JRA1
REGIONAL RVS GUIDELINES AND GENERIC DESIGNS

Bubble sweep down avoidance

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Background

- The bow breaking produces *clouds* of bubbles travelling downstream
- Bubbles may induce disturbances to the measurements devices
  - ✓ noise,
  - ✓ false spots,
  - ✓ and sometime hiding completely the measure.

- Among the mechanisms responsible for the interference of bubbles with instrumentation
  - ✓ operating and environmental conditions,
  - ✓ ship motions.

Objective & Approach

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

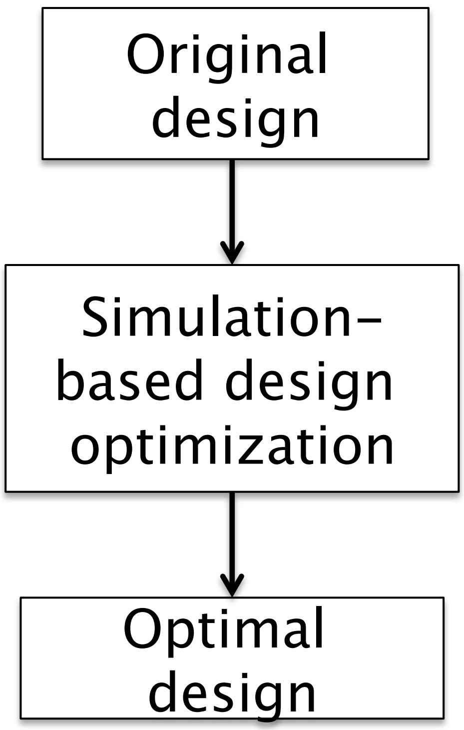
- To mitigate the interference of bubbles with on board instrumentations
  - ✓ the local flow at the bow, minimizing the local value of the mean downward vertical speed component for the design/operating speed;
  - ✓ heave and pitch motions, minimizing the overall normalized root mean square of the vertical acceleration at the bow.

Problem formulation and Simulation-based Design Optimization (SBDO)

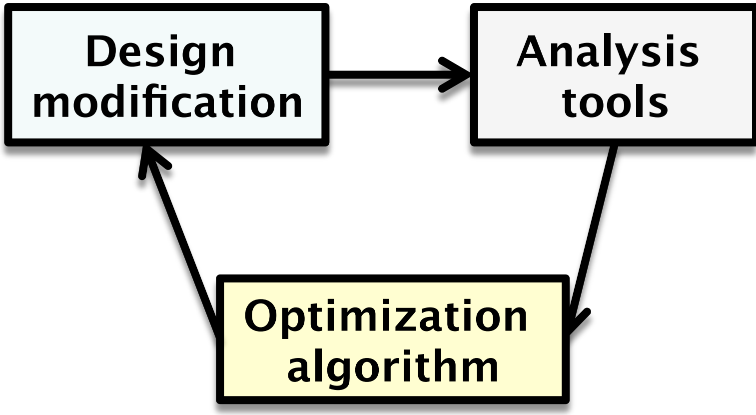
The general global optimization problem is defined as

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

- *f* is the objective of optimization task (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.



Optimization procedure at a glance (SBDO)



Optimization Objectives

- ✓ Mean downward vertical speed component at the bow evaluated in calm water (F1).
- ✓ RMS of the vertical acceleration component at the bow evaluated at sea state 2 (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).

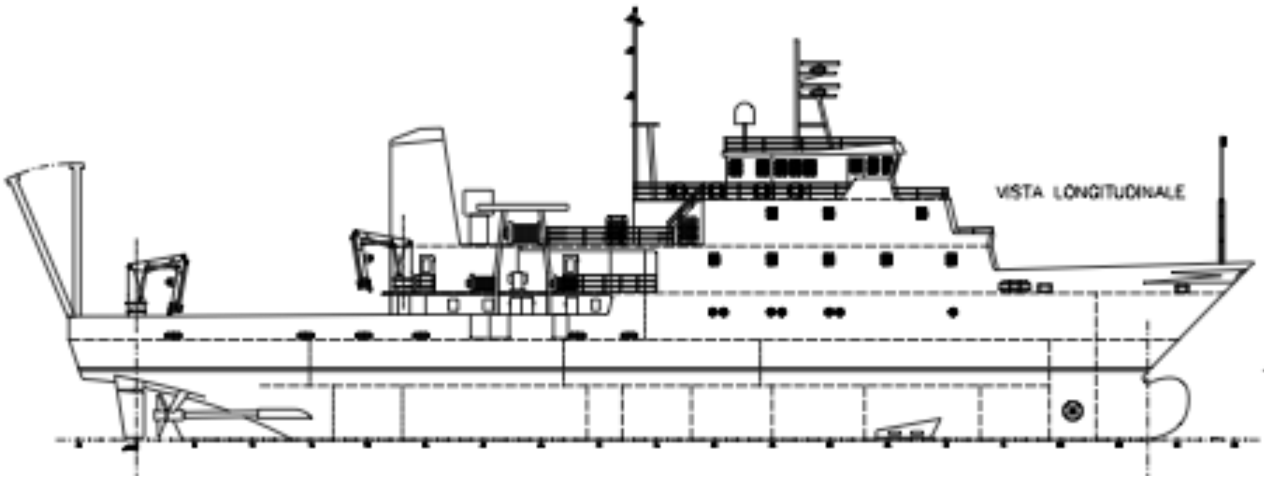
SBDO approach/algorithms

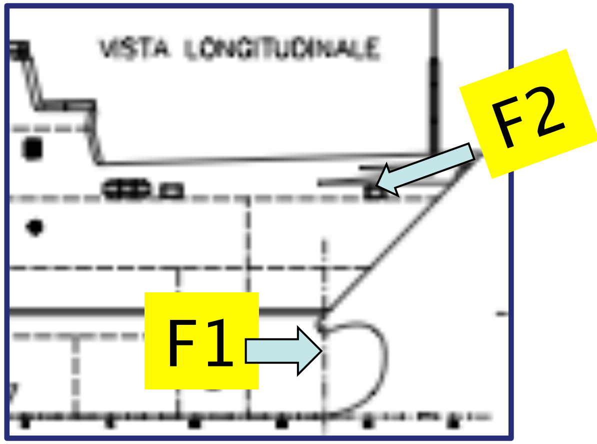
- ✓ Single-objective deterministic particle swarm optimization.
- ✓ Multi-objective deterministic particle swarm optimization.

Tasks

1. Definition of domain and grids for CFD solvers; identification of resistance curve and motions response.
2. Definition of hull and bulb shape modification design space, using orthogonal patches.
3. Single and multi objective design.

