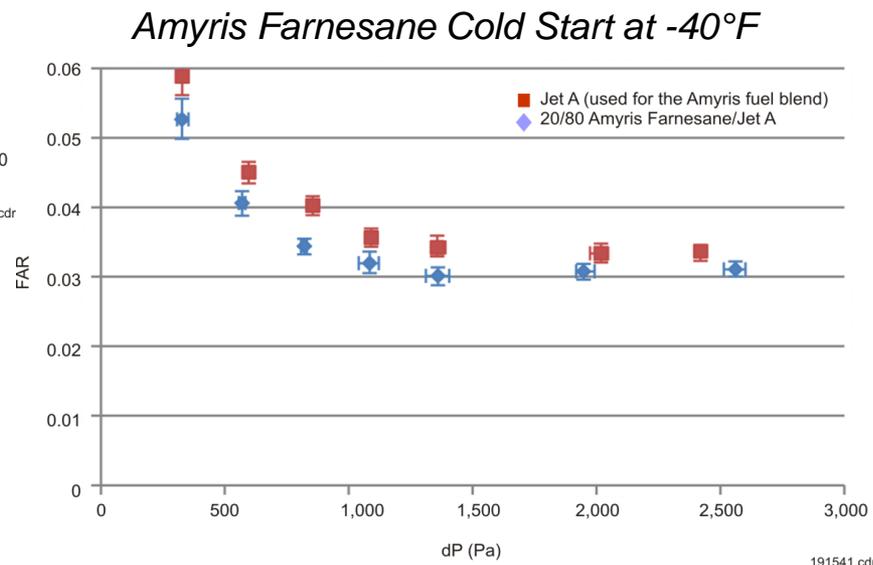
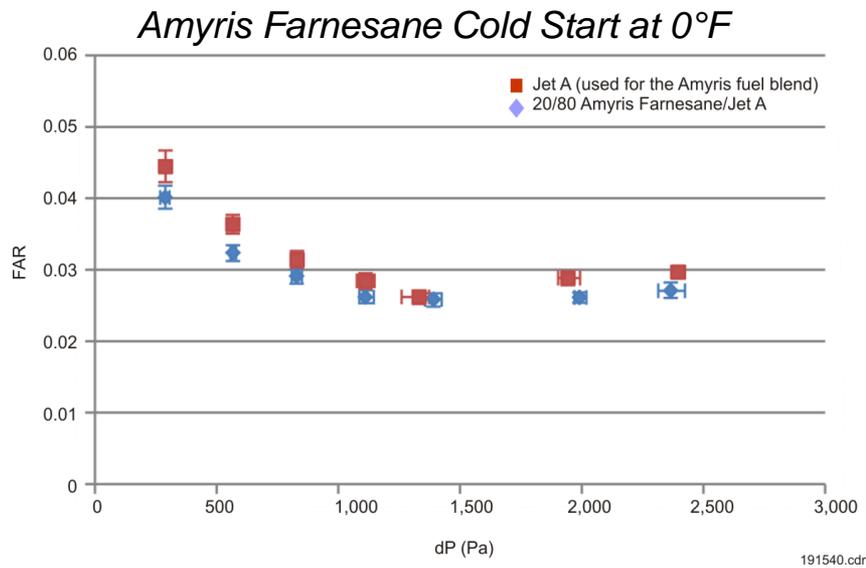


Biofuel blend within the experimental scatter for Jet A-1 fuel

THREE ALTERNATIVE FUEL TEST PROGRAM



Combustor can cold start



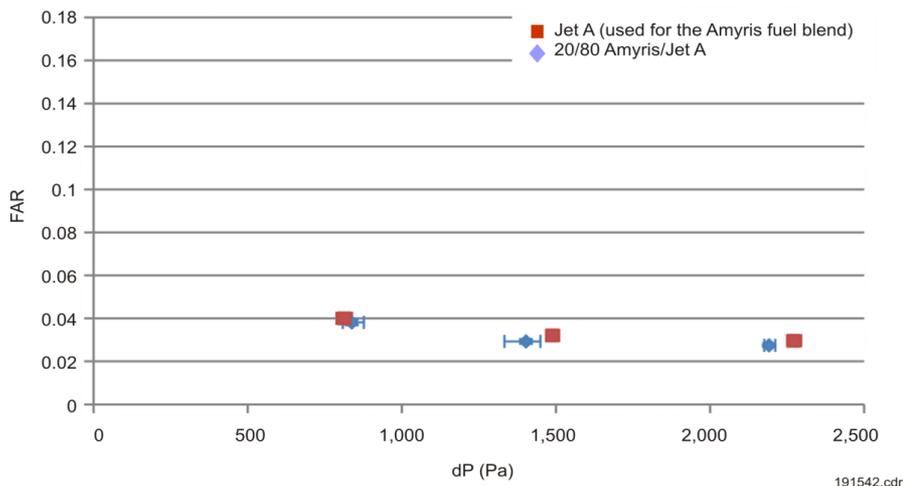
Biofuel blend behaved similarly to the baseline Jet A-1 fuel

