BETTER SHIPS, BLUE OCEANS

CFD calculations on channel type bow thrusters

TKI report

Report No.	:	33178-2-MO
Date	:	February 22, 2023
Version	:	0.1
		Draft report

CFD CALCULATIONS ON CHANNEL TYPE BOW THRUSTERS

TKI report

Draft report

MARIN Order No.	: 33178.602
MARIN Project Manager	: J.W. Settels
Ship model No.	: -
Propeller model No.	: -
Model Scale ratio	: 14.444

Ordered by : TKI Deltatechnologie

Reference : Virtual Manoeuvring Basin

Reported by : J.W. Settels
Reviewed by : D. van Heel

Version	Date	Version description
0.1	February 22, 2023	Draft report

Page intentionally left blank

CONTENTS

PAGE

REVIEW OF TABLES vii

REVIEW OF FIGURES ix

1 INTRODUCTION 1

2 SCOPE 3

3 COMPUTATIONAL DOMAIN 5

4 GRID GENERATION 7

5 VISCOUS FLOW SOLVER 9
- 5.1 Propeller implementation . . . 9
- 5.2 Turbulence modeling . . . 9
- 5.3 BOUNDARY CONDITIONS . . . 9
  - 5.3.1 Inflow . . . 9
  - 5.3.2 Outflow . . . 9
  - 5.3.3 Symmetry . . . 10
  - 5.3.4 Wall . . . 10
  - 5.3.5 Pressure . . . 10

6 PRESENTATION AND DISCUSSION OF RESULTS 11
- 6.1 Overview . . . 11
- 6.2 Single bow thruster active . . . 11
- 6.3 Two bow thrusters active . . . 16

7 CONCLUSIONS 23

REFERENCES 25

App. I: Sign convention A1.1

Page intentionally left blank

REVIEW OF TABLES

PAGE

1 Main particulars of used vessel) 5
2 Global force perpendicular to quaywall 11

Page intentionally left blank

REVIEW OF FIGURES

PAGE

1 Overview of the computational domain . . . 5
2 Overview of the bow thruster geometry . . . 6
3 Visualisation of computational mesh around thruster . . . 7
4 Detailed view of the computational mesh inside thruster . . . 7
5 Time-averaged velocity field of BT2 with T=1N . . . 12
6 Time-averaged velocity field of BT2 with T=2N . . . 12
7 Time-averaged velocity field of BT2 with T=4N . . . 13
8 Time-averaged velocity field of BT2 with T=6N . . . 13
9 Time-averaged velocity field of BT2 with T=8N . . . 14
10 Time-averaged velocity field of BT2 with T=10N . . . 14
11 Time-averaged velocity field of BT2 with T=20N . . . 15
12 Time-averaged velocity field of BT2 with T=30N . . . 15
13 Time-averaged velocity field of BT1 with T=2N . . . 16
14 Time-averaged velocity field of BT2 with T=2N . . . 17
15 Time-averaged velocity field of BT1 with T=4N . . . 17
16 Time-averaged velocity field of BT2 with T=4N . . . 18
17 Time-averaged velocity field of BT1 with T=6N . . . 18
18 Time-averaged velocity field of BT2 with T=6N . . . 19
19 Time-averaged velocity field of BT1 with T=8N . . . 19
20 Time-averaged velocity field of BT2 with T=8N . . . 20
21 Time-averaged velocity field of BT1 with T=10N . . . 20
22 Time-averaged velocity field of BT2 with T=10N . . . 21

Page intentionally left blank

1 INTRODUCTION

The calculations presented in this report are carried out in the TKI-Deltatechnologie project ”Schroefstraal OnderzoeksProgramma (SOP)”, which is carried out as part of the CROW working group ”Schroefstralen”, which aims at better understanding and quantification of propeller jet loading on hydraulic infrastructure as described in the roadmap ”Schroefstraalbelasting” of Rijkswaterstaat (RWS). This quantification is desired to assess and possibly revise the guidelines for bottom protection.

In this TKI project three measurement approaches were taken: Full scale field measurements of the flow velocities, pressures and line forces induced by channel type bow thrusters were measured in 2020 in the Port of Ghent [1] [2]. Model scale measurements were carried out by Deltares using particle image velocimetry (PIV) to measure flow velocity fields and near wall velocities [3]. Finally, numerical simulations using computational fluid dynamics (CFD) were carried out by MARIN, as described in this report. This project thus aims at combining the insights of different measurement techniques and provides the different parties with valuable validation material.

Page intentionally left blank

2 SCOPE

The scope of this project entails numerical simulations performed in ReFRESCO for a selection of the conditions which were tested on model scale at Deltares [3]. This consists of one fixed distance to the quay side. The water depth was set to the measured value at full scale during the field measurements. All computations are performed at model scale, to make it possible to make a direct comparison with the model tests carried out at Deltares.
The initial proposal described three different power settings, with either one or both channel thrusters active. During the calculations it proved difficult to match the generated side force exactly, so additional computations were carried out. This resulted in a total of 8 power settings for a single channel thruster active and 5 power settings with both channel thrusters active.

Page intentionally left blank

3 COMPUTATIONAL DOMAIN

The chosen computational domain is depicted in figure 1. It extends one ship length in front of and aft of the vessel, which is placed in the longitudinal center of the domain. The full scale distance from the vessel to the quay wall is 3.0 meters and the water depth was set to 6.4 meter at full scale, which results in an Under Keel Clearance (UKC) of 2.52 meters. The far side boundary lies 1 ship length from the centerline of the ship. The scale factor was chosen identical to the scale factor used in the model scale experiments as reported by Deltares and equal to 1:14.444.

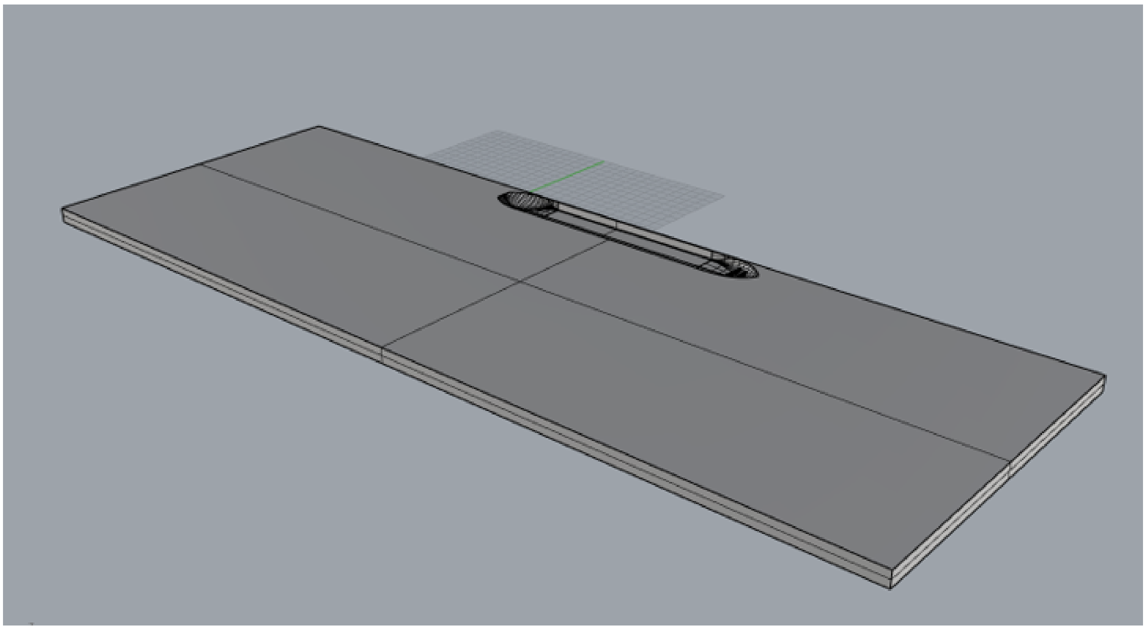


Figure 1: Overview of the computational domain

The main particulars of the vessel at full scale and model scale are given in table 1.

