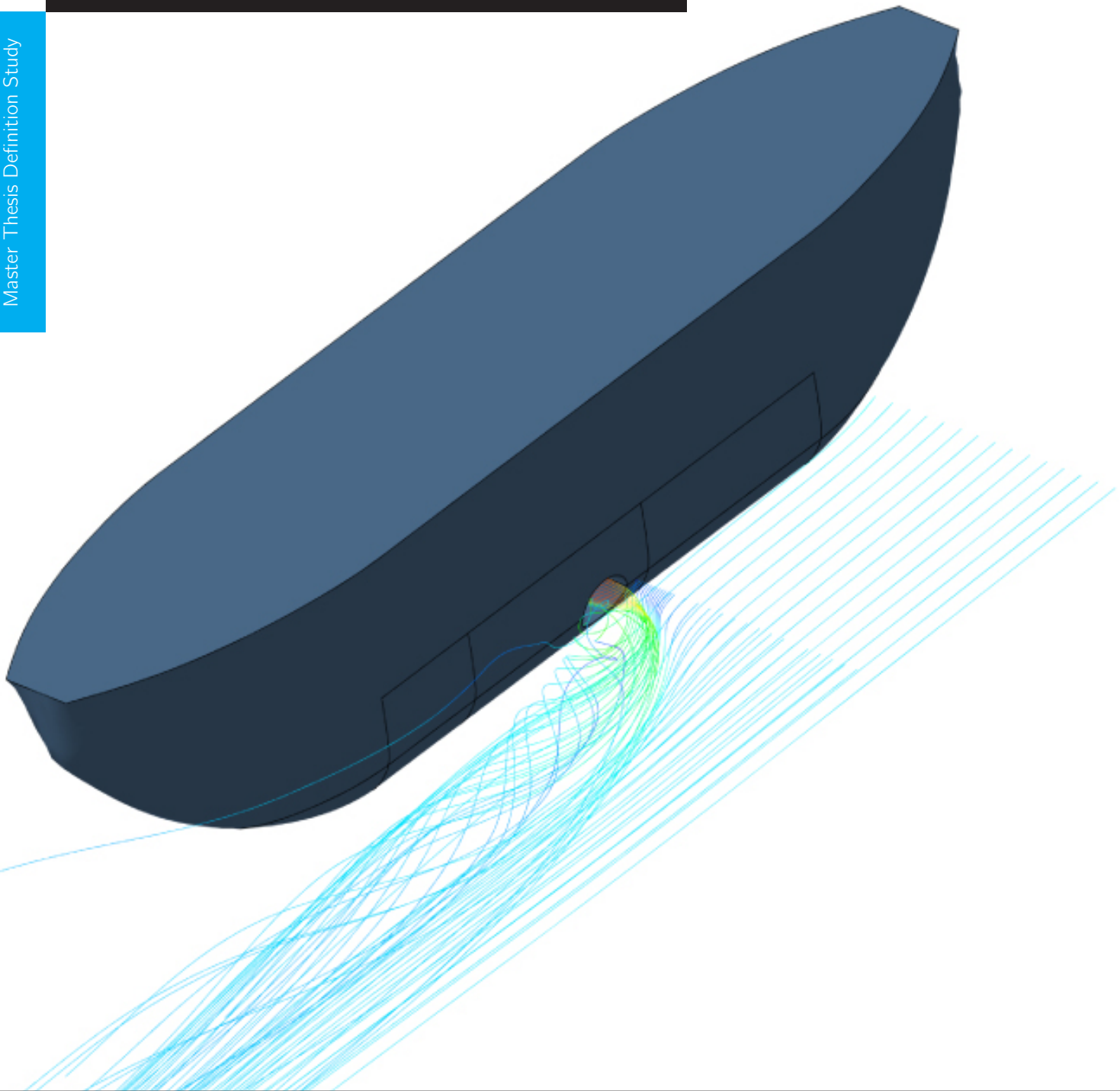


Changing the cross-sectional geometry of a bow tunnel thruster

Effects on the performance of the thruster at slow forward motion using Computational Fluid Dynamics

Tobias Schaap

Master Thesis Definition Study



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Definition Study

by

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Abstract

In this master thesis the flow behavior and the performance of a bow tunnel thruster at slow forward vessel motion is studied using Computational Fluid Dynamics (CFD). In this Definition Study a literature study is made, fundamental theory is explained and a roadmap for the master thesis is developed.

At Royal IHC it is noticed that trailing suction hopper dredgers experience a significant decrease in turning ability, using the bow tunnel thrusters, when sailing at speeds of 5 [kts] in comparison to zero forward speed. Dredgers are often operating at those speeds, using the bow tunnel thruster to keep course and therefore often experience this effect in practice.

Theory of different fields that can be used to describe the behavior of the flow through the tunnel and the interaction with the ship flow is given. The literature review focus on the parameters that influence the behavior of a bow tunnel thruster at slow forward vessel motion and indicates possible solutions. Based on the literature review a hypothesis is derived that is tested using CFD computation with the commercial solver Numeca FineMarine. The details and planning of those numerical tests are developed in a roadmap.

The literature review revealed a potential improvement of the turning ability of a vessel, when the cross-section of the bow tunnel thruster is changed towards a streamlined cross-section. Next to that model tests of Nienhuis using a simplified ship hull (Nienhuis wedge) are available and will be used as validation case for the CFD computations. The roadmap consists of two stages: a validation study of the Nienhuis wedge and a systematic variation of the tunnel cross section using a simplified trailing suction hopper dredger (Hopper wedge).

The results of the CFD study are reported in an additional document.

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1

Introduction

A vessel keeps its speed using propellers and its heading using rudders. Trailing suction hopper dredgers, Figure 1.1, operate often in shallow water, where they have excellent course-keeping capabilities compared to open water. However, during berthing, the ability to maneuver becomes more important. Here, the bow thruster finds its use, providing extra thrust used for manoeuvring. When a vessel however has forward speed and the bow tunnel thruster is used the effect of the thruster is decreased. Dredging vessels often use a bow tunnel thruster at slow forward speed, during dredging in shallow water and encounter the negative effect regularly.



Figure 1.1: The trailing hopper suction dredger Vox Maxima. Picture adapted from: [1].

The aim of this study is to investigate if a change in cross-sectional geometry of the bow tunnel has a positive effect on the performance of the bow tunnel thruster at low forward speed.

1.1. Background

The vessel is moving at relative low forward speeds along a straight line during dredging. In general hopper dredgers have one suction tube on one side of the vessel which is close to or even on the seabed. The suction tube is the main contributor to the resistance of the dredger while dredging. The suction tube and the propellers of the dredger are not situated at the same distance from midship, which results in moments mostly yaw and surge that turn the ship. The course is constantly corrected by using the rudder(s) of the ship to avoid turning. If only the rudder(s) are used for the correction of the heading the vessel will drift through the water. The crew tries to avoid drifting sideways by using the bow tunnel thrusters in the front of the ship, compare Figure 1.2.

A dredger normally dredges at 2 [kts] forward speed. In rivers and other coastal areas the current can reach speeds of up to 5 [kts], which means that the dredger experiences velocities through the water of 4 to 7 [kts] during dredging. Sea trials where the effect of the bow thruster is tested have shown that for ship speeds through the water of 5 [kts] the ship does not turn when the bow thruster operates. These

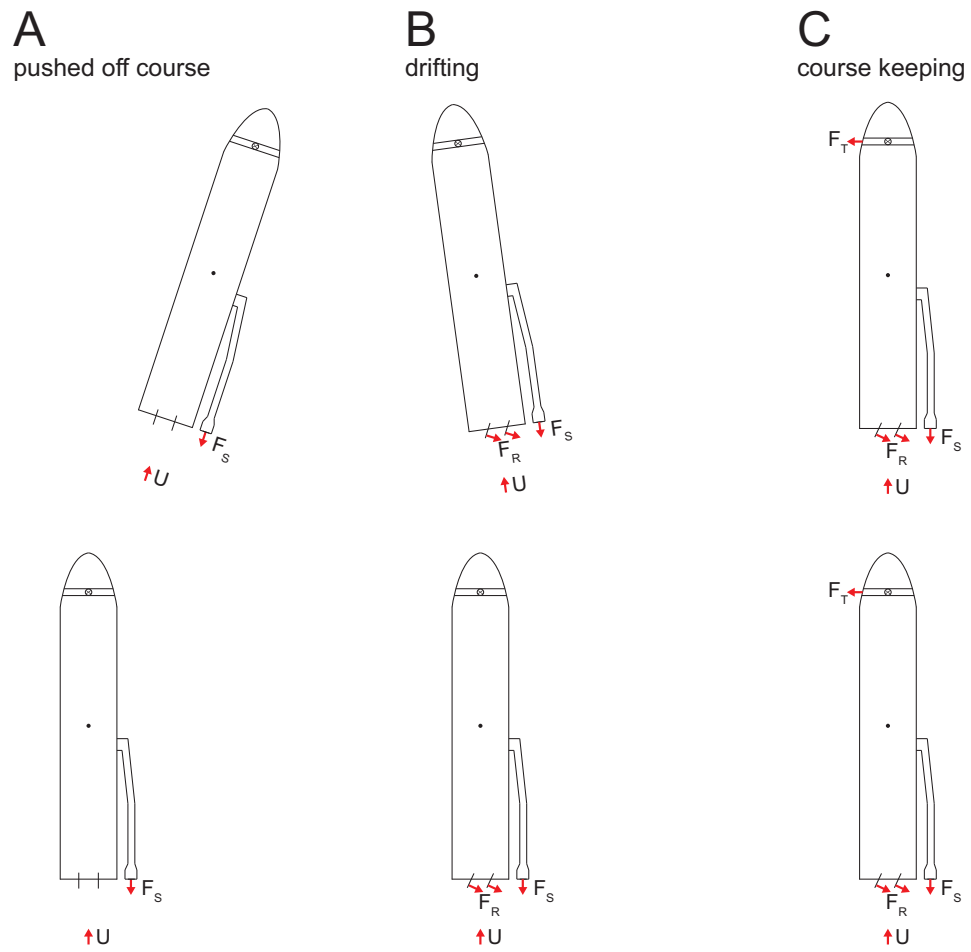


Figure 1.2: Forces acting on a hopper dredger while dredging. Case A: only the suction tube is used, which results in turning. Case B: the rudders are used to keep course, which results in drifting. Case C: also the bow thruster tunnels are used, which results in course keeping.

results were obtained for all trailing suction hopper dredgers of Royal IHC. Based on this the research question for this study is developed.

1.2. Research question and hypothesis

The main research question of this thesis is defined in the proposal presented in Appendix C and is as follows:

Can the design of the bow tunnel thruster of a trailing suction hopper dredger be changed in order to improve the ability to turn the ship at slow forward motion?

The following two points are analyzed during a literature study in this Definition study in order to answer the research question:

- What are the characteristics of the flow in and around of a bow thruster tunnel at slow forward speed?
- Which factors influence the performance of a bow thruster?

Based on the literature study the following hypothesis is formulated:

A streamlined bow tunnel thruster cross-section increases the transverse force by 20 [%] compared to a circular cross-section with the same cross-sectional area at 5 knots forward speed for a trailing suction hopper dredger, based on CFD.

This hypothesis is based on the following assumptions:

- The CFD code of Numeca FineMarine can be used for this type of computations
- Verification and validation studies are performed and give a positive outcome
- The results, of the CFD analysis are in accordance with literature in a qualitative and quantitative matter
- The amount of transversal force increase is based on a paper of Karlikov & Sholomovich [2].
- A systematic variation of the cross-section is used to find a better solution
- A simplified hull form of the ships hull geometry can be used to analyze the aforementioned effects
- A forward speed of 5 [kts] is representative for the phenomena

The overall objective of this thesis is to test the hypothesis and answer the research question.

1.3. Scope of this document

The purpose of this document is to present the literature survey and planning of the aforementioned study which was performed by the author during a nine-month master thesis project at Royal IHC in Kinderdijk the Netherlands for a degree in Maritime Technology at the Delft University of Technology. The master thesis consists of two main phases: definition study phase, master thesis phase. During the definition study phase a definition study is written, which includes the answering of the research question, based on literature, a plan of approach and a road-map for the master thesis phase. The results of the Definition Study are presented in this document. The results of the master thesis phase are presented in [3] and consists of a computational fluid dynamics (CFD) study of the Nienhuis wedge and a systematic tunnel cross-section variation for a Hopper wedge.