COMBUSTOR CAN ALTITUDE RELIGHT

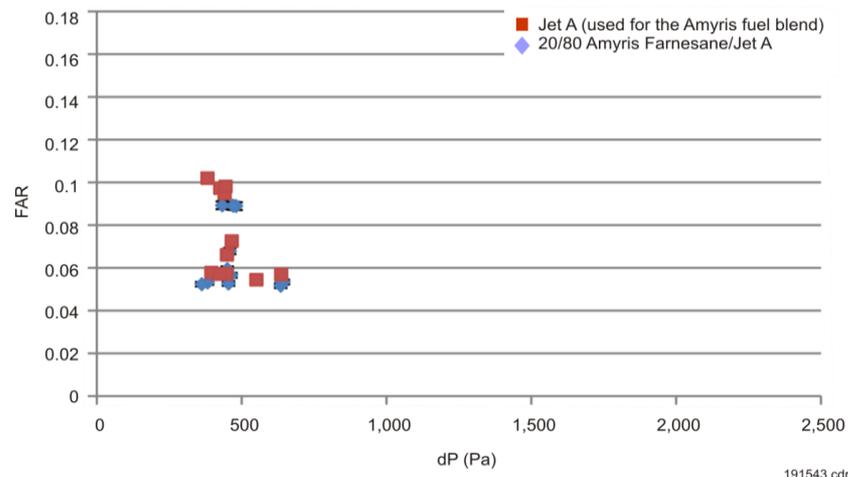


Combustor can altitude relight

Amyris Altitude Relight at 15kft



Amyris Altitude Relight at 30kft



Biofuel blend behaved similarly to the baseline Jet A-1 fuel

PWAP APU TEST ON SWEDISH ALCOHOL-TO-JET



FAA teamed with AFRL and Swedish Air

Test start date January 2015

50/50 ATJ/JP-8 Blend

Fuel Injector Bench Spray Test

Pilot injector will be tested at 4 selected conditions using JP-8 and ATJ at ambient and -40F

Combustor Rig Test

- Performance testing at normal operating conditions
 - ✓ 3 operating conditions ground to 41K ft.
 - ✓ Combustor pattern factor, radial temperature profile, emissions
- Cold temperature fuel ignition testing
 - ✓ Range of conditions from sea level to 41Kft.

OEM D4054 SUPPORT OF ALTERNATE FUELS



Work with engine/airplane OEM team to support evaluation and approval

- **Provide Support to ASTM International Alternative Fuels Task Forces**
 - ✓ Provide task forces w/ technical & procedural guidance
 - ✓ Review task force data as generated & provide feed back
 - ✓ Guidance in compiling & review of ASTM Research Report
 - ✓ OEM team develop staged-gate approach for initial D4054 approval based on lower blend percentages
- **Provide Internal Engineering Review, Approval Disposition, Incorporate in Service Bulletins/Engine Manuals**
 - ✓ Brief commercial and military chief engineers and discipline chiefs
 - ✓ Gain engine/airplane OEM team consensus for approval of fuel process
 - ✓ Incorporate new alternative fuel into engine OEM service bulletins

