Optimization of Sail Settings using RBF Mesh Morphing

Mechanical Engineering Degree Thesis

Enterprise Engineering Dept, University of Rome "Tor Vergata"

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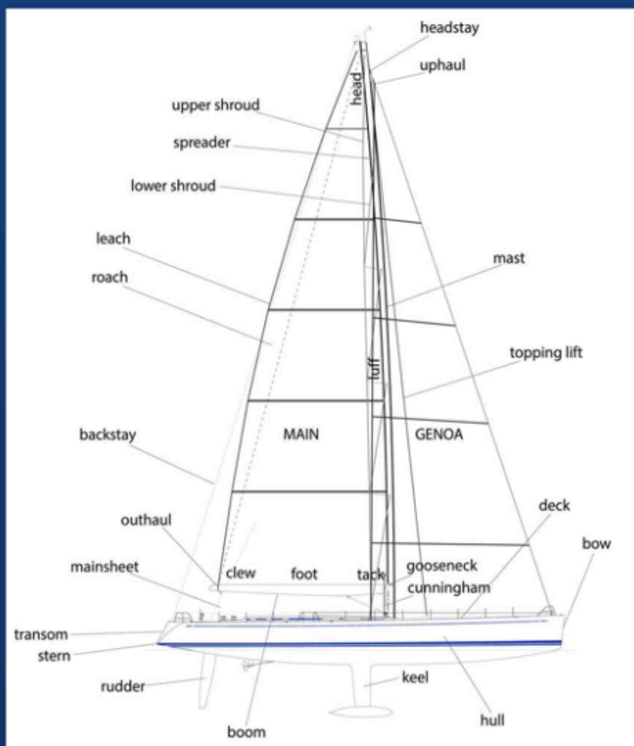
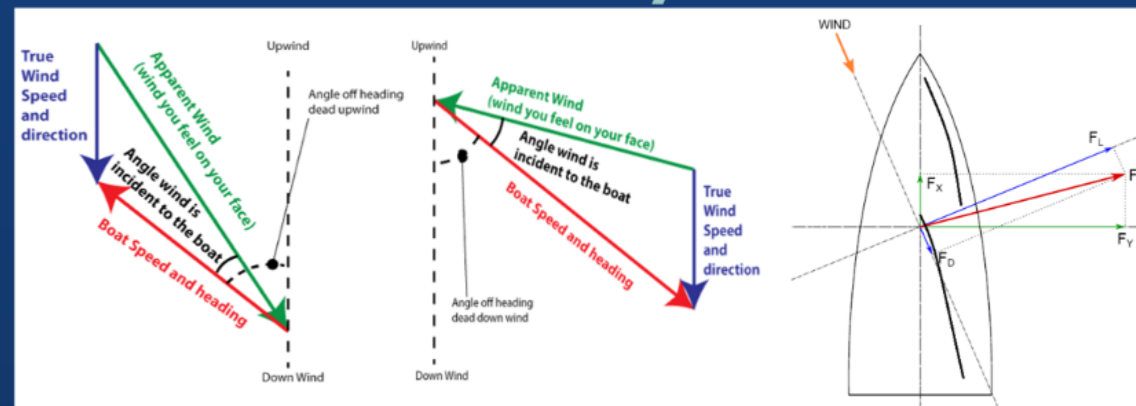
Introduction to Sail Aerodynamics



Drawing of a Swan 80 FD, © Nautor Holding.



Vector diagrams of wind speed, vessel speed and aero dynamical forces.

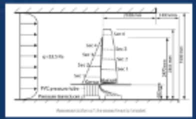
$Cl = Fl/(0.5d(v^2)S)$; $Cd = Fd/(0.5d(v^2)S)$;

$Cx = Fx/(0.5d(v^2)S)$; $Cy = Fy/(0.5d(v^2)S)$.

Method

The *CFD* Model

Virtual model based on a past experimental wind-tunnel simulation



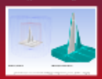
- AC33-Class 2007 Luna Rossa Challenge
- 1,443,840 exahedrical cells mesh
- ANSYS Fluent® 14.0
- RANS Newtonian incompressible with solver pressure and finite volumes based solver
- k-eps SST for low Re
- SIMPLEC schematic combination pressure-speed

Mesh Morphing Elaboration

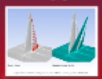
Elaboration of the mesh geometry morphing with the use of RBF Morph™ libraries installed on ANSYS Fluent®.
This is based on RBF algorithms which allow an effective and efficient shape modification and volume smoothing of the mesh parametrized geometry.

mainsail and genoa sheeting angles

apparent wind angle



heeling angle



Set-up & Run of the *DOEs*

Two different tables were generated:

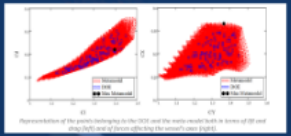
16-*dp DOE*)
- low-density
- high range exploration
- one parameter per time modification

100-*dp DOE*)
- high-density
- low range exploration
- all parametrs toghether modification

The project tables' computation was carried out using DesignXplorer within ANSYS Workbench. that interacts with Fluent®.
Different strategies of computational resources expenditure were faced, with different hardware stations.

