Parametric Design and Optimization of a Battery-driven Catamaran in CAESES

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Agenda

- Project Outline
- CAESES Parametric model
- Potential flow calculations
- Surrogate Models
- Global Optimization
- Conclusions

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Project Outline

- Parametric design & hydrodynamic optimization of a catamaran vessel, developed in the framework of the European R&D project TrAM (Transport: Advanced and Modular)

- Objectives of TrAM project:
    - ➢ To develop a series of zero emission fast passenger ferry designs
    - ➢ To lower production cost by modular design
    - ➢ To prove the viability of electric-powered high-speed vessels
        - ✓ A prototype will be built during the project period and put into operation in Stavanger, Norway

CAESES Parametric model

Background information

- Sketch of General Arrangement developed by Fjellstrand Shipyard in agreement with vessel operator

- Main Dimensions:
  - ➢ Length OA 31.0m
  - ➢ Beam OA 9.0m
  - ➢ Demihull Length OA 30.6m

- Based on the background information, a parametric geometry model for the hullform was created by NTUA in CAESES

Set of Parameters

Grid definition

Lackenby Transformation

Surfaces Generation

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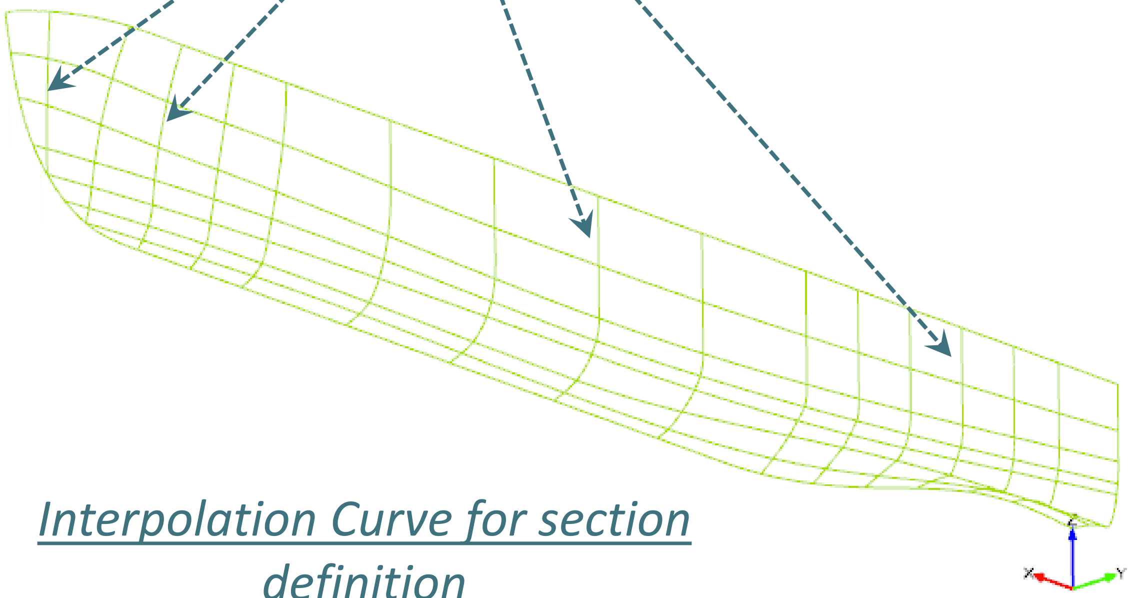
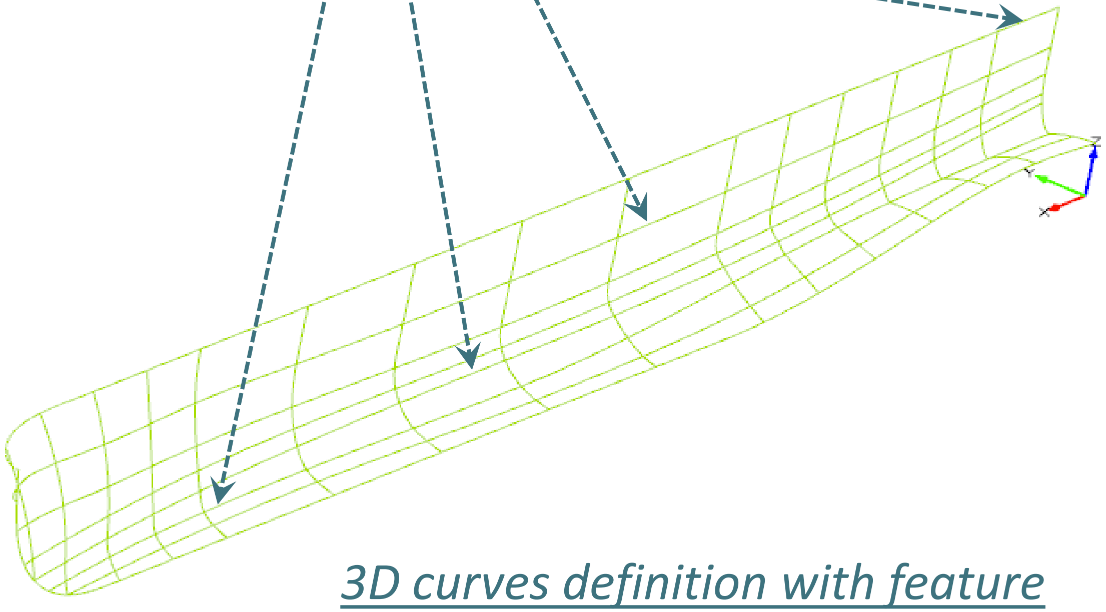
Definition Curves

FInterpolationCurve



Interpolation Curve for section definition

Curve3DFrom2PlanarCurves

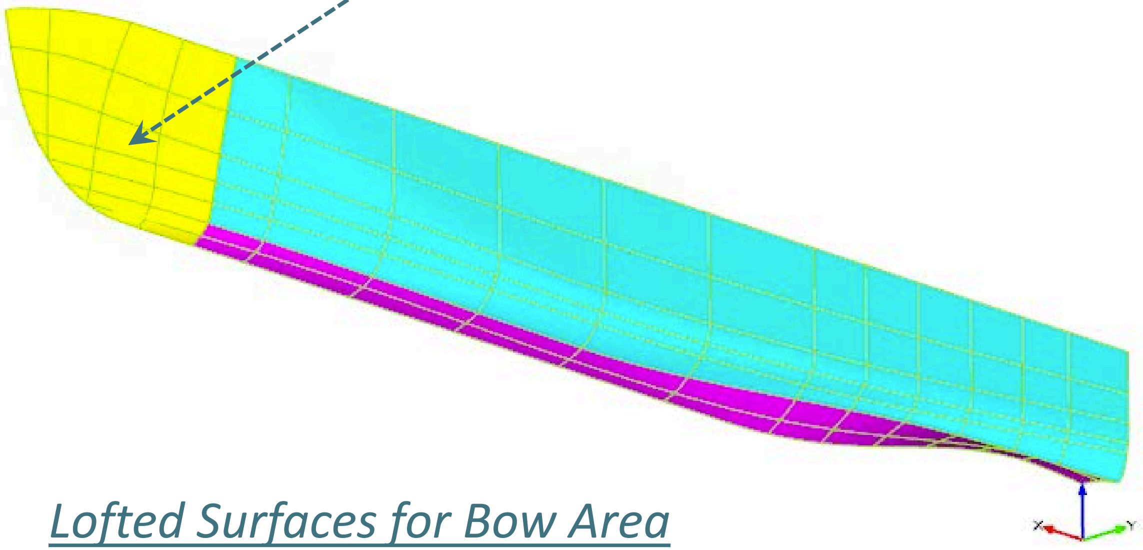


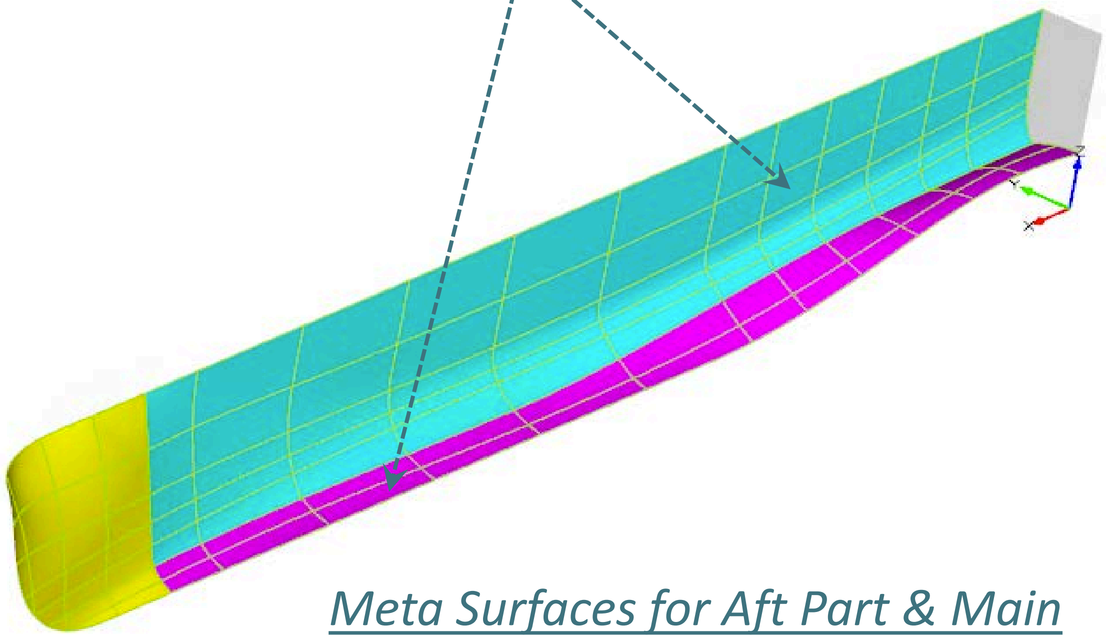
3D curves definition with feature Curve3DFrom2PlanarCurves

Surfaces

FLoftedSurface

FMetaSurface





Lofted Surfaces for Bow Area definition

Meta Surfaces for Aft Part & Main Hullform definition

Hullform after Lackenby Transformation

- After the hullform definition, a Lackenby transformation was used

Prismatic coefficient adjustment

longitudinal position of the centre of buoyancy adjustment

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Main Global Parameters

- **Waterline Length**

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Main Global Parameters

- Waterline Length
- **<u>Beam</u>**

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Main Global Parameters

- Waterline Length
- Beam
- **Draught**

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Main Local Parameters

- **Transom width**

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Main Local Parameters

- ➢ Transom width
- ➢ **<u>Transom Chine Height</u>**

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Main Local Parameters

- Transom width
- Transom Chine Height
- **Shape of fwd profile**

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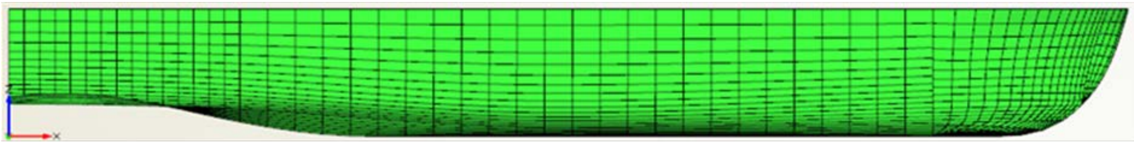
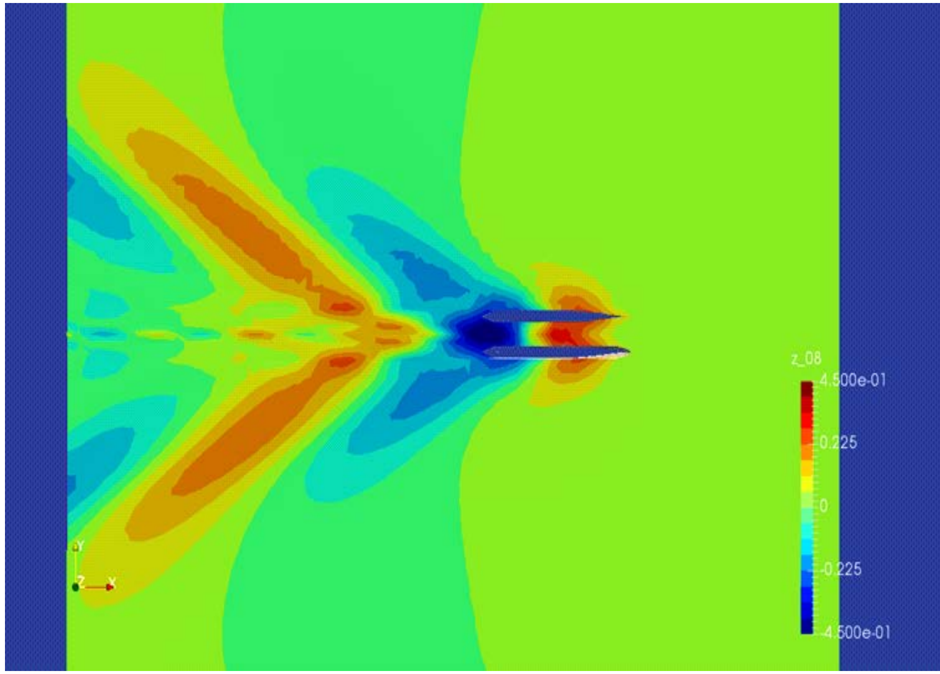
Potential Flow Calculations using the Parametric Model by HSVA

Background of HSVA in-house code ν-SHALLO



- ν-Shallo is a potential flow/ 3D panel method for the calculation of the wave resistance
- The code estimates viscous resistance by empirical Method (ITTC), while considering
  - accurate wetted surface
  - inhomogeneous velocity distribution
- Accounts for the effect of transom sterns
- Automatic re-panelling for each iteration
  - Ship hull
  - automatic control of free surface mesh
- Graphical User Interface



