CLEEN II Consortium Program Update – Public Plenary GE Aviation

Nov 21, 2019

Approved for Public Use

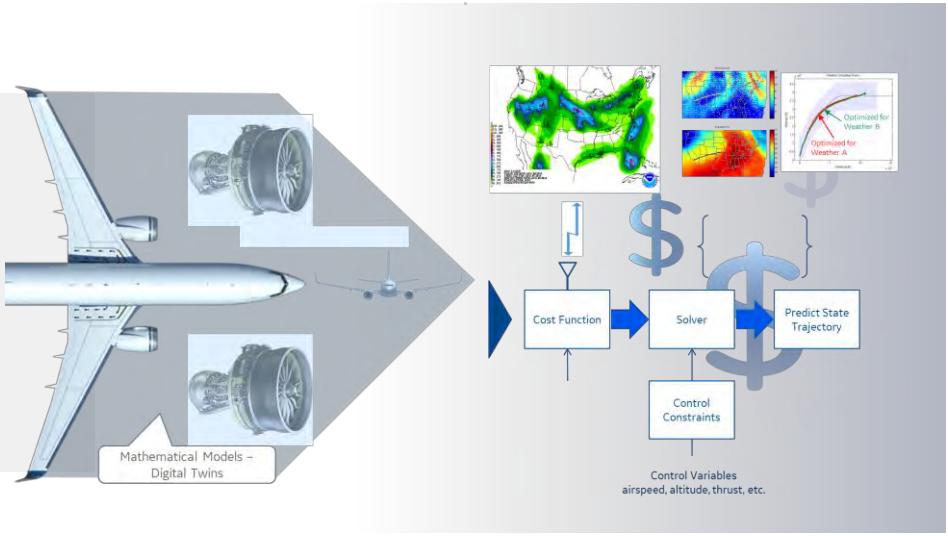
GE CLEEN Technologies Summary

CLEEN Technology Name	Goal Impact	Benefits and Application
FMS	Fuel burn	Up to 4% benefit, 1.0% fleetwide average
Sustainable Alternative Fuels	Alternative Fuels	Advance approvals of multiple synthetic fuels on ASTM roadmap
MESTANG	Fuel burn	Up to 3% benefit for single-aisle aircraft
Advanced Acoustics	Noise	Up to 3 EPNdB cum with neutral fuel burn impact

Flight Management System (FMS)

Dave Lax

Executive Summary



Objective

- Develop algorithms to optimize performance to minimize cost of flying city pairs, complying with IFR
- High accuracy/ resolution model of the atmosphere; wind-optimized cruise; unified climb, cruise, descent; optimal required times of arrival
- Reduction in community noise & emissions

Results To Date:

- Up to 4% fuel savings relative to legacy (constant alt)
- Up to 3% fuel savings relative to legacy w/ AOC-assisted step climb

2018 Accomplishments

- **Gen B** – Wind optimal cruise altitude
- **Gen C** - Unified Climb, Cruise, and Descent with steps in cruise

2019 Milestones

- Detailed Design Review (completed Feb/2019)
- Complete demonstration and final report
- Complete benefit assessments

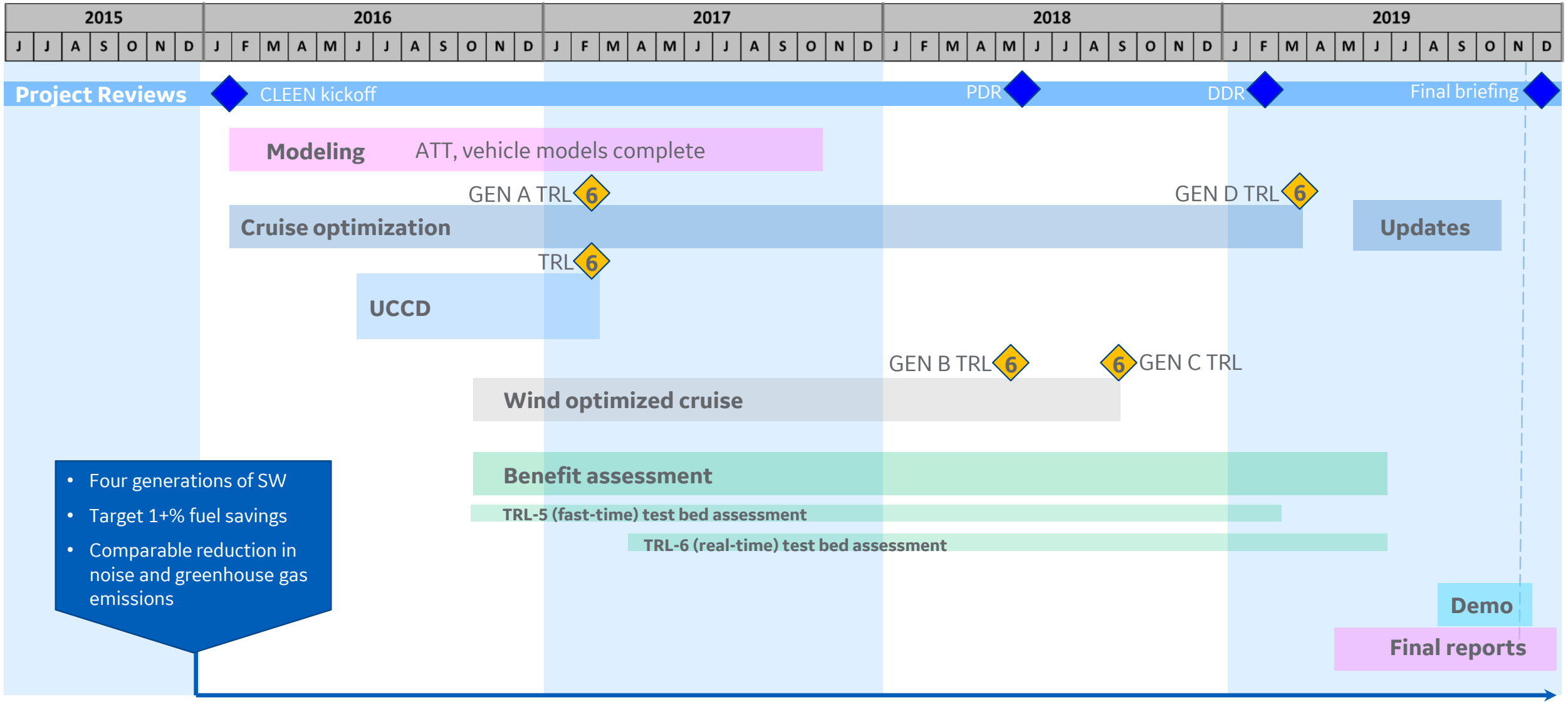
Past 6 Months

- **Algorithm Performance Improvements**

Benefits enabled by Connected FMS

Utilizes a set of algorithms that create a cost function / prediction sequence to help determine the optimal flight path

Project Schedule



- Four generations of SW
- Target 1+% fuel savings
- Comparable reduction in noise and greenhouse gas emissions

Improved optimization delivers better performance to CLEEN II FMS.

