Turbulence modelling investigation for 3.5:1 prolate spheroid using adaptive-mesh refinement in OpenFOAM®

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During regular flight airships are often subjected to crosswinds, causing high angles of attack and sideslip. The associated flow phenomena are typical for bluff bodies and include three-dimensional separation from smoothly curved surfaces as well as complex wake topologies. The flow is strongly dependent on the Reynolds number, with laminar-to-turbulent transition being an additional factor.

As an initial study to develop simulation best practice for realistic airships, a prolate spheroid with a major-to-minor axis ratio of 3.5:1 is investigated here. The geometry is based on a model that has been studied numerically and experimentally by Carbone et al. [1], and features the support strut used in the wind tunnel campaign. The investigated Reynolds number based on the major axis length is $Re_L = 2.57 \times 10^6$, where simulated angles of attack range from 0° to 35°. Extensive experimental benchmark data is available for validation, which includes both force / moment coefficients as well as surface pressure measurements along different sections of the spheroid.

Two aspects of the numerical setup are assessed in particular, i.e. the turbulence modelling approach and the grid resolution sensitivity of the CFD solution. Different RANS models are evaluated, ranging from standard linear eddy viscosity models such as k-ω SST to more elaborate approaches such as the elliptic-blending lag model of Lardeau & Billard [2], which seeks to model the misalignment of the principal components of the strain and stress tensors using additional transport / Laplacian equations. The grid resolution study is centred around an adaptive-mesh refinement (AMR) strategy developed by Upstream CFD, where volume refinement is performed automatically for each respective flow angle based on a generally-applicable sensor function [3] and starting from a base surface grid (see Figure 1). This allows the grid to be tailored to each flow angle individually, thus saving computational resources as well as accounting for the changing flow topology without additional user input. The base grid is generated using snappyHexMesh, where both low-Re ($y^+_{max} < 1$ with ~ 30 prism layers) as well as hi-Re grids are compared ($y^+ \sim 30$ with wall functions).

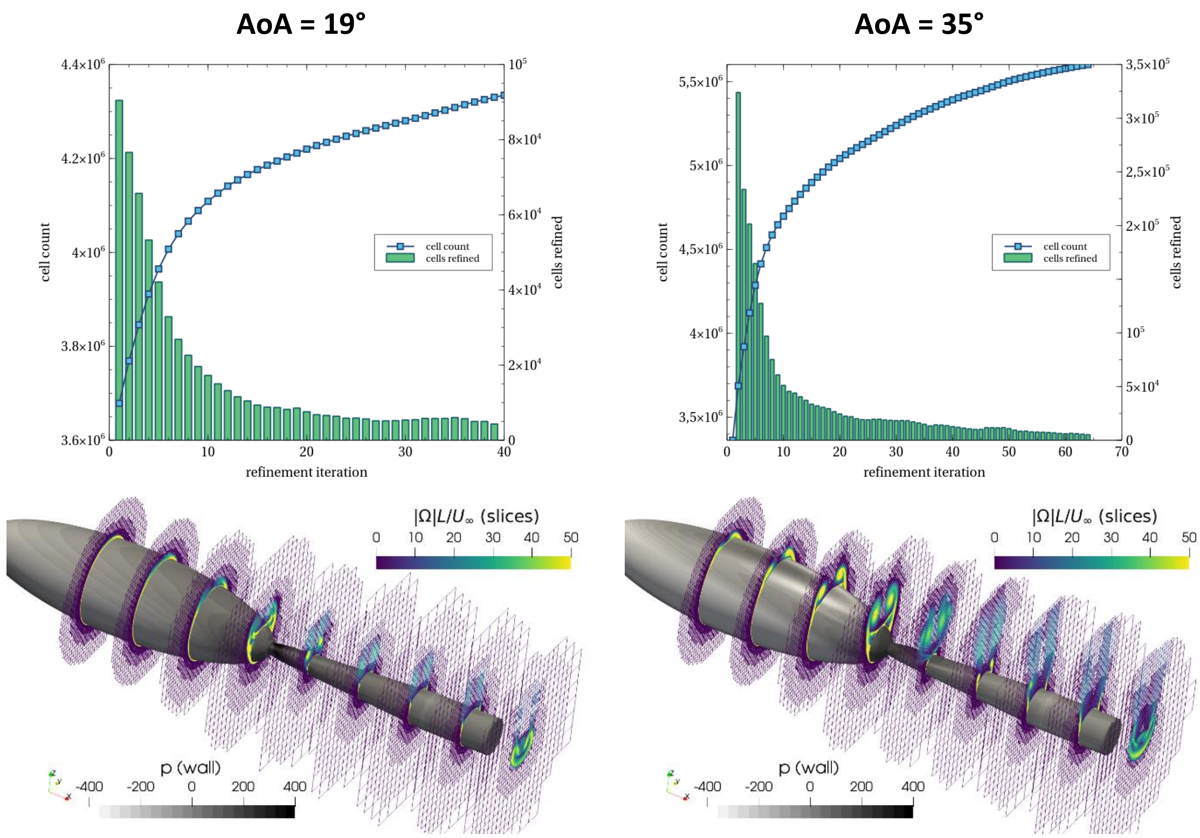

Figure 1: Preliminary results for prolate spheroid test case using the SST-RANS model with adaptive mesh refinement in OpenFOAM®. Top row: Generated additional cells per AMR refinement iteration. Bottom row: Slices through RANS solution showing vorticity magnitude and final grid resolution.

References

[1] G. Carbone, G. Martinat, D. Farcy, J.L. Harion: *Aerodynamic investigation of a 3.5:1 prolate spheroid*, to be presented at AIAA Aviation 2020.

[2] S. Lardeau, F. Billard: *Development of an elliptic-blending lag model for industrial applications*, 54th AIAA Aerospace Sciences Meeting, 4-8 January 2016, San Diego / CA

[3] M. Fuchs, T. Knacke, C. Mockett: *DES and Adaptive-Mesh RANS Simulations for the SAE Notchback Case using OpenFOAM®*, Contribution to 1st Automotive CFD Prediction Workshop, 11-12 December 2019, Oxford / UK.