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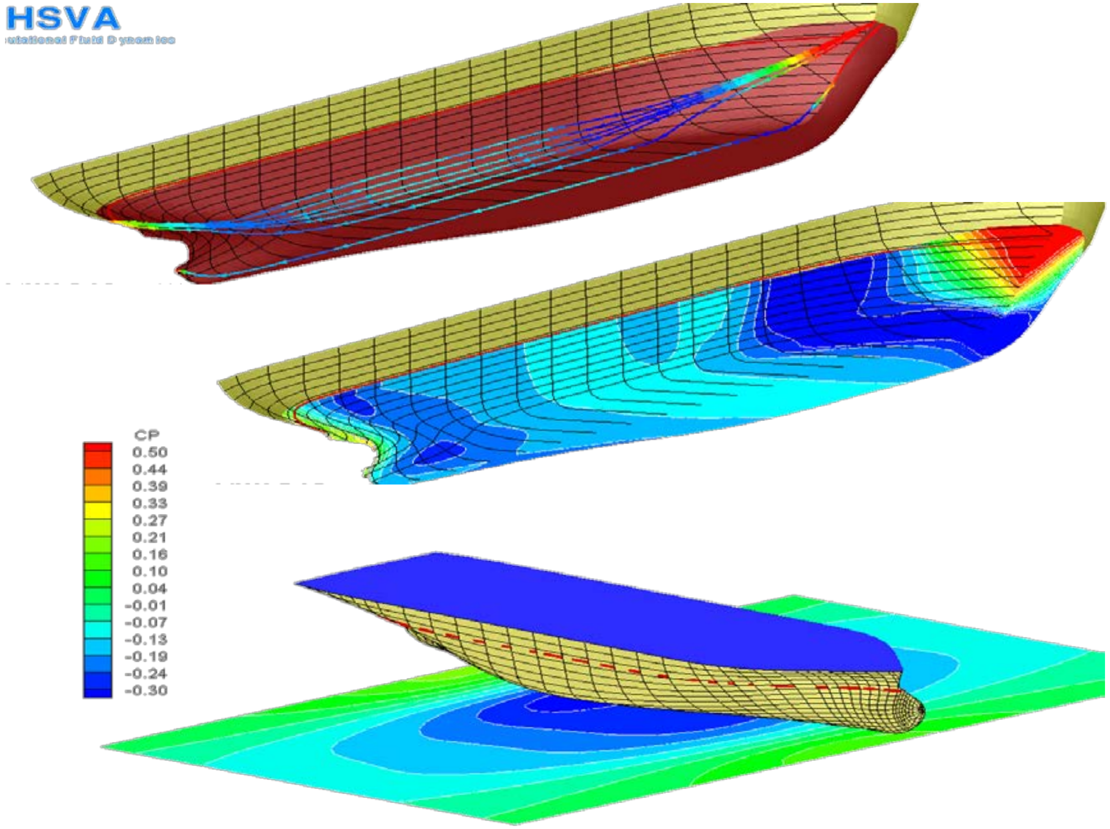
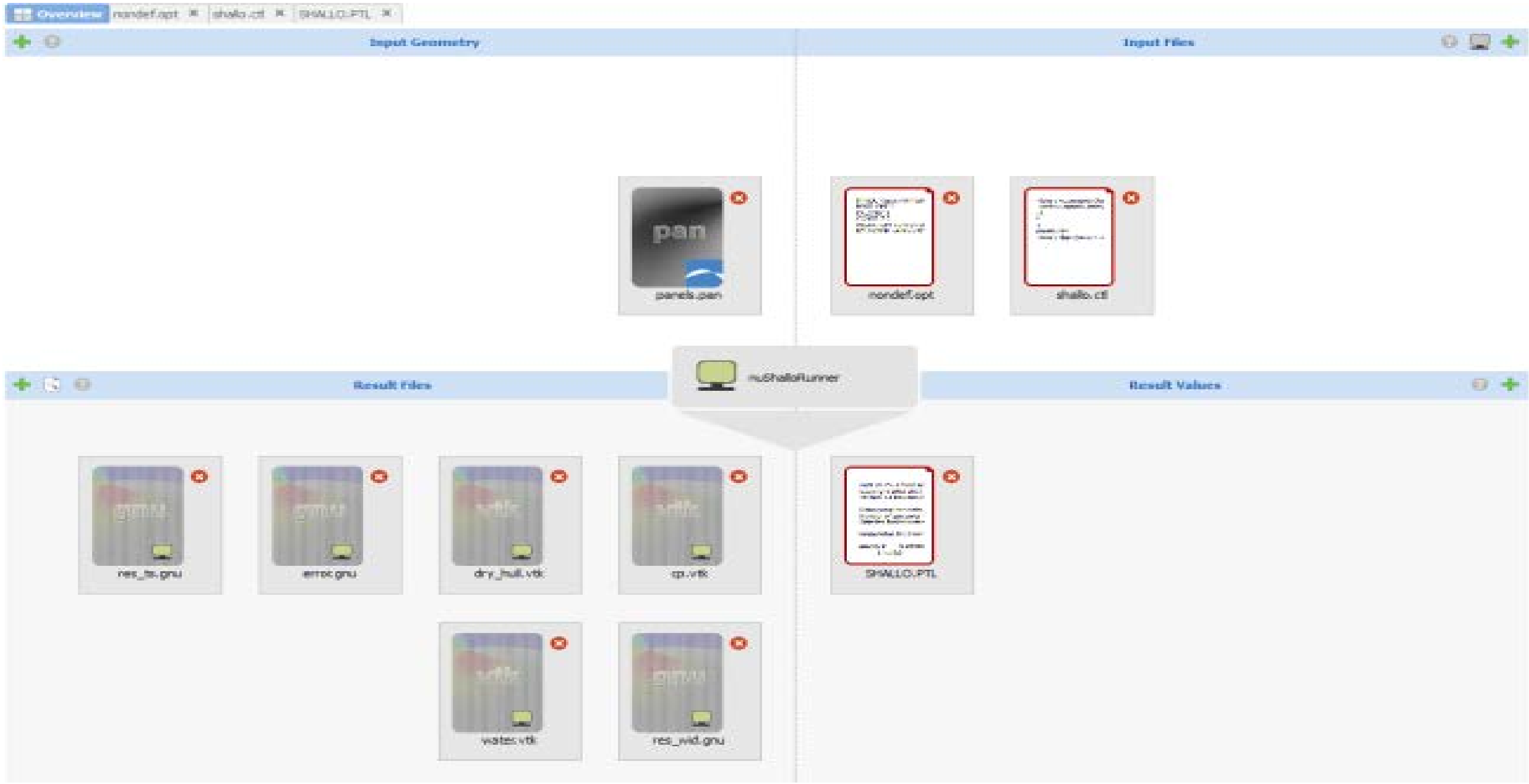
HSVA wave resistance panel code-what can ν-SHALLO do?

- Indication on improvement through study of details of flow and wave pattern
- Automatic hull form optimisation by use of defined objective function
- Assessment of wave wash by evaluation of pressure at sea bottom and radiated wave field



ν-SHALLO Integration into CAESES

- ✓ ν -SHALLO was the first of HSVA's simulation tools with completed integration into the CAESES framework
- ✓ Optimisation can be run per mouse-click under either linux or wondows



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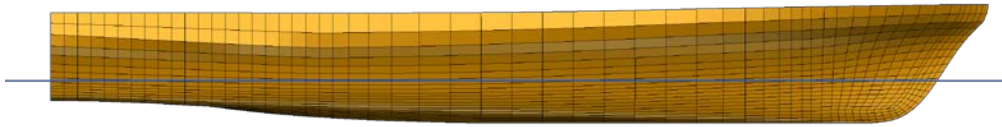
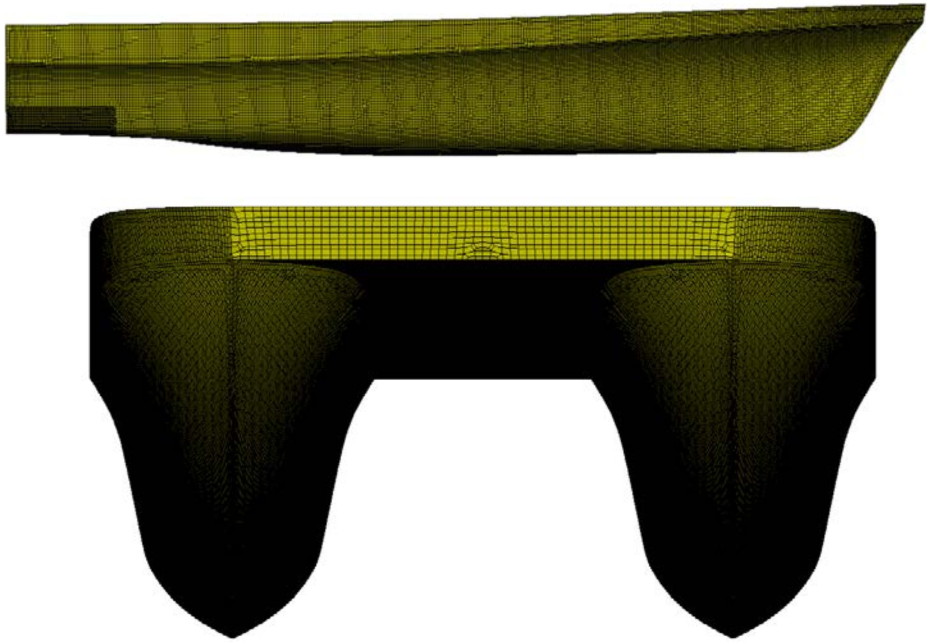
Preliminary calculations for Reference Case using ν-SHALLO and FreSCo+ (HSVA in-house RANSE code)

Principal Dimensions of a reference catamaran

	Symbol	Model	Ship
Length Overall	L_{OA} (m)	4.622	35.00
Length on designed waterline	L_{WL} (m)	4.373	33.11
Length between Perpendiculars	L_{pp} (m)	4.411	33.40
Beam moulded	B (m)	1.334	10.10
Beam waterline	B_{WL} (m)	0.668	5.060
Draught at ½ L_{pp}	T (m)	0.202	1.533
Draught at FP	T_{FP} (m)	0.202	1.533
Draught at AP	T_{AP} (m)	0.202	1.533
Volume of Displacement	Δ (m^3)	0.304	131.9
Prismatic coefficient	C_P	0.694	0.694
Block coefficient	C_B	0.463	0.463
Midship section coefficient	C_M	0.666	0.666
Longitudinal C.B. rel. to L_{pp}/2	LCB % (L_{pp})	-7.506	-7.506
Wetted surface	S (m^2)	4.526	259.5



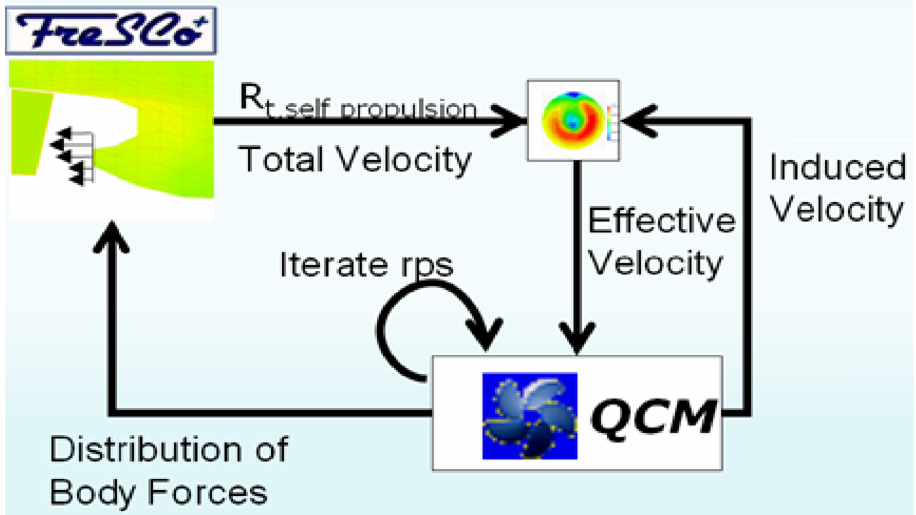
ν-Shallo Panel mesh



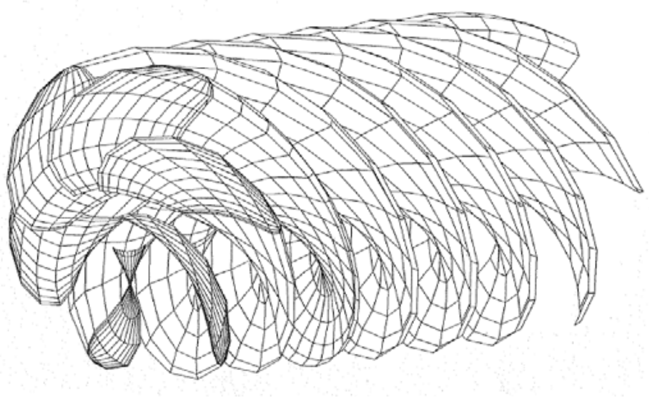
RANSE surface mesh

What is HSVA in-house RANSE code FreSCo+?

- In-house RANS Solver FreSCo+
  - ✓ Finite Volume method
  - ✓ Unstructured grid discretisation (including overlapping grids)
  - ✓ Turbulence modelling
  - ✓ VOF method for free surface (HRIC scheme etc.) and cavitation computation
  - ✓ Overlapping grid technique and 6-DoF ship motion
  - ✓ Parallel computing using MPI communications protocol



- QCM for Propeller
  - ✓ A vertex lattice method
  - ✓ Blades of propeller reduced to lifting surface



- RANS-QCM Self-Propulsion Calculation for Local Optimisation as On-going Work in TrAM Project

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Free Surface Deformation at different speeds

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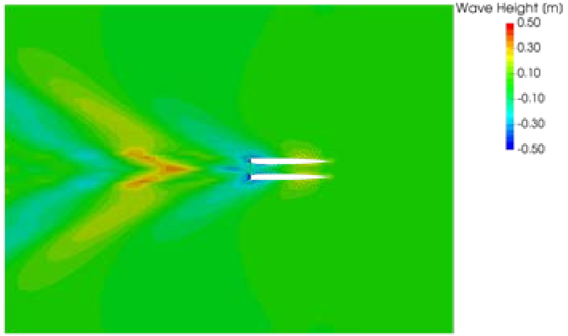
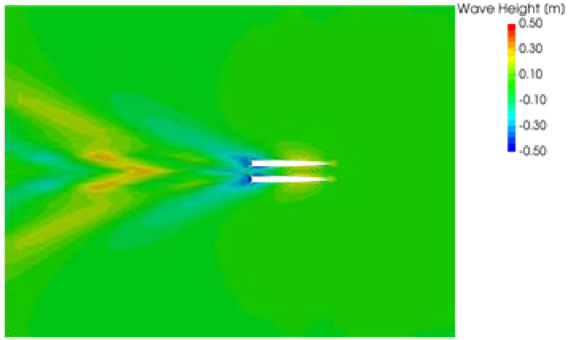
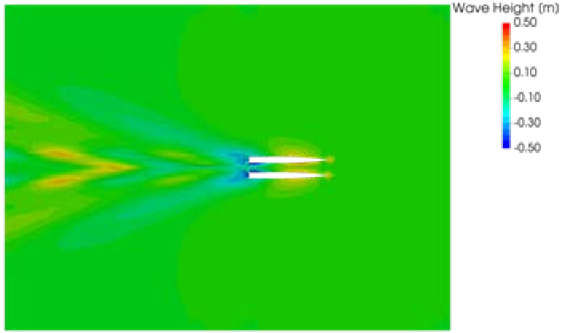
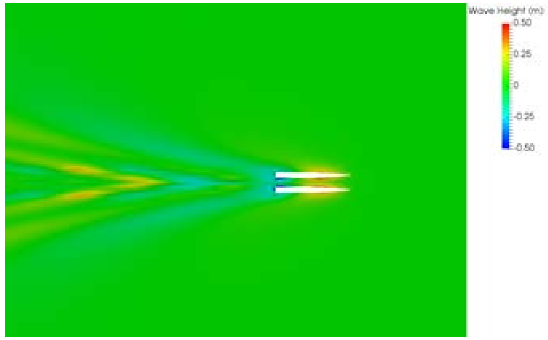
ν-Shallo



