Aerodynamic Analysis of A Ski Jumper: A CFD Approach

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Introduction: At the 2006 Winter Olympics, the jump length difference between first and second place was only 5cm. Experiments such as those shown in Figure 1, conducted with ski jumpers in large-scale wind tunnels showed that changes in position can lead to marked changes in the lift and drag forces. The disadvantages of performing these tests have led to the proposition of CFD as a possible alternative.

Figure 1. Wind tunnel measurements with A. Goldberger (Muller, 2008)

This study uses the k-ε and SST (Shear Stress Transport) turbulence models of the CFD module in COMSOL Multiphysics® for an aerodynamic analysis of a ski jumper.

Computational Methods:
Using the dimensions of an average built human body; the computational model shown in Figure 3 was developed in SOLIDWORKS®. This model was imported into the model builder of COMSOL Multiphysics® using the LiveLink™ for SOLIDWORKS®. The computational model was developed to allow for the posture angles to be easily adjusted. This was achieved by using component parts for the human body model and creating an assembly with suitable mates.

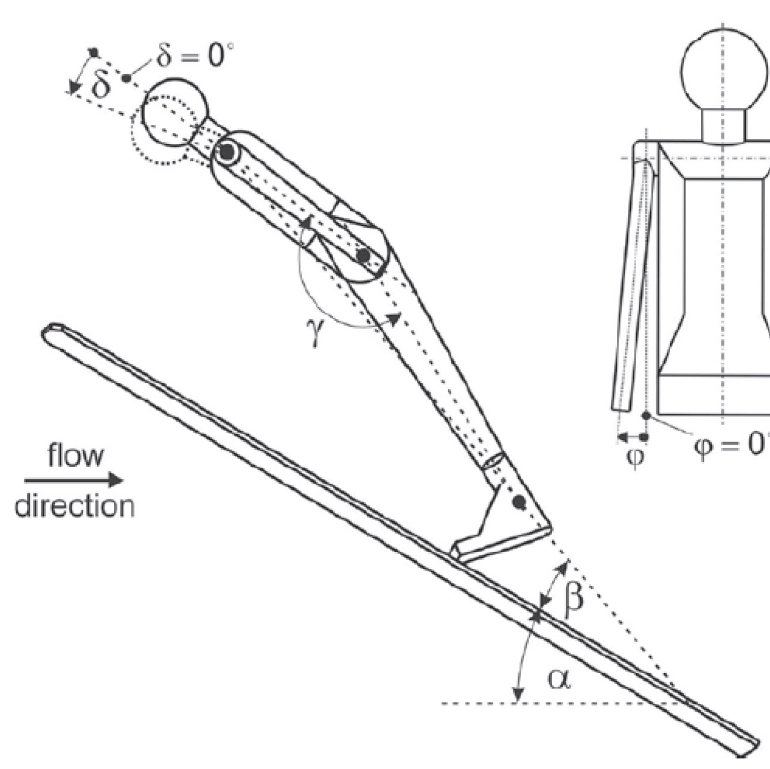


Figure 2. Angle nomenclature of the V-style (Meile et al, 2006)

Figure 3. Computational model of the ski jumper

The computational domain used is a rectangular parallelepiped having dimensions of 300 cm x 325 cm x 600 cm in the x, y and z directions respectively.

