Energy, Efficiency & Emissions

The projected growth by a factor of two of the nation's air transportation system within the next 20 years has the potential to increase emissions of greenhouse gases, such as carbon dioxide (CO_2), nitrogen oxide (NO_X), and water vapor. As a result, NASA's Fundamental Aeronautics Program has established aggressive goals to reduce fuel burn in future aircraft, which correlates to reduced CO_2 and NO_X emissions. This research has taken on increased significance due to the recent instability of aviation fuel prices and supplies.

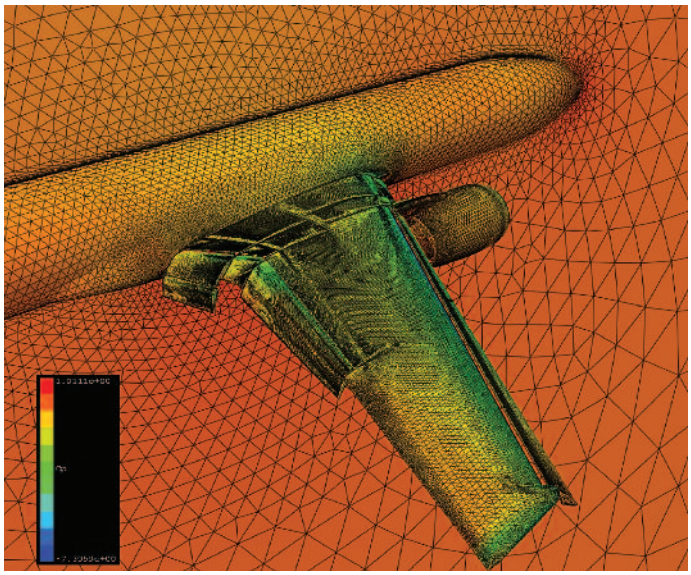
Reductions in fuel burn will be achieved through the development of new technologies to reduce drag, engine-specific fuel consumption, and aircraft and engine weight. In addition, novel integrated aircraft configurations are being developed to improve aircraft performance dramatically.

Subsonic Fixed Wing Aircraft Goals			Supersonic Aircraft Goals		
Aircraft Generation	Fuel Burn Reduction Goal	LTO NO_X Goal	Aircraft Generation	Fuel Burn Reduction Goal	Cruise NO_X EI Goal
N+1 (2015 Entry into Service) – Conventional tube and wing, B737/ CFM56 baseline	-33%	-60% (below CAEP 6)	N+1, (2015 Entry into Service) – Supersonic business jet aircraft	Baseline	Equivalent to subsonic
N+2 (2020 Initial Operating Concept) – Unconventional configuration like Blended Wing Body, B777/GE90 baseline	-40%	-75% (below CAEP 6)	N+2, (2020-25 Entry into Service) – Small supersonic airliner	-15%	<10
N+3 (2030-35 Entry into Service) – Advanced concept aircraft, relative to 2005 technology baseline	Better than -75%	Better than -75% (below CAEP 6)	N+3, (2030-35 Entry into Service) – Efficient Multi-Mach aircraft	-25%	<5

Reducing Drag

Aircraft fuel burn is directly related to drag. Looking at a given wetted area on an aircraft, a turbulent boundary causes significantly more skin friction drag than does a smooth, or laminar, boundary layer. The program is conducting research to maintain significant lengths of laminar boundary layer through natural laminar-flow control and hybrid laminar-flow control. In natural laminar flow, surfaces providing favorable pressure gradients are used to delay transition. Hybrid laminar-flow control employs surfaces that provide favorable pressure gradients, along with either active or passive local suction surfaces, to delay transition from laminar to turbulent.

Laminar-flow technology offers the potential for a 12 percent reduction in aircraft fuel burn. The photo shows wind tunnel testing of a hybrid laminar-flow control concept.



Advanced grid-generation techniques, such as this grid showing pressure contours for a state-of-the-art transport in landing configuration, are being employed to predict flow conditions.

The program has a strong focus on development and validation of high-fidelity computational fluid dynamics (CFD)-based capabilities that will enable analysis and design of advanced drag-reduction concepts with improved accuracy and reduced computational time. Capabilities being developed include prediction of three-dimensional, high-Reynolds-number flow separation and progression; boundary layer transition; advanced unstructured grid generation for complex geometries; and quantification of uncertainties.

NASA and GE Aviation are working in partnership on a 2009 - 2010 wind-tunnel test program at the Glenn Research Center to evaluate open rotor jet engine designs featuring counter-rotating fan-blade systems. Open rotors tested in the 1980s showed a 30-percent reduction in fuel consumption compared to similar-sized jet engines with conventional, ducted front-fan systems, but with higher noise levels. The component-rig test will be evaluated using advanced computational tools and data acquisition systems.

