

**CONFIDENTIAL**

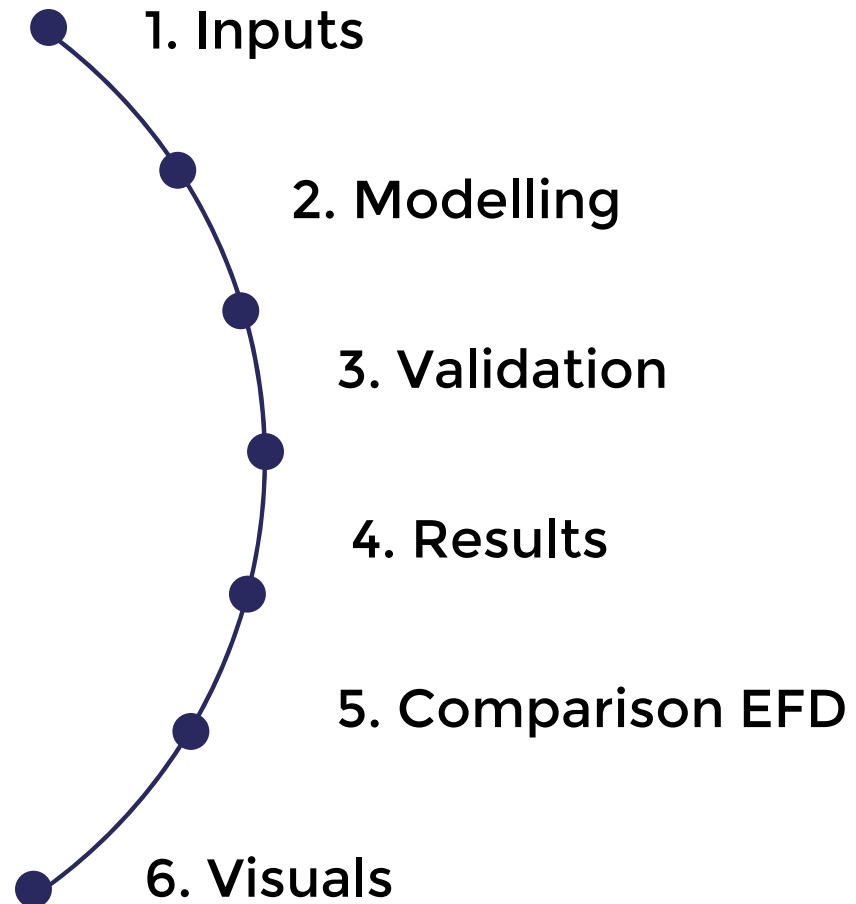


**Context :** This presentation aims to detail the results obtained through Computational Fluid Dynamics (CFD), as part of a validation study comparing the experimental data from the Naval Surface Warfare Center of May 2017 (*Experimental Results for the Calm Water Resistance of the Generic Prismatic Planing Hull (GPPH)* by Evan Lee, Ph.D., Charles R. Weil, P.E., and Anne Fullerton, Ph.D.) with the results from the digital test basin developed by NepTech. The study focuses on validating the hydrodynamic performance of the GPPH model, using an intermediate mesh. This model has been used as a benchmark for hydrodynamic studies and provides valuable reference data for CFD validation in the context of planing vessel performance.

## **Abbreviations :**

- AGR = « Adaptive Grid Refinement »
- CFD = « Computational Fluid Dynamics »
- ITTC = « International Towing Tank Conference »
- LCG / TCG / VCG = Longitudinal / Transverse / Vertical Position of the Center of Gravity
- QS = « Quasi-Static »
- URANS = « Reynolds-averaged Navier-Stokes »
- VoF = « Volume of Fluid »
- SST = « Shear-Stress Transport »

| Date | Author        | Approved by     |
|------|---------------|-----------------|
|      | Tanguy Teulet | Clément Rousset |





# 1. INPUTS



|    | Description                                   | Unit              | GPPH               |
|----|-----------------------------------------------|-------------------|--------------------|
| 0  | Water density                                 | kg/m <sup>3</sup> | 995.5600           |
| 1  | Static equilibrium (sinkage ; trim ; heel)    | mm ; deg ; deg    | 0 ; -0.132 ; 0.000 |
| 2  | Displacement, $\Delta$                        | kg                | 101.51             |
| 3  | Immerged volume, $\nabla$                     | m <sup>3</sup>    | 0.102              |
| 4  | Block coefficient, $C_B$                      | -                 | 0.493              |
| 5  | Prismatic coefficient, $C_P$                  | -                 | Not_Computed       |
| 6  | Beam OverAll (one float), BOA                 | mm                | Not_Relevant       |
| 7  | Beam OverAll, BOA                             | mm                | 742                |
| 8  | Beam at WaterLine (one float), $B_{WL}$       | mm                | Not_Relevant       |
| 9  | Beam at WaterLine, $B_{WL}$                   | mm                | 665                |
| 10 | Distance between the demihull at waterline, h | mm                | Not_Relevant       |
| 11 | Distance between the demihull centers, s      | mm                | Not_Relevant       |
| 12 | Draft, D                                      | mm                | 147                |
| 13 | Length OverAll, LOA                           | mm                | 2414               |
| 14 | Length at WaterLine, $L_{WL}$                 | mm                | 2110               |
| 15 | Waterplane surface area, $S_f$                | m <sup>2</sup>    | 1.191              |
| 16 | Wetted surface area, $S_w$                    | m <sup>2</sup>    | 1.448              |
| 17 | Center of Buoyancy, [LCB ; TCB ; VCB]         | mm ; mm ; mm      | 844 ; 0 ; -52      |
| 18 | Center of Flotation, [LCF ; TCF]              | mm ; mm           | 898 ; 0            |

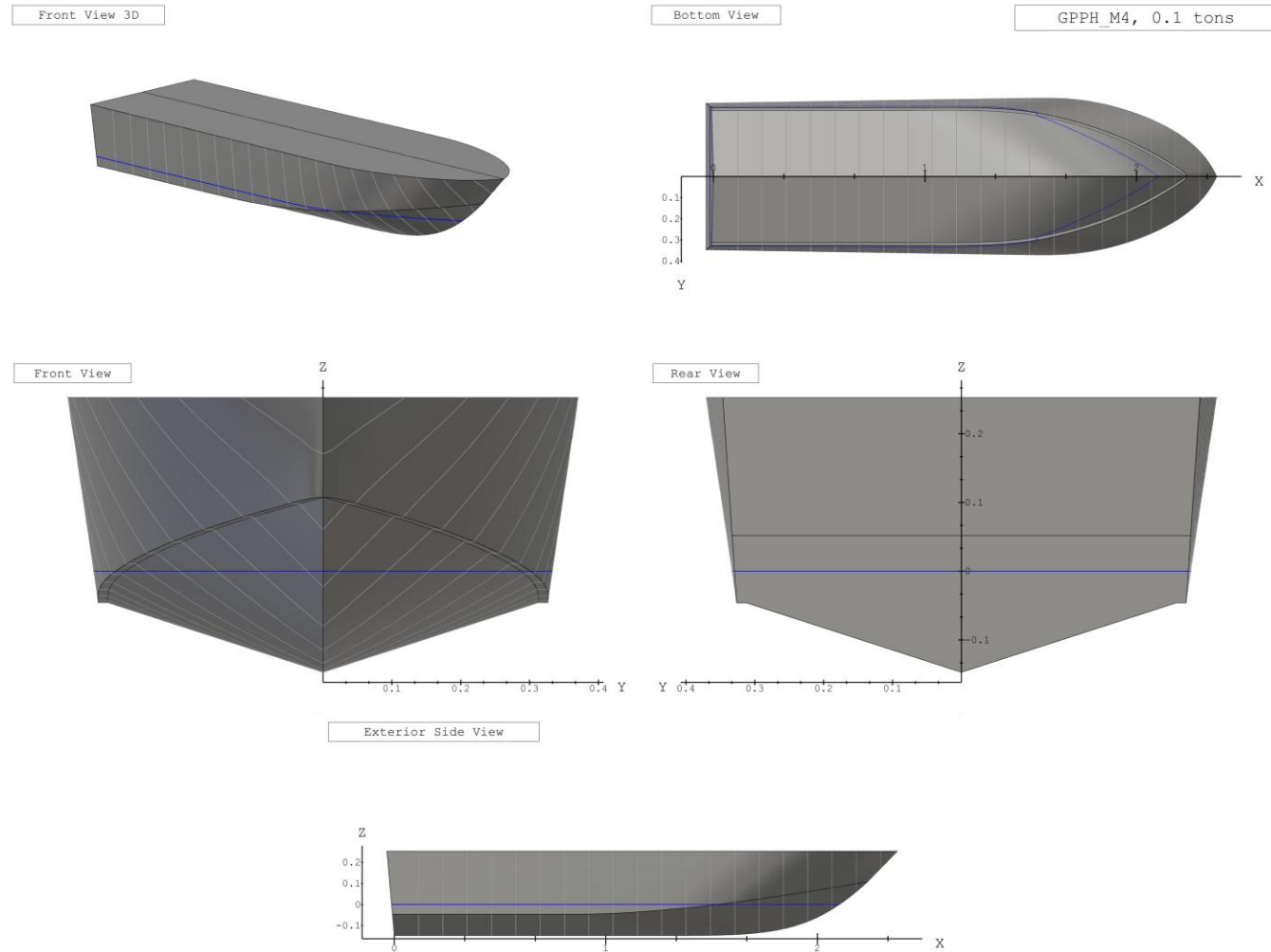
*Detailed characteristics of the hull*

## Hull geometry :

- Type : Barehull
- NepTech hull reference : GPPH
- Loading case : 101.51 kg

|   | Description                   | Unit | GPPH         |
|---|-------------------------------|------|--------------|
| 0 | $\frac{L_{WL}}{B_{WL}}$       | -    | 3.17         |
| 1 | $\frac{B_{WL}}{D}$            | -    | 4.52         |
| 2 | $\frac{L_{WL}}{\nabla^{1/3}}$ | -    | 4.52         |
| 3 | $C_B$                         | -    | 0.493        |
| 4 | LCB                           | %    | 39.99        |
| 5 | $\frac{s}{L_{WL}}$            | -    | Not_Relevant |
| 6 | $\frac{h}{L_{WL}}$            | -    | Not_Relevant |

*Global characteristics of the hull*



*Hull*



## 2. MODELLING

- a. Sign convention
- b. Softwares
- c. Hypothesis
- d. Environmental conditions
- e. Numerical models

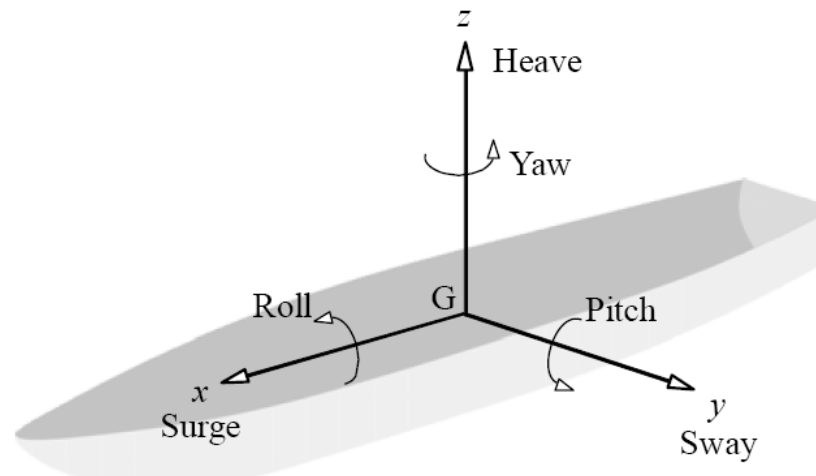
### a. Sign convention

#### Heave

The heave values correspond to the dynamic elevation of the vessel at the center of gravity, relative to its hydrostatic position, in the absolute reference frame with the vertical axis Z oriented upwards. A positive heave value thus corresponds to a hull rise, while a negative value indicates the hull sinking.

#### Pitch

The pitch values correspond to the dynamic trim of the vessel at the center of gravity, relative to its hydrostatic position, in the absolute reference frame where the transverse axis is Y. A positive trim corresponds to a bow-up attitude of the hull.



### b. Softwares

Mesh : Hexpress™, version 12.1 developed by CADENCE

Resolution : Fidelity Fine Marine, version 12.1 developed by CADENCE

Solver : ISIS-CFD developed by CNRS and Centrale Nantes

Computing infrastructure : 2 virtual machines of 32 cores « C2D\_STANDARD\_32 », optimized for computation on Google Cloud Platform.

Post-processing :

- CFView™, version 12.1 developed by CADENCE
- Programming language Python version 3.11.6

*\*NepTech has automated the entire process, from mesh creation to post-processing of the results, to eliminate any risk of human errors.*



### c. Hypothesis

Modeling scale : model scale, with a symmetry plane along the vessel's median axis. This approach helps reduce computation time while maintaining identical results.

Domain : the dimensions of the simulation domain are conformed to ITTC recommendations, ensuring that the boundaries are positioned sufficiently far from the vessel to avoid any influence on the solution. It is crucial, especially for the exit boundary, to place it in a way that prevents the reflection of the wave field generated by the vessel.

Hydrostatic equilibrium : the coordinates of the center of gravity are defined as follows

$$LCG = 0.8440 \text{ m} ; TCG = 0.0000 \text{ m} ; VCG = -0.0097 \text{ m}$$

### d. Environmental conditions

Water : corresponds to fresh water, which is

$$\begin{aligned}\rho_{water} &= 995.56 \text{ kg/m}^3 \\ \mu_{water} &= 0.7972 * 10^{-3} \text{ Pa.s}\end{aligned}$$

Air : corresponds to air at a temperature of 15°C, which is

$$\begin{aligned}\rho_{air} &= 1.2256 \text{ kg/m}^3 \\ \mu_{air} &= 1.788 * 10^{-5} \text{ Pa.s}\end{aligned}$$

### e. Numerical models

#### Dynamic equilibrium

- The Quasi-Static (QS) method is used since we are interested in the vessel's dynamic equilibrium state. This method relies on a succession of predictions of the vessel's physical attitude to reach the dynamic equilibrium state in record time.
- Two movements of the vessel, heave and pitch, are left free to ensure convergence toward the vessel's dynamic equilibrium position.

#### Flow

The Reynolds-Averaged Navier-Stokes (URANS) equations are used to describe the flow, and they are coupled with the  $k - \omega$  SST turbulence model as the closure model.

#### Free surface

The air-water interface is modeled using the Volume of Fluid (VoF) method. Adaptive Grid Refinement (AGR), developed by CNRS (French National Center for Scientific Research) and Ecole Centrale de Nantes (French Engineering school), is used to model the free surface. This iterative process allows for dynamic adjustment of the mesh according to the solution's needs during the calculation, making refinement decisions based on the physics of the flow.



### 3. VALIDATION

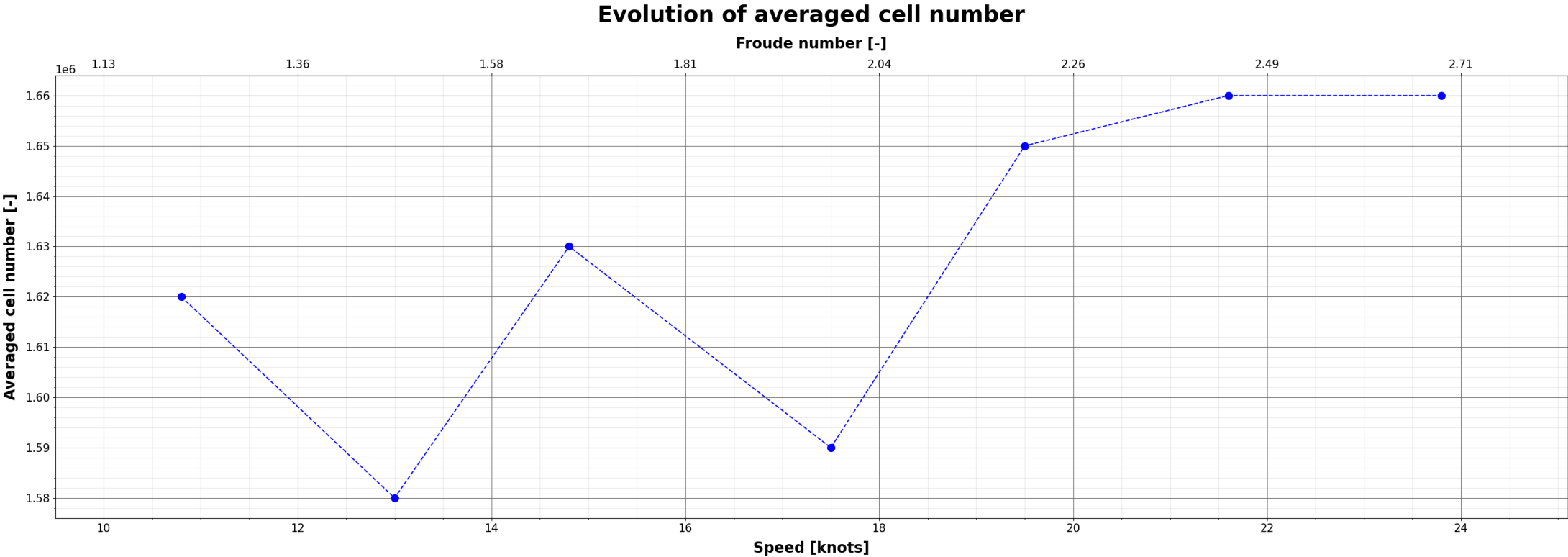
#### a. Mesh

1. Number of cells
2. Free surface
3. Hull

#### b. Courant number

#### c. $Y^+$

a. Mesh (Number of cells : total)



|   | Speed [knots] | Froude number [-] | ● Averaged cell number [-], GPPH_M4 |
|---|---------------|-------------------|-------------------------------------|
| 0 | 10.80         | 1.22              | 1.62e+06                            |
| 1 | 13.00         | 1.47              | 1.58e+06                            |
| 2 | 14.80         | 1.67              | 1.63e+06                            |
| 3 | 17.50         | 1.98              | 1.59e+06                            |
| 4 | 19.50         | 2.20              | 1.65e+06                            |
| 5 | 21.60         | 2.44              | 1.66e+06                            |
| 6 | 23.80         | 2.69              | 1.66e+06                            |



### 3. VALIDATION

#### a. Mesh

1. Number of cells

2. Free surface

3. Hull

b. Courant number

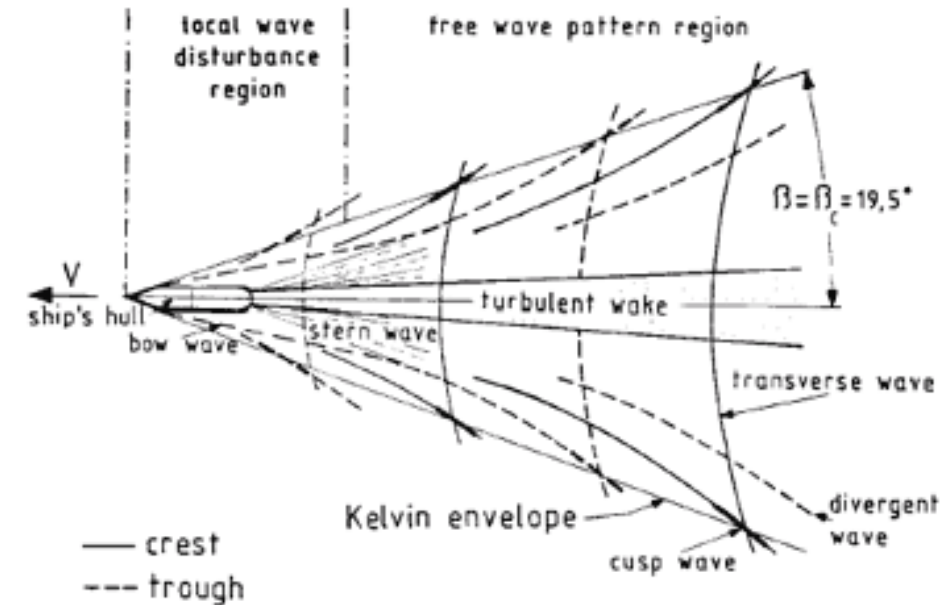
c.  $Y^+$

#### a. Mesh (Free surface)

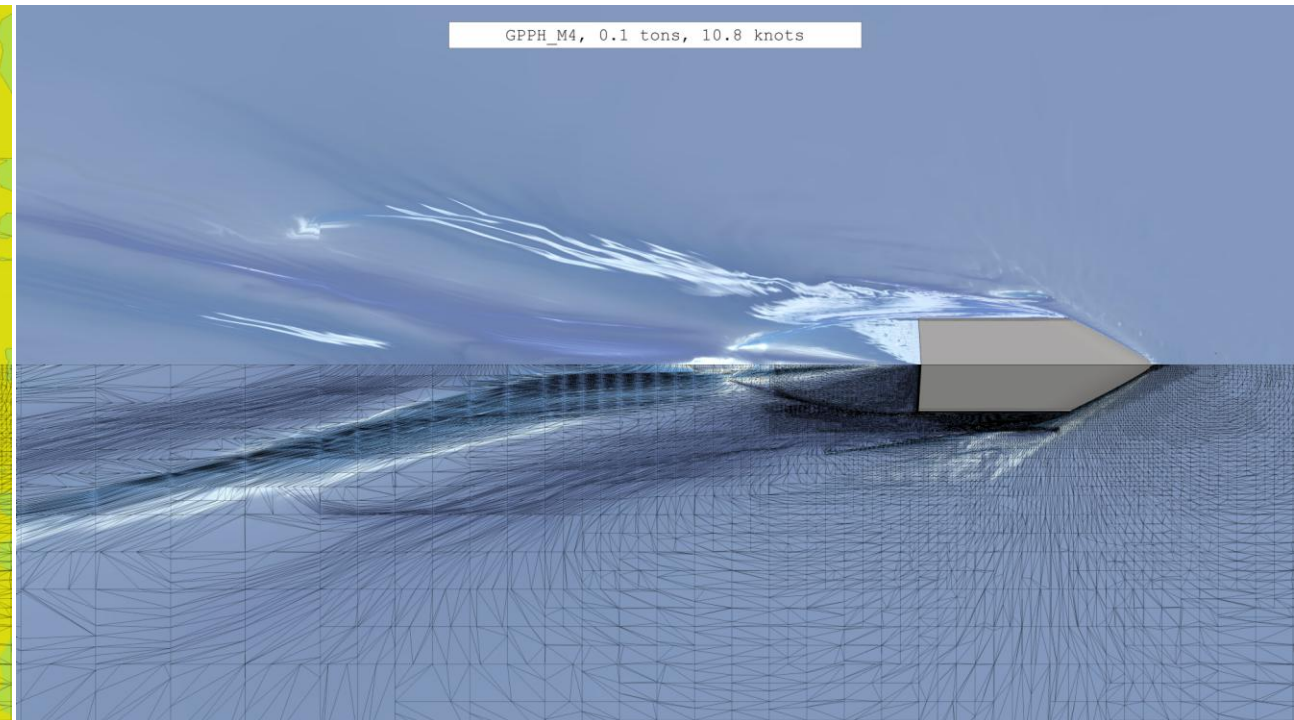
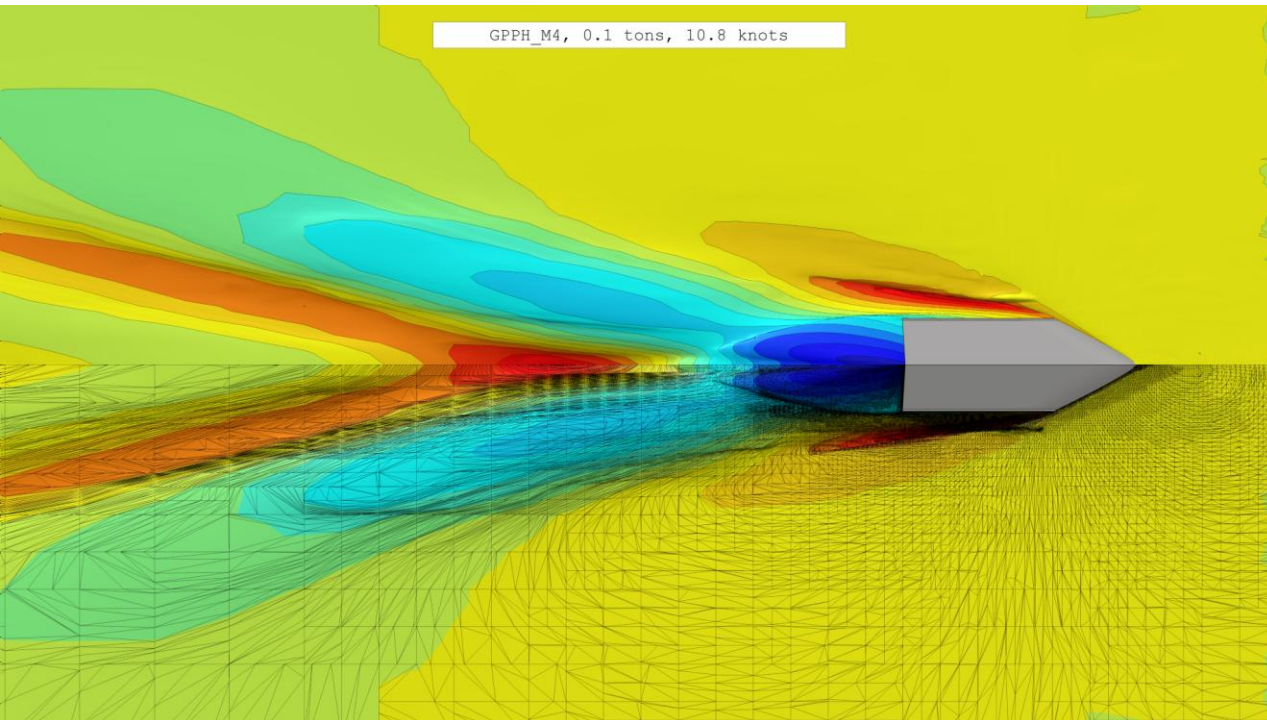
The accuracy of the results regarding pressure resistance mainly depends on how the air-water interface (i.e., the free surface) is captured during the simulation. This resistance is induced by the wave field generated by the vessel, and the quality of the mesh for the latter plays a crucial role in this accuracy.

The AGR allows :

- Dynamically adapting the mesh based on the generated wave field.
- Achieving maximum precision, as it is one of the most advanced and reliable methods to date.
- Reducing computation time by converging more quickly toward the dynamic equilibrium state.

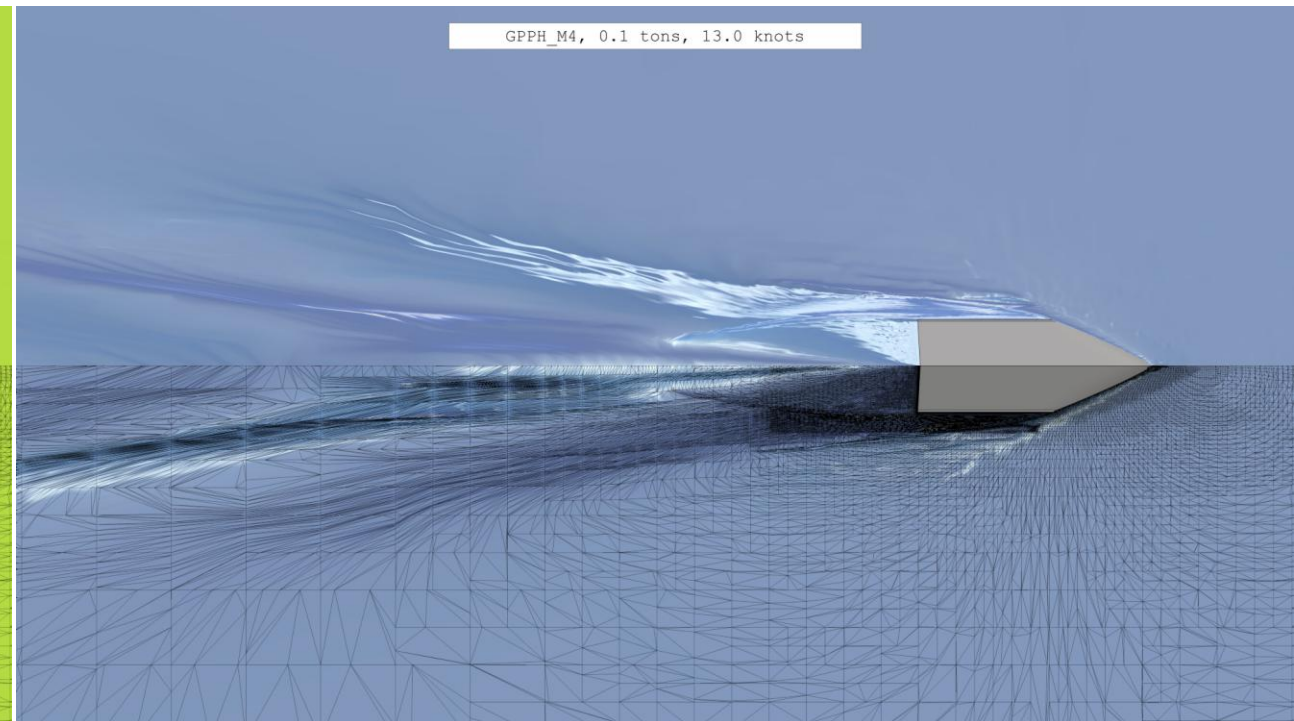
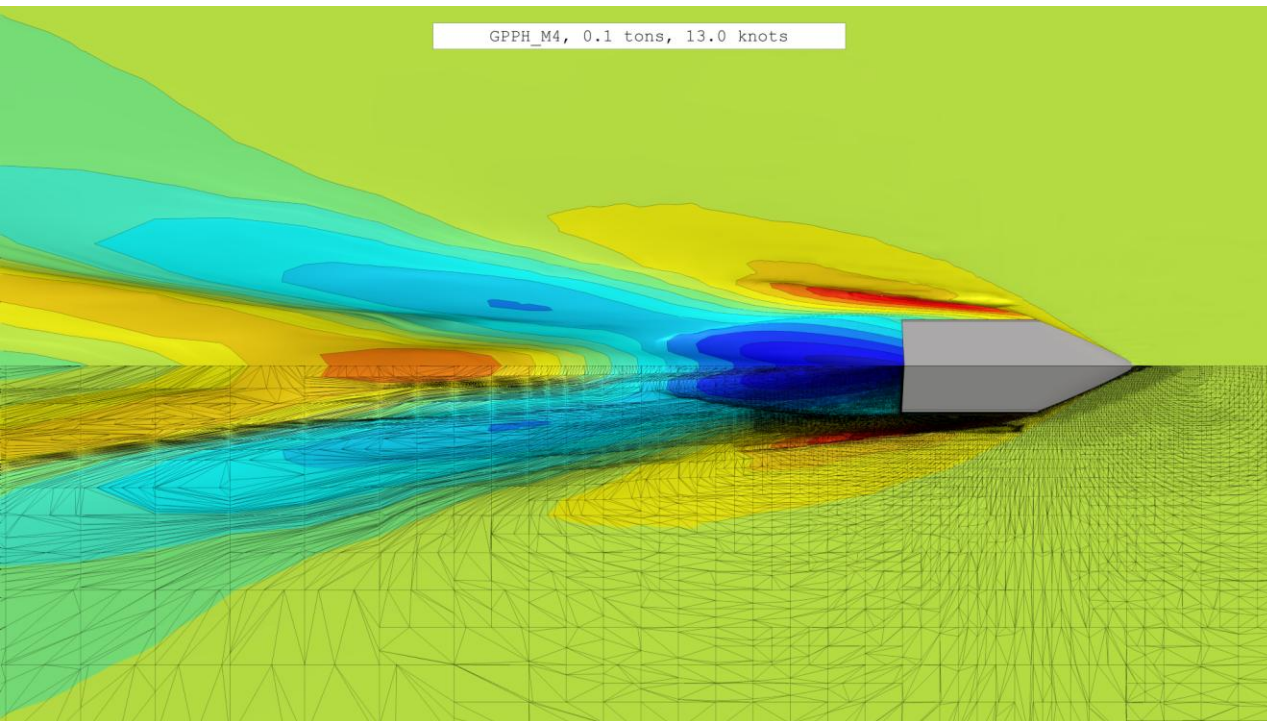


#### a. Mesh (Free surface)



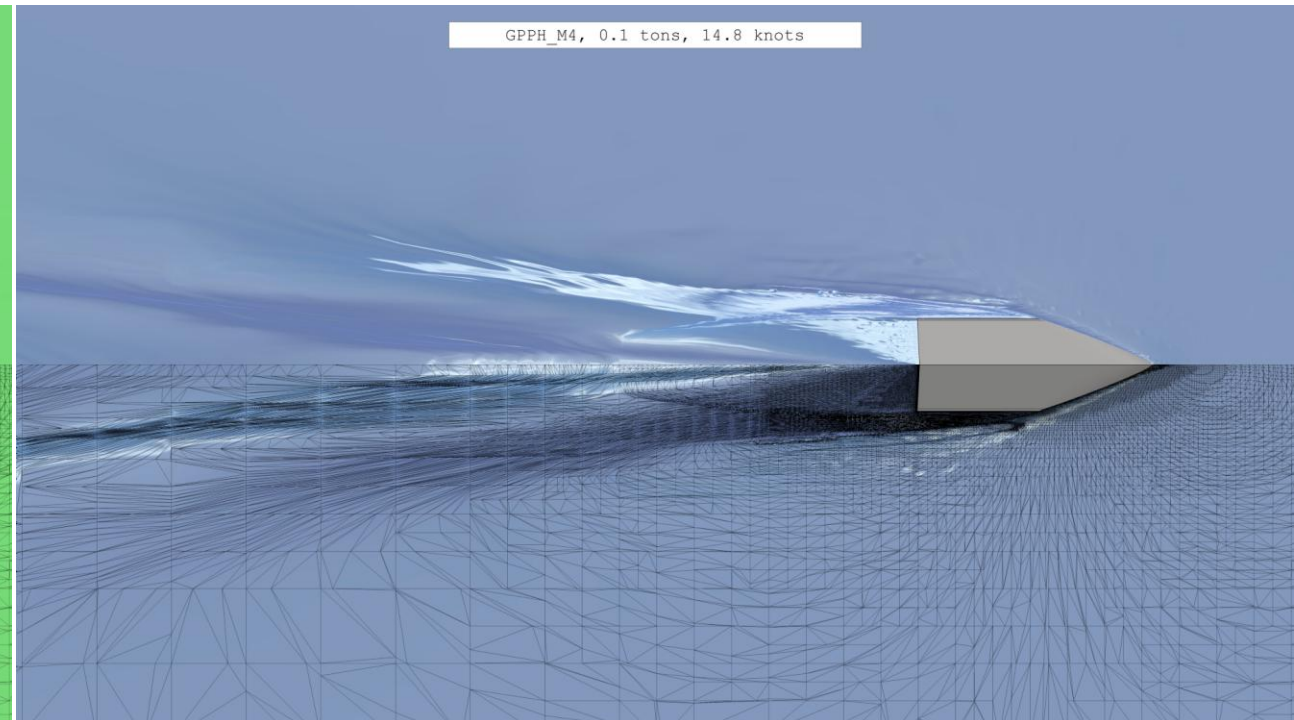
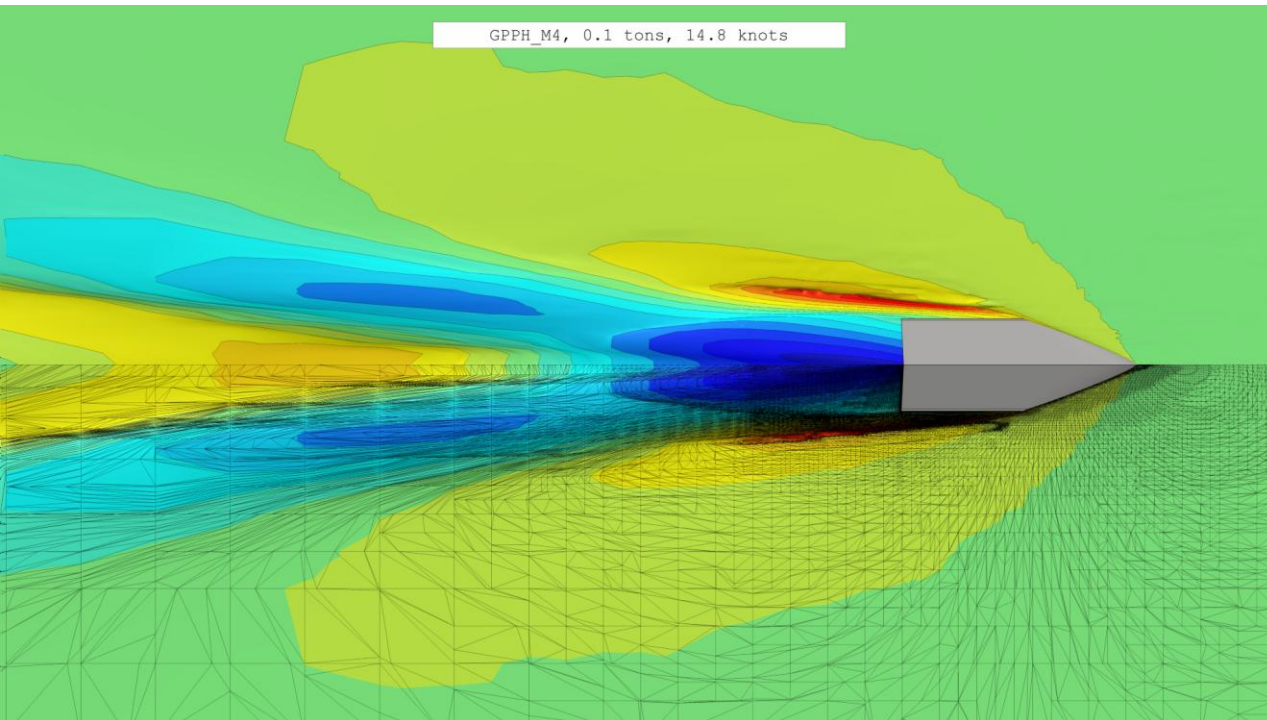


#### a. Mesh (Free surface)

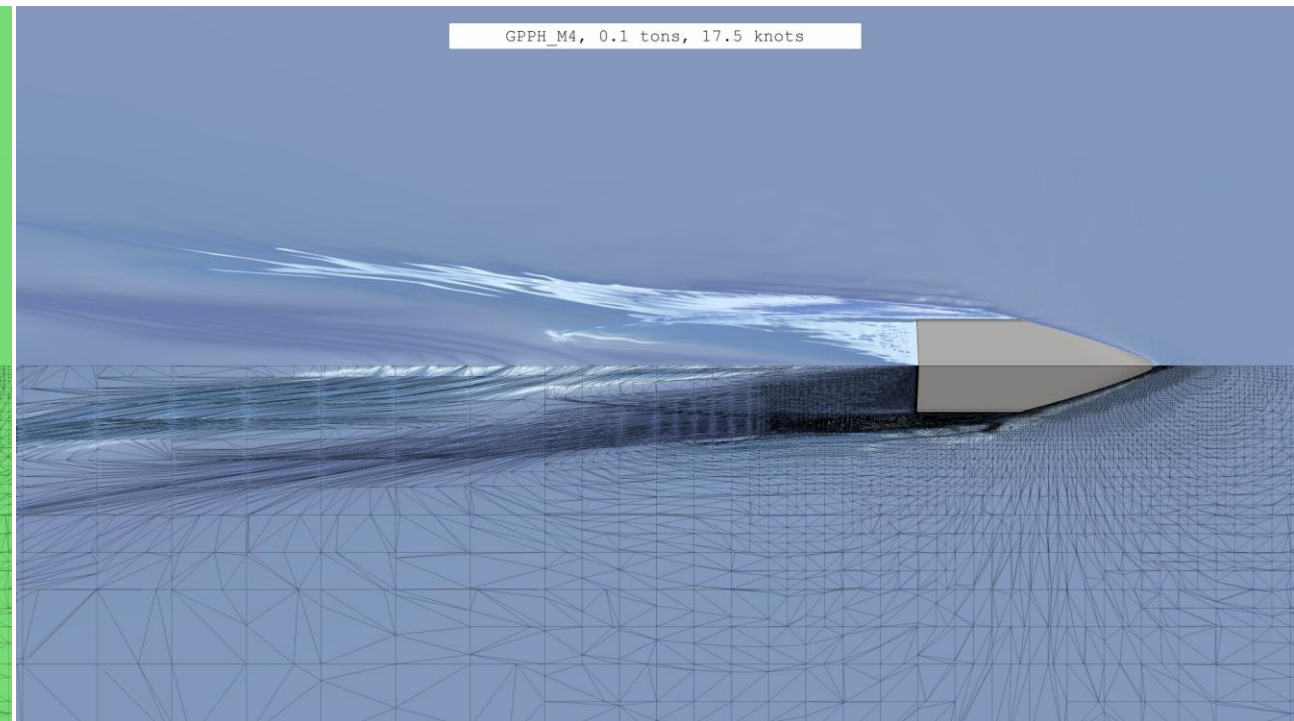
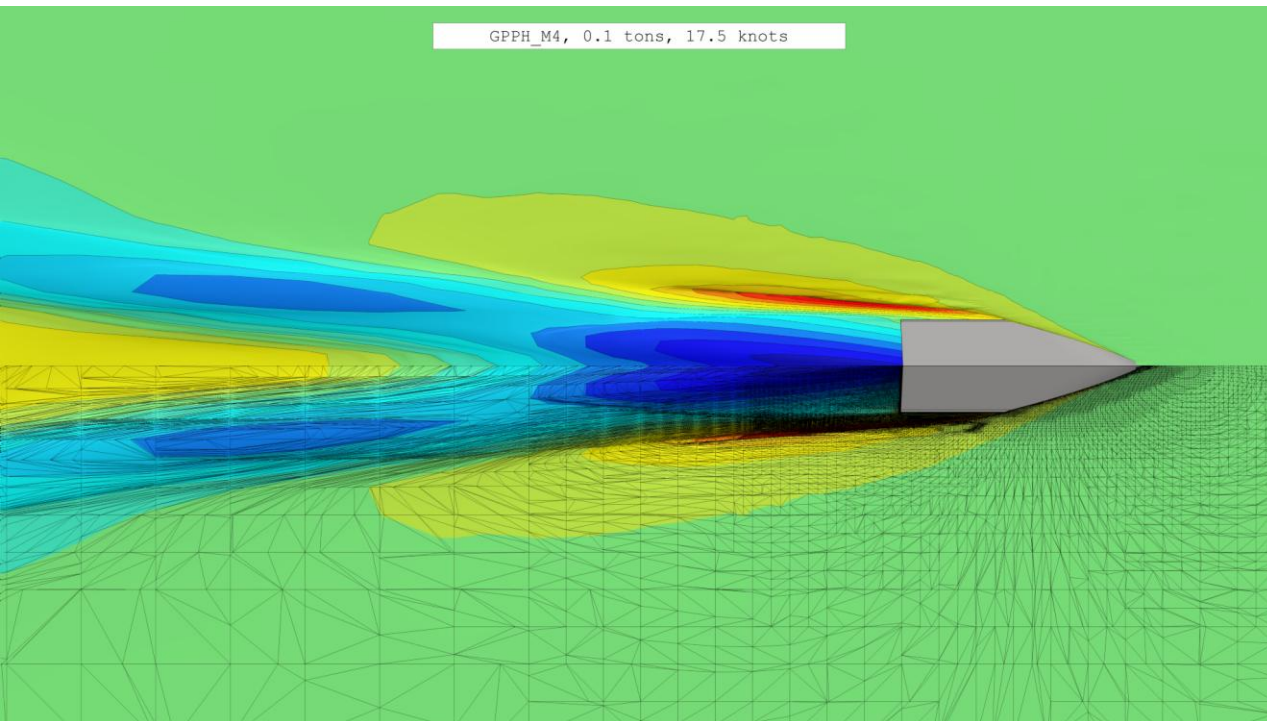




#### a. Mesh (Free surface)

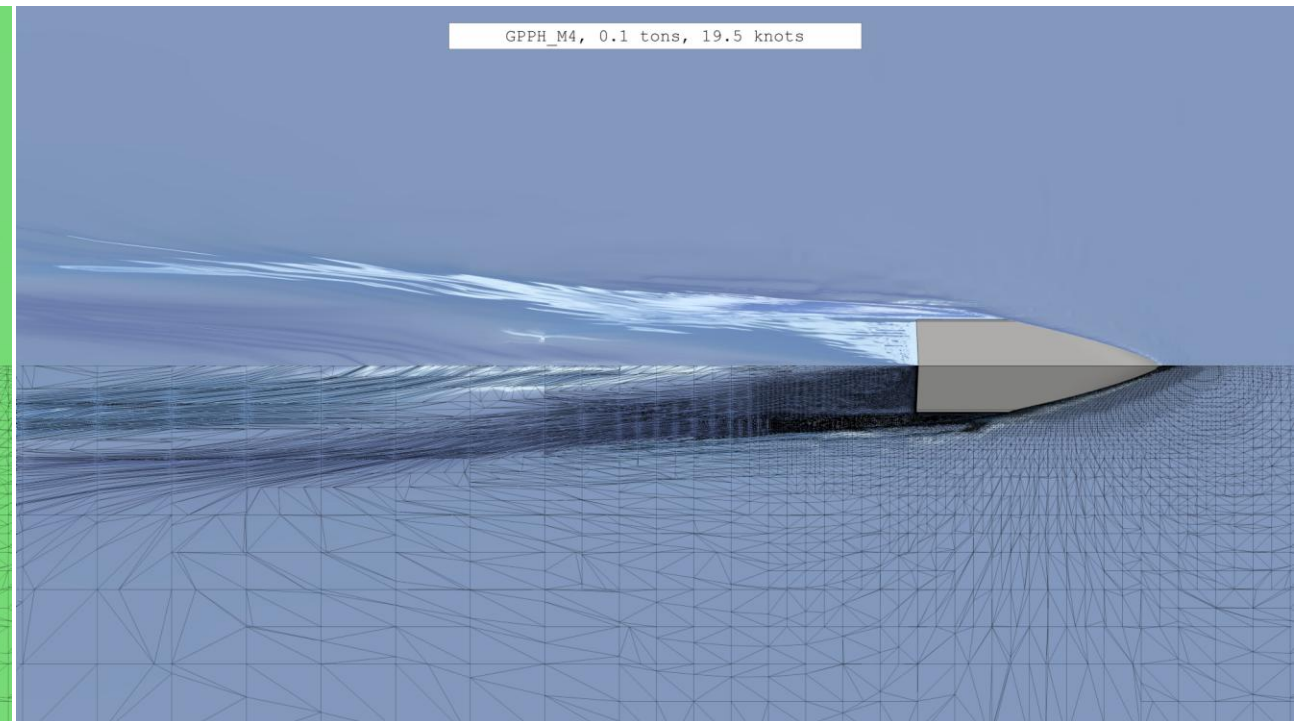
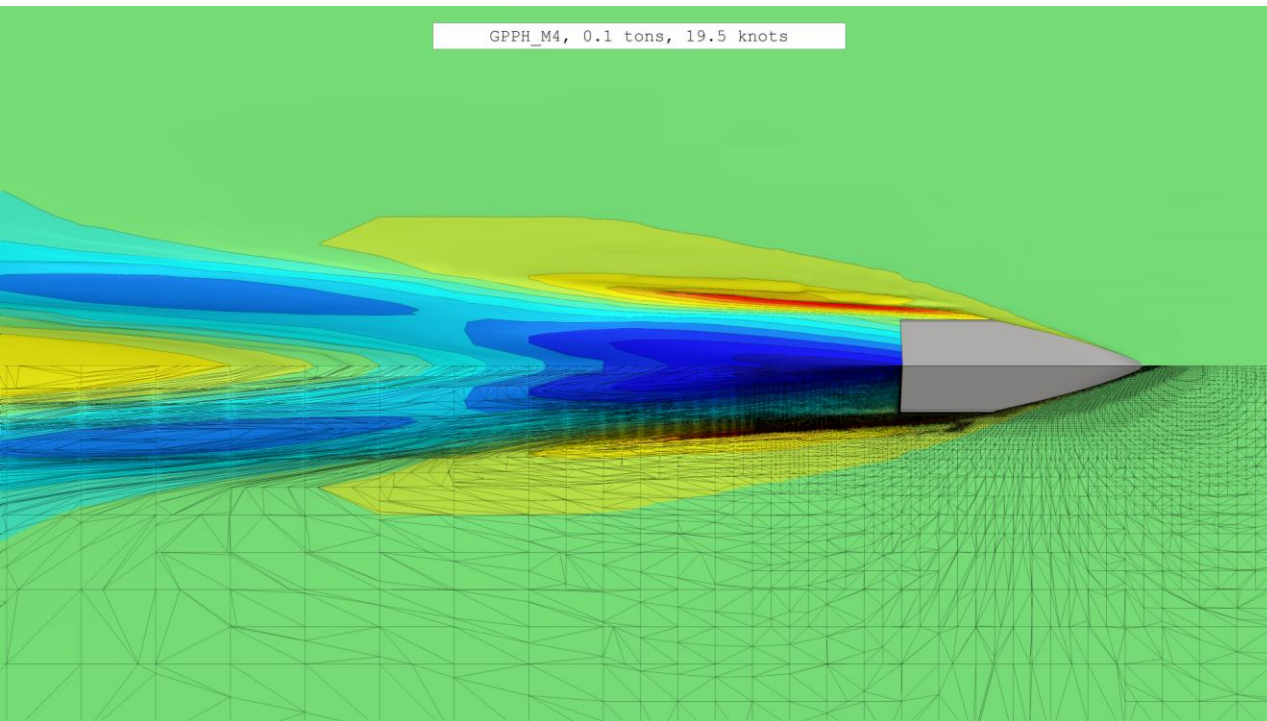


#### a. Mesh (Free surface)

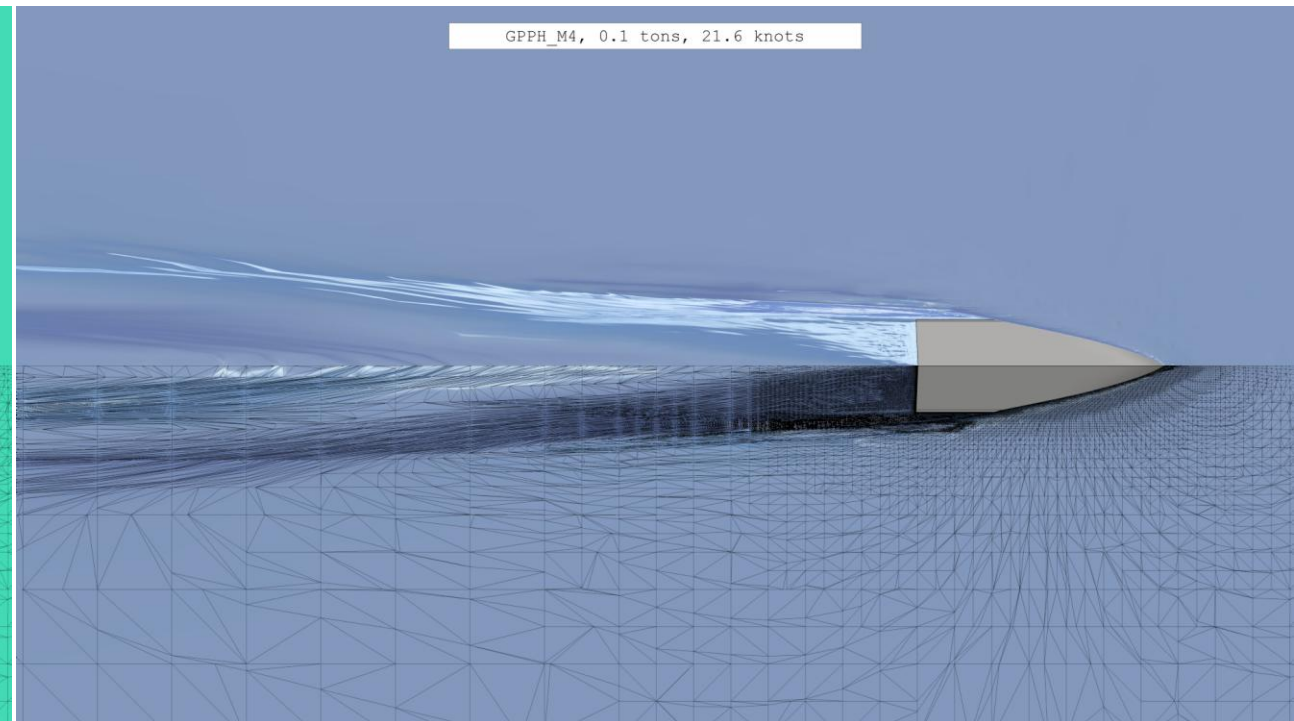
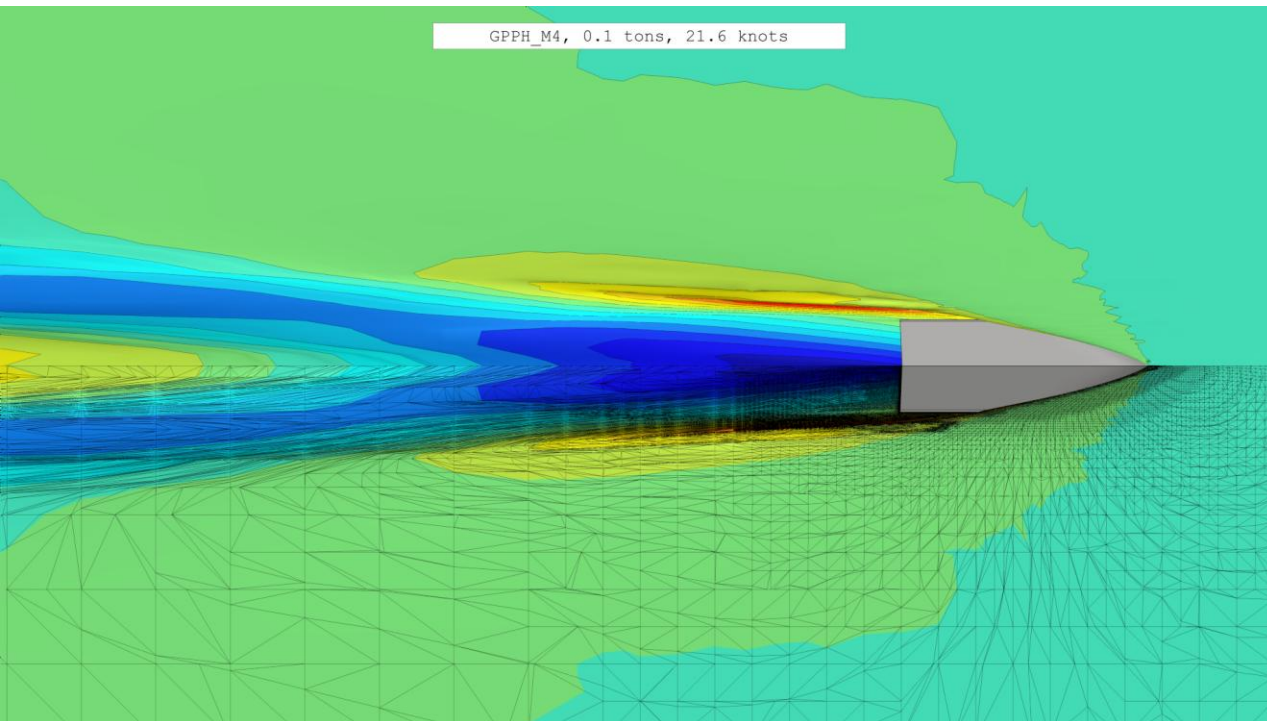




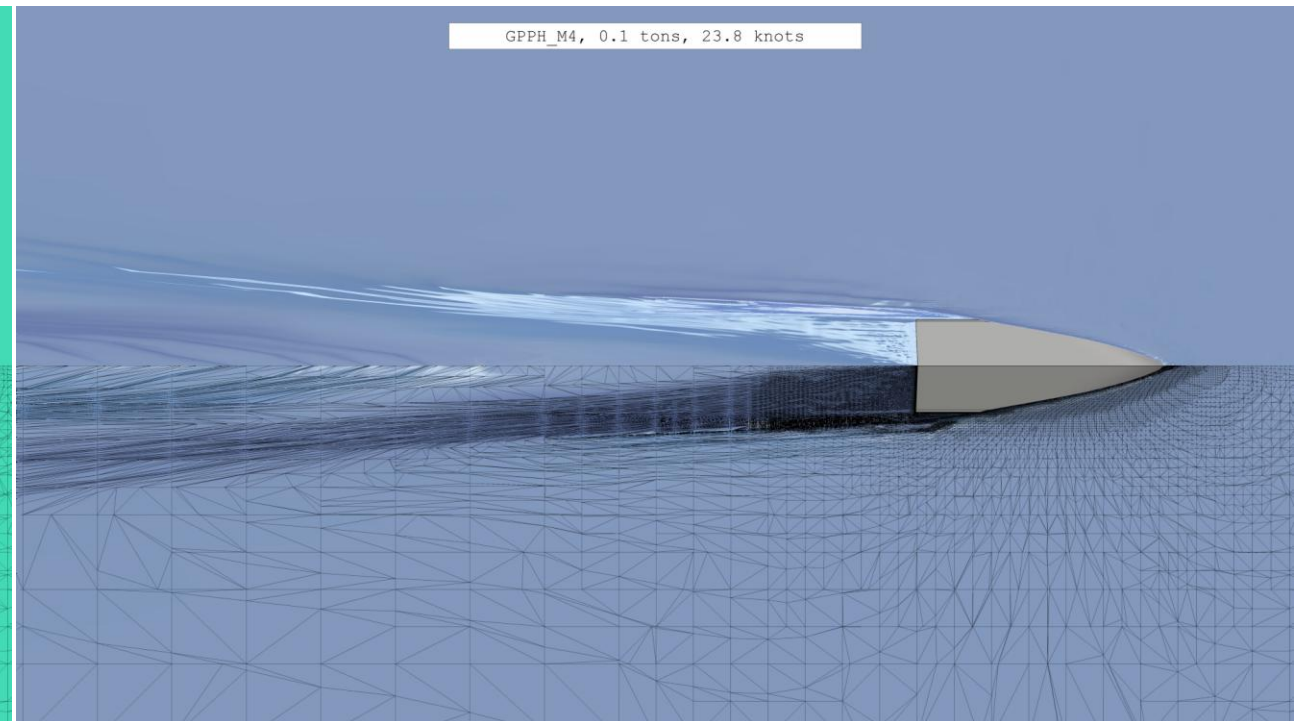
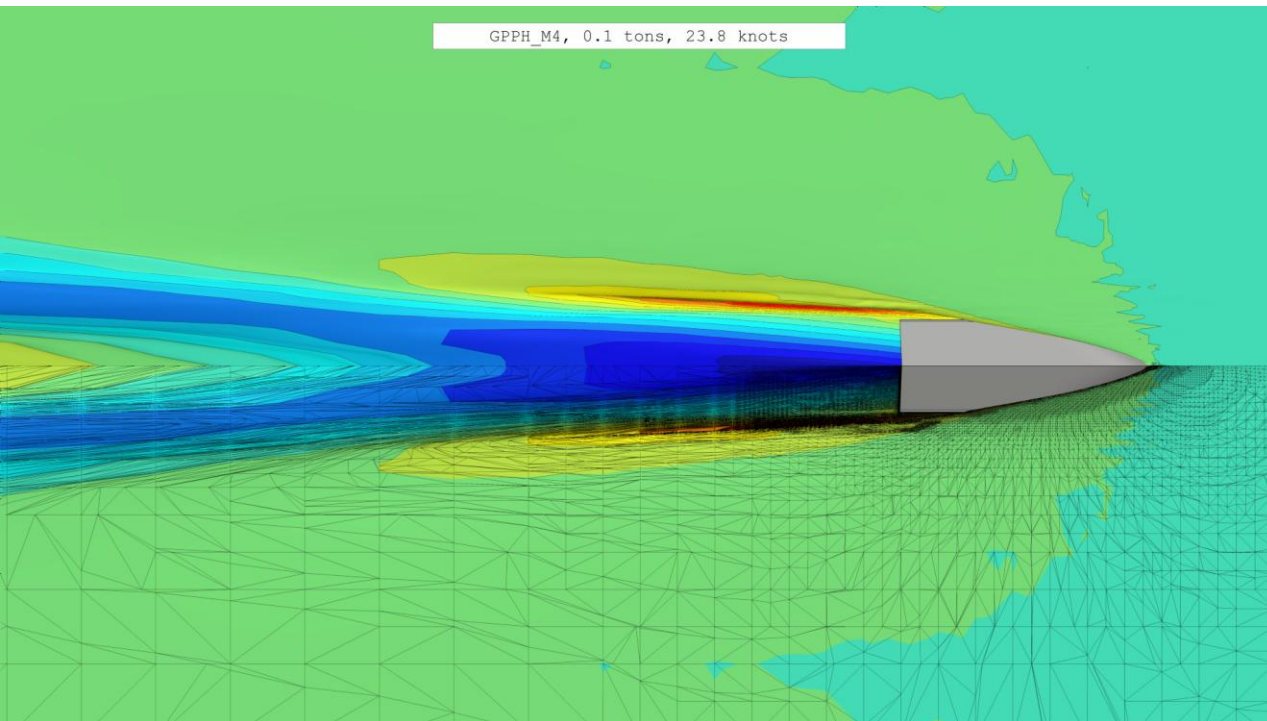
#### a. Mesh (Free surface)



#### a. Mesh (Free surface)



#### a. Mesh (Free surface)





### 3. VALIDATION

#### a. Mesh

1. Number of cells
2. Free surface

#### 3. Hull

#### b. Courant number

#### c. $Y^+$

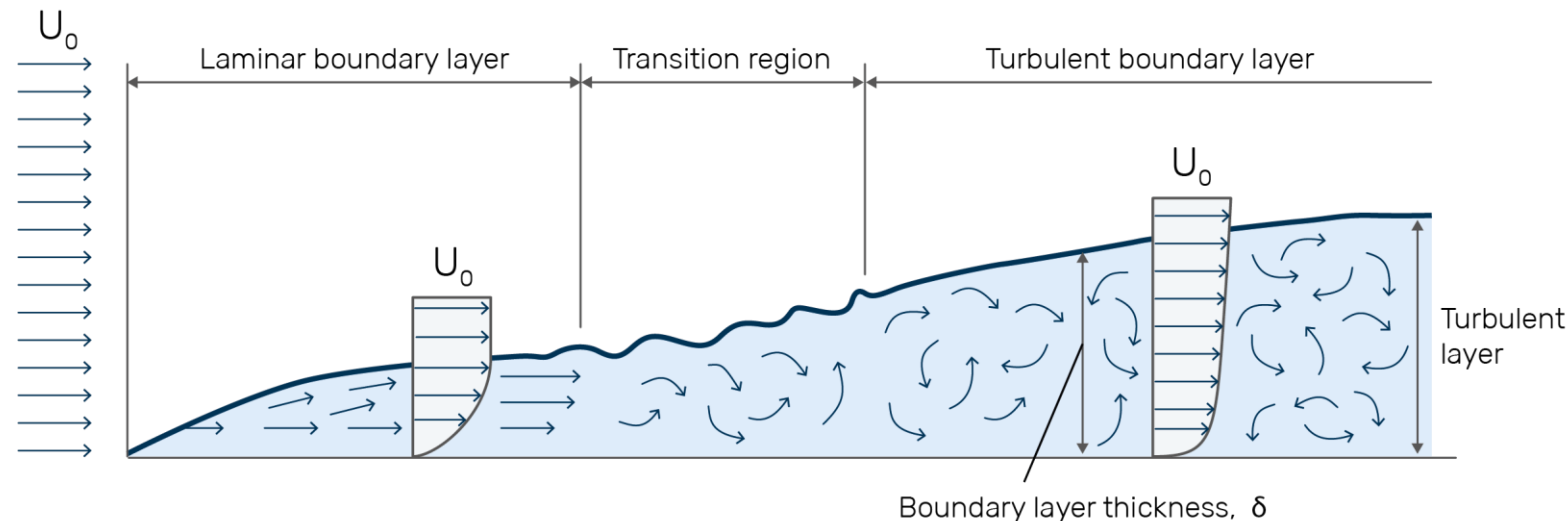


#### a. Mesh (Hull)

The accuracy of the results regarding viscous resistance mainly depends on the mesh of the hull. This resistance is caused by the entrainment of a thin fluid film: the boundary layer.

An appropriate mesh of the boundary layer is essential to correctly capture local phenomena such as viscous effects and rapid variations in fluid properties near the surface. It also allows for better capture and resolution of turbulent phenomena if they are present.

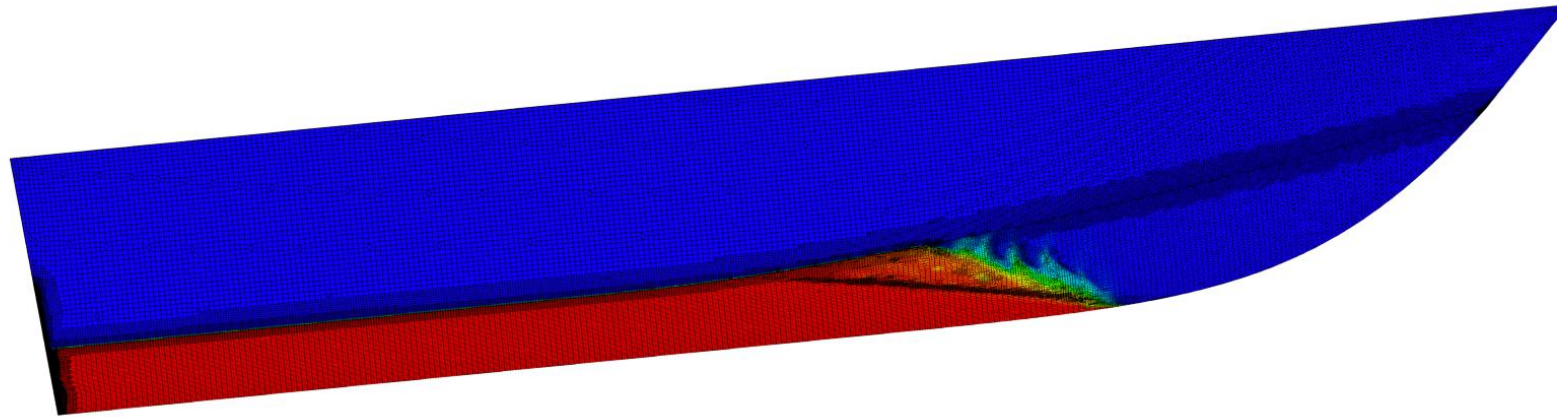
The quality of the hull mesh also affects the fidelity of the 3D model representation. A clean and regular mesh improves the reliability of the simulation, making the simulated model more representative of the actual vessel.



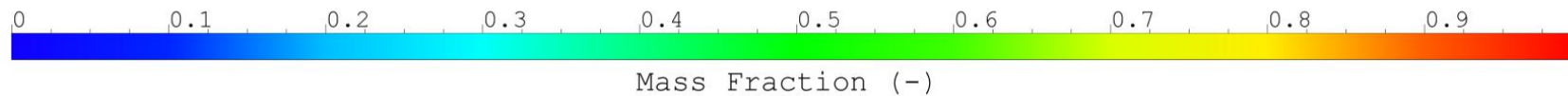


#### a. Mesh (Hull)

GPPH\_M4, 0.1 tons, 10.8 knots

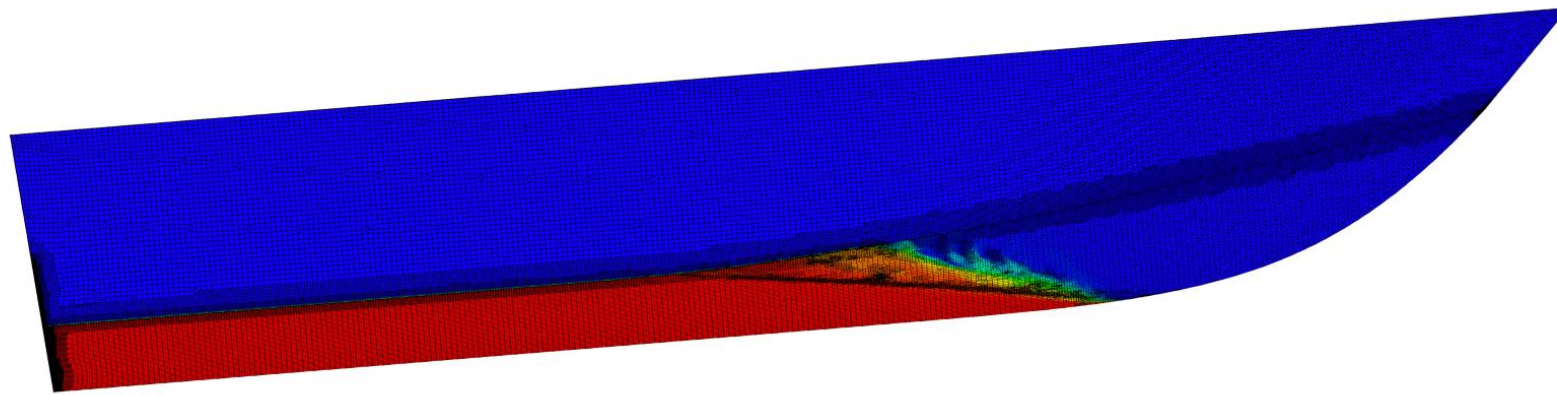


Exterior Side View

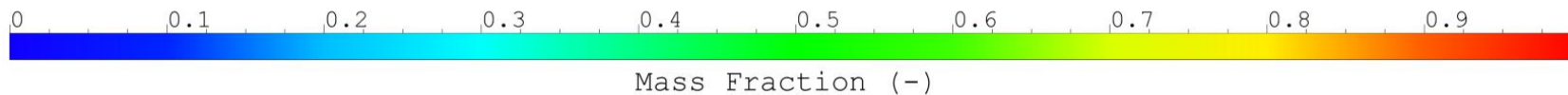


#### a. Mesh (Hull)

GPPH\_M4, 0.1 tons, 13.0 knots

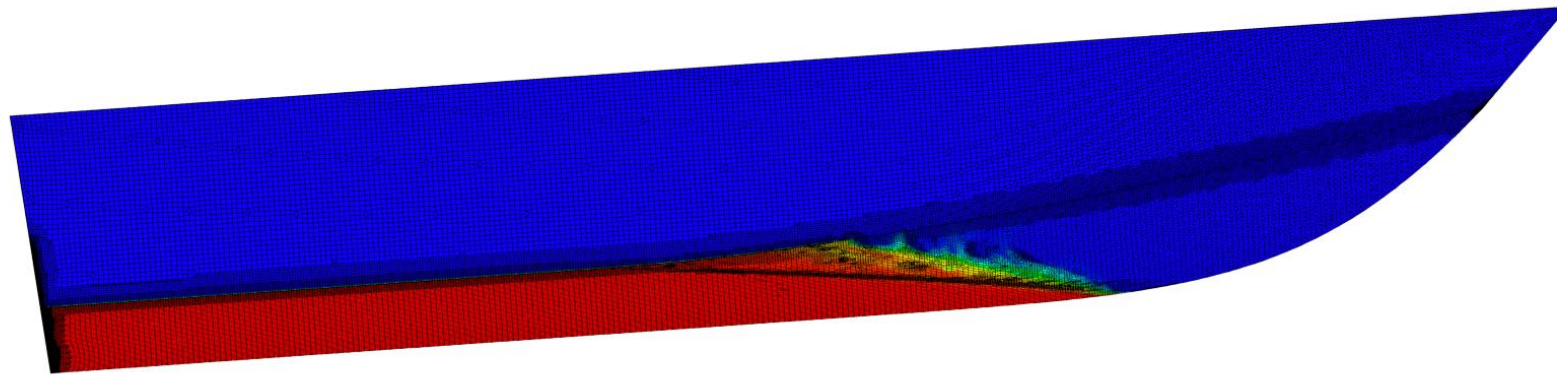


Exterior Side View

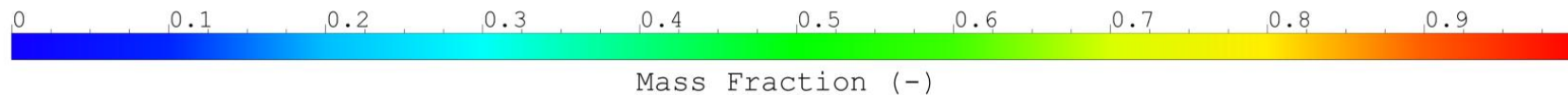


### a. Mesh (Hull)

GPPH\_M4, 0.1 tons, 14.8 knots

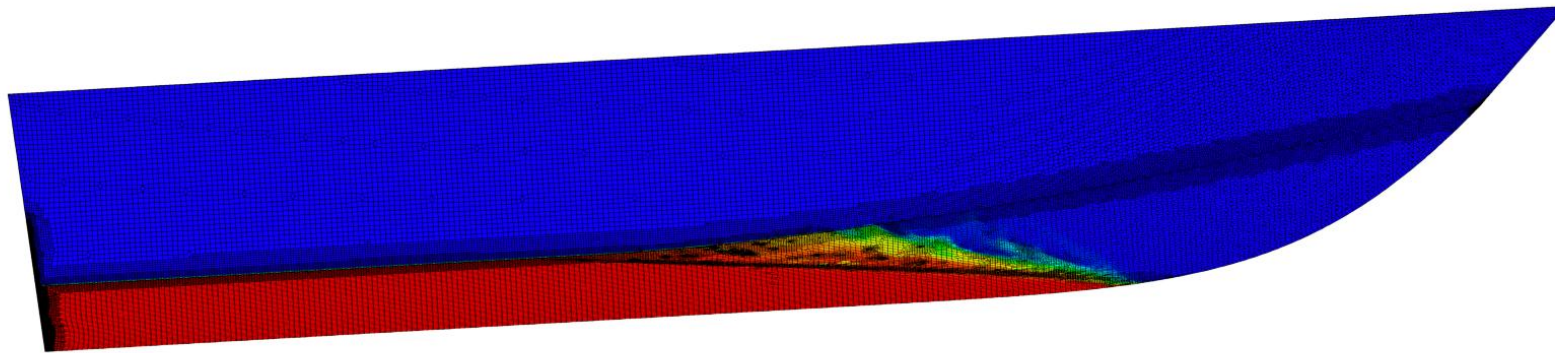


Exterior Side View

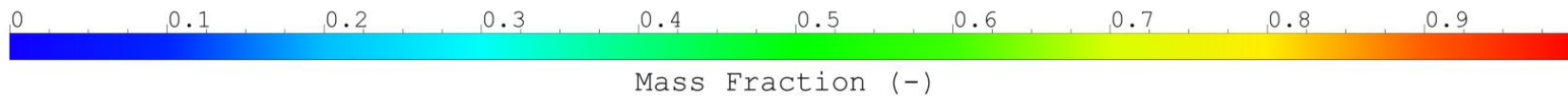


#### a. Mesh (Hull)

GPPH\_M4, 0.1 tons, 17.5 knots

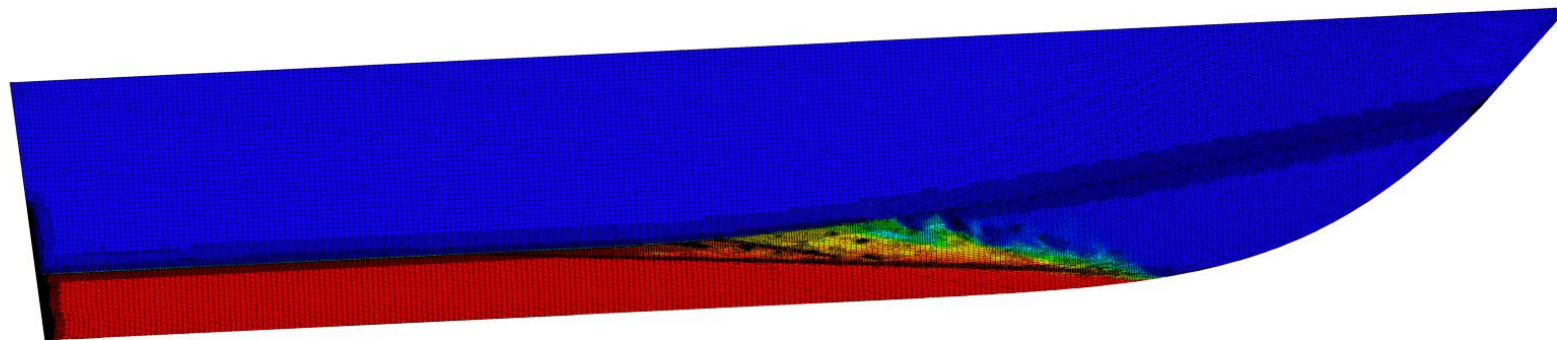


Exterior Side View

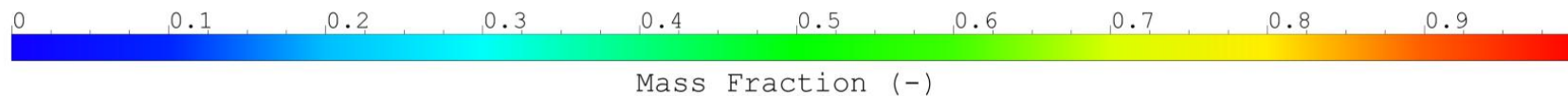


#### a. Mesh (Hull)

GPPH\_M4, 0.1 tons, 19.5 knots



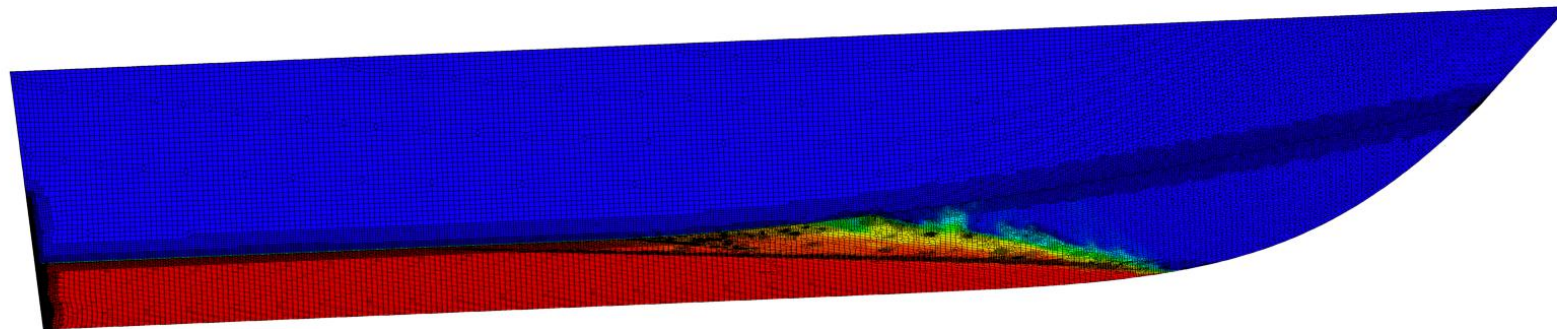
Exterior Side View



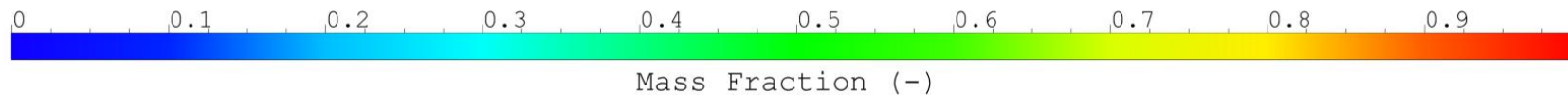


#### a. Mesh (Hull)

GPPH\_M4, 0.1 tons, 21.6 knots

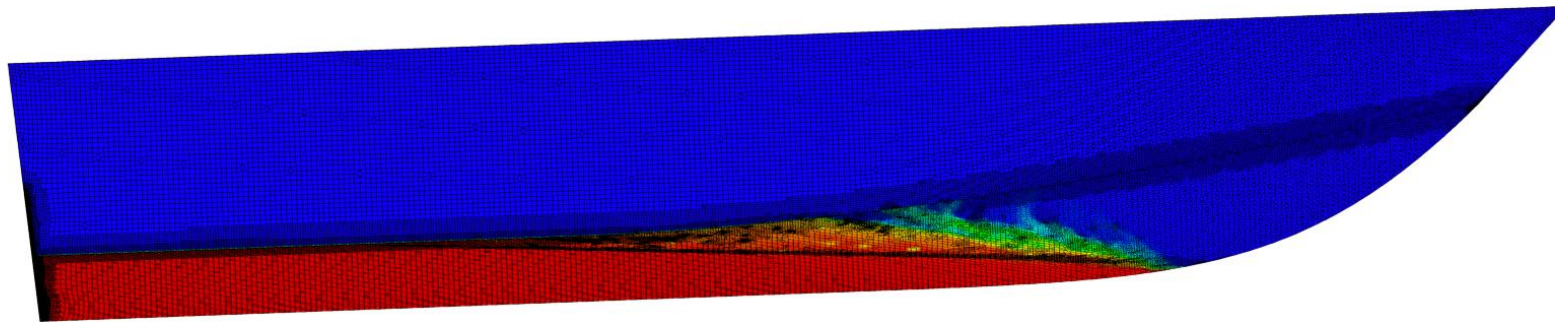


Exterior Side View

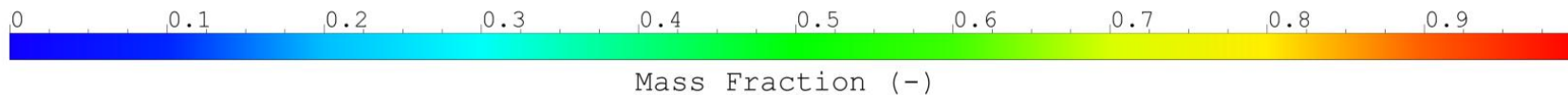


### a. Mesh (Hull)

GPPH\_M4, 0.1 tons, 23.8 knots



Exterior Side View





### 3. VALIDATION

#### a. Mesh

1. Number of cells
2. Free surface
3. Barehull

#### b. Courant number

#### c. $Y^+$

### b. Courant number

The Courant number, also called the CFL (Courant-Friedrichs-Lewy) number, is a crucial parameter in computational fluid dynamics (CFD). It **measures the numerical stability** of the discretization scheme used in the simulation.

**An inappropriate Courant number can lead to numerical instabilities, compromising both convergence and the accuracy of the results.** In CFD, the Courant number is related to the size of the numerical time steps. It is calculated by comparing the speed of fluid particles with the size of the cells in the simulation domain.

