Aircraft level assessment of contrail mitigation

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ONERA
THE FRENCH AEROSPACE LAB

retour sur innovation

Objectives

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

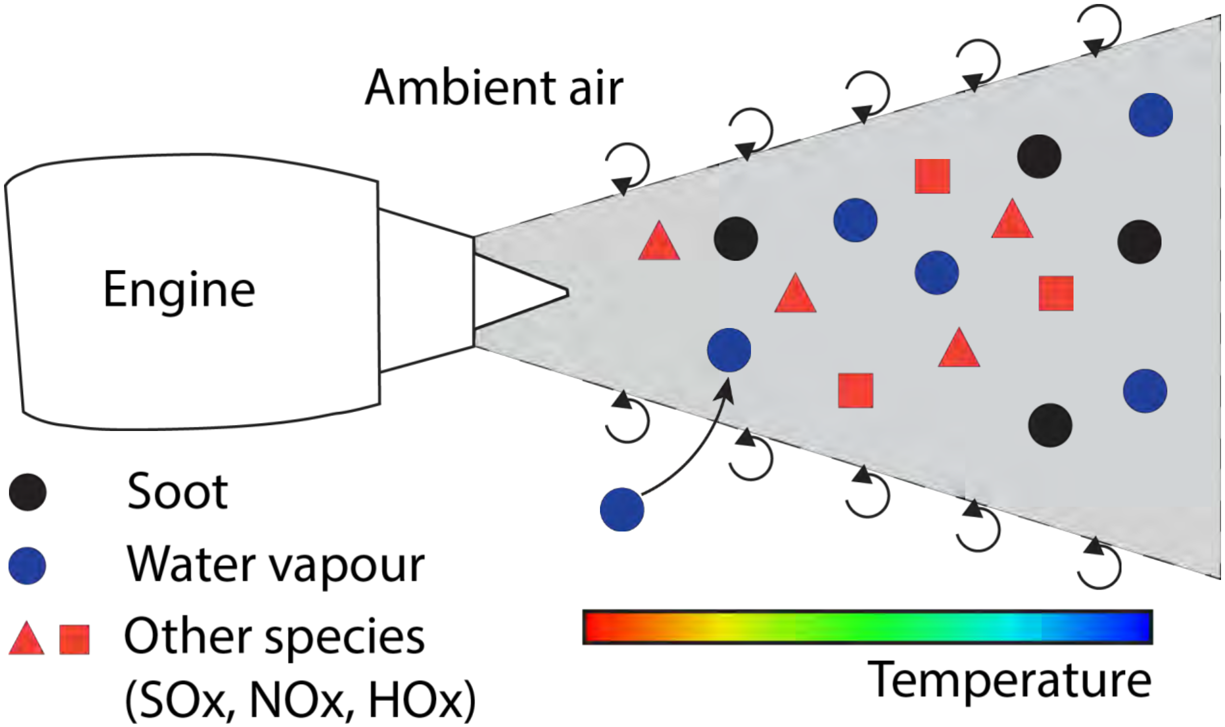
- Development of a **multi-physics** simulation tool:
  - Aerodynamics
  - Plume's chemistry
  - Microphysics