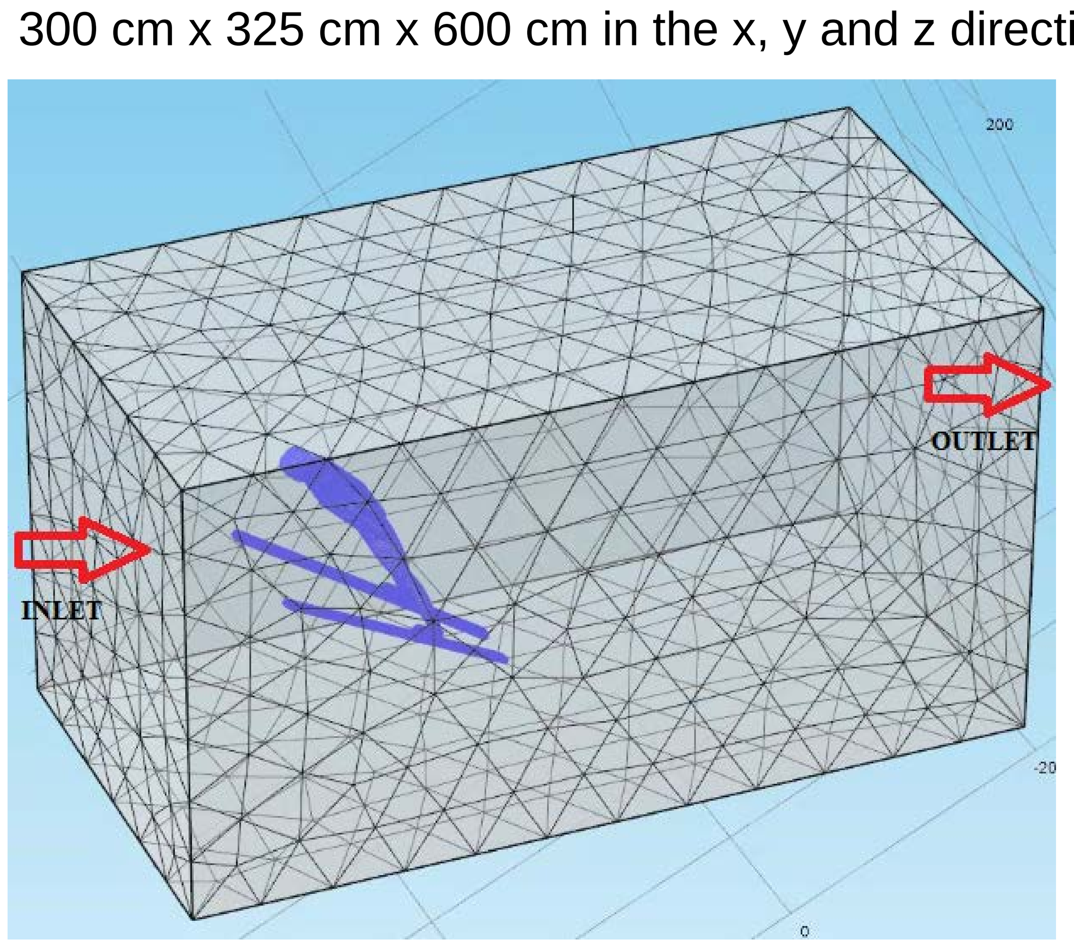


Figure 4. Computational domain showing the inlet and outlet boundaries

Boundary Conditions

- Inlet condition:
  Normal inflow velocity of 30 m/s.
- Outlet condition:
  Pressure of 0 Pa.
- Open boundaries:
  Symmetry boundary

The fluid flow is modeled by the following Reynolds-Averaged Navier-Stokes (RANS) equations.

$$\rho\frac{\partial \mathbf{u}}{\partial t} + \rho(\mathbf{u}\cdot\nabla)\mathbf{u} = \nabla\cdot[-p\mathbf{I} + \mu(\nabla\mathbf{u} + (\nabla\mathbf{u})^T)] + \mathbf{F}$$

$$\rho\nabla\cdot\mathbf{u} = 0$$

u : velocity vector
F : volume force vector
p : pressure
ρ : density

Results:

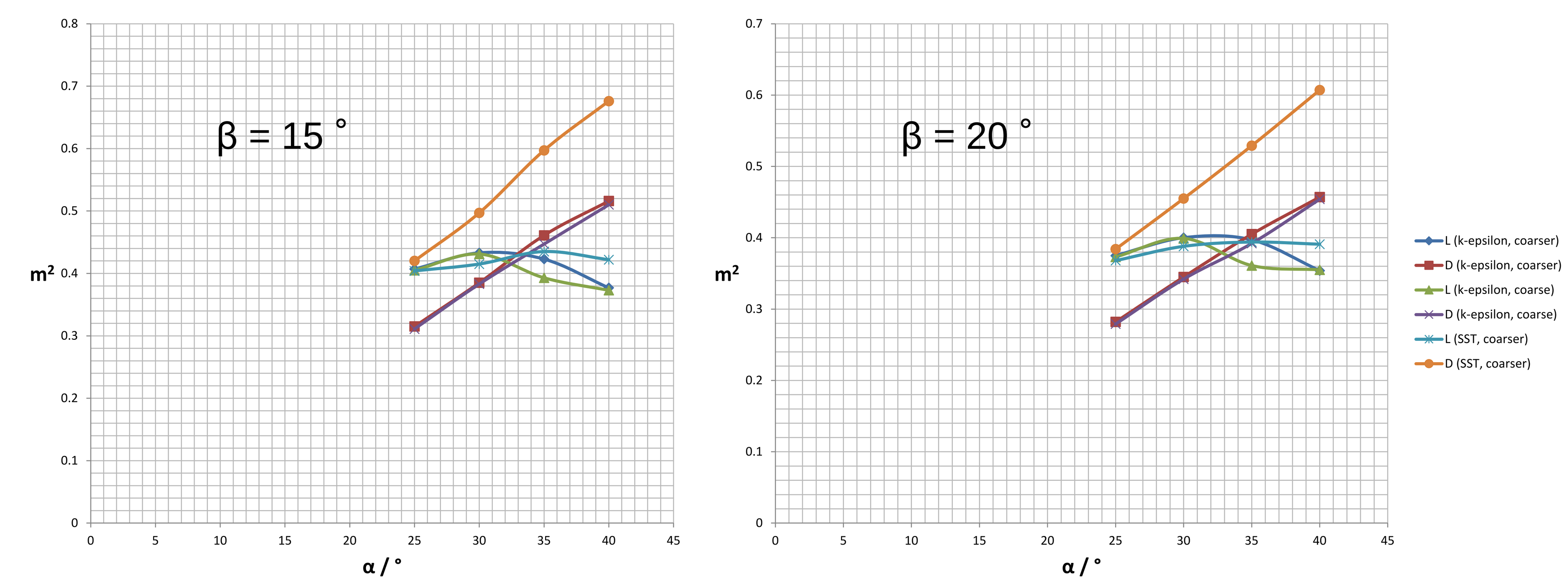
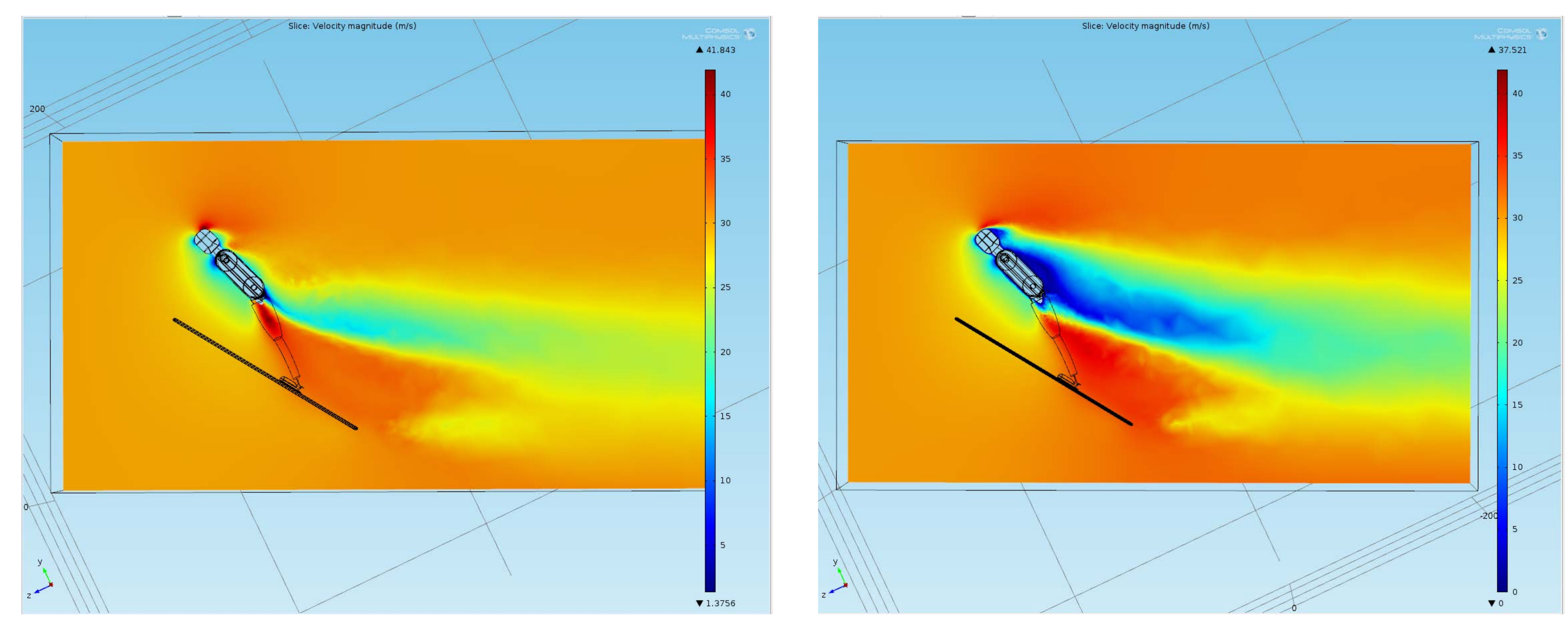


