PUSHING THE AIRCRAFT AND ENGINE TECHNOLOGY ENVELOPE TO REDUCE CO_2 EMISSIONS

BY THE INTERNATIONAL COORDINATING COUNCIL OF AEROSPACE INDUSTRIES ASSOCIATIONS (ICCAIA)

It is widely known that improvements in aerodynamic, propulsion, and light-weight materials technologies have a direct link to aircraft emissions reduction. However, it is less well known that improvements in design and manufacturing technology are also key to achieving future CO_2 reduction goals for existing and new aircraft.

In the past five years, entirely new advanced long-range airplanes (such as the Boeing 787-8 and 787-9, the Airbus A350-900) have entered into operational service with significant improvements in each of these technology areas. Completely new shorter-range aircraft (such as the Bombardier C Series) and several derivative aircraft with major propulsion and airframe technology upgrades (such as the Airbus A320neo, the Boeing 737MAX, and the Embraer E2 family), have entered, or will enter into service soon; resulting in further substantial reductions in fuel burn per aircraft. Also, new and derivative business-jet and regional aircraft have been introduced with important reductions in CO_2 emissions.

Large national and international research programs have been started in the past decade with cooperation involving industry, government and academia. These alliances are considered key enablers to advance and mature the state of the art in breakthrough technologies that can lead to further reduction in aviation's environmental footprint. Flight demonstrations offer important technical and integration data to advance progress on potential game changers such as laminar flow, adaptive materials, and electrically powered aircraft. Integration and certification challenges are significant, and the time frame necessary to deploy improvements into production is probably 10-20 years. Nevertheless, the continued development and enhancement of these technologies represents equally huge opportunities for the aeronautical sector's environmental footprint.

Aerodynamics

Profile (skin-friction) drag and lift-dependent drag, are by far the largest contributors to aerodynamic drag on commercial aircraft. Advances in materials, structures, and aerodynamics are enabling significant reduced lift-dependent drag by increasing the effective wing span. Wing-tip devices can increase the effective aerodynamic span. Eventually, to further increase wing span in flight, airplanes may include a folding wing-tip mechanism for use on the ground to alleviate span constraints. Wing-span increase without significant concomitant weight increase is facilitated by suitably reliable systems for load alleviation, will allow reduced aerodynamic design loads while maneuvering and in gusty conditions.

Skin-friction drag remains an area with potentially significant opportunities to increase aerodynamic efficiency. Progress is being made in developing and testing of practical aerodynamic and manufacturing technologies to reduce *laminar* and/or *turbulent* boundary-layer flow skin friction on portions of wings, nacelles, empennages, and fuselages.

Significant *turbulent* skin-friction reduction with very small riblet geometries applied to the surface has been shown in previous research tests to allow significant net benefit. Development and demonstration efforts to practically apply and maintain riblet shapes (**Figure 1**) to painted aircraft surfaces are continuing to progress the improvement of operational riblets.

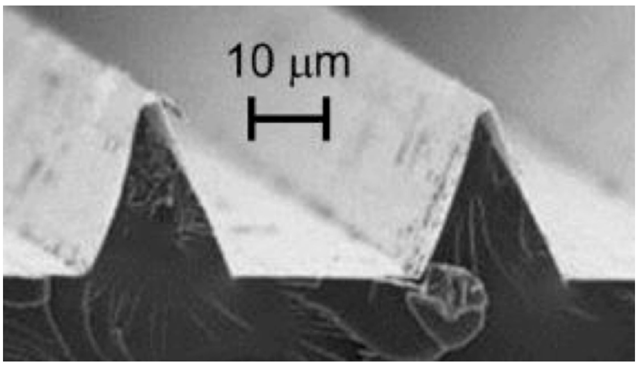

Figure 1. Microscopic Image of Surface With Riblet Shape[1].

Significant reduction in viscous drag is possible by maintaining laminar flow on forward sections of nacelles and wing surfaces. Surfaces intended for *Natural Laminar Flow* (NLF) are present on in-production commercial and business-jet aircraft (i.e., on nacelle-inlet lips and wing tips of some large aircraft, and on wings of some business jets).

Achievement of laminar flow requires validated aerodynamic, structural, and practical manufacturing methods that meet required surface tolerances. Progress has been made towards flight test demonstrations to assess potential integration challenges for *NLF* applied to wing surfaces of large passenger aircraft. Under the European *Clean Sky 2* program[2], flight test design is underway for testing *NLF* integration on modified outboard wings of a large demonstrator aircraft (**Figure 2**). In the USA, under the *NASA Environmentally Responsible Aviation* (ERA) public-private partnership research program[3], flight tests were conducted on a modified B757 flight test aircraft (**Figure 3**) to assess the impact of advanced surface coatings to minimize contamination impact on laminar flow.

