International Civil Aviation Organization

WORKING PAPER

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GROUP ON INTERNATIONAL AVIATION AND CLIMATE CHANGE (GIACC)

THIRD MEETING

Montréal, 17 to 19 February 2009

Agenda Item 2: Review of aviation emissions related activities within ICAO and internationally

UPDATE ON CAEP ENVIRONMENTAL WORK

(Presented by the Secretariat)

1. INTRODUCTION

1.1 This paper provides an update on the activities of the ICAO Committee on Aviation Environmental Protection (CAEP) related to aviation CO_2 emissions with relevance to the activities of Group on International Aviation and Climate Change (GIACC). It includes on-going work in establishing technological and operational environmental goals and the work related to the assessment of future CO_2 emissions trends. This paper also contains an overview of work on guidance material on operational measures to reduce fuel burn and on studies on market-based measures.

2. CAEP'S WORK ON ESTABLISHING GOALS

2.1 The seventh meeting of CAEP (CAEP/7) held in February 2007 decided that work should be undertaken to establish medium (10 years) and long-term (20 years) environmental goals relating to the reduction of fuel burn through airframe and engine technological development, as well as through operational measures (e.g. improvement of air traffic management). In order to ensure transparency, it was agreed that the goals would be established by panels of Independent Experts (IE). The technological and operational improvements for the mid term and the long term will be incorporated into the assessment of progress toward ICAO environmental goals[1] for the years 2016, 2026, 2036.

2.2 CAEP, at its last Steering Group (SG) meeting (Seattle, 22-26 September 2008), agreed that the "Commercial Aircraft System Fuel Efficiency Metric" would be used as the fuel-efficiency metric for assessment of the ICAO goal related to aviation CO_2 emissions.

2.3 Technological Development Goals

2.3.1 For the work on establishing mid and long term (10 and 20 years) technology goals for fuel burn, a phased approach was agreed by the last CAEP SG meeting whereby, as a first step, the

[1] For Environmental Protection three goals have been adopted as set forth in ICAO Assembly Resolution A36-22:
- limit or reduce the number of people affected by significant aircraft noise;
- limit or reduce the impact of aviation emissions on local air quality; and
- limit or reduce the impact of aviation greenhouse gas emissions on the global climate.

manufacturers (ICCAIA) would produce a paper on technology advances to reduce fuel burn with a preliminary industry view on prospects for future fuel burn scenarios. This paper is included as Appendix C of this working paper.

2.3.2 The preliminary industry view summarizes the on-going technology development in fuel burn reduction being carried out by the aircraft and engine manufacturers in the four core areas of weight reduction, aerodynamic improvement, engine fuel efficiency improvement, and aircraft system optimization. The industry view also provides scenarios for fuel burn reduction for average in-production aircraft ranging from 0.95 to 1.16 per cent per year for 2005-2050. For comparison, the 1999 IPCC Special Report projected an average fuel burn reduction of 0.95 per cent per year for 1997-2015 and 0.57 per cent per year for 2015-2050.

2.3.3 It should be carefully noted that CAEP WG3 (Emissions Technical Working Group) welcomed the manufacturers' view as reflected in Appendix C as a step towards developing a good understanding of the potential technology advances, noting that:

a) the document provides initial industry views that could assist GIACC/3;

b) some CAEP WG3 members expressed concerns that there was a lack of some essential detail and assumptions that would assist GIACC in their deliberations; and

c) these preliminary results will be further examined during the Fuel Burn Reduction Technology Workshop in March 2009, the results of which will be presented to the next CAEP SG meeting (June 2009) and could be made available for GIACC/4.

2.3.4 An IE panel will review the expected environmental improvements from, but not limited to, the summarized list of on-going technological developments by the aircraft and engine manufacturers in the Appendix A of this working paper.

2.4 **Operational Goals**

2.4.1 An IE panel has also been established to review environmental improvements expected from air traffic management (ATM) and other operational initiatives in the mid-term (2016) and long-term (2026). The IEs are working with the ATM experts from the ICAO Air Navigation Bureau as well as with relevant experts from around the world. The initial workshop took place from 4 to 5 December 2008, and the IE review report is expected in time for the GIACC/4 meeting.

2.4.2 The format of the results expected from this work should be somewhat similar to those from the IPCC 1999 Special Report on Aviation and the Global Atmosphere. That IPCC report, in its chapter related to "air transport operations and relation to emissions", concluded that estimated improvements in ATM could improve overall fuel efficiency by 2 to 12 per cent and that the potential for other operational measures was 2 to 6 per cent. It is expected that these numbers would be updated and would have narrower uncertainty bands relative to what was provided 10 years ago in light of better definition of operational initiatives and improved modeling capabilities. The IE review is scheduled from 26 to 28 January 2009, and its initial result could be available to GIACC/3 if possible.

2.4.3 The IE panel will review the expected environmental improvements from, but not limited to, the summarized list of ATM and other operational initiatives in the Appendix B of this working paper.