FAA CLEEN PROGRAM STATUS

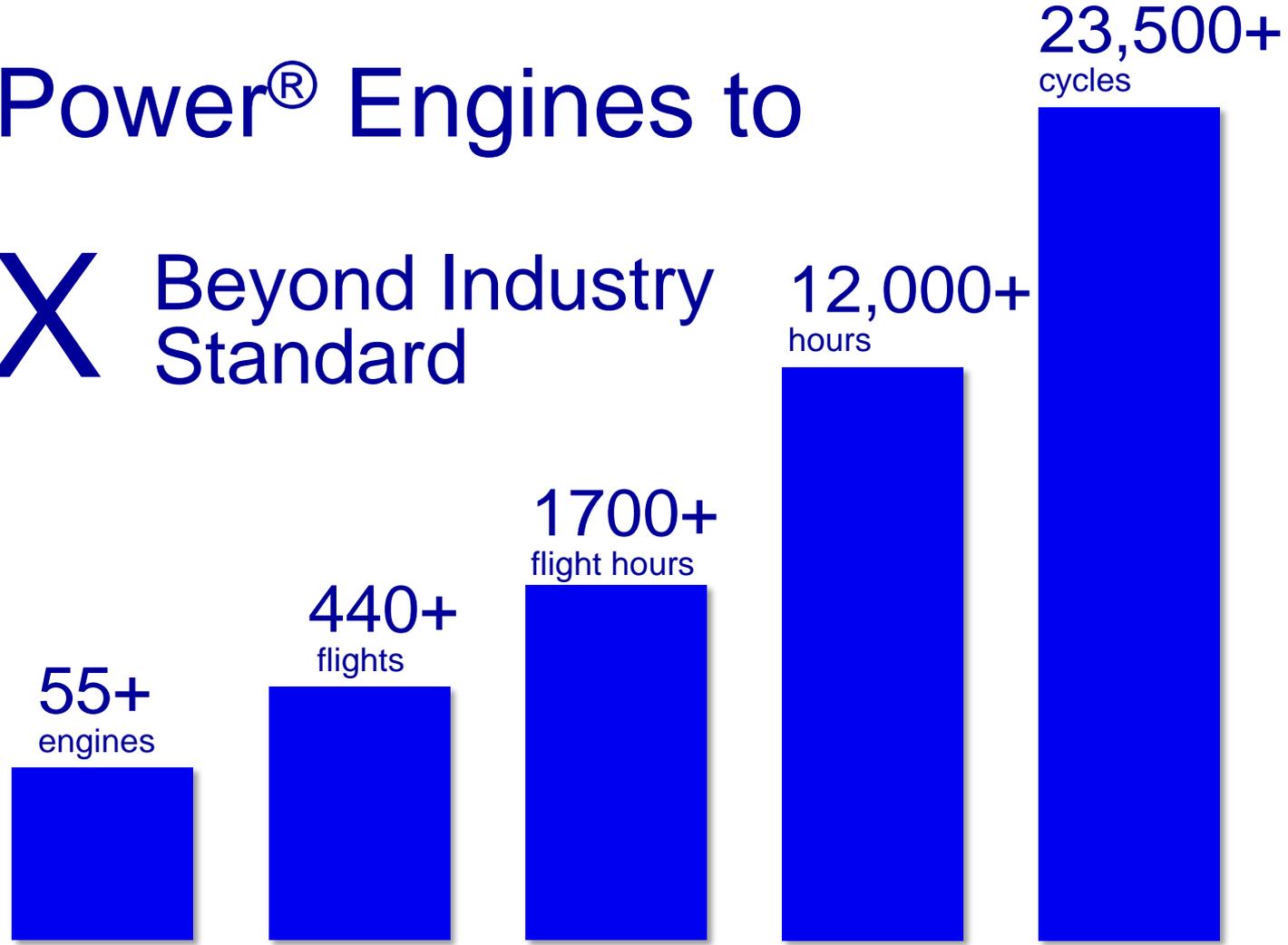
FAA CLEEN PROGRAM STATUS



Unprecedented testing validates UHB potential

PurePower[®] Engines to Date

>3X Beyond Industry Standard



This Page Contains No Technical Data Subject to the EAR or the ITAR
This document has been publicly released

FAA CLEEN PROGRAM STATUS



PW1500G Program in Aircraft Certification Accomplishments

- ✓ Flight testing resumed September 2014
- ✓ Event understood
- ✓ Propulsion system meeting all requirements
- ✓ Powerplants delivered for 5 flight test aircraft
- ✓ Building maturity for all models