Table 1: Main particulars of used vessel)

Description	Symbol	Magnitude full scale	Magnitude model scale	Unit
Length overall	L_{oa}	135.00	9.346	m
Length between perpendiculars	L_{pp}	134.57	9.317	m
Maximum breadth	Bwl	17.50	1.212	m
Maximum Depth	D	6.10	0.422	m
Mean Draught	T	3.88	0.287	m

The channel thrusters were implemented following the drawings of the vessel tested in the Port of Ghent during the field measurements. Only the inlet channel and port side outlet channel were included in the simulations for both bow thrusters. Figure 2 shows an overview of the bow thruster geometry as modelled. The geometry of the vessel including the channel geometries was shared with Deltares for this project and subsequently used in the PIV measurement campaign. This enables direct comparison between the PIV measurements at model scale and the model scale CFD computations.

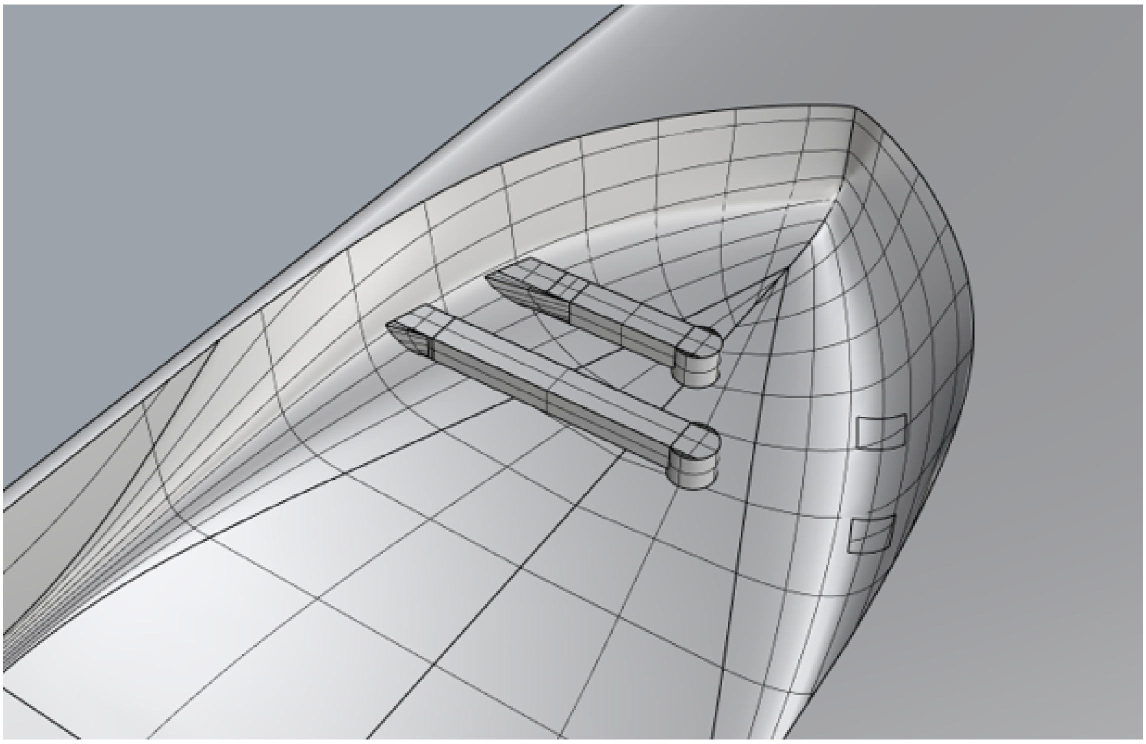


Figure 2: Overview of the bow thruster geometry

4 GRID GENERATION

The computational domain as descirbed in the previous section was discretised using the commercial grid generation package Hexpress by Cadence, formerly named NUMECA. This grid generator was used to generate hexahedral cells in a volume mesh. The initial grid is a Cartesian mesh, from which the cells are removed that intersect the geometry of the vessel. Subsequent refinements capture the relevant features of the vessel and are snapped onto the surface. Finally, a viscous sublayer is inserted on the relevant features of the vessel to capture the boundary layer.

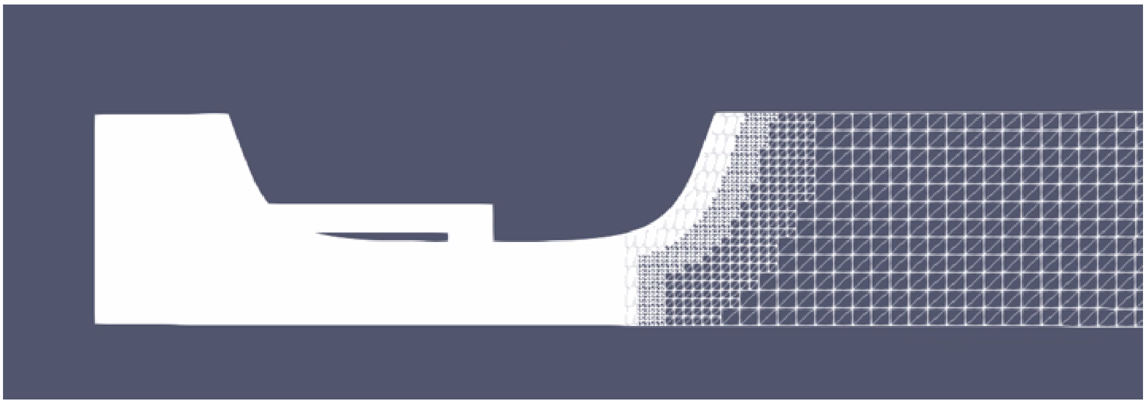


Figure 3: Visualisation of computational mesh around thruster

Figure 3 shows a cross section of the mesh around the channel thruster. A more detailed visualisation is depicted in figure 4. The total grid for these computations consists of 44.6M cells. Grid refinement studies

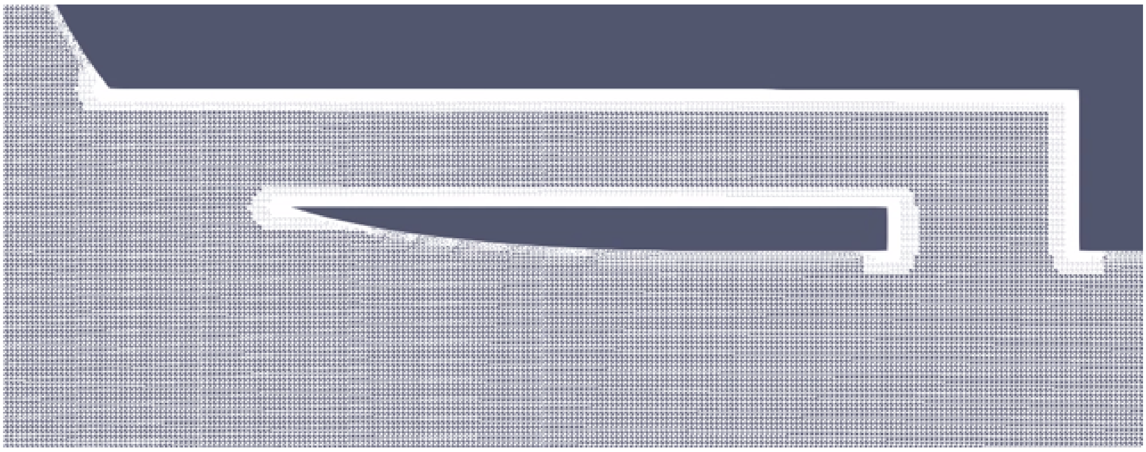


Figure 4: Detailed view of the computational mesh inside thruster

were not included in the scope of this research. However, the number of cells is chosen relatively large to avoid too large discretisation uncertainties.

Page intentionally left blank

5 VISCOUS FLOW SOLVER

ReFRESCO is a community-based CFD software package, developed at the Maritime Research Institute Netherlands (MARIN) in collaboration with several non-profit organizations around the world. It solves (unsteady) incompressible viscous flows based on the Navier-Stokes equations, complemented with turbulence models, cavitation models and volume-fraction transport equations for multiple phases. The equations are discretised in conservative form using a finite-volume method with all variables co-located in the cell centers. Time integration is performed implicitly using first- or second-order schemes that support variable step sizes. The system of mass and momentum equations is linearised with Picard's method and solved either with a segregated or a coupled method, both based on the SIMPLE pressure-correction algorithm. All remaining equations are solved with a segregated method. The implementation is face-based, which permits the use of structured and unstructured meshes with arbitrary elements (tetrahedra, hexahedra, prisms, pyramids or any kind of polyhedra) including local refinements with hanging nodes. The solver is parallelised using message passing interface (MPI) and subdomain decomposition, and runs on Linux workstations and high performance computing (HPC) clusters.

