

PRESAGE project: extension of the SE-Workbench for the computation of aircraft infrared signatures

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1. INTRODUCTION

The IR signature of an aircraft is the result of several major contributions, namely:

- Hot engine parts of the tail pipe and/or the air intakes
- Combustion hot gases (and in some cases hot carbon particles) in the plume
- Skin of the airframe, due to the thermal emission resulting from aerodynamic heating and internal heat sources and the reflected ambient radiation from the sun, the sky and the ground.

The aim of this paper is to present how the SE-Workbench-EO from OKTAL-SE has been extended in the frame of PRESAGE project (with the financial support of DGA) for computing the IR signature of a jet aircraft taking all these major contributions into account and what kind of results can be obtained both for non real time and real time rendering.

In particular the paper addresses the solution adopted for computing the radiative transfer through the plume, using SLG (Single-Line-Group) or MLG (Multi-Line-Group) band model and the Curtis-Godson approximation. The implementation has been optimized to make faster computation and obtain a SW easier to maintain. The SW has been integrated in the non real time rendering module of the SE Workbench-EO, SE-RAY-IR, for computing IR images of jet plumes taking into account the atmosphere segment between the sensor and the plume but also the presence of clouds on the LOS between the sensor and the plume. Especially for properly computing the atmospheric propagation along a LOS that intersects the plume, SE-ATMOSPHERE module is used for pre-computing high spectral resolution atmospheric radiation data.

The paper also focuses on the approach that has been adopted for taking into account the effects of internal thermal sources (such as the hot part of the engine) on the IR signatures of the aircraft. A new concept called “thermal influence node” has been implemented for that purpose.

The paper illustrates the use of SE-RAY-IR for computing the IR signature of various kinds of aircraft (military aircrafts and helicopters), including the plume, either as isolated targets in the sky or with the background behind. The paper also explains how we can render the aircraft with its plume in real time using SE-FAST-IR and a pre-computation of the plume with SE-RAY-IR. Images obtained using both approaches (non real time and real time rendering) are compared in order to show the level of precision that can be achieved in real time with comparison to the ray tracing approach considered as the reference.

Finally the paper presents the different packages of the SE-Workbench that should be available for customers in the future for aircraft IR signature computation in a complex 3D environment.

2. PRESAGE ARCHITECTURE

2.1 Overall architecture

PRESAGE overall application can be divided into three parts (see figure 1):

- The aircraft physical pre-computation
- The scenario edition part
- The rendering part.

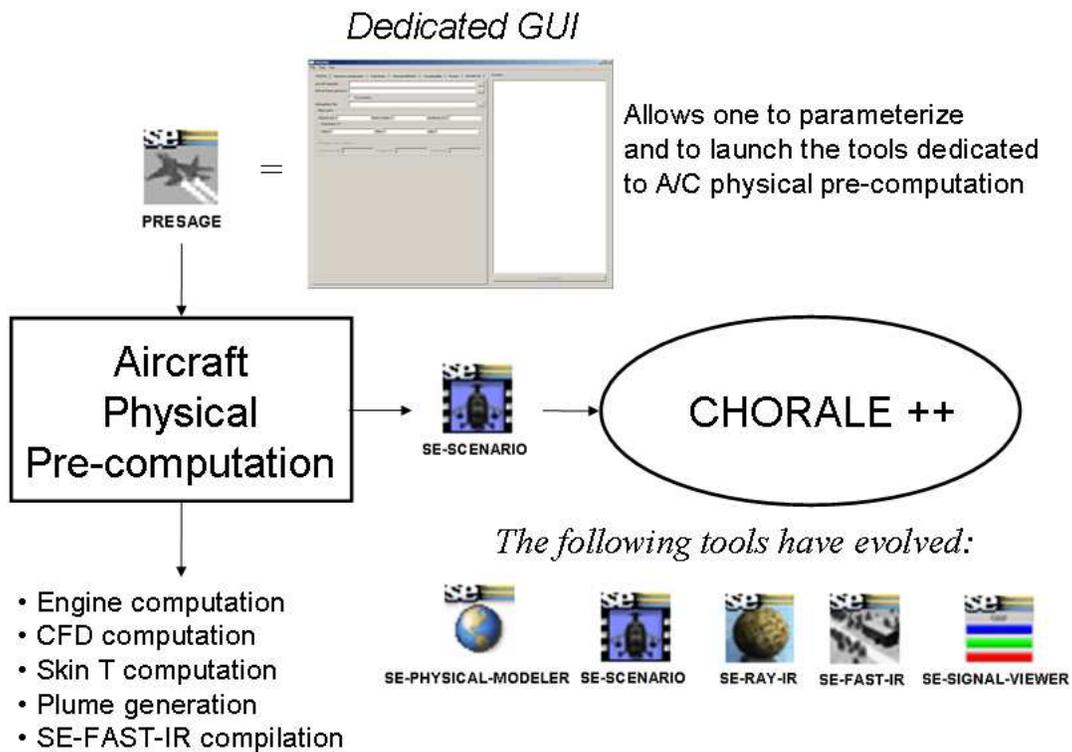


Figure 1. Global architecture of PRESAGE

As shown on figure 1, the scenario edition and rendering parts rely on CHORALE which has been extended to take into account the aircraft with its plume rendering issues.