**Recommended values** : For typical resistance simulations, **it is recommended to keep the Courant number below or close to 1** to ensure maximum accuracy and reliability. Local spikes in this parameter may occur, but it is essential to control them to maintain numerical stability and the quality of the results.

#### b. Courant number (Free surface)

| Speed [knots] | Mininimum value | Maximum value | Mean value |
|---------------|-----------------|---------------|------------|
| 10.80         | 0.00            | 115.79        | 0.18       |
| 13.00         | 0.00            | 108.86        | 0.16       |
| 14.80         | 0.00            | 152.82        | 0.13       |
| 17.50         | 0.00            | 110.00        | 0.11       |
| 19.50         | 0.00            | 116.57        | 0.10       |
| 21.60         | 0.00            | 120.53        | 0.10       |
| 23.80         | 0.00            | 128.63        | 0.09       |



#### b. Courant number (Hull)

| Speed [knots] | Mininimum value | Maximum value | Mean value |
|---------------|-----------------|---------------|------------|
| 10.80         | 0.80            | 62.80         | 1.36       |
| 13.00         | 0.78            | 61.95         | 1.34       |
| 14.80         | 0.77            | 64.56         | 1.34       |
| 17.50         | 0.75            | 66.30         | 1.33       |
| 19.50         | 0.74            | 84.80         | 1.31       |
| 21.60         | 0.73            | 85.94         | 1.30       |
| 23.80         | 0.73            | 86.58         | 1.28       |



### 3. VALIDATION

#### a. Mesh

1. Number of cells
2. Free surface
3. Barehull

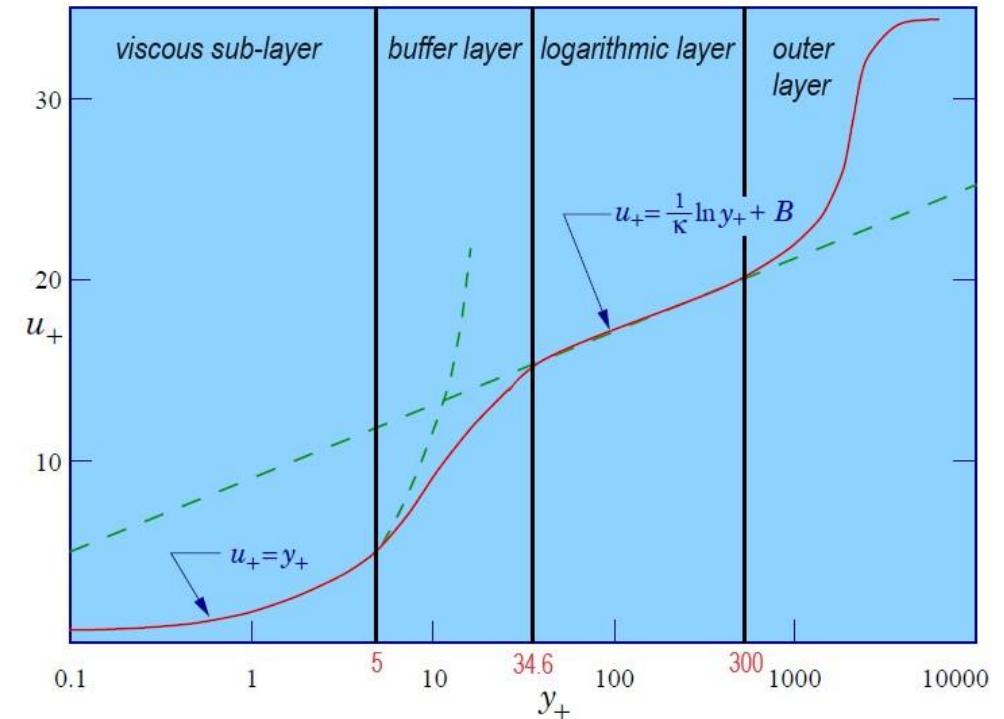
#### b. Courant number

#### c. $Y^+$

### c. Y+

In the naval field, managing the Y+ parameter is crucial in computational fluid dynamics (CFD) simulations. Y+ measures the quality of the boundary layer resolution along the submerged surfaces of ship hulls by **evaluating the distance between the first mesh point and the wall relative to the boundary layer thickness**. Maintaining an appropriate Y+ is essential to ensure reliable results in predicting resistance, drag, lift, and other critical hydrodynamic phenomena. An improper Y+ can lead to significant errors in the prediction of forces, drag coefficients, and other key parameters.

**Recommended values :** For typical resistance simulations, **it is recommended that the Y+ value be between 30 and 300**. This value may be lower depending on the choice of boundary layer modeling. Local spikes in this parameter may occur, but it is essential to control them to maintain numerical stability and the quality of the results.



#### c. Y+

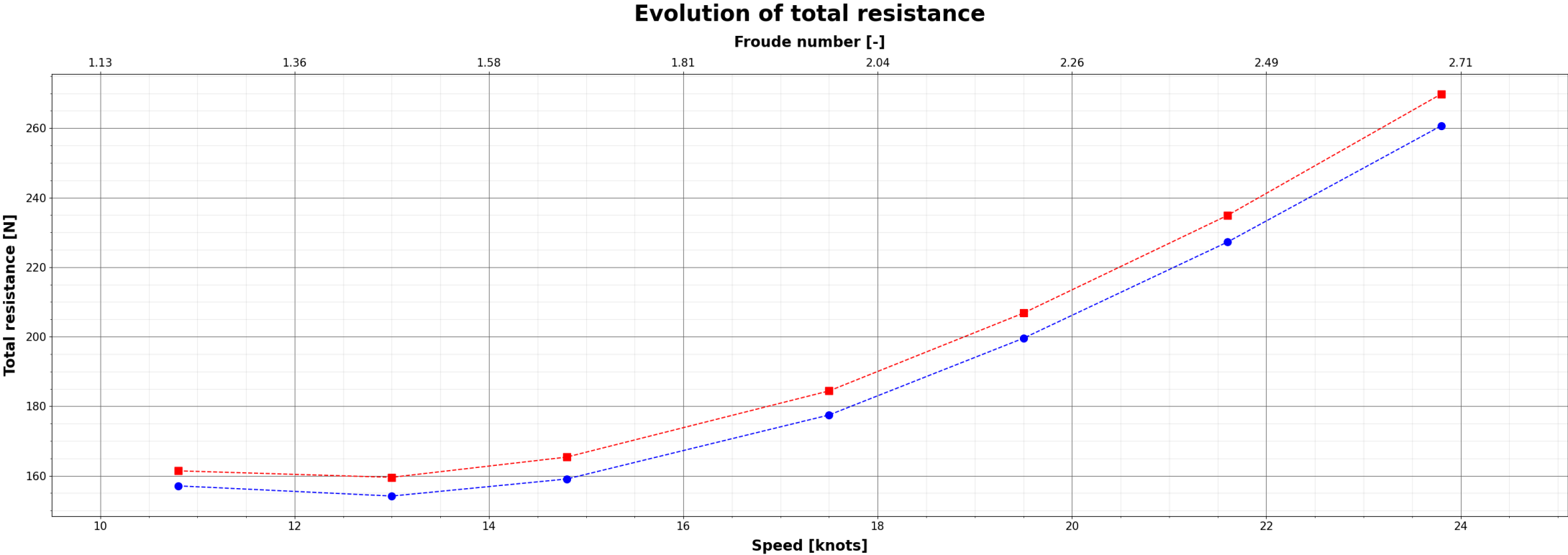
| Speed [knots] | Mininimum value | Maximum value | Mean value |
|---------------|-----------------|---------------|------------|
| 10.80         | 0.67            | 173.32        | 120.10     |
| 13.00         | 1.21            | 170.17        | 121.25     |
| 14.80         | 1.04            | 169.37        | 122.25     |
| 17.50         | 1.46            | 183.61        | 123.70     |
| 19.50         | -0.25           | 177.11        | 123.78     |
| 21.60         | -0.25           | 187.64        | 124.68     |
| 23.80         | -0.28           | 171.95        | 124.67     |



## 4. RESULTS

- a. Forces
- b. Heave
- c. Pitch
- d. Wetted surface

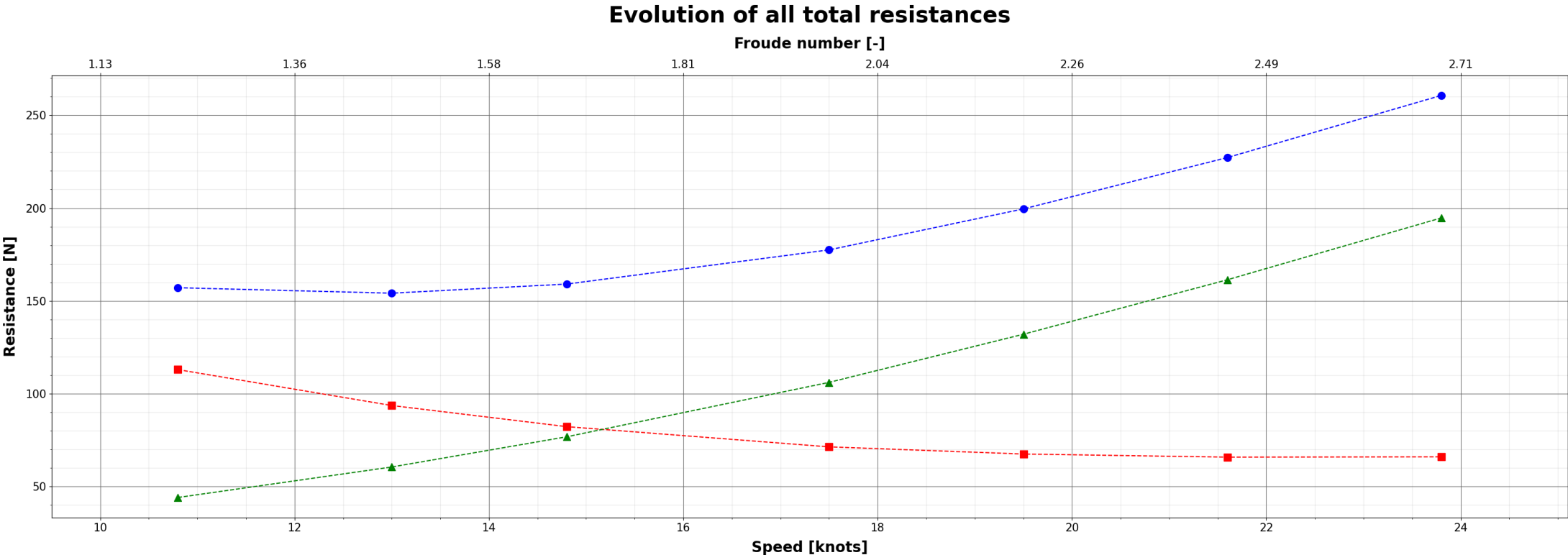
a. Forces



|   | Speed [knots] | Froude number [-] | ● Total resistance [N], GPPH_M4 | ■ Total resistance [N], GPPH_EFD |
|---|---------------|-------------------|---------------------------------|----------------------------------|
| 0 | 10.80         | 1.22              | 157.10                          | 161.42                           |
| 1 | 13.00         | 1.47              | 154.17                          | 159.56                           |
| 2 | 14.80         | 1.67              | 159.07                          | 165.38                           |
| 3 | 17.50         | 1.98              | 177.49                          | 184.42                           |
| 4 | 19.50         | 2.20              | 199.57                          | 206.80                           |
| 5 | 21.60         | 2.44              | 227.24                          | 234.91                           |
| 6 | 23.80         | 2.69              | 260.69                          | 269.83                           |

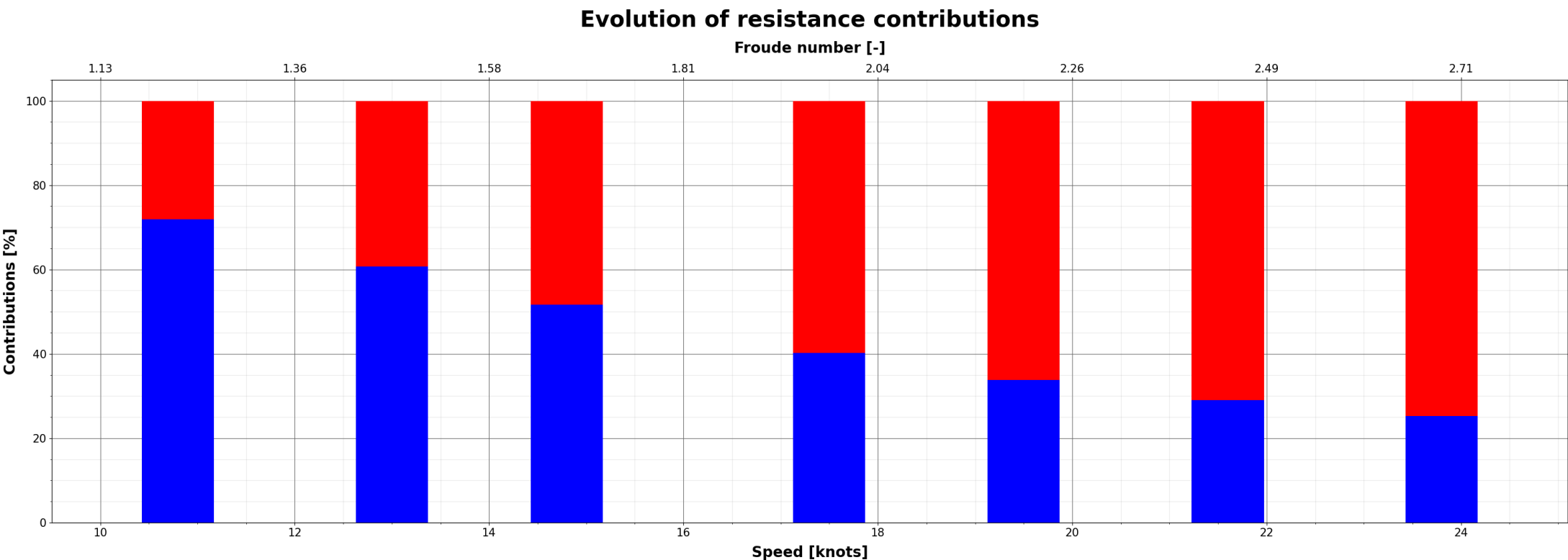


a. Forces



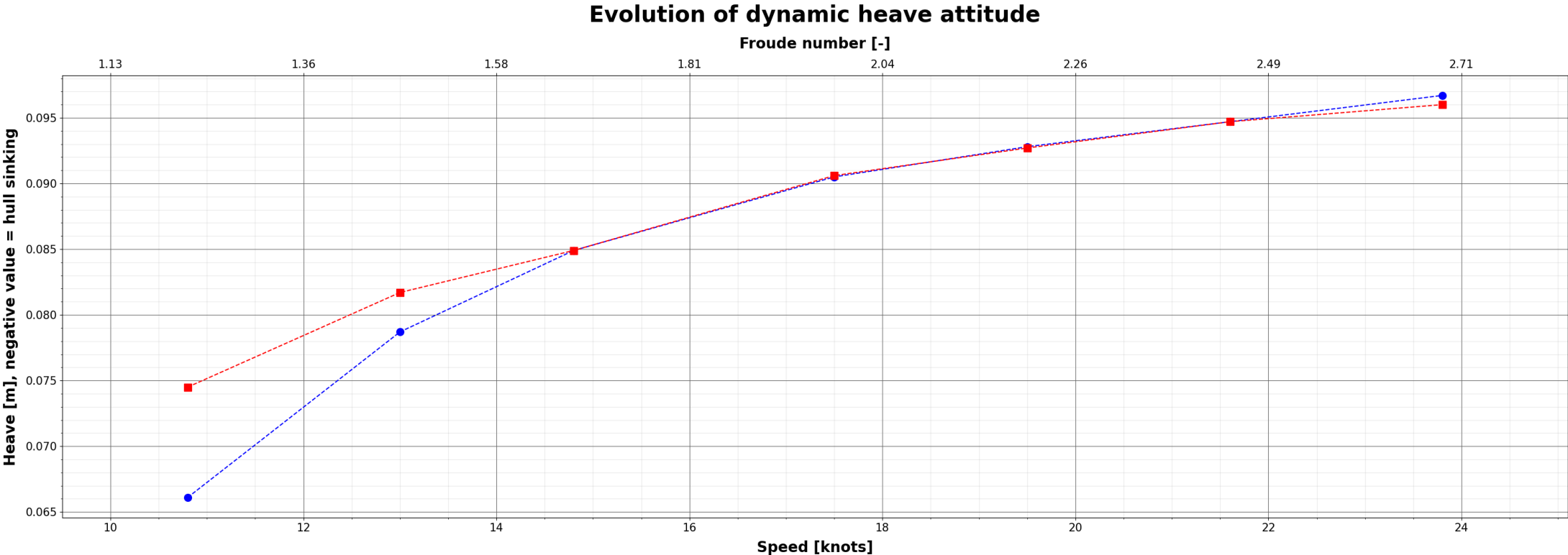
|   | Speed [knots] | Froude number [-] | Total [N] | Pressure [N] | Viscous [N] |
|---|---------------|-------------------|-----------|--------------|-------------|
| 0 | 10.80         | 1.22              | 157.10    | 112.99       | 44.11       |
| 1 | 13.00         | 1.47              | 154.17    | 93.65        | 60.53       |
| 2 | 14.80         | 1.67              | 159.07    | 82.27        | 76.80       |
| 3 | 17.50         | 1.98              | 177.49    | 71.38        | 106.11      |
| 4 | 19.50         | 2.20              | 199.57    | 67.52        | 132.05      |
| 5 | 21.60         | 2.44              | 227.24    | 65.83        | 161.41      |
| 6 | 23.80         | 2.69              | 260.69    | 65.99        | 194.70      |

a. Forces (contributions)



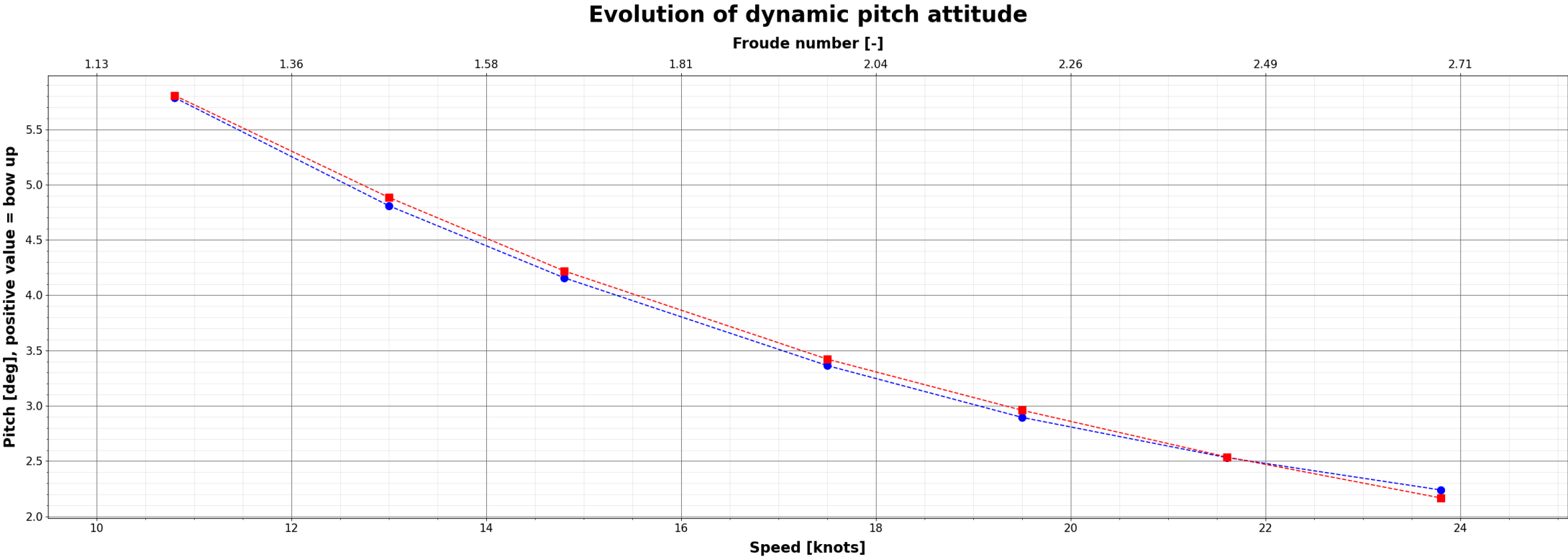
|   | Speed [knots] | Froude number [-] | Contribution of pressure resistance [%] | Contribution of viscous resistance [%] |
|---|---------------|-------------------|-----------------------------------------|----------------------------------------|
| 0 | 10.80         | 1.22              | 71.92                                   | 28.08                                  |
| 1 | 13.00         | 1.47              | 60.74                                   | 39.26                                  |
| 2 | 14.80         | 1.67              | 51.72                                   | 48.28                                  |
| 3 | 17.50         | 1.98              | 40.22                                   | 59.78                                  |
| 4 | 19.50         | 2.20              | 33.83                                   | 66.17                                  |
| 5 | 21.60         | 2.44              | 28.97                                   | 71.03                                  |
| 6 | 23.80         | 2.69              | 25.31                                   | 74.69                                  |

b. Heave



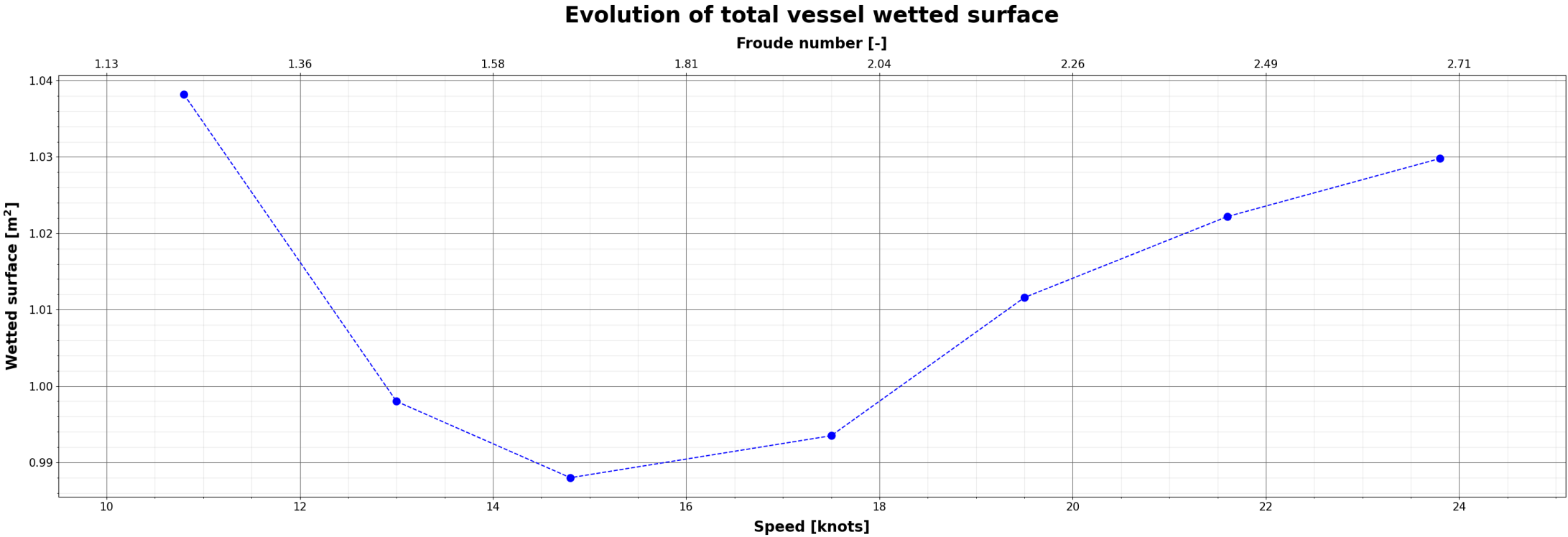
|   | Speed [knots] | Froude number [-] | ● Heave [m], GPPH_M4 | ■ Heave [m], GPPH_EFD |
|---|---------------|-------------------|----------------------|-----------------------|
| 0 | 10.80         | 1.22              | 0.0661               | 0.0745                |
| 1 | 13.00         | 1.47              | 0.0787               | 0.0817                |
| 2 | 14.80         | 1.67              | 0.0849               | 0.0849                |
| 3 | 17.50         | 1.98              | 0.0905               | 0.0906                |
| 4 | 19.50         | 2.20              | 0.0928               | 0.0927                |
| 5 | 21.60         | 2.44              | 0.0947               | 0.0947                |
| 6 | 23.80         | 2.69              | 0.0967               | 0.0960                |

c. Pitch



|   | Speed [knots] | Froude number [-] | ● Pitch [deg], GPPH_M4 | ■ Pitch [deg], GPPH_EFD |
|---|---------------|-------------------|------------------------|-------------------------|
| 0 | 10.80         | 1.22              | 5.7859                 | 5.8054                  |
| 1 | 13.00         | 1.47              | 4.8081                 | 4.8832                  |
| 2 | 14.80         | 1.67              | 4.1567                 | 4.2191                  |
| 3 | 17.50         | 1.98              | 3.3635                 | 3.4218                  |
| 4 | 19.50         | 2.20              | 2.8950                 | 2.9597                  |
| 5 | 21.60         | 2.44              | 2.5321                 | 2.5376                  |
| 6 | 23.80         | 2.69              | 2.2388                 | 2.1666                  |

d. Wetted surface



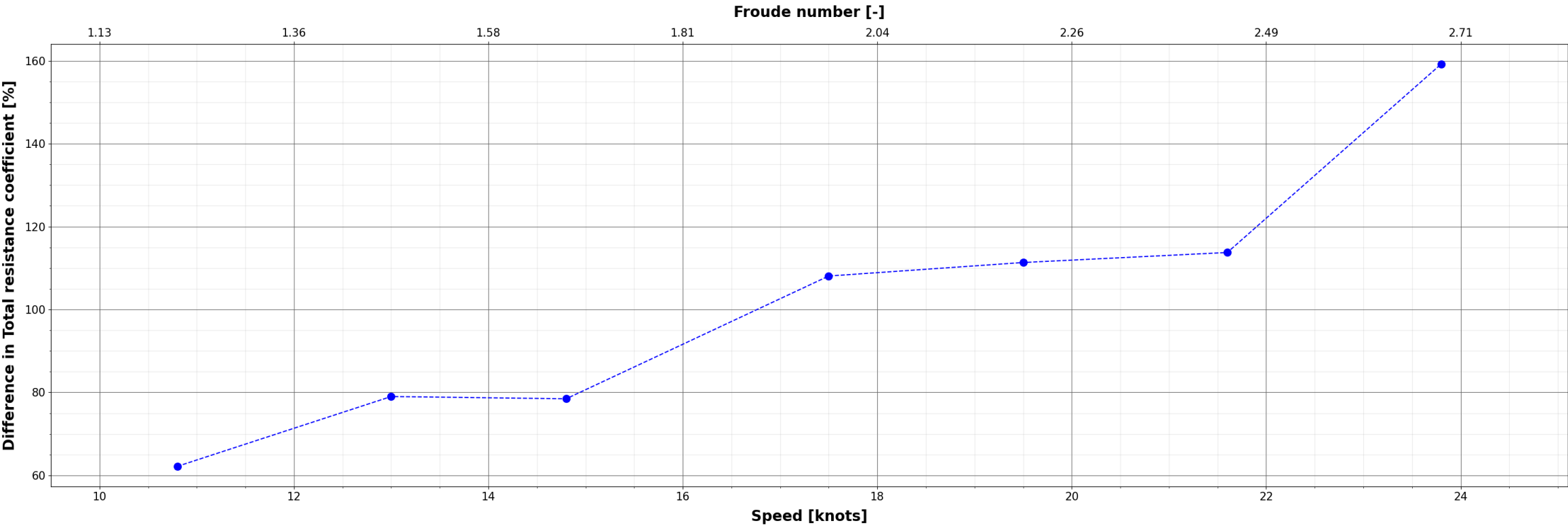
|   | Speed [knots] | Froude number [-] | Wetted surface [m²], GPPH_M4 |
|---|---------------|-------------------|------------------------------|
| 0 | 0.00          | 0.00              | 0.5285                       |
| 1 | 10.80         | 1.22              | 1.0382                       |
| 2 | 13.00         | 1.47              | 0.9980                       |
| 3 | 14.80         | 1.67              | 0.9880                       |
| 4 | 17.50         | 1.98              | 0.9935                       |
| 5 | 19.50         | 2.20              | 1.0116                       |
| 6 | 21.60         | 2.44              | 1.0222                       |
| 7 | 23.80         | 2.69              | 1.0298                       |



## 5. COMPARISON EFD/REF

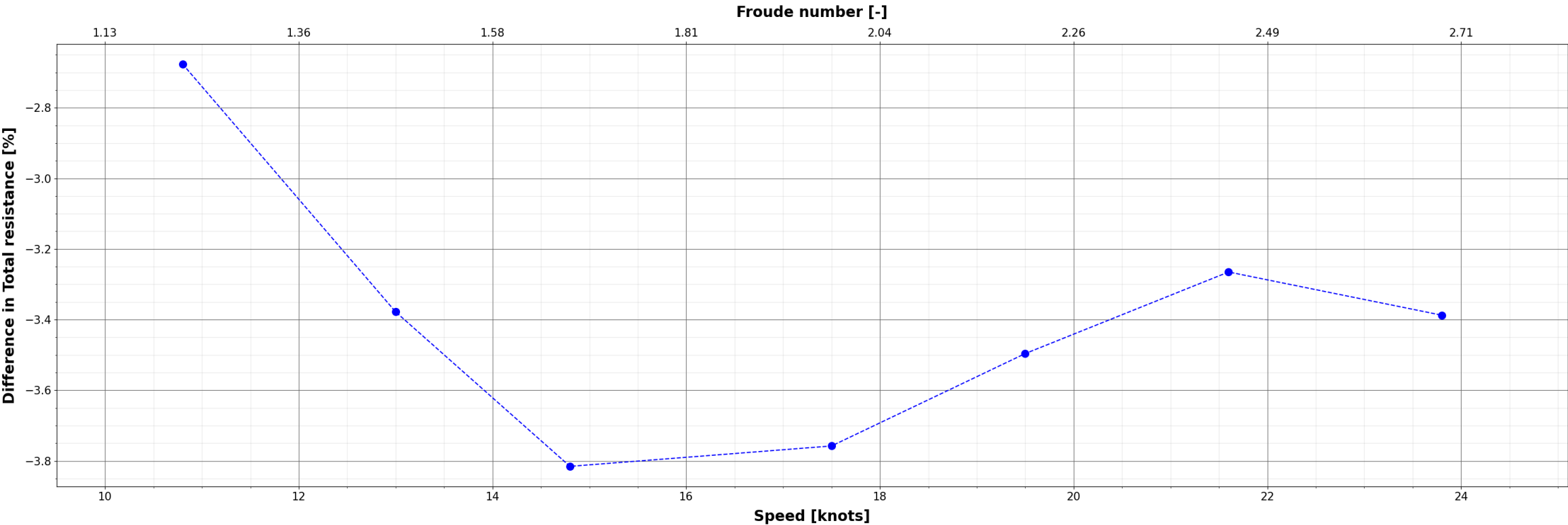


Comparison of Total resistance coefficient :  $(X_{\{i\}} - GPPH\_EFD) / GPPH\_EFD$



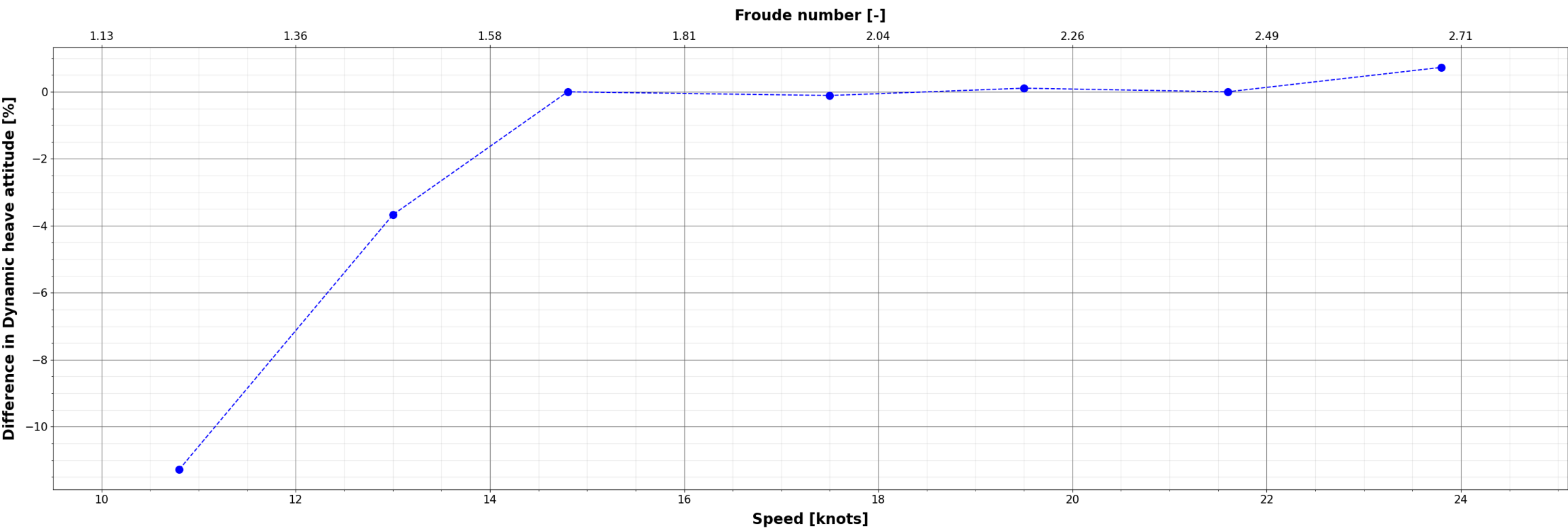
|   | Speed [knots] | Froude number [-] | X_0 = GPPH_M4, [%] |
|---|---------------|-------------------|--------------------|
| 0 | 10.80         | 1.22              | 62.16              |
| 1 | 13.00         | 1.47              | 79.01              |
| 2 | 14.80         | 1.67              | 78.47              |
| 3 | 17.50         | 1.98              | 108.07             |
| 4 | 19.50         | 2.20              | 111.34             |
| 5 | 21.60         | 2.44              | 113.75             |
| 6 | 23.80         | 2.69              | 159.22             |

Comparison of Total resistance :  $(X_{\{i\}} - GPPH\_EFD) / GPPH\_EFD$



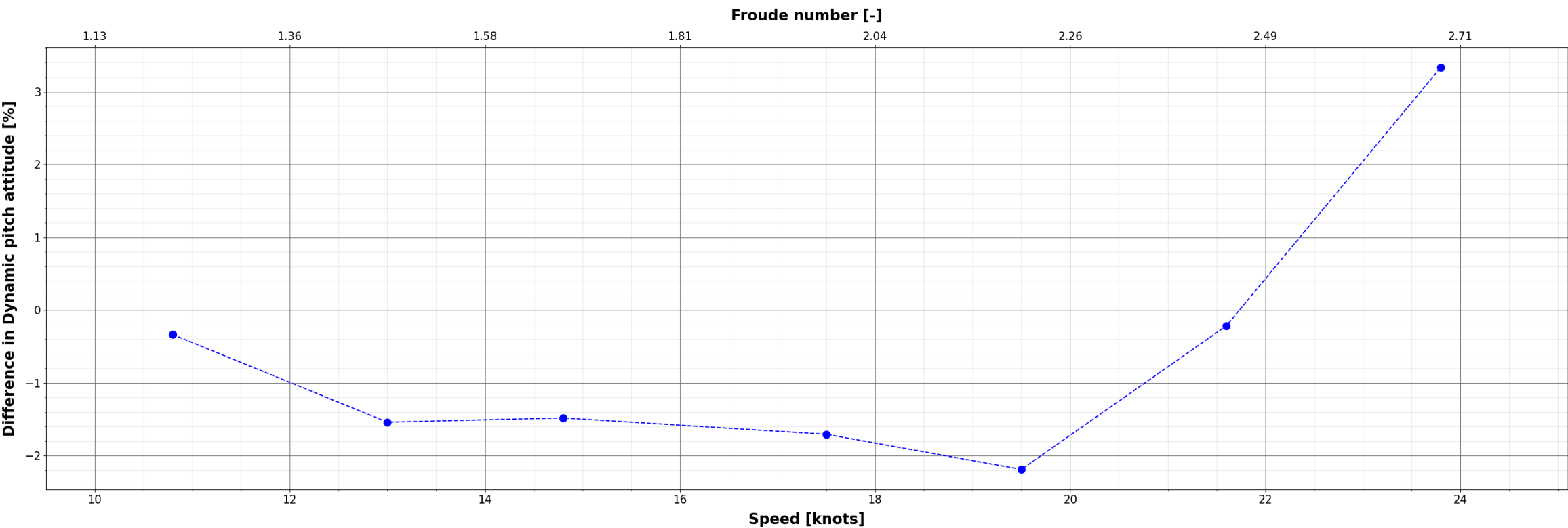
|   | Speed [knots] | Froude number [-] | X_0 = GPPH_M4, [%] |
|---|---------------|-------------------|--------------------|
| 0 | 10.80         | 1.22              | -2.68              |
| 1 | 13.00         | 1.47              | -3.38              |
| 2 | 14.80         | 1.67              | -3.82              |
| 3 | 17.50         | 1.98              | -3.76              |
| 4 | 19.50         | 2.20              | -3.50              |
| 5 | 21.60         | 2.44              | -3.27              |
| 6 | 23.80         | 2.69              | -3.39              |

Comparison of Dynamic heave attitude :  $(X_{\{i\}} - GPPH\_EFD) / GPPH\_EFD$



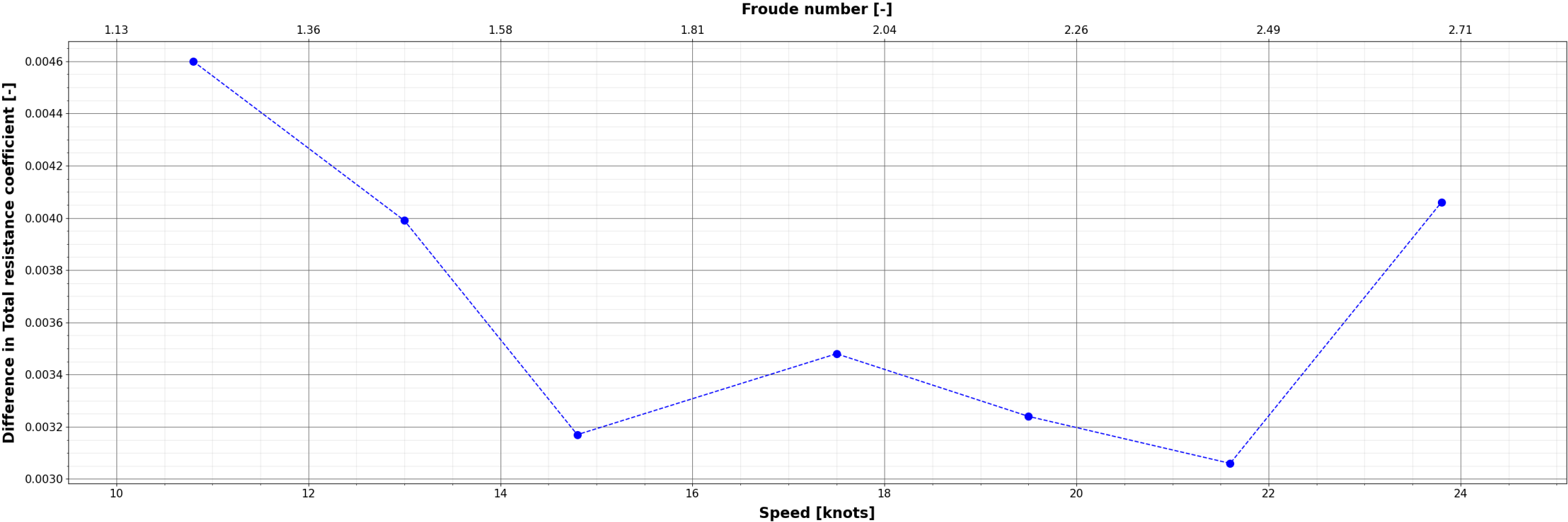
|   | Speed [knots] | Froude number [-] | X_0 = GPPH_M4, [%] |
|---|---------------|-------------------|--------------------|
| 0 | 10.80         | 1.22              | -11.28             |
| 1 | 13.00         | 1.47              | -3.67              |
| 2 | 14.80         | 1.67              | 0.00               |
| 3 | 17.50         | 1.98              | -0.11              |
| 4 | 19.50         | 2.20              | 0.11               |
| 5 | 21.60         | 2.44              | 0.00               |
| 6 | 23.80         | 2.69              | 0.73               |

Comparison of Dynamic pitch attitude :  $(X_{\{i\}} - \text{GPPH\_EFD}) / \text{GPPH\_EFD}$



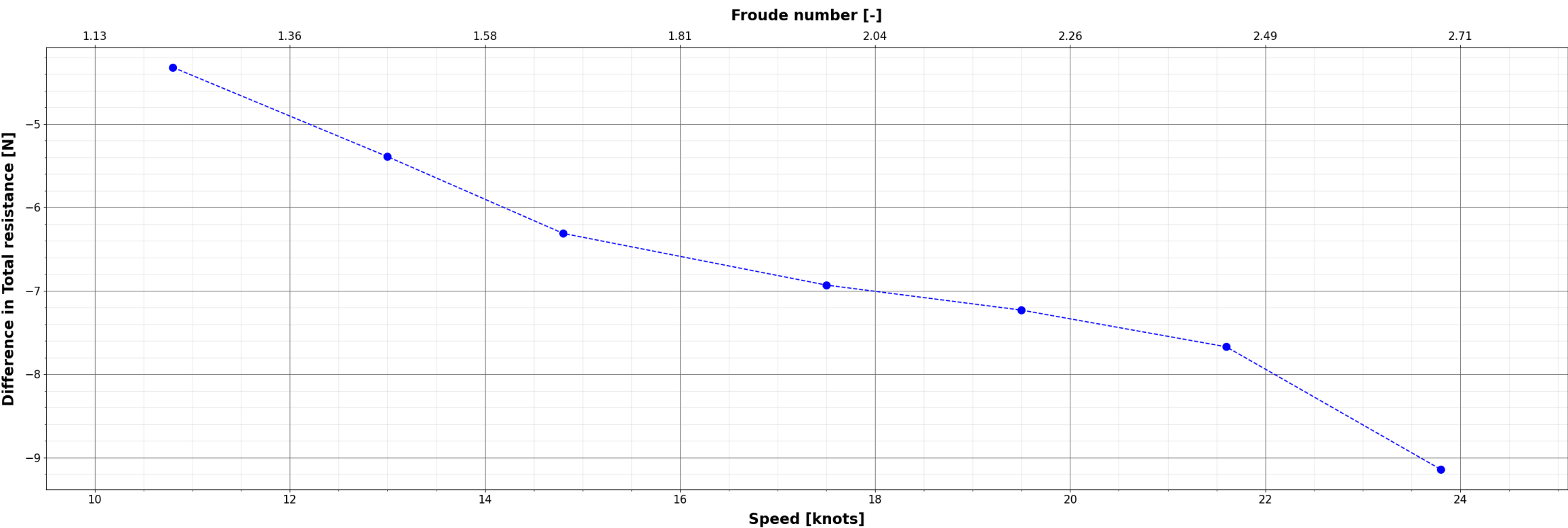
|   | Speed [knots] | Froude number [-] | X_0 = GPPH_M4, [%] |
|---|---------------|-------------------|--------------------|
| 0 | 10.80         | 1.22              | -0.34              |
| 1 | 13.00         | 1.47              | -1.54              |
| 2 | 14.80         | 1.67              | -1.48              |
| 3 | 17.50         | 1.98              | -1.70              |
| 4 | 19.50         | 2.20              | -2.19              |
| 5 | 21.60         | 2.44              | -0.22              |
| 6 | 23.80         | 2.69              | 3.33               |

Comparison of Total resistance coefficient :  $X_{\{i\}}$  - GPPH\_EFD



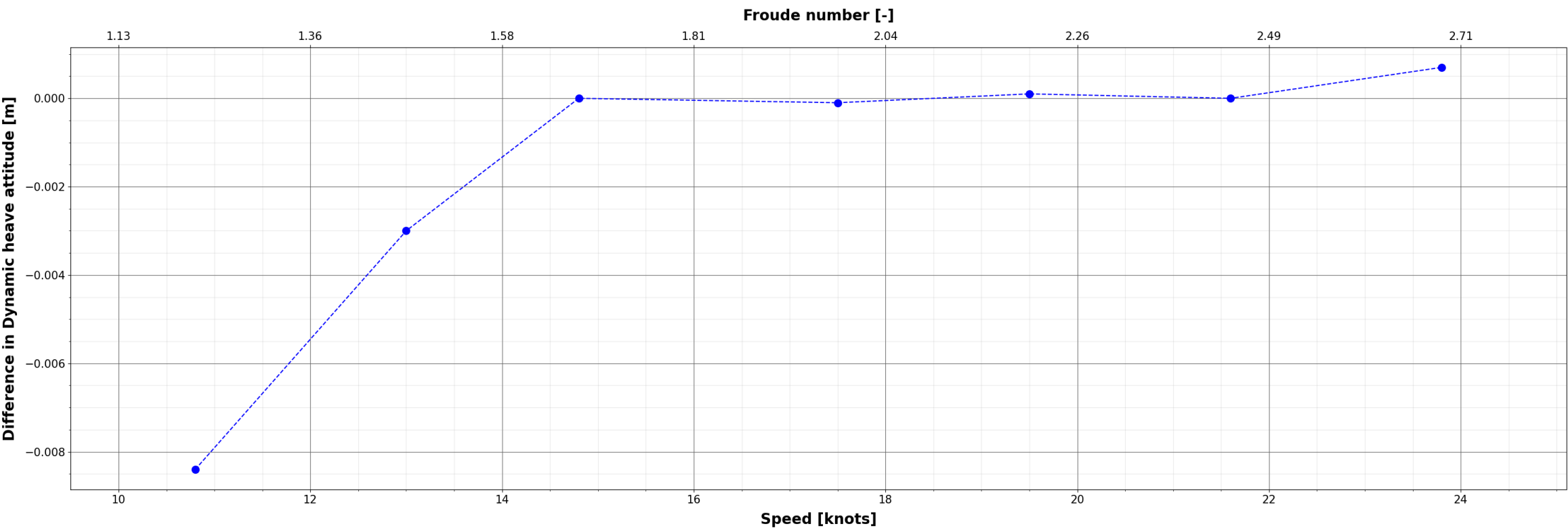
|   | Speed [knots] | Froude number [-] | $X_0 = \text{GPPH\_M4, [-]}$ |
|---|---------------|-------------------|------------------------------|
| 0 | 10.80         | 1.22              | 4.60e-03                     |
| 1 | 13.00         | 1.47              | 3.99e-03                     |
| 2 | 14.80         | 1.67              | 3.17e-03                     |
| 3 | 17.50         | 1.98              | 3.48e-03                     |
| 4 | 19.50         | 2.20              | 3.24e-03                     |
| 5 | 21.60         | 2.44              | 3.06e-03                     |
| 6 | 23.80         | 2.69              | 4.06e-03                     |

Comparison of Total resistance :  $X_{\{i\}}$  - GPPH\_EFD



|   | Speed [knots] | Froude number [-] | $X_0 = \text{GPPH\_M4, [N]}$ |
|---|---------------|-------------------|------------------------------|
| 0 | 10.80         | 1.22              | -4.32                        |
| 1 | 13.00         | 1.47              | -5.39                        |
| 2 | 14.80         | 1.67              | -6.31                        |
| 3 | 17.50         | 1.98              | -6.93                        |
| 4 | 19.50         | 2.20              | -7.23                        |
| 5 | 21.60         | 2.44              | -7.67                        |
| 6 | 23.80         | 2.69              | -9.14                        |

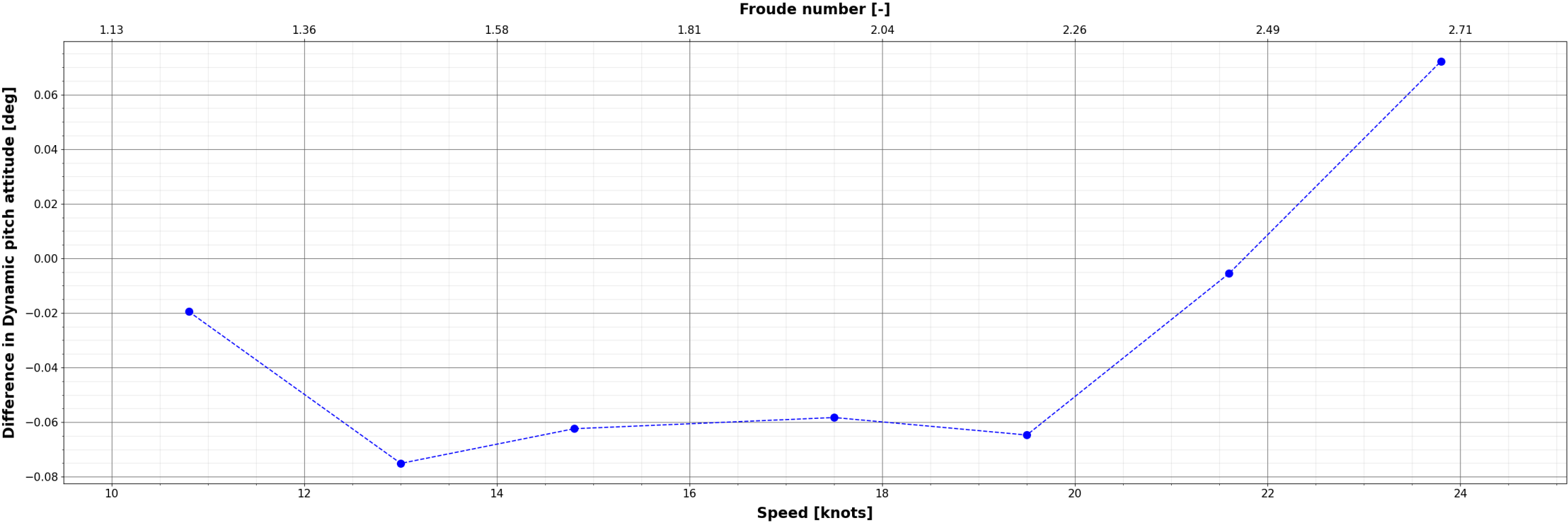
Comparison of Dynamic heave attitude :  $X_{\{i\}}$  - GPPH\_EFD



|   | Speed [knots] | Froude number [-] | $X_0 = \text{GPPH\_M4, [m]}$ |
|---|---------------|-------------------|------------------------------|
| 0 | 10.80         | 1.22              | -0.008                       |
| 1 | 13.00         | 1.47              | -0.003                       |
| 2 | 14.80         | 1.67              | 0.000                        |
| 3 | 17.50         | 1.98              | -0.000                       |
| 4 | 19.50         | 2.20              | 0.000                        |
| 5 | 21.60         | 2.44              | 0.000                        |
| 6 | 23.80         | 2.69              | 0.001                        |



Comparison of Dynamic pitch attitude :  $X_{\{i\}}$  - GPPH\_EFD



|   | Speed [knots] | Froude number [-] | $X_0 = \text{GPPH\_M4, [deg]}$ |
|---|---------------|-------------------|--------------------------------|
| 0 | 10.80         | 1.22              | -0.019                         |
| 1 | 13.00         | 1.47              | -0.075                         |
| 2 | 14.80         | 1.67              | -0.062                         |
| 3 | 17.50         | 1.98              | -0.058                         |
| 4 | 19.50         | 2.20              | -0.065                         |
| 5 | 21.60         | 2.44              | -0.006                         |
| 6 | 23.80         | 2.69              | 0.072                          |



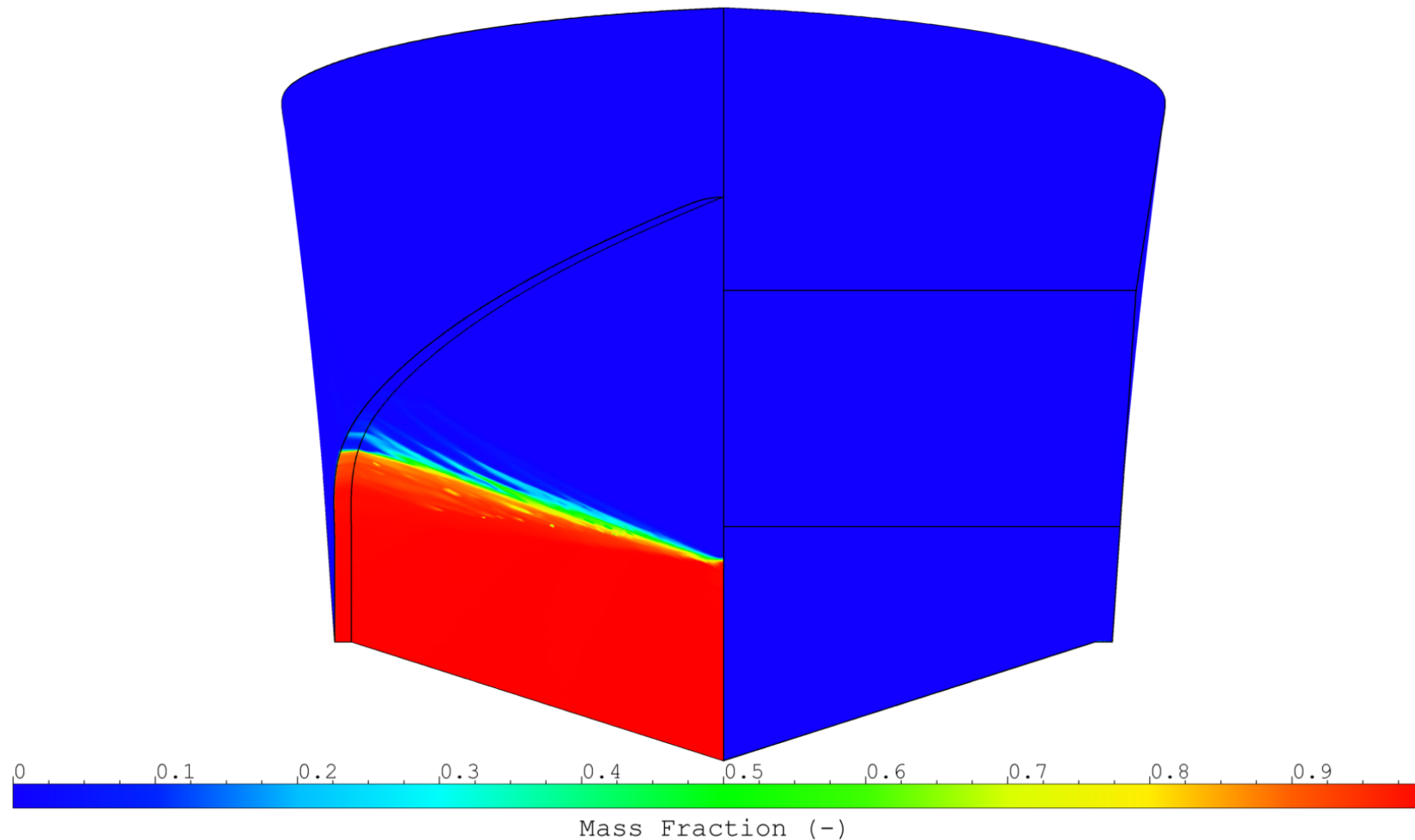
## 6. Visuals

- a. Mass fraction
- b. Pressure coefficient
- c. Free surface
- d. Streamlines
  - 1. Surfacic
  - 2. Volumic

### a. Mass fraction : front and rear view

Wetted Surface = 1.04 m<sup>2</sup>

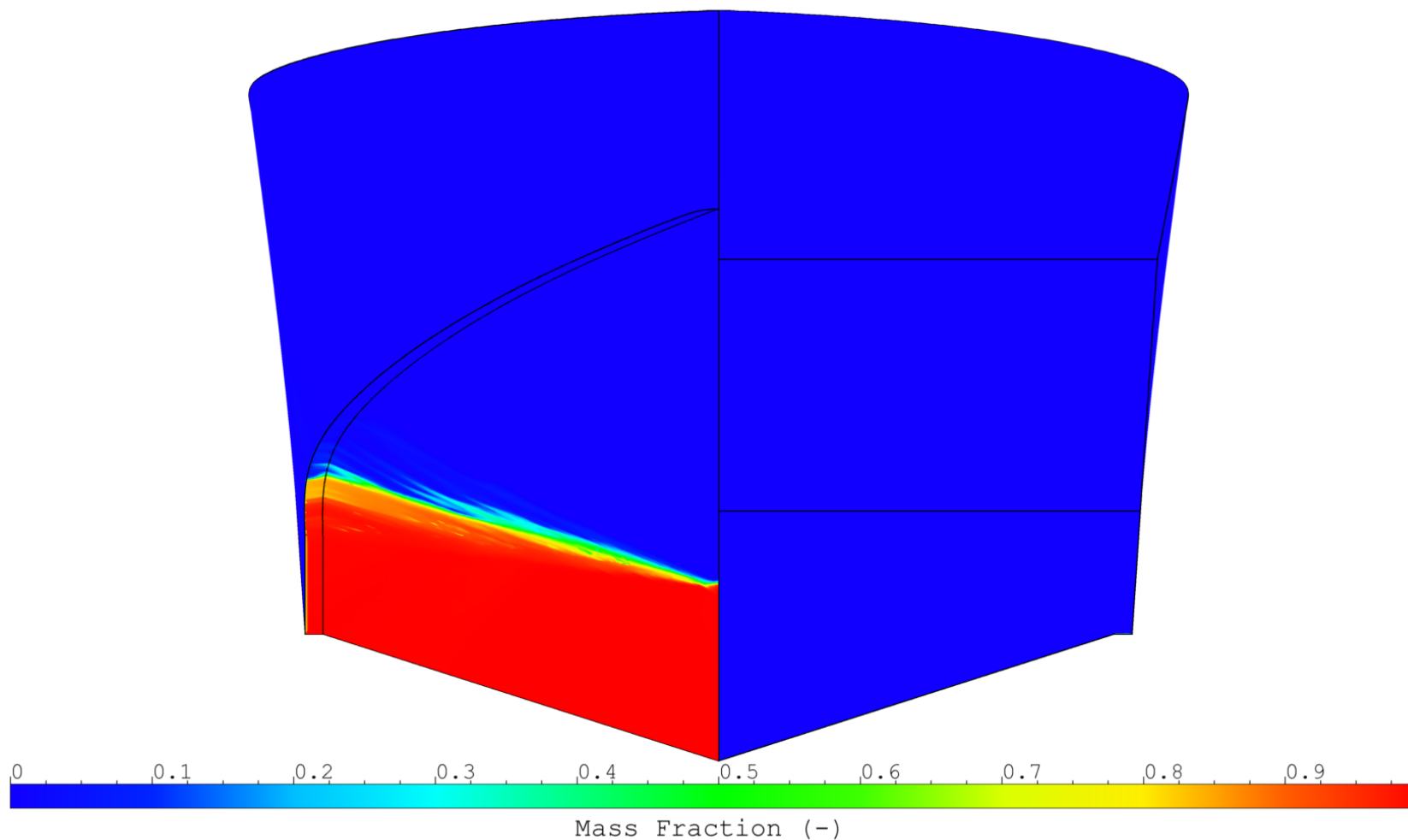
GPPH\_M4, 0.1 tons, 10.8 knots



### a. Mass fraction : front and rear view

Wetted Surface = 1.00 m<sup>2</sup>

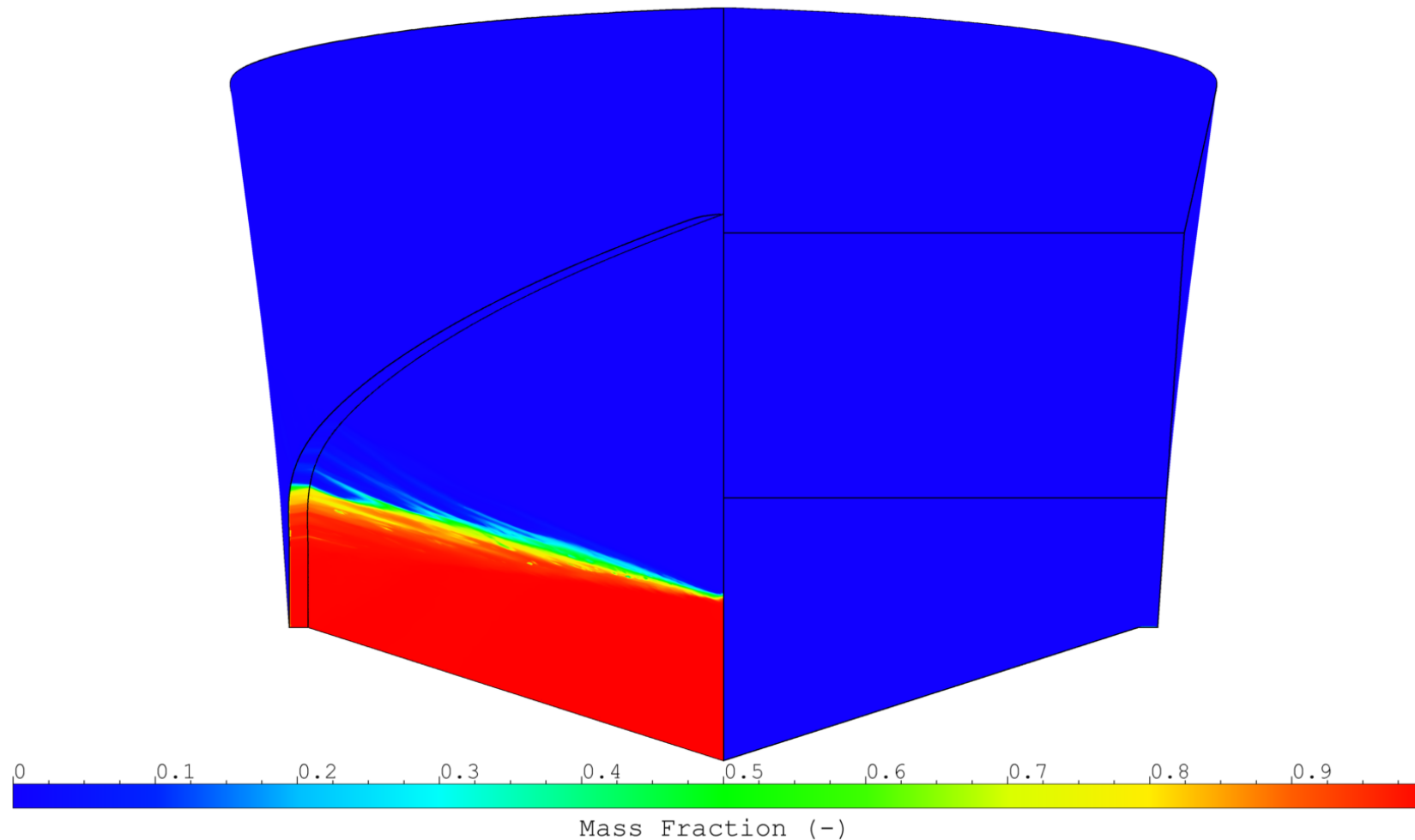
GPPH\_M4, 0.1 tons, 13.0 knots



### a. Mass fraction : front and rear view

Wetted Surface = 0.99 m<sup>2</sup>

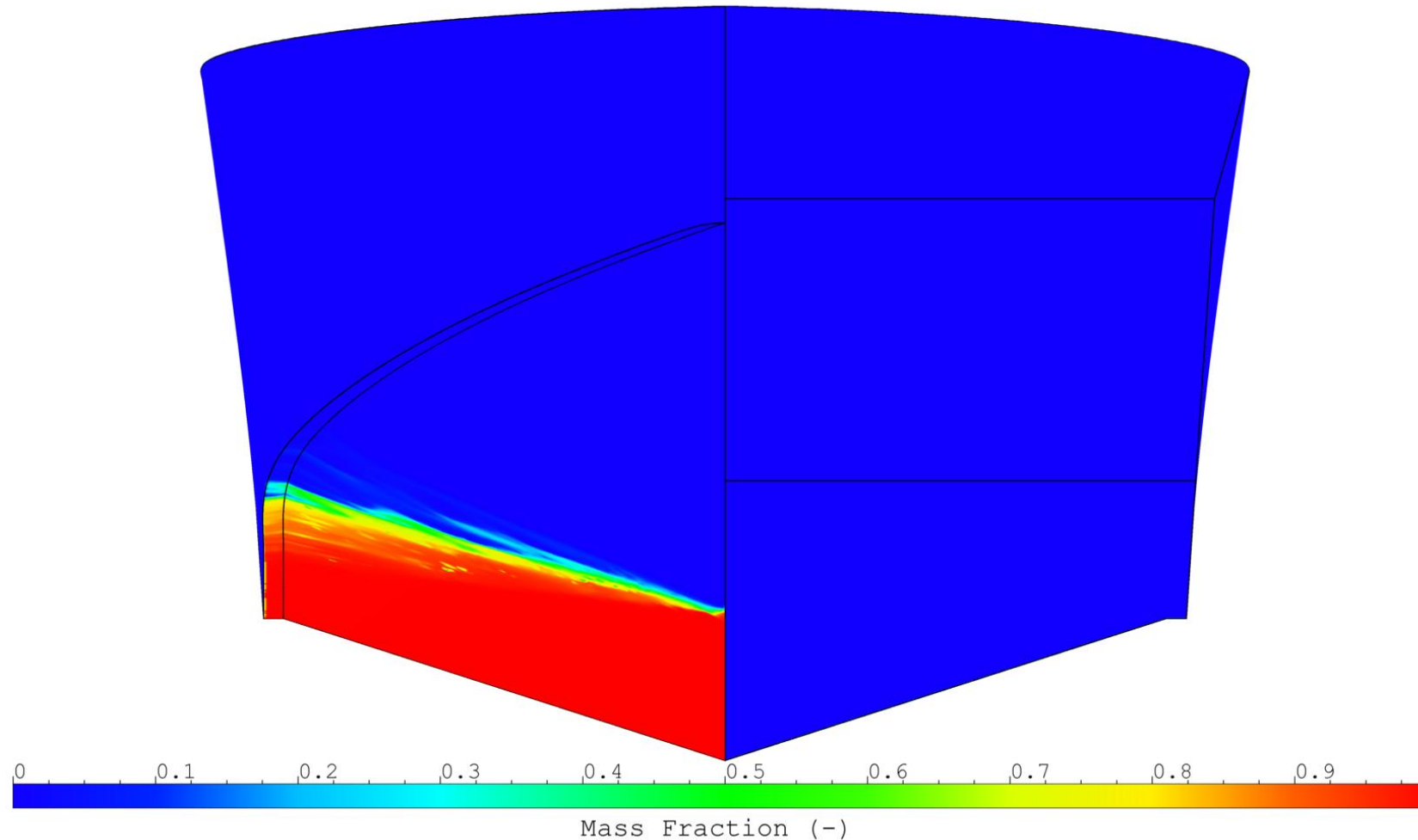
GPPH\_M4, 0.1 tons, 14.8 knots



### a. Mass fraction : front and rear view

Wetted Surface = 0.99 m<sup>2</sup>

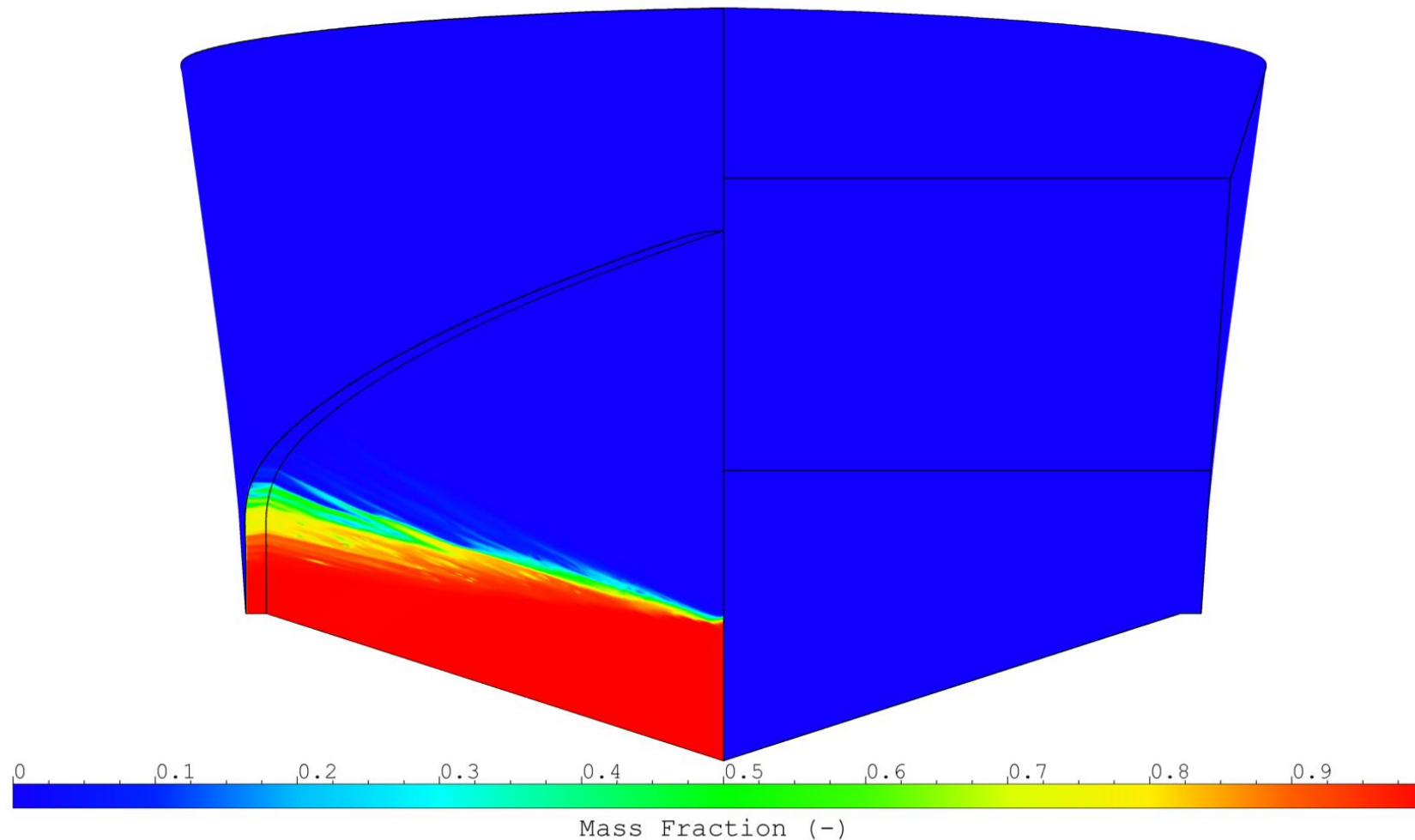
GPPH\_M4, 0.1 tons, 17.5 knots



### a. Mass fraction : front and rear view

Wetted Surface = 1.01 m<sup>2</sup>

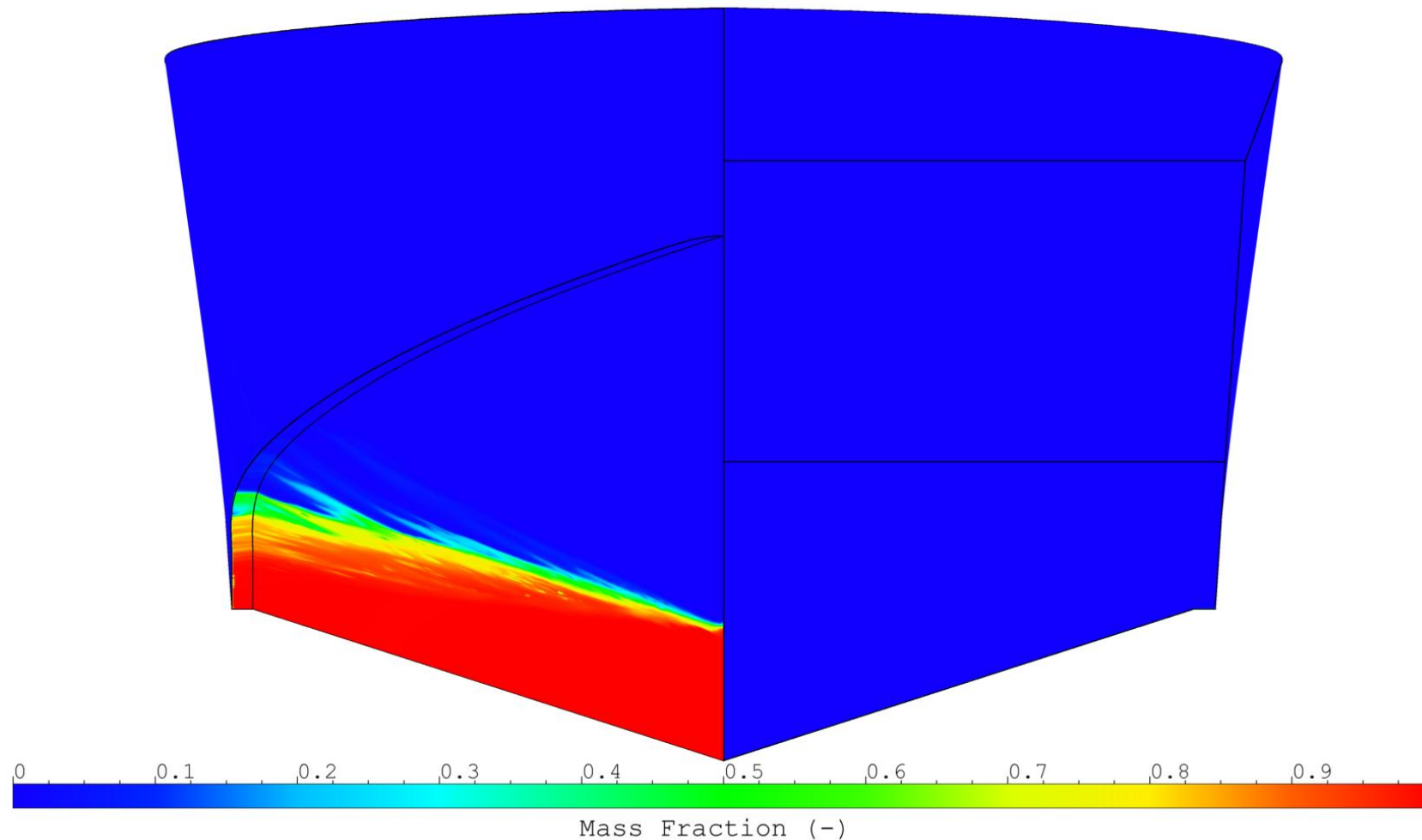
GPPH\_M4, 0.1 tons, 19.5 knots



### a. Mass fraction : front and rear view

Wetted Surface = 1.02 m<sup>2</sup>

GPPH\_M4, 0.1 tons, 21.6 knots

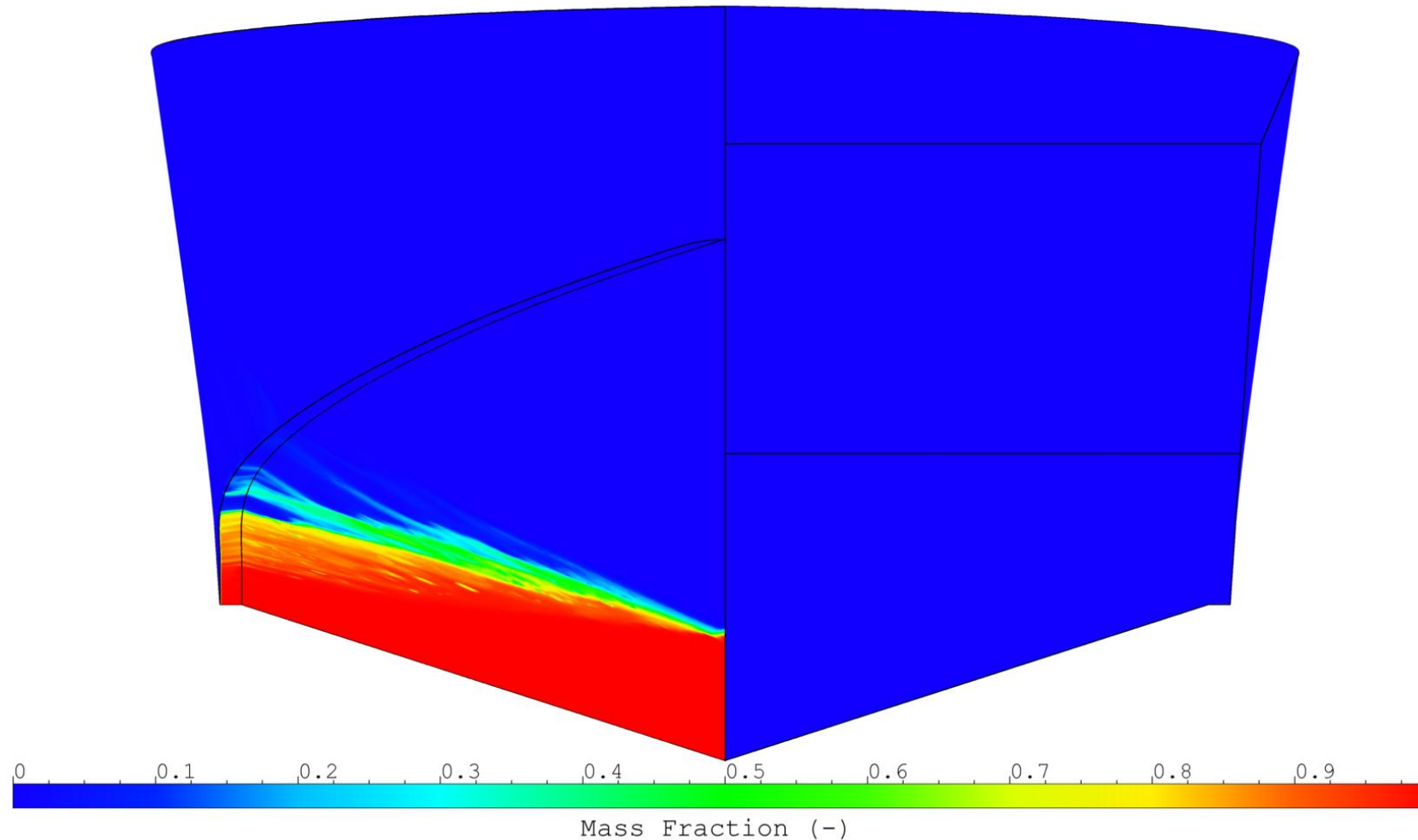




### a. Mass fraction : front and rear view

Wetted Surface = 1.03 m<sup>2</sup>

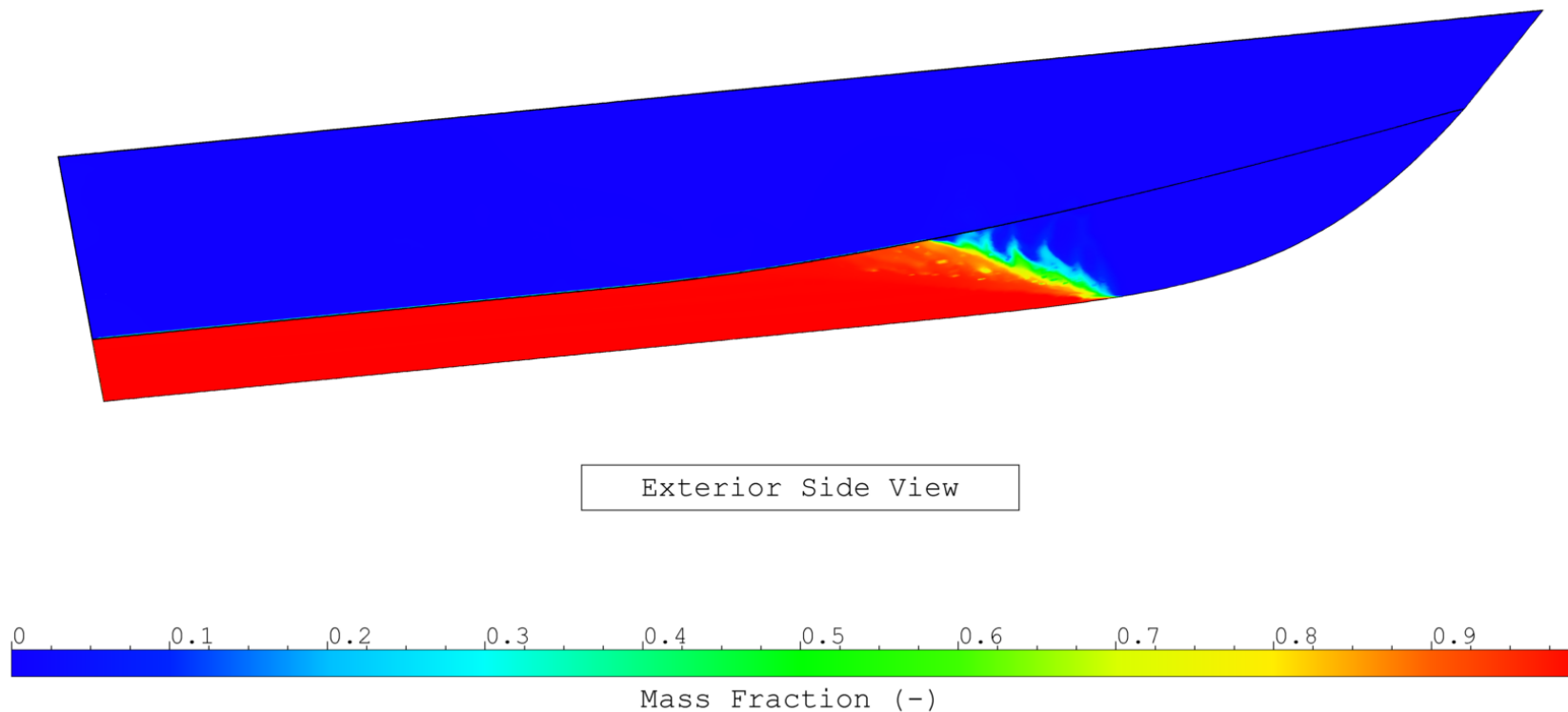
GPPH\_M4, 0.1 tons, 23.8 knots



### a. Mass fraction : side view(s)

Wetted Surface = 1.04 m<sup>2</sup>

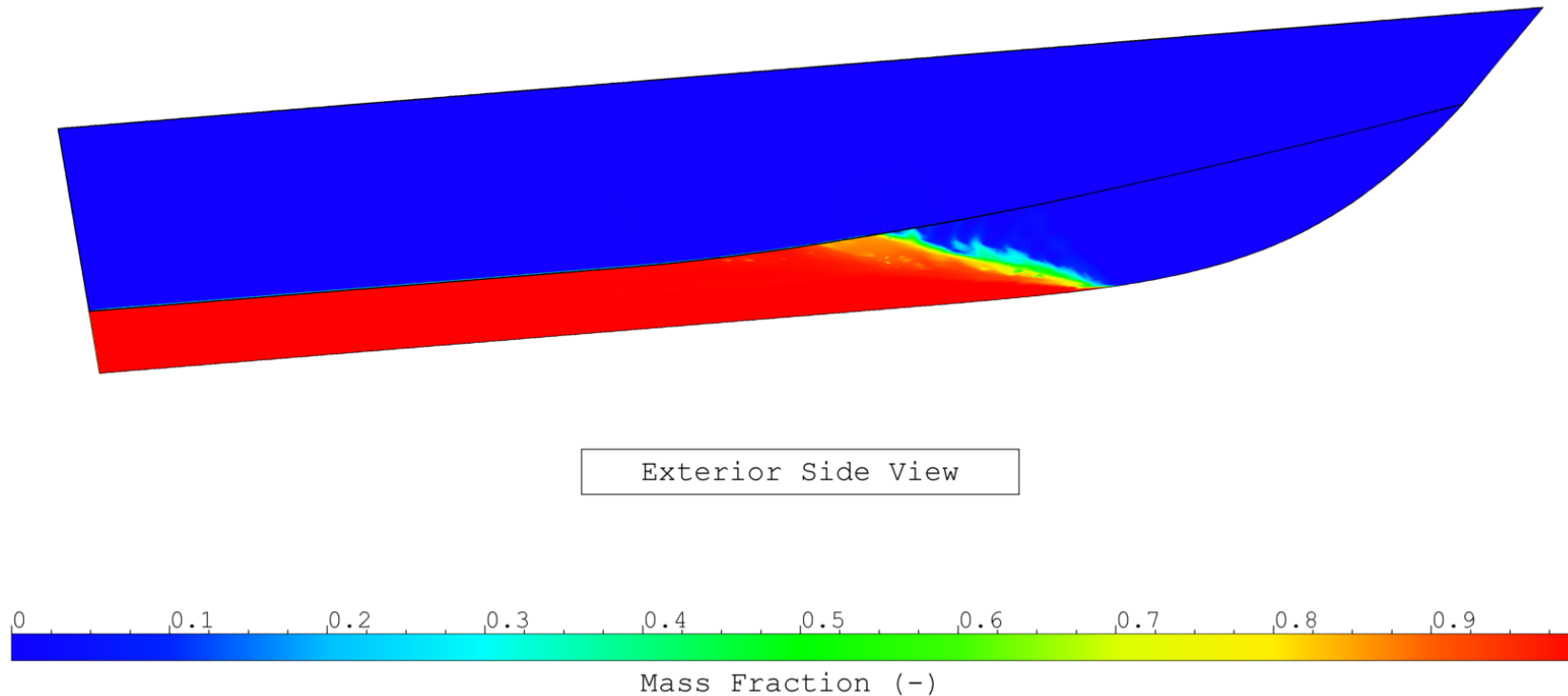
GPPH\_M4, 0.1 tons, 10.8 knots



### a. Mass fraction : side view(s)

Wetted Surface = 1.00 m<sup>2</sup>

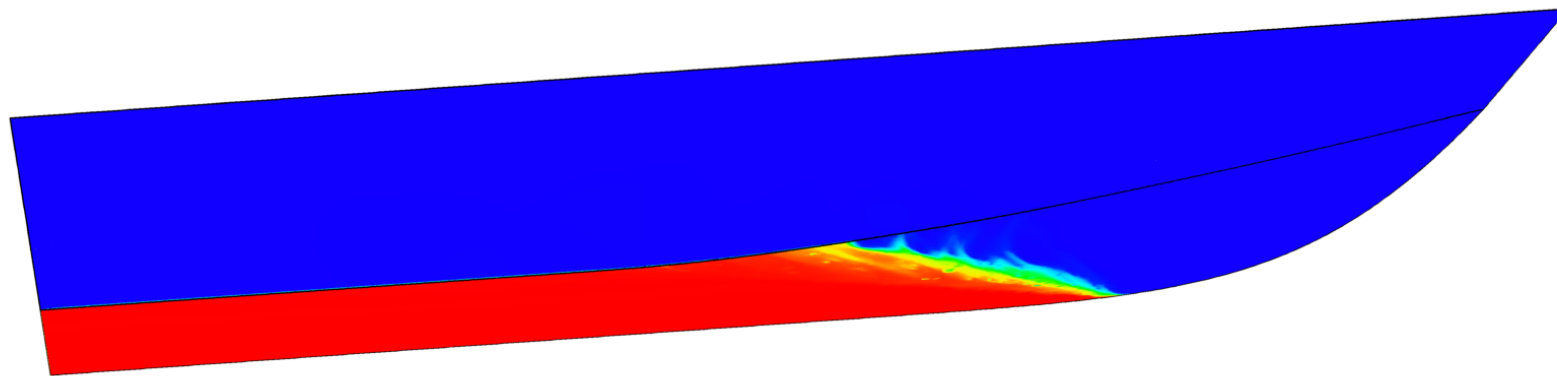
GPPH\_M4, 0.1 tons, 13.0 knots



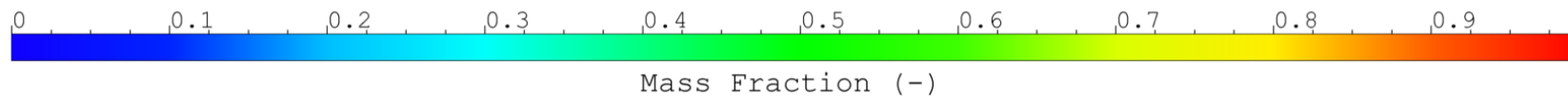
### a. Mass fraction : side view(s)