Base RRV hull – input for CFD tools

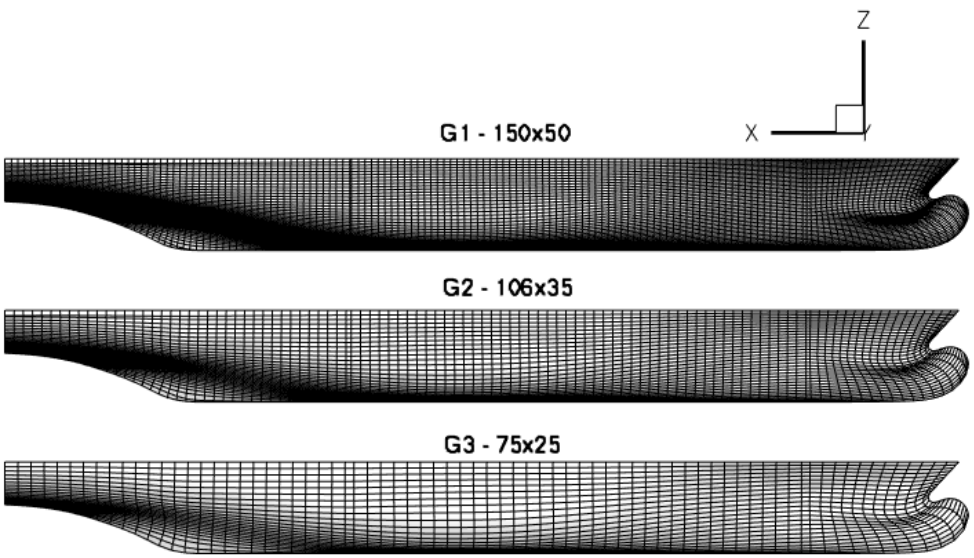


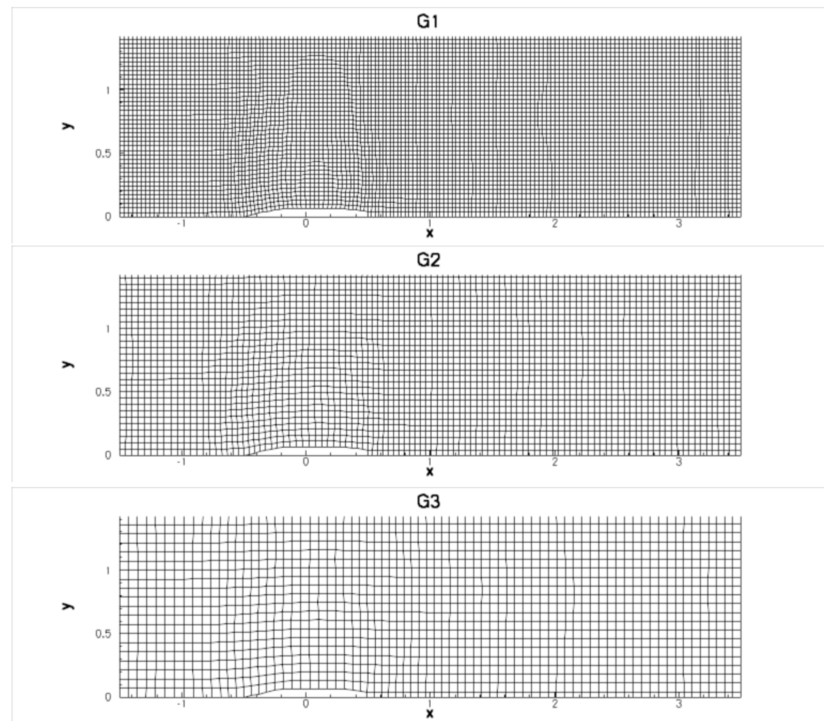


	L_{OA}[m]	L_{PP} [m]	B_{OA}[m]	T[m]	Δ [t]	v [kn]	Sea-state
URANIA	61.50	52.50	11.10	3.30	1200	8-12	2/6

Definition of domain and grids for CFD tools

Grid	Refinement ratio	Hull grid	Domain dimension (5x1.5)			Total
			Upstream	Hull side	Downstream	
G1		150x50	30x44	30x44	90x44	14k
G2		106x35	21x31	21x31	64x31	7k
G3		75x25	15x22	15x22	45x22	3.5k