The aircraft physical pre-computation part relies on both highly trustable COTS, such as FLUENT for CFD computation, and specific modules that have been developed in the frame of PRESAGE project. Among them one can find the PRESAGE specific GUI dedicated to the parameterization and execution of the various tools used for pre-computing the aircraft.

SE-PHYSICAL-MODELER has been extended to offer the following new functionalities:

- ATH and DTH edition
- IPS texture edition
- Surface temperatures visualization (see figure 2, hereafter).

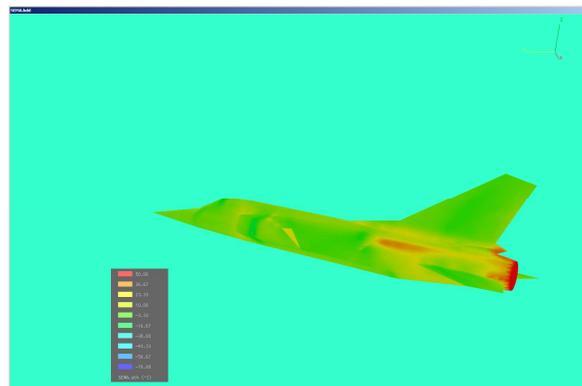


Figure 2. Surface temperatures visualization in SE-PHYSICAL-MODELER

SE-SCENARIO can now load a plume entity as a .plu file and offers a new GUI panel for entering the parameters related to the plume rendering.

SE-RAY-IR has been extended for taking into account the radiative transfer through the plume for the scene rendering.

SE-FAST-IR has been extended for taking into account the plume pre-compilation products.

SE-SIGNAL-VIEWER which replaces SE-ADVANCED-SCENE-VIEW dedicated to .sps images visualization offers new functionalities for the analysis of an image or a sequence of images that have been developed in the frame of PRESAGE project. It also enables to compare two images or two sequences of images (see figure 3 hereafter).

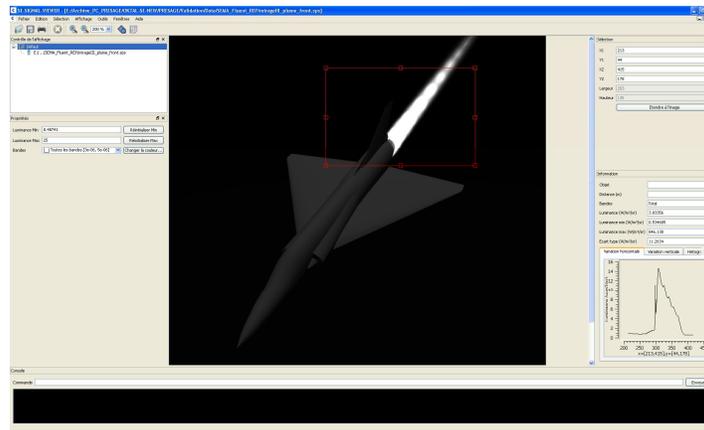


Figure 3. SE-SIGNAL-VIEWER GUI illustrating new analysis functionalities

2.2 Detailed architecture

Figure 4 hereafter shows the commercial software tools and the CHORALE's modules that are used in PRESAGE applications.

