Flanders
State of
the Art

23_074_1
FH reports

Scientific research accessibility of supply ships to Port of Ostend

Towing tank tests ship model H40

DEPARTMENT
MOBILITY & PUBLIC WORKS

www.flandershydraulics.be

Scientific research accessibility of supply ships to Port of Ostend

Towing tank tests ship model H40

Van Zwijnsvoorde, T.; Villagomez, J.; Eloot K.

Flanders Hydraulics
Flanders State of the Art

Cover figure © The Government of Flanders, Department of Mobility and Public Works, Flanders Hydraulics

Legal notice

Copyright and citation

D/2024/3241/285

This publication should be cited as follows:

Van Zwijnsvoorde, T.; Villagomez, J.; Eloot K. (2024). Scientific research accessibility of supply ships to Port of Ostend: Towing tank tests ship model H40 . Version 4.0. FH Reports, 23_074_1. Flanders Hydraulics: Antwerp

Document identification

Customer:	Flanders Hydraulics	Ref.:	WL2024R23_074_1
Keywords (3-5):	Towing tank Antwerp, scale model, manoeuvring, dredger, installation vessel		
Knowledge domains:	Harbours and waterways -> manoeuvreergedrag -> open water-> open water manoeuvring -> scale model tests		
Text (p.):	23	Appendices (p.):	3
Confidential:	☒ No	☒ Available online	

Author(s):	Van Zwijnsvoorde, T.; Villagómez, J.

Control

	Name	Signature
Reviser(s):	Villagómez, J.	Getekend door:Jose VILLAGOMEZ ROS Getekend op:2024-12-11 09:30:40 +01:0 Reden:Ik keur dit document goed José Villagómez Vlaamse overheid
Project leader:	Eloot, K.	Getekend door:Katrien Eloot (Signature) Getekend op:2024-10-29 18:52:47 +01:0 Reden:Ik keur dit document goed Eloot Katrien Vlaamse overheid

Approval

Head of Division:	Bellafkih, K.	Getekend door:Abdelkarim Bellafkih (Sig Getekend op:2024-10-29 21:35:48 +01:0 Reden:Ik keur dit document goed Bellafkih Abdelkarim Vlaamse overheid

Abstract

This report is a “helper report” to the project 23_074. It describes the preparation of the test program and the execution of the test program for the H40 model ship as part of the project. The report does not describe the mathematical modelling which is done in another part of 23_074 by the external contractor VTT. The report does also not aim to give a high level overview of the project.

Contents

List of tables

List of figures

1 Introduction and content

The 23_074 project aims at building mathematical models for a selection of design vessels which are representative for manoeuvres in the port of Ostend, Belgium. As the port area is a shallow water area for vessels with significant drafts, a specialised shallow water manoeuvring model needs to be built. At Flanders Hydraulics (FH), Towing Tank Tests, where a (physical) scaled version of the ships are studied, are used as input to build such specialised shallow water mathematical model.

Two reports are generated to document the model test series, one for each ship model. This report deals with the hopper dredger *Charles Darwin*. The derived ship model is the *H40* which is the scaled *Charles Darwin* at scale 1:50. The following chapters are included in the report :

- **Chapter 2 'Ship properties'** properties of the full scale vessel used as basis to make the scale model. It also discusses the tendering and selection process for the three tenders which were needed to get the scale models manufactured.
- **Chapter 3 'Scale model test preparation'** describes the preparation phase for the scale model test program. It starts off with a list of the required channels to steer and measure the correct amount of variables during the experiments. It continues with the selection of the loading conditions for the model tests. After small sections on force gauge ranges, open water characteristics and notes on back-and-forth discussions on parameter settings, the definitions in the ship database "SHP file" and Zeeman "ENV file" are listed for all tested environments.
- **Chapter 4 'test execution'** gives whoever wants to use the model test data – for either further analysis or basis of a new test campaign – insight in some of the challenges which were encountered and how they were managed.
- **Chapter 5 'Summary test matrix'** gives an overview table of the ENV and corresponding SHP files which were tested in this test campaign.