Wetted Surface = 0.99 m<sup>2</sup>

GPPH\_M4, 0.1 tons, 14.8 knots



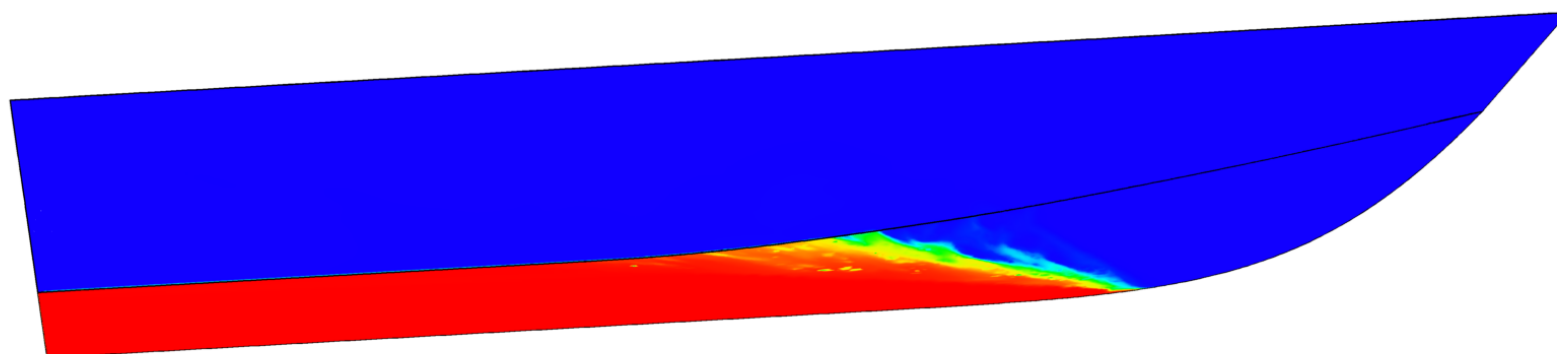
Exterior Side View



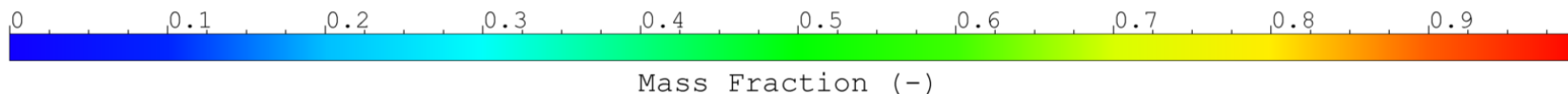
### a. Mass fraction : side view(s)

Wetted Surface = 0.99 m<sup>2</sup>

GPPH\_M4, 0.1 tons, 17.5 knots



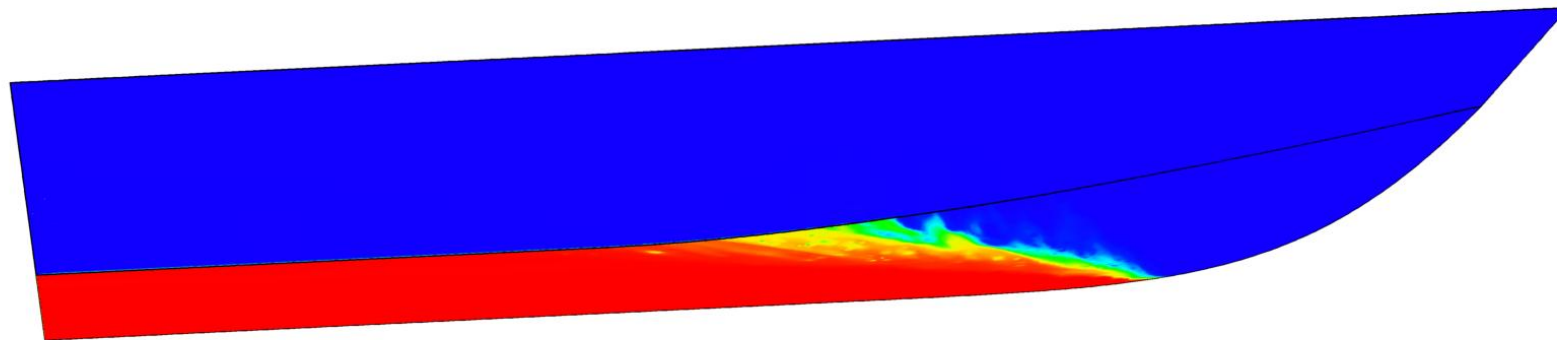
Exterior Side View



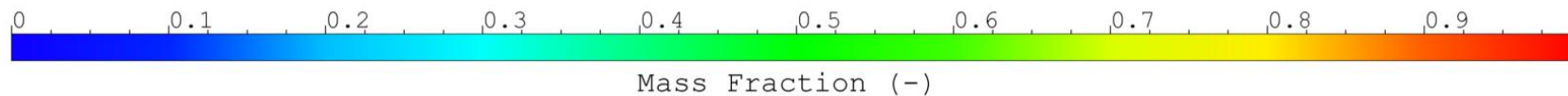
### a. Mass fraction : side view(s)

Wetted Surface = 1.01 m<sup>2</sup>

GPPH\_M4, 0.1 tons, 19.5 knots



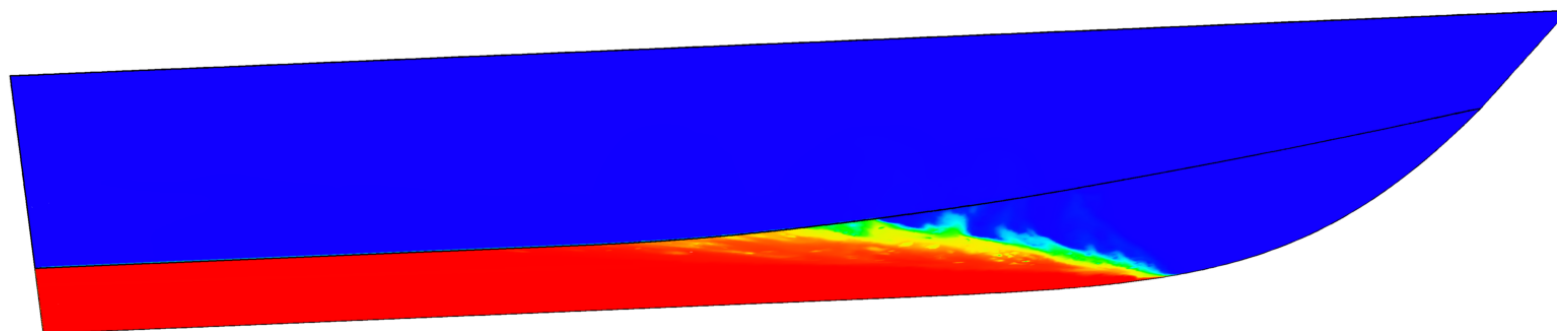
Exterior Side View



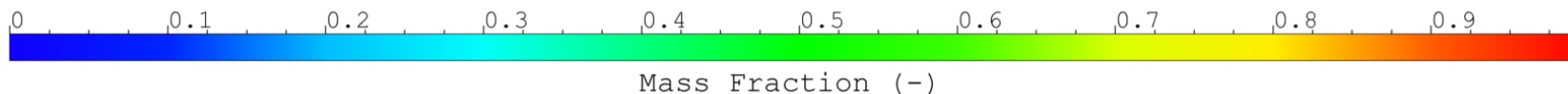
### a. Mass fraction : side view(s)

Wetted Surface = 1.02 m<sup>2</sup>

GPPH\_M4, 0.1 tons, 21.6 knots



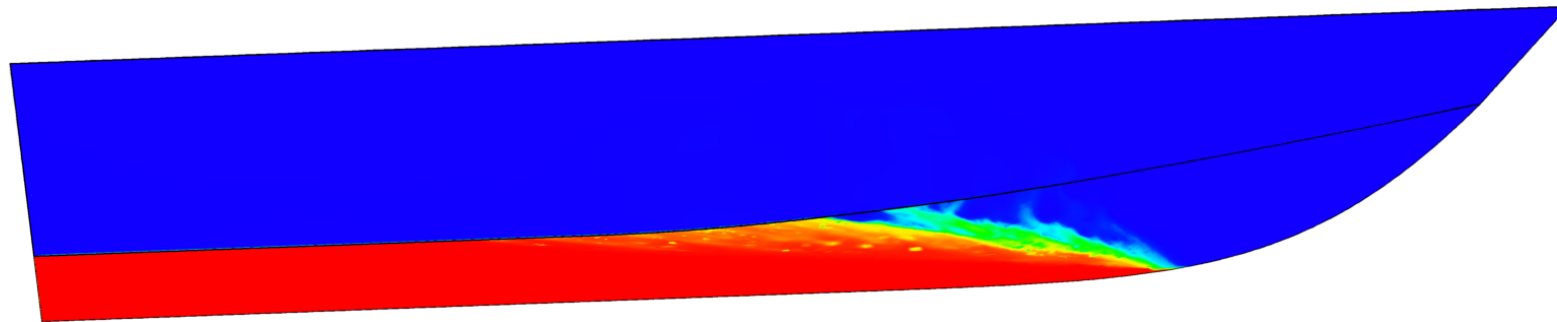
Exterior Side View



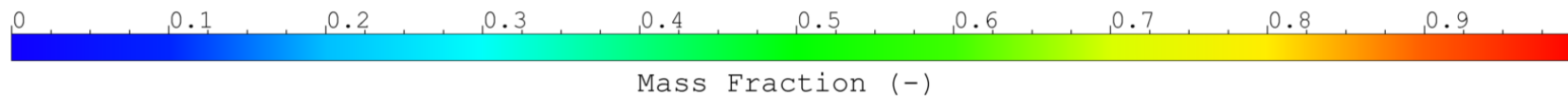
### a. Mass fraction : side view(s)

Wetted Surface = 1.03 m<sup>2</sup>

GPPH\_M4, 0.1 tons, 23.8 knots



Exterior Side View







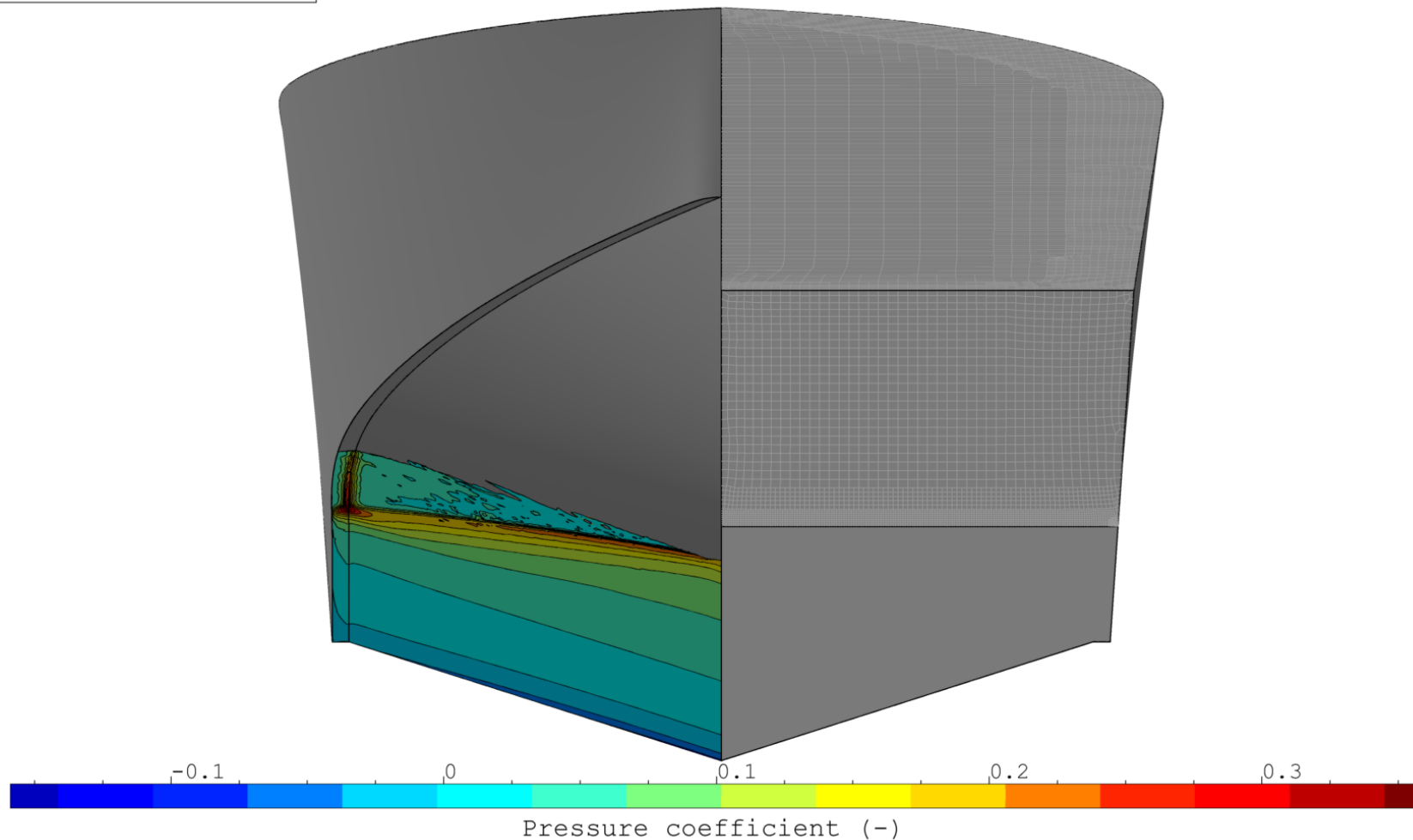
## 6. Visuals

- a. Mass fraction
- b. Pressure coefficient
- c. Free surface
- d. Streamlines
  - 1. Surfacic
  - 2. Volumic

### b. Pressure coefficient : front and rear view

Min value = -0.154 (-)  
Max value = 0.362 (-)

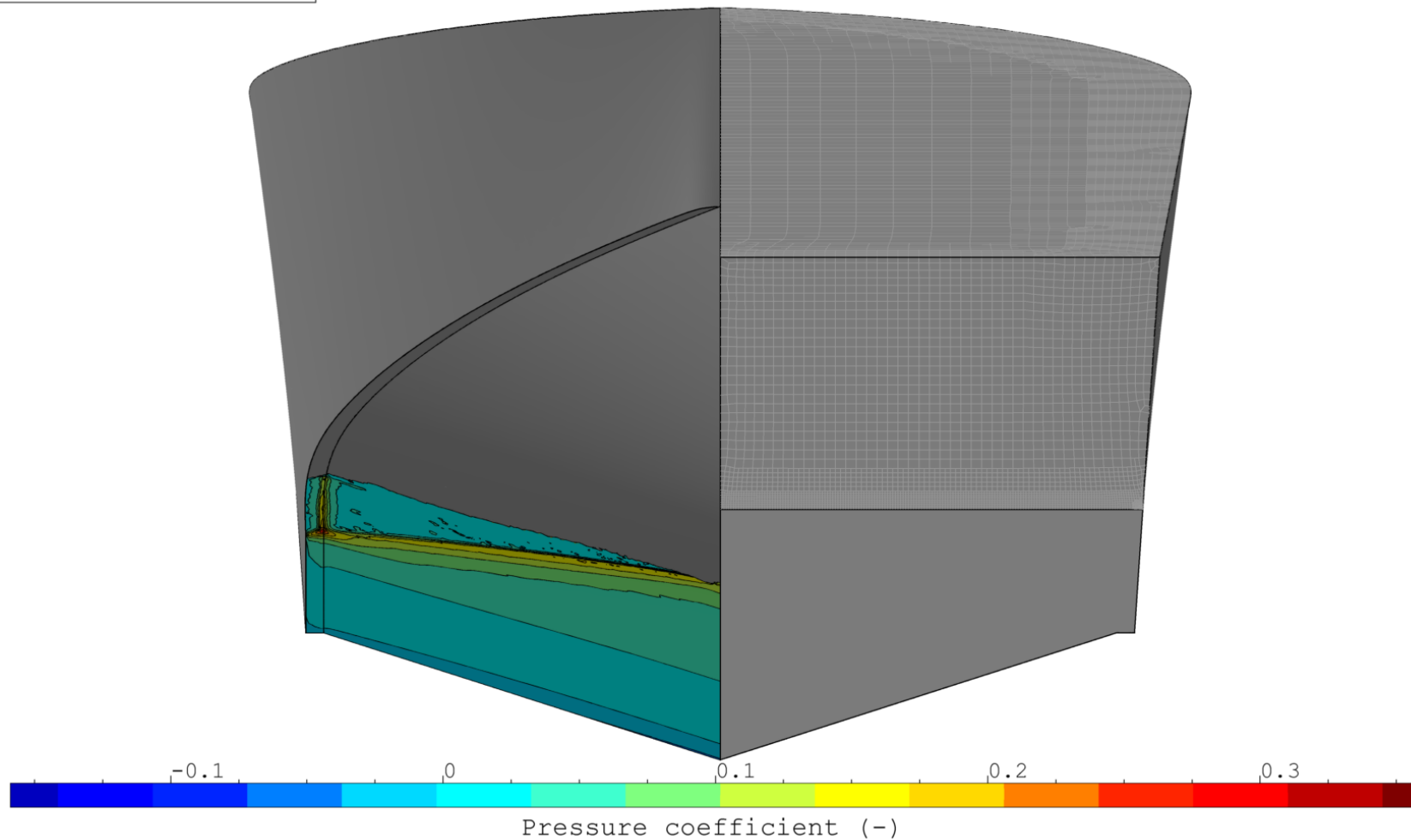
GPPH\_M4, 0.1 tons, 10.8 knots



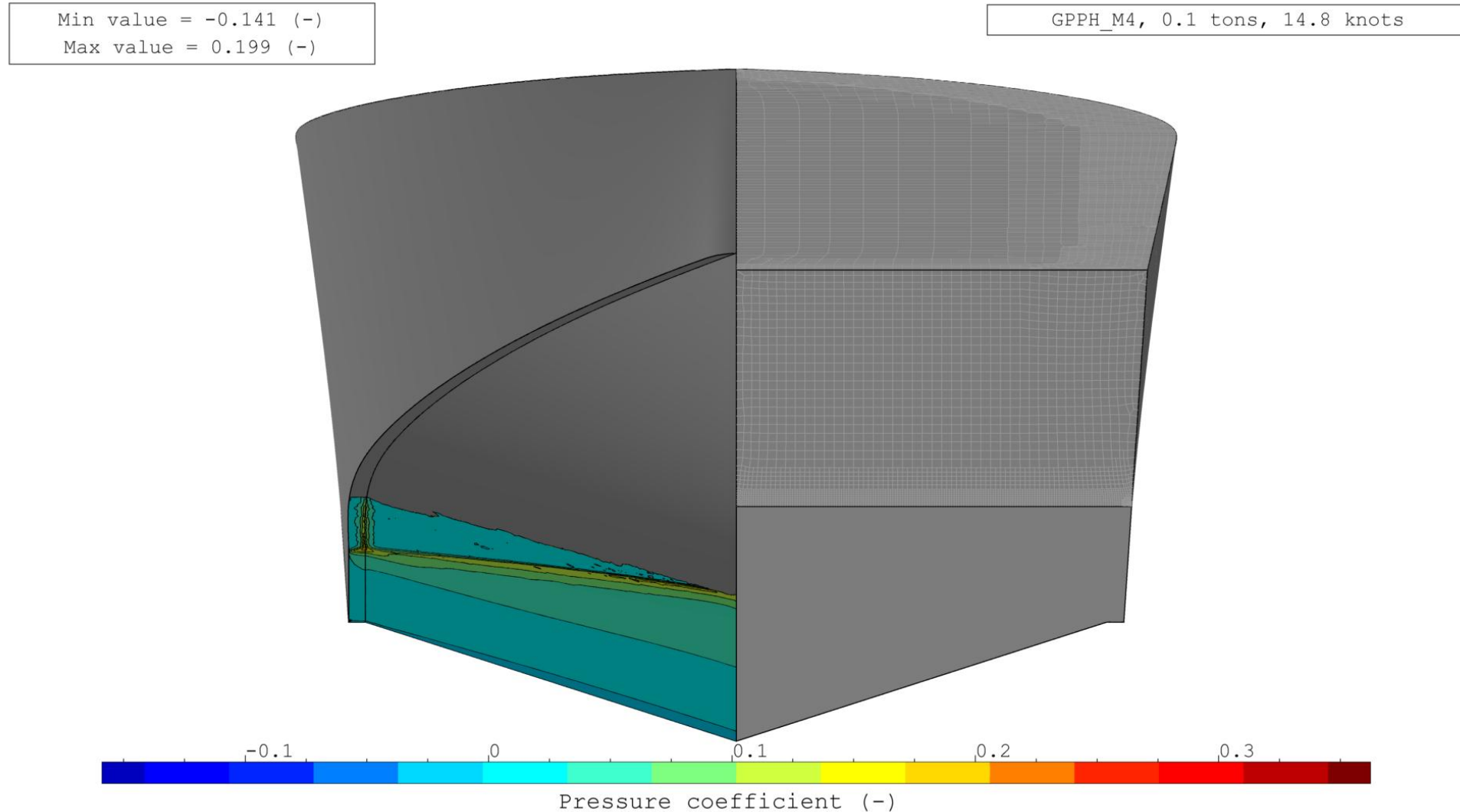
### b. Pressure coefficient : front and rear view

Min value = -0.159 (-)  
Max value = 0.265 (-)

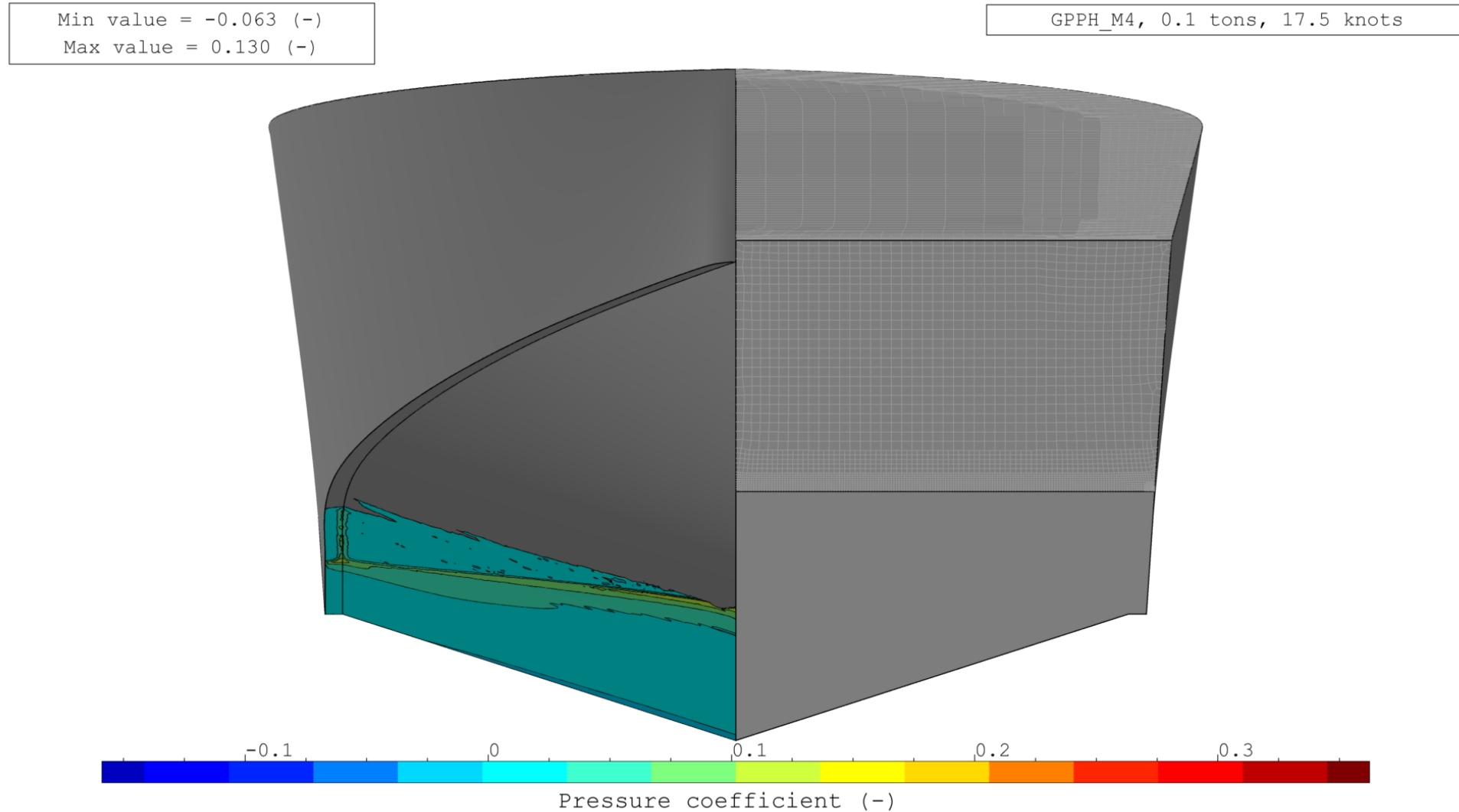
GPPH\_M4, 0.1 tons, 13.0 knots



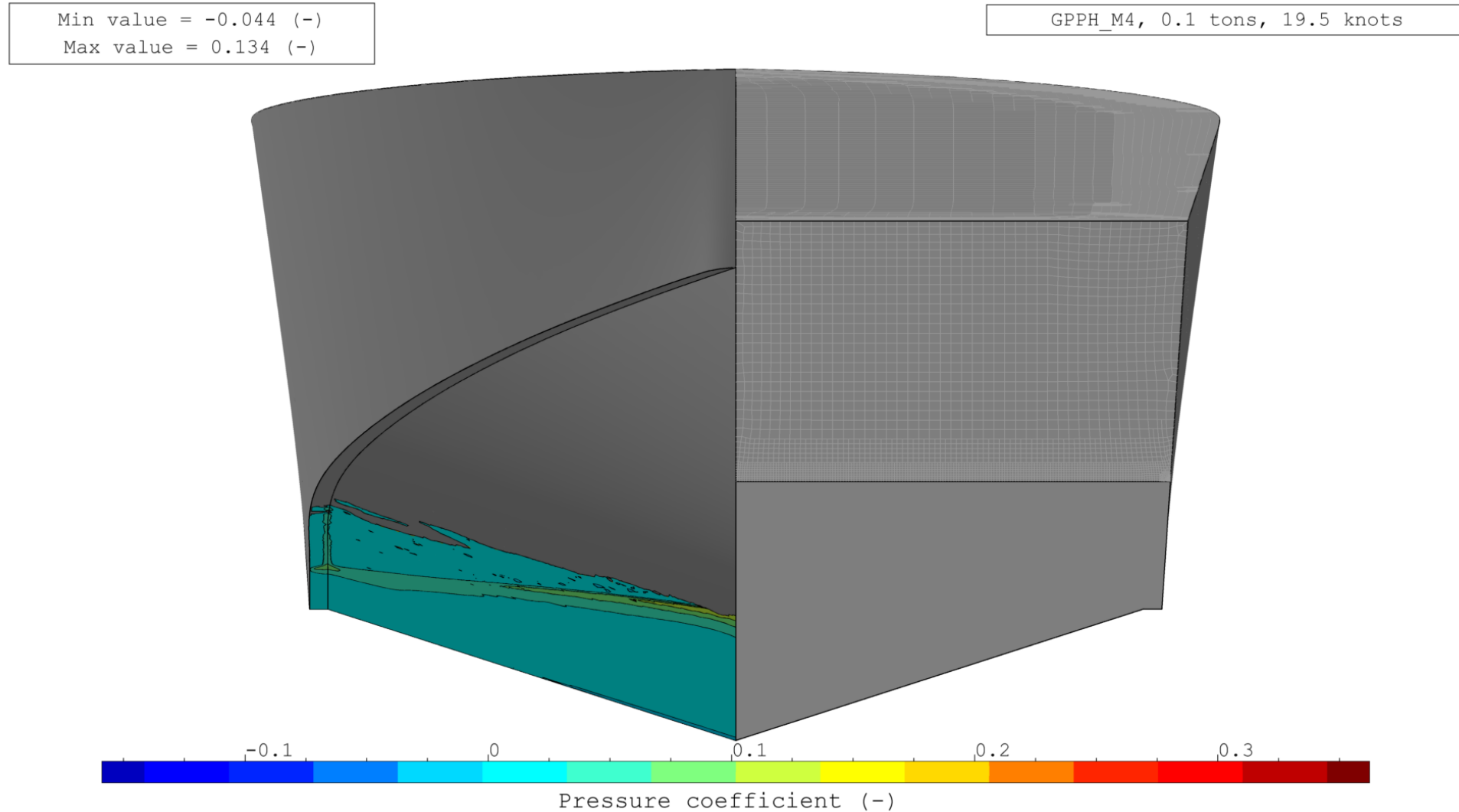
## b. Pressure coefficient : front and rear view



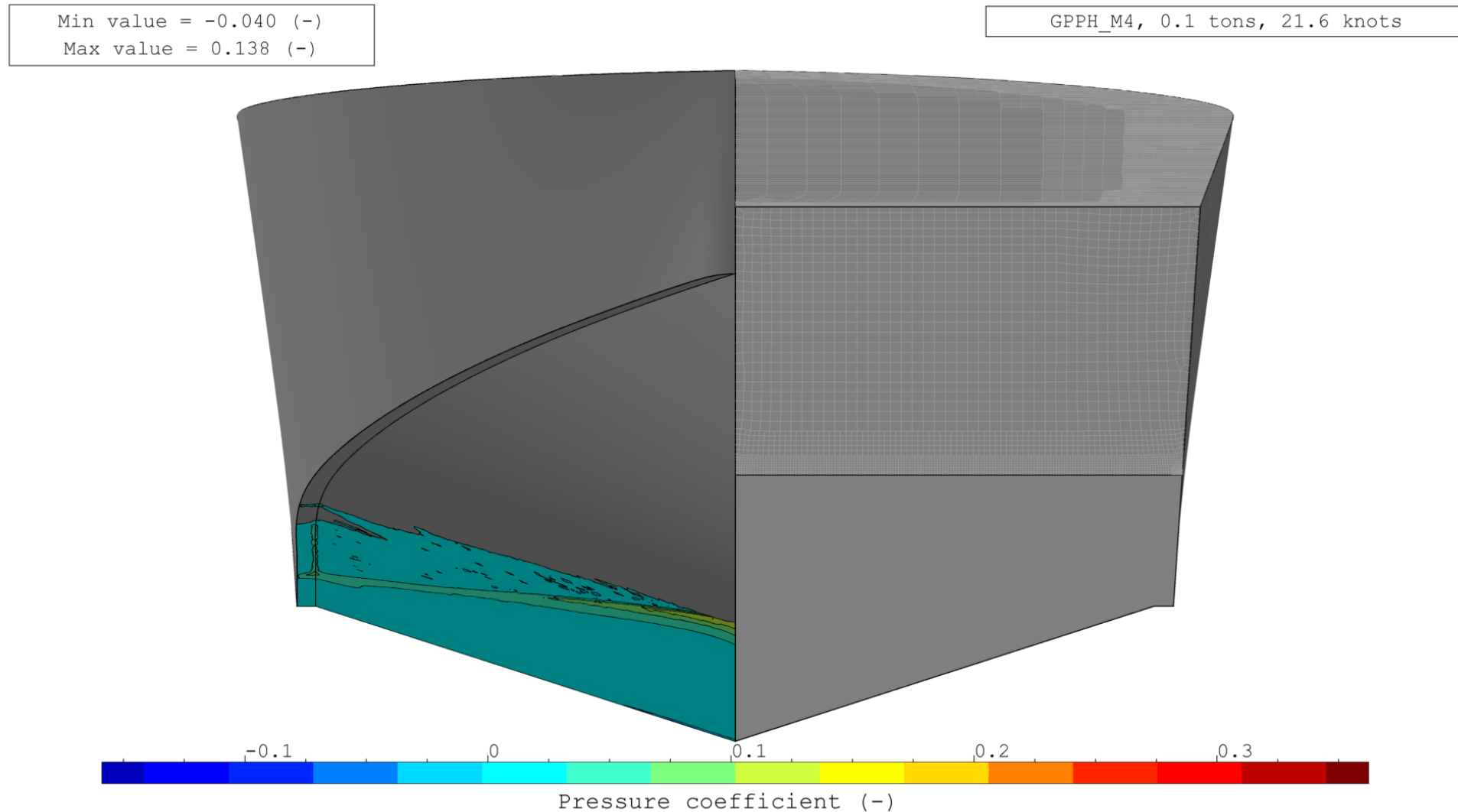
### b. Pressure coefficient : front and rear view



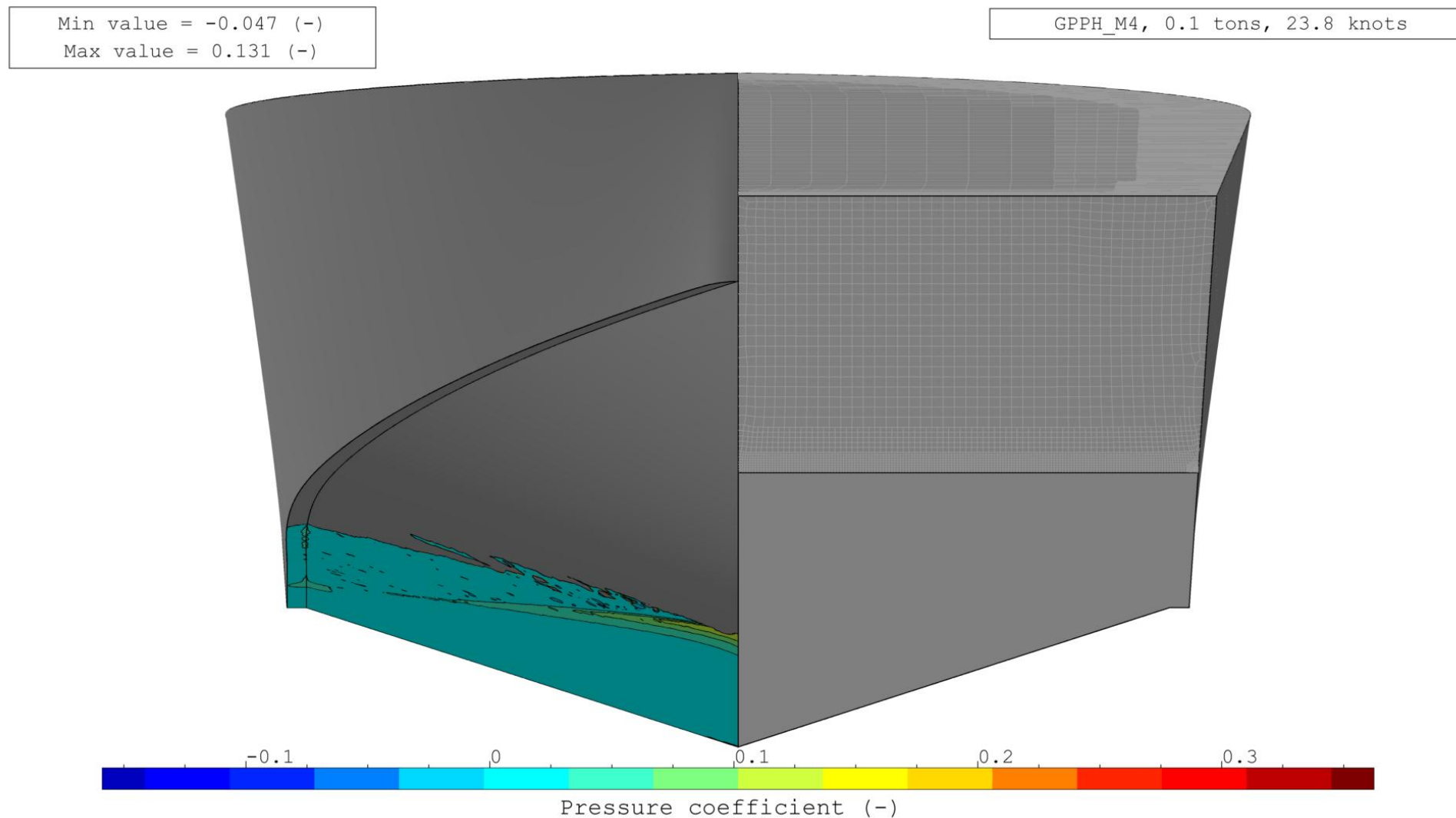
### b. Pressure coefficient : front and rear view



### b. Pressure coefficient : front and rear view



## b. Pressure coefficient : front and rear view

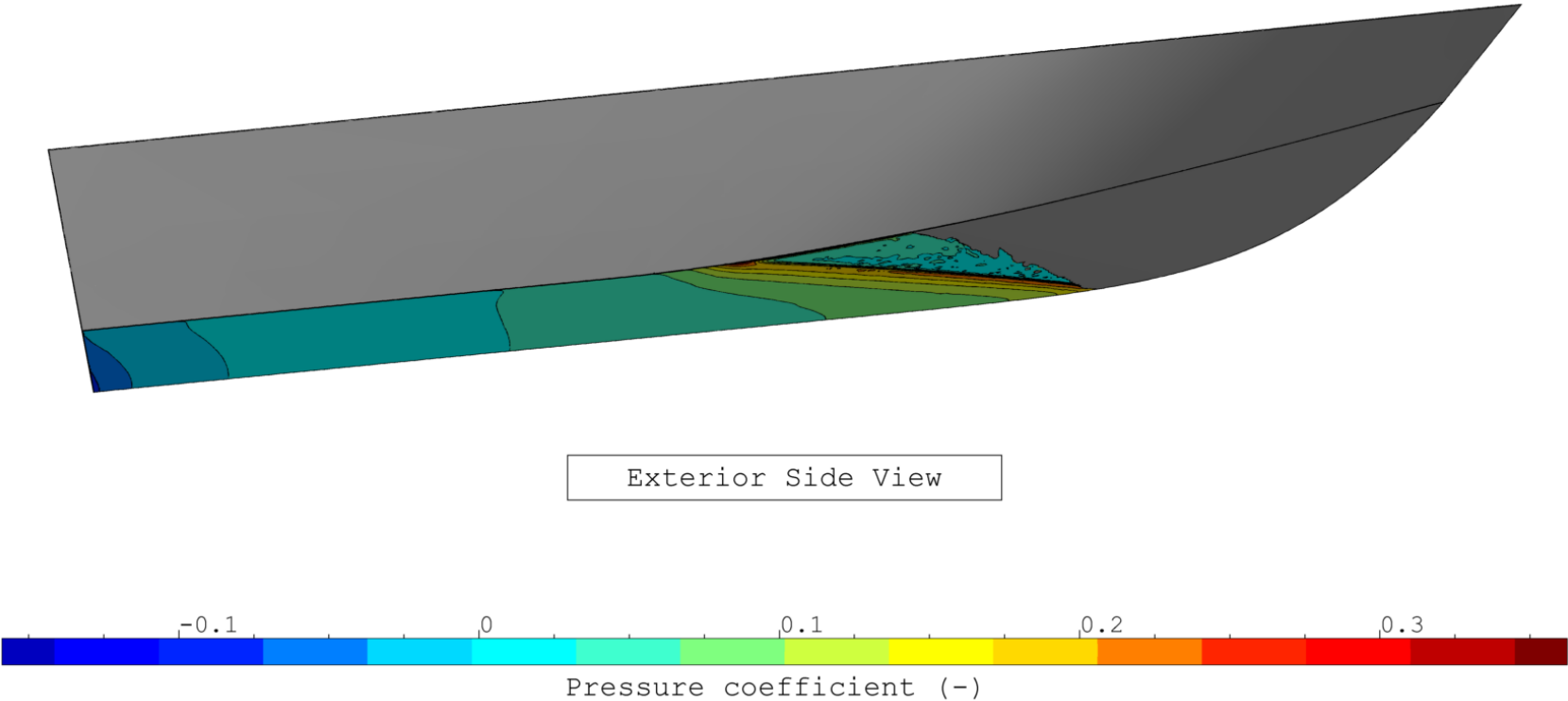




b. Pressure coefficient : side view(s)

Min value = -0.154 (-)  
Max value = 0.362 (-)

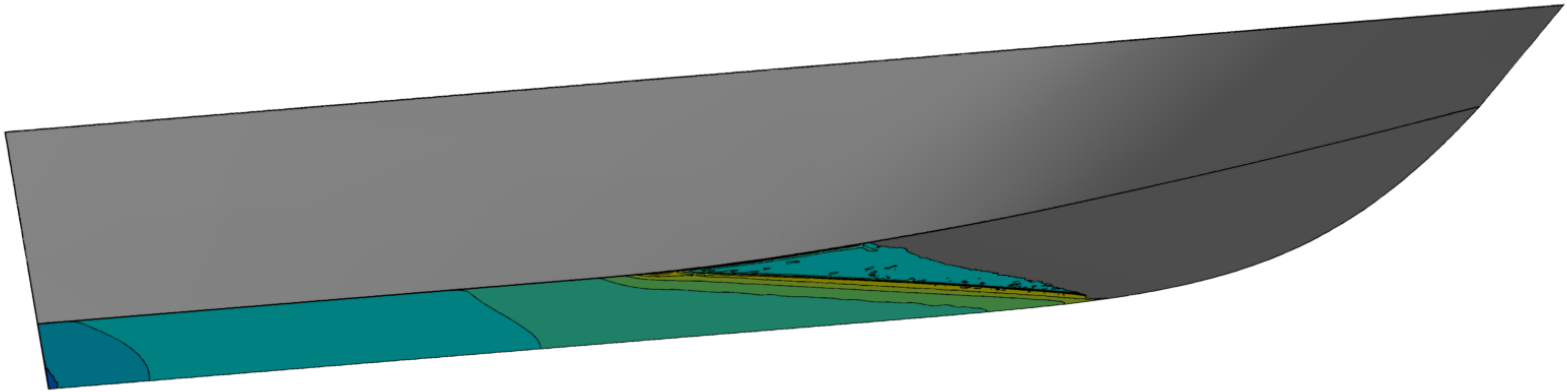
GPPH\_M4, 0.1 tons, 10.8 knots



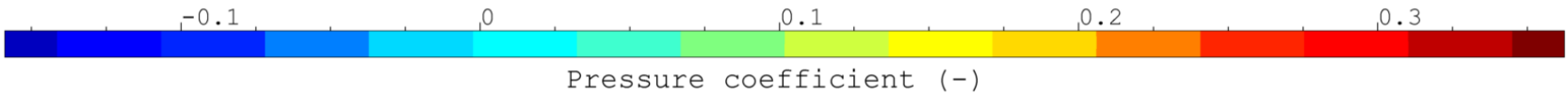
b. Pressure coefficient : side view(s)

Min value = -0.159 (-)  
Max value = 0.265 (-)

GPPH\_M4, 0.1 tons, 13.0 knots



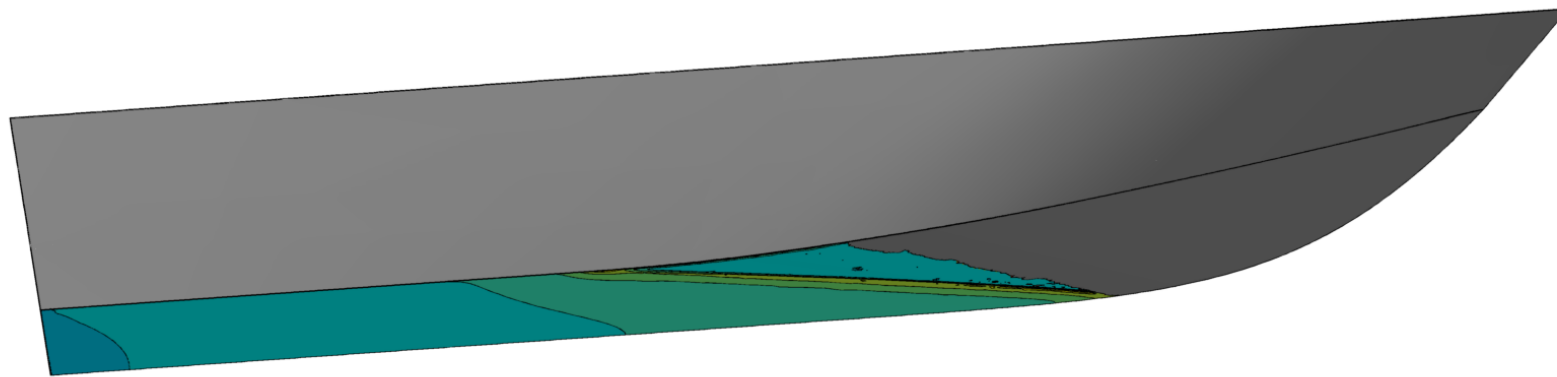
Exterior Side View



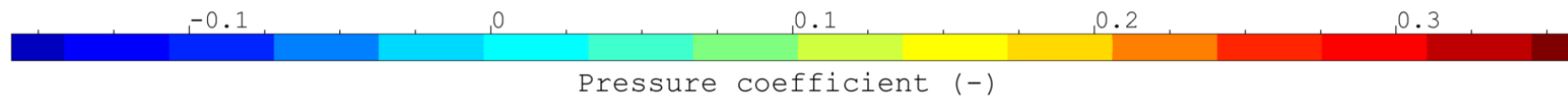
### b. Pressure coefficient : side view(s)

Min value = -0.141 (-)  
Max value = 0.199 (-)

GPPH\_M4, 0.1 tons, 14.8 knots



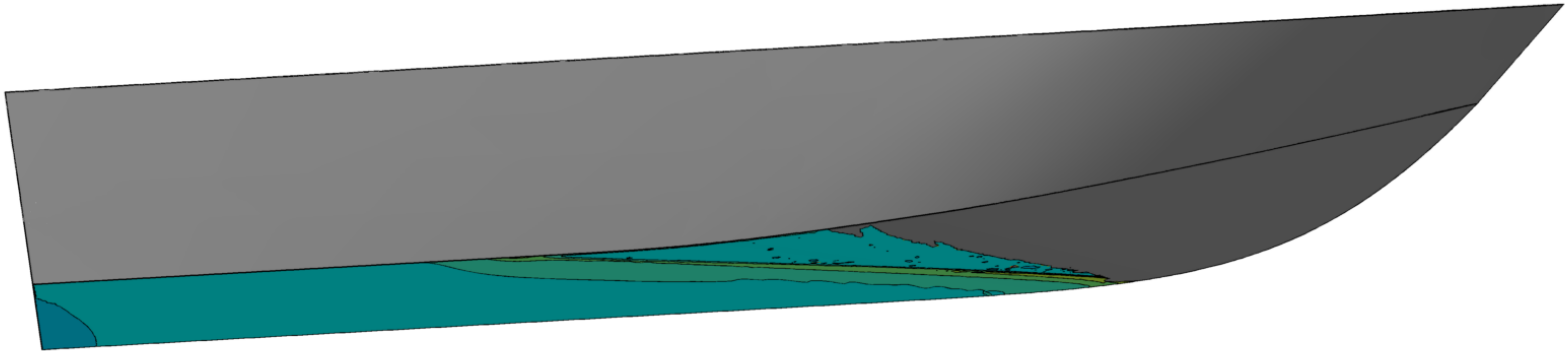
Exterior Side View



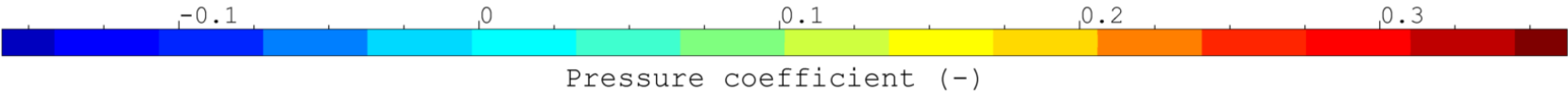
b. Pressure coefficient : side view(s)

Min value = -0.063 (-)  
Max value = 0.130 (-)

GPPH\_M4, 0.1 tons, 17.5 knots



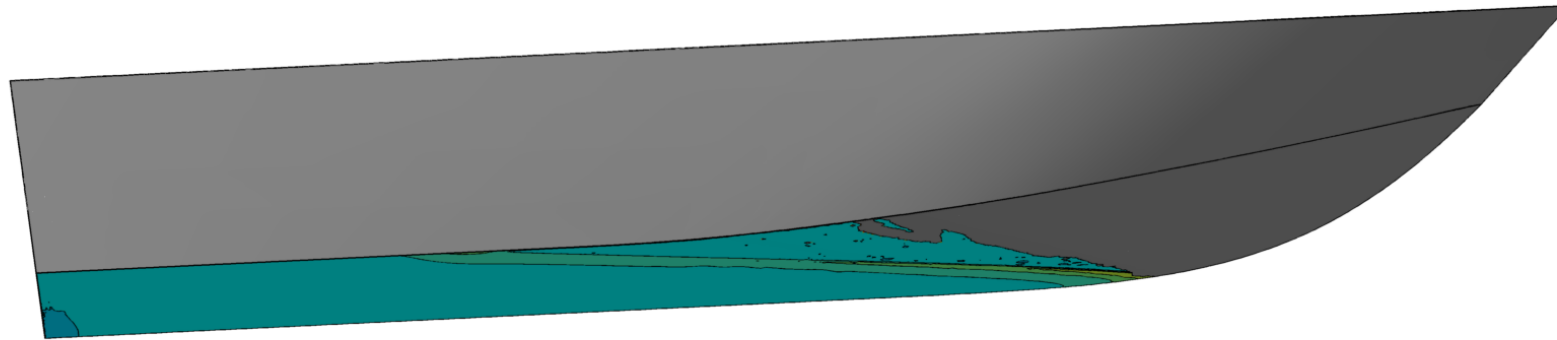
Exterior Side View



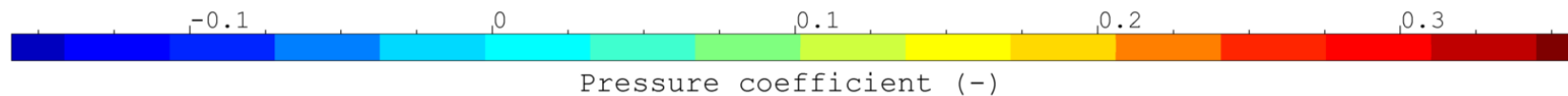
## b. Pressure coefficient : side view(s)

Min value = -0.044 (-)  
Max value = 0.134 (-)

GPPH\_M4, 0.1 tons, 19.5 knots



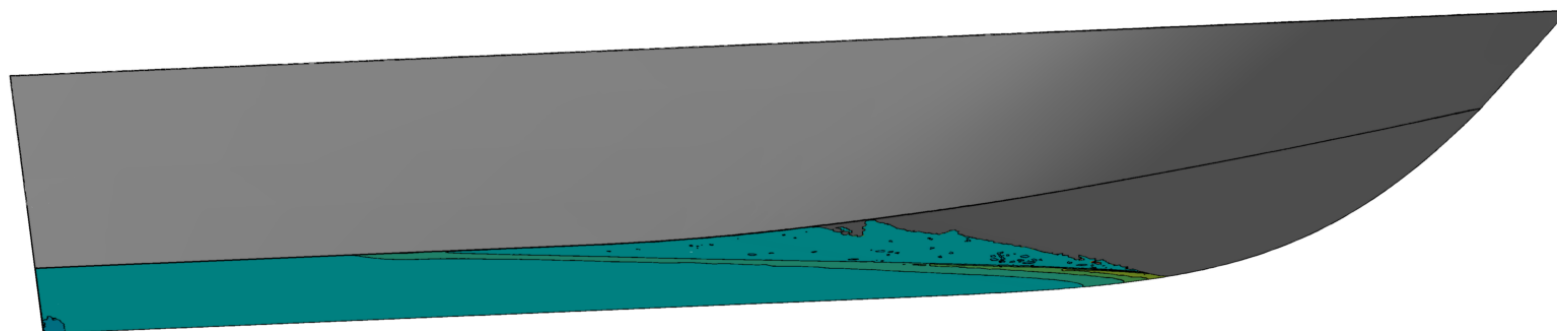
Exterior Side View



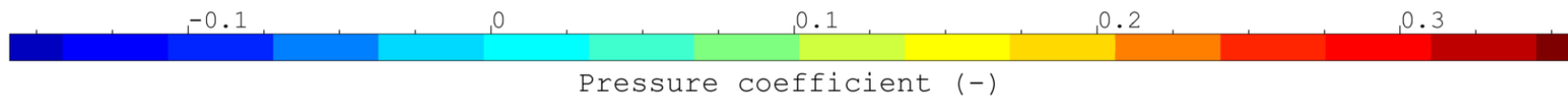
## b. Pressure coefficient : side view(s)

Min value = -0.040 (-)  
Max value = 0.138 (-)

GPPH\_M4, 0.1 tons, 21.6 knots



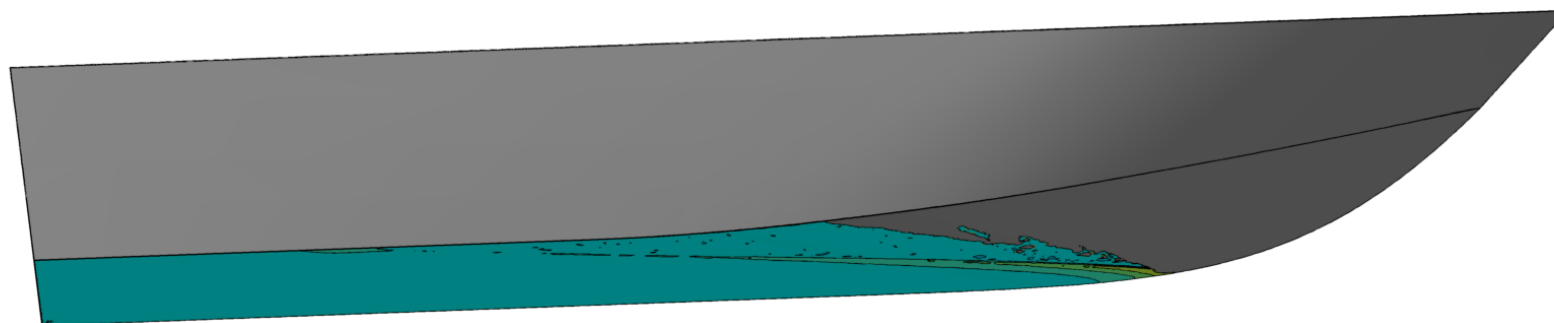
Exterior Side View



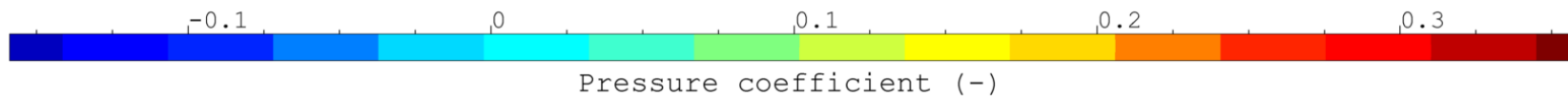
## b. Pressure coefficient : side view(s)

Min value = -0.047 (-)  
Max value = 0.131 (-)

GPPH\_M4, 0.1 tons, 23.8 knots



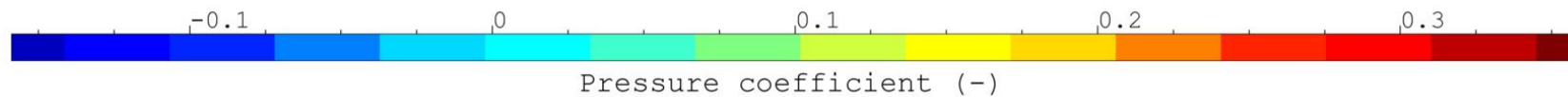
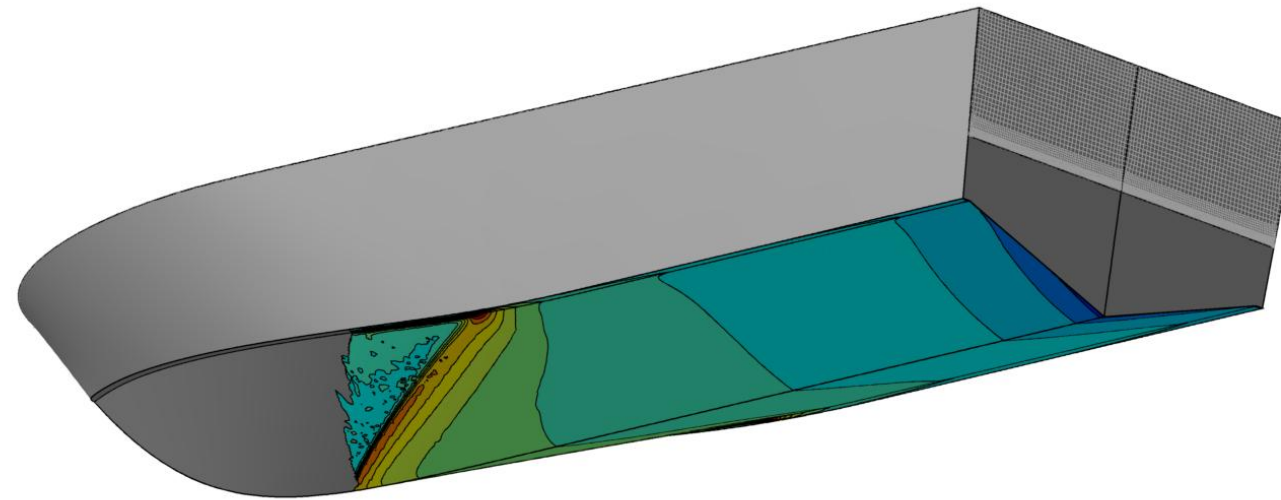
Exterior Side View



### b. Pressure coefficient : $\frac{3}{4}$ rear view

Min value = -0.154 (-)  
Max value = 0.362 (-)

GPPH\_M4, 0.1 tons, 10.8 knots

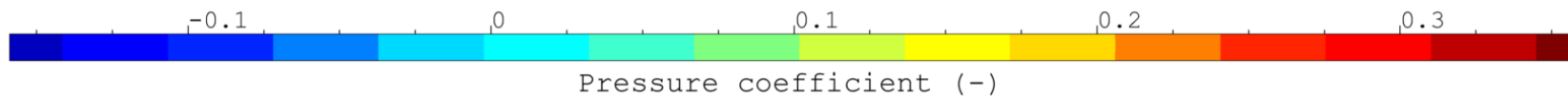
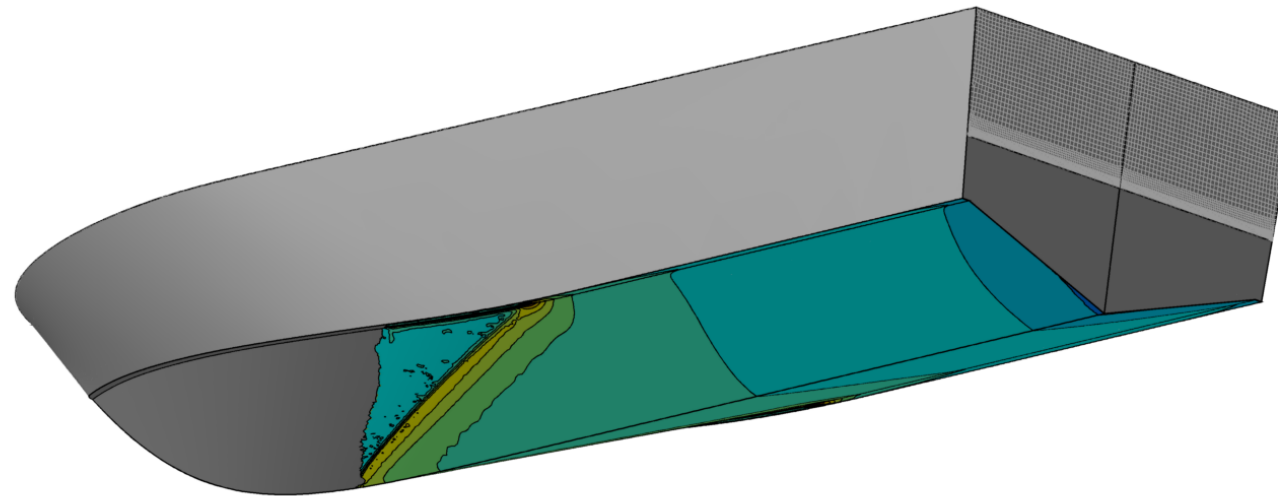




### b. Pressure coefficient : $\frac{3}{4}$ rear view

Min value = -0.159 (-)  
Max value = 0.265 (-)

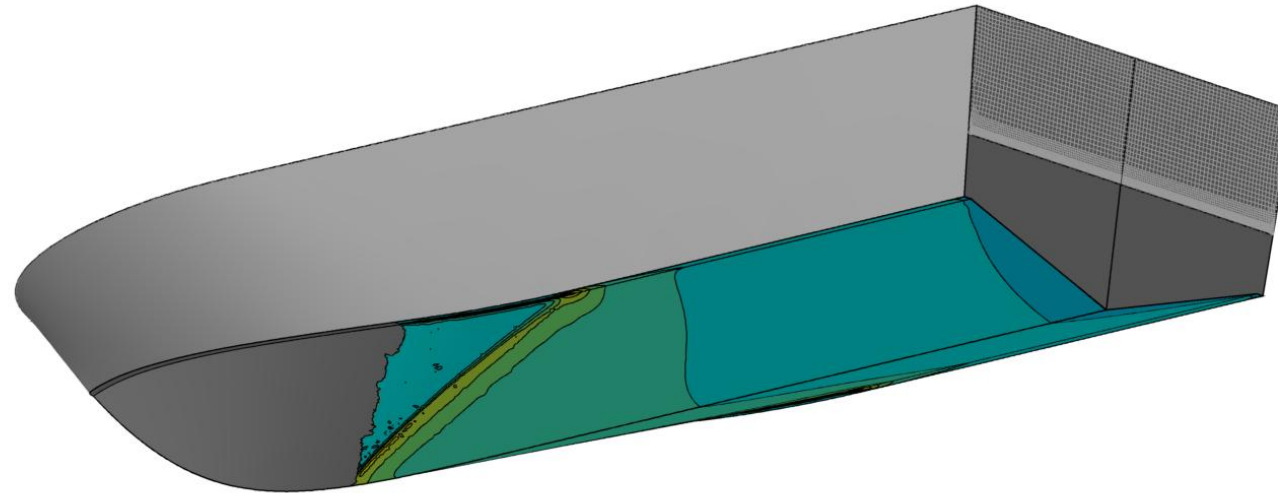
GPPH\_M4, 0.1 tons, 13.0 knots



### b. Pressure coefficient : $\frac{3}{4}$ rear view

Min value = -0.141 (-)  
Max value = 0.199 (-)

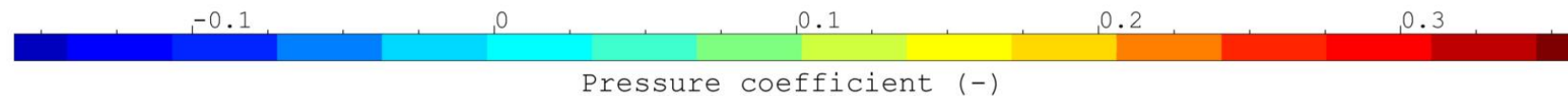
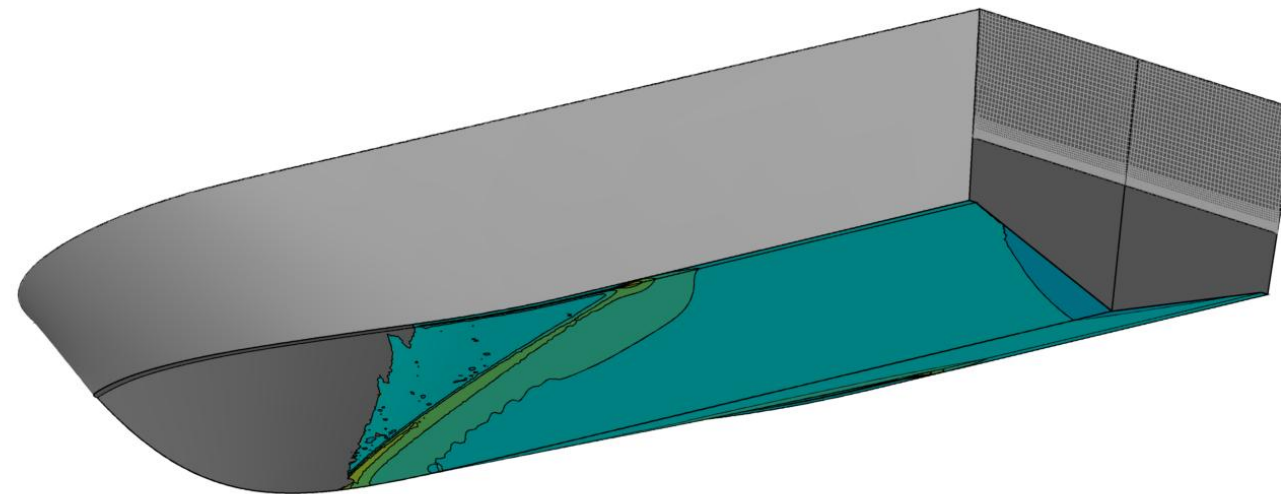
GPPH\_M4, 0.1 tons, 14.8 knots



### b. Pressure coefficient : $\frac{3}{4}$ rear view

Min value = -0.063 (-)  
Max value = 0.130 (-)

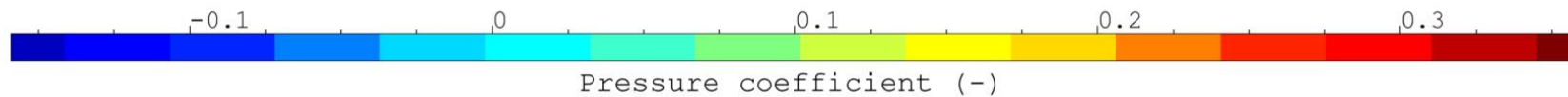
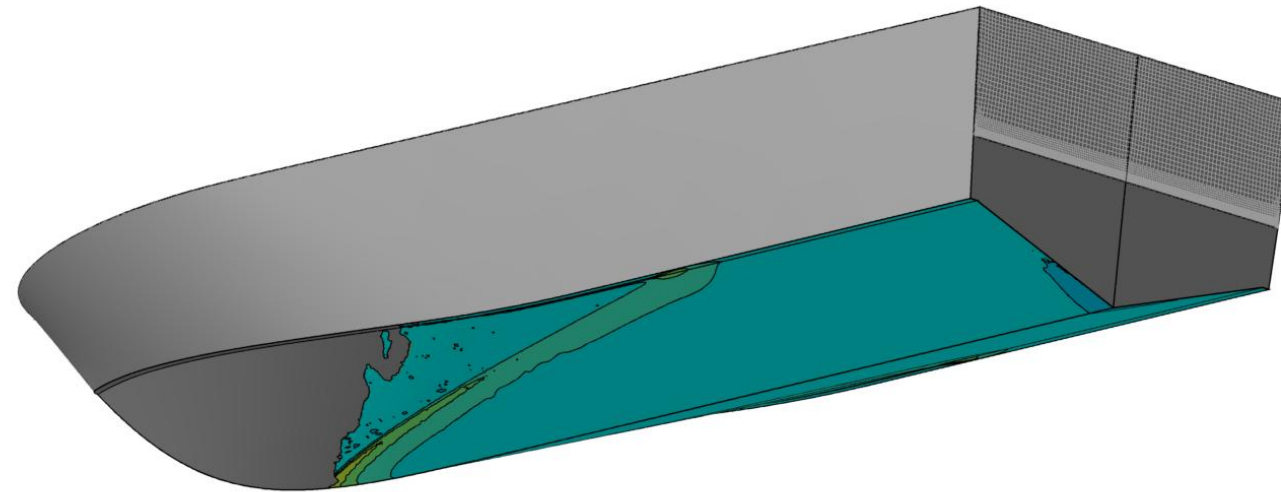
GPPH\_M4, 0.1 tons, 17.5 knots



### b. Pressure coefficient : $\frac{3}{4}$ rear view

Min value = -0.044 (-)  
Max value = 0.134 (-)

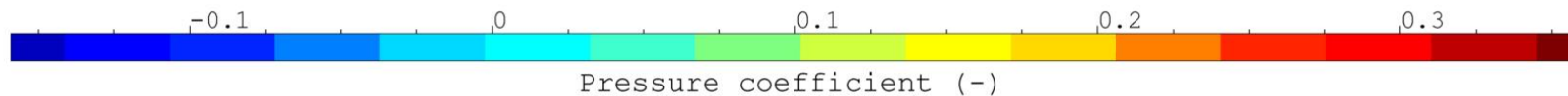
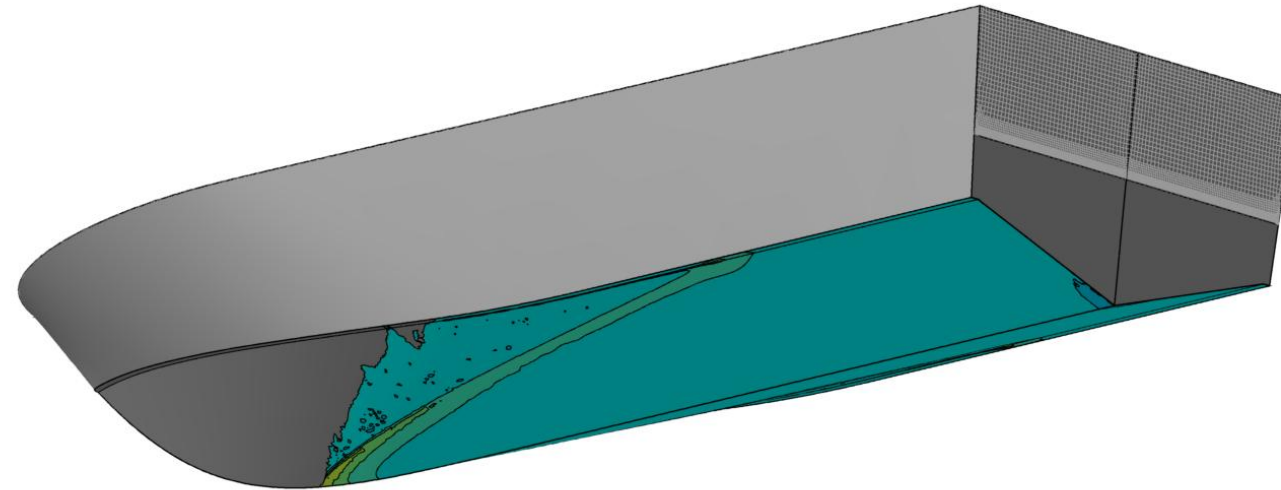
GPPH\_M4, 0.1 tons, 19.5 knots



### b. Pressure coefficient : $\frac{3}{4}$ rear view

Min value = -0.040 (-)  
Max value = 0.138 (-)

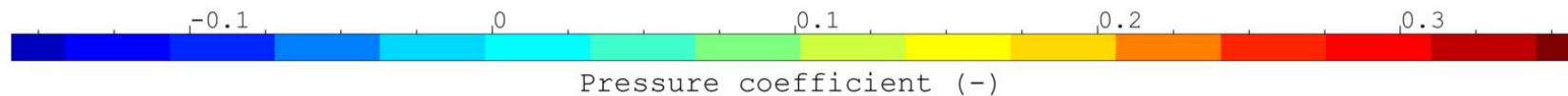
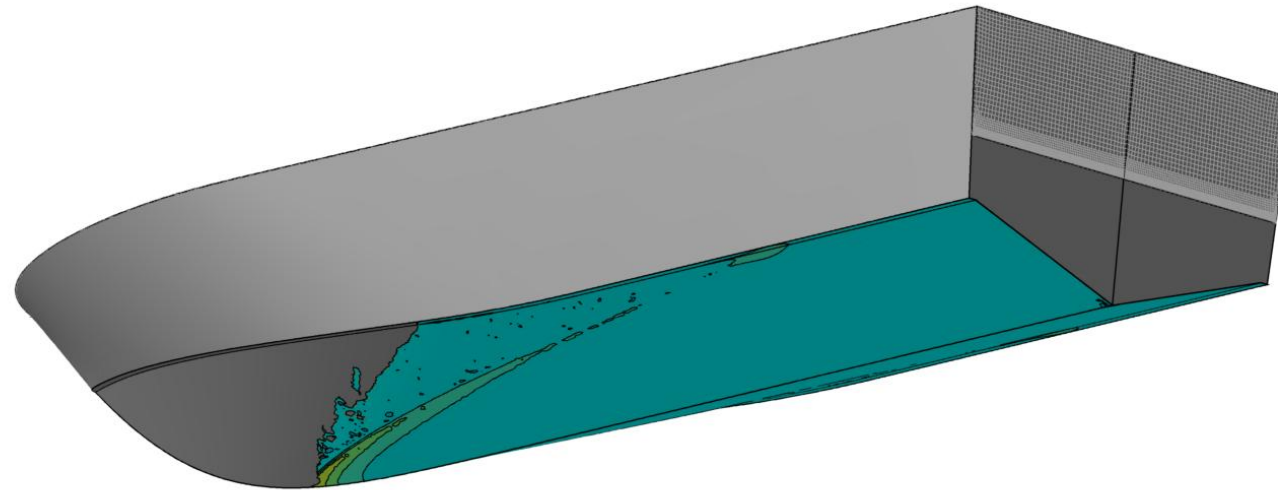
GPPH\_M4, 0.1 tons, 21.6 knots



### b. Pressure coefficient : $\frac{3}{4}$ rear view

Min value = -0.047 (-)  
Max value = 0.131 (-)

