CLEEN I and II Projects
February 2, 2018

Aurora Flight Sciences

Aurora, under CLEEN II, is developing and demonstrating composite airframe technologies that will enable an unconventional aircraft configuration that could reduce fuel burn, emissions, and noise. The company is designing an all-composite half-scale fuselage for what is known as the double-bubble advanced aircraft concept, using materials and manufacturing processes that demonstrate configuration feasibility and weight benefits. The technologies developed will enable fabrication of the fuselage of the double-bubble aircraft concept.

- In 2017, Aurora fabricated and load tested a set of manufacturing exploration elements in order to improve the manufacturing approach and validate Finite Element Method (FEM) models of key fuselage components. Aurora built and tested a key subsection of the double-bubble fuselage configuration to validate its structural performance.
- Double-bubble advanced aircraft concept are estimated to provide a 20 percent reduction in fuel burn, up to 16 EPNdB (Effective Perceived Noise level in dBs) cumulative noise reduction, and 21 percent LTO cycle NO_X reduction toward the CLEEN II goals. These benefits represent the improvements this configuration change provides, on which additional technology benefits could be applied. This configuration, with advancements in engine integration beyond the CLEEN II timeframe holds the potential for up to 49 percent fuel burn reduction, 40 EPNdB cumulative noise reduction, and 52 percent reduction in LTO cycle NO_X emissions.

Boeing

The technologies matured by Boeing during CLEEN I included the Adaptive Trailing Edge (ATE) on the aircraft wing and a Ceramic Matrix Composite (CMC) acoustic nozzle at the engine exhaust. Boeing also conducted research jointly with the University of Dayton Research Institute on how alternative jet fuels effect on-aircraft fuel systems.

- In 2012, Boeing demonstrated that the ATE system provides up to a 2 percent reduction in aircraft fuel burn and reduces aircraft noise levels by 1.7 decibels (dBs). When used fleet-wide in the United States, a 2 percent reduction relative to 2009 fuel usage could save 340 million gallons of fuel with operating cost savings of $1.2 billion.
- In 2014, Boeing tested the CMC nozzle on a 787 aircraft. This technology can withstand higher temperatures, is made of lighter weight material, and lowers fuel consumption. The CMC nozzle technology can also accommodate acoustic treatments that reduce community noise. The CMC nozzle reduces fuel burn by up to 1 percent and provides up to a 2.3 dB noise reduction.

For CLEEN II, Boeing is developing and demonstrating advanced aircraft wing technologies that could reduce aircraft fuel burn by up to 3.5 percent. The Structurally Efficient Wing (SEW) provides large weight reductions through new manufacturing techniques and advanced composite material technology, resulting in a reduction of aircraft fuel burn. The cumulative predicted impact to the fleet over twenty years is an estimated fuel consumption savings of approximately 200 million tons of jet fuel and avoidance of approximately 660 million tons of CO_2 production.

- In 2017, Boeing completed preliminary design for the SEW and has moved into the detailed design phase. In parallel with this design process, Boeing has conducted manufacturing and material-risk reduction activities, including trial builds of sub-components and testing of material properties. These activities support and inform refinement of the design of a full-scale Wing Component Test Article for ground demonstration scheduled to occur in 2018.
- In 2017, Boeing also began preliminary design work on a compact nacelle inlet and thrust reverser design for Ultra-High Bypass engines. The technology is expected to reduce weight and allow for improved acoustic treatment.

Delta Tech Ops / MDS Coating Technologies / America's Phenix
The team of Delta Tech Ops, MDS Coating Technologies and America's Phenix is developing and demonstrating a protective leading edge coating for gas turbine engine fan blades. This coating protects against fan blade erosion, a source of lost aerodynamic efficiency in engines in service.

- In 2017, the team completed flight certification tests for the fan blade coating. They will next install on-wing and begin flight service evaluation. The flight test schedule will demonstrate the coating protection on operational aircraft for an extended period — extending into the year 2019 — with the goal of proving its robustness and benefits. The resulting retained efficiency will reduce fuel consumption over the life of the engine, estimated at up to 1 percent fuel savings during aircraft cruise and up to 2 percent fuel savings at maximum power.

GE Aviation
Under CLEEN I, GE developed and demonstrated several aircraft technologies that reduce fuel burn, emissions, and noise. These technologies are the open rotor engine, advanced engine combustor known as the Twin Annular Premixed Swirler (TAPS) II, Flight Management System-Air Traffic Management (FMS-ATM) System Integration, and Flight Management System-Engine Integration.