5.1 Propeller implementation

The implementation of the thruster in the computations is achieved by modeling the geometry of the channel in the computational domain and subsequent computational grid as described in the preceding section. An Actuator Disc (AD) is placed in the inlet of the channel thruster providing a prescribed thrust. This is a higly simplified but robust model of a propeller. Since the inflow to the propeller is relatively unrestricted, unlike the main propeller at speed which acts in the wake field of a ship, and the sharp bend of the flow inside the channel geometry this simplification of propeller modeling is assumed to be justified.

5.2 Turbulence modeling

The turbulence model used in the simulations is the $k - \omega \; SST \; 2003$ model. This is a two-equation eddy-viscosity turbulence model which is widely used in maritime CFD applications.

5.3 BOUNDARY CONDITIONS

The chosen boundary conditions have a significant influence on the computational results when using CFD codes. For the computations in this study the following conditions were used:

5.3.1 Inflow

The inflow of the domain was placed in front of the vessel at the domain edge. An inflow boundary condition was used. An initial inflow velocity of $10^{-6}m/s$ in the direction of the vessel was used. This is a very small value and thus does not influence the results but was used for numerical stability purposes.

5.3.2 Outflow

The outflow of the domain was placed aft of the vessel at the domain edge. An outflow boundary condition was used, which matches the inflow boundary condition, thus ensuring the global conservation of mass during the simulations.

5.3.3 Symmetry

The still water surface was modelled as a symmetry boundary condition, which is comparable to a free-slip wall condition. This approach does not account for deformation of the water surface due to thruster action. However, the pressure and velocity equations are still solved for the flow below the undisturbed water surface. Since the main focus of this study are hydrodynamic effects this assumption is deemed to be acceptable.

5.3.4 Wall

The quay wall, bottom and vessel, including the channel thruster geometry are modelled as a no-slip wall boundary condition. This enables the formation of physical boundary layers on these surfaces. The roughness of the walls is not accounted for, thus the surfaces are assumed to be perfectly smooth at their surface.

5.3.5 Pressure

The domain edge towards the side of the vessel is set to a pressure boundary condition with a reference pressure of 0. Since this wall is far away from the vessel it is assumed the pressure fluctuations from the ship do not reach this side boundary, while the boundary condition provides numerical stability in the pressure equations.

6 PRESENTATION AND DISCUSSION OF RESULTS

The computations were performed with the aft most tunnel thruster (BT2) active, or with both (BT1 & BT2) active. Both of these conditions were calculated using incremental prescribed AD thrust settings. In the following section the resulting forces perpendicular to the centerline of the vessel are summarised. These are the forces acting on the vessel. Furthermore, the mean outflow velocity of each bow thruster is determined for each prescribed AD thrust setting. This is obtained by taking the average velocity in the square section of the bow thruster channel near the outflow. This mean flow velocity is depicted as U_0. Next, the time-averaged velocity fields are shown. All velocities are divided by the mean outflow velocity of the thruster resulting in a non-dimensional quantity. The viewpoint coincides with a plane through the center of the channel thruster (BT1 or BT2) perpendicular to the ships longitudinal axis. The quay wall is positioned at the left side of the figure.

6.1 Overview

The used thrust settings are summarised in table 2, followed by the resulting force acting on the vessel (F_Y) and mean outflow velocity.

Table 2: Global force perpendicular to quaywall

Active thruster	T_{AD} [N]	F_Y [N]	U_0 $[m/s]$ BT1	U_0 $[m/s]$ BT2
2	1	0.507	-	0.371
2	2	0.983	-	0.539
2	4	1.820	-	0.775
2	6	2.729	-	0.958
2	8	3.735	-	1.115
2	10	4.429	-	1.248
2	20	8.829	-	1.781
2	30	12.18	-	2.162
1&2	2	2.450	0.580	0.553
1&2	4	4.732	0.822	0.797
1&2	6	6.941	1.022	0.975
1&2	8	9.551	1.160	1.138
1&2	10	11.82	1.314	1.266

The conditions with both bow thrusters active show a resulting force on the ship which is more than double the value obtained with BT2 only, indicating that BT1 might be more effective than BT2. Calculations to confirm this effect might be desired.

6.2 Single bow thruster active

Figure 5 to 12 show the time-averaged non-dimenional velocity fields for incremental values of AD thrust. It is observed that these flow fields and patterns are similar between different power settings. The higher thrust settings of 20N and 30N result in more distinct phenomena at the suction side of the channel thruster, indicating instabilities in the flow which urges caution to compare these results. The time-averaged approach might not be valid anymore in these cases.