Goals for last 6 months…

May 2019 Shortfalls

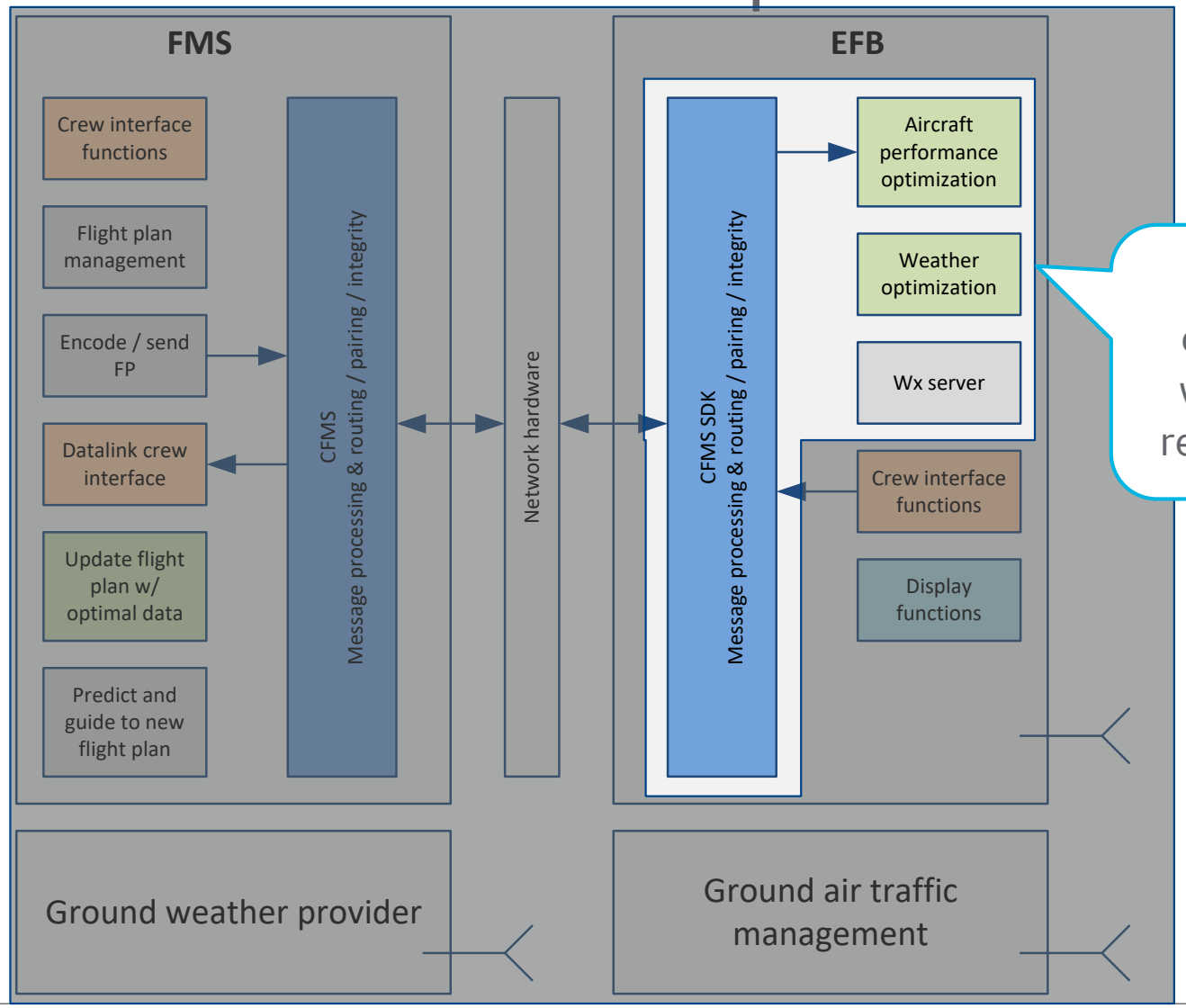
0.7% average benefit	>0.7% average benefit
3 minutes average runtime	<3 minutes longest runtime
~10% cases fail	<5% cases fail
~30% cases do not save fuel	<10% cases do not save fuel

2H2019 Goals

Performance improvement encourages mainstream adoption of CLEEN II FMS

State of the art optimization structure enables reuse to solve for additional benefits (NextGen goals of noise, lateral, etc.)

In parallel (non-CLEEN): Additional Productization Options



Reusable optimization core with CFMS can be rehosted anywhere.

Typical operatior

FMS

Enable pairing

Ena

ype pairing

Gath

Gen B

Disp

Augm

Send

Review o

E:

Pilot actions

Visuals

Fleet-Wide Mean Benefit Assessment Update

Legacy

Constant cruise altitude

Legacy++

AOC ground tool altitude steps

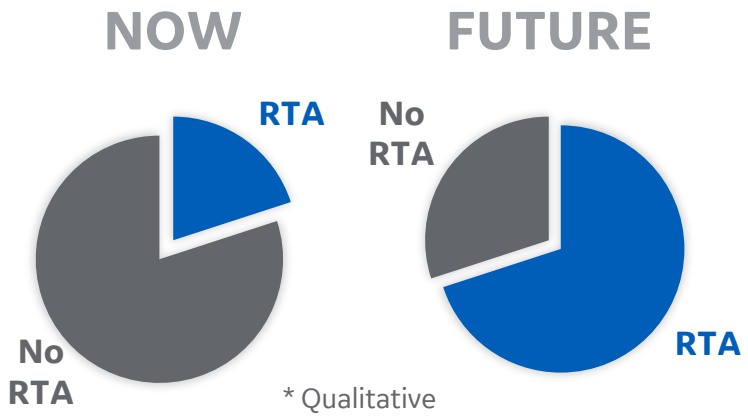
Generation C

Variable thrust / variable speed climb + cruise altitude steps with weather

Generation D

Generation C optimization w/ RTA constraint

Fuel Savings (Cost Index 0)	No RTA (GEN C)	With RTA (GEN D)
Legacy	1.0%	0.8%
Legacy++	0. 4%	0.5%

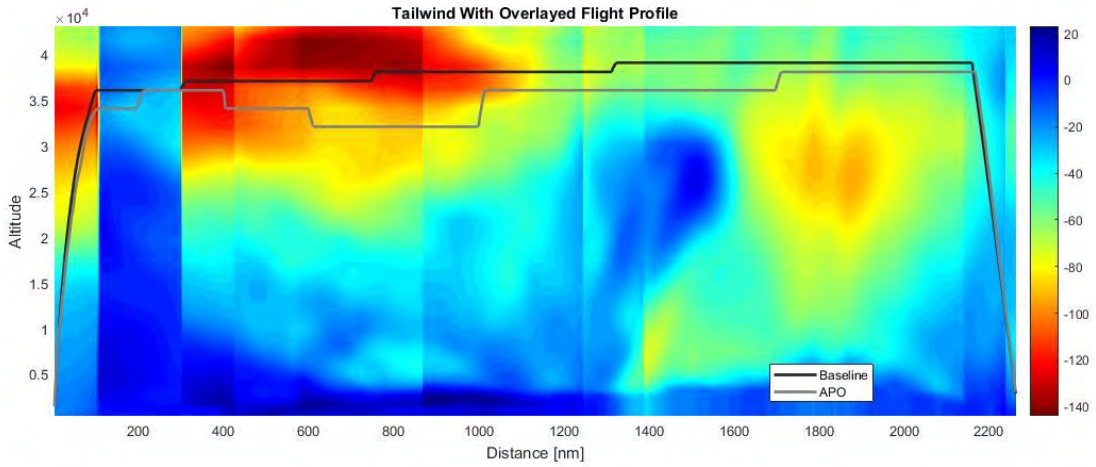


* Qualitative

Unified Climb-Cruise-Descent Optimization with High Fidelity Weather and Cruise Steps

