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# ACCURATE DRAG PREDICTION OF HELICOPTER AIRFRAME WITH HPC

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# Summary

- Statement of Research
- Computational Model
- Mesh Generation and Refinement
- Code Performance
- Aerodynamic Forces Calculations
- Results and Discussion
- Conclusions

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# Goal of Present Research

- To calculate airframe aerodynamic forces and moments at most flight conditions
  - Effects of angle of attack (drag polar)
  - Effects of side-slip (effect of gusts and flight conditions)
  - Vertical flow (aircraft climb & rotor effects)
  - Side flow (effects of gusts)
- Validation of CFD methods by intelligent applications rather than brute force.

# Status of the Research

- Airframe drag is 40-50% of total drag
  - *Fuselage drag major limit to rotorcraft speed*
  - *Bluff body at high incidence*
- Recent Past: Airframe aerodynamics simulated with panel methods
- CFD methods made advances
- Virtually no validation of CFD methods for aerodynamic forces

# Status of the Research /2

- No examples of rotorcraft forces in yaw
- Few examples of rotorcraft forces in vertical flow

# Computational Model

- 3D multi-block, fully-structured NS code.
- SIMPLE algorithm for velocity-pressure coupling.
- Second-order TVD upwind scheme  the convective terms.
- Code fully optimised for MPI.
- Runs routinely on 100+ Linux processors.
- *Run on HPCx with up to 200 processors*

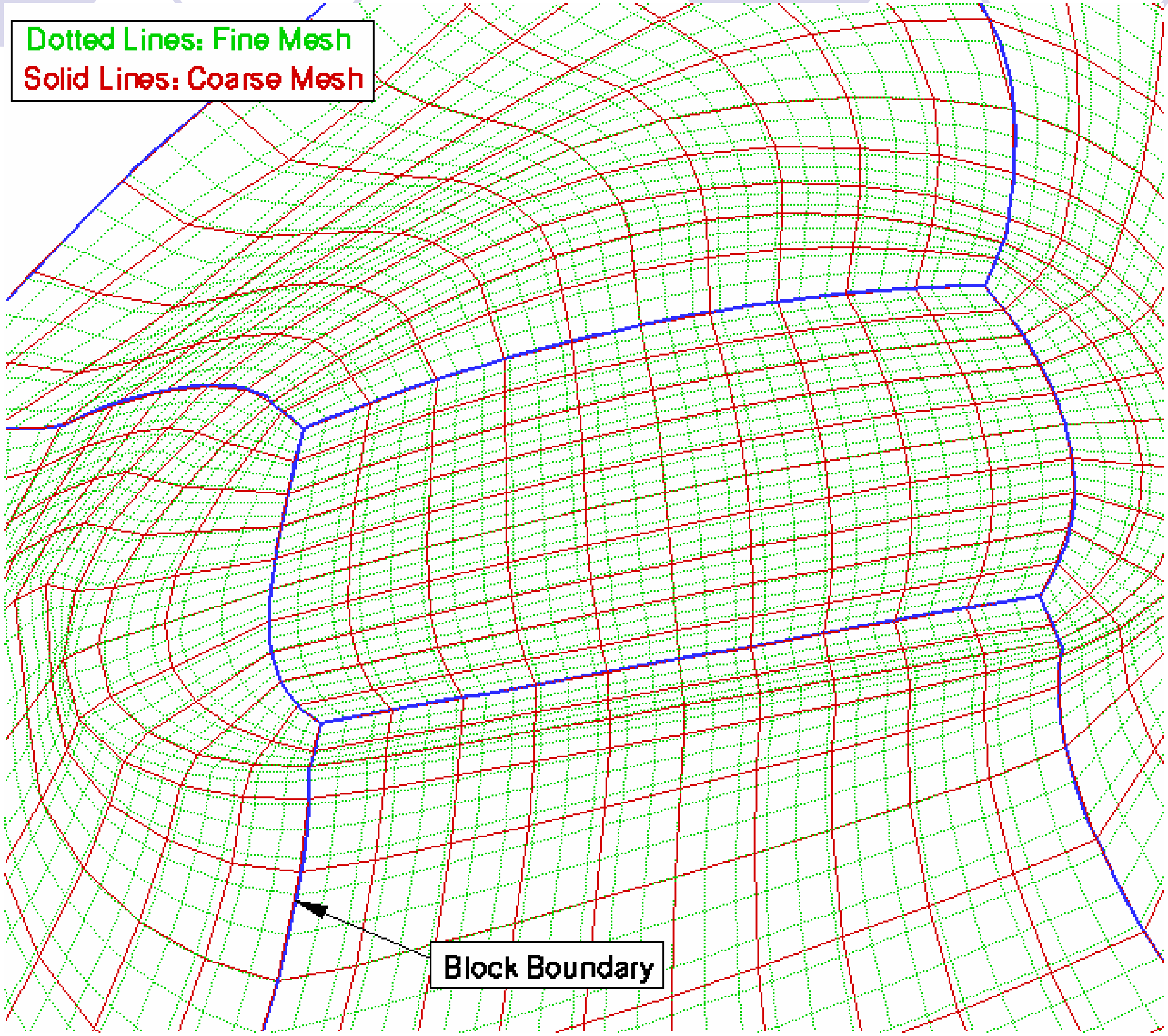
# Computational Model /2

- Basic airframe with engine cowlings
- Mesh: 198 blocks x $n^3$ cells
- n = 20, 24, 28, 32 …
- Ideal for multi-grid
- Surface cells = 66 x $n^3$
- Calculations Fully Unsteady
- Turbulence model K-omega SST

# Mesh Topology

- Surface topology generated from ICEM-CFD and CAD model
- Half-plane mesh: Hyperbolic equations
  - Orthogonality and smoothness guaranteed
- Mesh refinement: high-order interpolation, block-by block

# Resolution Problems



# Code Performance

- MPI for parallelisation on distributed memory
- Load balance optimal if `nblocks = nprocs`
- No treatment for domain decomposition
- HPCx:
  - Batches of 32 processors
- Linux cluster:
  - When the blocks cannot be distributed evenly, redundant processors can be shut down

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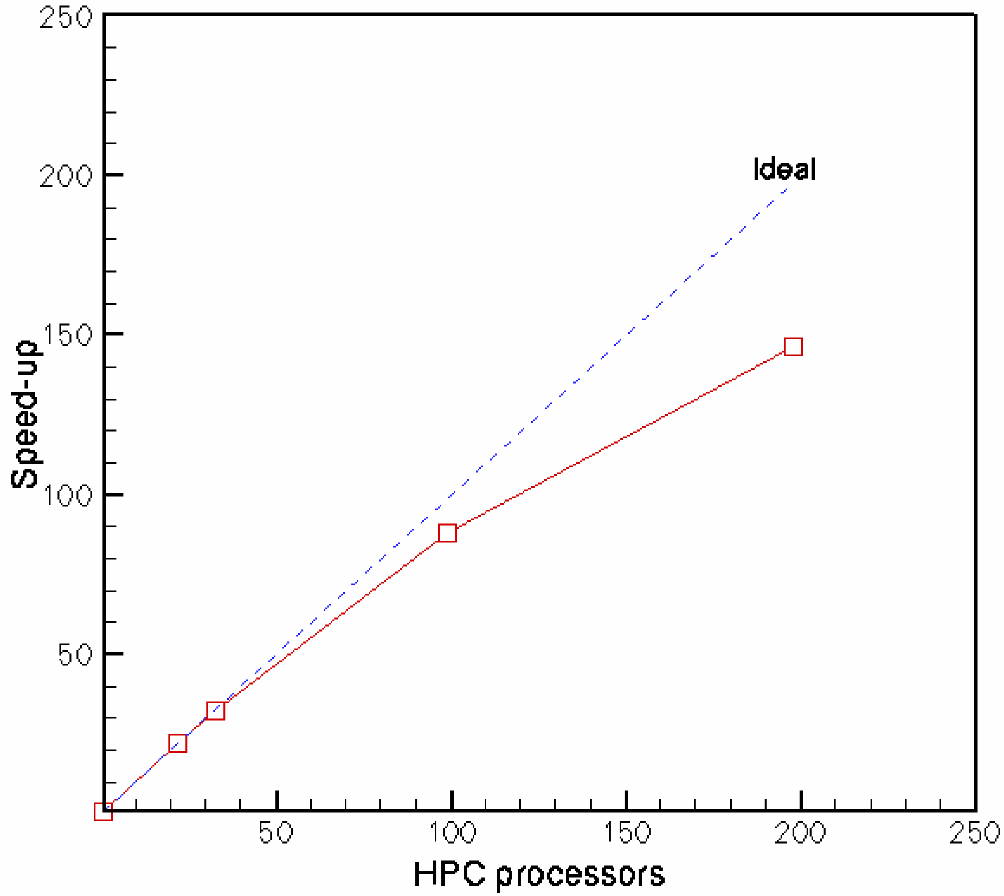
# Code Performance /cont'd