In this document the research question is answered based on literature. For this public available literature of different fields is studied and is summarized in Chapter 2. At the end of the literature research one potential influencing parameter, variation of the cross-section geometry of the tunnel thruster, is selected and is analyzed in the main stage of the master thesis [3].

Most of the presented studies in literature were performed in between 1950 and 2000 for hull shapes of those times. Since then ship design has progressed and the hull shapes are outdated. Recently a joint industry project, lead by MARIN, has been established to put again a focus on the performance and design of tunnel thrusters [4].

1.4. Relevance of the work

A decrease in bow thruster performance and slow forward speeds has been studied by many authors. Different studies analyzed the effect of different influencing factors. Most of these studies are based on model testing. In public literature not many computational fluid dynamic (CFD) results exist on the matter, besides Nienhuis [5] and non-public CFD reports such as [6]. Next to that most of the studies are performed between 1950 and 1990, with different hull forms. Since then the hull shapes have evolved. This underlines the need for more research in this area. Recently a joint industry project lead by MARIN started on this topic, which shows a need for this specific research in the industry.

The hypothesis of this study is based on a paper by Karlikov and Sholomovich [2] who reported a significant increase in bow thruster tunnel performance by changing the cross-section of the bow thruster tunnel. The study is based on model test results of one container vessel model. The goal of this thesis is to contribute to the knowledge of the effect of a streamlined tunnel cross-section on the performance of a bow tunnel thruster.

1.5. Axis definition

The general axis definition used in this study is as follows. The positive x-direction points towards the stern with its origin at the forward most point of the bow, the positive y-direction is defined from midship towards portside. The positive z-direction is pointing upwards with its origin at the keel of the ship. Next to the general definition a local bow tunnel based coordinate system is used. The origin for that local coordinate system is at the most forward point of the tunnel in x-direction, at midship in the y-direction and the centerline of the tunnel in z-direction. The origin is therefore at (1.475,0,0.152) [m] for the Nienhuis wedge and at (1.475,0,0.1096) [m] for the Hopper wedge. Figure 1.3 shows the axis definition. The velocities are denoted u for the x-direction, v for the y-direction and w for the z-direction.

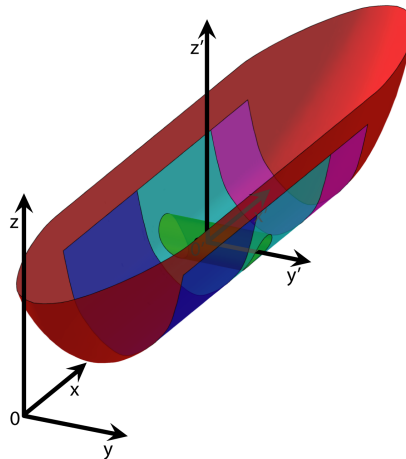


Figure 1.3: Axis definition.

1.6. Structure of this document

The structure of this document is as follows: In Chapter 2 theory and a literature study is presented on the performance of bow tunnel thrusters. At the end of that chapter the hypothesis is derived. In Chapter 3 a road-map is given for the master thesis main stage. This road-map illustrates the plan and approach of the study. The conclusions of the definition study are presented in Chapter 4. In the back of this document three appendices are presented: A small study on the trailing suction hopper dredger that IHC has build in recent years in Appendix A, a time planning for the complete master thesis project in Appendix B and the project proposal in Appendix C.

2

Theory and literature review

The physical background of the performance of a tunnel bow thruster at slow forward speed is influenced by multiple physical effects. In general the following behavior is noticed in experiments and full scale observations [5],[7]:

- The thruster inside the tunnel sucks the water at the inlet of the tunnel inside the tunnel, by the rotation of the thruster blades [5],[7].
- At the thruster blades the water is accelerated due to the inflow velocity and the circumferential speed [8].
- The jet is released at the outflow in a cross-flow and is bent in the cross-flow direction [5],[7].
- The flow of water creates pressure fields around the in- and outlet of the tunnel[5],[7].
- The pivoting point of the vessel is moved ahead while sailing ahead and therefore the lever of the turning moment is reduced in comparison with a ship at rest [7].

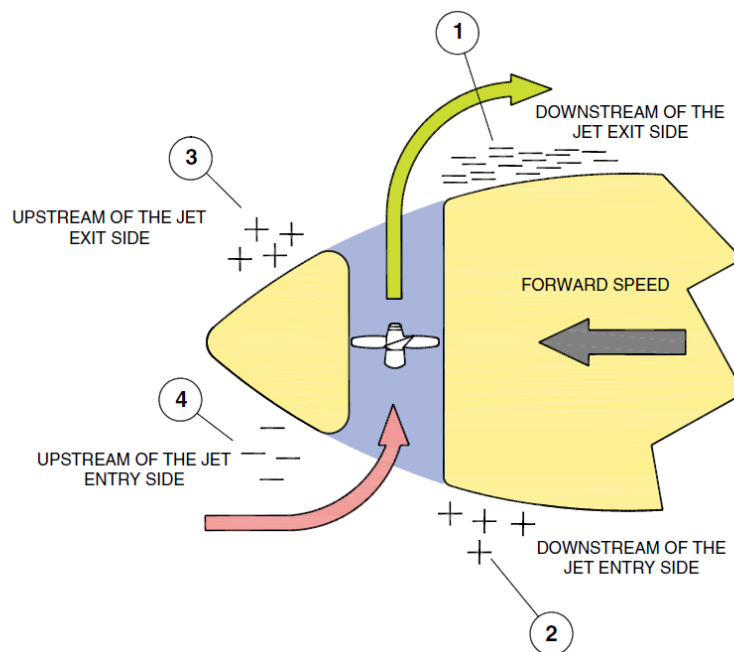


Figure 2.1: Flow through a tunnel bow thruster at slow speed ahead. Adapted from [7].

The described phenomena is illustrated in Figure 2.1 with the corresponding pressure regions. In the following influence factors on the performance of the tunnel bow thruster are discussed in Section 2.2.

First some basic fluid dynamics theory is presented that is needed to understand the flow behavior around and in the bow thruster tunnel. Afterwards a literature review is given on the tops.

2.1. Theory

The flow of a tunnel thruster at low forward speed can be described in three phases:

- The inlet side and flow through the tunnel is best covered by pipe flow theory
- The water is accelerated by the bow thruster propeller
- When the flow leaves the outlet side the flow behaves as a jet in a cross-flow.

In the following section the three phases are described in more detail.

2.1.1. Dimensionless coefficients

In this section an overview is given on dimensionless coefficients that are important during the study.

Hydraulic diameter

As the hopper dredgers have different amounts of tunnel thrusters the hydraulic diameter is used to characterize the tunnel thruster diameter. In general the hydraulic diameter is the fraction between the cross-sectional area A and the perimeter of the cross-section P [9, Eq. 6.59]:

$$D_H = \frac{4A}{P} \quad (2.1)$$

The hydraulic diameter can also be used for multiple thrusters. For n thrusters of the same diameter D and a circular cross-section the hydraulic diameter becomes:

$$D_H = \sqrt{n}D \quad (2.2)$$

The hydraulic diameter is a common way to represent a flow in non-circular pipes and channels.

Reynolds number

The dimensionless Reynolds number gives the relation between inertia and viscous forces and is used to characterize types of flows. The Reynolds number is defined as [9, Tab. 5.2]:

$$Re = \frac{\text{inertia}}{\text{viscosity}} = \frac{uL}{\nu} \quad (2.3)$$

In this study different velocities u and length L are used to derive different Reynolds numbers. As the properties of water do not change the kinematic viscosity ν of water is used in all cases. Therefore the Reynold number is written as: $Re(\text{Length, Velocity})$. $Re(D_H, u_s)$ therefore stands for the Reynolds number that is calculated using the hydraulic diameter D_H the ship speed u_s with the kinematic viscosity of water ν_w .

Froude number

The Froude number gives the relation between inertia and gravitational forces and is defined as [9, Tab. 5.2]:

$$Fn = \frac{\text{inertia}}{\text{gravity}} = \frac{u}{\sqrt{gL}} \quad (2.4)$$

As gravity g is assumed to be constant the Froude number is denoted as $Fn(\text{Length, Velocity})$. The Froude number $Fn(L, u_s)$ is therefore the Froude number based on the ship length L and the ship speed u_s .

Velocity ratio

The ratio between the velocity of the tunnel thruster (jet velocity v_j) and the ship speed (cross-flow velocity) u_s is defined as:

$$m = \frac{u_s}{v_j} \quad (2.5)$$

The velocity ratio gives an indication on the qualitative behavior of the tunnel flow in comparison with the surrounding flow due to the ship velocity (cross-flow) [2].

2.1.2. Propeller working principle

In the following the actuator disk theory is described in order to explain the difference between a propeller in a free stream and a propeller in a tunnel. The actuator disk or axial momentum theory gives an idealized relation for the thrust, velocities and pressures in the propeller stream. The following assumptions are made in the upcoming derivation [10],[11],[8]:

- Energy is added in the propeller plane
- The propeller is modeled as a disk (Number of propeller blades is therefore infinity)
- Rotation of the propeller is not included
- Only axial components are considered
- The fluid is considered to be friction-less and in-compressible
- Continuity and momentum theory apply
- The volume flux is assumed to be constant
- The distance between the propeller blade and the tunnel wall is negligible

The derivation for the actuator disk can be found in many textbooks such as [8], [11], [9], the presented method follows the derivation of Bohl [11].

Actuator disk in a free stream

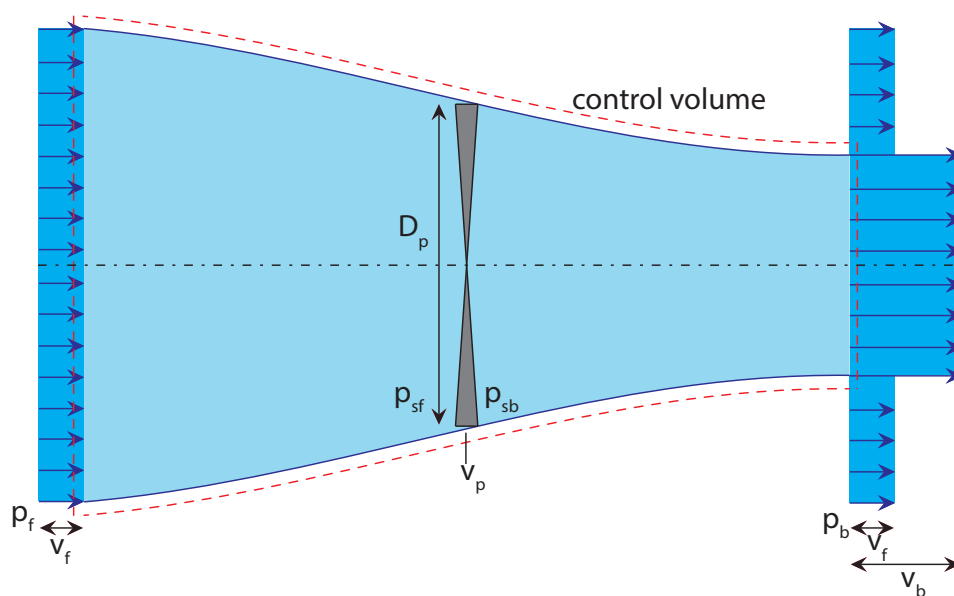


Figure 2.2: Schematic view of an actuator disk in free stream. Based on [10].

