Advancing Technology Opportunities To Further Reduce CO_2 Emissions

By International Coordinating Council of Aerospace Industries Associations (ICCAIA)

INTRODUCTION

Improvements in aerodynamic, propulsion and structures technologies have a direct link to aircraft emissions reduction. Improvements in systems design and manufacturing technology are also key to achieving future aircraft CO_2-reduction goals.

In the past 5 years, additional advanced long-range twin-aisle airplanes with significant improvements in each of these technology areas have entered operational service (the Boeing 787-9 and -10, the Airbus A350-900 and -1000), while the new Boeing B777-9 aircraft with a completely new composite wing is being prepared for certification testing. Moreover, several recently introduced new single-aisle aircraft (such as the Airbus A220-100 and -300) and several derivative aircraft with major propulsion and airframe technology upgrades (such as the Airbus A320neo and A330neo, the Boeing B737MAX family, and the Embraer E-Jets E2), have entered operational airline service and provide substantial reductions in fuel burn.

Large-scale national and international research programs with cooperation between industry, government and academia continue to be key enablers to advance and mature the state of art in breakthrough technologies that can lead to further reduction in aviation's environmental footprint.

Flight demonstrators offer important technical and integration data to progress technologies such as laminar flow, advanced structural designs as well as more electric systems and propulsion.

Integration and certification challenges associated with advanced technologies are significant and affect the time frame needed to mature and adopt viable new technologies into production (on the order of 10-20 years). Maturation and adoption of key technologies summarized in this Chapter would provide significant additional opportunities to reduce aeronautical emissions.

AERODYNAMICS

Skin-friction drag and lift-dependent drag are the largest contributors to aerodynamic efficiency of commercial aircraft. Advances in materials, structures and aerodynamics are enabling significantly reduced lift-dependent drag by increasing effective wing span. Wing-tip devices typically increase the effective span, and to further increase wing span in flight some airplanes may include a folding wing-tip mechanism (Figure 1) for use on the ground to mitigate span constraints of existing airport infrastructure.

FIGURE 1: On-ground folding wing tip to maximize in-flight wing span (Boeing B777-9) (Image courtesy Boeing)

Progress is being made in development and testing of practical aerodynamic and manufacturing technologies enabling reduced skin friction through *laminar* and/or conditioned *turbulent* boundary-layer flow on portions of wings, nacelles, tails, and fuselages.

Methods to apply robust micro-scale 'riblet' geometries for *turbulent-flow* skin-friction reduction continue to be developed and tested to progress maturation to practicality. Estimates suggest opportunities on order of 1 - 2% fuel-burn reduction on new and existing aircraft with significant areas covered by practical 'riblets' (Ref. 1). More significant reduction in skin-friction drag is possible by maintaining *laminar* flow on forward areas of engine nacelles, wings and tails. Surfaces intended for Natural Laminar Flow *(NLF)* are already present on some in-production commercial and business-jet aircraft (e.g., nacelle-inlet lip and winglets on some larger aircraft, and portions of wing and fuselage on some business jets). Achieving laminar flow on aircraft requires well-balanced aerodynamics and structural designs together with aligned manufacturing methods to meet necessary surface quality.

Research and developmental flight testing of integrated wing structures that offer substantial laminar flow as well as allow high-rate production are critical for technology maturation. Within the European Clean-Sky 2 Program (Ref. 2), the *BLADE* (*B*reakthrough *L*aminar *A*ircraft *D*emonstrator in *E*urope) project has delivered important data on such wing *NLF* design concepts. Flight tests conducted on an Airbus A340-300 (with modified outer wings that are built to enable *NLF*) explored limits of robust laminar flow at various flight conditions (Figure 2).

FIGURE 2: Integrated wing NLF (Natural Laminar Flow) integration concepts installed on modified outboard wings of A340-300 (Clean-Sky 2 flight demonstrator BLADE) (Ref. 3)

On wings of very large aircraft and on geometries with significant sweep such as a vertical fin, laminar flow can only be realized using suitable surface suction (Hybrid Laminar Flow Control*, HLFC*). Recent flight testing of a vertical-fin *HLFC* configuration on a single-aisle aircraft under the European *AFloNext* (Active Flow, Loads & Noise control on Next generation wing) program (Figure 3) complements first *HLFC* application on the Boeing B787 tail. Overall, practical and robust achievement of significant laminar flow on wings and other surfaces could reduce aircraft fuel burn on order of 5%. The magnitude of potential benefit depends on the fraction of airplane surfaces manufactured to achieve laminar flow.