The towing tank test definitions have been made by FH based on the expectations of VTT, the external party who is tasked with doing the mathematical modelling. This is the reason that the test types and their parameter choices differ at some points from what FH manoeuvring programs usually look like. At two occasions, a small window was found to execute a test matrix in line with FH usual manoeuvring test matrix definitions. Any tests of this type are clearly labelled with 'FH test matrix'. If there is no explicit mentioning of 'FH test matrix', one can assume that the tests made according to VTT's expectations.

Disclaimer (1)

The rudders and propellers for this model test program were numbered from SB side to PS, so SB rudder = rudder **1** etc, SB propeller = propeller **1** etc. This is contradicting the governing towing tank procedure, which states that all appendages are numbered 'in the direction of the positive y-axis' also described as 'in the direction of reading'. *At this point this procedure / report has not been located.*

Some mistakes have been introduced in SHP files (see section 3.7) when it comes to the definition of the position of the appendages. *At this point no impact on post-processing by Zeeman has been established. Please recheck when data is re-examined for future projects.*

Disclaimer (2)

Some references are made to documents on the project "P-drive". After completion of the project, this will be archived which will cause a change in the link to the folder. The folder structure within the project should remain intact however.

2 Ship properties (model and full scale)

This report discusses the full scale existing dredger *Charles Darwin* of the Jan de Nul dredging fleet. Based on the properties of the ship, the scaled ship model *H40* (dredger) is created. This chapter is the only chapter where the full scale equivalents will be treated and named as such.

2.1 Data locations

Full scale ship dimensions as received by Jan De Nul are located on

P:\23_074-WetschapOnderzOostende\2_Input_gegevens\CONFIDENTIEEL_Schaalmodel1

Data shared with ship model manufacturer (selection of above) in

P:\23_074-WetschapOnderzOostende\2_Input_gegevens\Schaalmodel 1_BSHC

Information on the ship models is located on

W:\sleept\scheepsrompen_schroeven_roeren\H40

Overview of ship dimensions, background discussions on scaling etc can be found on the excel sheet 'voorbereiding_ontwerpschepen' on the 23_074 Pegasus project page.

2.2 Ship dimensions

The full scale properties and the model scale equivalent can be found in Table 2-1. The scale factor is 50.

Table 2-1 : Full scale and model scale dimensions ship H40, Charles Darwin.

Ship name	**Full scale**	**Model scale (1:50)**
General dimensions		
L_{OA} [m]	183.2	3.66
L_{pp} [m]	161.5	3.23
B [m]	40.0	0.80
T_d [m]	13.0 / 10.0*	0.26 / 0.20
D [m]	17.5	/
Steering and propulsion (main)		
Description	Twin screw (ducted), twin rudder, CPP	Twin screw (ducted), twin rudder, FPP
D_p [m]	4.8	0.096

rpm	130.7	924
Power / propeller [kW]	10476	/
A_r [m²]	20.5	0.0082
Thrusters		
Description	Two bow, one stern	/
D_p [m]	2.25	/
rpm	890	/
Power / propeller [kW]	1350	/

* when reading the datasheet ‘CD Datasheet.pdf’ on page 5, it actually mentions that the T = 10 m draft condition is the mean draft, as the ship is slightly trimmed, with T_a = 10.9 m , T_f = 9.2 m. The selection of the loading condition for the model tests is further discussed in section 3.2.

2.3 Choice scale factor

The scale factor needs to be chosen so that the ship can be tested as optimal as possible in the towing tank, the following considerations are taken into account,

The scale factor should be chosen as large as possible (small ship model) so that

- The ship fits in the harbour of calibration
- The ship’s displacement is not too large (force measurement)
- The ship’s full scale speed equivalent can be met in the confined tank
- The ship does not feel too much of the confinement of the tank

The scale factor should be chosen as small as possible (large ship model) so that

- The propeller radius is as large as possible, 10 cm is normally seen as the cut-off to get good data for assessing propeller properties and scaling to full scale
- The forces measured are not too small for the measuring equipment
- The ship’s model scale speeds are not too small
- It could be tested in the Ostend Towing Tank in the future.