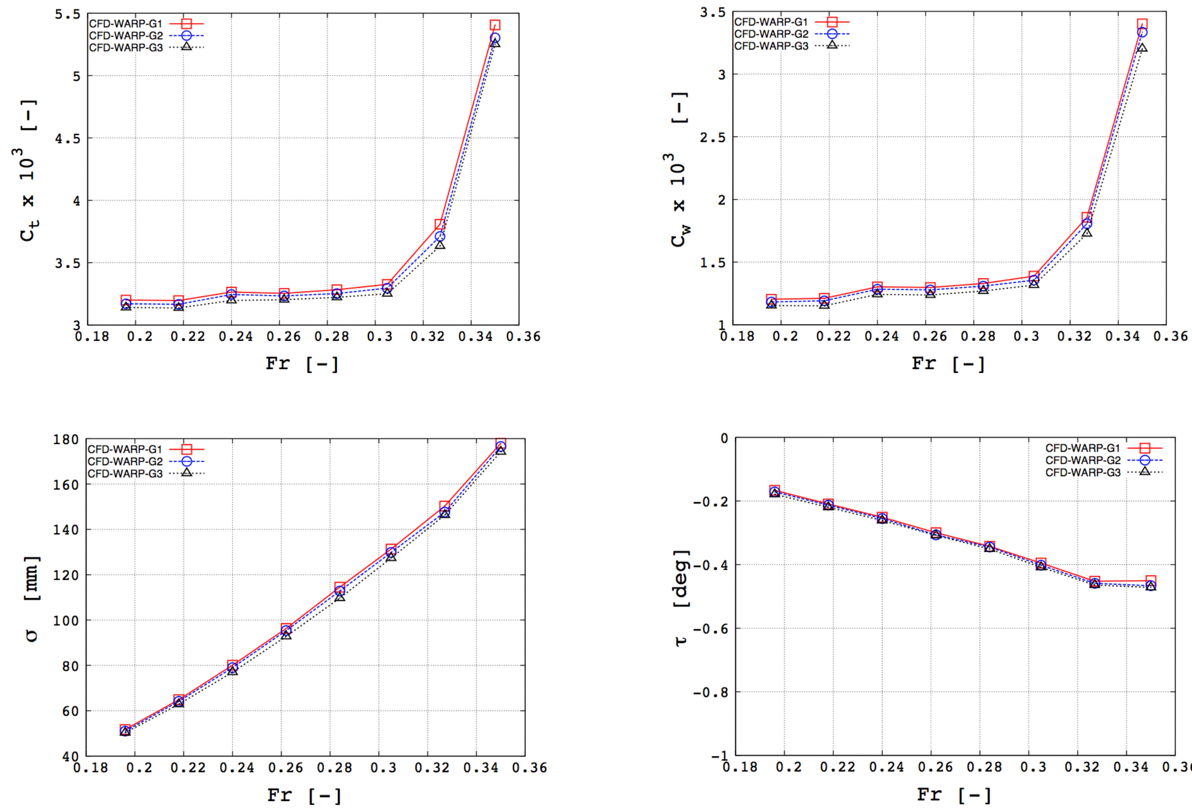




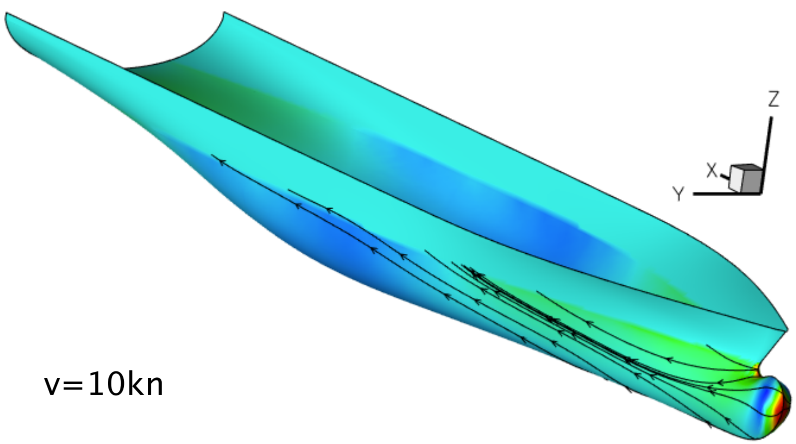
Steady PF results using WARP

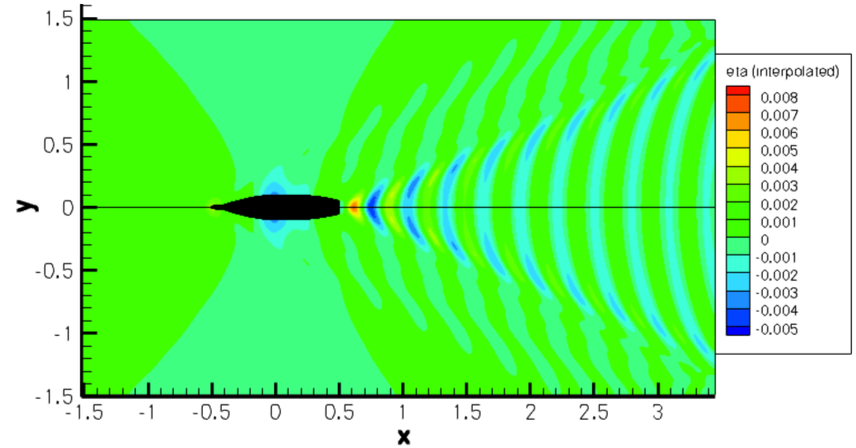
- The calm-water resistance coefficients, sinkage and trim are monotonic grid convergent.

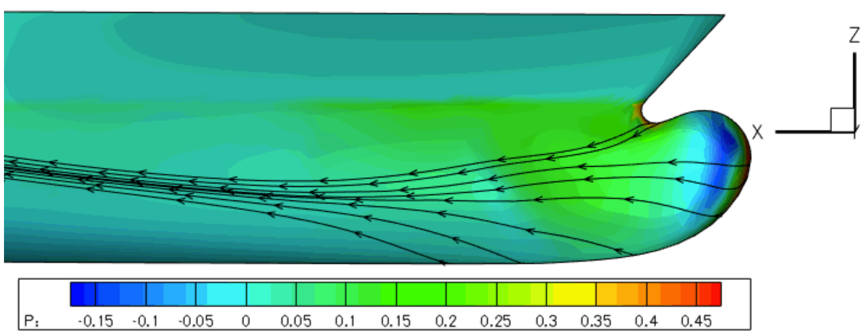
Grid sensitivity

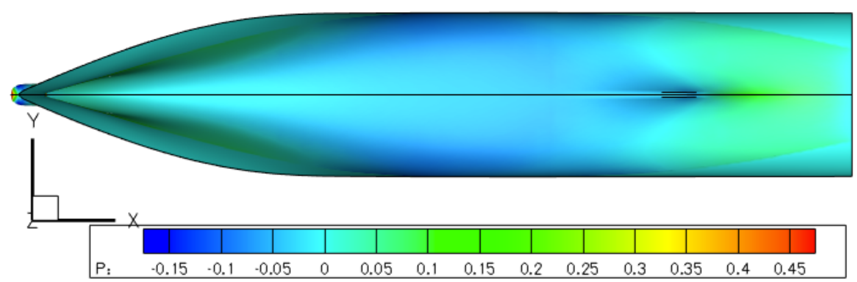


Steady PF results using WARP







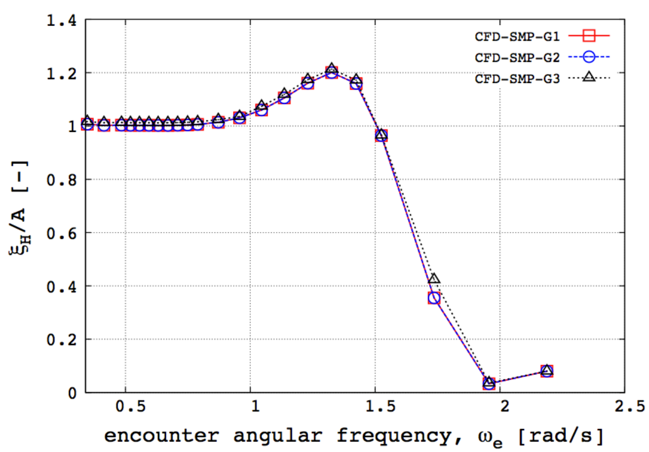


Seakeeping predictions using SMP

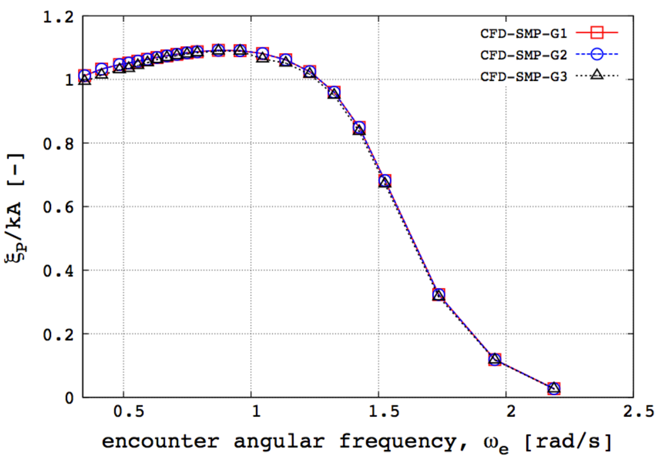
- Figures show the seakeeping performance sensitivity to the grid.
- Heave (ξ_H/A) and pitch (ξ_P/kA) amplitude RAOs, for the three grids, are compared.