GEN C

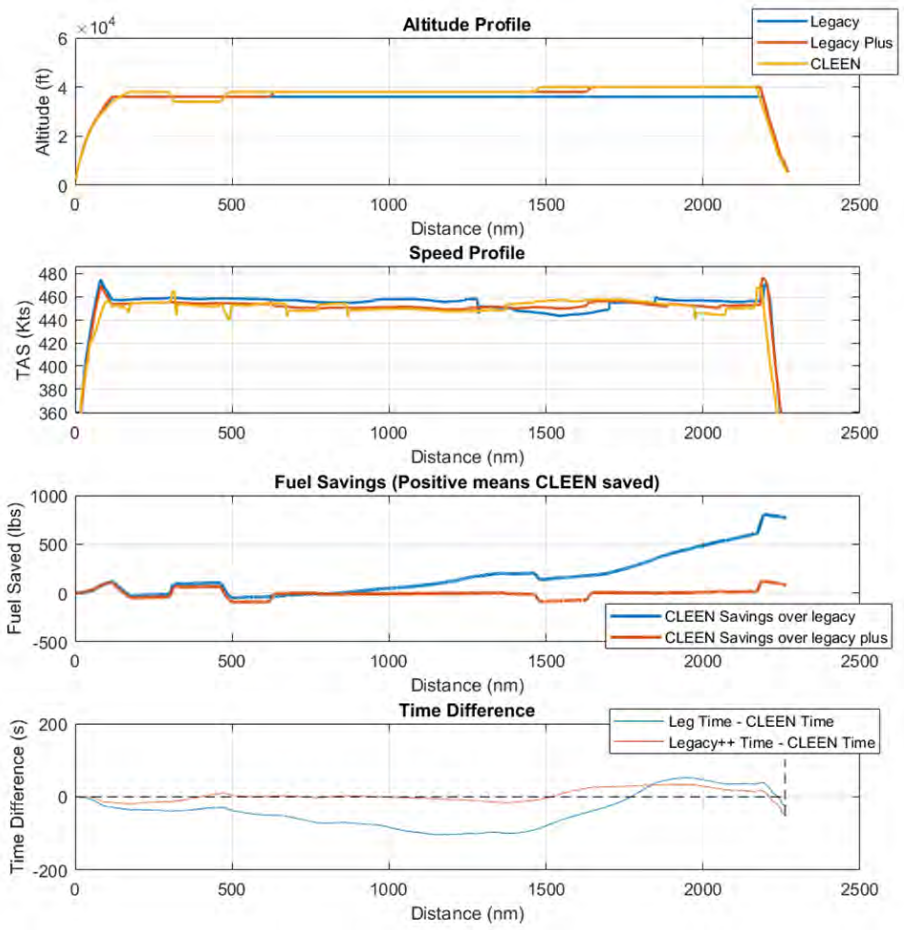
Up to 4.0%	Max fuel savings against Legacy FMS
Up to 2.5%	Max fuel savings against existing AOC tools
130x	More Weather Data



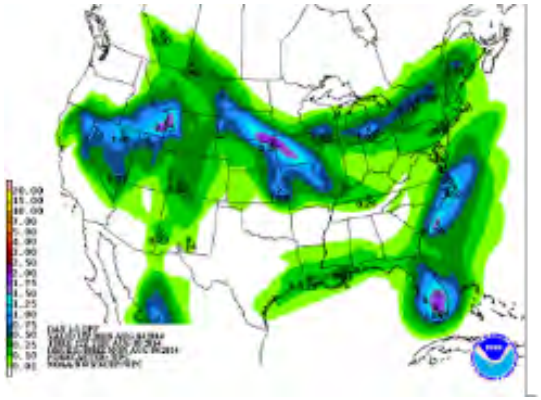
Unified Climb-Cruise-Descent Optimization with Required Time of Arrival (RTA)

GEN D

Up to 3.5%	Max fuel savings against Legacy FMS
Up to 3.0%	Max fuel savings against existing AOC ground tools
2.6x	Fewer repredicts – decreased trajectory negotiation
52%	Wider achievable RTA window



Project Technology



Anticipated Benefits:

- 0 – **4%** fuel savings relative to legacy FMS
- 0 – **3%** fuel savings relative to legacy FMS assisted by AOC-defined step climbs
- Comparable reduction in community noise and greenhouse gas emissions

Risks/Mitigation Plans:

- Low cost, rapid introduction into service ⇨ EFB application integrated with FMS
- Community acceptance ⇨ Consulting with OEMs, Airlines, NASA, and NextGEN Program Office

Objective: Develop algorithms that find the set of optimum controls to minimize the cost of flight while compling with IFR.

Work Statement:

- GEN A ⇨ Reformulate cruise, integrate with climb and descent (UCCD)
- GEN B ⇨ Add high-resolution weather
- GEN C ⇨ Add variable cruise altitude
- GEN D ⇨ Constrain to arrive at required times (RTA)
- GEN D++ ⇨ Improve performance

Accomplishments/Milestones:

- GEN A UCCD (TRL 6) ⇨ Completed Nov 2016
- GEN B Hi Fidelity Weather (TRL 6) ⇨ Completed Jun 2017
- GEN C Optimal Step (TRL 6) ⇨ Completed Sept 2018
- GEN D RTA Constrained (TRL 6) ⇨ Completed Feb 2019

Schedule:

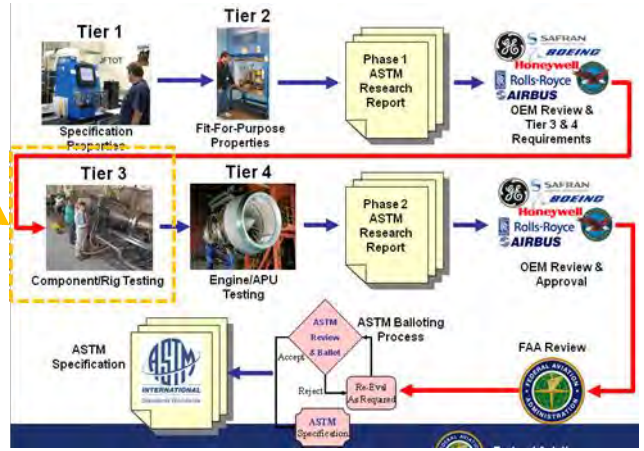
- PDR ⇨ Completed Jun 2018
- DDR ⇨ Completed Feb 2019
- TRL 6 FMS & EFB prototype ⇨ Completed Mar 2019
- Final Report and Demonstration ⇨ 20194Q

