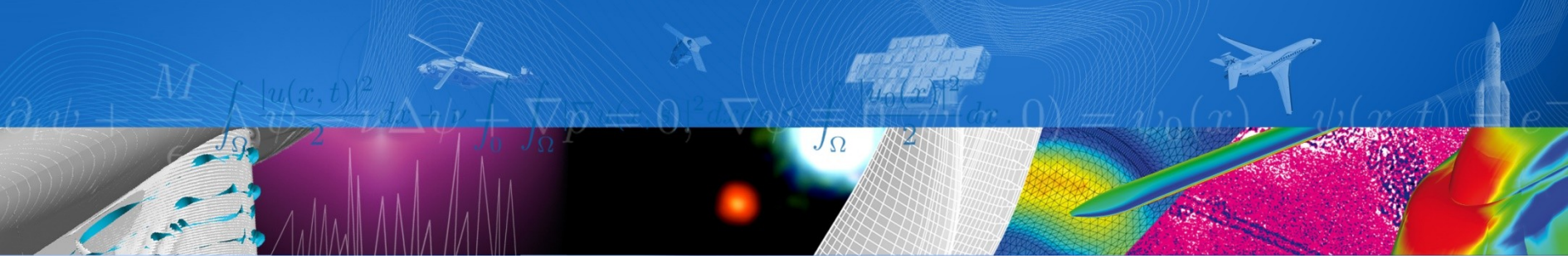

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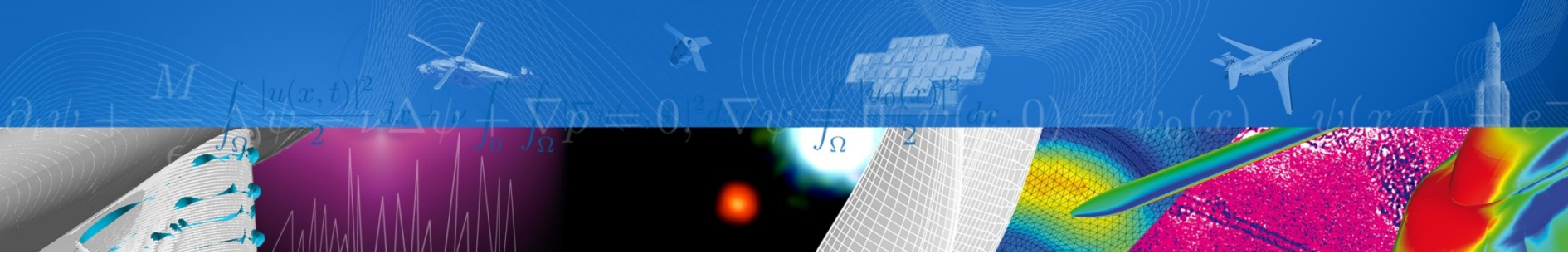

Parametric study of Contrails formation

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Outlines

1. Contrails issue
2. Objectives
3. Contrails birth description
4. Models description
5. Aircraft configuration
6. Results
7. Conclusion

Contrails issue

Fig. 1

Fig. 2

Fig. 3

Objectives

The main goal of these studies is to contribute to reduce the environmental impact of contrails and aircraft emissions.

Simulation tool

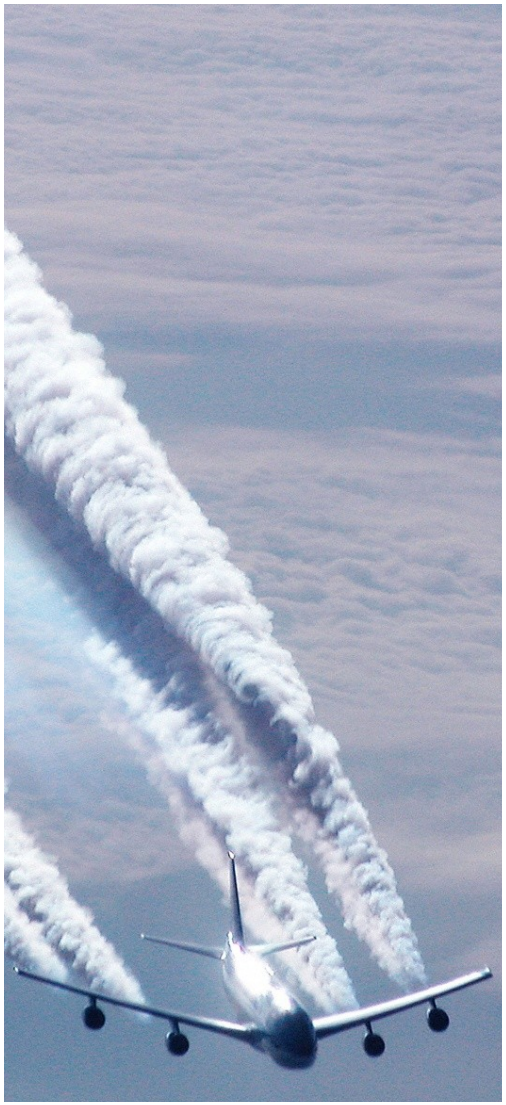
- Improving the characterization and prediction of **macroscopic** and **microscopic** properties of contrails