Based on the above factors (see also discussion ‘voorbereiding_ontwerpschepen’)the following scale factor has been chosen

Charles Darwin at scale factor 1:50

Ensuring sufficient size of propellers was the dominant factor leading to the choice of scale factor.

2.4 Ship model tendering

The ship model has been tendered following the OPZB – OnderhandelingsProcedure Zonder voorafgaande Bekendmaking.

- WL2023_20 : ship hull *Charles Darwin*, two ducted propellers, two rudders. Optional aft thruster. Bow thrusters not to be fabricated, only recess in hull needs to be foreseen

The tender and relevant communication can be found on EPM. The following responses were obtained for tender WL2023_20 :

- SVATech Potsdam for 41400 € (basic) (excl. VAT)
- BSHC for 34944 € (basic), 37836 € (with option) (excl. VAT)

BSHC was chosen. It was decided to only grant the basic tender, without stern thruster. The stern thruster tunnel will be fabricated by BSHC.

March 2024, a “Bijakte” was created attached to WL2023_20 (it fulfilled the requirements for “Bijakte”). It concerns the execution of open-water propeller tests for the *H40* ship model. Quotation form BSHC and “Bijakte” can be found on EPM and are also stored under

W:\sleept\scheepsrompen_schroeven_roeren\H40

2.5 Data locations model test data

The Zeeman software tool and its related databases form the core of the FH towing tank testing. As the Zeeman databases are ‘background databases’ which are not meant to access directly – only via the Zeeman GUI, the test definitions ‘PFT” and test results “DOC” are kept on following locations :

- *W:\sleept\opwagen\23_074_H40* Location on W-drive where test definitions are placed (DPT)
- *W:\sleept\vanwagen\23_074_H40* Location on W-drive where test results are placed (DOC)

Details on the SHP parameters (loading condition) and equipment (rudder, propeller, duct) as well as the equipment calibration can be found on

- https://wlsow.vlaanderen.be/shpgenerator/default.aspx

In the “lijst Prototypeschepen” and the lijst “Scheepsrompen” the items *Charles Darwin* and *H40* are added respectively. Detailed information on the SHP files and their content is given in section 3.6.

3 Scale model preparation

3.1 Requirements measurement and steering signals

The ship is tested in captive mode, using the U-beam measurement mode. In the requirement section, the needed input and output channels are discussed, according the following convention:

- Data from Zeeman PFT to Towing Carriage = UIT
  - DIGUIT = Digital signal (0/1)
  - ANUIT = analogue signal (volt, typically from -10 V to + 10 V)
- Data from towing carriage to Zeeman DOC = IN
  - DIGIN = Digital signal (0/1)
  - ANIN = analogue signal (volt, typically from -10 V to + 10 V)

Table 3-1 shows the standard signals for all captive tests. Specifically for the H40, two rudders and two propellers need to be added. Table 3-2 gives the instructions included in PFT test definition sent to Towing Tank; Table 3-3 shows the measurements from Towing Tank back to DOC.

Table 3-1 : Analogue (ANIN) and digital (DIGIN) input signals (Towing carriage -> DOC)

X_{voor} [N]	ANIN01	$z_{voor,BB}$ [mm]	ANIN07	Sinkage limit [0/1]	DIGIN01
X_{achter} [N]	ANIN03	$z_{voor,SB}$ [mm]	ANIN08	Sinkage limit [0/1]	DIGIN02
Y_{voor} [N]	ANIN02	$z_{achter,BB}$ [mm]	ANIN09	Rolkracht [Nm]	ANIN16
Y_{achter} [N]	ANIN04	$z_{achter,SB}$ [mm]	ANIN10		