Figure 5. Variation of L and D with α for γ = 160, V = 35 and δ = 0˚



(a) k-ε turbulence model (b) SST turbulence model

Figure 6. Velocity magnitude plot using a predefined coarser mesh

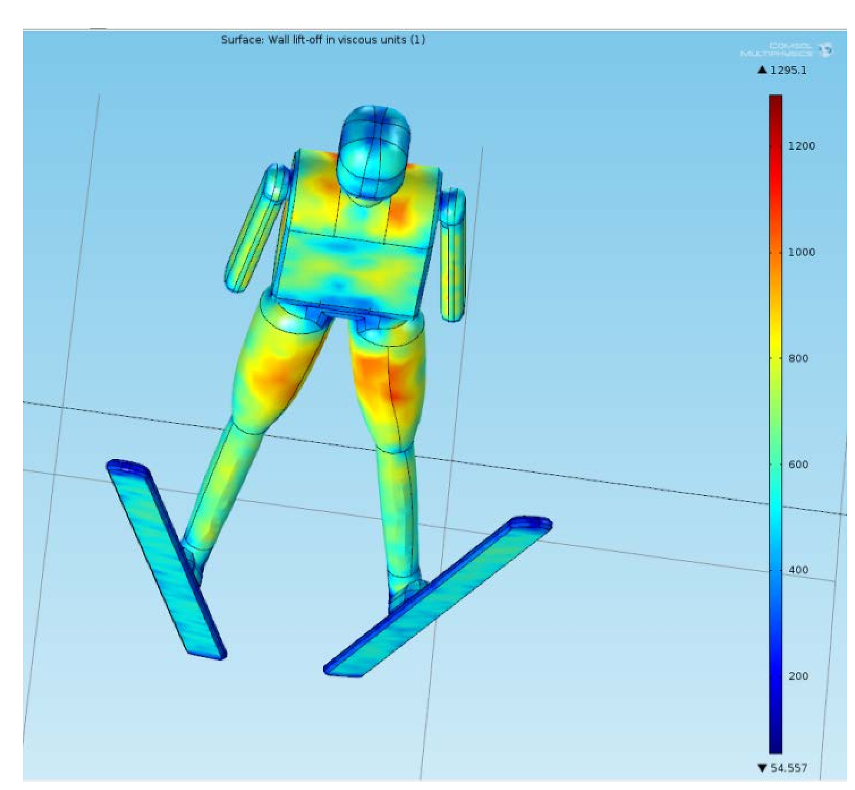


Figure 7. Wall lift-off plot of the k-ε model (predefined coarse mesh)