- Developing strategies for **technological** and **operational mitigation**

Positioning

- Study of **contrails forming mechanisms**, in the **near-field** of the aircraft

Objectives

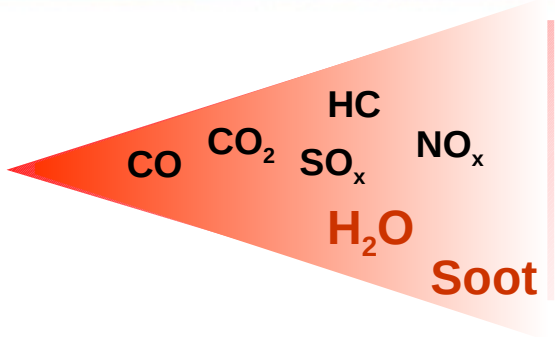


- **3D spatial CFD simulation** with code **CEDRE** of ONERA
- Development of a **multi-physics** simulation tool:
  - Aerodynamics
  - Plume's chemistry
  - Microphysics

  } Coupling processes
- Taking into account a **realistic geometry** of a commercial aircraft

Contrails birth description

Jet

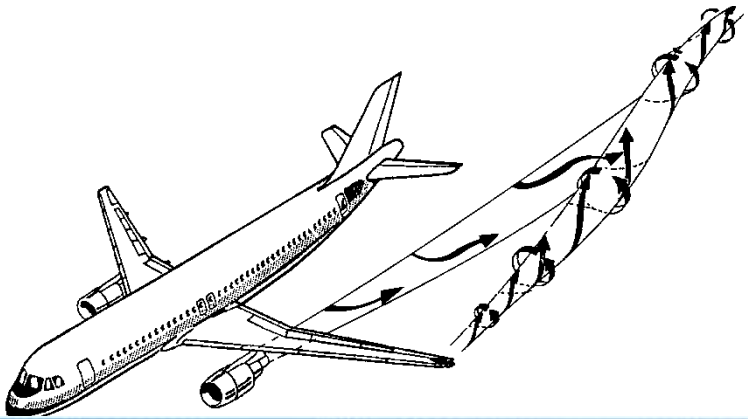


- Composition (fuel, engines)
- Flow rate (engines thrust)

Vortex

- Wing airfoil
- Wing loading distribution

Interaction



- Engine position
- Wing span

Models description: Aerodynamics, Gas-phase chemistry and microphysics

Aerodynamic models

- **An unstructured Compressible Navier-Stokes** solver
- Reynolds Averaged Navier-Stokes Approach
- Turbulent model : k-^ SST

Chemical kinetics scheme

- Complex **gas phase chemical reactions mechanism**
  - 23 species (SOx, NOx, HOx, COx)
  - 60 reactions

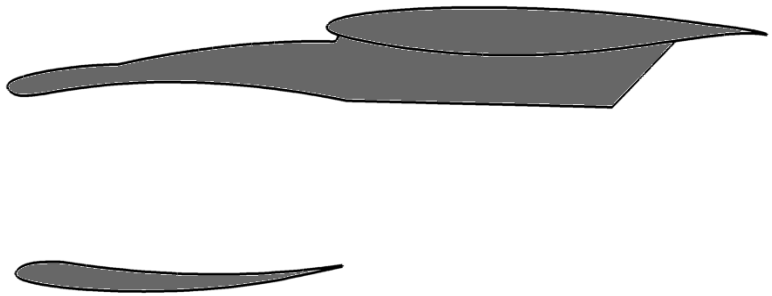
Microphysics processes

- **Particles transport** using an **Eulerian approach**
- Soot **activation** by **adsorption of H_2SO_4 and SO_3 molecules**
- **Condensation/Evaporation** of vapor water onto soot particles:
  - Evaluation of the Condensation/Evaporation rate
  - Taking into account the Kelvin effect

Aircraft configuration: Common Research Model+ (CRM)

- An aircraft representative of a B777 (~60 m wingspan);
- A full configuration (wing, fuselage, HTP, VTP) but a flow through nacelle