Grid sensitivity

Head waves (v=10kn)



Head waves (v=10kn)



Definition of hull and bulb shape modifications

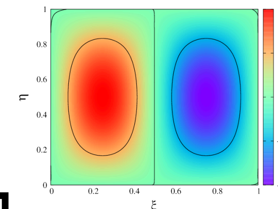
Orthogonal patches method

- Shape modifications are defined by superposition of orthogonal patches ψ_j.
- Modifications may be applied in *x*, *y*, or *z* direction (k_j = 1, 2 or 3 respectively), where:
  - ✓ α_j is the corresponding (dimensional) design variable;
  - ✓ p_j and q_j define the order of the function in ξ and η direction respectively;
  - ✓ φ_j and χ_j are the corresponding spatial phases;
  - ✓ A_j and B_j define the patch dimension;
  - ✓ $\mathbf{e}_{k(j)}$ is a unit vector

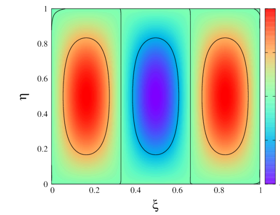
$$\begin{cases} \boldsymbol{\psi}_j(\xi,\eta) := \alpha_j \sin\left(\dfrac{p_j \pi \xi}{A_j} + \phi_j\right) \sin\left(\dfrac{q_j \pi \eta}{B_j} + \chi_j\right) \mathbf{e}_{k(j)} \\ (\xi,\eta) \in [0; A] \times [0; B] \end{cases}$$

						Domain			
Patch	p	ϕ_p	q	ϕ_q	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

Hull modifications



j=1, k=2



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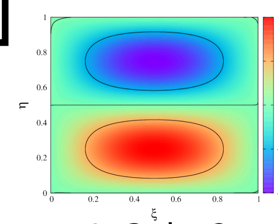
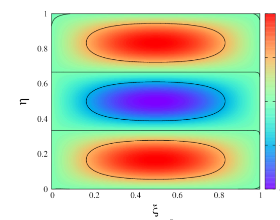
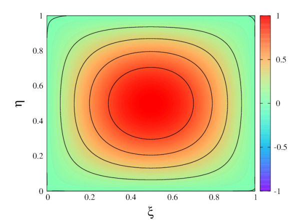


j=3, k=2

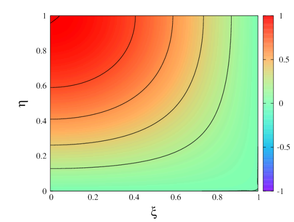


j=4, k=2

Bulb modifications



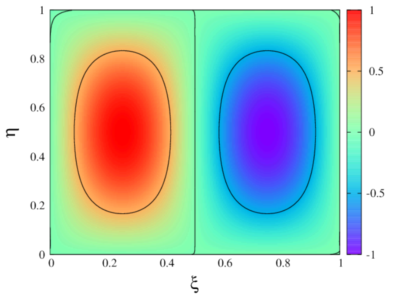
j=5, k=2



j=6, k=3

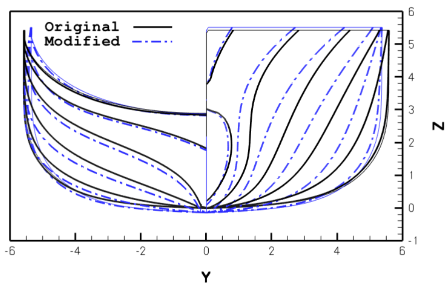
Definition of hull and bulb shape modifications

