CLEEN II Consortium Program Update – Public Plenary GE Aviation

May 13, 2020

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GE CLEEN Technologies Summary

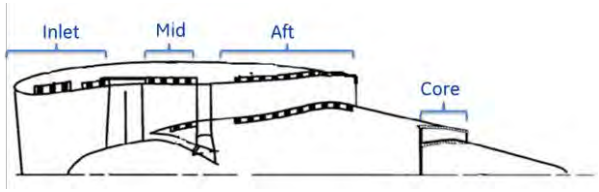
CLEEN Technology Name	Goal Impact	Benefits and Application
Advanced Acoustics	Noise	Up to 3 EPNdB cum with neutral fuel burn impact
MESTANG I	Fuel burn	Up to 3% benefit for single-aisle aircraft
MESTANG II	Fuel burn	Additional fuel burn benefits 1-2%
Sustainable Aviation Fuels	Alternative Fuels	Advance SAF approvals and evaluation tools
FMS	Fuel burn	Up to 4% benefit, 1.0% fleetwide average
TAPS III –Technology	Emissions	35% reduction relative to CAEP/8 (55 OPR)

Low Pressure Ratio (LPR) Advanced Acoustics

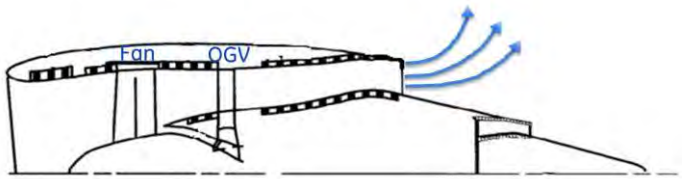
Tim Depuy

Project Technology

Novel Liners



Fan Source Strength Reduction



Anticipated Benefits:

Improved Acoustic Liner Benefit re: Single Degree Freedom Liners,
Target ~ 2EPNdB Cum, Neutral Performance.

Improved Fan Noise Source Strength Reduction re: LEAP.
Target ~ 1 EPNdB Cum, Neutral Performance.

Objectives:

To Develop Novel Acoustic Liners.
To Develop Fan Source Strength Reduction Concepts.

Work Statement:

Design, Develop, Fabricate and Test Novel Acoustic Liner.

Aeroacoustic Design and Testing of Fan noise source strength reduction concepts.

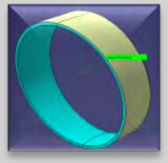
Accomplishments/ Milestones:

- *Developed several novel liner cores.*
- *Tested several liners with at NASA's Grazing Flow Impedance Tube facility*
- *Downselected to a specific liner design.*

Fan Noise Source Reduction

- *Completed Fan Source Strength Reduction design reviews.*
- *Started manufacture of subscale hardware to validate acoustic benefit and performance.*

Project Schedule

Technology	Earlier	FY 2018	FY 2019	FY 2020
1. Novel Acoustic Liner Technology Test part geometry	Concepts Developed and Tested in Normal Impedance Tube <5” X 5” 	Grazing Flow Test Rig Round 1 2.5” X 21”	Grazing Flow Test Rig Round 2 2.5 X 21” 	Large scale samples 
TRL/MRL		3/3	4/4	4/4
2. Fan Noise Source Strength Reduction	Down Select and Identify Source Strength Reduction Concepts	Preliminary Design of one Aeroacoustic fan Source Strength Reduction Design	Pre test Prediction & Final Reviews	Hardware Manufacture for Wind Tunnel UPS test
TRL		3		3

Summary and Next Steps

Novel Liners

- Completed Phase 2 of Grazing Flow tests
- Manufacturing 2 final liner panels which are optimized for a full scale design
- Manufacturing a large sample panel

Fan Source Strength Reduction

- Subscale test hardware being manufactured

More Electric Systems and Technologies for Aircraft in the Next Generation (MESTANG I)

Dr. Venkatesh Saligrama

MESTANG Technology Overview

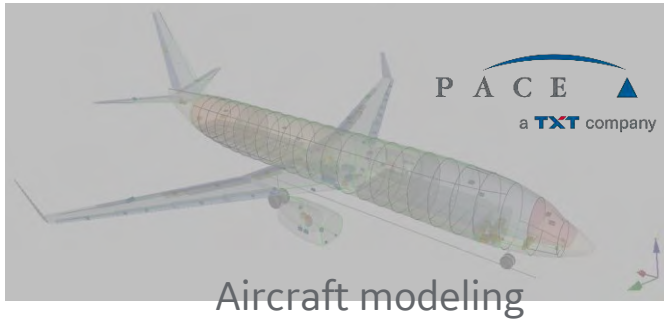
Next-gen Commercial Aircraft will need a "more-electric" power system to realize practical fuel savings and/or mission capability