In Figure 2.2 a schematic view of a disk in a free stream is shown with the corresponding control volume and local parameters. First of all it should be noticed that the cross-sections in front of the propeller, in the propeller plane and behind the propeller are different:

$$A_f \geq A_p \geq A_b \quad (2.6)$$

The thrust T delivered by the propeller is the change in momentum which is:

$$T = \rho \dot{V} v_b - \rho \dot{V} v_f = \rho \dot{V} (v_b - v_f) \quad (2.7)$$

The volume flux \dot{V} through the propeller plane is:

$$\dot{V} = A_p v_p = \pi \frac{D_p^2}{4} v_p \quad (2.8)$$

Combining Equations 2.7 and 2.8 results in the thrust in the propeller plane:

$$T = \rho A_p v_p (v_b - v_f) \quad (2.9)$$

Based on Bernoulli the unknown velocity in the propeller plane v_p can be found. Applying Bernoulli to the front of the propeller disk gives:

$$p_f + \frac{1}{2}\rho v_f^2 = p_{pf} + \frac{1}{2}\rho v_p^2 \quad (2.10)$$

And applying Bernoulli to the back of the propeller disk yields to:

$$p_b + \frac{1}{2}\rho v_b^2 = p_{pb} + \frac{1}{2}\rho v_p^2 \quad (2.11)$$

It is assumed that the pressure far away from the propeller disk p_f and p_b are equal ($p_f = p_b$) while the local velocities are different ($v_f \leq v_p \leq v_b$). Applying the assumption and subtracting Equation 2.10 from Equation 2.11 gives:

$$p_b - p_f + \frac{1}{2}\rho (v_b^2 - v_f^2) = p_{pb} - p_{pf} + \frac{1}{2}\rho (v_p^2 - v_p^2) \quad (2.12)$$

$$\Delta p = p_{pb} - p_{pf} = \frac{1}{2}\rho (v_b^2 - v_f^2) \quad (2.13)$$

The thrust based on the pressure difference must be equal to the thrust in the propeller plane in Equation 2.9:

$$T = \Delta p A_p = \frac{1}{2}\rho A_p (v_b^2 - v_f^2) = \rho A_p v_p (v_b - v_f) \quad (2.14)$$

The speed at the propeller plane is then:

$$v_p = \frac{v_b + v_f}{2} \quad (2.15)$$

Using the speed at the propeller plane v_p in Equation 2.9 yields to:

$$T = \rho A_p \frac{v_b + v_f}{2} (v_b - v_f) \quad (2.16)$$

Actuator disk in a tunnel

For a tunnel the disk theory needs to be modified. A schematic view of a propeller disk in a tunnel can be found in Figure 2.3. First of all it should be noticed that in contrast to the free stream case the cross-section area is constant for the propeller plane and inside the tunnel ($A_p = A_b$). The thrust derived

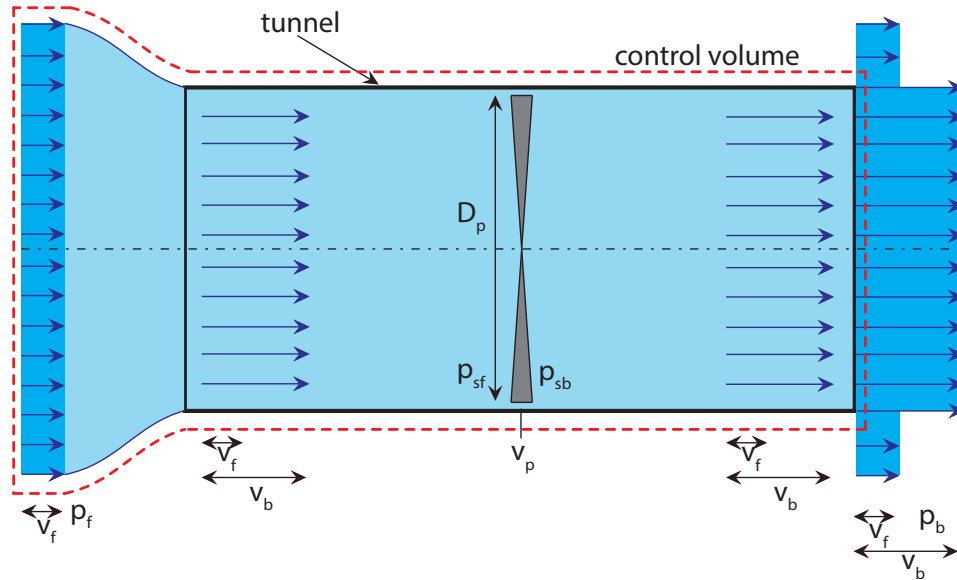


Figure 2.3: Schematic view of an actuator disk in a tunnel. Based on [10].

from the momentum theory is the same as in the free stream condition (Equation 2.7):

$$T_T = \rho \dot{V}_T v_b - \rho \dot{V}_T v_f = \rho \dot{V}_T (v_b - v_f) \quad (2.17)$$

As the cross-section area in the tunnel is constant the velocities have to be constant as well, based on the continuity equation. Therefore the volume flux at the propeller disk can be written as:

$$\dot{V}_T = A_p v_p = \pi \frac{D_p^2}{4} v_p = \pi \frac{D_p^2}{4} v_b \quad (2.18)$$

The thrust at the propeller plane is therefore:

$$T_T = \rho A_p v_b (v_b - v_f) \quad (2.19)$$

The ratio τ between the free stream thrust and the tunnel thrust is defined as:

$$\tau = \frac{T}{T_T} = \frac{1}{2} \left(1 + \frac{v_f}{v_b} \right) \quad (2.20)$$

If the inflow velocity v_f is equal to zero the ideal tunnel thrust coefficient τ is 0.5 [-]:

$$\tau(v_f = 0) = \frac{1}{2} \quad (2.21)$$

In this case half of the thrust is delivered by the propeller and the other half is created by the suction effect at the tunnel entry. In reality losses exist inside the tunnel, at the in- and at the outlet side of the tunnel and the relative contribution of the propeller is increased and thus, the tunnel thrust coefficient τ is increased, as well [12].

Mean flow velocity

In order to calculate the mean velocity of the slip-stream far behind the propeller a bollard pull condition is assumed ($v_f=0$). Using the definition for the thrust coefficient K_T :

$$K_T = \frac{T}{\rho n^2 D^4} \quad (2.22)$$

equation 2.19 becomes:

$$K_{T(tunnel)} = \frac{\rho \frac{1}{4} \pi D^2 v_b^2}{\rho n^2 D^4} \quad (2.23)$$

Solving for the velocity in the slipstream v_b yields to [13, Eq. 8]:

$$v_b = \sqrt{\frac{4}{\pi}} n D \sqrt{K_{T(tunnel)}} \quad (2.24)$$

The thrust coefficient for a propeller using Equation 2.16 becomes:

$$K_{T(prop)} = \frac{\rho \frac{1}{4} \pi D^2 \frac{v_b^2}{2}}{\rho n^2 D^4} \quad (2.25)$$

The velocity in the slipstream becomes [13, Eq. 9]:

$$v_b = \sqrt{\frac{8}{\pi}} n D \sqrt{K_{T(prop)}} \approx 1.60 n D \sqrt{K_{T(prop)}} \quad (2.26)$$

As the thrust coefficient is not always known, Blaauw and van de Kaa [13] suggest to use a relation presented by Schneiders and Pronk [14] between the thrust and the power P_D . Resulting in the following relation for ducted propellers [13, eq. 26]:

$$v_b = v_0 = 1.15 \left(\frac{P_d}{\rho D^2} \right)^{\frac{1}{3}} \quad (2.27)$$

Chislett and Björheden [15] on the other hand suggest to use the following relation between the thrust and the mean flow velocity:

$$v_0 = \sqrt{\frac{T}{\rho A}} \quad (2.28)$$

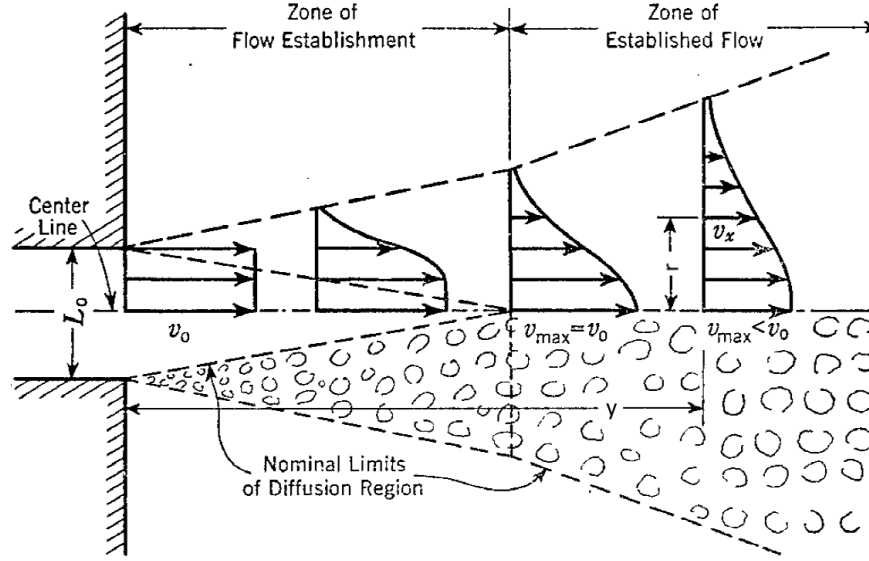


Figure 2.4: Schematic representation of the diffusion region. Adapted from [16].

Diffusion of submerged jets

The mean velocity is used to describe the jet diffusion. Albertson et al [16] divided the diffusion region in two zones: zone of flow establishment and zone of established flow as is shown in Figure 2.4. For both the velocity profile can be calculated with the following assumptions [16]:

- The pressure is hydrostatically distributed throughout the flow
- The diffusion process is dynamic similar under all conditions
- The longitudinal component of velocity within the diffusion region varies according to the normal probability function at each cross-section

The velocity at a distance y in the y -direction and r from the centerline of the tunnel is in the zone of flow establishment defined as [13]:

$$v(y, r) = \begin{cases} v_0 & \text{if } r \leq \left(\frac{D}{2} - cy\right) \\ v_0 \exp \left[-\frac{(r + cy - \frac{D}{2})^2}{2(cy)^2} \right] & \text{if } r > \left(\frac{D}{2} - cy\right) \end{cases} \quad (2.29)$$

Where v_0 is the velocity at the tunnel outlet, c is a constant which is taken as 0.18 [-] and D the diameter of the tunnel outlet.

A similar equation can be derived for the zone of established flow [13]:

$$v(y, r) = v_0 \frac{1}{2c} \frac{D}{y} \exp \left[-\frac{1}{2c^2} \frac{r^2}{y^2} \right] \quad (2.30)$$

The transition between the zone of flow establishment and the zone of established flow is at [16]:

$$\frac{y}{D} = \frac{1}{2c} \approx 2.78 [-] \quad (2.31)$$

2.1.3. Pipe flow

In this section a short summary is given on relevant pipe flow theory. For a more in depth study the reader is advised to have a look in fluid mechanics textbooks such as White [9]. The following theory description is based on White [9].

First of all the Reynolds number of the flow inside a tunnel based on the flow speed and the tunnel diameter is for full scale in the turbulence regime, for model scale in the laminar or transition to turbulence regime. The following ranges can be defined according to White [9]:

- $100 < Re < 10^3$ laminar
- $10^3 < Re < 10^4$ transition to turbulence
- $10^4 < Re < 10^6$ turbulent, moderate Reynolds number dependence
- $10^6 < Re < \infty$ turbulent, slight Reynolds number dependence

Upstream of the entrance of a tube a nearly in-viscid flow converges and enters the tube. Inside the tube the boundary layers grows and accelerates the flow core due to in-compressible continuity. After an entrance length L_e the velocity profile is fully developed and constant, the pressure drops linearly with the distance and the wall shear is constant. A fully developed flow is unlikely to occur in a tunnel thruster, as the entrance length is significantly higher than typical tunnel thruster length. In Table 2.1 the entrance length L_e divided by the tunnel diameter D is shown for multiple turbulent Reynold numbers Re_d .

Table 2.1: Turbulent entrance length based on Reynolds number. Adapted from [9, p. 364].

Re_d [-]	4000	10^4	10^5	10^6	10^7
L_e/D [-]	13	16	28	51	90

An increase in pipe length increases the friction losses inside the pipe. The same applies for a tunnel thruster. This can be seen by analyzing the Darcy-Weisbach Equation [9, Eq. 6.10]:

$$\Delta p = f_D \frac{L_T}{D_H} \frac{\rho v_j^2}{2} \quad (2.32)$$

In the Darcy-Weisbach equation the pressure loss due to friction Δp is a function of the Darcy friction factor f_D , the length-diameter ratio of the tunnel $\frac{L_T}{D_H}$, the density ρ and the flow speed speed inside the tunnel v_j . The equation clearly indicates that the pressure losses are proportional to the length-diameter ratio.

A short tunnel causes losses due to turbulence and therefore the preferred range of tunnel length is $1D$ to $4D$, with a optimum at around $2D$. Tunnel length up to $7D$ are feasible, but with high losses [7, p. 636].

Next to friction losses due to the length of the tunnel also other losses, such as entrance losses, can occur in pipe flows. In general the losses can be calculated as [9, Eq. 6.79]:

$$\Delta p = \frac{1}{2} \rho v_j^2 \sum K \quad (2.33)$$

Where K is a dimensionless loss coefficient. Different aspects of a pipe system have different loss coefficient. A summation of all loss coefficients of a pipe system results in the total pressure loss.