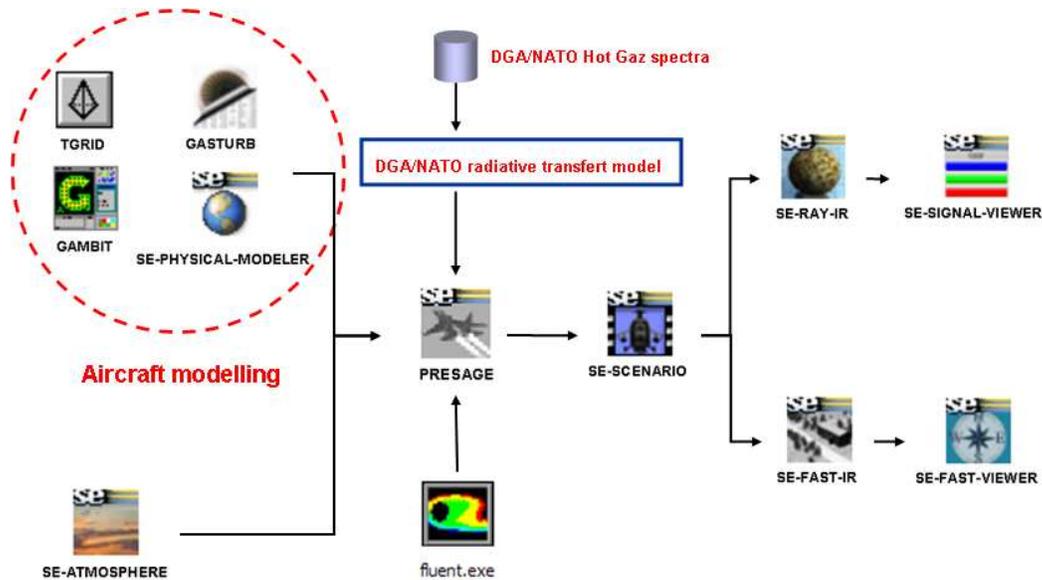


Figure 4. Detailed architecture of PRESAGE

FLUENT is used for computing both the air flow around the aircraft body and the dispersion of the plume from the engine exhaust conditions provided by the engine computation software. The latter is GASTURB in the case of a gas turbine (for airplane and helicopter engines) and CET93 US code in the case of a missile engine. FLUENT can be replaced by REP in the case of axisymmetric plumes which is typically the case of a missile plume.

It has to be noticed that FLUENT could also be used for computing the 3D internal thermal conditions inside an aircraft if the detailed internal structure of this aircraft is known and can be modeled precisely. As such data are very difficult to obtain, especially in the case of a foreign aircraft, we have developed another approach more phenomenological that is based a new concept in CHORAL called “thermal influence node” (see part 4 of this paper).

2.3 CFD computation process

Figures 5 and 6 hereafter show the CFD computation process in the case of FLUENT and REP respectively for the plume dispersion computation.

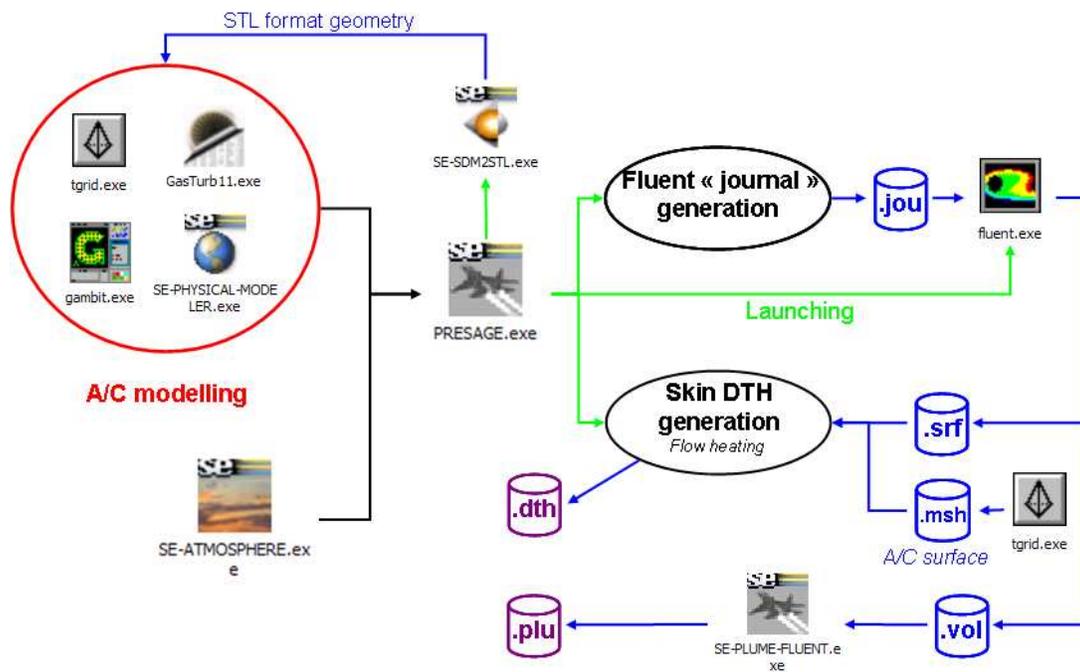


Figure 5. CFD computation process in the case of FLUENT plume dispersion computation