Response Surface Creation

A meta-modelling approach was used to drive the interpolation through the resulting output points obtained by the *CFD* processing of the *DOEs'* input points. This *RBF* based method allowed the estimation of a very accurate continuous-fashion response surface.



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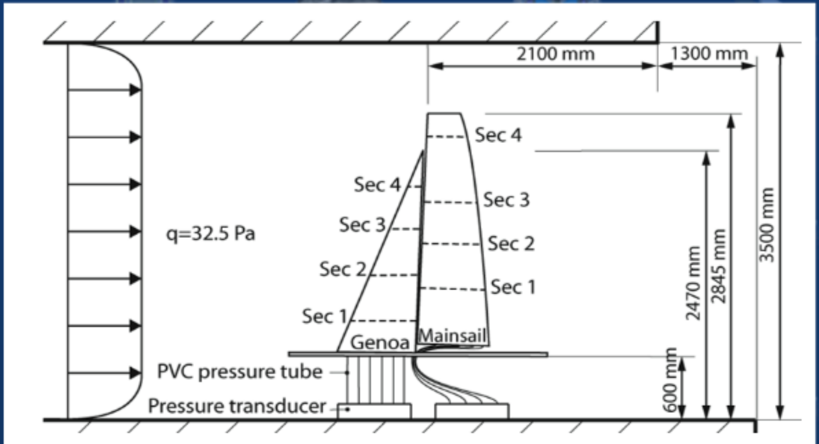

Representation of the experimental model.

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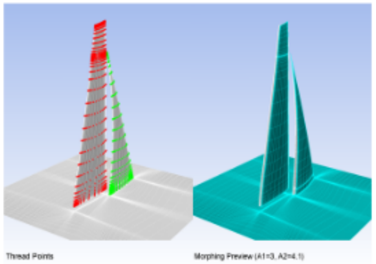
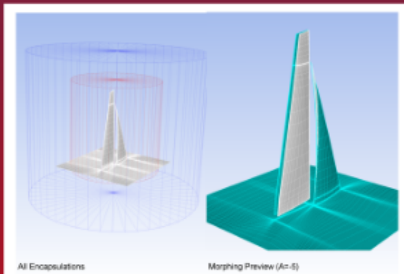


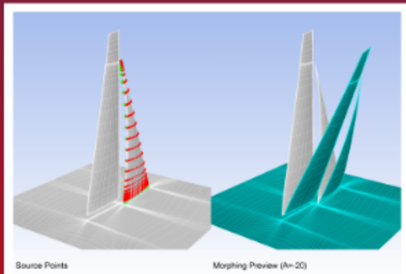
Thread points (left) and morphing preview set with the amplification values above (right).

apparent wind angle



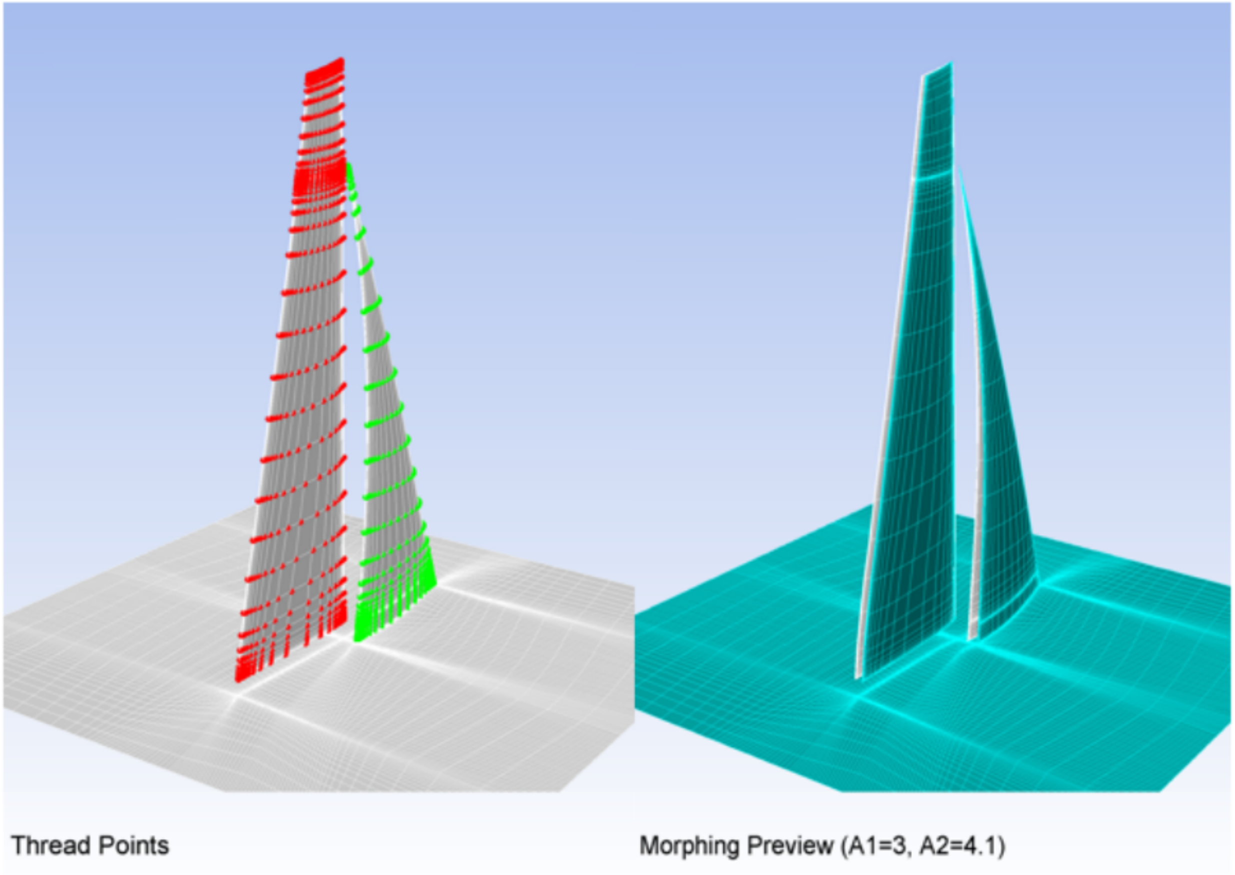
Cylindrical encaps used to control the AWA (left) and deformation preview @ AWA = 5° (right).

