Numerical simulation of thrust reverser for rear mounted engine

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ABSTRACT

The objectives of the study were to establish the feasibility of the evaluation of the performances of thrust reverser systems through numerical simulations, with Onera's Cedre computation code. Two configurations were retained, the first one was an isolated engine and the second one was an installed engine in a rear mounted generic configuration. The first configuration concerns the aft part of the engine, comprising the primary and secondary nozzles, the internal lobbed mixer, the central plug, the nacelle walls and the thrust reverser system consisting of deployed doors at the motor exit. The second configuration concerns the installed engine. For this configuration, the engine exit plane was chosen at the mixer exit plane where the boundary condition was constructed from the first configuration computation. This permitted to run the installed configuration with realistic engine data. This work established the feasibility of such complex computations and the realism of the computed flow as well as the interest of such computations in the design process, thanks to numerical evaluation of thrust.

NOMENCLATURE

F_x : reverser thrust
F'_x : sum of X-momentum fluxes on specific boundaries
L : turbulent mixing length
k : turbulent kinetic energy
M : mach number
n : normal vector
P : local static pressure
P_a : ambient static pressure
P_i : total pressure
ρ : density
T_i : total temperature
v : velocity

INTRODUCTION

The objectives of the study were to establish the feasibility, including robustness and accuracy, of the evaluation of the performances of thrust reverser systems through numerical simulations. The approach consisted to start with a isolated engine configuration, then to apply numerical settings to a generic rear mounted engine configuration. Due to the complex geometrical arrangements of the system under scrutiny, the choice of the unstructured code CEDRE, developed by Onera, was made. CEDRE is a multi-purpose code that can handle meshes comprising any combinations of polyhedral cells which facilitates the grid generation work. CEDRE is a multiphysics computational tool for numerical simulations in the field of energetics (with particular emphasis on propulsion application) developed and validated by ONERA [1][2]. The code can handle several coupled physical subsystems through internal or external couplings. It solves the multi-species, reactive Navier-Stokes equations, thanks to an iterative implicit time marching algorithm (GMRES). Auto-adaptive local time stepping algorithms can be used for steady state computations. This considerably enhances the code robustness. The spatial discretization relies on second order flux splitting MUSCL schemes. Several turbulence models can be activated, comprising an in-house (k, L) RANS model, complemented by ad-hoc wall treatments, which was used for the present works. Built in procedures permit to retrieve particular flux integrals that permit an easy monitoring of instantaneous thrust of the engine and its thrust reverser system, during the computations.

ISOLATED ENGINE COMPUTATION

Study configuration description

Due to symmetry, one simulated one half of the engine. The engine was placed inside one half of cylinder. This cylinder delimited the computational domain. One considered a dual stream engine with sixteen lobbed mixer (see Figure 1).

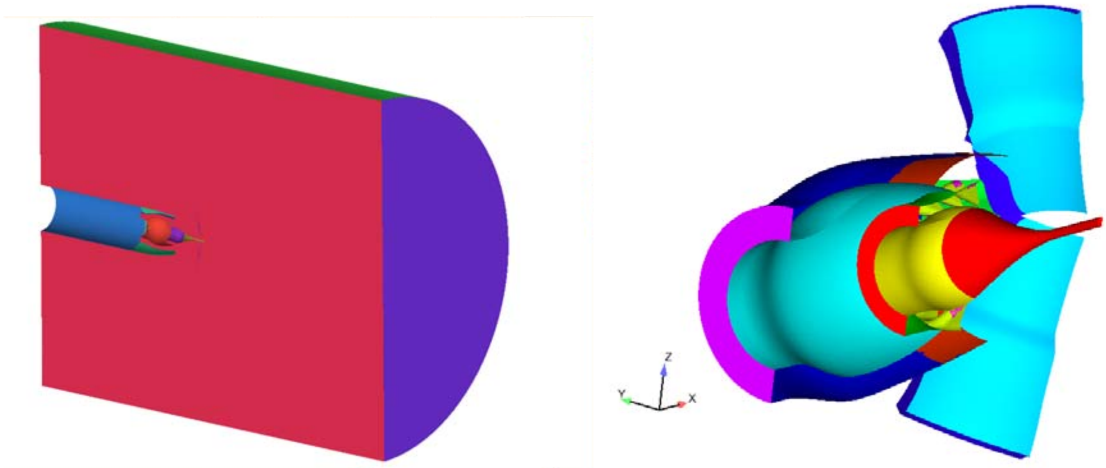

Figure 1 – Isolated engine whole computational domain, and, zoom on the reverser

Mesh

The 3D hybrid unstructured mesh is constituted of tetrahedrons and prisms. Boundary layers are described by prisms grown from walls. The mesh includes about six millions cells.