Project objectives:

- Prove ±270 VDC primary power system feasibility through lab demonstration and modeling
- 150kW ±270 VDC High Pressure Spool Starter / Generator (HPSG), including Power Conversion Unit (PCU)
- Demonstrate all-SiC based Starter / Generator / Motor Controller (SGMC)
- Demonstrate dual spool equivalent power extraction
- Prove up to 3% fuel savings by performing aircraft + engine + power system aircraft modeling
- Testing to limited TRL 6 rating by September 2020 at EPISCENTER

Customer objectives:

More Electric Systems and Technologies for Aircraft in the Next Generation (MESTANG), is an integrated aircraft power system designed to support future "more-electric" aircraft architectures that reduce fuel burn by up to 3 percent for single-aisle aircraft while improving performance at equivalent cost

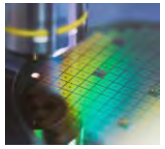


Project Schedule

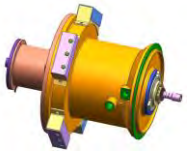
FY/CY 2019 - 2020 Accomplishments / Milestones:

- ✓ FAA Consortium – November 19-22, 2019
- ✓ HPSG and PCU, open loop test – January 30, 2020
- ✓ SGMC HW – February 29, 2020
- FAA Consortium – April 28 - 30, 2020
- HPSG Unit & PCU Unit – June 30, 2020
- System Test & Demo – September 18, 2020

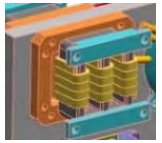
Fabricated GE Gen3 SiC

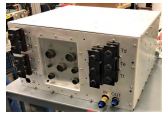


✓ Generator Preliminary Design



Design for EMI





TRL 4 SGMC

TRL 5 SGMC

✓Consortium ✓Consortium ✓Consortium ✓Consortium Consortium

Q1 - Q4 '17 | Q1 - Q4 '18 | Q1 - Q4 '19 | Q1'20 | Q2'20 | Q3'20 | System Demonstration 2020