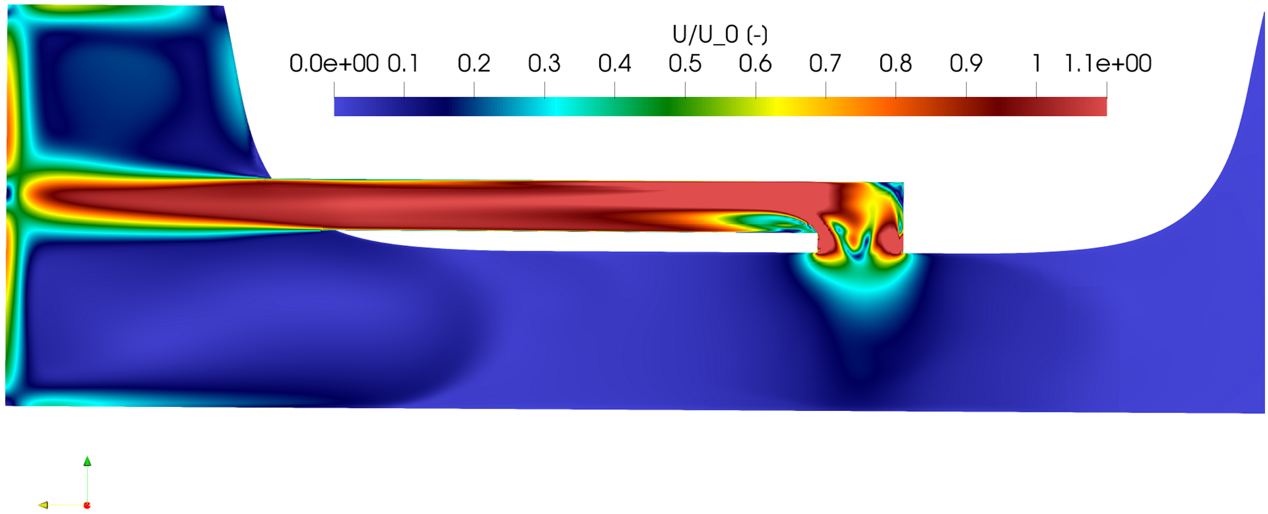


Figure 5: Time-averaged velocity field of BT2 with T=1N

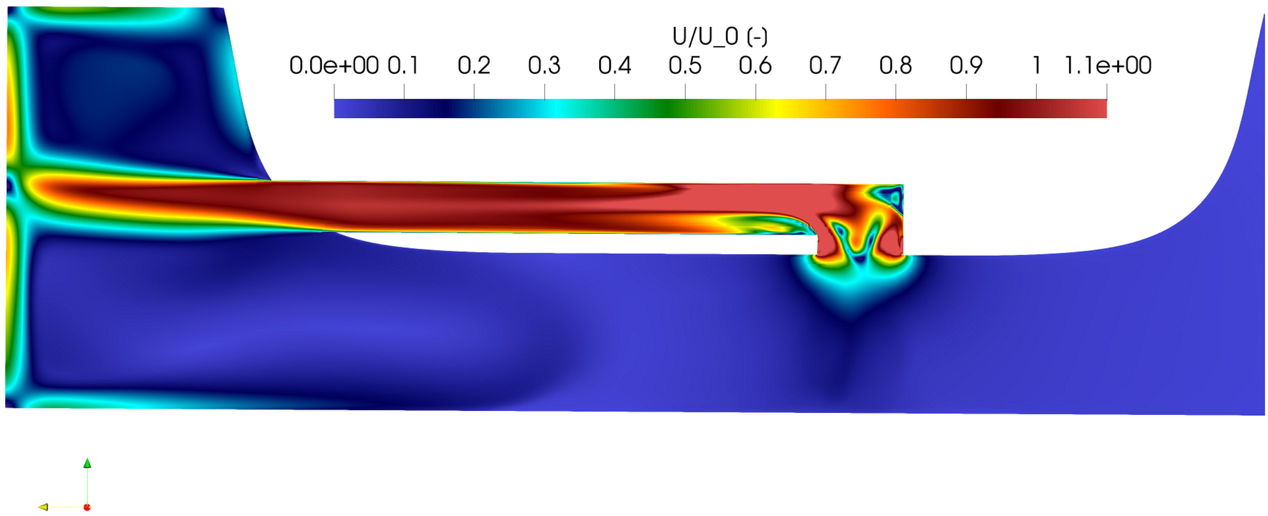


Figure 6: Time-averaged velocity field of BT2 with T=2N

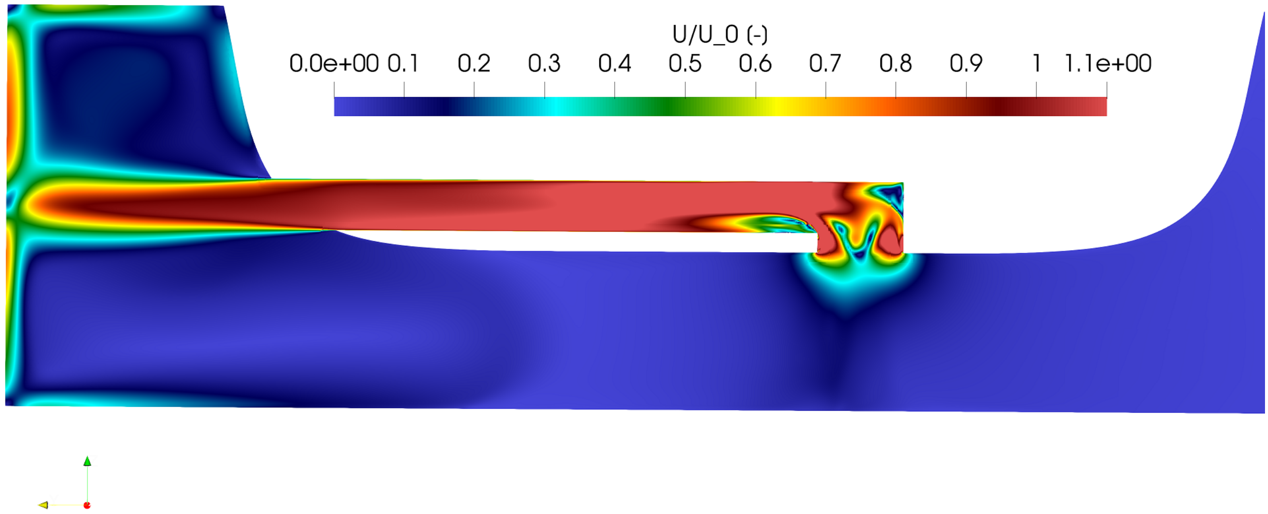


Figure 7: Time-averaged velocity field of BT2 with T=4N

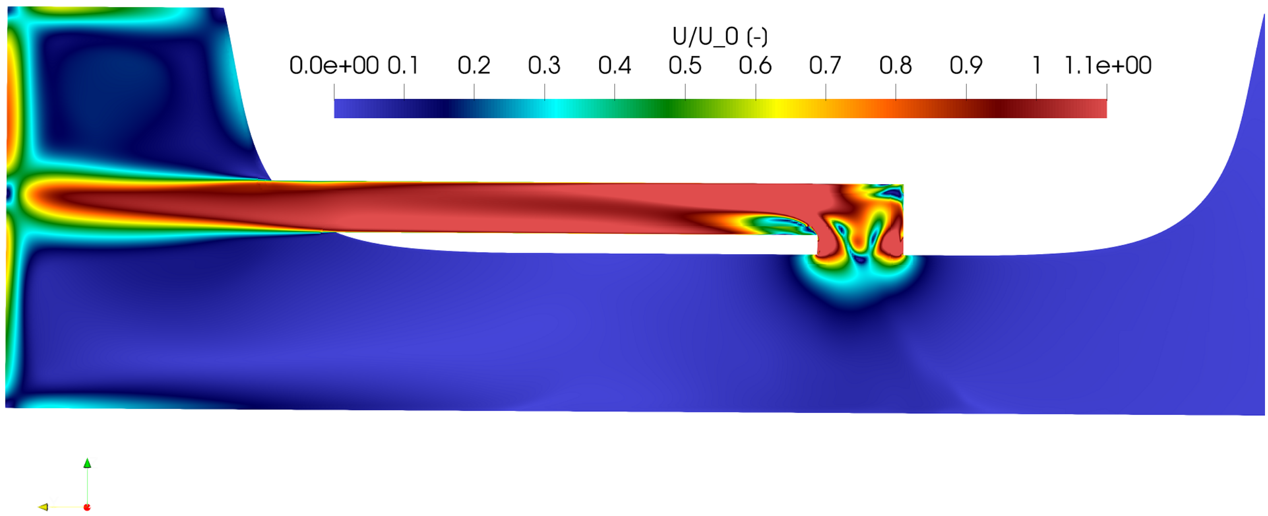


Figure 8: Time-averaged velocity field of BT2 with T=6N

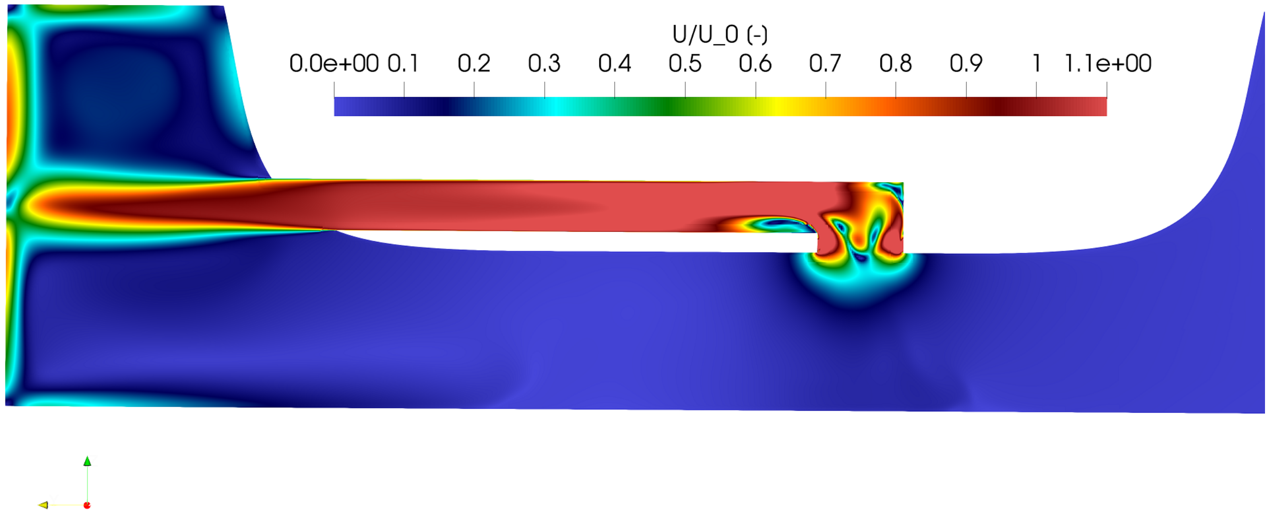


Figure 9: Time-averaged velocity field of BT2 with T=8N

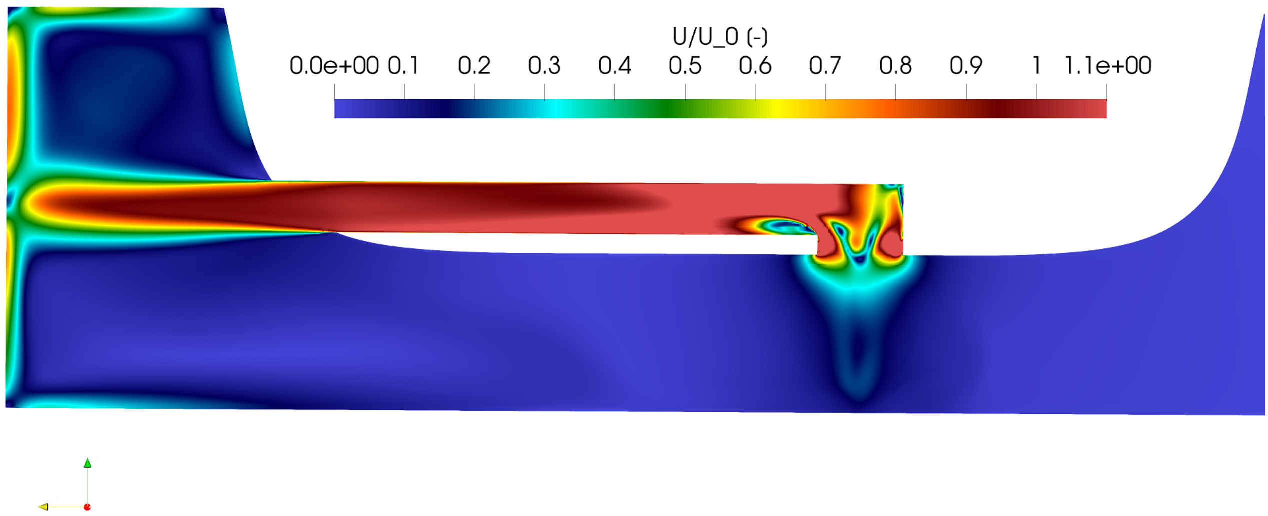