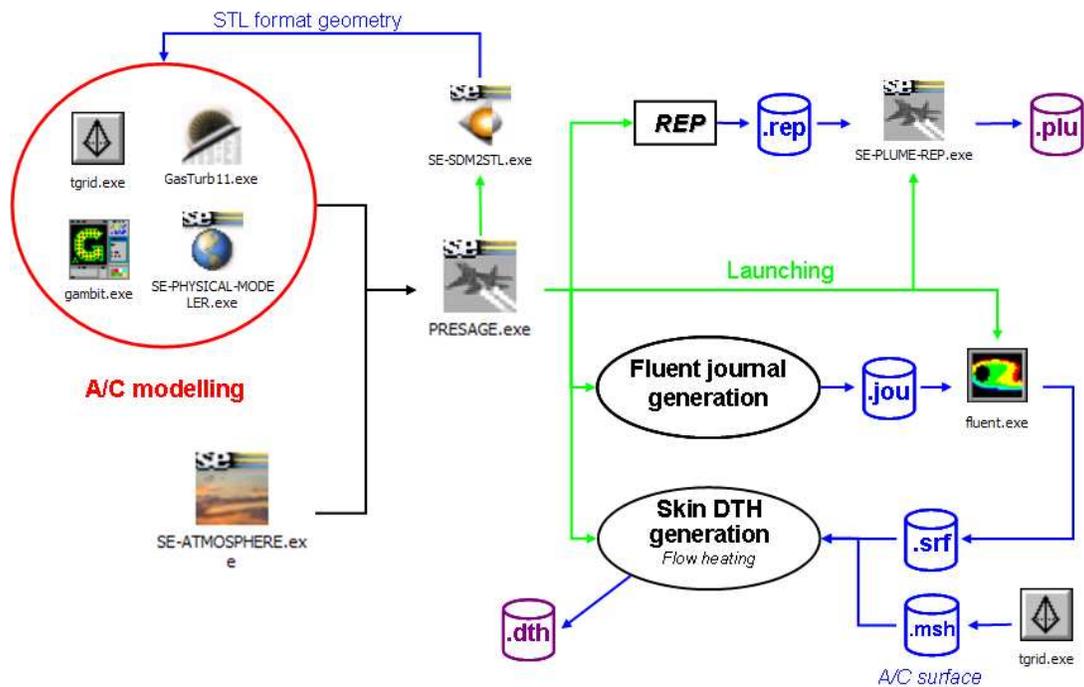


Figure 6. Computation process in the case of REP plume dispersion computation

Once the fluid dynamics computation has been done, the results data are converted in order to extract the temperature, pressure and species concentrations needed by the SE-WORKBENCH computations. The airframe and the plume are processed separately.

3. PLUME RENDERING

3.1 Spectral data

Whereas the concentrations of gas species come from the CFD computation, the spectral data of each species come from a molecular database which contains the values of the absorption coefficient and the line spacing coefficient. This consists in tables function of temperature and wave number. The handled species are classified in three categories:

- Active species: that contribute directly to the radiance and attenuation of the plume (H_2O , CO_2 , CO)
- Inactive species: that only contribute indirectly by modifying the behavior of the active species if they are present (N_2 , O_2)
- Particle species: that uses a distinct rendering algorithm and could cause scattering (C).

All these species are defined according to a temperature sampling, for example in the case on the NIRATAM database 8 temperatures in the range 100 K to 3000 K and a thin spectral sampling 921 wave numbers from 400 cm^{-1} to 5000 cm^{-1} with a step of 5 cm^{-1} .

3.2 Preparing the scenario

Once all data have been converted, the original airframe geometry associated with its skin thermal definition and the plume files are loaded in a scenario using SE-SCENARIO software tool. This software enables to define the simulation sensor, to load atmospheric conditions computed with SE-ATMOSPHERE and to edit object trajectories. The software can be used to define the scenario for both studies (SE-RAY) and real time (SE-FAST) simulations.

3.3 Non real-time simulation

For non-real time rendering SE-RAY-IR is then used to compute IR images of the scenario. The airframe is rendered using the standard ray tracing provided by the software according to its physical material and the skin temperature definition.

The plume is rendered using an advanced radiative transfer approach based on a high resolution spectral computation using gas concentrations and atmospheric conditions as input. This algorithm is a line-by-line rendering approach based on the Curtis-Godson approximation model. The solution adopted is inspired from NATO NIRATAM software package [1]. The radiation from hot gases is computed using SLG (Single-Line-Group) or MLG (Multi-Line-Group) band model depending on the temperature along the LOS and the Curtis-Godson approximation is used for the mean transmissivity through inhomogeneous gases. The radiative transfer model implementation has been revisited to make it faster and easier to maintain and the new plume radiative transfer module has been extended in terms of number of species and spectral resolution.

Then this new plume radiative transfer module has been integrated in the non real time rendering module of the SE-Workbench-EO, SE-RAY-IR, for computing IR images of jet plumes taking into account the atmosphere between the sensor and the plume but also the presence of clouds on the LOS between the sensor and the plume. Especially for computing properly the atmospheric propagation along a LOS that intersects the plume SE-ATMOSPHERE module is used for pre-computing high spectral resolution atmospheric radiation data.

For a given ray of evaluation travelling through the plume, the plume data are used to determine the temperature profile along the path using a k-nearest neighbor approach. According to this profile, the path is cut in slabs based on a constant temperature definition. Then, for each slab, the pressure and concentrations are also determined using a k-nearest neighbor approach. The path is finally processed to compute its radiance and attenuation. If a ray goes through the plume, the atmosphere computation is done using a narrow band approach in order to ensure the coherency while composing the radiance of the hot plume with the radiance and attenuation of the cold atmosphere. The results are obtained line-by-line, and then are integrated on the visualization bands of the sensor.