HW Component Tests

System/ HW-SW Integration Tests

✓PDR

✓DDR

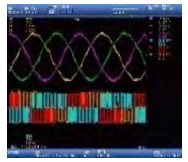
✓System Test Spiral V

TRL 5 *

TRL 5 *

Final System Test Spiral

Manufactured ±270 VDC Silicon Carbide Modules



Powered Converter Tests

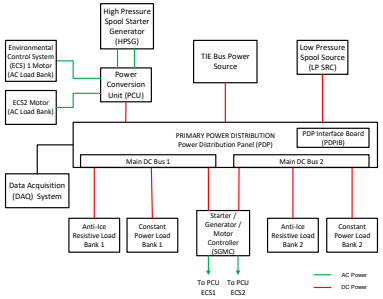
TRL 4
✓ HPSG

✓ PCU

HPSG

PCU

* HPSG & SGMC HW SW Lab Integration



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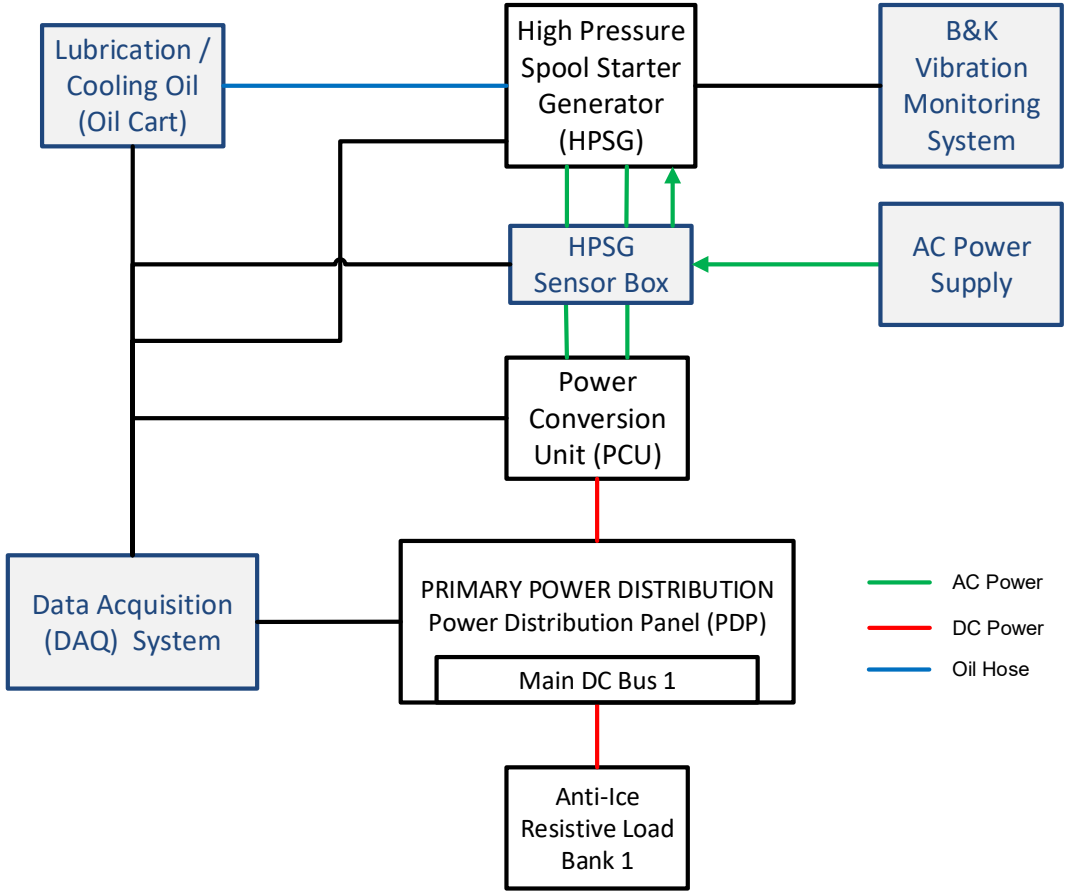
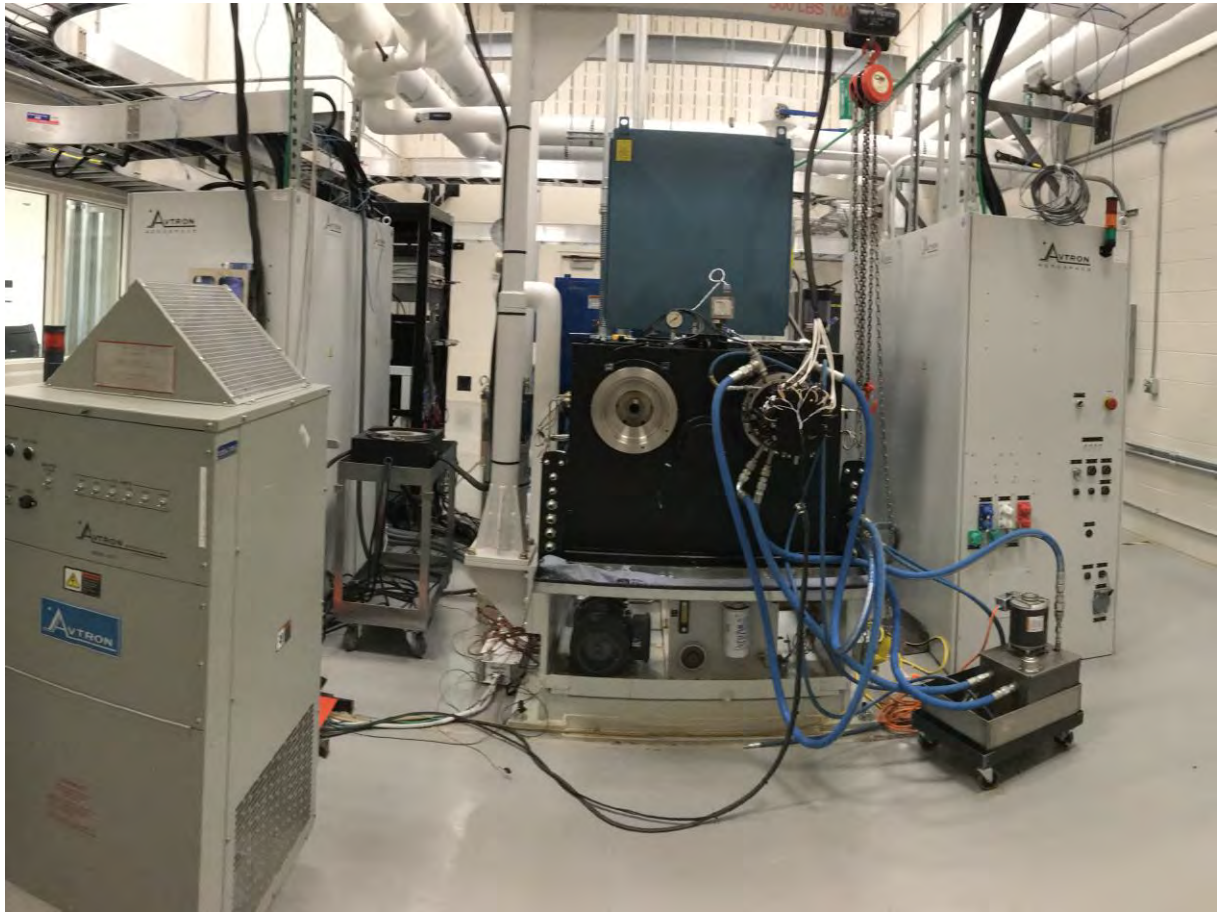
HPSG and PCU Testing