Figure 2. Integrated NLF Design Concepts Installed on A340 Wing Tips of Clean Sky 2 Flight Demonstrator[2].

On wings of very large aircraft and on geometries with significant sweep (such as a vertical fin), laminar flow can be realized using boundary-layer suction control (*Hybrid Laminar Flow Control, HLFC*). Recent incorporation of an *HLFC* system on an in-production airplane indicates progress in laminar-flow manufacturing and suction-surface technologies.

Active flow control (AFC), using modest localized blowing from small embedded actuators can be used on highly deflected surfaces (such as a rudder) to keep the flow streamlined near the surface This application may allow reduction in size (weight and drag) of vertical fin and rudder. A recent B757 research test as part of the *NASA ERA* program was conducted to verify *AFC* rudder effectiveness (**Figure 3**). Potential applications of *AFC* to wings and flaps at low-speed flight conditions are also being studied, e.g., as part of the European AFloNExt research effort[4].

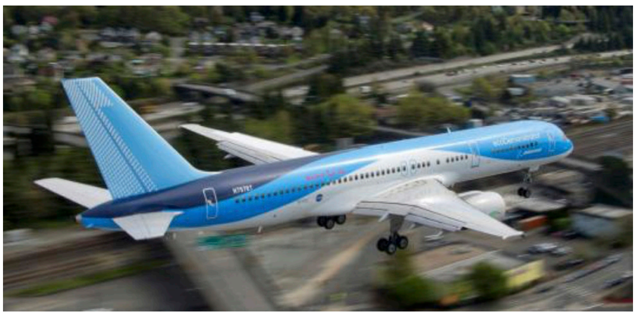

Figure 3. B757 EcoDemonstrator With AFC on Vertical Fin[3])

Previous estimates[5] suggest skin-friction drag reduction opportunities on order of 1% to 2% for riblets and on order of 5+% for laminar-flow. The magnitude of potential benefit is greatly dependent on the area of the airplane surface with laminar flow or with riblets.

Propulsion

There are three fundamental technology paths to reduce the fuel consumption of propulsion systems: increase thermal efficiency (by increasing the compressor Overall Pressure Ratio); increase propulsive efficiency (by increasing the engine ByPass Ratio - BPR); and decrease installed engine weight and drag. Over the last decade, newly introduced aircraft and major derivatives with new engines have followed these paths as diameters of engines have increased relative to wing chord length.

In the near-term, through 2020, new technology engines will enter service on new aircraft equipped with newly designed engines aircraft of various sizes. New technology engines at BPR = 9 to 12 for regional jets and single-aisle aircraft such as the MRJ, E2 jets, C Series, A320neo, 737MAX, MC-21 and C919 will provide a dramatic 15% reduction in fuel burn relative to earlier technology BPR~5 engines. Next generation engines for new production wide-body aircraft including A330neo and 777-9 will deliver 10% fuel burn reduction relative to current technology.

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Below is a summary of several major programs aimed at demonstrating and advancing promising propulsion technologies along these three paths:

The US national research program CLEEN (Continuous Lower Energy, Emissions, and Noise) Phase II[6] is an FAA-led public-private partnership effort to accelerate development and deployment of promising certifiable aircraft technologies towards reducing aircraft fuel burn by as much as 40%. So far, *CLEEN* Phase I benefits (**Figure 4**) have demonstrated the potential for a 1% fuel-burn reduction with: a Ceramic Matrix Composite engine exhaust nozzle (demonstrated on a B787); 5% with improved impeller/turbine materials and seals; and, either 20% with Ultra-High Bypass ratio engine (including Geared Turbofan technology), or 26% with an Open-Rotor engine configuration. Within the USA, *NASA's ERA* program[7] also contributed towards development and demonstration of propulsion technologies.