heeling angle



Surface set to control the heeling angle on genoa (left) and morphing preview @ 20° (right).

mainsail and genoa sheeting angles



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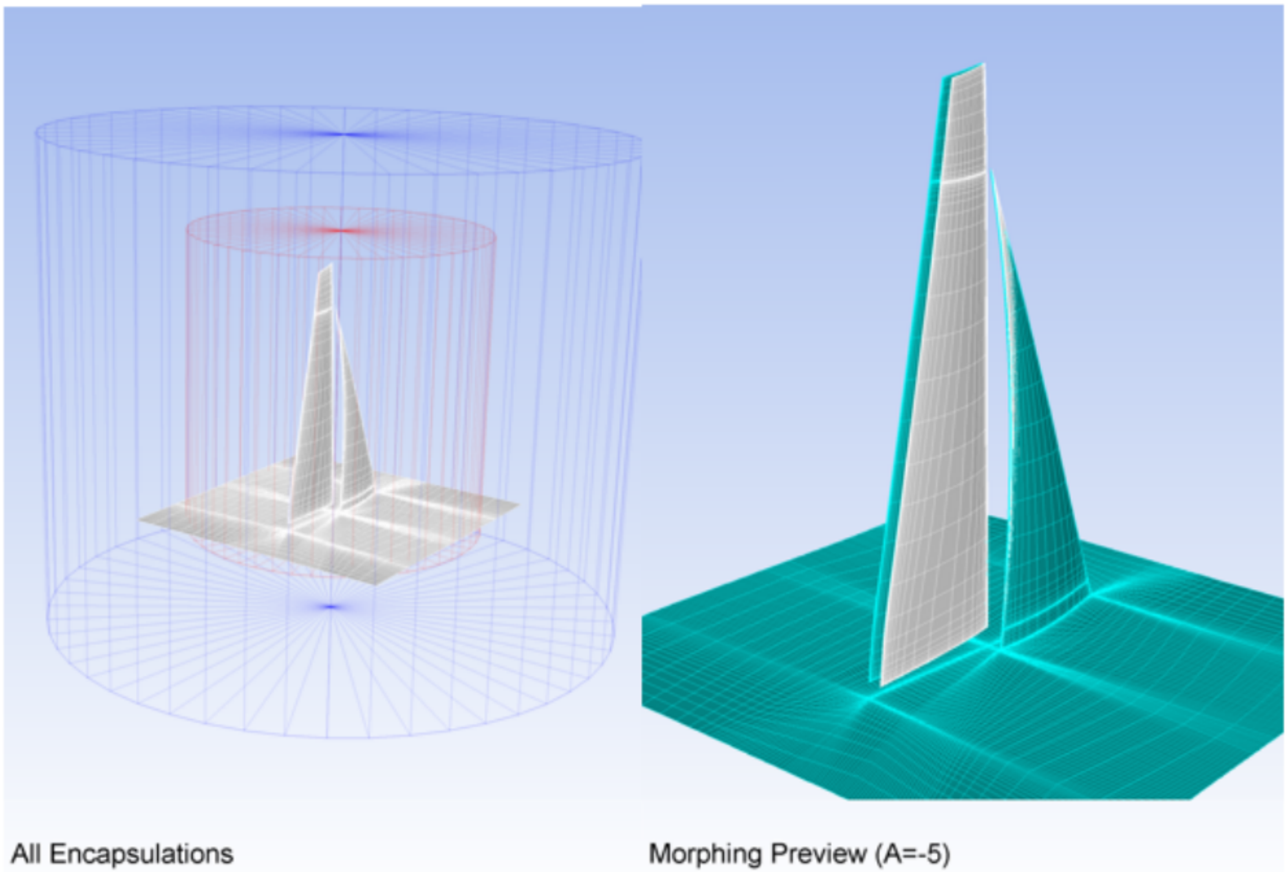