- ✓ Completed open loop testing up to full load of HPSG and PCU prototype. HPSG showed stable mechanical, thermal and vibration performance
- System level testing up to full load will be done with prototype scheduled by June 2020



EPISCenter Lab Setup

Front view of drive stand



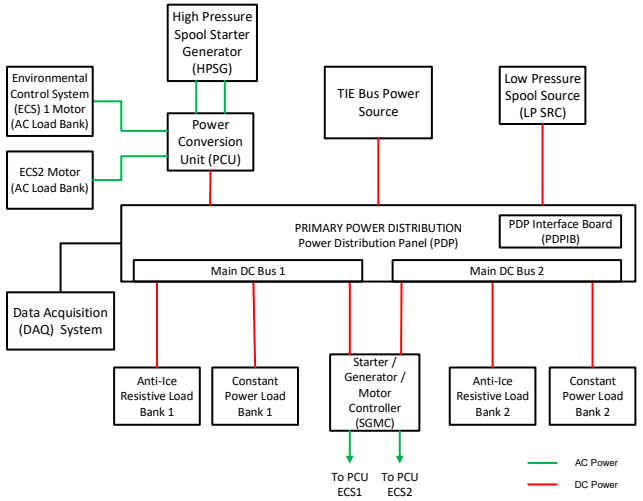
Drive stand control, oil cart, test rack

SGMC System Development and Testing

- ✓ SGMC prototype completed
- ✓ SGMC Exciter Inverter Close Loop testing.
- SGMC Exciter Inverter + HPSG system control tuning (June 2020)
- SGMC + HPSG + PCU system testing (July 2020)

Project Technology – HPSG, SGMC

Demonstration Architecture



Benefits:

- More efficient +/- 270VDC power system to realize practical fuel savings and/or mission capability
- 600kW aircraft power system
- Capable of electric engine starting
- Demonstrate all-SiC power system
- Limited TRL 6 by 2020 at EPISCENTER

Objectives:

Mature an integrated aircraft power system consisting of a bleedless, dual-spool engine, and +/- 270VDC more-electric primary power system

Work Statement:

- Gain up to 3% Fuel Savings in Single-Aisle A/C Family using the proposed power system model
- Full power system solution with improved performance at equivalent cost

Key CLEEN II Accomplishments:

• Program Kick Off	4/1/2016
• Architecture Trade Study and initial 300 kW Architecture	10/19/2016
• Enhanced 300 kW Architecture for PDR	3/21/2017
• Preliminary Design Review (FAA)	5/1/2017
• Completed initial Systems Requirement Document (SRD)	12/8/2017
• Completed initial Interface Control Document (ICD)	4/6/2018
• Detailed Design Review (FAA)	4/25/2018
• Completed PACE Baseline and MEA Model SFC calculation	10/12/2018
• Completed HPSG v1.0 + PCU v1.0 prototypes	10/31/2019
• Completed HPSG v1.0 open loop test at full load	1/302020
• Completed SGMC v1.0 HW test	2/29/2020

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More Electric Systems and Technologies for Aircraft in the Next Generation (MESTANG II)

Fabian Isaza

MESTANG Technology Overview

Next-gen Commercial Aircraft will need a “more-electric” power system to realize practical fuel savings and/or mission capability

Customer objectives:

More Electric Systems and Technologies for Aircraft in the Next Generation (MESTANG), is an integrated aircraft power system designed to support future “more-electric” aircraft architectures that reduce fuel burn by up to 3% for single-aisle aircraft while improving performance at equivalent cost

Project objectives:

- Advance kV-Class DC primary power system feasibility through lab demonstration
- MW-Class Flight Altitude Generator
- Demonstration with MW-Class SiC converter (NASA SLIM)
- TRL6 demonstrator at GE EPISCenter and NASA’s NEAT Facility
- Demonstrate fuel burn benefit (1-2%) over ± 270V MESTANG Power System