Sustainable Alternative 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:

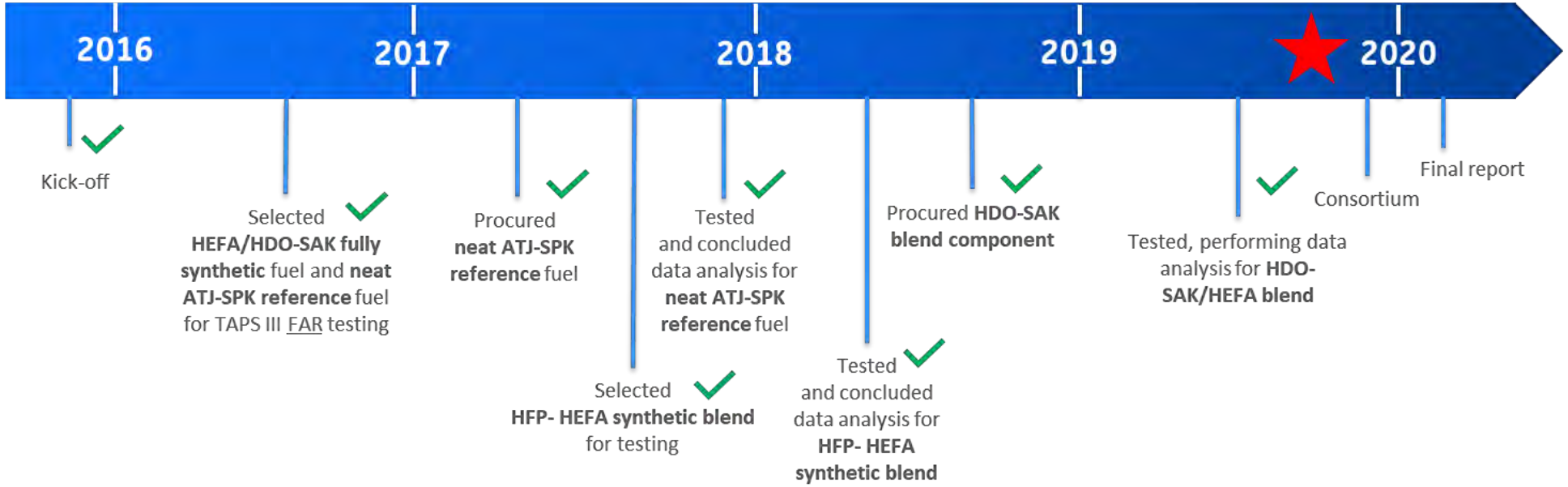
- Test two fuels, one fully synthetic and one blend, in ASTM roadmap – (FAR* test)
- Test one fuel defined by FAA's National Jet Fuel Combustion Program (NJFCP) – (FAR test)

*FAR: Full Annular Combustor Rig

Since May 2019 Consortium:

- Completed combustor rig operability evaluation of HDO-SAK (Virent) in July

Schedule



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

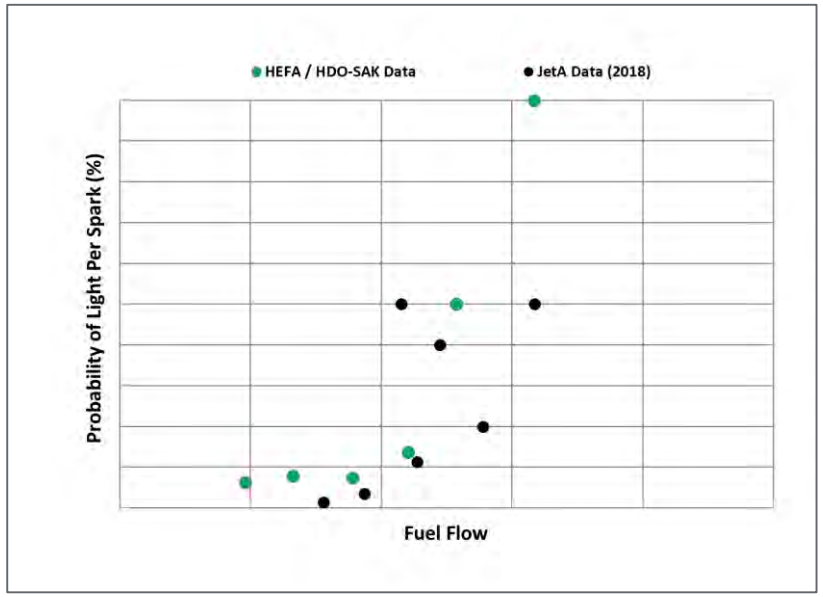
Program Objectives Status

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**

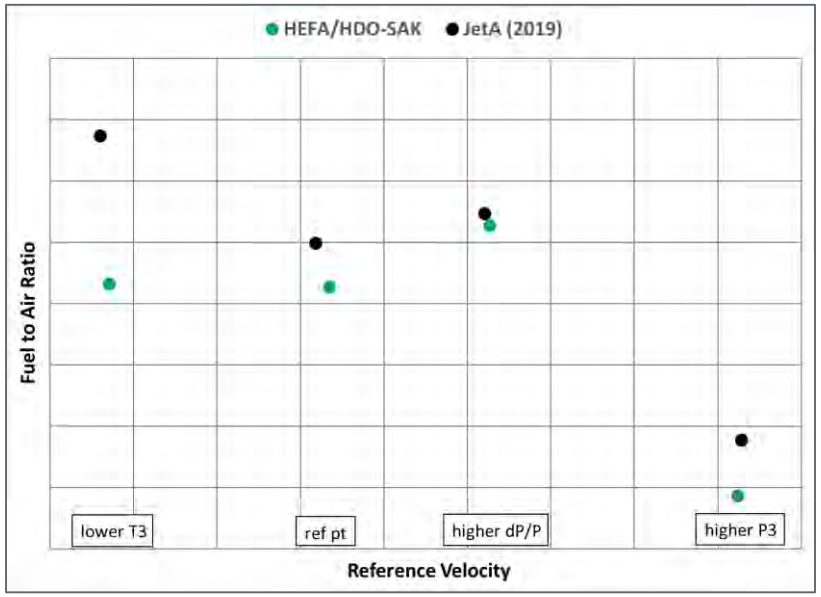
HEFA/**HDO-SAK** 75/25% Blend (July '19)

- Full Annular Combustor Rig Tests – Ignition, LBO
- HDO-SAK from Virent is in ASTM approval process