FIGURE 3: AFLoNext HLFC empennage flight test on DLR's A320 test aircraft (Image courtesy DLR)

Lastly, opportunities for Active Flow Control *(AFC)* using localized blowing to keep flow attached over deflected flaps or over the nacelle-pylon/wing junction have also been investigated. Such *AFC* systems if demonstrated practical may facilitate integration of larger turbofan engines on wings of future aircraft.

PROPULSION

Three technology paths can reduce propulsion-system fuel consumption: increase thermal efficiency by increasing the compressor Overall Pressure Ratio (with consequent increase in core engine operating temperatures); increase propulsive efficiency by increasing the engine Bypass Ratio (*BPR*) and consequently fan diameter; and, reduce installed engine weight and drag.

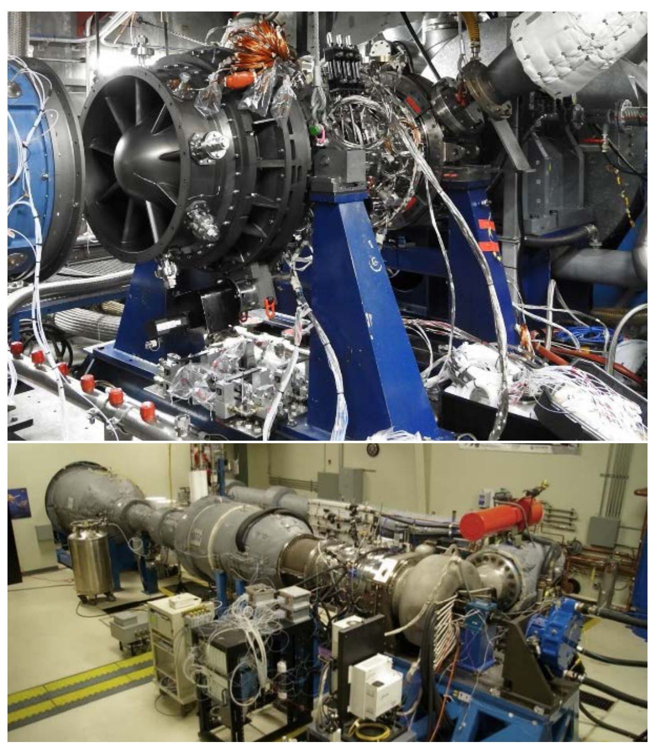
Over the last decade, newly introduced aircraft and major derivatives with new engines have followed these paths as diameters of engines have increased while aircraft manufacturers have maintained acceptable installation and integration penalties. Between 2016 and 2023, advanced technology engines have entered or will enter service on new and re-engined aircraft. New technology engines at *BPR*'s 9 to 12 for regional jets and single-aisle aircraft (such as the E2, A220, A320neo, B737MAX, MRJ, MC-21, and C919) provide a significant 15% reduction in fuel burn relative to earlier *BPR*~5 engines. Latest generation engines for new production twin-aisle aircraft (A330neo and B777-9) can deliver 10% fuel-burn reduction relative to 2014 in-service reference.

Major research programs continue to provide important contributions to develop, mature and demonstrate promising propulsion technologies along the three technology paths:

- Within the US, NASA's *ERA (Environmentally Responsible Aviation)* program (Ref. 4) significantly contributed towards development and demonstration of advanced propulsion (Figure 4). The US national research program *CLEEN (Continuous Lower Energy, Emissions, and Noise*) (Ref. 5) is an FAA-led public-private partnership effort to accelerate development and deployment of promising certifiable technologies towards reducing fuel burn by up to 40% compared to a 2005 baseline. *CLEEN Phase-I* benefits have demonstrated potential for 1% fuel-burn reduction with a Ceramic Matrix Composite engine exhaust nozzle (demonstrated on a Boeing 787); 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. *Recent CLEEN Phase-II* contributions are demonstrating the potential for up to 1% fuel-burn reduction (each) through compressor and turbine efficiency gains (PW); 3% with electric aircraft systems (GE's *MESTANG - More Electric Systems and Technologies for Aircraft in the Next Generation*), 1% through advanced turbine seals (Honeywell), and 1%

FIGURE 4: NASA ERA Wind-Tunnel Test (Top), FAA CLEEN Phase-I High BPR, Short Inlet Fan Rig and Engine Demonstrator Program (Bottom)

FIGURE 5: FAA CLEEN Phase-II Compressor (Top) and Turbine Core Technology Rigs (Bottom)



through new technology combustor impact on turbine temperature capability (RR) – see Figure 5.