3.4 Scattering by particles

In the case of soot particles generated by a gas turbine, the particles are treated by the new radiative transfer module as a fictitious gas in the same way as the real gas species.

In the case of particles generated in a solid propellant missile engine (such as Al_2O_3), we have implemented a phenomenological model based on scattering sources and a grid of scattered radiation estimation points (see figure 7 hereafter).

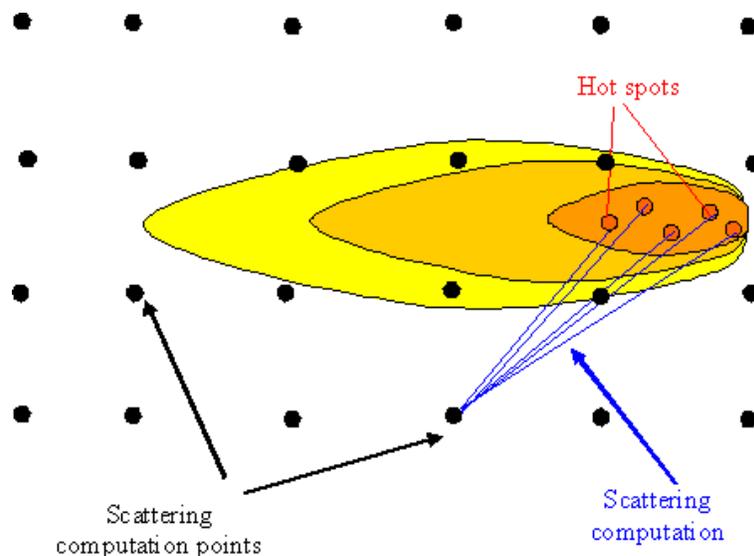


Figure 7. Particles scattering phenomenological model

This simple phenomenological model is highly tunable through the number of scattering sources (called “hot spots” on figure 7) and the density of the grid of scattered radiation estimation points (called “scattering computation points” on figure 7).

3.5 Real-time simulation

The scenario can also be used in a real-time application based on the SE-TOOLKIT and SE FAST-IR. However, the airframe and plume data must be pre compiled, that is prepared for real-time simulation. The airframe is pre compiled using SE-FAST-IR-COMPILER, which consists in preparing the data that will be used in the rendering shaders of graphic cards.

The plume is compiled using SE-FAST-IR-PLUME-COMPILER. Whereas the approach of the two compilers is the same one, the data needed for surface and volume are not the same. As for surfaces, the compiled plume should be viewed for all orientations. While for surfaces the radiance is reconstructed directly from the material properties and textures for all orientations, an accurate plume simulation is costly in terms of time and memory and so it is not possible to compute it in real-time. Our idea is then to use a sort of image-based rendering: the radiances and attenuations of the plume and its surrounding atmosphere are pre-computed using the same accurate algorithm as the one implemented in SE-RAY-IR, for a set of positions and orientations, and stored in textures. These textures are then used in the shaders to reconstruct the radiance and transmission for any orientation using simple interpolations (see figure 8 hereafter).

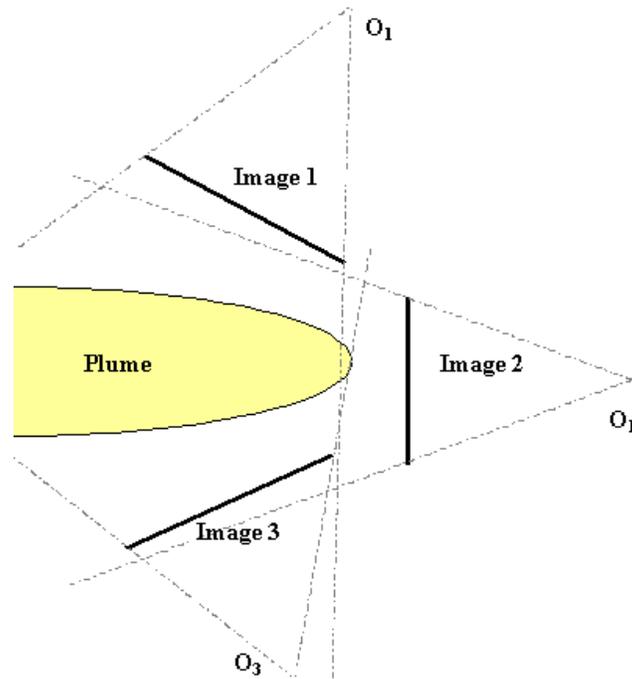


Figure 8. Particles scattering phenomenological model

This enables to move around the plume in real-time and to obtain results comparable with the SE RAY IR simulation results. Unfortunately, as the plume needs to be pre compiled in the atmosphere in order to take correctly into account the hot/cold gas combination, an error is done when using the plume in conditions very distinct from the compilation one.