Light-off



Lean Blow-out



Tested with -25F & 5F fuel temperature @ various operating conditions

Acknowledging USAF/AFRL for support

Equal/better operability performance compared to baseline Jet A

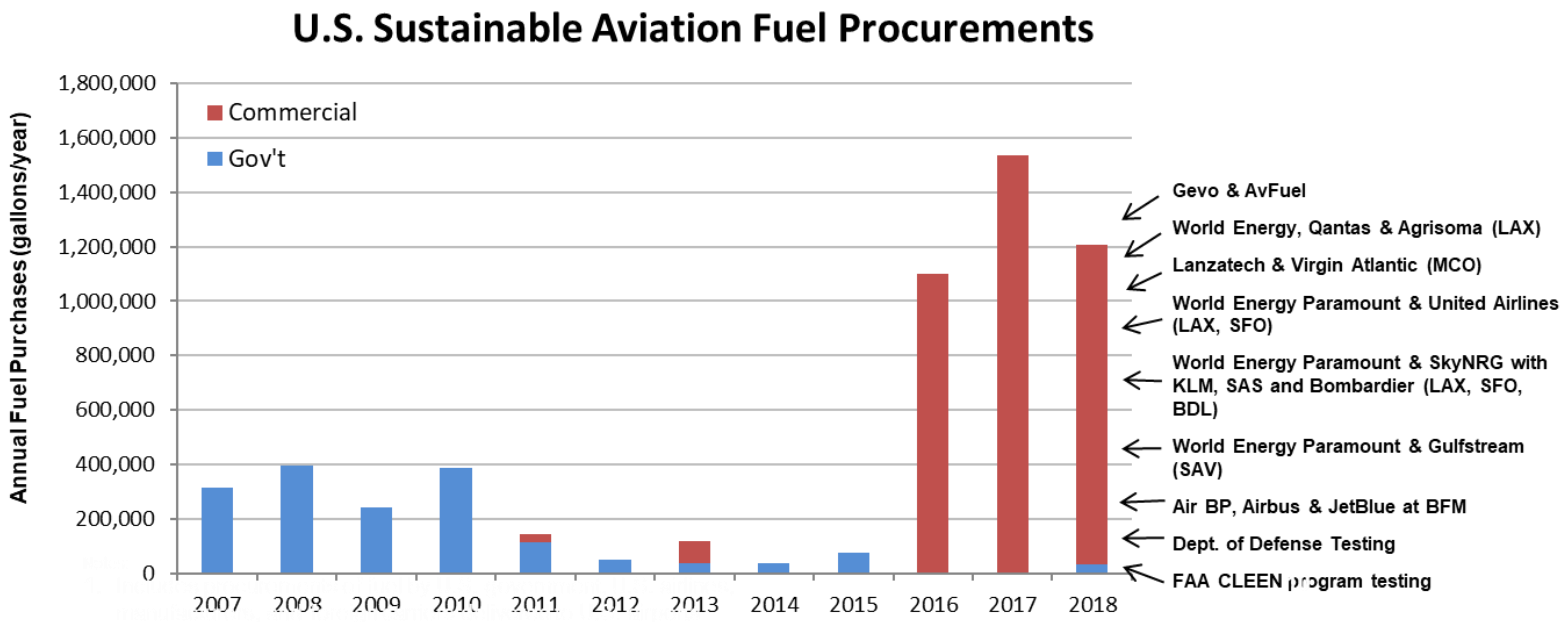
Fuel	Sample	SG (60F), kg/L	Viscosity (cst@100F)	Viscosity (cst@60F)	LHV (BTU/lb)	Hydrogen %	Sulfur % (mass)	Total Water (ppm)
Jet A Specification		min 0.775, max 0.840		max 8.0	min 18400		max 0.30	
HDO-SAK/HEFA	*Trailer*	0.7889	1.21	1.66	18574	13.90	~0	102
HDO-SAK/HEFA	*Rig*	0.7888	1.21	1.66	18578	13.90	~0	96
Jet A (2019)	*Rig*	0.8163	1.56	2.26	18558	13.80	~0	44

Summary – CLEEN II

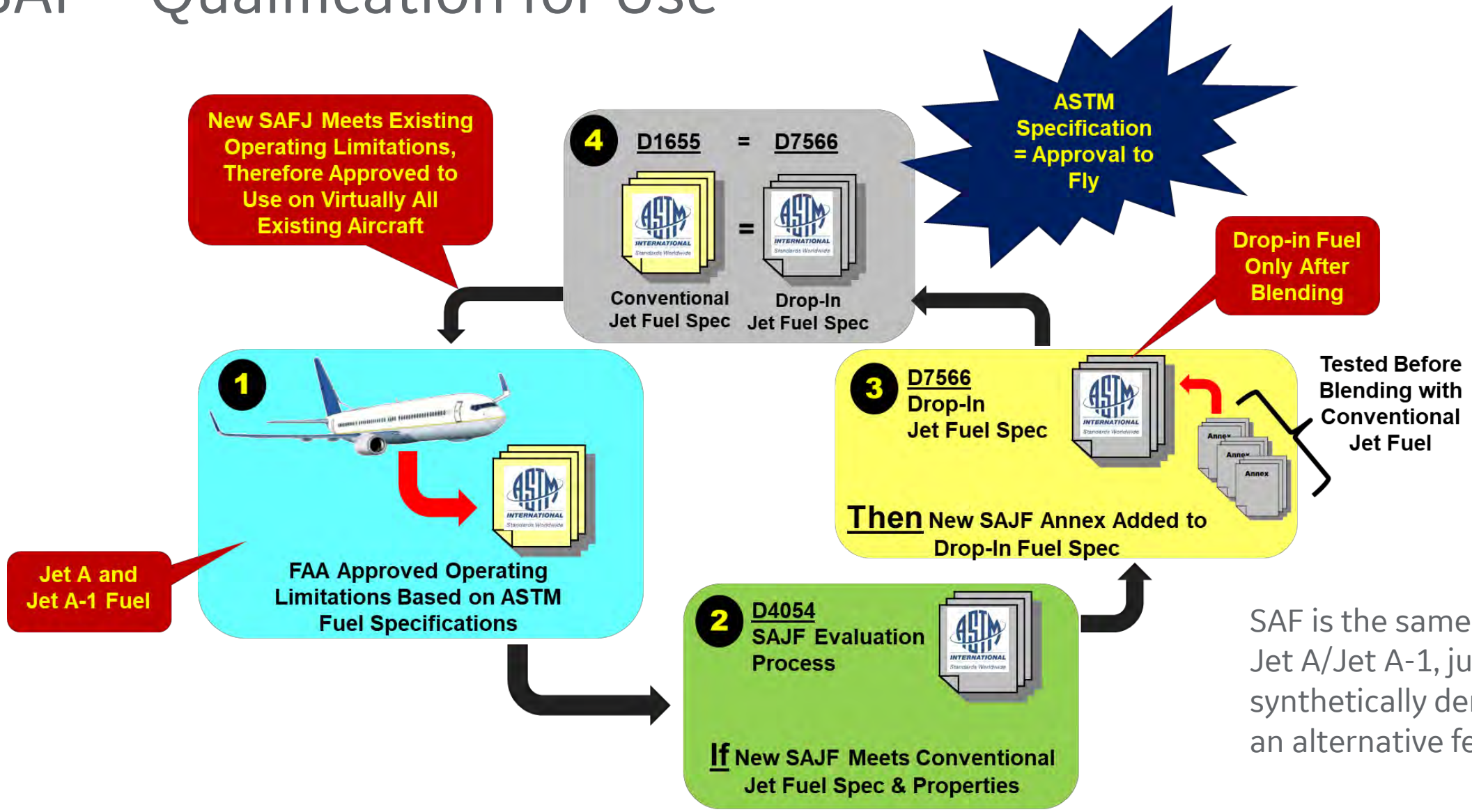
- Completed evaluation/testing of all three fuels with immediate impact to ASTM approvals of practical fuels and other fuels programs
- Practical fuels revealed no adverse impact on operability
- Research fuel did show impact as anticipated; the effect matched NJFCP trends
- Looking forward to continue SAF work in CLEEN III