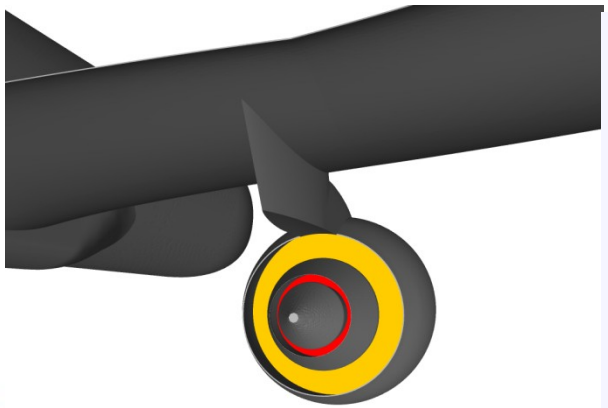
Double core flow engine

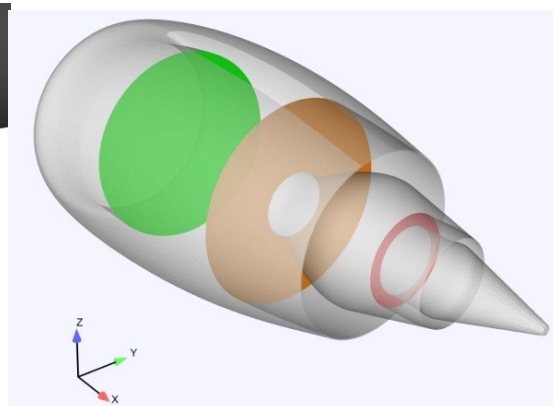


(a) Original Through Flow Nacelle of the CRM

(b) Internal engine designed

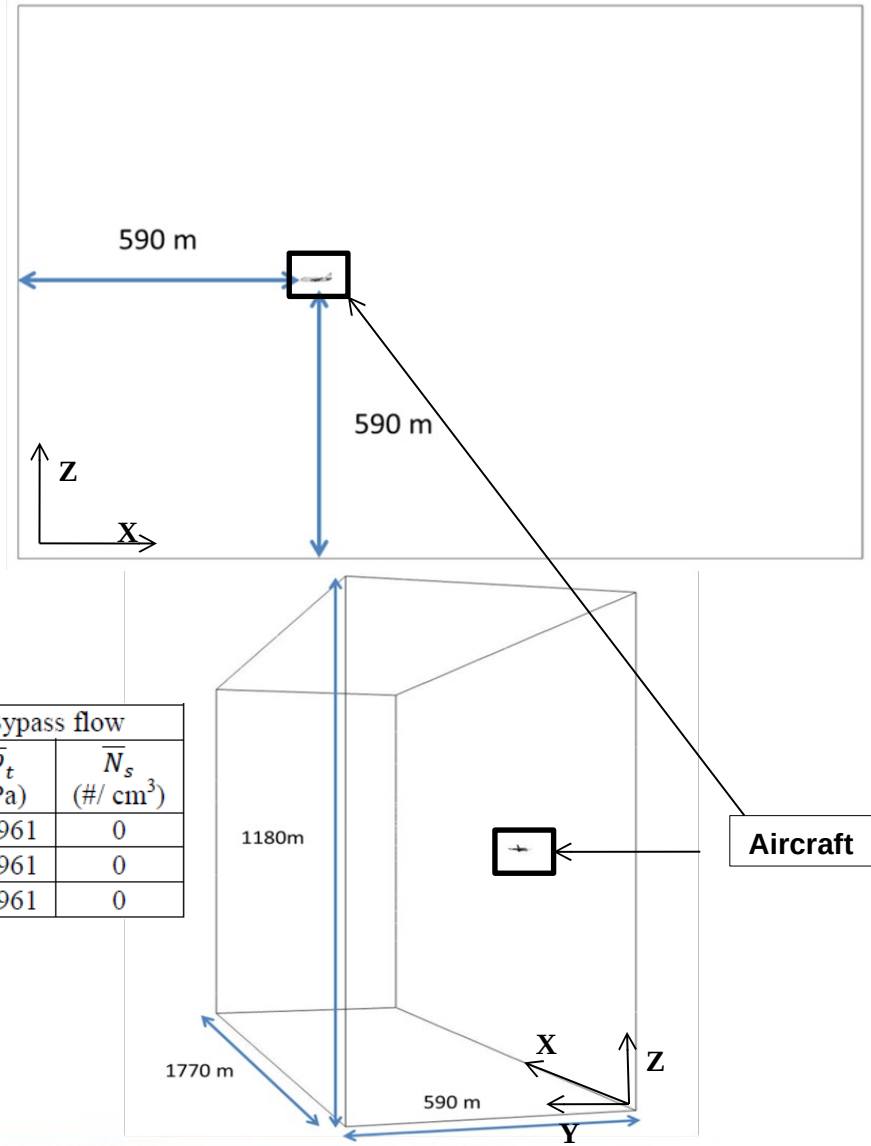
The bypass ratio of the designed engine is of 12.