4. THERMAL MODELLING

4.1 Skin temperature

The first step is to extract the temperature mesh from the FLUENT output file and to construct the skin thermal definition of the airframe. It consists in constructing a mesh for which the temperature of each vertex is known. This mesh does not need to be the same as the airframe geometry, and is mostly the tessellated mesh used for fluid computations. Then, when computing the radiance for at an intersection point between a ray and the aircraft body, the skin mesh is used to search the nearest vertex temperature or to extrapolate the temperature from the nearest triangles.

4.2 Internal thermal sources modeling

For modeling the internal thermal sources a new concept has been introduced in CHORALE called “Thermal Influence Node” (hereafter referred to as “TIN”).

Three different kinds of such node have been defined as described on figure 9 hereafter.

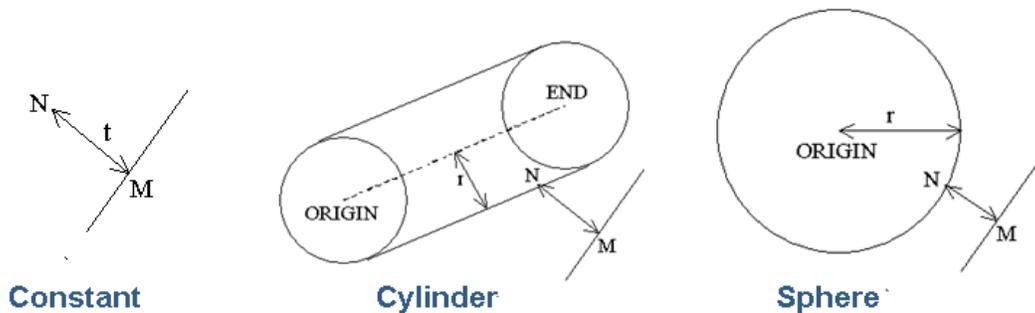


Figure 9. The 3 kinds of Thermal Influence Node introduced in CHORALE

Each type of node has its own parameters and is related to a specific algorithm for computing the distance between an influenced polygon of the 3D mockup of the aircraft and the thermal influence node.

Figure 10 hereafter illustrates the effect of a cylinder type thermal influence node on the surface temperatures of a cylinder.

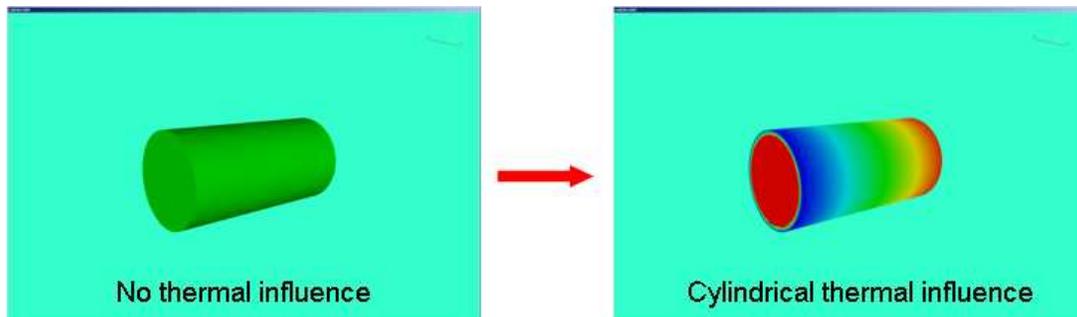


Figure 10. Thermal effects due to the presence of a cylinder type TIN inside a 3D object (here a cylinder)

5. SOME RESULTS

5.1 Internal validation tests

On figure 11 hereafter, some results related to the internal validation tests made in OKTAL-SE in the frame of PRESAGE project are shown. They illustrate the results given by the particles scattering phenomenological model and by SE-FAST-IR plume compilation process implemented in CHORALE.