Reducing Engine-Specific Fuel Consumption

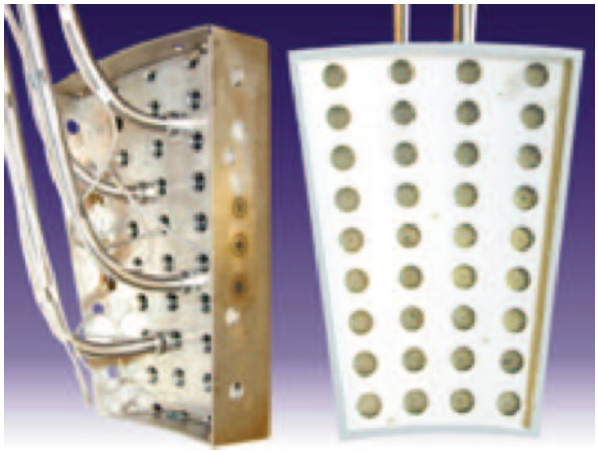
Enabling technologies under development in the Fundamental Aeronautics Program will provide significant reductions in fuel burn while dramatically improving the environmental performance of future aircraft.

Research efforts are focused on improving engine efficiency, both propulsive and thermal, to reduce specific fuel consumption. Since the propulsive efficiency is improved by increasing the bypass ratio, there is growing interest in developing ultra high bypass (UHB) engines for subsonic fixed wing aircraft. Such engines pose significant integration challenges with modern aircraft configurations. The program is addressing these challenges by developing integrated performance models and validating them through wind tunnel testing.

Studies of an advanced UHB concept, the open rotor, demonstrated significant reduction in fuel burn in the late 1980s. This research has been restarted, and the challenges being addressed include propeller efficiency at cruise speeds, noise and vibration, and installation aerodynamics.

The approaches for increasing thermal efficiency of engines include:

- Increasing turbomachinery efficiency through active flow control (such as variable-tip flow and blade-tip clearance control) for reducing stall margin and increasing stage loading
- Improving cooling effectiveness to reduce cooling flow



The Lean Direct Injection multipoint fuel injection concept offers potential for significant NO_X reduction.

Advanced Hybrid Wing Body aircraft configurations such as the Blended Wing Body (X-48B) will achieve significant reductions to drag and weight.

- Developing higher-temperature compressor and turbine materials that allow for operating at higher pressure ratios and reducing cooling requirements

The program is also investigating the applicability of alternate fuels, such as biofuels, with the potential to reduce CO_2 emissions from gas turbine engines. With the growing international interest in alternative fuels, it is likely that future engines will need to operate safely and reliably and continue to meet their low emissions objectives while operating on fuels derived from a range of petroleum and non-petroleum sources.

Disk with 1500° F temperature capability

CMC turbine airfoil

High-temperature disk and turbine blade materials will enable high-pressure-ratio engines.

The PMC fan containment system with multifunctionality and high-temperature capability will reduce the weight of engine structures.

The program is focusing on the design of fuel-flexible combustors to ensure that combustor performance attributes are maintained when operating on alternative fuels.

Reducing Airframe and Engine Weight

Lightweight, multi-objective, and multifunctional structures—structures that can carry load and attenuate noise at the same time—are being developed to reduce both aircraft and engine weight. Adaptive and flexible wing structures with aeroelastic tailoring offer significant weight reduction by eliminating a heavy actuation system.

Extensive use of polymer matrix composites (PMCs) in airframe and engine structures where applicable will offer significant weight reduction opportunities. Research on composite technology is focused on developing alternate processes that will enable fabrication of large structures; increasing the temperature capability toward greater usage in engine and supersonic airframe structures; developing advanced structural concepts; and modeling damage initiation and progression in composite structures.

Novel Aircraft Configurations

Achieving N+2 and N+3 goals will require novel aircraft configurations. The program is evaluating a number of alternate aircraft architectures, including hybrid wing body (HWB) configurations, which have thick center bodies that can accommodate passengers and cargo without the extra wetted area and weight of the fuselage, with significant reductions in drag and weight.

Reducing NO_X Emissions

The strategy for reducing NO_X involves increasing fuel/air mixing in time and space, minimizing combustion zone residency time, maintaining unburned hydrocarbon and particulate burnout, and reducing or eliminating combustor liner cooling. This strategy will be accomplished through development of alternative combustor concepts, such as flameless catalytic, as well as advanced fuel/air mixers, high-temperature ceramic matrix composite combustor liners, alternate fuels, and active combustor control.

The development of advanced low-NO_X combustor concepts is facilitated by high-fidelity, CFD-based computational tools incorporating integrated multi-phase and combustion modeling for large-eddy simulation in realistic, gas-turbine combustors.

Enabling technologies under development in FAP will provide significant reductions in fuel burn while dramatically improving the environmental performance of future aircraft.