- Europe's *Clean-Sky 2* Joint Technology Initiative aims to develop and demonstrate breakthrough technologies for civil aircraft that could reduce CO_2 emissions by 20% (2025) to 30% (2035) at aircraft level compared to current state-of-the-art aircraft (Ref. 4). In the propulsion arena, research builds on the success of previous *Clean-Sky 1* Sustainable and Green Engines (*SAGE*) program to validate more radical engine architectures, including:
  - Exploitation of Contra Rotative Open Rotor (*CROR*) demonstrator results from the successful Safran campaign in 2017 (Figure 6);
  - Design, development and ground test of a propulsion system demonstrator to validate selected low pressure modules and nacelle technologies for short/medium-range aircraft;
  - A short-range regional turboprop demonstrator (1800-2000 shp class) and small aero-engine demonstration projects for fixed-wing piston/ diesel and small turboprop engines;
  - Full scale ground-test in 2017 (Figure 6) and flight-testing planned for 2023 of Advanced Geared and Very High Bypass Ratio large turbofan engine configurations for large and middle-of-market type aircraft.
- European collaborative projects completed in 2017-2018, such as *ENOVAL* (ENgine mOdule VALidators - led by MTU Aero Engines), *LEMCOTEC* (Low Emissions Core-Engine Technologies - led by Rolls-Royce Deutschland) and *E-BREAK* (Engine Breakthrough Components and Subsystems - led by Safran Helicopter Engines) established propulsive efficiency improvements, higher thermal efficiency, and technological enablers for higher Overall Pressure-Ratio engines, respectively.

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

FIGURE 6: Ground and Flight Demonstrators in Clean-Sky 2 Program (Ref. 4).

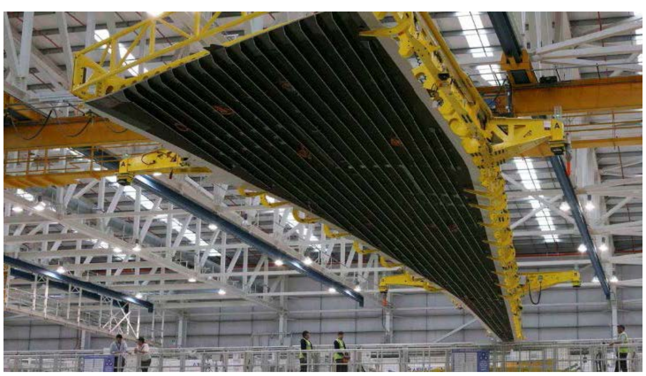
STRUCTURAL DESIGN AND MATERIALS

A key opportunity to reduce fuel burn and CO_2 emissions is further minimization of aircraft structural weight. Reduction in empty weight while maintaining structural requirements (strength, stiffness and safety) may be done with several levers:

- Further optimization of established structural technologies and/or materials;
- Introduction of new materials and/or structural technologies; and
- Alternate aircraft architectures.

Composite materials and structures technology have been developed and introduced in several new small and large aircraft (Figure 7). There is still progress anticipated in allowable margins linked to existing materials and in new designs targeting improved assembly process (such as bonding, stitching and welding). Aircraft manufacturers recognize the individual advantages of composites and advanced metallic alloys - and aim for optimum balance of both materials. For metallic materials, new alloys have been developed to be competitive with composites for thin parts applications (such as fuselages).

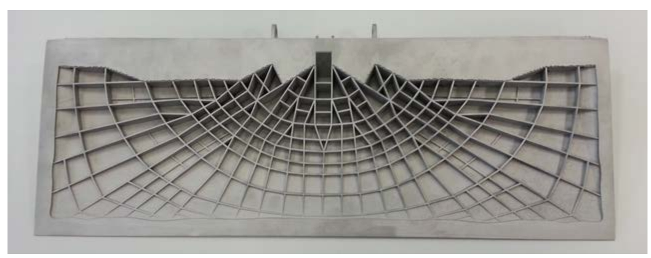
FIGURE 7: Composite upper wing skin with composite stiffeners for Twin-Aisle aircraft (Ref. 7)



Materials and structural design and optimization is now more efficient thanks to greatly improved computational simulation methods. This improved capability can be coupled with new design and manufacturing technologies like *ALM* (Additive Layer Manufacturing) to further reduce structural weight while optimizing load-carrying performance (Figs. 8 and 9). Multi-functionality is another axis of improvement by using the structure to fulfill additional roles. Structural multi-functionality can be reached by modifying the material (e.g., via nanotechnology) or via designs that can provide selected systems' functionality and/or geometry adaptivity.

