Aerodynamic analysis of aircraft at high sideslip crosswind gust
&
Simulation of hydroplaning effects

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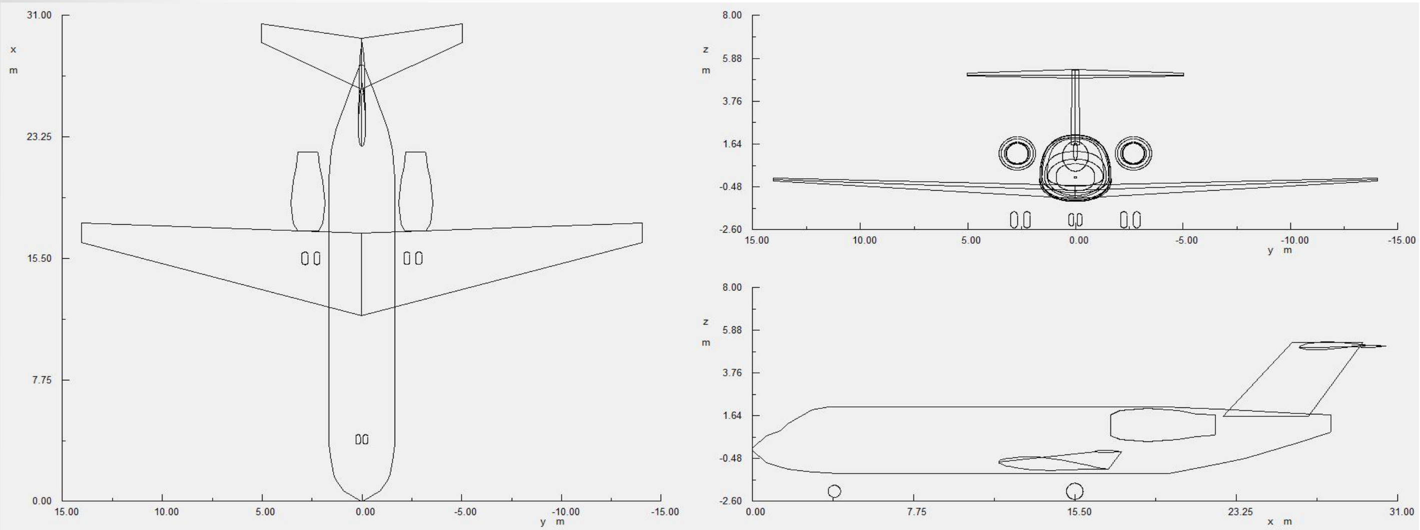
Contents

Context – Part 1 – Crosswind Aerodynamics

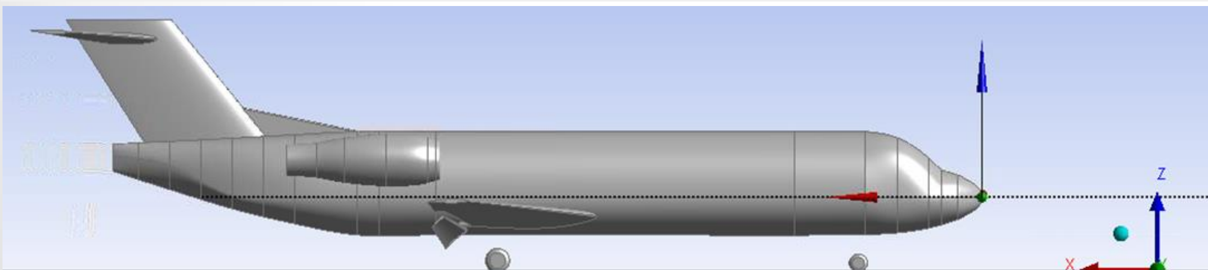
- The problem that is developed within task 3.1.2 is the analysis of aerodynamic characteristics under crosswind conditions, during landing for a Fuselage Mounted Engine aircraft configuration
- The evaluation of the longitudinal and lateral aerodynamic coefficients (in body axis) at high sideslip angles (up to 45°) are being treated.
- Landing configuration for high lift devices.
- Landing gear is in contact with the ground in all 3 points.
- Ground effects were taken into account .
- The results of the CFD analysis will be used, as input data, in Task 3.1.4, dynamic interaction between aircraft/pilot and ground reactions.

Aircraft model

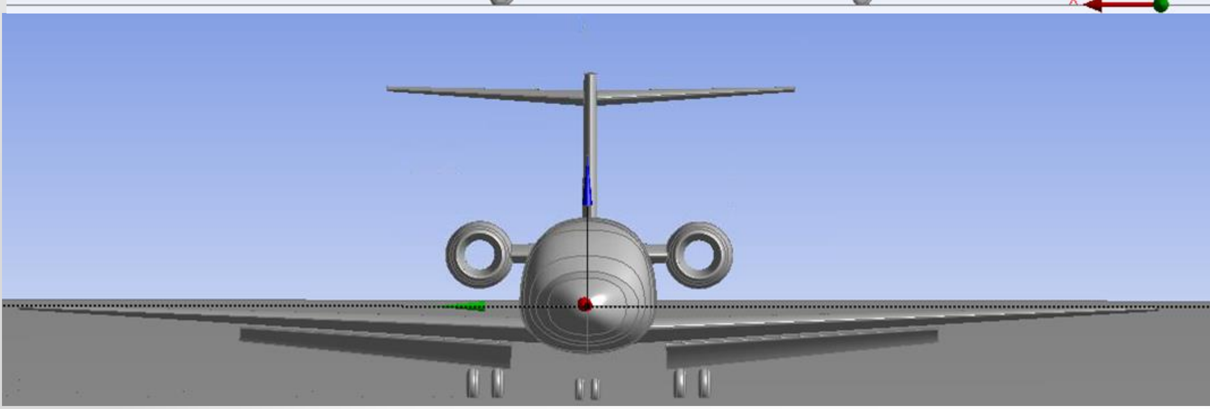


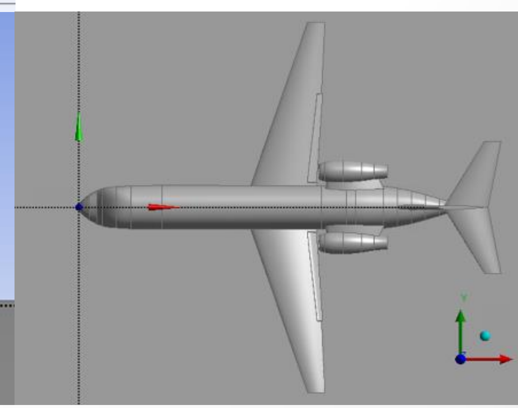
Reference Values

Area (m2)	91
Density (kg/m3)	1.225064
Enthalpy (j/kg)	292594.5
Length (m)	3.5
Pressure (pascal)	101325
Temperature (k)	288.15
Velocity (m/s)	71.99563
Viscosity (kg/m-s)	1.7894e-05
Ratio of Specific Heats	1.4



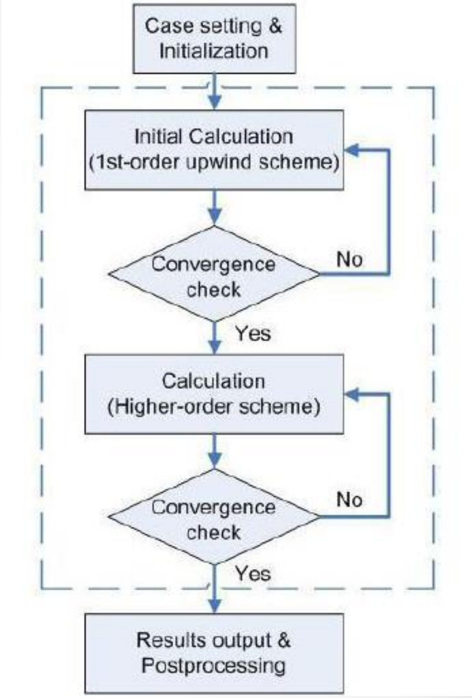
- Constructed in Advanced Aircraft Analysis 3.0 from data available in the literature for similar aircraft types!
- Note the Reference System !

