EUROFLEETS2

JRA1: Regional Research Vessels guidelines and generic designs

Bubble Sweep Down Avoidance

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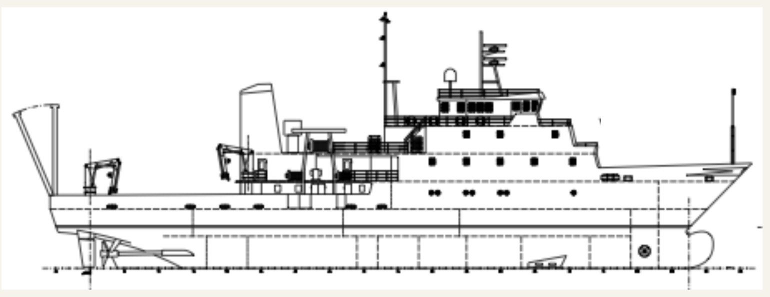
Introduction

- **Background:** train of bubbles travelling downstream the hull vessel may induce disturbances to the measurements devices mounted in RRVs inducing
  - ✓ noise,
  - ✓ false spots,
  - ✓ and sometimes hiding completely the measure.
- **Objective:** provide guidelines and recommendations on bubble-sweep down avoidance for Regional Research Vessels (RRVs). The effect is strongly dependent on the vessel characteristics (essentially hulls' shape as well as inertia distribution) and on the environmental and operating conditions.
- **Approach:** in order to mitigate the interference of bubbles with on board instrumentations, two effects have been investigated:
  - ✓ the local flow at the bow,
  - ✓ and heave and pitch motions (generating extra air bubbles and force the transport from the water surface along the flow lines to the vessel bottom).

  Specifically, the former has been treated minimizing the local value of the downward vertical speed component (F1) for the design/operating speed of the vessel (bubbles flow along streamlines), the latter minimizing the overall normalized root mean square of the vertical acceleration (F2) at the bow (seakeeping performances).

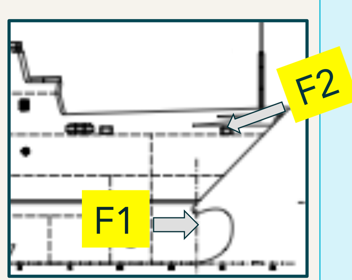
  Outcomes of preliminary CFD analysis on an existing vessel (URANIA) have been used to define modification of the hull and/or bulb shapes leading to mitigation of the effects due to bubbles occurrence.



	L_{OA}[m]	L_{PP} [m]	B_{OA}[m]	T[m]	Δ [t]	v [kn]	SS
URANIA	61.5	52.5	11.1	3.30	1200	8-12	2/6

Original design → Simulation-based design optimization → Optimal design

A first single-objective optimization stage for F1 and F2 has been performed.
A second multi-objective optimization, considering F1 and F2 combined has been performed.



Optimization problem

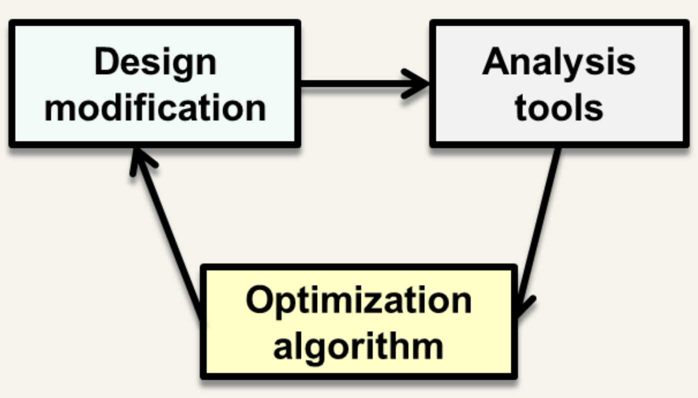
The general global optimization problem is defined as

$$\begin{array}{lll} \text{minimize} & f(\mathbf{x}) & \mathbf{x} \in D \\ \text{subject to} & h_m(\mathbf{x}) = 0 & m = 1, \ldots, M \\ \text{and to} & g_n(\mathbf{x}) \leq 0 & n = 1, \ldots, N \end{array}$$

- f is the objective of optimization (f=F1, f=F2, and f(F1,F2));
- h_m represents the m-th equality constraint;
- g_n is the n-th inequality constraint;
- **x** is the vector collecting design variables.

Simulation-based design optimization framework

Three interconnected elements are embedded in the SBDO toolbox



Optimization objectives

- ✓ Vertical speed component at the bow evaluated in calm water at 10 kn (F1).
- ✓ RMS of the vertical acceleration component at the bow evaluated at sea state 2 and 6 (v=10kn) (F2).