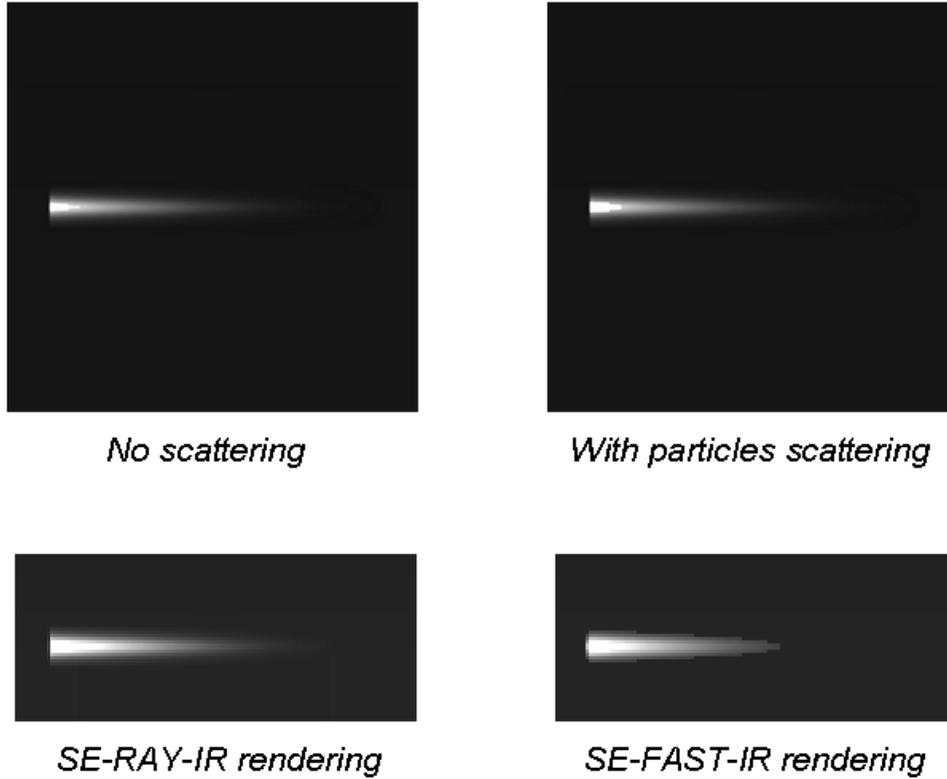


Figure 11. PRESAGE results obtained during the internal validation phase of the project

5.2 Results on a military aircraft

Figure 12 hereafter show IR images of a military aircraft along with its plume obtained using PRESAGE. The plume dispersion has been computed using REP. The Mach disks can be easily distinguished on these MWIR band images.

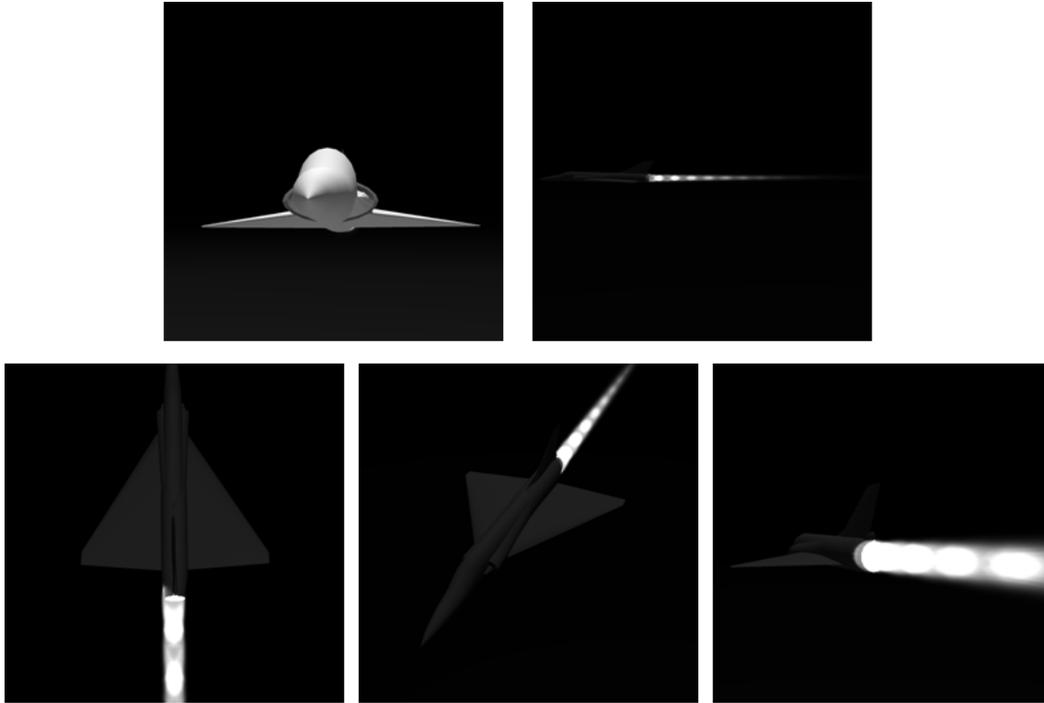


Figure 12. MWIR band images computed using PRESAGE with REP as plume dispersion computation software

5.3 Tests of PRESAGE on a helicopter

On figure 13 hereafter the capacities of PRESAGE for computing the IR signature of a helicopter are illustrated. Especially one can clearly distinguish the heating of the tail due to the main rotor flux effect on the engine hot plume. These results have been obtained using the Virtual Blade Model (VBM) implemented in FLUENT for computing the plume dispersion in the presence of the main rotor flux.