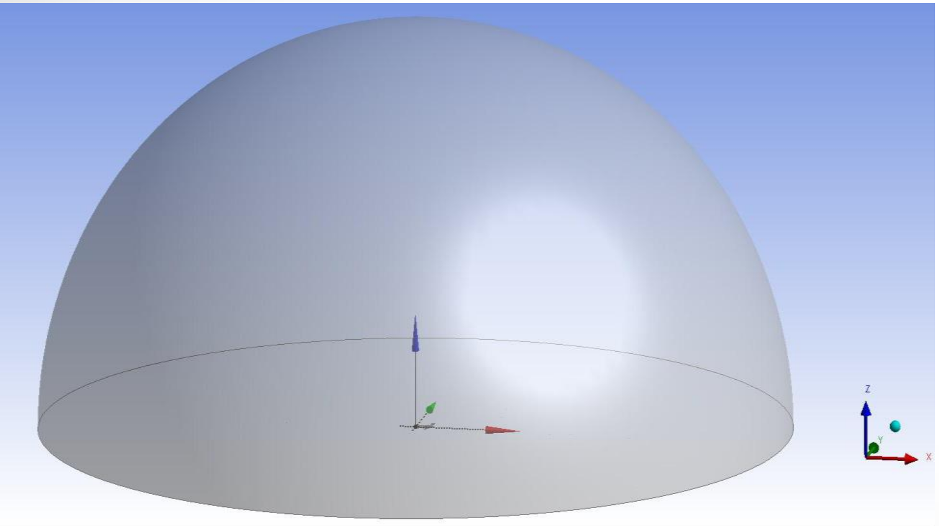


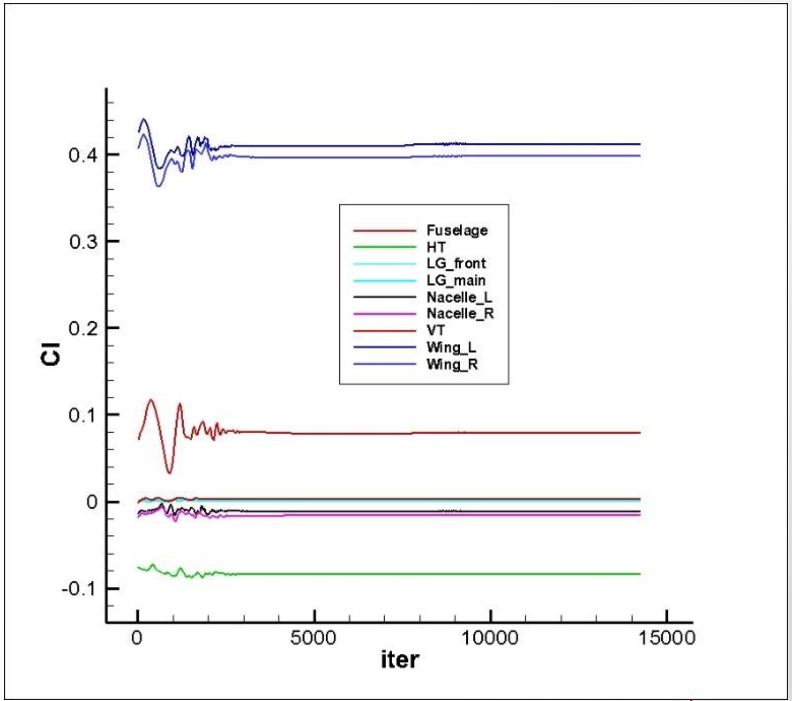


CFD methodology.

- **Ansys Fluent v16** :
  - Density based flow solver – compressible flow.
  - Steady state.
  - RANS – Realizable k-epsilon turbulence model - **Suitable for complex flows with large strain rates (rotation, separation).**
  - Non-equilibrium wall treatment - **are recommended for use in complex flows involving separation, reattachment, and impingement** where the mean flow and turbulence are subjected to pressure gradients and rapid changes. Has a two layer concept which makes it y+ insensitive!
  - Roe scheme for convective fluxes.
  - Second-Order Upwind reconstruction.
  - Production limiter option is activated.
- **Numeca Hexpress v4** - hexahedral unstructured meshing tool.
- Flow domain in a sphere with 500m radius.
- Reynolds number based on MAC is approx. 17e6.







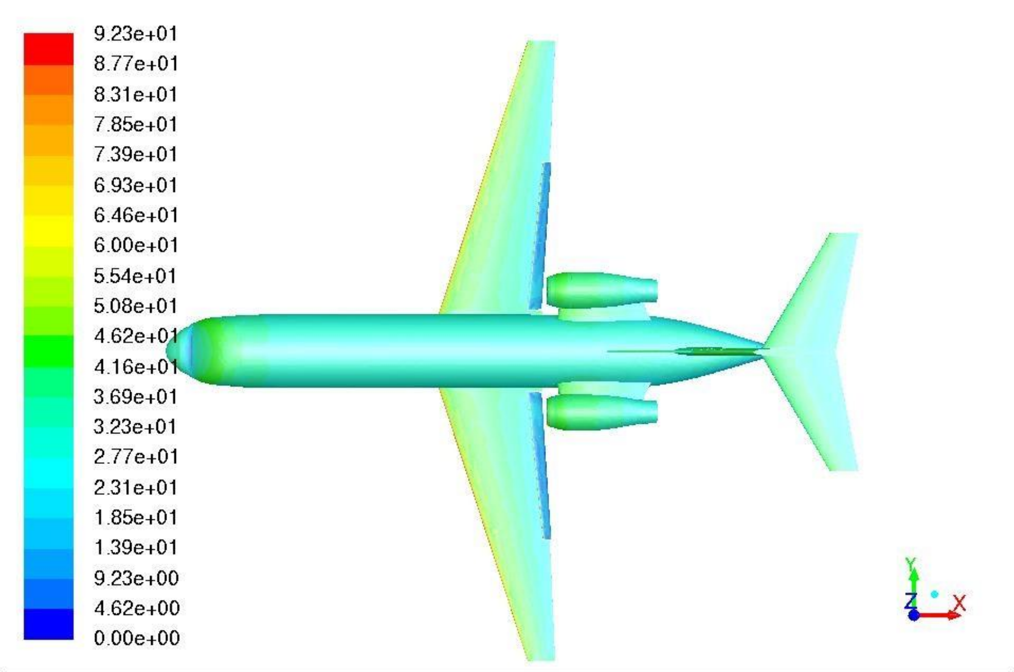
Mesh; grid independence

- The mesh resolution is kept the same for the near wall region.
- 3 mesh levels for grid convergence studies with 1.5 element size factor:
    - Coarse (11Million Cells),
    - Medium (14 Million cells),
    - Fine (24 Million cells)
- The smallest surface element is approx. 5mm - Fine, ; 7.5mm - Medium, 11.25mm – Coarse.
- Y+ value targeted to be around 35, and a stretching factor of 1.2.
- Refinement over LE, TE, control surfaces and wake.