Figure 10: Time-averaged velocity field of BT2 with T=10N

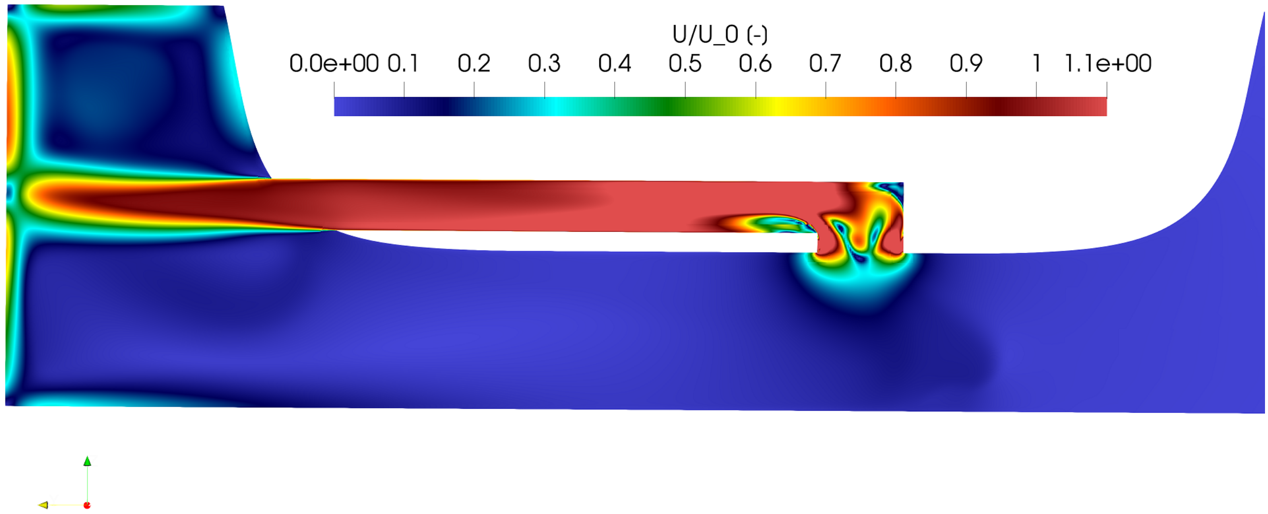


Figure 11: Time-averaged velocity field of BT2 with T=20N

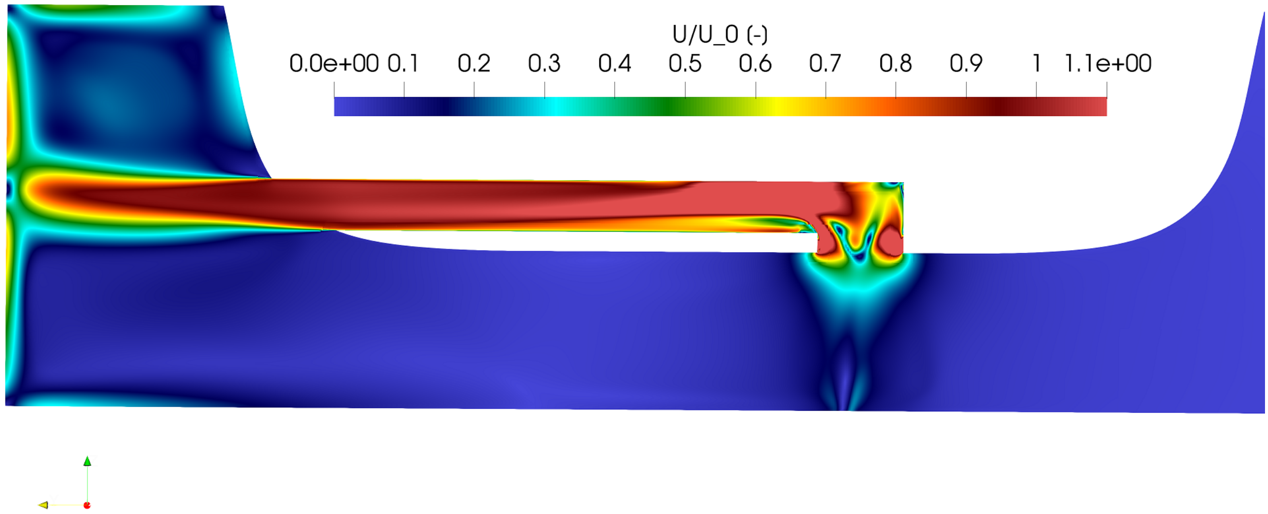


Figure 12: Time-averaged velocity field of BT2 with T=30N

6.3 Two bow thrusters active

Figures 13 to 22 show the time-averaged non-dimensional flow velocities for incremental values of AD thrust for both BT1 and BT2 active. From these computations it becomes apparent that the outflow of BT2 is directed more towards the bottom when BT1 is also active.

