EVOLUTION OF EQUIPMENT AND SUB-SYSTEMS FOR THE FUTURE GREEN AIRCRAFT

Joseph HUYSSEUNE, Olivier HIERNAUX
THALES Aerospace Division

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Abstract

Preserving the environment at global level has become a major societal challenge in the western world, as evidence is being made that the emission of greenhouse gases (GHG) is causing significant climate changes.

Though it contributes to just a few percents of the global emission of GHG, the Air Transport Industry has undertaken to address this challenge very seriously. Numerous initiatives are launched at individual, national and continental levels.

Reaching these targets requires working in many fields: the design of new aircraft configurations, new engines, new materials, but also new on-board systems.

This paper focuses on initiatives currently being taken in Europe by Equipment and Systems manufacturers, to contribute to the goal of "greener" aircraft, i.e. with a lower environmental impact, for both gas and noise emissions. Particular emphasis is made on the Clean Sky initiative: a major research project launched by the European Commission in 2008, specifically dedicated to this environmental objective, with outcome expected after 2015. Clean Sky developments will be made in close synergy with SESAR, the other initiative on future European ATM system.

1 General Introduction

The evidence of different phenomena: shrinking of the ozone layer, reduction of the Arctic ice field, elevation of temperature in different parts of the world and local climate changes, give credit to the theory that the global atmosphere is changing rapidly and at a growing pace, and that human activities contribute to these changes, notably through the consumption of fossil fuels, resulting in greenhouse gases.

A large number of studies have been achieved in the past years, resulting notably in the publication of the IPCC Fourth Assessment Report [1], and the Stern Review Report [2].

These reports acknowledge the fact that Aviation counts for 2 to 3 % of global CO_2 production, but since this percentage is expected to rise as an effect of the growing demand for Air Transport in the next decades, they call for immediate actions to counter this growth.

Despite this relatively small contribution, Aviation industry is indeed more than any other industry under political pressure to reduce it further, probably because of its high public visibility, the lack of awareness that environment and fuel saving have already been a steady concern for it, and because its community is made of a reduced number of key actors, which is not the case of the other industries.

In addition to this, the growing population in major airports areas puts an increasing pressure, through organizations created for that purpose, to consider noise as a societal "environmental nuisance" on its own, and claims it should be reduced by all means.

We will introduce and deal separately with these two environmental impacts of commercial Aviation: perceived noise in terminal areas on one hand, and gases and other pollutants emissions on the other hand. We will then provide an overview of actions undertaken to reduce them, through the design and development of new on-board systems.

2 Current situation

2.1 Noise impact of Aviation

Numerous large airports are surrounded with highly populated areas, and noise impact is perceived today as a real issue –even if aircraft are fully compliant with regulations in place-. The expected increase of air traffic in the next years can only worsen the situation if no significant breakthrough can be reached.

Two kinds of noise are produced by commercial aircraft: engines noise, on one hand, and airframe noise, on the other hand, caused by air flow on all aerodynamic surfaces. The former is dominant in the take-off and climb phase, whilst the latter is usually the highest in the approach and landing configuration

Simulation tools for noise level prediction around airports and measurement systems are in place for characterizing aviation noise. Measurement methods are defined accurately, using commonly accepted rules such as average on day time or nights.

The figure 1 shows typical noise contour around a large airport (Paris CDG).

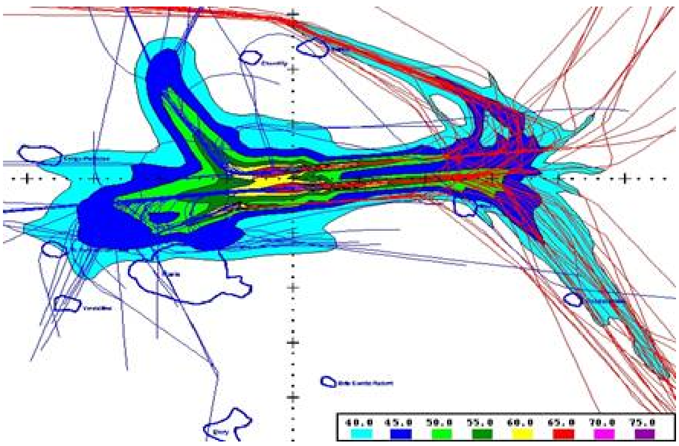

Fig. 1: typical noise contour around Paris CDG airport

2.2 Emissions of gases and other pollutants

Combustion of petroleum-based fuel by engines produces two main components: carbon dioxide and water. Aircraft fuel combustion also generates, in a smaller proportion, NOx and other pollutants such as SO2, CO, particles (soot), volatile organic compounds…