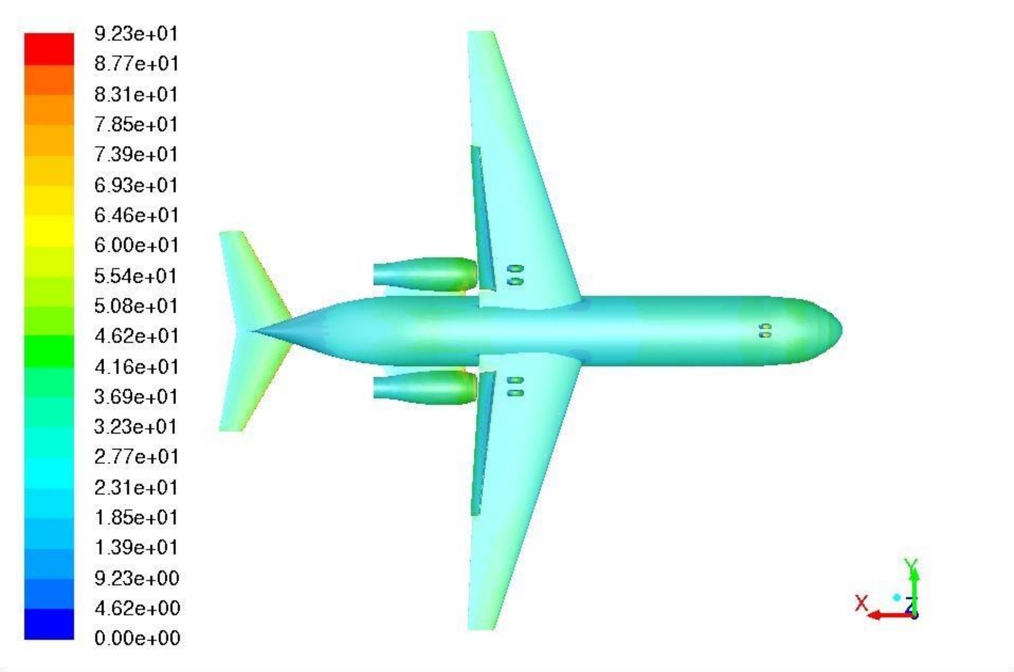
Mesh; grid independence (cont.)

y+ distribution for AoS = 0°.

- y+ varies on the surface, the need for a y+ insensitive treatment is justified.
- y+ is in the log-law/fully turbulent region of the boundary layer for most of the surface.

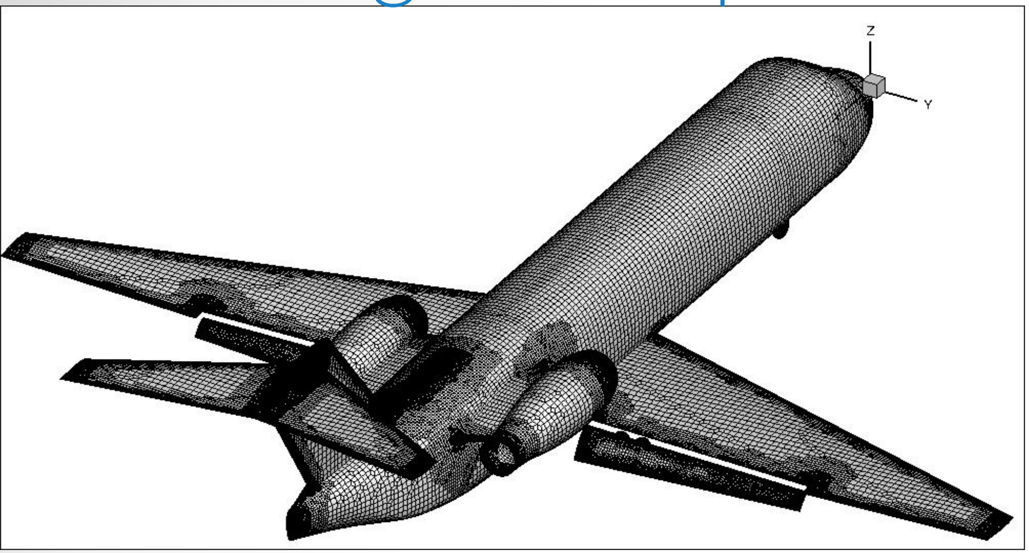


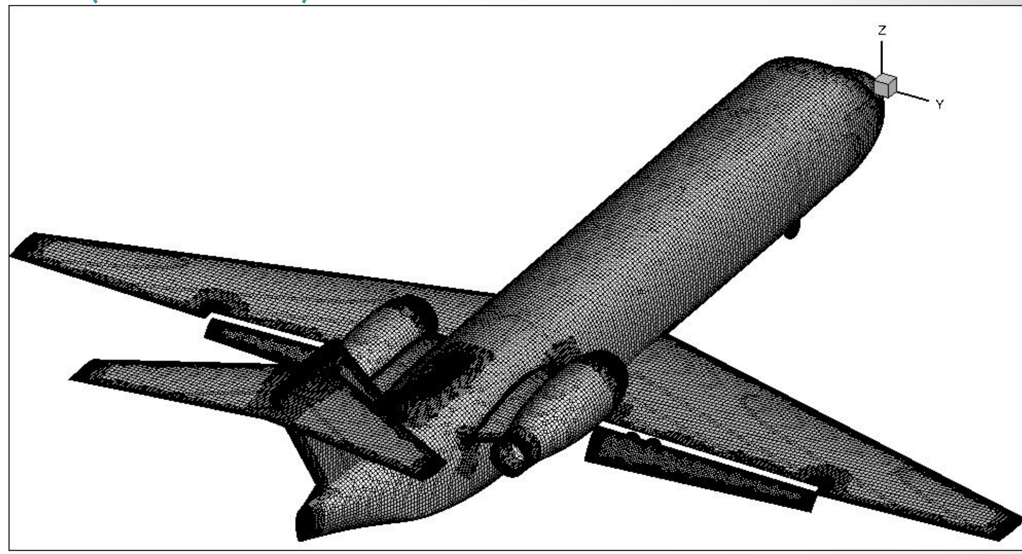
Contours of Wall Yplus

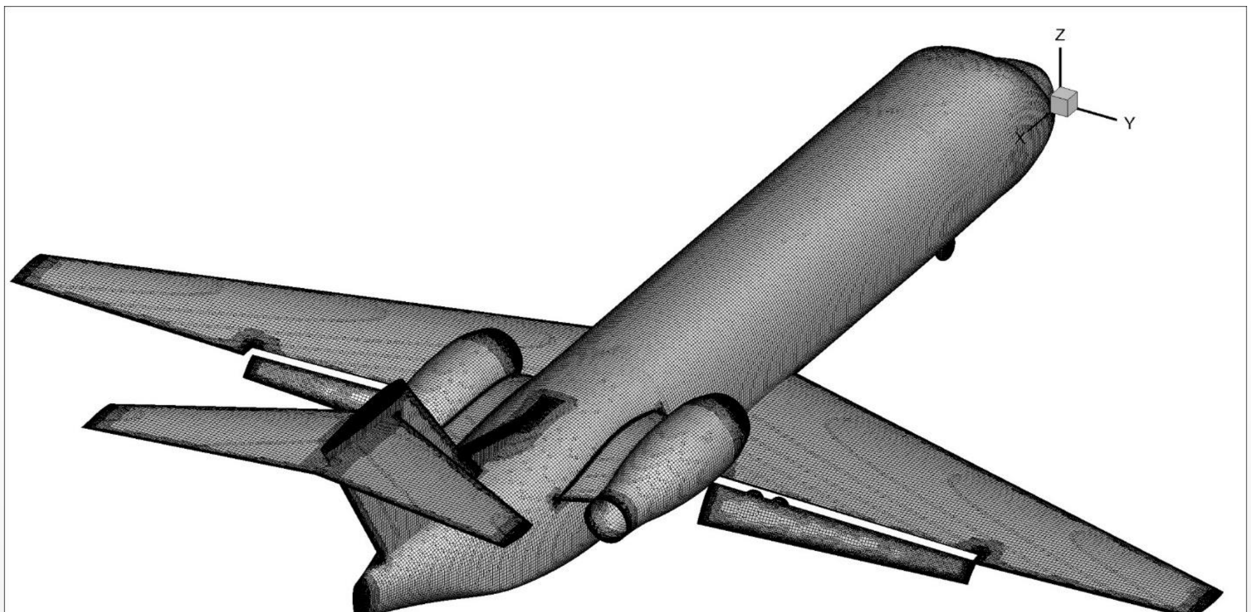


Contours of Wall Yplus

Mesh; grid independence (cont.)