For tunnel thrusters the entrance and exit losses are of importance. Exit losses are independent of the form and have a value of $K \sim 1.0$ [-] according to White [9]. The entrance side losses decreases from $K = 0.5$ [-] for sharp-edged to as less as $K = 0.05$ [-] for a radius diameter fraction of 0.2 [-]. This can be seen in Figure 2.5

As a result of these losses most of the modern tunnel thrusters have a smooth transition between the tunnel in/outlet and the hull. Thereby the rounding is a compromise. An inlet creates less losses when it has a smooth transition between the hull and the tunnel itself. For an outlet on the other hand a sharp transition helps to concentrate the jet flow in a straight line. As tunnel thrusters are designed to work in both directions a compromise is taken to get the optimum for this configuration.

2.1.4. Jet in a cross-flow

The outflow pattern of the tunnel bow thruster at forward speed can be described as a jet in a cross-flow [2]. A jet in a cross-flow is generally analyzed for a round shape nozzle entering perpendicular to a cross-flow. The jet interacts with the cross-flow and bends towards it, similar to the outflow of a tunnel bow thruster. Next to the path of the jet also the pressure system downstream of the outlet is comparable and is influenced by the same physical effects.

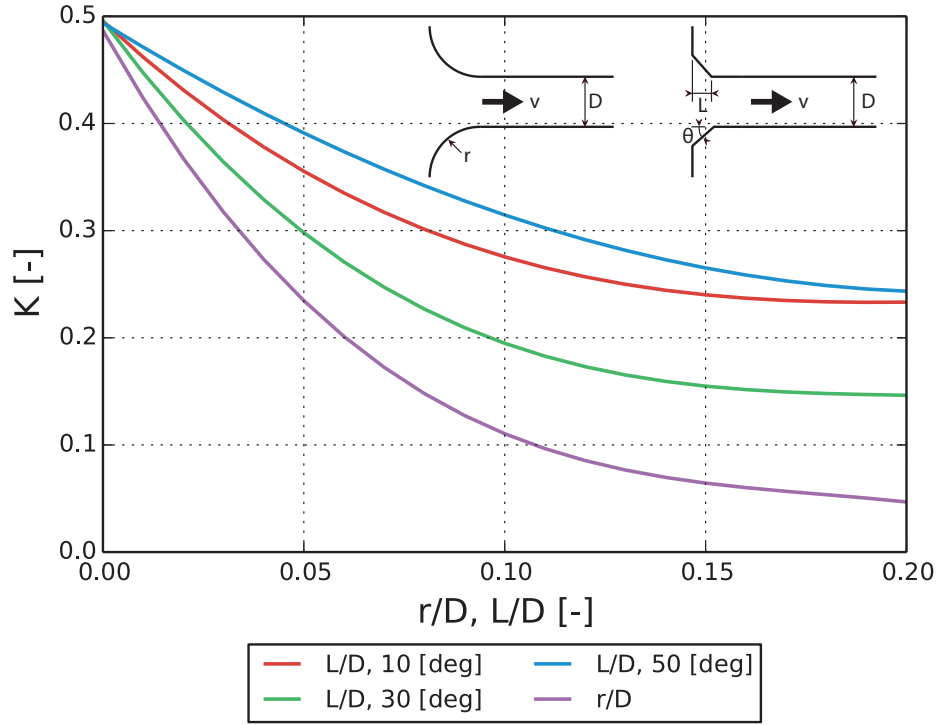


Figure 2.5: Entrance loss coefficients. Based on [9, Fig. 6.21].

In the study of cross-flows the following non-dimensional parameters are used for in-compressible transverse jets [17, Eq. 1]:

$$m = \frac{u_s}{v_j} \quad (2.34)$$

where m is a dimensionless velocity ratio, v_j is the velocity of the jet and u_s is the velocity of the cross flow (ship speed). The momentum flux ratio J is defined as [17, Eq. 1]:

$$J = \frac{\rho_j v_j^2}{\rho_s u_s^2} = \frac{\rho_j}{\rho_s} \frac{1}{m^2} \quad (2.35)$$

If the fluids in the jet and the cross-flow are the same, the densities drop from the Equation 2.35 and the momentum flux ratio is equal to the inverse square of the velocity ratio m .

In this study both fluids, the cross-flow and the jet, are (sea) water and are assumed to be equal to each other in all cases. For a tunnel bow thruster the velocity ratio m is in the range of 0 to 1[-] [2].

2.2. Literature review

In this section an overview is given on the present literature of the performance of bow tunnel thrusters. During the literature study the focus was on identify influencing parameters and to find a comparable study which can be used to validate the computational fluid dynamics calculations.

2.2.1. Influencing parameters

The influencing factors on the performance of the tunnel thruster can be divided in two groups [12]:

- Influences on the thrust and the turning moment based on the design of the tunnel
- Influences on the thrust and the turning moment based on the movement of the vessel

In the following both groups are discussed.

Influences based on the design of the tunnel

Some of the influencing parameters based on the design of the tunnel were already mentioned in Section 2.1.3 and a complete list is given below.

- The position of the tunnel is important. The position has a direct influence on the turning lever. To maximize the lever the tunnel is normally placed as far forward as possible [7].
- A clearing distance of approximate $1D$ to the keel is needed to prevent re-circulation [7],[18].
- A clearing distance of approximate $1D$ to the water surface is needed to prevent air inclusion [7],[18].
- The length of the tunnel should be at least $2D$, longer tunnels increase frictional losses [9],[7],[18].
- The tunnel hull interface should be smooth and a round off radius of $0.05D$ is recommended based on [7],[18],[10]
- Grid bars should be placed in the streamline direction at both sides of the tunnel. Grid bars are placed in order to prevent the thruster from mechanical damage. Multiple studies showed a decrease in the tunnel performance based on grid bars. [12], [18], [7].
- It is advised to design the tunnel such that the angle between the tunnel and the side of the hull is 90 degrees. Other angles increase the losses of the tunnel thruster [12], [18], [7].
- Karlikov and Sholomovich concluded in their study that a streamlined tunnel cross-section can improve the behavior of the thruster at slow forward speed [2].

All of the influences are applicable for trailing suction hopper dredgers. Based on their bow shape and the small draft, the tunnel thrusters are designed far off the optimum in most cases. In order to change this a redesign of the complete bow would be needed. The biggest contributions to the decrease in performance are assumed to be due to the large tunnel length (usually more than $10D$), large inclination angle and small clearance between keel and tunnel, as well as between tunnel and water surface. An optimization of the interface between the tunnel and hull, by changing the angle between them or the round off the tunnel together with an optimization of the grid bar design is assumed to result in negligible improvements as both are designed within the range of the recommendations. The shape of the cross-section of the tunnel however seems to be a promising approach to increase the overall performance of the bow thruster tunnel.

Influence based on the movement of the vessel

Many authors have investigated the behavior of the transverse force of a tunnel thruster at forward speed. English et al. [19, 20] found that up to a certain speed the transverse force decreases with an increase in forward speed compared to the ship at zero speed. Above this certain speed the forces recover. The same effect is mentioned by many others including Beveridge [21], Nienhuis [5], Baniela [7], Karlikov & Sholomovich [2], Fujino et al. [22] and Chislett & Björheden [15].

This effect is comparable to the effects observed in other industries. For example a similar behavior occurs for airplanes as Jordinson [23] and Gregory et al. [24, 25] have shown.

All the above mentioned authors that studied the effect of bow tunnel thrusters attribute the reduction in side force to an unfavorable pressure redistribution on the ship's hull near the in- and outlet of the tunnel thruster. This pressure redistribution at the outlet side is due to the deflection of the jet towards the hull [5].

According to Nienhuis [5, p. 157] the reduction in efficiency is mainly due to the change in the pressure field on the jet outlet side and to a smaller extend on the inlet side. Next to the change in pressure field Nienhuis' main findings are:

- The side force of the thruster decreases with increasing ship speed until a certain speed is reached, after that speed a small recovery is noticed.
- The change in efficiency is only affected to a minor extend from a change of impeller forces. These forces can be compensated by an increase in pitch or RPM of the propeller.
- A favorable increase in horizontal resistance compared to a ship at rest is noticed, therefore the ship speed is decreased and can turn easier.
- An anti-suction tunnel running parallel to the thruster tunnel can reduce the losses by reducing the low pressure field downstream of the tunnel outlet. The anti-suction tunnel must be located very close to the thruster tunnel in order to work properly.
- Torque and tangential velocities of the thruster are insignificant for the thruster efficiency.

- In shallow water the thrust degradation is more severe than in deep water. Both horizontal forces and the turning moment are affected.
- A 3D time-averaged Navier-Stokes calculation is capable of showing the main phenomena.

A trailing suction hopper dredgers operational profile consists of long dredging periods. A typical ship speed through the water is 4 to 5 [kts]. An analysis of the IHC hopper dredgers has shown that no turning performance of the bow thrusters is remaining for speeds of 5 to 7 [kts]. During dredging at these low speeds it is mandatory to keep the dredger in place, which is done by using the bow tunnel thrusters and main propellers. As most of the dredgers are equipped with a propeller rudder combination, their turning ability at low speeds is limited due to the physics. A hopper dredger is therefore an unique case that often encounters the problem of a decreased turning ability. As all dredgers of IHC suffer from the same problem at roughly the same speed, it seems that the phenomena is not Froude number dependent, as the problem is mainly due to the flow interaction which is dominated by the Reynolds number.

Another important factor is the jet speed in comparison to the cross flow speed. A typical bow thruster operating range is $0 \leq m \leq 1$ [-]. Based on the speed ratio m Karlikov & Sholomovich [2] suggested to divide the jets in "weak" and "strong" jets. Weak jets ($0.45 \leq m \leq 0.63$ [-]) show despite the turbulent mixing of the flow an analogues behavior to that of an obstacle in a flow. Strong jets ($m < 0.2$ [-]) on the other side show an analogues behavior to that of a flow past a point sink [2, p. 316].

It should be noticed that the reduction of bow thruster performance is not only dependent on the speed ratio m . Karlikov & Sholomovich [2] showed on model scale that two different ship speeds result in two different curves when plotting them against the speed ratio m . Both curves show a similar trend, but are shifted along the speed ratio m [2, Fig. 4] Their graph is shown in Figure 2.6 for two jet speeds 6.0 and

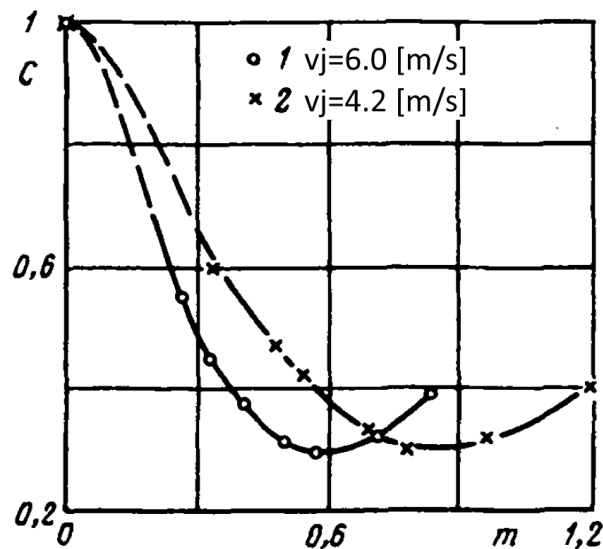


Figure 2.6: Dependency on the speed ratio m . Results of model tests with 6.0 and 4.2 [m/s] ship speed. Adapted from [2].

4.2 [m/s] for the speed ratio m versus a dimensionless force coefficient C . The force coefficient C is the force at a ship speed - tunnel thruster speed combination divided by the tunnel thruster speed when the ship is at rest.

In this study the tunnel thruster velocity for the IHC dredgers is calculated based on the installed thrust by means of the actuator disk theory as is shown in Appendix A. The speed ratio m with a ship speed u_s of 5 [kts] is between 0.32 and 0.53 [-] and therefore close to the range of weak jets. It is therefore expected, that for a speed ratio of roughly 0.5 [-] the tunnel jet is bent directly to the side of the ship. For speed ratio's in the 'strong' jet regime it is expected, that the ship velocity has only a minor influence on the bending of the tunnel jet and therefore a smaller low pressure region is expected.

2.2.2. Validation cases

In order to assess the computational fluid dynamics (CFD) setup of this work a validation case is needed. The main requirement for a validation case is that a quantitative and qualitative comparison can be made between the CFD set-up and the reported literature. The qualitative description of bow thruster behaviors at slow forward speed is based on observations presented in literature.

Furthermore a significant amount of literature describes the bending of the tunnel flow in the stream-wise direction as a dependency of the velocity ratio m [5], [2], [7], [12], [15], [21], [18]. In other industries jet in a cross-flow research show a similar dependency. This means that for the qualitative part of the results multiple references are available.