The Canadian *Green Aviation Research and Development Network (GARDN)* is a non-profit organization funded by the Business-Led Network of the Canadian Government and the Canadian aerospace industry[8]. Running from 2014 to 2019, one

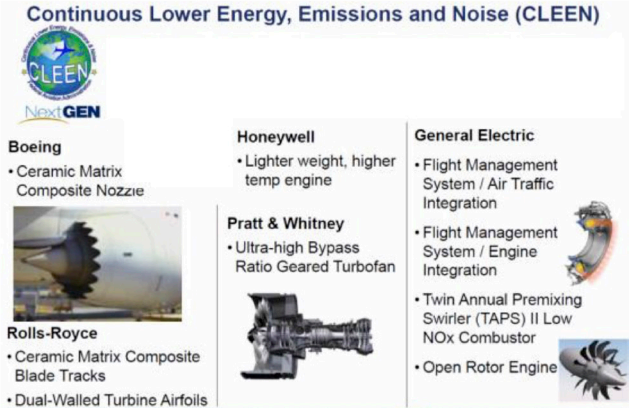


Figure 4. Propulsion Research Topics Studied Under FAA CLEEN Program[6].

project deals with energy-efficient aircraft configurations and operations, including studies on advanced propulsion systems to enable cleaner Unmanned Aerial Vehicles operations.

Europe's *Clean Sky 2* Joint Technology Initiative aims to develop and demonstrate breakthrough technologies for the civil aircraft market that could reduce CO_2 emissions by 20% (2025) to 30% (2035) compared with current state of the art aircraft [9]. *Clean Sky 2* intends to shorten the time to market for new and cleaner solutions tested on full-scale demonstrators, thus contributing significantly to reducing the environmental footprint of aviation. *Clean Sky 2* will build on the success of the previous *Sustainable and Green Engines (SAGE)* program to validate more radical engine architectures, including:

- Flight Test of a second Geared Open Rotor demonstrator **(Figure 5)**
- Ultra High Propulsive Efficiency demonstrator addressing Short/Medium-Range aircraft market, 2014-2021: design, development and ground test of a propulsion system demonstrator to validate selected low-pressure modules and nacelle technology topics.
- A short-range regional turboprop demonstrator, in the 1,800-2,000 shp class and small aero-engine demonstration projects for fixed-wing piston/diesel engines to small turboprop engines.
- Full-scale ground and flight test demonstration of advanced geared and very high bypass ratio large turbofan engine configurations for large aircraft and Middle of Market demonstrator.

Figure 5. Open Rotor Configuration Studied in Clean Sky Program[9].

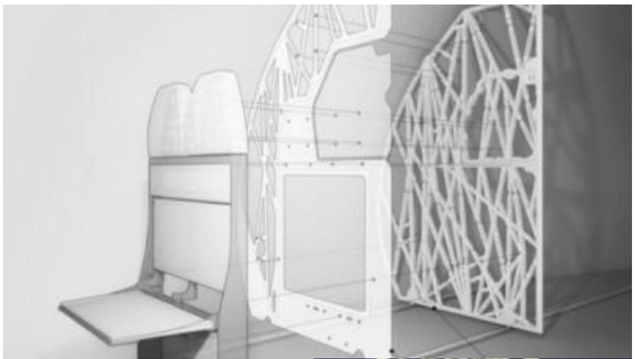
Beyond these demonstration program examples, research of future more radical system architectures, such as hybrid-electric, and distributed propulsion opportunities are being pursued by government, industry, and academia.

Structural Design and Materials

A key factor to be addressed when looking for ways to reduce fuel burn, and thus CO_2 emissions, is the aircraft empty weight. Significant use of advanced composite materials for the structure has become the baseline for new aircraft such as: Airbus A350XWB, Boeing 787, and 777-9 aircraft, as well as the Bombardier C Series. However, the aircraft manufacturers recognize the individual advantages of using both composites and advanced metallic alloys, aiming for an optimum balance of both materials.

Research on light alloys is expected to grow in the coming years, including the use of *Additive Layer Manufacturing (ALM)* technologies, or 3D printing, whereby instead of manufacturing a part by machining material away from a solid block of metal, the part is built layer-by-layer, from the inside out. Such parts can provide more efficient structural geometries and be much lighter than conventional parts.

For instance, Airbus (and its subsidiary APworks) came up with a new design shape, inspired by nature, for a partition wall for cabin interiors (**Figure 6**). The component was created with custom algorithms that generated a design that mimics human cellular structure and bone growth in nature. This "bionic" inspired design was then produced using 3D printing techniques. This breakthrough in design, supported by new alloys, developed specifically for ALM solutions, has been made possible by the increased capacity of computational technology. This ALM-based "bionic" partition is structurally very strong while weighing about 45% less than current designs. Flight tests are in progress.



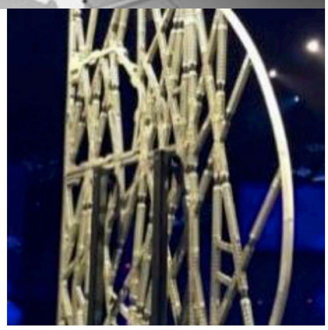


Figure 6. Additive Layer Manufacturing (ALM) "Bionic" Partition Demonstrator (Airbus)[10].