SAF – Operational Experience

- Three years of sustained commercial production and airline use
- >1.2 million gallons in 2018 from additional producers, users, and airports
- New fuels under evaluation & construction of new facilities under way
- Potential for 250+ million gallons/year in <five years

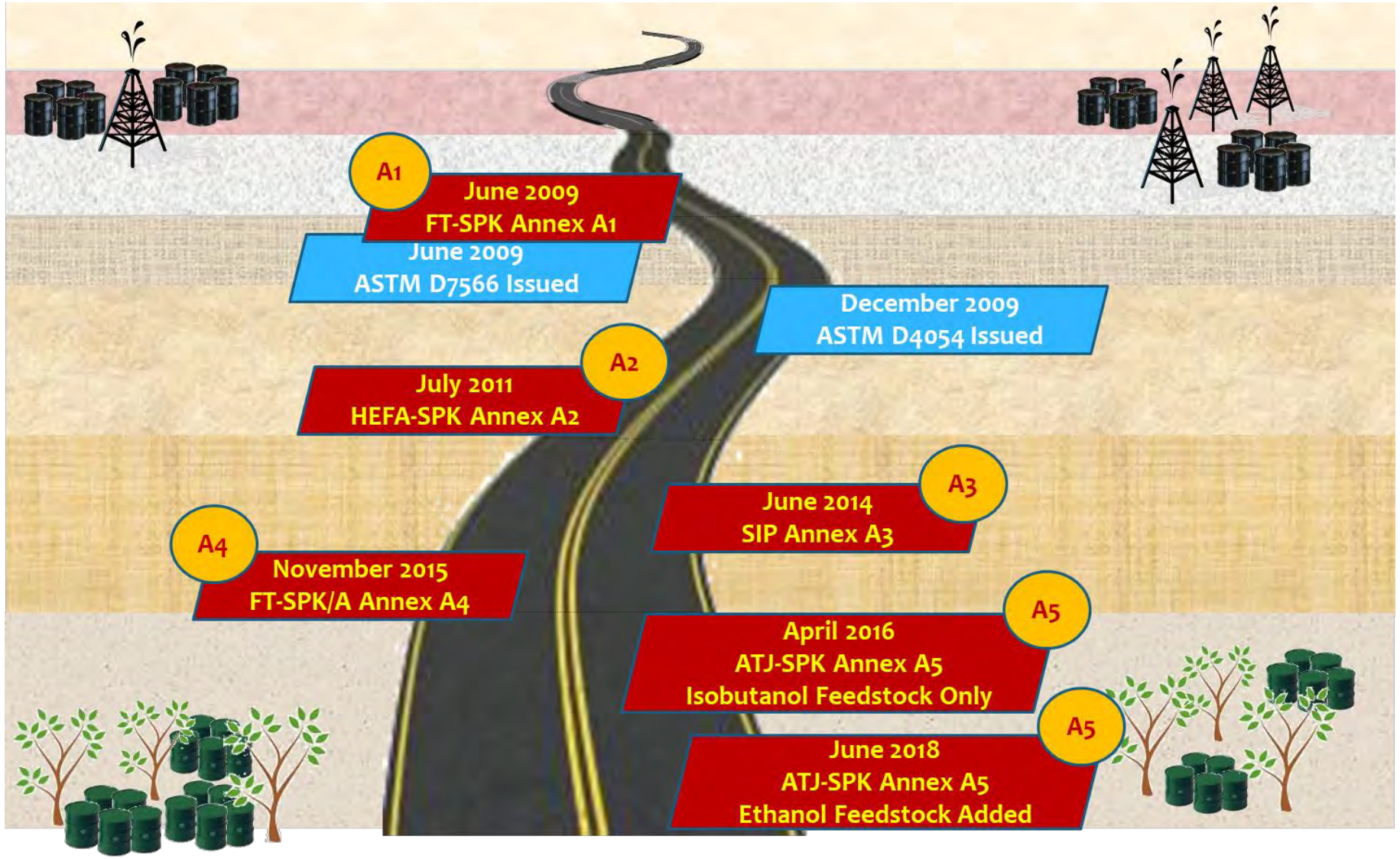


SAF – Qualification for Use

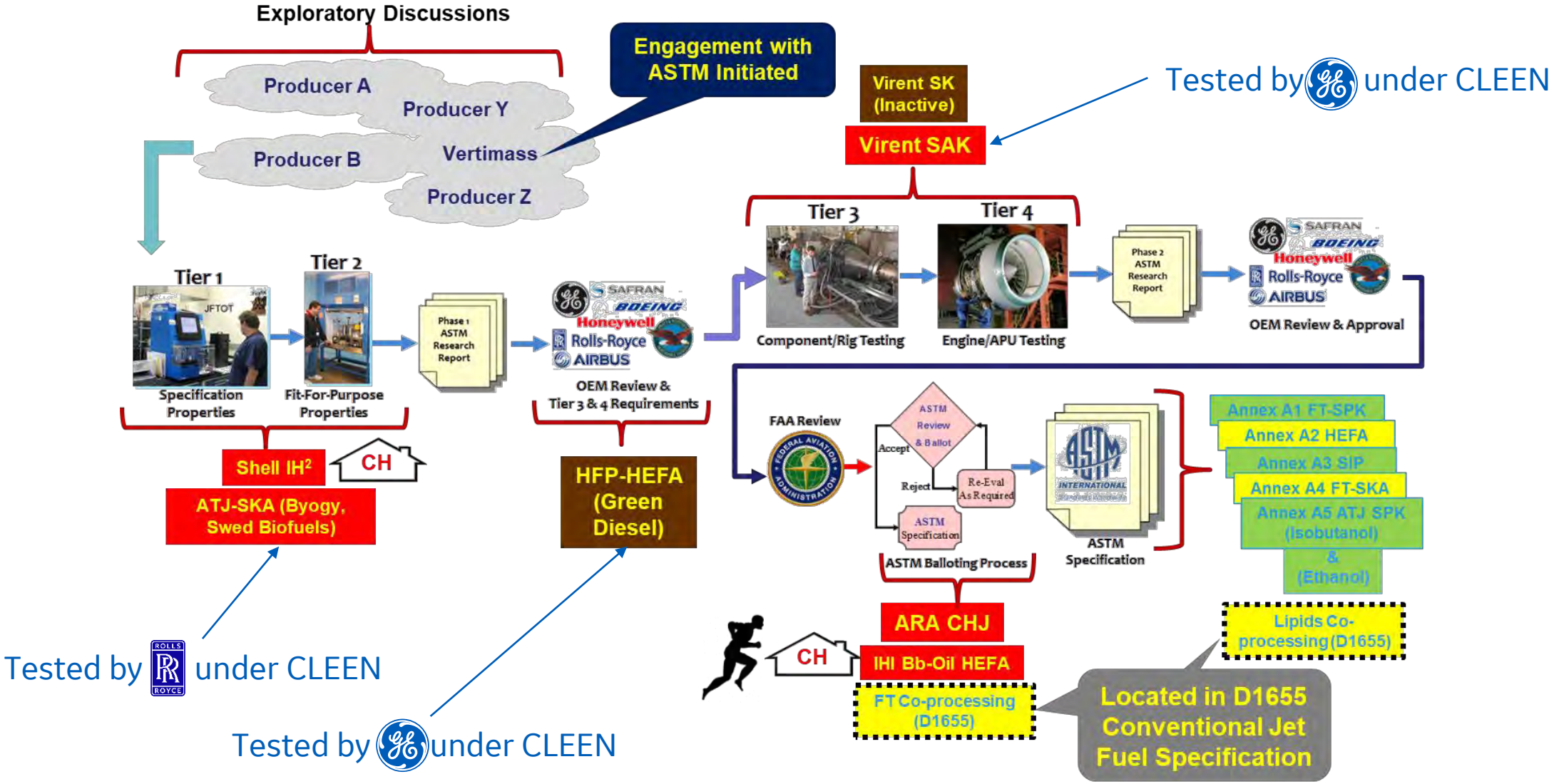


SAF is the same product w/ Jet A/Jet A-1, just synthetically derived from an alternative feedstock

SAF – In 10 years



SAF – Current Approval Landscape



Summary – SAF General

- Aviation community is progressing with the deployment of SAF
  - Now at the “millions of gallons” per year level
  - Regular operations out of LAX
- Government/Industry policy is catching up
  - ICAO CORSIA will drive increase in demand
  - National/State carbon emissions regulations increasingly including jet fuel
- Five approved SAF conversion pathways
  - Several more in progress
- Airlines actively seeking agreements with SAF producers

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

Dr. Venkatesh Saligrama

MESTANG Technology Overview

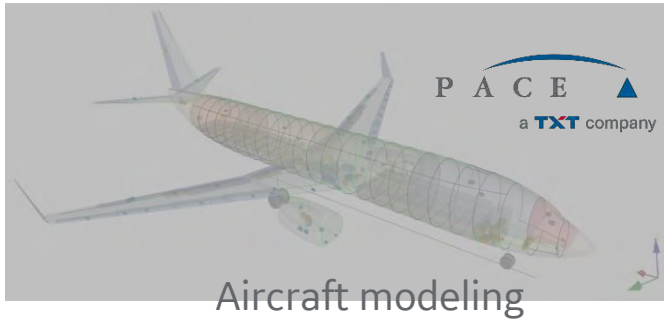
Next-gen Commercial Aircraft will need a "more-electric" power system to realize practical fuel savings and/or mission capability

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
- Limited TRL 6 rating by 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

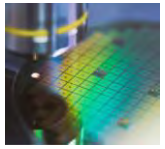


Project Schedule