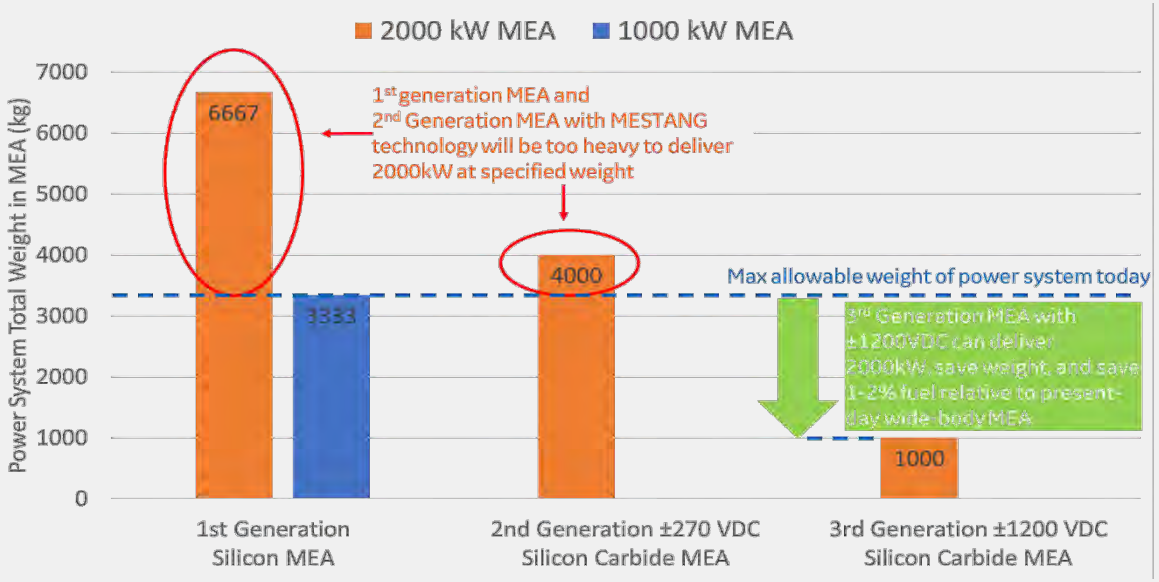
kV/MW Class Generator Benefits

System Weight

kV-Class components enable High Power Density:

- 6+ kW/kg Generators
- 10+ kW/kg Converters
- 2+ kW/kg Power Generation System

B787 Widebody Power System Baseline



Fuel Burn

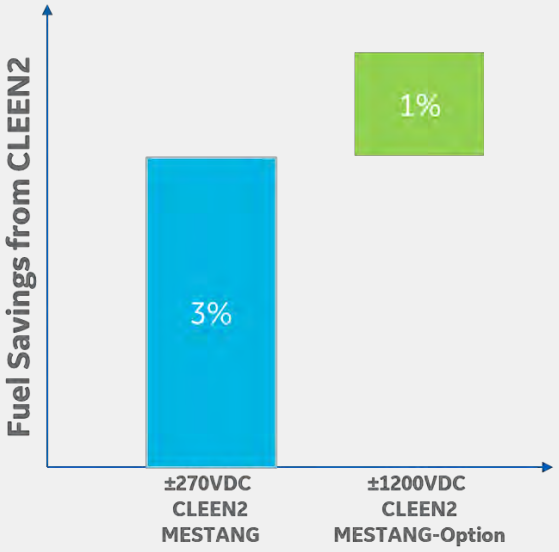
For Widebody aircraft, kV-Class components power density enable fuel burn benefits:

- 1-2% over MESTANG
- 2-3% over 1st Gen MEA

Assumes 4000nm mission

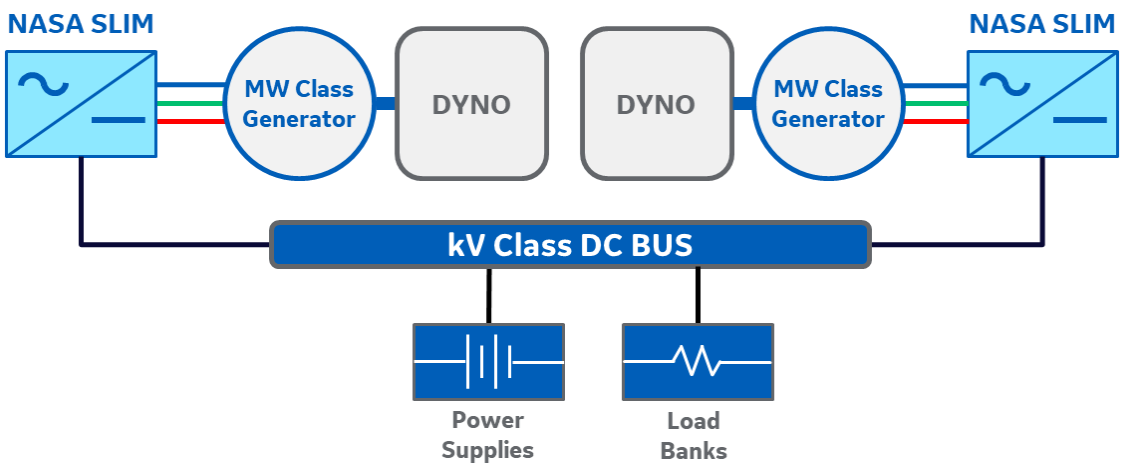
Add'l Opportunities:

- Bleed less
- Electric start
- ECS and actuation
- eTaxi
- System optimization



High Voltage Power System enables weight and system optimization

Project Technology: kV/ MW Class Generator



Anticipated Benefits:

- Additional fuel burn benefits of 1-2%
- Higher power density…
  - >2kW/kg Power Generation System
- High efficiency power distribution
- Optimization of electrical system

Objectives:

- TRL6 for high voltage and high power generator
- Specific Power system density >2 kW/kg

Work Statement:

- Design and test of altitude flight high voltage and high power generator

Accomplishments/ Milestones:

• Test Facility preparation	Complete
• Rotor Assembly	Complete
• Stator Assembly	Complete
• Generator Assembly	May 2020

Schedule:

4Q 19	1Q 20	2Q 20	2nd Half 20
Design ✓ Complete	Manufacture ✓ Sub-Assemblies	Assy/Install Comp. Test	System Test

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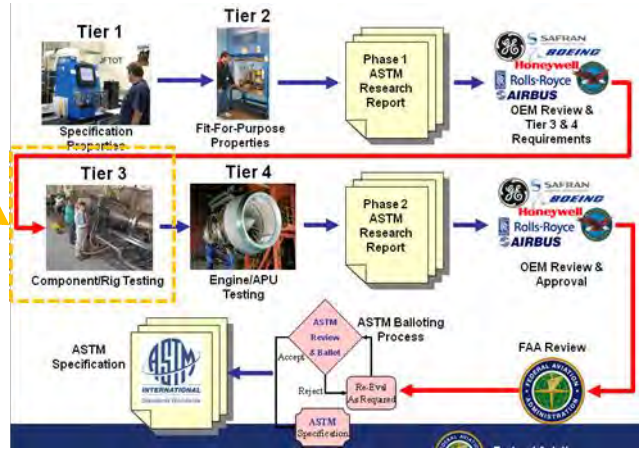
Sustainable Aviation Fuels

Dr. Gurhan Andac

CLEEN II Sustainable Aviation Fuels

Rig test evaluations



ASTM D4054

Benefits:

- Advance to fully synthetic fuels.
- Advance approvals of multiple synthetic fuels on ASTM roadmap.
- Extend further to lean combustion systems evaluations.
- Determine if sensitivities of combustion parameters observed at component level could be duplicated at system level, or are they washed out?

Objectives:

- Advance approval and intro of "drop in" fuels:
  - Support ASTM D4054 – testing/demo phase
  - Conduct work complimentary to other FAA programs

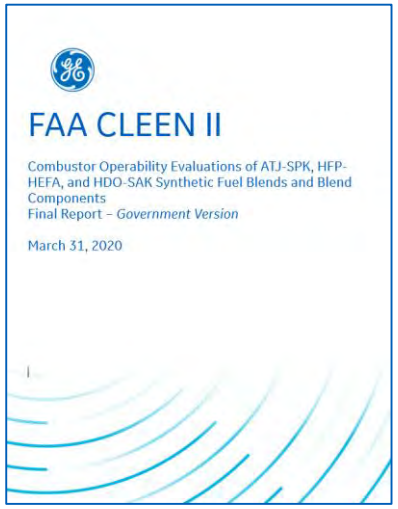
Work Scope:

- Test two fuels, one fully synthetic and one blend, in ASTM roadmap – (FAR* test)
- Test one fuel defined by FAA's National Jet Fuel Combustion Program (NJFCP) – (FAR test)

*FAR: Full Annular Combustor Rig

Since November 2019 Consortium:

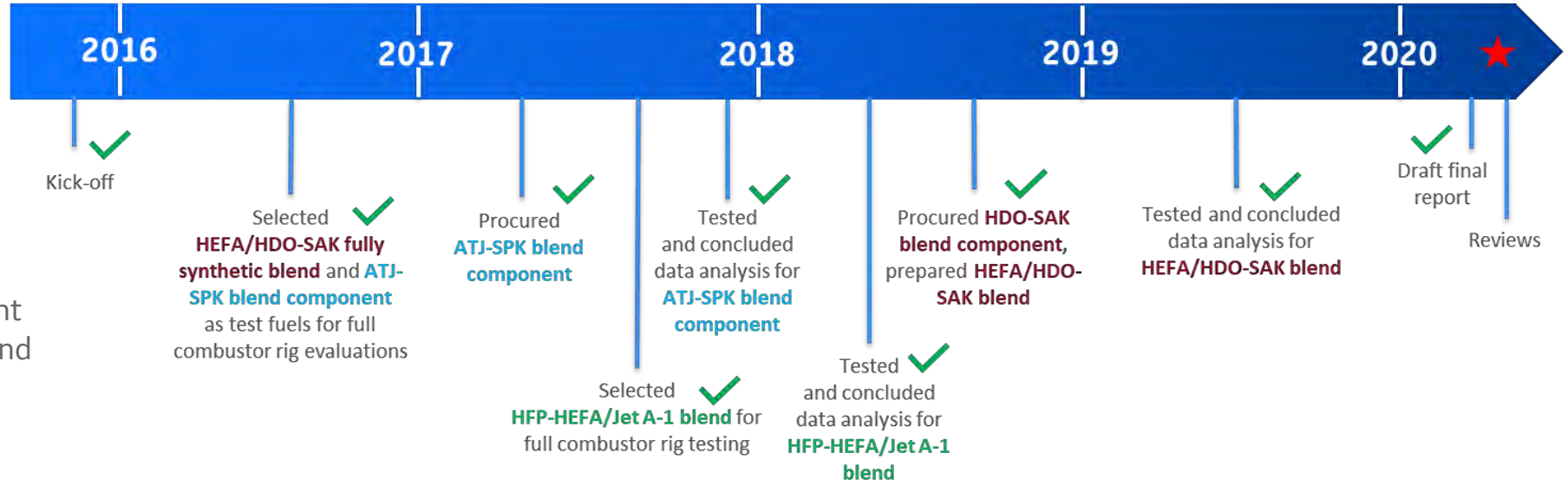
- Draft Final Report written and submitted to FAA
- CLEEN III SAF proposals submitted to FAA


FAA CLEEN II

Combustor Operability Evaluations of ATJ-SPK, HFP-HEFA, and HDO-SAK Synthetic Fuel Blends and Blend Components
Final Report – *Government Version*

March 31, 2020

Schedule



Blend ratios:
100% ATJ-SPK Blend Component
16%HFP-HEFA/84% Jet A-1 Blend
75%HEFA/25%HDO-SAK Blend

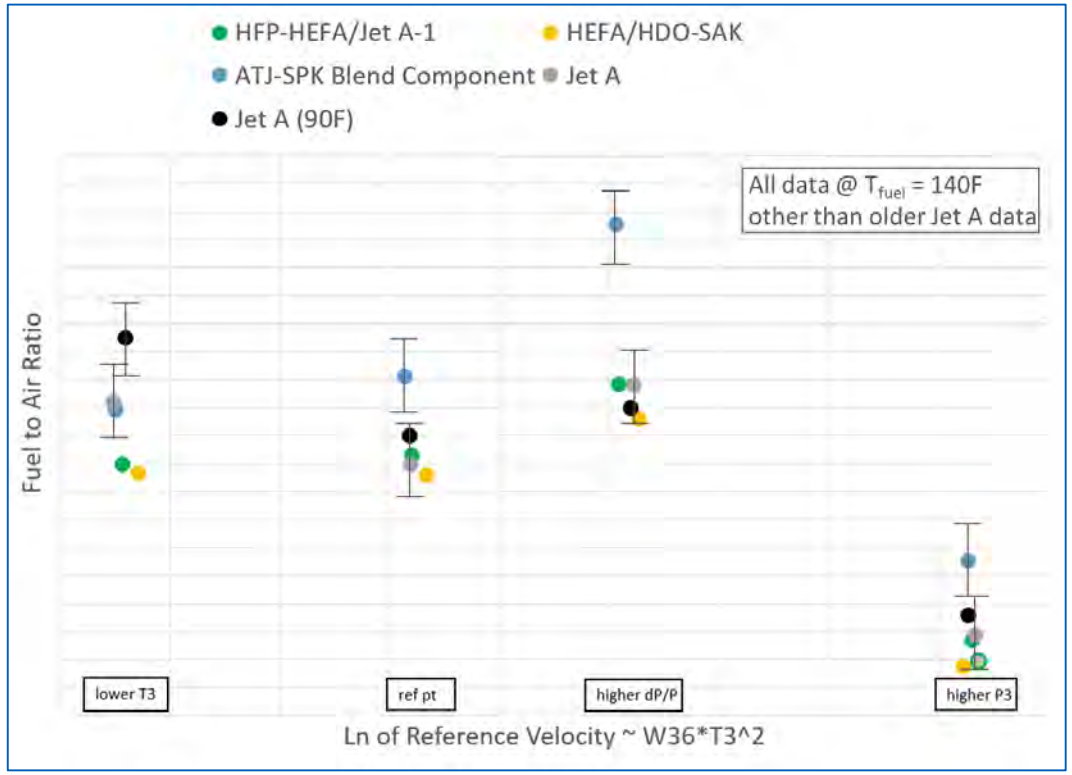
Operability focused evaluations: ignition & blow-out for all fuels, sub-idle efficiency & high-power fuel cut for HFP-HEFA only

