CHEMICAL IMPACT OF AVIATION IN AIPORTS AREAS

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Keywords: *airports air quality, dispersion, pollution, aviation, simulation*

Abstract

Reducing aviation environmental impact is currently one of the challenging objectives in the aeronautical field especially as aviation traffic is continuously growing. ONERA (The French Aerospace Lab) supports several studies dealing with this issue. One of them concerns the local impact of aircraft emissions. This includes dispersion modelling and chemical evolution of the emitted species. One of the distinctive features of our study is that aircraft engines are considered as individual sources. Furthermore, several parameters are taken into account like aircraft trajectories, kinematics of the sources along the corresponding trajectories, emissions characteristics (species, temperature and velocity), meteorology and platform topography (ground and buildings).
This labor was made possible thanks to a collaborative work between several teams at ONERA within IESTA project (The Infrastructure for Evaluating Air Transport Systems) which aims to address technical and scientific requests to improve air transport systems. The first application of IESTA is called "Clean Airport" intended to evaluate noise and emissions impact of air traffic in airports surroundings.

1 Introduction

The objective of this work is to provide a modelling of aircraft emissions dispersion and their interaction with the atmosphere all around in order to evaluate the local impact of aviation.
A particular attention will be given to the influence of the considered parameters (trajectories, emissions, meteorology, etc.) on the impact. Hence the comparison between different scenarios will be performed to determine the way that each parameter plays.

Simulations are carried out using an ONERA CFD code called CEDRE. CFD has been chosen because it offers the best available physical modelling of dispersion. Additionally, since CEDRE is an in-house code, it allows us to easily introduce any required developments and adaptations. We will present theses developments thereafter.

CFD is the chosen approach to deal with dispersion modelling. It's recognized as the best way to describe dispersion even if it's also the most expensive one in terms of numerical cost. We have made this challenging choice given that computer performances are becoming higher and higher. All the more we have CEDRE, the ONERA code which is widely known and approved for several applications. We will give a brief presentation of its use fields. Then, we will present the developments carried out to adapt the code to the impact of aviation in airports areas. The first results obtained from theses developments are presented next. Finally, we will present the future developments to be done.

The work performed until now enable effective connexion between several modules of the platform, the use of the data produced by these modules and the modelling of moving emission sources corresponding to aircraft engines when the aircraft is itself in move. Furthermore, emissions from aircraft engines are considered both in terms of chemical composition, velocity and temperature at the engine outlet.

2 IESTA and Clean Airport aims

2.1 IESTA

This is an ONERA project which aims to evaluate air transport systems. It consists in a platform including a couple of tools gathered to evaluate existing or innovative technologies [2].

The first application of IESTA is Clean Airport presented hereunder.

2.2 Clean Airport

This application was both the occasion of developing the platform as a support system and to develop physical modeling to deal with the impact on aviation in airports and surroundings [1]. The impact we are interested in is the acoustic and the chemical impact. The principal parameters taken into account to perform this are: aircraft trajectories, engines emissions characteristics, meteorology and topography. Each parameter is provided by a dedicated module in the platform as shown in Figure 1. Our contribution corresponds to the CHEMISTRY box in Figure 1. The ACOUSTICS box is related to the impact of aviation in terms of noise. The other boxes allow other computations which especially provide input data for the acoustic and chemistry boxes.

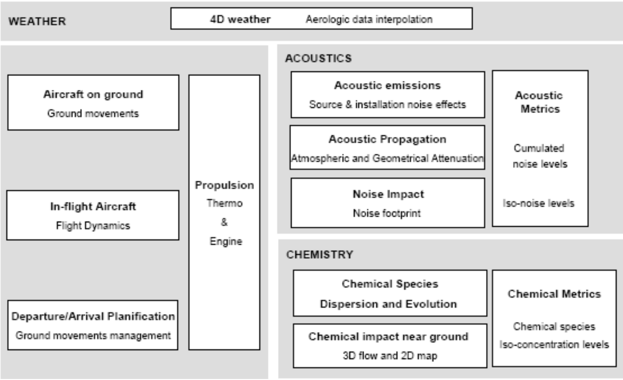

Figure 1 : Main physical modules for IESTA "Clean Airport" application [1]

3 CEDRE

CEDRE is a multiphysic computational fluid dynamics software [3], [4]. It has been developed at ONERA for several years to carry out numerical simulations in the energetic field. In the beginning, a particular attention had been given to propulsion applications. Then, it has been adapted to many other applications. It includes multiple subsystems to deal with gases flows, liquid and particles transport, heat conduction in solid walls, radiation, etc.