For a quantitative comparison the hull and tunnel geometry needs to be comparable. Nienhuis [5] conducted model tests with a wedge and a installed thruster for which the geometry is available. Next to the availability of the geometry a wedge is a simplification of the ships bow section. Thus, the Nienhuis wedge is selected as a validation case for the current work.

2.2.3. Derivation of the hypothesis

As mentioned in Section 2.2.1 multiple parameters of a bow tunnel thruster have a proven effect on the performance of a bow tunnel thruster both in general and at slow forward motion. The largest gains have been reported when the design of the tunnel thrusters is changed completely [2].

One of the solutions is to install steerable thrusters, however this option and other option that are located underneath the keel are not suitable, as dredgers are often operating in shallow waters and are exposed to the sand bed. Other options, for example reducing the tunnel length, need a redesign of the entire bow section of a vessel, this is not advised as the bow design is optimized for dredgers.

In the field of jet in cross-flow studies good results have been obtained by steering the jet pointing towards the cross-flow. The jet flow will bent as well, but at a higher distance from the hull. With that it is expected that the low pressure downstream of the tunnel jet will be reduced for such a configuration. This is an interesting and possible option, but is not analysed any further in this study.

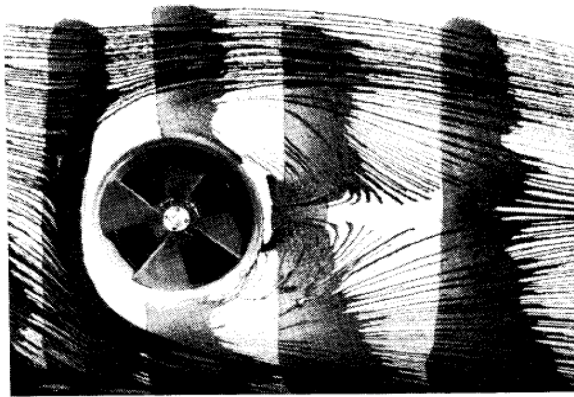
Another promising option was noticed by Karlikov and Shalomovich [2], who measured an increase in bow tunnel performance by more than 30 [%] for a streamlined, airfoil like, tunnel cross-section in comparison to a circular cross-section. Besides this small study no more is known about the influence of the cross-section on the performance of a tunnel thruster at slow forward speed.

The fundamental idea behind a change in cross-section is related to the low pressure region downstream of the tunnel jet. The tunnel jet is assumed to have higher speeds compared to the ship speed. The flow along the ship encounters the high speeds of the jets and flows around them. The expected flow pattern is comparable to the flow around a cylinder. For a flow around a cylinder it is known that in the wake region behind the cylinder a large low pressure region is present. The corresponding drag coefficient of a cylinder is therefore relative large. If the cross-section of the tunnel jet has not the form of a cylinder but that of an airfoil, it is assumed that the flow pattern around the tunnel jet is similar to the flow field around an airfoil, resulting in a small wake region, a small low pressure region and with that a lower drag coefficient. In Figure 2.7a a snapshot of the streamlines of the flow around a tunnel jet is shown for a bow tunnel thruster. In Figure 2.7b the flow around a cylinder is shown, which shows a large wake region and turbulent behavior. The flow around a bow tunnel thruster in Figure 2.7a looks similar to the mean flow past a sphere in Figure 2.7c. In Figure 2.7d the flow around an airfoil is presented, which has a significant smaller wake region.

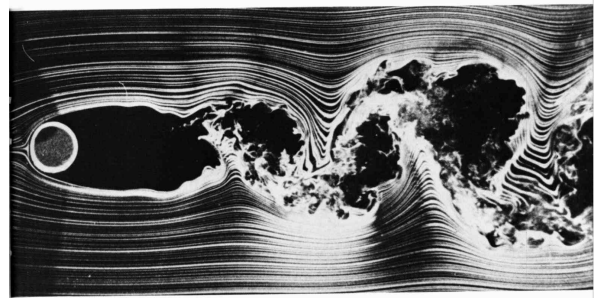
To establish a streamlined cross-section a systematic cross-section variation is developed in Chapter 3. The derived equation assumes a constant cross-sectional area and is constructed of two semicircles which are connected by a plate. This combination is chosen as it can be fully described by two factors and it is easily constructed during the building of a vessel.

Thus the hypothesis becomes:

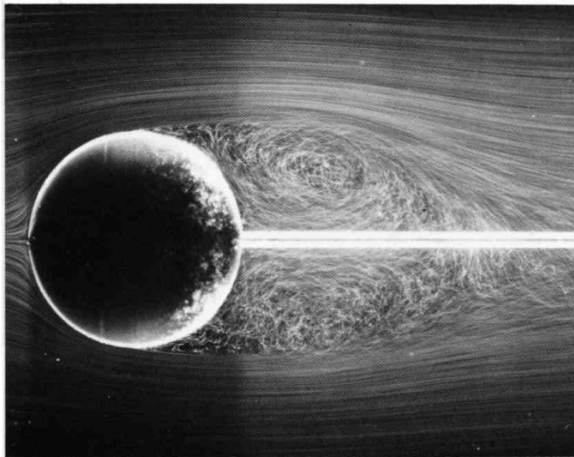
A streamlined bow tunnel thruster cross-section increases the transverse force by 20 [%] compared to a circular cross-section with the same cross-sectional area at 5 knots forward speed for a trailing suction hopper dredger, based on CFD.



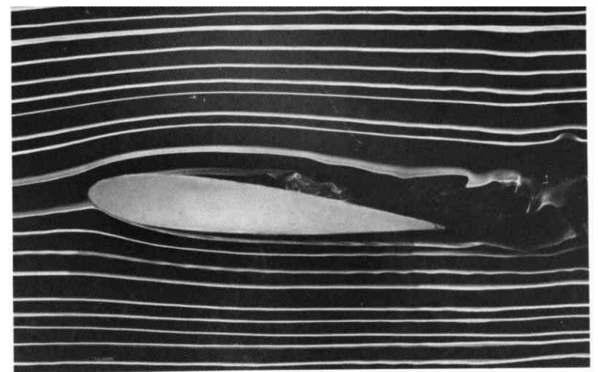
(a) Streamlines around a tunnel thruster. Adapted from [18].



(b) Flow past a circular cylinder at a Reynolds number of 10000 [-]. Adapted from [26, Fig. 48].



(c) Mean flow past a sphere at a Reynolds number of 15000 [-]. Adapted from [26, Fig. 56].



(d) Symmetrical airfoil in a wind tunnel at a Reynolds number of 20000 [-]. Adapted from [26, Fig. 72]

Figure 2.7: Flow pattern around the tunnel opening, a cylinder, a sphere and an airfoil.

3

Road-map

Based on the literature research a road-map is developed for the master thesis main stage. The main stage is divided into two phases: first an in depth validation of the Nienhuis wedge is made and in the second phase the cross-section geometry of the tunnel thruster is varied in a systematic manner. In the following both phases are illustrated shortly, a time scope is given and deliverables are discussed. In Appendix B the time planning can be found in more detail.

3.1. Validation of the Nienhuis wedge

As the geometry of the Nienhuis wedge is known the wedge is analysed in CFD in order to validate the computational set-up and approach. The objective of this phase is to find the optimal set-up for calculating the Nienhuis wedge test cases. The objectives are:

- Find the best possible settings for the Nienhuis wedge at a speed ratio of $m=0.5$ [-] (2.5 weeks)
 - Perform an in-depth grid study and time-dependency study
 - Define the way of simulating the propeller: Actuator Disk (Different settings)
- Calculate the entire range tested by Nienhuis [5] (4 weeks)
- Qualitative comparison with a variety of literature
- Quantitative comparison with Nienhuis [5] and other literature, if possible.

The geometry of the Nienhuis wedge can be seen in Figure 3.1a and the thruster geometry in Figure 3.1b. Nienhuis derived the wedge geometry from the frame of a container ship at the position of the bow thruster and extended it to 10 tunnel diameters in length. The thruster is placed in the middle of a circular tunnel. The main particulars of the original geometry can be found in Table 3.1. It should be noticed that this geometry is different from a dredger. A dredger is much wider at the bow tunnel, compared to the Nienhuis wedge.

Table 3.1: Main particulars of the Nienhuis wedge as reported by Nienhuis [5] and as used in this study.

Particular	Unit	Model [5, Tab. A.5]	CFD model
Length straight section	[m]	1.5	1.5
Length overall	[m]	1.5	3.1
Beam	[m]	0.546	0.546
Draft	[m]	0.508	0.508
Block coefficient straight section	[-]	0.715	0.715
Tunnel diameter	[m]	0.15	0.15
Tunnel center z location above keel	[m]	0.152	0.152

The frame of the used CFD model was created by data points that were extracted from the original drawings of Nienhuis using a point extraction algorithm [27]. The resulting frame geometry can be seen in Figure 3.2.

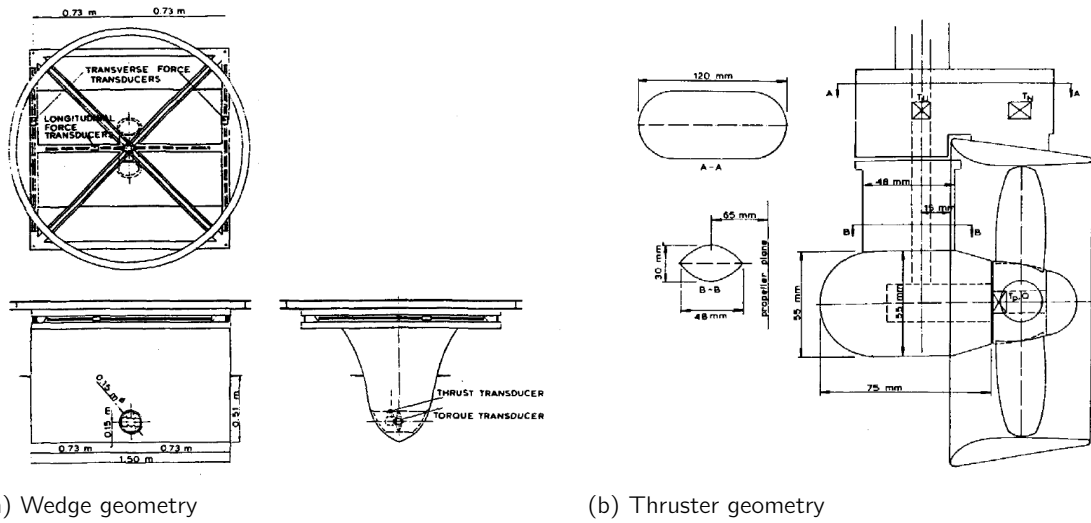


Figure 3.1: Technical drawings of the original wedge and thruster model used by Nienhuis. Adapted from [5].

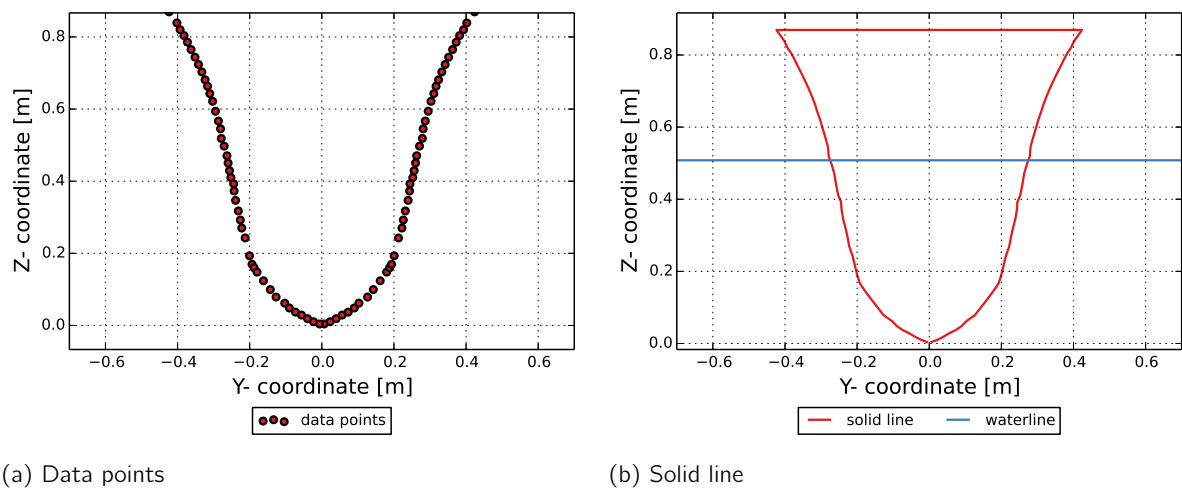


Figure 3.2: Frame of the CFD model of the Nienhuis wedge. The data points and the resulting frame using solid lines.

