NUMERICAL SIMULATION OF WAKE VORTICES

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INCOMPRESSIBLE NAVIER-STOKES EQUATIONS

- Temporal/spatial simulation behind an A300 Airbus model

- Spatial simulation of trailing vortices in the vicinity of the ground

COMPRESSIBLE NAVIER-STOKES EQUATIONS

- L.E.S. of turbulent jet and wake vortex interaction
INCOMPRESSIBLE NAVIER-STOKES EQUATIONS

Unsteady incompressible Navier-Stokes equations

A Poisson equation for pressure obtained by divergence operator to the momentum equation

SPATIAL DISCRETISATION: 2\textsuperscript{nd} order finite difference schemes

TIME INTEGRATION: 2\textsuperscript{nd} order semi-implicit method
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INCOMPRESSIBLE NAVIER-STOKES EQUATIONS

COMPRESSIBLE NAVIER-STOKES EQUATIONS
EXPERIMENTS
in F2 wind tunnel at ONERA with EADS Airbus partnership

vertical planes surveyed by L.D.V. measurements: \( y/b = 0.5, 1, 3, 5 \) and 9 wing spans

1/100 scale A300 with permeable engine nacelles
span \( b = 0.448 \) m
tunnel velocity \( V_0 = 50 \) m/s
\( \text{Re}_c = 200 \text{,}000 \)

Experimental study:
Ref: L. Jacquin et al.
AIAA 2001-1038
COMPARISON BETWEEN SIMULATION AND EXPERIMENTS OF MAIN VORTEX TRAJECTORY

SIMULATION DOMAIN WITH EXPERIMENTAL GRIDS

Y/b=0.5

Y/b=1.

Cartesian grid: 351x181x201
STREAMWISE VORTICITY

Y/b=0.5

Y/b=1.

Y/b=5.
STREAMWISE VORTICITY AT $y/b=9$. 

EXPERIMENTAL DATA

SIMULATION RESULTS
CONCLUSION

- second experimental section leads to better numerical results, since the extent of the measured domain is larger compared to the section \( y/b = 0.5 \)

- numerical simulations are able to reproduce satisfactorily the topology of the wake at the different locations

- the dynamics of the flow mostly governed by the shear layer roll-up, 2-D simulation yields satisfactory results at smaller costs than fully 3-D simulations
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EXPERIMENTAL SET-UP

Hydrodynamical Tunnel THALES (Onera)

Re_c = 200 000

3 components laser anemometer in cross sections YOZ: X=0.5, 1.1, 1.2 et 1.5 m
EXPERIMENTAL DATA IN THE NUMERICAL DOMAIN (X=0.5)
VERTICAL VELOCITY (X=0.5)

EXPERIMENTAL DATA

NUMERICAL INITIALISATION
SIMULATION PARAMETERS

0.5 < X < 2.5  
-0.25 < Y < 0.25  
-0.1065 < Z < 0.1934  

Grid points: 176 x 1010 x 88  
\( \Delta y/10c = \Delta z/10c = 10^{-4} \)

Boundary conditions

Lateral walls: extrapolation  
Horizontal walls: Dirichlet  
Inflow: Dirichlet  
Outflow: extrapolation
ISO-VORTICITY LINES $\Omega_x b/U_0$
VORTEX TRAJECTORY

simulation

O O O O O exp. data
STREAMWISE VORTICITY AT DIFFERENT SECTIONS

Contra-rotating vortex
CONCLUSIONS

- Treatment of experimental data in order to initialize the numerical domain

- Boundary conditions take into account the conveyor belt

- Vortex trajectories show some discrepancies with experimental results.

- Main vortex rebounds on the lower wall with the ejection of a contra-rotating vortex
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Numerical and experimental studies on the mixing of engine jets with aircraft wake vortices

- Brunet et al. (1999) experimental results of a hot jet behind a generic wing planform.
- Fereira Gago et al. (2002) 3-D temporal simulation to study interaction between a jet and a vortex wake.
- Labbé et al. LES to study the influence of the jet position on the vortex.
UNSTEADY COMPRESSIBLE NAVIER-STOKES EQUATIONS

**SUBGRID MODELING**
- hybrid model:
  - similarity model (Bardina *et al.*)
  - mixed scales model (Sagaut *et al.*)

**Spatial derivatives:**
- convective terms: $6^{th}$ order compact finite-differences
- diffusive terms: $2^{nd}$ order finite-differences

**Time integration:** $3^{rd}$ order Runge-Kutta method

**Boundary conditions:**
- streamwise direction: periodic conditions
- lateral boundaries: non-reflexive conditions (Thompson)
STEP I : HOT JET SIMULATION

positive/negative vorticity $\Omega_z [-3,3]$  

passive scalar iso-surface $Z=0.4$

$T=20$

$T=50$
STEP II : interaction with a Lamb-Oseen vortex ($Y/b=0.5$)

Re=$\frac{\Gamma_c}{2\pi \nu}=5000$
Mach=0.2
$d_c=0.012\text{m}$
$U_{\Theta_{\text{max}}}=9\text{ms}^{-1}$
$\Delta_{x,z}=0.15\ d_c$
Grid points: $163\times61\times163$

D=distance between jet and wake vortex
3 cases : D, D/2 and D=0
Experimental position

Jet closer to the vortex

Jet in the vortex center

Longitudinal component of vorticity $\Omega_y$
Jet: azimuthal vorticity (blue: 0.4, red: -0.4); vortex: iso-surface of vorticity $\Omega_y^{+2}$ in yellow.
Turbulent kinetic energy

PASSIVE SCALAR

\( \langle Z'Z' \rangle \ Y/b=12.5 \)
CONCLUSION

-Large-eddy simulations have been carried out in two steps:
  I: hot jet development
  II: interaction of the turbulent jet and wake vortex
- the position of the turbulent hot jet is shifted in order to understand
  the mechanisms that contribute to the mixing and the dispersion of engine exhausts.

- the turbulence induced by the jet field interacts with the vortex,
  resulting in large-scale structures generated around the vortex.

- Distributions of passive scalar (initially included in the jet) cannot enter
  the vortex core for the cases $D$ and $D/2$, but injected in the vortex ($D=0$)
  the value of the passive scalar remains high and cannot get out of the vortex core.