GPPH\_M4, 0.1 tons, 23.8 knots

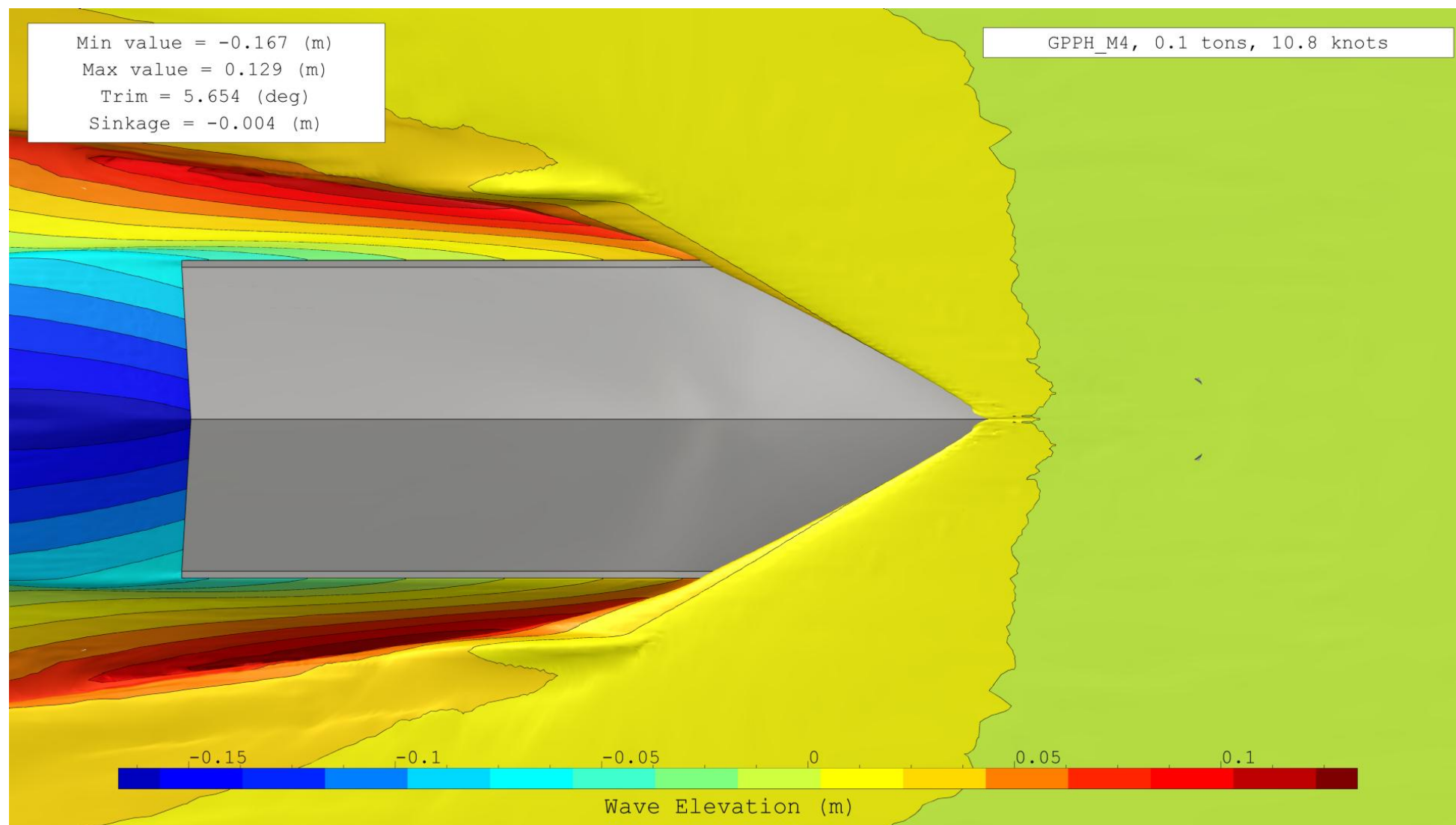




## 6. Visuals

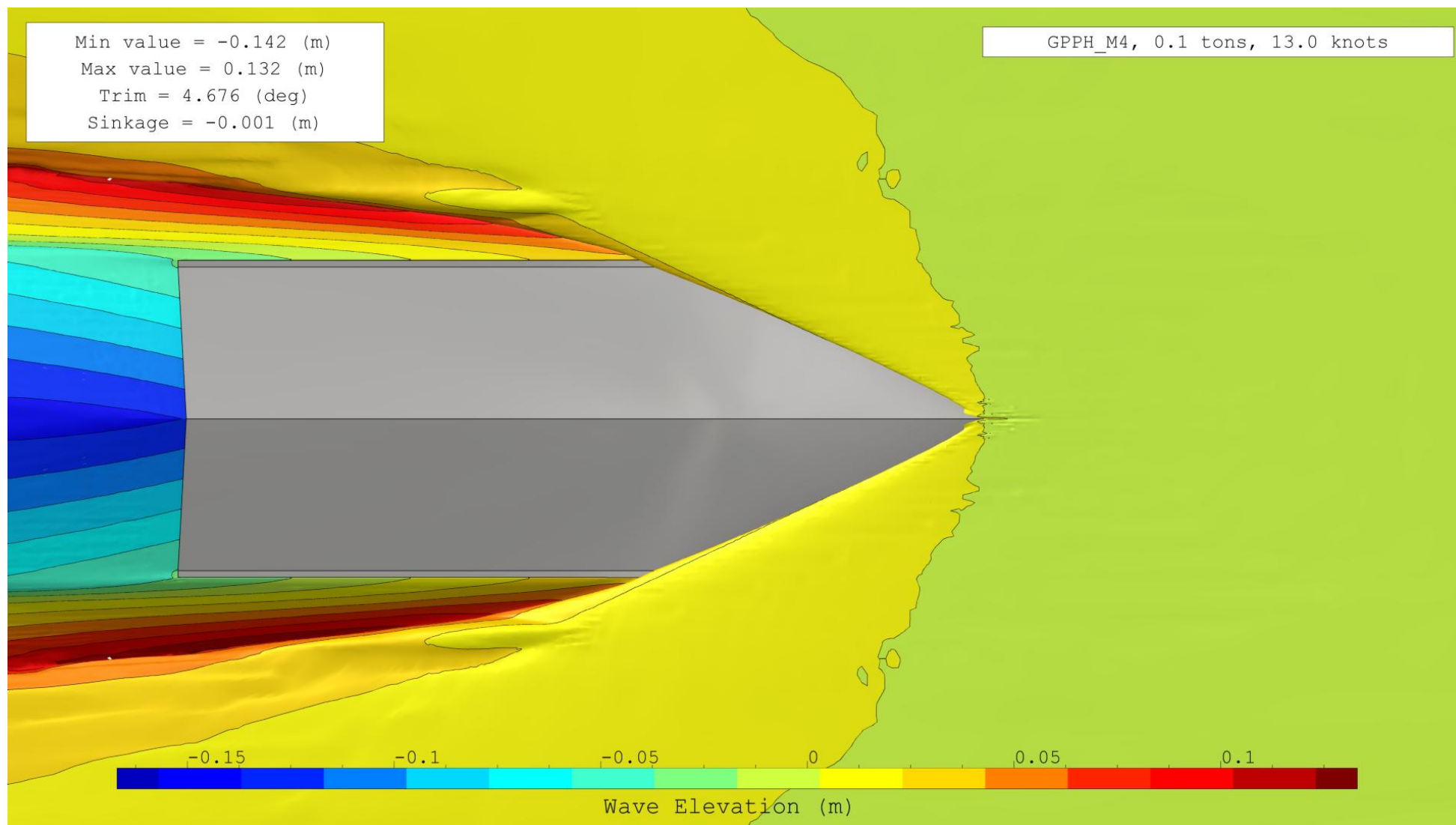
- a. Mass fraction
- b. Pressure coefficient
- c. Free surface
- d. Streamlines
  - 1. Surfacic
  - 2. Volumic

## c. Free surface : near wall (common scale)

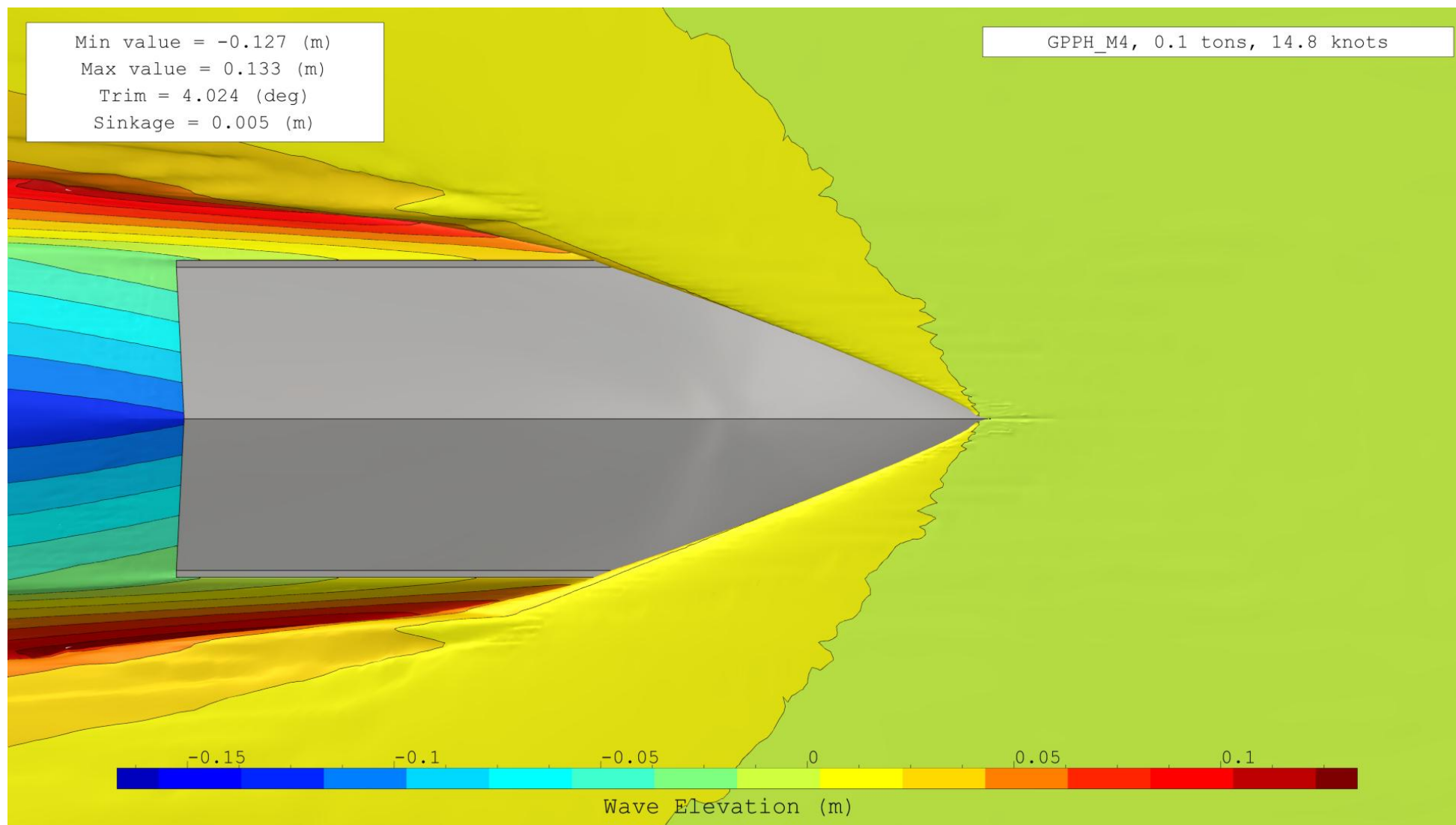




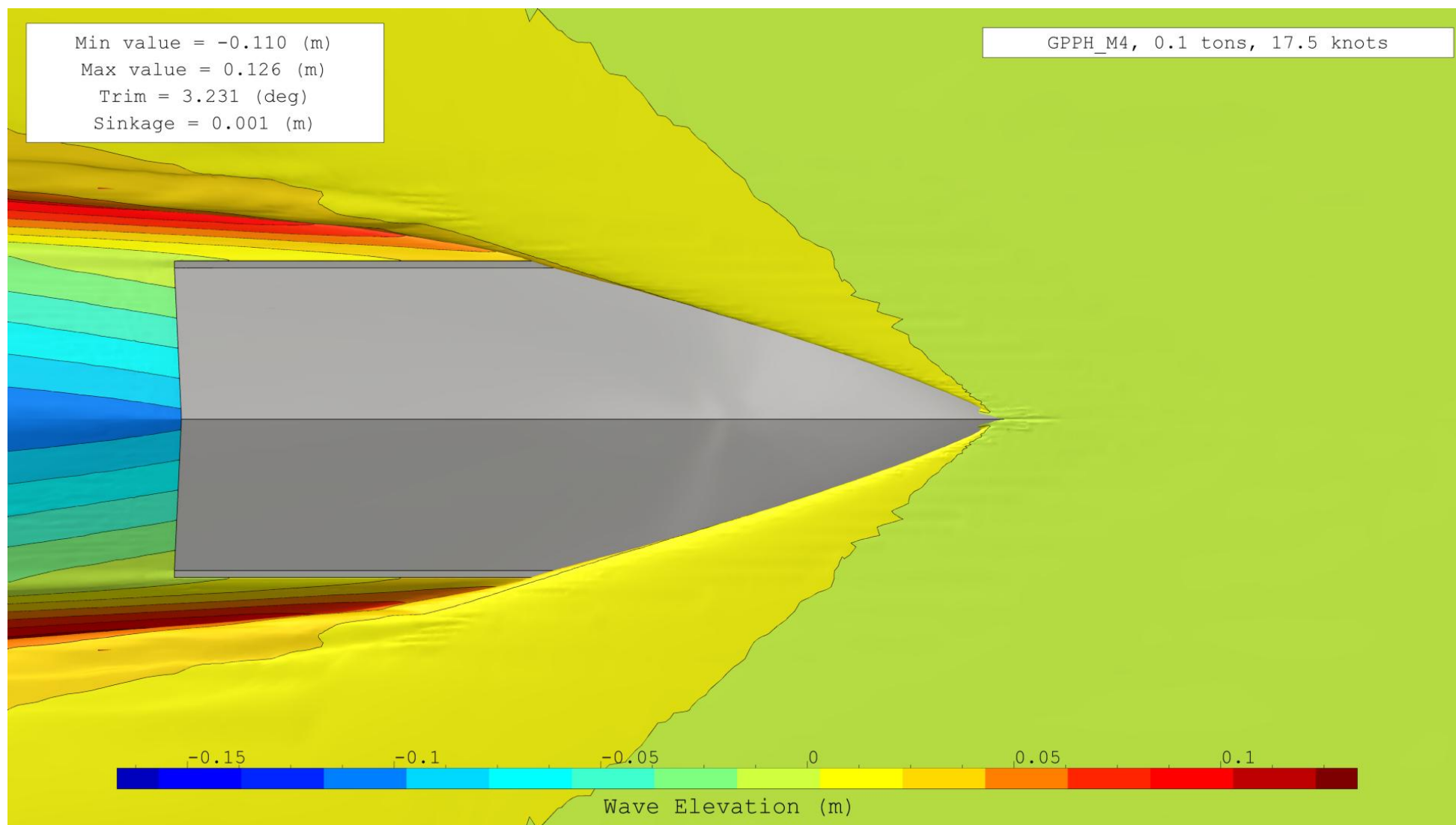
## c. Free surface : near wall (common scale)



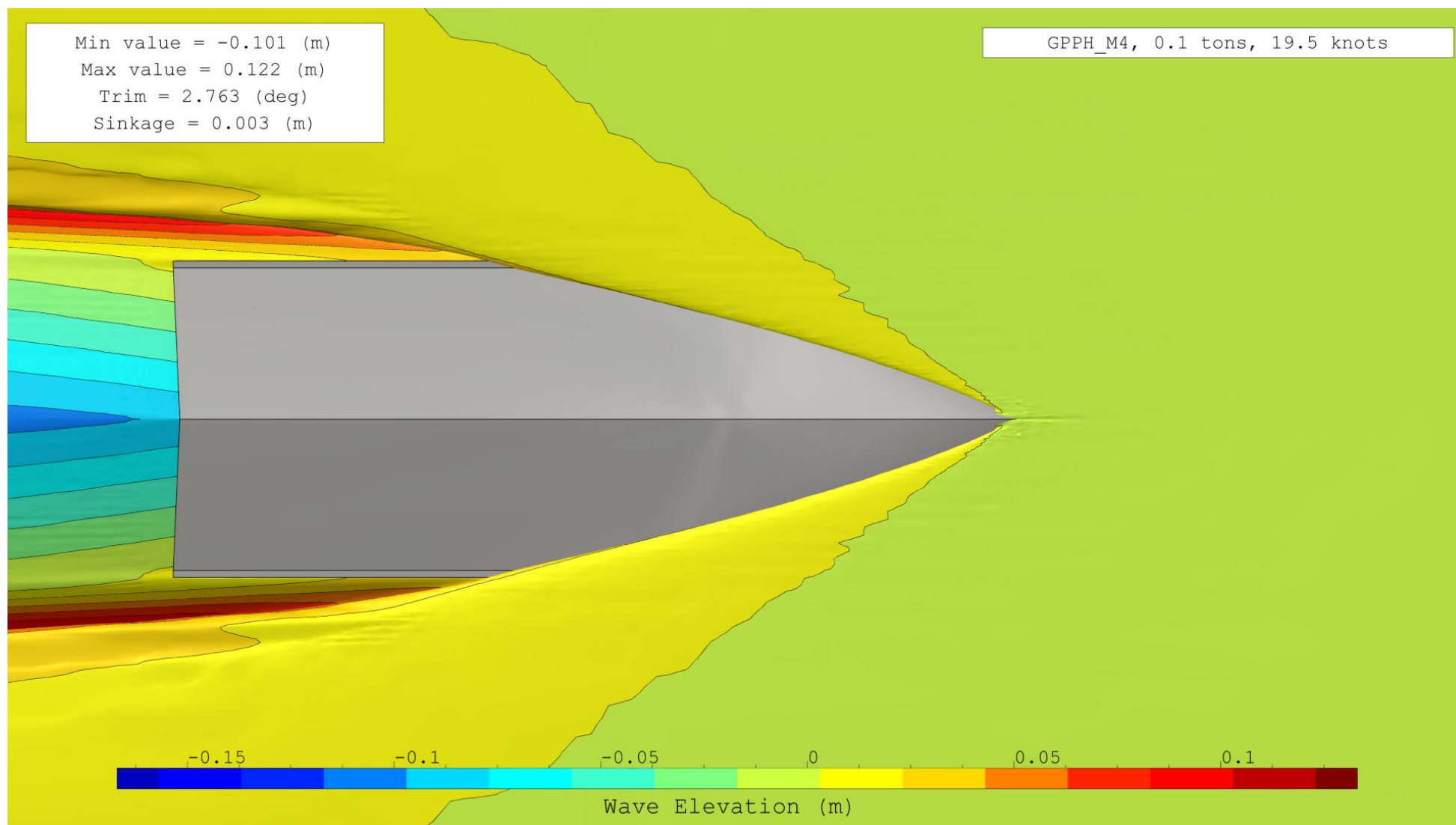
## c. Free surface : near wall (common scale)



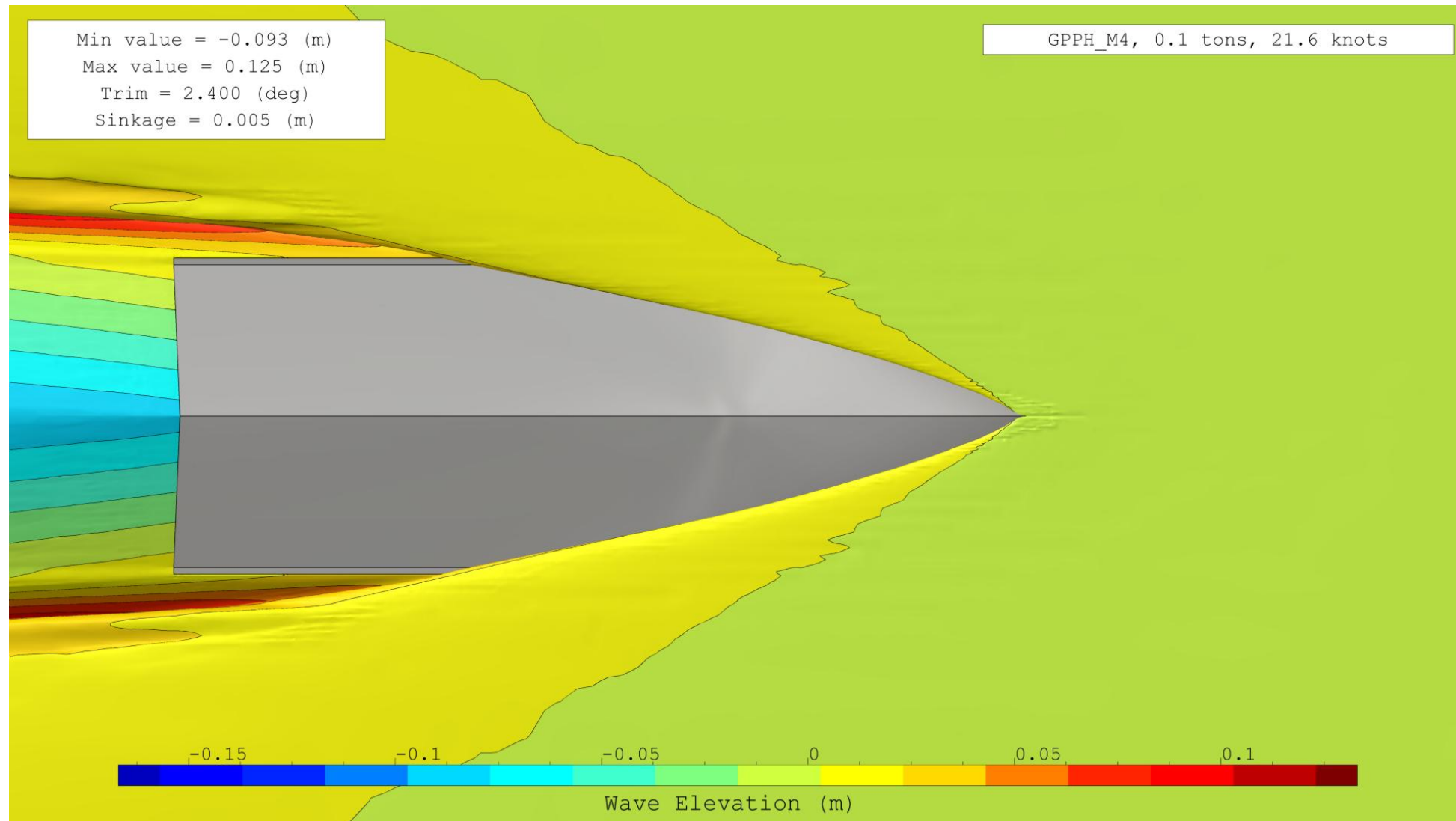
## c. Free surface : near wall (common scale)



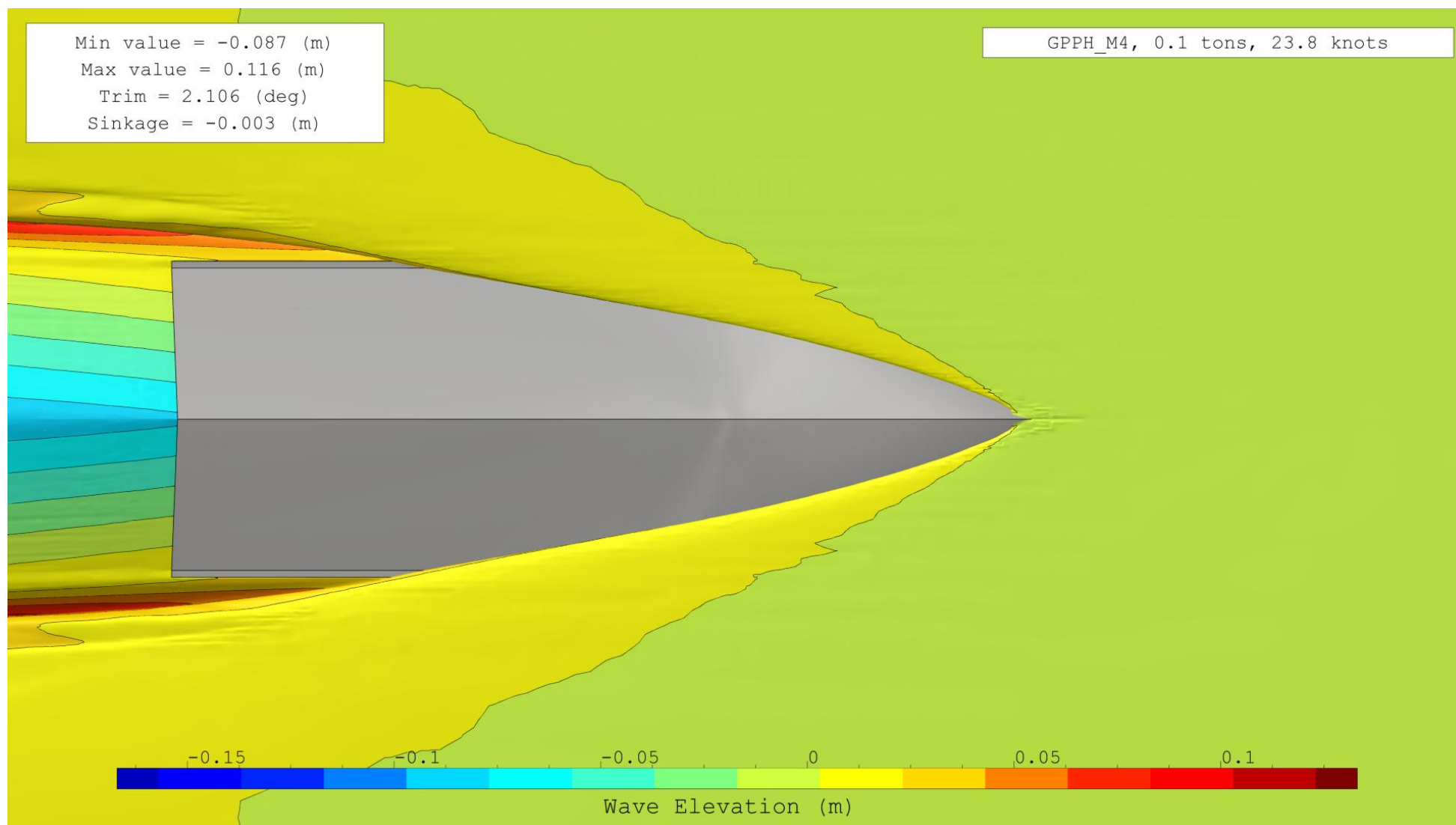
## c. Free surface : near wall (common scale)



## c. Free surface : near wall (common scale)

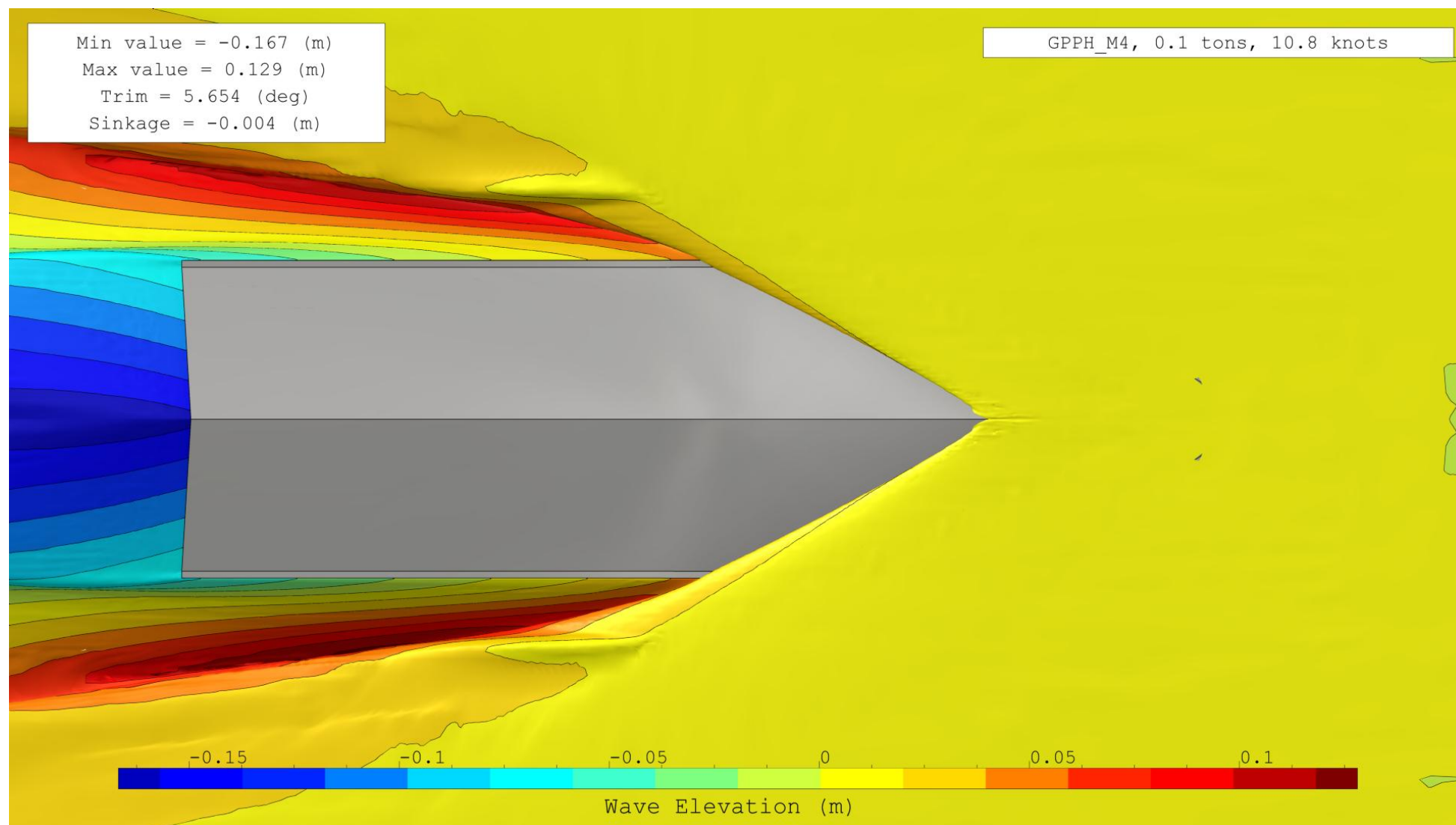


## c. Free surface : near wall (common scale)

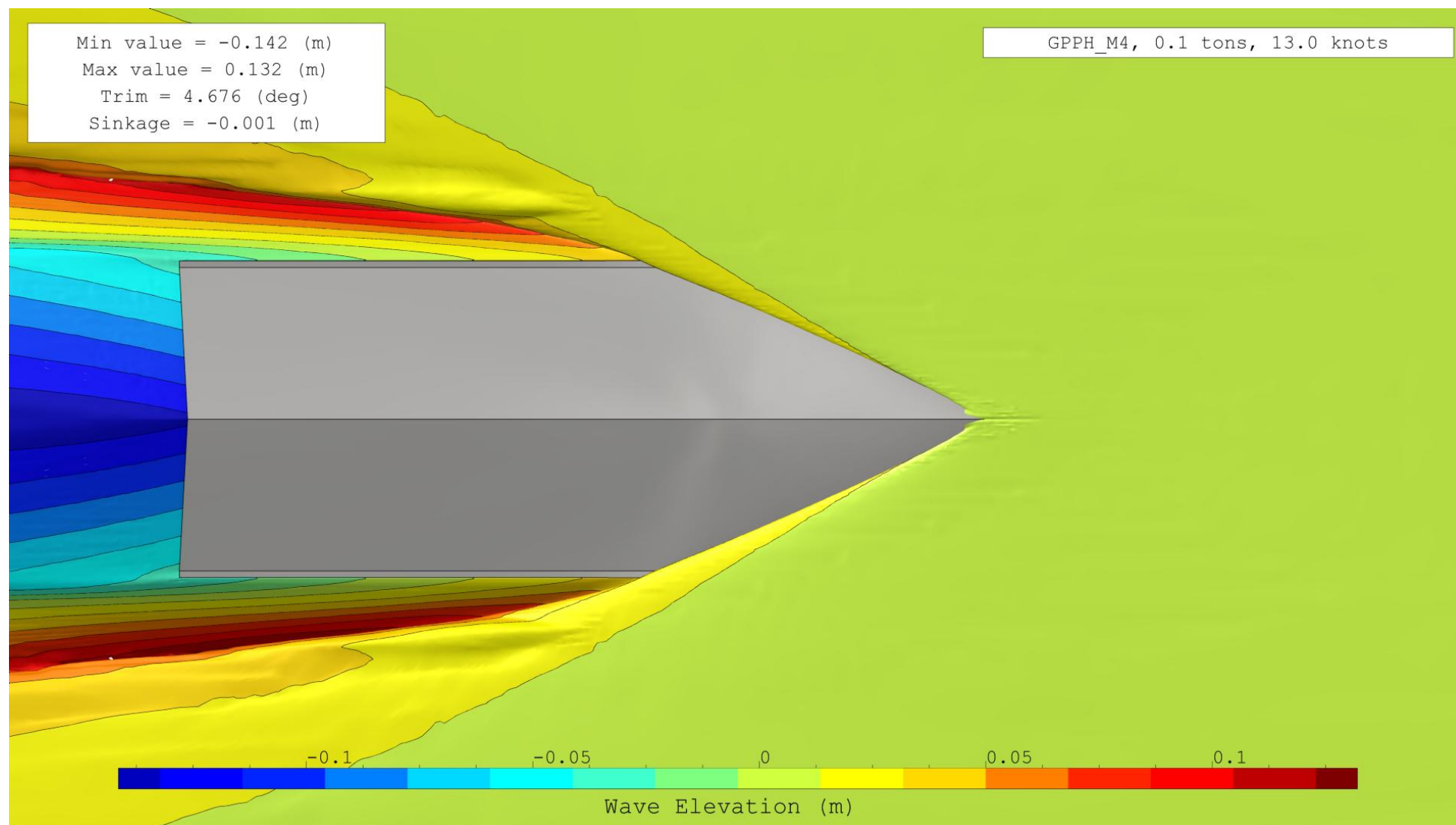




## c. Free surface : near wall (independant scale)

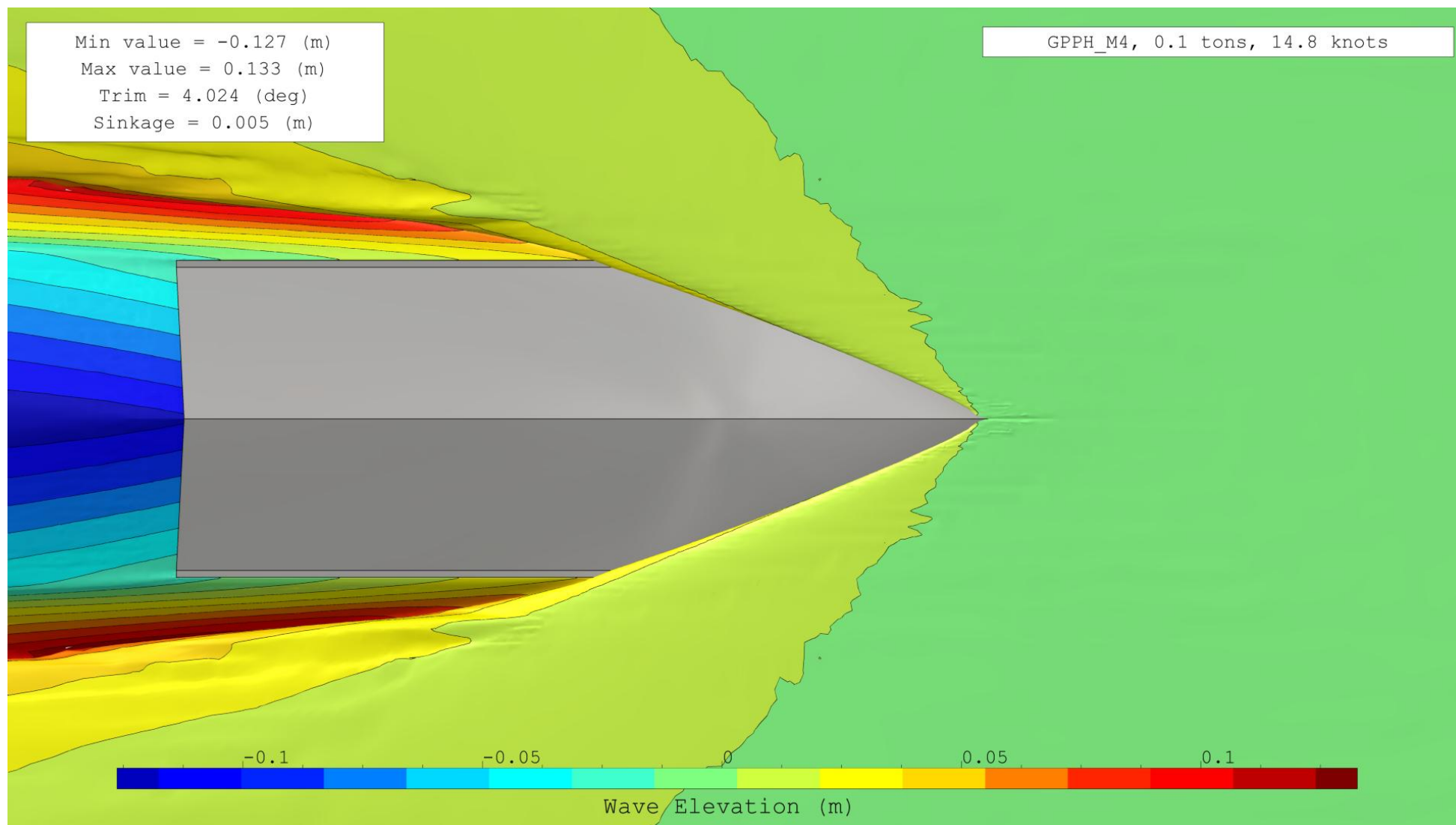


## c. Free surface : near wall (independant scale)

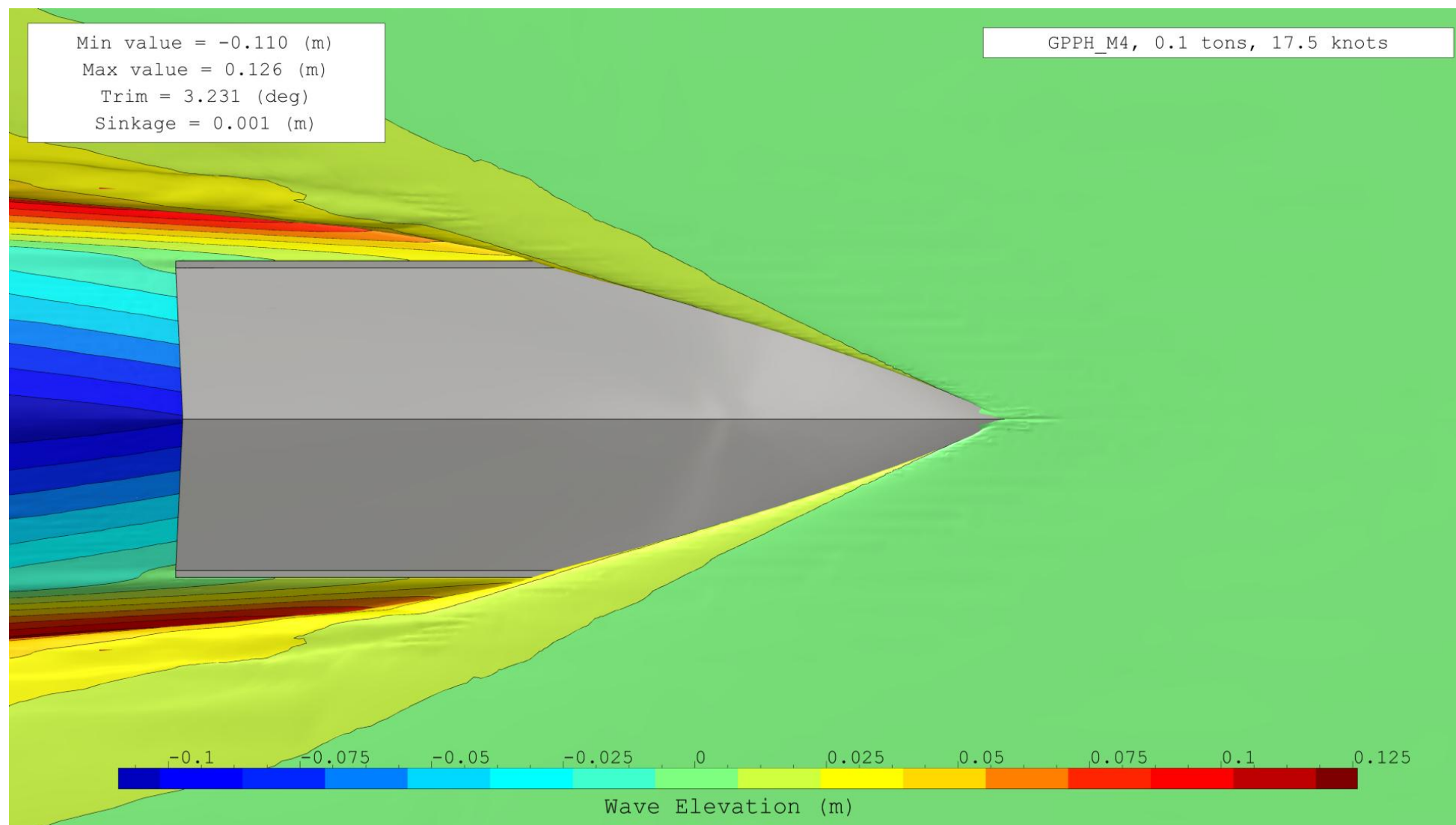




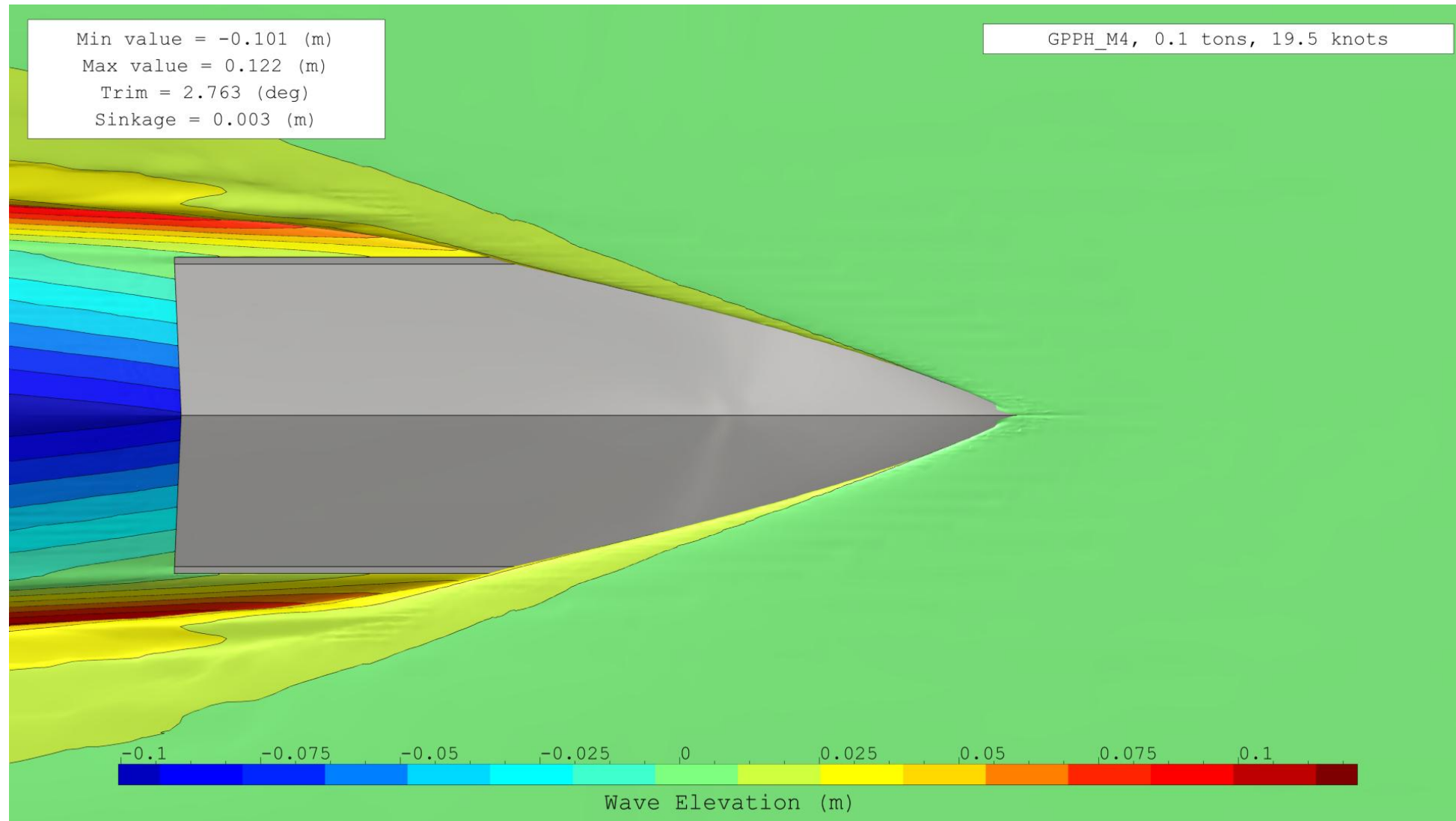
## c. Free surface : near wall (independant scale)



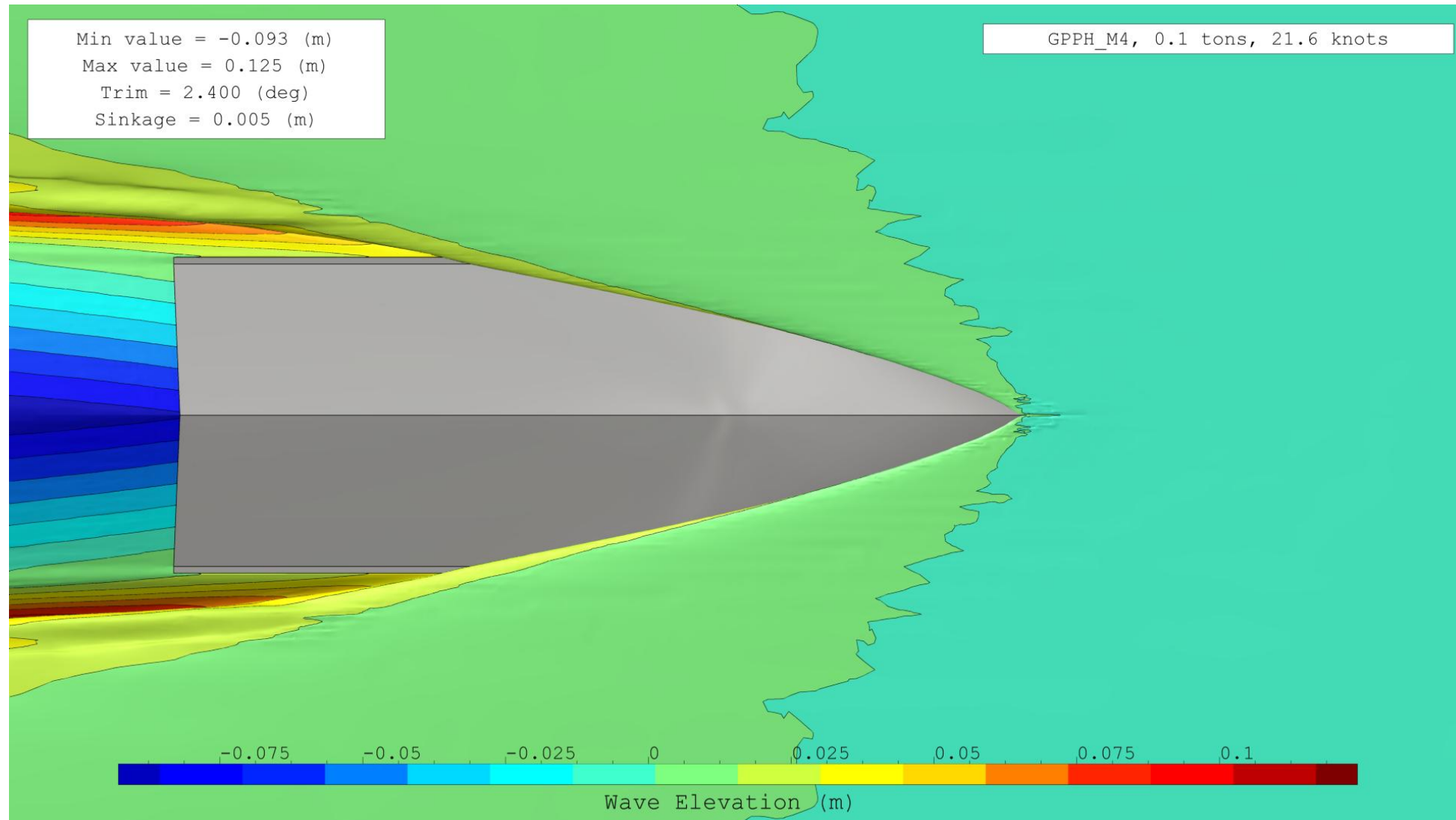
## c. Free surface : near wall (independant scale)



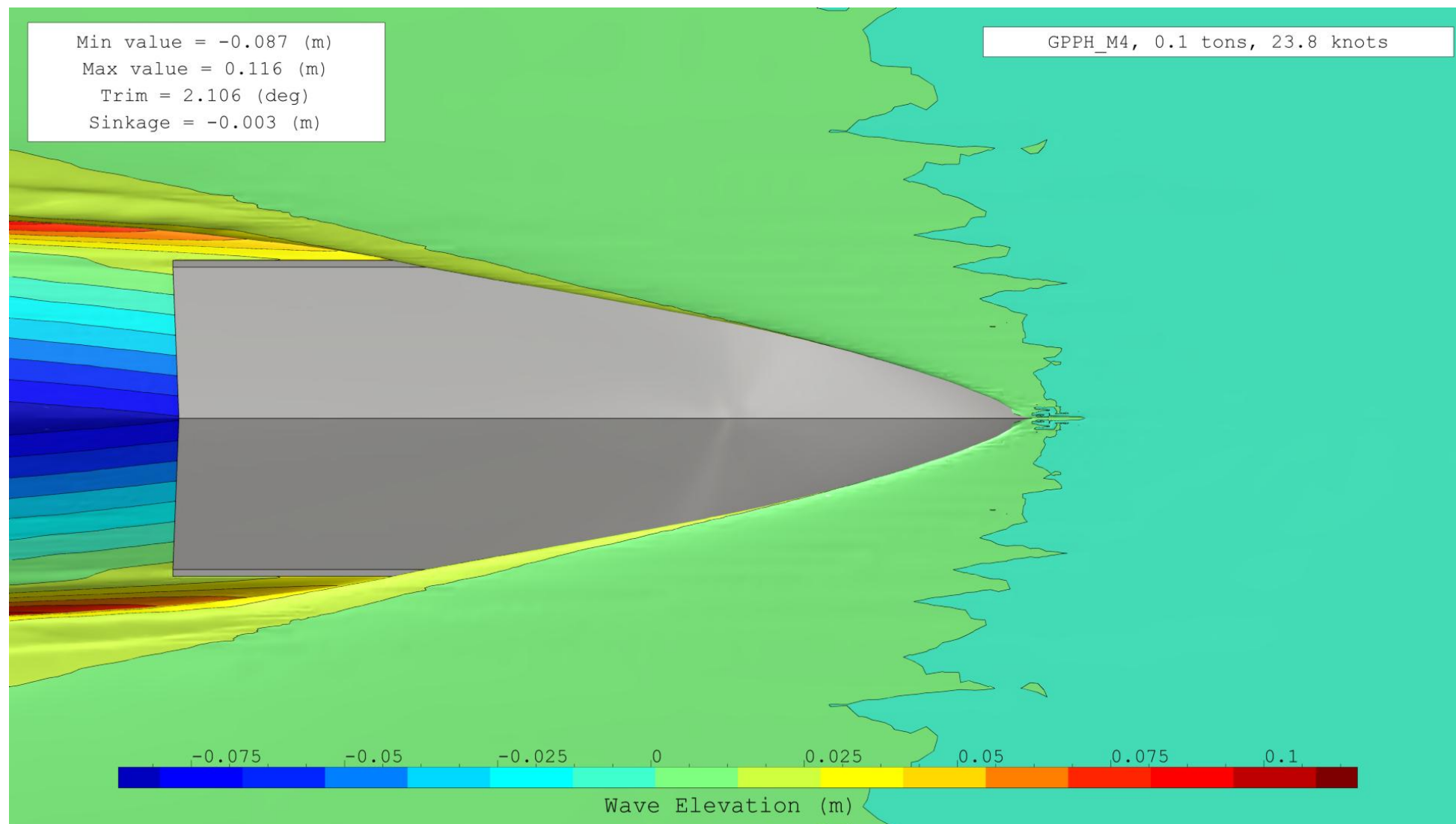
## c. Free surface : near wall (independant scale)



## c. Free surface : near wall (independant scale)

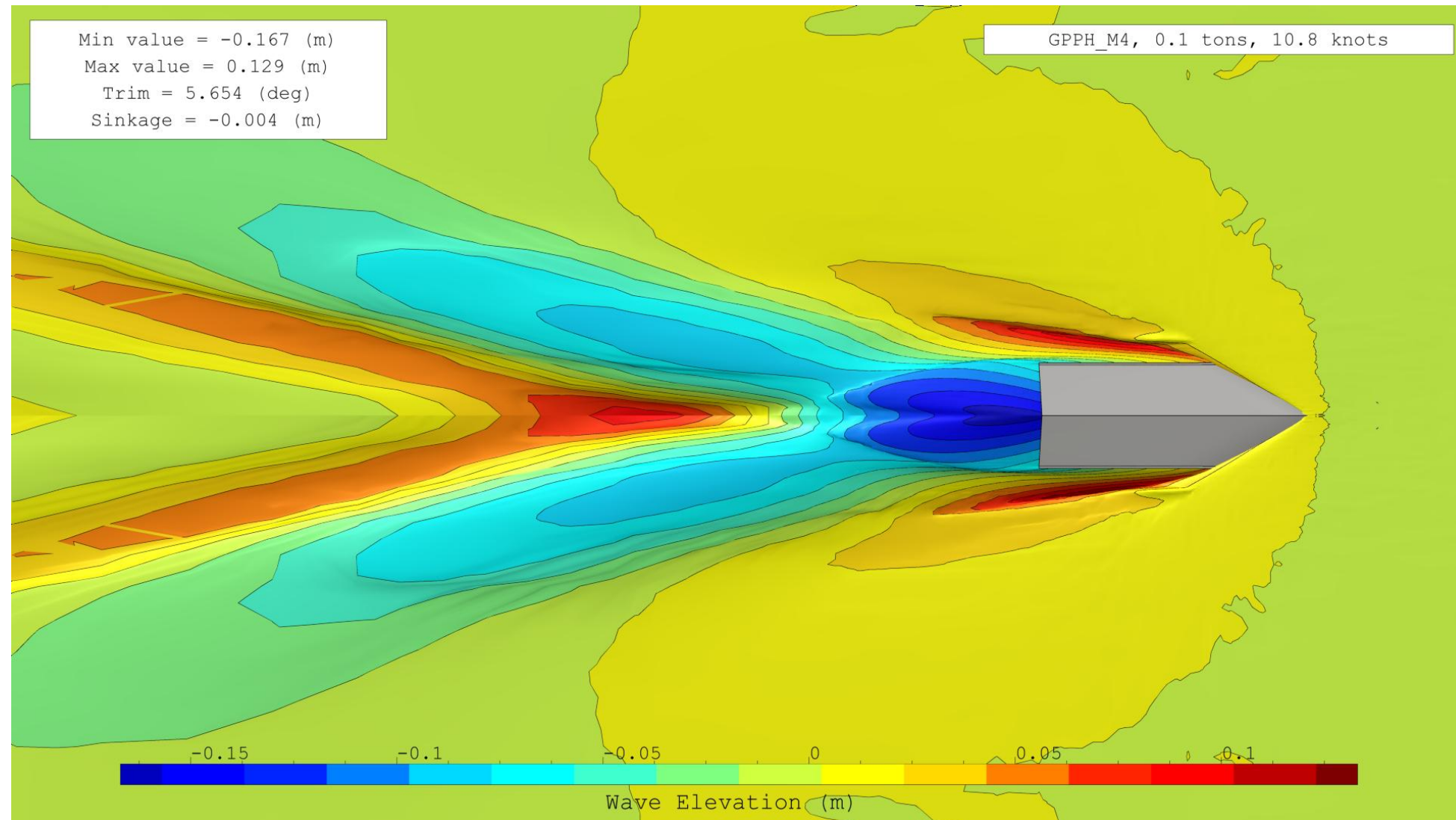


## c. Free surface : near wall (independant scale)

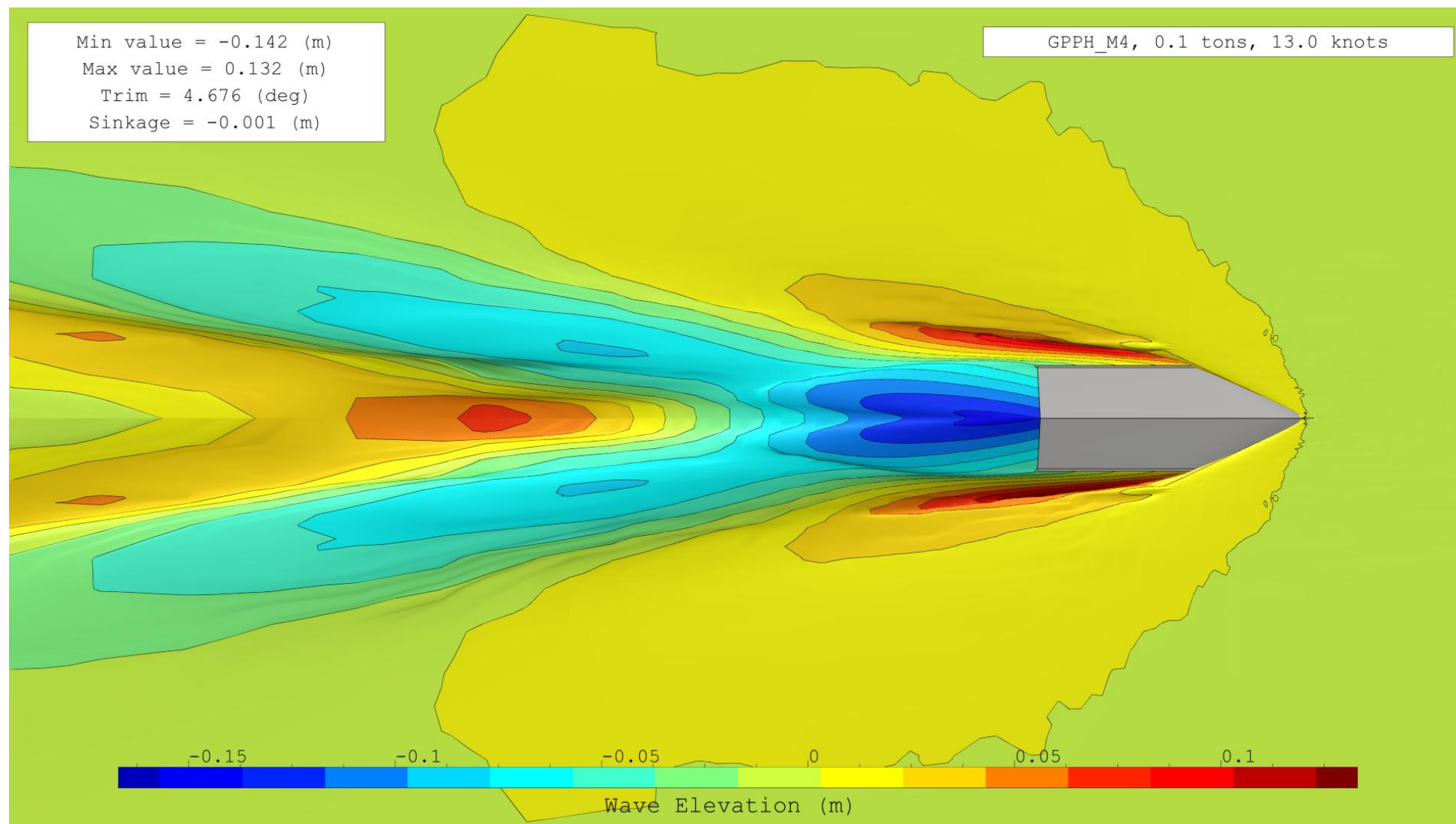




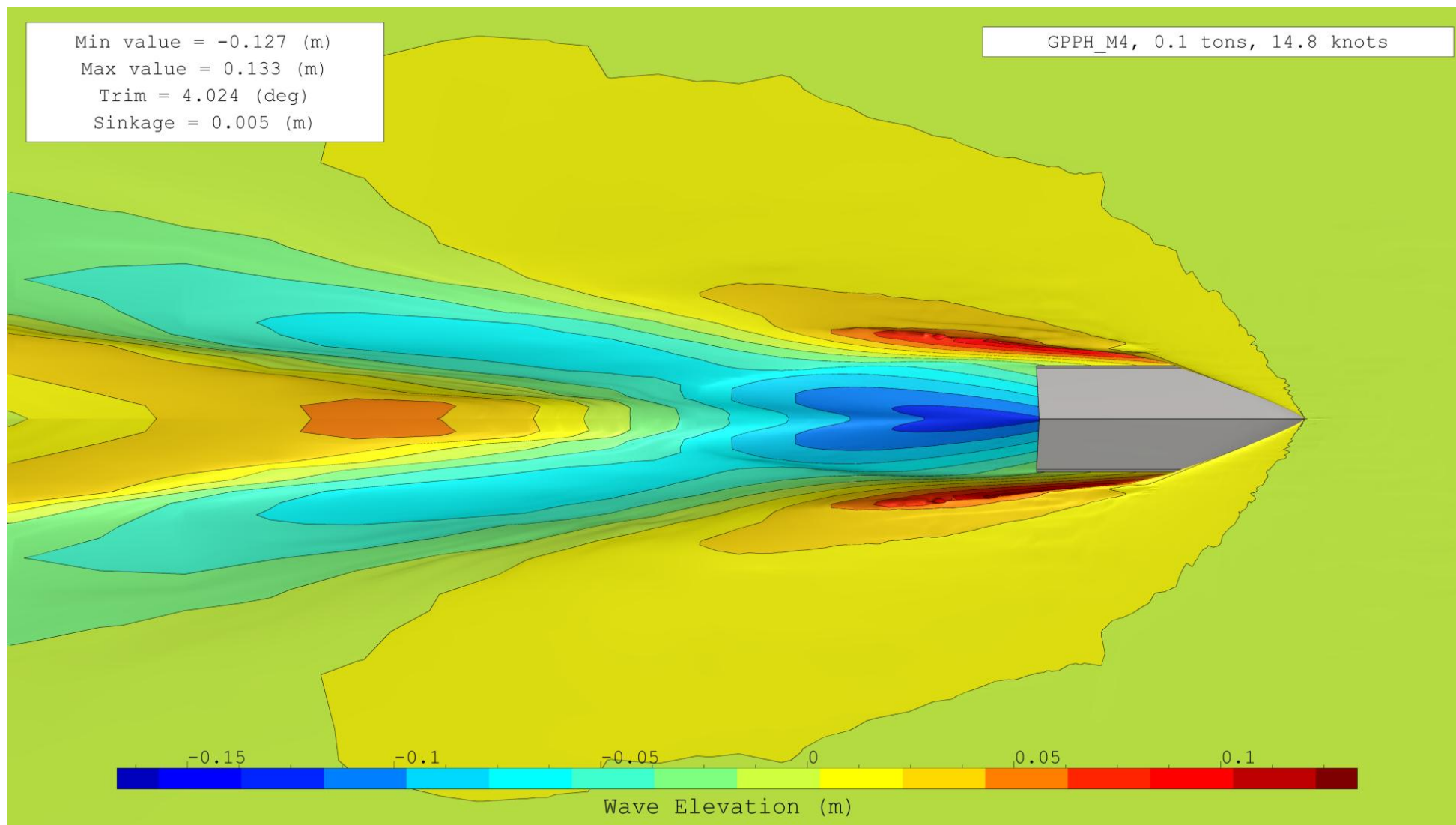
## c. Free surface : far field (common scale)



## c. Free surface : far field (common scale)

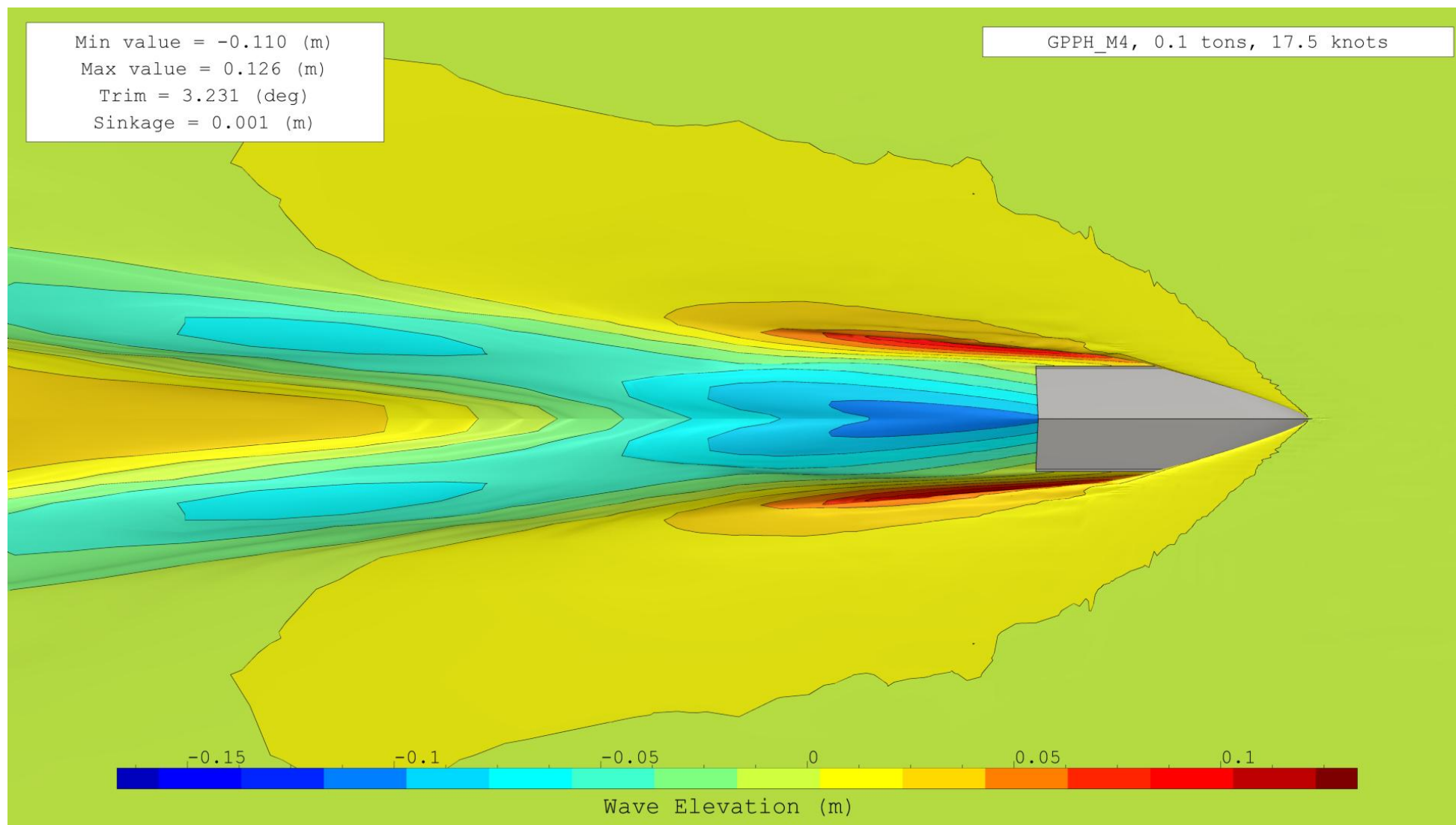


## c. Free surface : far field (common scale)

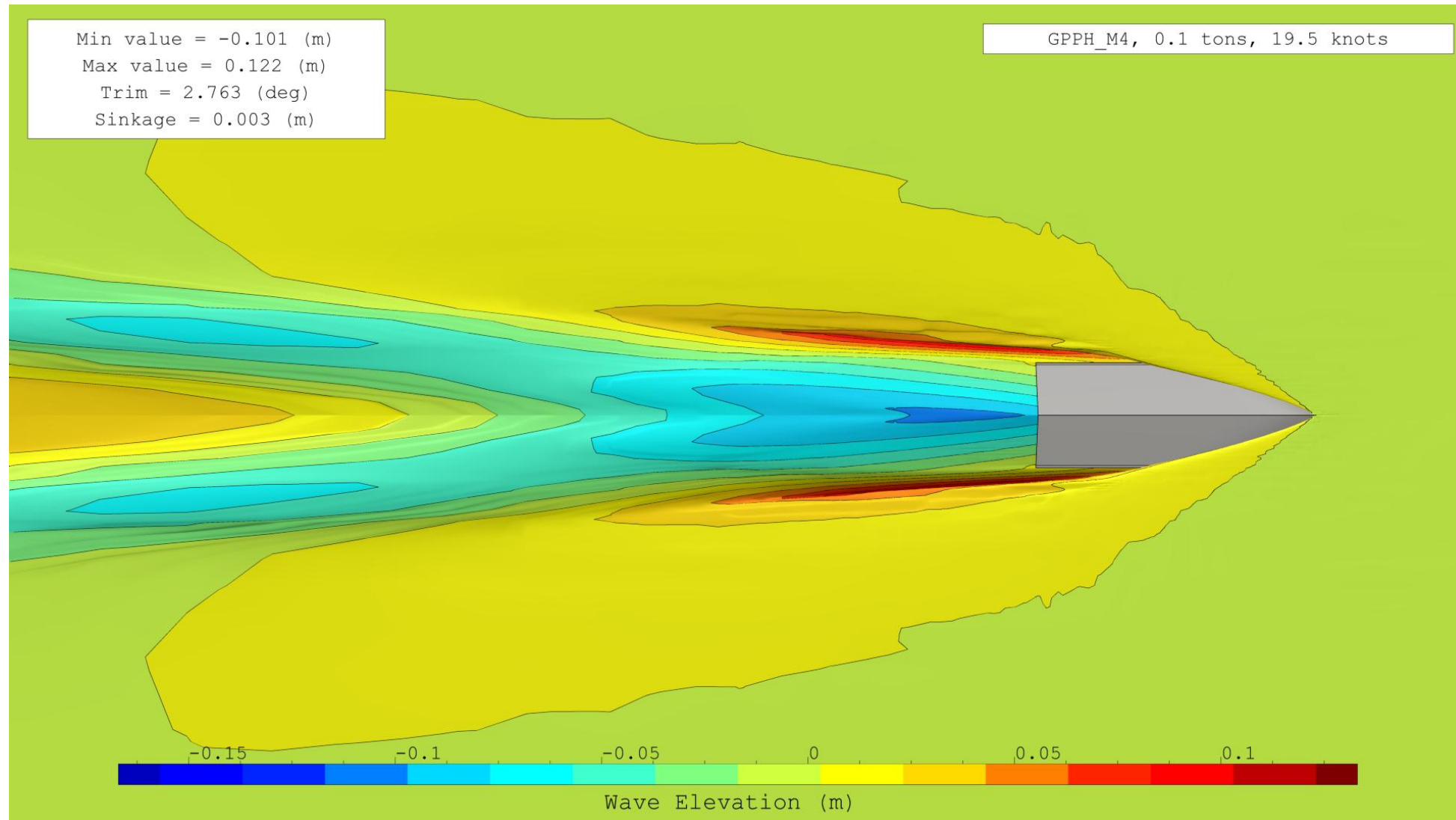




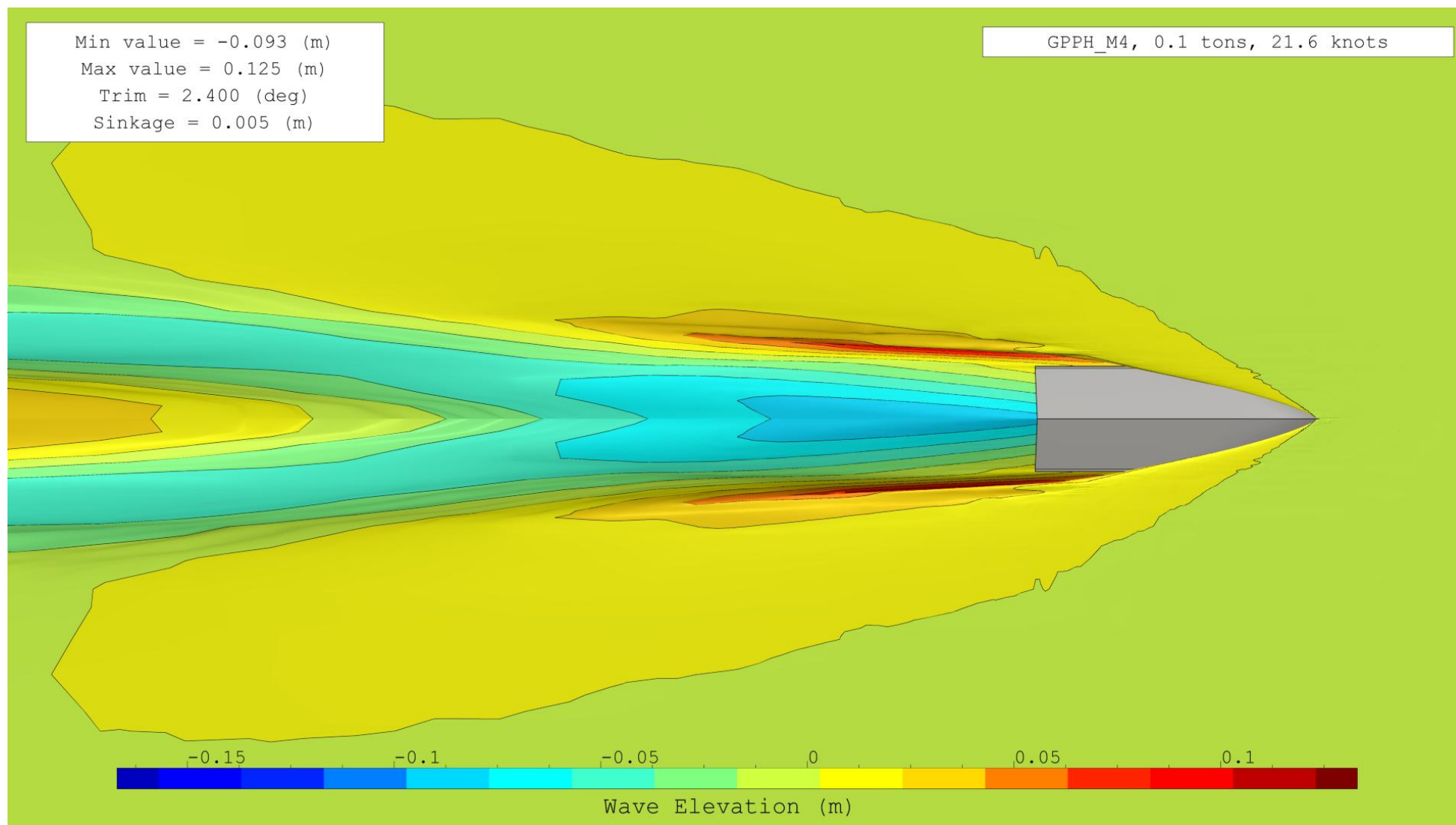
## c. Free surface : far field (common scale)



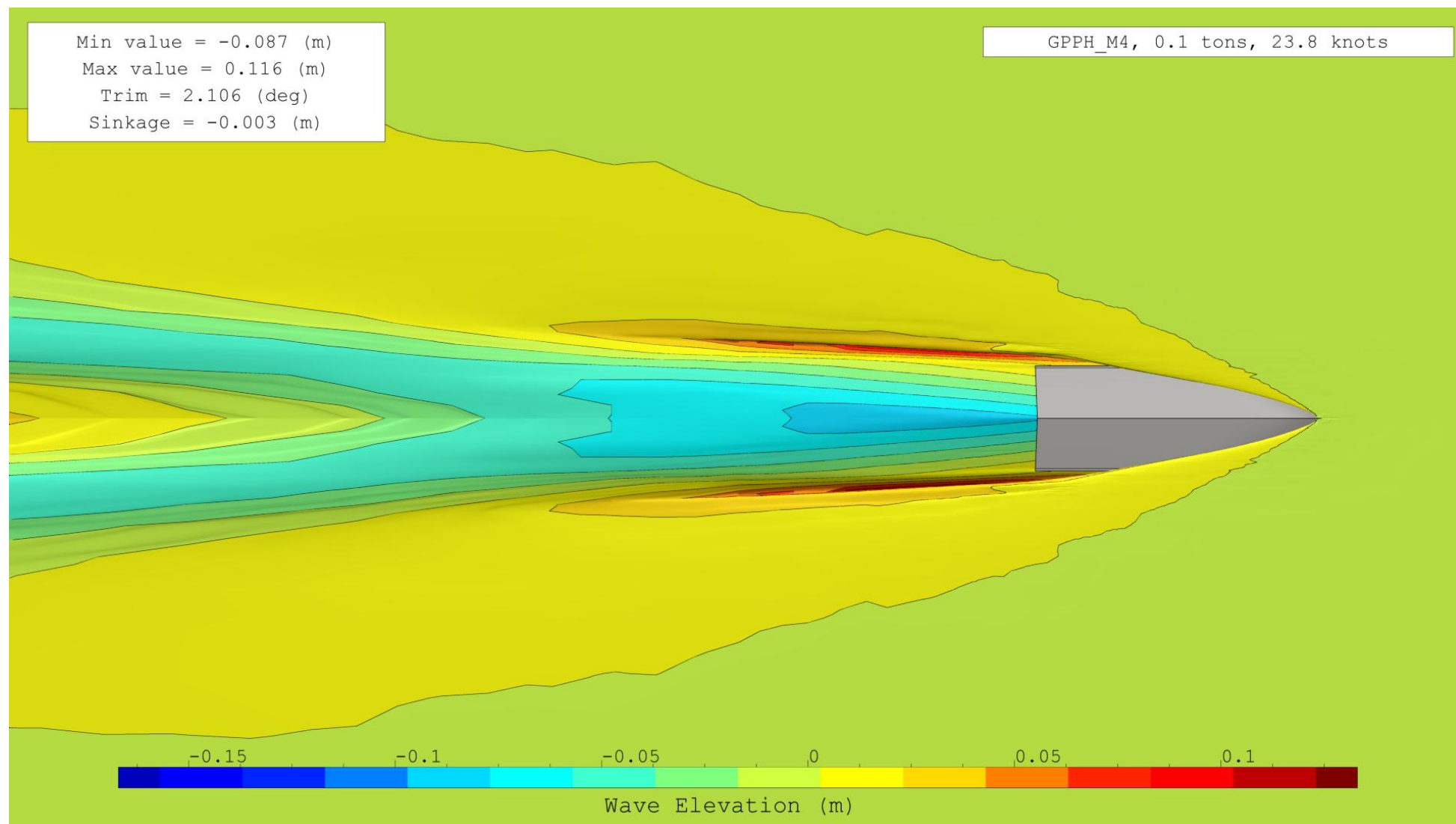
## c. Free surface : far field (common scale)



## c. Free surface : far field (common scale)

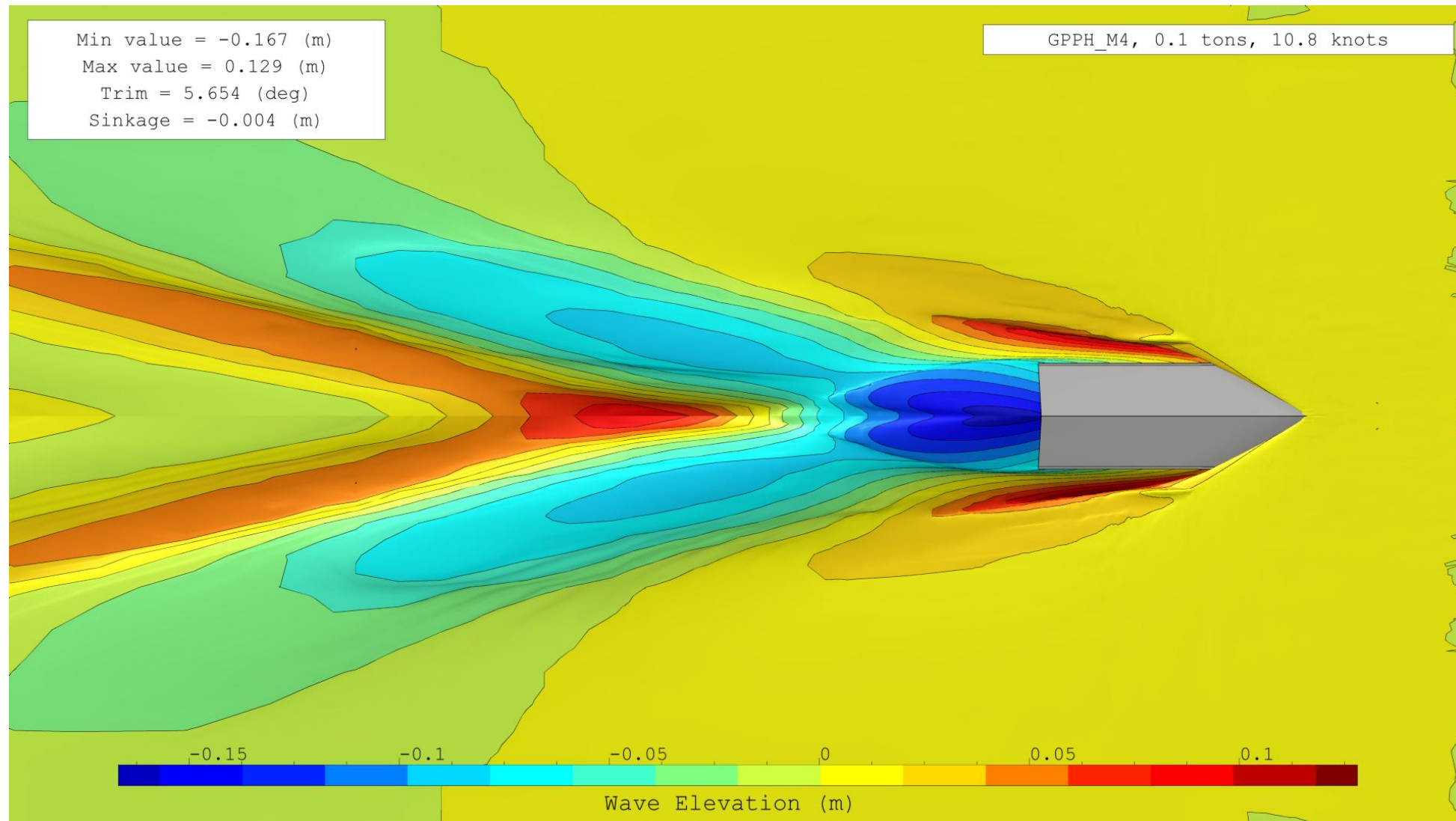


## c. Free surface : far field (common scale)

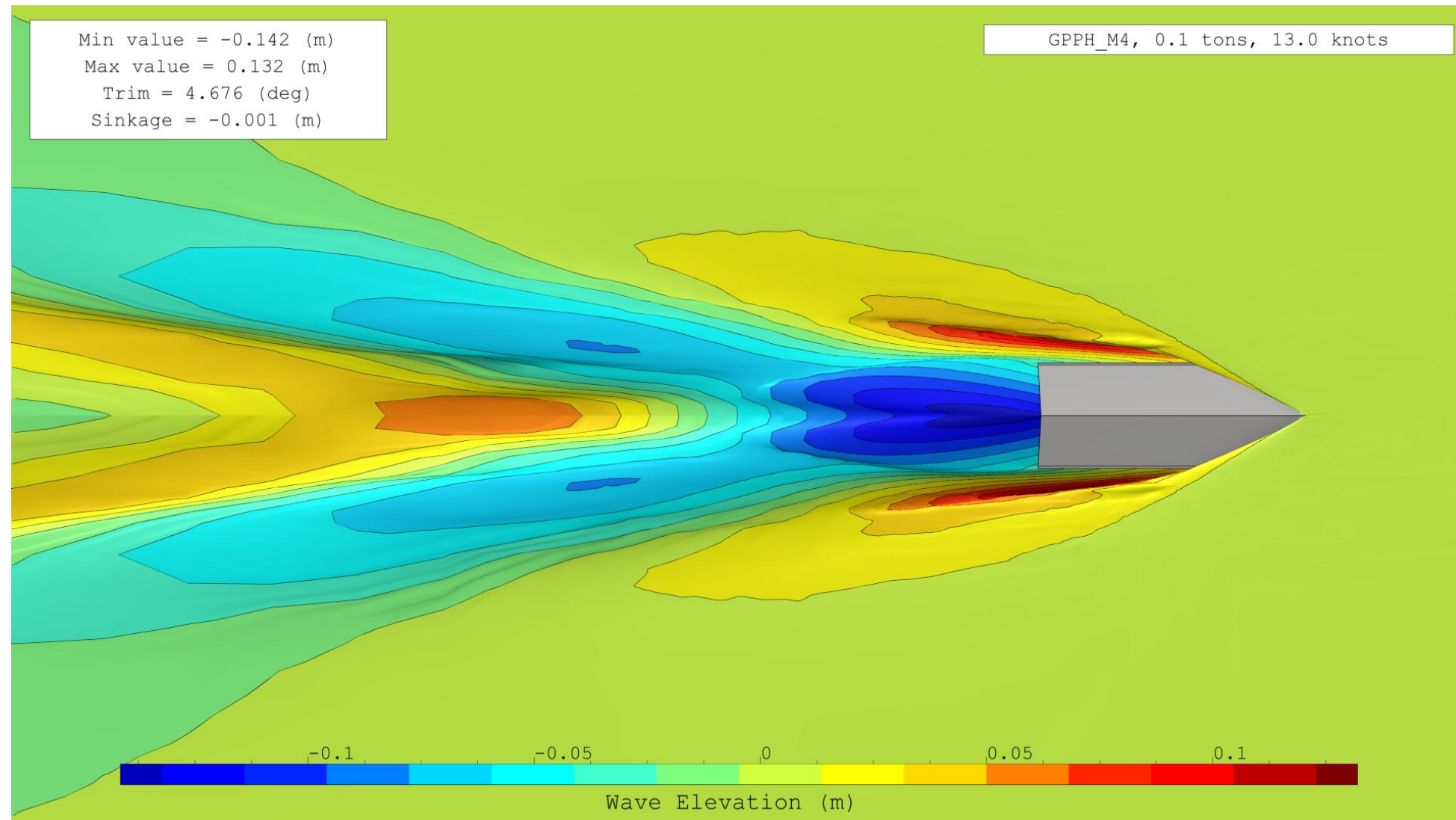




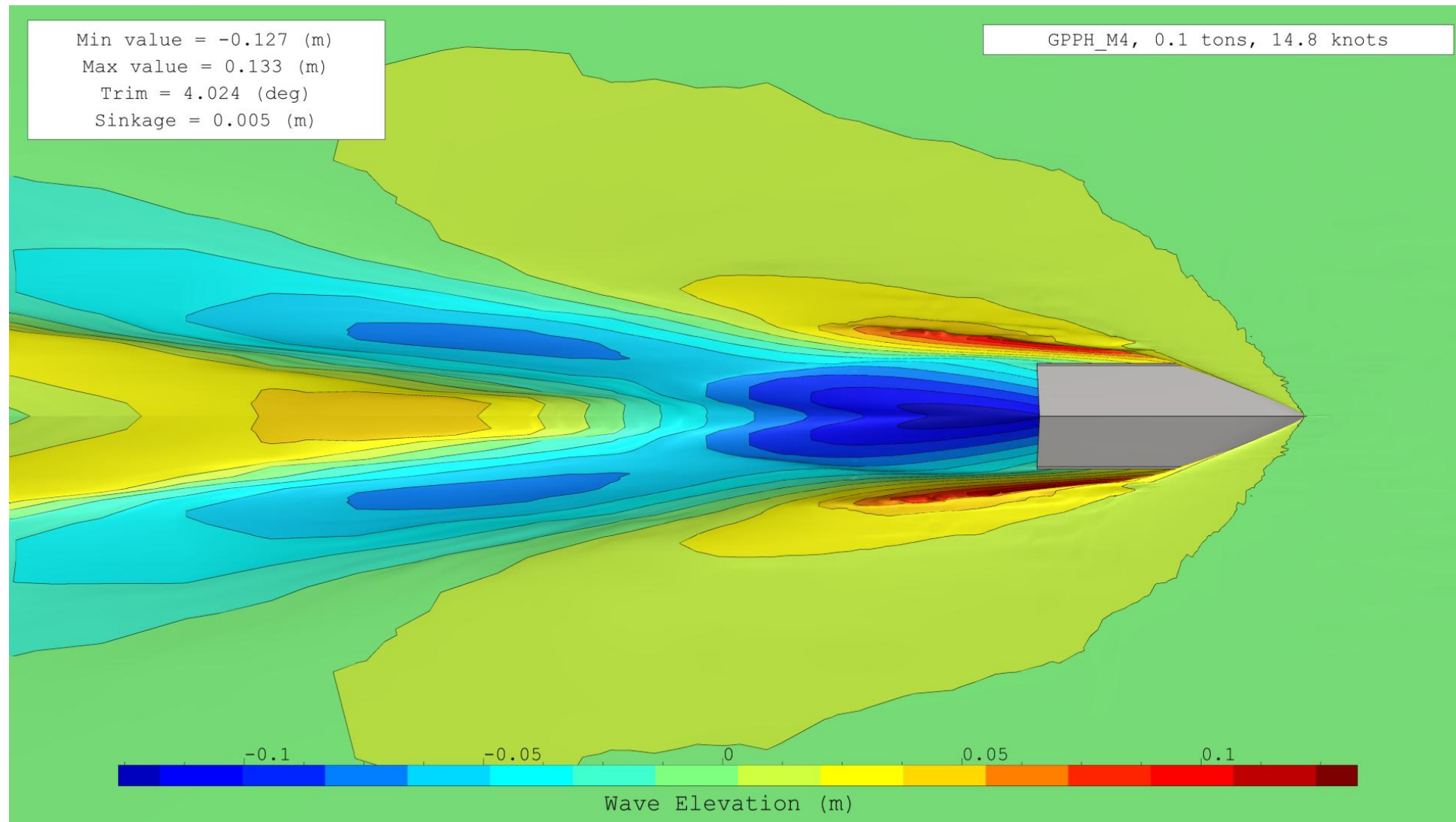
## c. Free surface : far field (independant scale)