Boundary conditions

- Nozzle inlet (upstream of the mixer) : P_i, T_i, **n**, k, L
- External boundaries : flight conditions (M=0.1)
- Adiabatic walls
- Symmetry plane

Computations

Computation was performed on Onera cluster (Itanium 2 Montecito) on sixty-four CPU. It took two thousand time steps to achieve global convergence of the reverser thrust. CPU time of the computation was three hundred and seventy hours. Thus, physical time of the computation on the cluster was roughly six hours. This duration was judged compatible with industrial design processes.

Convergence criteria

First, one considered global inlet/outlet mass flow rate convergence. Fluctuations still existed at the end of the computation. Nevertheless, fluctuations level was less than one per cent of the total inlet mass flow rate. This result was considered sufficient to consider that global mass flow rate convergence had been achieved.

Then, one considered reverser thrust convergence. Indeed, X-momentum fluxes on boundaries are direct outputs from CEDRE code. Let one introduce, F'_x, sum of X-momentum fluxes on well-chosen boundaries :

$$F'_x = \int_{JetInlets+SpecificEngineWalls} \left(Pn_x + \rho(\vec{v}.\vec{n})v_x\right)ds$$

Moreover, one can write an expression of the reverser thrust :

$$F_x = \int_{EngineOutletSection} \left((P - P_a)n_x + \rho(\vec{v}.\vec{n})v_x\right)ds$$

And, on the closed surface, one can write :

$$F_x + F'_x - \int_{JetInlets+SpecificEngineWalls} P_a n_x ds = 0$$

Then, one can write an the expression of the reverser thrust F_x, supplied by CEDRE :

$$F_x = -\int_{JetInlets+SpecificEngineWalls} \left(Pn_x + \rho(\vec{v}.\vec{n})v_x\right)ds + P_a \int_{JetInlets+SpecificEngineWalls} n_x ds$$

As P_a is a constant, one can consider that F_x convergence is achieved when F'_x convergence is achieved. Though, the evaluation of the P_a term in the equation above is necessary to evaluate the value of the reverser thrust, and its convergence level in percentage. F'_x convergence is shown on Figure 2.

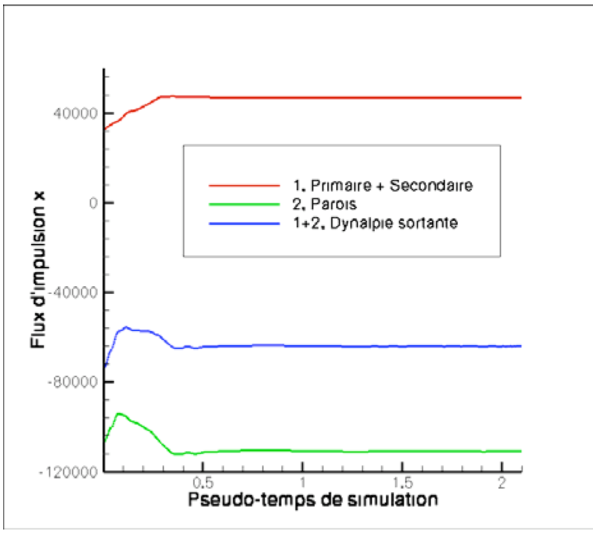

Figure 2 – Convergence on F'_x, supplied by CEDRE

The convergence ratio of F'_x was 0,1%. Including the P_a term, the reverser thrust – F_x – convergence was estimated to about 2%. These fluctuations can be explained by some undamped large scale eddies downstream of the reverser doors.

Example of results

Figure 3 shows total pressure iso-contours, and, V_x (around zero) iso-contour, in the symmetry plane. One can see the extent of the mixing zone between the jet and the main coflowing air.

