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# RANS CALCULATIONS ON SUBMERGED BODIES

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**Abstract:** *The study of the total resistance of a submerged body is a matter of interest not only for the development of submerged vehicles like submarines or ROV, but also for the study of particular appendages that are fitted on a vessel, like a sonar dome or the under-keel of a sailing yacht. For this purpose RANS calculations can give an accurate estimate of the resistance without too much calculation effort. To perform an accurate estimate, a validation study, using STARCCM+ solver, has been carried out on a standard geometry of the 58 Series. The validated mesh has been used for the resistance evaluation of a new body.*

**Keywords: CFD calculations, Validation study, 58 Series, Submerged body.**

## 1. Introduction

The determination of the resistance of a fully submerged body can be determined by means of different kind of approaches. Once it will be not possible to perform dedicated model tests on the selected geometry, use can be made of systematic series. For the particular case of a submerged body, the only available material covering a wide range of geometries is the 58 Series (Gertler, 1950). Once the selected geometry is not falling inside the definition range of the series, dedicated calculation should be performed. Calculations can be made by means of codes based on non-lifting potential theory (Hess and Smith, 1964), where viscous effects are not directly considered, or an approach based on RANS equation can be used. For this purpose STARCCM+ solver has been used to determine the total resistance of a submerged body. Prior to the effective calculation, a validation study has been carried out to determine calculation uncertainty and mesh independence on geometry of the 58 Series, where model test data were available. Thereafter the same settings of the validated mesh have been used to determine the resistance of a new submerged body having geometrical parameters different from the 58 Series ones.

## 2. Geometry of the submerged bodies

The geometries selected for this study are the 4164 hull of the 58 Series and a generic body (named SB01) designed to be used as sub-keel appendage on a sailing yacht for ORC competitions. The main dimensions of the two geometries are reported in Tab. 1 and an overview is given in Fig. 1.

*Tab. 1: Main dimensions of 4164 and SB01.*

| | Symbol | 4164 | SB01 | unit |
|---|---|---|---|---|
| Length overall | *L* | 2.7432 | 2.7432 | m |
| Maximum Diameter | *D* | 0.3919 | 0.4040 | m |
| Wetted Surface | *S* | 2.726 | 2.611 | $m^2$ |
| Volume | $\nabla$ | 0.231 | 0.216 | $m^3$ |
| Length diameter ratio | *L/D* | 7.000 | 6.790 | - |

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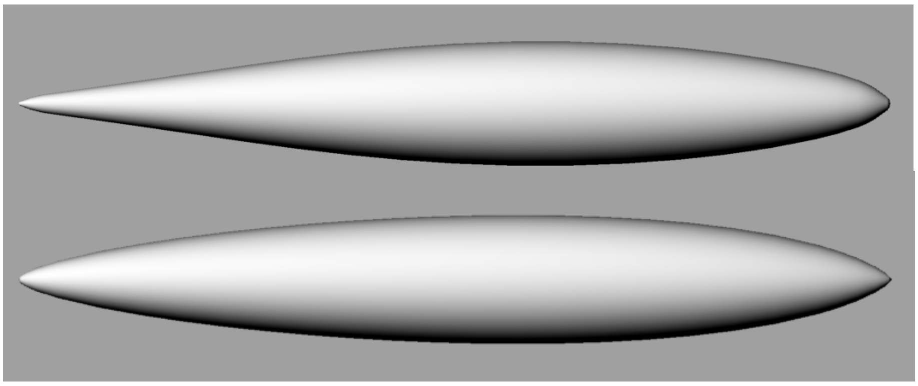

*Fig. 1: 4164 (top) and SB01 (bottom) geometries.*

The geometries are streamlined bodies of revolutions; all the hulls of the 58 Series got this peculiarity and the designers of SB01 decided to maintain this configuration to reduce construction costs. For the calculations this will be also an advantage because in such a case just a quarter of domain can be modeled, reducing consequently the calculation time.