The geometric difference between the original drawings of Nienhuis and the CFD model is less than 0.01 [%] and therefore insignificant. Calculations with an 3D representations of the Nienhuis wedge as shown in Figure 3.3a resulted in numerical instabilities due to the flat ends up- and downstream of the wedge. In order to allow more stable numerical results an artificial bow is made with a length of 0.8 [m] it is created based on linear scaling of the frame. These bow section is added to the front and back of the wedge and extending its length overall to 3.1 [m]. As the flow around the tunnel outlet is of importance, it is assumed that the added bow and stern have no influence on this. A 3D rendering of the CFD model as used in the validation study is shown in Figure 3.3b.

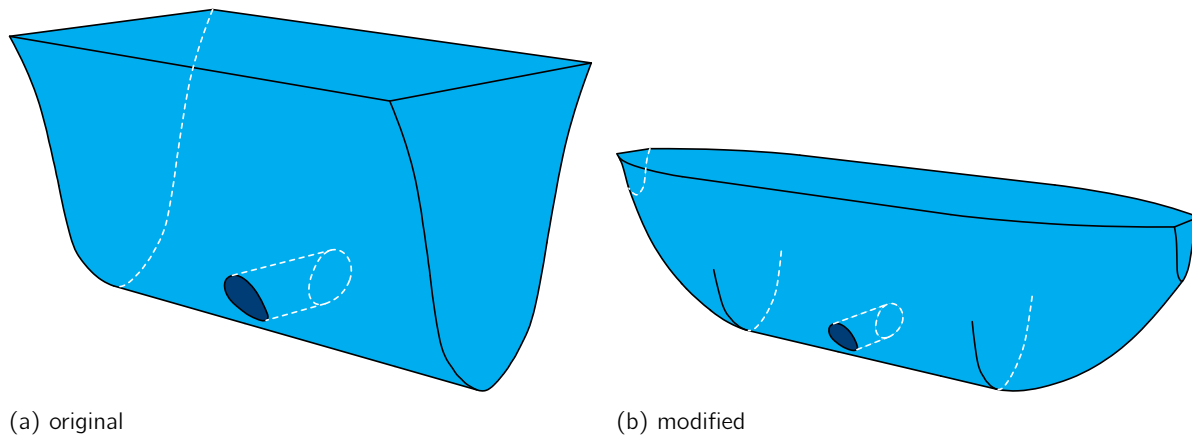


Figure 3.3: 3D rendering of the CFD model of the Nienhuis wedge of the original and the modified model.

3.2. Systematic variation of the cross-section of the tunnel

In the second phase of this study a systematic variation of the tunnel cross-section is performed. In order to get more insight in the bow thruster performance of trailing suction hopper dredgers a wedge is developed based on the frame of a typical hopper dredger. The wedge will be created following the same steps which were used by Nienhuis to create his wedge. After the hopper wedge is created the systematic tunnel variation is performed. Furthermore a small range of ship velocities is considered. The goals of this phase are:

- Design a hopper wedge base case in the same way as the Nienhuis wedge (4 weeks)
 - Same settings as the validation case for the Nienhuis wedge
 - Quantitative and qualitative comparison with Nienhuis wedge
- Change the cross-section of the tunnel using the suggested systematic variation (4 weeks)
 - Create at least five computational cases for each tunnel
 - Analyse and draw conclusions
- Draw general conclusions based on outcome and write report/ presentation (4 weeks)

At the moment it is suggested to analyze at least the following five cases for each tunnel: two different ship velocities (u_s) and one thrust (T). This results in the testing matrix shown in Table 3.2.

Table 3.2: Suggested testmatrix

Ship velocity	Thrust	Reasoning
0	T	Performance at zero ship speed ($m=0$)
u_{s1}	0	Resistance at ship speed 1
u_{s1}	T	Performance at ship speed 1 with thruster operating ($m \approx 0.15$)
u_{s2}	0	Resistance at ship speed 2
u_{s2}	T	Performance at ship speed 2 with thruster operating ($m \approx 0.4$)

3.2.1. Systematic tunnel cross-section series

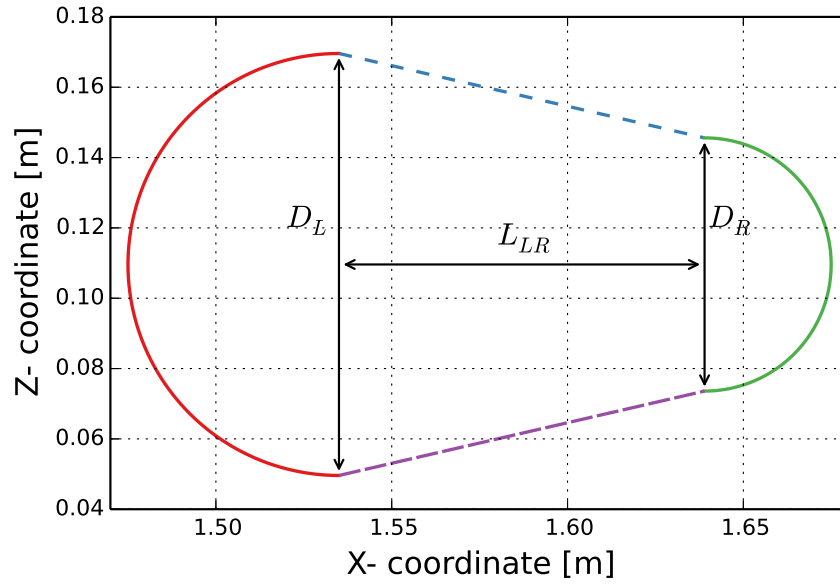


Figure 3.4: Definition of the systematic tunnel cross-section series SAABB

To systematically vary a streamlined tunnel cross-section a series has been developed. The cross-section as defined in Figure 3.4 consists of two semicircles which ends are connected by a straight line. The diameter of the semicircles are D_L and D_R for the left and right semicircle, respectively. The systematic tunnel cross-section series SAABB is defined by two values AA and BB . Dividing the values for AA and BB by ten results in the ratios r_{AA} and r_{BB} . The ratio r_{AA} between a reference diameter D_{ref} and the left diameter D_L is defined as:

$$r_{AA} = \frac{D_L}{D_{ref}} \quad (3.1)$$

The ratio between the left and the right diameter is defined as r_{BB} :

$$r_{BB} = \frac{D_R}{D_L} \quad (3.2)$$

To allow a comparison of all tunnel cross-sections the area of the systematic outlet series is the same as the area of a reference circle with diameter D_{ref} . The area of the outlet can be expressed using the two diameters of the semicircle and the distance L_{LR} between the semicircles as:

$$A = \frac{\pi}{8} (D_L^2 + D_R^2) + L_{LR} \left(\frac{D_L}{2} + \frac{D_R}{2} \right) = \frac{\pi D_{ref}^2}{4} \quad (3.3)$$

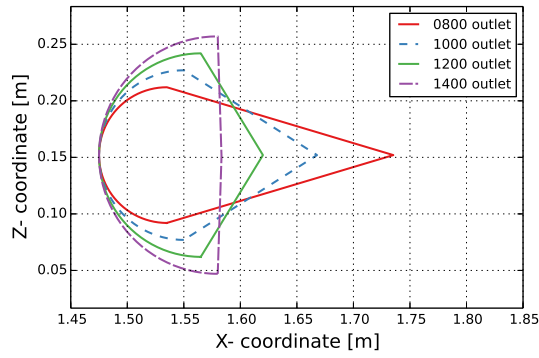
The distance L_{LR} can therefore be determined as:

$$L_{LR} = \frac{\pi (D_{ref}^2 - 2D_L^2 - 2D_R^2)}{2(D_L + D_R)} \quad (3.4)$$

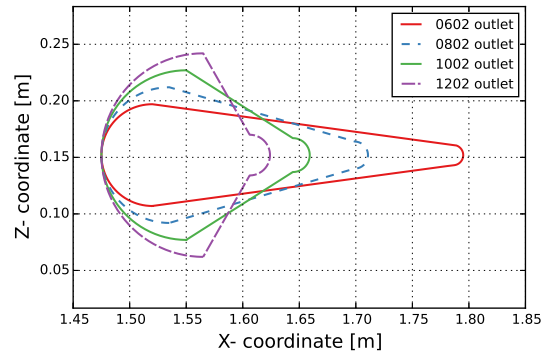
The perimeter P can be calculated as:

$$P = \frac{\pi}{2} (D_L + D_R) + 2\sqrt{L_{LR}^2 + \left(\frac{D_L - D_R}{2} \right)^2} \quad (3.5)$$

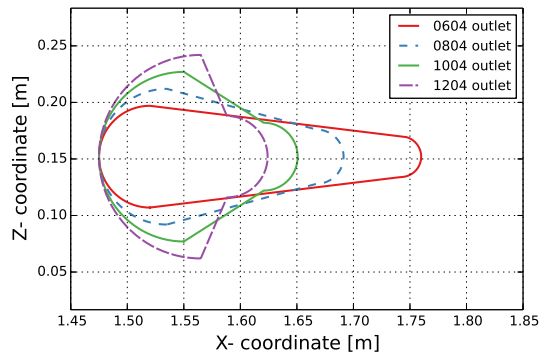
It should be mentioned, if both ratios are one (S1010) the distance L_{LR} is zero and the cross-section represents a circle of diameter $D_{ref} = D_L = D_R$. The range for ratio r_{AA} is defined as $0 < r_{AA} \leq 1.4$. If the ratio r_{BB} is one the cross-section represents an area equal to two semicircle of equal diameter with a rectangle in between as can be seen in Figure 3.5f. If the ratio r_{BB} is equal to zero the right side of the outlet is a point, as can be seen in Figure 3.5a. The ratio r_{BB} is defined for $0 \leq r_{BB} \leq 6$. An overview of possible cross-sections using this approach are shown in Figure 3.5 and 3.5.



