A NOVEL APPROACH TO AIR TRANSPORT SYSTEM ENVIRONMENTAL IMPACT EVALUATION THROUGH PHYSICAL MODELLING AND SIMULATION

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Keywords: *modelling and simulation, air transport, environment*

Abstract

The European air transport system, presently close to its limit, is facing the challenge of a continuously growing demand with a wish of sustainable and economically viable development. The air transport industry is aware that it needs in particular to significantly reduce its environmental impact.

In this context, the Infrastructure for Evaluating Air Transport Systems (IESTA) aims to gather the multidisciplinary knowledge of the aeronautical research in physical modelling guarantying the ability of the evaluation platform to handle innovative concepts. Complementary to real time simulators with operator in the loop, IESTA intents to go further than existing evaluation platforms mainly based on existing software limited to current traffic modelling and simulation.

The first application of IESTA is focused on the environmental (acoustic and chemical) impact of air traffic surrounding airports.

1 Introduction

The Advisory Council for Aeronautics Research in Europe (ACARE) has strongly warned the aeronautical community that the European Air Transport System (ATS), presently close to its limit, is facing the challenge of a continuously growing demand with a wish of sustainable and economically viable development [1]. Moreover, the impact of the air transport on our environment becomes a more pressing issue with global warming taking on increased importance in addition to noise and gaseous emissions around airports. Although air transport can be seen as a minor contributor (currently at a global scale, about 3% of CO_2 emissions would derive from aircraft [1]), the continuously growing air traffic demand implies anyway a reduction of the air transport environmental impact.

Since the initial introduction of jet transport aircraft, the introduction of high bypass ratio turbofans and of low emissions annular combustion systems has resulted in significantly reduced aircraft fuel consumption, noise, NO_x and other gaseous emissions. Continuing efforts to introduce new technologies have resulted in further improvements to both aircraft and engines.

However, as technical advance becomes more and more difficult, further necessary improvements driven by continuously growing demand become more and more expensive.

The challenge is to accommodate the forecast increase in air traffic as well as reducing the relative impact of aviation with respect to noise and emissions.

The ACARE has identified four goals to address the environmental challenge [1]:

- To reduce fuel consumption and CO_2 emissions by 50%.
- To reduce perceived external noise by 50%.
- To reduce NO_x by 80%.
- To make substantial progress in reducing the environmental impact of the

manufacture, maintenance and disposal of aircraft and related products.

CO_2 together with emissions of water vapour and NO_x at cruise altitude are considered to contribute to global warming and on top of that CO_2 reduction would be the most demanding.

Although the physical processes and the contribution from these different elements at different altitudes are still poorly understood, it is reasonable to assume, with current fuels, that CO_2 production and hence fuel consumption is the primary contributor.

The goals emphasize the efforts air transport industry needs to make in order to reduce the environmental impact in the following areas:

- Global warming
- Community noise nuisance
- Airport pollution

This more than expected mid and long-term improvement of the system presupposes the ability to evaluate the benefit of innovative concepts and technologies through the whole set of complex and contradictory performance criteria.

Indeed, in the sole field of environment, the goals and solutions are inter-related. For example, changes that improve engine efficiency and reduce CO_2 may make the reduction of NO_x emissions and noise more difficult.

2 Evaluating the air transport system: state of the art

2.1 Operation-oriented ATS simulation

One major way to evaluate the air transport system is to develop Air Traffic Management (ATM) simulators dedicated to test and validation of the operational environment with operators in the loop.

As an illustration of this family of simulators, this paragraph mentions two simulators developed by European research centres.

The DLR "air traffic simulator" (http://www.dlr.de) is designed to support the development and validation of Pilot Assistant Systems dealing with airborne separation assurance systems and air traffic management tools. It is as well suitable as a “proof of concept simulation” for new ATM-concepts or operations. The Traffic Simulator supports two kinds of traffic scenarios:

- Surrounding traffic of one aircraft for airborne separation assurance tools
- Departure and arrival traffic for air traffic management tools

As another example, the AT-One Airport and Control Centre Simulator (ACCES) (http://www.dlr.de) has been developed as a test and validation environment for ATM related control room applications.