FAA CLEEN PROGRAM STATUS

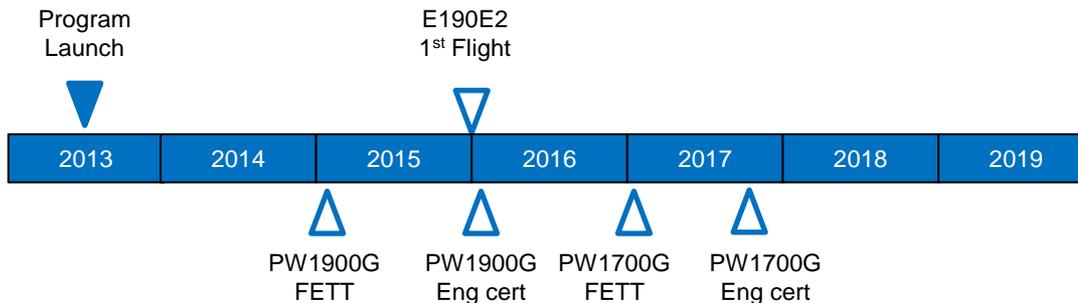


PW1900G/PW1700G Engine Programs

Embraer E-Jets® E2

Accomplishments

- ✓ Launched at 2013 Paris Air Show
- ✓ E190E2/E195E2 powered by PW1900G
- ✓ E175E2 powered by PW1700G
- ✓ E190E2/E195E2 Joint Development phase complete
- ✓ E175E2 Joint Development phase underway



FAA CLEEN PROGRAM STATUS



PW1100G Program

Accomplishments

- ✓ First flight September 25th
- ✓ FAR33 certification nearing completion
- ✓ Flight test progressing



FAA CLEAN PROGRAM STATUS



MRJ Roll Out October 18th Powered by PW1200G

Accomplishments

- ✓ Block 1 engine testing completed
- ✓ Block 2 engine validation testing started
- ✓ FTV1 powerplants delivered & installed
- ✓ FTV1 aircraft rollout



FAA CLEEN PROGRAM STATUS



Integrated Technology Demonstrator Plan

2014 Accomplishments/Actions

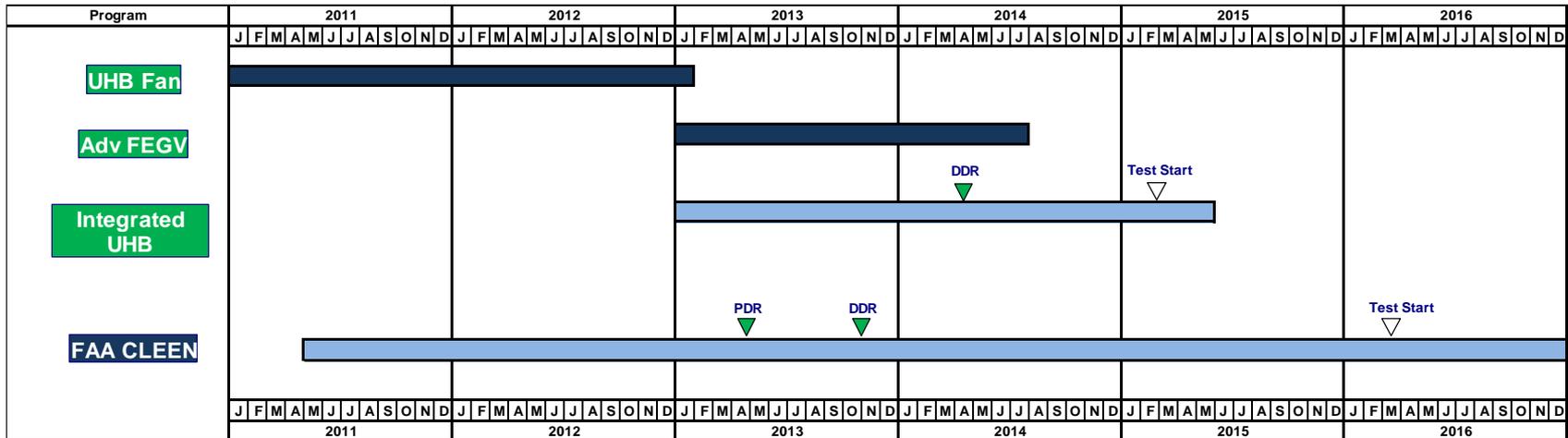
- All hardware completed detail design reviews
- Second UHB fan rig completed advanced FEGV testing
- Integrated UHB (scaled CLEEN engine) completing hardware fabrication
- CLEEN engine assembly moved to Q4 2015