2.5 Commercial Aircraft System Fuel Efficiency Metric

2.5.1 The establishment of a fuel efficiency metric is related to both the fuel burn technology goals and the operational goals. CAEP has proposed the “Commercial Aircraft System Fuel Efficiency Metric”, which uses the product of payload and distance as the denominator with fuel mass used as the numerator:

Commercial Aircraft System Fuel Efficiency Metric = Fuel Mass Consumed / Payload × Distance

2.5.2 The last CAEP SG meeting endorsed the use of this metric for environmental goals assessment through CAEP modelling activities and agreed that CAEP should evaluate the need for refinement of the fuel efficiency metric in the future, to encompass the complete life cycle analyses of the fuel used.

2.6 Environmental Goals Assessment

2.6.1 A robust modelling framework for the goal assessment of CO_2 emissions from international aviation is required. There has been satisfactory progress on development of models within CAEP. Various models have been evaluated and found to be fit within the CAEP process. To ensure that these models work from common inputs, a significant effort has been made to update and reach consensus on global databases such as those for airports, aircraft movements and fleet.

2.6.2 CAEP is now concentrating on producing quantified projections to be used in policy recommendations and decisions. The result of environmental goals assessment will be fuel burn projections for 2016, 2026, and 2036 relative to a 2006 baseline that incorporate the expected technological and operational improvements resulting from the IE review process in paragraphs 2.3 and 2.4.

3. CAEP’S WORK ON THE LIST OF MEASURES TO REDUCE EMISSIONS

3.1 Updates to Guidance on Operational Opportunities to Minimize Fuel Use and Reduce Emissions

3.1.1 In 2004, ICAO published *Operational Opportunities to Minimize Fuel Use and Reduce Emissions* (Circ 303). This guidance identifies and reviews various operational opportunities and techniques for minimizing fuel consumption and hence CO_2 emissions, in civil aviation operations. Operations covered in the guidance are: ground-level and in-flight aircraft operations, ground service equipment (GSE) and auxiliary power units (APUs), with potential actions to facilitate their broader application.

3.1.2 CAEP is now preparing guidance that will update and replace Circular 303 with new information on current initiatives relating to fuel burn reduction. The last CAEP SG meeting agreed that the new guidance will not only provide an update on current initiatives but also extend provisions covering 1) environmental impact assessment methodology applied to CNS/ATM, 2) guidance on computing, assessing and reporting on aviation emissions, and 3) environmental indicators. The draft guidance is expected in time for the GIACC/4 meeting.

3.2 Market-based Measures

3.2.1 With regard to market-based measures, ICAO has developed policies and guidance material and has been collecting information on three market-based measures: 1) voluntary measures; 2) emission-related charges; and 3) emissions trading.

3.2.2 ICAO developed a template in 2004 for voluntary agreements between aviation industries and public organizations, and has collected and disseminated information on voluntary actions to reduce aviation CO_2 emissions by Contracting States and various stakeholders in 2007, with a view toward helping other entities to initiate similar measures or improve their current measures. In 2007, ICAO published guidance on local emission-related charges (*Guidance on Aircraft Emissions Charges Related to Local Air Quality*, Doc 9884) and developed the guidance for use by States for incorporating international aviation emissions into their trading schemes (*Guidance on the Use of Emissions Trading for Aviation*, Doc 9885).

3.2.3 CAEP is now studying issues related to linking emissions trading schemes including aviation. It is also reviewing the various emissions offset measures to mitigate effects of aviation on climate change.

4. CONCLUSION

4.1 Elements of the CAEP Work Programme are closely related to the activities of GIACC, particularly the work on fuel burn technology and operational goals; the environmental goals assessment; and the new guidance replacing Circular 303, which will support the development of global aspirational goals and the list of measures to reduce emissions, respectively. It is important that CAEP and GIACC continue to cooperate to maximize efficiency in this area and leverage the synergies between activities of both groups.

5. ACTION BY THE GROUP

5.1 The Group is invited to:

d) note the information in this paper; and

e) consider how CAEP can further support the activities of GIACC in its deliberation of the ICAO Programme of Action.

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APPENDIX A

SUMMARY LIST OF TECHNOLOGICAL DEVELOPMENT

1. Weight Reduction using advanced materials, structural layout and manufacturing methods, including:

- Advanced light and hard alloys;
- New composite materials and manufacturing processes;
- Self healing materials;
- Smart structures;
- Nanotechnologies; and
- New joining processes.

2. Aerodynamic Improvements, including:

- Reduce local skin friction by maintaining laminar flow via NLF (Natural Laminar Flow) or HLFC (Hybrid Laminar Flow Control) and/or by reducing turbulent skin friction;
- Reduce wetted area while minimizing flow separation, optimize surface intersections/junctures and fuselage aft-body shapes, and use flow-control devices to minimize flow separation;
- Minimize manufacturing excrescences (including antennas);
- Optimize air inlet/exhaust devices; and
- Suitable wing-tip devices (winglets or wing tips).