Numerous and extensive studies have been performed in the past 20 years to assess the production and forecast of gases and pollutants across all sectors, including aviation. Estimates of commercial aircraft CO2 and NO_x production vary significantly between surveys, but estimate the contribution of Aviation to 2 to 3% of total emission, increasing to 3 to 4 % in the next decade. These quantities can appear negligible, in percentage, but this is in no way a reason not to reduce it, since the stake is to preserve the global atmosphere.

Moreover, consideration must be given to the fact that most of these gases are emitted at high altitude, between 29000 and 36000 ft for commercial jets, and between 17000 and 25000 ft for turboprop aircraft, with high exhaust temperature, which may leverage their atmospheric effect.

2.3 Condensation trails and cirrus clouds

Condensation trails generated by aircraft at high altitude and corresponding cirrus clouds are also considered as contributors to global warming. They are often described as one of the three environmental impacts of Aviation. However, they are not dealt with in this paper, due to the lack of scientific accurate data and demonstration and the difficulty to significantly avoid their production.

3 Systems-based solutions envisaged for reducing the aircraft noise

There are two ways for reducing aircraft noise perceived on the ground: either by reducing it at the source (engines, aircraft aerodynamics in take-off and landing configurations), or by modifying the aircraft flight path, vertically (for a steeper / Continuous

Descent Approach (CDA), for instance) and/or laterally (avoiding flying over sensitive populated zones, for instance).

This paper focuses on the contributions of aircraft Systems to this second way of reducing noise.

Several studies have been conducted in the past years to try and find ways to reduce noise of aircraft through new trajectories during the approach and take-off phases,. This notably includes the European projects SOURDINE in the 4th Framework Program (FP4), SOURDINE II [5] in FP5 and the OPTIMAL FP6 Project [6], which held its Final Forum in Paris on the 25th and 26th of June 2008. These studies were based on computer modeling and simulation, followed by flight trials for OPTIMAL.

Though it may appear simple at a glance, modeling of noise perception by human population is a complex issue. It requires taking into account the noise environment: configuration of buildings, absorption characteristics of surfaces on ground, presence of other variable noise sources (such as intense road traffic), which may decrease the nuisance from the aircraft, as well as the dominant effect of wind patterns in the airport area.

This means that optimization of a flight path with respect to noise must take into account the very detailed nature of the airport area, on the one hand, and the variability of the context, on the other hand. To be valuable, a solution must be robust to these natural, uncontrolled and random changes.

Defining a theoretical noise-optimum and robust path is one thing, making it operational is another. Any solution makes sense if it can be implemented operationally.

This implies three main constraints:

- The new solutions must be such that the airport capacity and safety levels will not be affected
- The enabling technology, for both the air and ground segment, must be affordable, and have a potential for worldwide implementation
- The solutions must be delivered together with an acceptable implementation plan, under aviation standards, through which all stakeholders will be able to migrate concurrently from the current situation to the new, improved one.

Essential results from the OPTIMAL Project are that:

- Under certain conditions[1], trajectories optimized vertically, with a CDA profile, can bring noise reduction between 2dBA and 9dBA from 45 km up to 20 km of the runway threshold. This results in a local increase (up to 4 dBA) approx. 5 km before the Glide capture.