Table 3-2 : Digital (DIGUIT) and anlogue (ANUIT) steering signals (PFT -> Towing carriage) for H40

Enable schroef1 [0/1]	DIGUIT01	n schroef 1 [rpm]	ANUIT01
Enable schroef2 [0/1]	DIGUIT02	n schroef 2 [rpm]	ANUIT02
Enable droer1 [0/1]	DIGUIT03	n roer 1 [°]	ANUIT03
Enable droer2 [0/1]	DIGUIT04	n roer 2 [°]	ANUIT04

Table 3-3 : Analogue (ANIN) input signals (Towing carriage -> DOC) for H40

d roer 1 [°]	ANIN12	d roer 2 [°]	ANIN25	n schroef 1 [rpm]	ANIN11	n schroef 2 [rpm]	ANIN22
X roer 1 [N]	ANIN13	X roer 2 [N]	ANIN26	T schroef 1 [N]	ANIN05	T schroef 2 [N]	ANIN23
Y roer 1 [N]	ANIN14	Y roer 2 [N]	ANIN27				
Q roer 1 [Nmm]	ANIN15	Q roer 2 [Nmm]	ANIN28	Q schroef 1 [Nmm]	ANIN06	Q schroef 2 [Nmm]	ANIN24

3.2 Selection of the loading condition

The design draft for the ship is given in Table 2-1, 0.20 m (mean draft). However, the loading condition used for the model tests (two drafts) still need to be defined. This should be chosen based on the following considerations

- Maximum draft of such vessels when manoeuvring in the Port of Ostend region.
- Additional draft

The selection of the drafts is done based on input from Jan De Nul (via email) and is summarized in the excel sheet voorbereiding ontwerpschepen, tab 'step_1_H40Detail'. In the excel sheet, discussions and explanations for certain assumptions are given. Hydrostatic calculations were performed using Rhino and can be consulted in the folder

*P:\23_074-WetschapOnderzOostende\3_Uitvoering\WL_2023_20_Schaalmodel1\3D_model_BSHC**

All relevant ship properties can always be consulted in the SHP files on the WLSOW ship database. The loading condition design parameters are given in Table 3-4. Bear in mind when attempting to realise the loading conditions from Table 3-4 in practice (so-called ballasting process in the towing tank), the achieved parameters might slightly deviate from the theoretical values. There are several explanations for this, of which some are mentioned here

- The positions of the ballast weights and their size / weight is limited
- All parameters are finally calculated based on actual measured values; this could differ from a (theoretical) Rhino calculation
- The target is to get the draft (fore, mid, aft) within one millimetre from the target draft.

The values from Table 3-4 are used as target values during the ballasting procedure. The final obtained values, based on draft verification and ballast computation are found in the SHP file and summarized in Table 3-5.

Table 3-4 : Description of the loading conditions model ship H40 calculated based on the CAD model with Rhino.

	Loading condition 1	**Loading condition 2**
T_F [m]	0.131	0.200
T_M [m]	0.145	0.200
T_A [m]	0.159	0.200
x_G [m]	-0.047	-0.033
z'_G [m] *	0.157	0.200
z'_B [m] *	0.077	0.105
BM_T [m]	0.348	0.255
BM_L [m]	5.645	4.231

* Notation of z' is used as the coordinates are expressed with respect to the keel, positive upwards, whereas towing tank convention usually defines z with respect to still waterplane, positive downwards.

Table 3-5 : Loading conditions H40 as tested in towing tank, data gathered from SHP files.