3. Propulsion System and Power Generation Developments, including:

- Propulsive efficiency (decreasing fan pressure ratio and increasing the engine bypass ratio);
- Thermal efficiency (increasing engine pressure ratio); and
- Transmissive efficiency (improved component efficiencies).

4. Aircraft Configuration Optimization and Systems Development, including:

- More electric aircraft (bleedless engine, fuel cell, electric flight control); and
- Fly-by-Wire and Fly-by-Light

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APPENDIX B

SUMMARY LIST OF AIR TRAFFIC MANAGEMENT AND OTHER OPERATIONAL MEASURES

1. Air Traffic Management Initiatives, including:

- Flexible use of airspace
  - optimize and balance the use of airspace between civil and military users, through both strategic coordination and dynamic interaction;
- Reduced vertical separation minimum (RVSM)
  - reduce vertical separation to 1000 ft above FL 290 from the current 2000 ft, thereby providing six additional flight levels;
- RNAV and RNP (performance-based navigation:PBN)
  - exploit area navigation (RNAV) and required navigation performance (RNP) capabilities in aircraft and allows more efficient routes and aircraft trajectories that are not directly tied to ground-based navigation aids;
- Air traffic flow management (ATFM)
  - the implementation of strategic, tactical and pre-tactical measures aimed at organizing and handling traffic flows; and
- Terminal area design and management
  - the optimization of the terminal control area through improved design and management techniques.

2. Other Operational Measures accrued from optimization of airport/aircraft operations.

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APPENDIX C

PROGRESS REPORT ON AIRCRAFT TECHNOLOGIES FOR FUEL BURN REDUCTION

(Presented by ICCAIA in CAEP WG/3 Meeting in Tokyo – Nov 17-21, 2008)

Summary

- ICCAIA has observed there is increased interest in projecting what potential aviation emissions reductions could be in the mid and long term. In support of MODTF CAEP/8 Environmental Goals Assessment exercise, ICCAIA recently developed recommended scenarios of new and in-production aircraft fuel burn improvement over time.

- Significantly better consumption scenarios than the forecasted fuel burn made through the 1999 IPCC Special Report On Aviation were identified by ICCAIA to better reflect the current technology status and forecast. (Refer CAEP8_WG3_LTTG5_WP05 for more information).

- As an interim status to the Fuel Burn Technology Goals Review Process, this paper summarizes the on-going industry technology developments, which are being transitioned in the near future to upcoming products or are being studied for next-generation aircraft, in support of the fuel burn scenarios identified for the MODTF exercise.

- Dedicated and sustained research programs supported by funding bodies play a critical role in the continuous success of technology into maturity and their implementation within aviation industry.

1. INTRODUCTION

Aviation has voluntarily reduced its fuel consumption by a significant amount over the past forty years. These challenges have been met by aggressive revolutionary and evolutionary technology development while maintaining unprecedented levels of safety. ICCAIA is committed to further decreasing the environmental footprint of aviation and to supporting its customers in achieving their environmental commitments, including greenhouse gas emissions reduction goals. To achieve this, ICCAIA is dedicated to aggressive environmental objectives, specifically with regards to overall aircraft technology development and insertion when required maturity levels are achieved.

The purpose of this paper is to report to LTTG and WG3 the progress and status of on-going fuel burn reduction technology developments explored by different engine and airframe manufacturers which are being transitioned in the near future to the upcoming products. Promising and less mature technologies that are further out into the future are also summarized. These preliminary results will be further validated during the Fuel Burn Reduction Technology Workshop in March 2009 and Fuel Burn Reduction Technology Review in 2010.

The fuel burn technology developments covered herein are based on kerosene type fuels. No consideration have been given at this time to alternate fuels since current study focuses on fuel burn reduction technologies that reside on the aircraft itself. Any use of alternative fuels is assumed to be on a "drop in" basis. As "drop in" fuels reach the technology readiness for implementation, industry can adopt them.

2. TECHNOLOGY ADVANCES IN PRODUCTS ENTERING REVENUE SERVICE IN 2007 – 2015

Over the past forty years, aircraft and engine manufacturers have aggressively continued product development, with a key design driver being a focus on fuel burn reduction technologies. Extending this trend, newly certified aircraft entering revenue service in next 7 years will provide at least 15% fuel burn reduction relative to the products they replace. Some of these products just introduced or arriving in the near term are: Airbus A380, Sukhoi Super Jet 100, Boeing B787 family and B747-8, Airbus A350 family, Bombardier CRJ1000 and CSeries, Mitsubishi Regional Jet MRJ90, and Chinese Regional Jet ARJ21.