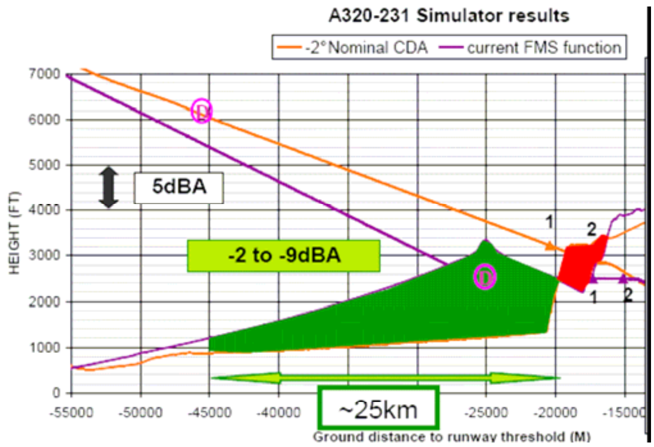

Fig. 2: Acoustic gains from A320-231 simulator tests: Existing FMS procedure versus. OPTIMAL function. Airbus simulations on A320-231 performed in the frame of OPTIMAL.

- The application of CDA procedures may reduce the maximum throughput capacity. As an example, for a specific

[1] a) CDA procedures studied in Optimal are ACDA (Advanced CDA), and based on RNAV. An ACDA is a continuous descent with optimised speeds, deceleration while descending.
b) the gains and penalty mentioned here are specific to one of the studied profile: "nominal 2° profile".
c) the reference profile used for the comparison is a FMS full managed profile. (a comparison to a controller vectored trajectory could provide higher gains)
d) the acoustic gains and penalties are strongly dependant on the A/C type; the results here are specific to A320-231

scenario studied in Optimal for Schiphol airport with some changes in the airspace management, capacity has been reduced typically to 33 mvts/ hour, due to the spacing required to ensure safety with margins.

In essence, there is a significant potential for noise reduction for the population around airport through optimised profiles, but this work must be pursued, to define solutions preserving and even increasing the runway throughput. This effort needs to involve all relevant stakeholders, and to be supported actively in the relevant standardisation groups.

In Europe, one essential objective of Clean Sky will be precisely to pursue this work. Clean Sky will go further in the definition of optimum and robust green trajectories, applicable to different airports configurations, and will design on-board functions enabling the aircraft to fly them. The SESAR Project [7], which involves ATM and ATC authorities, will act complementarily on all procedural aspects. It will also deal with all communications and information sharing related to these new solutions. A strong cooperation between these two projects is planned, to ensure that the overall objective is met.

4 System-based solutions envisaged for reducing fuel consumption and emissions of gases and pollutants

At aircraft level, there are five different and complementary ways for reducing fuel consumption and gas emissions:

- Use of more efficient and less polluting engines,
- Aircraft aerodynamic optimization
- Aircraft weight reduction
- More efficient use of on-board energy
- Smarter ways of flying / taxiing

Systems and Equipments, can contribute to the two last items and on the third one, for the energy sub-systems parts.

4.1 Management of electrical energy on-board the aircraft

A very significant part of energy produced by the engines is used for other purpose than propulsion. It is distributed to, and consumed by, aircraft systems in three different forms: pneumatic, hydraulic and electrical.

The table below is provided as a reminder of the extreme variety of functions consuming energy on-board:

Cockpit electronics *(we include in this item all equipment linked to cockpit functions, up to the radar and transmission systems)*
Engines starter-generator
Braking and steering
Landing gear extraction – retraction
Flaps and slats extraction – retraction
Control surfaces actuation
Engine command/control systems
Fuel management
Cockpit electronics *(we include in this item all equipment linked to cockpit functions, up to the radar and transmission systems)*
Cabin pressurization, ventilation and air conditioning
Cabin lighting
In-flight entertainment
Catering heating and cooling
Water management
Wing ice protection
Aircraft external lighting
On-board energy distribution

This list is expected to grow with the next generation of aircraft. As an example, airframers are working on active aerodynamic wing devices, based on new functions and systems, adding one more consumer function for the electrical energy distribution.

The performance of all these functions in all conditions of flight at the required safety level leads to the design of complex systems including numerous electric, hydraulic and pneumatic devices.

4.1.1 Solutions at equipment level

First, any component in an energy chain has its own efficiency (measured as the percentage of energy lost).

Second, any extra weight on-board requires extra energy, and generates an increase in fuel consumption. Similarly, volume occupied by systems reduces the space available for passengers or payload, i.e. the aircraft capacity. Consequently, one straightforward solution to improve aircraft performance is to increase the efficiency, or to reduce the weight and volume of each individual component of each sub-system.