Hull modification x_1

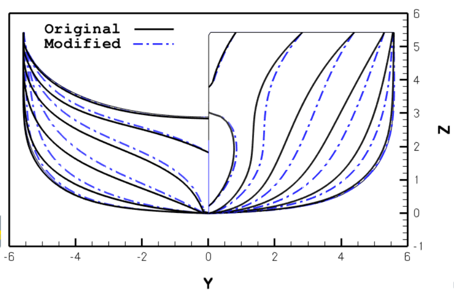


volume back/front

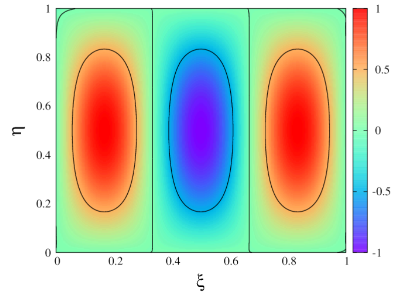
$x_{1,min}$



$x_{1,max}$

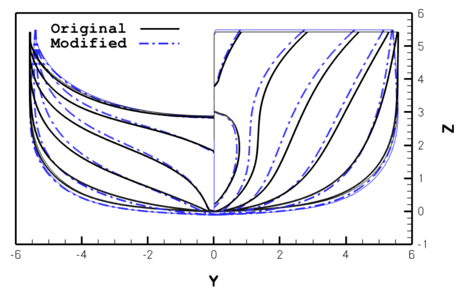


Hull modification x_2

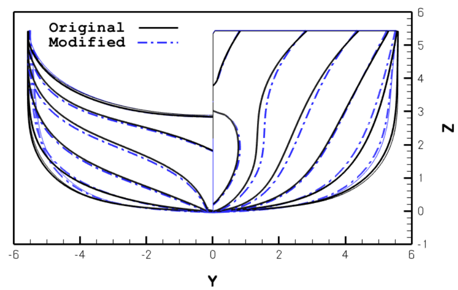


volume back/front

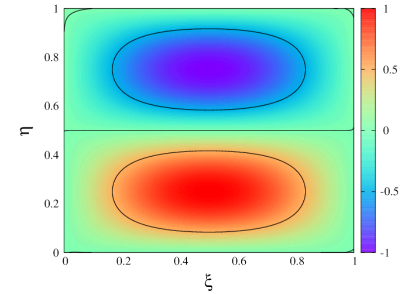
$x_{2,min}$



$x_{2,max}$

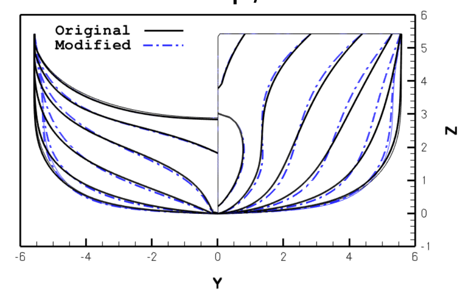


Hull modification x_3

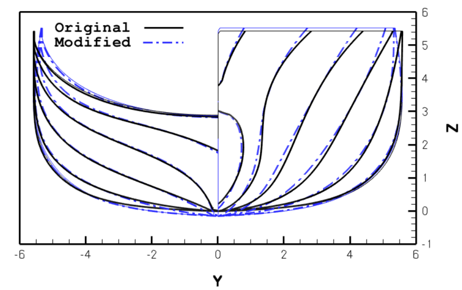


volume up/down

$x_{3,min}$

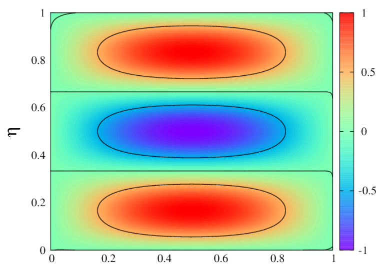


$x_{3,max}$



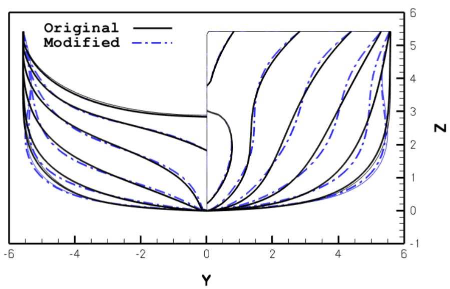
Definition of hull and bulb shape modifications

Hull modification x_4

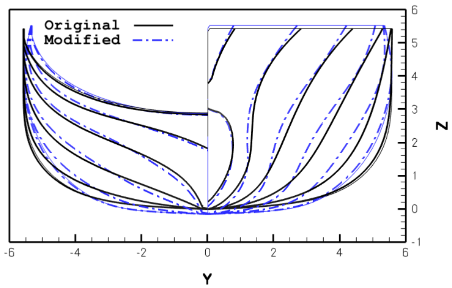


volume up/down

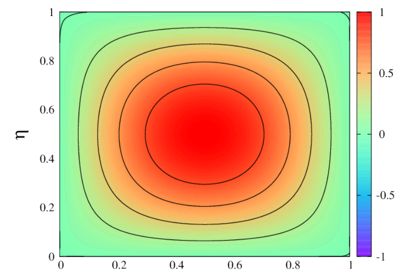
$x_{4,min}$



$x_{4,max}$

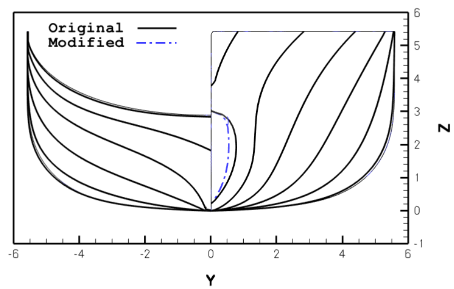


Bulb modification x_5

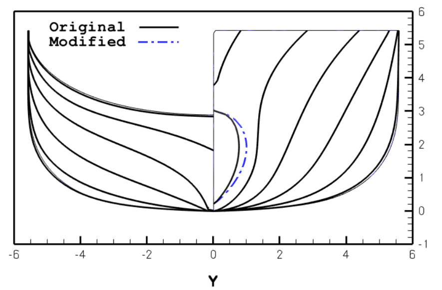


bulb width decrease/increase

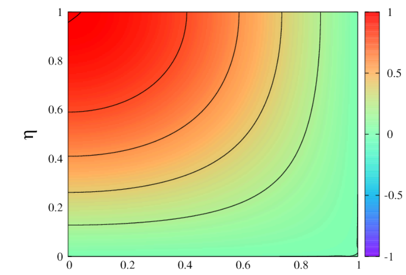
$x_{5,min}$



$x_{5,max}$

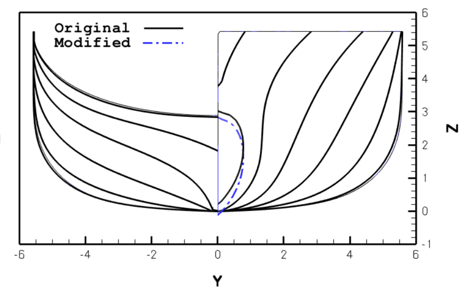


Bulb modification x_6

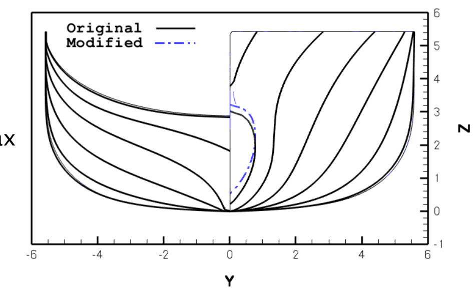


bulb down/up

$x_{6,min}$



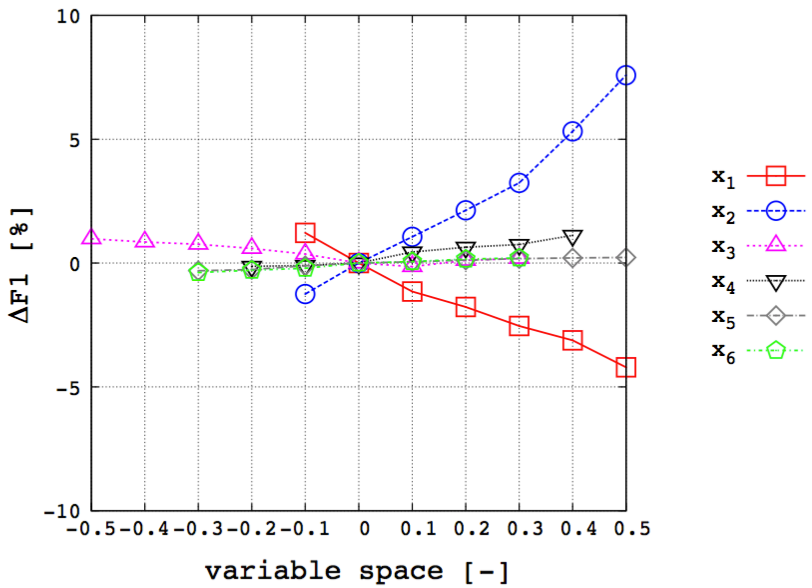
$x_{6,max}$



Definition of hull and bulb shape modifications

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.
- Moving volume back to front and up to down 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, increasing bulb width, and raising it up lead to a performance decrease.