  } Coupling processes

- Taking into account a **realistic geometry** of a commercial aircraft

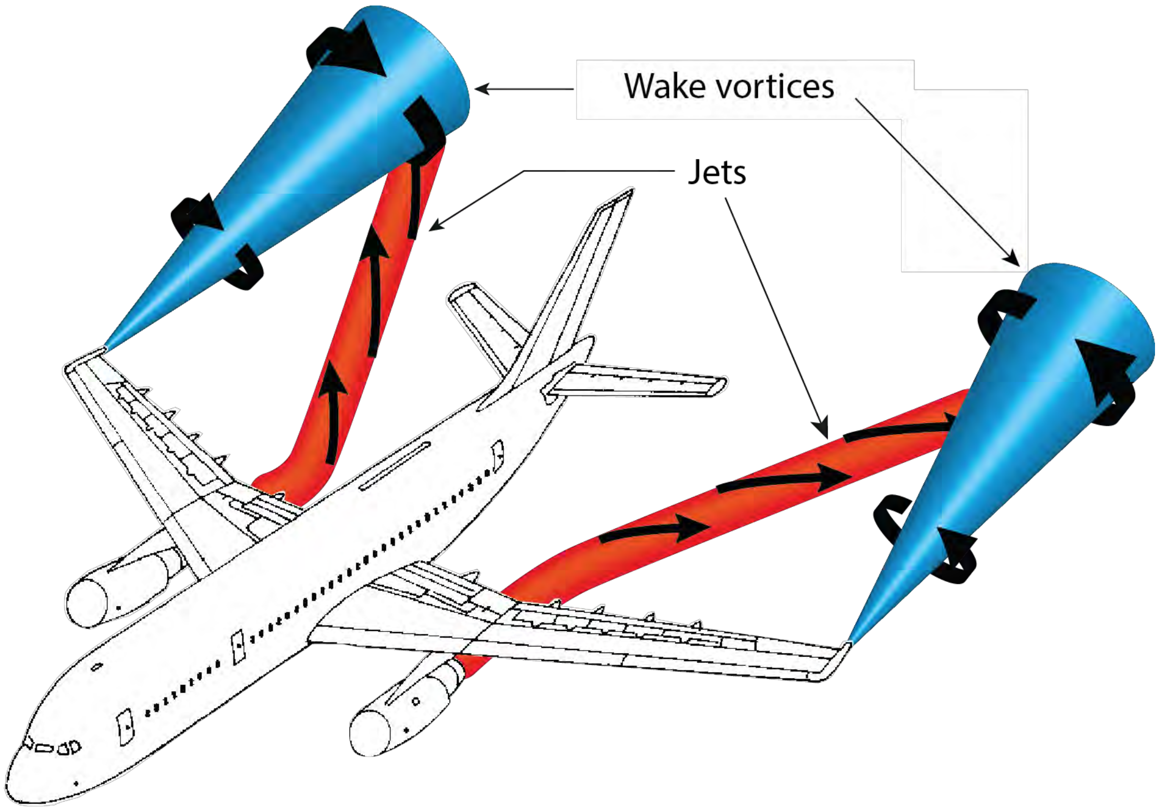
Models description

Engines emission



Models description

Jet/vortex interaction



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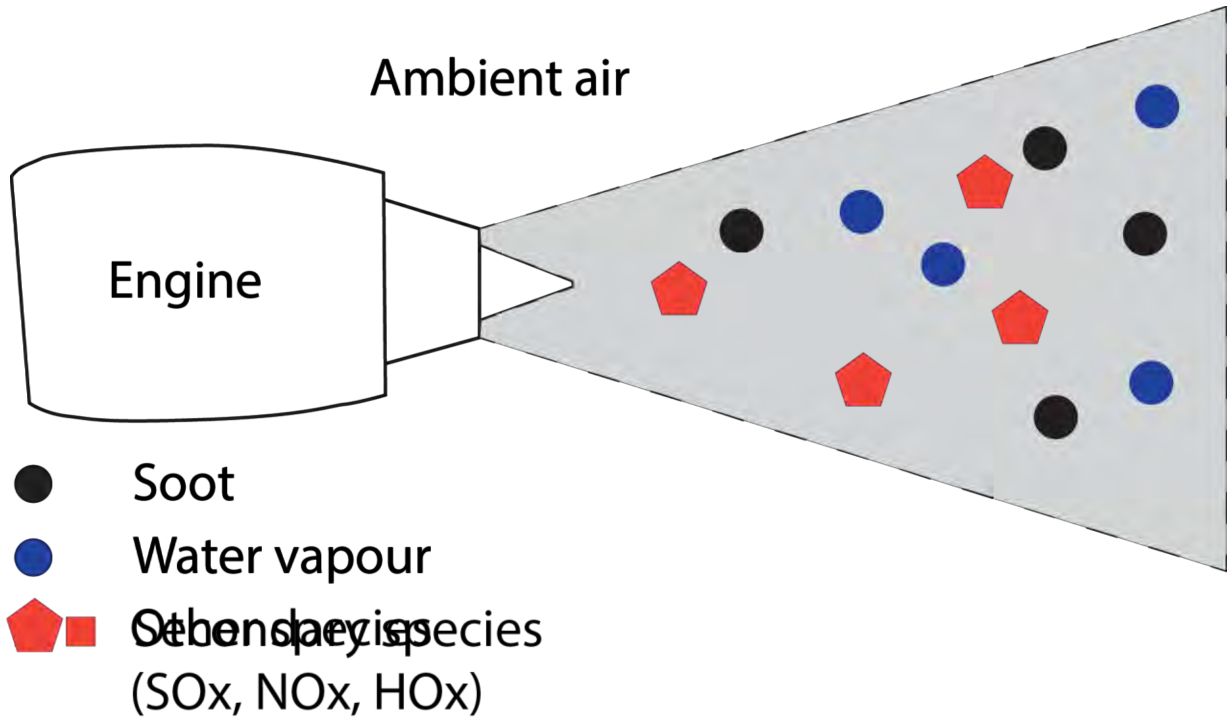
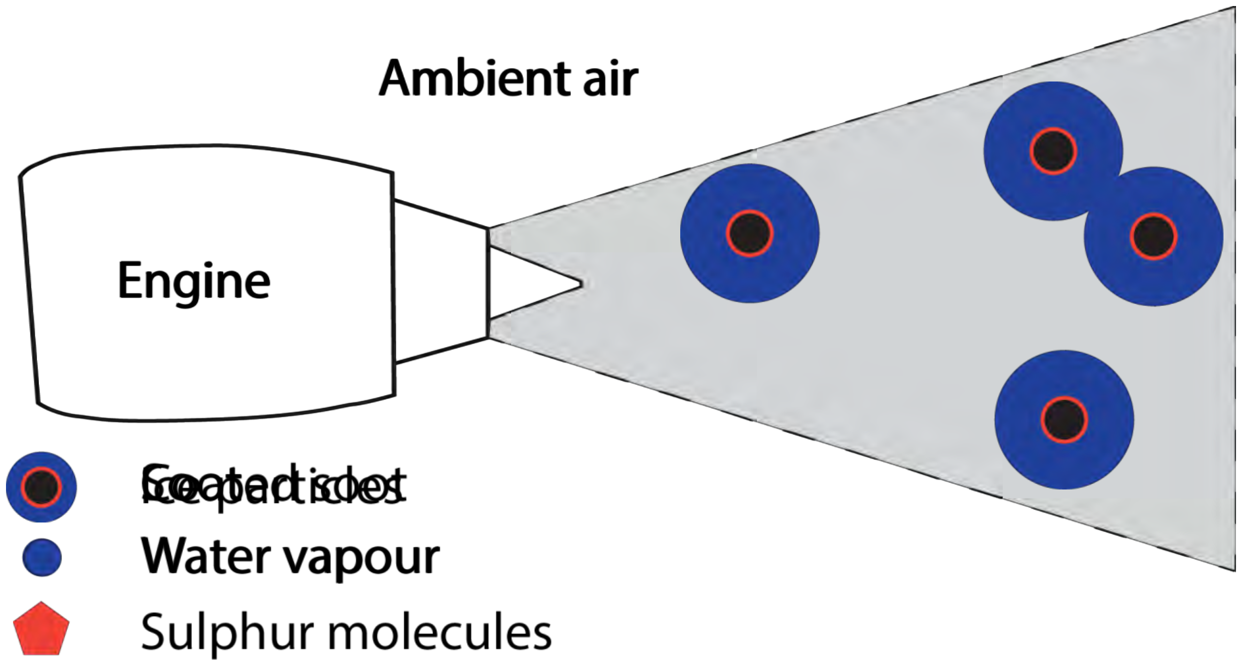
Models description

Chemical processes



Models description

Microphysics processes



Models description

Aerodynamic models

- **Navier-Stokes** equations
- Reynolds Averaged Navier-Stokes Approach
- K-l Turbulence model