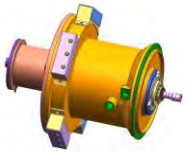
FY/CY 2019 - 2020 Accomplishments / Milestones:

- ✓ FAA Consortium – May 7-9, 2019
- ✓ HPSG v1.0 and PCU – October 11, 2019
- FAA Consortium – November 19-22, 2019
- SGMC v1.0 HW – December 13, 2019
- System Test Spiral VI & Demo – April 6, 2020

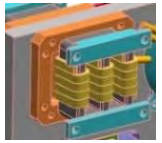
Fabricated GE Gen3 SiC



✓ Generator Preliminary Design



Design for EMI



✓Consortium ✓Consortium ✓Consortium Consortium Consortium

TRL 4 Prototype **SGMC** v1.0

Prototype **SGMC** v2.0

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

HW Component Tests

System/ HW-SW Integration Tests

✓PDR ✓DDR ✓**System Test Spiral V**

TRL 5 *

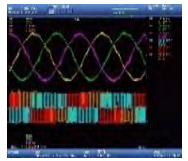
System Test Spiral VI

System Test Spiral VII-VIII

System Test Spiral IX

TRL 6 **

Manufactured ±270 VDC Silicon Carbide Modules

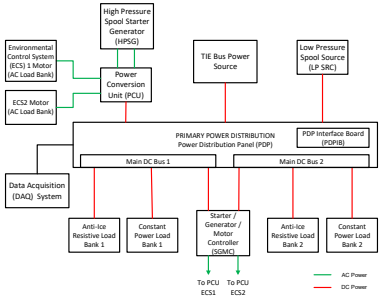


Powered Converter Tests

TRL 4 Prototype **HPSG** v1.0

Prototype PCU v1.0

Prototype **HPSG** v2.0

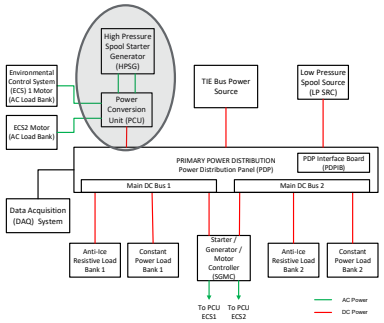


* HPSG & SGMC HW SW Lab Integration

** HPSG & SGMC Limited Environmental Testing along with Final HW SW Lab Integration

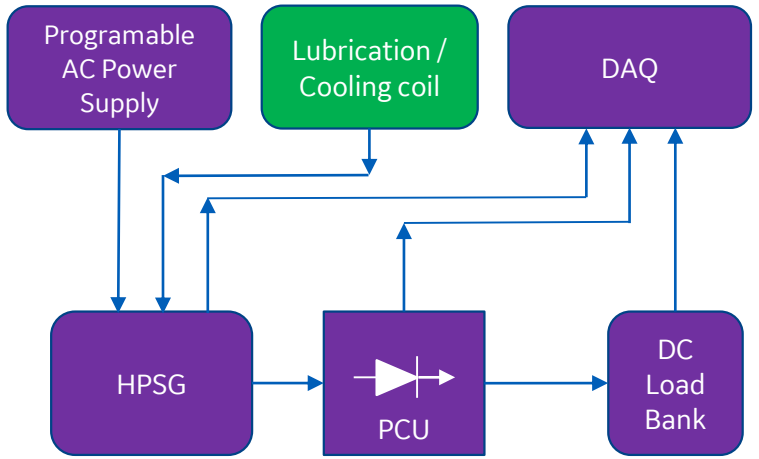
HPSG, PCU Manufacturing & Testing

Bangalore Engineering Center (BEC), India



- ✓ Completed load testing up to 101kW (67% load) of the first HPSG and PCU prototype. HPSG showed stable mechanical performance
- Testing limitation was due to Test stand issue
- The HPSG and PCU is being shipped to the EPISCenter, Dayton, Ohio to continue higher power testing