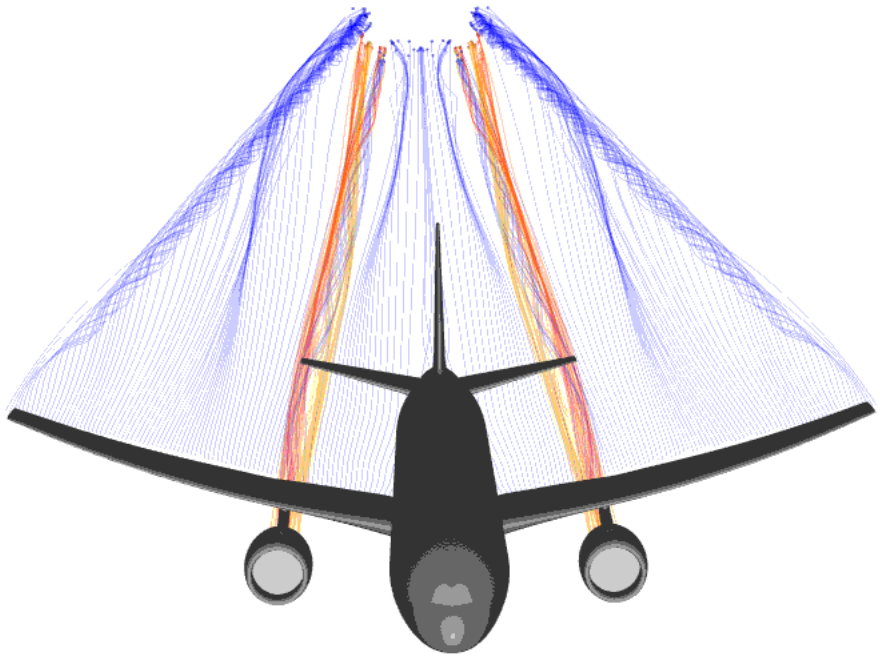
Computational domain, initial and Boundary conditions

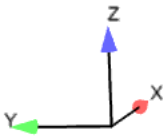
- Domain extension behind the wingtip (wingspan b ~ 60m):
  - Nearly 1 km;
  - Corresponding to 4.5 s.
- AoA set to 2.75°



#	Ambient conditions				Engine core flow			Engine Bypass flow		
	$\overline{T}$ (K)	$\tilde{u}$ (m/s)	$\overline{p}$ (Pa)	RH (%)	$\overline{T}_t$ (K)	$\overline{p}_t$ (Pa)	$\overline{N}_s$ (#/ cm^3)	$\overline{T}_t$ (K)	$\overline{p}_t$ (Pa)	$\overline{N}_s$ (#/ cm^3)
1	223.15	254.38	26437	41	626.41	53001	10^{12}	297.23	69961	0
2	223.15	254.38	26437	0	626.41	53001	10^{12}	297.23	69961	0
3	230.15	254.38	26437	19	626.41	53001	10^{12}	297.23	69961	0