Chemical kinetics scheme

- Complex **gas phase chemical reactions mechanism** (Kärcher et al., 1996)
  - 22 species (SOx, NOx, HOx, COx)
  - 60 reactions

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Models description

Microphysics processes

- **Particles transport** using an **Eulerian approach**
  - Passive scalar representing the particle number density N_s

- Soot **activation** by **adsorption of H_2SO_4 and SO_3 molecules**
  - Evaluation of the number of impaction between acid molecules and soot particles
  - **Surface fraction of activated particles**

$$\theta_{ads} = \frac{n\left(\mathrm{SO}_{3\,ads}\right) + n\left(\mathrm{H_2SO}_{4\,ads}\right)}{\sigma_0}$$

  - Hypothesis: **Condensation limited** to the activated part of the soot particle

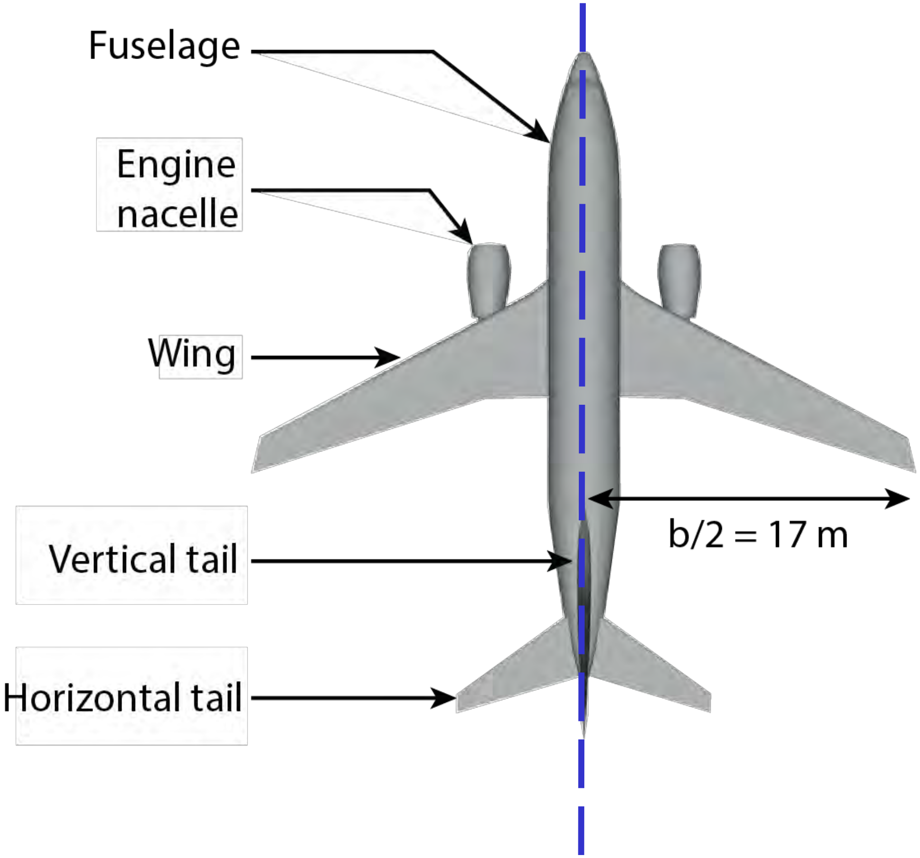
Microphysics processes

- **Condensation/Evaporation** of water onto soot particles:
  - Evaluation of the Condensation/Evaporation rate depending on
    - Water saturation
    - Properties of the ice particles (Diameter, Concentration)

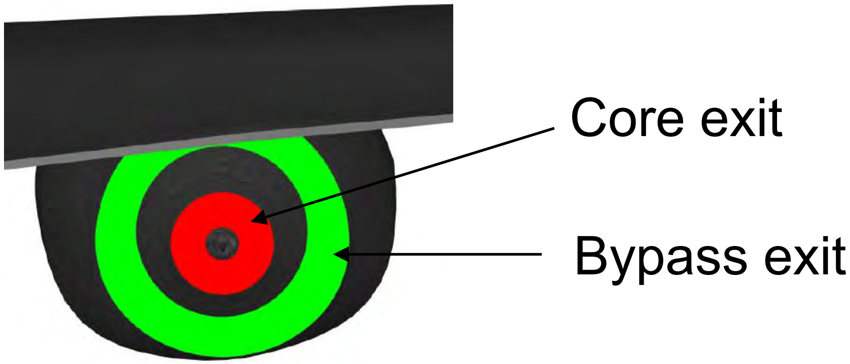
  - Taking into account the Kelvin effect

