Learning from Results: Bulb Influence on Ship Wave Resistance

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Introduction. Simulations are even more accessible by companies, helped by the reduction of the cost and the "democratization" of CFD Software. Even more engineers have a strong knowledge about the use of the CFD and companies tend to use CAE also in preliminary stage of the projects. For this reason, it is necessary to extrapolated most information as possible from the exploration phases and previous projects. A good **post-processing phase** is mandatory, also if normally is avoid for the amount of data, time and cost needed and the knowledge in statistic required. **Statistics** and **Big Data Analysis** tools can be imported from economics for study better and faster the project. Engineers are now helped also by more user-friendly (and open-source) software, like **Python** and **R**. With prepaid scripts, it is possible to calculate different statistical data, helping engineers in an analytic analysis of the problem. Here, as examples, **correlation** and **What-if-Analysis** are shown. In order to simplify the achievement of the huge amount of data necessary to have significant results, here two tools are proposed: **Free Form Deformation** (for the creation of different geometry) and **Polynomial** and **Kriging Surrogate Surfaces**. Two methods for decoupling the results from the deformation design variables, in order to perform different exploration on each parameter individually, are also studied.

For this project, it is exploited the influence of the **bulb** geometry on the ship resistance, using **CAESES** for the deformation of the ship, **DAKOTA** as optimizer and **ShipFlow** as solver. The graphics and the statistical analyses are later done using some simple **Python** scripts.

CAESES · SHIPFLOW for naval architects · python · DAKOTA Explore and predict with confidence

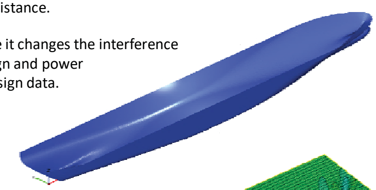
Keywords: **Optimization, Free Form Deformation, Surrogate Surface, Kriging Surface, Data Analysis, Data Post-Processing, Dakota, Python**

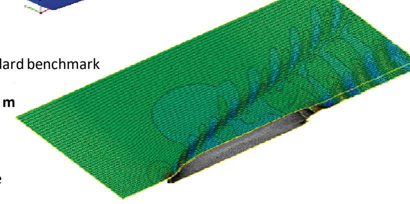
1. Main Targets of the Project.

The goal of this project is the study of some tools for the analysis of the influence of some design variables and coefficients on **CFD results**. This project would show to companies and engineers how simple can be the use of these analyses, how many different results can be achieved and try to improve their **"democratization"**.
The test case is the analysis of the bulb geometry influence on the ship resistance.

2. Baseline CAD.

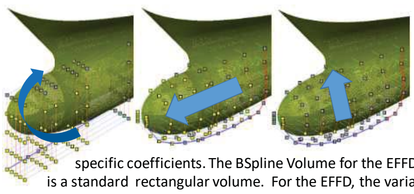
The bulb has a strong hydrodynamic influence because it changes the interference between the waves generated by the hull. Despite this, the corrected design and power prediction of ships with bulbous bow are still difficult due to the lack of design data.
This influence changes at different speeds and some bulbs have to be redesign when the ship changes her standard speed.
Some auto-adaptive bulbs are being also studied, in order to have the best hydrodynamic effect in each speed.
This problem is studied since the beginning of the naval architecture. Despite this, there isn't a common standard definition of bulb and the coefficients normally used are not standardized enough.
For this project, the modern geometry of the **Duisburg Containership**, standard benchmark for naval CFD Optimization, is used.
This ship is a **Post-Panamax 14'000 TEU Containership**, with a length of **355 m** and a beam of **51 m**. The wave resistance coefficient (CWTWC) is calculated with the BEM Solver **ShipFlow**, standard for naval studies.





3. Bulb Coefficients Definition.

Some quantitative bulb **coefficients** are necessary for delineation of the bulb form. According with **Krach** (Design of Bulbous Bow, SNAME Translation, 1978), for all practical purposes, only **6 coefficients** are necessary, three linear and three nonlinear. Despite this, they are not analytically defined. In particular, there isn't a good definition of "Bulb". For this reason, it is decided to start it at L= 342 m, where the keel line starts to be curved. In order to **calculate them automatically**, a robust script in CAESES is created, using transversal sections and the waterline. These sections are later used also for the construction of the **BSpline Boxes**.