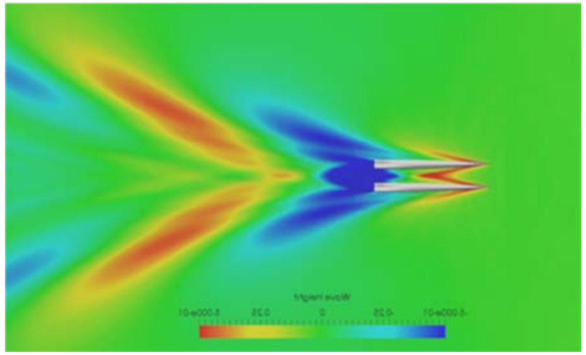


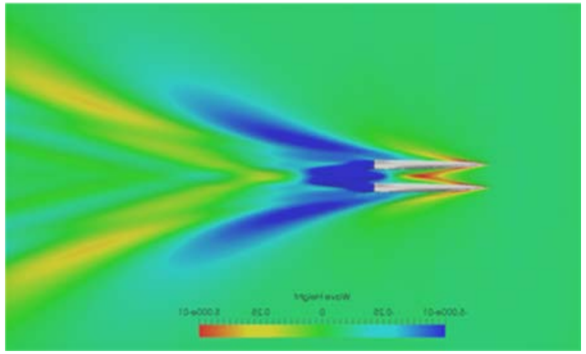


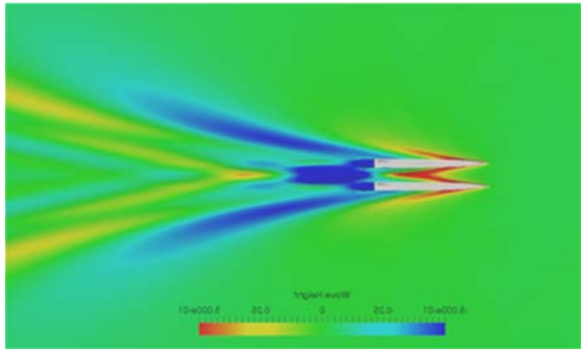


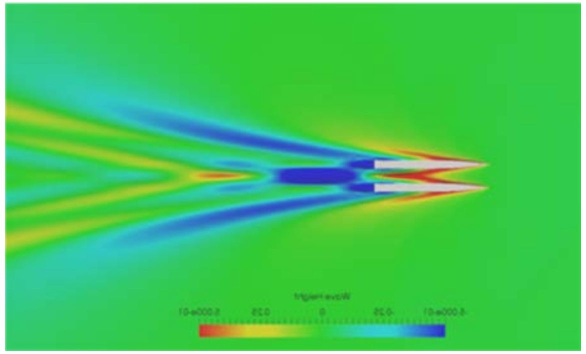
V_s=25kts V_s=30kts V_s=35kts V_s=40kts

FreSCo+









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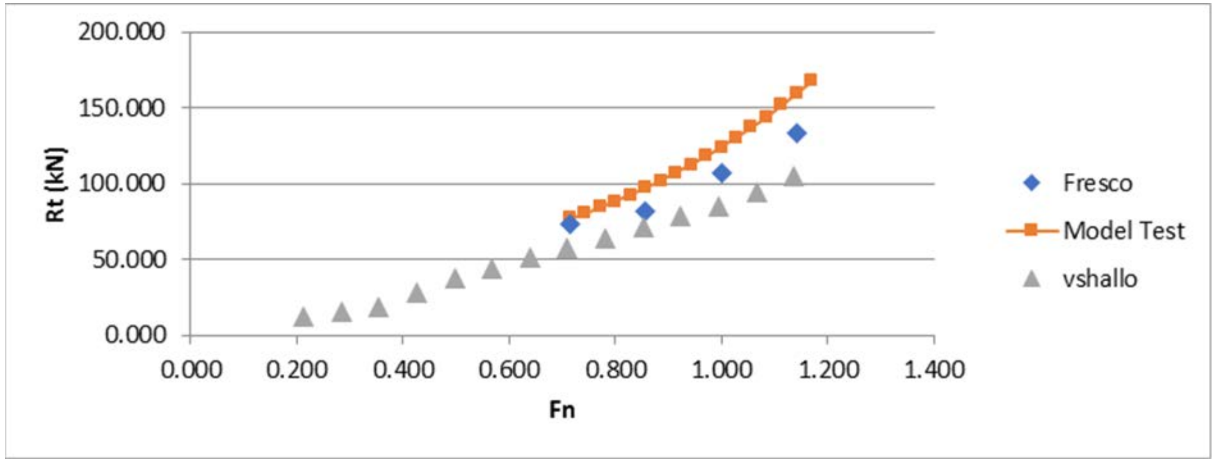
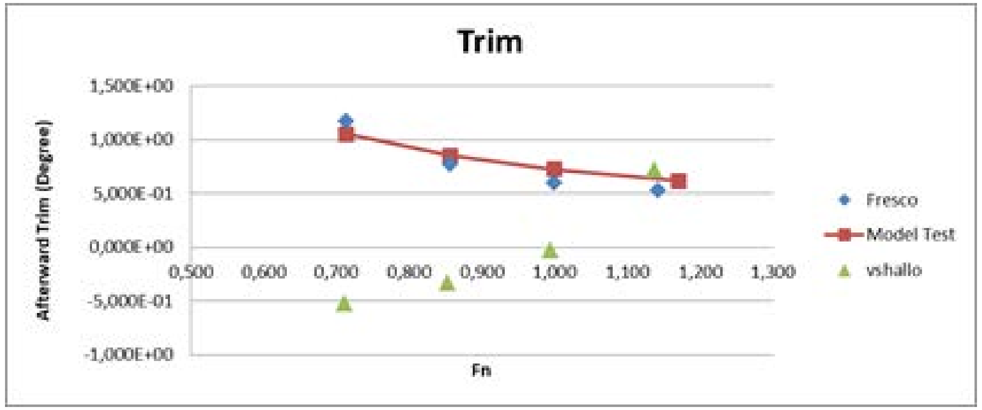
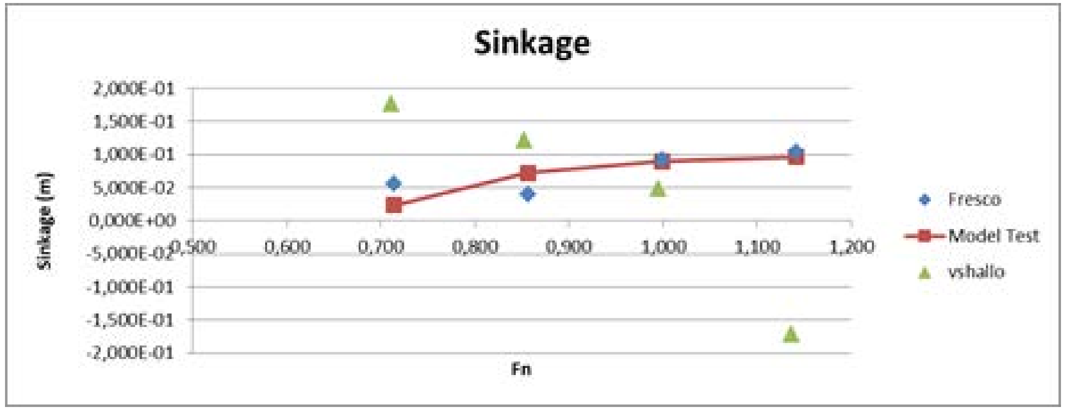
Comparison on resistance results of ν-SHALLO and FreSCo+ with available model tests

- Both FreSCo+ and ν-SHALLO under-predicte the total calm water resistance; The resistance predcited by FreSCo+ is quite satisfactary, especially in lower speed range (area of interest);
- Good agreement with experiment in terms of trim, sinkage by FreSCo+ and the trim and sinkage predicted by ν-SHALLO is completely off;
- ν-SHALLO is prefered tool for global optimisation due to its advantage in performance; The resistance predicted by ν-SHALLO however needs to be corrected (in form factor) for practical applications ;







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Design of Experiments (DoE) for Stavanger Demonstrator using ν-SHALLO

DoE for Stavanger Demonstrator	Description	Overall Beam of 9.0m	Overall Beam of 9.5m
(Global) Design Variables for demihull	LWL	29~30.2m	28~29.2m
	HB (half Beam)	1~1.3m	1~1.3m
	T_INIT	1.2~1.6m	1.2~1.6m
	CHINEY_RATIO (transom)	0.8~0.85	0.8~0.85
Design Conditions	Weights	75, 80, 85 m^3	75, 80, 85 m^3
	Ship Speed	21, 23, 25 kn	21, 23, 25 kn
Design Constraints	Battery space	1634x2029mm	1634x2029mm
Design Variants	For each condition	200	200
Design Results	Number of calculations	1800	1800
Evaluated Variables (some examples are listed here)		RT	RT
		Sinkage/Trim	Sinkage/Trim
		Sep_deminhull	Sep_deminhull

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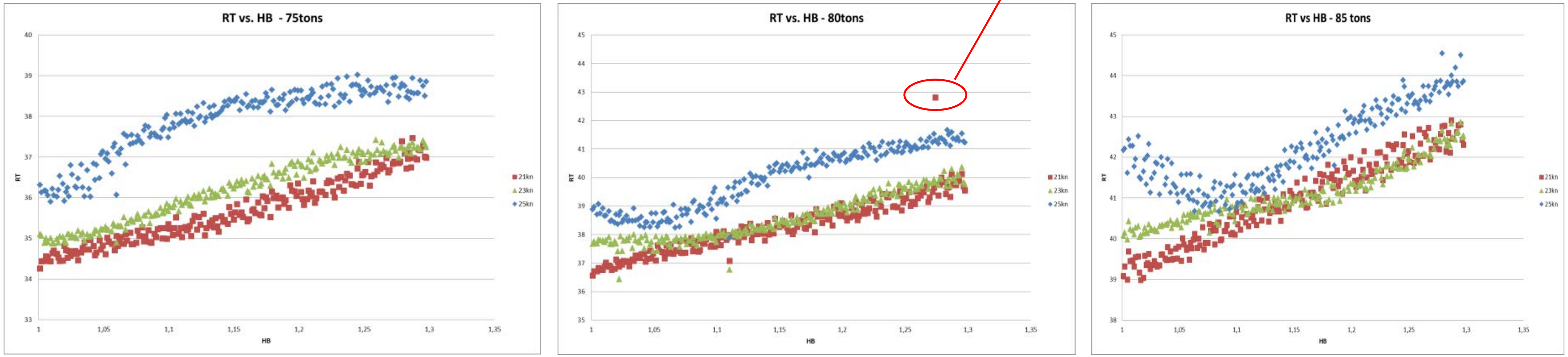
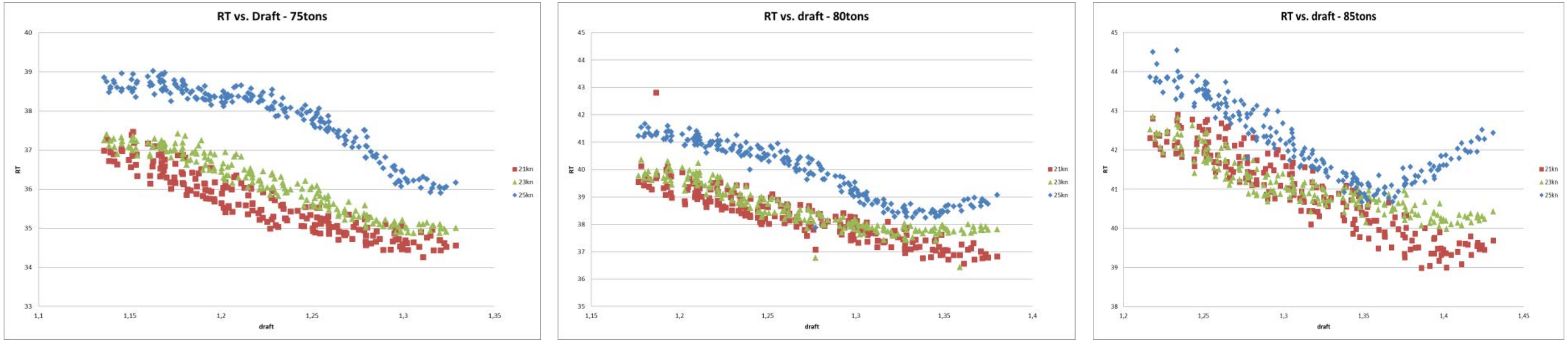
ν-SHALLO (Sobol) DoE results

Not converged!



RT vs. HB (half Beam of demihull)



RT vs. Draft

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ν-SHALLO results correction using Form Factors (1+*k*) calculated by FreSCo+

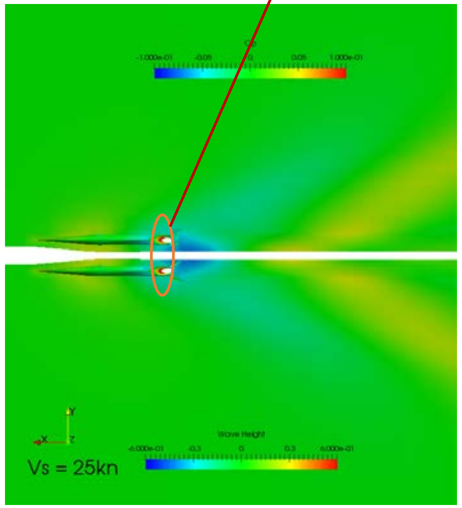
The total resistance coefficient computed by n-SHALLO can be subdivided into two parts:

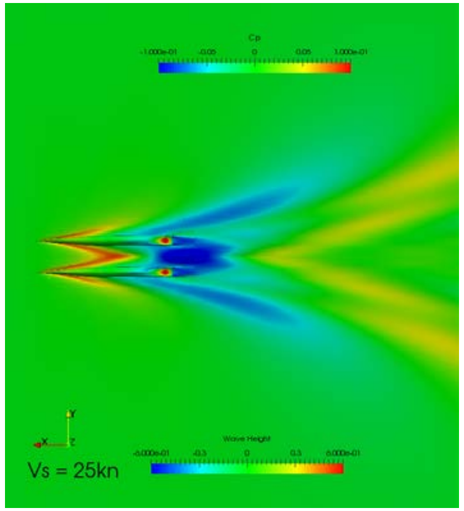
$$C_t = C_w + (1 + k) * C_f$$

The second part contains a friction coefficient from the ITTC 1957 correlation line multiplied by a form factor (1+*k*), where *k* is determined as follows:

$$1 + k = \int_{S_{wetted}} \vec{v^2}\, dS / u^2 S_{initial}$$

Dry tunnel area

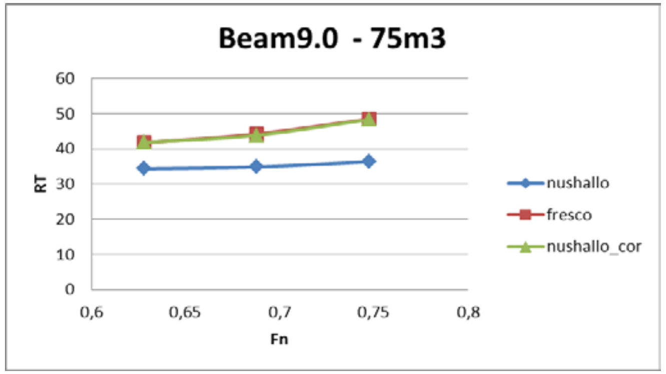


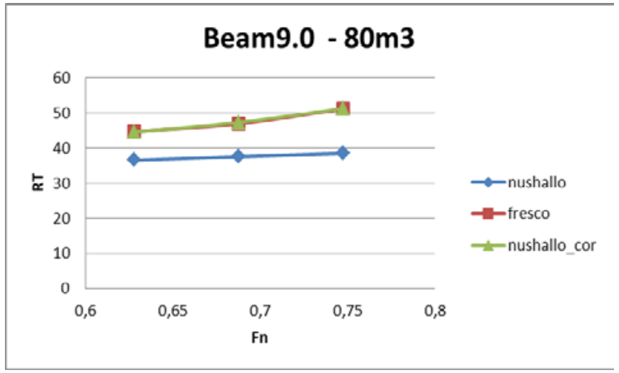


This form factor accounts for the change in wetted surface as well as for the inhomogeneous velocity distribution.