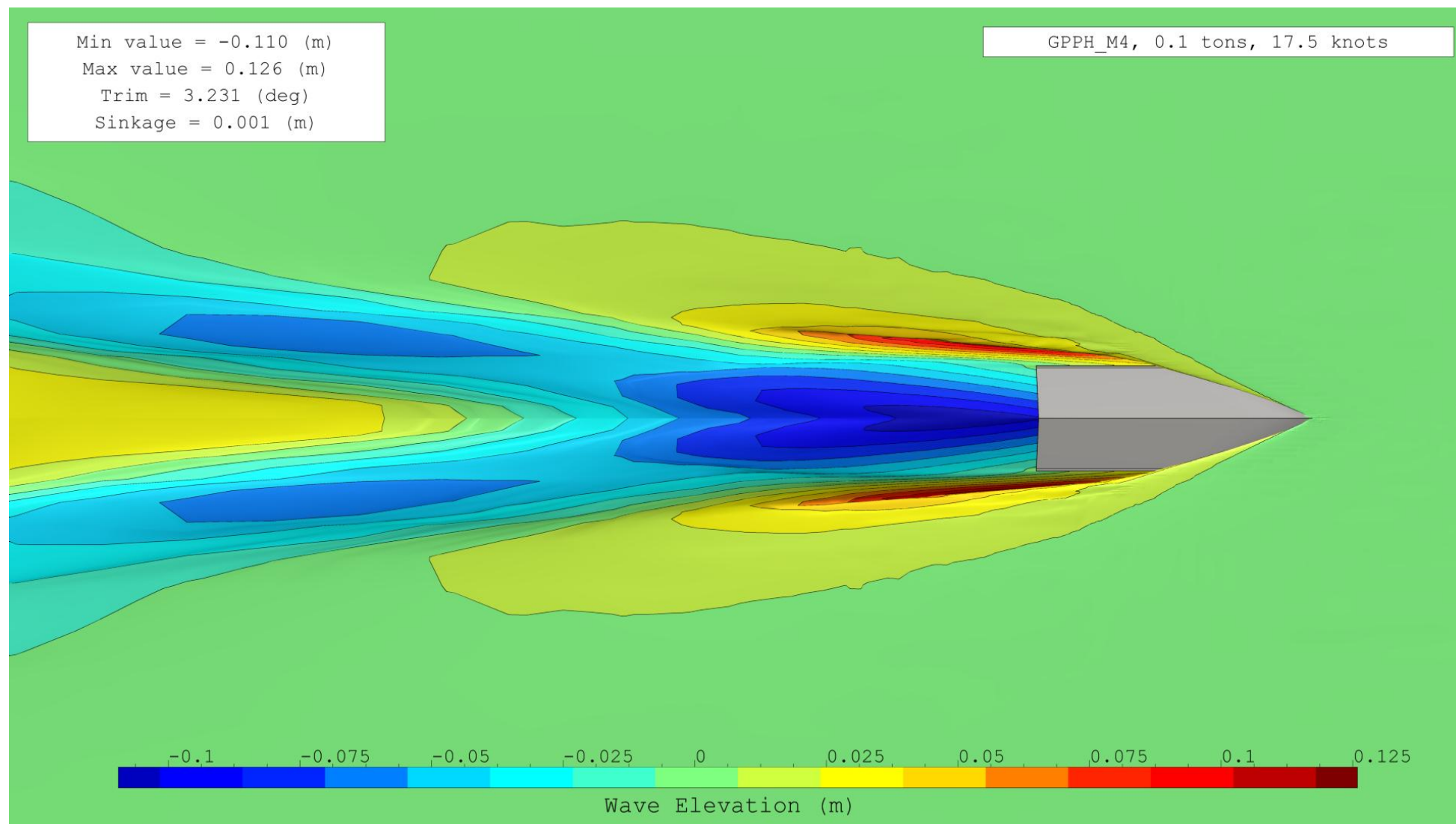
## c. Free surface : far field (independant scale)



## c. Free surface : far field (independant scale)

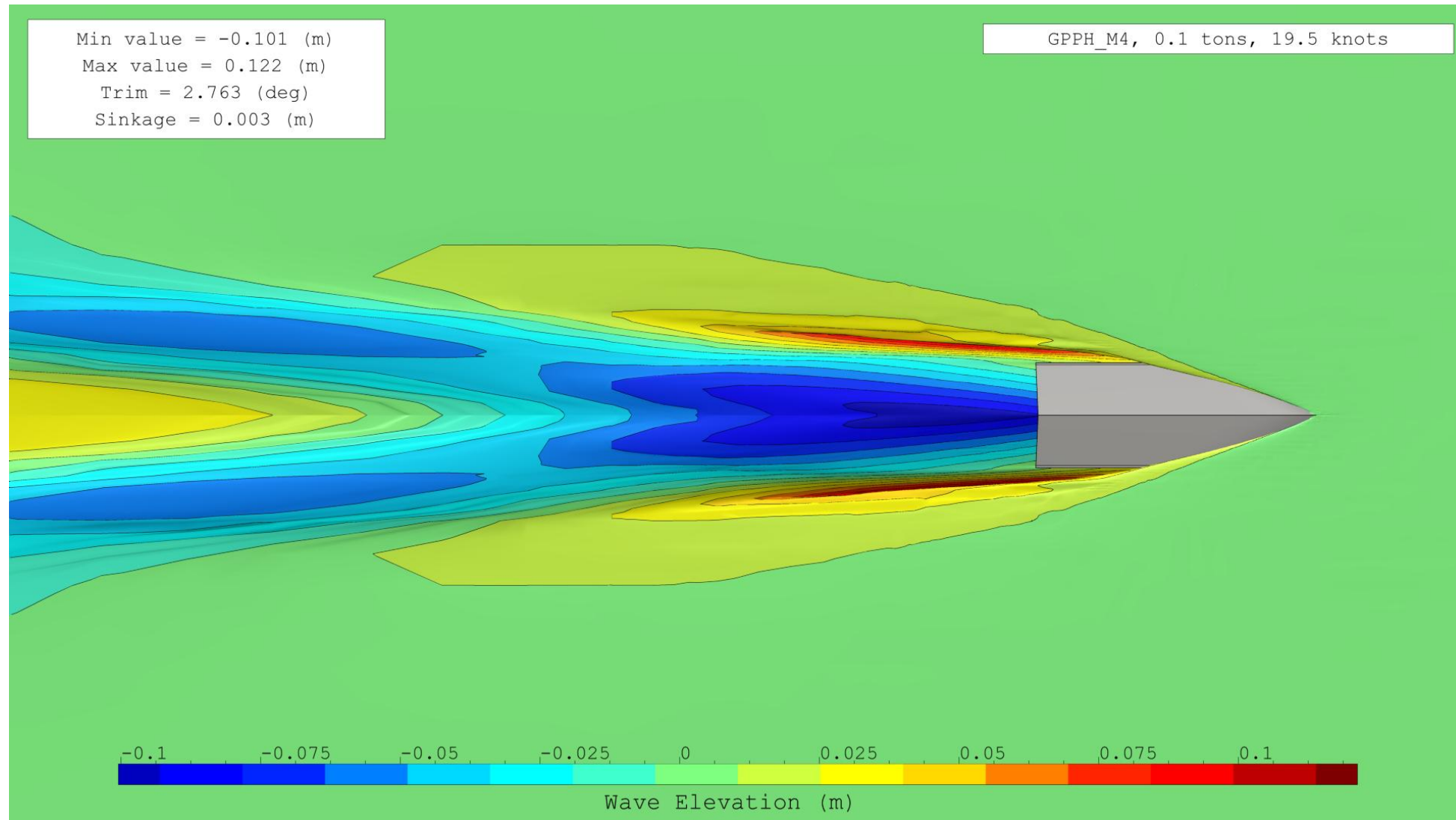


## c. Free surface : far field (independant scale)

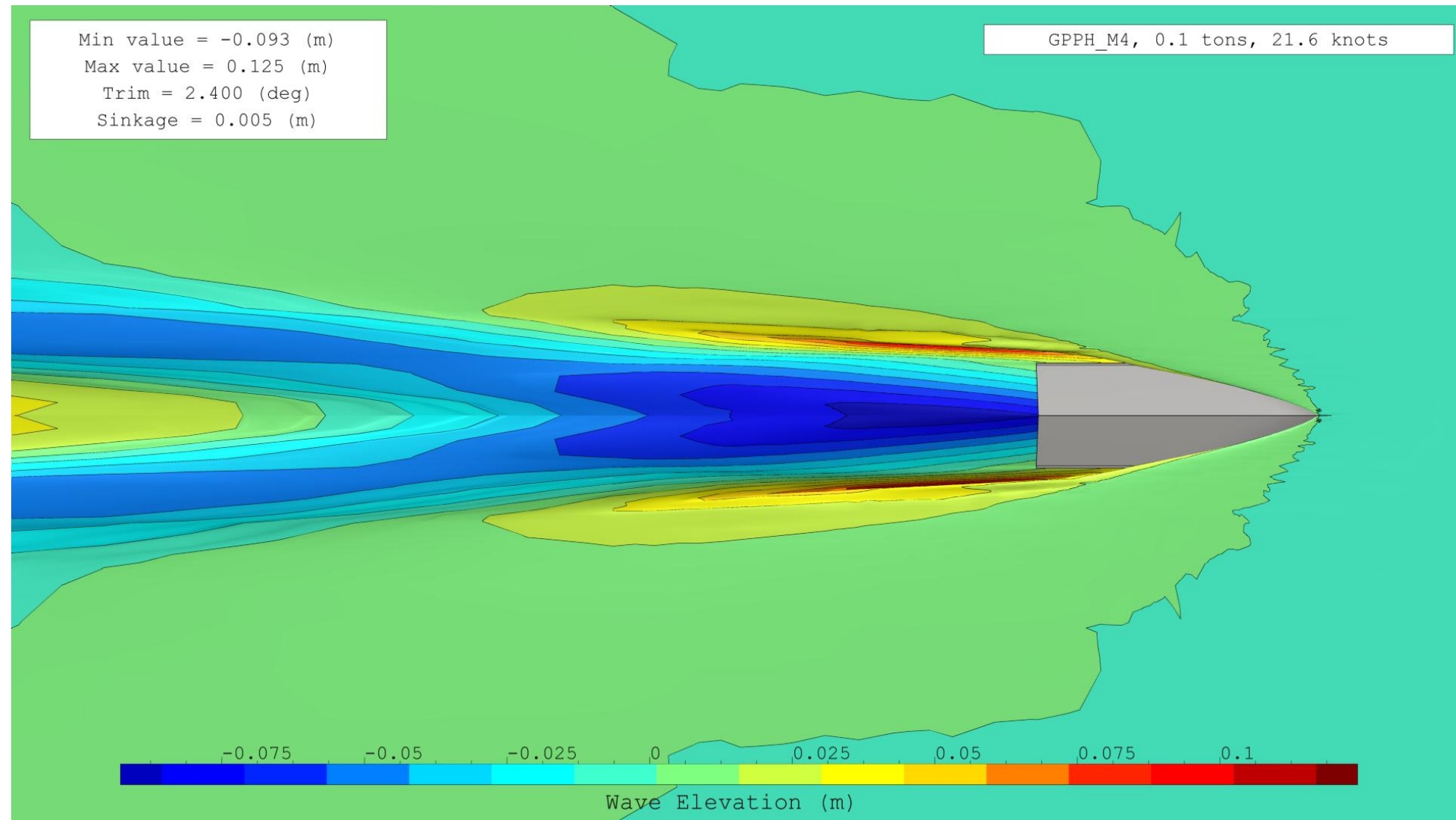




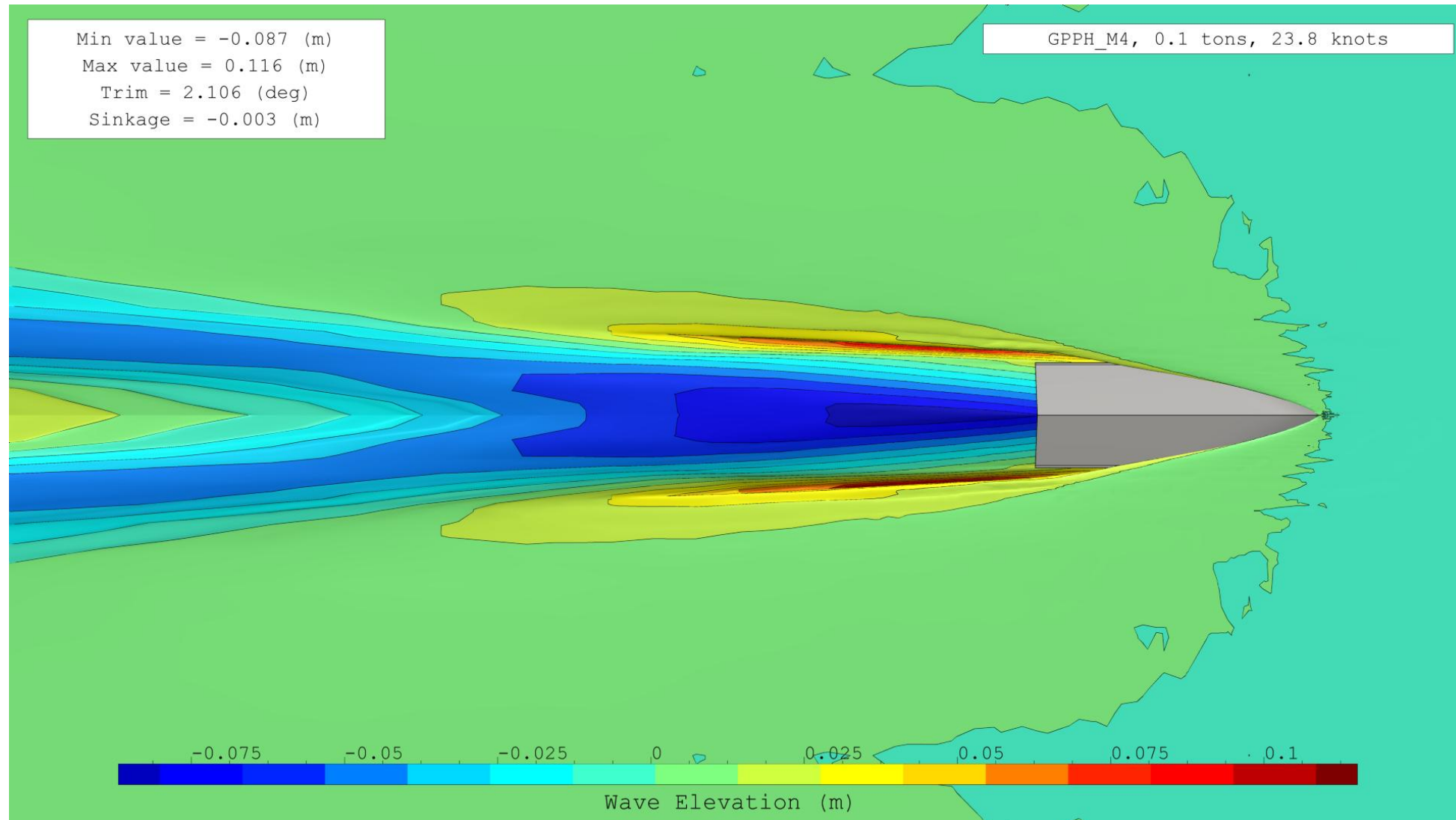
## c. Free surface : far field (independant scale)

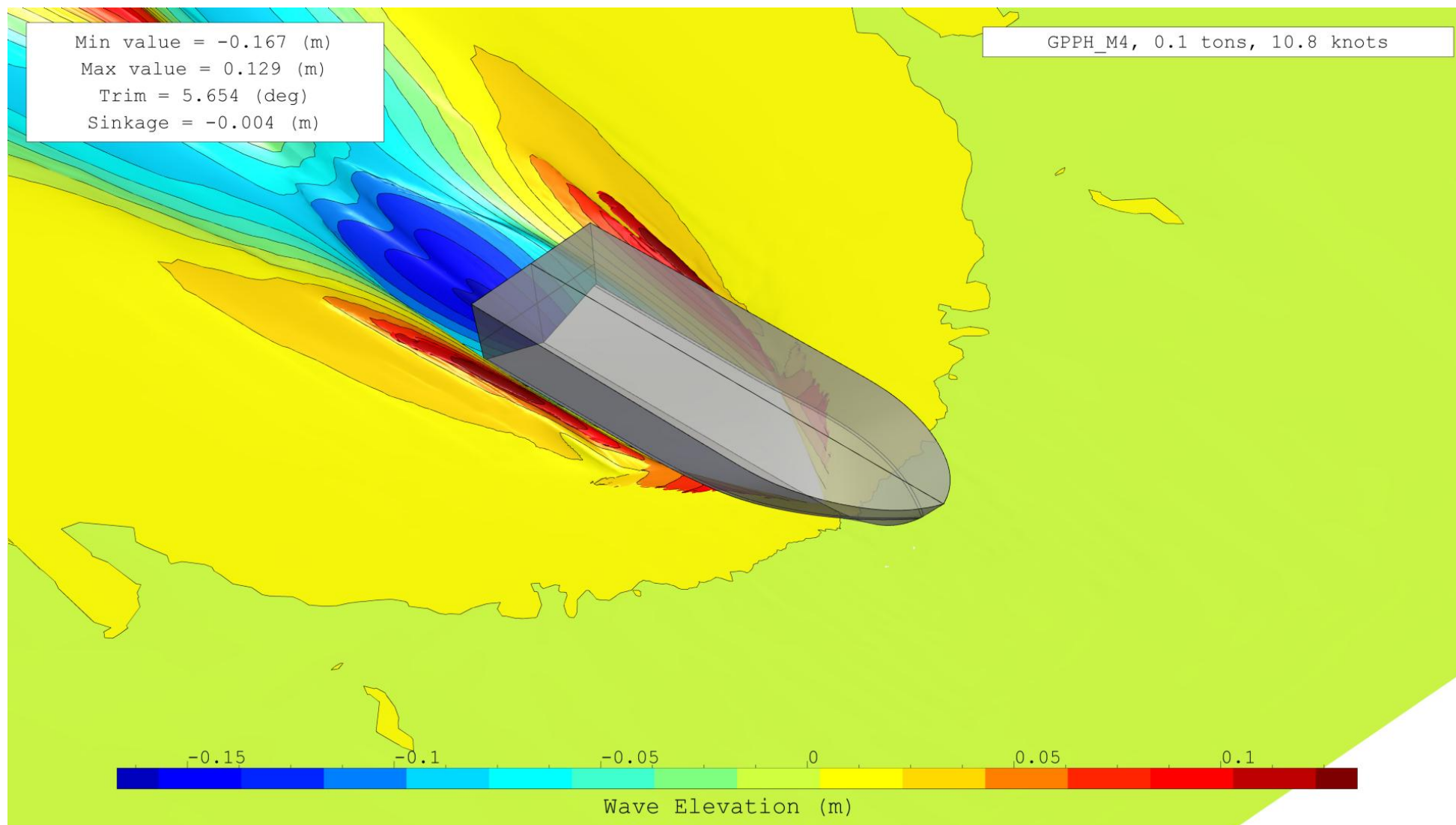


## c. Free surface : far field (independant scale)

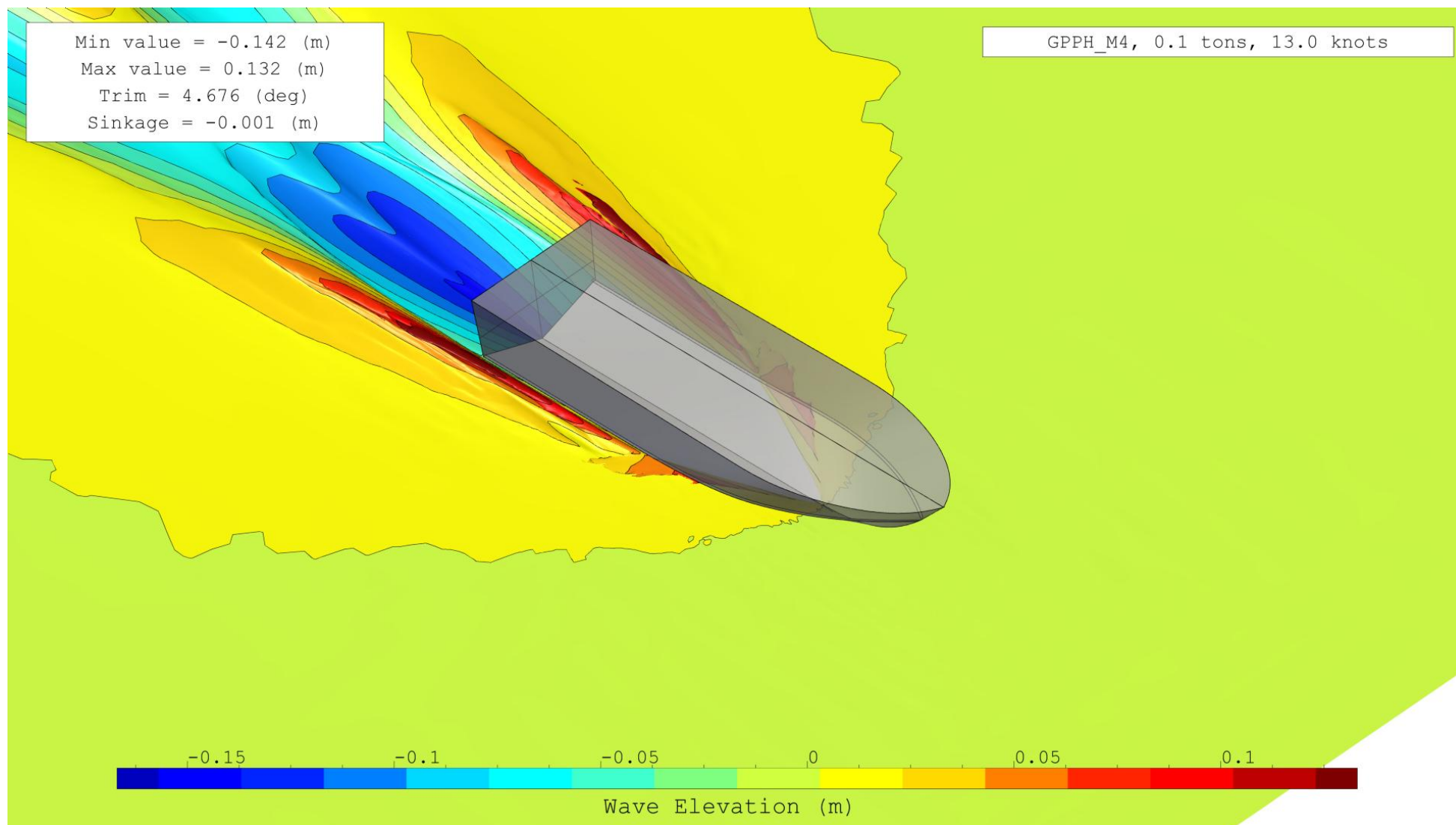


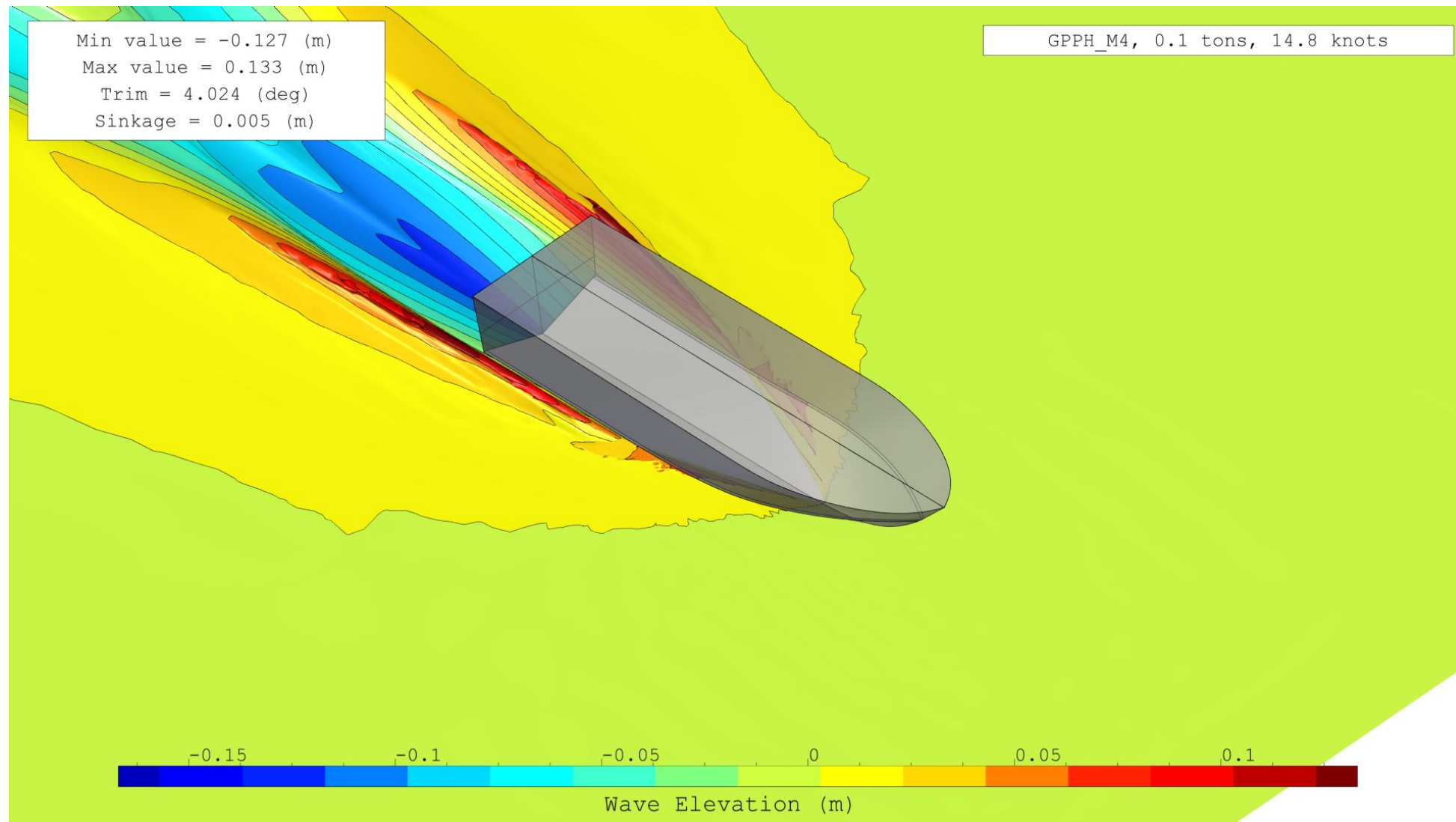
## c. Free surface : far field (independant scale)

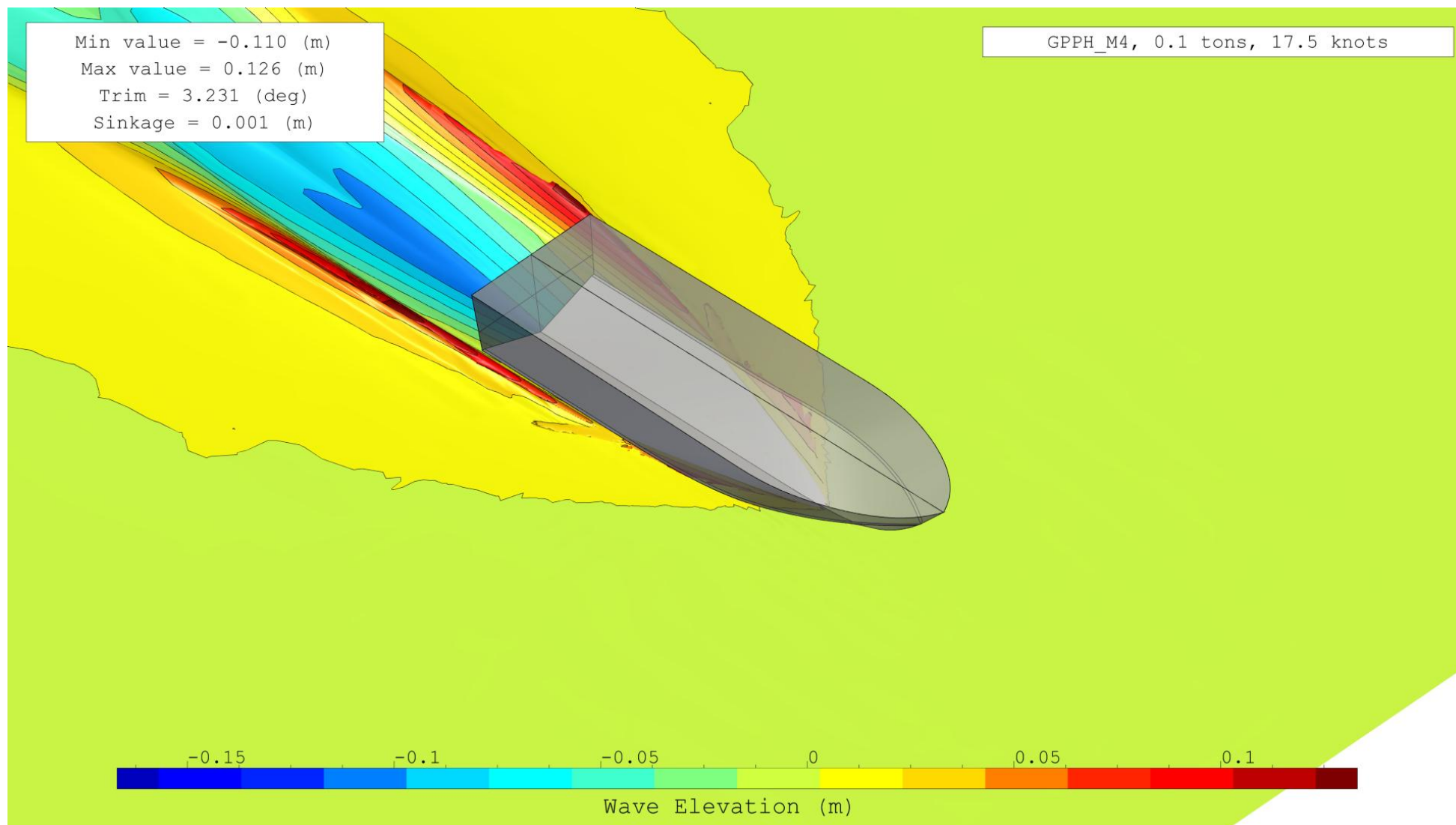


c. Free surface :  $\frac{3}{4}$  front view (common scale)

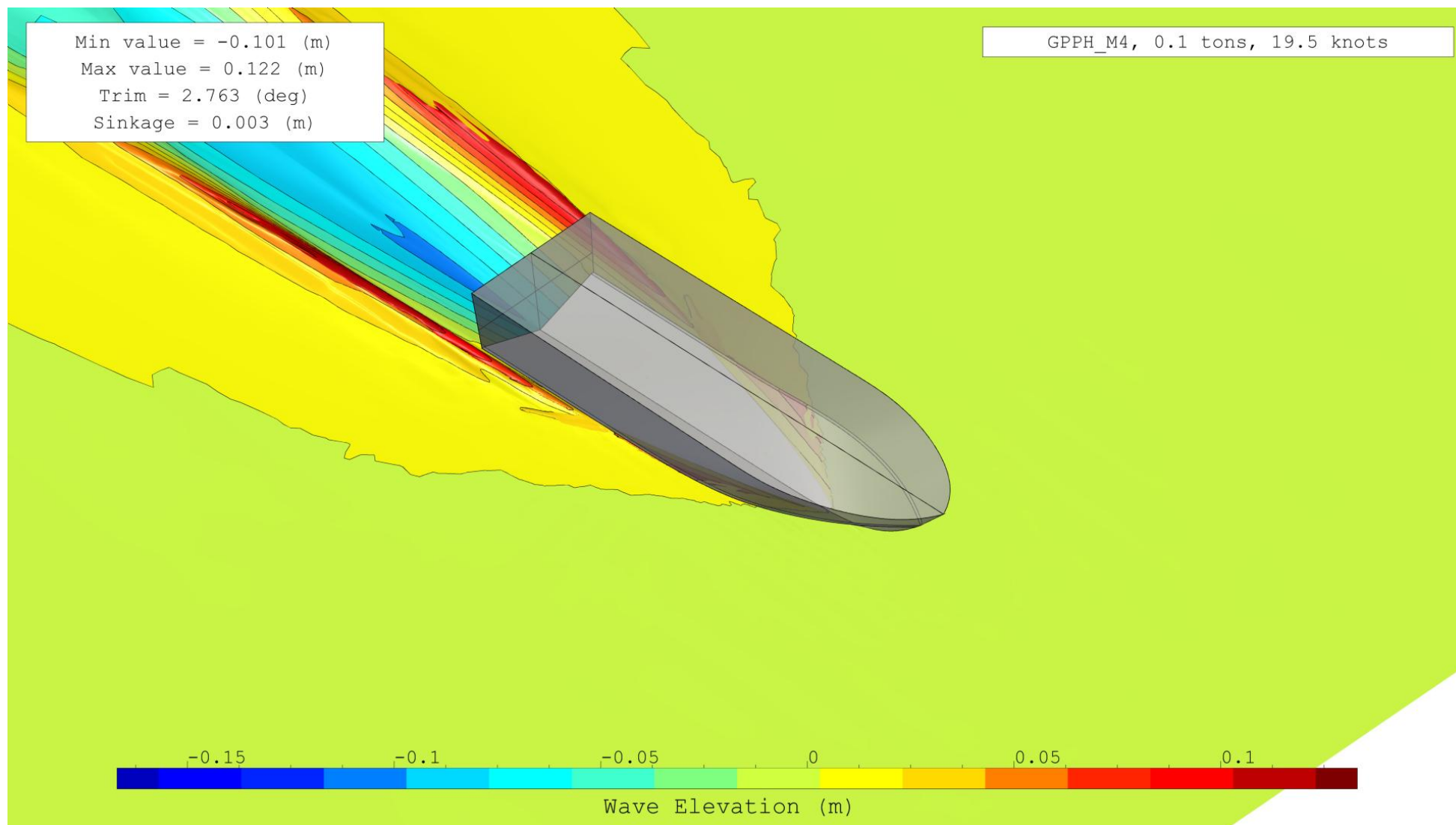


c. Free surface :  $\frac{3}{4}$  front view (common scale)

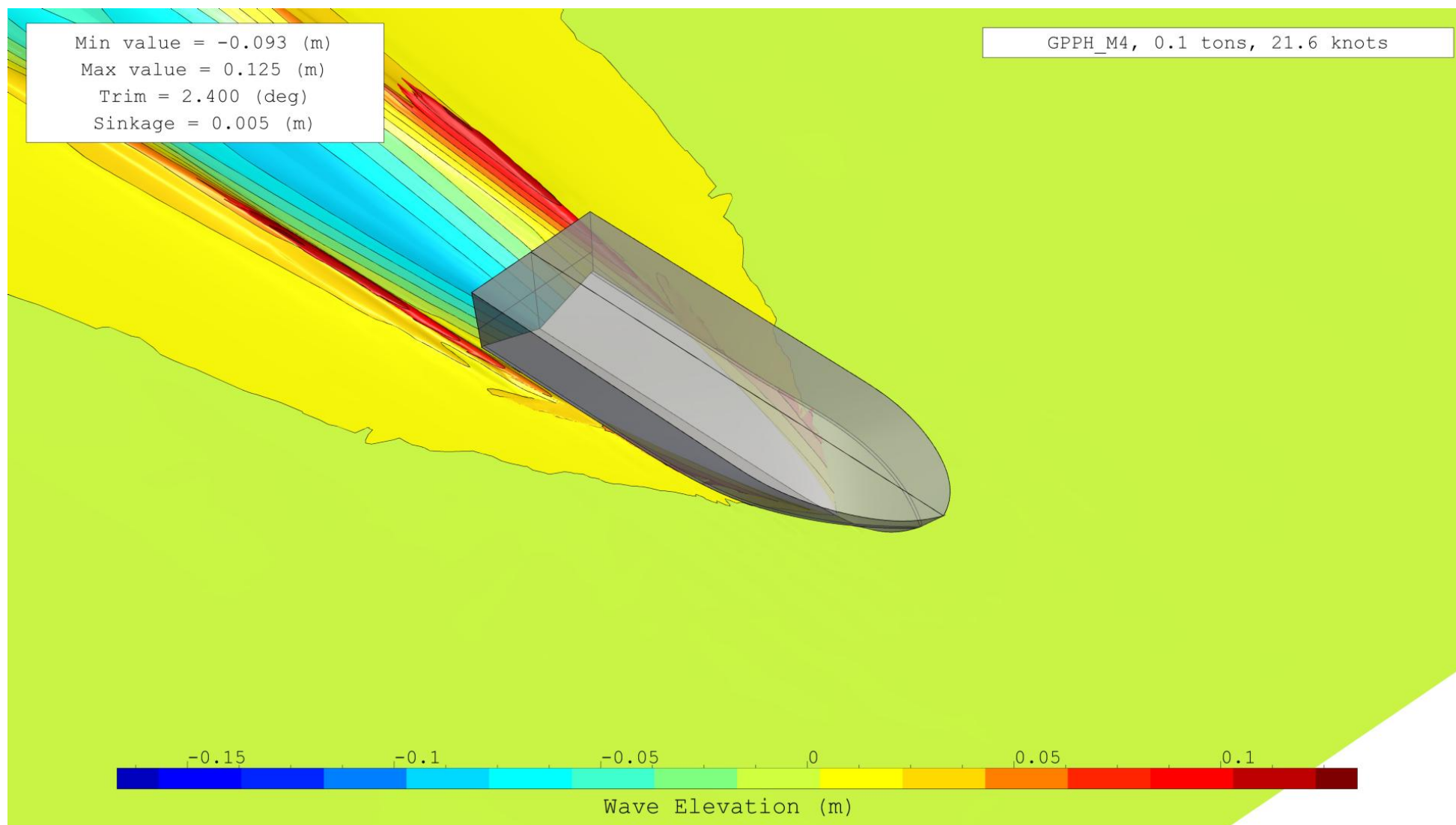
c. Free surface :  $\frac{3}{4}$  front view (common scale)

c. Free surface :  $\frac{3}{4}$  front view (common scale)

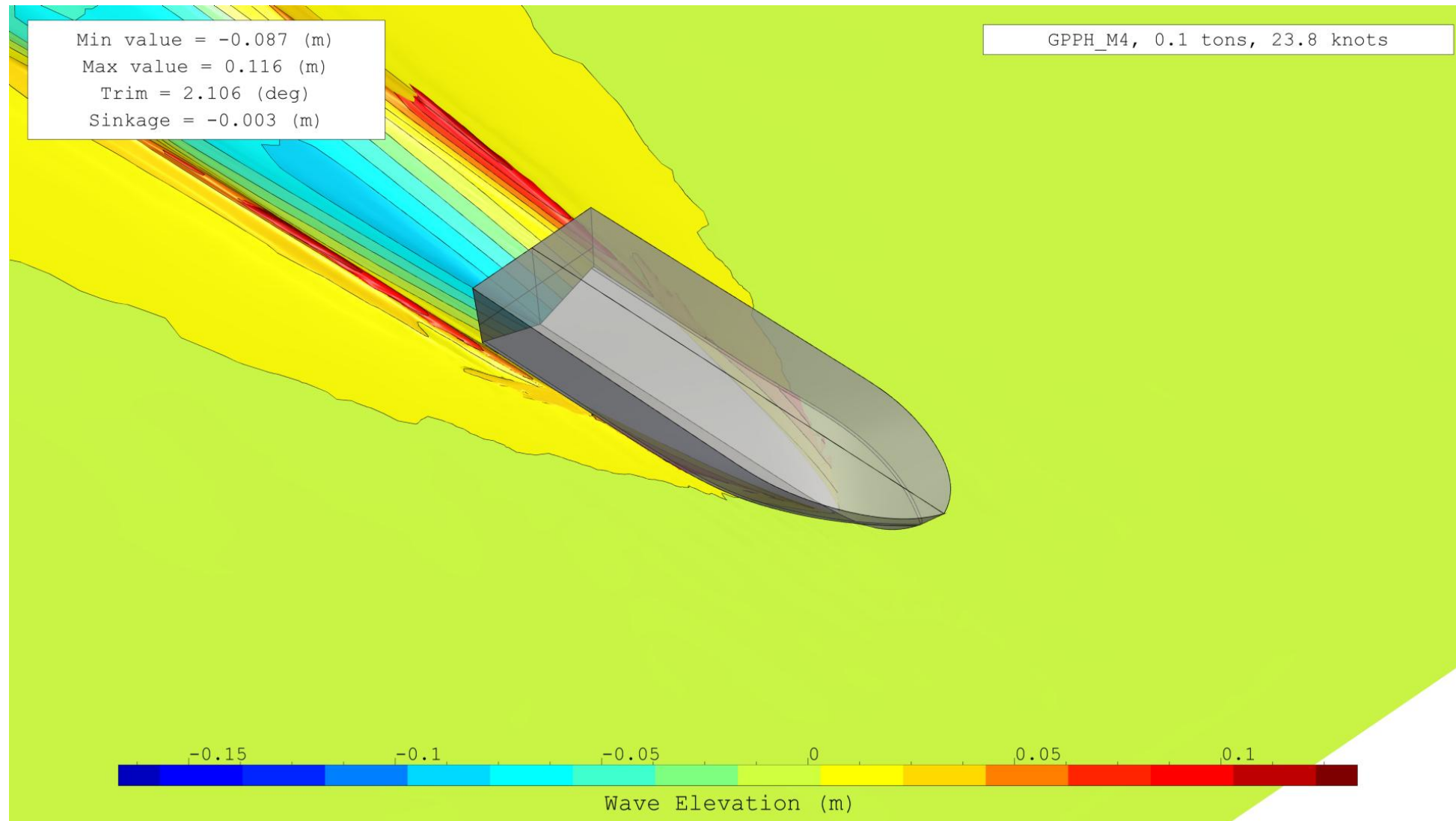
## c. Free surface : ¾ front view (common scale)

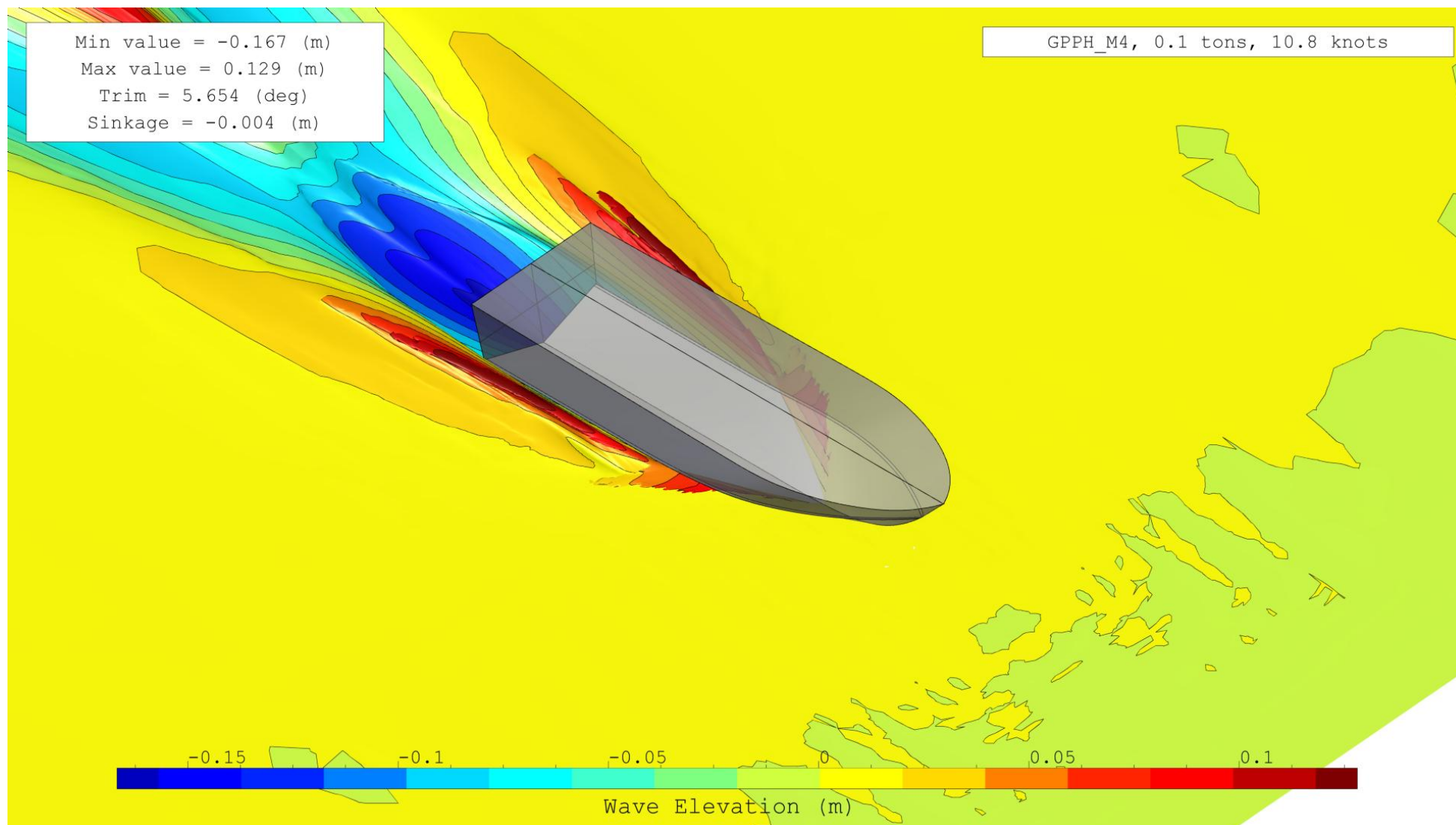


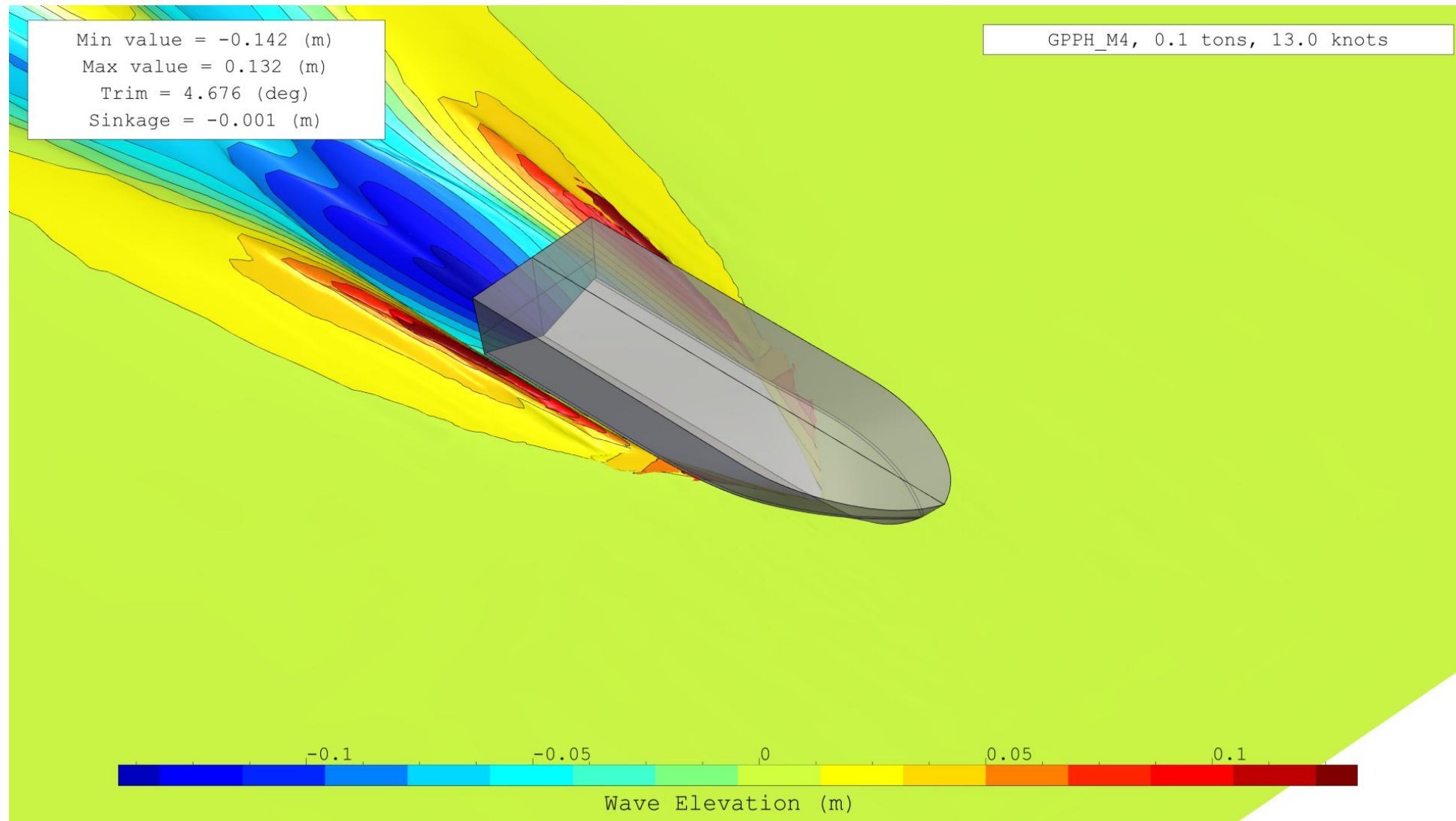


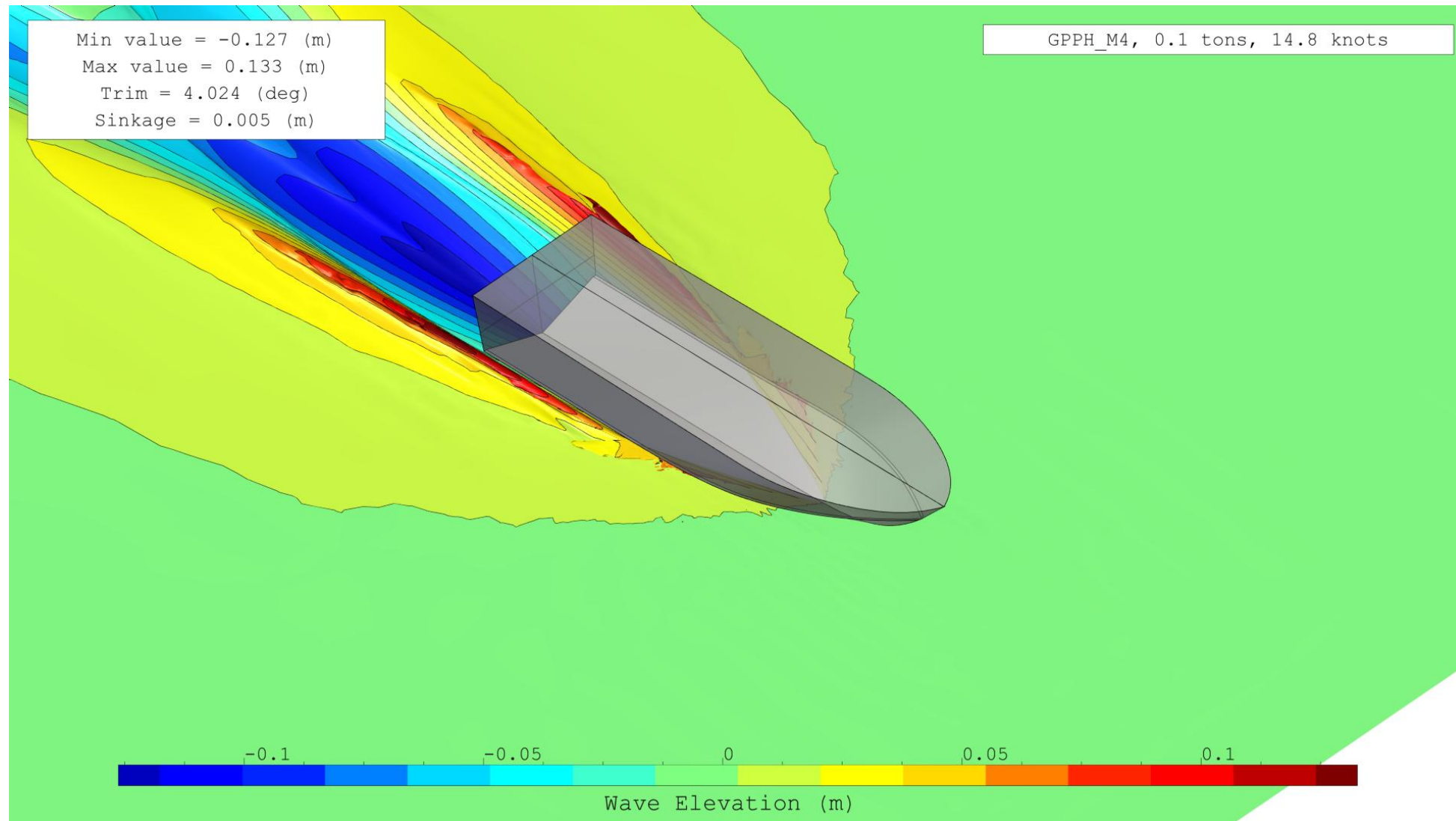
c. Free surface :  $\frac{3}{4}$  front view (common scale)

## c. Free surface : ¾ front view (common scale)

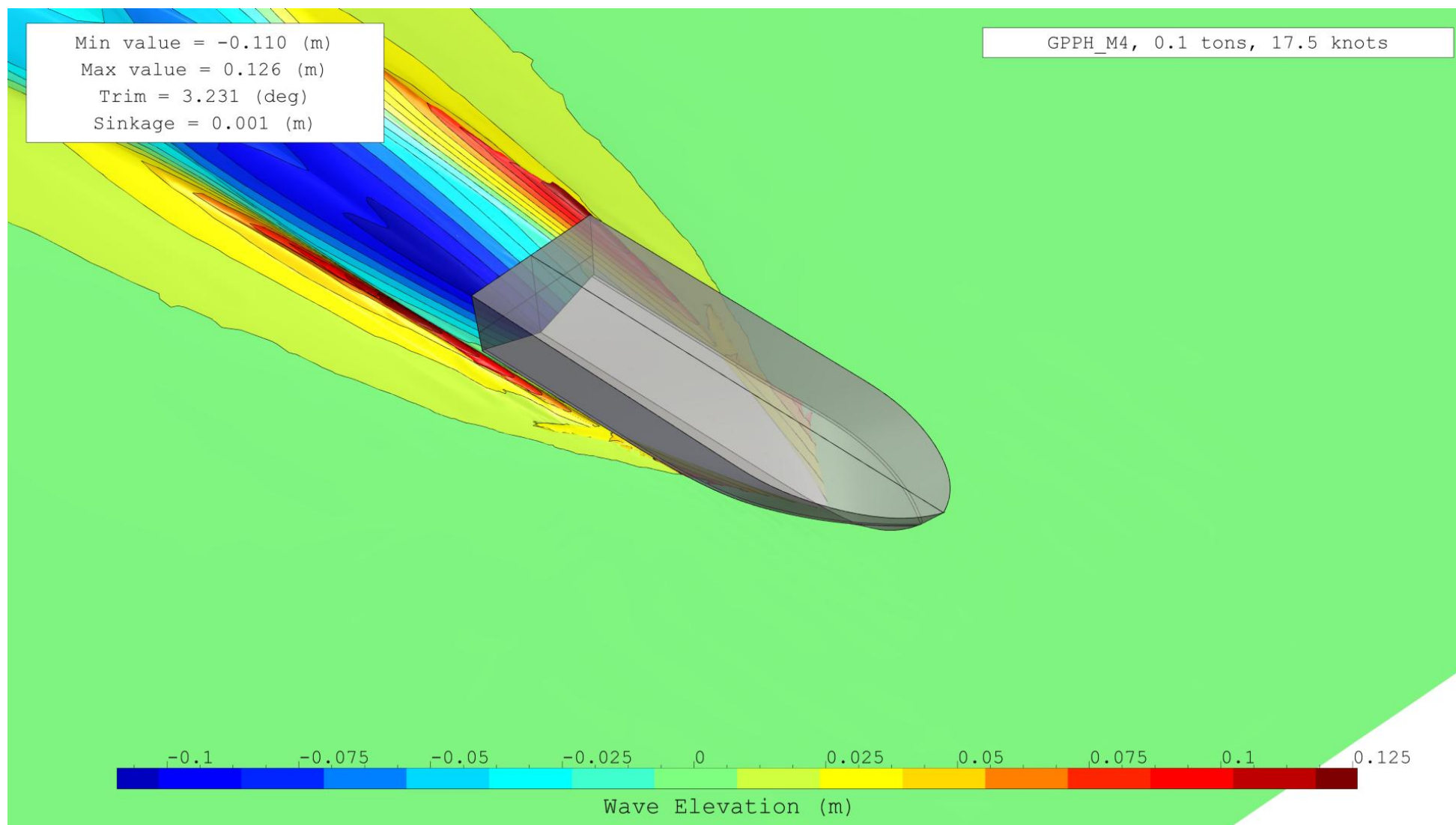


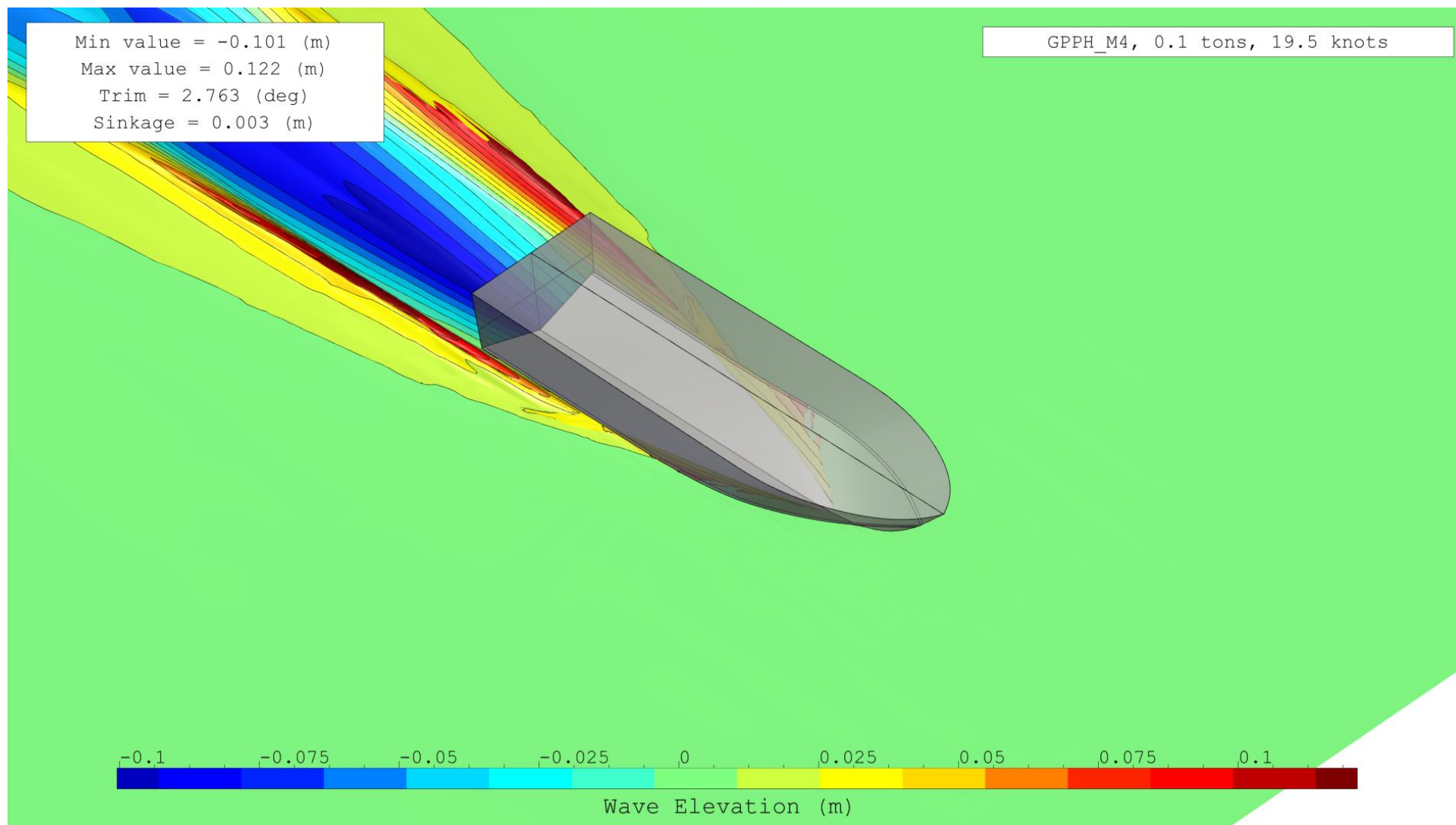
c. Free surface :  $\frac{3}{4}$  front view (independant scale)

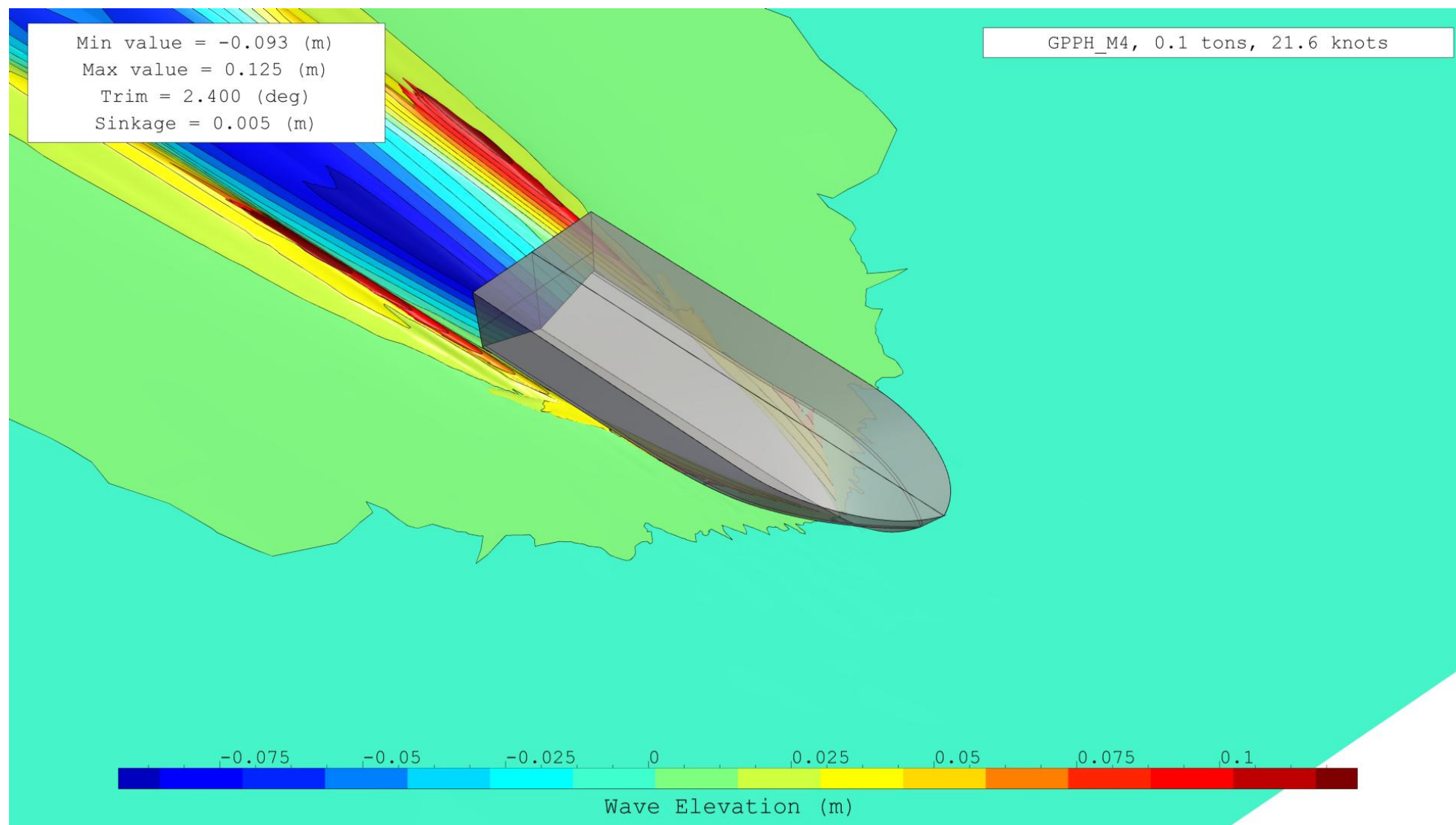
c. Free surface :  $\frac{3}{4}$  front view (independant scale)

c. Free surface :  $\frac{3}{4}$  front view (independant scale)

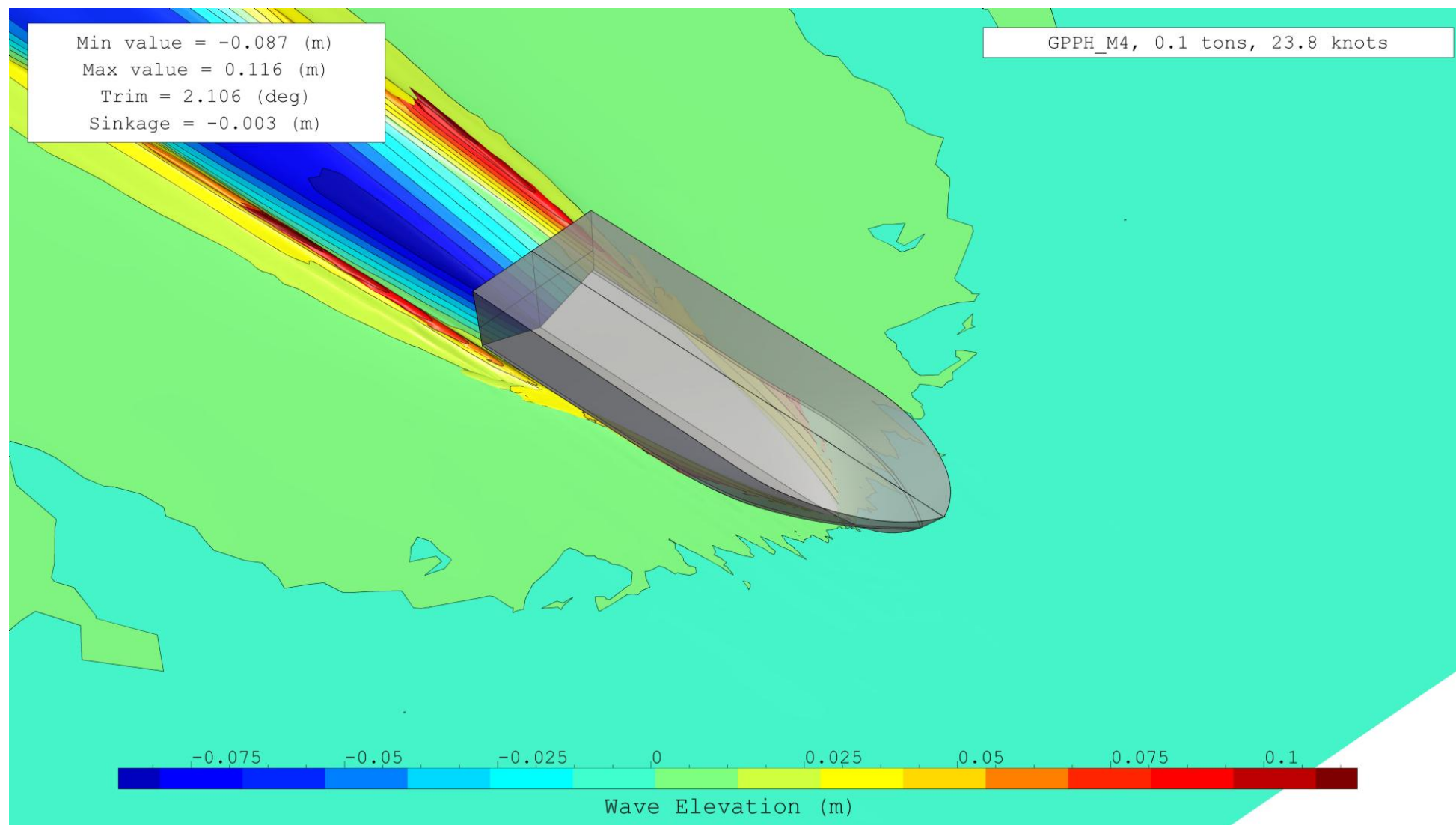


c. Free surface :  $\frac{3}{4}$  front view (independant scale)

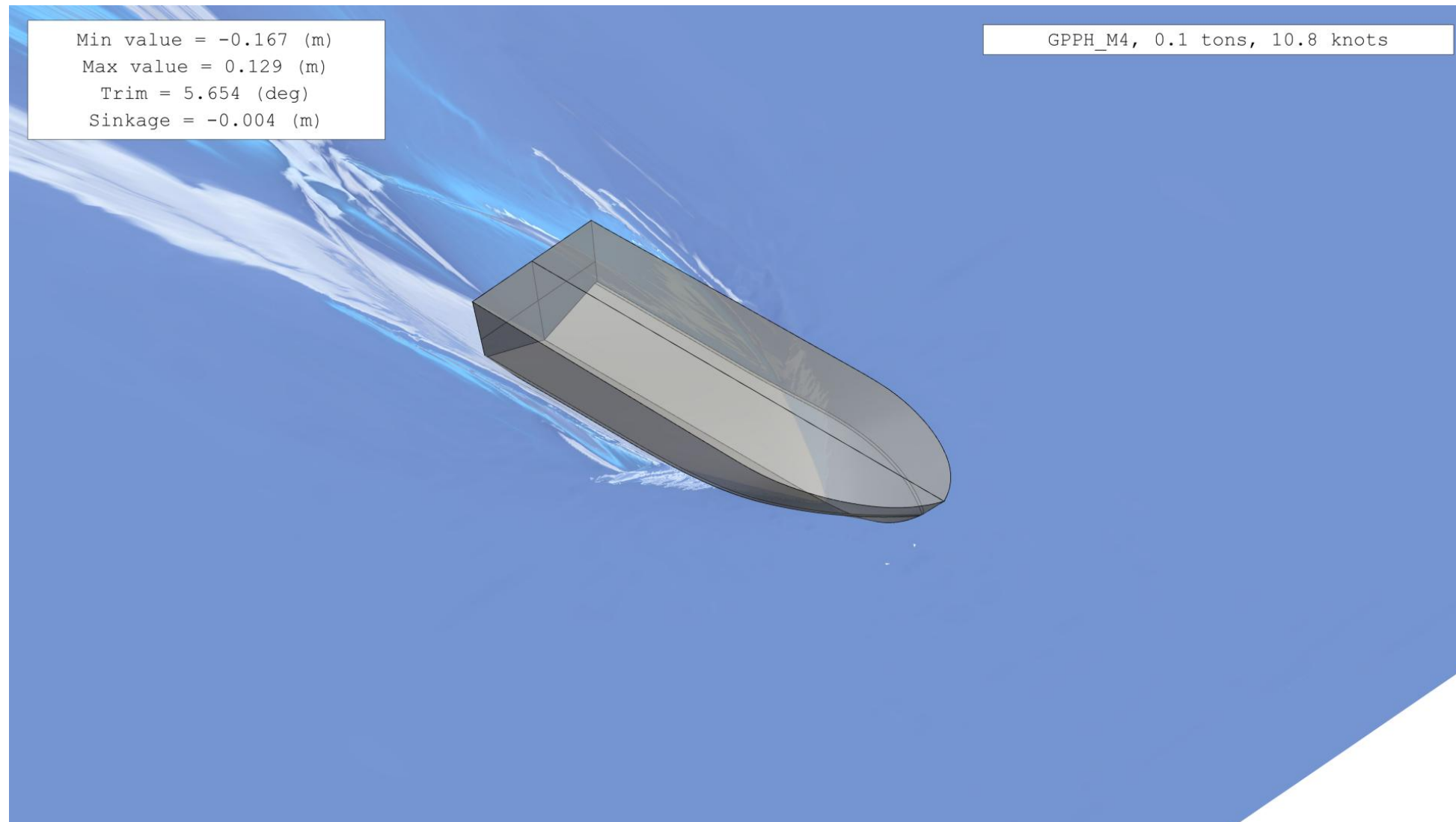
c. Free surface :  $\frac{3}{4}$  front view (independant scale)

c. Free surface :  $\frac{3}{4}$  front view (independant scale)

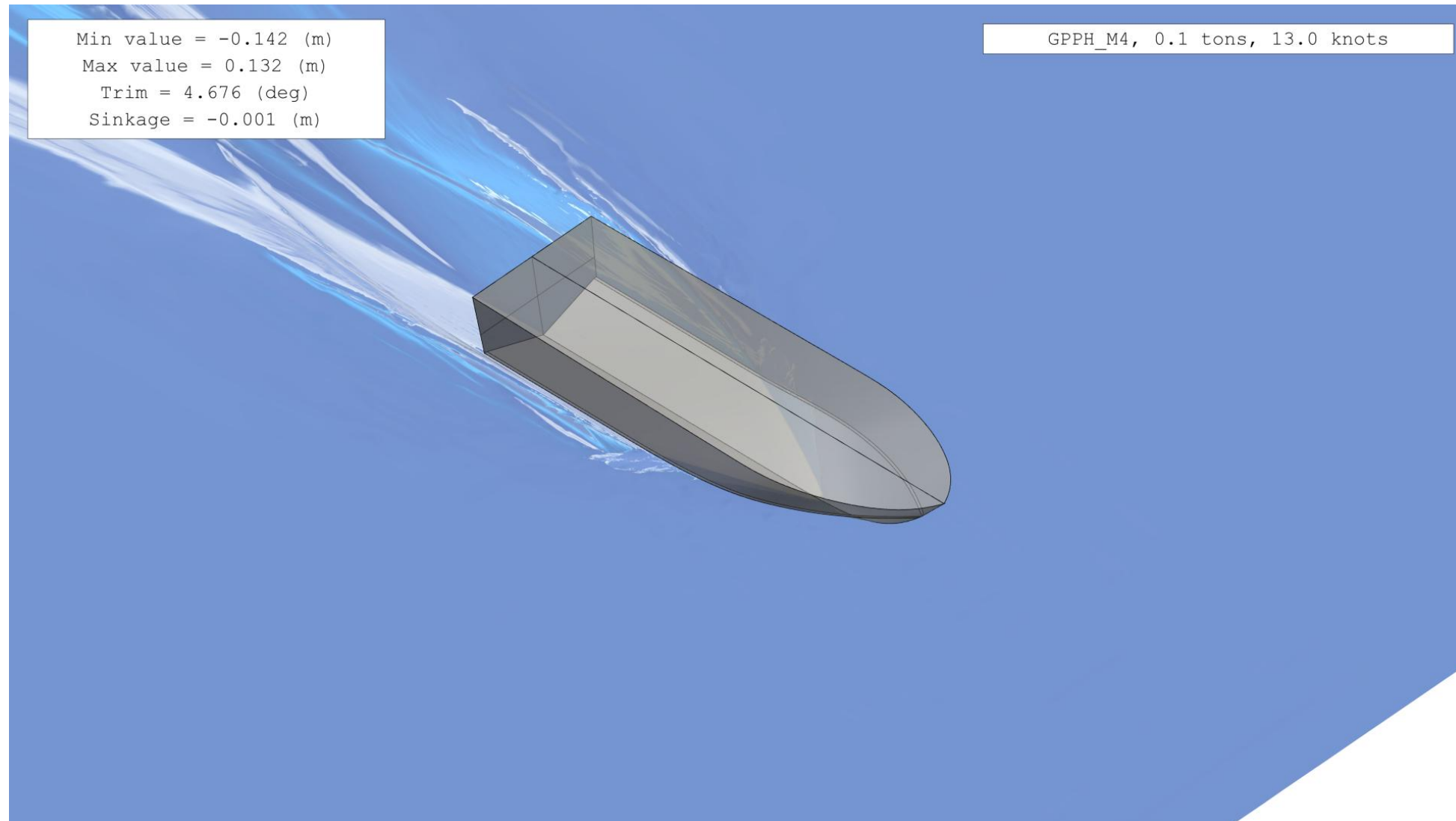


c. Free surface :  $\frac{3}{4}$  front view (independant scale)