Geometry

B737 type aircraft



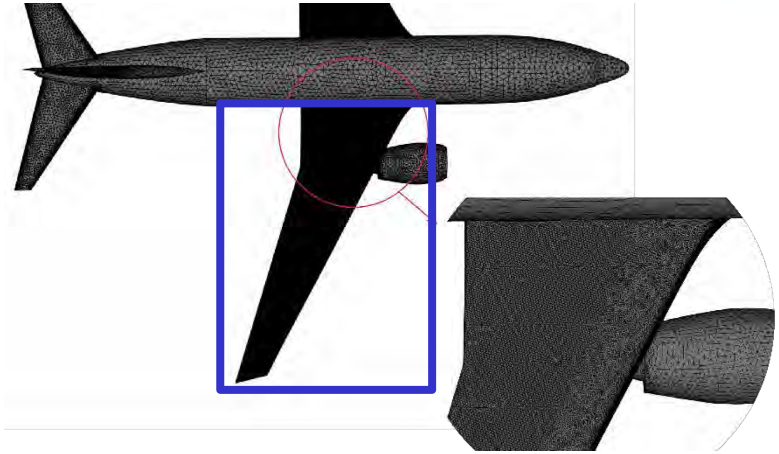
Double-flow engine



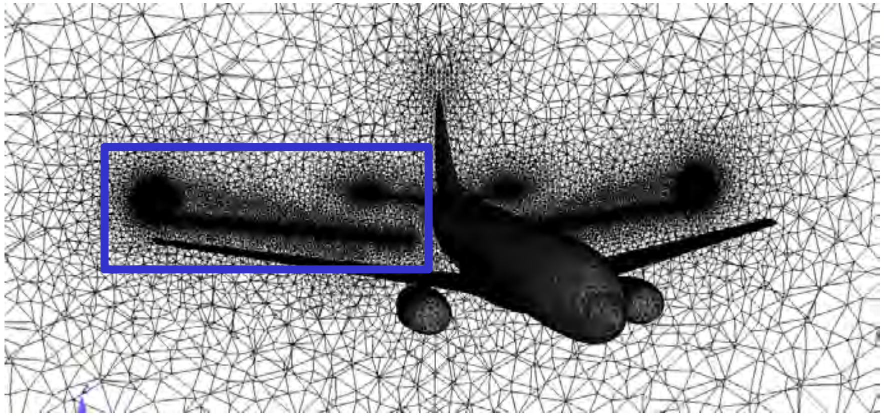
- Using the **symmetry** of the aircraft
- Computational domain
  - **4** wingspans
  - Age of the plume: ≈ 0.5 **s**

Meshes

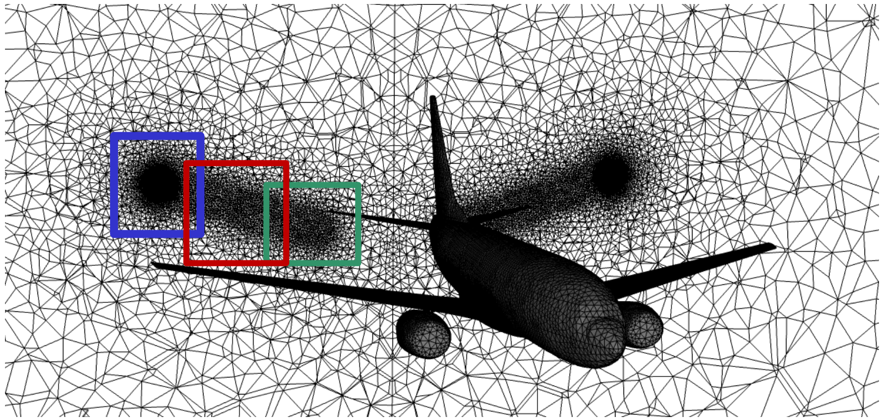
Surface mesh of the aircraft



½ span cross section



1 span cross section

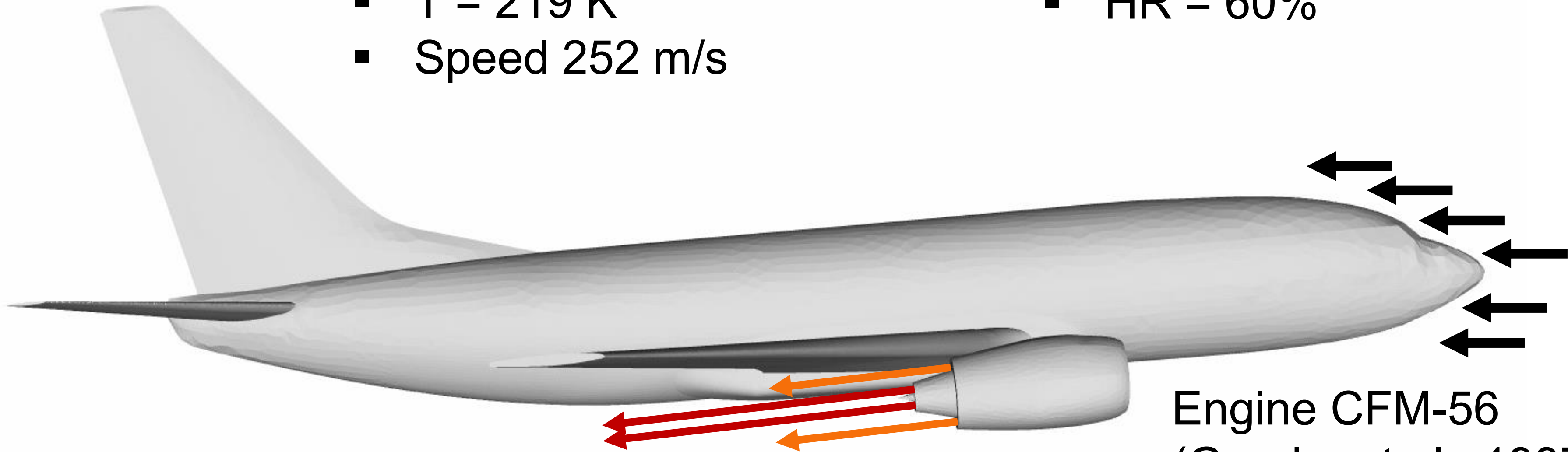


- Area of refined mesh
  - Wake vortices
  - Jet
  - Jet/vortex interaction
- ~ 27 million cells

Initial and boundary conditions

Cruise conditions
- 36000 feet altitude
- P = 24000 Pa
- T = 219 K
- Speed 252 m/s

Ambient air relative humidity
- HR = 60%



Engine CFM-56
(Garnier et al., 1997)