- Problem considered must have certain size, else …
- Inter-processor communication ``eats up'' possible speed gain
- Memory required: 0.8 to 1.0 kb/cell

# Speed-up Chart on HPCx



# Calculation of Forces/Moments

- Viscous & Pressure Contributions
- Forces variable with time/time-step
- Forces not always convergent
- Forces oscillate around average value
- Error bars of CFD can be large

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# Calculation of Forces

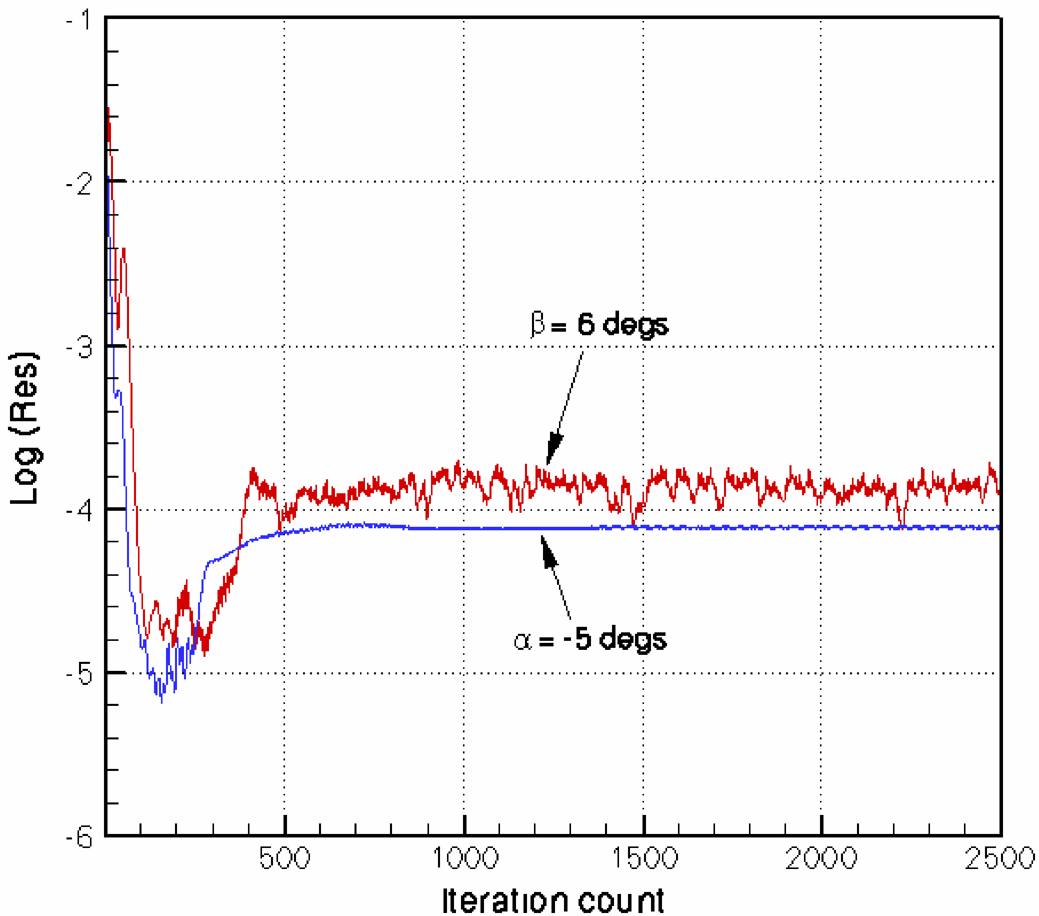
- Depend on iteration count
- Residual stagnates after 1,000 iterations or more

$$F_x = \sum_k (p\mathbf{n}\cdot\mathbf{S} + \boldsymbol{\tau}\cdot\mathbf{S})_x,$$

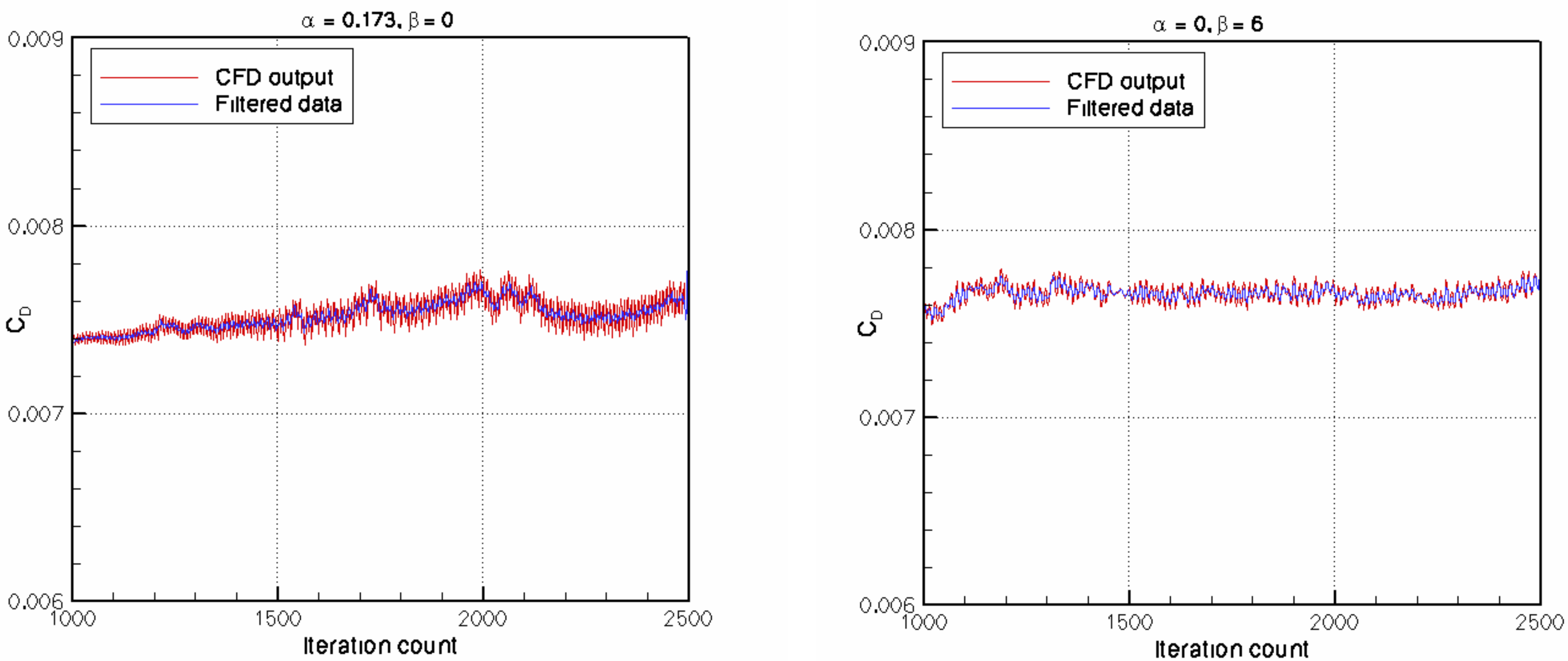
$$F_y = \sum_k (p\mathbf{n}\cdot\mathbf{S} + \boldsymbol{\tau}\cdot\mathbf{S})_y,$$

$$F_z = \sum_k (p\mathbf{n}\cdot\mathbf{S} + \boldsymbol{\tau}\cdot\mathbf{S})_z$$