Results:
Jet / Vortex interaction

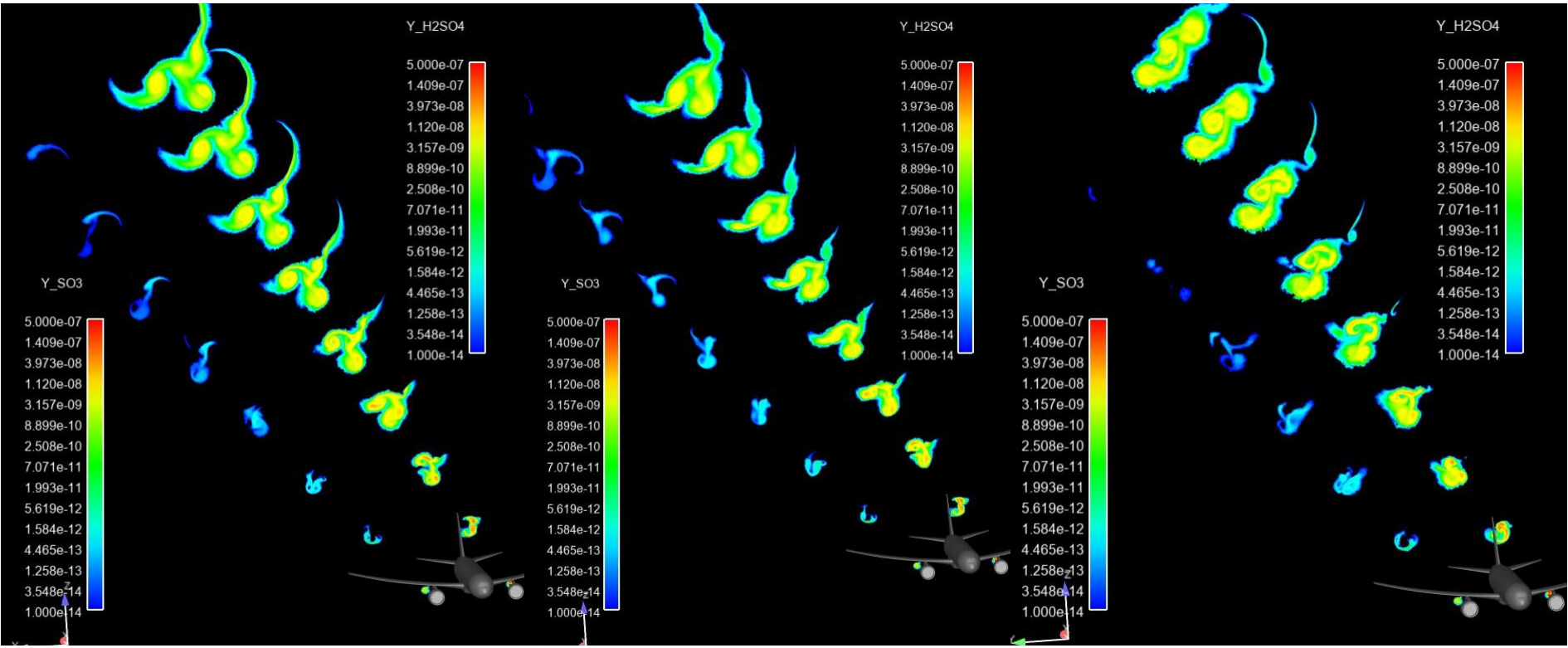




- Theoretical distance between the two vortices ~ 47.1 m
- In the present case, distance ~ 45.4 m

Results:
Gas-phase chemistry

H_2SO_4 and SO_3 mass fraction fields downstream of the aircraft



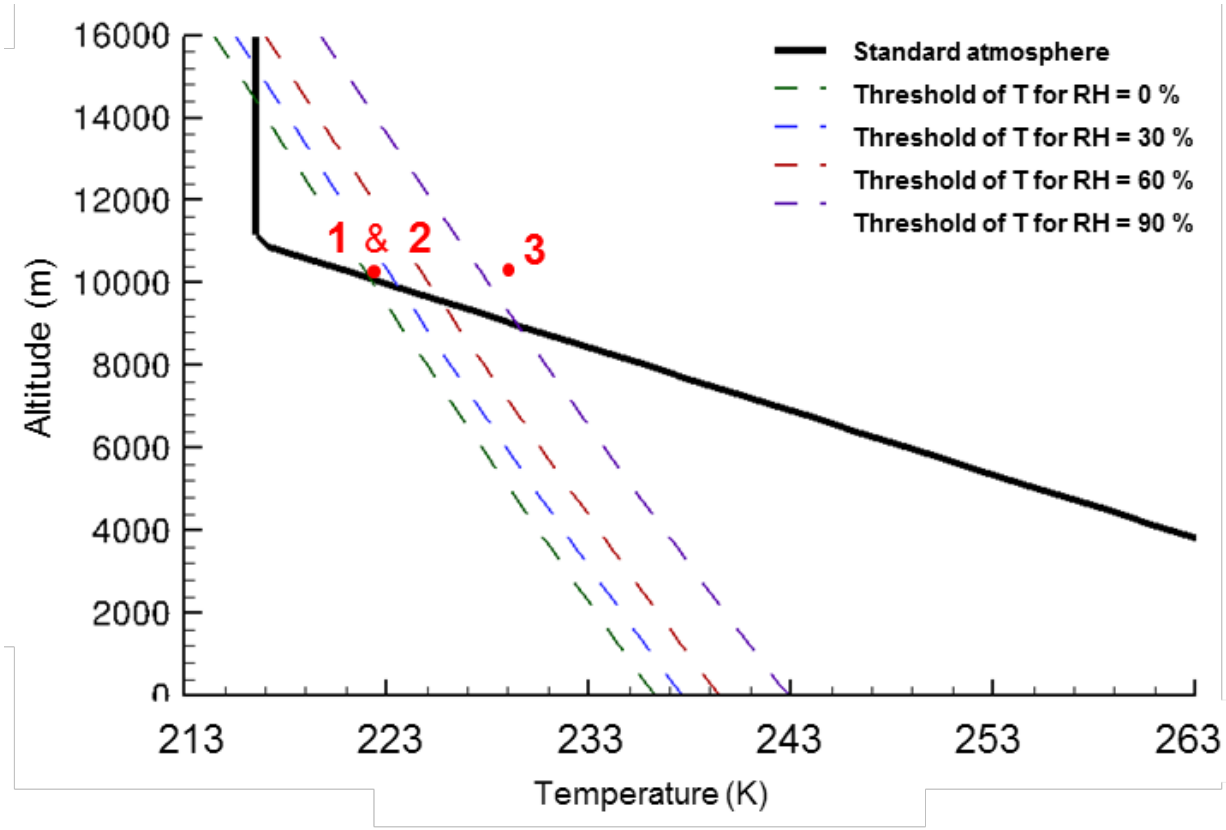
Case #1
RH = 41%
OAT = 223.15K

Case #2
RH = 0%
OAT = 223.15K

Case #3
RH = 19%
OAT = 230.15K

Results: Schmidt-Appleman criterion

- Schmidt-Appleman criterion



- A boolean-like criterion :
  - **Contrails**
  - **No contrails**
- Mainly depending on:
  - Emission Index Water Vapor
  - Engine Exhaust Temperature
  - Outside Air Water Vapor
  - Outside Air Temperature