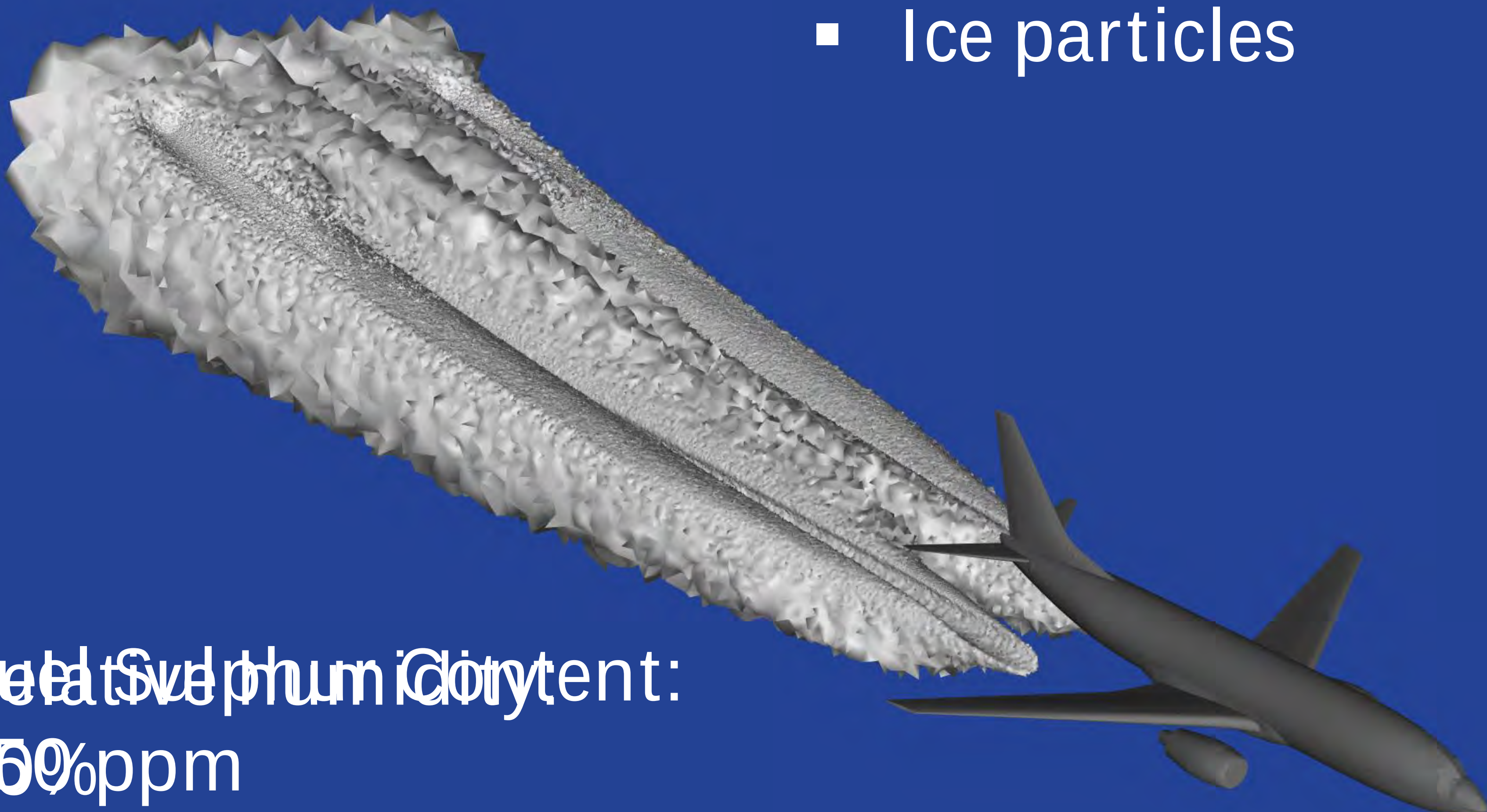
Core flow
- V = 480 m/s
- T = 580 K

- Monodispersed soot
  - $N_s = 10^{12}$ #/m^3
  - r_s = 20 nm
- Exhaust gas

Bypass flow
- V = 311 m/s
- T = 253 K

Simulation results

- Ice particles



Fuel Sulphur Content: 350ppm

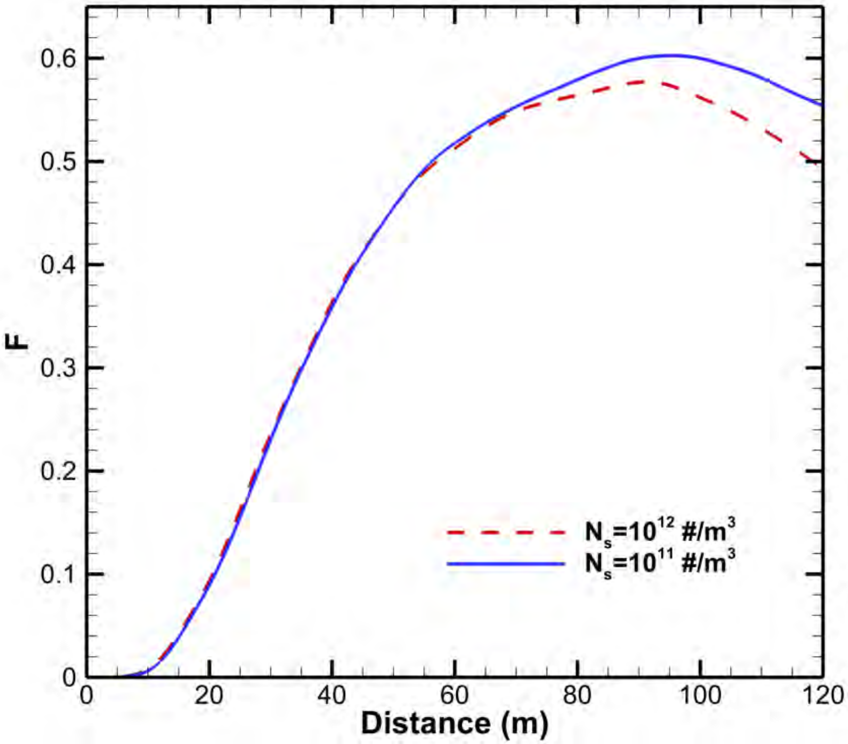
Relative humidity: 60%

Sensitivity study

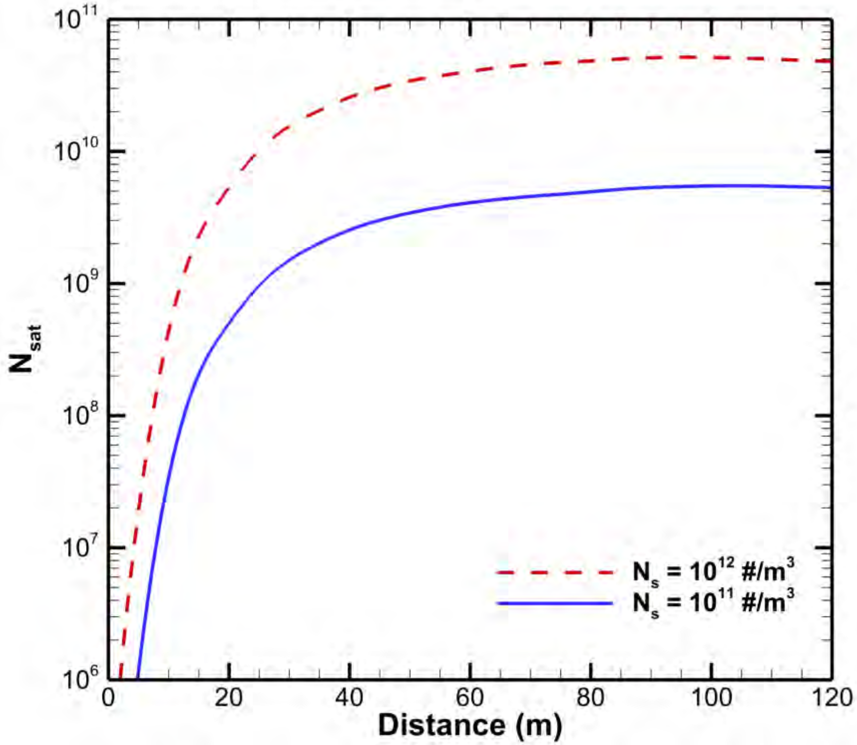
Soot emission concentration