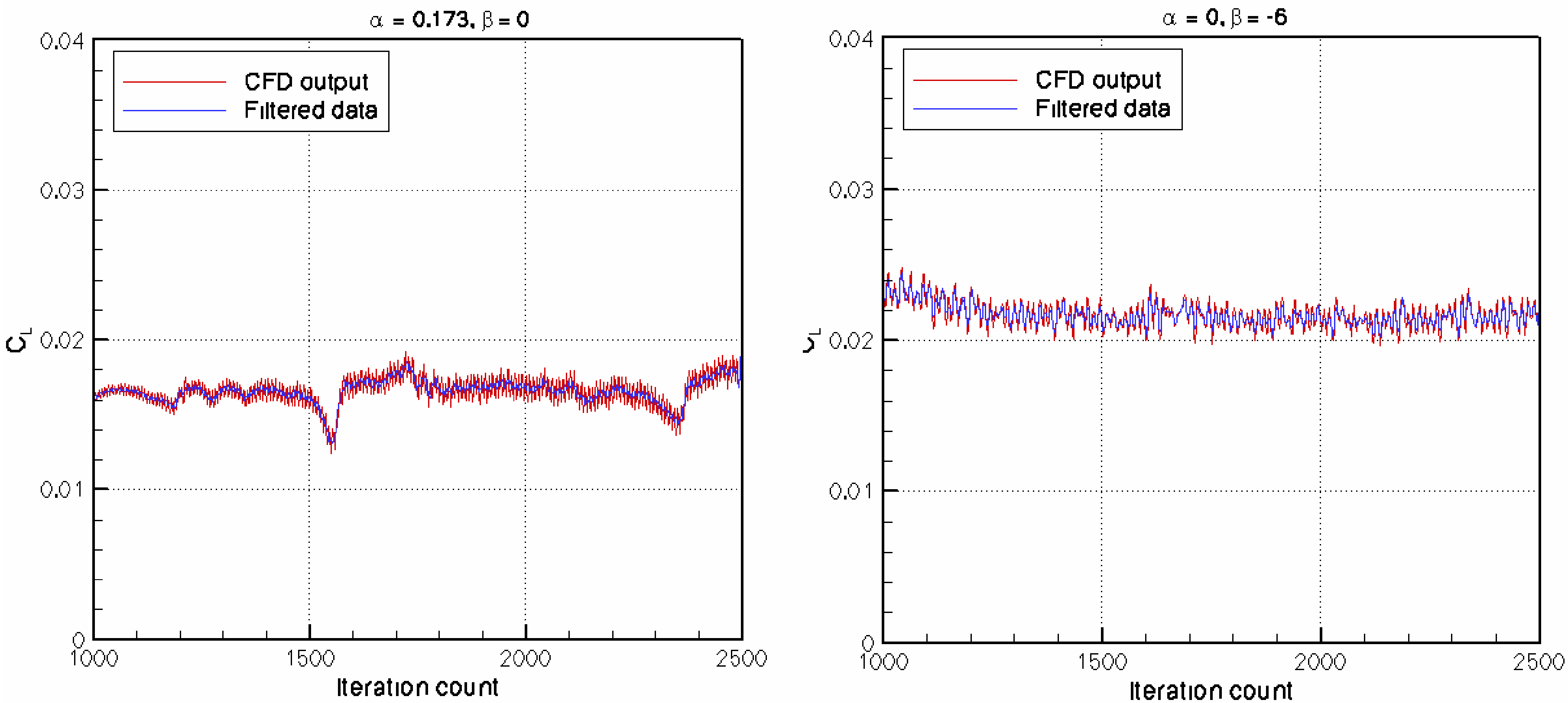
# Iteration History



# Time History of Drag Coefficient

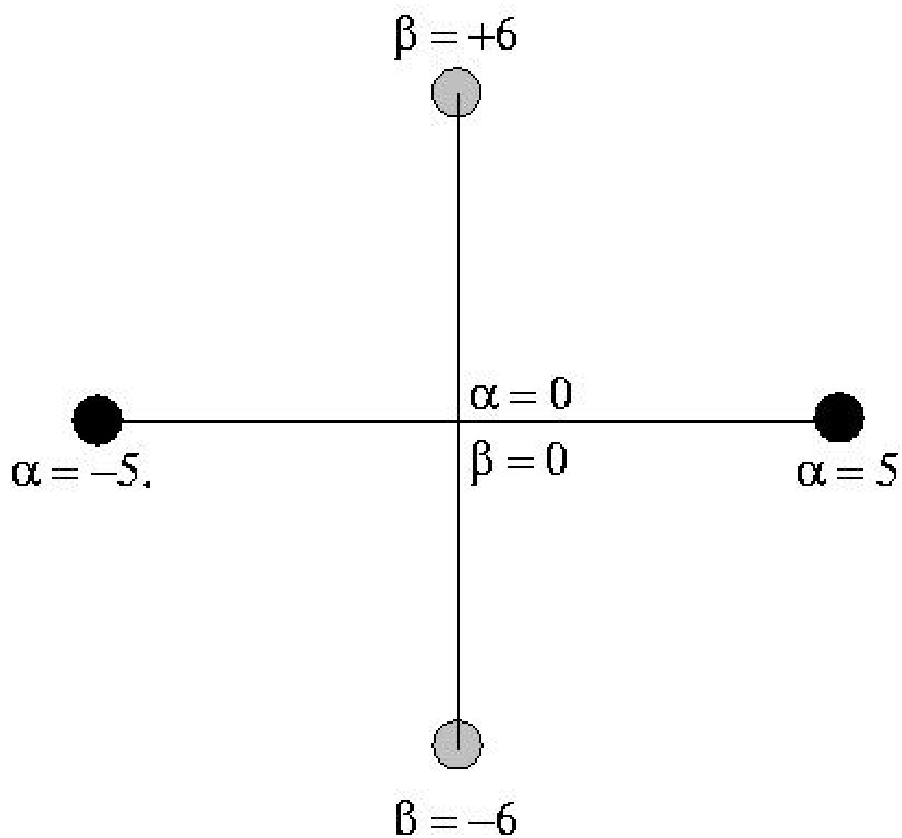


# Time History of Lift Coefficient

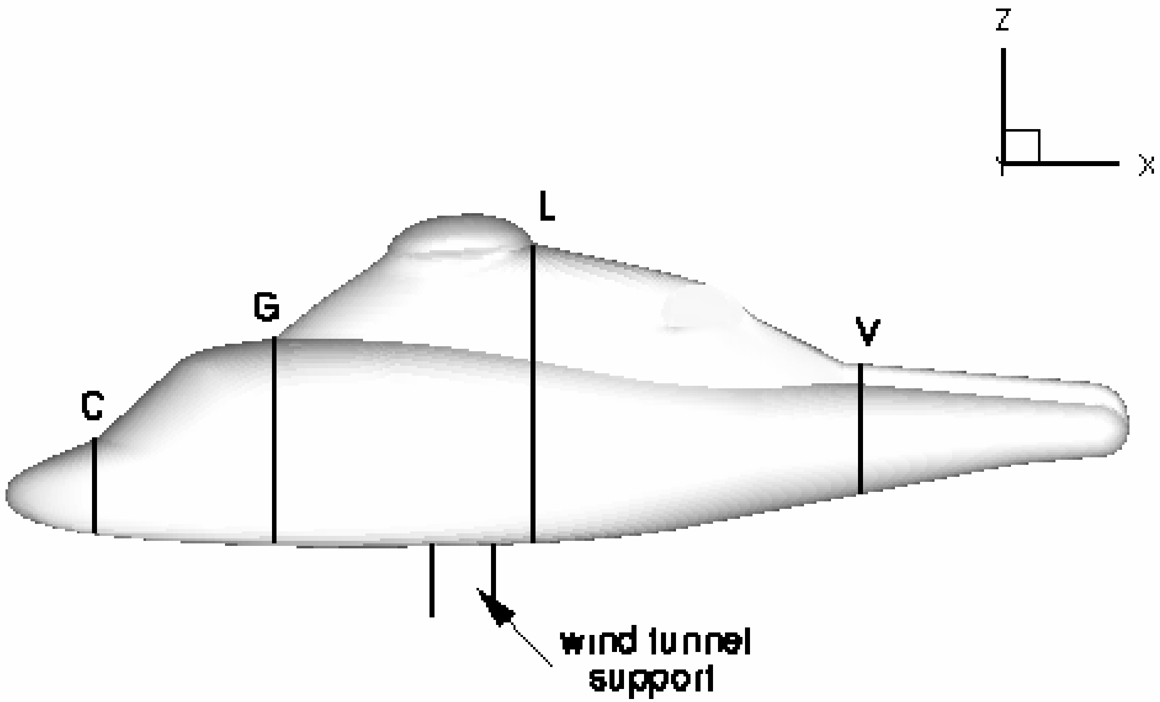


# Test Matrix with experimental data

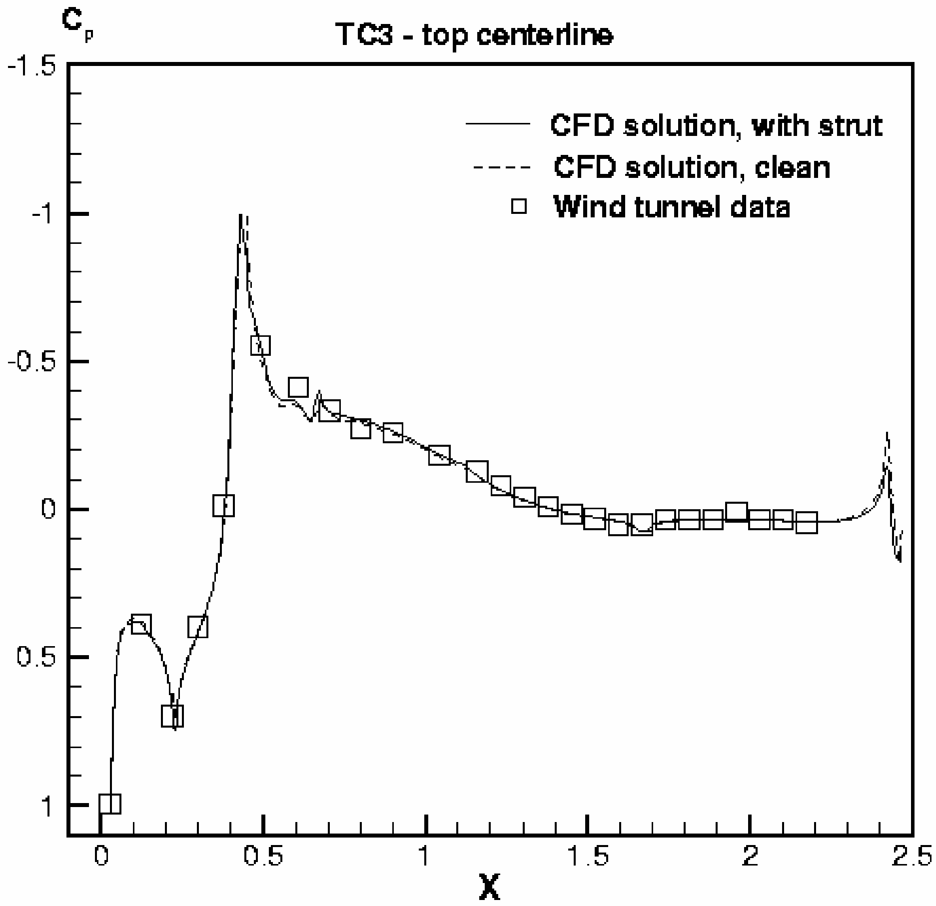
- Re= 30 million (flight condition)