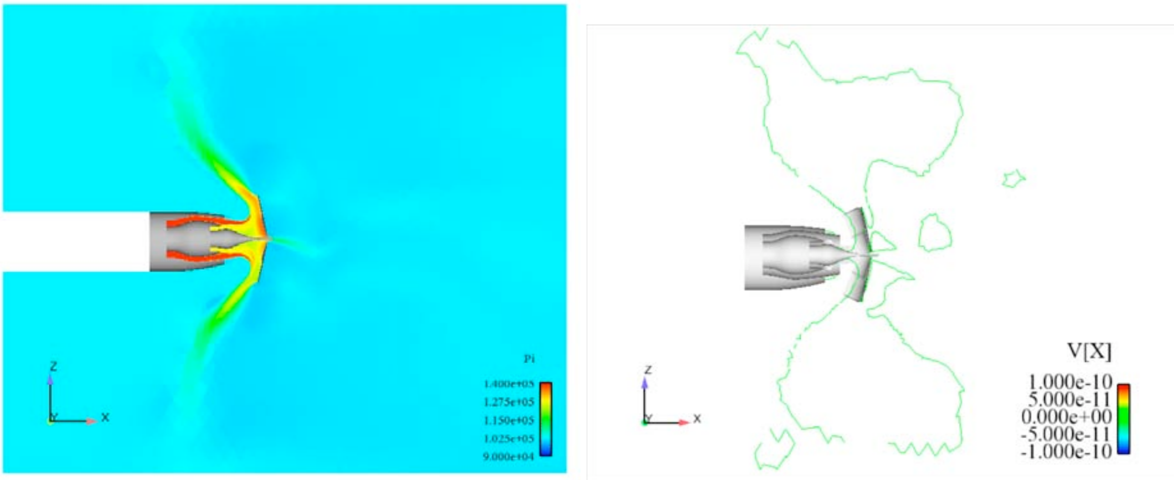

Figure 3 – Total pressure iso-contours, and, X-velocity (around zero) iso-contour, in the symmetry plane

INSTALLED ENGINE COMPUTATION

Study configuration description

Due to symmetry, one simulated one half of the aircraft. The aircraft was placed inside a box. This box delimited the computational domain (see Figure 4).

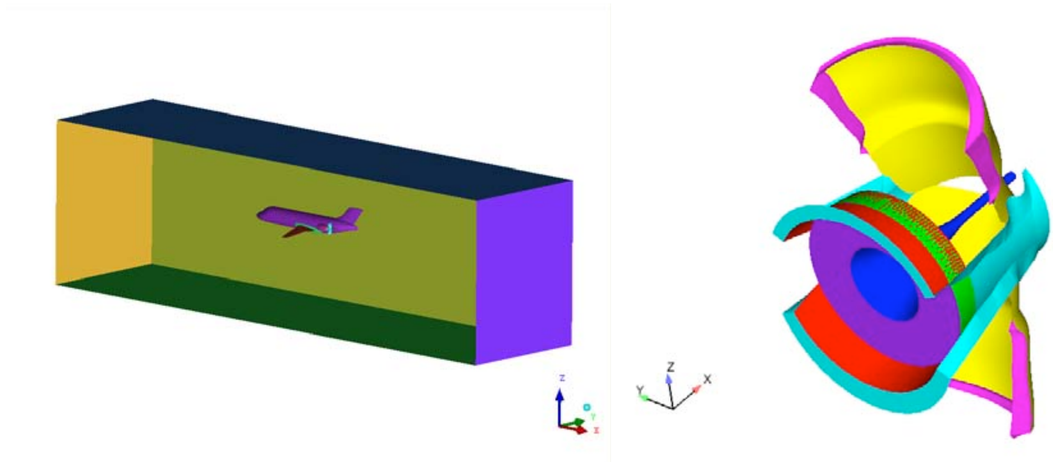

Figure 4 – Installed engine whole computational domain, and, zoom on the reverser

Mesh

As in the isolated engine case, the 3D hybrid unstructured mesh is constituted of tetrahedrons and prisms. Boundary layers are described by prisms grown from walls. The mesh of this installed engine case includes about height millions cells.

Boundary conditions

Pressure was specified at the engine air intake plane (representative of the engine operating point) and the engine exit plane was chosen at the mixer exit plane where the boundary condition was constructed from the first configuration computation. This permitted to run the installed configuration with realistic engine data. Figure 5 illustrates this configuration.

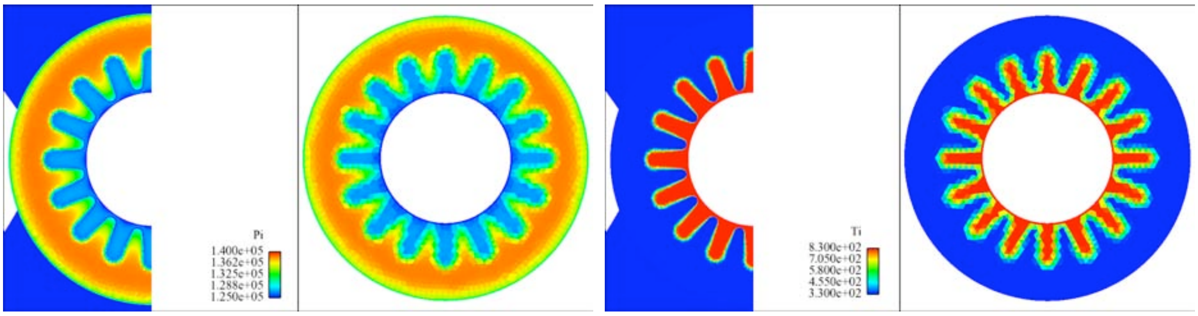

Figure 5 – Realistic nozzle boundary conditions (right) supplied by isolated engine computations (left)

Boundary conditions are listed below :

- Engine inlet (outlet for the computational domain) : P
- Nozzle (exit plane of the mixer) : P_i, T_i, **n**, k, L profiles
- External boundaries : flight conditions (M=0.1)
- Adiabatic walls
- Symmetry plane

Computations

As in the isolated engine case, computation was performed on Onera cluster (Itanium 2 Montecito) on sixty-four CPU. It took one thousand and nine hundred time steps to achieve global convergence of the reverser thrust. CPU time of the computation was height hundred and ninety hours. Thus, physical time of the computation on the cluster was roughly fourteen hours. This duration was judged compatible with industrial design processes.