$$N_s = 10^{11} \,/\, 10^{12} \; \#.\mathrm{m}^{-3}$$

Impact of soot emission concentration

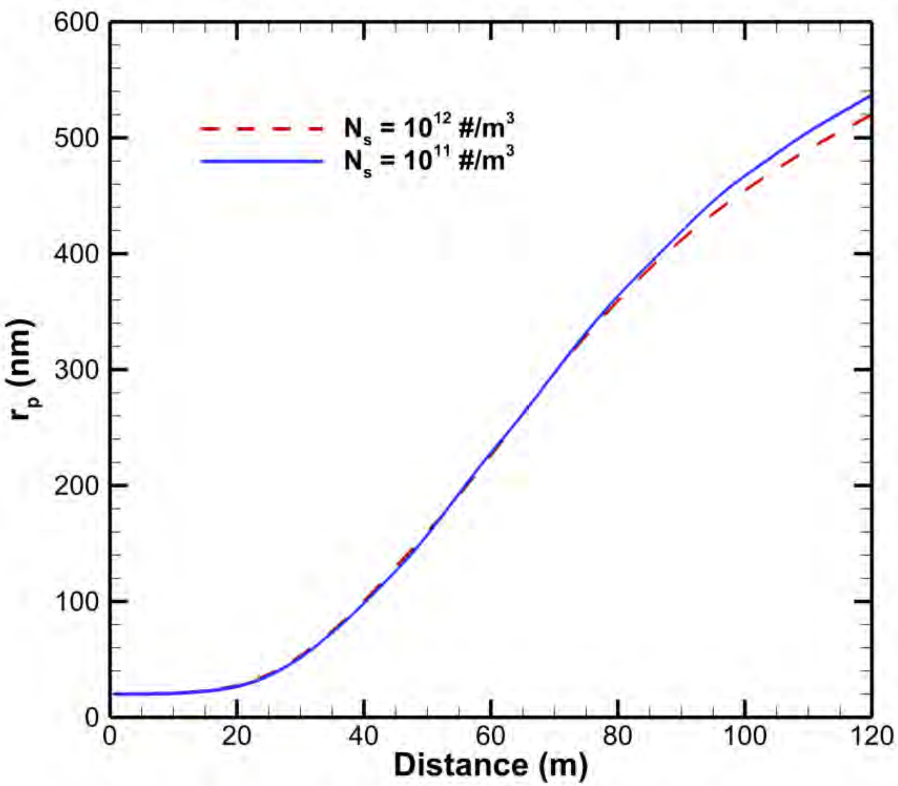


Distance evolution of the fraction of particles in supersaturated area

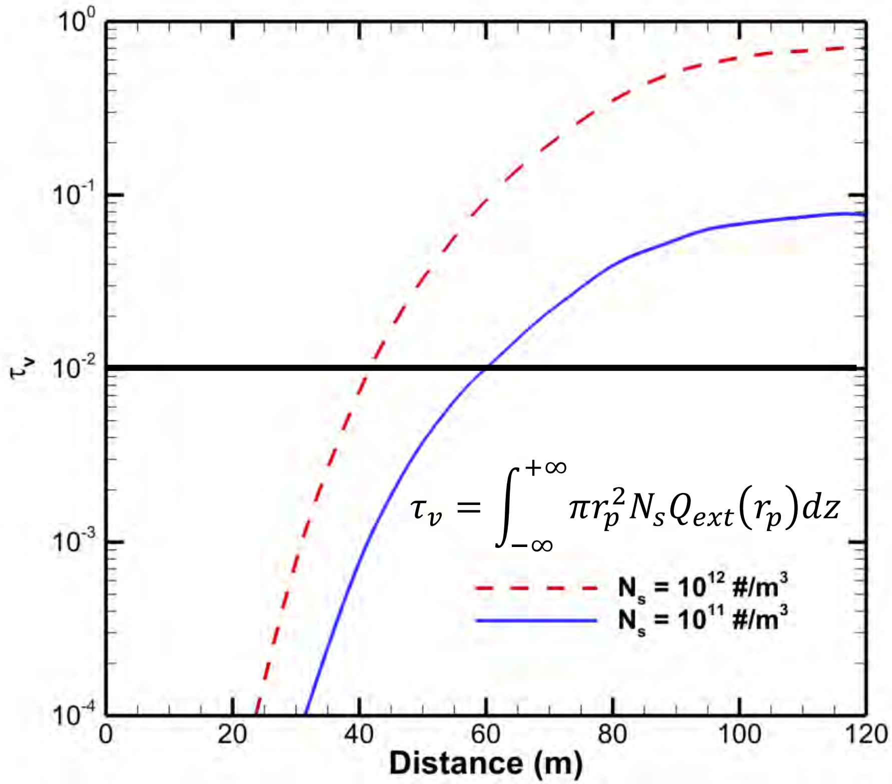


Distance evolution of the number of ice particles

Impact of soot emission concentration



Distance evolution of particles mean radius

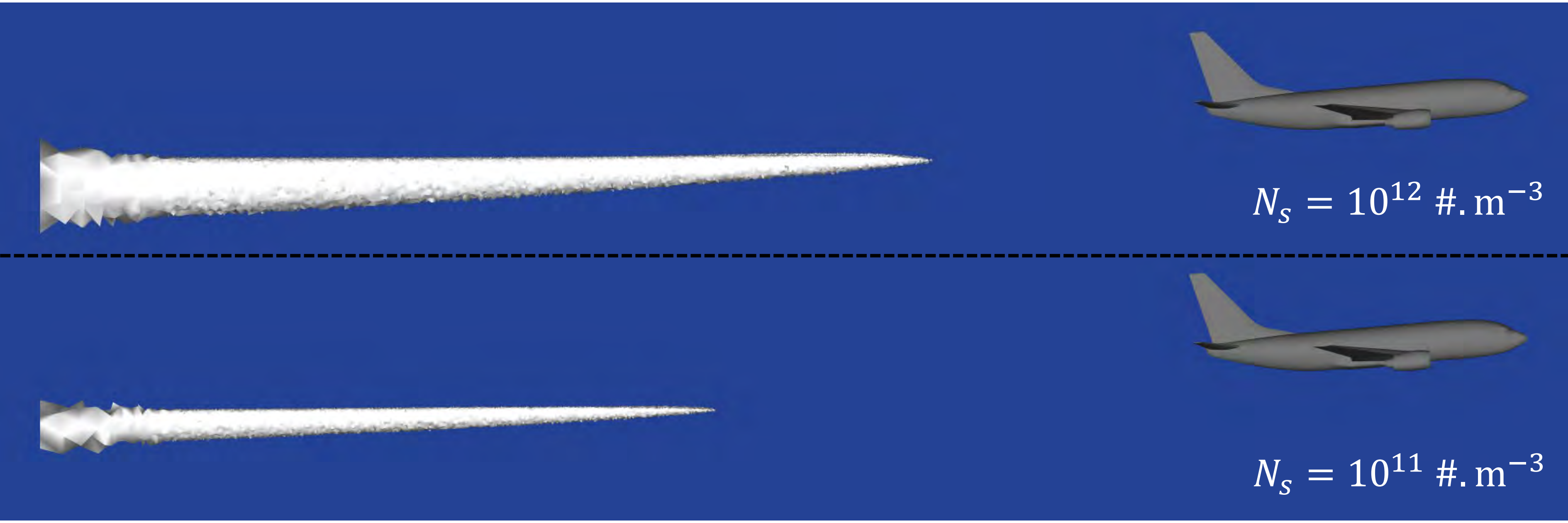


Distance evolution of contrail's optical thickness