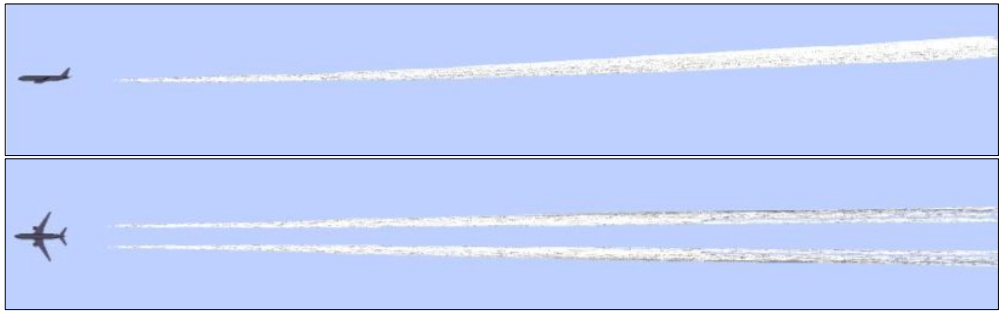
Case #1
RH = 41%
OAT = 223.15K

Case #2
RH = 0%
OAT = 223.15K

Case #3
RH = 19%
OAT = 230.15K

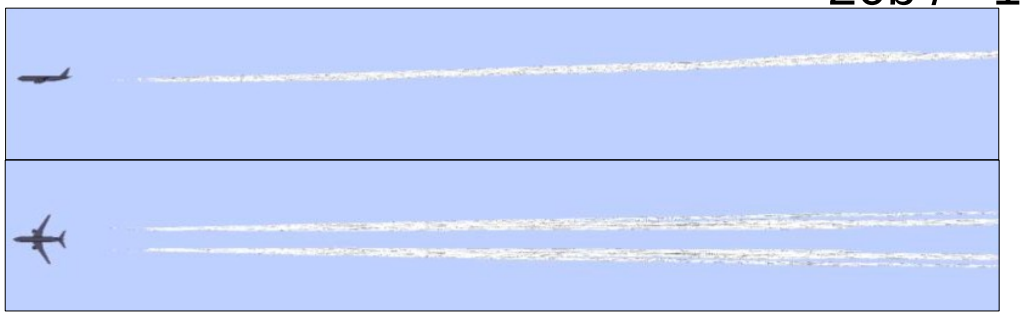
Results:
Contrails formation

- Contrail highlighting based on optical depth above 0.03

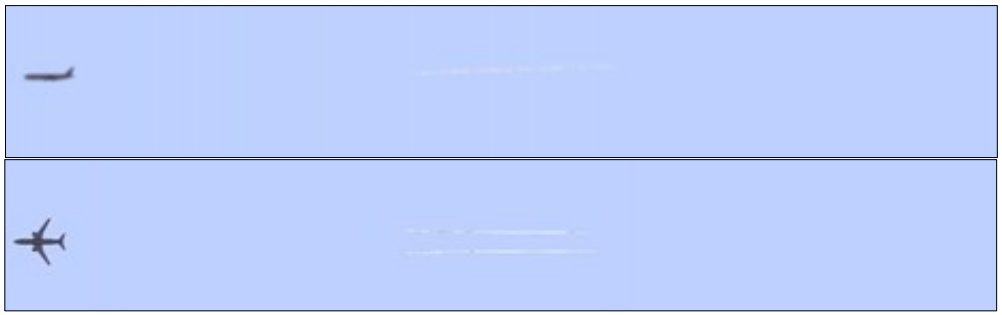


Case #1
RH = 41%
OAT = 223.15K

~20b / ~1240 m



Case #2
RH = 0%
OAT = 223.15K



Case #3
RH = 19%
OAT = 230.15K

Conclusions

- Achievement of a **multiphysics contrails formation simulation tool:**
  - **A 3D RANS spatial simulation** in the near field taking into account aerodynamic, gas-phase chemistry and microphysics interaction with a **complete aircraft geometry**