Equipment suppliers are constantly struggling to design products performing the same (or more) functions with improved reliability and safety performances, while lowering weight, volume, power requirement and cost.

In Clean Sky, this approach will be adopted for all main components of the energy generation, distribution and consumption chain, for all types of commercial aircraft: large, regional, business jets and rotorcraft.

4.1.2 Solutions at sub-systems level

A second approach consists in looking for new architecture designs for individual sub-systems, and selecting trade-offs between different configurations, providing the best ultimate energy efficiency, taking into account the overall sub-system weight, volume, and constraints.

As an example, this approach has been used to consider dual use of power converters, in engine start or landing gear actuation.

4.1.3 Solutions at aircraft level

The demand for the most efficient solution leads naturally to the search for trade-offs at aircraft level, across all sub-systems.

The concept of "more electrical aircraft" (and its extreme, the "all electrical aircraft"), has been a topic for extensive research in recent years, because such an approach should allow more precise and intelligent control with better maintainability and availability of power systems. However this has raised a number of difficulties, such as the extra weight and drag induced by electrical systems, while it was admitted that better efficiency of electrical chains should lead to lower fuel consumption. As a consequence, questions still remain on the insertion of such technologies in future programmes, independently from their individual maturation timeframe (e.g. bleed / no bleed aircraft)

The idea is quite old and has been tested on aircraft as early as in the 50s'. However, demonstrated benefits have not met expectations yet, and no implementation has been made at a current large aircraft level.

To properly consider the power systems, it is necessary to adopt a mindset that is not pre-empted by existing architectures, because architectural vision always require to consider the level immediately higher than the current scope of supply. More generally, power systems should not be considered as ancillary systems, but encompassed in the global vision of the aircraft when considering its high level key targets. As an example, providing energy to the passenger could enhance his perception of comfort, and this would have drastic influence on the Power Systems architecture thus impacting the business model of the operating airlines.

The key idea there is that an effective architectural vision requires considering three perspectives together: the operational standpoint, the functional or system standpoint and the technology standpoint. Inserting new technologies into a legacy architecture may be sub-optimal, because there is a mutual generation (interaction?) between the two aspects. So it is necessary to set up a wide architectural framework approach to deal with this, including operational analysis capability and system engineering methodology with early validation approach.

This approach is adopted notably by Thales in their internal innovative research actions. The fundamental idea supporting this approach is that an “individual” optimisation of each “generator-to-load” functional chain will not deliver significant breakthrough. Introducing dependencies between these chains through a global functional analysis of the Power Systems domain will allow for example efficient sharing of resources, better dispatch, mechanical optimization, common cooling protection & health management, power coordination and modular fault tolerance benefits.

At this stage, it appears very clearly that the “electrical approach” is the only means to achieve commonalities between functional chains that handle forms of energy as different as hydraulic and pneumatic. In other words, “more electrical aircraft” should not mean replacing non-electrical technology by electrical technology per se, but providing a lever to optimize the Power Systems architecture through the use of a “common language” which is electricity.

Of course, this requires a cross-ATA vision and no intellectual limitations; as an example the approach studied by Thales to integrate Power electronics and transducer (motor) in modular power electronics elements can be locally a better solution as power filtering between converter and transducer can be minimized.

Such concepts will be worked through at a large scale in the Clean Sky collaborative project, Systems ITD (Integrated Technology Demonstrator) [4]. The first phase of the *Management of Aircraft Energy* strand will be dedicated precisely to the design of new architectures, and to trade-off studies between them for different types of aircraft.

Clean Sky will combine the three approaches at aircraft, systems and components levels:

- For the main and auxiliary energy generation, work on of new electrical power plant systems for:
  - Electrical Nacelle Unit
  - Nacelle Anti-Ice
  - Nacelle Actuation
  - Cooling technologies
- For the Electrical Power Generation and Conversion System (EPGCS), work on new generation of:
  - Starter-generators (main and auxiliary) with variable frequency
  - Power Primes
  - Fuel cells
  - Batteries
- For the energy transport: work on new generation of Electrical Wiring Interconnection System (EWIS) for MEA (More Electric Aircraft) and MCA (More Composite Aircraft).
- For the electrical energy usage, a particular focus will be made on:
  - Environmental Control System
  - Electro-Mechanical Actuation for rotorcraft
  - Wing Ice Protection
- For the Electrical Power Distribution System (EPDS), work on new solutions for:
  - HVDC reversible network
  - Electrical power centre
  - Electrical load management
- For the Thermal management system, work on new solutions for:
  - Thermal energy generation
  - Thermal energy exchange
  - Interactions with engine thermal management technologies