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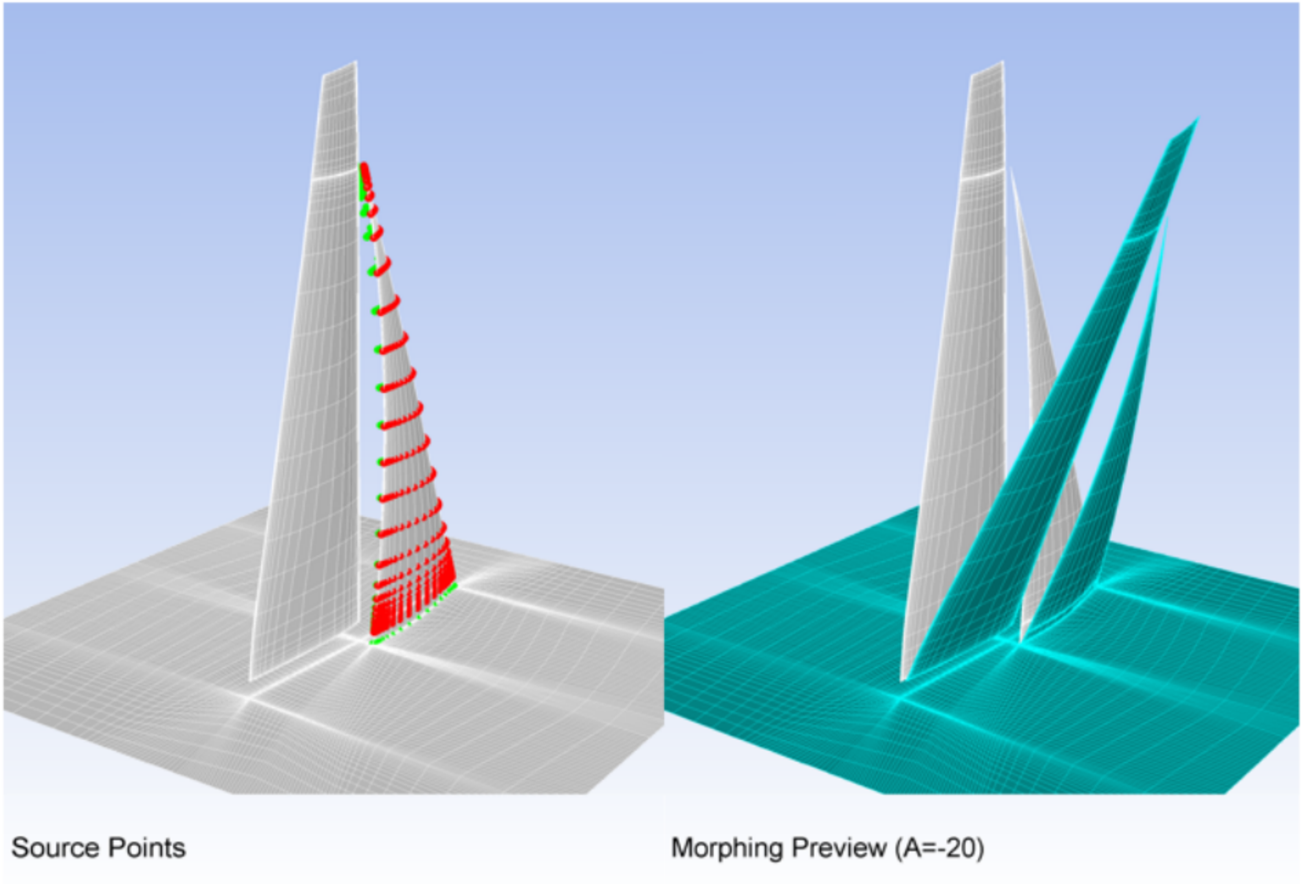

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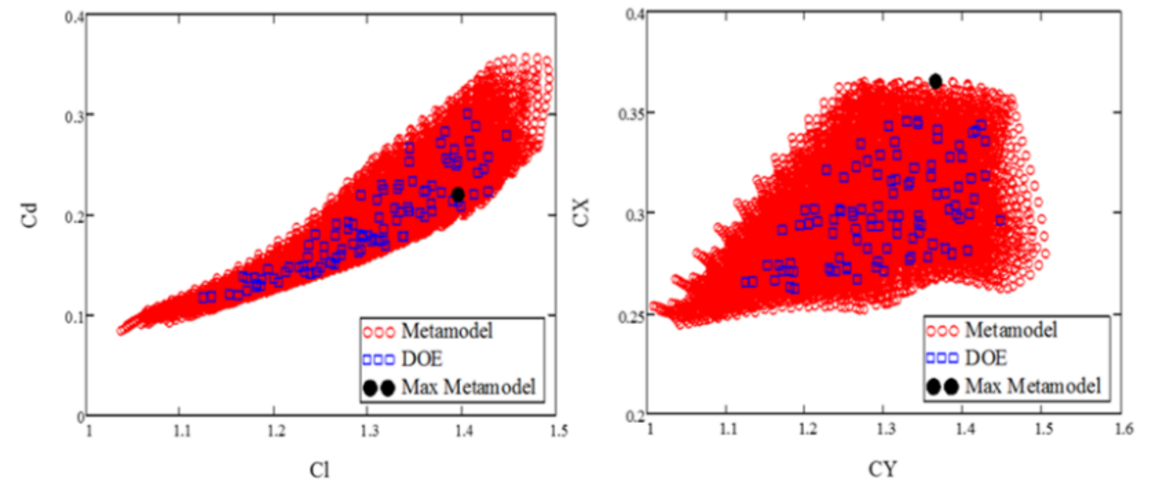
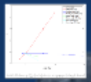


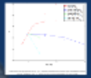
Representation of the points belonging to the DOE *and the meta-model both in terms of lift and drag (left) and of forces affecting the vessel's axes (right).*

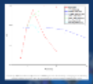
Results

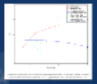
Sensitivity Analysis

Sensitivity analysis was undertaken both on the 16-dp table, and on the response surface created out of the 100-dp table.