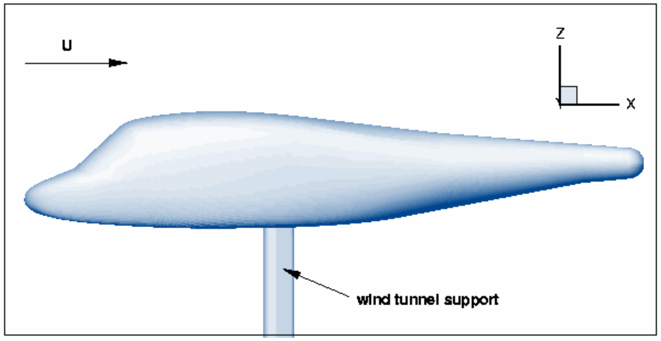


# Surface Pressure Analysis

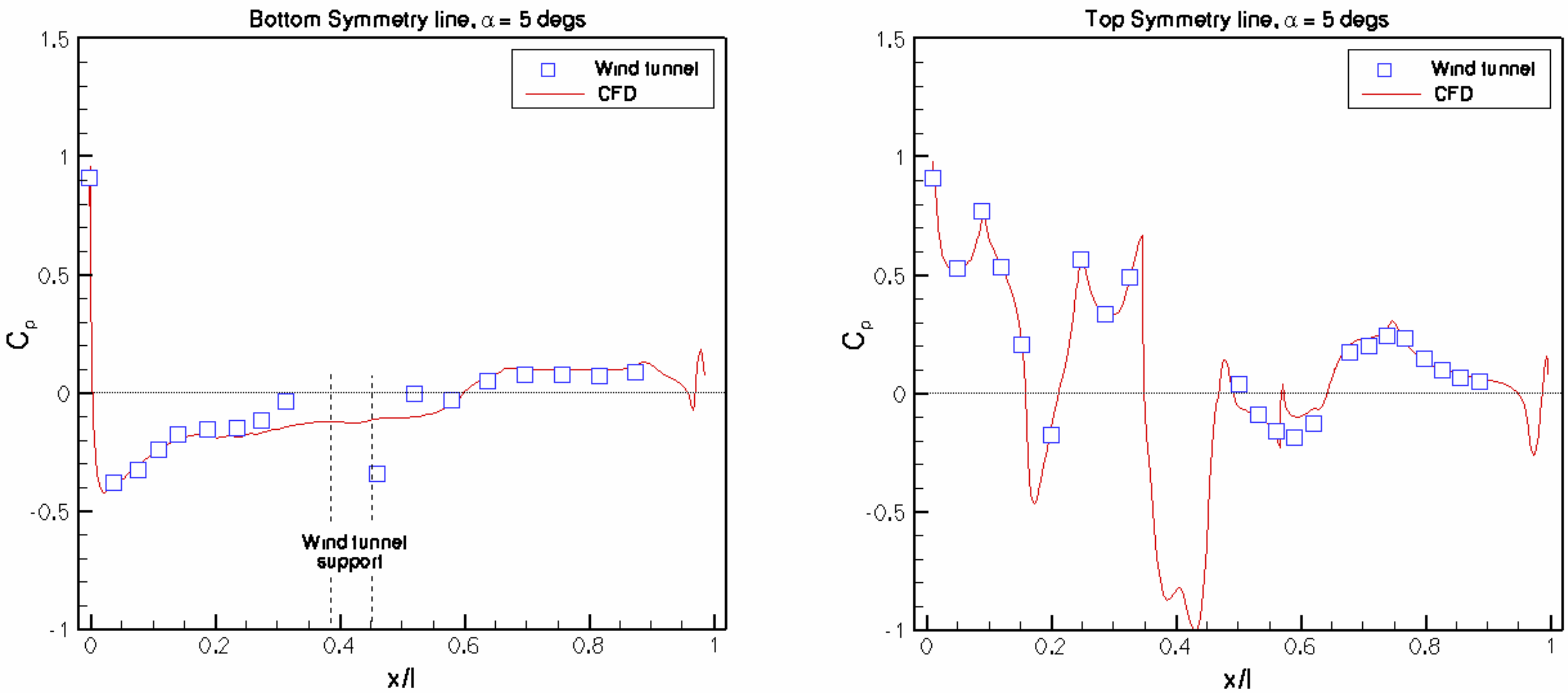


# Airframe Pressure, CFD Analysis



# Surface Pressure Analysis, α = 5



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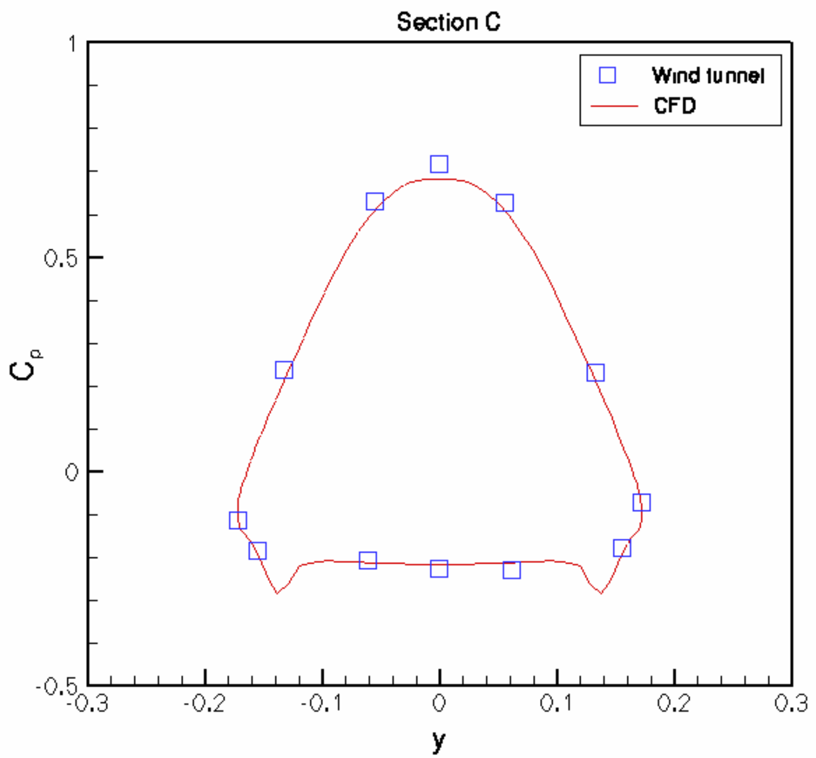