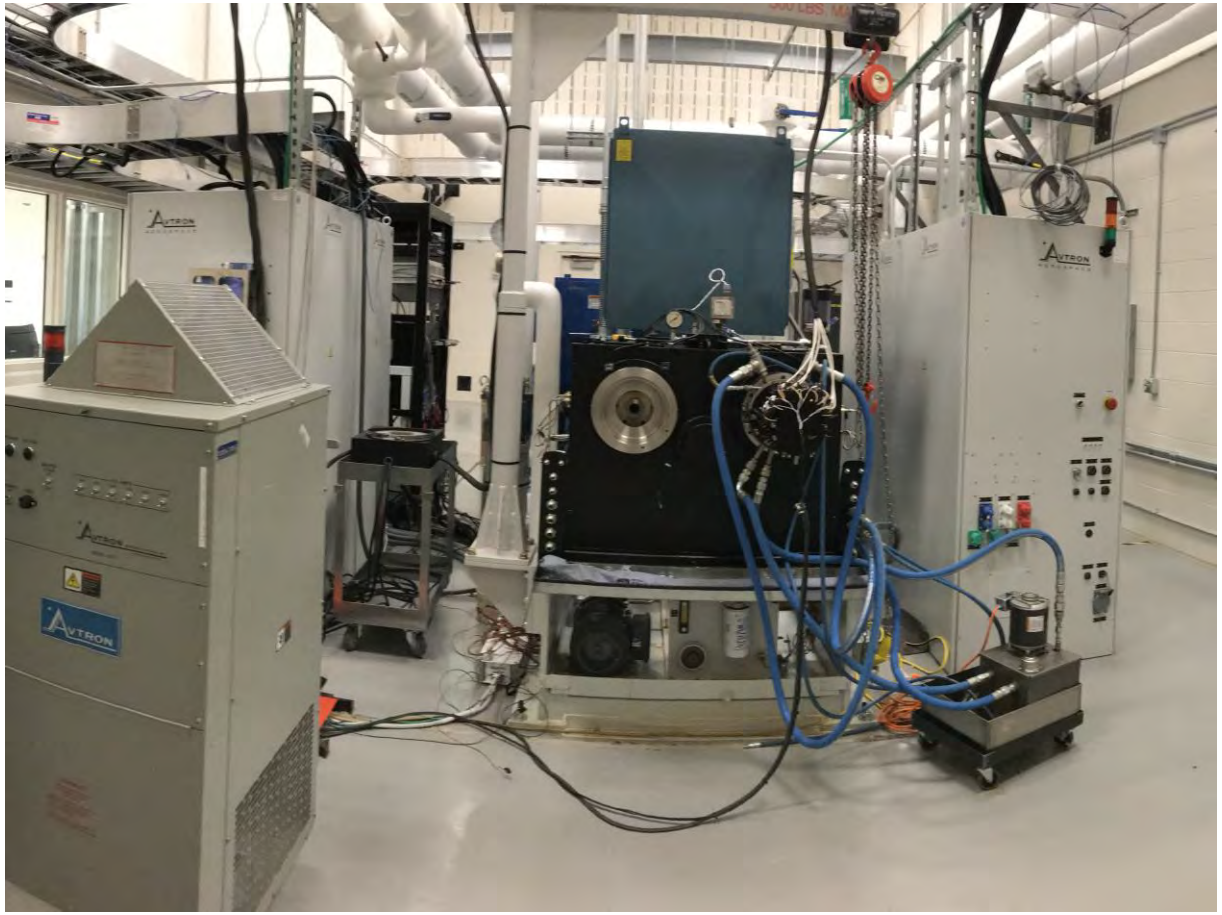
First Prototype – 101kW!



Test stand integration

EPISCenter Lab Setup Status

Front view of drive stand

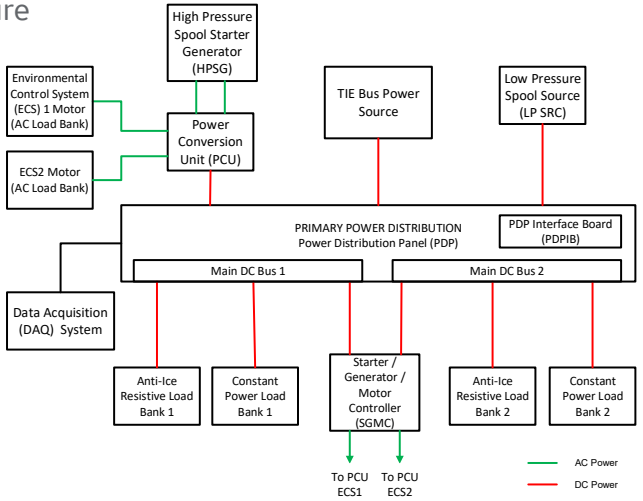


Drive stand control, oil cart, test rack

SGMC Development

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
- Demonstrate electric engine start capability
- 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:

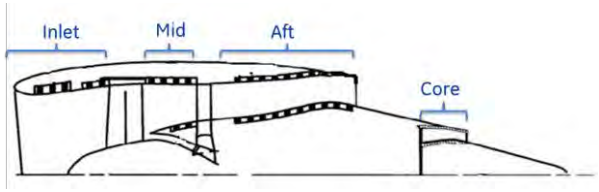
• Program Kick Off	4/1/2016
• Architecture Trade Study and initial 300 kW Architecture	10/19/2016
• Enhanced 300 kW Architecture for PDR	3/21/2017
• Preliminary Design Review (FAA)	5/1/2017
• Finalized 300 kW Architecture	9/14/2017
• Completed initial Systems Requirement Document (SRD)	12/8/2017
• Completed 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
• System Test Spiral V	12/14/2018
• HPSG v1.0 (TRL4) + PCU (GE Bangalore, India)	10/11/2019

Low Pressure Ratio (LPR) Advanced Acoustics

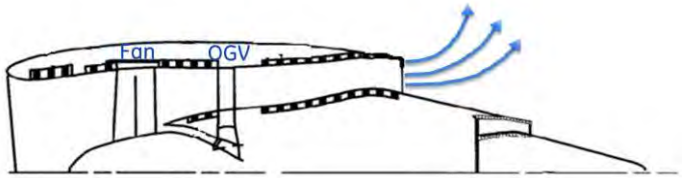
Tim Depuy

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.

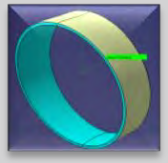
Accomplishments/ Milestones:

- *Tested several Novel Liner Concepts in a Normal Impedance tube.*
- *Manufacturing Novel Designs samples for test at NASA Langley GFIT*
- *Completed Fan Source Strength Reduction Detailed Mechanical Design Review- Q3 2019.*

Schedule:

	FY 2018	FY 2019	FY 2020
Novel Acoustic Liner	TRL/MRL- 3/3	TRL/MRL- 4/4	TRL/MRL- 4/4
Fan Noise Source Strength Reduction	TRL-3		TRL-4

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” 	Full 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 & Fabrication	Wind Tunnel UPS test
TRL		3		4

Summary and Next Steps

Novel Liners

- Fabricating Novel Liners for Phase 2 Grazing Flow Tests – End 2019
- Full scale liner detailed design with manufactured sample planned in FY 2020

Fan Source Strength Reduction

- Detailed Mechanical Design Review completed Q3 2019
- Start manufacture of the subscale test hardware - End 2019