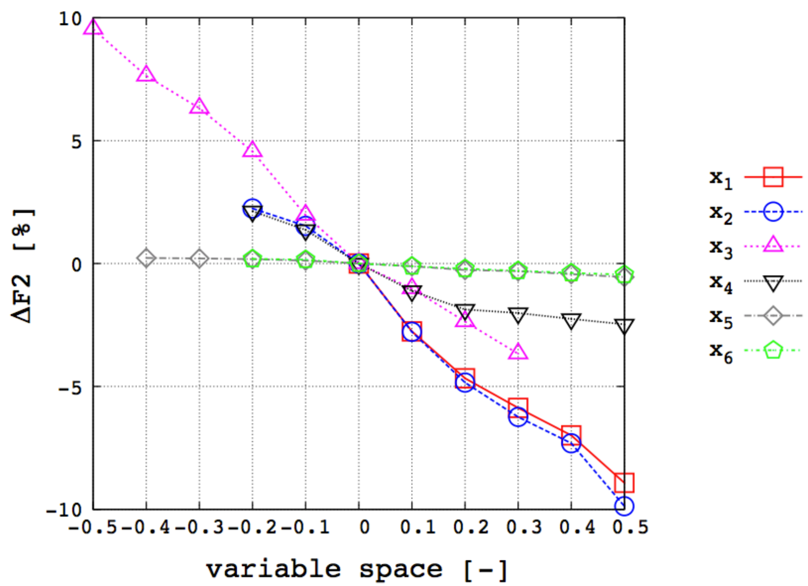


The results show a possible reduction of the objective function F1 close to 5%.

Definition of hull and bulb shape modifications

Sensitivity analysis for F2

- Seakeeping sensitivity analysis is performed with SMP.
- The overall objective function F2 is studied.
- Figures show 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).
- Unfeasible designs are not reported.
- moving volume back to front and up to down, always result in performance improvements.



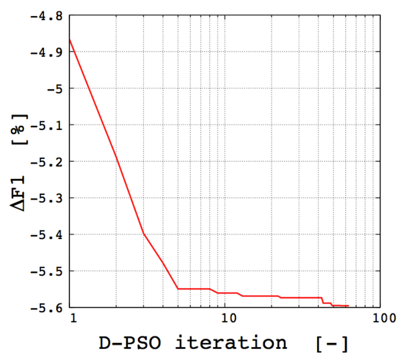
The results show a possible reduction of the objective function F2 close to 10%.

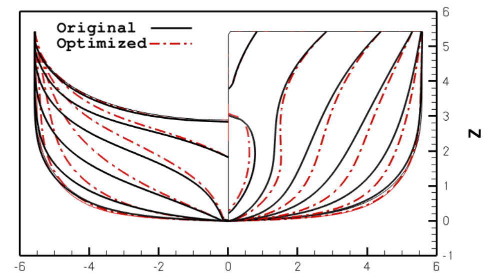
Single objective design optimization for F1

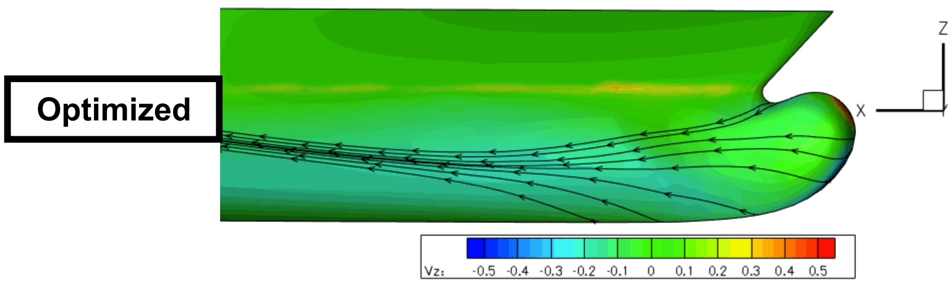
- The optimization for the selected design space reaches a reduction of 5.6% for the objective function F1.

- **Convergence rate**

  The optimization problem is solved with SO-DPSO set following Serani et al. (2014), using function $256 \times N_{DV}$ function evaluations.

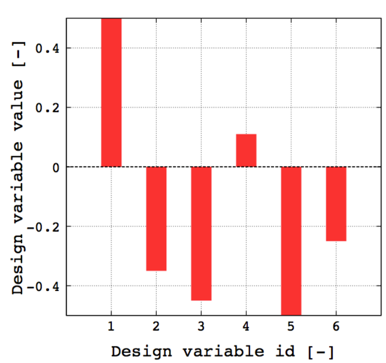


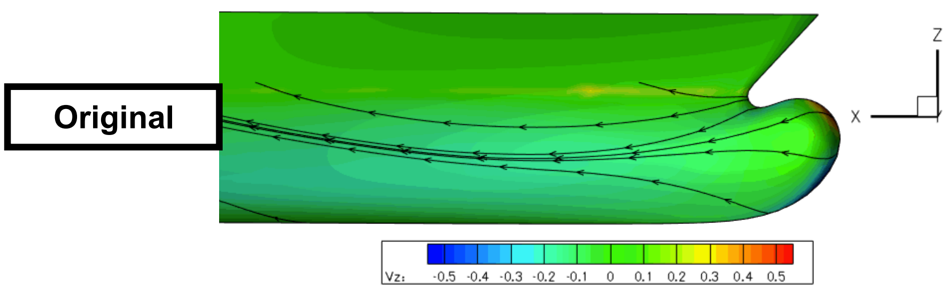




- **Optimum design variable**

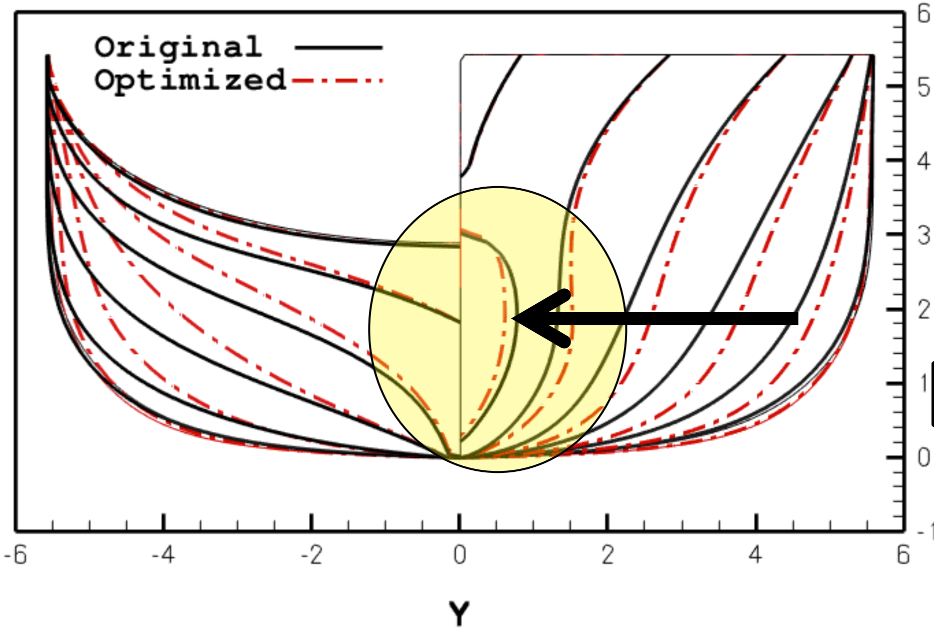
  Design optimization is performed with box constraints defined by $-0.5 \leq x_j \leq 0.5$.