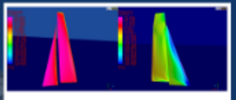
Optimization Process

Analysing the response surface thus obtained we can determine an optimal point defined as follows:

- mainsail sheeting angle = 3°
- genoa sheeting angle = 5°
- AWA = 24°
- heeling angle = 0°

- Cd = 0.220
- Cl = 1.397
- Cx = 0.366
- Cy = 1.366

A complete CFD computation of the project point in question, defined by the aforementioned input values, was performed. With the exception of the heeling angle, which was set as 8°, in order to undertake fluid dynamic post-processing analysis with ANSYS CFD-Post.



Map of the absolute pressure on the upwind side (left) and downwind side (right).

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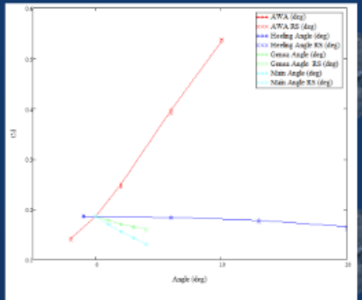
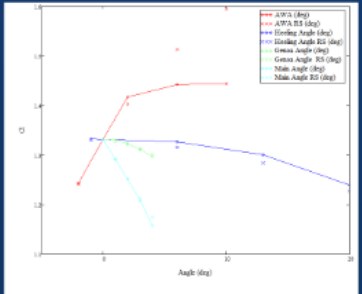
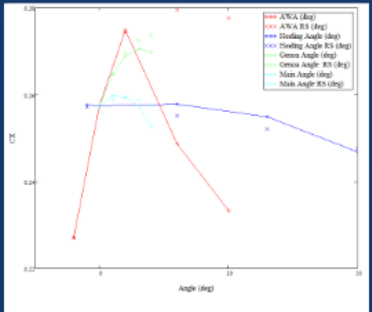


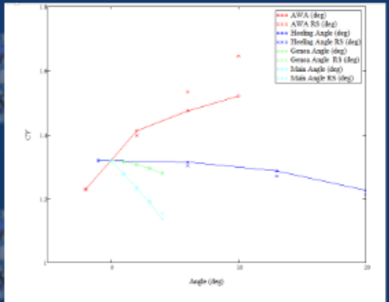
Sensitivity of the drag versus AWA (referred to the baseline), heeling angle and sheeting angle of mainsail and genoa. The "RS" values are the ones interpolated with the meta-model.



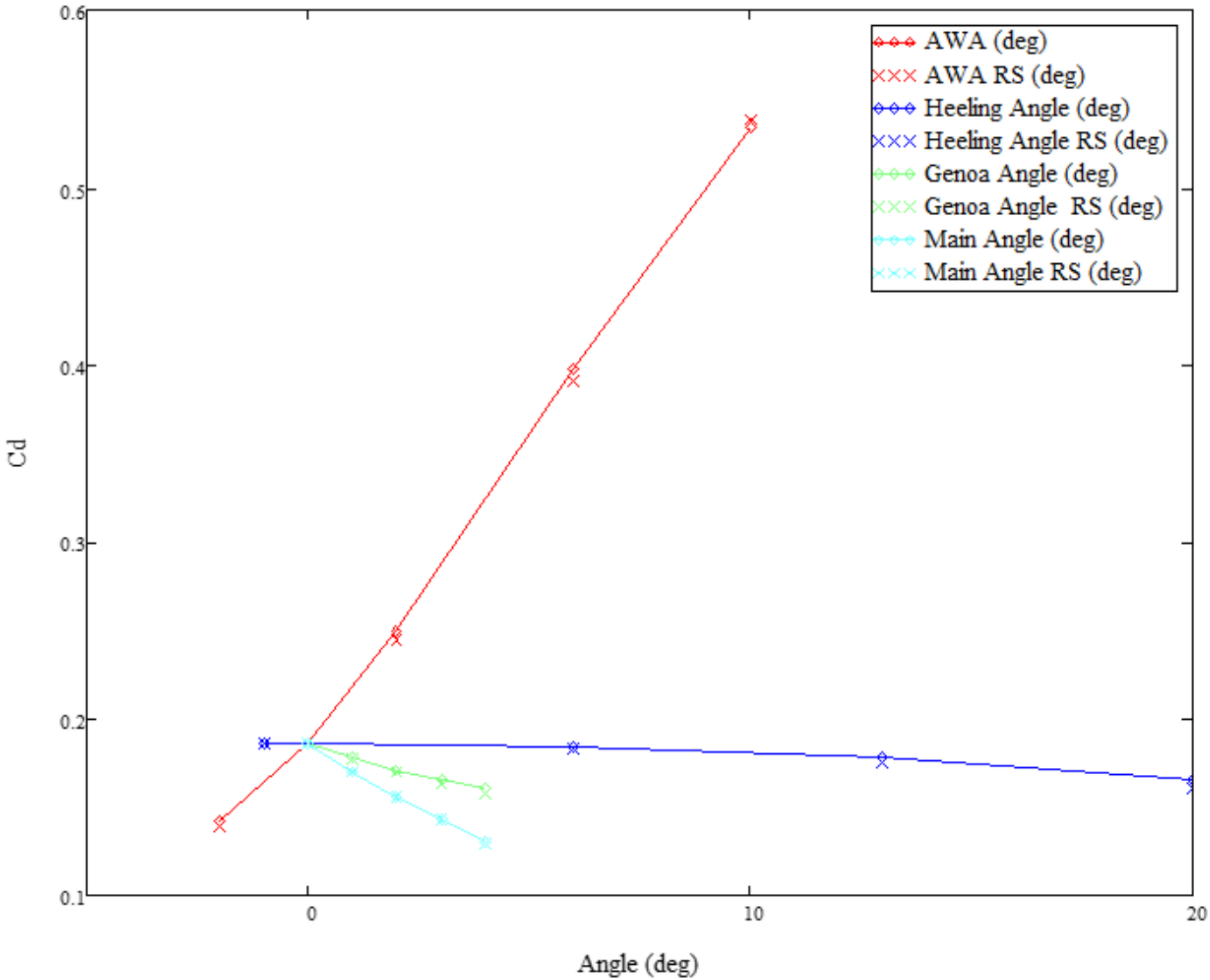
Sensitivity of the lift coefficient versus AWA (referred to the baseline), heeling angle and sheeting angle of mainsail and genoa. The "RS" values are the ones interpolated with the meta-model.