SHP file	H4001010101	H4001020101	H4002010101	H4002020101	H4003010101	H4004010101	H4005010101
ENV files	H4001A01 H4001A02	H4002A01 H4002A02	H4003A01 H4003A02	H4004A01 H4004A02	H4005A02	H4006A01 H4006A02	H4007A02
T_F [m]	0.160	0.160	0.200	0.200	0.200	0.160	0.160
T_M [m]	0.146	0.145	0.200	0.200	0.200	0.145	0.145
T_A [m]	0.160	0.130	0.200	0.200	0.200	0.130	0.130
m[kg]	288.6	288.6	412.0	413.9	412.0	288.6	288.6
x_G [m]	-0.0448	-0.0448	-0.0280	-0.0251	-0.0280	-0.0448	-0.0448
z_G [m]	-0.0120	-0.0120	-0.0010	-0.0020	-0.0010	-0.0120	-0.0120

3.3 Force gauge range check

Depending on ship size (displacement) and L/T, B/T, L/B ratios, the forces and sinkages which are measured in the towing tank will vary between the projects. In fact, the expected forces should be checked with the measurement gauges which are present in the towing tank set-up. An assessment of the main properties of the *H40* can be found in the excel sheet voorbereiding ontwerpschepen tab 'fore_gauge_range_check'. The dredger *H40* is the widest ship (excl. push convoys) which has been tested at the Antwerp Towing Tank. The overall displacement however is not extraordinary and means that it can be expected that the existing measurement devices should perform well for the *H40* case.

3.4 Open water characteristics

End of march 2024, the contract for scientific support for the mathematical modelling was awarded to VTT. They confirmed an earlier statement from the open competitor dialogue that they want open water characteristics for the propellers of *H40*. These tests were executed by the manufacturer of hull and propellers according to the tender described in section 2.4.

3.5 Appendage numbering and position

The ANIN , ANUIT and DIGUIT channels for rudders and propellers are named "1" and "2" for this double screwed ship. The numbering is given in Figure 3-1. The port side (PS) rudder and propeller channel are denoted by "2" and the starboard side (SB) rudder and propeller channel are denoted by "1". Both propeller and rudder are angled in the horizontal plane with respect to the centreline of the ship. The propeller is angled at 2° and the rudder at 4°. The PS propeller and rudder are angled towards SB side ; the SB side propeller and rudder are angled towards PS. On Figure 3-1 one could denote this as "inward". These angles are inserted in the SHP file (section 3.6). Bear in mind that some mistakes have been made in the definition of the SHP file, as explained in section 3.6.

As was indicated in the introduction, the numbering of the rudder and propeller in this program is not according to the towing tank convention, which states that numbering needs to be done "in the direction of the positive y-axis" or "as you would read from left to right". In this concrete example, the PS ruder and propeller should have been named "1" and the SB propeller and rudder should have been named "2".

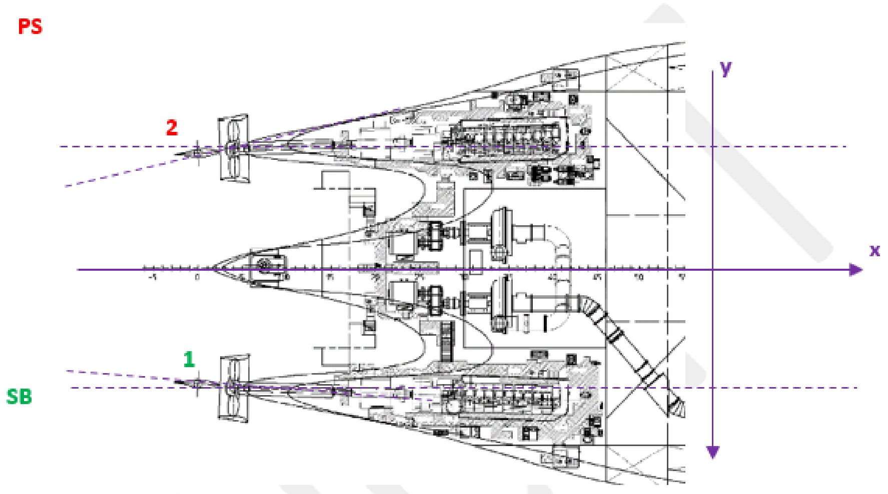


Figure 3-1 : Aft ship of H40 from general arrangement plan full scale ship Charles Darwin : numbering used for project

3.6 Ship database and ENV definition

Prototype ship and ship model have been added (see section 2.5).