UHB Scaled Fan Rig (2012 to 2015)



CLEEN Engine Testing (2016)



FAA CLEEN FAN RIG PROGRAM STATUS

UHB Propulsor Aerodynamic Performance

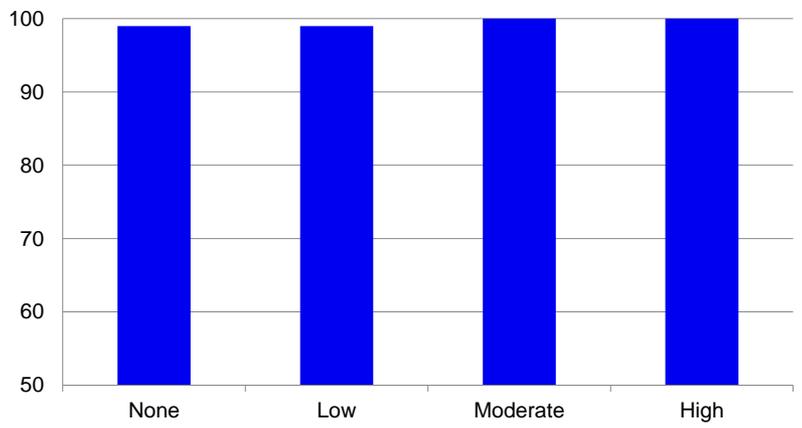
Over 200 hours of testing

Blade aero-mechanical performance consistent with advanced CFD predictions over range of angle of attack (AoA) /crosswind (Xwind) conditions

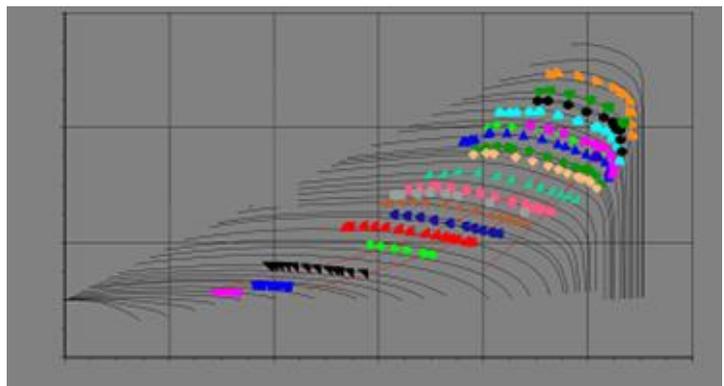
Fan efficiency confirmed

Stability and structural behavior meet design requirements

Improved efficiency inlet aero performance consistent with advanced CFD predictions over range of AoA /Xwind conditions



Impact of Angle of Attack on Measured Fan Flow Short Inlet as % of Conventional Inlet
Acceptable Impact on Measured Efficiency



Fan Performance Met Goals Across Operating Range

FAA CLEEN FAN RIG PROGRAM STATUS



Novel Flow Visualization Enabled Detailed Understanding Of Aerodynamic Design Space