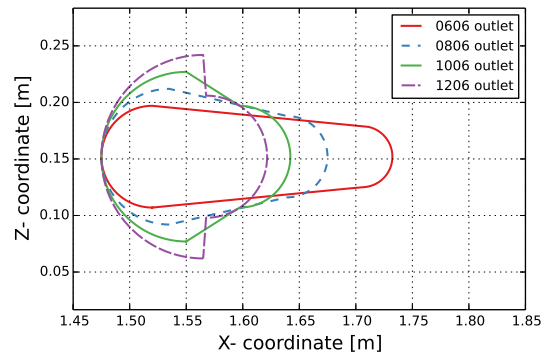
(a) SAA00 Series



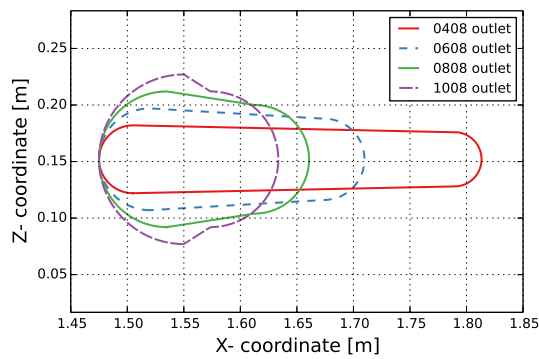
(b) SAA02 Series



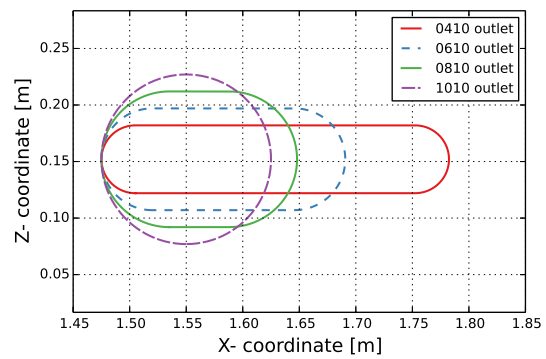
(c) SAA04 Series



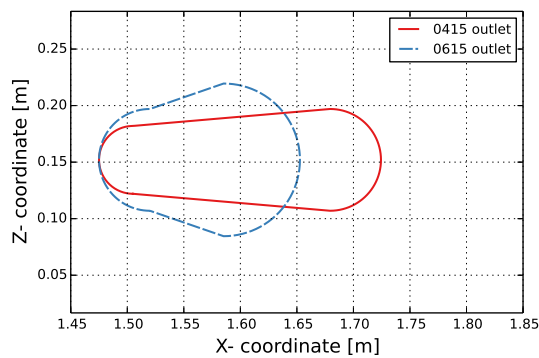
(d) SAA06 Series



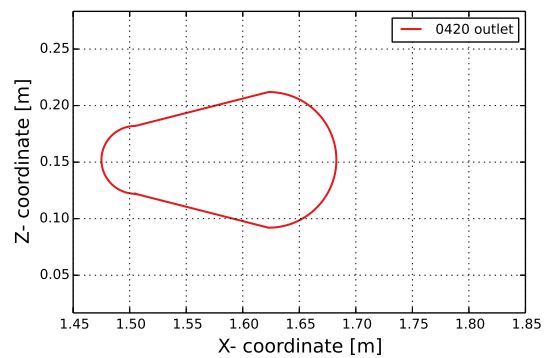
(e) SAA08 Series



(f) SAA10 Series

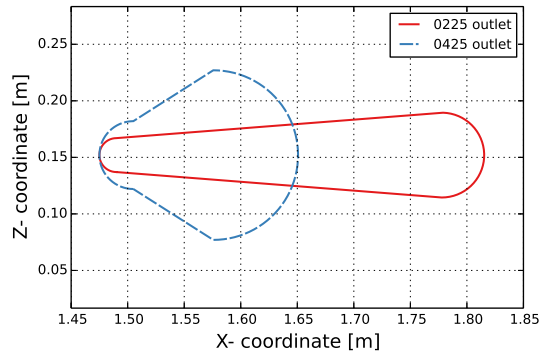


(g) SAA15 Series

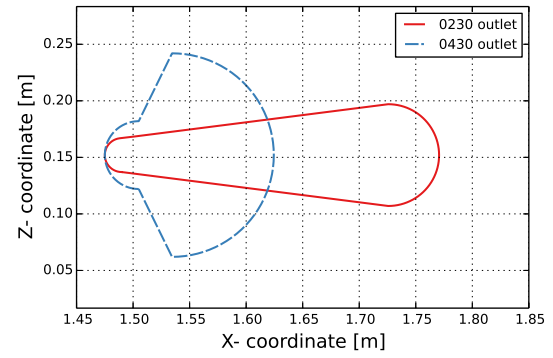


(h) SAA20 Series

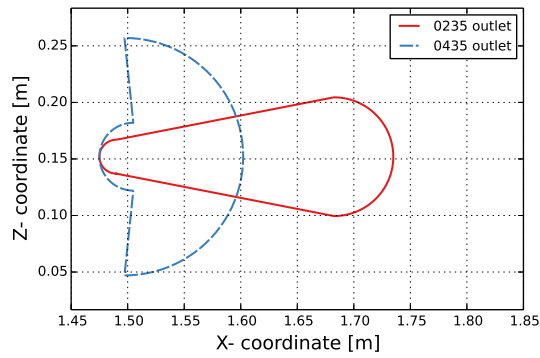
Figure 3.5: Overview of the range of the SAABB series BB 00 to 20



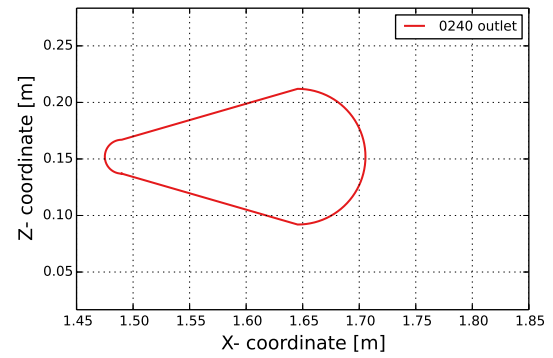
(a) SAA25 Series



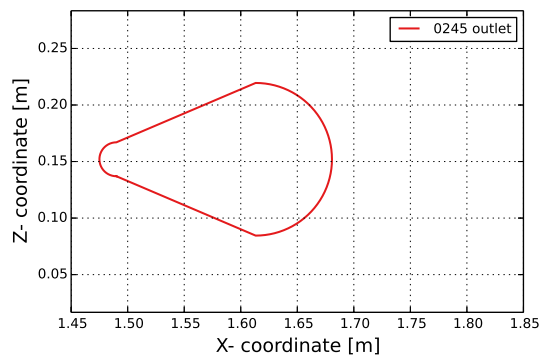
(b) SAA30 Series



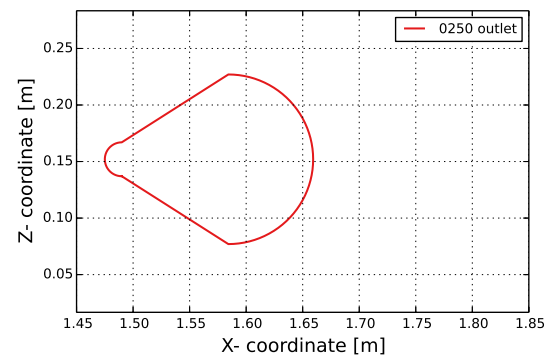
(c) SAA35 Series



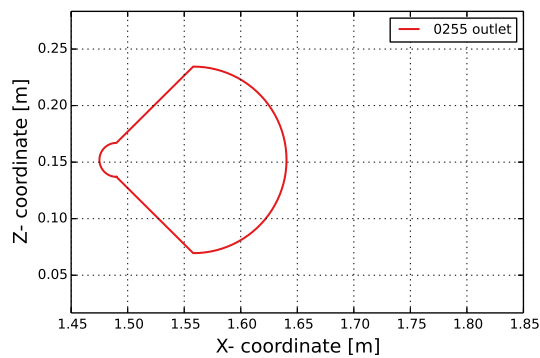
(d) SAA40 Series



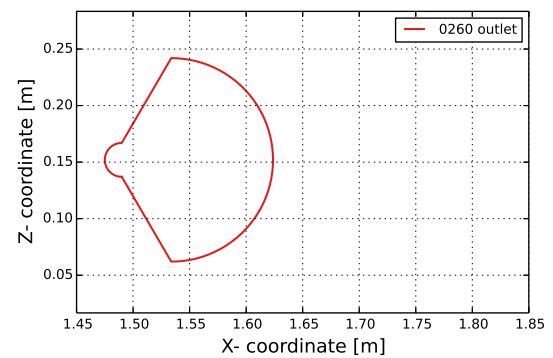
(e) SAA45 Series



(f) SAA50 Series



(g) SAA55 Series



(h) SAA60 Series

Figure 3.6: Overview of the range of the SAABB series BB 25 to 60

4

Conclusion

From the presented literature study the research question can be answered:

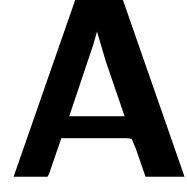
How should the design of the bow tunnel thruster of a trailing suction hopper dredger be changed in order to improve the ability to turn the ship at slow forward speed?

Multiple aspects have an influence on the performance of a bow tunnel thruster. Two aspects the steering of the tunnel jet flow and the change of the cross-section of the bow tunnel thruster seem to be the most promising, as little changes to the bow of the dredger need to be made and large improvements are expected as the flow behavior is changed. It is therefore advised to change the cross-section of the bow tunnel thruster or to develop a device to steer the tunnel jet flow to the front.

What are the characteristics of the flow in and around of a bow thruster tunnel at slow forward speed? The flow of a bow thruster at slow forward motion can be compared with a jet in a cross-flow problem. The induced pressure systems at both sides of the tunnel thruster are the main contributors to the decrease in ability to turn a vessel at slow forward motion with a bow tunnel thruster.

Which factors influence the performance of a bow thruster? The influencing factors are:

- The position of the tunnel in the vessel.
- Distance of the tunnel to the water surface and to the keel
- Length of the tunnel
- The tunnel-hull interface
- Grid bars
- Angle of the hull raising at the intersection with the thruster tunnel
- Form of the cross-section of the tunnel
- Angle of the tunnel outlet towards the surrounding ship flow



Analysis of IHC hopper dredgers

At Royal IHC it was noticed that all hopper dredgers suffered from a large decrease in turning ability at speeds around 5 knots. The general data of 35 hopper dredgers is used to describe typical hopper dredger coefficients. In the following the data of the 35 dredgers is analyzed and presented.

All vessels have at least one bow tunnel thruster installed and their length varies between 62.3 to 185 [m]. In Figure A.1 boxplots of dimensionless coefficients for the IHC hopper dredgers are shown. The average, minimum, maximum, median and 1st and 3rd quartile are listed in Table A.1.

Table A.1: Statistical data of IHC hopper dredgers

	L/B	L/D_H	B/D_H	T/D_H	m	$Re(D_H, v_j)$	$Re(D_H, u_s)$
Average [-]	4.8	63	13	4.5	0.39	1.1E+07	4.4E+06
Minimum [-]	3.9	39	8	3	0.32	5.6E+06	2.2E+06
Maximum [-]	6	98	19	7.4	0.53	2.3E+07	8.8E+06
Median [-]	4.9	63	13	4.3	0.39	9.6E+06	4.2E+06
1. Quartile [-]	4.5	54	12	3.7	0.35	7.1E+06	3.1E+06
3. Quartile [-]	5.1	68	15	5.1	0.41	1.5E+07	5.7E+06

First of all it can be seen that the length over breadth coefficient is in the range of 4 to 6 [-]. The length L in this case is the length between perpendicular and the breadth B is the molded breadth. The ship length L divided by the hydraulic diameter D_H shows a wide scatter between 40 and 100 [-].

The breadth B divided by the hydraulic diameter D_H gives an indication on the tunnel length L_T . As the exact tunnel length L_T is not known for most of the vessels this gives a good indication. It can be seen that 50 [%] of the vessels have a breadth of diameter ratio of 12 to 15 [-].

Another interesting ratio is the draft-diameter ratio. It should be noticed that the trial draft T is used in this comparison. A hopper dredger has a relative small draft when completely empty and a relative high draft when fully loaded. For the trial draft a ratio between 3 and 7.4 [-] is found.

As mentioned earlier the speed ratio m is an indication for the behavior of the tunnel flow into the cross-flow. It can be noticed that the speed ratio m , is for all cases between 0.32 and 0.53 [-]. For the calculation of m a constant cross-flow speed u_s of 5 [kts] is assumed and the jet velocity v_j is calculated based on the thrust T , water density ρ_w and the hydraulic diameter D_H as:

$$v_j = \sqrt{\frac{T}{\rho_w A}} = \sqrt{\frac{4T}{\rho_w \pi D_H^2}} \quad (\text{A.1})$$

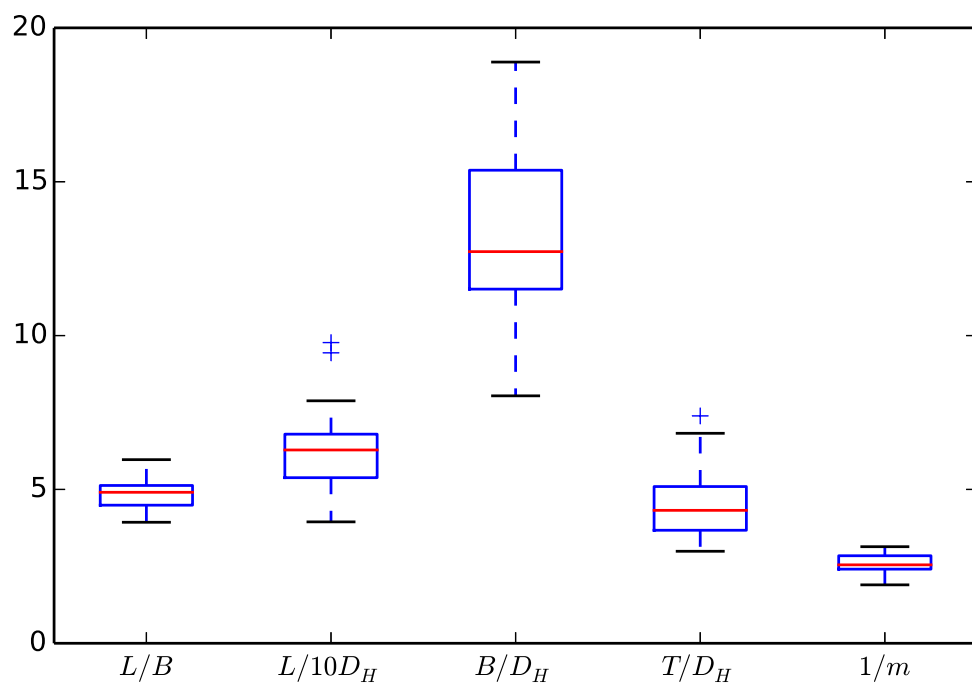


Figure A.1: Boxplot of different aspects of analyzed IHC hopper dredgers

B

Time planning as of 8 June 2015

Weekno

[illegible]

C

Thesis proposal 9 March 2015

Master Thesis Proposal

Hydromechanical performance of bow thruster in slow forward condition (dredging) of a trailing suction hopper dredger using Computational Fluid Dynamics

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1 Introduction

In this document a proposal is given for a Master Thesis research as part of the Master Degree in Marine Technology, Science Track at the Delft University of Technology. The proposal is developed and shall be carried out in cooperation with Royal IHC, Kinderdijk, The Netherlands and focuses on the hydro-mechanical performance of a bow thruster. This document defines the problem, proposes a solution and gives a time frame for the thesis.