Specific airframe and engine technologies that contribute to the significant fuel burn reduction in these new products include:

- Natural Laminar Flow and other aerodynamic refinements such as blended winglets and raked wingtip
- Advanced aircraft systems, including Electric Aircraft Architecture and Advanced Fly-by-Wire control laws
- Composite materials and advanced metal alloys on primary structure components including wing and fuselage components
- Advanced Turbofan Engines with Higher Bypass Ratio configurations including geared and ungeared fan architectures
- Further Aircraft Configuration Optimization, integration

3. ADVANCES IN CORE TECHNOLOGIES UNDER DEVELOPMENT

Aviation, a domain dominated by multiform and sophisticated technologies, where complex optimization and trade-offs are involved, carries a significant challenge when assessing technology progress, as technologies require a thorough and complete life cycle assessment. Additionally, while individual technologies may provide unique and individual benefits, careful consideration must be given when assessing the potential benefit at aircraft level. Indeed, individual technology benefits are not necessarily cumulative. Any assessment requires an appropriate integration of all the various technologies, an evaluation of technology interactions and the subsequent benefits to the overall aircraft configuration, performance, airworthiness and safety.

Fuel burn reduction technologies can be attributed to developments in one of the four following Core Aircraft Technology Design Areas:

- Weight reduction using advanced materials and structural layout, including innovative manufacturing methods,

- Aerodynamic improvements resulting in lift/drag optimization and configuration refinements
- Engine specific fuel consumption (SFC) reduction: Propulsion and power-generation developments, and
- Aircraft configuration optimization and systems integration

Fuel burn technologies are also not "one size fits all". The benefit for a specific technology will be dependent on aircraft and engine size, and mission design parameters. In general, aircraft and engine manufacturers are committed to introducing sufficiently mature technologies into service at the earliest possible practical time on existing or on entirely new configurations.

3.1 Advanced Materials, Structural Layout and Manufacturing Methods

Minimizing overall aircraft weight is a key driver for airframe design. Any excess weight requires the overall aircraft system to be oversized (e.g., resulting in higher wing area to lift the maximum takeoff gross weight, additional thrust for takeoff and cruise, and subsequent increases in drag and noise, and requirements for additional fuel to provide the same range.) Lighter and stronger materials are therefore enablers to enhanced aircraft performance and fuel burn.

The basic material properties (strength, fatigue behavior, damage tolerance, density, stiffness, etc.) are key to selecting the best material for a given airframe part. Furthermore, aspects such as manufacturability, repairability, cost, supplier availability and other environmental aspects (such as recycling expectations) also need to be considered.

For future aircraft airframes, a large range of materials, manufacturing processes and technologies are under investigation, with different maturity levels. Some examples of opportunities are:

- Advanced light and hard alloys (e.g., Aluminium-Lithium alloys, advanced Titanium alloys, Aluminium-Magnesium-Scandium alloys)
- New composite materials and manufacturing processes (e.g., thermoplastic, advanced thermosets)
- Self Healing Materials
- Smart structures (e.g., morphing, self-reacting structures, multi-functional structures)
- Nanotechnologies (e.g., surface treatment and protection, advanced composite materials) and
- New joining processes (e.g., Laser Beam Welding, Friction Stir Welding, advanced bonding).

To illustrate the progress made so far, back in the 1990s aircraft primary structure was composed of no more than about 10 per cent of composite materials. New and future products will contain close to (or more than) 50% of composite material, with a total of at least 70% of advanced materials. Continued and progressive improvements are made by the aviation industry to further consider advanced materials introduction into future aircraft and engines. The best material will be chosen for each application.

In addition to new materials, new manufacturing process such as the laser beam welding (LBW) has recently been introduced in the production of primary structure. Currently expanding to the commercial aircraft industry to complement or replace other conventional welding techniques or riveting processes, LBW improves the quality of the joining of metallic structure and offers opportunities to reduce aircraft weight.

3.2 Aerodynamic Improvements

Aerodynamic efficiency is a key driver for airframe design. Efficient aerodynamics allows an aircraft to carry a given payload further or to reduce the aircraft fuel consumption for a given range. Technologies associated with aerodynamic improvements are being explored by all aircraft manufacturers. They include: improved winglets or alternate wing-tip devices, optimization using advanced CFD (Computational Fluid Dynamics), excrescence drag reduction, laminar flow and turbulent-skin-friction reduction.

The typical breakdown of total airplane drag into the main drag components is shown in Fig. 1 for a large twin commercial aircraft configuration in the cruise condition. The main drag components are: lift-dependent (or induced) drag, shock-wave drag, excrescence drag and viscous (or profile) drag.