Computed Form factors from Doule Body RANSE computations using three grid resolutions:

Grid resolution	Form Factor (1+k)
Coarse grid	1.10
Middle grid	1.09
Fine grid	1.08





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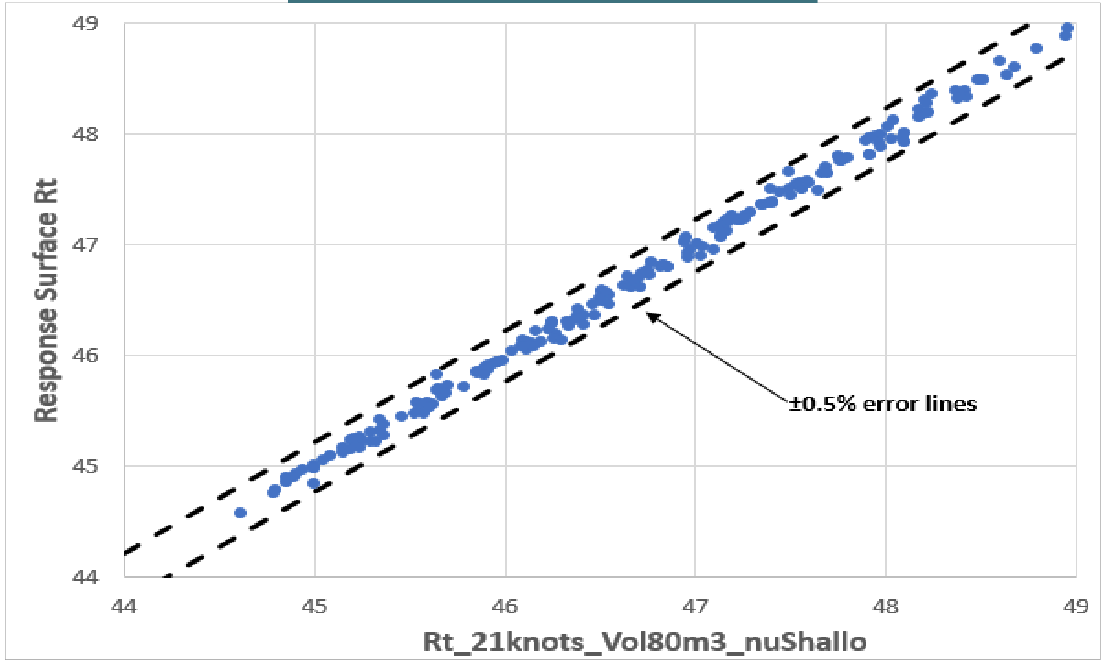
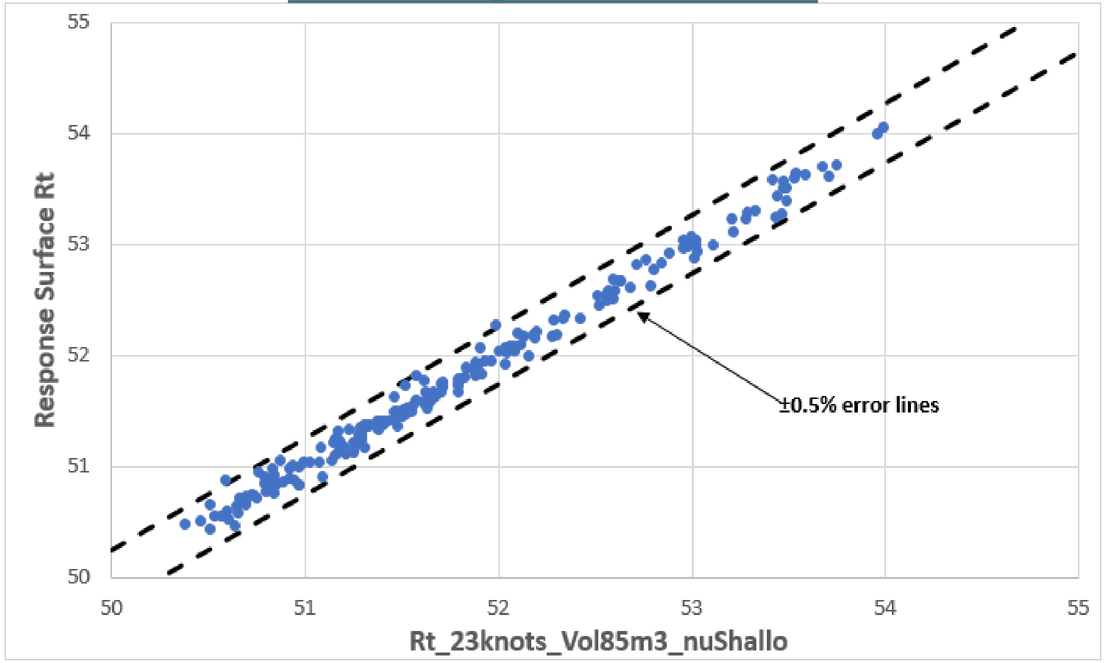
Use of Surrogate Models instead of Direct Calculations for Reduced Computational Time

1. Various surrogate models were generated and tested for calm water resistance calculation based on ν-Shallo results.
2. Most accurate and fast method: MARS (Multivariate Adaptive Regression Splines) (error ≤ ±0.5%).
3. Surrogate models replaced direct calculations by CFD tools in optimization studies.

Volume of 80m³ at 21kn



Volume of 85m³ at 23kn



National Technical University of Athens

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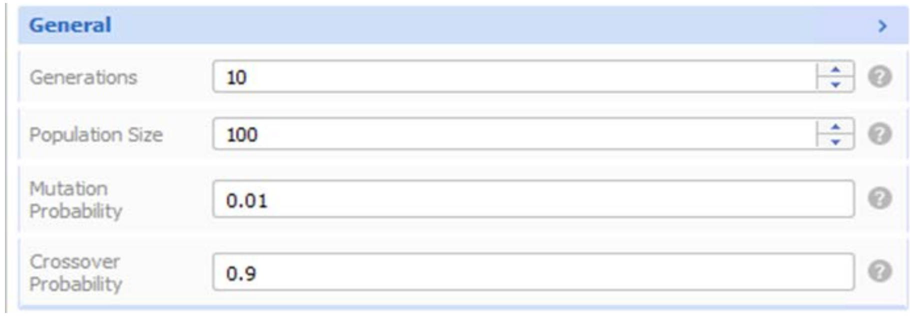
Global Optimization Studies

TFAM

1. Global optimization studies performed using NSGA-II genetic algorithm



1. Objective of the study: to minimize calm water resistance of the bare hull
2. To obtain hullform with superior characteristics in a range of displacements & speeds, the following weighted objective function is used:

$$R_{T_{OF}} = 0.12R_{T,21kn,75m^3} + 0.20R_{T,23kn,75m^3} + 0.08R_{T,25kn,75m^3} + \\ 0.09R_{T,21kn,80m^3} + 0.15R_{T,23kn,80m^3} + 0.06R_{T,25kn,80m^3} + \\ 0.09R_{T,21kn,85m^3} + 0.15R_{T,23kn,85m^3} + 0.06R_{T,25kn,85m^3}$$

1. Constraints:
    1. Minimum demihull width & height for installation of batteries
    2. Height of tunnel at centreline for propeller installation

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Design Variables

- According to the 1st Design Scenario:
  - ➢ catamaran's length overall fixed at 31.0m
  - ➢ beam overall fixed at 9.0m

- Design variables considered:
  - Waterline Length
  - Demihull's Beam
  - Initial Draught
  - Transom width

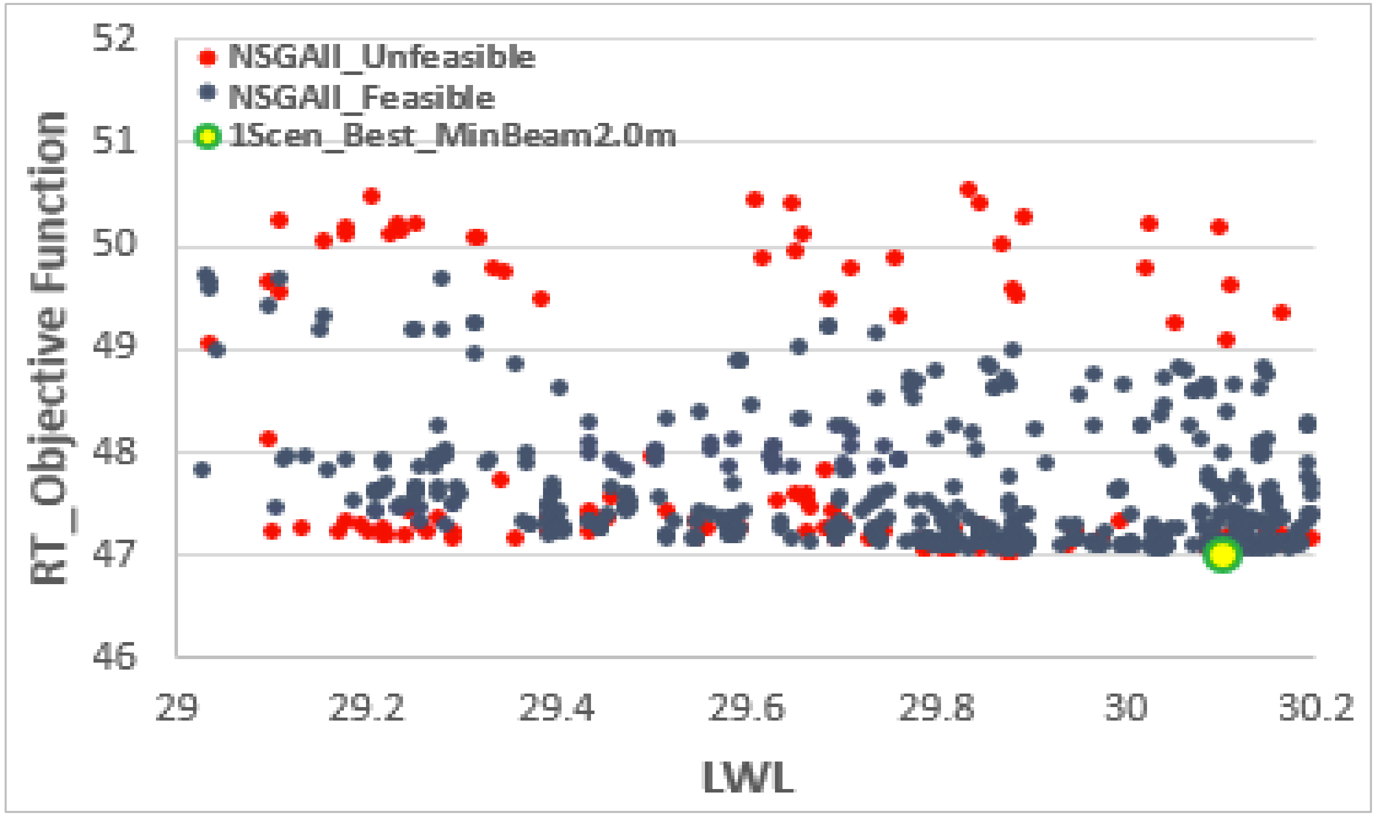
Design Variables

	Design Variable	Lower	Value	Upper	Active
1	01_LWL	29	30.1	30.2	✖
2	02_HBDES	1	1.1	1.3	✖
3	03_TINIT	1.2	1.3	1.6	✖
4	01_CHINEY_ATS0_RATIO	0.8	0.81	0.85	✖