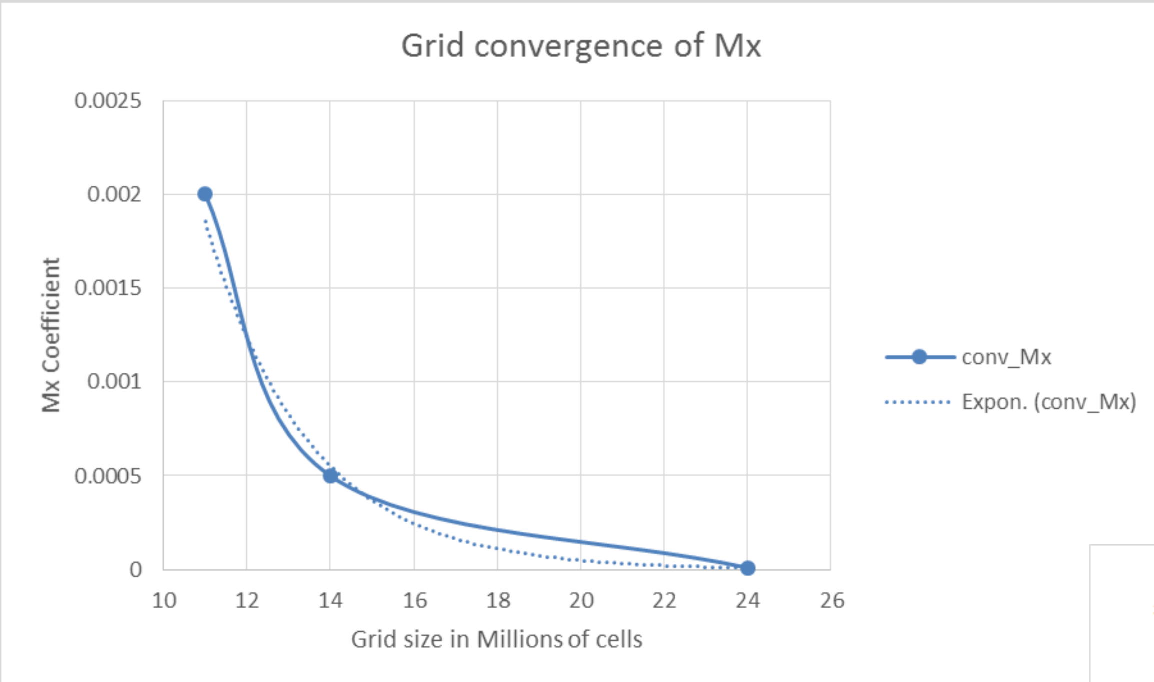






Fine Grid

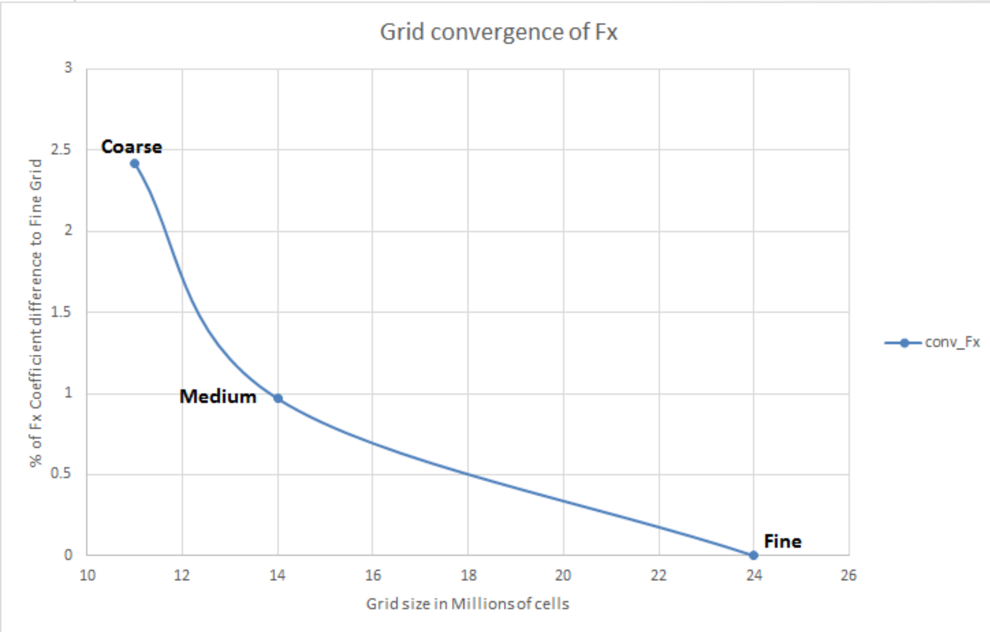
Mesh; grid independence (cont.)



Grid Independence:

- No experimental data available for validation.
- Performed only for AoS = 0°.
- Roll and Drag are used to check the flow and mesh symmetry and for mesh convergence!

- **Fine grid is chosen!**



Results- non-dimensional values

All aerodynamic coefficients are given in body axis reference system and are computed with the following:

$$cF = \frac{Force}{0.5\rho_{ref} S_{ref} V_{ref}^2}$$

$$cM = \frac{Moment}{0.5\rho_{ref} S_{ref} l_{ref} V_{ref}^2}$$

CG location
X = 14.05m
Y = 0 m
Z = 0 m

Wing Area

MAC

Reference Values

Area (m2)	91
Density (kg/m3)	1.225064
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Pressure (pascal)	101325
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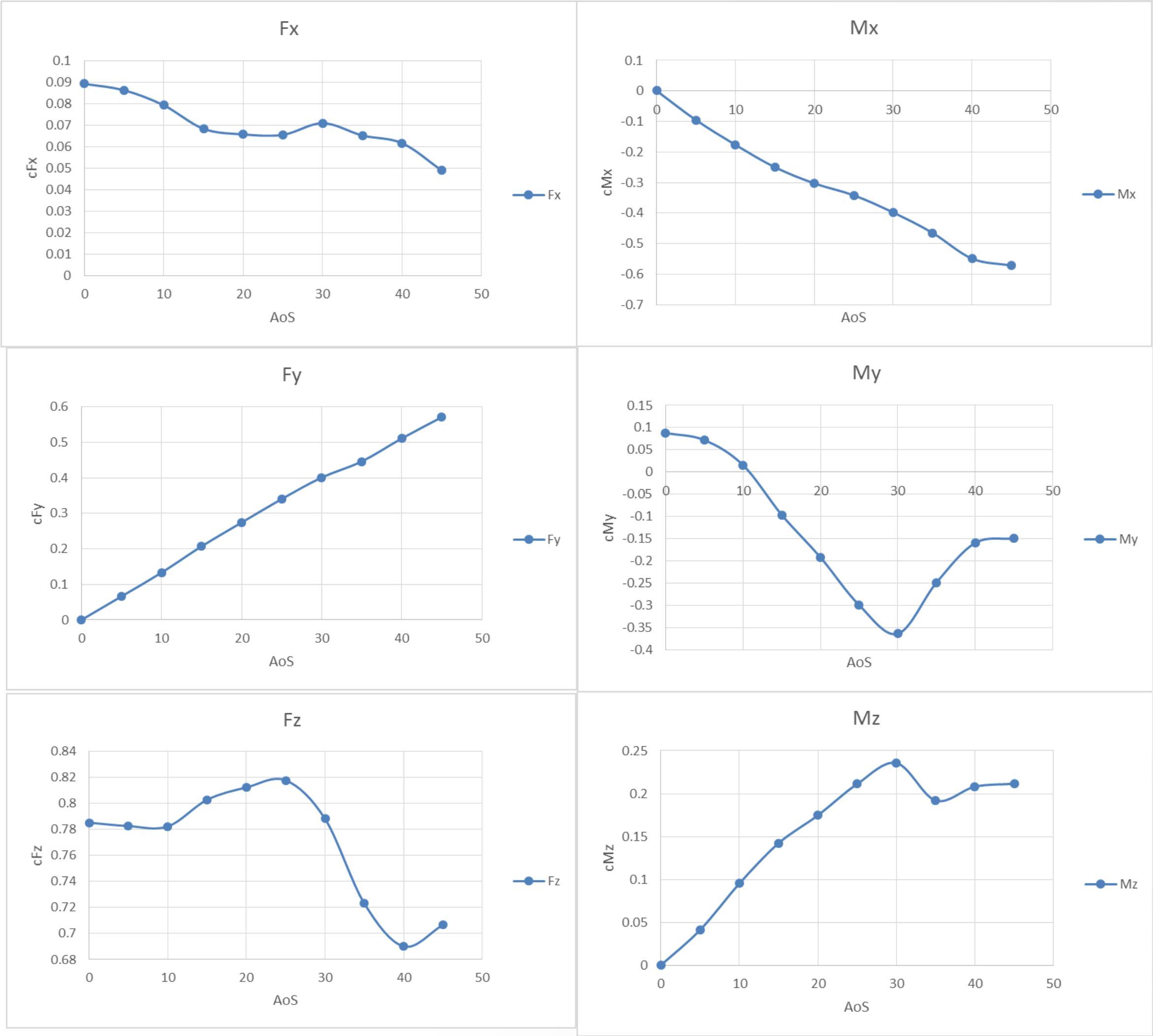
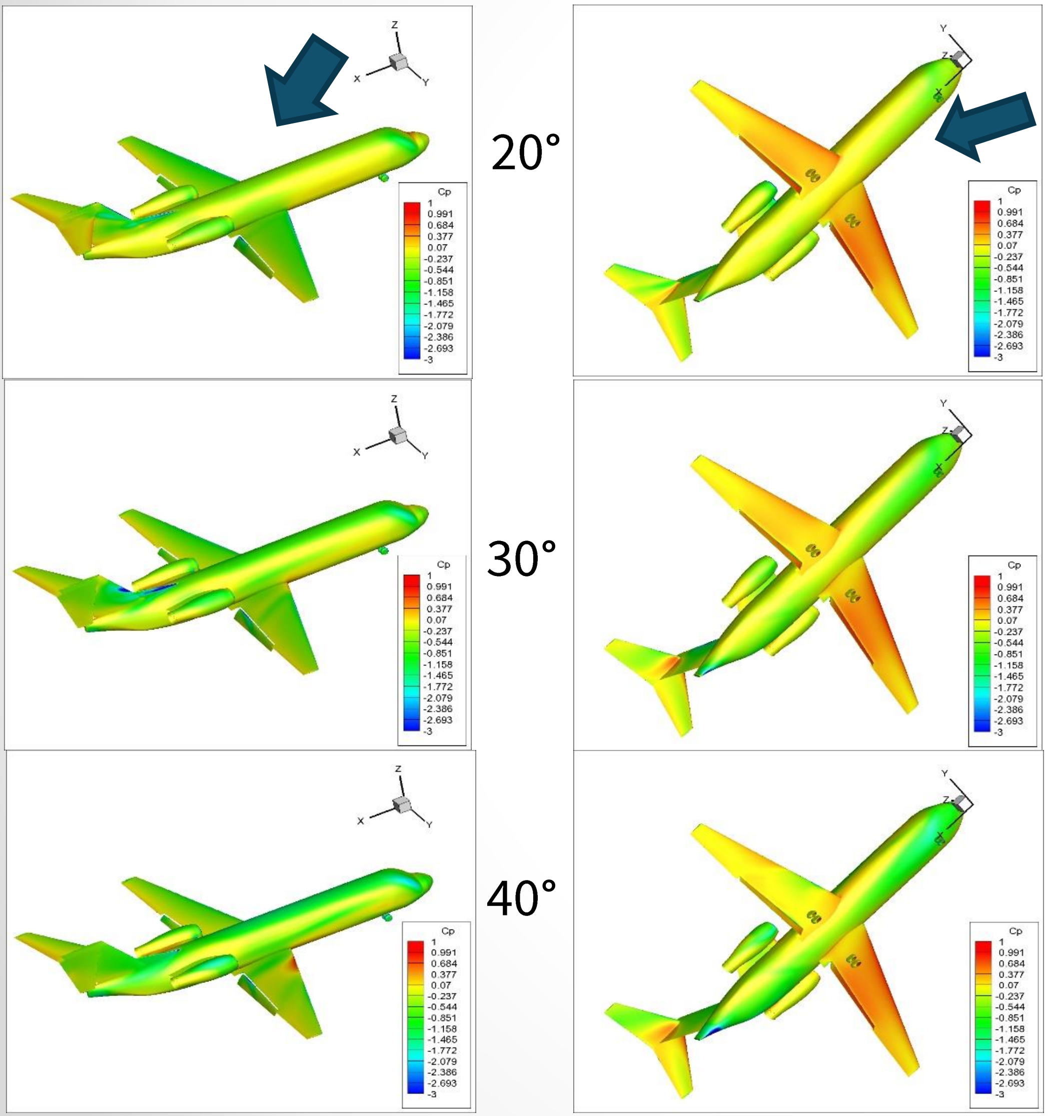
Ratio of Specific Heats	1.4

Results- aerodynamic coefficients

- Linear behavior for **Lateral Force** up to AoS = 45°.
- Linear behavior for **Yaw** moment up to AoS = 30°. CFD simulation show a strong flow separation for VT and fuselage at a higher AoS, more that 30°
- **Pitch** - minimum and AoS = 30°, due to VT stall and shielding of the HT. Since the wake of VT affects the suction side of the HT the increase in Pitch is severe and affects the reaction forces on the LG.
- **Axial Force** - plateau and rise at AoS = 30° due to drag increase associated with stall of the VT.
- **Lift** - increase towards a maximum at AoS = 25° (due to the shielding of the HT by the VT) and afterwards a drop (due to the detached flow on the downstream- right wing at AoS ≥ 25°)
- **Roll** - linear up to AoS = 40°, then flattens due to the flow on the right wing being in the detached wake of the fuselage.



Results- Yaw breakdown



Observe how:

- the VT tail stall affects the HT
- the fuselage's wake and front LG affect the right wing
- The nacelles are always stabilizing with respect to Yaw

A/C component	cMz_20deg	cMz 30deg	cMz_35deg
fuselage	**-0.2655**	**-0.3526**	**-0.3891**
ht	0.0256	0.0164	0.0156
lg_front	-0.0060	-0.0088	-0.0106
lg_main	0.0019	0.0025	0.0029
nacelle_l	0.0043	0.0052	0.0058
nacelle_r	0.0338	0.0397	0.0450
vt	**0.3651**	**0.5174**	**0.5003**
wing_l	0.0599	0.0562	0.0535
wing_r	-0.0443	-0.0401	-0.0312
Destabilizing yaw moment contributiont	-0.3158	-0.4016	-0.4310
Stabilizing yaw moment contributiont	0.4906	0.6372	0.6231
Total Mz moment coefficient	0.1748	0.2357	0.1922

Conclusions

The importance of a study of the A/C aerodynamics in crosswind at high sideslip and ground effect is related to a confident dynamic simulation of the airplane mechanics in ground rolling travel at landing.

- This report is a complex research activity which aims with practical results for the aerodynamic coefficients in crosswind and ground effects.
- The mesh used in CFD simulation were calibrated with specific methods for the results to be “stable” and converge to a realistic solution.
- The aerodynamic forces and moment coefficients were given in an A/C body system that is clearly presented in the report. The specific notation of the coefficients is also presented in the study.
- The lateral stability of the FME is considered to be normal for the whole span of AoS studied, proved by the value and the behavior of the lateral aerodynamic coefficients.
- The influence and interference of different aircraft components is analyzed for the most relevant aerodynamic coefficients.
- Yawing moment breakdown at high sideslip angles gives confident information about specific flow separation.