2 Problem Statement

During operation it was noticed that the tunnel thruster performance of a dredger is very poor at low forward speeds. At a speed of 5 [kts] the turning performance has been severely reduced compared to the performance at zero speed. The target is to analyse the phenomena and to suggest an improvement.

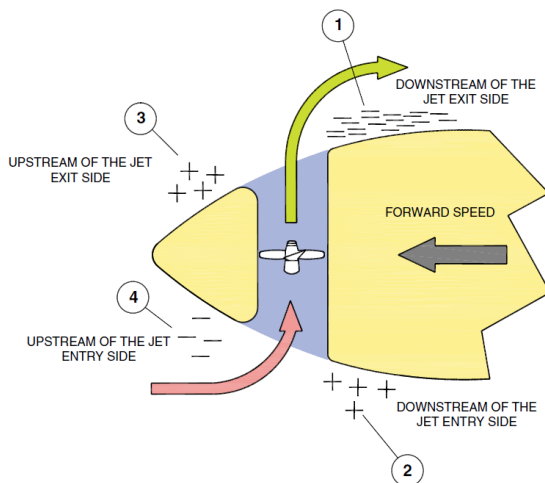


Figure 1: Flow through a tunnel thruster with slow speed ahead. Adapted from [2].

According to literature the decrease in turning performance of a vessel at low speeds is a fundamental problem and it has been investigated in various cases [1, 2, 3, 4]. A typical flow pattern is sketched in Figure 1, the same pattern was also noticed in a CFD study by MARIN for a IHC dredger [5].

In the following some of the main contributing factors are illustrated:

2.1 Pressure field at the jet outlet

The change in pressure field downstream of the tunnel outlet is a main contribution to reduce efficiency [1, 2, 3, 4]. Next to that the pressure field downstream of the inlet decreases the efficiency as well, but according to Nienhuis 1992 [1] to a smaller extent than at the outlet.

2.2 Pivoting point

The ship's pivoting point is located forward of the midship for a ship sailing forward [2]. The distance between the pivoting point and the bow thruster tunnel is therefore decreased for a ship travelling at low speed compared to rest, which results in a decrease of the lever of the turning moment. The pivoting point is approximately located at $1/4 L$ for a ship sailing ahead according to many ship handling handbooks [2].

2.3 Shape and position of the tunnel

According to Baniela 2009 the shape of the ship hull at the location of the bow thruster has a significant influence [2]. The paper claims that an angle of 90° to the adjacent flow would give the best results. Next to that many design parameters have a (potential) influence on the performance of the tunnel thruster, these include, but are not limited to: shape, length, diameter, vertical position, horizontal position, design of tunnel fairings, water depth (shallow water effects).

2.4 Anti suction tunnel (AST)

A possibility to decrease the lost of performance of a tunnel thruster is the concept of a passive anti suction tunnel. Such a tunnel is installed directly behind the tunnel thruster to equalise the pressure fields behind the tunnel [2, 1].

2.5 Jet in a cross-flow

From a fluid dynamics point of view, the jet leaving the tunnel thruster is a jet in a cross-flow type problem. In this field of fluid dynamics many studies have been compared for different fluids and Reynolds numbers.

2.6 Effect of appendages

The present of appendages at full scale results in better course-keeping abilities. The influence on the thruster tunnel performance is unknown, but it is expected that at low forward speeds the present of appendages such as a skeg reduces the performance.

3 Definition study

In the definition study of the master thesis the background and basis of the master thesis is analysed. The study contains a literature survey, elaborates on the problem statement and objectives and presents a scope and plan for the master thesis work.

3.1 Objectives

The objectives for the definition study are:

- Overview and understanding of current literature on the subject
- Basic experience with the CFD tool FineMarine. Have some insights in the possibilities and limitations of the program and have some experience with solving reference cases (e.g. Tutorials)
- Derivation of research questions and a hypothesis.
- Derive a plan of approach, time schedule and testing plan

3.2 Deliverables

At the end of the definition study a report is submitted, which can be read stand alone and a presentation is given to the project partners at a meeting. Next to that, parameters that are going to be analysed in the thesis need to be identified.

3.3 Time frame

The definition study shall take 8 to 14 weeks. The target is to finish the definition study by the end of week 21 (Friday, 22 May 2015). In week 21 a presentation is given to the supervisory board and the scope and plan are discussed in detail. The length is flexible, depending on the progression and availability of material.

4 Master thesis study

After the definition study a clear scope of the thesis exists. Based on the parameters and aspects of the definition study a testing matrix is derived and carried out. The main study will be performed using the computational fluid dynamics software FineMarine. The results will be verified and validated based on model tests and other material.

4.1 Objectives

The objectives of the main phase of the master thesis are as follows:

- Qualitative and quantitative answer to the research questions and hypothesis
- Present all results including an uncertainty study and draw conclusions based upon it
- Present recommendations
- Include a self-reflection.

4.2 Deliverables

A report describing the background, theory, testing set-up, testing, validation and results of the study will be written and submitted to the supervisory board. Next to that two meetings will be held with the supervisory board and a master thesis defence will be held on the end of the project in front of a general audience.

4.3 Time frame

The thesis main phase will be 18 to 23 weeks. After a green light meeting at the end of the main stage a finalization phase of 4 to 5 weeks will follow before the defence of the thesis. The current plan is to have a progress meeting in week 36 (First week of September 2015); End of main phase/ green light meeting in week 46 (Second week of November 2015) and the defence of the thesis takes place in week 50 (Second week of December 2015).

5 Methods and tools

The following methods and tools are going to be used during the project:

5.1 Literature

Public available literature and internal literature of IHC and the TU Delft are the primary source of information for the literature study.

5.2 Computational fluid dynamics (CFD)

The computational fluid dynamics software FineMarine by Numeca is available at IHC and will be used to carry out numerical investigations. An error estimation of the results is going to be made and the results are verified and validated as much as possible.

5.3 Model test

To increase the accuracy of the numerical results and to make comparisons it is advisable to perform model tests or full scale measurements.

5.4 TT JIP Marin

Currently MARIN is developing a tunnel thruster joint industry project (TT JIP). IHC has shown interest in contributing to this JIP. It should be analysed how this study can benefit from the JIP and if the results of this study can be used within the JIP.

References

- [1] Nienhuis U. (1992), *Analysis of thruster efficiency for dynamic positioning and low speed manoeuvring*, Delft University of Technology, PhD thesis
- [2] Baniela S.I. (2009), *The performance of a tunnel bow thruster wutg a slow speed ahead: a revisited issue*, The Journal of Navigation 62, 631-62, The Royal Institute of Navigation, doi: 10.1017/S0373463309990166
- [3] Carlton J.S. (2007), *Marine propellers and propulsion*, Second Edition, Butterworth- Heineman, ISBN: 978-0-7506-8150-6
- [4] Karlikov V.P. and Sholomovich G.I. (1998), *Some features of body-flow interaction in the presence of transverse jets*, Fluid Dynamics, Vol. 33, No.3
- [5] Lafeber F.H. (2014), *CJK01 dredger (122m); Bow thruster computation*, Draft Report, 25868-1-POW, MARIN

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Bibliography

- [1] Maritime Journal, *Boskalis and Van Oord create sand engine to reinforce Dutch coastline*, [Website: maritimejournal.com](http://maritimejournal.com) (2011).
- [2] V. Karlikov and G. Sholomovich, *Some features of body-flow interaction in the presence of transverse jets*, Fluid dynamics **33**, 313 (1998).
- [3] T. Schaap, *Changing the cross-sectional geometry of a bow tunnel thruster - Effects on the performance of the thruster at slow forward motion using Computational Fluid Dynamics*, Master Thesis, Delft University of Technology, Faculty of Mechanical, Maritime and Materials Engineering (2015).
- [4] D. Ligtelijn and J. Dang, *Wageningen TT-Series - Project Proposal*, (2014).
- [5] U. Nienhuis, *Analysis of thruster effectivity for dynamic positioning and low speed manoeuvring*, Ph.D. thesis, TU Delft, Delft University of Technology (1992).
- [6] F. Lafeber, *CJK01 dredger (122 M); bow thruster performance computations*, MARIN Report, Confidential report made for IHC **25868-1-POW** (2014).
- [7] S. I. Baniela, *The performance of a tunnel bow thruster with slow speed ahead: A revisited issue*, Journal of Navigation **62**, 631 (2009).
- [8] H. Klein Woud and D. Stapersma, *Design of propulsion and electric power generation systems* (Institute of Marine Engineering, Science and Technology (United Kingdom), London (United Kingdom): IMarEST, ISBN: 1-902536-47-9, 2002).
- [9] F. M. White, *Fluid Mechanics (SI Units)* (Mcgraw-Hill Education - Europe. 7th revised edition. ISBN: 978-007-131121-2, 2011).
- [10] K. Bladt, *Beitrag zur Auslegung von Querschubanlagen mit Propeller für Schiffe (in German)*, (2013).
- [11] W. Bohl, *Technische Strömungslehre (in German)*, 6th Edition (VEB Fachbuchverlag Leipzig, 1984).
- [12] R. Verbeek, *De netto stuwkracht van thrusters (in Dutch)*, Lips technical report **5330-8201** (1982).
- [13] H. Blaauw and E. Van de Kaa, *Erosion of Bottom and Sloping Banks Caused by the Screw Race of Manoeuvring Ships* (Antwerp, Delft Hydraulics laboratory, 1978).
- [14] C. Schneiders and C. Pronk, *Performance of thrusters*, in *Offshore Technology Conference* (OTC 2230, vol. I, pp. 808-816, 1975).
- [15] M. S. Chislett and O. Björheden, *Influence of ship speed on the effectiveness of a lateral-thrust unit* (Hydro-and Aerodynamics Laboratory, Hydrodynamic Section No. 8, 1966).
- [16] M. L. Albertson, Y. Dai, R. Jensen, and H. Rouse, *Diffusion of submerged jets*, Transactions of the American Society of Civil Engineers **115**, 639 (1950).
- [17] K. Mahesh, *The interaction of jets with crossflow*, Annual Review of Fluid Mechanics **45**, 379 (2013).
- [18] J. Grevink, *Transverse thrusters*, Delft University of Technology, lecture note OE5663- DP systems by Wärtsilä (2015).
- [19] J. W. English and B. N. Steele, *The performance of lateral thrust units for ships as affected by forward speed and proximity of a wall*, National Physics Laboratory, Ship Division, Feltham, United Kingdom (1962).

- [20] J. W. English, *The design and performance of lateral thrust units for ships: Hydrodynamic considerations*, Quart. Trans. Royal Institute of Naval Architects (1963).
- [21] J. L. Beveridge, *Design and performance of bow thrusters*, Tech. Rep. (DTIC Document, 1971).
- [22] M. Fujino, T. Saruta, and T. Ida, *Experimental studies on the effectiveness of the side thruster*, Journal of the Kansai Society of Naval Architects (1978).
- [23] R. Jordinson, *Flow in a jet directed normal to the wind*, Technical report R and M 3074, Aeronautical Research Council (1956).
- [24] N. Gregory and W. S. Walker, *Measurements of lift and ground interference on a lifting-fan wing at zero forward speed*, Technical report R and M 20006, Aeronautical Research Council (1958).
- [25] N. Gregory and W. G. Raymer, *Wind tunnel tests on the boulton-paul rectangular wing (aspect ratio 2) with lifting fan*, Technical report R and M 20356, Aeronautical Research Council (1958).
- [26] M. van Dyke, *An Album of Fluid Motion* (Fourth print. The parabolic press, California, U.S.A. ISBN: 0-915760-02-9, 1988).
- [27] A. Rohatgi, *WebPlotDigitizer Version 3.8*, (2015).