Global Optimization Results

Total Designs Produced: 1000

- 824 Feasible
- 176 Unfeasible



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Global Optimization Results

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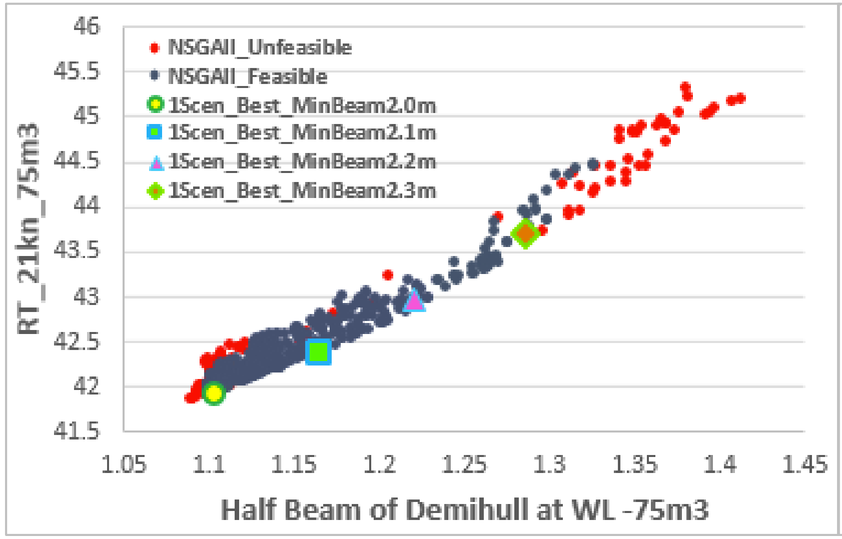
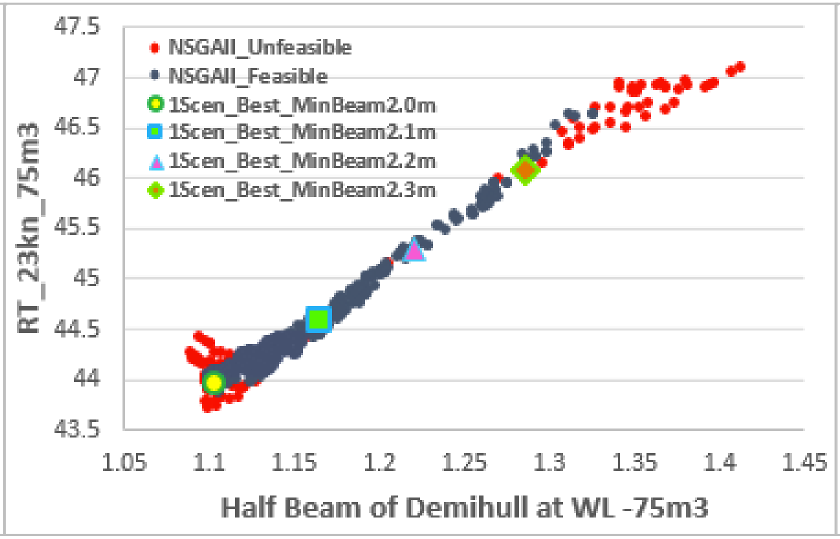
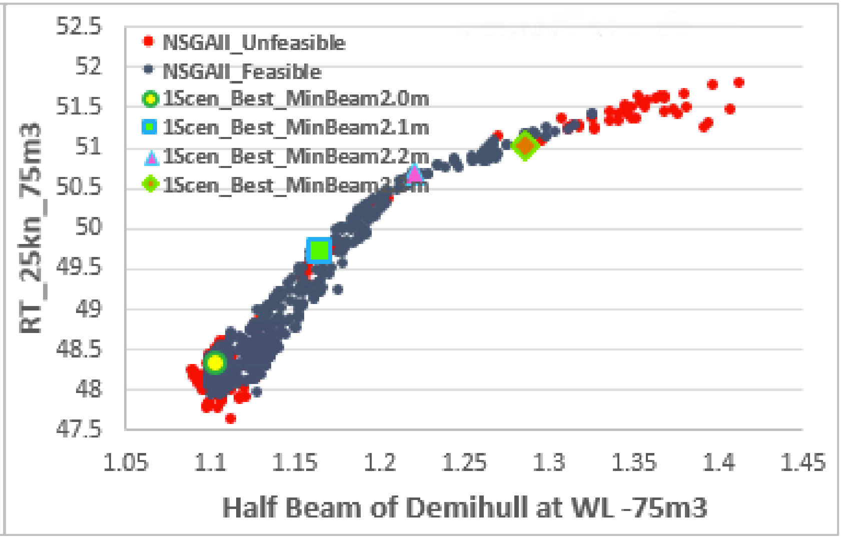
Displacement Volume: $75m^3$







Vs=21kn **Vs=23kn** **Vs=25kn**

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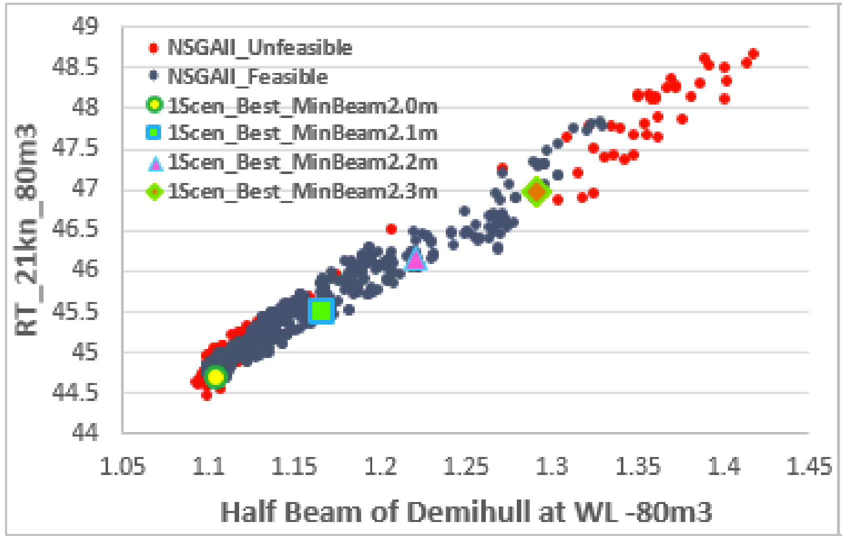
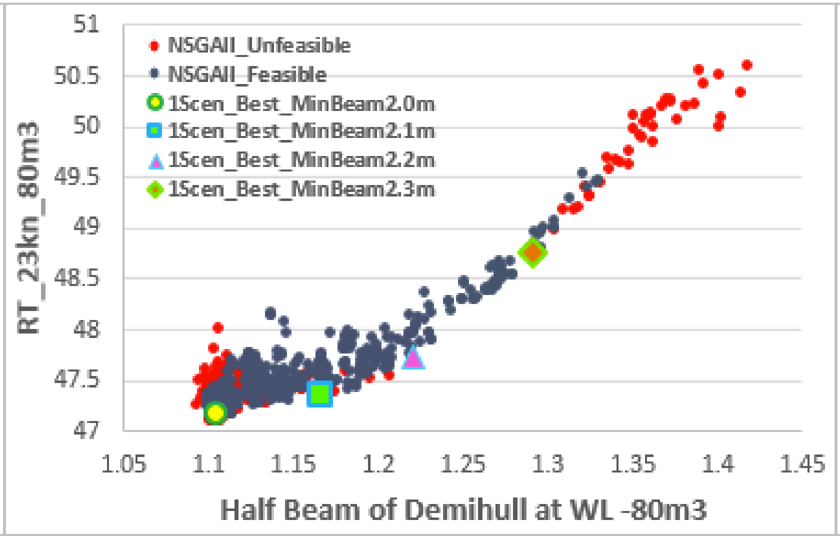
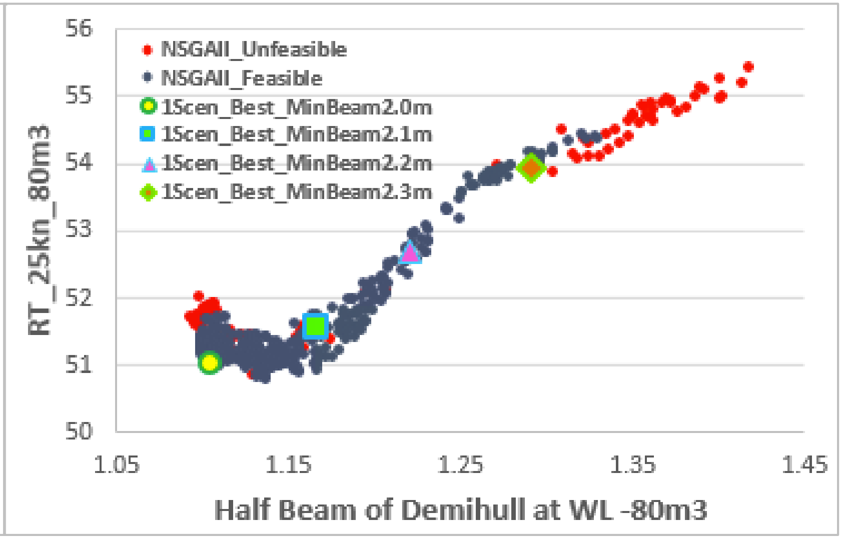
Global Optimization Results

TEAM

Displacement Volume: $80m^3$







Vs=21kn **Vs=23kn** **Vs=25kn**

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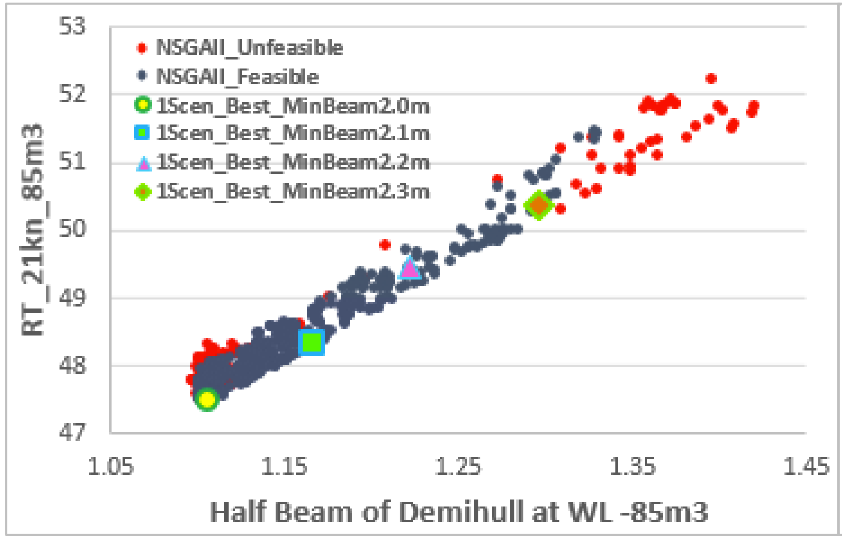
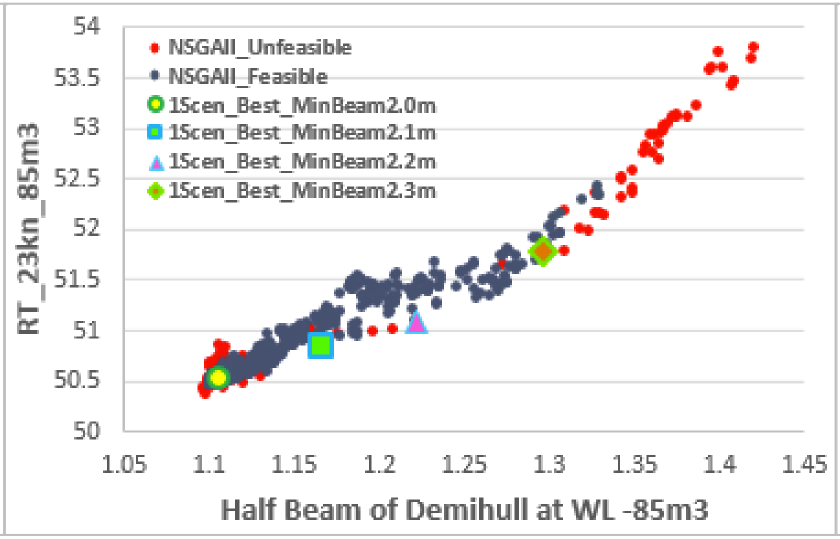
Global Optimization Results

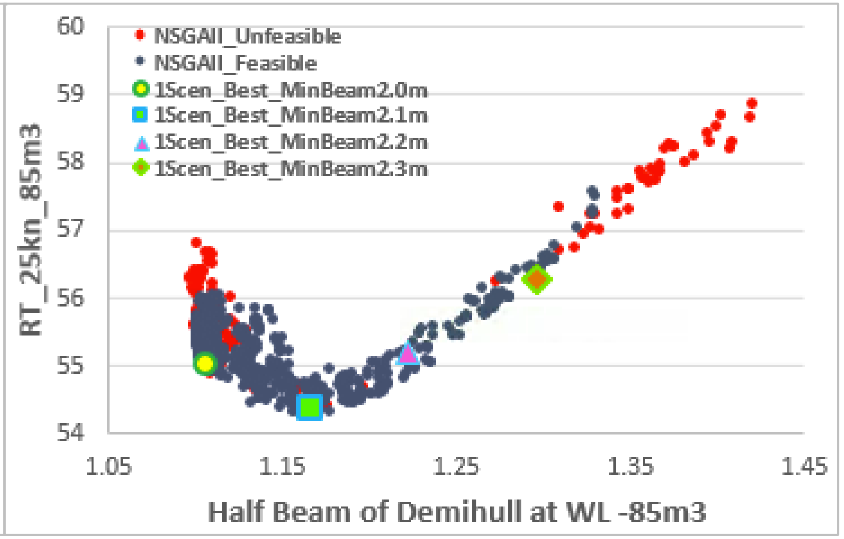
Displacement Volume: $85m^3$



Vs=21kn



Vs=23kn



Vs=25kn

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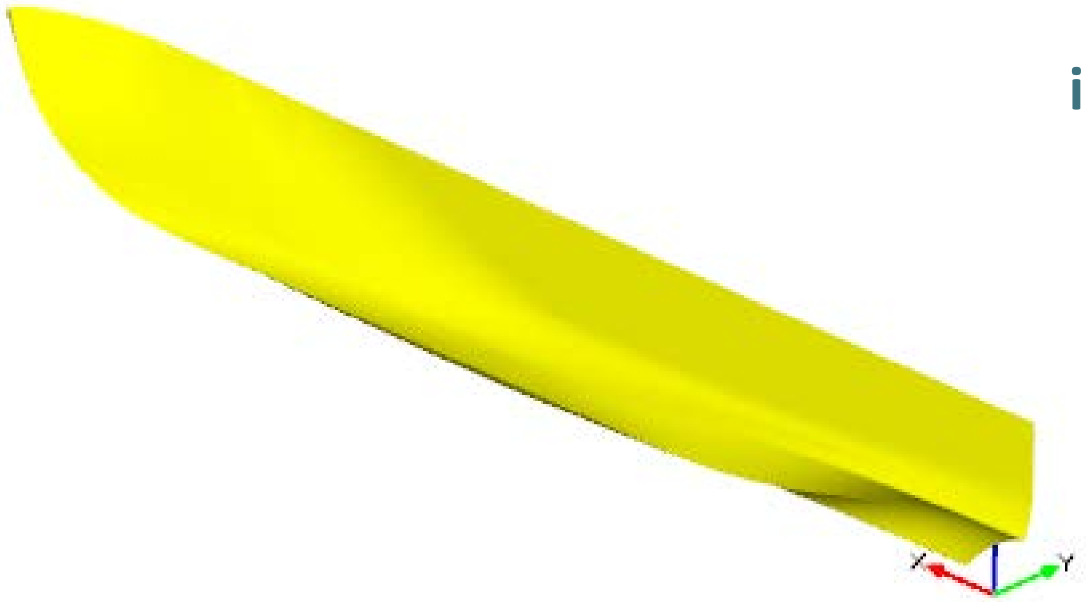
Optimum Design Selection

- ✓ Based on hydrodynamic characteristics and construction/maintenance issues, an overall optimum design was selected



i. Design Variables:

01_LWL	29.84
02_HBDES	1.11
03_TINIT	1.22
01_CHINEY_ATS0_RATIO	0.831

ii. Results:

	at 75m3	*at 80m3*	*at 85m3*
LWL	29.29	29.34	29.39
Beam at WL	2.442	2.442	2.444
Draft	1.226	1.272	1.317
Rt_21kn	42.979	46.162	49.443
Rt_23kn	45.290	47.724	51.085
Rt_25kn	50.671	52.690	55.197