The next step forward involves dynamic programmable materials, like adaptable carbon fiber (**Figure 7**), or *Metallic Shape Memory* materials that are able to change shape when exposed to external conditions (e.g. pressure, loading, or temperature). For example, today's environmental-control and ventilation air inlets are generally static, so the air flowing through them varies greatly according to the speed of the aircraft. Programmable material embedded in the structure would allow the air inlet to adjust the air flow automatically to an optimized value, allowing reduced drag, and avoiding installation of mechanical actuation. The industry is exploring the feasibility, benefits and technical risks of these technologies for possible future realization.

Figure 7. Programmable Adaptable Carbon Fiber (laboratory test coupon).

In the nearer term, aircraft systems architecture changes could provide significant improvements to aircraft weight. Wireless technologies, recently authorized by the International Telecommunication Union in 2015 are good examples. Aircraft systems engineers believe that up to 30% of the electrical wiring harness may be substituted by wireless systems, thus reducing aircraft weight, and hence fuel consumption.

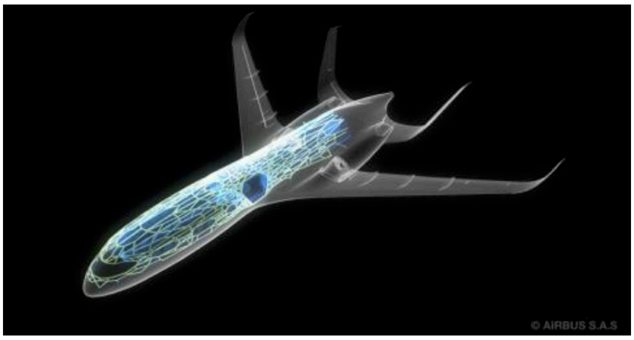


Figure 8. Conceptual Sketch of Aircraft Configuration Using "Bionic" Inspired Structural Design.

These potential materials and technologies can trigger major transformations in the way engineers of tomorrow will design and build airframes. They may enable significant CO_2 reductions while providing safe and certified aircraft structures and systems with novel design, manufacturing processes, and novel materials; all aided by innovative computational methods. Moreover, transformative structural and adaptable-material design and integration methods can facilitate new aircraft configurations with synergistic aerodynamic, propulsion, control systems and structural integration to further improve fuel efficiency. **Figure 8** provides a conceptual example using "bionic" inspired fuselage concepts.

Summary

New fuel-burn efficient aircraft, as well as derivative airplanes with very significant improvements in fuel-burn-reduction technologies, are entering into the global aviation system today and are expected to continue to do so at an accelerated pace in the coming years.

Airframe and engine manufacturers are working with governmental, regulatory, and academic research agencies to continue the progressive development of promising fuel-burn-reduction technologies in the areas of propulsion, aerodynamics, and structural design. These new technologies must be safe, economical, and easy to integrate into existing and new highly optimized aircraft. Continued support and cooperation from these bodies is needed to progress technology concepts from laboratory-scale testing and computational research, to full-scale demonstration and validation, towards operational and certification readiness. Opportunities in propulsive technology, aerodynamic drag reduction methods, manufacturing and structural design, and aircraft configuration design, can be expected to result in further continued reductions in aircraft emissions.

In general, in addition to technology readiness, practical operational and economic considerations need to be assessed, when evaluating fuel-burn-reduction aircraft and engine technologies. Due to integration complexity, some of the above-mentioned technologies may require incorporation into a new airplane design (versus retro-fitting a part of the geometry of an existing aircraft).

References

1. http://cordis.europa.eu/docs/results/271838/final1-pictures-rft-finalreport-270214-upload.pdf
2. http://www.cleansky.eu/content/page/sfwa-demonstrators
3. http://www.nasa.gov/image-feature/nasa-tail-technology-could-someday-reduce-airplane-fuel-use
4. http://www.aflonext.eu/
5. ICAO, Document 9963 (2010). Report of the Independent Experts on the Medium and Long Term Goals for Aviation Fuel Burn Reduction from Technology, Montreal.
6. http://www.faa.gov/about/office_org/headquarters_offices/apl/research/aircraft_technology/cleen/
7. http://www.aeronautics.nasa.gov/iasp/era/index.htm
8. http://gardn.org/
9. http://www.cleansky.eu/
10. http://www.apworks.de/en/