Program Objectives Status

Objective	Status
Supplement other FAA programs	ATJ-SPK tests to validate adequacy of NJFCP tools **completed**
Advance practical fuel approval	HFP-HEFA selected, testing and data analysis **completed**
Advance fully synthetic fuels approvals	HDO-SAK/HEFA fully synthetic blend, testing and data analysis **completed**
Final report	Draft final report **submitted**

Data examples & summary

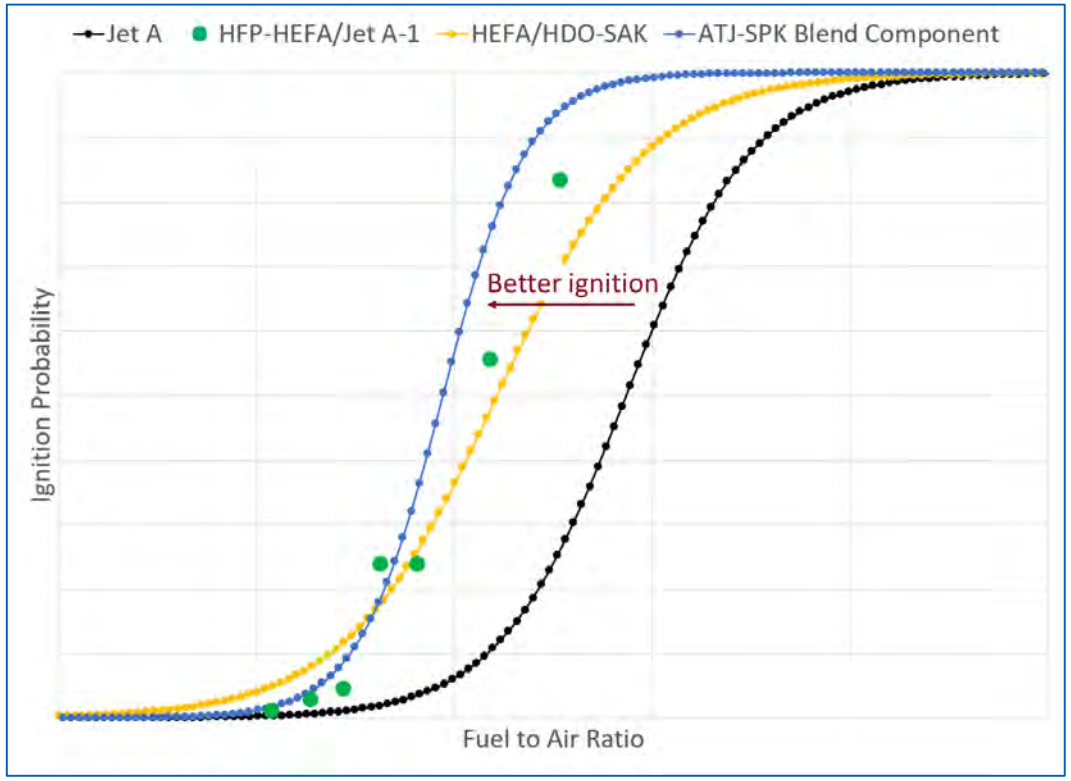
Lean Blow-out (FAR Rig)



- Impact of lower fuel temperature (higher viscosity) observed at low loading is consistent with NJFCP observation for systems that are evaporation limited with respect to Lean Blow-out performance.

- Impact of ATJ-SPK Blend Component chemistry consistent with NJFCP observation for systems that are not evaporation limited with respect to Lean Blow-out performance.

Cold Start at -30 °F & low dP/P (FAR Rig)



- The alternative fuels (or blend component) yielded somewhat better ignition performance than the reference Jet A fuel at the most severe condition tested.

- ATJ-SPK Blend Component ignition performance at this condition in the Referee Rig (NJFCP) is similar to best case Jet A as defined by that program.

Overall summary

- **Completed evaluation/testing of all three fuels with immediate impact** to ASTM approvals of practical fuels and other national fuels programs

- **Practical fuels revealed no adverse impact** on operability
  - HDO-SAK Phase II report OEM review starts within months
  - HFP-HEFA approval effort gaining momentum again

- **Research fuel did show impact as anticipated**; the effect matched NJFCP trends **validating small scale predictive tool**

Thank you FAA for helping towards a sustainable future!