Context – Part 2 - Hydroplaning

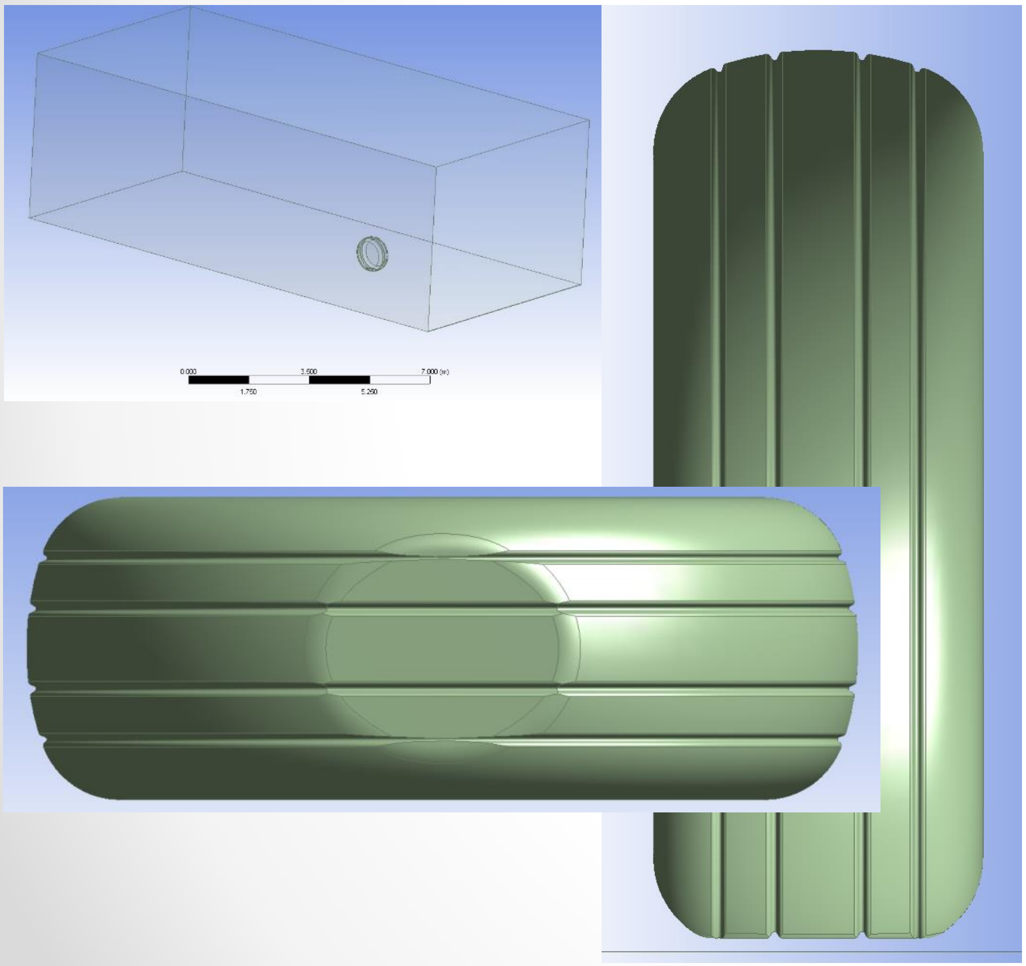
- The problem that is developed within task 3.2.2 is the analysis of wheel friction coefficient due to water layer depth.
- CFD research on the hydroplaning effect will take into account three water layer depths: 3mm, 6mm and 12mm.
- The models considered will be a grooved and a used tyre.
- The results will be delivered in D3.17.

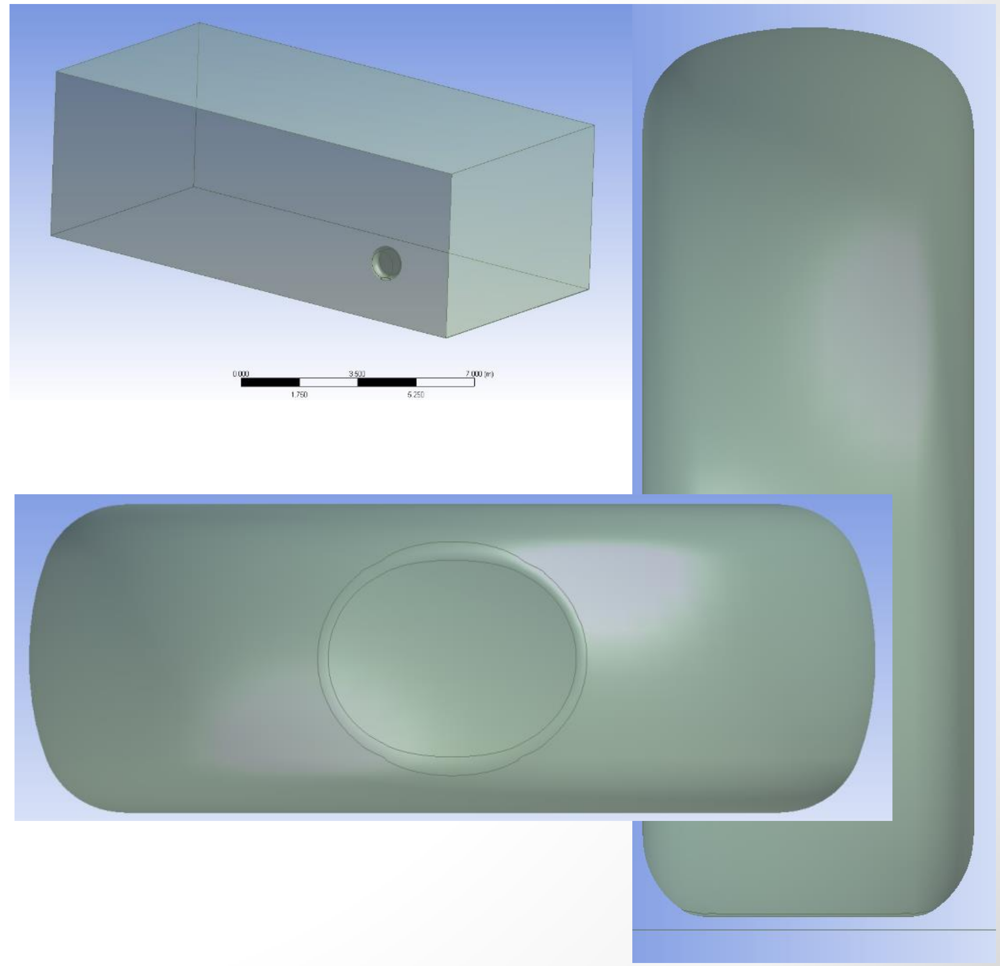
Tyre models

Tyre measured on a loaded aircraft (A320/B737 type) at ROMAERO Bucharest, both front and main landing gear.

Tyre models

New and used main landing gear tyres are reconstructed from measurements and pictures.





CFD methodology.

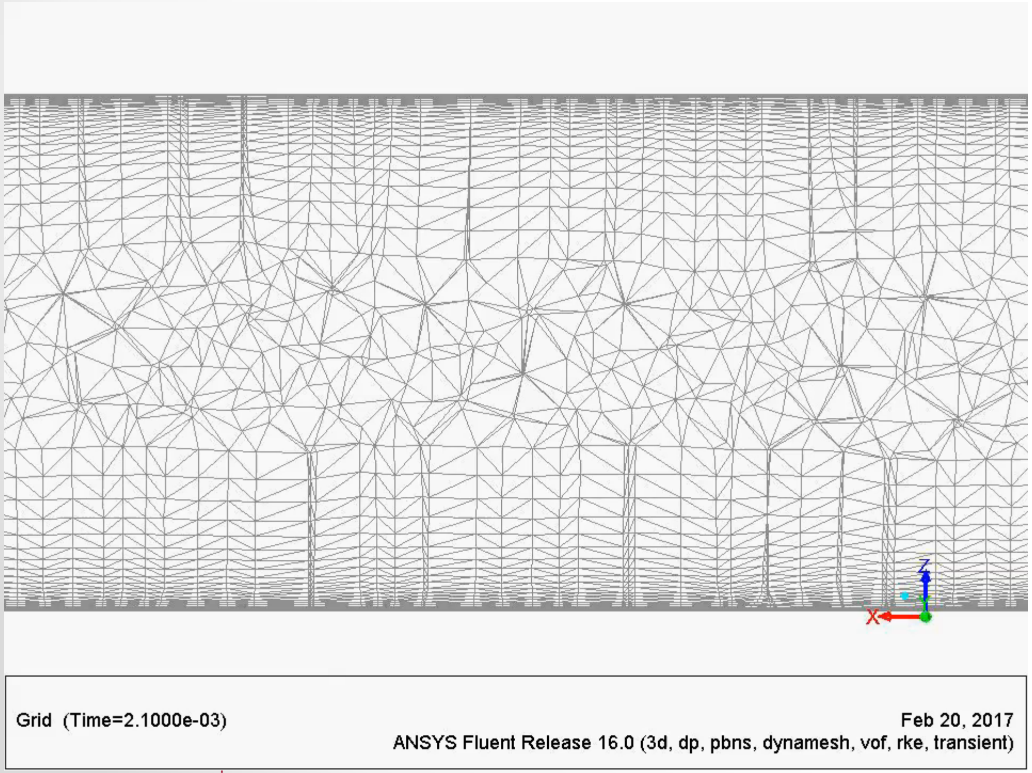
Use Ansys Fluent for CFD computations:

- Volume of Fluid multiphase model (air and water phases)
- Unsteady simulation with imposed tyres movement on the vertical axis with 2m/s and time steps of 5e-5s.
- Pressure based solver (SIMPLE method) – incompressible flow regime, increased robustness for VoF and remeshing strategy.
- Tyre geometry and resulting footprint **are fixed**!
- Use compiled User Defined Function to define tyre vertical motion.
- Use dynamic mesh (not to be confused with sliding mesh!).
- Use either Realizable k-epsilon or k-omega SST turbulence models.
- For Rk-e the use of Menter-Lechner wall treatment is the best option since is the best available y+ insensitive wall function.
- The y+ of the meshes vary strongly during computations due to dynamic mesh update. The gap between tyre and ground can vary from 15 mm to 0.5mm
- If mesh update fails, than generate mesh from the previous tyre position and interpolate results for computation resume.

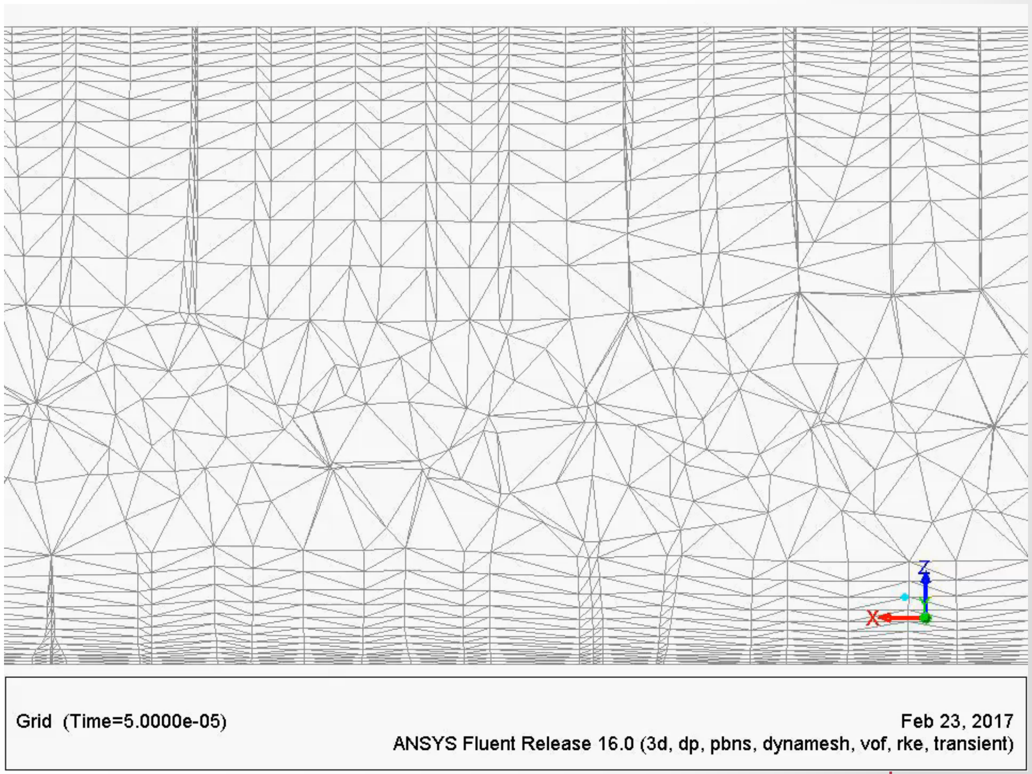
CFD methodology.

Better mesh quality and robustness for large deformations obtained with **diffusion** analogy!
Multiple meshes have been experimented to find the best solution in terms of robustness and quality after remeshing.
Automatic mesh update – detail of the tyre-ground gap:

Spring analogy



Diffusion analogy

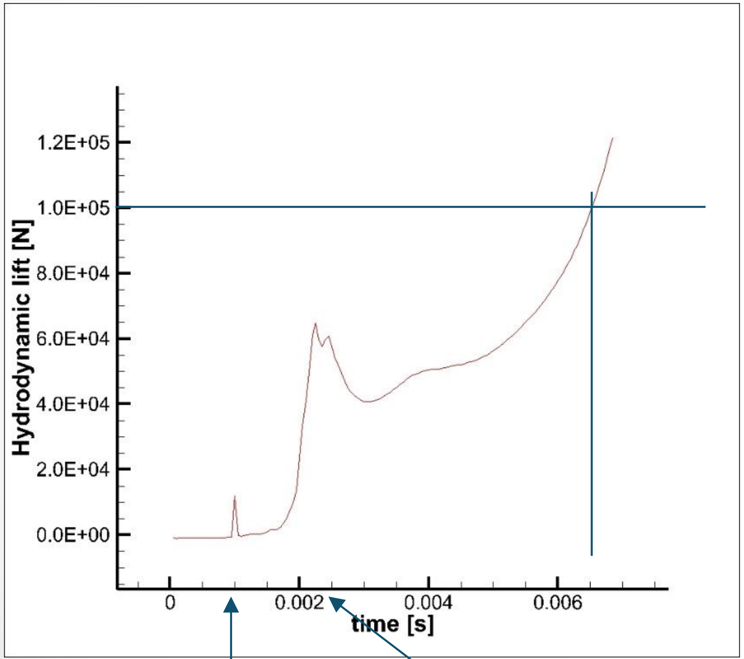


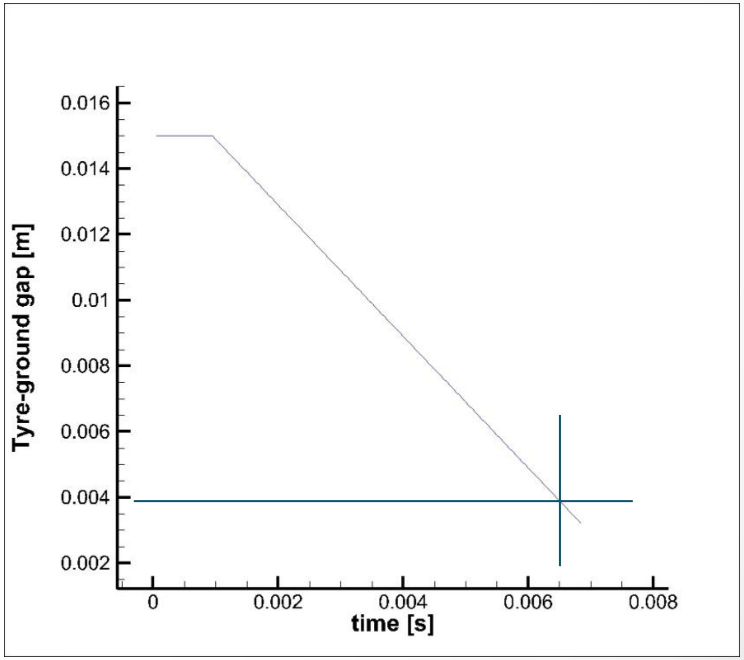
Progress.