- In 2012, GE engine emissions tests of the TAPS II combustor had results that were more than 60 percent below the 2004 ICAO CAEP NO_X standards.
- In 2012, GE also completed scaled open rotor wind tunnel tests, which resulted in a 15 dB reduction relative to the Stage 4 noise standards and a 26 percent fuel burn reduction relative to specific current jet engines.
- In 2013, GE demonstrated flight trajectory synchronization between aircraft and the En-Route Automation Modernization (ERAM) system. These technologies provide pilots and controllers with better predictability of an aircraft's location, enabling greater fuel savings through more efficient aircraft routing.

- In 2013, GE developed probabilistic advisory spacing and vertical flight path optimization technologies. These two technologies are anticipated to reduce fuel burn by 0.7 percent and 1 percent, respectively.
- In 2015, GE completed ground engine and flight tests of their Flight Management System-Engine Integration technologies, showing a significant reduction in aircraft fuel burn.
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Under CLEEN II, GE is developing three aircraft technologies and undertaking one alternative fuel project:

- 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. The MESTANG technologies under CLEEN II may reduce fuel burn by up to 3 percent for single-aisle aircraft. GE is conducting detailed design work on new power extraction, generation, distribution, and conversion systems for the MESTANG program. This is expected to be completed in 2018 and followed by component and system level test demonstrations during the 2018-2020 timeframe;
- GE is also developing the Twin Annular Premixing Swirler (TAPS) III low emissions combustor via a technology enhancement package for the 777X’s GE9X engine. This technology package expects to meet the CLEEN II goal for reductions in LTO NOX emissions. In 2017, GE trial built and tested a number of fuel nozzle and mixer aero designs for the TAPS III combustor. Modeling and test results are being used to inform detailed mechanical design and manufacturing plans;
- Flight Management System (FMS)-Engine Integration technology software algorithms will optimize aircraft performance during the cruise and descent phases of flight. This project estimates to provide up to 1 percent fuel burn reduction. In 2017, GE completed lab prototype demonstrations for their GEN-A Cruise Optimization and Unified Climb/Cruise/Descent FMS algorithms.
- GE will perform combustor rig testing of alternative jet fuels to support ASTM approval of novel alternative jet fuels. GE is advancing the approval of “drop-in” alternative jet fuels. GE has selected three alternative jet fuels for testing: a 100% synthetic fuel (Hydro-processed Esters and Fatty Acids [HEFA] Synthetic Paraffinic Kerosene [SPK] + Synthesized Kerosene with Aromatics [SKA] blend), a 100% ATJ-SPK, and High Freeze Point HEFA. Testing will focus on operability of these fuels in a lean combustion system to further their potential for approval within the scope of the ASTM process.

Honeywell

Under CLEEN I, Honeywell developed and demonstrated engine core technologies that increase engine efficiency and reduce engine weight. Honeywell also tested alternative jet fuels.

- In 2011, Honeywell completed testing of HEFA alternative jet fuel that expedited its international approval.
- In 2015, Honeywell completed final engine core and engine endurance testing of all of its CLEEN I technologies, validating fuel burn reduction and maturity for those technologies. Together with complementary engine upgrades, the technologies offer a 15.7 percent overall reduction in fuel burn relative to current engine designs.

Under CLEEN II, Honeywell is developing and demonstrating two technologies: a compact, low emissions combustor and an advanced turbine Blade Outer Air Seal (BOAS). The compact low emissions combustor uses advanced aerodynamics and fuel injection technologies to reduce engine NO_X emissions while reducing weight, and thereby reducing fuel burn. Honeywell's advanced turbine blade outer air seal increases high pressure turbine efficiency, resulting in reduced fuel burn. The two technologies contribute to an engine level improvement of 27 percent fuel burn reduction with 53 percent margin to the CAEP/8 NO_X emissions standard.

- In 2017, Honeywell completed design and analysis for their compact combustor technology demonstration configurations and began fabrication of initial test articles. They also completed design of the planned CLEEN II combustor rig.
- In 2017, Honeywell completed preliminary design for the turbine BOAS system and performed initial materials characterization testing.

Pratt & Whitney
Under CLEEN I, Pratt & Whitney developed and demonstrated an ultra-high bypass ratio Geared Turbofan^{TM} (GTF) engine and associated advanced technologies. Pratt & Whitney also supported qualification of alternative jet fuels via rig and auxiliary power unit testing.