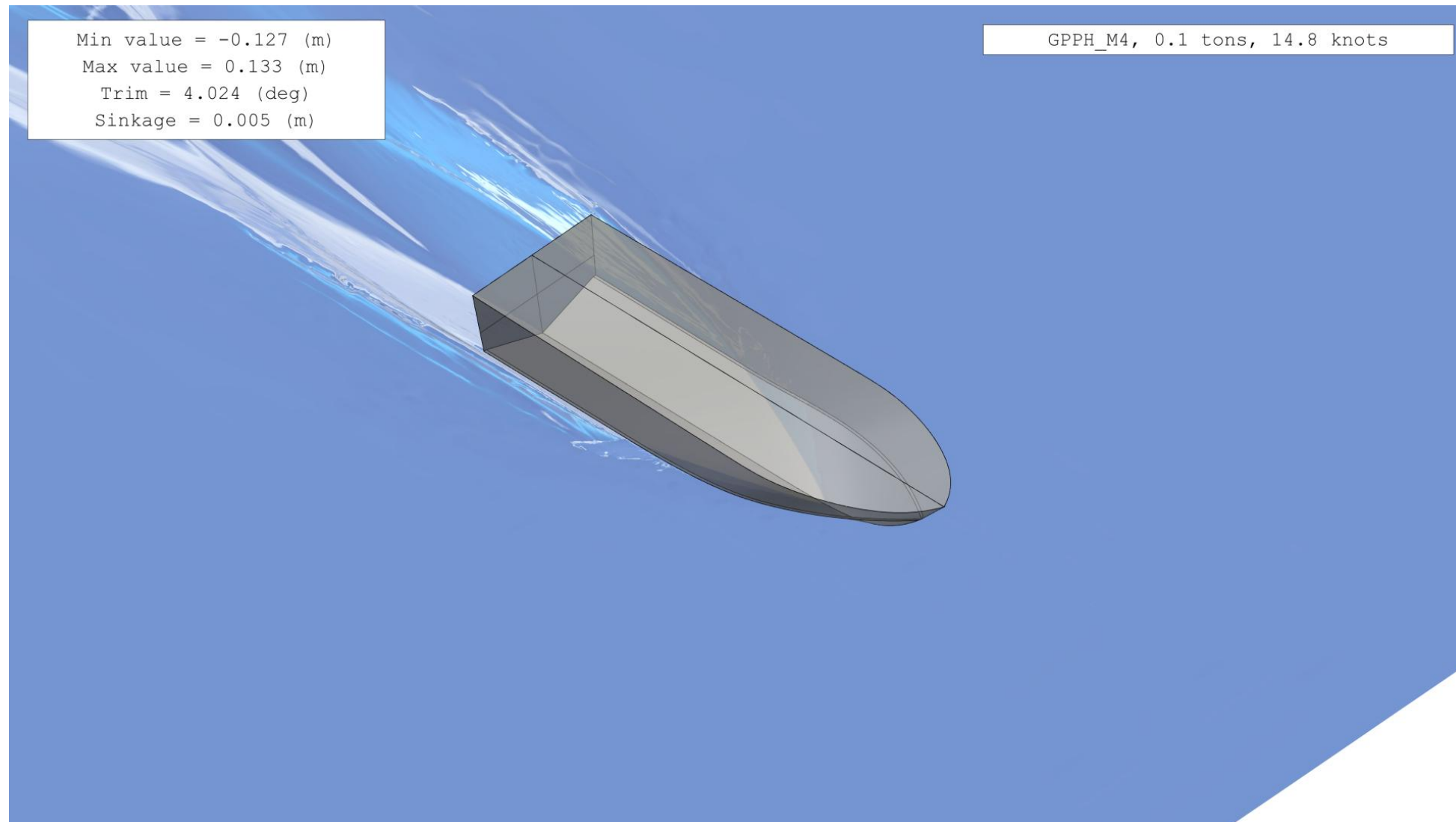
### c. Free surface : $\frac{3}{4}$ front view, realistic rendering



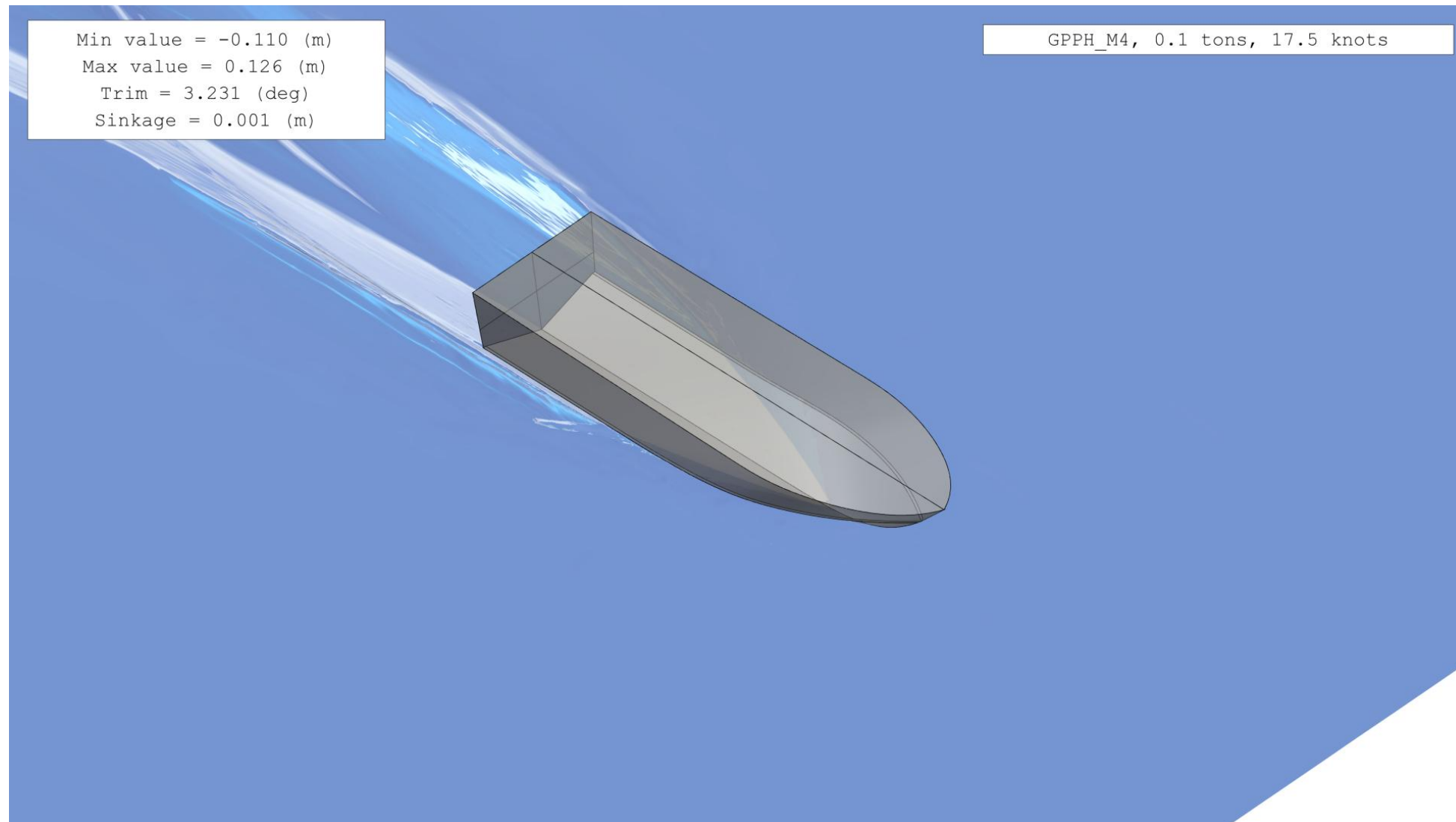
### c. Free surface : $\frac{3}{4}$ front view, realistic rendering



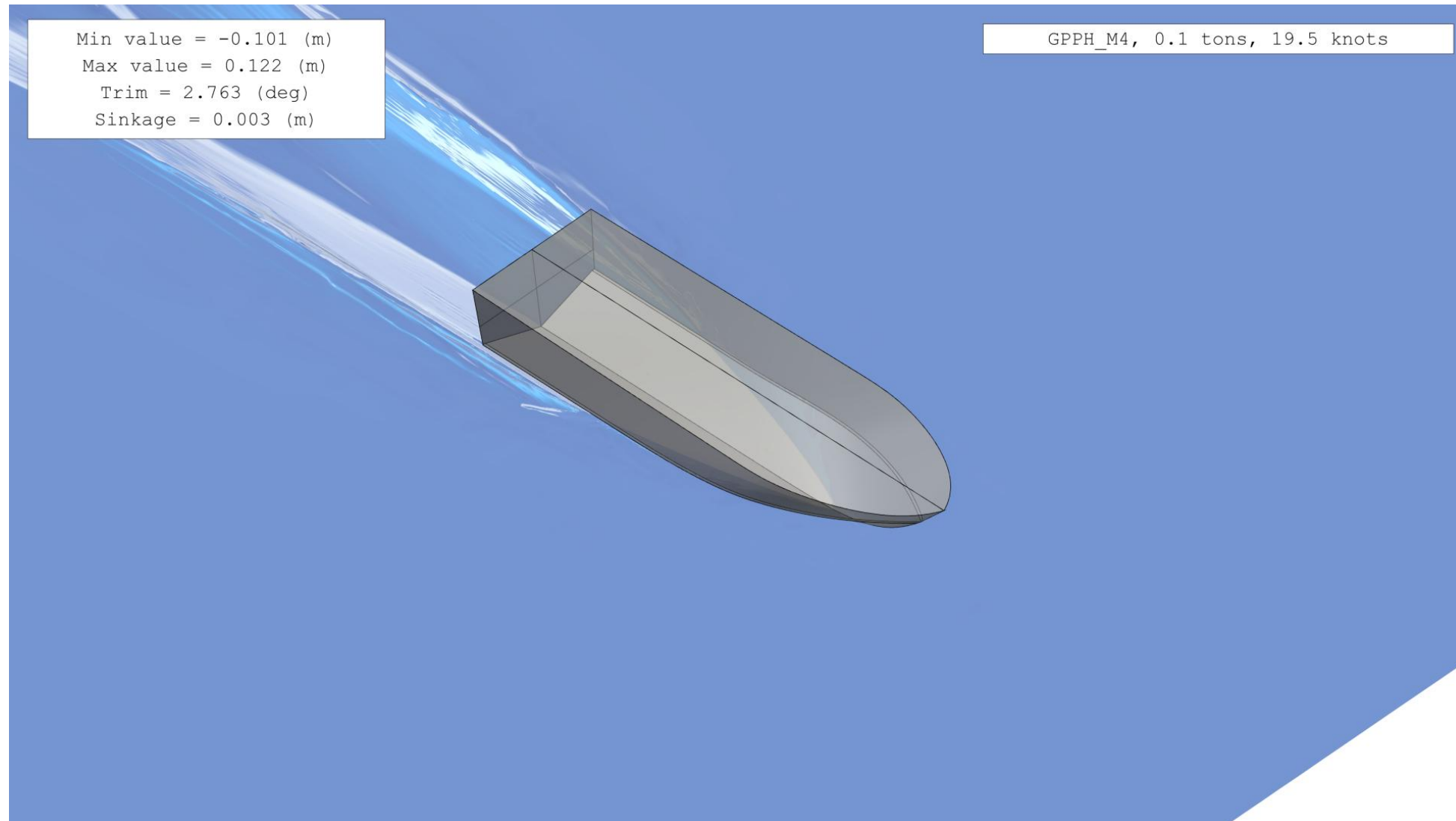
### c. Free surface : $\frac{3}{4}$ front view, realistic rendering



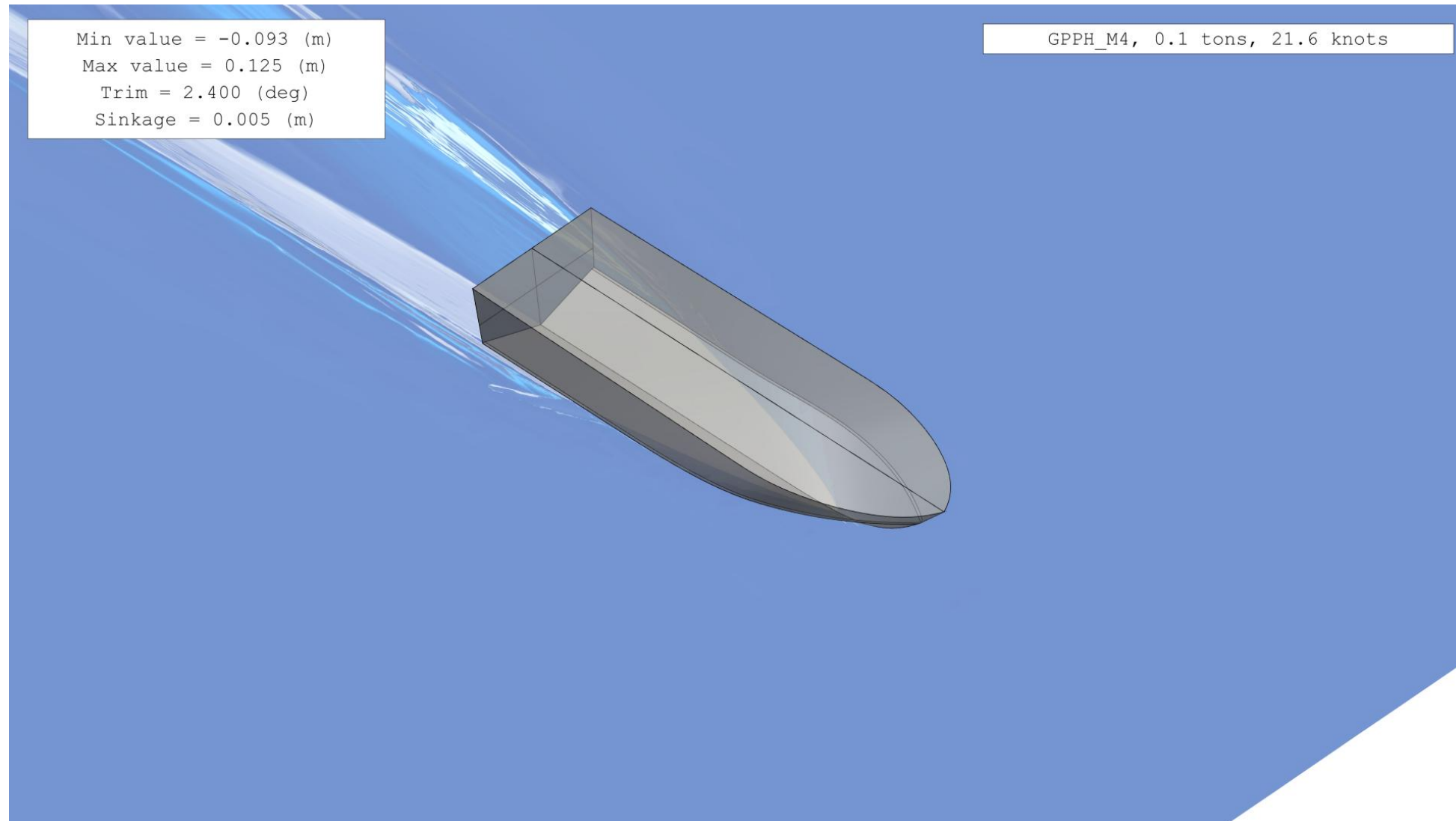
### c. Free surface : $\frac{3}{4}$ front view, realistic rendering



### c. Free surface : $\frac{3}{4}$ front view, realistic rendering

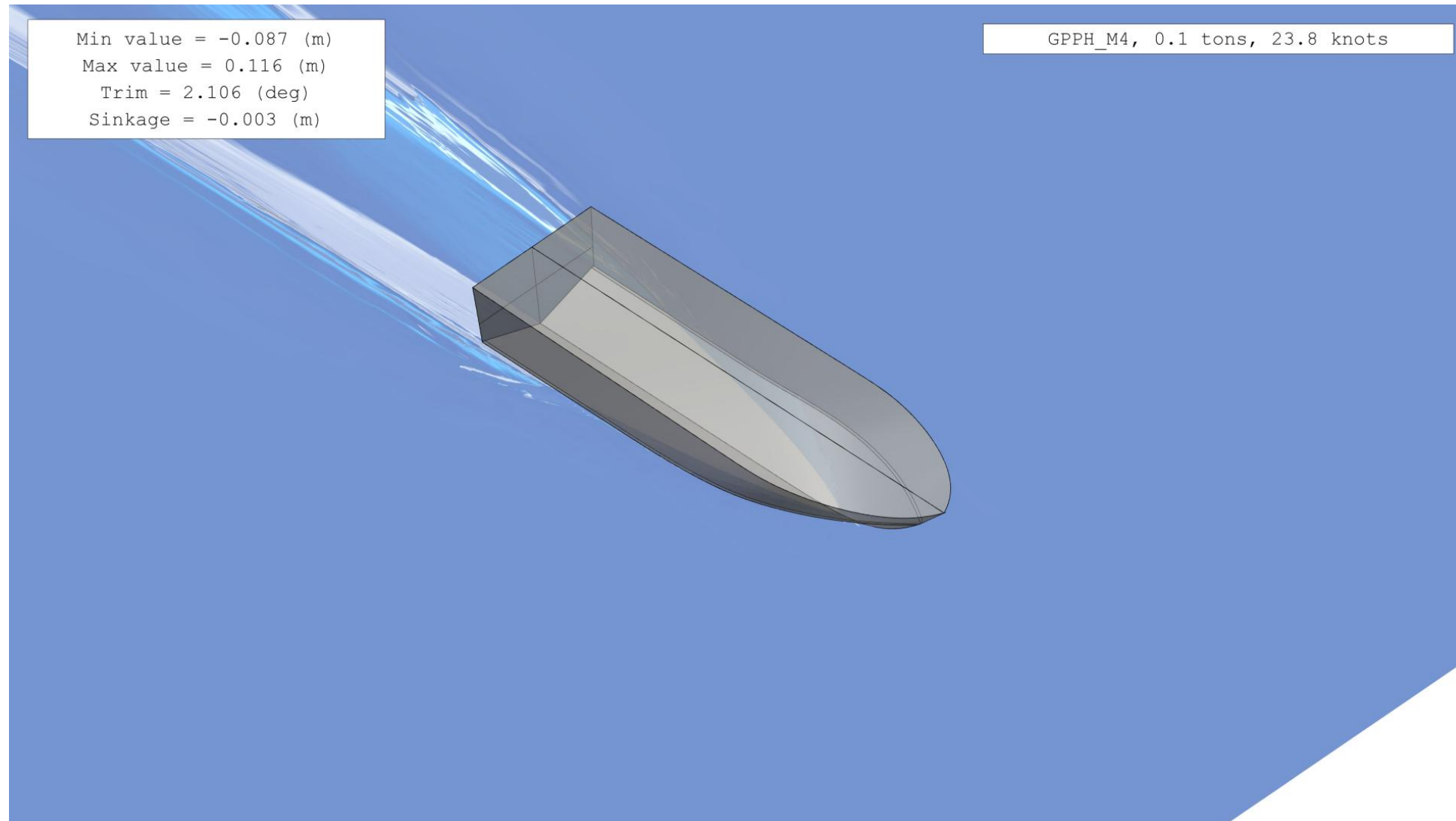


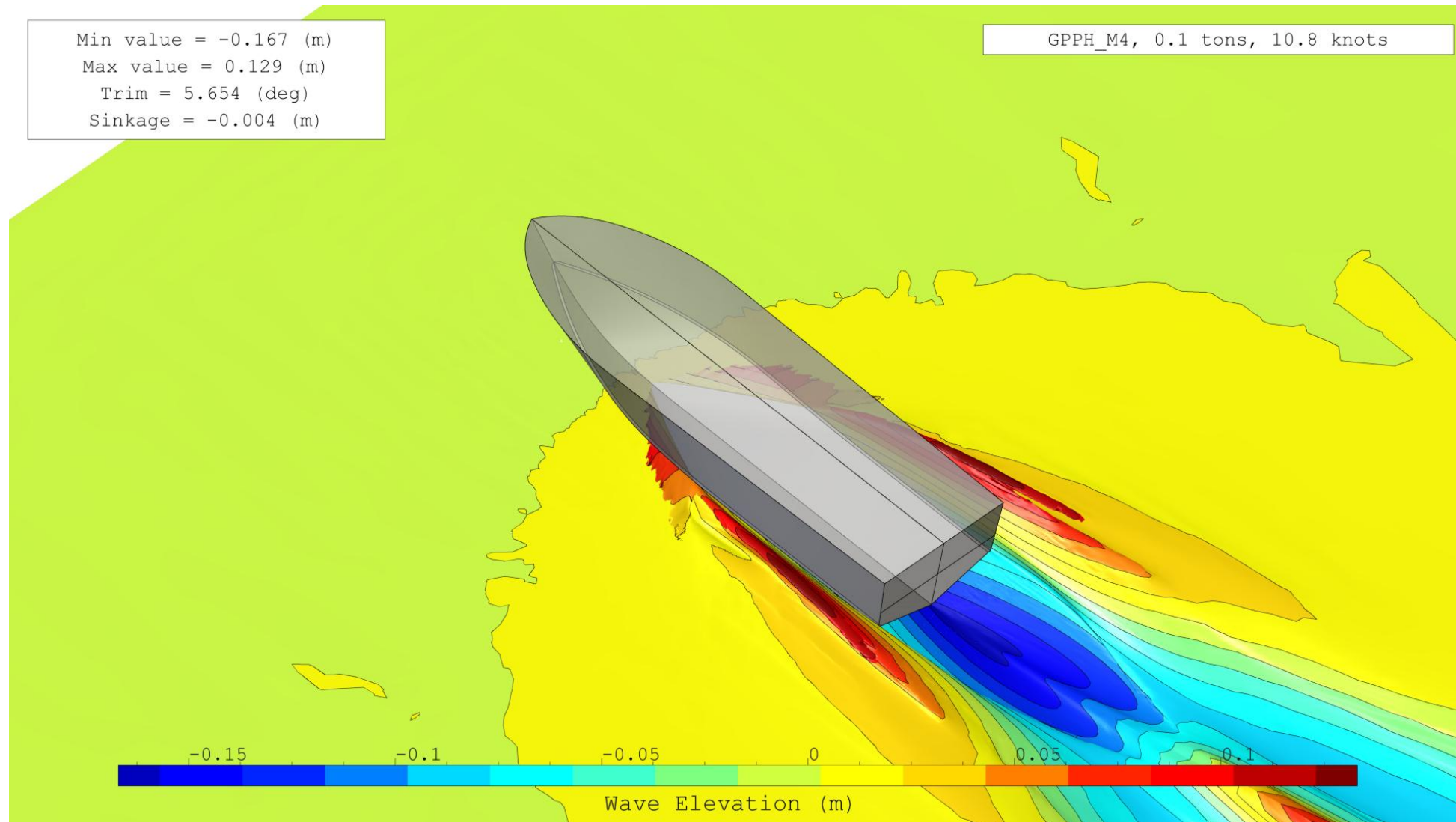
### c. Free surface : $\frac{3}{4}$ front view, realistic rendering

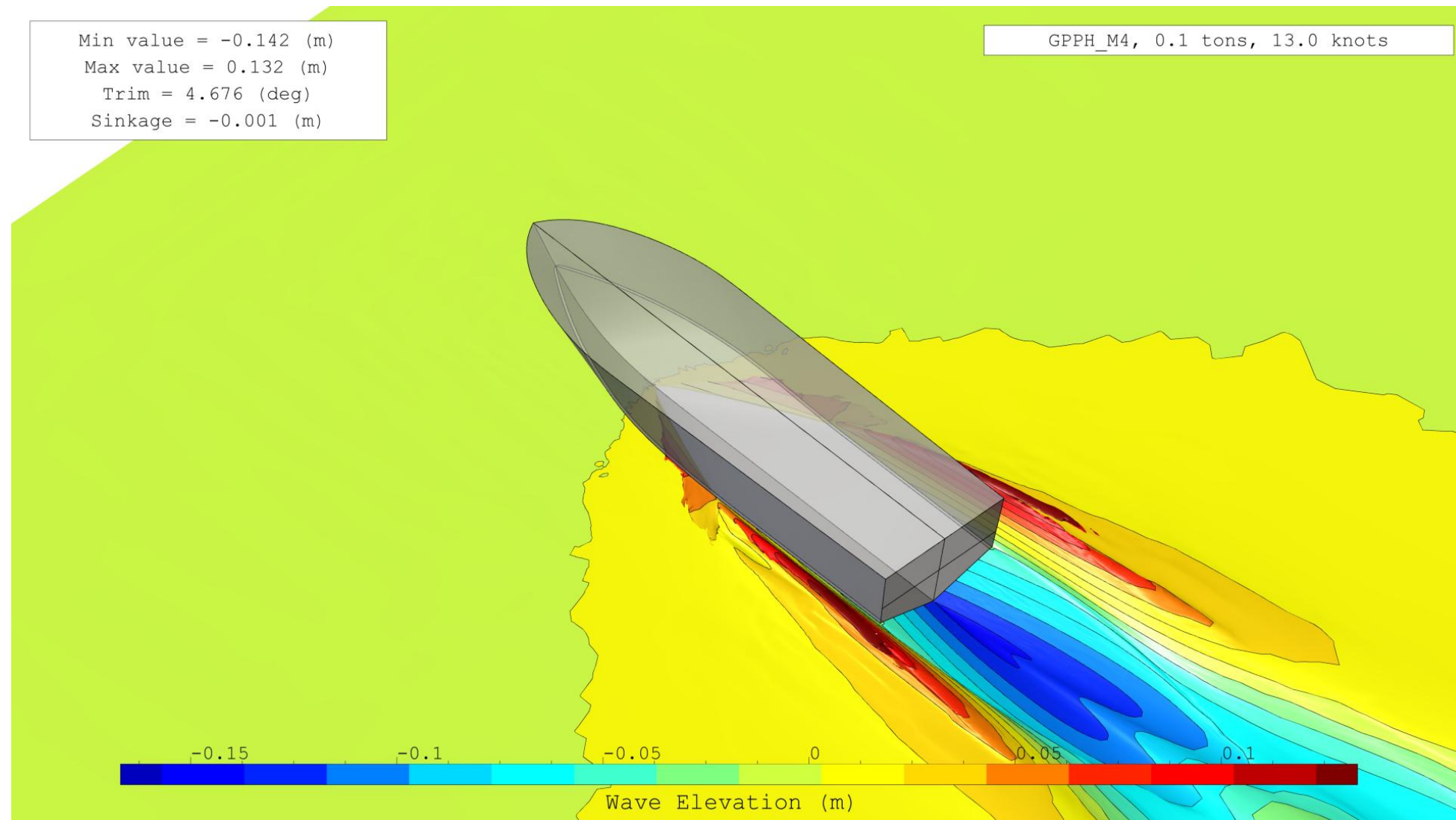


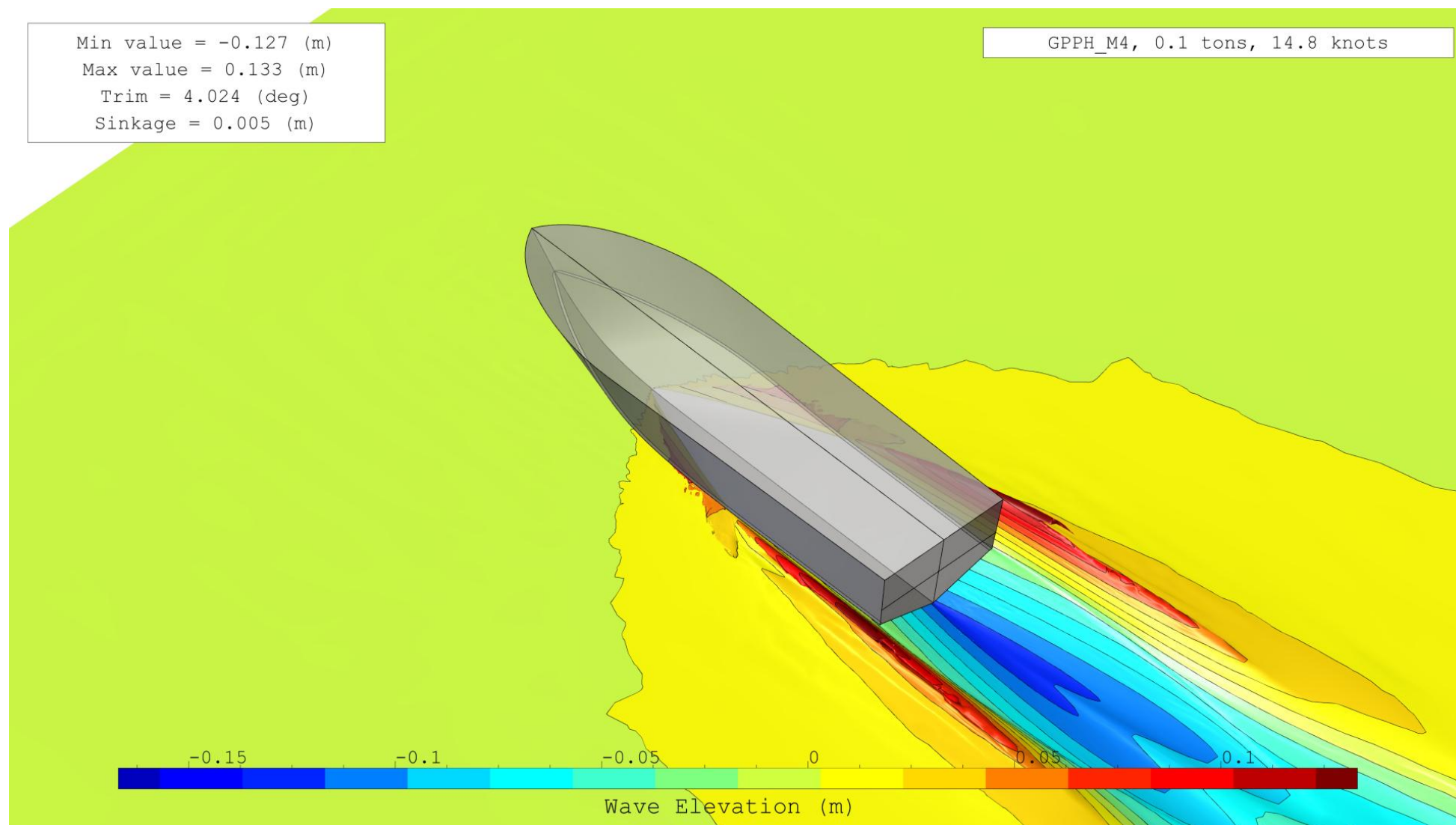


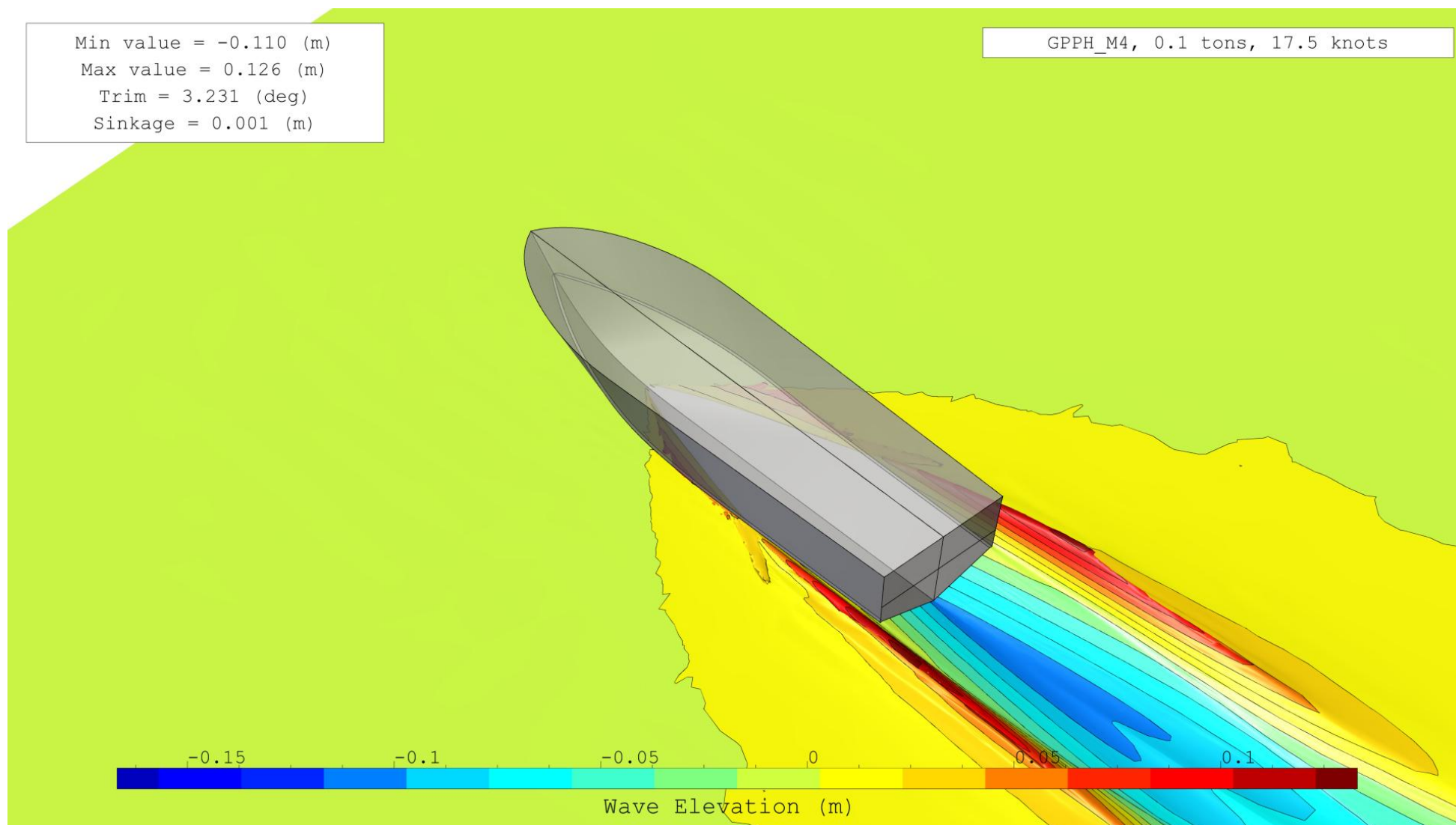
### c. Free surface : $\frac{3}{4}$ front view, realistic rendering



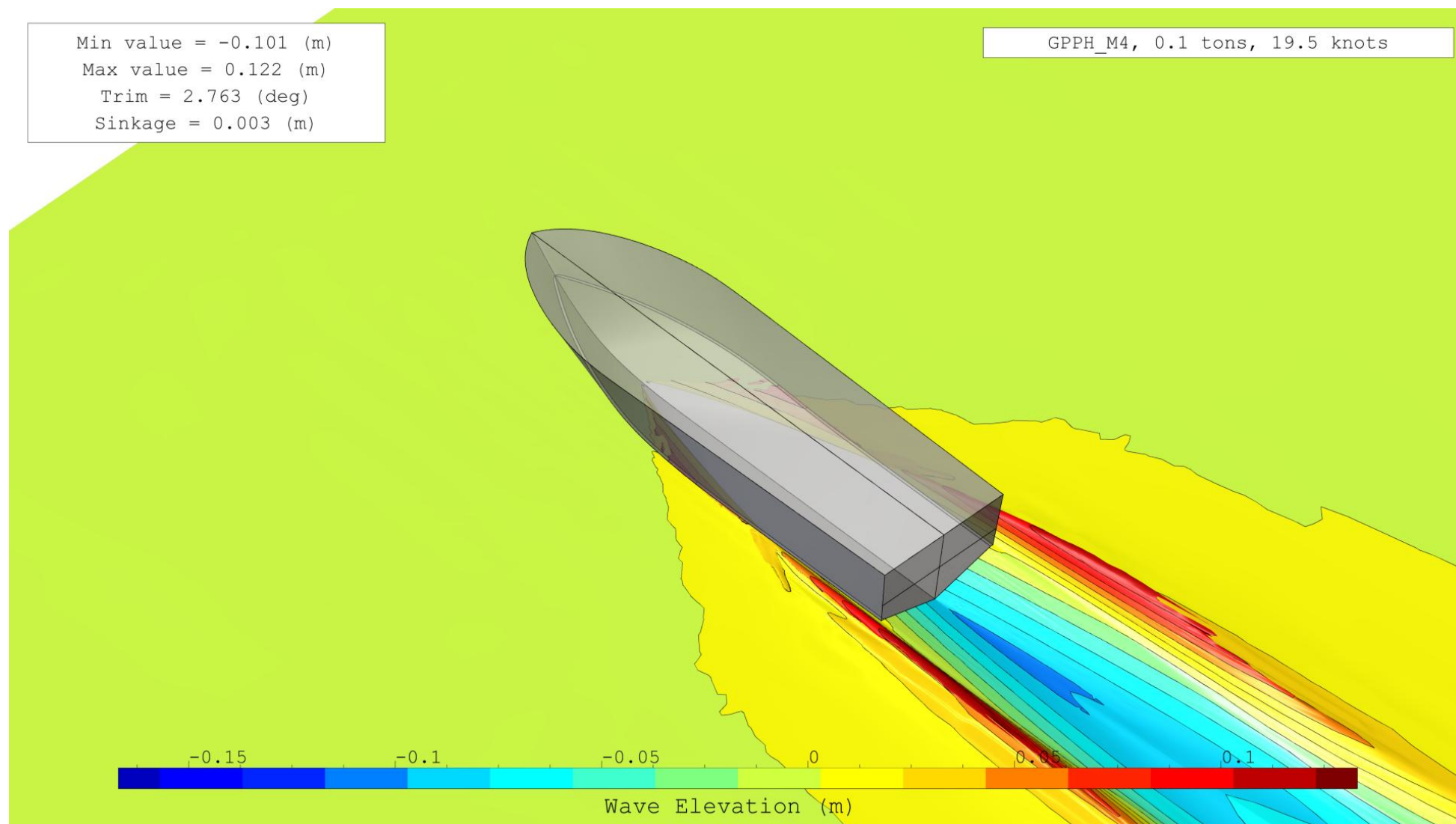
c. Free surface :  $\frac{3}{4}$  rear view (common scale)

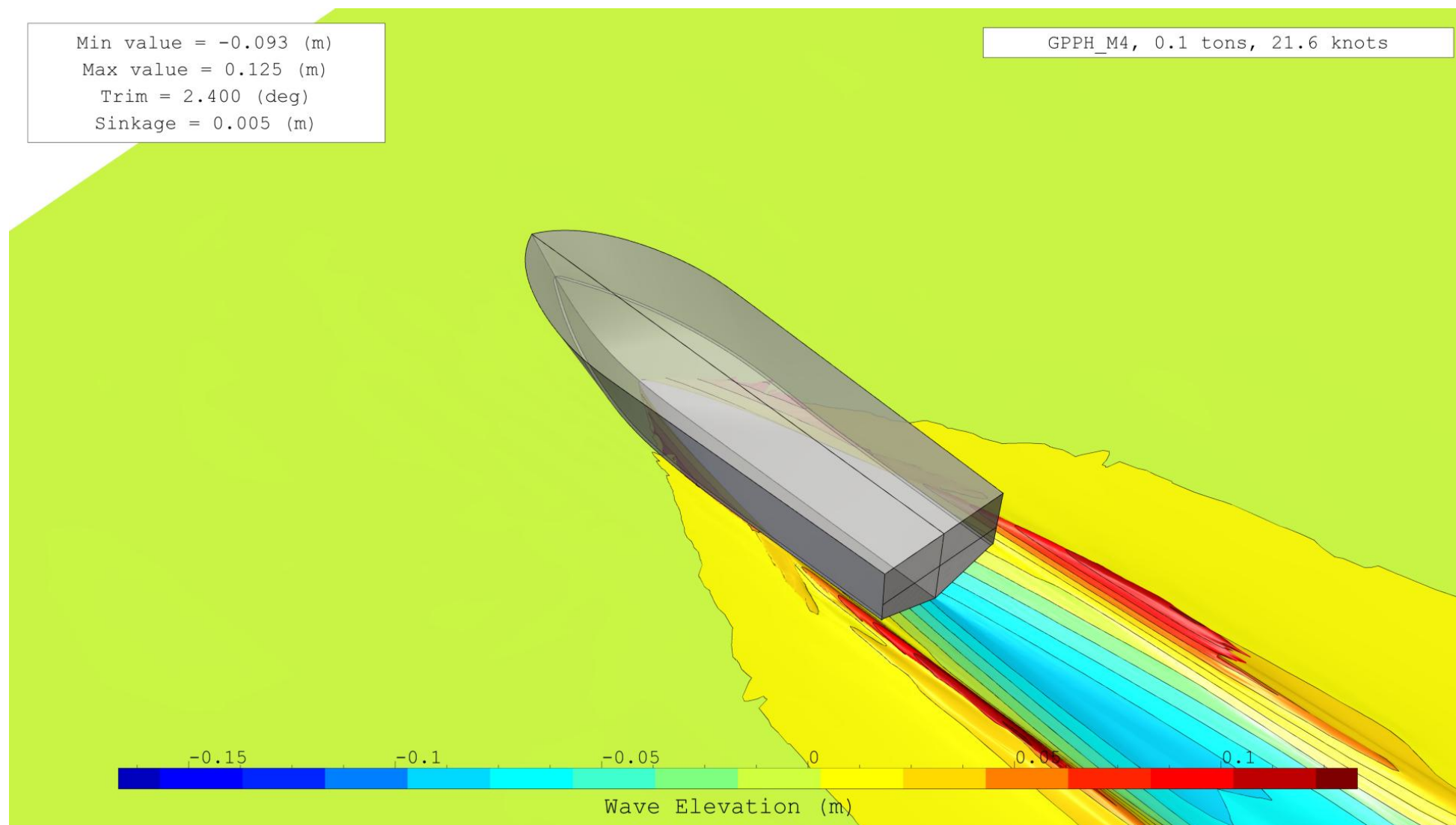
c. Free surface :  $\frac{3}{4}$  rear view (common scale)

c. Free surface :  $\frac{3}{4}$  rear view (common scale)

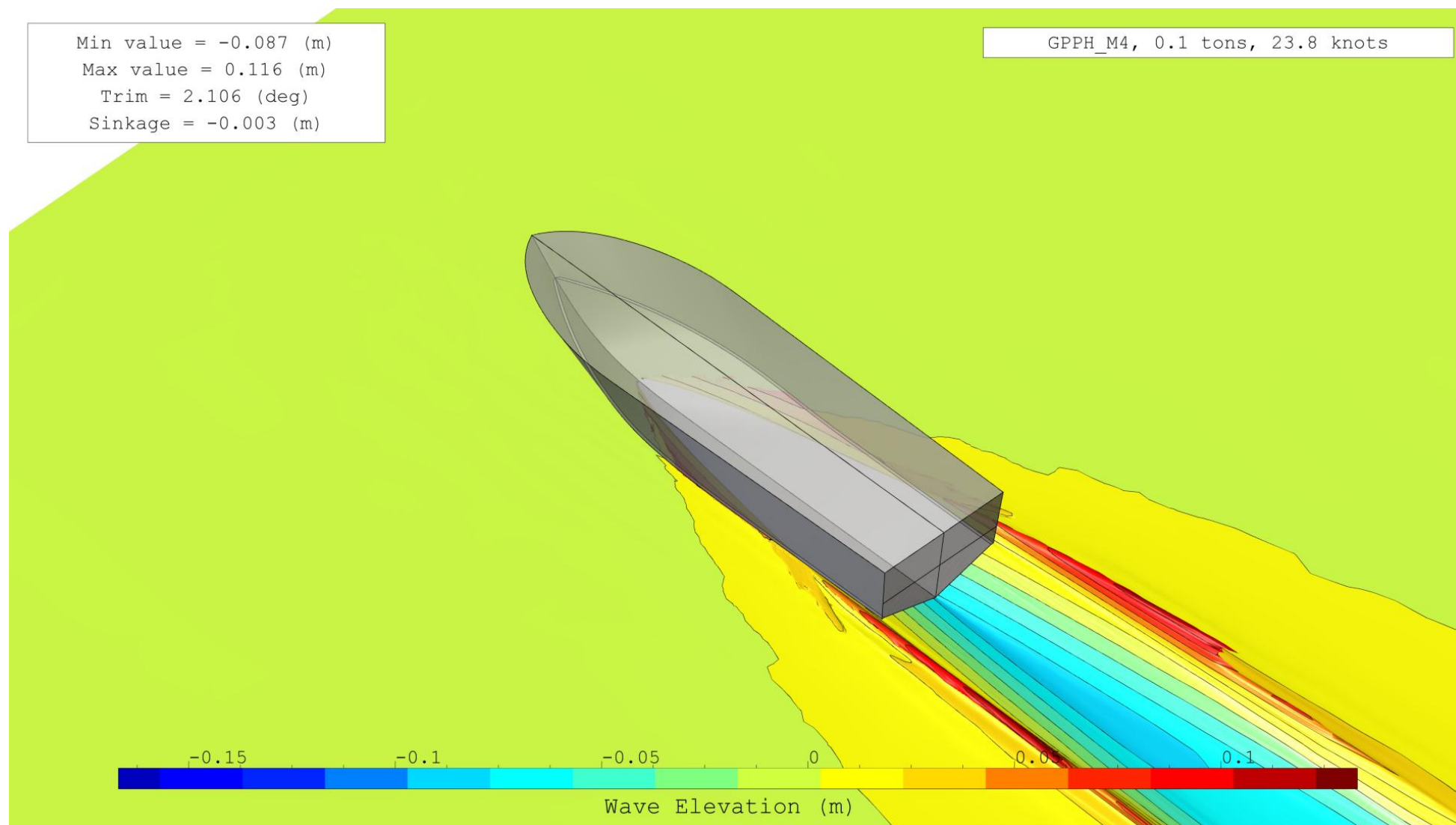
c. Free surface :  $\frac{3}{4}$  rear view (common scale)

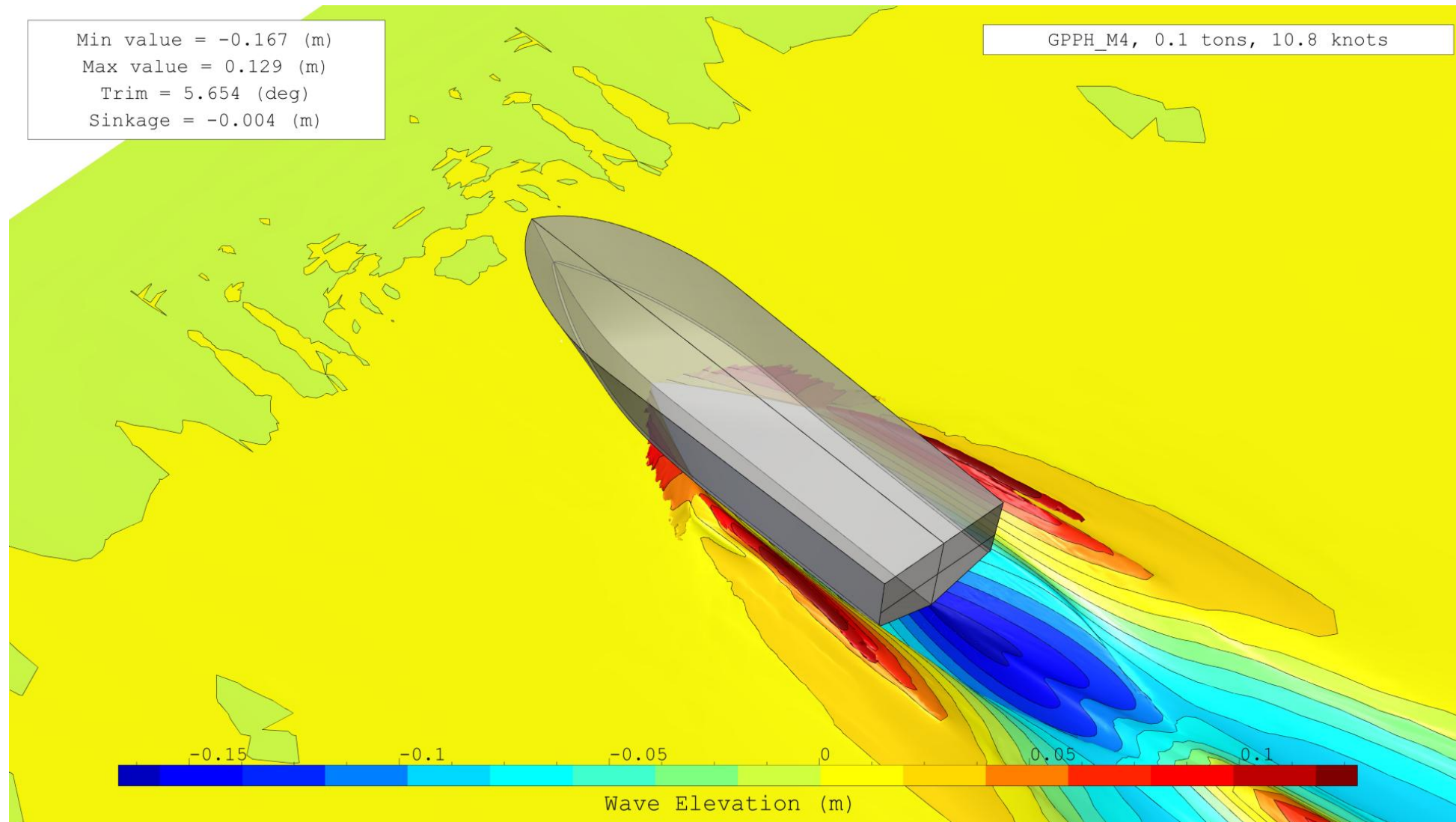


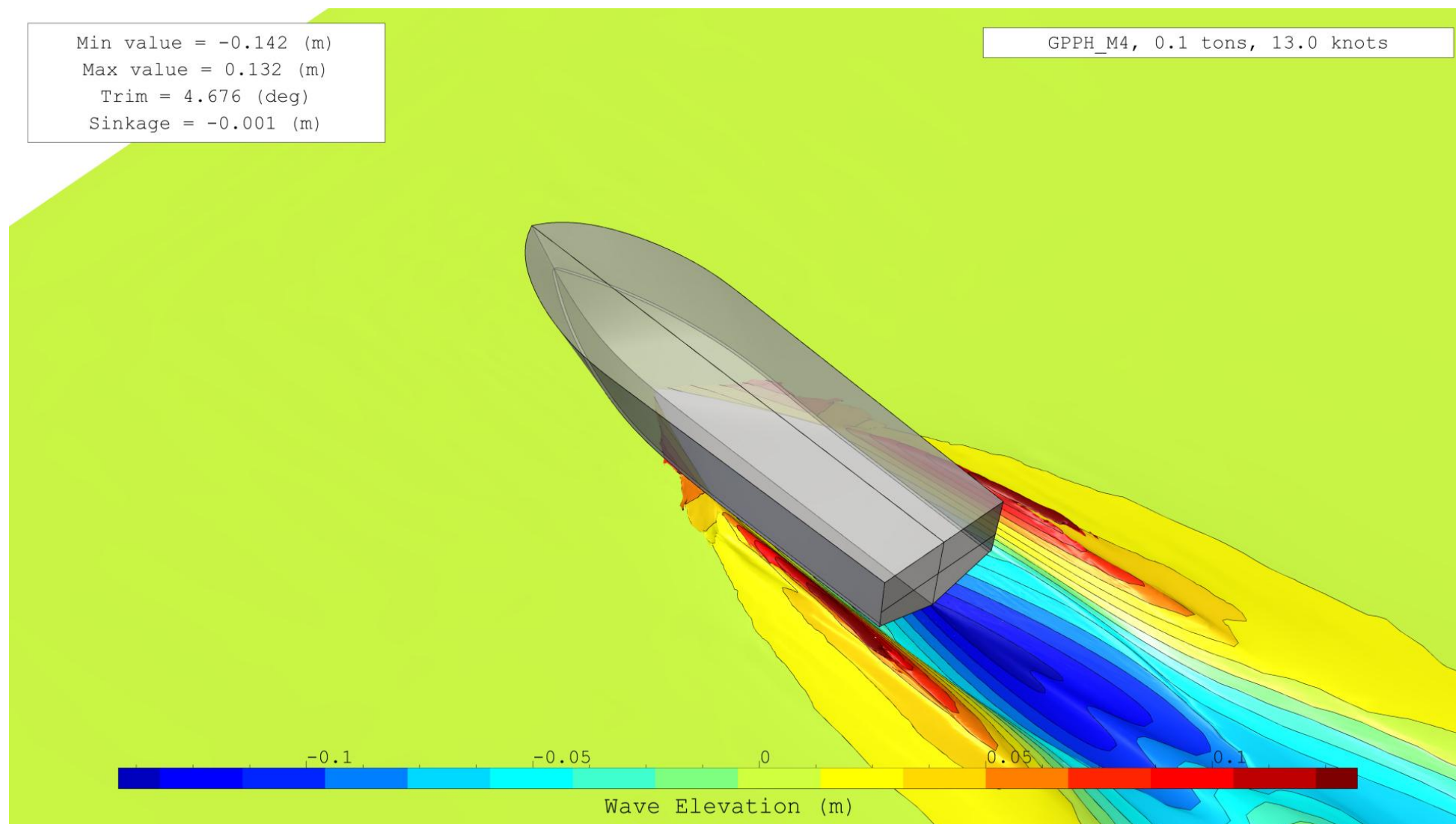
c. Free surface :  $\frac{3}{4}$  rear view (common scale)

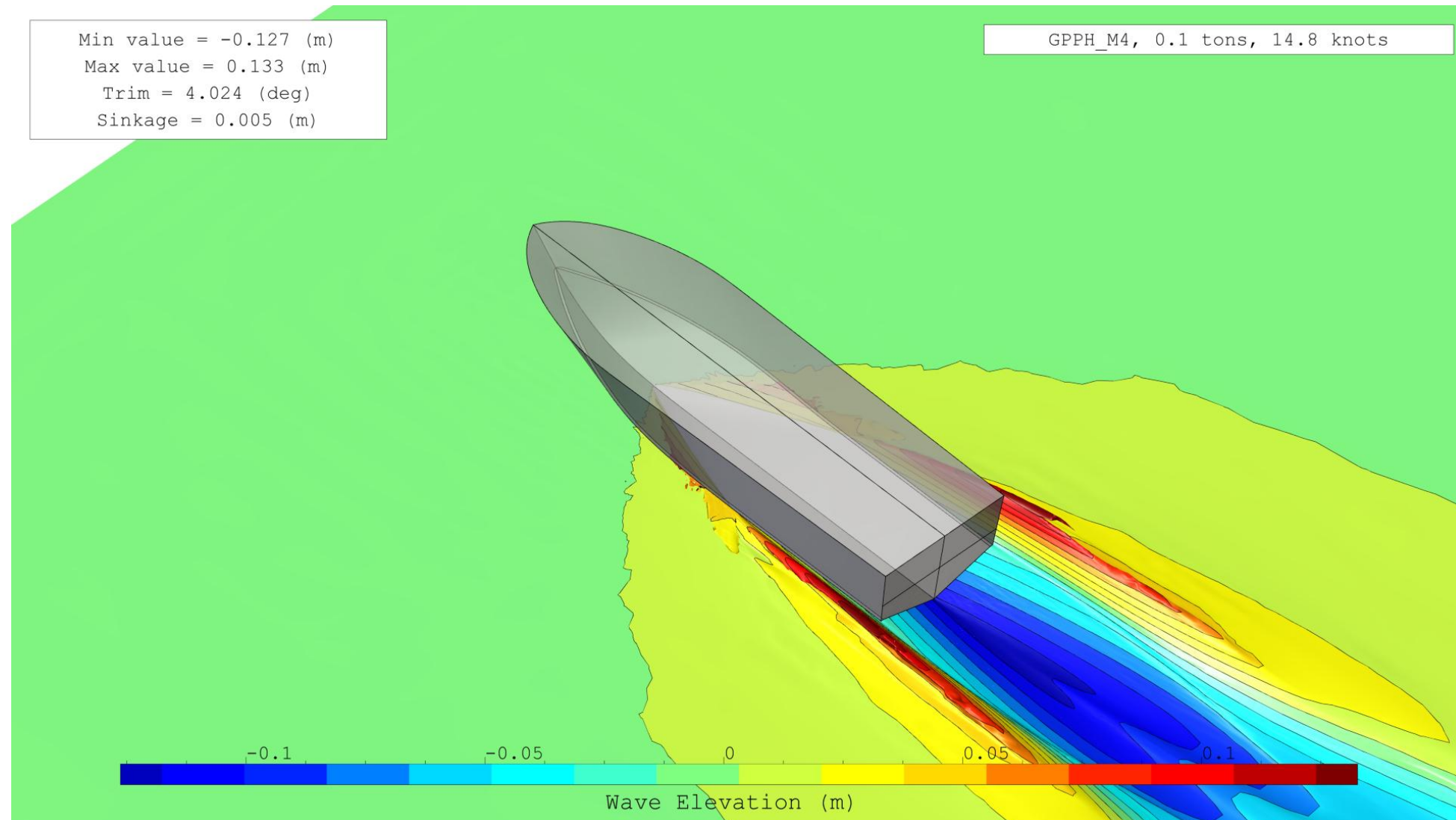
c. Free surface :  $\frac{3}{4}$  rear view (common scale)



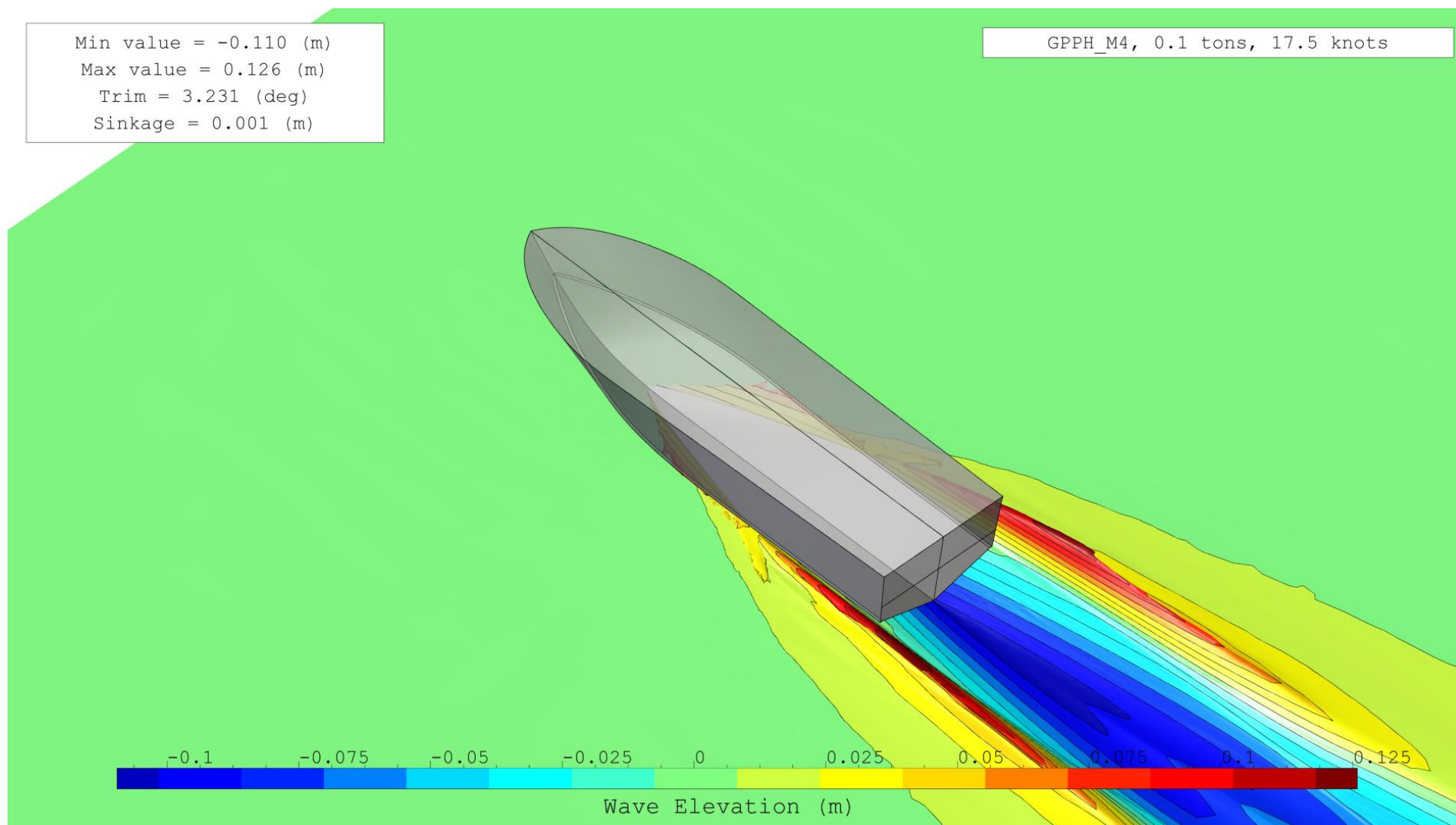
c. Free surface :  $\frac{3}{4}$  rear view (common scale)

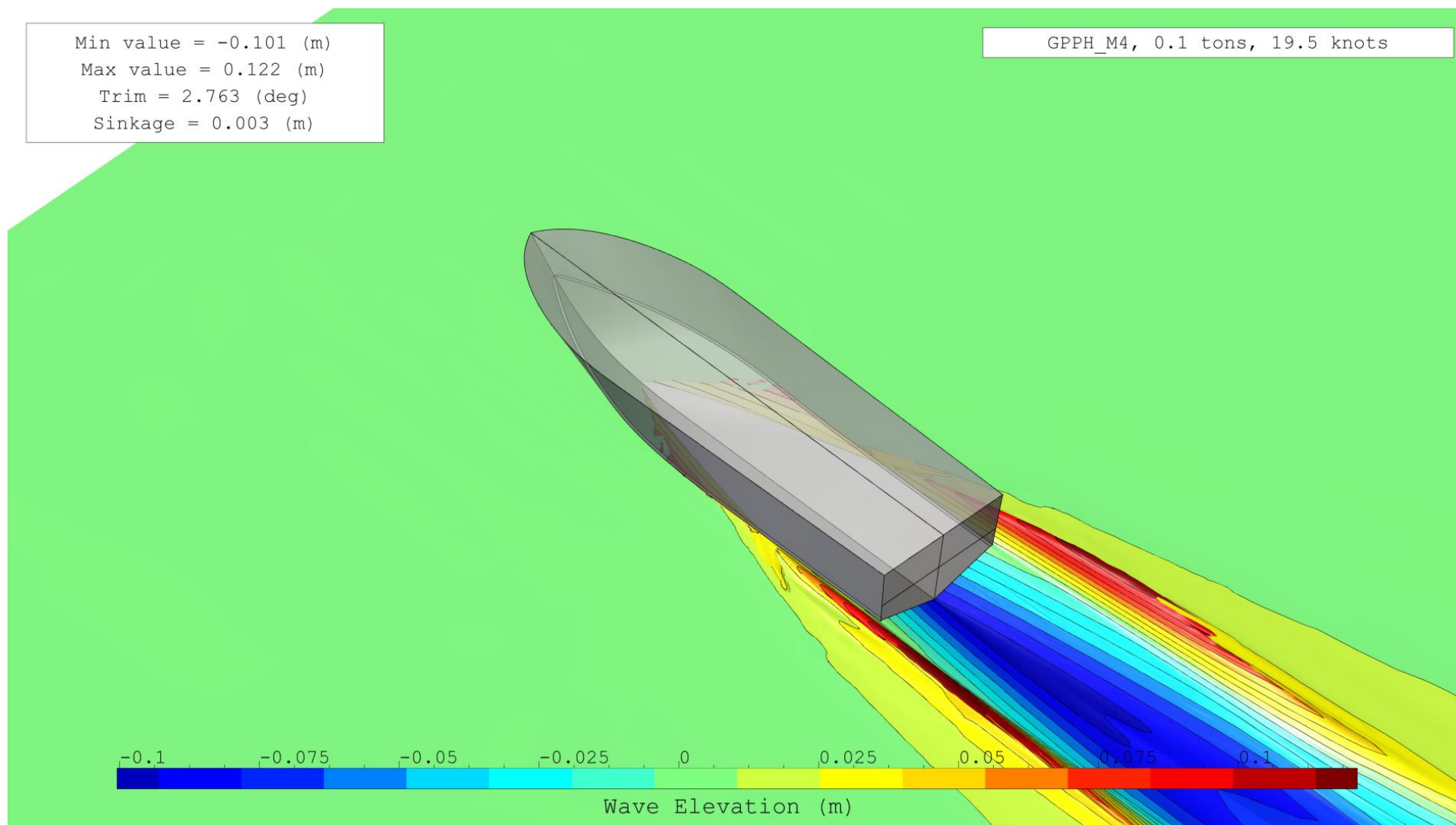
c. Free surface :  $\frac{3}{4}$  rear view (independant scale)

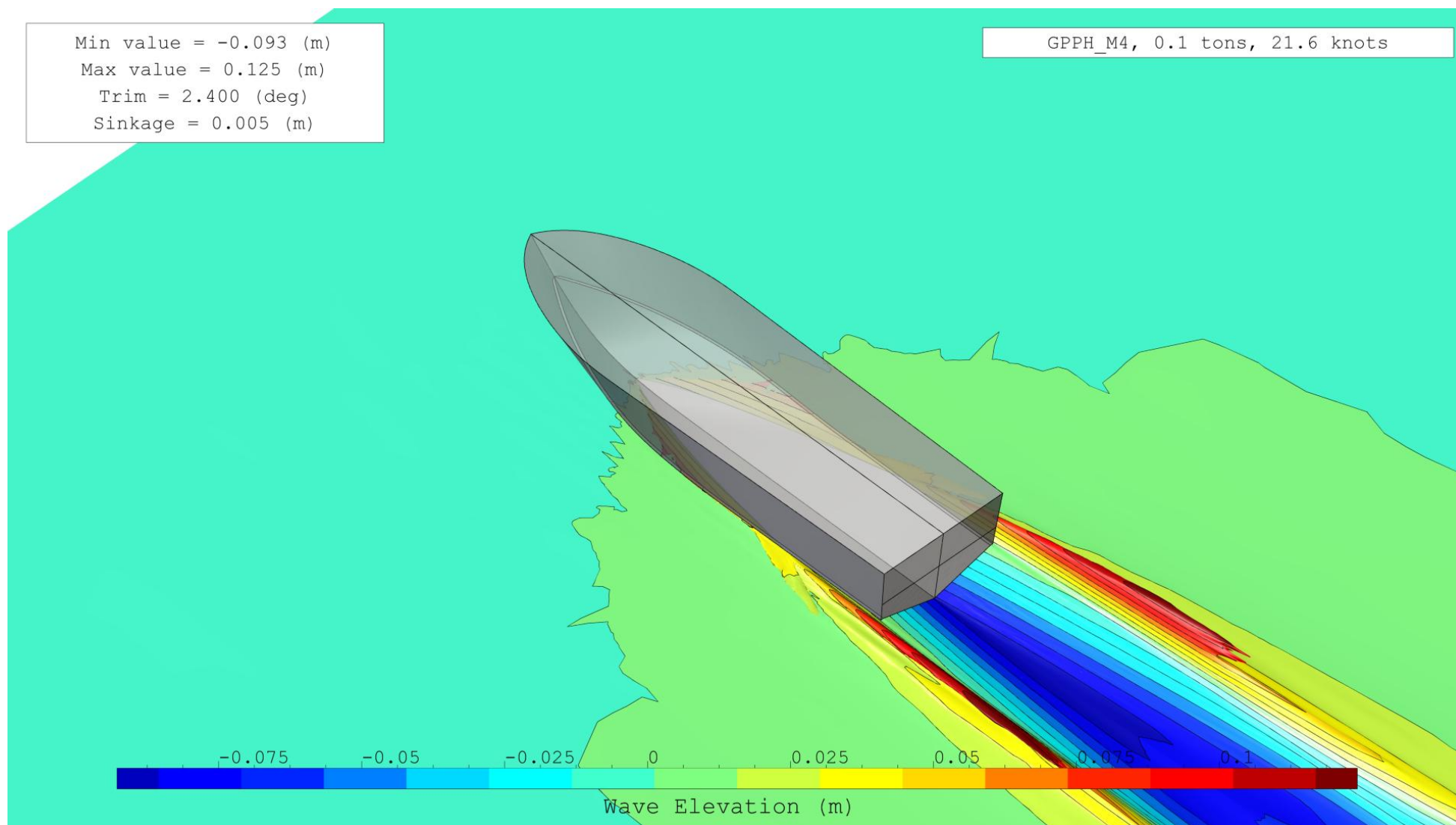
c. Free surface :  $\frac{3}{4}$  rear view (independant scale)

c. Free surface :  $\frac{3}{4}$  rear view (independant scale)

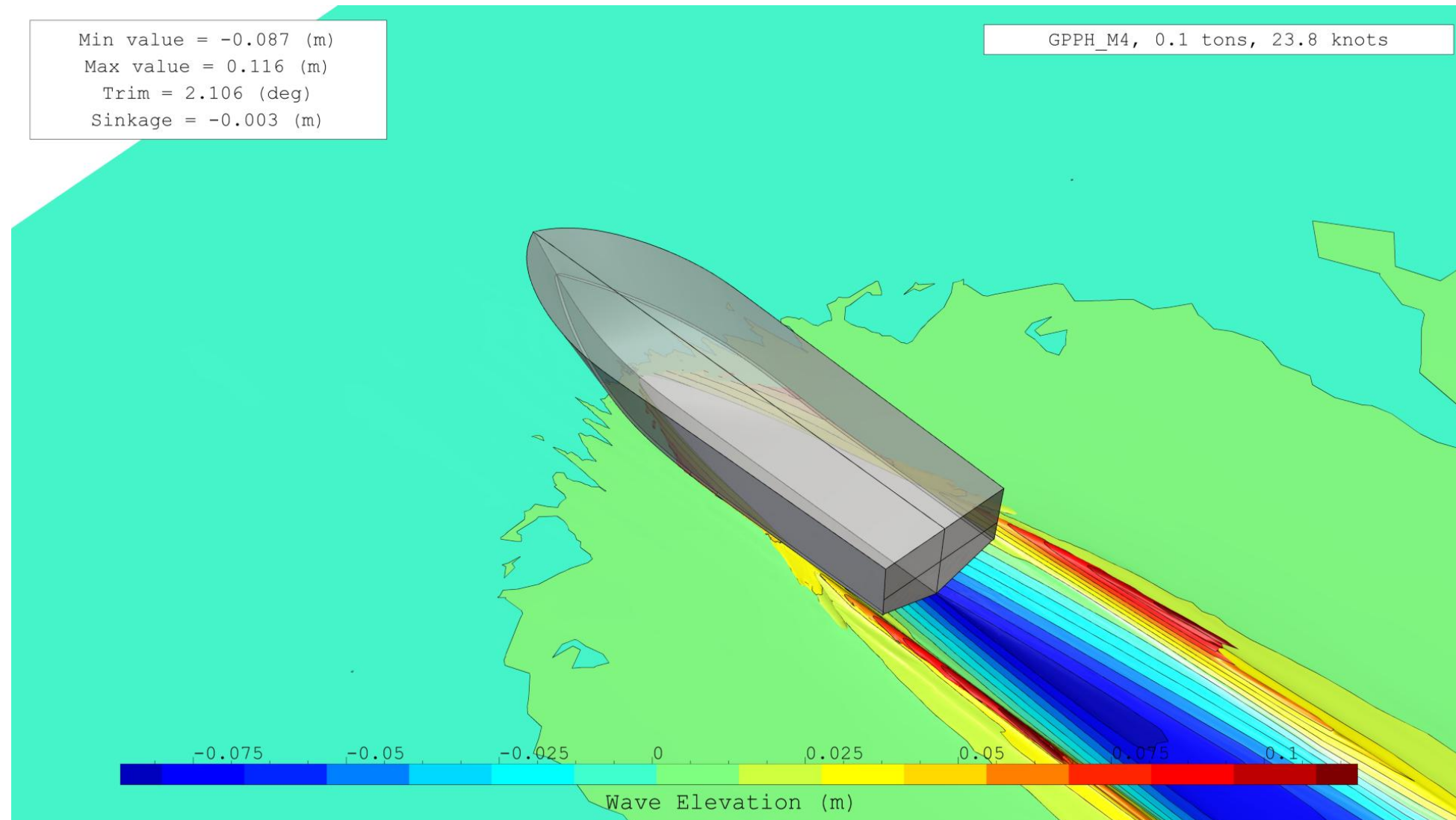


c. Free surface :  $\frac{3}{4}$  rear view (independant scale)

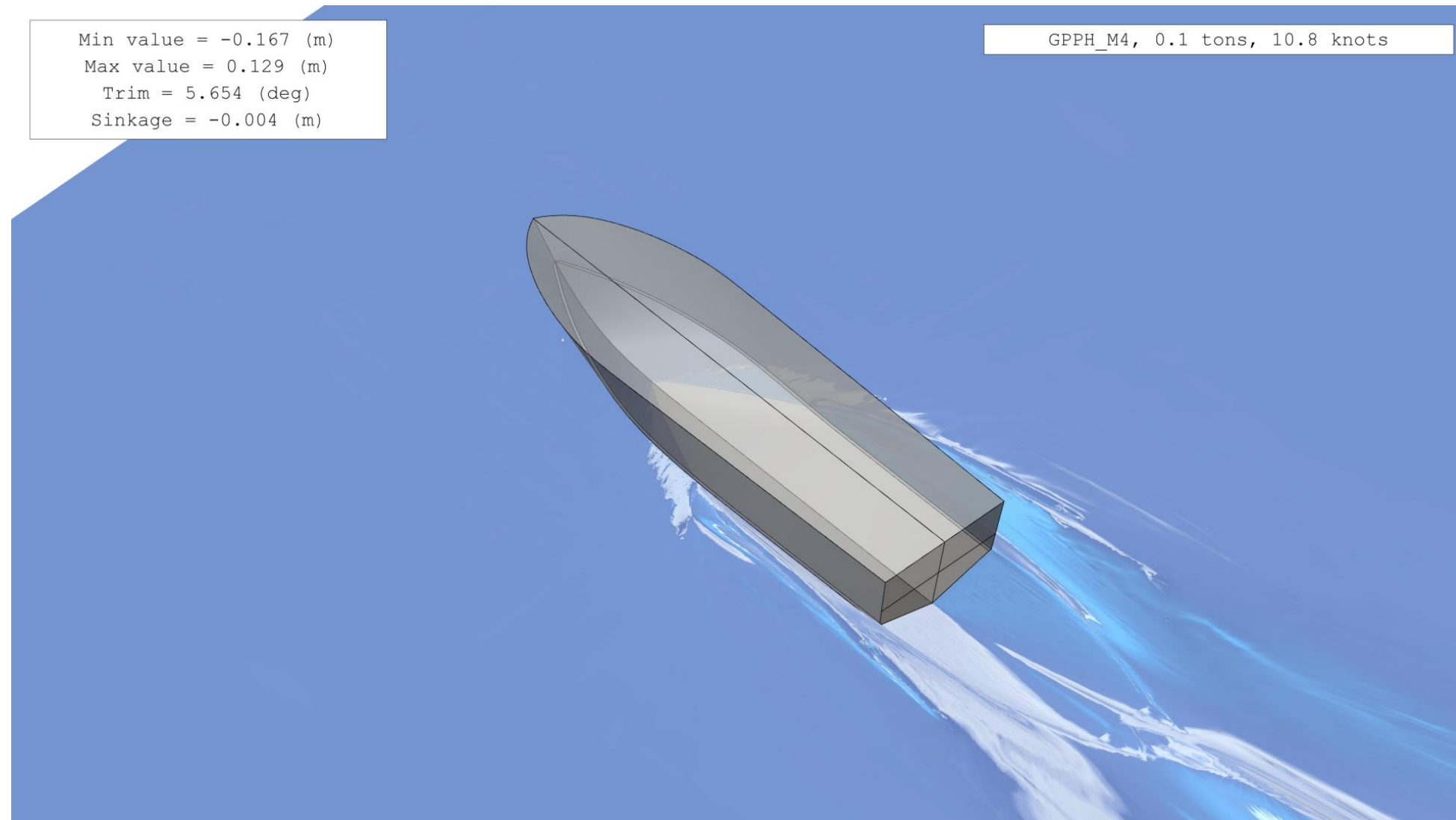
c. Free surface :  $\frac{3}{4}$  rear view (independant scale)

c. Free surface :  $\frac{3}{4}$  rear view (independant scale)

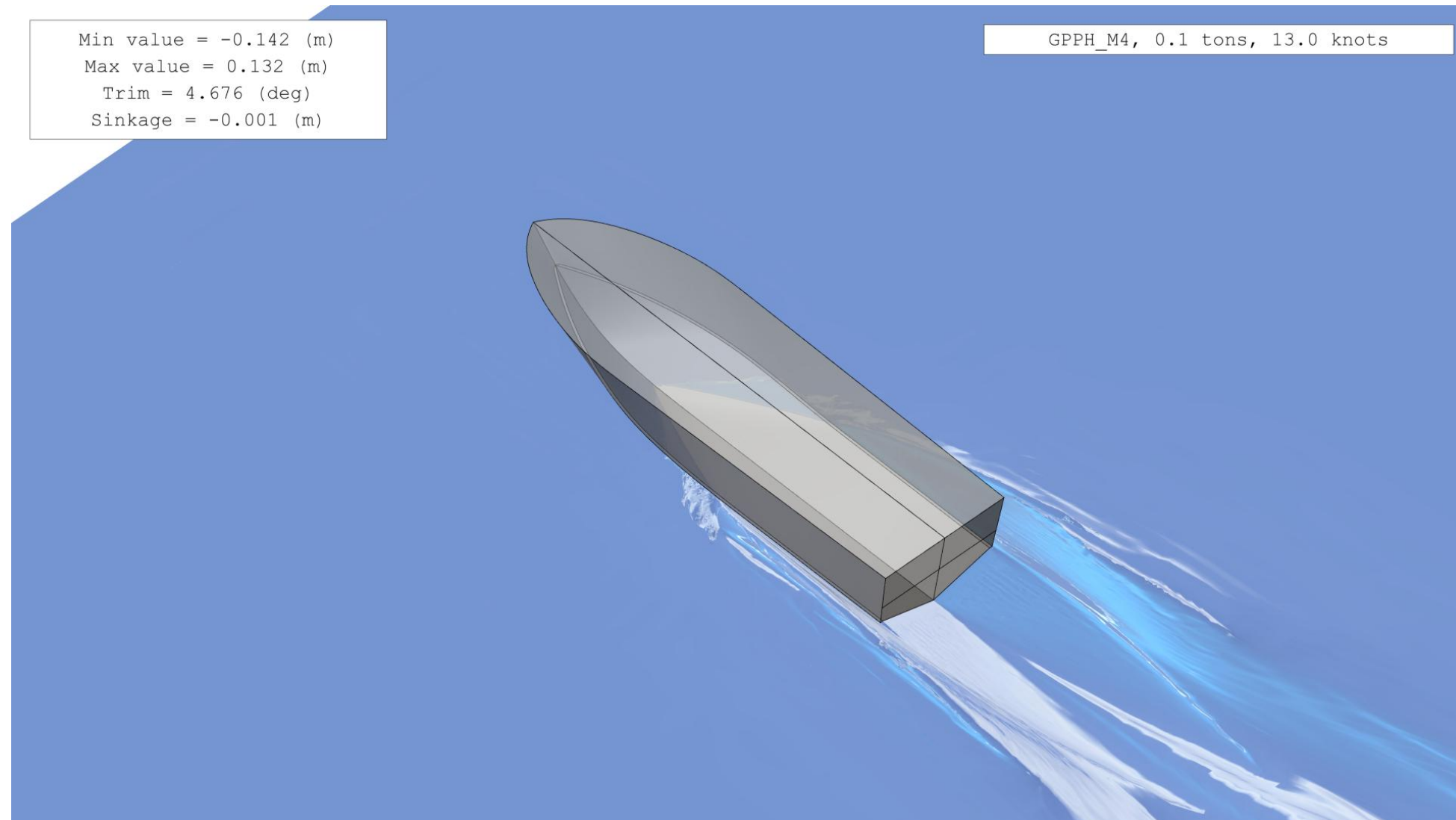


c. Free surface :  $\frac{3}{4}$  rear view (independant scale)

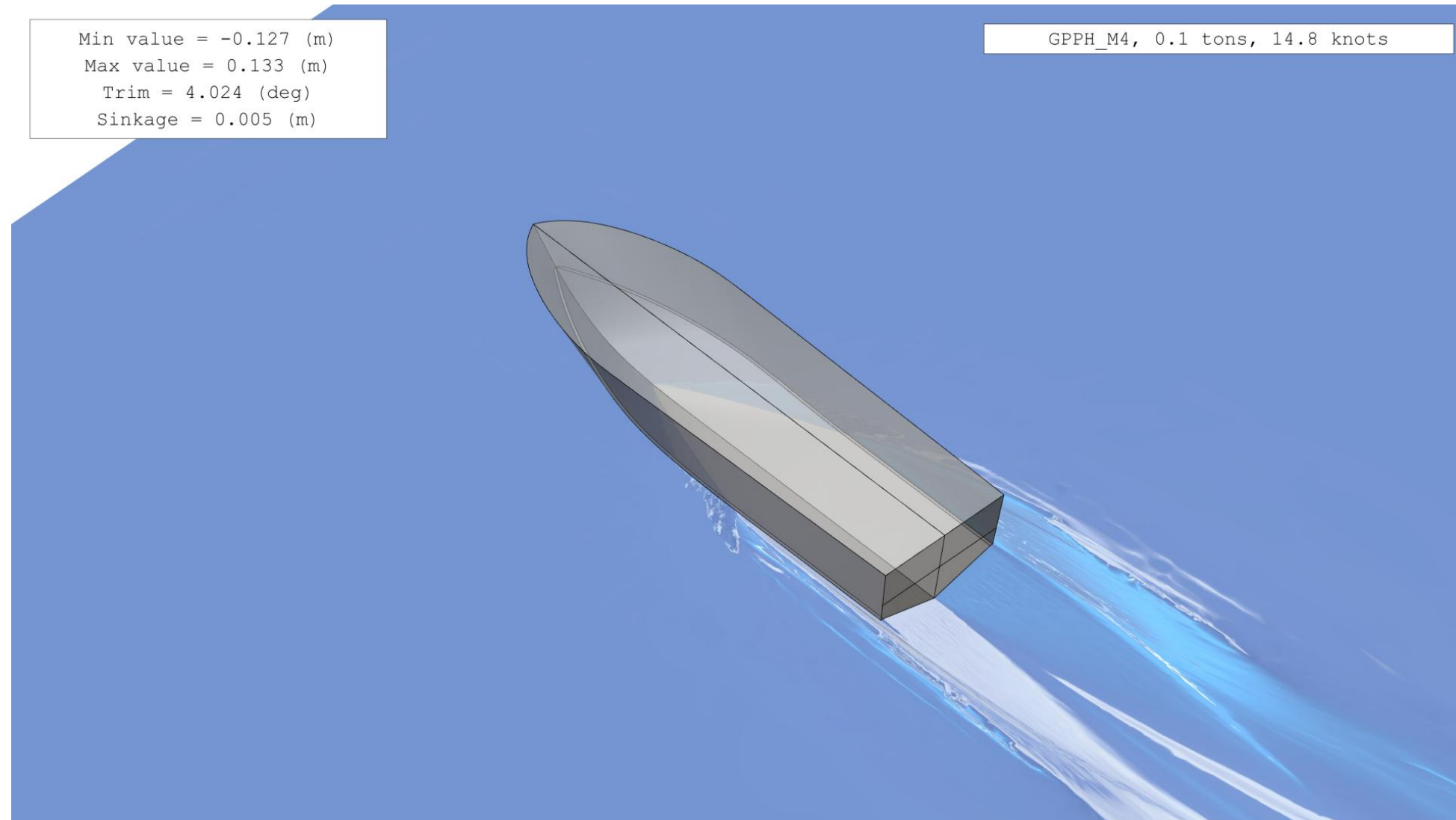
### c. Free surface : $\frac{3}{4}$ rear view, realistic rendering