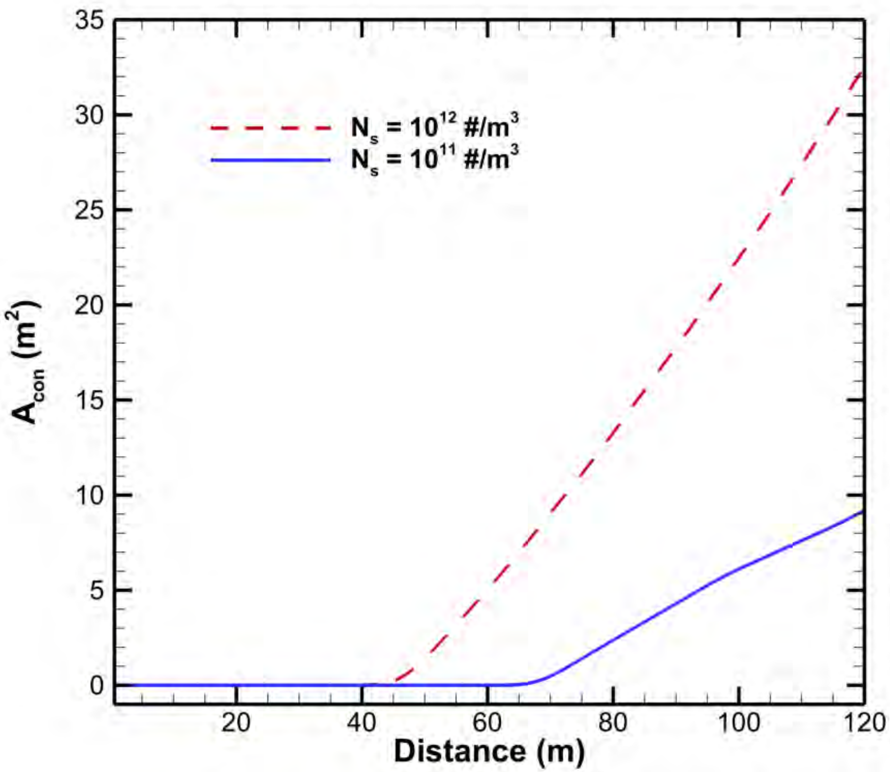
Impact of soot emission concentration

Contrail visibility

Visibility criteria: $\tau_v > 0{,}01$



Impact of soot emission concentration



Distance evolution of contrail cross section area

Sensitivity study results

- Reduction of soot emission indices should lead in the near field to:
  - Smaller concentration of ice particles
  - Less opaque contrail
  - Less spread contrail