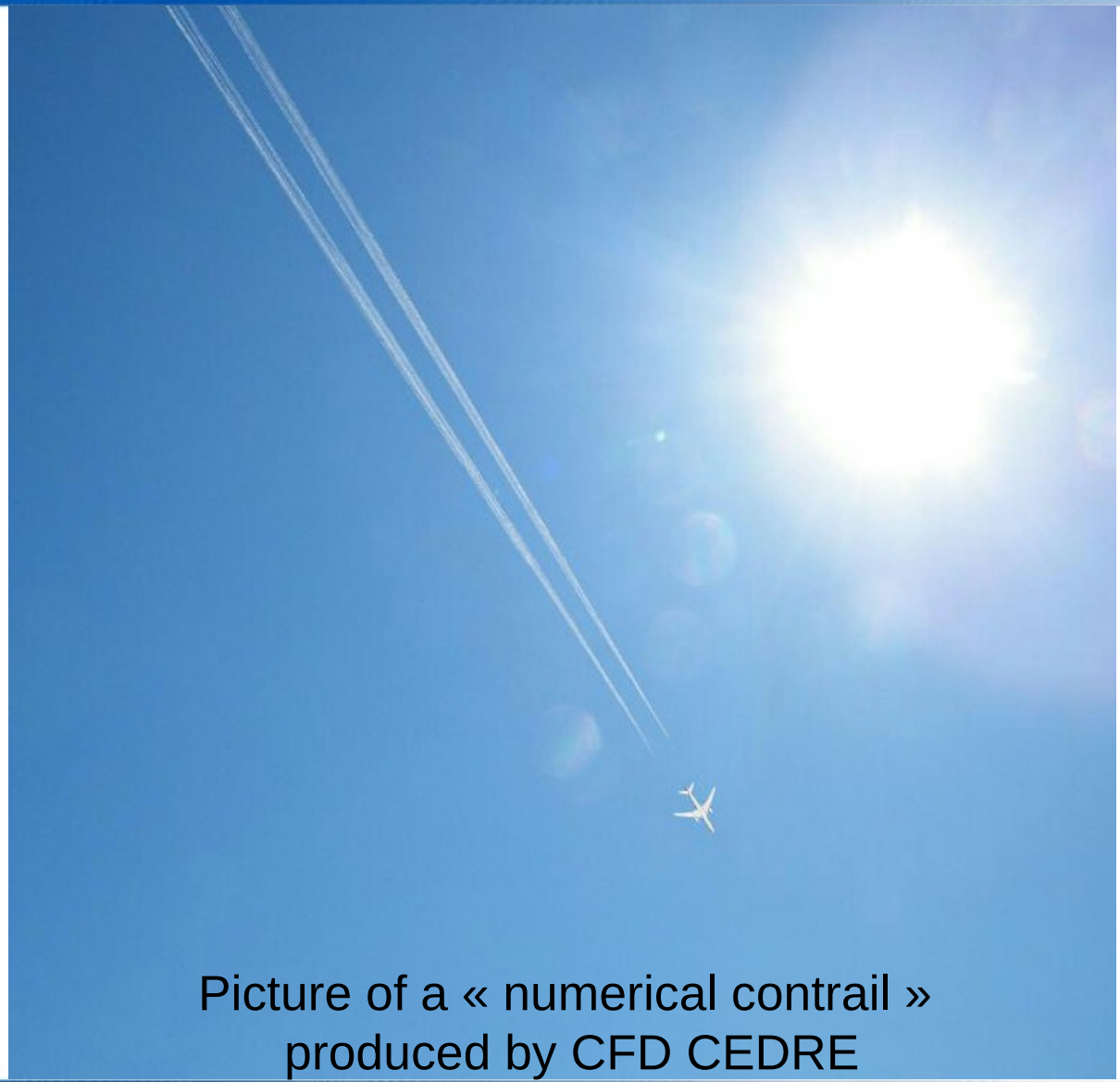
- Mesh refinement procedure that allows to recover the main feature of the vortex system downstream of the wake and the hot jet

- First comparison between 3D simulation and Schmidt-Appleman criterion for contrails formation

Perspectives

- Study the influence of the aircraft geometry issues such as the engine position:
  - the results show some effects in the jet/vortex dynamics but it is not clear to quantify how it affects the contrails formation.
- Inclusion of volatile-particle microphysics;
- Other activation pathways through soot-vapor interactions could also be addressed including the effect of organic compounds and the oxidation of soot-surface functional chemical groups;
- ZDES numerical approaches are currently assessed in order to evaluate the gain regarding contrails formation.