- In 2015, Pratt & Whitney completed a series of tests in support of ASTM approval of the following alternative jet fuels: Amyris Direct Sugar to Hydrocarbon (DSHC) Farnesane; Kior Hydrotreated Depolymerized Cellulosic Jet (HDCJ); Applied Research Associates (ARA) Catalytic Hydrothermolysis (CH), and Swedish BioFuel ATJ-SKA.
- In 2017, Pratt & Whitney completed an ultra-high bypass engine test campaign, demonstrating aerodynamic performance, mechanical, and acoustic characteristics of advanced fan system technologies. Geared turbofan engine technologies contribute to a 20 dB aircraft noise reduction and a 20 percent fuel burn reduction because of increased engine efficiency.

Under CLEEN II, Pratt & Whitney is developing and demonstrating technologies for the engine compressor and turbine to improve engine thermal efficiency and reduce fuel burn of the Pratt & Whitney GTF engines. The development work will focus on advanced aerodynamics, cooling, and durability optimization.

- In 2016, Pratt & Whitney completed a compressor rig test that demonstrated improved high pressure compressor efficiency and validated performance predictions. The Pratt & Whitney CLEEN II compressor technologies are estimated to result in 0.8-1.0% fuel burn reduction relative to a state-of-the-art engine.
- In 2017, test facility upgrades were completed at the Pennsylvania State University Steady Thermal Aero Research Turbine (START) Lab that will enable Pratt & Whitney to advance turbine aero-efficiency and durability technologies. Pratt & Whitney is conducting baseline turbine rig testing at the START facility. This is to be completed in 2018. The Pratt & Whitney CLEEN II turbine technologies are estimated to result in 0.8-1.0% fuel burn reduction relative to a state of the art engine.

Rolls-Royce

Under CLEEN I, Rolls-Royce developed and demonstrated Dual-Wall Turbine Airfoil and CMC Blade Track technologies aimed at increasing thermal efficiency in the turbine section of the engine, thereby reducing fuel burn. Rolls-Royce also conducted laboratory and engine component tests of advanced sustainable alternative jet fuels that could be approved for commercial use by ASTM International.

- In 2013 and 2014, engine testing of the CMC Blade Track validated the technology's performance and benefits.
- In 2015, Rolls-Royce completed testing of the Dual Wall Turbine Airfoil. The testing showed that the Dual-Wall Turbine Airfoil and CMC Blade Track technologies will realize a fuel burn reduction of up to one percent overall for Rolls-Royce engines.
- In 2013, Rolls-Royce completed laboratory testing of new alternative jet fuels under development by nine fuel companies. Four of these fuels were tested in support of ASTM approval. One of the fuel candidates, HEFA, has been approved. ARA CH, Byogy ATJ-SKA, and Virent Synthesized Aromatic *Kerosene (*SAK) are currently in the ASTM International approval process.

Under CLEEN II, Rolls-Royce is developing and demonstrating low emissions combustor technology and undertaking alternative fuels testing work. Rolls-Royce's advanced Rich-Quench-Lean (RQL) combustion system employs advanced fuel injection and mixing technologies that will provide significant emissions reduction while simultaneously enabling the increase in Turbine Entry Temperature required by advanced engine cycles. The project will demonstrate a near-term configuration targeting NO_X emission levels 50 percent below CAEP/8 limits and a final configuration with NO_X levels 65 percent below CAEP/8, achieving significant progress toward the CLEEN II NO_X goal. Rolls-Royce will also conduct alternative fuels testing to support ASTM approval of novel fuels.

- In 2017, Rolls-Royce completed preliminary design of the combustion system as well as a number of component rig tests and manufacturing trials of key system components.
- In 2017, Rolls-Royce selected a fully synthetic fuel the alternative fuel test program after screening several candidates and producers. The selected fuel is a blend of 90% LanzaTech fuel with 10% Swift Fuels mesitylene aromatic. They anticipate receiving their first fuel shipment and subsequently beginning testing during 2018.

Rohr, Inc./UTC Aerospace Systems (UTAS)

Under CLEEN II, Rohr is developing and demonstrating a thrust reverser for a short, integrated, engine fan duct that enables ultra-high bypass quiet and efficient engines. It also implements advanced acoustic technologies that will reduce noise.

- In 2017, UTAS conducted preliminary design work for the short, integrated fan duct thrust reverser and achieved an architecture freeze for the design of their planned ground test demonstrator.

The UTAS thrust reverser and advanced acoustic technologies are estimated to directly reduce noise by 2.5 EPNdB (to offset short fan duct) and fuel burn by approximately 1 percent. It also enables the use of ultra-high bypass engines which will provide additional noise and fuel burn benefits.