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

TAPS III Combustor & Alternative Fuels

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

Problem:
Next-gen Commercial Aircraft will need a light-weight power system to realize practical fuel savings and/or mission capability

Project objectives:
• Retire risk for ±270 VDC solid state power system
• Technologies for 600 kW power system
• Demonstrate all-SiC power system
• TRL 6 power system by 2019-20 at EPISCENTER

Customer Outcomes:
• Up to 3% Fuel savings in Single-aisle aircraft family
• GE power system with improved performance at equivalent cost
• Leverages Low-spool extraction concepts

Aircraft level trade studies defined technical approach
GE Aviation Component Technology

Generation

High Spool Starter Generator
150 kW
+/- 270VDC

Distribution

Circuit Breakers with Arc-free Galvanic Isolation
GE: < 3 ms interrupt time
COTS: 20 ms

Conversion

150 kW Silicon Carbide based DC-AC inverters

Silicon Carbide based ±270 VDC to 28 VDC converters
GE: >95% efficiency
COTS: 90%
Aircraft Level Simulation

Goal

- Calculate Baseline Aircraft fuel burn for 500-NM mission
- Calculate More Electric Aircraft fuel burn for 500-NM mission
- Compare above two and show up to 3% fuel savings

Weight Analysis

Mission Setup

Mission Solution & Report

Non-propulsive Energy Demand Generation

<table>
<thead>
<tr>
<th>Baseline Aircraft</th>
<th>MEA</th>
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<tbody>
<tr>
<td>ECS</td>
<td>Pneumatic</td>
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<tr>
<td>Wing Anti-Ice</td>
<td>Pneumatic</td>
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<tr>
<td>Engine</td>
<td>One-spool</td>
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Summary

MESTANG Program Schedule

Objectives:
Mature an integrated aircraft power system consisting of a bleedless, dual-spool engine, and a second-generation more-electric primary power system

Customer Outcome:
• Up to 3% Fuel Savings in Single-Aisle A/C Family
• GE Power System with improved performance at equivalent cost
• Leverages Low-Spool extraction concepts

Benefits:
• Light-weight +/- 270VDC power system to realize practical fuel savings and/or mission capability
• 600kW – 1MW power system
• Demonstration all-SiC power system
• TRL6 Level System by 2019-2020 at EPISCENTER
• Subsystems certifiable for retrofits before 2026

Key CLEEN II Accomplishments:
• Finalized 600 kW Aircraft Level Simulation Architecture
• Finalized 300 kW Lab Demonstration Architecture
• Finalized System Power Quality requirements
• Completed Preliminary Designs:
  • High Pressure Spool Starter/Generator (HPSG)
  • Starter/Generator/Motor Controller (SGMC)
  • Hybrid DC Circuit Breaker (DCCB)
• Performed Concept demos of +/-270Vdc Generator and GE's Hybrid DC Circuit Breaker at GRC-NY
• Completed PDR on May 01, 2017 – Starting Detail Designs
TAPS III Combustor & Alternative Fuels
TAPS III Combustor

- Higher pressure
- Reduced cooling flow
- Advanced materials

CLEEN II:
- Improved premixer for <CAEP/12 NOx target
- Advanced modeling/design tools
- TRL6 Core Demo of emissions/performance

Objectives:
Advance the development of next-generation low-NOx TAPS III combustor to TRL6

Work Statement:
- Establish baseline NOx / performance
- Develop technologies: Fuel injection, aerodynamic mixing, modeling tools
- Staged advancement to TRL6 via rigs & core engine demonstration

Benefits:
- GE9X projected SFC ~10% below GE90-115B
- LTO NOx >35% margin to CAEP/8 @ 55 OPR
- Mission cruise NOx reduction below SOA
- Low-NOx technology for application in highest OPR/largest engines; design tools/methods for scaling to future applications and engine cycles

CLEEN II Progress since November 2016:
- 2 advanced premixer architectures, with multiple variants, released for manufacturing
- 1 concept screened in late Q4
- Manufacturing of 7 single-cup fuel nozzles and 5 mixer designs begun; all except 2 mixers are finished build
- Baseline: FAR2A mapping & emissions
- Combustion dynamics models validated against TCA3 data; analytical screening of new concepts has started
TAPS III Combustion System Development

Goals and Schedule

- LTO NOx emissions (FAA Goal) 35% margin to CAEP/8 @ 55 OPR
- Cruise NOx emissions (GE Goal) < SOA
- Solid Particulate Matter (GE Goal) 60% margin to CAEP/6 (based on Smoke no.)
- Combustor Durability (GE Goal) Increased TOW
Concept A2 tested; expected to meet CLEEN II objectives

Concepts C, D configs analytically predicted to further improve NOx & performance beyond Concept A2