CEDRE is an industrial code widely used in propulsion applications for instance. It has not been used yet for applications involving atmospheric flows. That is why, before using CEDRE for airports pollution issues, we made simulations to test the code capabilities to predict specific atmospheric behaviors [5]. These simulations showed that the use of CEDRE is an appropriate way to deal with dispersion of aircraft emissions even if some physical and technical developments are needed to handle properly our issue. Furthermore, CEDRE already includes kinetics. This will allow us to deal the evolution of chemical species from aircraft engines interacting with those of the atmosphere all around. Besides, CEDRE is an in house code which makes very comfortable developments possibilities as well as the interaction with the other developers of the code.

Modeling efforts carried out until now and those to come are presented bellow.

4 Performed developments

In spite of all the advantages of CEDRE, several developments had and have to be performed to make it usable for pollution issues in and around airports infrastructures. Theses developments may be distinguished into two classes:

- Technical improvements
- Physical modeling

The first one is related to the way that the traffic in a given airport is taken into account. The typical example is that aircraft's engines are considered as individual emission sources moving along their own trajectories. Aircraft emissions characteristics are given in the four dimensions spatiotemporal space.

The second one is related to several aspects such as the characterization of emissions (species, jet velocity and temperature), chemical kinetics and the atmospheric boundary layer.

In addition, don't lose sight of that the use of CEDRE as a link in the IESTA platform means that there are connections to be established between the platform's modules. These connections require adaptations in terms of inputs and outputs allowing the platform to have an automatic mechanism.

Among the items above-mentioned, the following have been accomplished.

4.1 Technical improvements

4.1.1 Moving sources

Moving sources modeling consists in the characterization of aircraft engines displacement along their trajectories.

To perform this, we use engines position at discrete instants given by the Trajectory module from the IESTA platform. Beyond the position of sources their kinematics is introduced into the code.

Expressly, we had to adapt the code to make the data above-cited (and others which we will introduce subsequently) as a part of the code inputs [6]. Furthermore, emission sources trajectories modeling consists in the identification of the mesh cells crossed over by these trajectories. In addition, the velocity of the moving source and its residence time in each cell is calculated. Figure 2 illustrates cells (greened cells) resulting from the intersection between an elementary two dimensional Cartesian mesh and a discretized trajectory. However, the developments have been carried out for three dimensional configurations as well.

This part belongs to the preprocessing in the code running. The selected cells are saved and used afterwards during the effective calculation if they are "emitting cells" according to physical instants of emission.

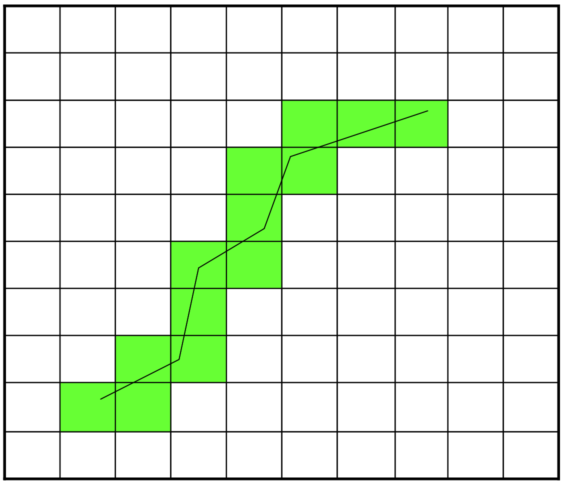

Figure 2: Cartesian 2D mesh crossed over by a discretized trajectory

4.2 Physical modeling

4.2.1 Mass contribution

Mass contribution corresponds to chemical species coming from engines outlets. The input data gives, $\dot{\omega}_k$, the species mass by time unit (flow rate: kg/s) for the species k. In the other hand, CEDRE solves the following quantity:

$$\rho \frac{DY_k}{Dt} \times v \qquad (2.1)$$

where Y_k is the mass fraction of the species k and ρ the mixture density. $\rho \frac{DY_k}{Dt}$ is the usual term in balance equations of species and v is a unit volume.