ACCES is designed to act as a test bed for new ATM tools and decision support systems. It is a validation platform dedicated to the development and test of procedures for tactical and strategic planning and decision making within the ATM and airport management. The ACCES control room provides at least ten ATM operator working positions.

2.2 Evaluation based on existing tools

The Federal Aviation Administration's Office of Environment and Energy is developing a comprehensive suite of software tools that will allow for thorough assessment of the environmental effects of aviation [2]. The main goal of the effort is to develop a new capability to assess the interdependencies between aviation-related noise and emissions effects. The Aviation Environmental Design Tool (AEDT) is based on the merging of existing tools.

The central building blocks used for the AEDT system are four existing FAA noise and emissions modeling applications:

- Integrated Noise Model (INM) for local noise;
- Emissions and Dispersion Modeling System (EDMS) for local emissions;
- Model for Assessing Global Exposure to the Noise of Transport Aircraft (MAGENTA) for global noise; and

- System for assessing Aviation's Global Emissions (SAGE) for global emissions.

In the field of noise and emissions evaluation, INM and EDMS are used worldwide. They are cheap public software and provide a very acceptable evaluation of current aircraft noise and emissions through a large database of measurement data. These software are likely to deal with new technologies with relevant input data but precisely because they are based on measurement data, they are not conceived for studying the new flight procedures or new aircraft concepts for which current measurement data are not applicable.

This paper deals with a new ATS evaluation approach aiming at handling innovative concepts.

3 A new ATS evaluation approach

3.1 Fast-time simulation

The IESTA (Infrastructure for Evaluating Air Transport Systems) programme aims to provide to the aeronautical community an efficient support in the design and modelling of innovative air transport systems through a global evaluation platform. This platform must not only be able to satisfy the evaluation needs of the aeronautical stakeholders within an acceptable time frame but also to fit the aeronautical research evolution within the next decades.

Complementary to real time simulators with operator in the loop (see §2.1), IESTA positions itself as a fast-time simulation tool, which allows studying various time scales: short scale of the order of the hour or the day but also larger cumulative time scales (week, month or year).

3.2 Deeper in the physics

The main objective of IESTA is not to evaluate the current air traffic but to look towards the future of the ATS, typically 2020 and beyond, and to be able to evaluate the air traffic as it will be at this time. This projection in the future presupposes the ability to model concepts not existing today.

Therefore, in order to go further than existing evaluation platforms mainly based on existing classical software limited to current traffic modelling and simulation (§2.2), IESTA aims to gather the multidisciplinary knowledge of the aeronautical research in physical modelling guarantying the ability of the evaluation platform to handle innovative concepts.

4 Environmental impact of air traffic around airports

4.1 Case studies

The first application of IESTA, currently under development, is focused on the environmental (acoustic and chemical) impact of air traffic surrounding airports (named "Clean Airport"). The evaluation scheme is based on predefined case studies regarding the modification of flight procedures, airport layout, traffic, airline fleet, aircraft or/and propulsion performance.

The list of case studies entails the management of a significant set of interacting "applicative" or "physical" databases and modules required to handle Clean Airport case studies: databases for scenario and results data management, physical models on aircraft performance, propulsion emission, traffic, acoustic emission and propagation, chemical propagation, evaluation metrics.

The term "physical" is used here to deal with models and components regarding the application, in opposition to components of the platform dedicated to the computing management and control of the platform.

4.2 Physical modelling

The platform manages and controls the execution of case studies, based on the following three physical model families (figure 1):

- Aircraft: flight performance, propulsion, movement in flight and on the ground;

- Acoustics: emission and propagation;
- Chemistry: dispersion and chemical reaction.