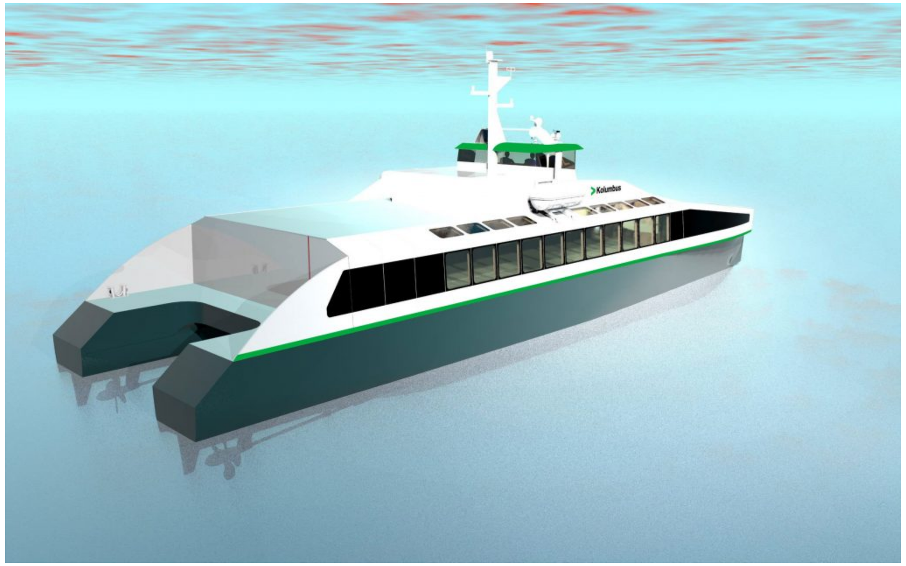
This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 769303

Conclusions & Next Steps

- Parametric model for fast catamaran design developed by NTUA in CAESES, integrated with HSVA's ν-Shallo
- Development of surrogate models for calm water resistance on the basis of CFD results
- Multi-objective Optimization studies using NSGA-II genetic algorithm
- Conducted global optimization studies show that:
  - Demihull hullforms with smaller beam have lower calm water resistance for lightest displacements
  - At higher speeds and displacements, beamier hullforms are performing better
  - The demihull separation distance proved less significant in the studied range
- Based on hydrodynamic characteristics and construction/maintenance issues an overall optimum was selected for more refined optimisation
- Local hullform optimization for improved resistance and propulsion characteristics are currently in progress using HSVA's CFD viscous flow RANS solver FreSCo+
- The resulting hullform will be tank-tested by HSVA and used for building of the Stavanger prototype

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 769303

Thank you for your attention



Parametric Design and Optimization of a battery-driven Catamaran in CAESES

Malte Mittendorf, FH Kiel

Thesis-Outline

1. Estimation of R_T by s/w *catares* and implementation in *CAESES*
2. Validation studies
3. Two-stage optimization procedure with *catares* and nuShallo
- Global Optimization: Resistance Optimization based on operational profile
- Local Optimization: Optimization with respect to wave resistance and wash
4. RANSE-Verification of results with FreSCo+

Introduction to Thin Ship Theory

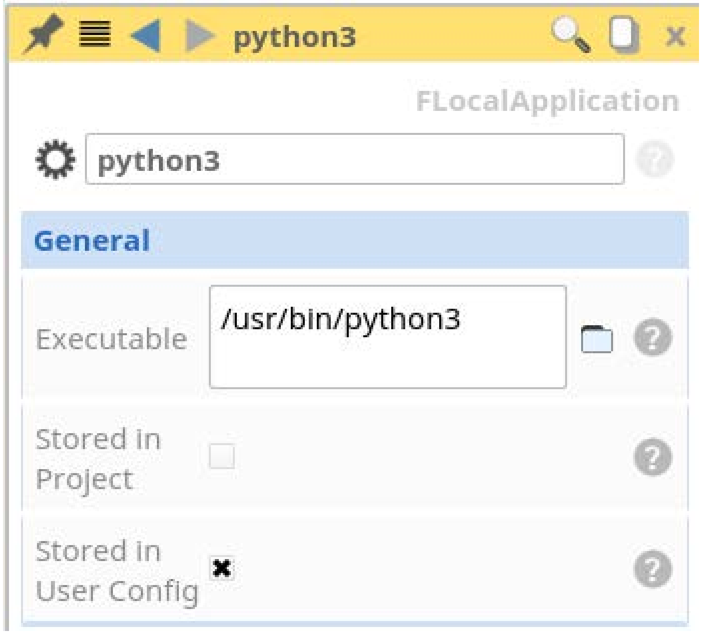
- Applies to Wave Pattern Resistance of symmetrical thin hulls (B/L<<1)
- Use of Green’s function for capturing free surface boundary condition
- Kelvin sources are placed on symmetry-plane of each demihull
- Source strength dependent on velocity and local slope of waterlines

$$\sigma(x,0,z) = -\frac{U}{2\pi}\frac{\partial f}{\partial x}(x,z)$$

- Source Deficit at Transom → fitting of a virtual appendage necessary
- Use of NTUA’s software RES based on *modified thin ship theory* → Kelvin sources placed on 3D panels

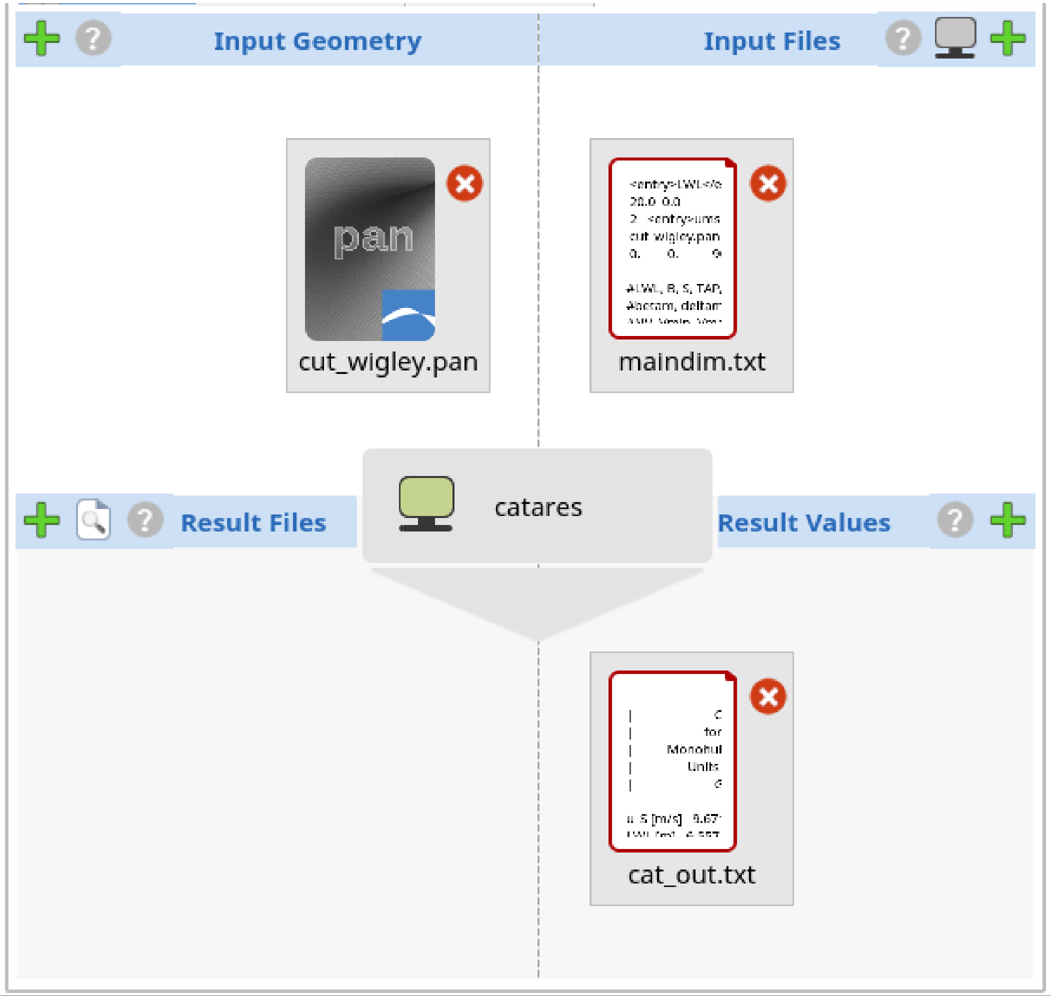
Implementation of *catares* in *CAESES*

- Python Compiler as Executable in Config



Implementation of *catares* in *CAESES*

- Python Compiler as Executable in Config
- Parse RES-Inputfile from .pan and ASCII file



Implementation of *catares* in *CAESES*

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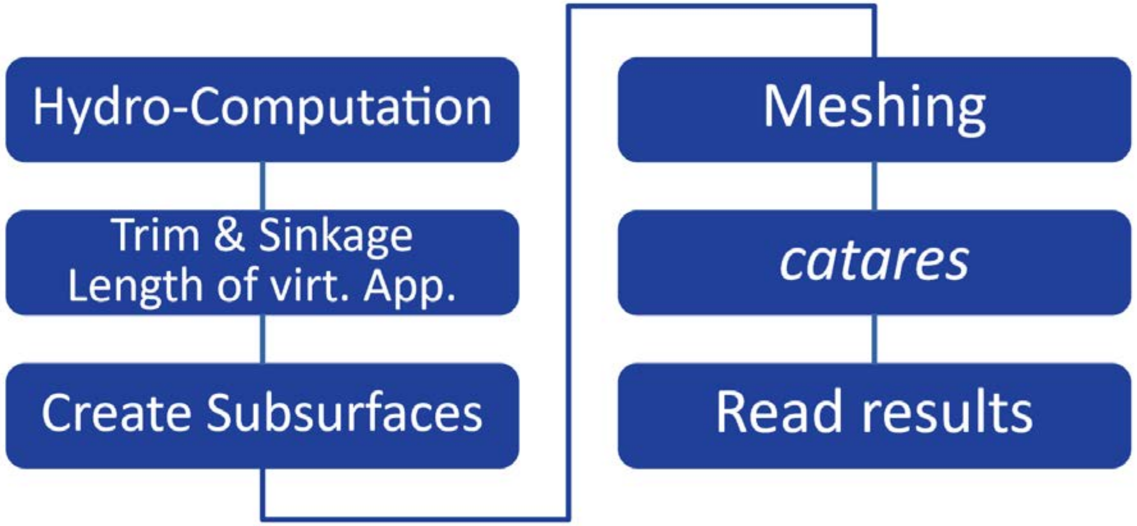
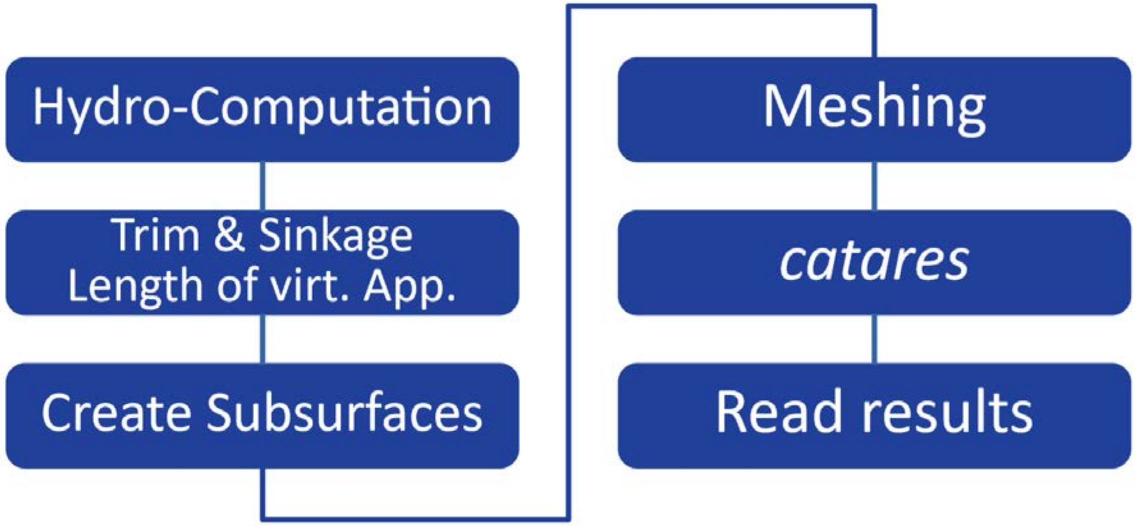
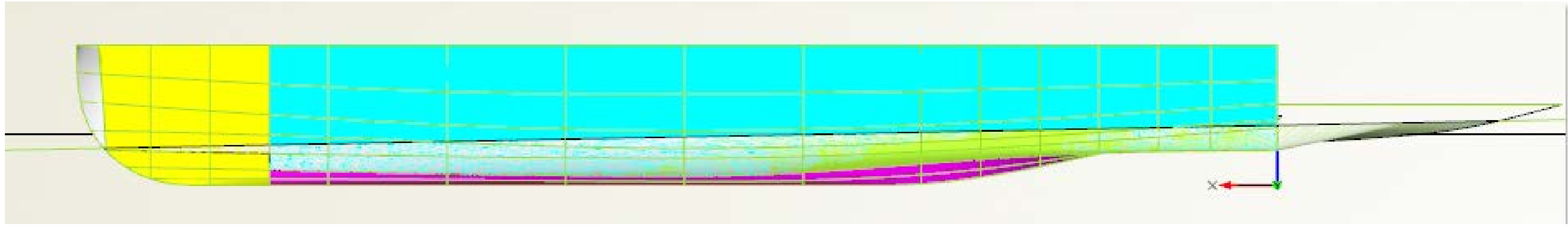


Implementation of *catares* in *CAESES*

- Python Compiler as Executable in Config
- Parse RES-Inputfile from .pan and ASCII file
- Define Subsurfaces on dynamic waterline
- MeshEngine for .pan-file
- Introduction of empirical calculations for viscous resistance component





Global Optimization

- 1st Scenario & 85m³ Displ. Design
- Objective Functions:

  $R_{T,21kts}$, $R_{T,23kts}$, $R_{T,25kts}$, $R_{T,27kts}$, $R_{T,30kts}$
- Additional Design Variables:

  SP9SHAPE_ATTDES, SP9SHAPE_LOW

→ forebody optimization

- Geometrical Boundary Condition: minimal Width at Doublebottom Height

Latin Hypercube Sampling

Sensitivity Analysis

Surrogate Model: MARS

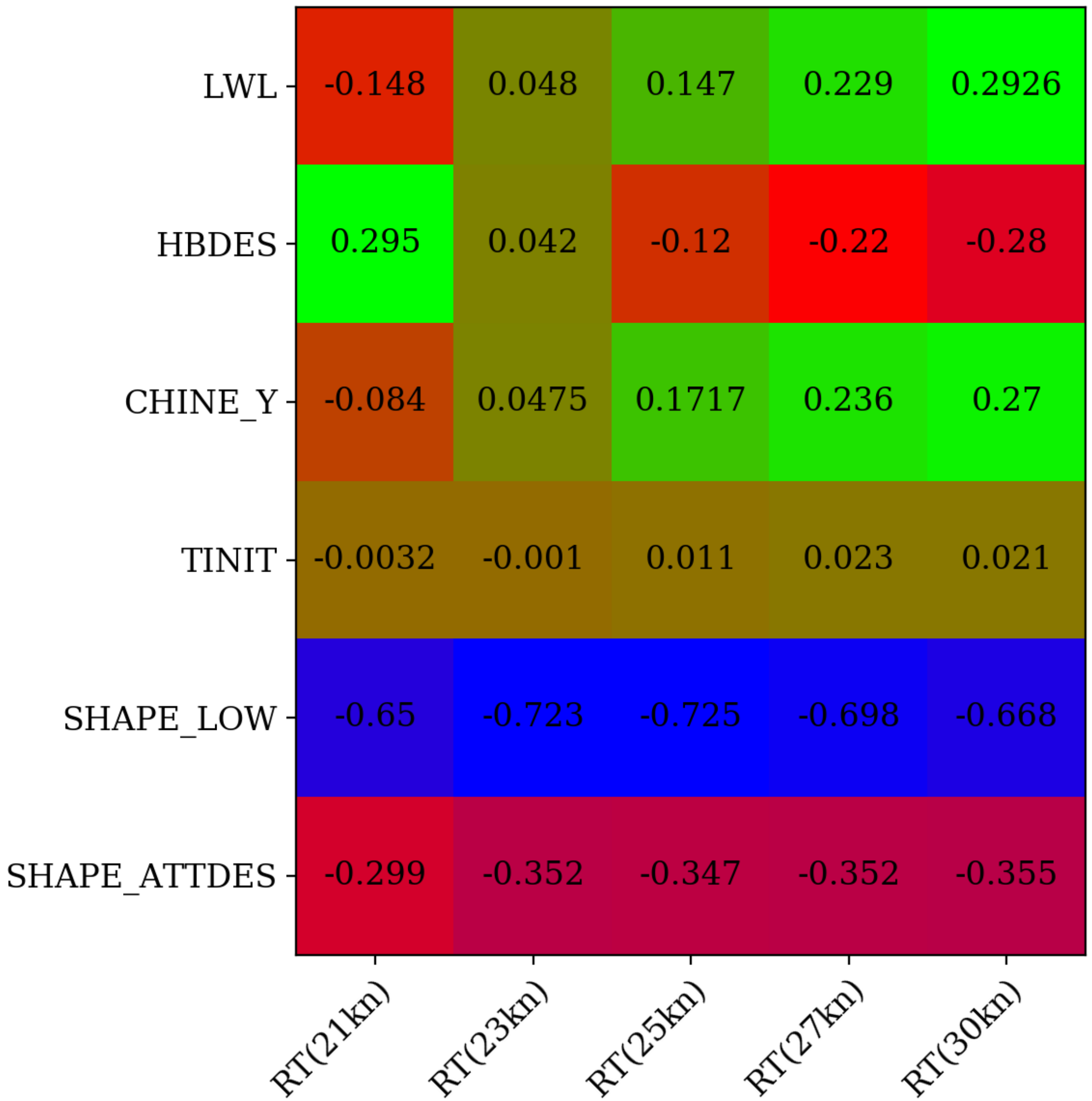
NSGA-II

MCDM

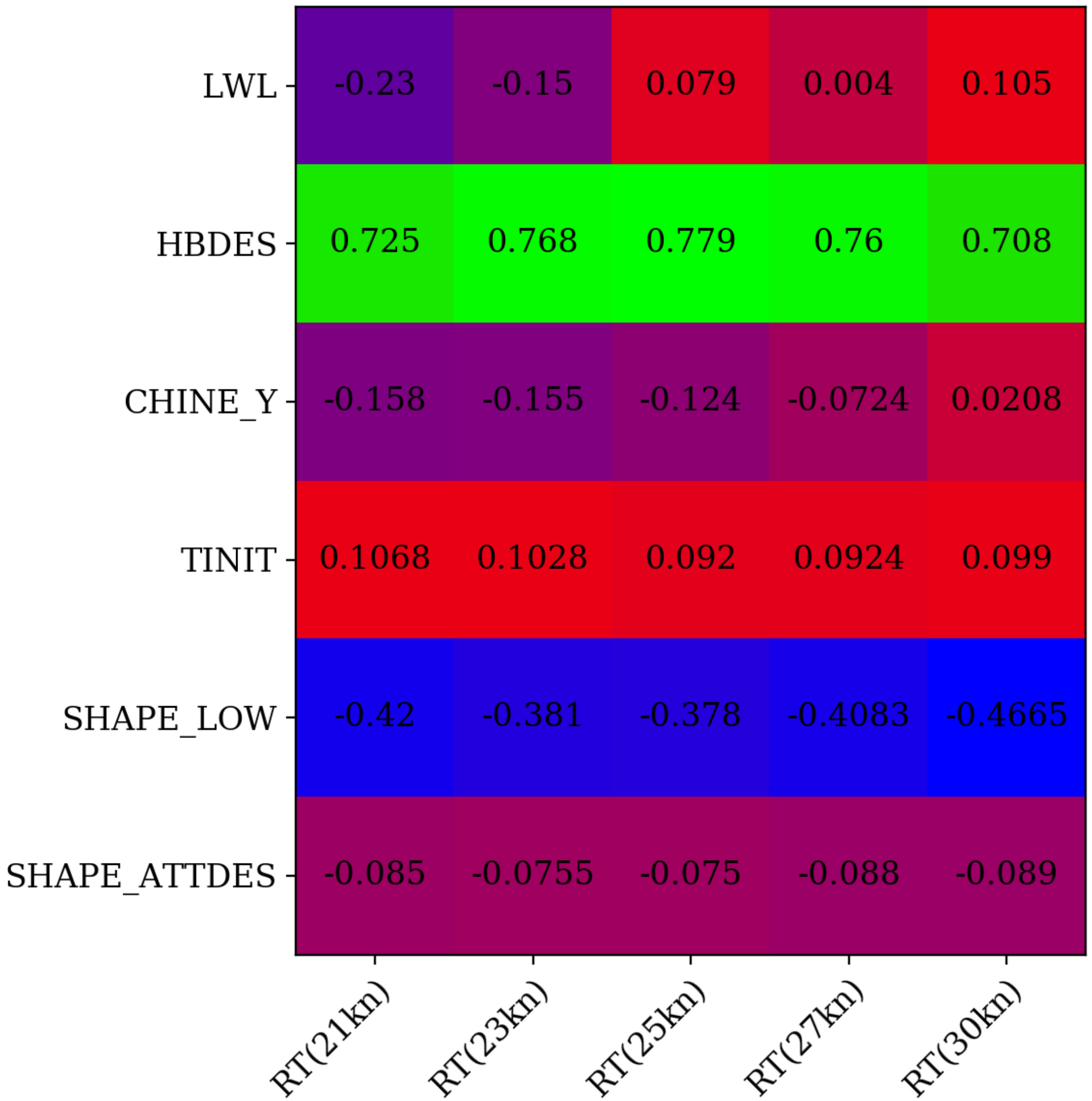
Global Optimization

Exploration

nuShallo

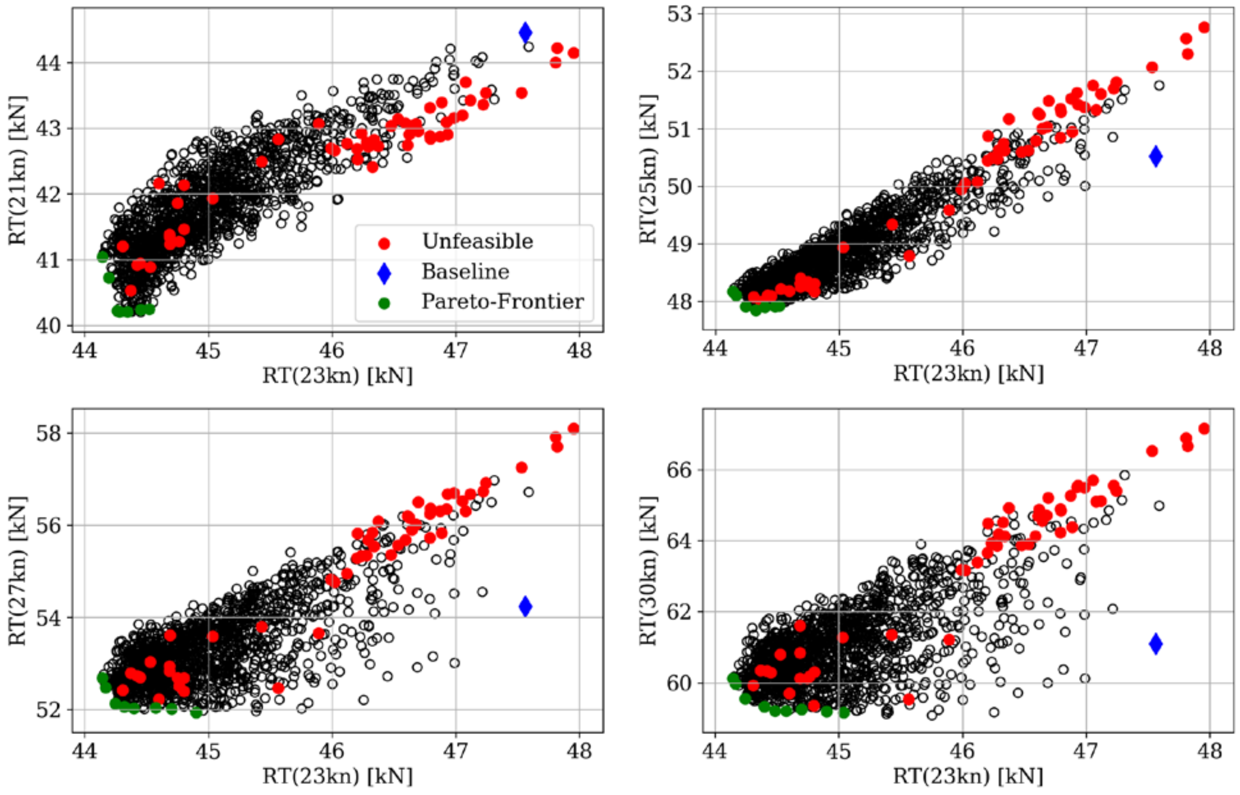


catares

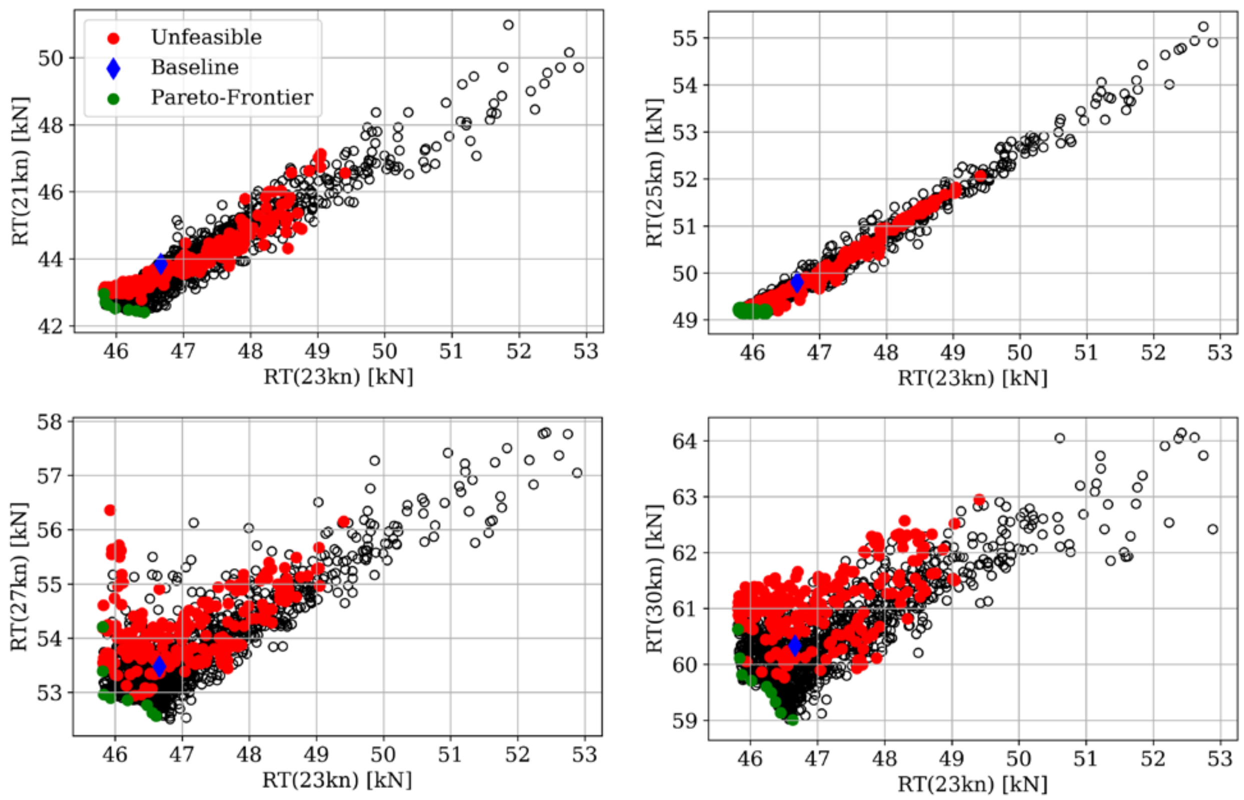


Global Optimization

Exploitation



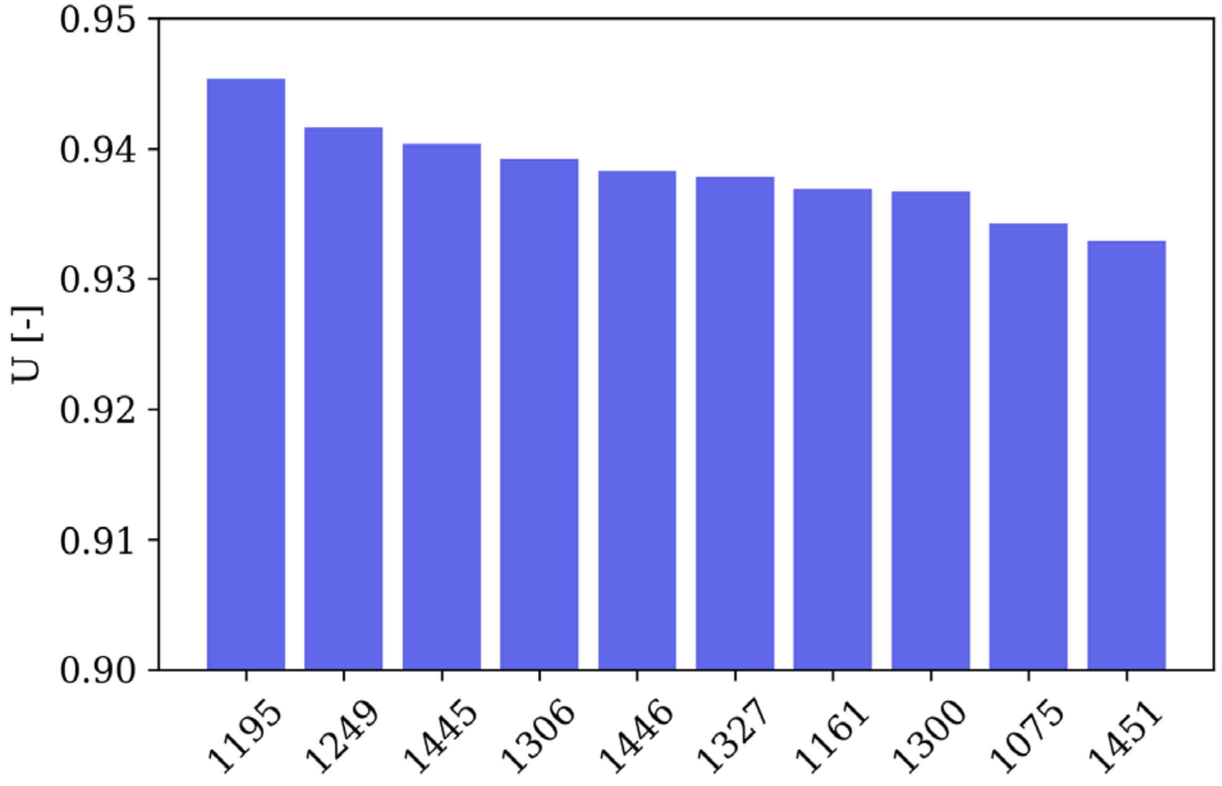
nuShallo



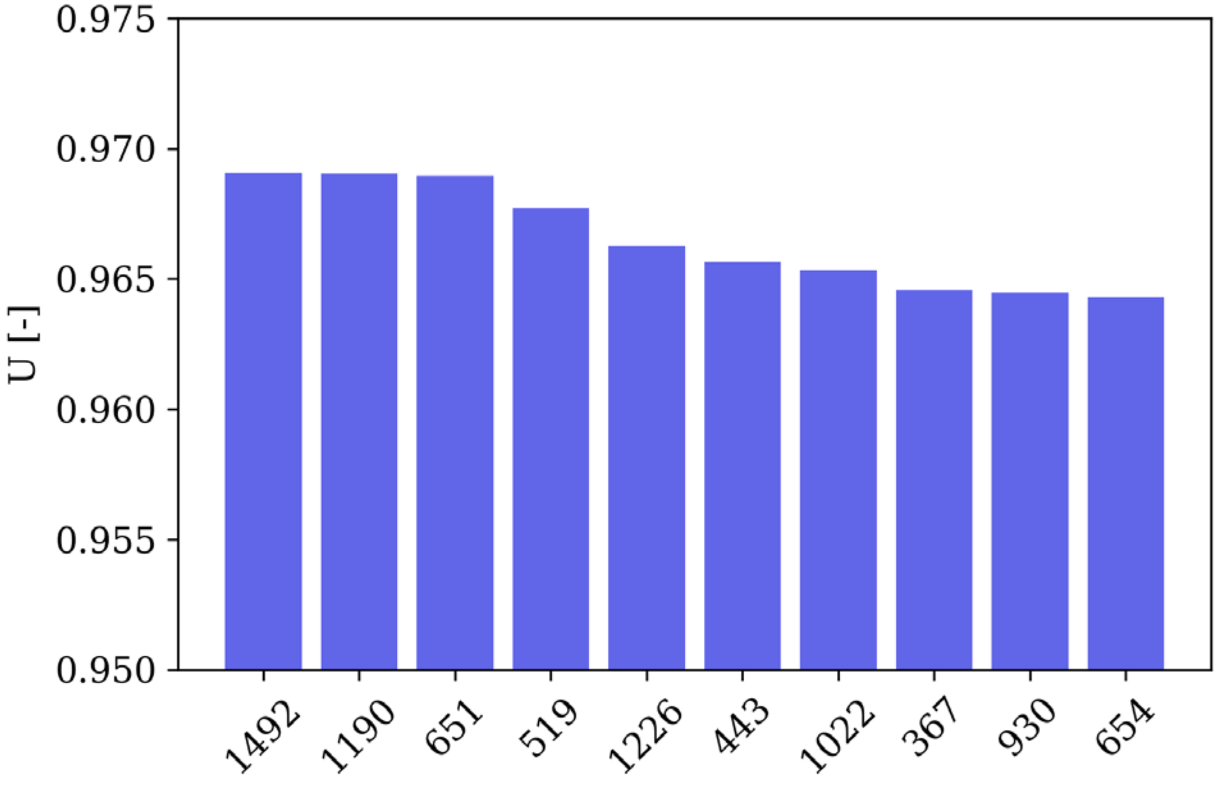
catares

Global Optimization

MCDM



nuShallo



catares

Global Optimization

Results

- Design Variables

Parameter	Unit	Baseline	ν-SHALLO	catares
$Index$	[-]		1195	1492
LWL	[m]	30.1	30.4011	30.2227
$HBDES$	[m]	1.1	1.0963	1.0637
$TINIT$	[m]	1.3	1.3920	1.4878
$CHINE\_Y\_ATS0$	[-]	0.81	0.8233	0.8318
$SP9SHAPE\_LOW$	[-]	1.2	1.4653	1.4629
$SP9SHAPE\_ATTDES$	[-]	0.85	1.0993	1.0647

- Hydrostatic Values

Parameter	Unit	Baseline	ν-SHALLO	catares
T	[m]	1.326	1.298	1.332
$S/\nabla^{\frac{2}{3}}$	[-]	9.868	9.884	9.861
LCB	[m]	13.87	14.28	13.98
LCF	[m]	12.11	12.55	12.33

Discussion of Results & Conclusions (1)

- Cross-check at 23 kts

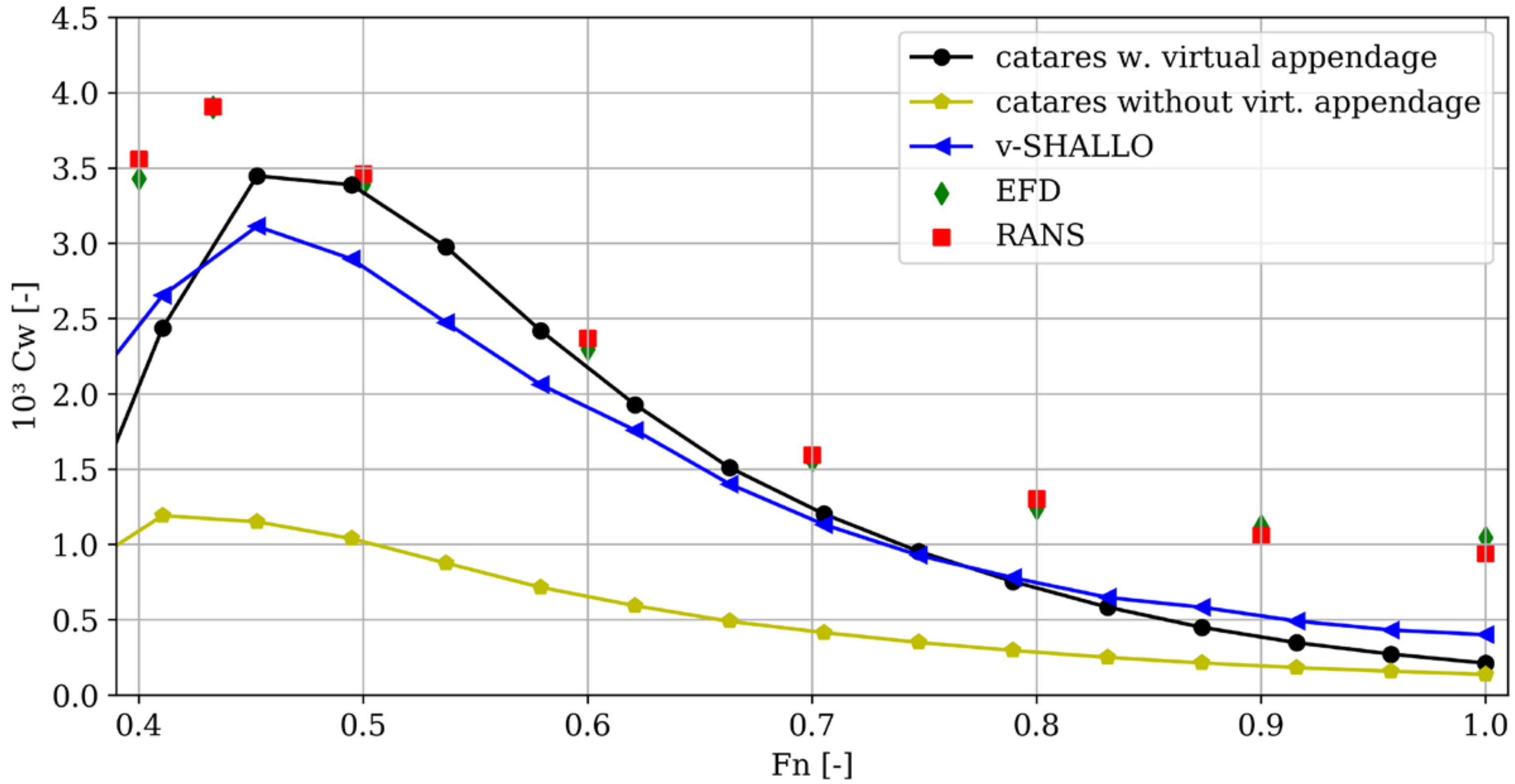
$R_T/\Delta\,[-]$	*catares*	Change [%]	ν-Shallo	Change [%]
Baseline	0.549	-	0.533	-
NS-1195	0.542	-1.32	0.525	-1.44
Cat-1492	0.541	-1.57	0.528	-0.91

- Resistance reduction for catares 1.57% → RANSE FreSCo+: 1.1%