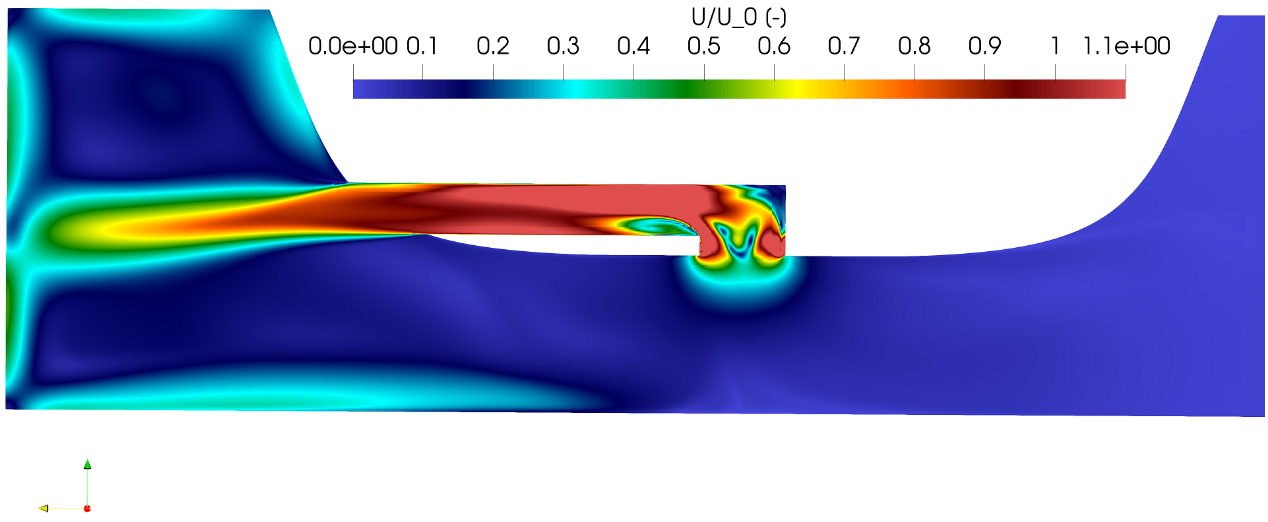


Figure 13: Time-averaged velocity field of BT1 with T=2N

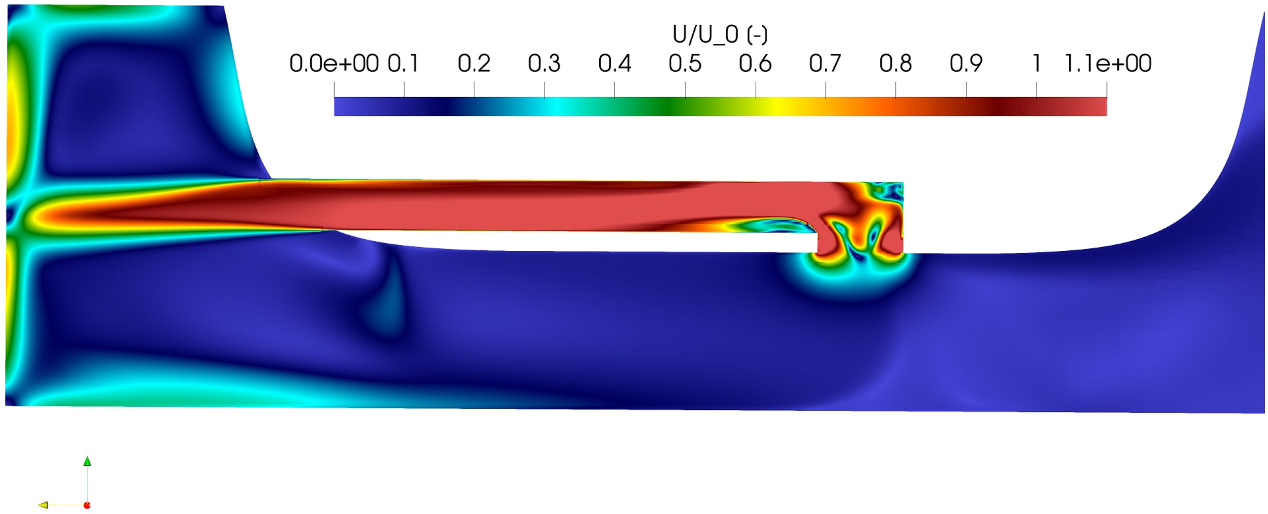


Figure 14: Time-averaged velocity field of BT2 with T=2N

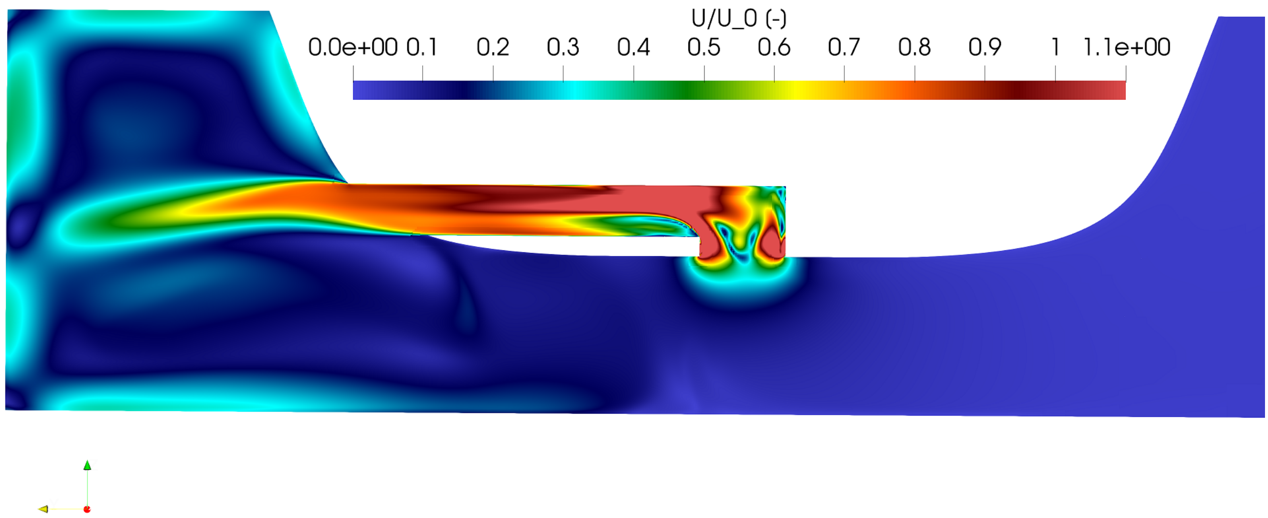


Figure 15: Time-averaged velocity field of BT1 with T=4N

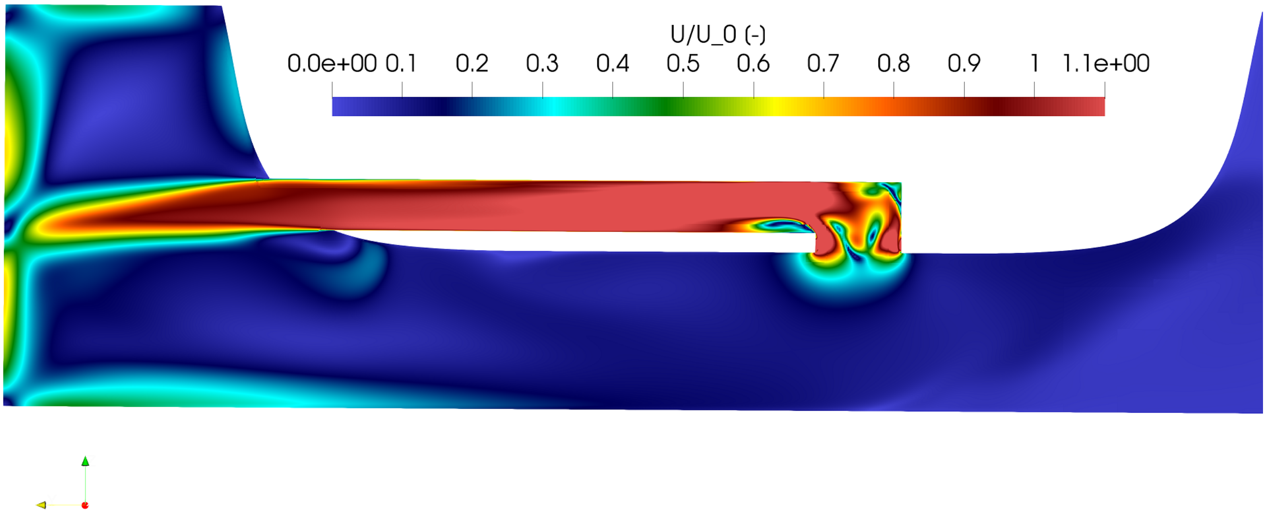


Figure 16: Time-averaged velocity field of BT2 with T=4N

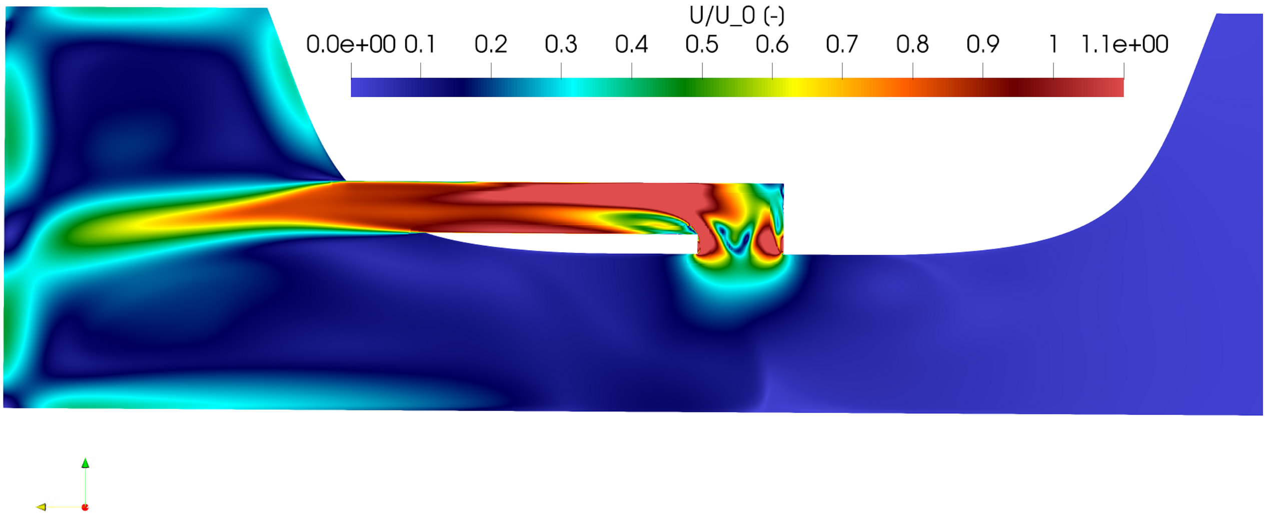


Figure 17: Time-averaged velocity field of BT1 with T=6N

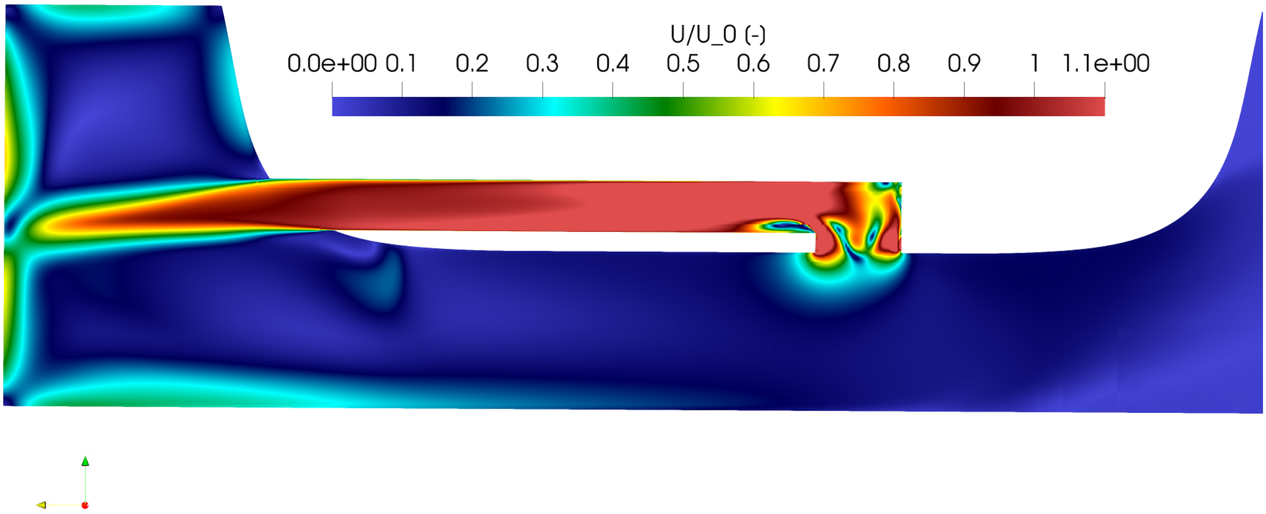


Figure 18: Time-averaged velocity field of BT2 with T=6N

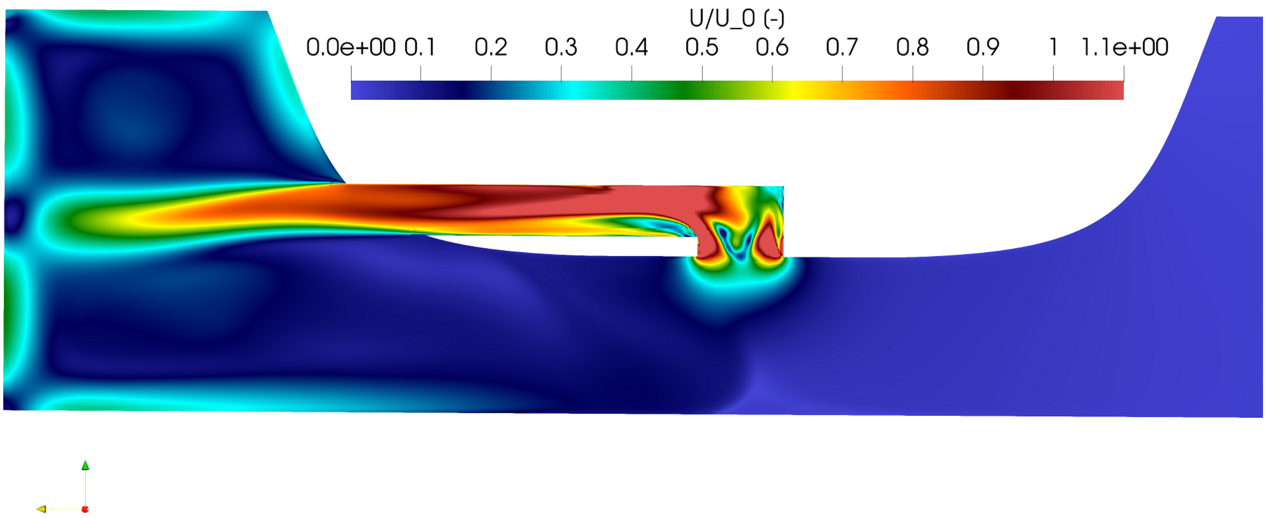


Figure 19: Time-averaged velocity field of BT1 with T=8N

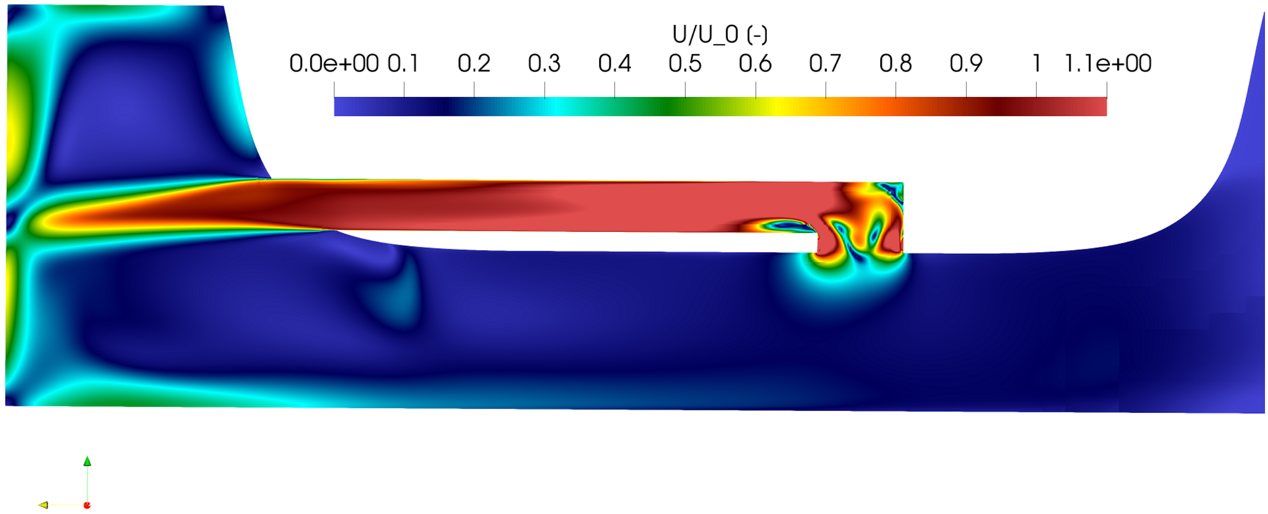


Figure 20: Time-averaged velocity field of BT2 with T=8N

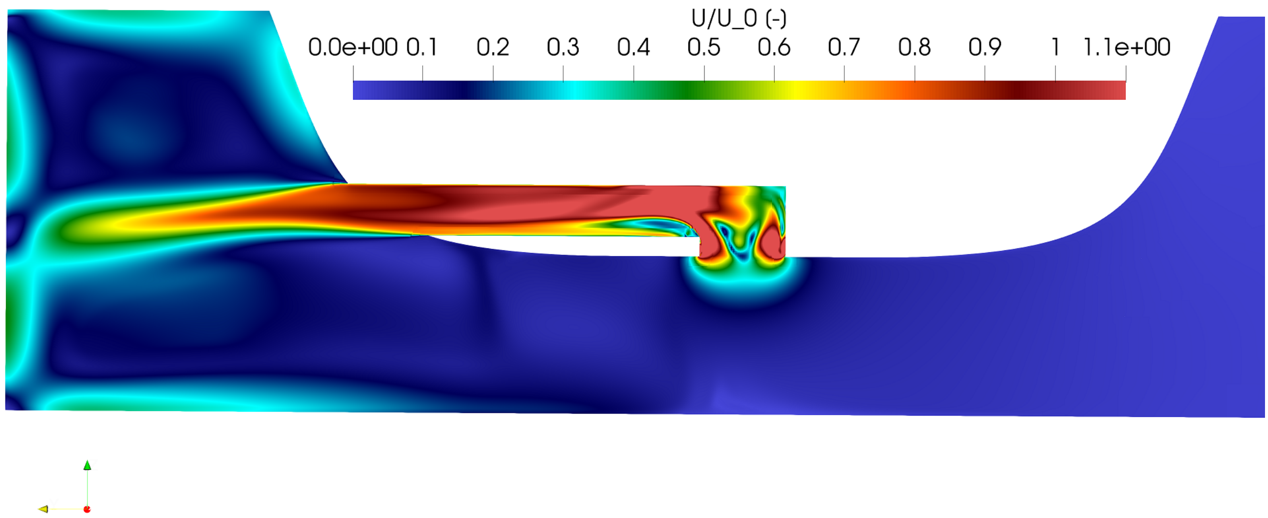


Figure 21: Time-averaged velocity field of BT1 with T=10N

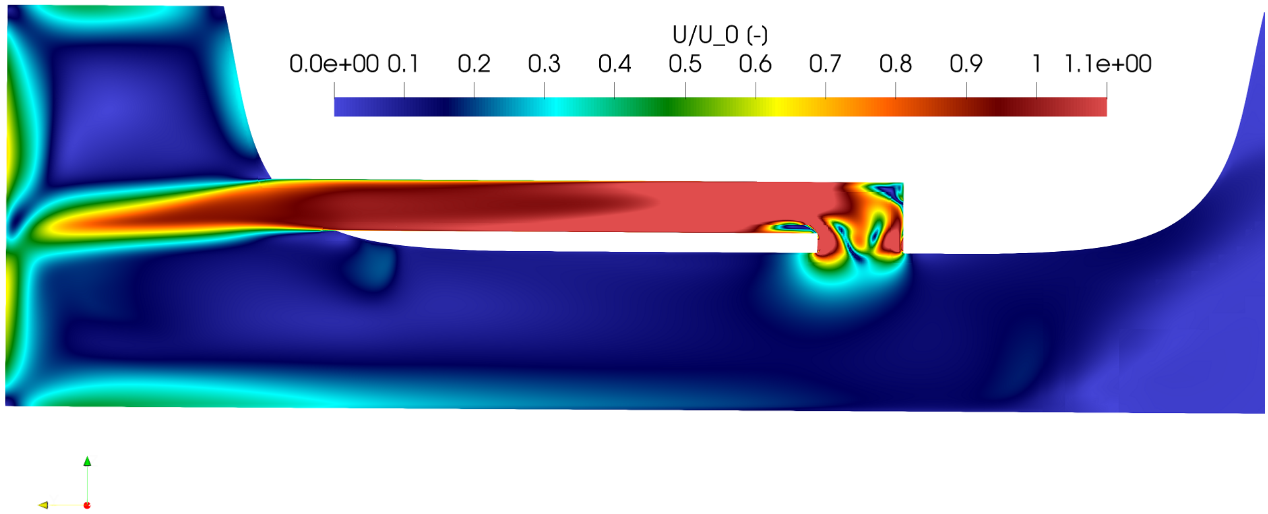


Figure 22: Time-averaged velocity field of BT2 with T=10N

Page intentionally left blank

7 CONCLUSIONS

- For the TKI Deltatechnologie project ”Schroefstraal OnderzoeksProgramma” (SOP) a number of computations were carried out in ReFRESCO at model scale. These computations were performed using the geometry of the vessel as used in the field tests in Ghent. The channel thruster geometries were implemented and shared with Deltares for the PIV measurement campaign.