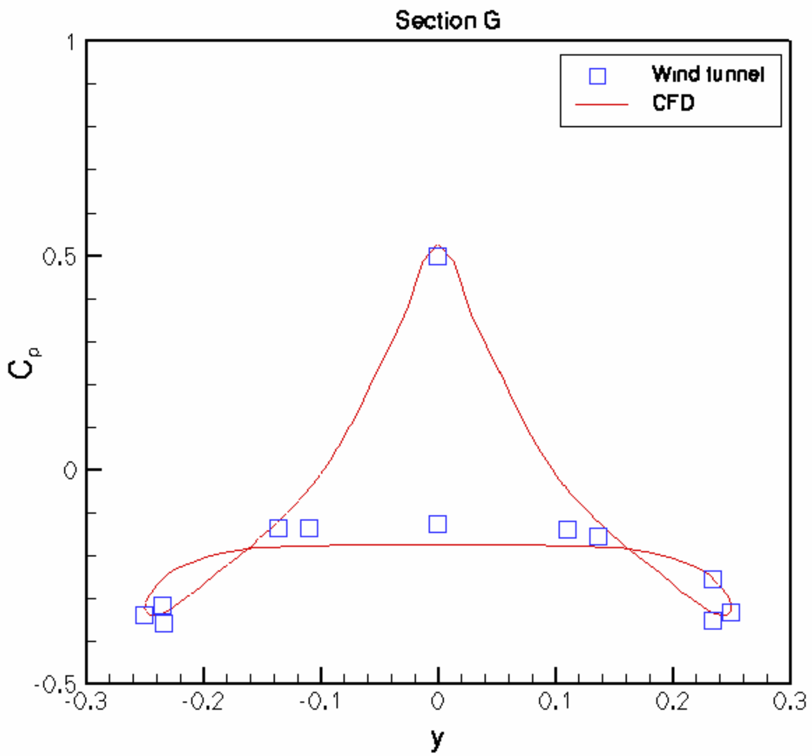

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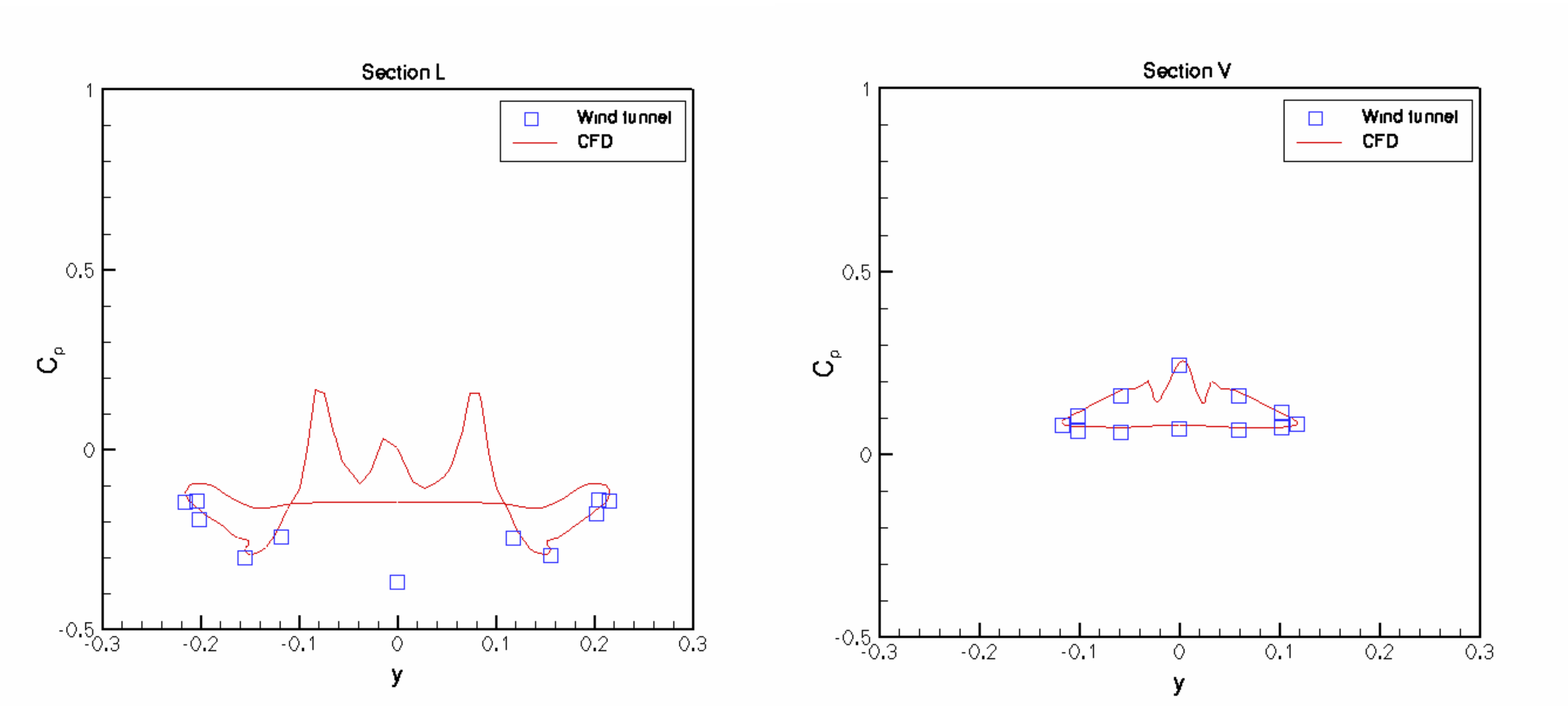
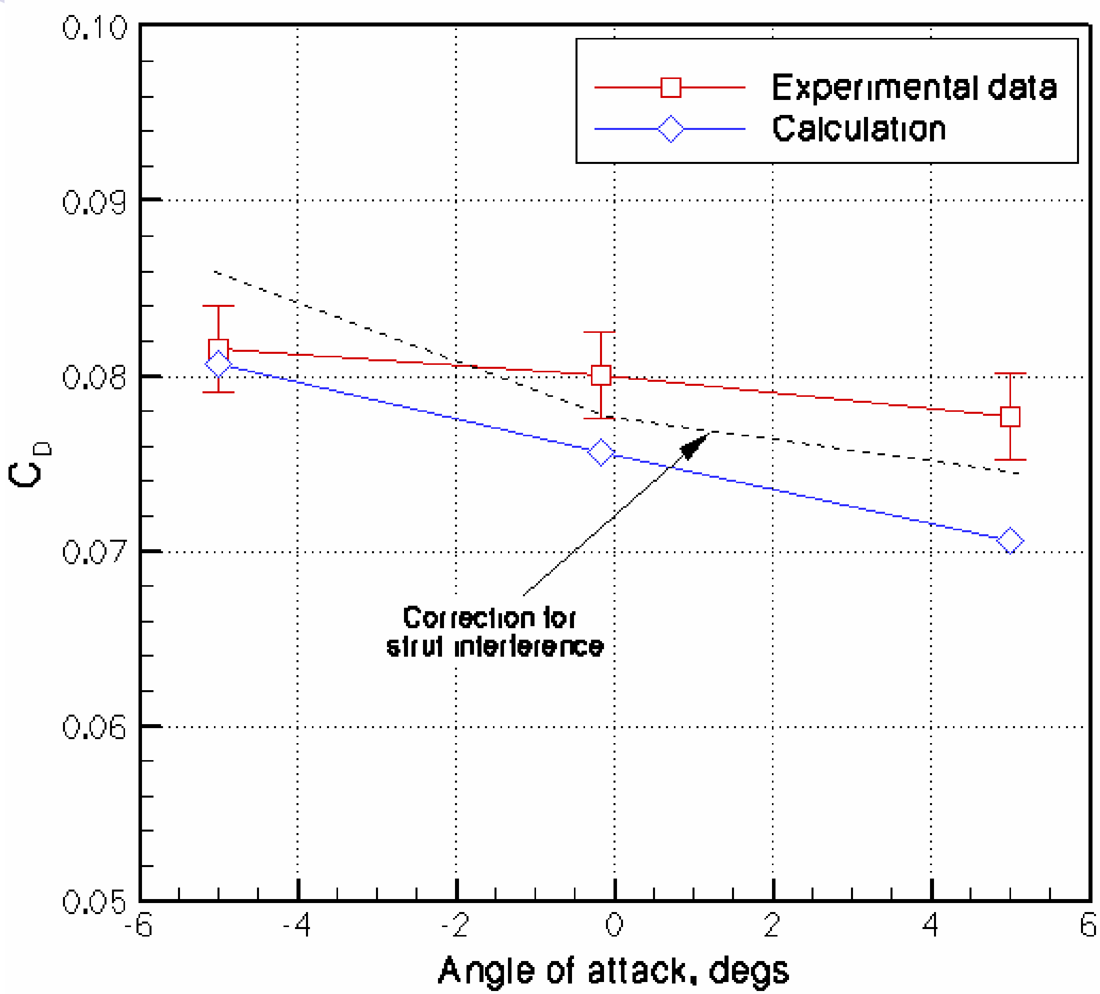