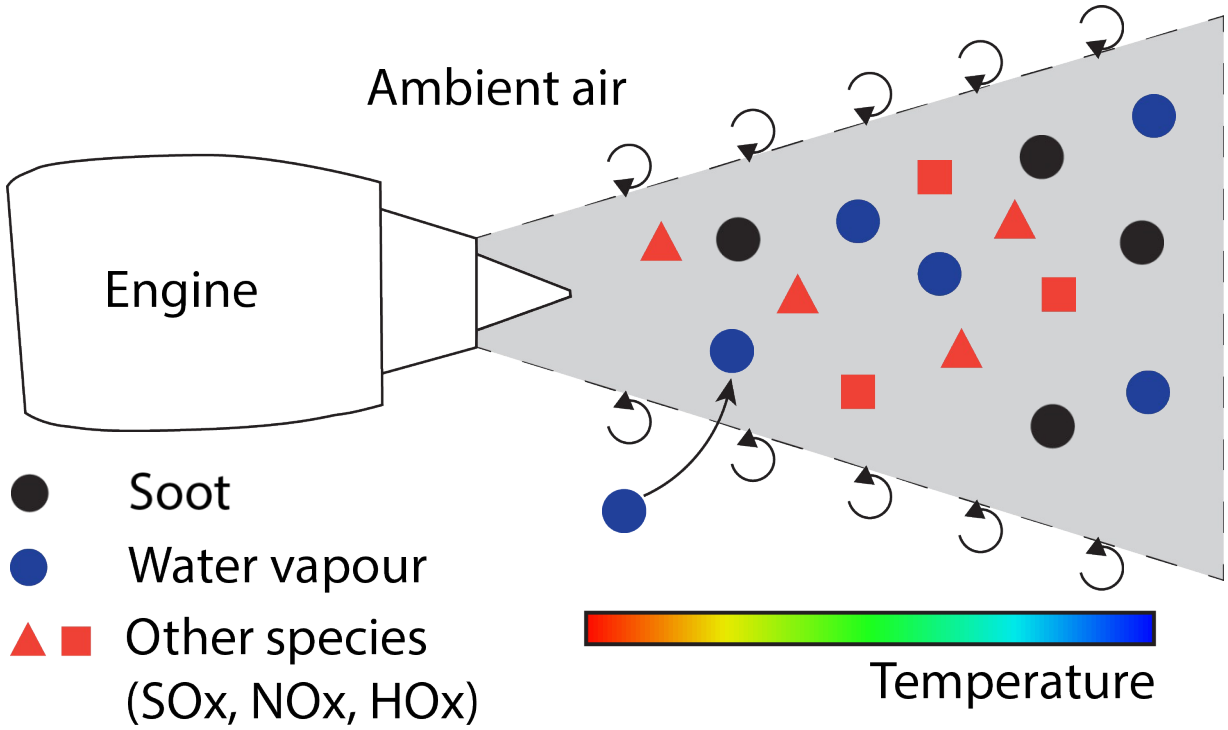
Thanks a lot for your attention…



Picture of a « numerical contrail »
produced by CFD CEDRE

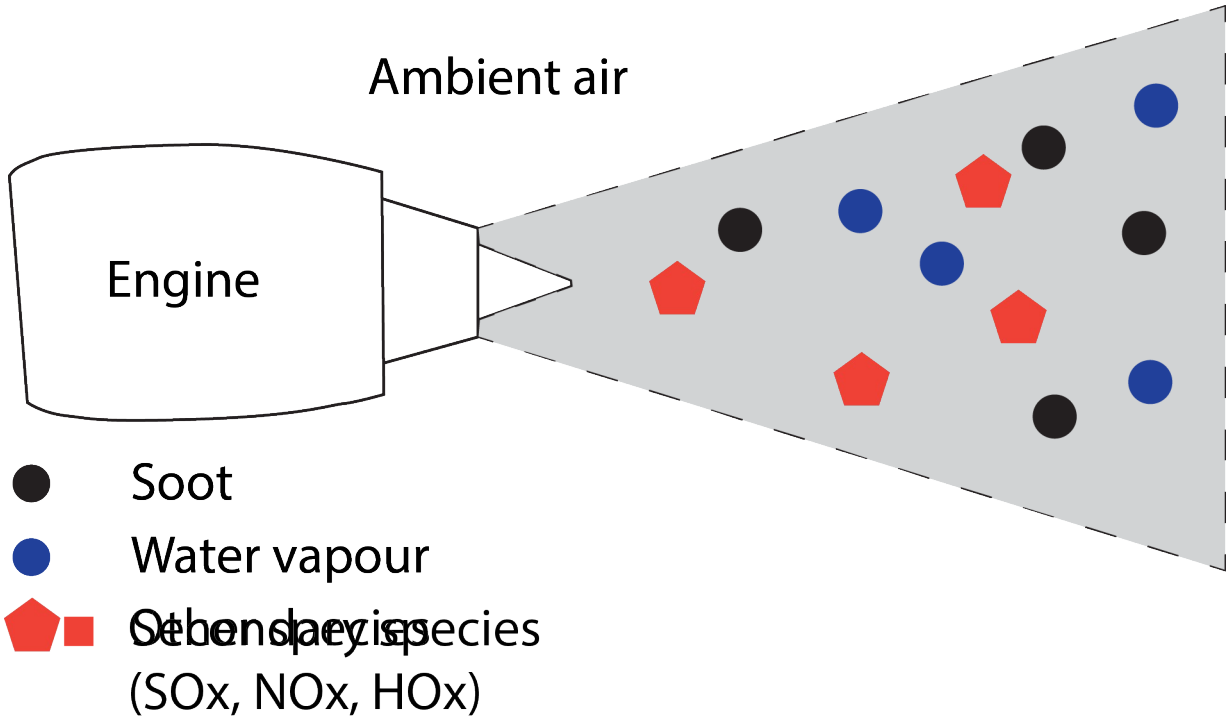
Models description: principles

Engine emissions



Models description: principles

Chemical processes



Models description: principles

Microphysics processes