Sensitivity of the propulsive coefficient versus AWA (referred to the baseline), heeling angle and sheeting angle of mainsail and genoa. The "RS" values are the ones interpolated with the meta-model.



Sensibilities of the lateral thrust coefficient versus AWA (referred to the baseline), heeling angle and sheeting angle of mainsail and genoa. The "RS" values are the ones interpolated with the meta-model.



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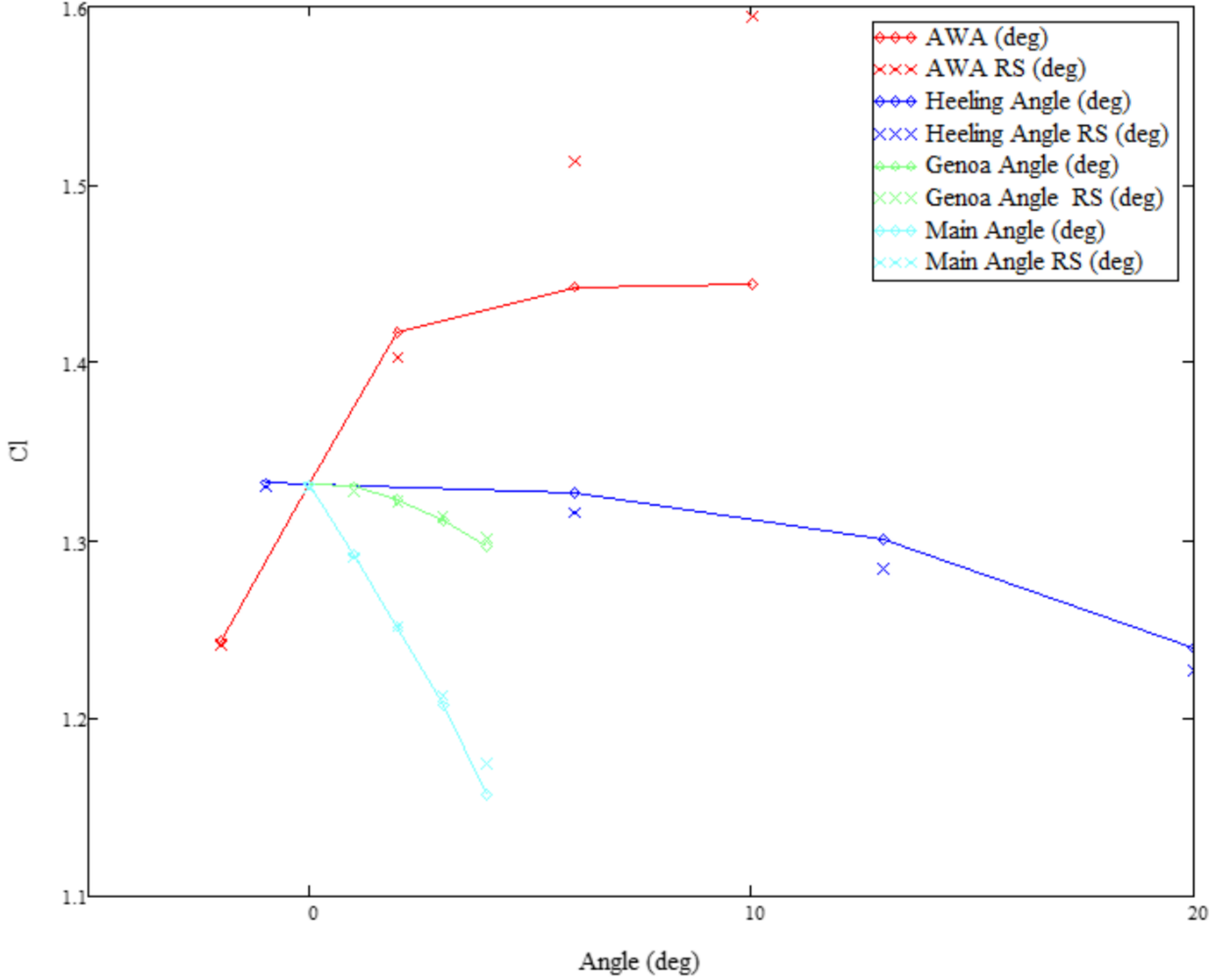