Consider a velocity of 150 knots, and a tyre inflation of 210 PSI, for a A320/B737 type of A/C and a 0.07m^2 contact surface we have a tyre theoretical loading of approx. 10t.

From the hydroplaning formula $V_{knots} = (6\ to\ 9)\sqrt{P_{PSI}}$ we get a hydroplaning speed of about 87 to 130knots.

From the preliminary CFD simulation (with water layer height of 12mm) of a used tyre we get a hydrodynamic force that exceeds the 10t load at a tyre-ground gap of approx. 4 mm.





Tyre begins to move

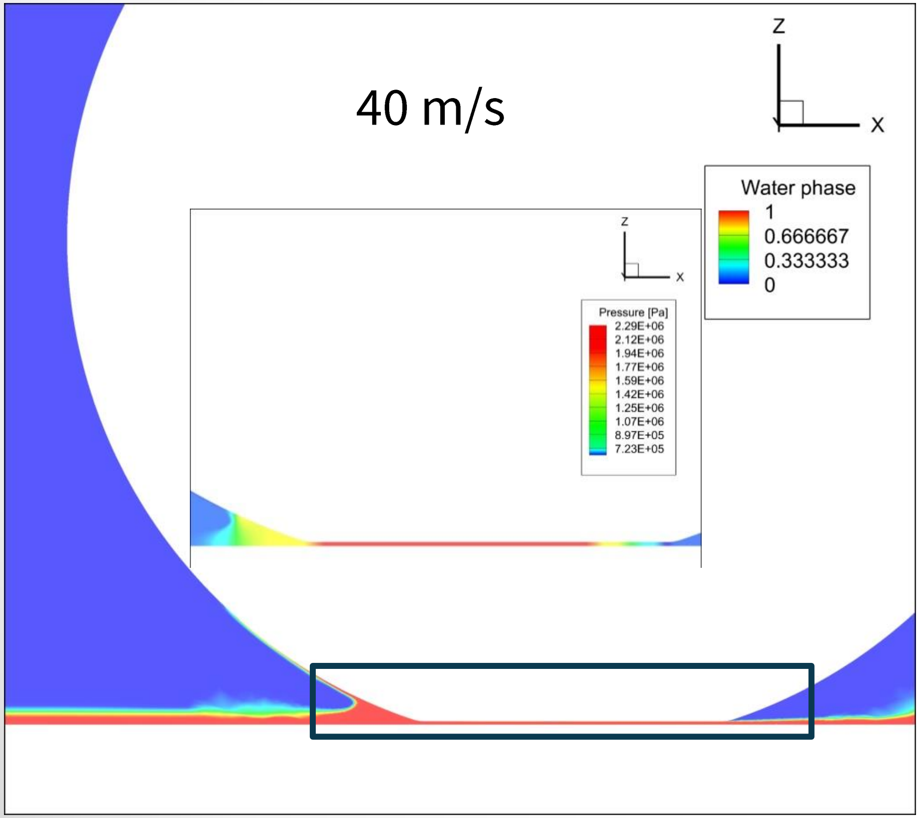
First contact of the tyre with the water

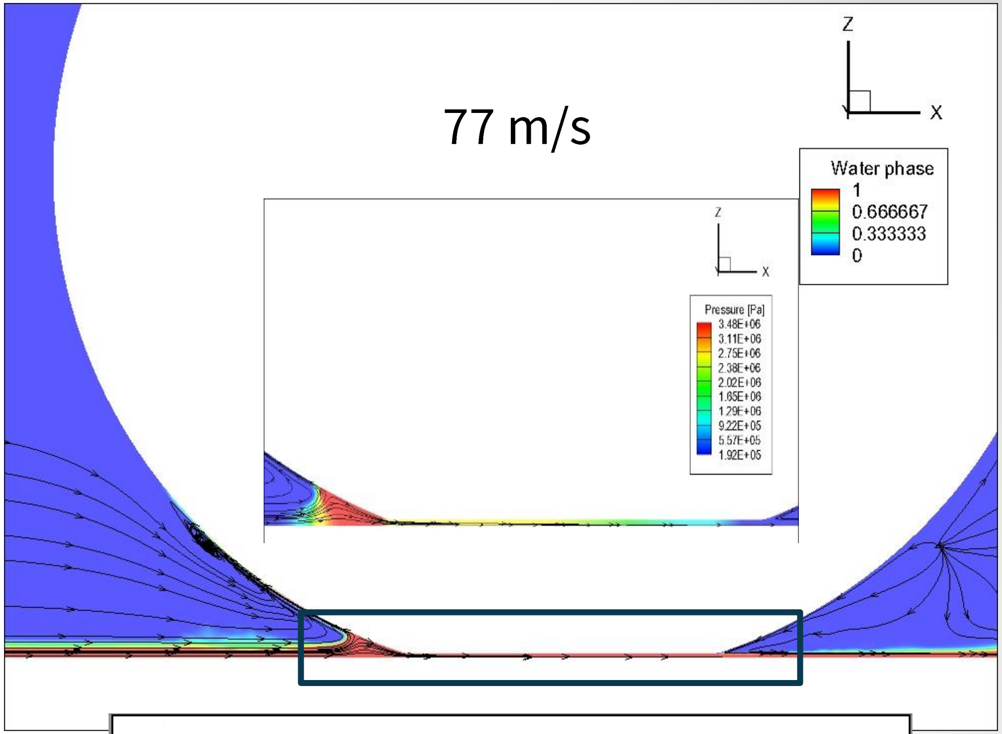
Progress.

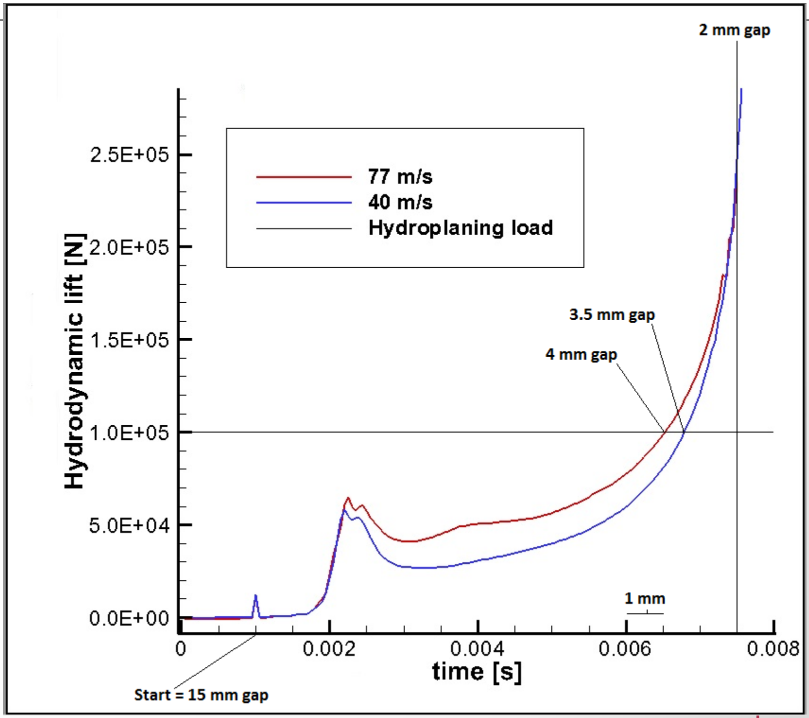
Median plane of the used tyre CFD results.

Water phase fraction and pressure distribution.

Saturation of hydrodynamic load.







Conclusions

- Hydroplaning CFD simulations have been started and are in the process of calibration.
- Velocity regimes are in the range of 70 – 150 knots.
- Mesh construction and mesh deformation algorithms are analyzed for robustness and accuracy.
- Preliminary results are being processed for a used tyre.
- For a 150 knots landing velocity the tyre hydrodynamic forces begin to exceed tyre loading at a tyre-ground gap of approx. 4mm.
- Hydroplaning CFD simulations continue for both new/used tyres and for braked/free wheel situation.

THANK YOU!

FUTURE SKY SAFETY

Consortium

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Office national d'études et de recherches aérospatiales
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