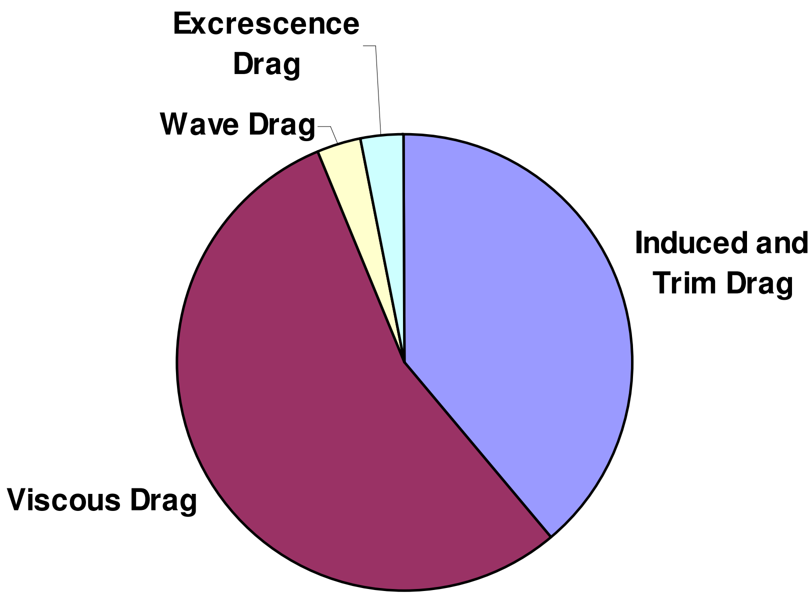

Figure 1 Typical Drag Breakdown for Subsonic Commercial Aircraft at Cruise Condition

Viscous and lift-dependent drags are the largest contributors to the total drag of subsonic aircraft.
For future airframes, a range of drag-reduction technologies are currently under investigation in these two dominant categories. Some examples of those technologies are given below.

<ins>Viscous drag reduction</ins> promises one of the largest areas for improved aircraft efficiency over the next 10 - 20 years. There are several opportunities for viscous drag reduction:

a) Reduce local skin friction by maintaining laminar flow via NLF (Natural Laminar Flow) or HLFC (Hybrid Laminar Flow Control) and/or by reducing turbulent skin friction (e.g., passively with riblets, or with active flow control, such as small low-energy plasma actuators or small oscillating-wall actuators)

b) Reduce wetted area while minimizing flow separation, optimize surface intersections/junctures and fuselage aft-body shapes, and use flow-control devices to minimize flow separation

c) Minimize manufacturing excrescences (including antennas), and

d) Optimize air inlet/exhaust devices.

Lift-dependent drag is dominated by physical wing span and by spanloading. Wing span is constrained by structural (weight) considerations as well as by airport infrastructure (e.g., terminal gate width and spacing between taxiways etc.) Advances in materials, structures and aerodynamics currently enable significant lift-dependent drag reduction by maximizing effective span extension, within airport constraints, using composites in primary wing structure. Suitable wing-tip devices (such as winglets or raked wing tips) together with appropriate spanloading can provide important increases in the effective aerodynamic span, resulting in reduced lift-dependent drag. Older-generation aircraft may have a large performance benefit with the addition of winglets; however, structural weight and aerodynamic optimization need to be combined to arrive at a best tip extension for a given airplane. In addition, for a given span, spanload tailoring is feasible with aeroelastic tailoring or variable camber employing trailing edge flaps or other devices throughout the mission including off-design operational conditions.

Aerodynamic drag benefits need to be traded against impact on manufacturing, aircraft weight, systems complexity, maintenance, reliability, and economical aspects to determine if a drag improvement results in a net benefit to the aircraft transportation system.

3.3 Engine SFC Reduction: Propulsion System and Power Generation Developments

Since the introduction of the gas turbine aero engine, fuel consumption has been improved year on year through improved efficiencies. Tomorrow's aero engines will continue to be further improved through insertion of advanced technology, as well as by introduction of novel engine architectures.

Generally, improvements in engine specific fuel consumption of aircraft engines can come from following three categories:

- Propulsive efficiency (decreasing fan pressure ratio and increasing the engine bypass ratio)
- Thermal efficiency (increasing engine pressure ratio)
- Transmissive efficiency (improved component efficiencies).

These three pathways for improvement as well as novel engine architectures are briefly discussed below. It should also be noted that focusing on improved SFC must be balanced by other (aircraft) design criteria to ensure that an overall net improvement in performance and customer acceptance is achieved. These design criteria include weight, drag, noise, and emissions, but also include operability, complexity, reliability, repairability, and cost of ownership.

Propulsive Efficiency

Propulsive efficiency is a measure of how efficiently the exhaust gas of the engine propels the aircraft. It is maximized by lowering the speed of the exhaust as close as possible to the speed of the aircraft. In future engines, propulsive efficiency improvements will continue to take place commensurate with the engine manufacturer's improvements in fan blade, fan case, and nacelle weight reductions, as well as drag control measures for the nacelles. Continued incorporation of composites or other light weight materials in the fan system will continue to provide weight reductions. However, tomorrow's engines are being optimized in the range of 10-12 bypass ratio. To continue to make propulsive efficiency improvements, either the nacelle system has to be revolutionized to reduce weight and drag, or the ducted nacelle approach needs to be eliminated. The former may facilitate the use of ultrahigh bypass ratio (UHBR) turbofans, while the latter infers the use of open rotor engines. Open rotor engines effectively run at a very high bypass ratio resulting in a very high propulsive efficiency and low SFC. However the removal of the nacelle introduces new challenges in installation (very large fan diameters requiring unique placement on the aircraft) and possible noise implications.