Geometrical constraints

- ✓ Fixed length between perpendiculars and fixed displacement.
- ✓ Limited variations on beam and draught (+/- 5%).
- ✓ Reserved volume for the bulb.

Design modifications

- ✓ Orthogonal basis-functions for hull and bulb.

Solvers for design optimization

- ✓ Calm water: WARP-SA V1.1 (linear potential-flow code),
- ✓ Motions: SMP (strip-theory, linear with corrections).

SBDO algorithms

- ✓ Single-objective deterministic particle swarm optimization (SO-DPSO).
- ✓ Multi-objective deterministic particle swarm optimization (MO-DPSO).

Definition of hull and bulb shape modifications

Orthogonal patches method

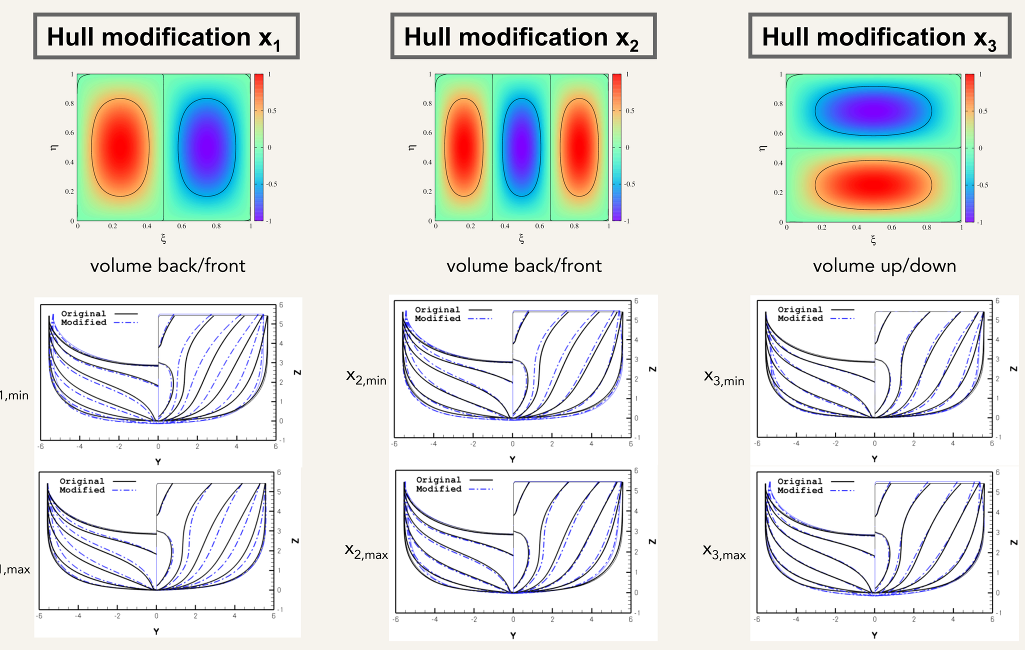
- Shape modifications δ_s are produced by superposition of orthogonal basis functions ψ_j, and controlled by N_{DV} design variables α_j, as

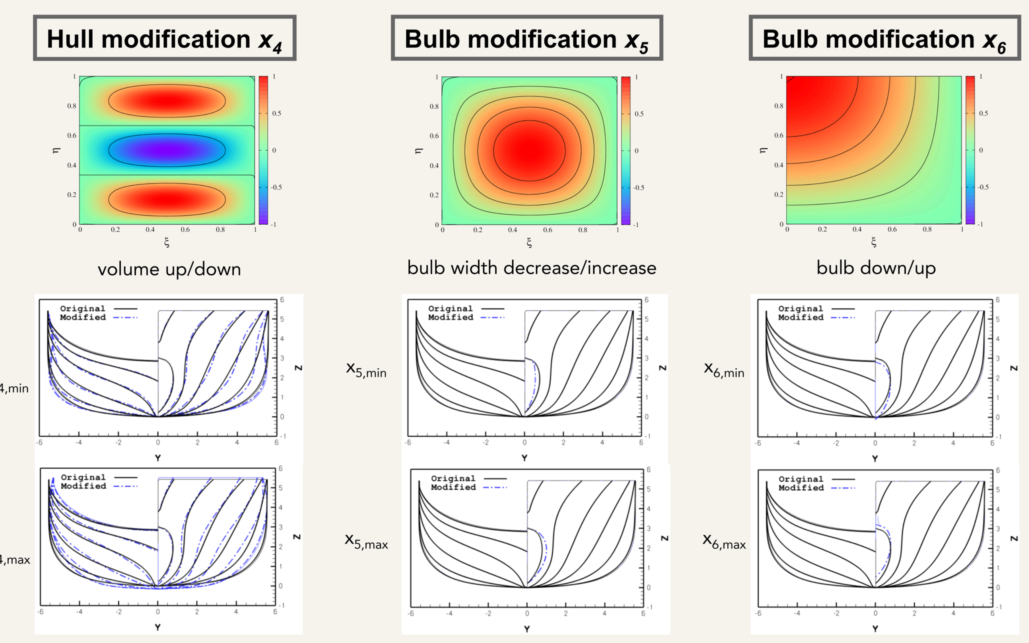
$$\boldsymbol{\delta}_s(\xi,\eta) = \sum_{j=1}^{N_{DV}} \alpha_j \boldsymbol{\psi}_j(\xi,\eta)$$