FIGURE 8: Additive manufacturing of optimized part for reduced component weight (courtesy Airbus)

FIGURE 9: ALM wing spoiler component with "bionic" type structural optimization (Ref. 8)



Advanced load alleviation is an example of favorable interaction between aerodynamics and wing structural design. Further wing-span increase without significant concomitant weight increase is facilitated by introduction of reliable load-alleviation systems. The principle is to provide aerodynamic means to alleviate critical wing loads via active or passive systems when wing loading exceeds defined limits (Figure 10). Suitable design of composite structure can contribute to passive load alleviation via optimized fiber lay-up (Refs. 9 and 10).

Overall, future weight-reduction opportunities derived from combination of described technologies is estimated to be as much as 8% relative to current state-of-the-art structural configurations.

FIGURE 10: Wing span-load alleviation system to reduce root bending moment (schematic)

Finally, alternate aircraft architecture concepts (e.g., blended wing or truss-braced wing) may enable further structural opportunities, allowing larger wing spans and advanced material technologies for additional fuel-burn reduction. Maturation of aircraft configurations that are dramatically different from currently operational architectures will require significant development and demonstration to ensure that the same level of safety and integrated optimization is achieved.

SUMMARY

Several new as well as derivative airplanes with significant further reduction in fuel-burn are entering the global aviation system today - and are expected to continue to do so in the coming years. Airframe and engine manufacturers are working with governmental, regulatory and academic research agencies to continue progress and maturation of promising technologies in the areas of aerodynamics, propulsion and structural designs that can be safely, economically, and practically integrated in existing and new highly optimized aircraft. Further advances in computational simulation within each discipline and at the integrated aircraft level can enhance multi-disciplinary optimization of advanced technologies, while satisfying manufacturing requirements.

Continued research and development programs are key to progress technology and aircraft integration concepts from laboratory and computational research stages to full-scale demonstration and validation towards operational and certification readiness. Manufacturing, operational and economic considerations need to be considered in technology maturation assessment.

Opportunities in aerodynamic drag reduction, propulsive technology, manufacturing, structural design, as well as in aircraft configuration integration are expected to result in continued reductions in aircraft emissions. Due to integration complexity, some of the mentioned technologies may require incorporation in a new airplane (versus retrofitting existing aircraft), or a new aircraft configuration architecture altogether.

This article was written in collaboration by the following ICCAIA members: Jean-Pierre Cabanac, Gerd Heller and Rudiger Thomas (all Airbus); Krisha Nobrega (Embraer); Simon Smith (Rolls-Royce); Andrew Murphy (Pratt & Whitney); Olivier Penanhoat (Safran); Greg Steinmetz (GE); and Daniel Allyn and Paul Vijgen (all Boeing).

REFERENCES

1. Document 9963 (2010). Report of the Independent Experts on the Medium and Long Term Goals for Aviation Fuel Burn Reduction from Technology, Montreal.
2. http://www.cleansky.eu/
3. https://www.airbus.com/newsroom/press-releases/en/2017/09/airbus_-_blade_-laminar-flow-wing-demonstrator-makes-first-fligh.html
4. https://ntrs.nasa.gov/search.jsp?R=20140012638
5. https://www.faa.gov/about/office_org/headquarters_offices/apl/research/aircraft_technology/cleen/
6. http://www.cleansky.eu/engines
7. https://www.newmaterials.com/News_Detail_Jec_composites_exhibition__carbon_fibre_prepreg_content_on_each_a350_xwb_is_worth_over_4_million_to_hexcel_12957.asp
8. http://additivemanufacturing.com/2016/01/27/airbus-group-pioneering-bionic-3d-printing-learning-from-nature/
9. https://www.nasa.gov/centers/armstrong/features/pat_wing.html
10. https://www.nasa.gov/centers/armstrong/features/highly_flexible_wings_tested.html