Thermal Efficiency

Thermal efficiency is a measure of how efficiently the energy content of the fuel can be converted to useful energy (gas-stream horsepower) for subsequently producing thrust. For turbofan engines, which today operate on a Brayton cycle, thermal efficiency is directly proportional to the engine's overall pressure ratio (OPR), or the level to which we can efficiently compress air within limitations set by the rest of the engine system. Today's commercial turbofan engines are limited in OPR to a level of about 50:1. Further increases in OPR will cause cooling air requirements to increase at a rate such that the energy discarded/lost by the cooling air overcomes the original benefit of increasing the OPR, and NOx emissions may become untenable due to associated increased gas temperatures. .

A further approach for improving thermal efficiency is related to manipulation of the Brayton cycle. This include concepts such as intercooling and recuperating (as discussed in 3.3.5 below), or via variable or adaptive cycle mechanism manipulation. All such concepts are being pursued in various demonstrator efforts by engine manufacturers.

Transmissive (Component Efficiency)

Engine manufacturers continue to improve on component efficiencies throughout the engine from mitigation of aerodynamic losses, or extensions of high-efficiency islands in the design space. The advances are a result of increased computing capability and increased analysis fidelity, and can lead to concepts such as increased stage loading to allow for blade and vane count reductions, or even entire elimination of a turbine or compressor stage.

Powerplant Installation effects

The impact of a powerplant, in term of fuel burn, is not only linked to its key parameters of propulsive and thermal efficiencies, but also other parameters. In fact, when regarding powerplant installation and integration effects, the engine manufacturer has to make, together with the airframer, a variety of compromises between parameters such as:

- Engine efficiency improvement versus weight
- Engine efficiency improvement versus drag from the engine's nacelle and interaction between nacelle and airframe
- Performance in cruise versus performance at other conditions in the mission (such as take-off)
- Energy extraction from engine (mechanical, electrical, and pneumatic, e.g., "hot" air for anti-ice /de-icing systems).

Engine Architecture Concepts under Consideration

Current engine manufacturers' focus includes the Advanced Turbofan (ATF), the Geared Turbofan (GTF), the (Counter-Rotating) Open Rotor engine, and Intercooled and Recuperated cycles. All of these concepts are being worked and are projected to have significant fuel burn improvement relative to today's engines. Further description of these architectures will be covered at the upcoming Fuel Burn Reduction Technology Workshop in early 2009.