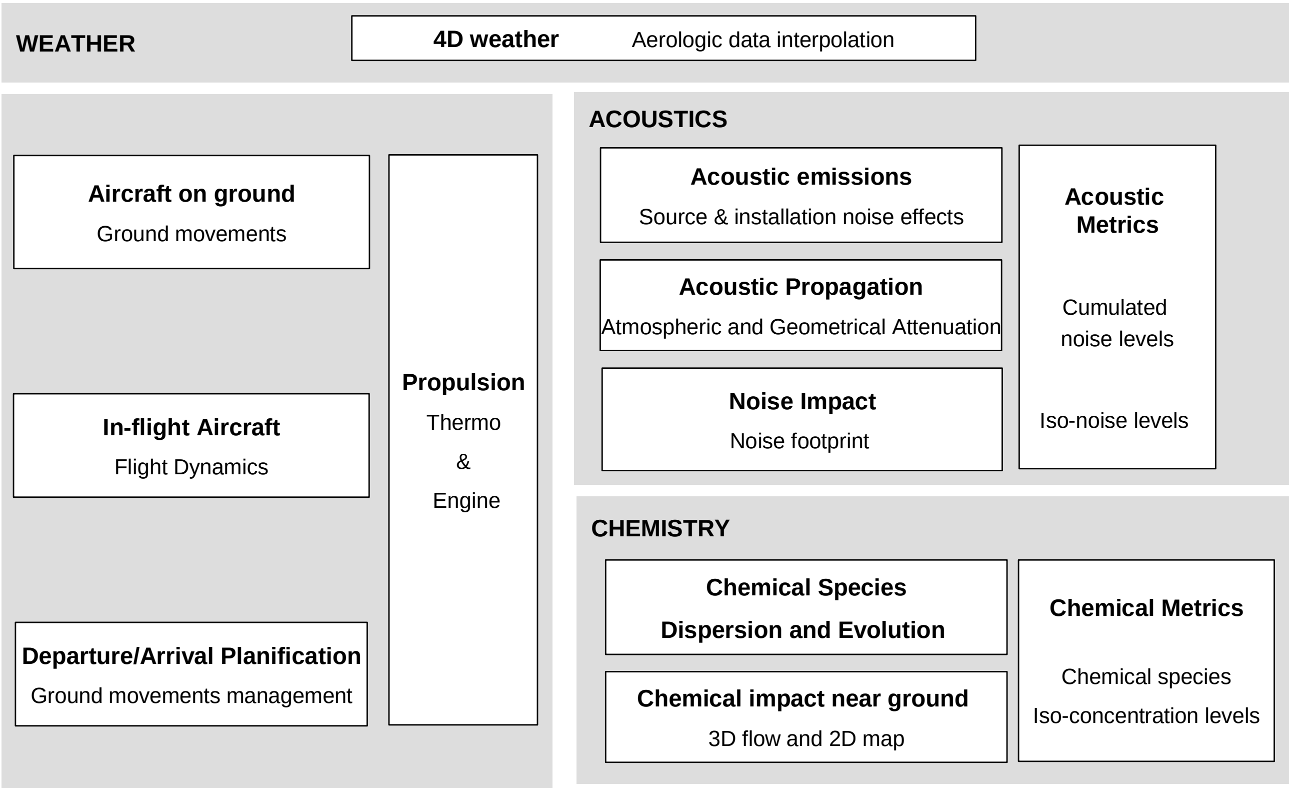

Fig. 1. Main physical modules for IESTA first application

4.2.1 In-flight aircraft

The "in-flight" aircraft model provides a discrete time simulation of different types of aircraft in a representative environment. The model has to represent realistic trajectories described in different ways. Position, attitude and aerodynamic configuration are determined at each temporal step of the simulation.

The trajectory description is the flight plan (succession of waypoints).

The model encompasses two phases:

- Trajectory generation with the Base of Aircraft DAta (BADA) from Eurocontrol[♣]
- Attitude, thrust and lift devices position computation

[♣]http://www.eurocontrol.int/eec/public/standard_page/proj_BADA.html

4.2.2 Aircraft ground planning and operating modules

The aircraft ground planning module organises the ground traffic within the movement area of the airport, from the gate to the runway threshold and conversely.