- From the performed computations the global forces acting on the vessel, mean outflow velocities and time-averaged velocity fields were obtained for a single water depth and distance of the vessel to the quay wall. The prescribed thrust values for the propeller model were varied. Furthermore these conditions have been calculated with the aft bow thruster active and with both bow thrusters active.
- These results enable direct comparison to the PIV measurements. The computational grids and settings can be readily used for future studies or extensions to this research.

Wageningen, February 22, 2023
MARITIME RESEARCH INSTITUTE NETHERLANDS

Hugo Ammerlaan
Manager MO

Page intentionally left blank

REFERENCES

[1] J.W.T. Tukker, *Decay of bow thruster induced near-bed flow velocities at a vertical quay wall*, Master Thesis, Technical University of Delft, 2021.

[2] G.D. Struijk, *Bollard Pull Measurement - Tunnel Thruster*, MARIN Report 33178-1-PaS, 2022.

[3] C. van Nieuwenhuizen, W. Bakker, H. dos Santos Nogueira, *Characterization of flows induced by propeller jets, physical scale model tests report*, Deltares Report, 2022.

Page intentionally left blank

APPENDICES

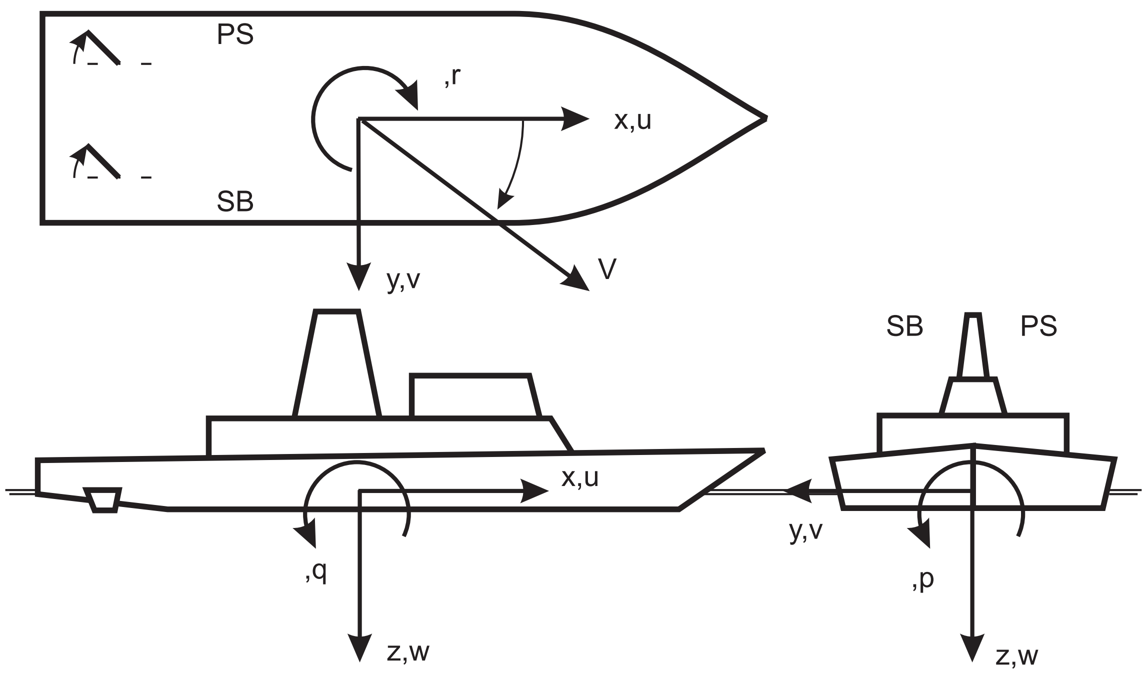
MARIN

APPENDIX I

MARIN SIGN CONVENTION FOR MANOEUVRING SIMULATIONS

In this report the following definitions and sign conventions are used:

DESIGNATION	SYMBOL	UNIT	POSITIVE FOR
Time	t	s	-
Linear scale ratio	λ	-	-
Froude number	F_n	-	forward speed
Ship speed in origin	V	kn, m/s	forward speed
Reference point of ship, CoG	CoG	-	centre of gravity
Longitudinal position	x	m	forward of O
Transverse position	y	m	SB of O
Vertical position	z	m	downward from O
Roll angle	ϕ	deg	SB down
Pitch angle	θ	deg	bow up
Yaw or course angle (heading)	ψ	deg	bow to SB
Velocity / acceleration along body x-axis	u	m/s	directed forward
Velocity / acceleration along body y-axis	v	m/s	directed to SB
Velocity / acceleration along body z-axis	w	m/s	directed downward
Roll rate / acceleration	p	deg/s	turning SB down
Pitch rate / acceleration	q	deg/s	turning bow up
Yaw rate / acceleration	r	deg/s	turning bow to SB
Notation of derivatives of velocities and rates	e.g. $\dot{r}$	deg/s^2	
Drift angle	β	deg	positive v
Dimensionless rate of turn		-	turning bow to SB



MARIN
P.O. Box 28
6700 AA Wageningen
The Netherlands
T +31 317 49 39 11
E info@marin.nl
I www.marin.nl