$$\boldsymbol{\psi}_j(\xi,\eta) := \sin\left(\frac{p_j \pi \xi}{A_j - B_j} + \phi_j\right) \sin\left(\frac{q_j \pi \eta}{C_j - D_j} + \chi_j\right) \boldsymbol{e}_{k(j)}, \quad (\xi,\eta) \in [A_j; B_j] \times [C_j; D_j]$$

- ✓ where (ξ,η) are curvilinear coordinates;
- ✓ p_j and q_j respectively define the order of the function in ξ and η direction,
- ✓ φ_j and χ_j are the corresponding spatial phases;
- ✓ A_j, B_j, C_j and D_j define the patch size;
- ✓ $e_{k(j)}$ is a unit vector.

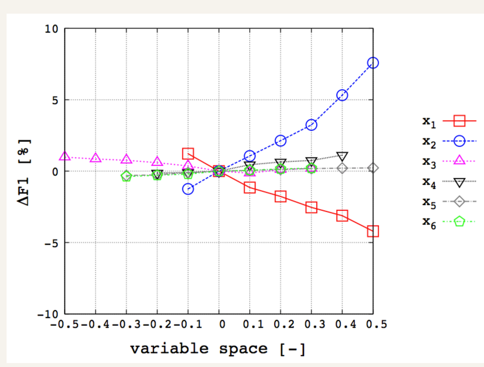
						Domain			
Patch	p	φ	q	χ	k	α_{min}	α_{max}	x_{min}	x_{max}
1	2.0	0	1.0	0	2	-1.0	1.0	-0.5	0.5
2	3.0	0	1.0	0	2	-1.0	1.0	-0.5	0.5
3	1.0	0	2.0	0	2	-0.5	0.5	-0.5	0.5
4	1.0	0	3.0	0	2	-0.5	0.5	-0.5	0.5
5	1.0	0	1.0	0	2	-0.25	0.25	-0.5	0.5
6	0.5	$\pi/2$	0.5	0	3	-0.5	0.5	-0.5	0.5





Sensitivity analysis for F1

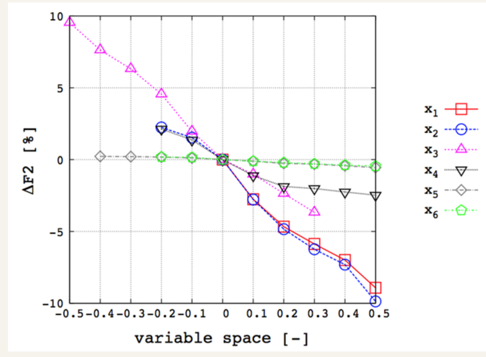
- Performed with WARP for calm water at v=10 kn (Fr=0.218).
- The overall objective function F1 is studied.
- Unfeasible designs are not reported.
- Positive values of design variables 1 and 3, which means moving volume back to front and up to down (using a p=2 order) always result in a increase of performances, whereas positive values of variables 2,4, 5 and 6, which mean moving volume back to front and up to down (using a p=3 order), increasing bulb width, and raising it up lead to a performance decrease.



- The results show a possible reduction of the objective function F1 close to 5%.

Sensitivity analysis for F2

- Seakeeping sensitivity analysis is performed with SMP.
- The overall objective function F2 is studied.
- The sensitivity of the normalized RMS of vertical acceleration of the bow (using a Bretschneider spectrum with a significant wave height equal to 0.3[m] and 5.0[m] and a modal period equal to 3.8[s] and 9.8[s], respectively for sea-state 2 and 6) is shown.
- Unfeasible designs are not reported.
- Positive values of design variables, which means moving volume back to front and up to down, always result in seakeeping performance improvements.