## 3. Physical assumptions and Numerical setup

The total resistance $R_T$ of a deeply submerged body can be split in a contribution given by shear stress $R_S$ and a second one given by normal stress (pressure) $R_P$. In absence of a free surface, gravitational effects (waves generation) can be neglected and both two components can be considered function of the Reynolds Number *Rn* without other dependency. Due to the streamlined shape of the geometry, a steady flow assumption has been adopted for the calculation, selecting a segregated approach for the RANS equations solution, using Rhie-Chaw interpolation for pressure-velocity coupling. The effect of turbulent fluctuations on the mean flow has been approximated by realizable $k$-$\varepsilon$ turbulence model. A three-dimensional rectangular domain has been used to represent the calculation environment. Because of the geometry symmetry and the deeply-submerged condition of the body, the domain takes in consideration the symmetry on vertical and horizontal plane, means that only a quarter of body and total domain are modeled. The finite volume domain is than meshed with a trimmed cell method, where a block refinement was inserted to capture with more detail the geometry wake and the flow around the body. A prism layer mesh has been adopted in the near-wall region, to generate orthogonal prismatic cells close to the body surface. The total prism layer thickness is obtained from geometrical progression of step *Pls* starting from the first cell thickness, calculated in such a way to reach a target $y^+$ of about 55 at all the *Rn* of the simulations. In order to obtain a mesh usable for different kind of geometries all the mesh parameters have been parameterized on the length *L* of the body to analyze, these parameters are reported in Tab. 2. As mentioned the right and the top side of the domain have been set as symmetry plane while the other faces are considered as velocity inlet, despite the pressure outlet on the backside. All the calculations have been carried out considering fresh water as reference fluid with a density $\rho$ of 997.561 kg/m$^3$ and a dynamic viscosity $\mu$ of 8.887 Pa s.

*Tab. 2: Main mesh parameterization details.*

| | **Symbol** | **value** |
|---|---|---|
| Domain length | $L_D$ | 5 L |
| Domain breadth | $B_D$ | 1 L |
| Domain height | $H_D$ | 1 L |
| Number of prism layers | *Npl* | 8 |
| Prism layer stretching | *Pls* | 1.3 |

## 4. Validation study on 4164 geometry form and SB01 resistance calculation

As first step of the validation study on 4164 geometry, a mesh sensitivity study has been carried out. The aim of this first investigation is to find a mesh where the discretisation error can be considered negligible.

In fact the numerical error consists of three parts (Roache, 1998): the iterative error, the round-off error and the discretisation one. The iterative error is related to equations resolution and can be discarded once solution convergence reaches machine accuracy (possible to obtain in steady state calculations). To estimate the discretisation error use has been made of the Grid Convergence Index (GCI) and Richardson Extrapolation of the real value (Eça et al., 2004). The selected speed for the sensitivity study is corresponding to *Rn* 1.2 E7, and a total of 6 meshes have been studied considering a base size refinement ratio of 1.25 per each mesh, resulting in a total number of cells going from 181380 up to 3870976. As it can be seen in Tab. 3, the results of the grid convergence study show that grid 2 is sufficient to ensure the grid independency for the total resistance $R_T$ estimation on the tested velocity.

*Tab. 3: Mesh sensitivity study results.*

| Grid | N°cells | $B_S$ | Ref ratio | $R_T$ (N) | GCI |
|---|---|---|---|---|---|
| 1 | 3870976 | 0.168 *L* | - | 53.39 | - |
| 2 | 2076984 | 0.210 *L* | 1.25 | 53.40 | 0.043 |
| 3 | 1118676 | 0.263 *L* | 1.25 | 53.44 | 0.085 |
| 4 | 581647 | 0.328 *L* | 1.25 | 53.57 | 0.266 |
| 5 | 328805 | 0.410 *L* | 1.25 | 53.84 | 0.654 |
| 6 | 181380 | 0.513 *L* | 1.25 | 53.94 | 0.837 |

Then, considering *E* the difference between the experimental data and the simulation, and $U_{TOT}$ the total uncertainty of the process (evaluated as the norm within numerical and experimental uncertainties), the simulation can be considered validated when the condition $|E|<U_{TOT}$ is satisfied. Assuming an experimental uncertainty of 2.5 % on the measured data (ITTC, 2011), the validation process has been carried out on a speed range from *Rn* 6.0 E6 to 2.4 E7and is reported in Tab. 4.

*Tab. 4: Validation study on 4164 geometry (E and $U_{TOT}$ expressed as $\%R_T$).*

| *Rn* (-) | *V* (m/s) | $R_T$ (N) | $R_{T58}$ (N) | $\|E\|$ | $U_{TOT}$ | Validated |
|---|---|---|---|---|---|---|
| 6.0 E6 | 1.910 | 14.37 | 13.91 | 3.307 | 3.380 | YES |
| 8.0 E6 | 2.546 | 25.05 | 24.80 | 1.008 | 3.420 | YES |
| 1.0 E7 | 3.183 | 38.02 | 38.04 | 0.001 | 3.439 | YES |
| 1.2 E7 | 3.819 | 53.40 | 54.27 | 1.603 | 3.468 | YES |
| 1.4 E7 | 4.456 | 71.25 | 72.24 | 1.370 | 3.463 | YES |
| 1.6 E7 | 5.093 | 91.47 | 92.83 | 1.465 | 3.465 | YES |
| 1.8 E7 | 5.729 | 114.01 | 115.57 | 1.350 | 3.463 | YES |
| 2.0 E7 | 6.366 | 138.87 | 140.78 | 1.357 | 3.463 | YES |
| 2.2 E7 | 7.002 | 165.99 | 168.63 | 1.566 | 3.467 | YES |
| 2.4 E7 | 7.639 | 195.35 | 198.63 | 1.651 | 3.469 | YES |