The inputs of this module are the considered airport layout, transformed into a graph, and the schedule of departures and arrivals planned or provided during simulation. The ground planning module starts before simulation to generate the airport map and uses this map during simulation to plan a conflict-free ground routing planning based an algorithm inspired from the minimum cost maximum flow algorithm family. The ground planning is provided to each aircraft through a list of waypoints associated to a temporal window and a control speed for each segment of the route graph.

Then, the "aircraft on ground" module is in charge of moving the aircraft on the movement area of the airport and managing ground movement phases transitions, from the gate to the runway threshold and conversely, in accordance with the aircraft ground planning module output.

4.2.3 Aircraft propulsion model

Thrust, fuel consumption, internal pressure and temperatures account for the characteristic of an aero engine. The role of the aircraft propulsion model is to compute these data. Such a model is based on an aerothermodynamic propulsion code which computes, for a trajectory point and a given engine, thermodynamic parameters (temperatures, pressures, etc.) and the performance (thrust, Cs) taking into account each component of the engine: compressor, turbine, main burner, nozzle exhaust, etc. The combination of all these elements enables the compilation of an infinite number of engine cycles.

The aircraft propulsion model takes as input, weather data and, from the in-flight and on ground aircraft modules, aircraft thrust, altitude, and speed. The outputs of the propulsion model, requested by the acoustic and chemical dispersion model are the following: ejection speed, jet temperature, output mach, air flows, etc.

4.2.4 Acoustic and chemical models

A special care is given in the field of physical modelling of environmental impact with regard to acoustics and chemical dispersion. Both acoustics and chemical dispersion modelling components, developed within a high level expertise in these domains, are described in a dedicated chapter below.

5 High level modelling on acoustics and chemistry phenomena

5.1 Acoustics modelling

5.1.1 Noise emission source model

The noise emission source model computes the acoustic field emitted by an aircraft. It is composed of two parts: "sources" model (S-model) and "integration" model (I-model).

The S-model [3] computes noise source levels coming from main noise components of current jet aircraft: jet, fan, high-lift devices and landing gear. This model is based on semi-empirical models requiring a limited number of variables.

The I-model [3] computes the propagation of the acoustic field close to the aircraft, taking into account the installation noise effects. The calculation of the total pressure field including the direct, reflected and diffracted fields is based on a geometrical method. The problem of diffraction is performed within the framework of the uniform Geometrical Theory of Diffraction (uniform GTD).

5.1.2 Noise propagation model

The noise propagation from the aircraft emission to the ground is based on a standard geometrical acoustics model, where the acoustical energy propagates along rays that follow trajectories impacted by wind profiles and temperature gradients [4].

The propagation model provides the attenuation of the acoustic power spectrum originating from the noise source.

The atmospheric attenuation is taken into account, in addition to the geometrical attenuation component due to the divergence of ray tubes along paths.

5.2 Chemical dispersion modelling

From the chemical emissions provided by the propulsion module (cf. §4.2.3), a module is dedicated to compute the dispersion of chemical species emitted by aircraft in the atmosphere and their reaction with it.

The chemical dispersion and reaction modelling of aircraft emissions is based on an Onera's high level Computational Fluid Dynamics code called "Two-phase Reactive Flow Computation for Energetics" (CEDRE).

CEDRE is a computation workbench dedicated to multi-physical energy flows on unstructured mesh.

It is applied here to compute the dispersion of chemical species emitted by aircraft around airports thanks to one of the numerous solvers available in CEDRE which is dedicated to aerothermochemistry and is based on the resolution of the Navier-Stokes equations [5].

For the IESTA application, this high-valued scientific code has been validated for the particular physical application of gaseous emissions in the atmosphere, and has been adapted to mobile sources of emissions.