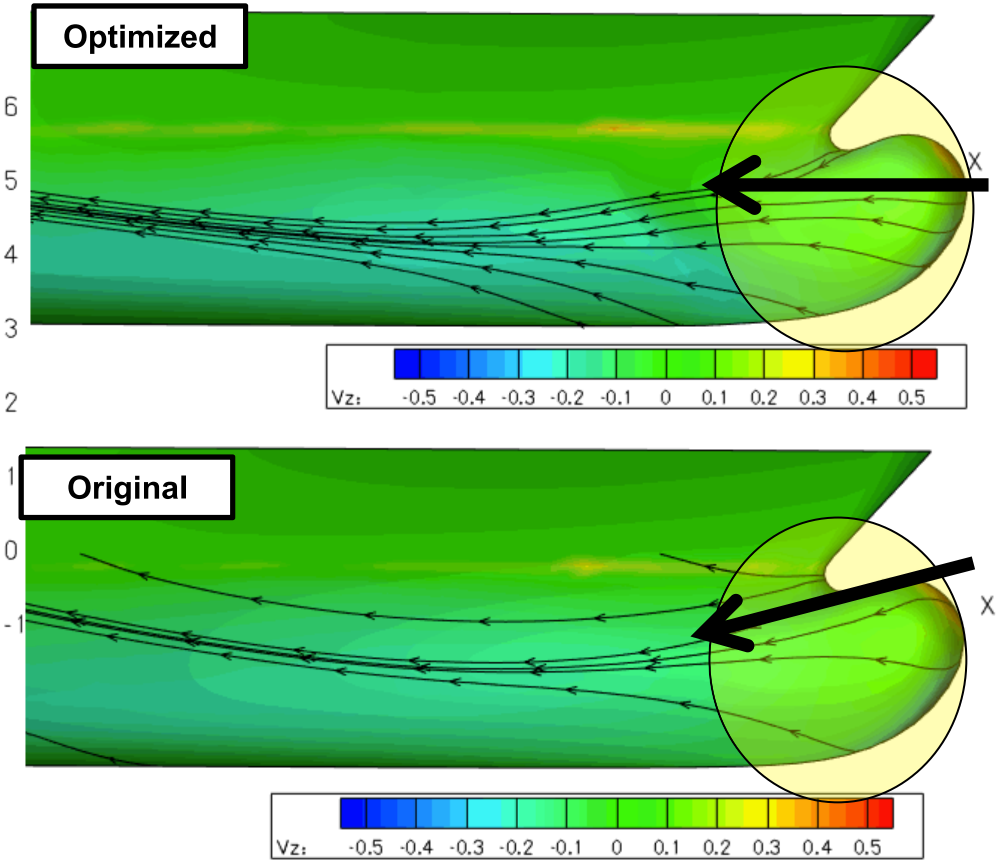




Single objective design optimization for F1

- A narrow bulb allows for decreasing the local downward speed component (F1)

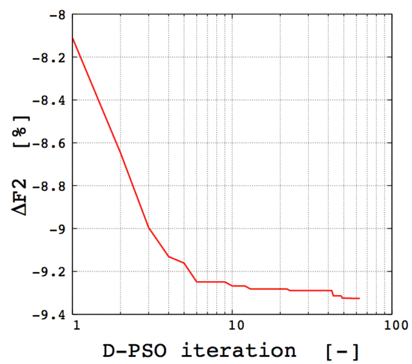


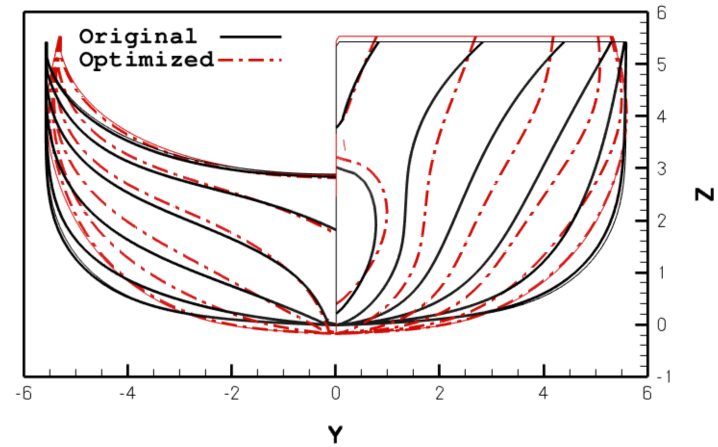


Single objective design optimization for F2

- The optimization for the selected design space reaches a reduction of 9.3% for the objective function F2.
- **Convergence rate**

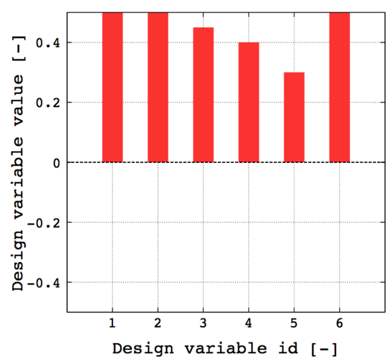
  The optimization problem is solved with SO-DPSO set following Serani et al. (2014), using function $256\times N_{DV}$ function evaluations.

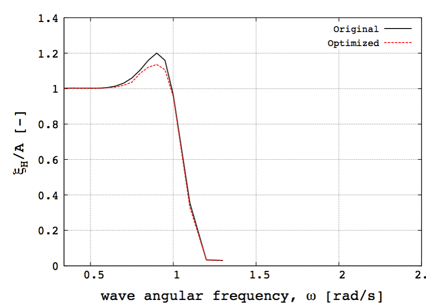


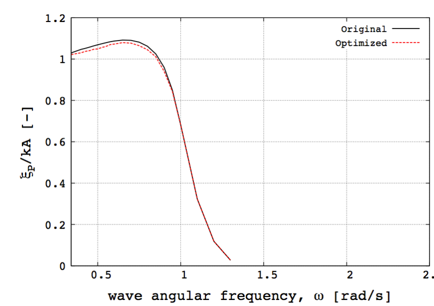


- **Optimum design variable**

  Design optimization is performed with box constraints defined by $-0.5 \leq x_j \leq 0.5$.