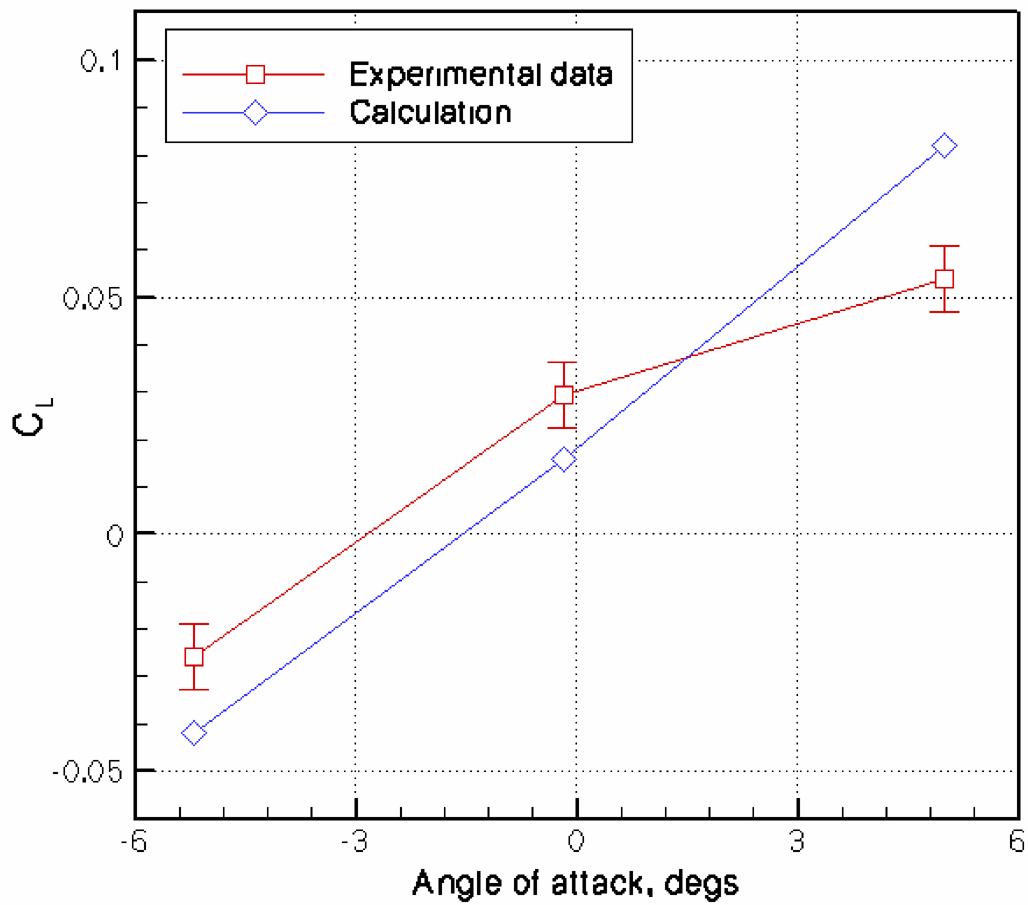
# Drag Analysis, AoA effects

- Re = 30M



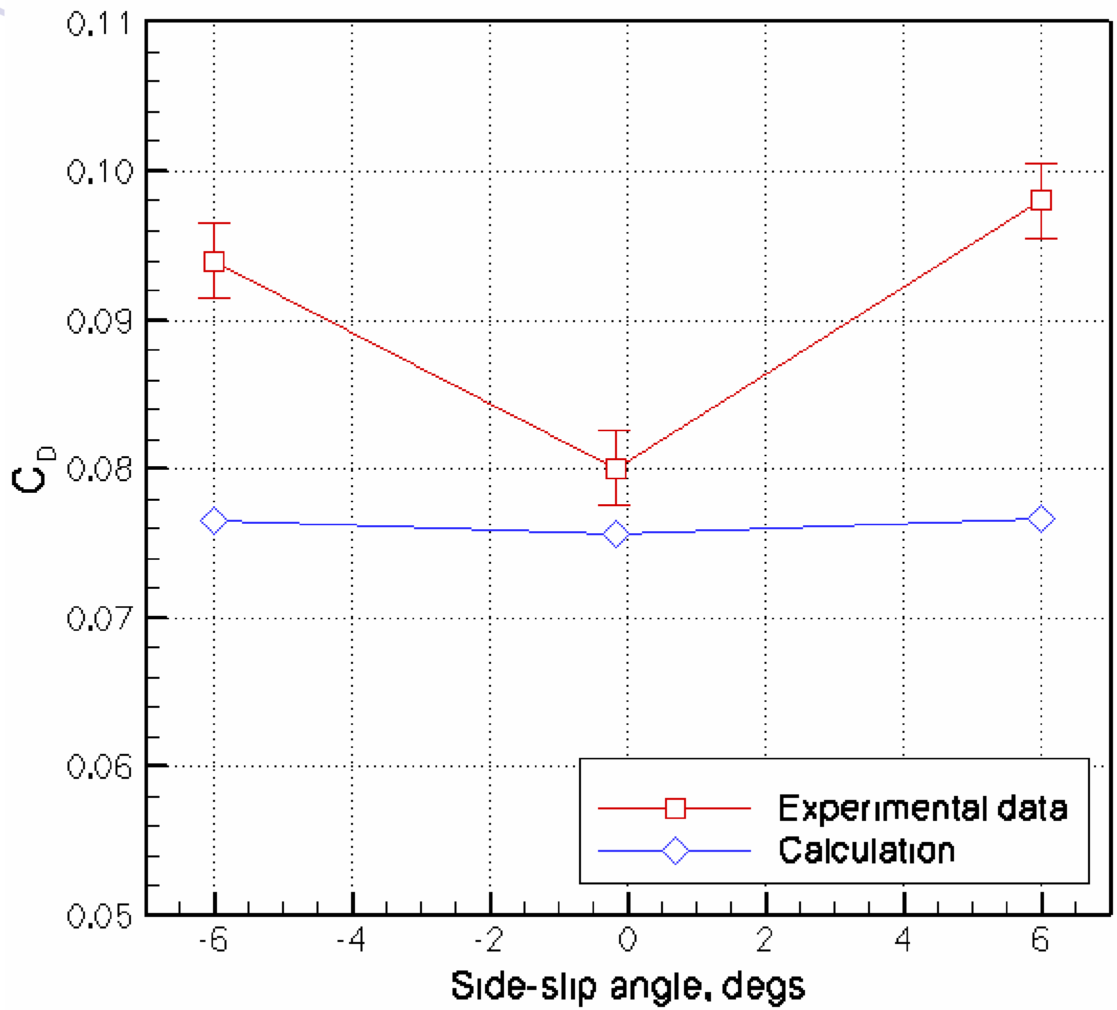
# Lift Analysis, A.o.A. Effects

- Re = 30M



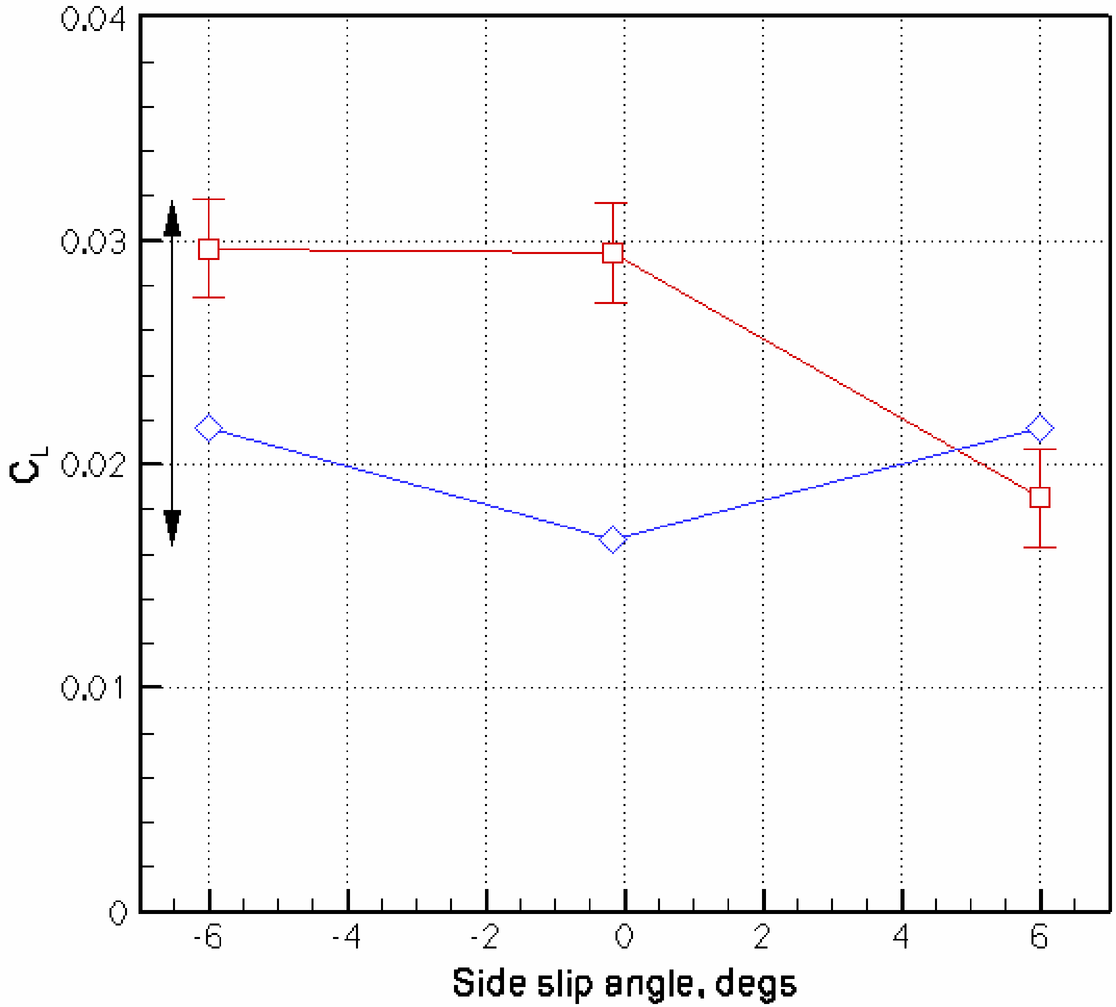
# Drag Analysis, Yaw Effects

- Re = 30M

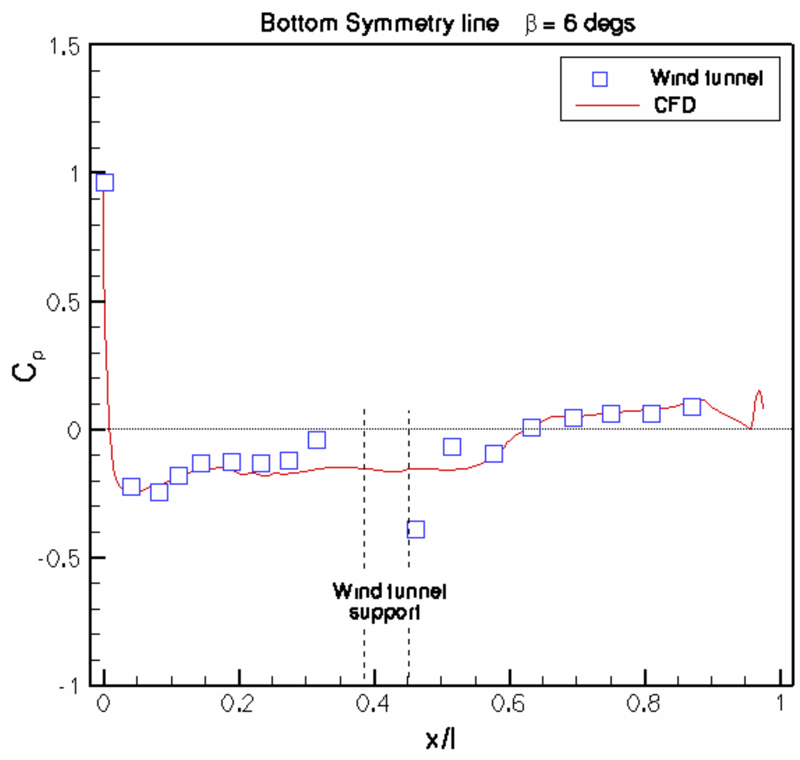


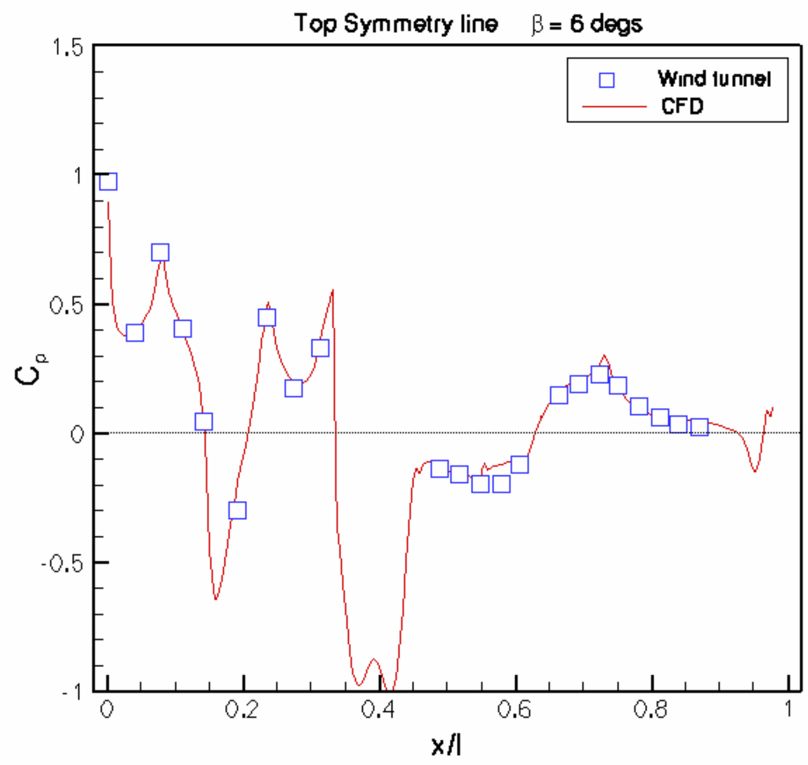
# Lift Analysis, Yaw Effects

- Re = 30M

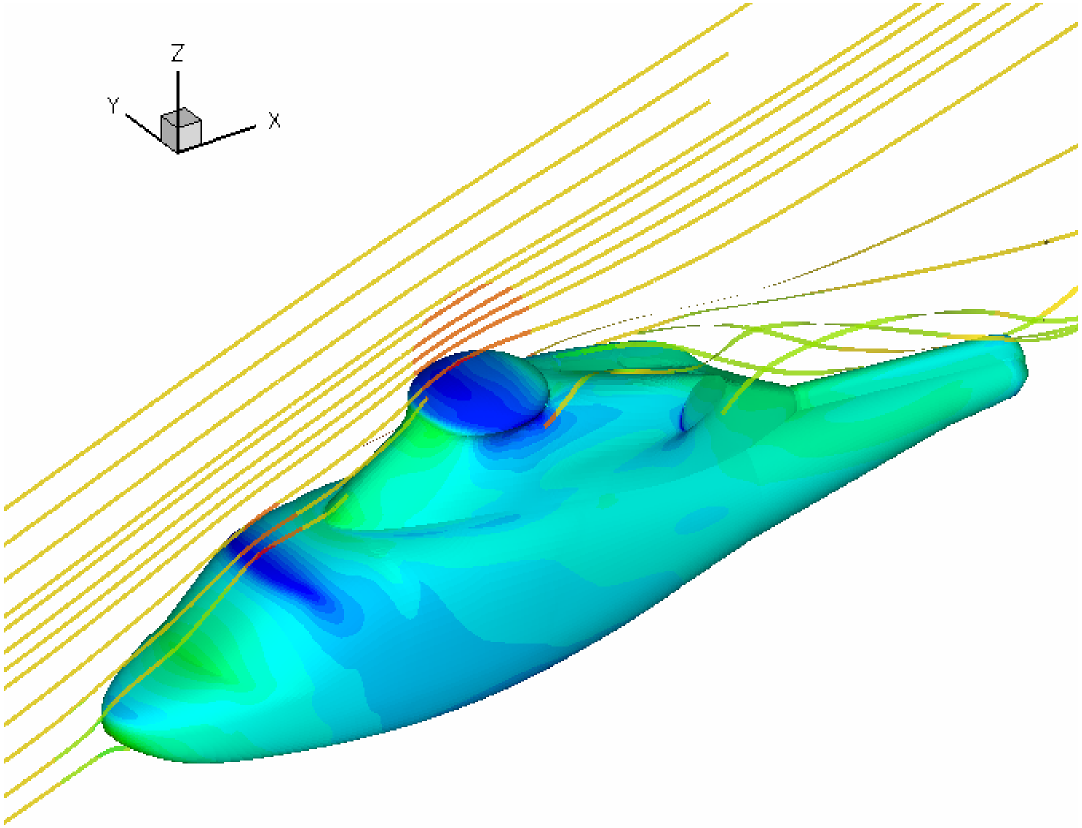


# Surface Pressure Analysis, β = 6

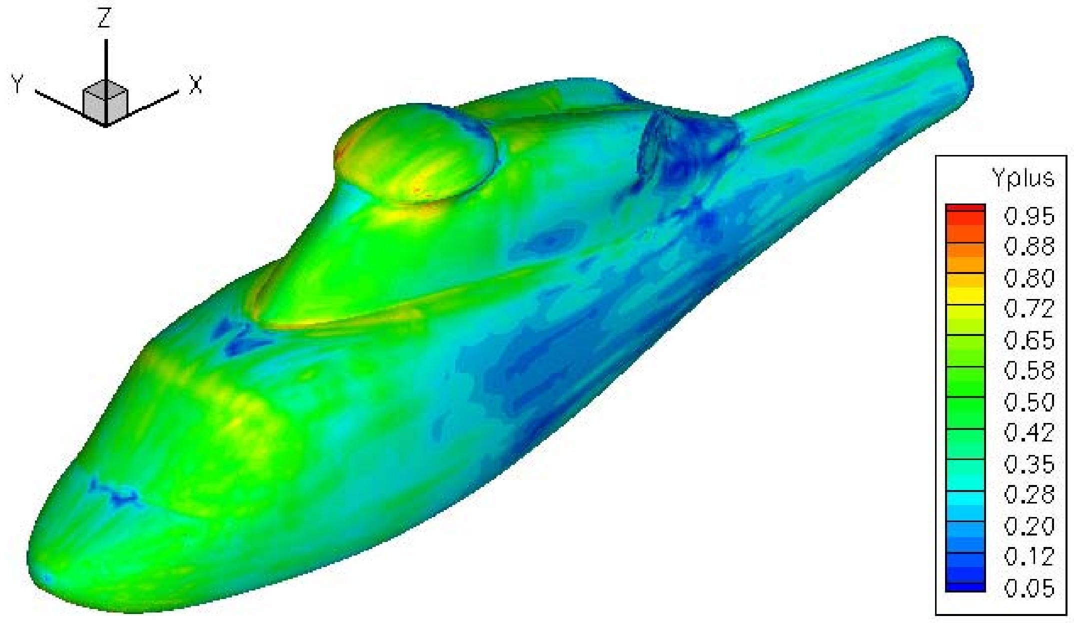