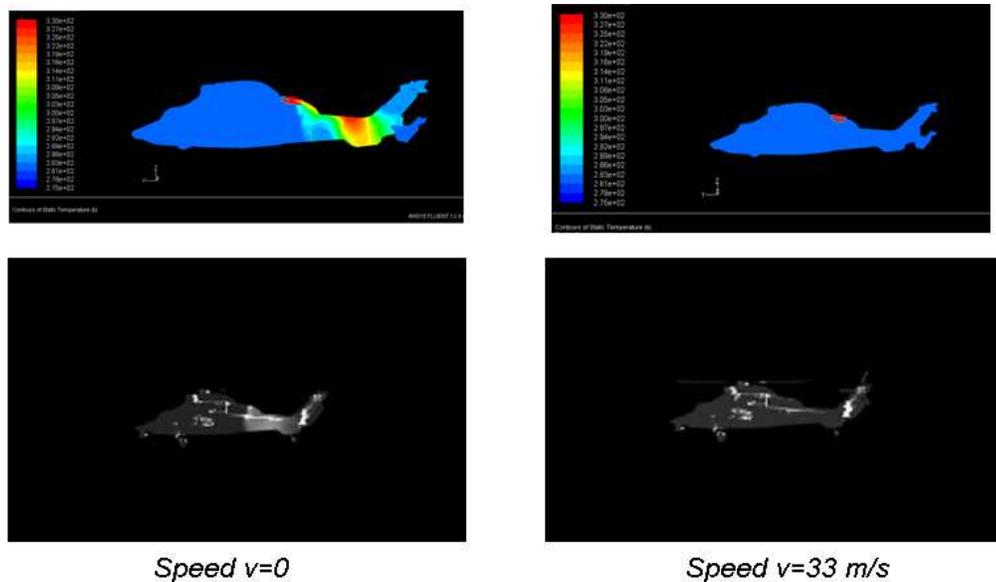


Figure 13. PRESAGE first results obtained in the case of a helicopter for two flight speed values

6. FUTURE WORKS

Future works concern mainly the validation of PRESAGE through comparison to existing validated codes such as CRIRA ONERA code and NIRATAM NATO code.

OKTAL-SE's concern is also to be able to define some commercial packages from PRESAGE project along with DGA. One of the possible commercial packages is shown on figure 14 hereafter. In this package the radiative transfer module and radiative molecular data of hot gases are provided by the customer. OKTAL-SE offers a "call back" mechanism that enables to use such an external radiative transfer model.

It can also be noticed that any CFD computation software can be used instead of FLUENT provided that the plume modeling interface is respected. It can be another commercial CFD software such as CFD++ or an open source CFD software such as Open Foam. Concerning the capacity of PRESAGE to work along with CFD++ a trial has been made successfully on the F16 military airplane (see OKTAL-SE's ITBM&S paper given in 2009 along with Go Virtual [2]).

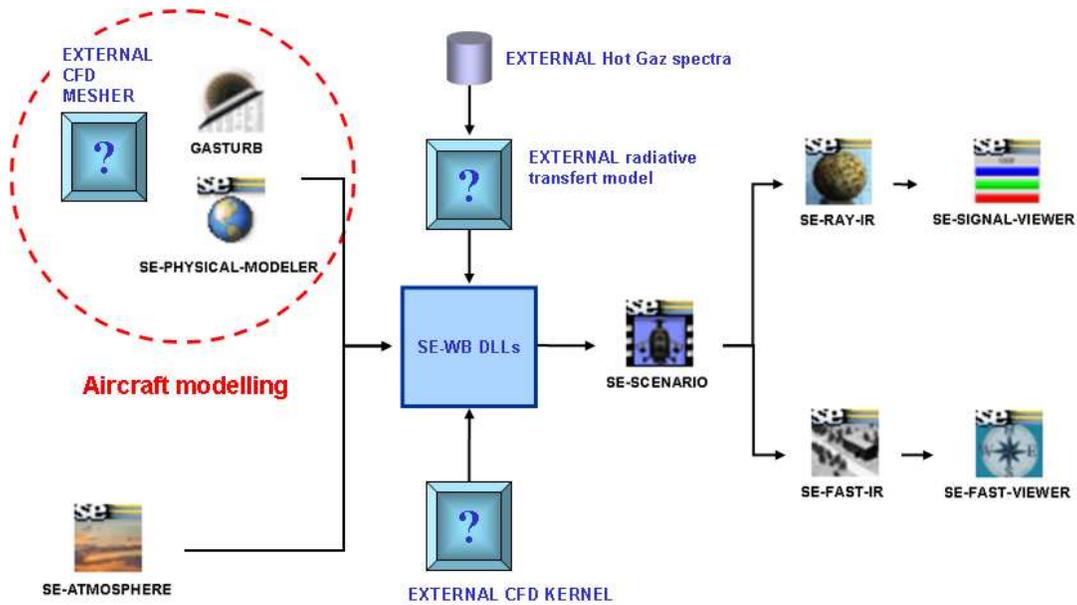


Figure 14. Future possible commercial package inspired from PRESAGE project

REFERENCES

1. K. Beier, *Infrared Signatures from Jet Engines*, in *AGARD Seminar*, p. 193, DLR Institute for Optoelectronics, September 1990
2. Sven Perzon, Nicolas Douchin, Thierry Cathala, André Joly, *Aircraft infrared signature, take into account body, engine and plume contributions*, ITBM&S 2009 workshop proceedings, Toulouse, June 2009.