4.2.2 Momentum contribution

Here is taken into account the velocity of the jet at the engine outlet. Its contribution is given by the following formula:

$$V\dot{\omega} \qquad (2.2)$$

where V is the jet velocity and $\dot{\omega}$ the total flow rate corresponding to:

$$\dot{\omega} = \sum_{k=1}^{k=N} \dot{\omega}_k \qquad (2.3)$$

where N is the species number.

4.2.3 Energy contribution

Two contributions are considered in this part: kinetic energy and heat energy. Then the total energy contribution is:

$$\dot{\omega}_T = \dot{\omega}_{kin} + \dot{\omega}_{therm} \qquad (2.4)$$

where $\dot{\omega}_T$, $\dot{\omega}_{kin}$, $\dot{\omega}_{therm}$ are respectively the total energy contribution, the kinetic energy contribution and the heat energy contribution. $\dot{\omega}_{kin}$ is calculated as following:

$$\dot{\omega}_{kin} = V^2 \dot{\omega} \qquad (2.5)$$

$$\dot{\omega}_{therm} = \sum_{k=1}^{k=N} \dot{\omega}_k \, h_k(T) \qquad (2.6)$$

where T is the jet temperature and h_k the enthalpy of species k .

5 Numerical simulations

We present here some results from simulations we have carried out using the new developments. We have chosen a simple configuration to illustrate the new possible uses of the code. The figures below (Figure 3, Figure 4, Figure 5 and Figure 6) give several instants of the simulation. Two sources moving along a trajectory are represented there. The trajectory is the dashed line where the black part is the one which belong to the calculation domain and the grey part is outside. It is obtained from the module of the platform IESTA giving aircraft trajectories including Landing, Take-Off and Taxiways. In our case, emissions come from two aircraft with two engines each of them. They follow the same trajectory including two phases: taxiway and take-off.

The presented field corresponds to a passive scalar representing emissions from the moving sources. The mean flow in this simulation is governed by the velocity $\vec{V}$ specified in terms of boundary conditions where $\vec{V} = (4,4,0) m/s$.

Figure 3 gives the evolution state at $t = 380s$. The first source is still on the ground. This corresponds to the taxiway step. In Figure 4 (at $t = 610s$) the first source is in the take-off phase and the second source starts emitting on the ground in its taxiway phase. Figure 5 gives the passive scalar field at $t = 930s$ when the first source is out of the calculation domain and the second source in the take-off phase. The emissions are transported by the mean flow following the velocity field as introduced above. In Figure 6 (at $t = 1210s$), both of sources are outside the calculation domain. A part of their emissions is still in the calculation area whereas the first emissions would be outside.