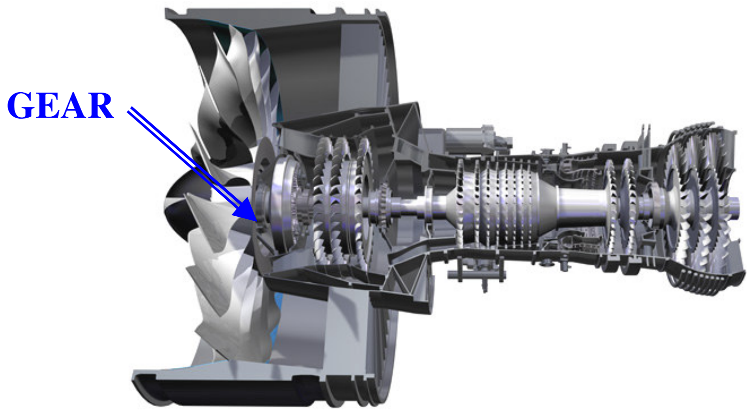

Figure 2 Typical GTF Cross-section

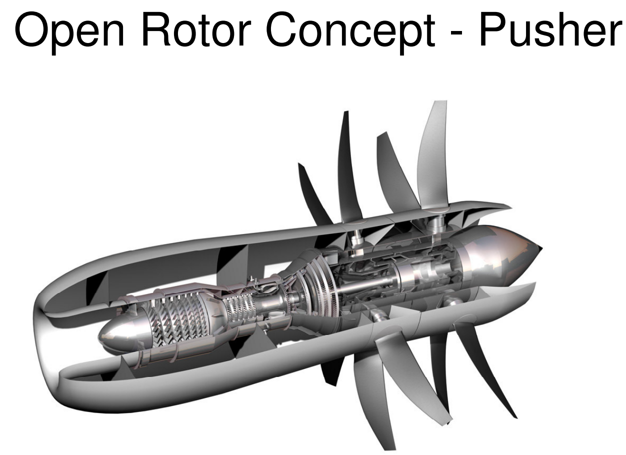

Figure 3 Typical Open Rotor Concept - Pusher

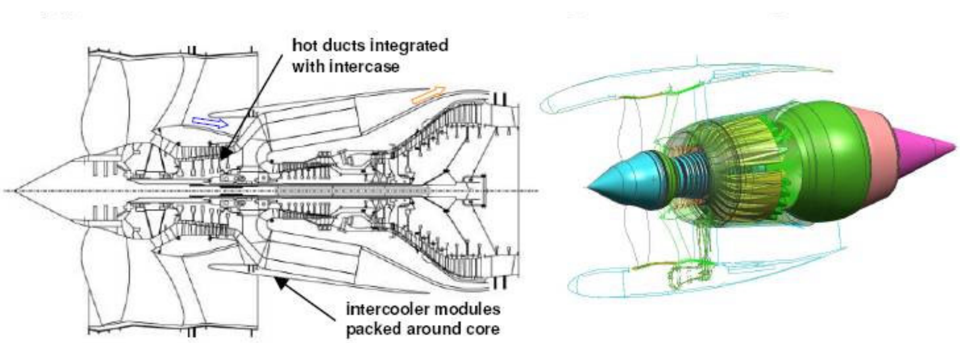

Figure 4 Possible Intercooler Aero Engine Configuration

3.4 Aircraft Configuration Optimizations and Systems Developments

Multi-disciplinary configuration optimizations through synergies between various disciplines are of significant importance and value when designing an aircraft with current standard aircraft configuration. Setting the design space with all the facts in mind while allowing design techniques that favour deeper exploration of the design space is of major importance.

Systems optimizations at the aircraft level are being explored continuously while ensuring that its implementation is justified for the given application and specific characteristics of the application. These are assessed using the life cycle cost modeling which can offer different conclusions for the same technology, being dependant on the aircraft and engine size, mission objectives and overall program and marketing requirements and objectives.

System optimization avenues that aircraft manufacturers are pursuing include:

- Even More Electric Aircraft (MEA)
    - Bleedless engine : as in medium term opportunities
    - Fuel cell : as a replacement for APU
    - Electric Flight Controls : as a replacement for hydraulic systems
- Active load alleviation through Fly-by-Wire control laws advancements
- Fly-by-Light (FBL)
- Integrated Utilities and multi functions components applications which offers parts count reduction and overall a/c efficiency improvement

Achievement of further significant improvements in aircraft efficiency may require future consideration of novel aircraft configurations (such as blended-wing body, strut-braced or spanloader aircraft concepts) to allow additional significant synergism between the core aircraft technologies. In addition to improving near-term efficiency, aircraft and engine manufacturers are involved in studies that evaluate alternate aircraft configurations.

Development to application and operational readiness of the technologies described in this section is highly dependent on the dedicated and sustained research and technology development at and by aircraft manufacturers and their suppliers, airline operators, government research agencies, airworthiness authorities and academia. Several large-scale programs involving all these important technology partners have been defined in Europe, United States, Japan etc, towards maturing some of the most promising core technologies in the next 10 – 20 years and their dedicated and sustained support is critical to the continued success of technology maturity and implementation.

4. TECHNOLOGY TRANSITION TO PRODUCT

Technology development and implementation into the operational fleet as retrofit or incorporated into an entirely new aircraft spanning over many years and requiring large and consistent funding, can be divided into two major steps

a) The first part is to start with a novel technology concept (or aircraft configuration concept) and to develop it to the point that it can be demonstrated in a realistic environment. While novel technologies are theoretically interesting, they are only partially proven and based on analytical and laboratory type analysis (i.e., CFD, and wind tunnel test with scaled models). This part is typically accomplished by national research organizations.

b) The second part is to transition the technology concept from the demonstration phase into a viable product. This is where industry takes over and bridges the gap between laboratory and market, maximizing the benefits while minimizing the industrialization roadblock and costs. Particular additional aspects that are evaluated include: Safety, Durability, Operability, Maintenance Costs, Production Costs, Reliability, Risk, Environment, Certification, and Market acceptance. The end objective being to assess and address concerns and problems, reduce the risks, identify the key fields or items where priority should be given and in the end, to demonstrate an overall benefit for the business case and increases possibility of novel configuration selection.

5. TRADE-OFFS

In the establishments of the fuel burn reduction trends and goals, one must take into account the effects that these technologies have relative to other environmental parameters. The trade offs were previously discussed within LTTG, WG3 and CAEP to a large extent. When new generation of aircraft and engines have been developed, manufacturers have worked in close cooperation to ensure the new generation is more environmentally friendly than the previous generation. Noise levels, local air quality emissions and fuel burn have all improved over the past decades. When making decisions on the appropriate trade-offs and investments in research, the industry has been guided by the various requirements defined by all the aviation stakeholders (operators, airports, populations close to the airport, passengers, etc). In general, the desires of those stakeholders have been aligned in the same directions. All environmental parameters are important and, ideally, manufacturers would like to select the solution that provides benefits to all of them. However, some of these environmental factors and other design drivers are inter-related and can go in different directions.

An example of environmental trades is fuel burn reduction versus noise reduction. For a turbofan engine, noise generally reduces with increasing fan diameter, whereas the increasing weight and drag mean that there is an optimum fan size for minimum fuel burn. The open rotor engine offers a step change improvement in fuel burn, but the lack of a nacelle means that it will probably not match an advanced turbofan on noise. Industry is aware of the challenges associated with possible trade-offs and all stakeholders need to be involved to achieve a satisfactory solution.