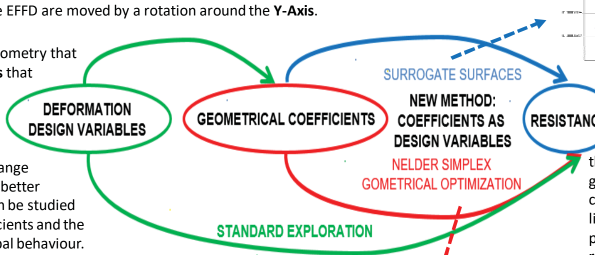


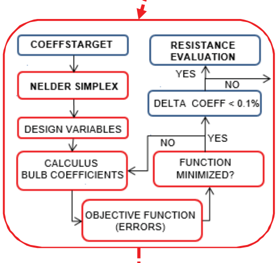
4. Free Form Deformation and Bulb Deformations.

The influence of the bulb decreases with the increase of the draft. For this reason, the Draft is fixed at the lower boundary (D=14.5m). The transformation applied has to not create bulbs with some points with a z≥14.5m. In order to improve the variety of deformation, it was decided to not use parametric deformation, but one **Free Form Deformation** with one variable and one **Extended Free Form Deformation** with two variables, not linked to specific coefficients. The BSpline Volume for the EFFD is created starting from transversal sections on the bulb. The FFD one is a standard rectangular volume. For the EFFD, the variables create a movement along the **X** and **Z-Axes**. In order to create a bigger variation in the geometries, the points of the EFFD are moved by a rotation around the **Y-Axis**.

5. Exploration.

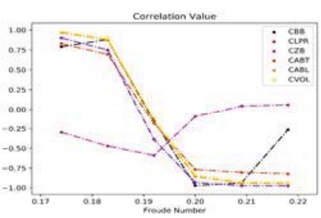
The **FFD** was chose for different geometry that can create and the **small number of design variables** that can be used. In this way, it is possible to investigate different coefficients combinations with **few simulations**. On the other hand, **is not possible** to perform an investigation directly on the geometrical coefficients: is not possible to change only one coefficient pro time in order to understand better the different influences. The trends of the results can be studied with a standard **correlation analysis** between coefficients and the resistance. It can give only a general idea of the global behaviour.
To analyze each single coefficient, two innovative methods are used: **surrogate surface** and an **exploration with a geometrical optimization as preprocessing**.





6. Correlation.

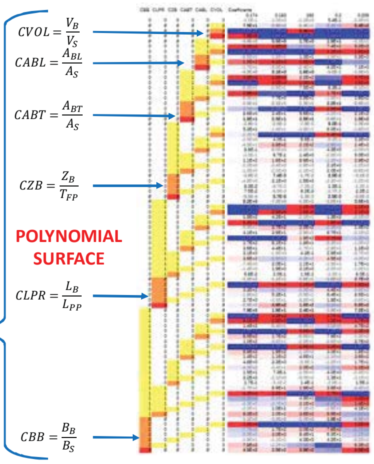
The **Pearson correlation coefficient** is a measure of the linear correlation between two variables. As supposed, the trends change at different speeds. Except of the **CZB**, it can be notice that high values of the coefficients are good for small speed and viceversa. The influences are also bigger for the extreme speeds, quite simmetrical, and similar to zero for FN 0.192. It means that the hull behind the bulb is **well designed** for that speed. The most important coefficient is quiet for all speed the **CVOL**, then the **CLPR** and **CBB**. The less important one, the **CZB**.



FN	CBB	CLPR	CZB	CABT	CABL	CVOL
0.174	0.79	0.90	-0.30	0.83	0.83	0.98
0.183	0.88	0.75	-0.47	0.69	0.69	0.89
0.192	-0.15	-0.39	-0.59	-0.18	-0.18	-0.12
0.200	-0.87	[illegible]	-0.10	-0.77	-0.77	-0.84
0.208	[illegible]	[illegible]	0.04	-0.80	-0.80	[illegible]
0.219	-0.26	[illegible]	0.06	-0.82	-0.82	[illegible]
MAX	0.88	0.90	0.06	0.83	0.83	0.98
MIN	[illegible]	[illegible]	-0.59	-0.82	-0.82	[illegible]
MAX ABS	0.97	0.97	0.59	0.83	0.83	0.98
MEDIA	-0.11	-0.27	-0.22	-0.18	-0.18	-0.16
DEV.ST	0.81	0.83	0.27	0.77	0.77	0.90

6. Surrogate Surface.

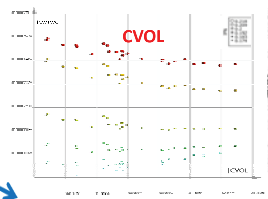
In order to decuple the resistance from the design variables, a **surrogate surface** can be used. In this case, it was used a **Kriging** and a **Polynomial one**. The coefficients of the last one (on the right, listed in column pro each different speed) can be used also to understand the coefficient influence, individually or combined. It is possible to notice that the **most influent coefficient is the CVOL**. All the coefficients that are inside the 10th or the 90th percentile (the colored ones) are coefficients related to the **CVOL**. It seems that the correlations between **CVOL and the resistance is cubic**, **positive (red) at FN 0.174, negative (blue) in the others**.