Pressure & temperature sensitive paint utilized over range of operating lines

Oil pigmentation utilized multiple times

Insight into aerodynamic behavior

No instrumentation impact

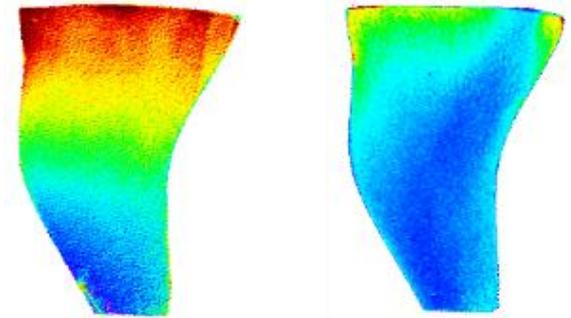


Image Credit: NASA

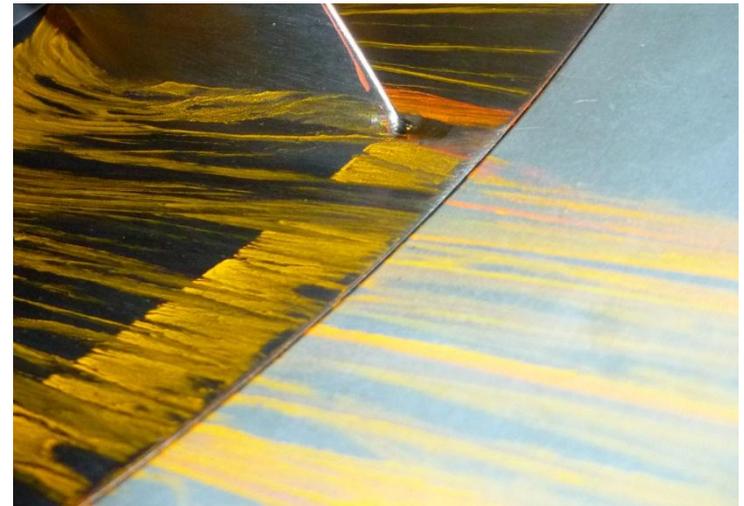


Photo Credit: Pratt & Whitney



FAA CLEAN FAN RIG PROGRAM STATUS

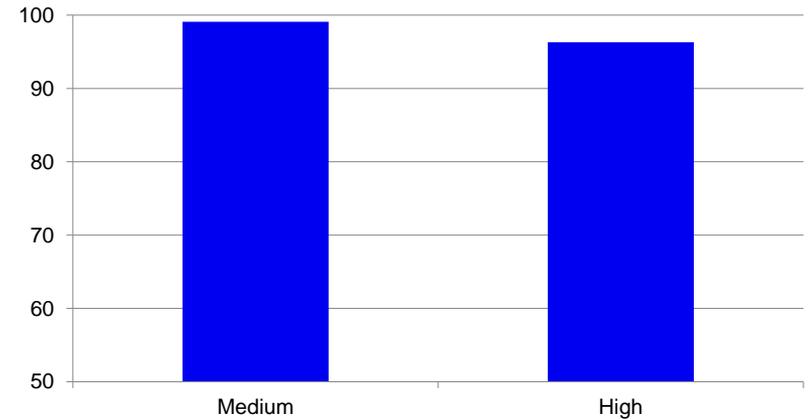
Advanced 6 Component Balance Capability Captures Critical System Performance Metrics

1st ever dynamic balance
integration

Functionality verified and values
validated against 2 component
balance

Enables system level
performance measurements over
range of angle of attacks

Test data in line with CFD based
predictions and measured aero
results



UHB Propulsor Power as a Percentage of Pre-Test
Predictions at Two Fan Speeds

FAA CLEEN FAN RIG PROGRAM STATUS

Integrated UHB Rig Test Readiness

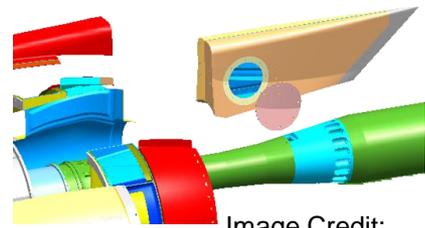
Extensive use of composites for simulated nacelle hardware



Photo Credit: Composites Universal Group

Rotor balance in process at NASA

Hardware fabrication tracking mid December assembly start



Pylon Duct Acoustic Configuration

Image Credit: Pratt & Whitney

Modular design features incorporated to facilitate configuration swaps



Photo Credits: Composites Universal Group



FEGV with Removable Vanes



Removable Vanes (Instrumented & clean)



Fan Blades Trial Fit to Rotor

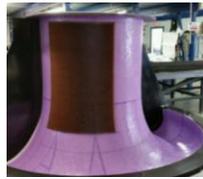
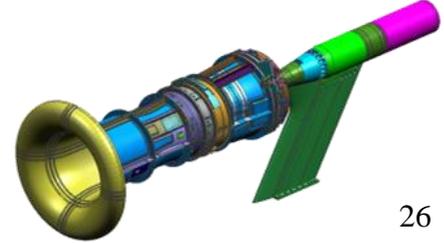