Convergence criteria

First, one considered global inlet/outlet mass flow rate convergence. Fluctuations still existed at the end of the computation. Nevertheless, fluctuations level was less than one per cent of the total inlet mass flow rate. This result was considered sufficient to consider that global mass flow rate convergence had been achieved. Moreover, one verified that static pressure specified in the engine upstream plane permitted to obtain the real engine mass flow rate. One verified, also, that nozzle exit plane conditions, specified thanks to isolated engine computation, permitted to obtain the real engine mass flow rate, as well. Good engine mass flow rate was obtained, within a tolerance of 1%, on both sides of the engine.

Then, one considered reverser thrust convergence. The convergence ratio of F'_x was 0,4%. Including the P_a term, the reverser thrust – F_x – convergence was estimated to about 5%. As well as in the isolated engine case, these fluctuations can be explained by some undamped large scale eddies downstream of the reverser doors. One obtained a value of the reverser thrust, combined with his error bar. This value was judged.

Example of results

Figure 6 shows total pressure iso-contours, and, engine jet streamlines.

On the left side, one can see that total pressure iso-contours are fairly similar to those obtained in the isolated case.

On the right side, one verified that the hot jet do not interfere with critical plane walls, such as the rear end and the vertical tail.

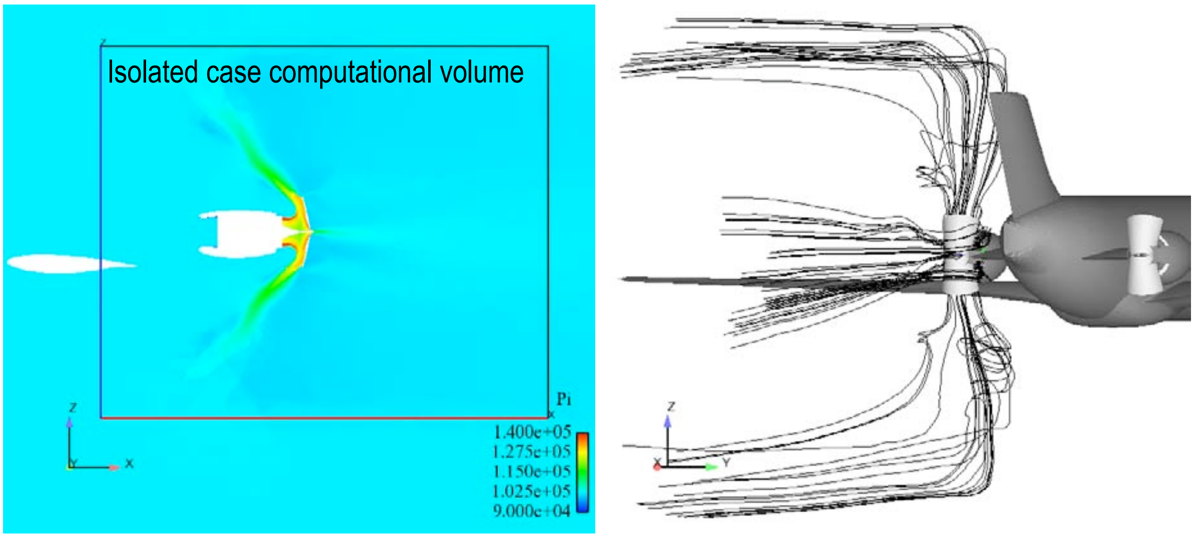

Figure 6 – Total pressure iso-contours, and, engine jet streamlines.

CONCLUSION

Both computations (isolated engine case and installed engine case) were carried out without numerical problems, thanks to meshes quality, and CEDRE code robustness. Our first numerical parameters allowed to achieve both computations until convergence. One can notice that these parameters were fairly close to CEDRE default parameters. Rather good convergence was obtained, with small residual fluctuations due to low frequency wake instabilities behind the thrust reverser doors. Mean physical time on the cluster was ten hours. Thus, this work established the feasibility of such complex computations and the realism of the computed flow as well as the interest of such computations in the design process.

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