- R_T decrease for the whole speed range; on average: 1.63% (nuShallo: 1.47%)
- Increased wetted surface WSA and thus R_T for nuShallo optimal design according to FreSCo+
- More convex lines in forebody lead to spray → fitting Sprayrails necessary

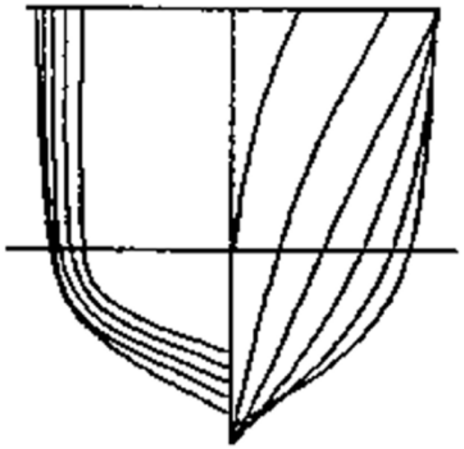
→ Modified Thin Ship Theory proves to be well applicable for resistance prediction and efficient optimization of fast displacement catamarans

Discussion of Results & Conclusions (2)

- Combination of NSGA-II, MCDM and Simplex prove very efficient (local optimization)
- Virtual Appendage to Thin Ship Theory method leads to increased accuracy by modelling the transom stern effect



NPL 5b Hull
S/L =0.3



Discussion of Results & Conclusions (2)

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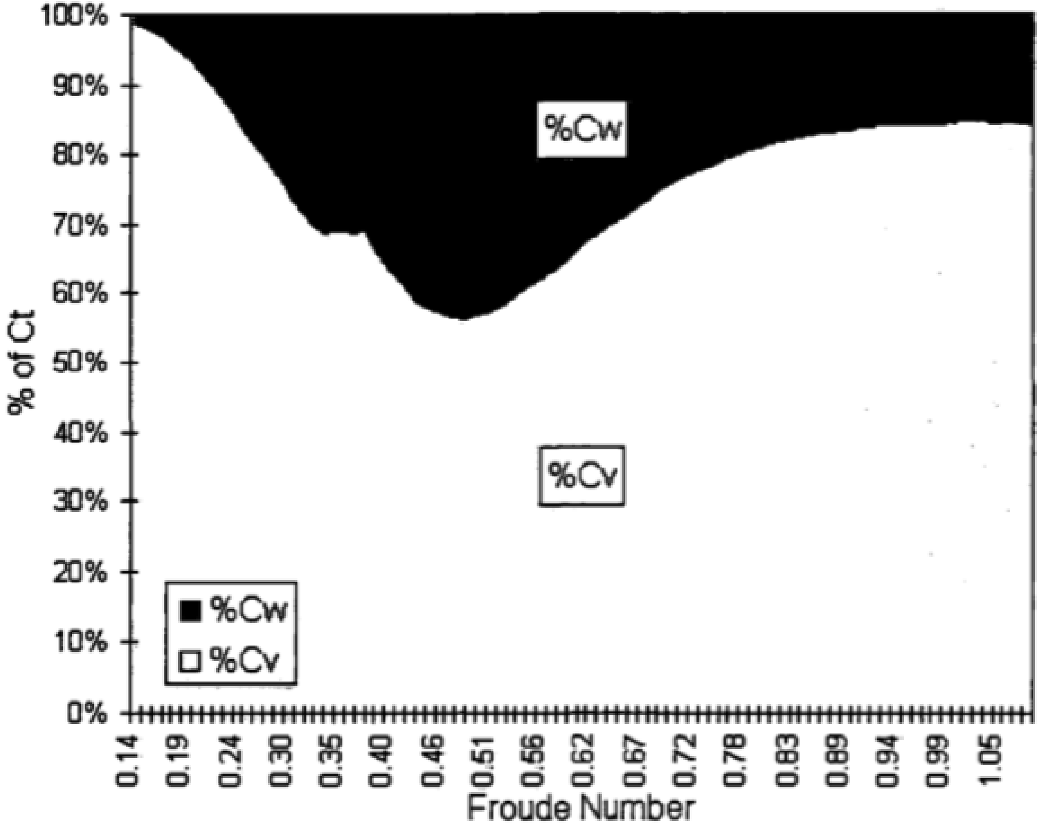

Discussion of Results & Conclusions (2)

- Combination of NSGA-II, MCDM and Simplex prove very efficient (local optimization)
- Virtual Appendage to Thin Ship Theory method leads to increased accuracy by modelling the transom stern effect
- Questionable applicability of used panel methods for high Fn
- Use of Adjoint CFD would have made more sense due to dominant viscous resistance
- CAESES proved to be a very userfriendly, easy to learn and powerful tool

Thank you for your Attention!

Any Questions or Suggestions?

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