6. FUEL CONSUMPTION TECHNOLOGY SCENARIOS

Based on improvements in core aircraft technologies identified above and the overall assessment of their benefits, ICCAIA recently concluded in an initial assessment, that fuel consumption reduction has been stronger than was anticipated by the 1999 IPCC report. The 1999 IPCC scenario may be considered as being primarily useful for historical reference. Because of this, new fuel burn reduction technology scenarios can better reflect the current technology ambitions. Shown in figure 5 (Ref CAEP8_WG3_LTTG5_WP05) below are three fuel burn technology scenarios (“1999”, “A”, and “B”). 1999 is the 1999 IPCC scenario that produces 0.95% year by year fuel consumption reduction between 1997 and 2015, and 0.57% per year reduction from 2015 to 2050. New Scenario A relies on intensive current and future research efforts and introduction of improved products reflecting actual achievements or ambitious targets and produces a 0.96% per year fuel burn reduction. New Scenario B requires even higher research commitment and effort levels than Scenario A, and includes the assumption that ambitious EU and US research programs will be funded and successful. Scenario B produces on average a 1.16% per year fuel burn reduction. All three scenarios are shown with a base year of 2006, are projected to 2050, and represent smoothed improvements of the in-production fleet (newly produced aircraft entering the operating fleet in a given year as required for aircraft replacement and fleet growth).

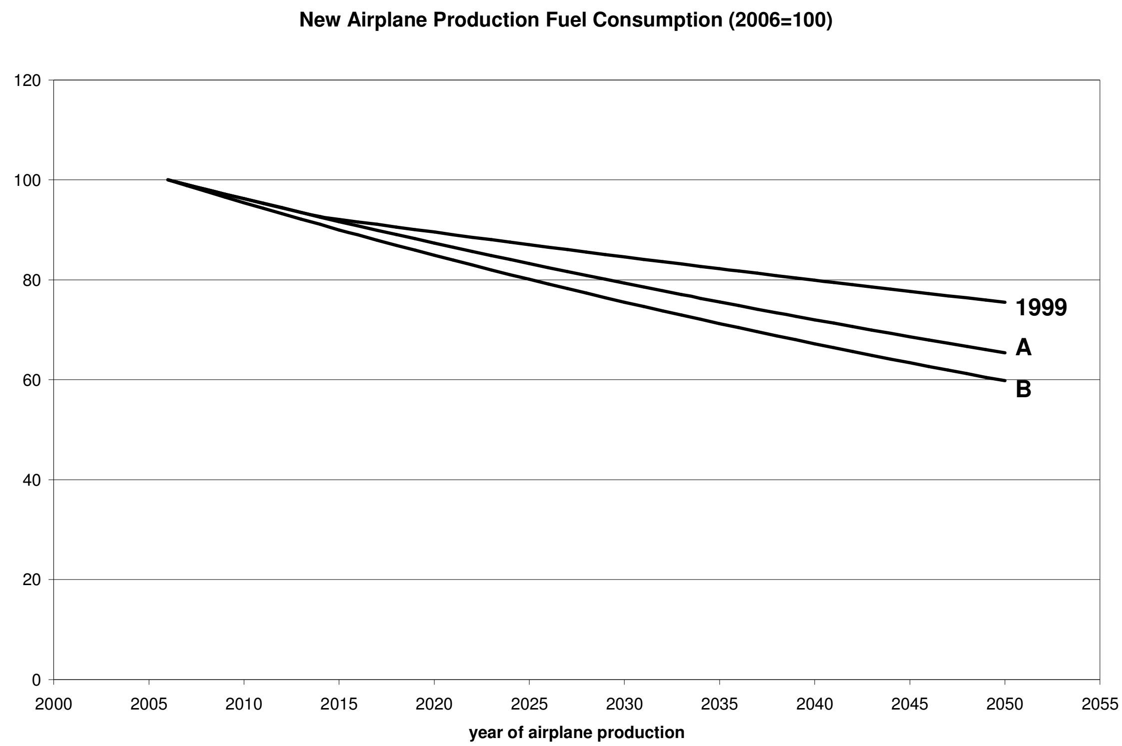

Figure 5 New Production Aircraft Fuel Consumption Scenarios

7. CONCLUSION

A list of significant improvements in aircraft core technologies (both in airframe and engine areas) has been identified. Development and implementation of these technologies when the appropriate readiness level is achieved will benefit current new-generation of aircraft as well as the next generation of aircraft. Numbers were provided to illustrate individual or specific technology improvements in terms of fuel burn. Those numbers are preliminary figures, and represent the best estimate from manufacturers at the time of writing. Those figures may be subject to evolution as the technology maturity increases.

Aircraft industry will continue to aggressively pursue these technologies in its commitment to further decrease the environmental footprint of aviation and to support its customers in achieving their environmental commitments, including greenhouse gas emissions reduction goals.

To achieve this, ICCAIA is dedicated to aggressive environmental objectives, in particular in terms of overall aircraft technology development and insertion, while also relying on the research establishment progression to bring technologies to a mature level that can make the technologies implementation and transition achievable on both new aeronautical products and on the existing fleet.

This paper is a progress report that and will be followed by a report based on the Fuel Burn Reduction Technology Workshop in March 2009 and the Fuel Burn Reduction Technology Review in 2010.

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