# Airframe Aerodynamics, α = 20

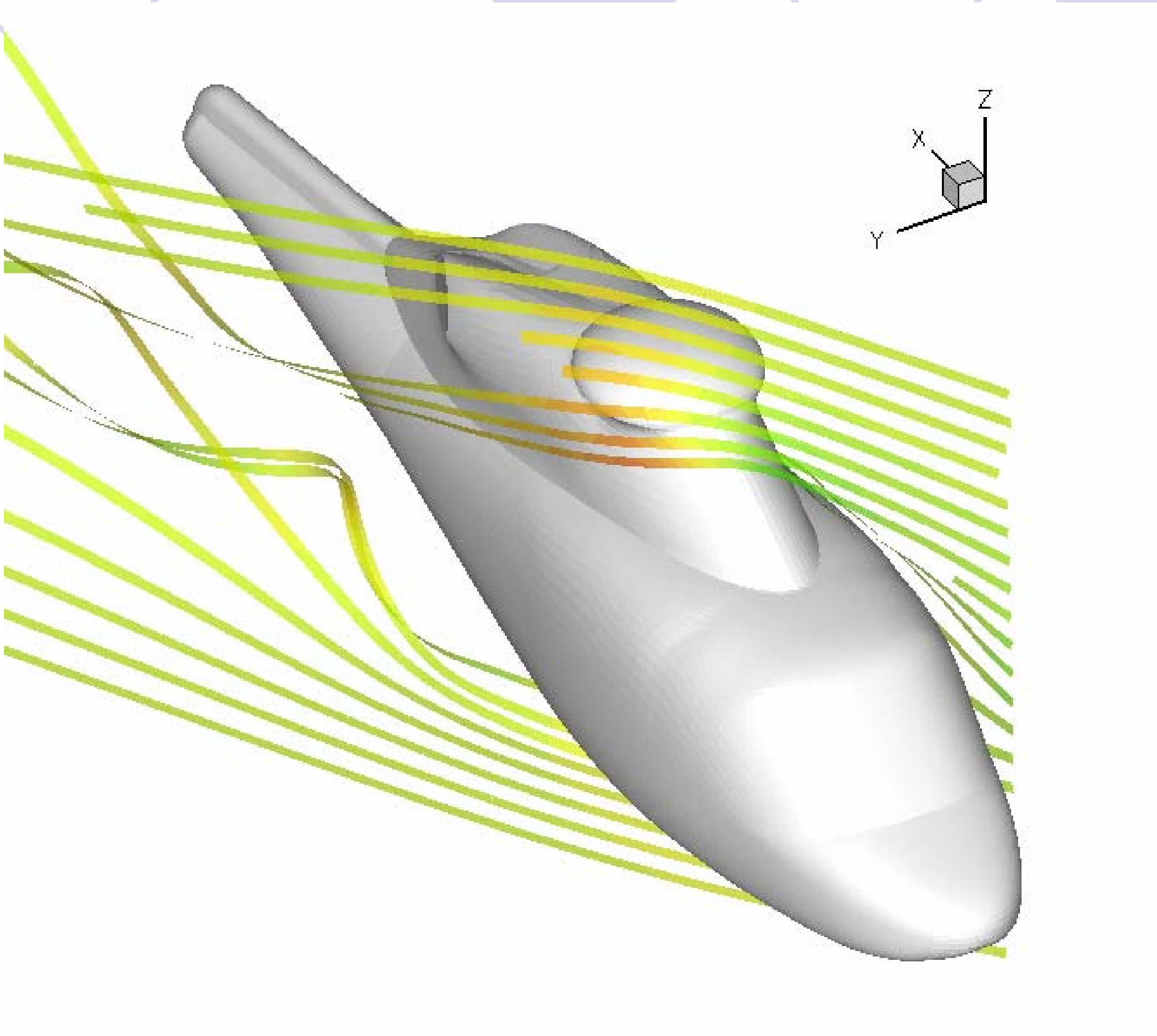


# Airframe Aerodynamics, α = 0



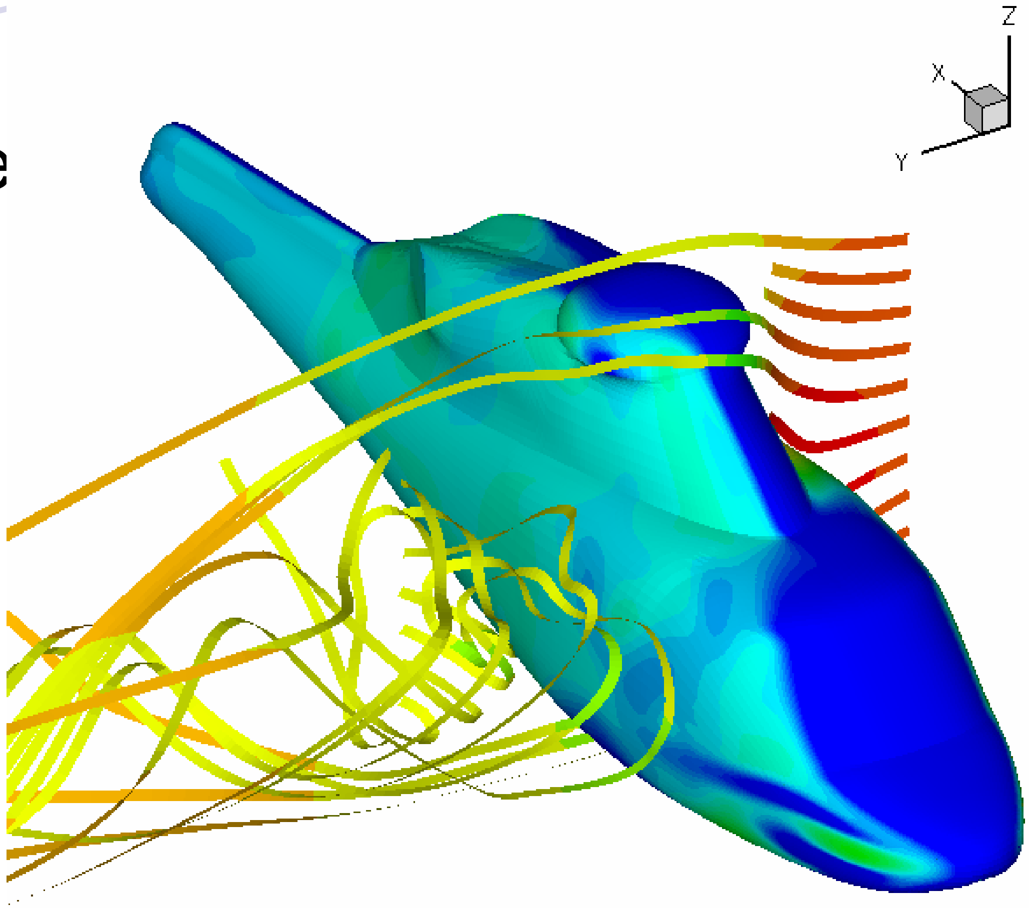
# Large Yaw Angles

- 30 deg
- Re = 30M



# Side Winds Effects

- Side gust
- Downwind vie



# Conclusions: Results Achieved

- Large-scale computations of bluff bodies
- Computations requiring 100+ CPU hours
- Realistic Helicopter Applications
- Prediction of Forces in Yaw
- Prediction of Forces at Angle of Attack
- Good comparison of Surface Pressure
- Good comparison of Surface Streamtraces
- Mixed results of aerodynamic coefficients

# Conclusions: Perspectives

- More Sophisticated Methods Required
  - Including Turbulence Models
- Errors in Wind Tunnel Results ?
  - Correct interpretation of WT results ?

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# Conclusions: Long-term Goals

- To compute drag polar with CFD methods
  - Angles -10 to +30 degrees
- To predict yaw and gust effects accurately
- To predict the helicopter download due to vertical drag