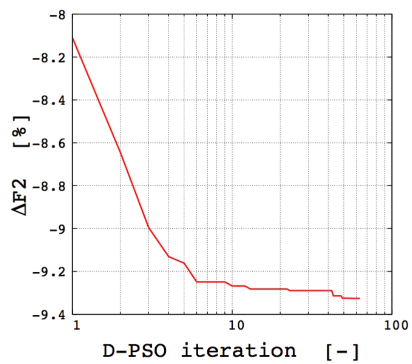


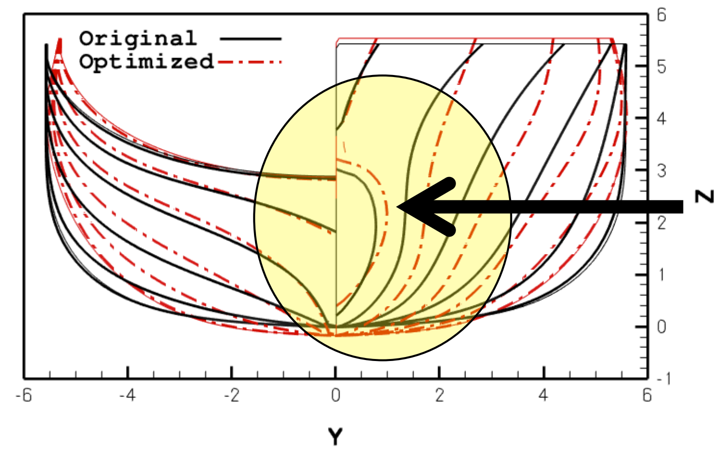
Single objective design optimization for F2

- Enlarged bulb allows for better seakeeping performances (F2)

- **Convergence rate**

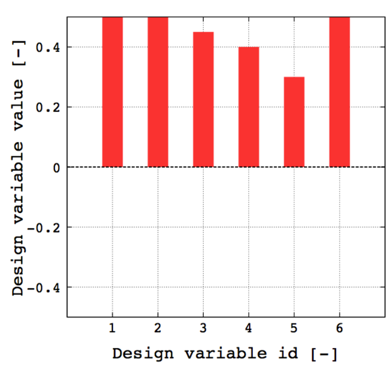
  The optimization problem is solved with SO-DPSO set following Serani et al. (2014), using function $256 \times N_{DV}$ function evaluations.

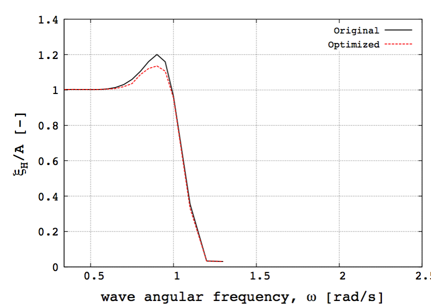


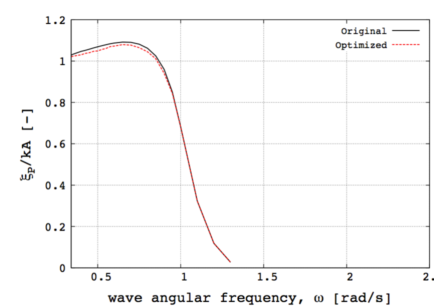


- **Optimum design variable**

  Design optimization is performed with box constraints defined by $-0.5 \leq x_j \leq 0.5$.





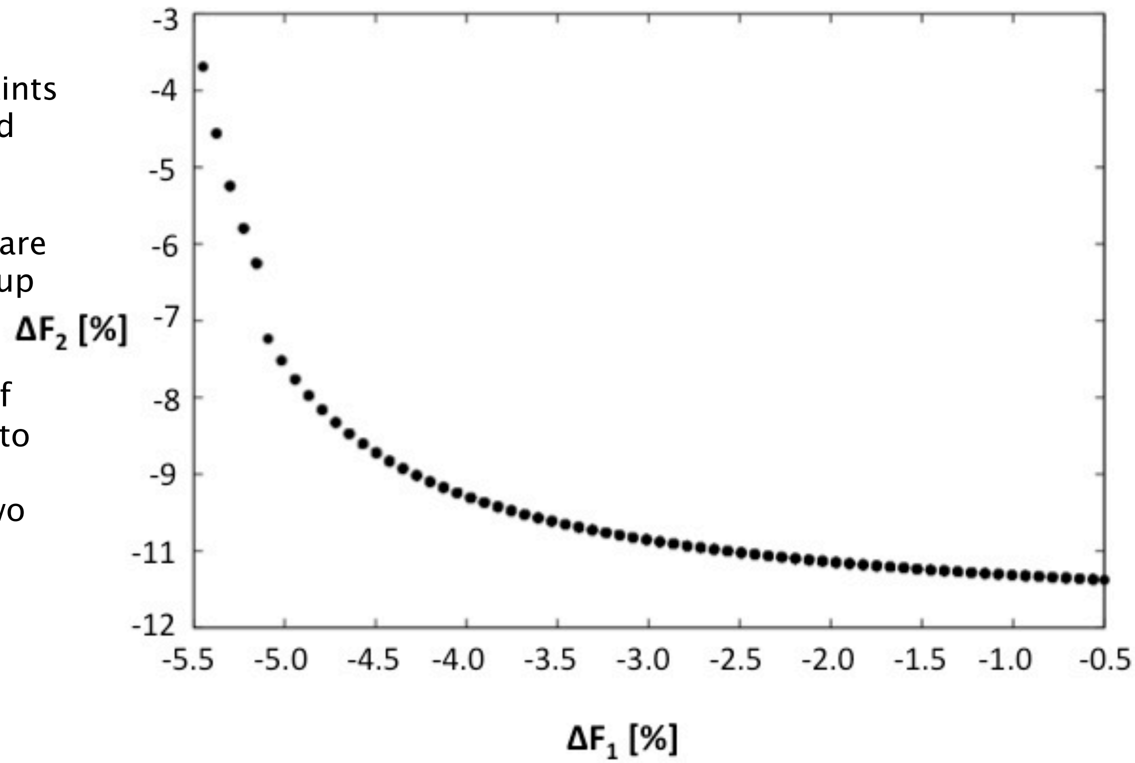


Multi objective design optimization

The optimization for F1 and F2 is conducted for two design spaces

Design optimization is performed with box constraints defined by $-0.5 \leq x_j \leq 0.5$ and $-1 \leq x_j \leq 1$

The optimization problems are resolved with MO-DPSO setup following Pellegrini et al. (2014), using 256 function evaluations. The selection of the optimal hull on the Pareto front comes from the best compromise between the two objective functions.



Closing remarks

- The same design space has been used for single-objective design optimization for separate:
  - ✓ mean vertical downward speed component at bow 5.6% improvement
  - ✓ vertical acceleration component at bow (sea-state 2 & 6), 9.3% improvement
- Multi-objective design optimization for the concurrent minimization of F1 and F2 has been also conducted.
- 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 depth and the position of the gondola along the hull should be identified by CFD analyses or tank tests.
- 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 and/or tank tests.