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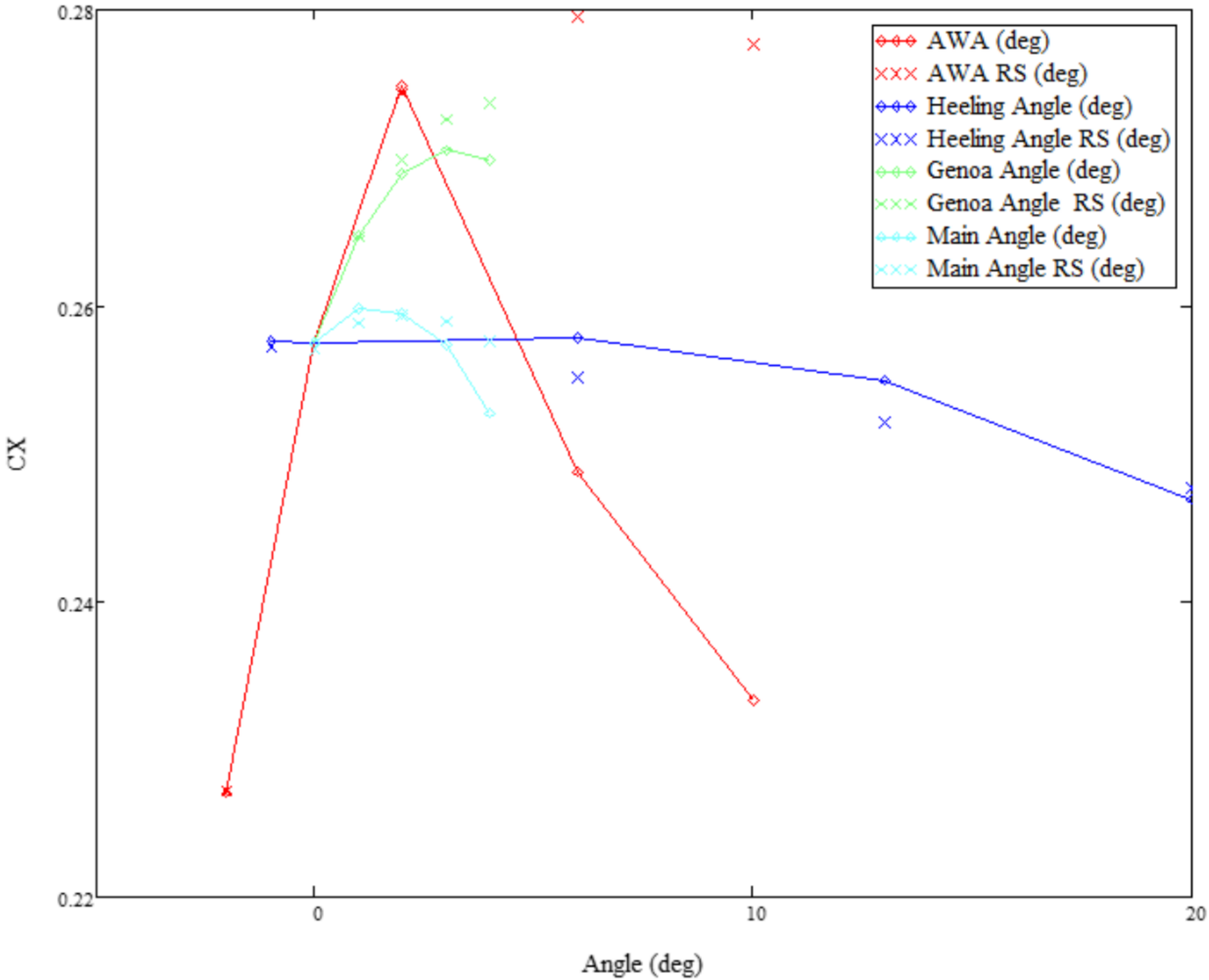