Image Credit: Pratt & Whitney

Bellmouth & VFEN Duct Performance Configuration



FAA CLEEN PROGRAM STATUS



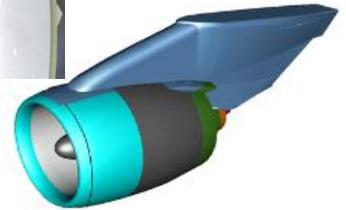
CLEEN Demonstrator Engine Status

Demonstrator engine assembly adjusted to incorporate PW1000G development requirements



Image Credit: Pratt & Whitney

Assembly to start November 2015



All nacelle technology hardware delivered



Fan hardware in final fabrication

Photo Credits: Pratt & Whitney

ID	Task Name	2010			2011				2012				2013				2014				2015				2016			
		Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	
1	CLEEN Technology Program	[Blue bar spanning all quarters from 2010 Q2 to 2016 Q3]																										
2	Technology Study Phase	[Blue bar]																										
3	Technology Design Phase				[Blue bar]																							
4	Hardware Fabrication												[Blue bar]															
5	Technology Demonstration																				[Blue bar]							
6	Technology Assessment																				[Blue bar]							

FAA CLEEN TECHNOLOGIES – P&W



CLEEN technologies advances UHB configuration

Ultra-High Bypass Propulsor (CLEEN)

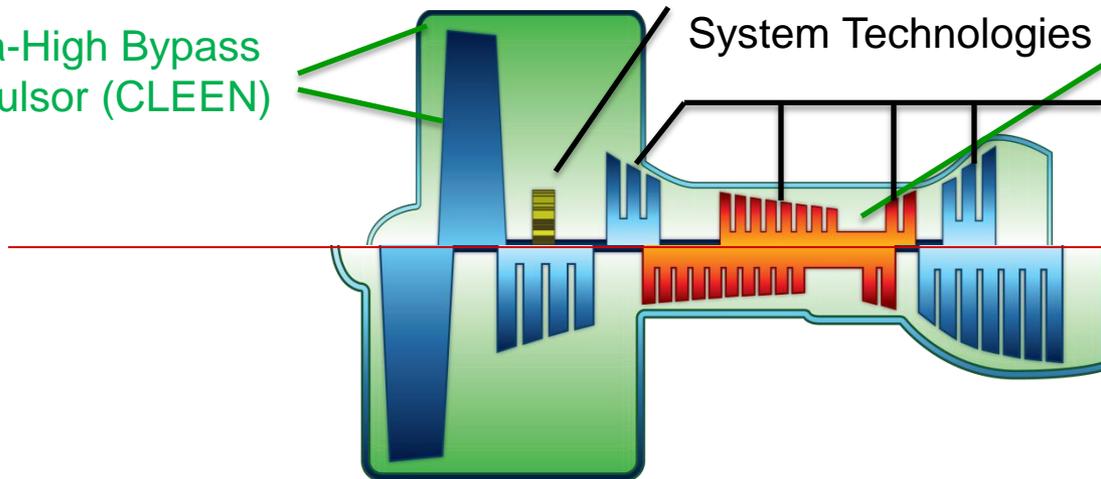
Advanced Fan Gear Drive System Technologies

Integrated Combustor/Turbine (NASA ERA Phase II)

Advanced Turbine & Compressor Technologies

UHB Propulsion Configuration

Conventional Propulsion Configuration



				CLEEN Rig and Engine Demonstrator Programs and Technologies	
Company	Technology	Goal Impact	CLEEN Goals	Very High-Bypass (2015 - 2020 EIS)	Ultra High-Bypass (2020+ EIS)
P&W	UHB Propulsion System	Fuel-burn	33% Reduction	15% Reduction	20% Reduction
		Emissions	60% Reduction in NOx (re: CAEP 6)	50% Reduction in NOx (re: CAEP 6)	>60% Reduction in NOx (re: CAEP 6)
		Noise	32 EPNdb Reduction	20 EPNdb Reduction (re: Stage 4)	>20 EPNdb Reduction (re: Stage 4)

SUMMARY



Alternative fuel engine & rig evaluation completed

No significant differences noted from test results

Fan rig testing validates expected UHB technology performance

Over 400 hours of rig testing completed

Validated with advanced CFD predictions

World class dataset for tool validation

Integrated UHB fan rig progressing to December assembly

Scaled CLEEN representative of engine installation

CLEEN demonstrator engine progressing to Q4 2015 assembly

Nacelle technology hardware delivered

Fan technology hardware on schedule to support assembly