4.2 Smarter ways of flying

The current way of operating aircraft is not optimised for fuel consumption. ATM and ATC constraints and procedures impose flight profiles significantly different from the optimal:

- Aircraft must fly through airways and waypoints, which may be significantly longer than a direct route. As an example, actual flown distance of a Paris-Munich flight is 910 km due to ATC restrictions, whilst the direct connection is 680 km. On average, European connections are 15% longer than great circle and intercontinental connections are 4% longer, due to ATC constraints.

- Aircraft must fly at imposed levels, with limited maneuvering freedom between them
- ATC Management of arriving aircraft at airports is made through instructions, including adjustment of time of arrival at entry points, which may impose the aircraft to go through holding patterns, and speed instructions possibly requiring extension of landing gear, flaps and slats, earlier than optimum operation would require.

Getting closer to optimum profiles will naturally require reshuffling of the complete ATM and ATC system.

SESAR and NextGEN are the two major programmes dedicated to modernization of the ATM system, respectively in Europe and USA. Whilst their primary focus will be to develop and implement systems capable of absorbing the increase of air traffic with maximum efficiency and maximum passengers fluidity, they have in their mandate also to come up with solutions allowing to achieve global environmental impact targets for Air Transport.

In Europe, SESAR and Clean Sky will work in a complementary way on this aspect, with Clean Sky defining and proposing scenarios and solutions based on new technologies for achieving best environmental performances, and SESAR looking at their operational feasibility, and ways of implementation. As both projects start at the same time, for similar durations, effective cooperation is expected for a maximum efficiency. Clean Sky will propose and demonstrate flights profiles optimizing whole mission fuel consumption, including trajectories locally optimized at airports according to multi-criteria, including perceived noise.

Clean Sky will also make use of its Technology Evaluator assessment tool and methodology to optimize environmental impacts of inserted new technologies, from single aircraft mission level, to global world fleet and Air Transportation system.

SESAR will also assess these missions and trajectories, and dialogue between the two projects will shape high performance solutions fitting in the newly designed ATM system.

Two key concepts arise from the Definition Phase of SESAR:

- Sharing of highly accurate and reliable information on air traffic situation and prediction between ground and airborne actors, based on a System Wide Information Management (SWIM),
- Definition of 4-D trajectories for each aircraft. These elements will also be taken as the basis for the Clean Sky work.

In fact, both projects will necessitate design and development of new on-board and on-ground systems and functions, notably:

- High performance positioning and navigation systems;
- Flight path prediction and optimization;
- Capacity to fly complex trajectories;
- Anticipation of adverse events, in particular meteorological ones;
- Automated data communication functions.

Work packages in SESAR and Clean Sky are defined in a complementary way, and synergy will be developed between all actors.

4.3 Smarter ways of taxiing

As of today, aircraft use their main engines to taxi on ground, which is very inefficient with regard to fuel consumption.

Alternative solutions are worth considering, such as a electrically motorized landing gear, powerful enough to replace engines thrust, possibly complemented by auxiliary ground means.

A specific study will be led in Clean Sky on this issue, to:

- Demonstrate the performance of an on-board system enabling aircraft electrical taxiing embedded within the overall landing gear system

Develop and demonstrate the performance and the management of an autonomous towing system (from push-back to taxiing and runway entrance).

5 Conclusion

The Aircraft manufacturing industry, and notably the Equipment and Systems sector, has undertaken specific actions to take part in the effort necessary to reduce environmental impacts of its activities over the next decades. A strong impetus has been given, in particular through the EC funded Clean Sky initiative in Europe, which should deliver results by 2014 at a Technology Readiness Level (TRL) of 6. This will involve complementary contributions by all actors in the supply chain.

This approach should be considered as an example for the other sectors of industry and transportation, which are responsible for most of the human related environment impact.

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