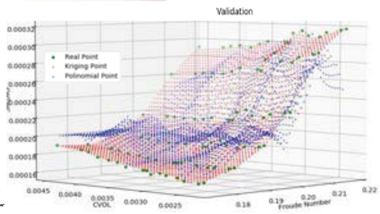


7. Surrogate Surface Validation.

The surrogate surface need a validation with **real random points**. The Kriging one shows a **small approximation error** in all points (**<1%**), instead of the Polynomial one (**<30%**), but both described the correct trends at the different speeds. The Polynomial one has a smaller error in the middle of the domain.

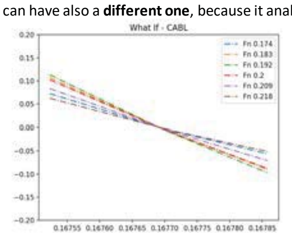
FN	% POLY	% KRIGING
0.174	14.38	0.67
0.183	22.63	0.192
0.192	16.15	0.339
0.2	22.74	0.188
0.209	29.35	0.433
0.218	27.15	0.485
MAX	29.53	0.67

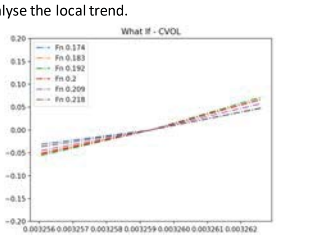


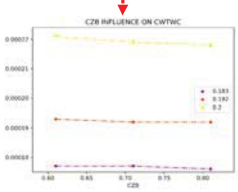


8. What-If-Analysis.

It is a technique of **sensitivity analysis** used in particular in **business and management**. It measures how changes in a set of independent variables impact a set of dependent variables. Unlike the correlation coefficient, the What-If-Analysis analyzes the **local trends**. Furthemore, since it is similiar to the gradient, it needs **three evaluations** for each variables on each points. For this resons, it is calculated on surrogate points. It answer to the question: "if the project should change a little for external reasons (i.e. tolerances, approximations and errors during the building phase, etc..) how much the **performance** will change?". It means that it tests the **robustness** of the results. As the other coefficients, it changes a lot with the speed. Normally has the same trend as the correlation coefficient, but sometimes (as the **CABL**) can have also a **different one**, because it analyse the local trend.



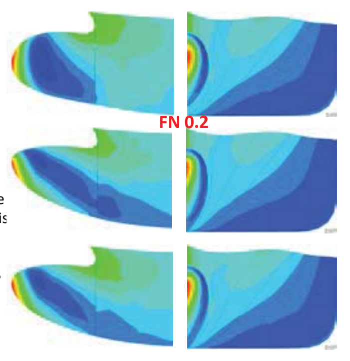




CZB	FN 0.183	FN 0.192	FN 0.2
0.61	1.77E-04	1.93E-04	2.21E-04
0.71	1.77E-04	1.92E-04	2.19E-04
0.81	1.77E-04	1.92E-04	2.18E-04

9. Exploration on Bulb Coefficients.

With the analysis of the exploration is not possible to understand the local influence of the single coefficient, on the other hand, the surrogate surface can show only numerically results, without an exploration of the **physical reason**. The solution is an **exploration on the coefficients**, with an optimization of the absolute percentage difference between the target value and the reached one as **pre-processing.** This phase is faster for the small number of the design variables. With this exploration, it can be understand the influence that have the **CZB** on the wave pattern and the pressure on the hull, also if it **has a small influence** on the resistance, as shown also by the correlation and the surrogate surfaces.



10. Analysis Discussion.

In this project is shown **how simple** can be the extrapolation of the meaning of the results with the use of different tools. It is shown how can be done a global or local analysis and how can be performed an exploration on coefficients different from the original design variables **with surrogate and real evaluations**. All these tools have positive and negative aspects and can be more or less complete and easier to use. Engineers have to understand which method is the **most suitable** for each project. Starting from these tools, it is possible to have a better and more complete **comprehension** of the project and reach **faster better results**. In this case, naval architects now know and have mathematical proves that the for different speed the bulb has different influence on the resistance and, once the speed is fixed, they can now **start to design** a bulb with higher or smaller coefficients, giving to the optimizer a better starting points and so, at the end, **reaching faster to the most suitable geometry**. Once these tools will be intensively used in the companies, we will surrounded by better and most suitable objects, from cars to washing machine, **living better, less stressed, and in a greener world**.

https://www.researchgate.net/publication/312535839_FREE_FORM_DEFORMATION_AND_SURROGATE_MODELS_FOR_EXPLORATION_SENSITIVITY_AND_OPTIMIZATION_OF_COMPLEX_HULL_FORMS