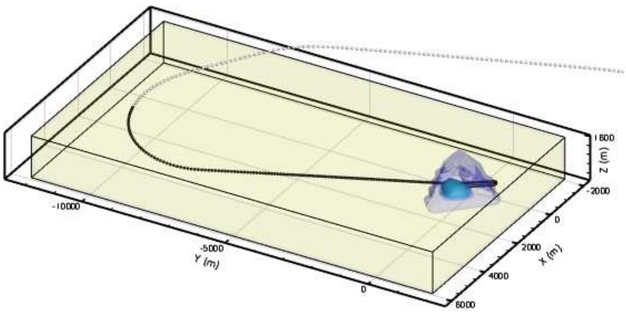

Figure 3: passive scalar field of emissions at $t = 380s$

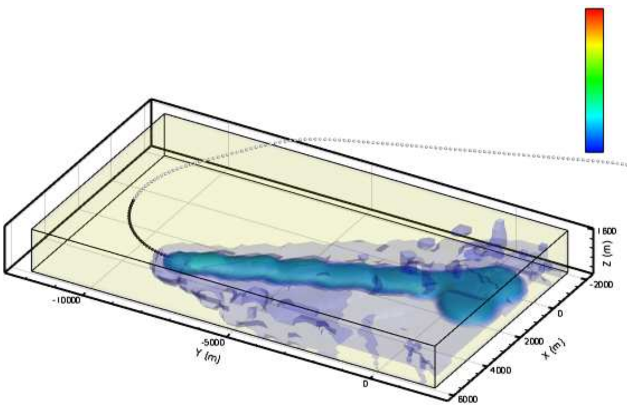

Figure 4: passive scalar field of emissions at $t = 610s$

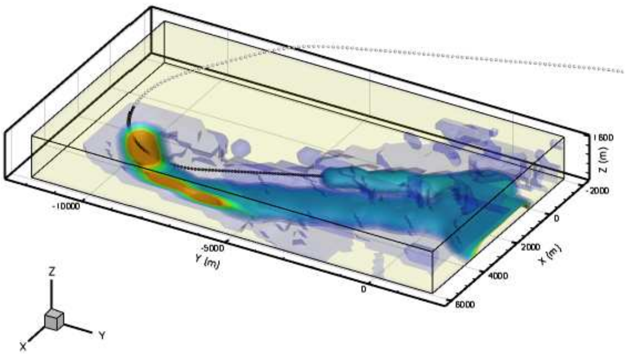

Figure 5: passive scalar field of emissions at $t = 930s$

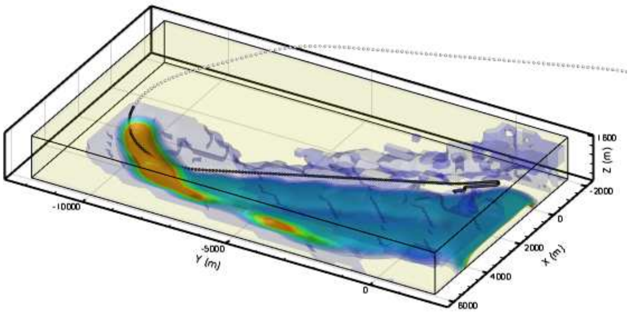

Figure 6: passive scalar field of emissions at $t = 1210s$

This simple configuration has been used to make basic validations of developments. Next, realistic configurations would be simulated. They will be applied to a real airport. Blagnac airport (Toulouse, France) is the one chosen for our first application. The topography as well as buildings are taken into account. Procedures, aircraft engines and meteorology will be considered too.

6 Future developments

To make studies of aviation impact in airport areas, we need additional developments and adaptations to include into CEDRE. We present here briefly those we are planning to do.

6.1 Chemical evolution of aircraft emissions

Emissions will be considered both in terms of gaseous species and particulates (ex: soot). Their evolutions should take into account their particularity as hot burnt gases coming form aircraft engines and the characteristics of the atmosphere all around where they are going to evolve. Then we will include species and chemical reactions into the code.

6.2 Atmospheric boundary layer modeling

Special attention will be given to this aspect since our applications are focused on the impact up to about *1000m* altitude. Indeed, atmospheric flows particularities have to be modeled properly to simulate dispersion of aircraft emission or any other emissions from other sources in and around airports.

6.3 Other contributions

Till now the only data in our possession are those corresponding to aircraft's emissions. This must be improved including the contributions from the other sources like APU, GSE, roads, etc.

7 Conclusion

Modeling approach regarding the local impact of aviation around airports has been presented in this paper.
Developments have been done to perform moving sources modeling considering both of aircraft trajectories and engines emissions. Sources are characterized in terms of mass, momentum and energy contributions. Connection of the modules of the IESTA platform has been carried out to provide an automatic linking between them.
The first results show that the objectives have been reached. Future developments are planed in order to make the software able to deal with impact of aviation impact issues taking into account the appropriate phenomena.

Acknowledgments

All the IESTA team is thanked for the collaborative work allowing the accomplishment of these studies.
Acknowledgments are given to François Vuillot and Bernard Courbet for there participation in the project as well as for there advices since its first steps.

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