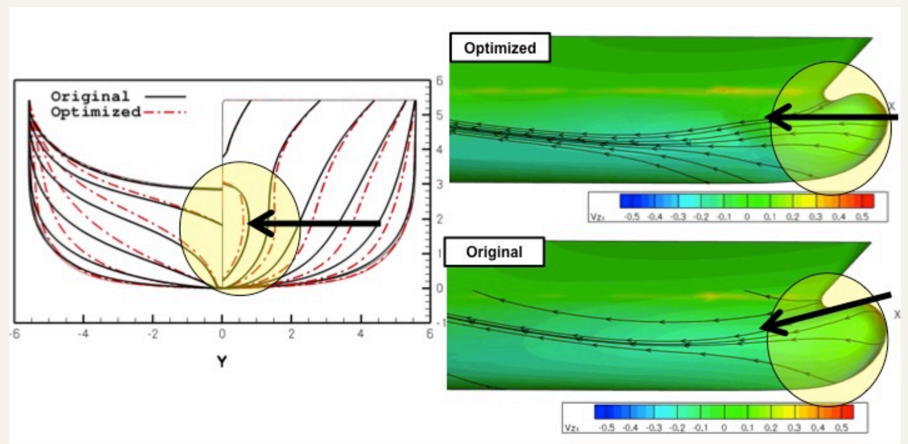


- The results show a possible reduction of the objective function F2 close to 10%.

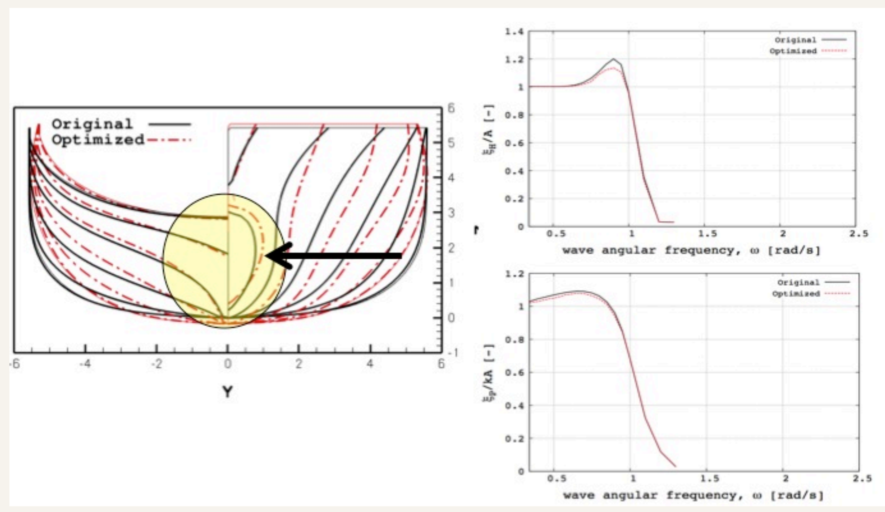
Optimization results

The overall effect of shape modifications is shown by the single-objective optimizations:

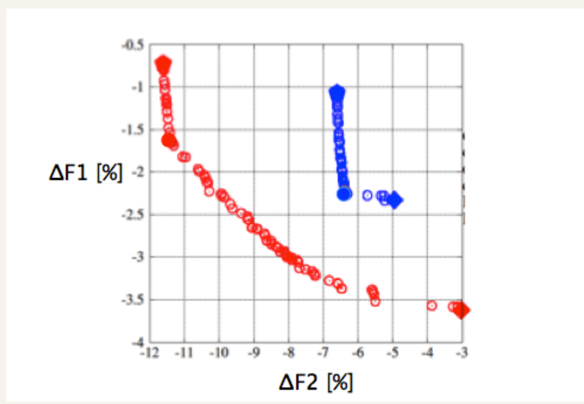
1. the optimal designs show partially conflicting results, e.g. a narrow bulb allows for decreasing the local downward speed component (F1),



2. whereas an enlarged bulb allows for better seakeeping performances (F2)



Multi-objective optimization allows for selecting a design on the basis of designer's or ship builder preference: better results in terms of F1 (local flow at the bow), induce a decrease in F2 (seakeeping results).



Closing remarks

Guidelines on hull forms designed to mitigate the bubble sweep-down phenomenon have been derived and indicate that: designers and/or ship builders mostly interested enhancing seakeeping performances will chose hull shapes characterized by volume distributions from back to front and up to down, and eventually bulb with pretty large width, whereas narrow bulbs should be preferred to enhance performances in terms of local flow at the bow.

Technical devices as a gondola can be used to improve bubble sweep-down performances. The gondola might prevent bubble sweep-down by moving the sonar transducers below the bubbles. However, it should it should be underlined that also the depth and the position of the gondola along the hull should be identified (by CFD analyses (or tank tests) to ensure the streamlines lie between the keel and the top surface of the gondola.

As a final indication, the bubble sweep-down phenomenon should be addressed from the early stages of the design process of a RV, including CFD calculations specifically performed on the configuration under analysis.