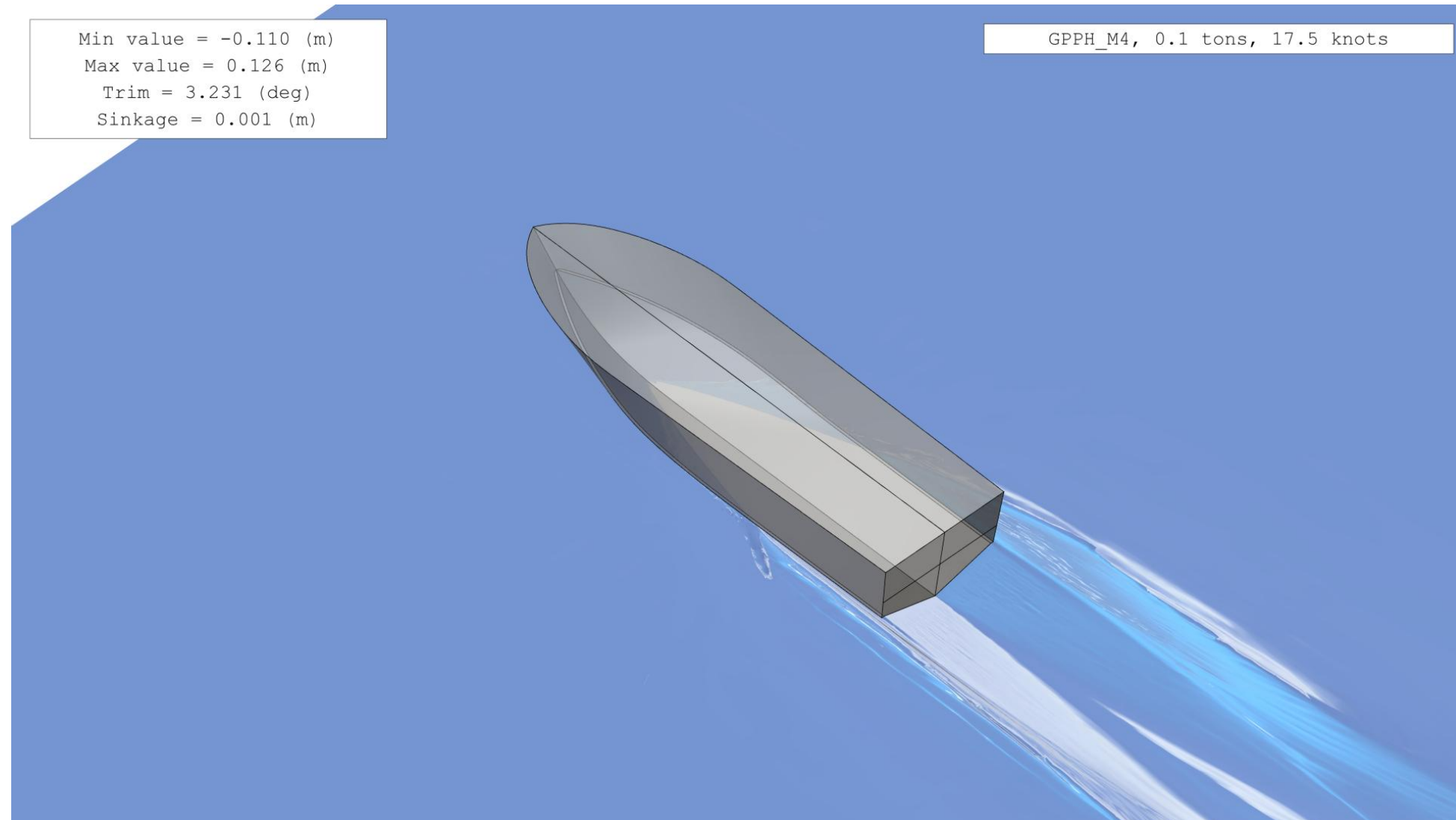
### c. Free surface : $\frac{3}{4}$ rear view, realistic rendering



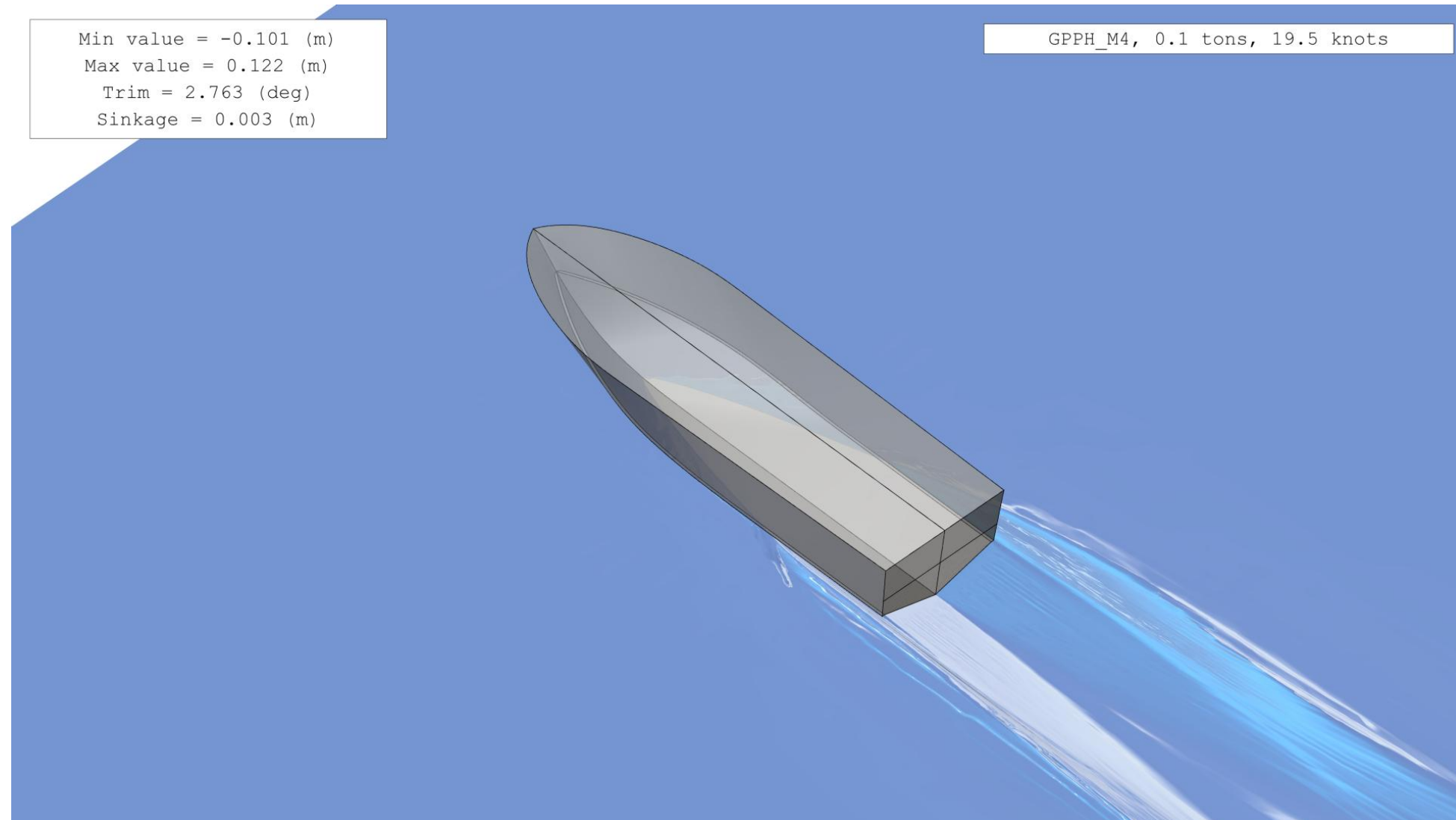
### c. Free surface : $\frac{3}{4}$ rear view, realistic rendering



### c. Free surface : $\frac{3}{4}$ rear view, realistic rendering

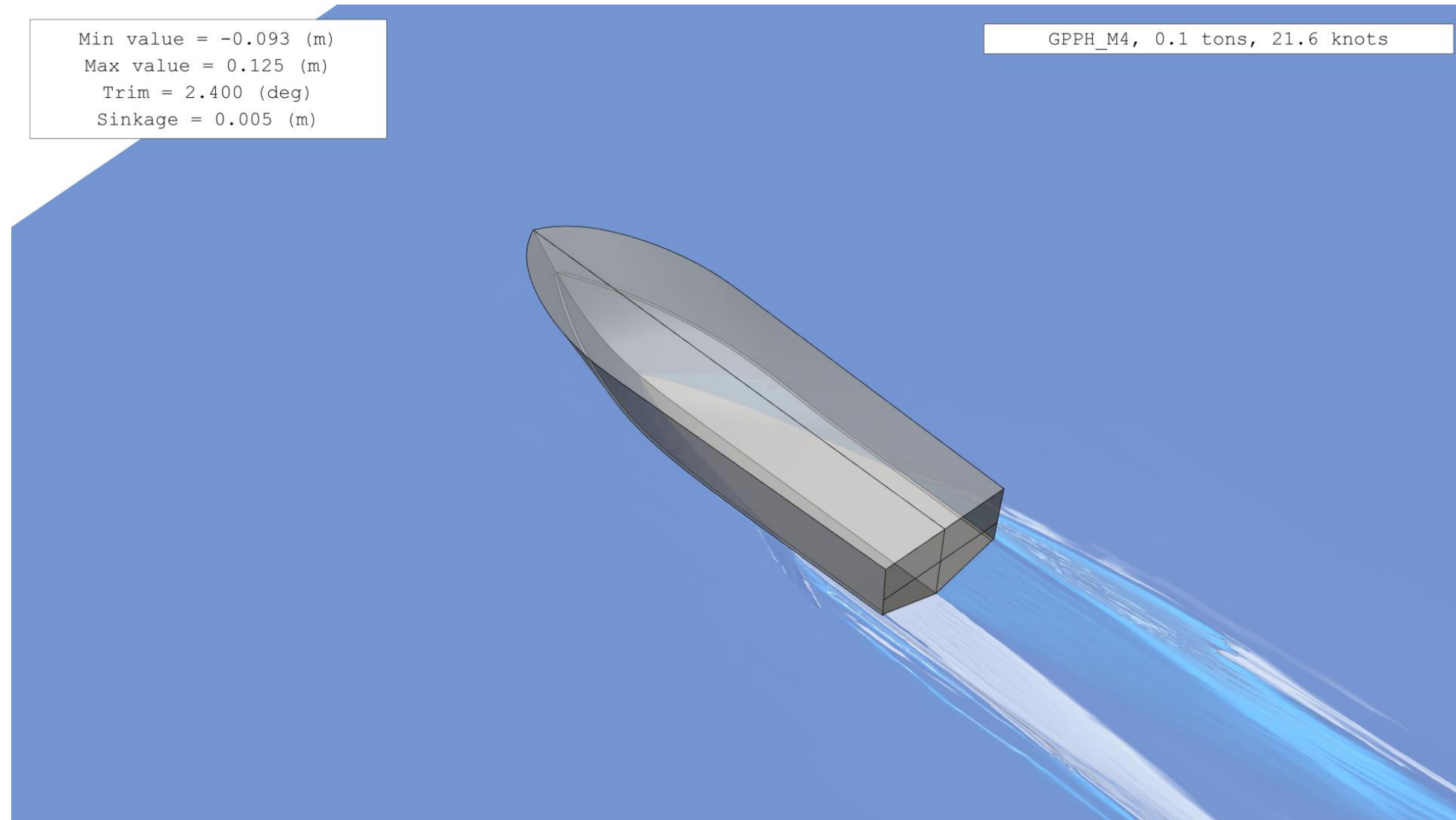


### c. Free surface : $\frac{3}{4}$ rear view, realistic rendering



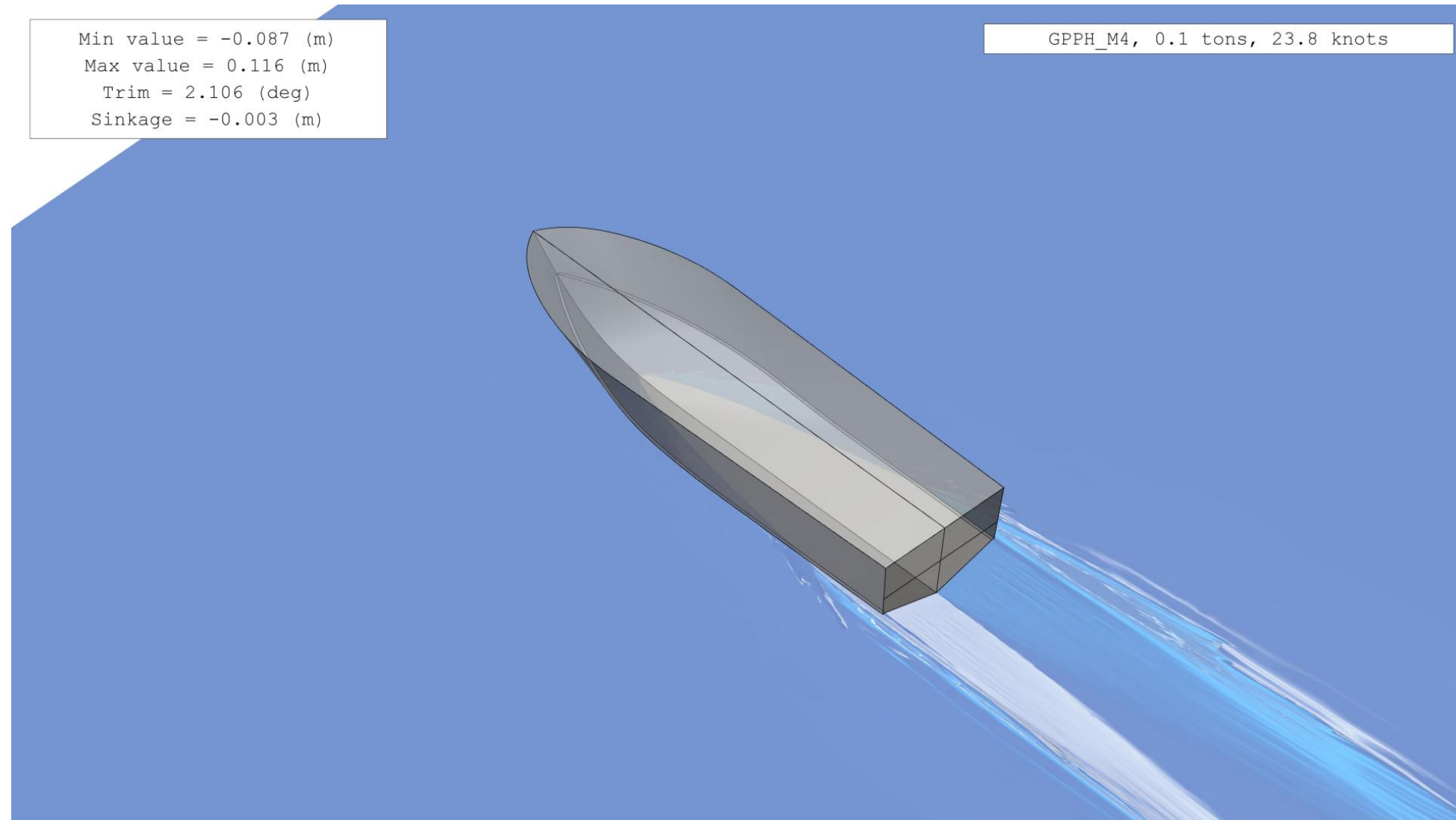


### c. Free surface : $\frac{3}{4}$ rear view, realistic rendering

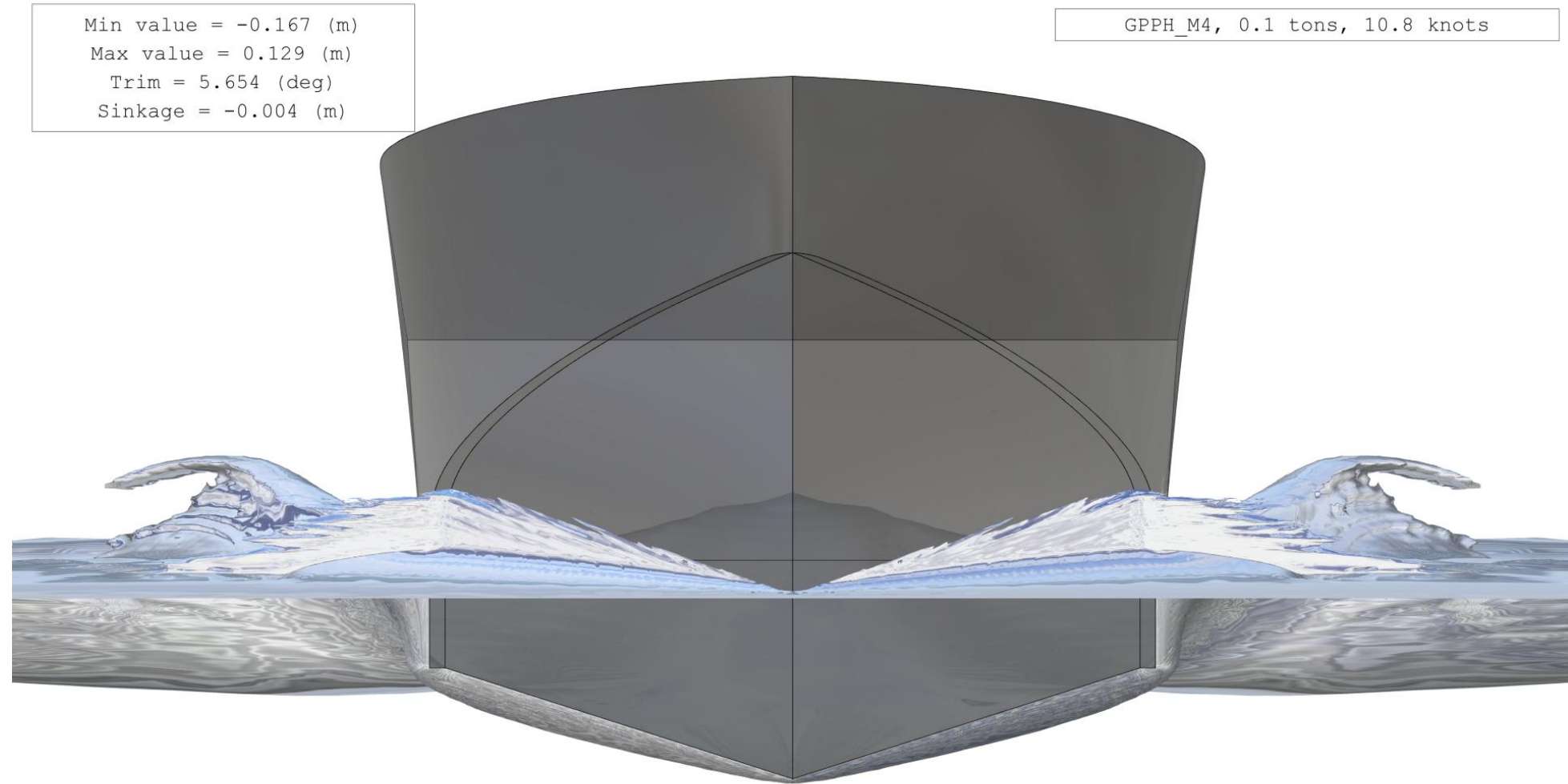




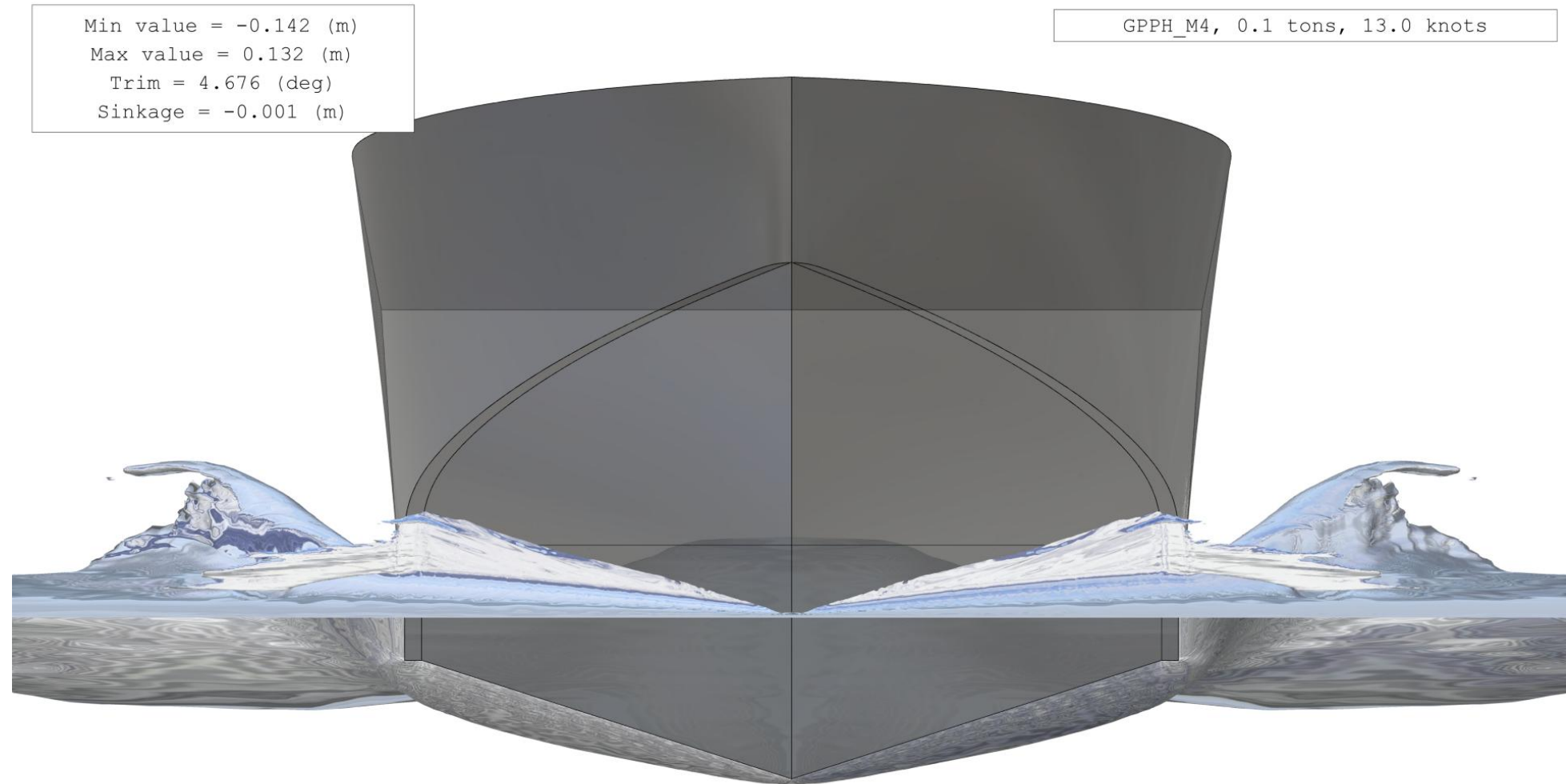
### c. Free surface : $\frac{3}{4}$ rear view, realistic rendering



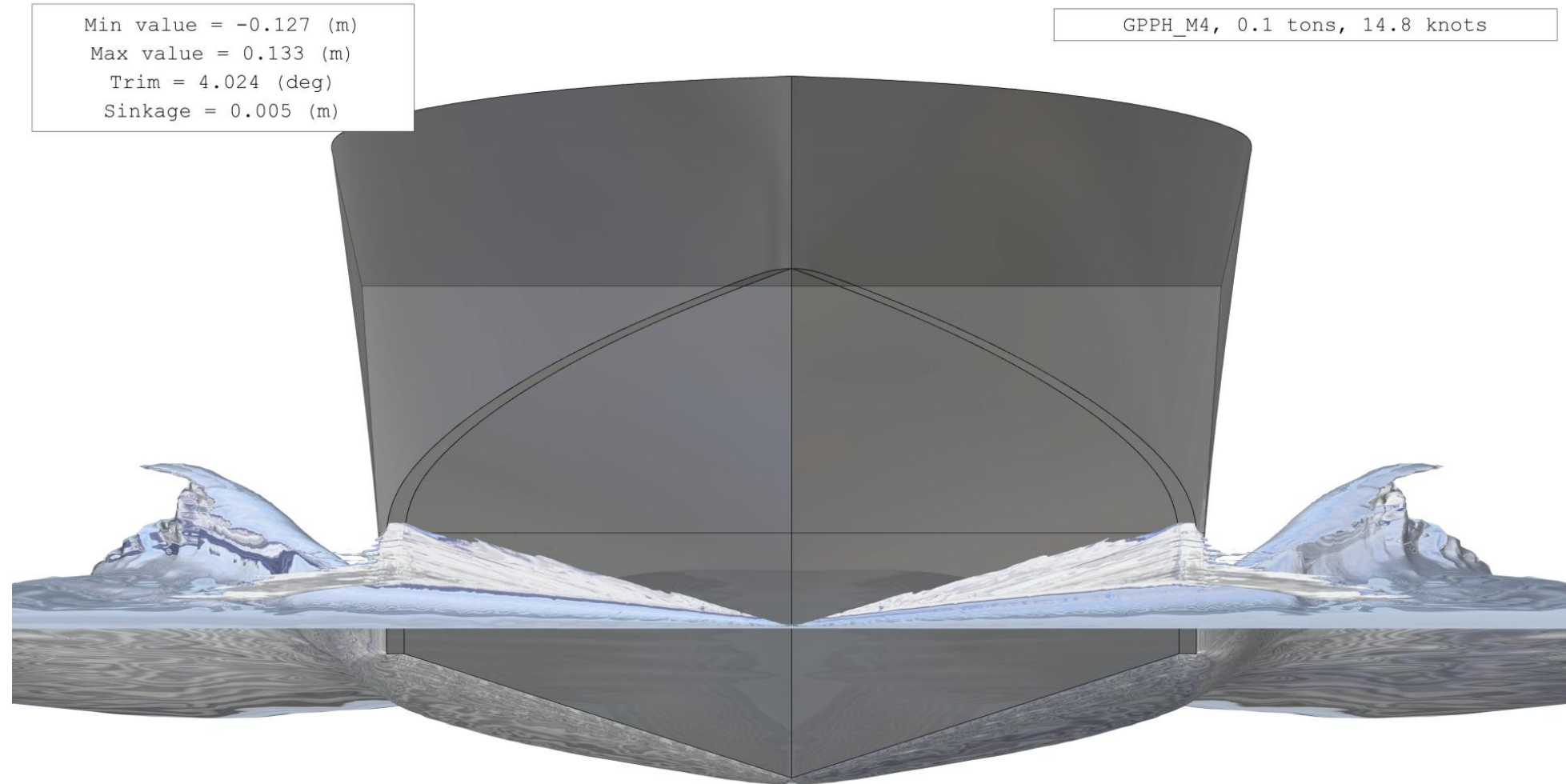
### c. Free surface : front view, realistic rendering



### c. Free surface : front view, realistic rendering



### c. Free surface : front view, realistic rendering

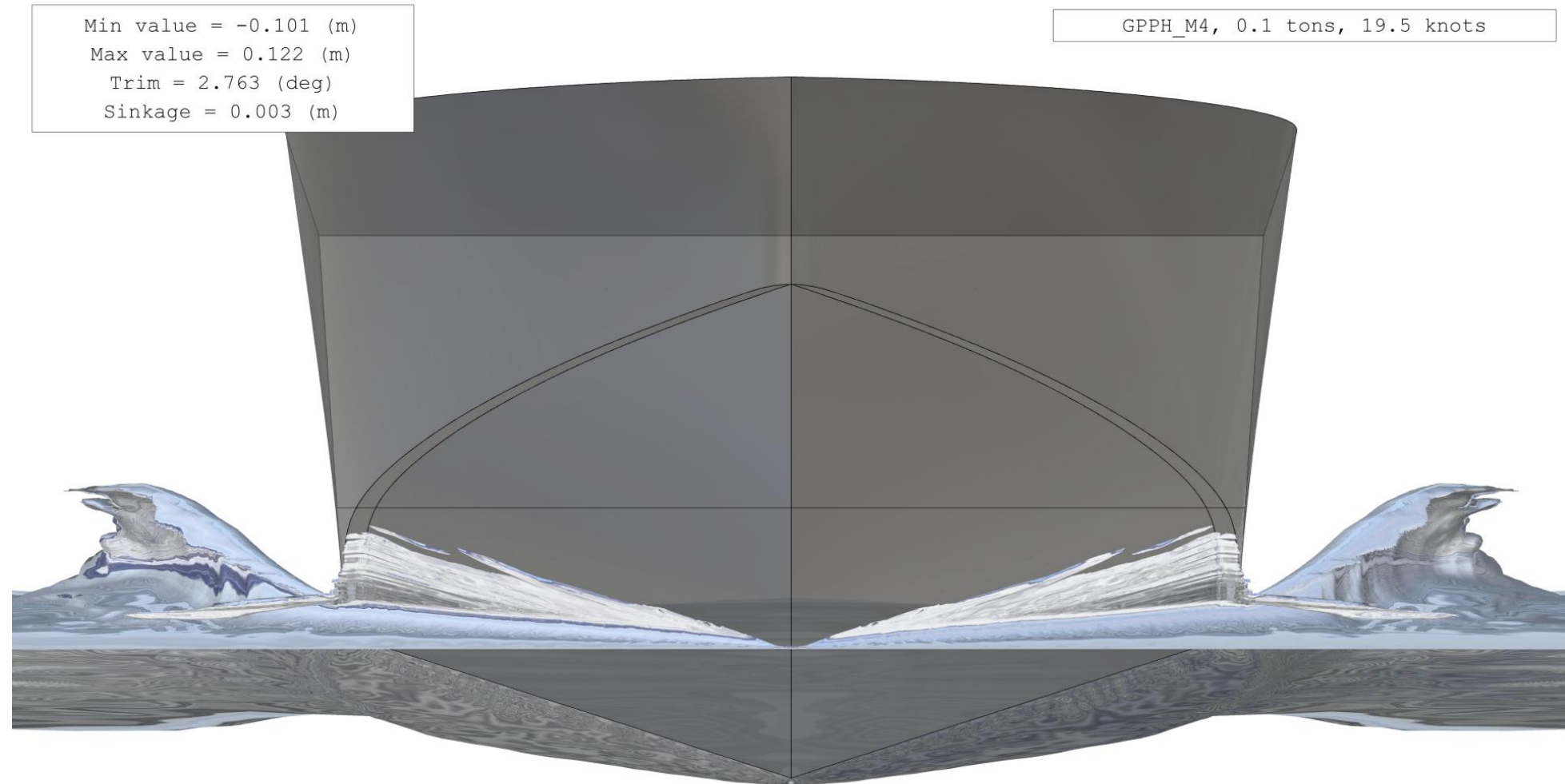


Min value = -0.110 (m)  
Max value = 0.126 (m)  
Trim = 3.231 (deg)  
Sinkage = 0.001 (m)

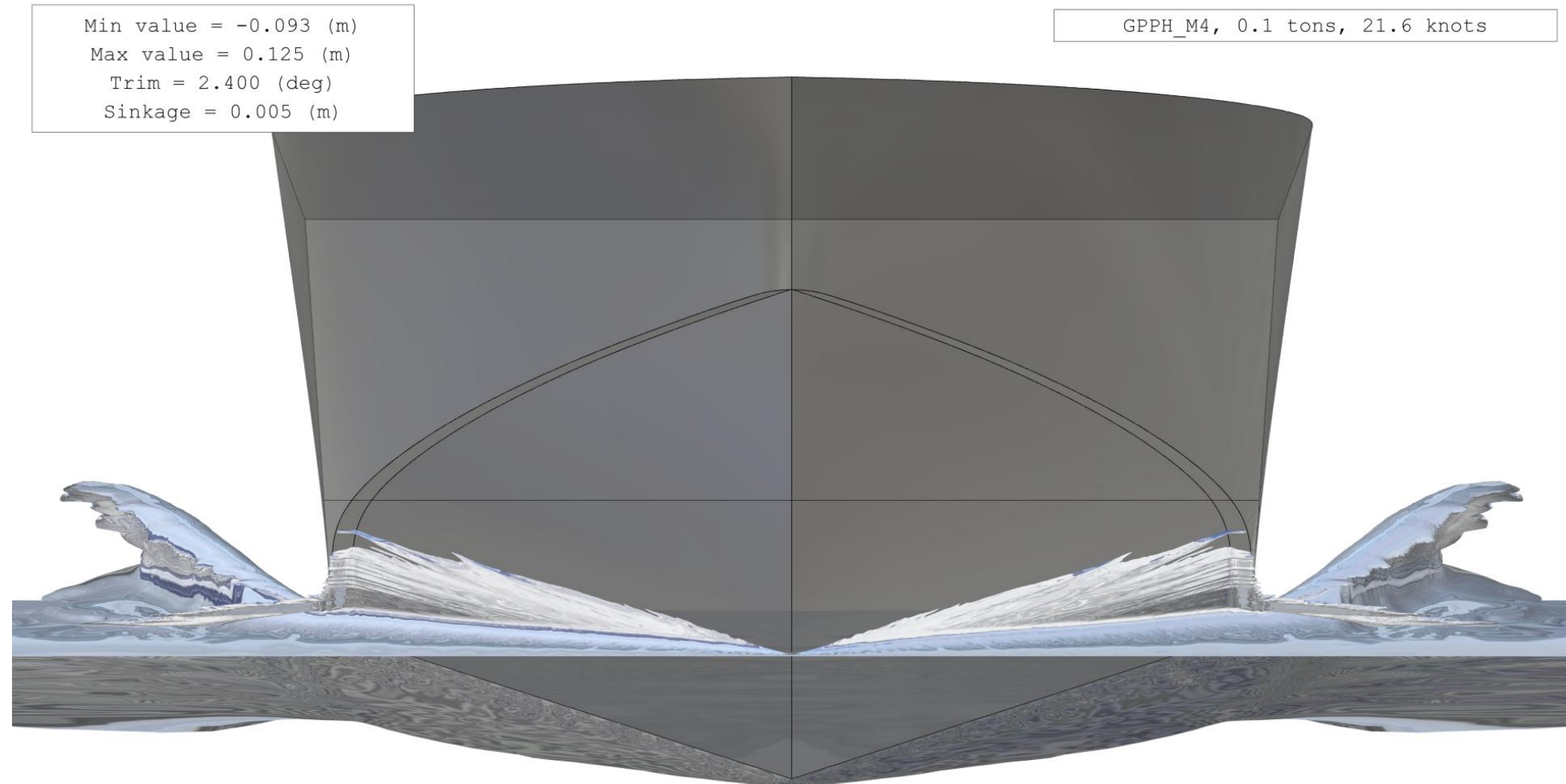
GPPH\_M4, 0.1 tons, 17.5 knots



### c. Free surface : front view, realistic rendering

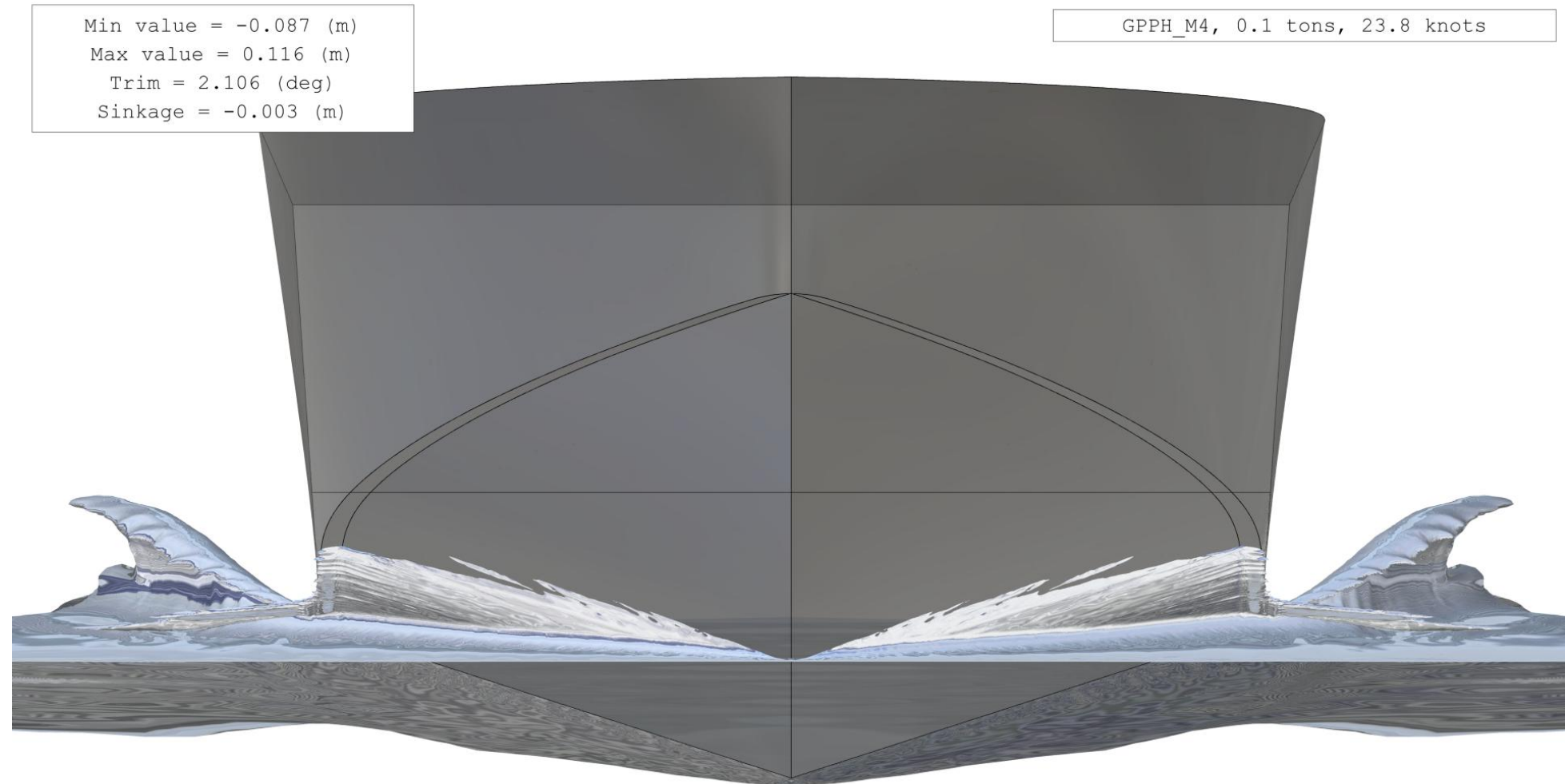


### c. Free surface : front view, realistic rendering





### c. Free surface : front view, realistic rendering





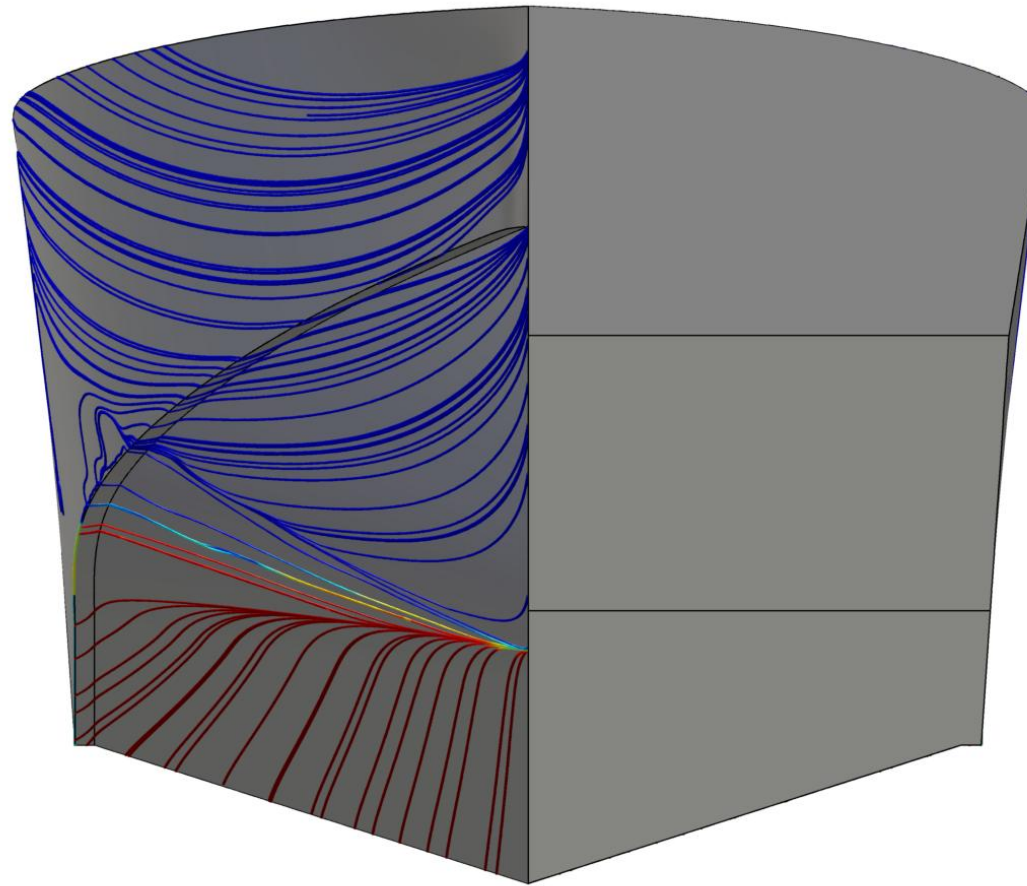
## 6. Visuals

- a. Mass fraction
- b. Pressure coefficient
- c. Free surface
- d. Streamlines
  - 1. Surfacic
  - 2. Volumic

### d. Streamlines (surfacic) : front and rear view

Surfacic streamlines (-)

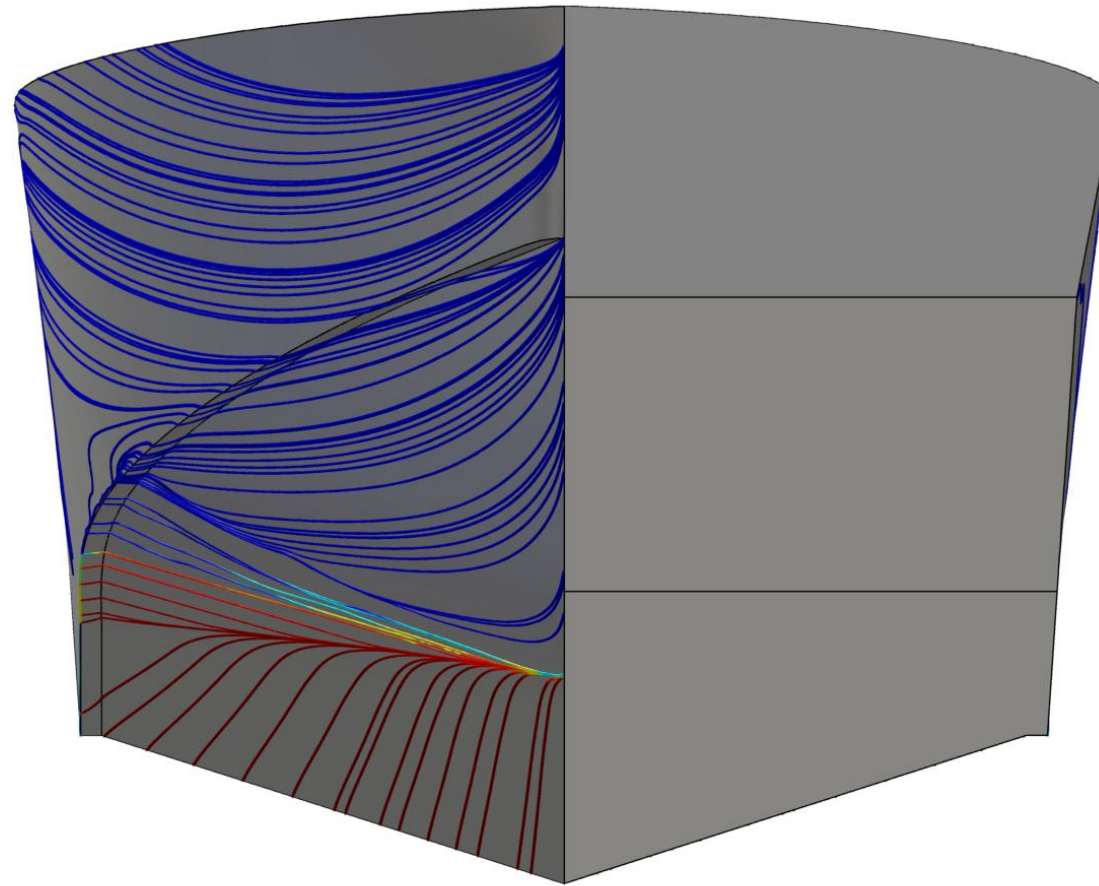
GPPH\_M4, 0.1 tons, 10.8 knots



### d. Streamlines (surfacic) : front and rear view

Surfacic streamlines (-)

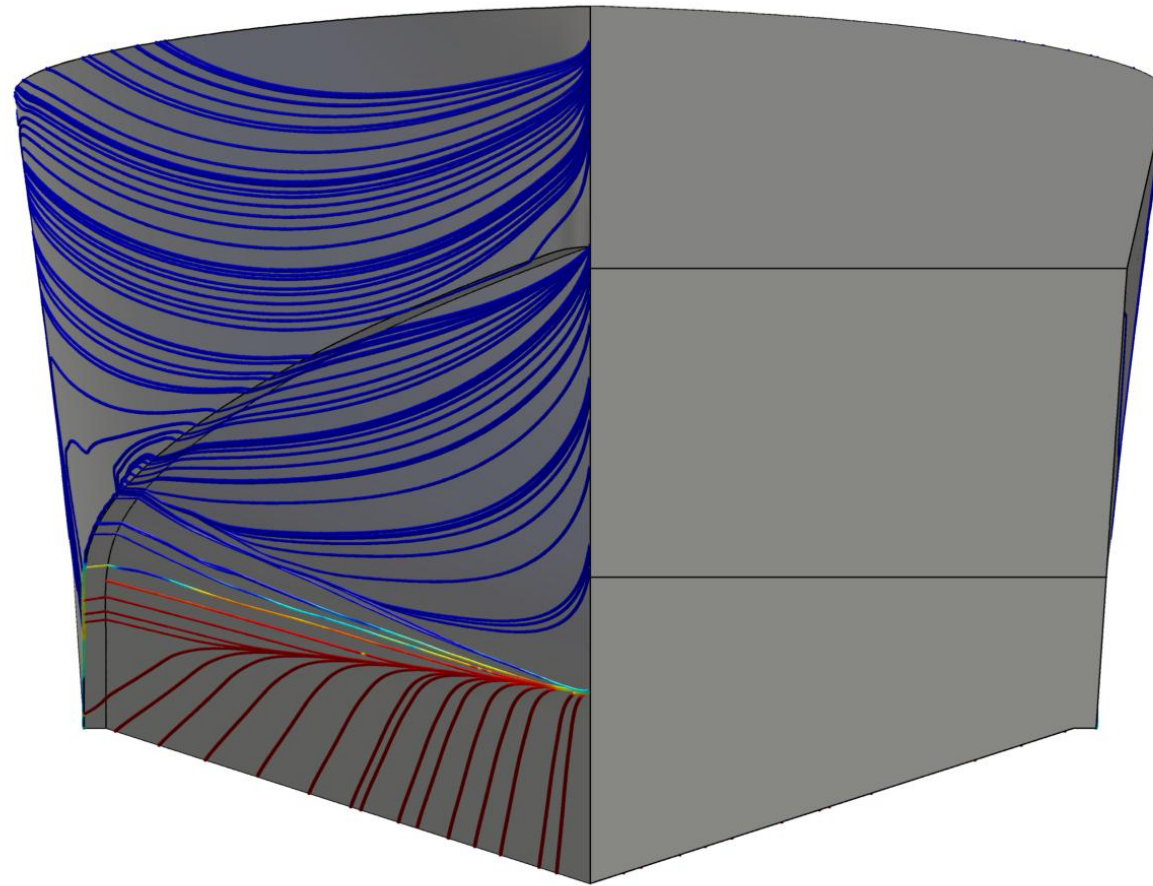
GPPH\_M4, 0.1 tons, 13.0 knots



### d. Streamlines (surfacic) : front and rear view

Surfacic streamlines (-)

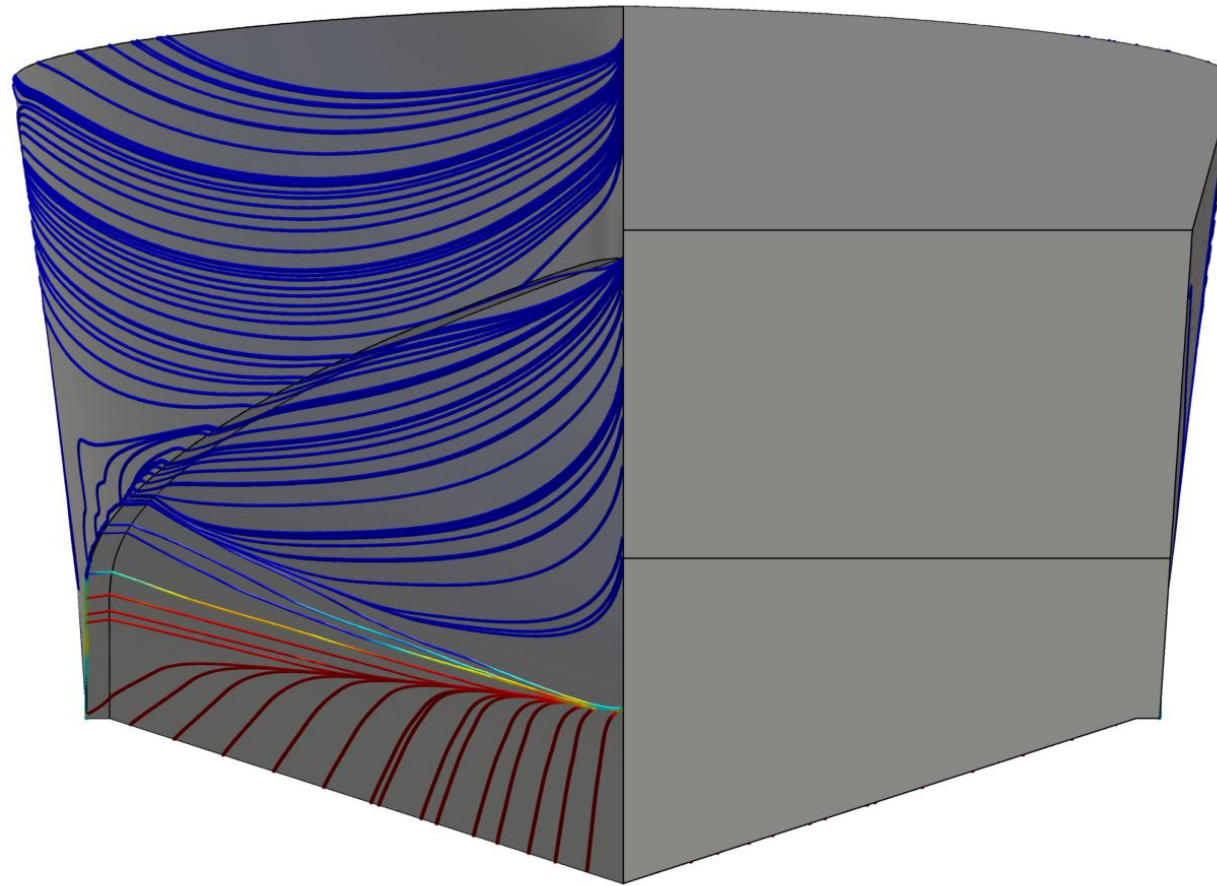
GPPH\_M4, 0.1 tons, 14.8 knots



### d. Streamlines (surfacic) : front and rear view

Surfacic streamlines (-)

GPPH\_M4, 0.1 tons, 17.5 knots

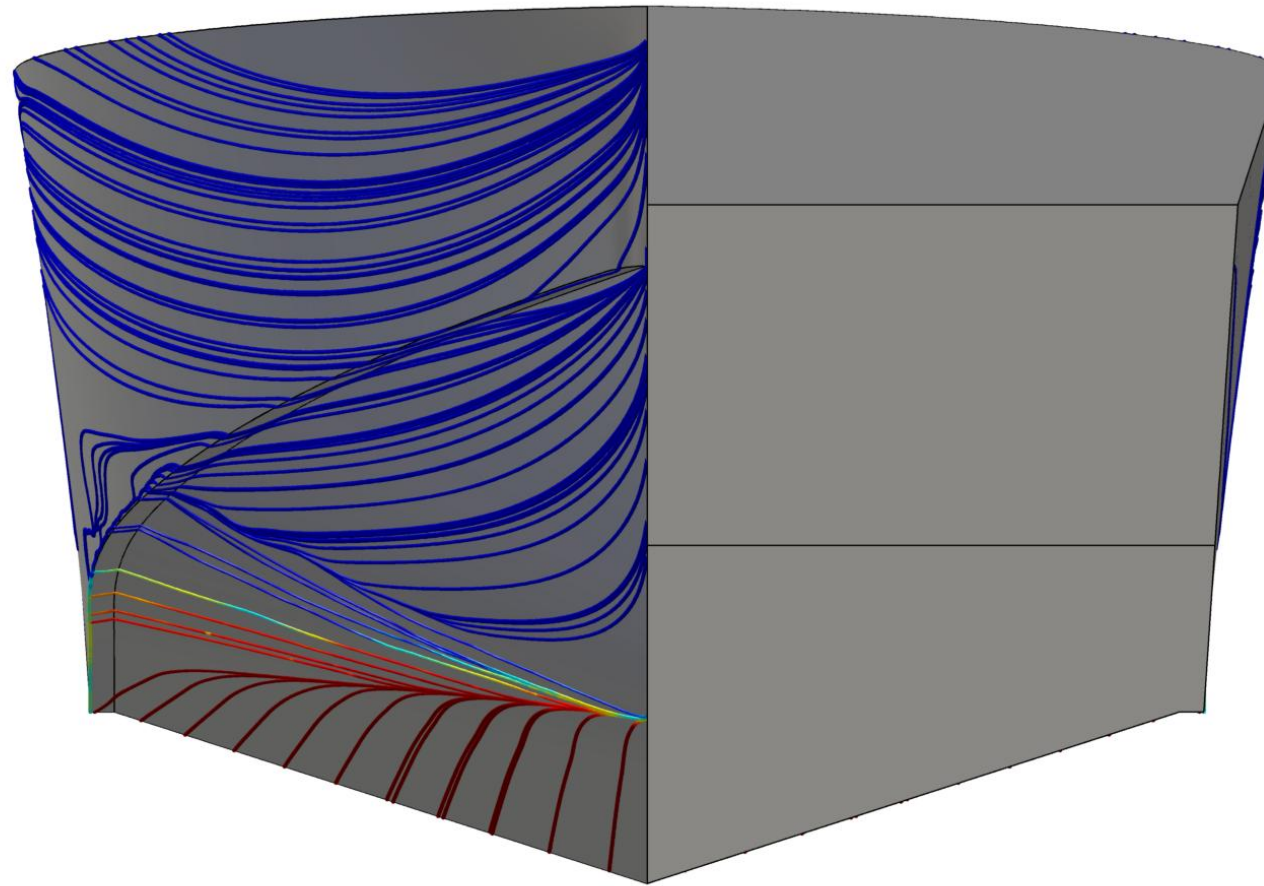




### d. Streamlines (surfacic) : front and rear view

Surfacic streamlines (-)

GPPH\_M4, 0.1 tons, 19.5 knots

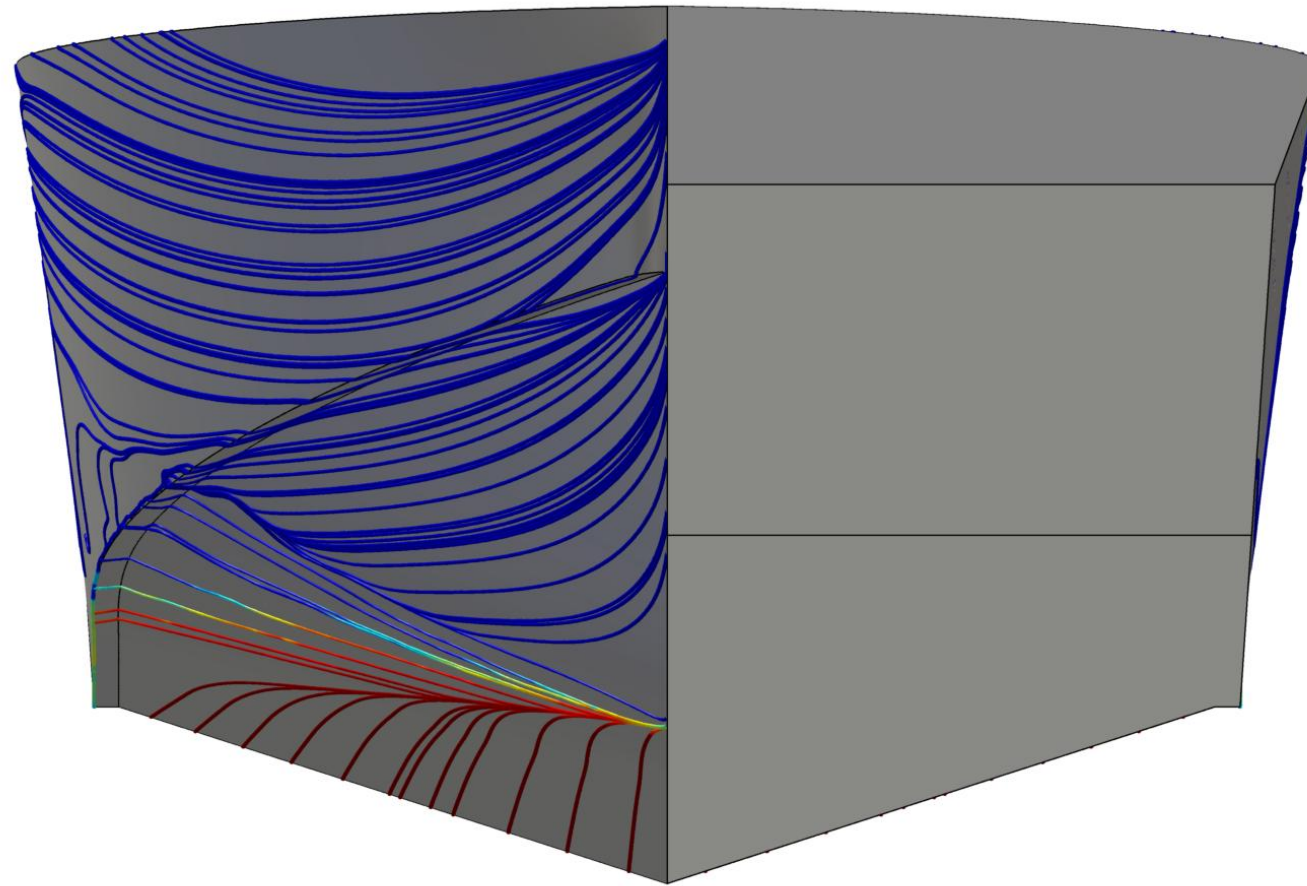




### d. Streamlines (surfacic) : front and rear view

Surfacic streamlines (-)

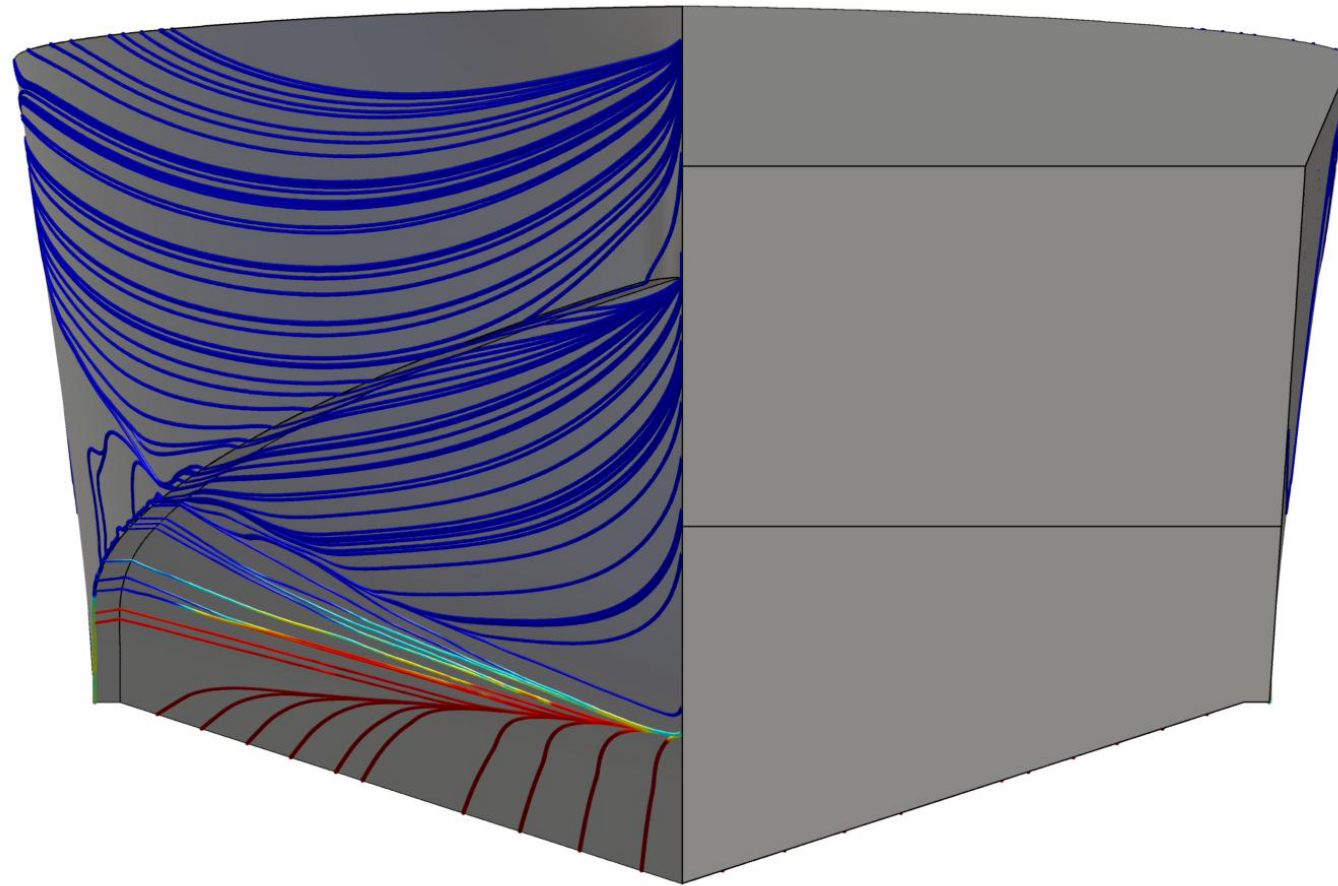
GPPH\_M4, 0.1 tons, 21.6 knots



### d. Streamlines (surfacic) : front and rear view

Surfacic streamlines (-)

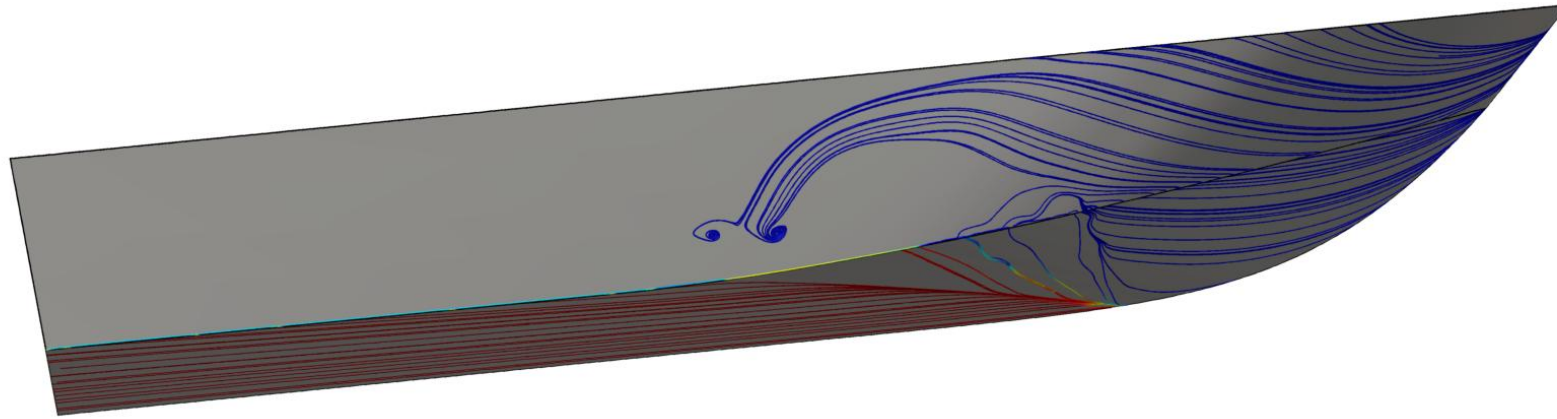
GPPH\_M4, 0.1 tons, 23.8 knots



### d. Streamlines (surfacic) : side view(s)

Surfacic streamlines (-)

GPPH\_M4, 0.1 tons, 10.8 knots

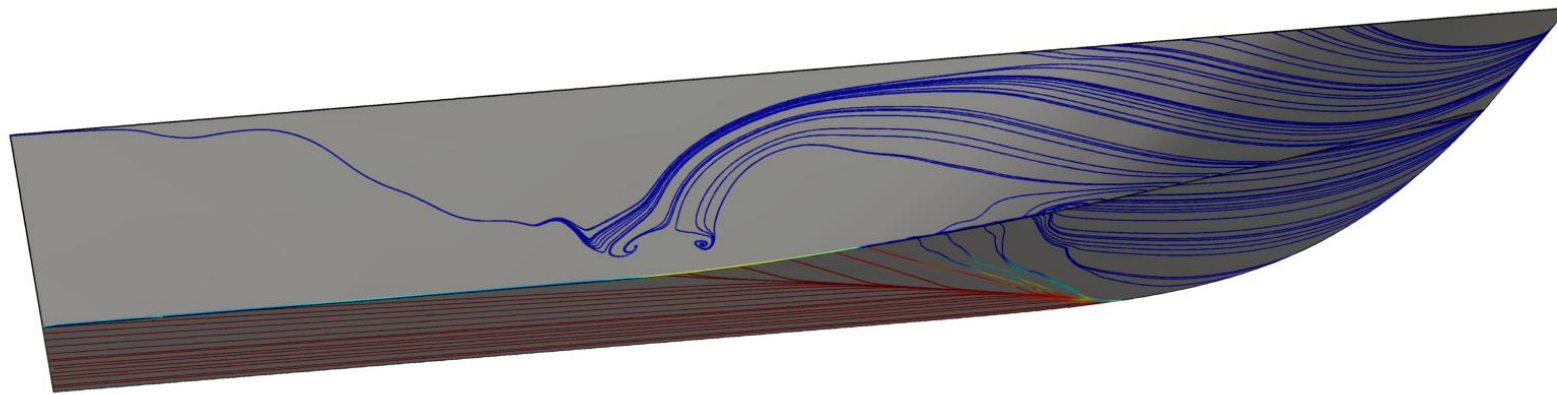


Exterior Side View

### d. Streamlines (surfacic) : side view(s)

Surfacic streamlines (-)

GPPH\_M4, 0.1 tons, 13.0 knots

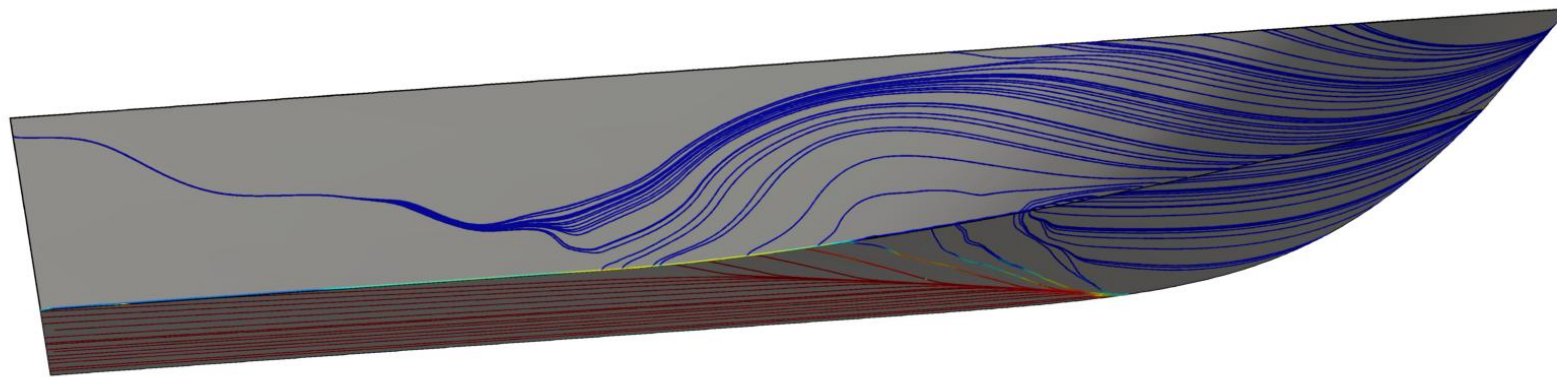


Exterior Side View

### d. Streamlines (surfacic) : side view(s)

Surfacic streamlines (-)

GPPH\_M4, 0.1 tons, 14.8 knots

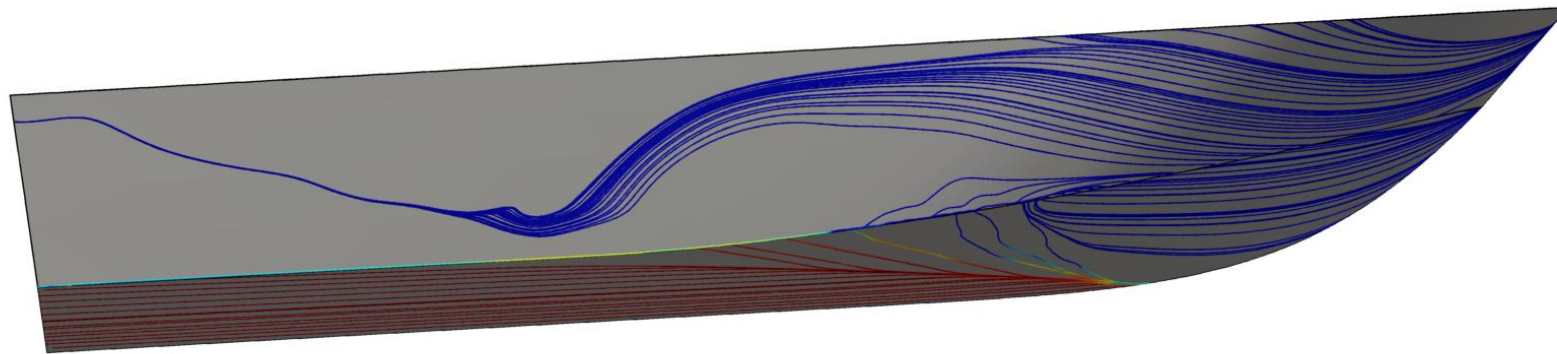


Exterior Side View

### d. Streamlines (surfacic) : side view(s)

Surfacic streamlines (-)

GPPH\_M4, 0.1 tons, 17.5 knots



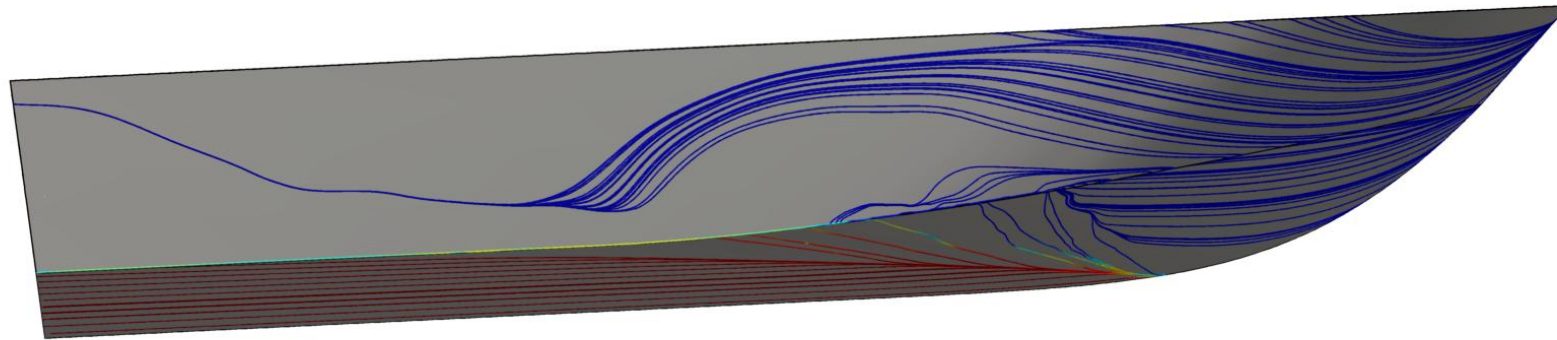
Exterior Side View



### d. Streamlines (surfacic) : side view(s)

Surfacic streamlines (-)

GPPH\_M4, 0.1 tons, 19.5 knots



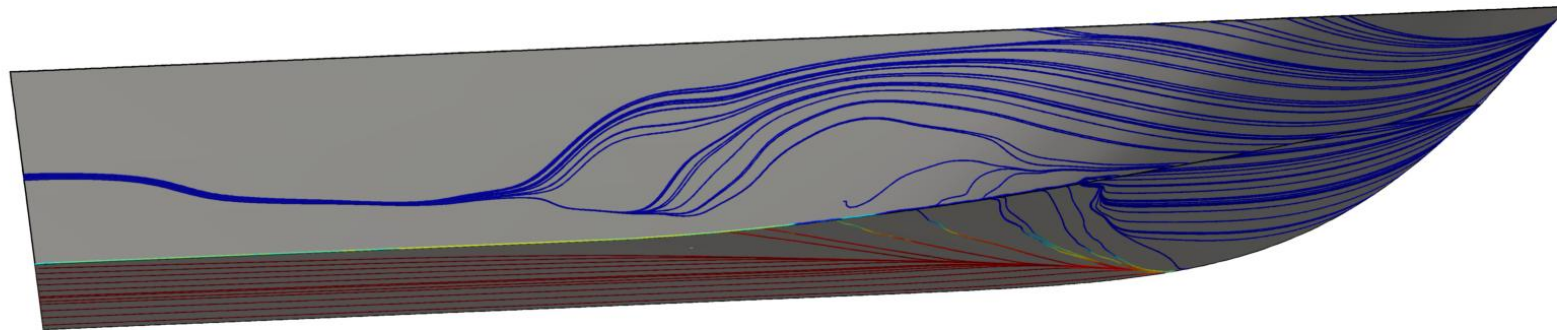
Exterior Side View



### d. Streamlines (surfacic) : side view(s)

Surfacic streamlines (-)

GPPH\_M4, 0.1 tons, 21.6 knots

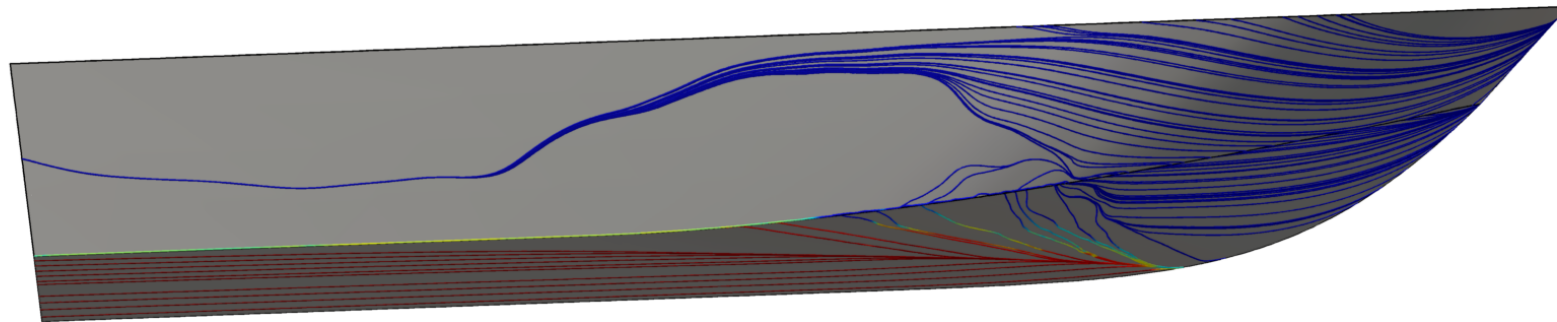


Exterior Side View

### d. Streamlines (surfacic) : side view(s)

Surfacic streamlines (-)

GPPH\_M4, 0.1 tons, 23.8 knots

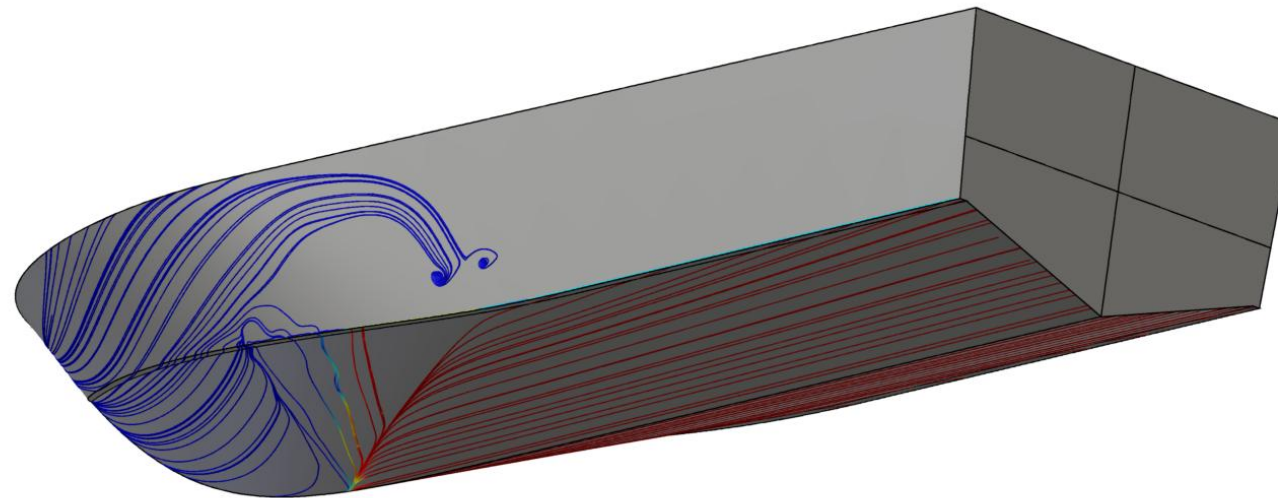


Exterior Side View

### d. Streamlines (surfacic) : $\frac{3}{4}$ rear view

Surfacic streamlines (-)

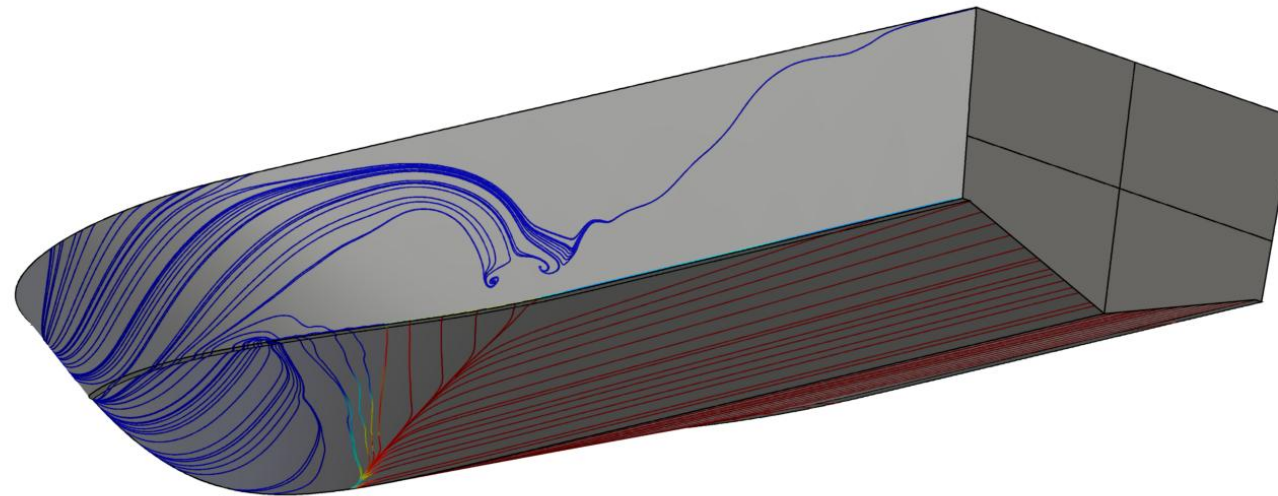
GPPH\_M4, 0.1 tons, 10.8 knots



### d. Streamlines (surfacic) : $\frac{3}{4}$ rear view

Surfacic streamlines (-)

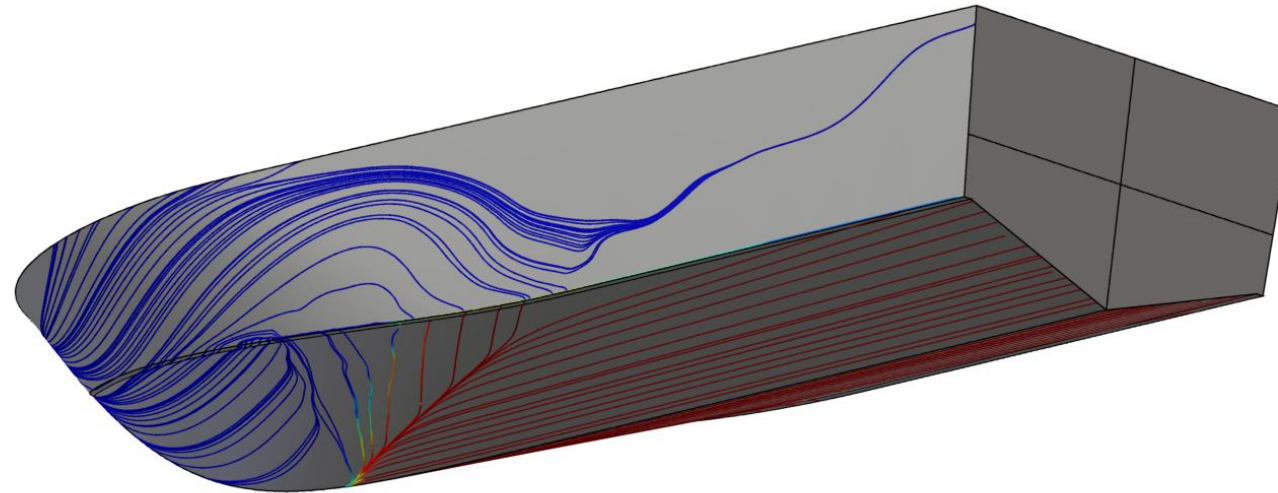
GPPH\_M4, 0.1 tons, 13.0 knots



### d. Streamlines (surfacic) : $\frac{3}{4}$ rear view

Surfacic streamlines (-)