7 nozzles, 5 mixers being produced

Single-cup (TRL3) tests up to max cycle conditions planned mid-2017
TAPS III Combustor Development – Test rigs

Rig tests establish reference NOx & performance

Criteria evaluated in FAR1C & FAR2A:
- Sub-idle efficiency
- Cruise efficiency
- Low- to intermediate-power NOx emissions
- Exit temperature patterns

FAR1C: semi-scale scale annular combustor rig

Concept A2

- 3 embodiments of TAPS III combustor rigs tested with Concept A2 fuel nozzle/mixer config
- Concept A2 expected to meet CLEEN II objectives for NOx
- Concepts C, D expected to enable higher engine performance, decreased LTO NOx
TAPS III Combustor Development – Modeling Tools

Combustion Dynamics model advancements validated against engine & rig data; applying to CLEEN II new concepts

**Modeling Goals**

1. Advance modeling approach for fuel spray dynamic coupling with acoustics
2. Develop fast-turnaround calculations
3. Improve mixer screening & acoustics amplitude prediction tools
4. Validate and refine best practice for liquid injection Self-Excited Dynamics methods

**Recent success:** Modeling rig tests
- Test 2 data with higher measured P4’ values accurately modeled
- Test 3 results accurately predicted

**Calculated Growth Rate**

<table>
<thead>
<tr>
<th>Rig Test</th>
<th>Measured</th>
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<tbody>
<tr>
<td>Rig Test 1</td>
<td>Predicted</td>
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<tr>
<td>Rig Test 2</td>
<td>Predicted</td>
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<tr>
<td>Rig Test 3</td>
<td>Predicted</td>
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- Balanced CLEEN II design will enable improved NOx & performance while managing lean combustion dynamics
- Modeling tools become part of design process; support timely decisions
Alternative Fuels

Benefits:

- Advance to fully synthetic fuels
- Extend further to lean combustion systems evals – synergize with TAPS III
- Determine: do sensitivities of combustion parameters observed at component level, have a significant impact at system level?

Objectives:

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

Work Statement:

- Test one fully synthetic fuel in ASTM roadmap – (FAR and Core Test)
- Test one “reference” fuel defined by FAA’s National Jet Fuel Combustion Program (NJFCP) – (FAR test)

CLEEN II Progress since May 2016:

- 100% synthetic fuel (HEFA SPK + SKA blend)
  - Agreement w/ the Producer established
- NJFCP fuel (100% ATJ-SPK)
  - Official quote received; procurement initiated
  - FAR scheduled for Q3
  - Test plan (TPS) generated
* Core synthetic fuel could be different than the FAR synthetic fuel

- Key figures of merit to be evaluated: Operability - L/O (ignition); blow-out

- Due to production campaign limitations the FAR fully synthetic fuel will follow the NJFCP testing at a later date.
  - Baseline data will not be repeated, but spot-checked for validity.
FMS Technologies
CLEEN II: GE FMS Public Program Update

Approved for Public Use
FMS Optimal Control – UCCD + GEN B

The solver determines the set of controls that minimize the cost function based on weather.
Unified Climb, Cruise, and Descent ... optimizing considering the tradeoffs

**Near-Term Plan**
- Discuss technology with OEMs, airlines, and ATC ... address potential barriers
- Demonstrate UCCD/GEN A technology in the TRL 6 lab
- Seek additional opportunities for FMS optimization with additional considerations (traffic, noise, etc.)

**Optimal transition from climb to cruise generates even greater savings**

**Variable profile results in most optimal control**

**Consideration the tradeoff between climb, cruise, and descent allows for optimal altitude selection**

**Longer flights will have larger benefit from wind optimization**
Weather Retrieval for GEN B

Expanding the optimization domain

Project 4-d weather data onto nominal predicted flight path ... extend altitude range optimization

Accomplishments
Utilizes high UCCD technology, high fidelity model
Modified solver ... accounts for potential non-convexity in the cost
Modified solver ... includes waypoint constraints, avoid infeasible solutions

Near-term plan
Assess product plan ... EIS 2020
Build TRL 6 laboratory prototype
Continue concept development ... incorporate step climb/descent
Advanced Technology Testbed (ATT) brings value to the process

**Accomplishments**
- PIANO model for six vehicle types have been validated in desktop computer simulation (TRL 5)
- Inter-changeable PIANO, FMS, and NPSS cycle-deck engine models have been validated
- All models available for use in TRL 6 real time simulator

**Near-Term Plan**
- Implement Georgia Tech narrow body future vehicle model in desktop simulation.
- Run Monte Carlo 3DoF physics simulation trials and extract a model of the block savings for various vehicle types.
- Collaborate with Georgia Tech to study overall impact of FMS updates in the future NAS.
Imagination at work