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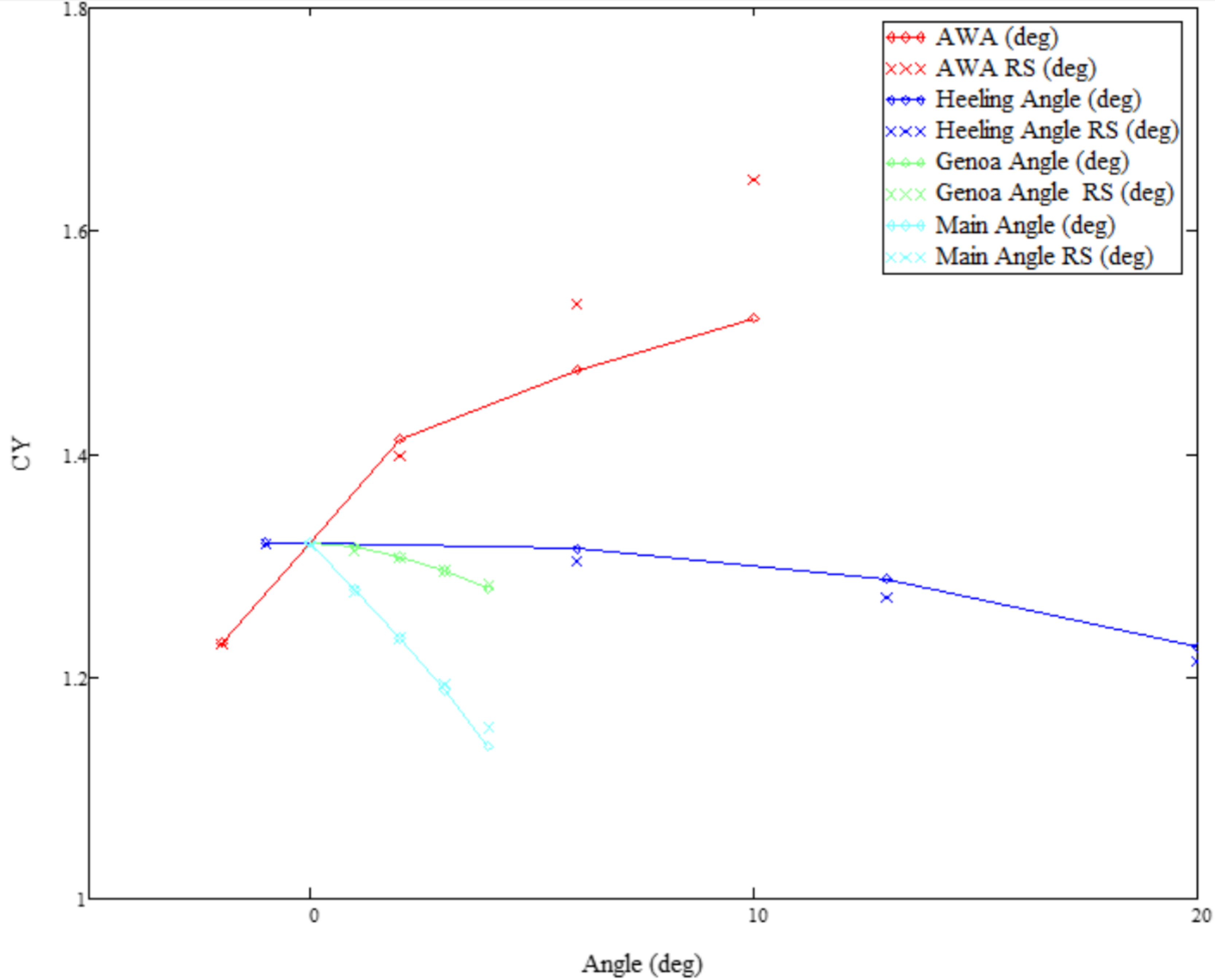

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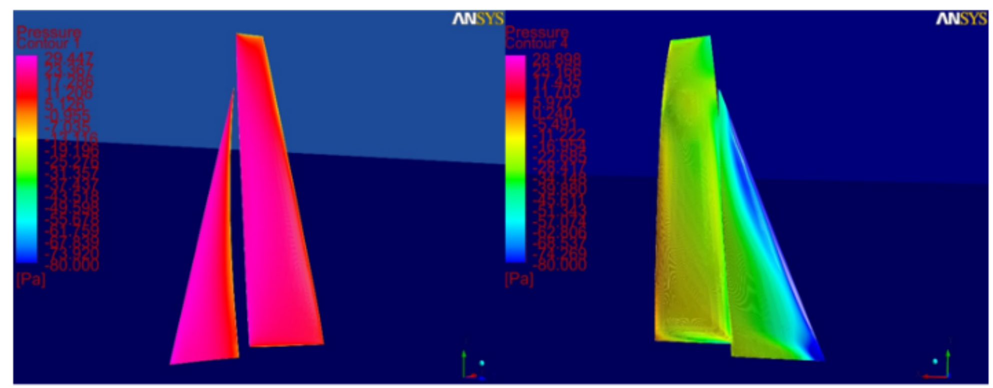

Map of the absolute pressure on the upwind side (left) and downwind side (right).

Possible Developments

The approach can easily be extended by increasing the complexity of the shape modifications and/or the complexity of the system itself. The compilation methods of the *DOE* tables and of estimation of the response surfaces can be utilised to carry out future experiments and as an instrument to represent in a rapid and effective manner the response of the sails to different adjustments, either within a *VPP* mission simulator, as an online tool for controlling the sails in real time, or as an evaluation tool for the adjustments obtained from rapid computational analysis overlaying images of real world conditions for joint verification.

The Rome Racing Team (Team for which the Author is Helmsman and Team Manager) during training in the home spot with a digital overlap of an image of RBF mesh morphing of the sails in a sequential multi-step amplification at different heeling angles. Photo by Luca Rossini Photographer, ©Rome Racing Team.