CEDRE requires from the other modules the following inputs:

- Aircraft emission characteristics from the propulsion module: jet speed, thrust, chemical species flow as HC, CO, CO_2, NO_x and sulphur species, temperature, nozzle diameter, fuel type, etc.
- Aircraft trajectories (position and speed) from the aircraft modules
- Atmospheric conditions (temperature, pressure and wind)
- Chemical atmospheric environment (chemical species concentration in the atmosphere where aircraft operate).

6 Evaluation outputs

6.1 Acoustic evaluation results presentation

With regard to the simulation architecture, the different acoustic physical modules (Cf. §5.1) are executed at different simulation steps and are completed by three other modules.

Firstly, the I-model and the propagation model are executed several times and stored before the simulation in order to prepare static acoustic data relative to a given scenario. Then, the S-model is executed during simulation at each instant and provides output to an additional module in charge of collecting them with the acoustic prepared data and providing the final noise levels on the ground.

A specific additional module transforms final noise levels into static or dynamic noise footprint related to geographical information like population density or location of particular public buildings devoted to a part of the population particularly sensitive to environmental aggressions (hospital, old people's home, child day care …) in order to present noise results in a didactic and convenient way for further analysis.

6.2 Chemical evaluation results presentation

The parameters related to chemical dispersion to be displayed at the output of CEDRE (Cf. §5.2) are numerous: pressure, speed, chemical species weight percent, turbulence, etc.

As for acoustic results, the best way to present chemical emissions and dispersion is to display a map at a reference altitude of the chemical species concentration all around airport surrounding.

7 Conclusion

This paper briefly describes the scientific and technical solutions chosen to develop the first application of the "Infrastructure for Evaluating Air Transport Systems" programme, focused on the impact of air traffic surrounding airports. The ambition of this programme is to provide to stakeholders of the air transport system a means to evaluate innovative concepts with a target frame of 2020 and beyond. Therefore, all applicative or "physical" models required are developed with an ambitious view of scientific excellence in order to offer the advantage of adapting themselves, from their very physical nature, to innovative concepts of air transport.

However, using sophisticated physical models in a fast-time simulation frame entails to solve limits of time computation and data storage. The implemented solution, which guarantees to save the quality of physical models, is to generate a data base with a large amount of computations whenever possible, within a preliminary step before the fast-time simulation itself.

All the IESTA components are available but their integration in the infrastructure is under development. The quantitative results of IESTA first application are expected in the spring 2009.

Following this first application regarding environmental impact study at a local scale, the IESTA programme aims to extend its field of application to a more global frame with the modelling and simulation of the global traffic and its impact on environment at the large scale of a country or a continent.

Acknowledgments

The IESTA programme is funded by a set of European (ERDF - European Regional Development Fund) and national French public credits.

The activities described in this paper reflect a collective work carried out by the whole team of the IESTA Applications & Modelling project inside the IESTA programme. Moreover, the IESTA programme owes its existence to a federative and close collaboration between several Onera scientific departments that gather a multi-disciplinary team of scientific experts of the wide range following domains: Long-Term Design & Systems Integration, Systems Control and Flight Dynamics, Computational Dynamics & Aeroacoustics, Physics, Instrumentation & Sensing, Aerodynamics & Energetics Modelling.

Finally, the IESTA team would like to thank Eurocontrol for its kind authorization to use its aircraft database BADA.

References

[1] Advisory Council for Aeronautics Research in Europe. Strategic Research Agenda 1, October 2002.

[2] FAA. Aviation Environmental Design Tool (AEDT) - System Architecture, *Doc #AEDT-AD-01*, 29 January 2007.

[3] Bulté J. Simplified Acoustic Modelling of Aircraft Noise during Take-off and Landing, *Onera Technical Report RTI2/F00201DPRS*, September 2003.

[4] Ménéxiadis G., Varnier J. Long range propagation of the sonic boom from Concorde airliner: analyses and simulations, Accepted in May 2008 to be published in *AIAA Journal*.

[5] Ramaroson R., Vuillot F. & All. Impact of air traffic emissions on airport air quality: Multi-scale modeling, test bed and field measurements, *American Geophysical Union*, San Francisco, USA, Fall Meeting 2004.

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