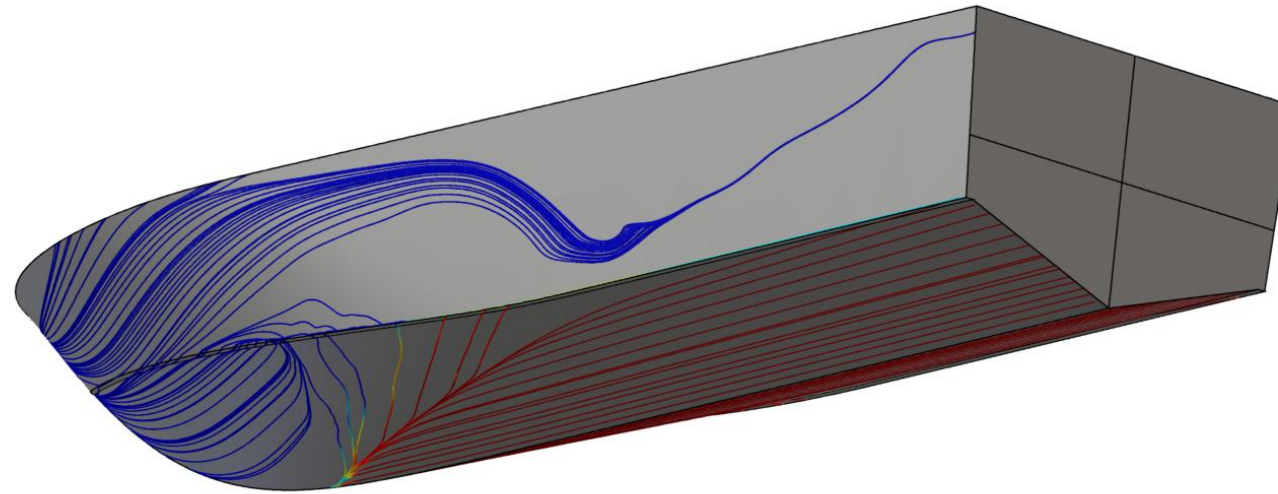
GPPH\_M4, 0.1 tons, 14.8 knots



### d. Streamlines (surfacic) : $\frac{3}{4}$ rear view

Surfacic streamlines (-)

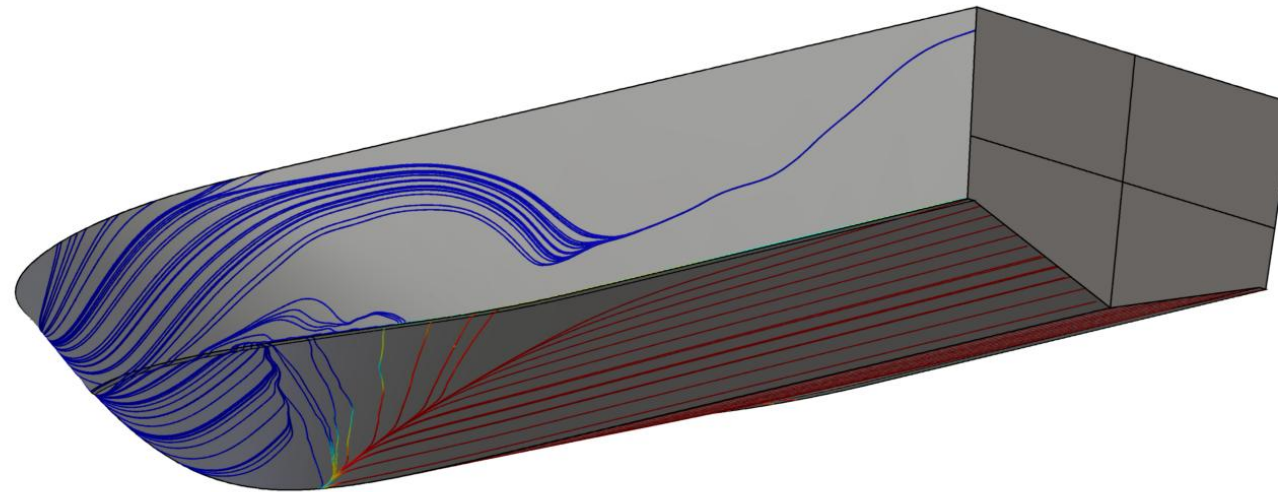
GPPH\_M4, 0.1 tons, 17.5 knots



### d. Streamlines (surfacic) : $\frac{3}{4}$ rear view

Surfacic streamlines (-)

GPPH\_M4, 0.1 tons, 19.5 knots

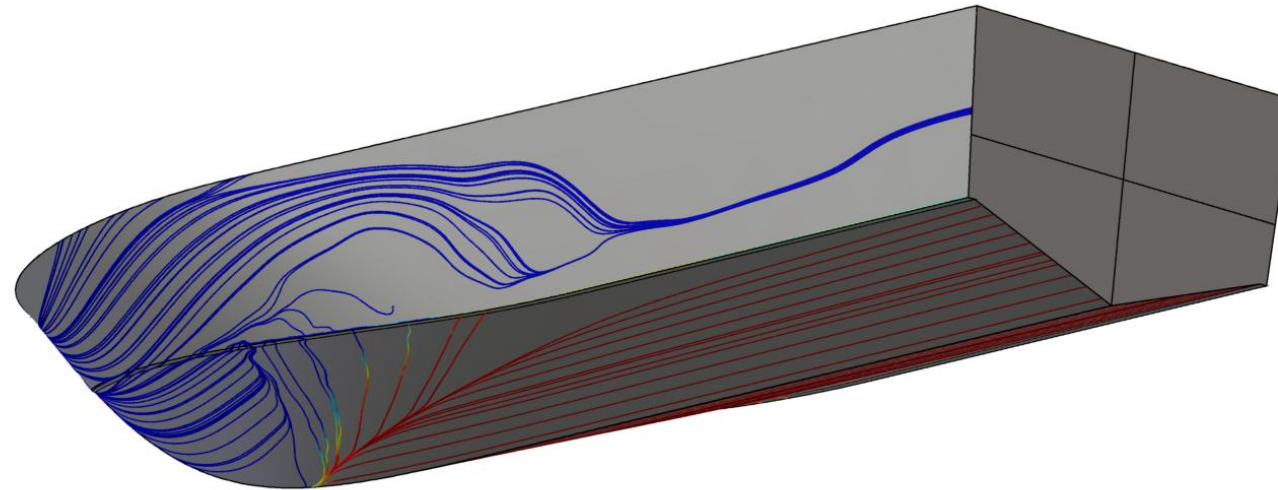




### d. Streamlines (surfacic) : $\frac{3}{4}$ rear view

Surfacic streamlines (-)

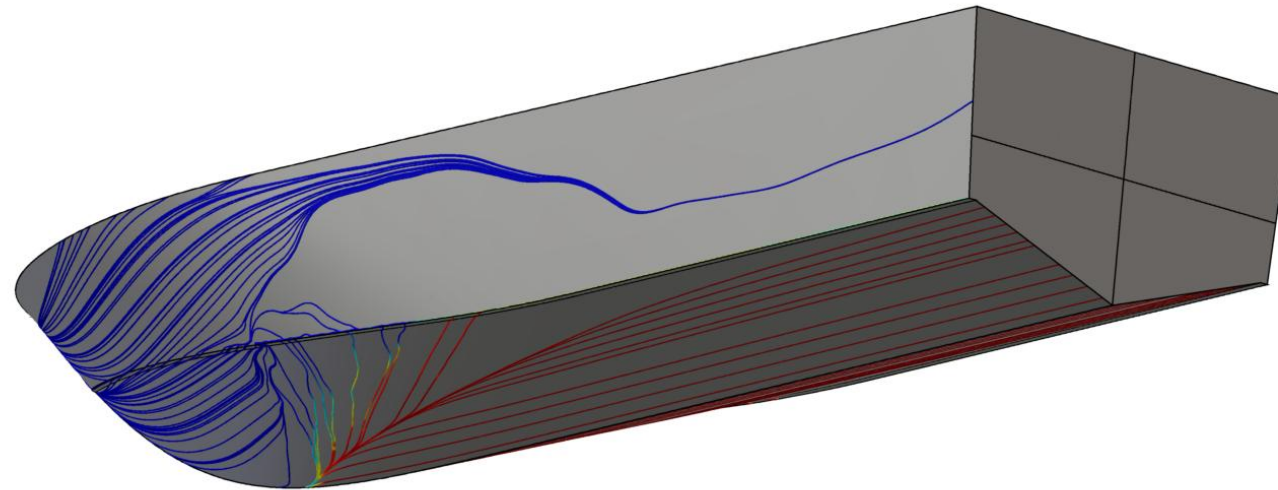
GPPH\_M4, 0.1 tons, 21.6 knots



### d. Streamlines (surfacic) : $\frac{3}{4}$ rear view

Surfacic streamlines (-)

GPPH\_M4, 0.1 tons, 23.8 knots

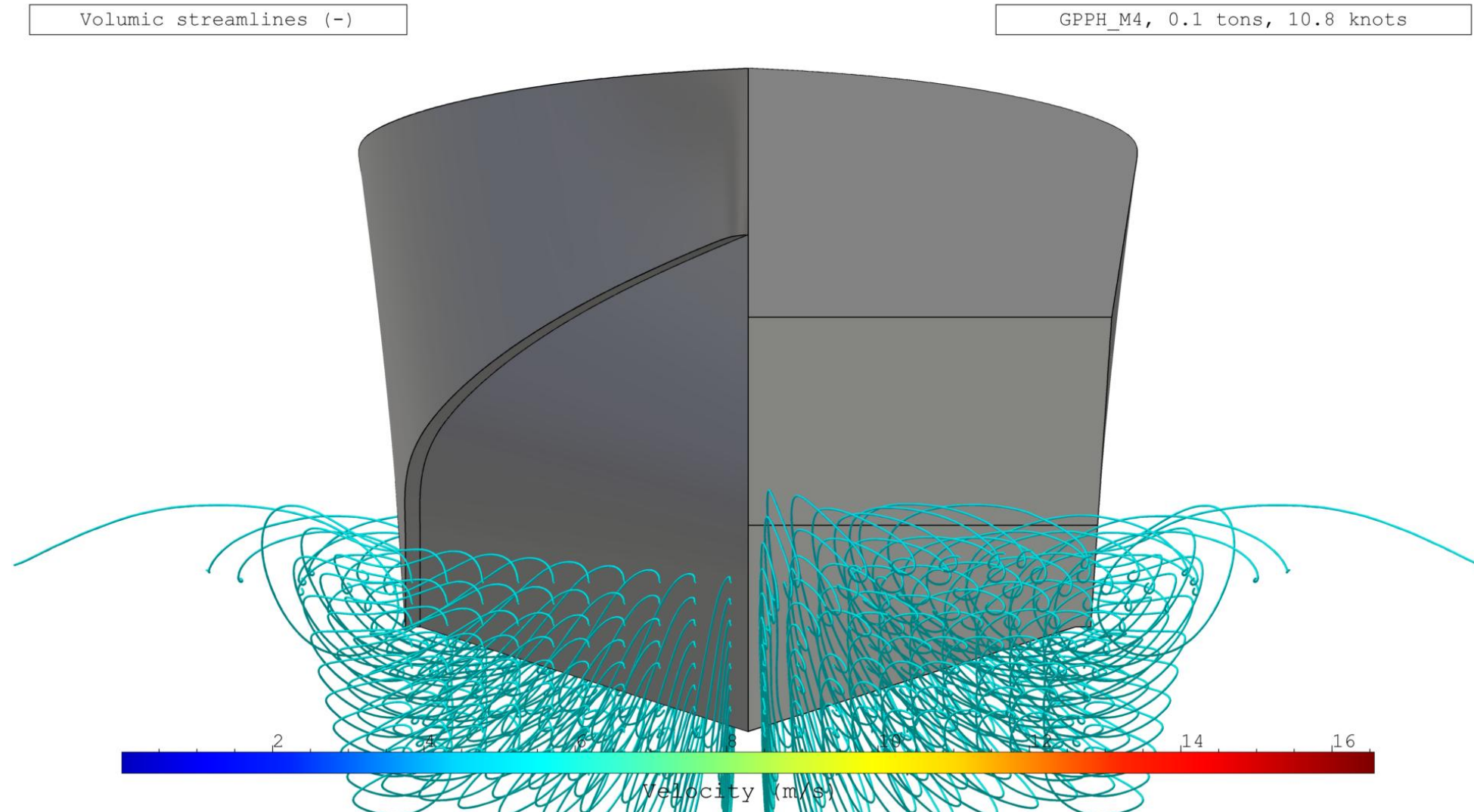




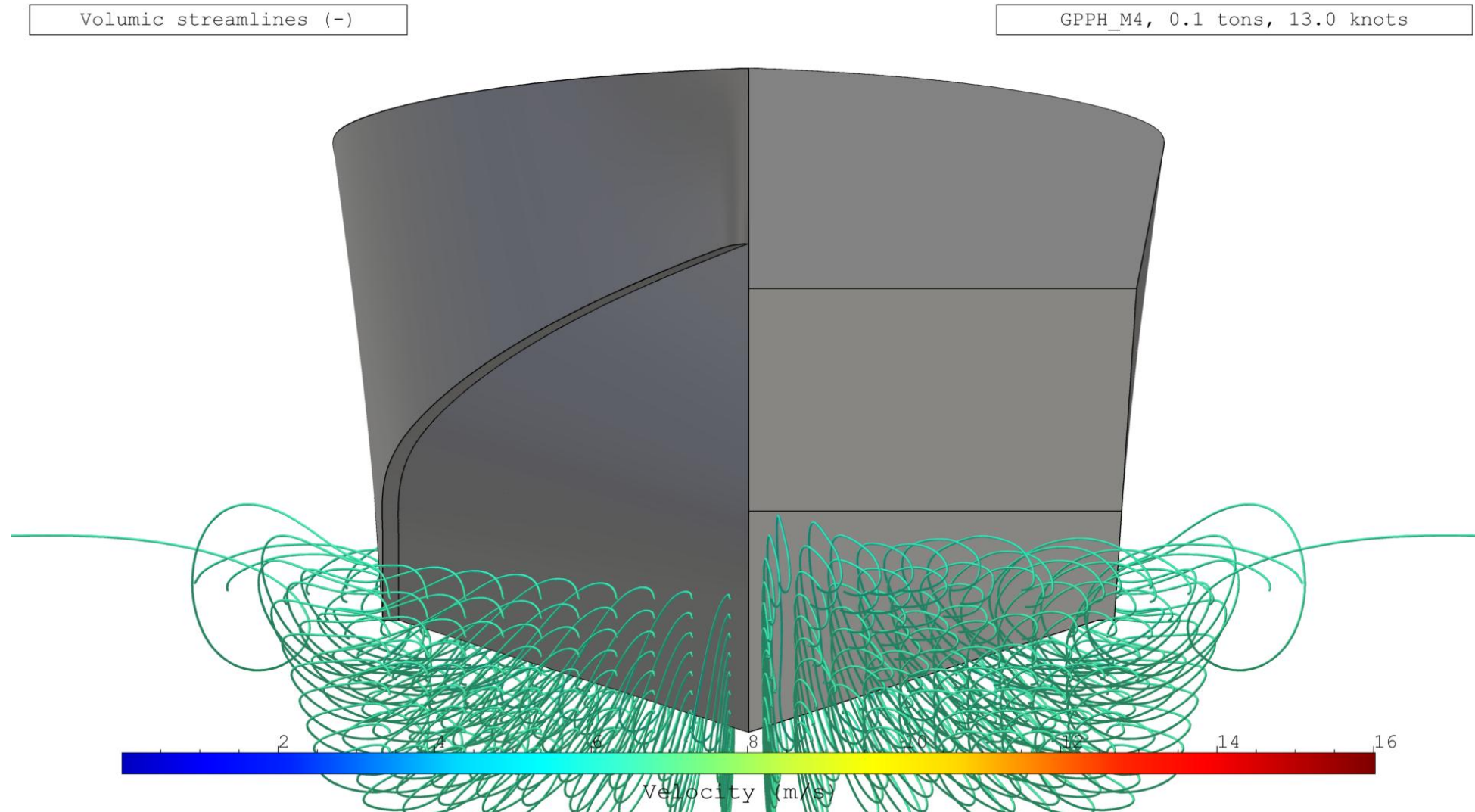
## 6. Visuals

- a. Mass fraction
- b. Pressure coefficient
- c. Free surface
- d. Streamlines
  - 1. Surfacic
  - 2. Volumic

### d. Streamlines (volumic) : front and rear view

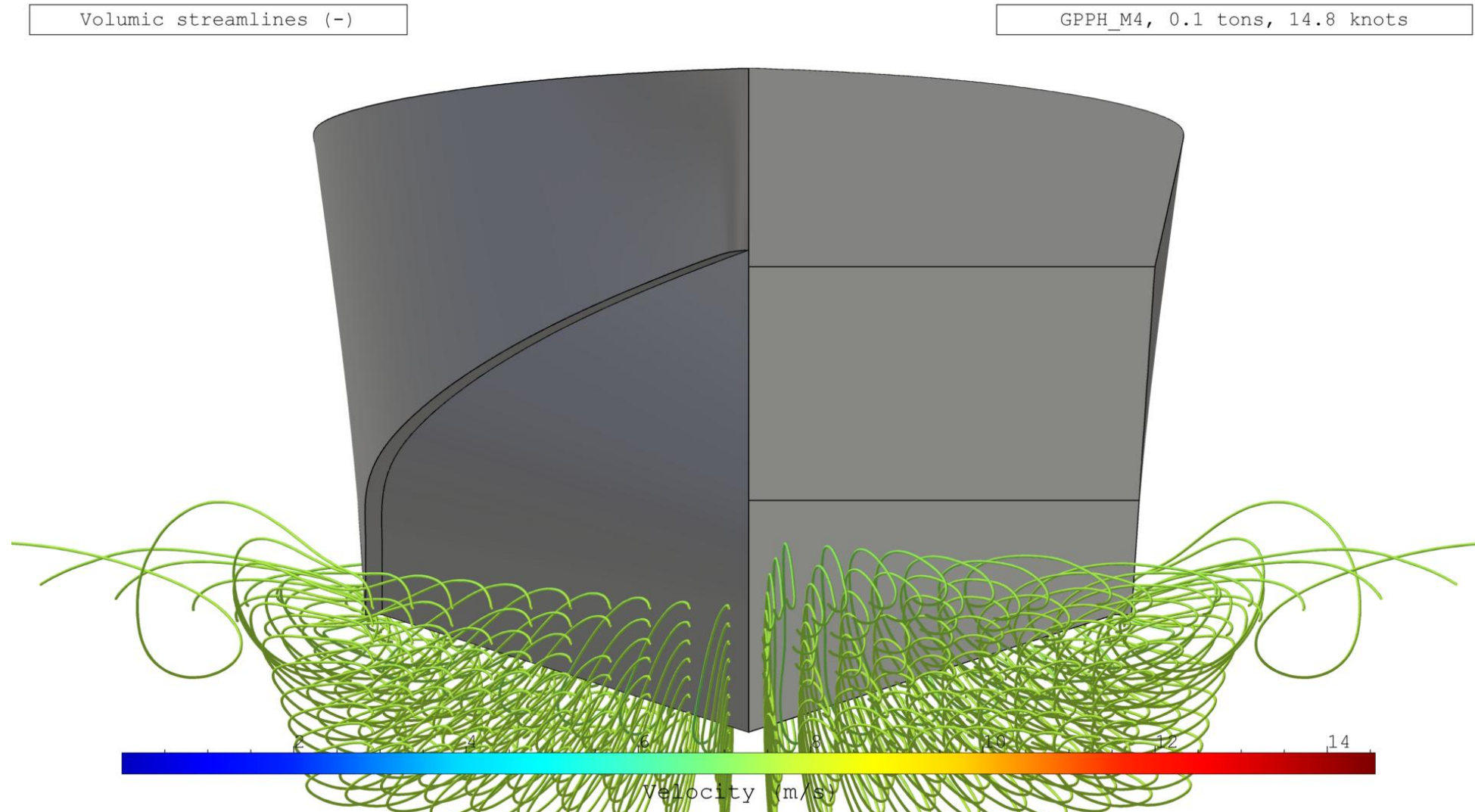


### d. Streamlines (volumic) : front and rear view

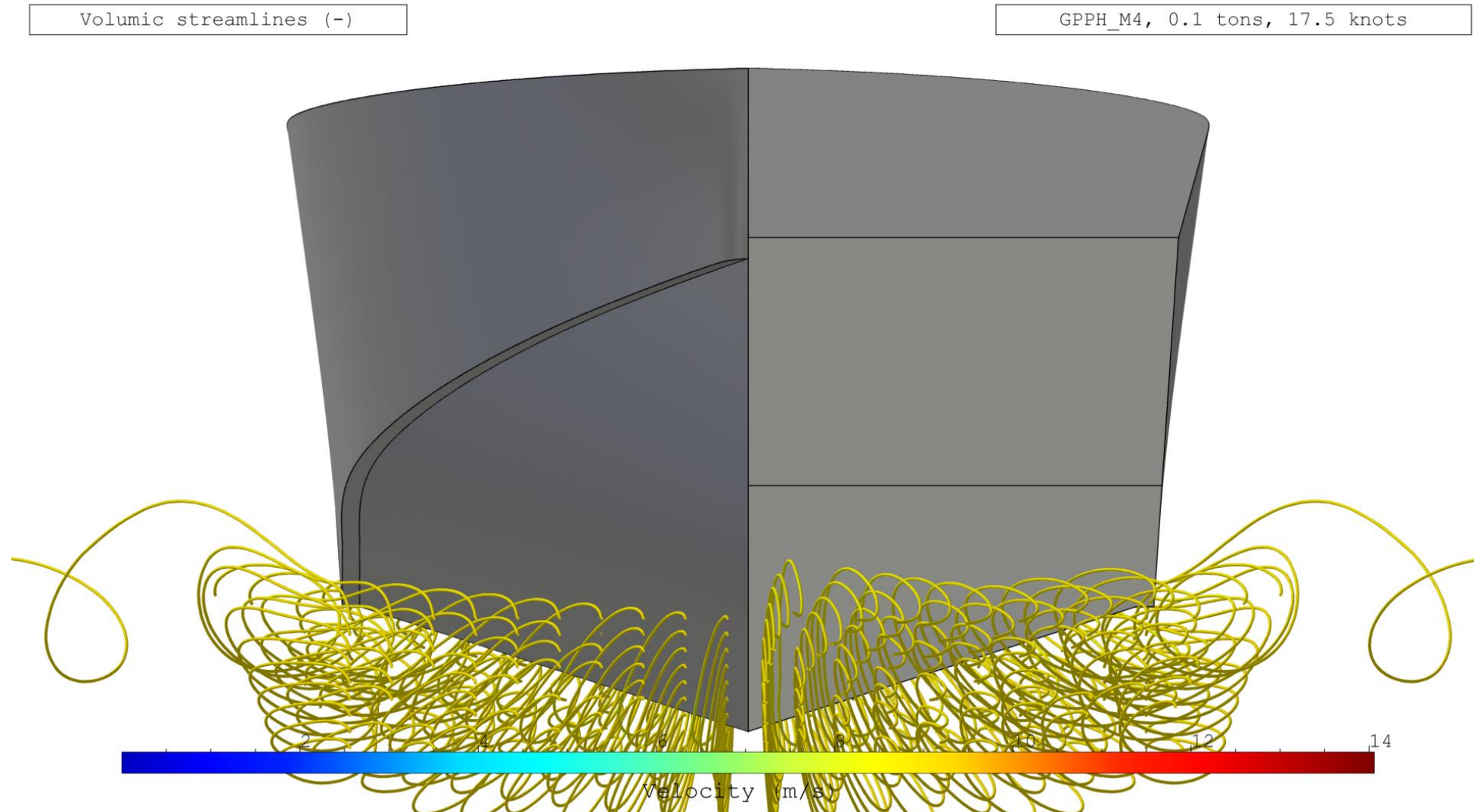




### d. Streamlines (volumic) : front and rear view

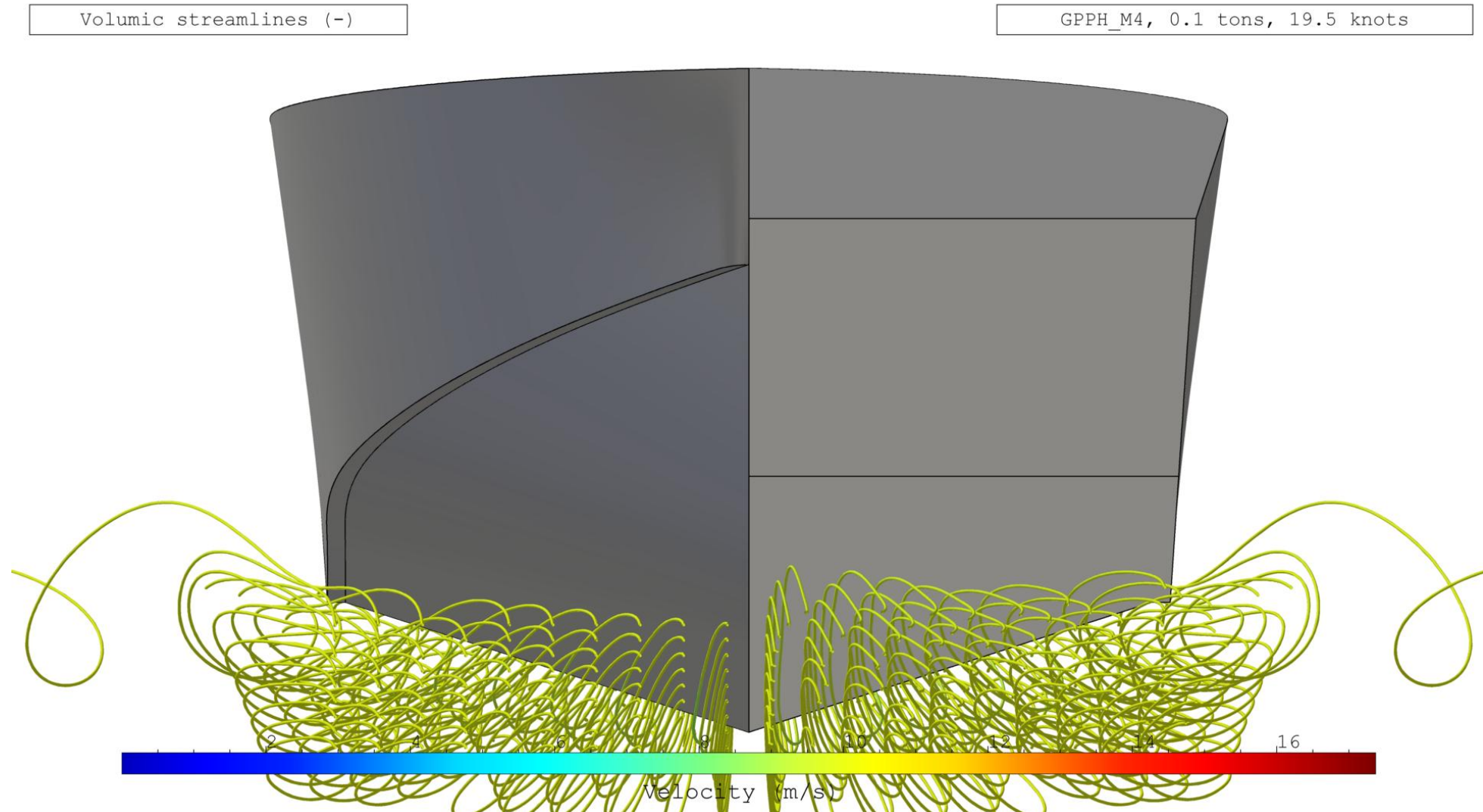


### d. Streamlines (volumic) : front and rear view

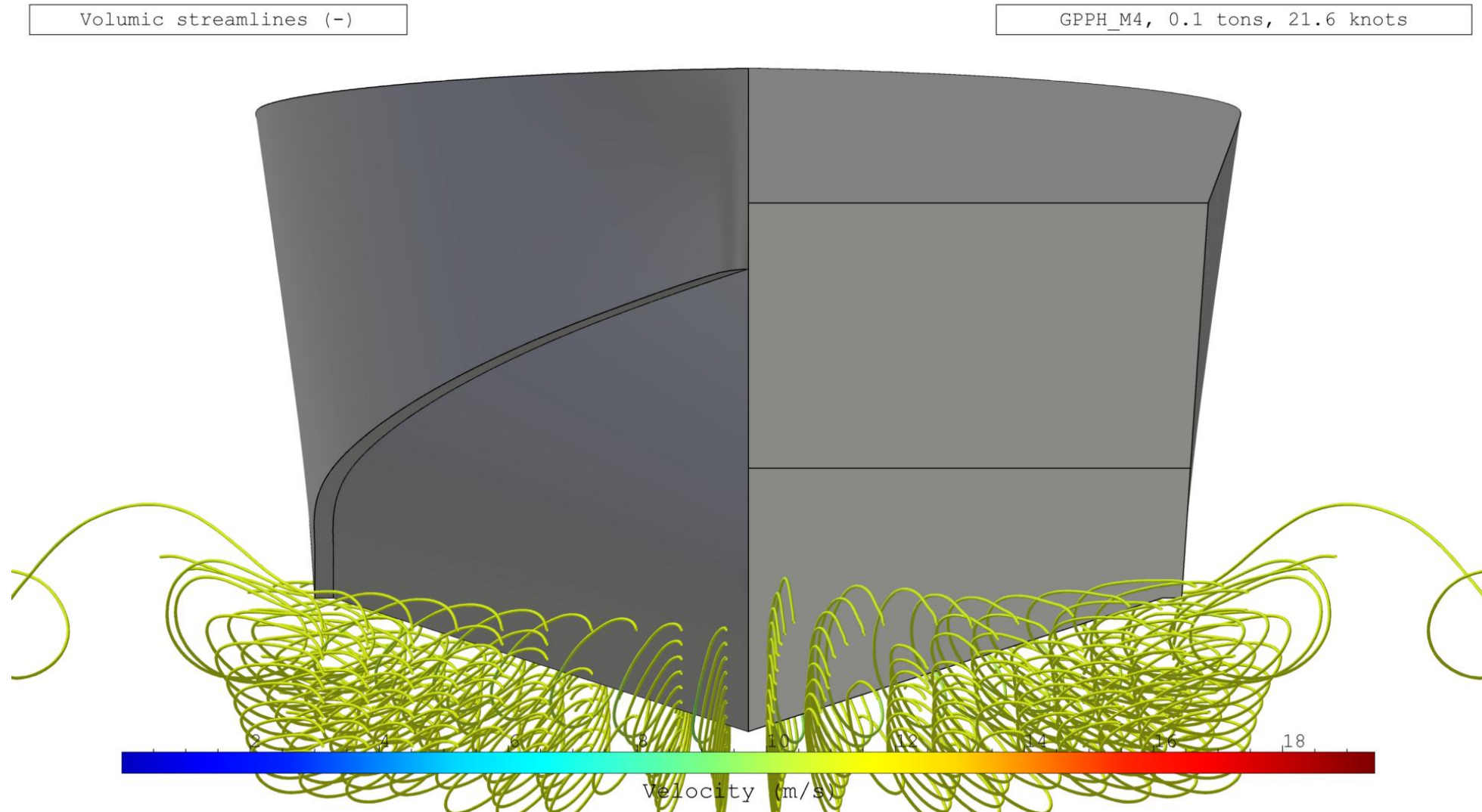




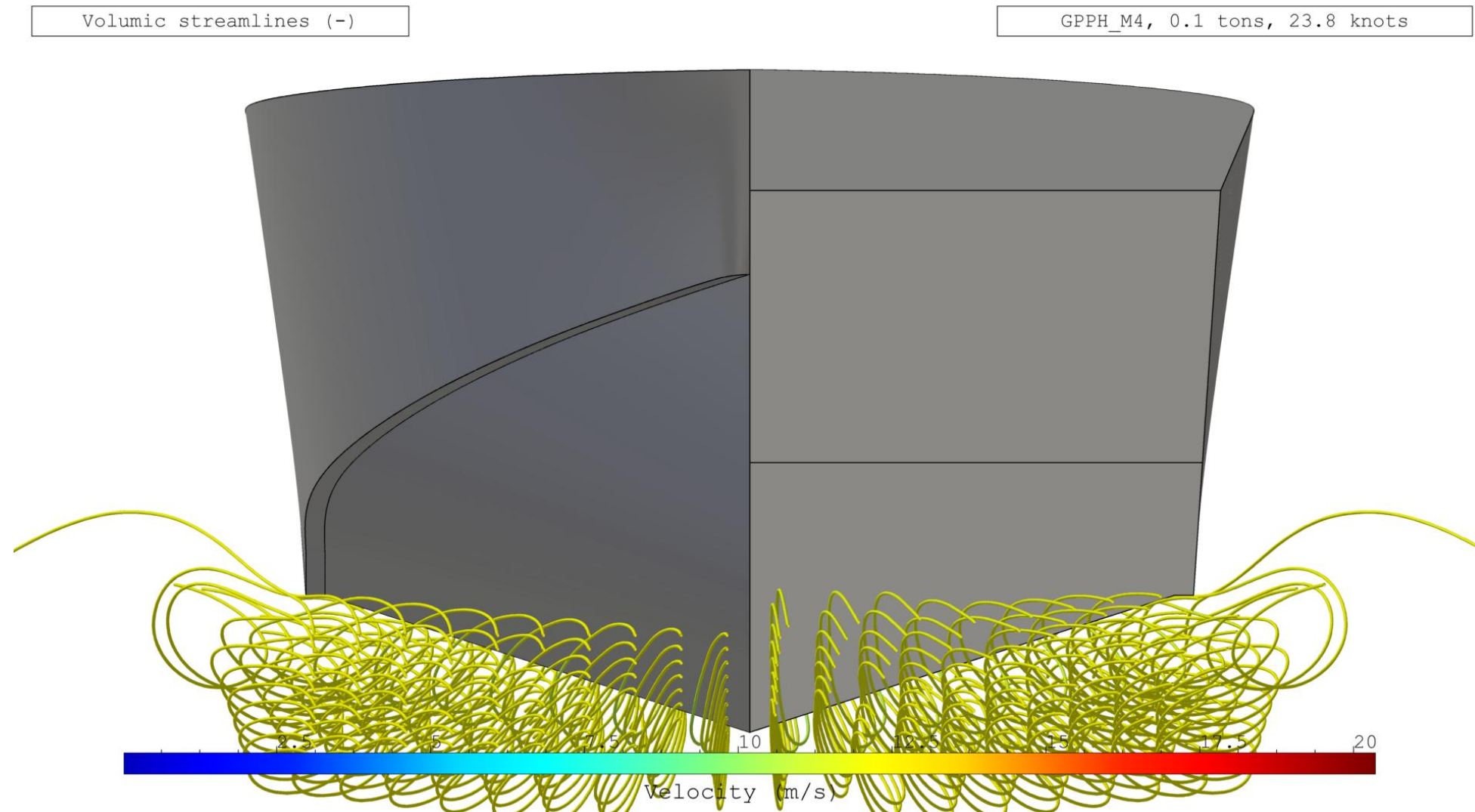
### d. Streamlines (volumic) : front and rear view



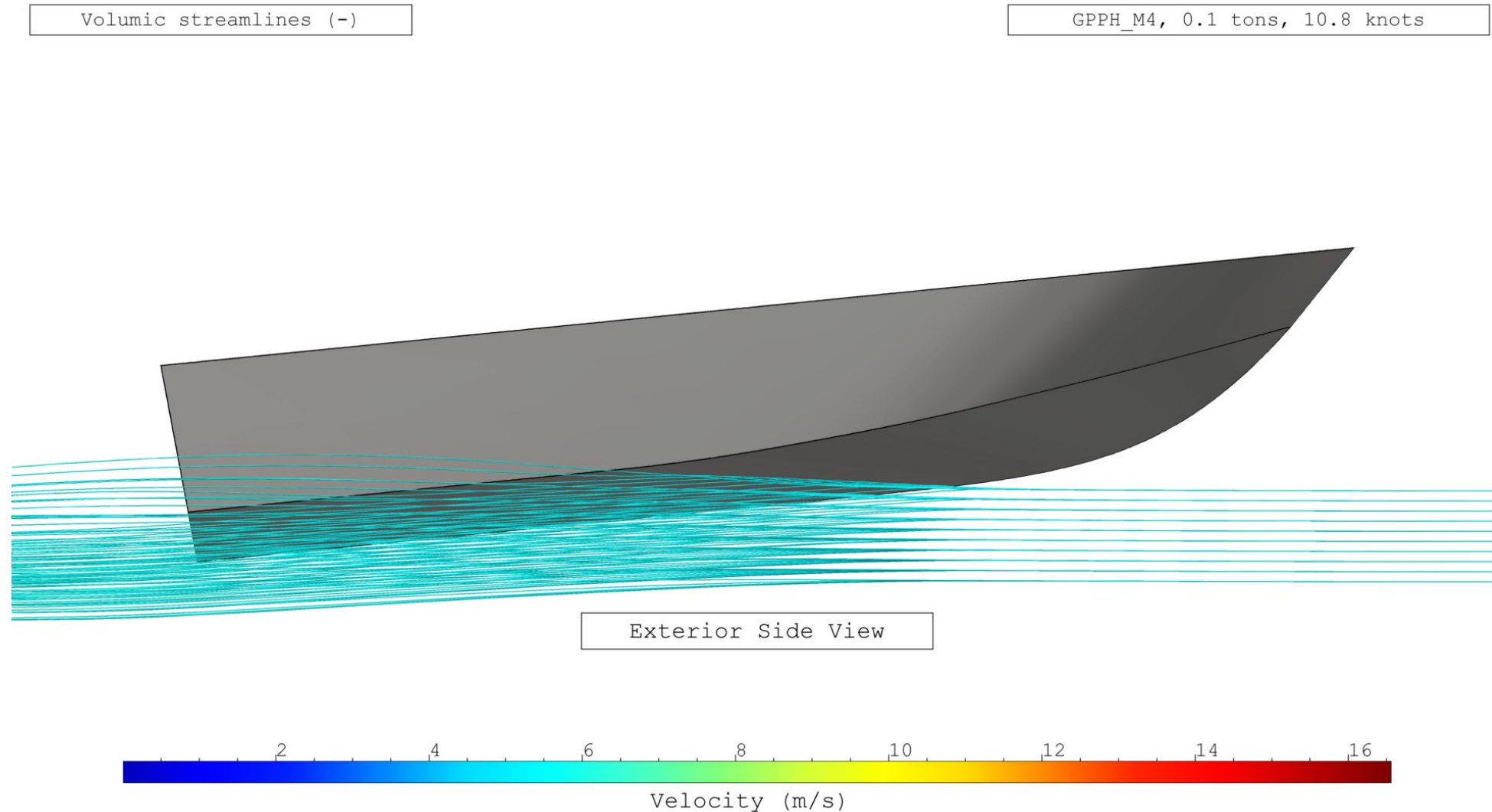
### d. Streamlines (volumic) : front and rear view



## d. Streamlines (volumic) : front and rear view

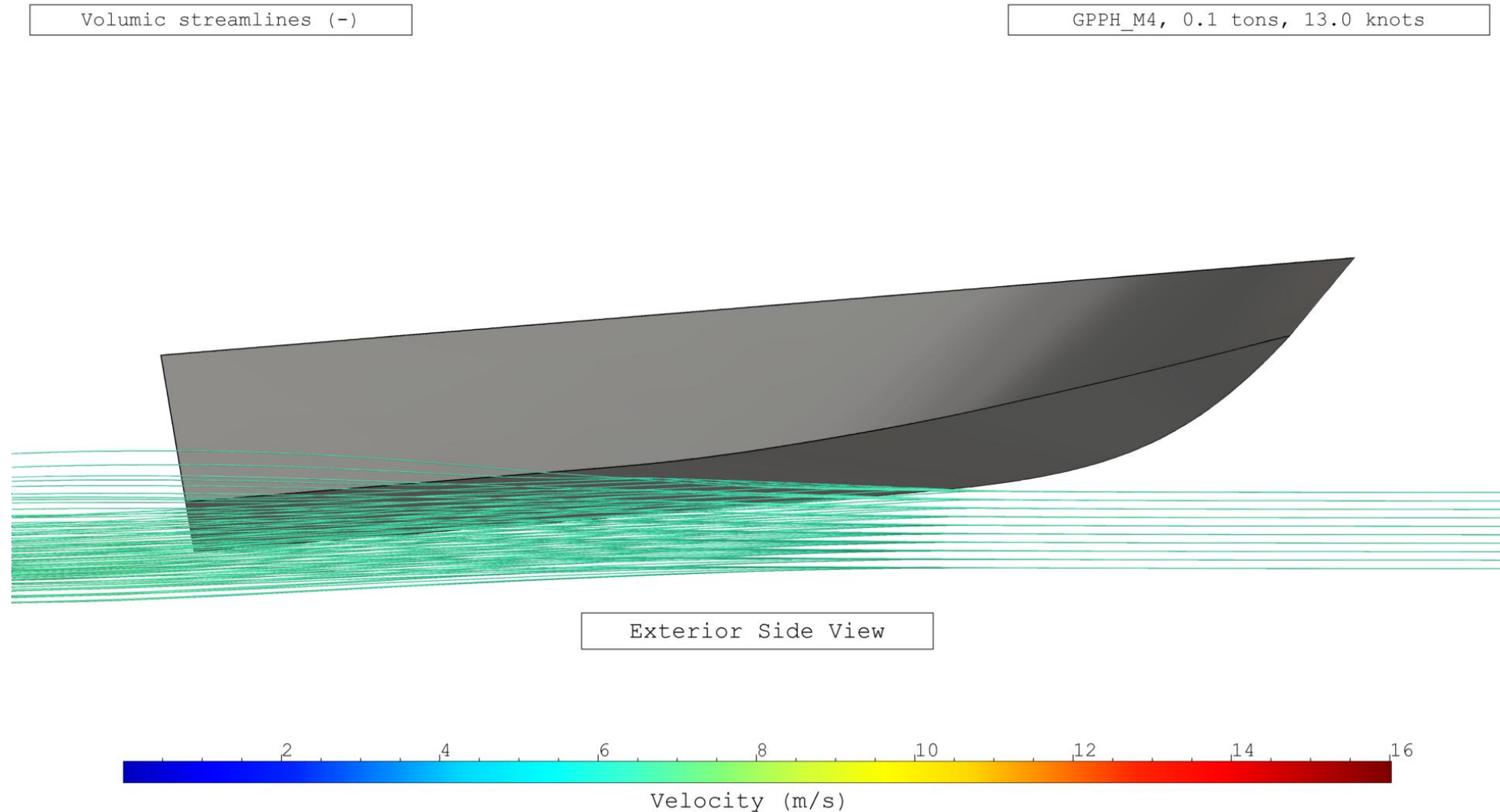


### d. Streamlines (volumic) : side view(s)

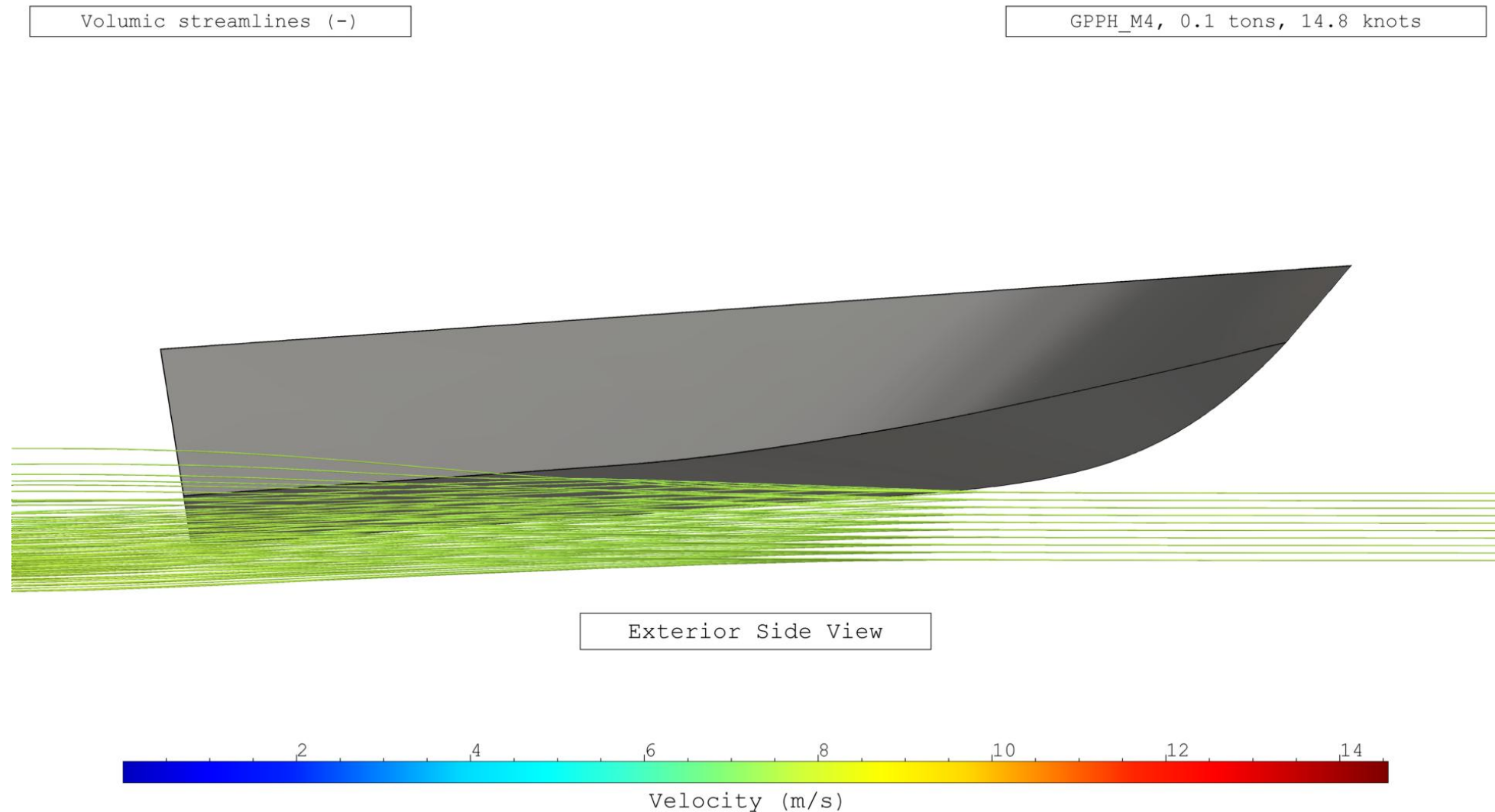




### d. Streamlines (volumic) : side view(s)



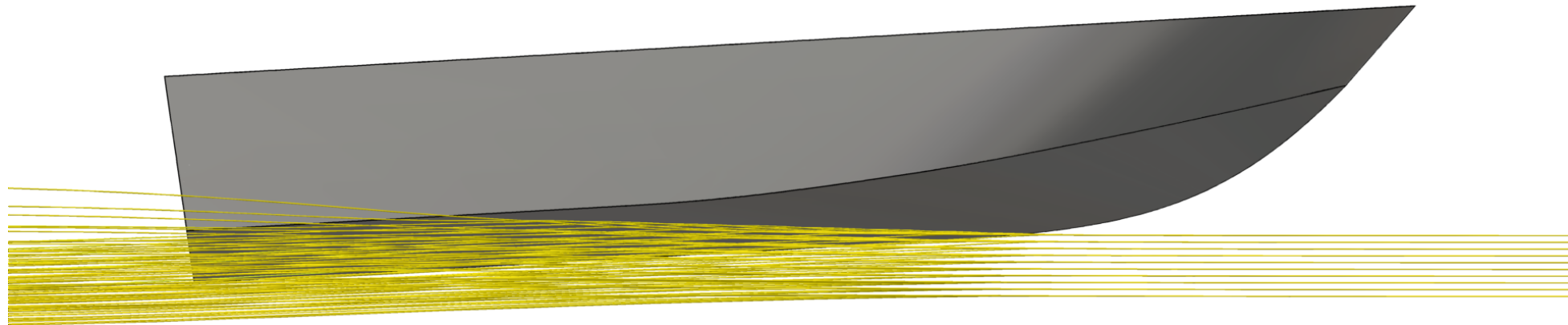
## d. Streamlines (volumic) : side view(s)



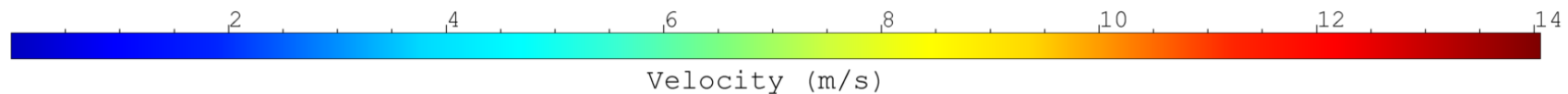
### d. Streamlines (volumic) : side view(s)

Volumic streamlines (-)

GPPH\_M4, 0.1 tons, 17.5 knots

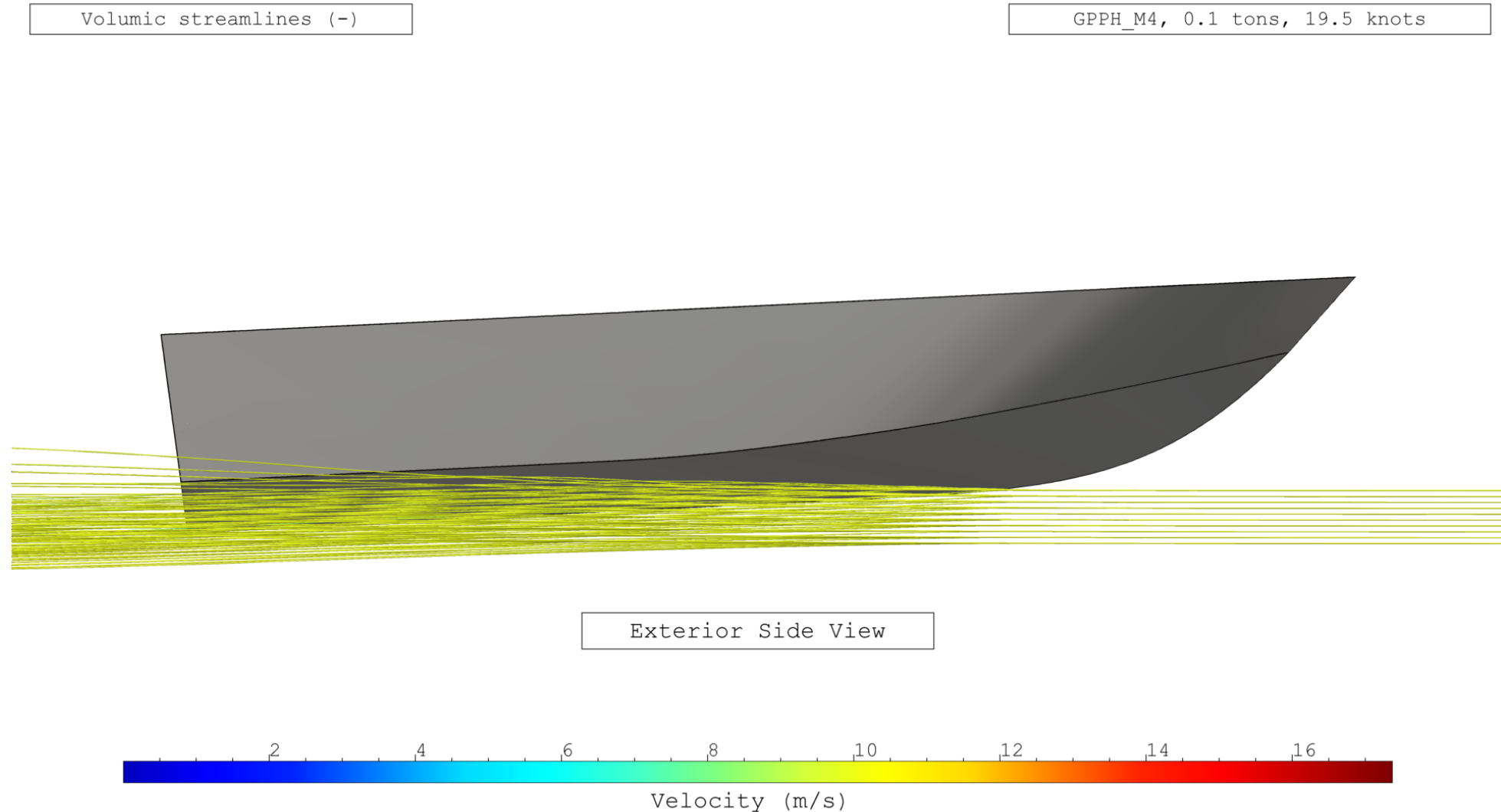


Exterior Side View

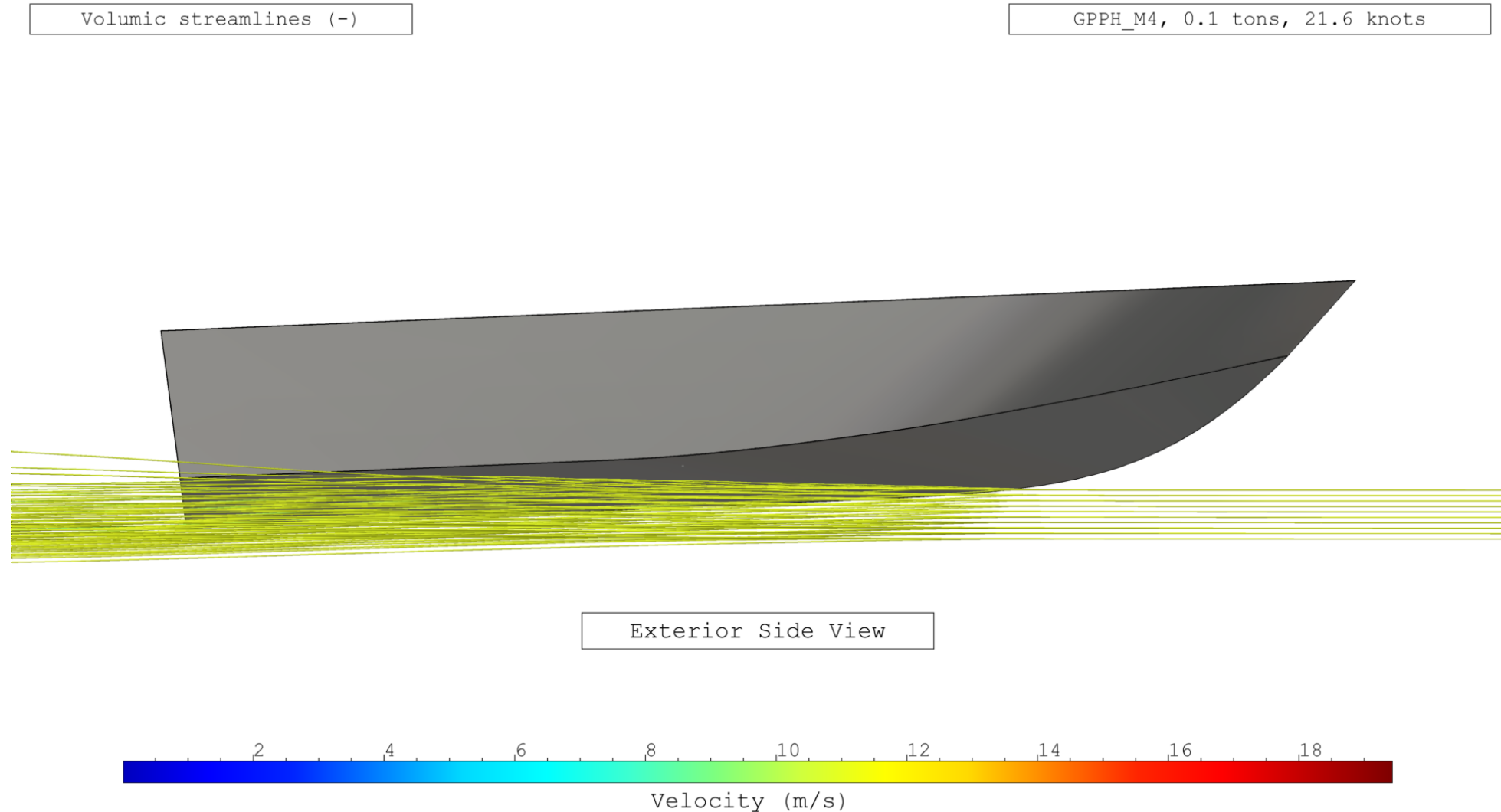




### d. Streamlines (volumic) : side view(s)



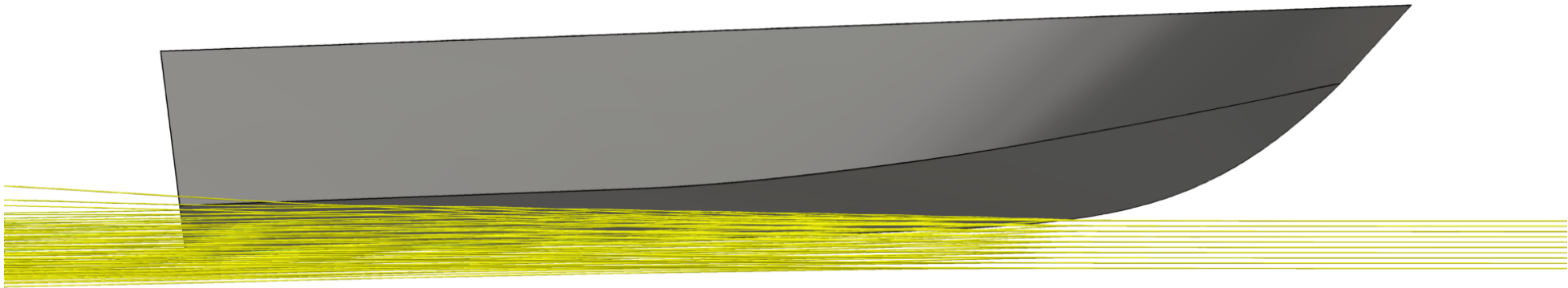
### d. Streamlines (volumic) : side view(s)



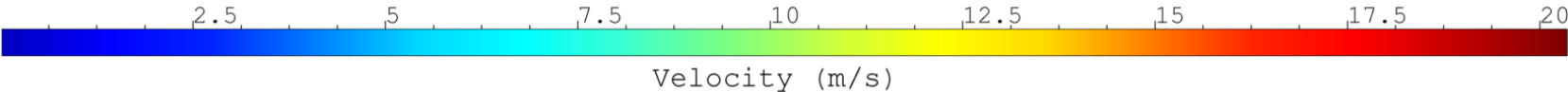
d. Streamlines (volumic) : side view(s)

Volumic streamlines (-)

GPPH\_M4, 0.1 tons, 23.8 knots



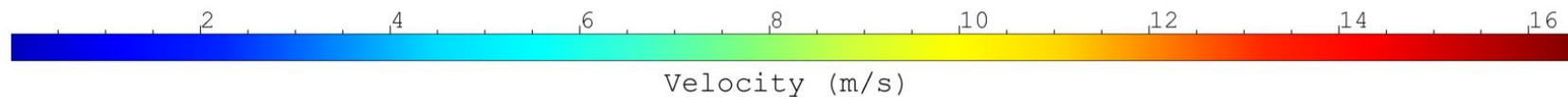
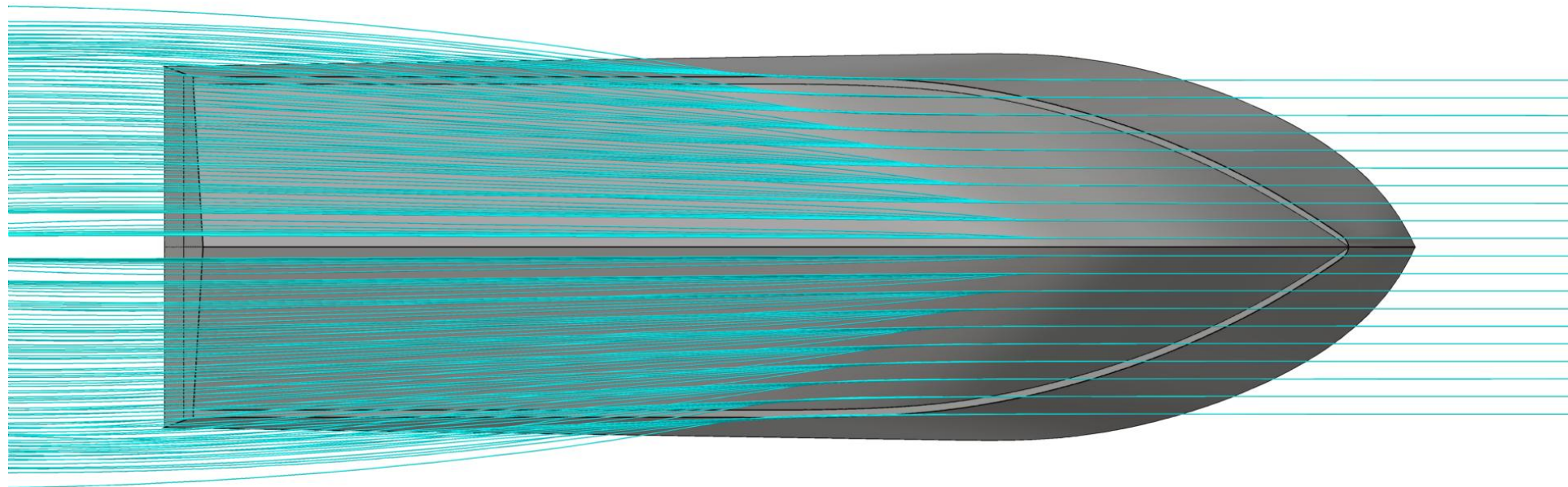
Exterior Side View



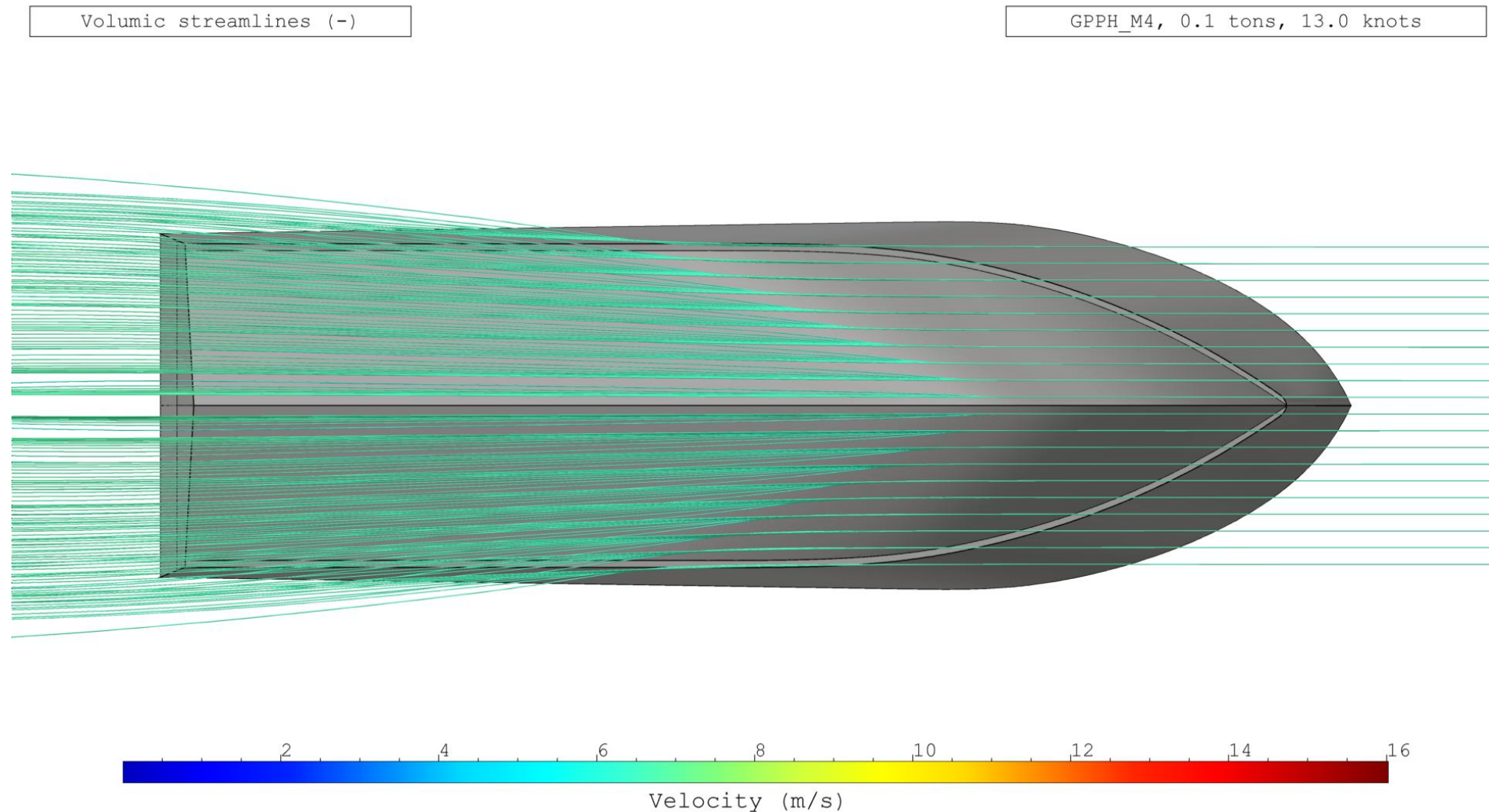
## d. Streamlines (volumic) : bottom view

Volumic streamlines (-)

GPPH\_M4, 0.1 tons, 10.8 knots

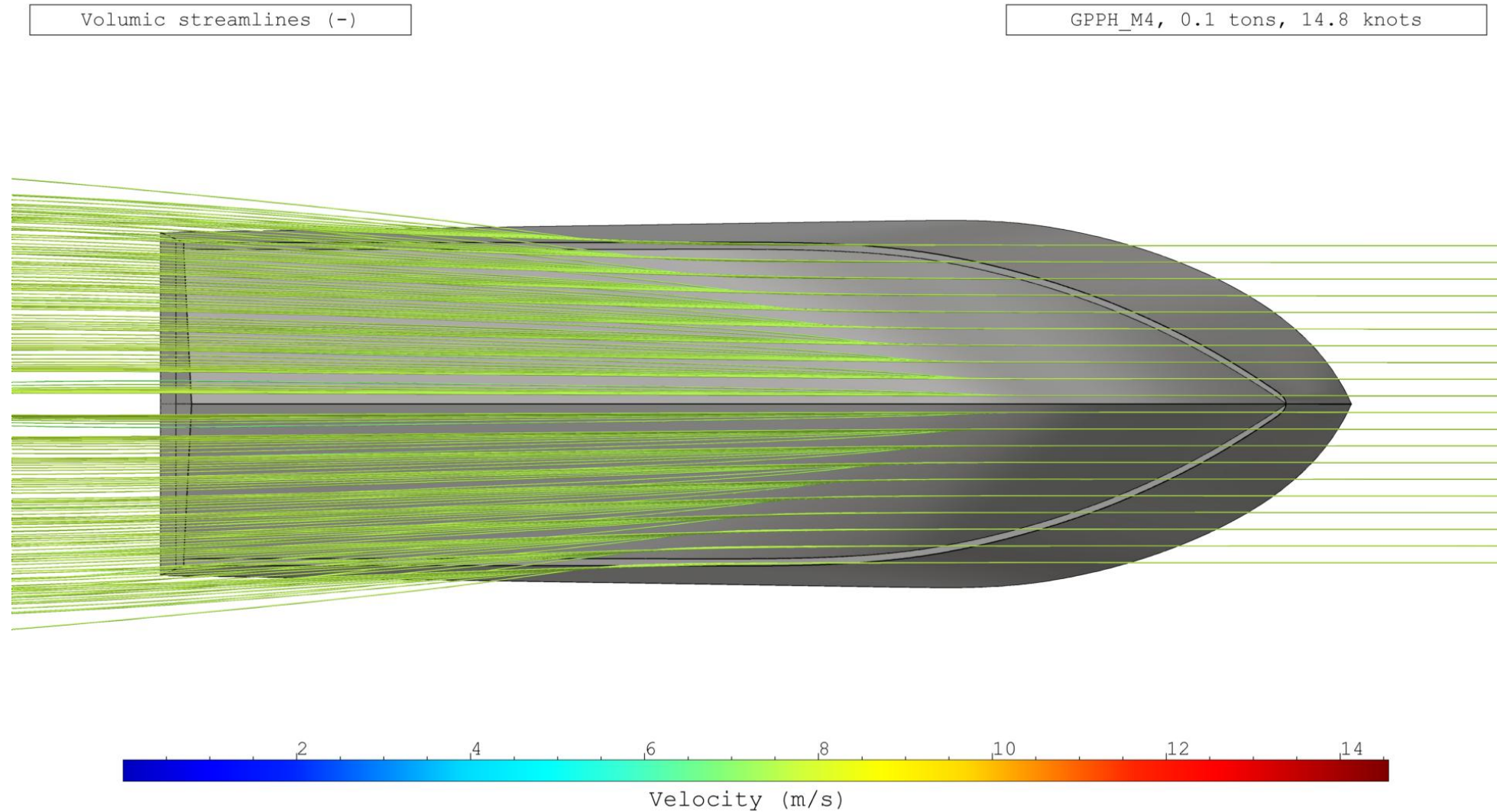


## d. Streamlines (volumic) : bottom view





### d. Streamlines (volumic) : bottom view

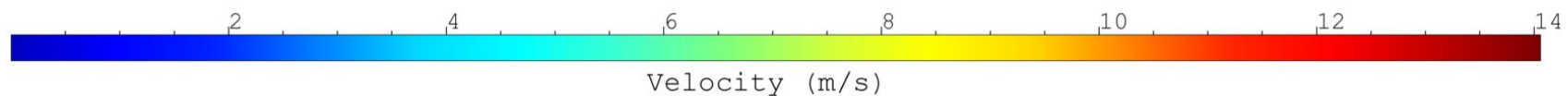
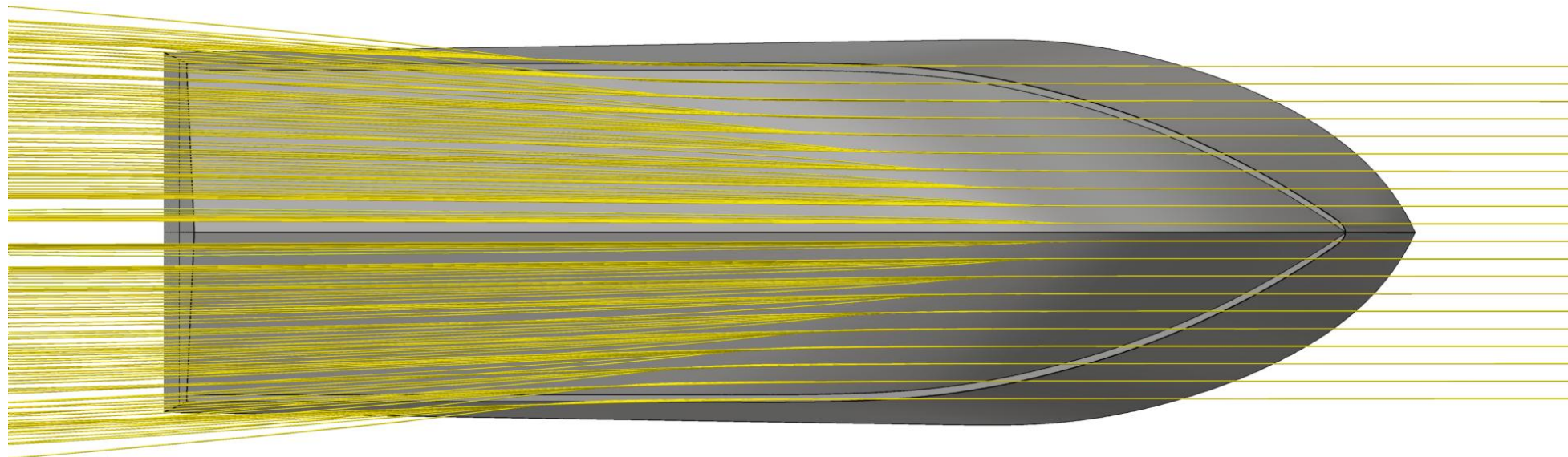




## d. Streamlines (volumic) : bottom view

Volumic streamlines (-)

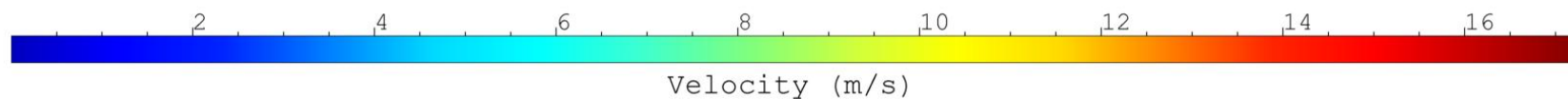
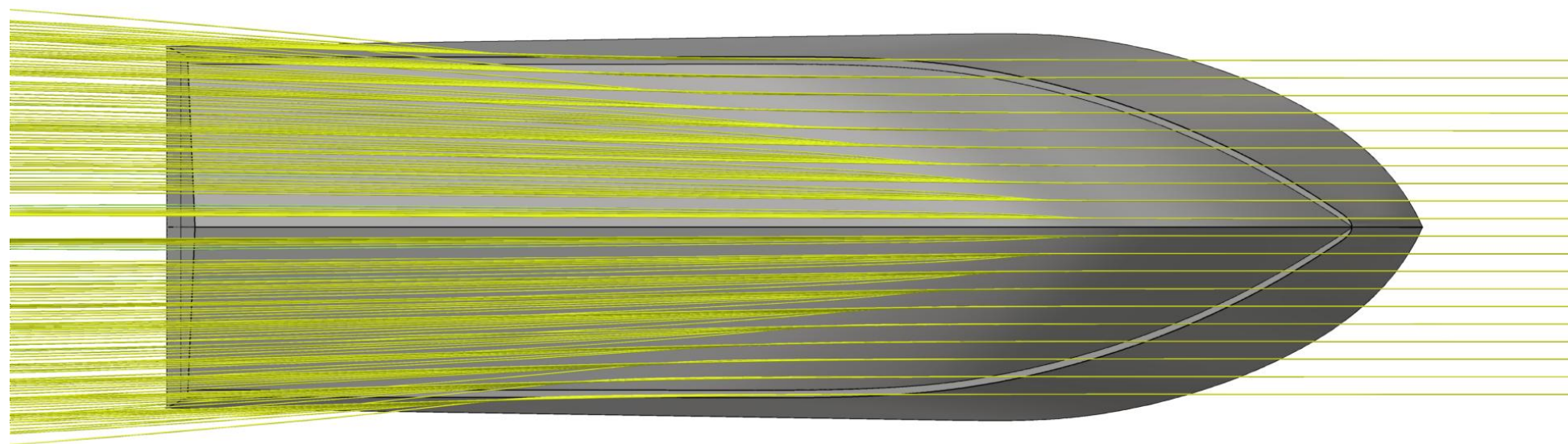
GPPH\_M4, 0.1 tons, 17.5 knots



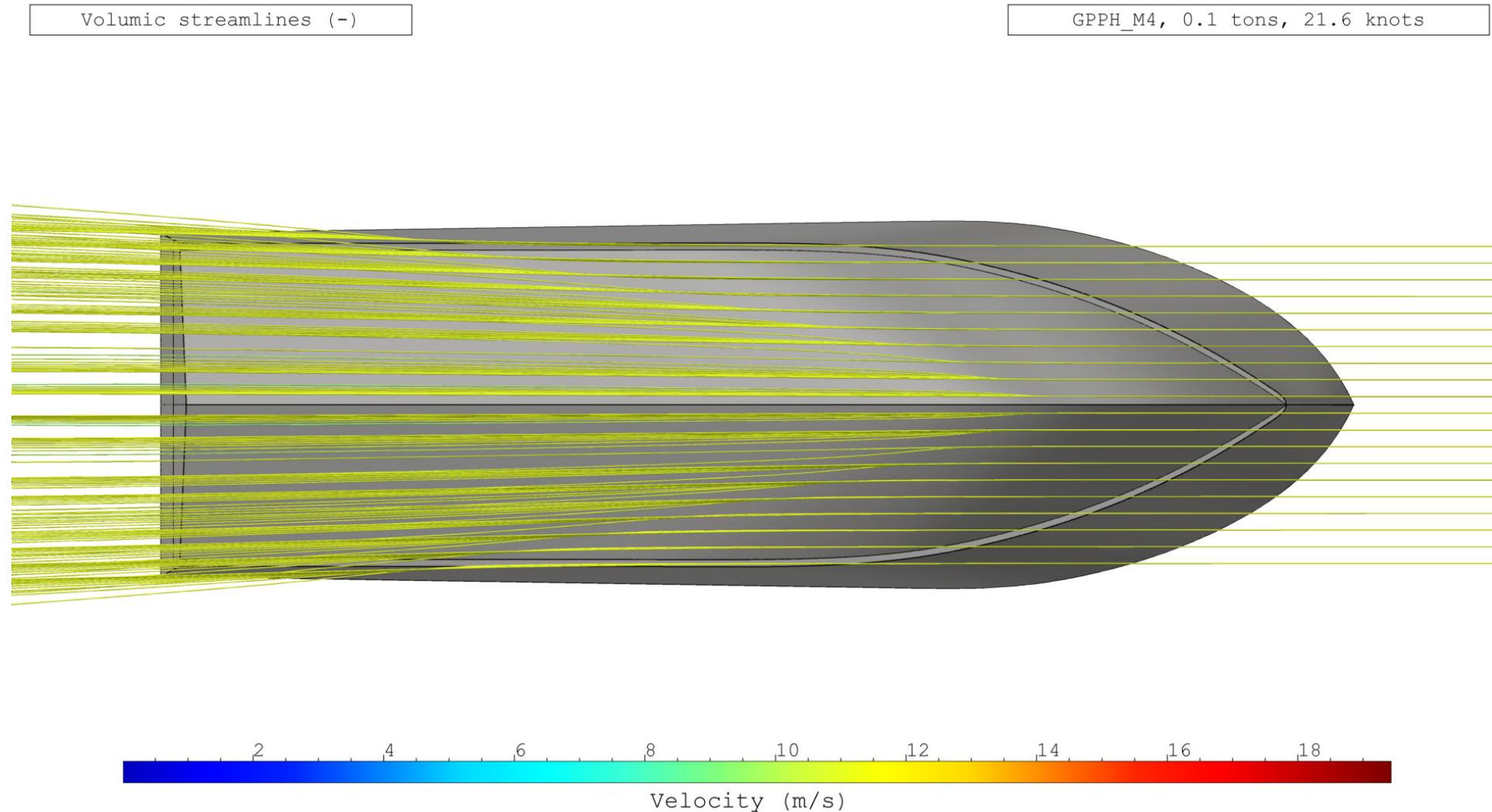
## d. Streamlines (volumic) : bottom view

Volumic streamlines (-)

GPPH\_M4, 0.1 tons, 19.5 knots



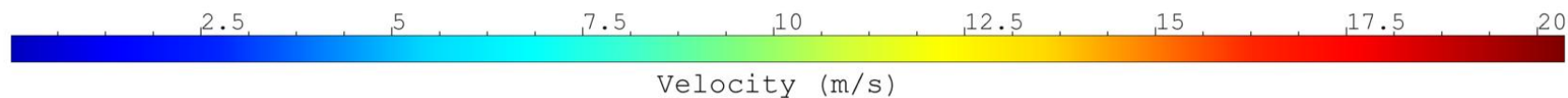
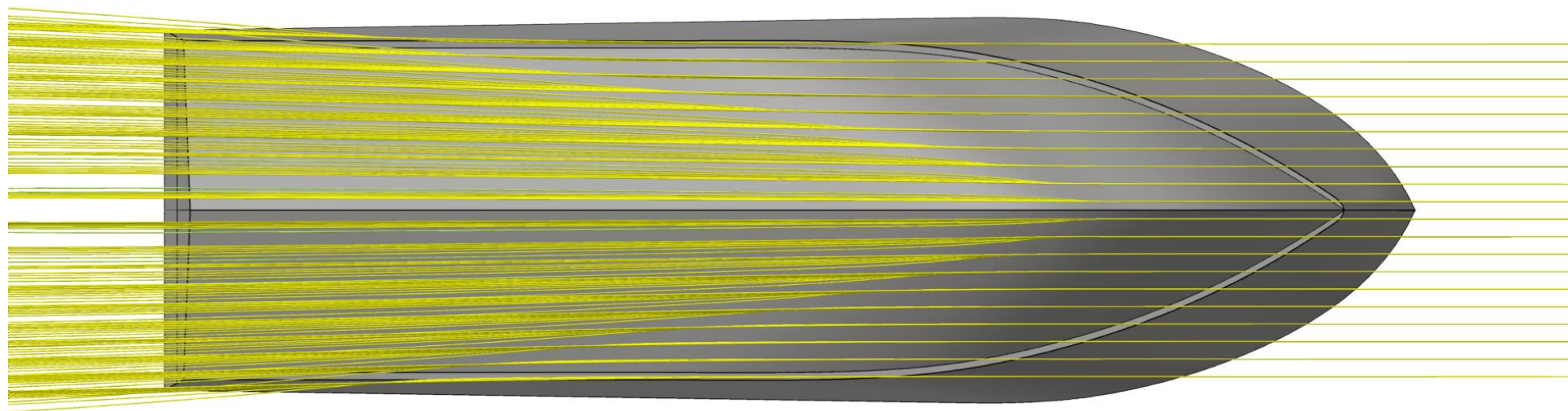
### d. Streamlines (volumic) : bottom view



## d. Streamlines (volumic) : bottom view

Volumic streamlines (-)

GPPH\_M4, 0.1 tons, 23.8 knots





# NepTech

Intelligent sea mobility