For the analyzed geometry the resistance curve is validated through all the selected speed range of interest. Adopting a mesh as the one validated for 4164 geometry, simulations were carried out on the SB01 through the validated speed range. Because the length L of the second geometry is equal to 4164 (see Tab. 1), the meshes result with the same dimensional parameter of the validated ones through all the speed range. In Fig. 3 the obtained resistance curve is presented and compared with the 4164 experimental and numerical results. As it can be seen the resistance level of the new geometry is higher than the 4164 hull. 4164 is the Series 58 geometry closer to SB01. By simply adopt the series as a reference the non dimensional coefficient $C_T$ of the 4164 can be scaled on the new geometry considering the new wetted surface of SB01. The change of volume can be also considered by scaling the speed according to the volumetric Reynolds number. By means of this process the total resistance $R_T$ would have been underestimated for the new geometry because both volume and wetted surface are lower than 4164 ones. A comparison between the pressure patterns along the two hulls is presented in Fig. 2, showing the differences in the pressure distribution at the same *Rn* for the two geometries.

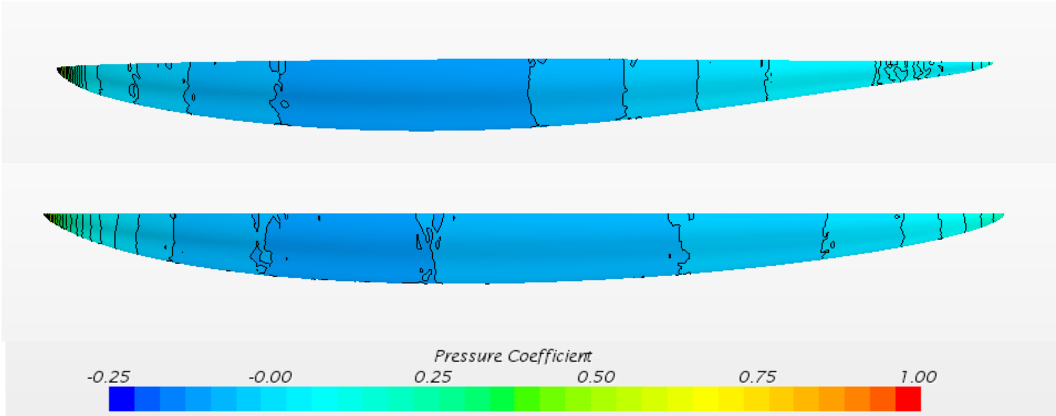


*Fig. 2: Pressure distribution on 4164 (top) and SB01 geometries at Rn 1.2 E7.*

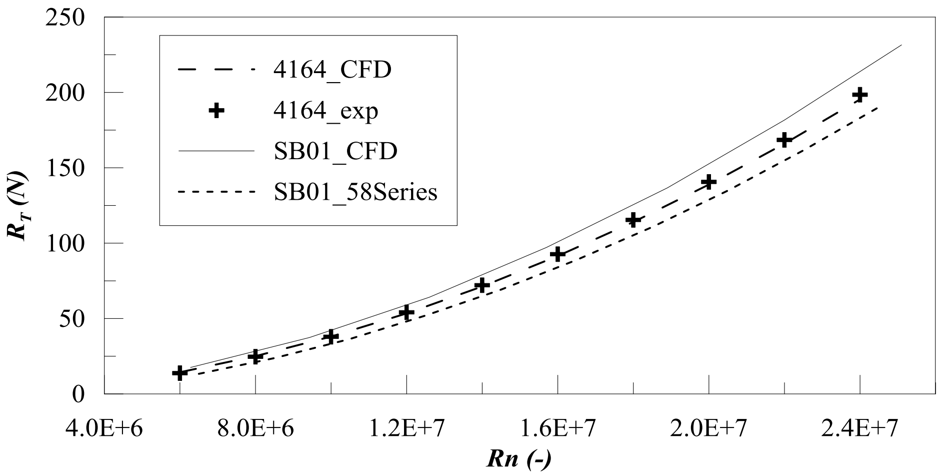


*Fig. 3: Comparison between the calculated resistance curves.*

## 5. Conclusions

The current work highlights that RANSE based method are for sure reliable for the total resistance prediction of a submerged body. However the reliability of the equation solver on the discrete domain should be validated with a correct methodology on standard test cases. Just a comparison between a measured and a calculated quantity is not sufficient to ensure the validation of a resistance curve. The present work is a starting point to perform different kind of analysis also on other aspects of the simulations, like the adoption of other turbulence models or the consideration of an unsteady flow condition. The obtained results for these particular bodies have to be intended as a good starting point to develop a more complex simulation on vessels with appendages, where, adopting a mesh like the validated one, the solution around the submerged appendage will give a reliable result.

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