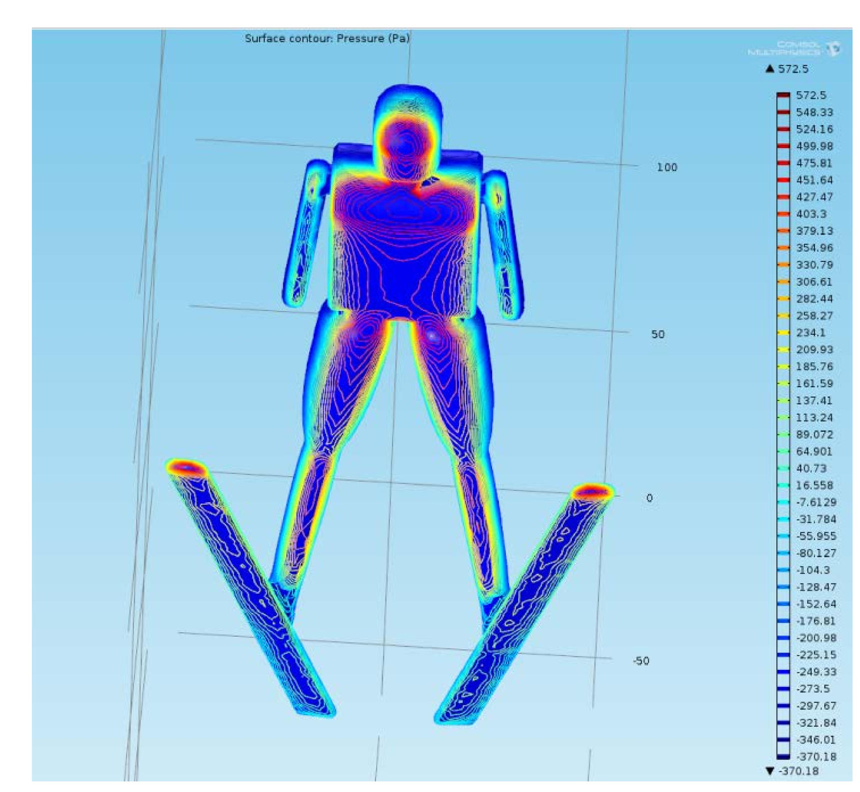


Figure 8. Contour pressure plot for the SST model (predefined coarser mesh)

Figure 5 shows the variation of the lift area, L and drag area, D with α, for β equal to 15 and 20. The graphs of all models exhibit similar characteristics to measurements made on Andreas Goldberger, World Cup winner 1994/95.

Examination of the flow velocity profiles of the two turbulence models (Figure 6) show a significant difference in the wake developed even though the parameters for both were the same.

The wall lift-off plot (Figure 7) ranges from 54 to 1295 viscous units which indicates that the result for this model is inaccurate because the mesh at the wall of the computational model is not fine enough. A value of 11.06 is desired.

Conclusions:

- Drag area, D increased as the angle of attack, α increased when all other angles were held constant.
- Lift area, L increased to a maximum and then decreased as the angle of attack, α increased when all other angles were held constant.
- L and D had similar values when α = 30, γ = 160, V = 35, β = 15˚
- The model may be improved by refining the mesh size around the wall of the computational model and adding further geometric complexities.

References:

1. W, Meile et al. Aerodynamics of ski jumping: experiments and CFD simulations. Experiments in fluids, 41(6), 949-964. (2006).
2. Wolfram, Müller. Performance factors in ski jumping. Sport Aerodynamics: CISM Courses and Lectures, Vol 506, 139-160. (2008).

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