Conclusions

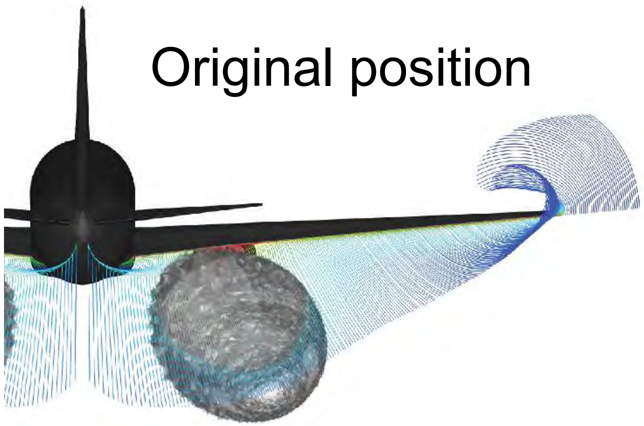
- ✓ Achievement of a **comprehensive contrails formation simulation tool**
- ✓ **First 3D spatial simulation** in the near field taking into account aerodynamic-chemical-microphysics interaction with a **complete aircraft geometry**
- ✓ Analysis of the role of soot emission indices, relative humidity (Khou et al., 2015), and Fuel Sulphur Content (Khou et al., 2016)

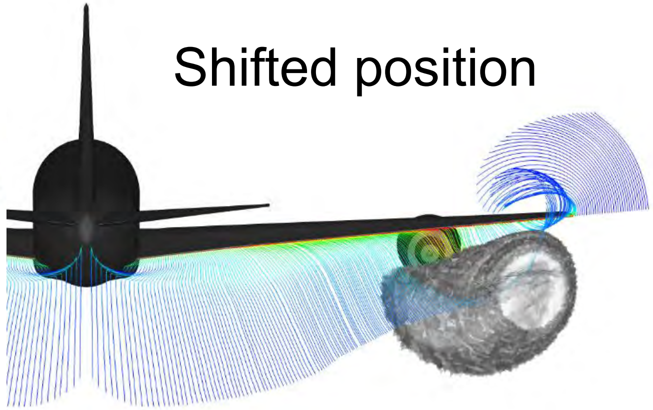
Ongoing work

Geometry impact studies

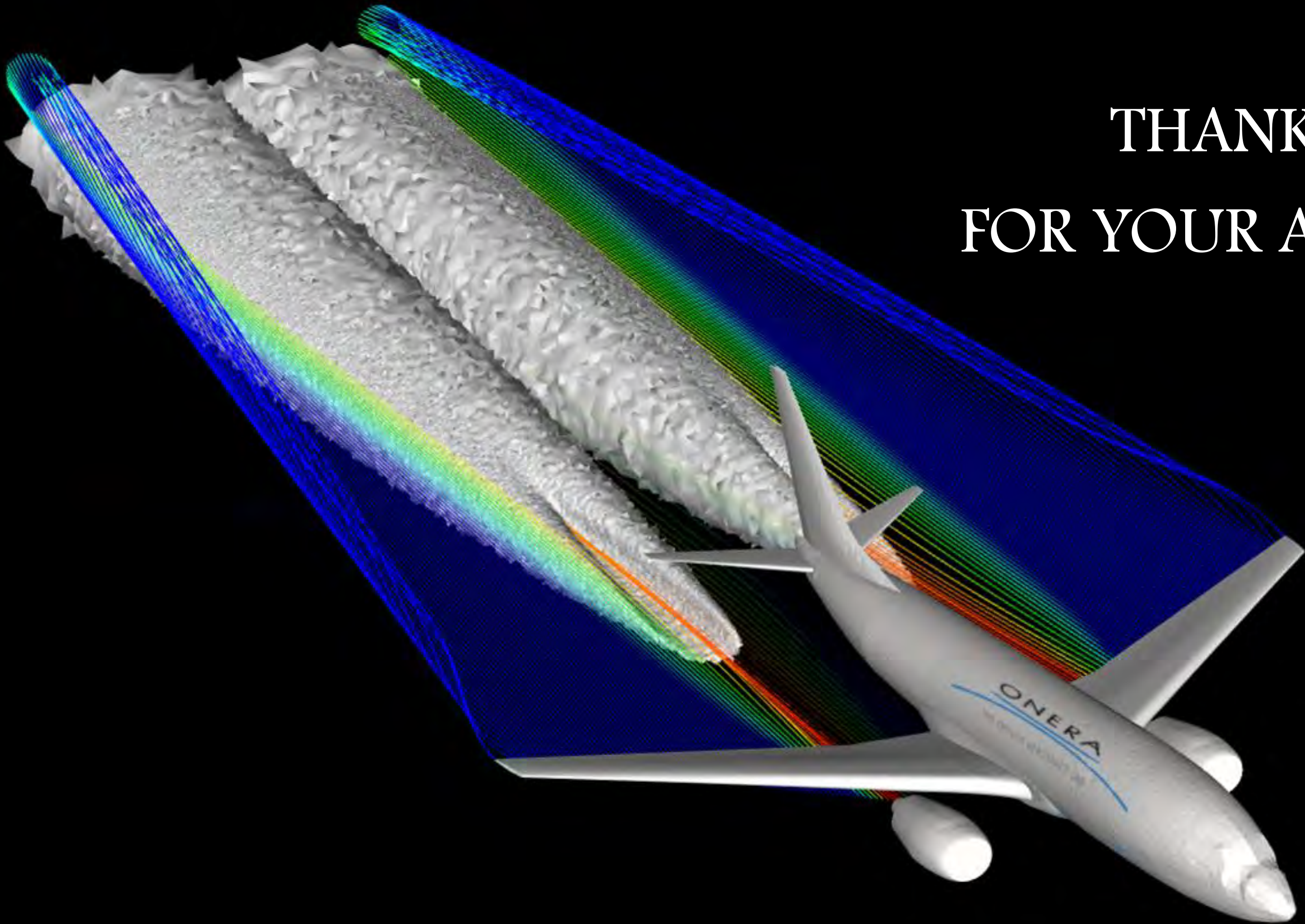
For example:

❖ Engine **position**





❖ **Size** and **type** of jet aircrafts and engines



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