Propellers and ducts need to be added as *componenten.* The name of the component according to towing tank definitions is indicated in blue.

- PS propeller left handed (schroef 36), SB propeller right handed (schroef 37) (outward over the top)
- PS duct (straalbuis 5) en SB duct (straalbuis 6)
- PS rudder (roer 33) en SB rudder (roer 34)
- Propeller data from BSHC report (library "openwaterkarakteristieken")
- Open water characteristics have been added and connected to propellers and ducts

The SHP file is formed based on multiple lists containing different parameter details. The available lists are

- Scheepsrompconfiguratie
- Modules
- Ladingscondities
- Ijkingswaarden

For this project, multiple ship files are defined, because of following reasons

- Change in loading condition = new SHP file
- Move from bare bull to appended = new modules = new SHP file
- Disconnect ship from beam = new calibration = new SHP file
- Change in definition of 100% rpm = new scheepsrompconfiguratie = new SHP file.

It could have been chosen to always define 100% rpm as the max. rpm for this ship, however this would mean that the test definitions would need specific rpm % definitions for the different ENV, as the max. rpm definition for VTT is related to the estimation of the self-propulsion point at a certain speed (section 4.6.1). It was chosen to instead change the 100% rpm definition in the SHP file.

In the following sections, the SHP files which are generated are described, along with any remarks on their definitions.

3.6.1 Bare hull, T_M = 0.145 m , trimmed

Table 3-6 : Description lists to generated SHP file H4001010101 used in ENV H4001A01 and H4001A02

List	Name	Remarks
Scheepsromp-configuratie	H4001	safety rectangle (-0.6,1.5) (0.6,1.5) because of large beam of model 1.5 instead of 2.0
Modules	H400101	Appendage 'nothing.app' has been added
Ladingscondities	H40010101	
Ijkingswaarden	H4001010101	
Omgevingsfiles	H4001A01 (A02)	

3.6.2 Appended, T_M = 0.145 m, trimmed

Table 3-7 : Description lists to generated SHP file H4001020101 used in ENV H4002A01 and H4002A02

List	Name	Remarks
Scheepsromp-configuratie	H4001	safety rectangle (-0.6,1.5) (0.6,1.5) because of large beam of model 1.5 instead of 2.0 max rpm = 796.15 = 100 % rpm based on estimation of self-propulsion point at 12 knots and 100% UKC
Modules	H400102	Appendages have been added : 2 propellers, 2 ducts, 2 rudders X,Y,Z,PSI positions added ; X,Y,Z propellers : most outward point of hull (middle point circle) as measured on model + PSI 2° rotation (measured on GA) {as defined in manual} X,Y duct = X,Y propeller + Z measured top contact point hull – duct ship side at PS. Z SB taken as same value. {manual definition not 100% clear} 2024/07/12 mistake y = 203 for BB should be -203 . 2024/08/01 mistake duct psi = 0 X,Y,Z rudder measured where rudder cone enters the hull + psi 4° as measured on GA + confirmed by JDN {as defined in manual} 2024/08/01 mistake in signs of all angles Change to SHP lists have not been made as the tests have already been performed
Ladingscondities	H40010201	
Ijkingswaarden	H4001020101	
Omgevingsfiles	H4002A01(A02)	

Ijkingsfile includes propeller and rudder calibration, some remarks

- When calibrating Y rudder, there is also a >2 V measurement on X signal with large R^2 . Similar observation for both rudders. E&O comments that this is not extraordinary and indeed when looking at one example from past, such cross talk on rudder is indeed present -+ it was more on Q in that file

3.6.3 Appended, T_M = 0.145 m , trimmed – repeat

Rerun of H4002A01(A02)because of error in rudder position for H4002A01(A02) (section 4.10.

Table 3-8 : Description lists to generated SHP file H4004010101 used in ENV H4006A01 and H4006A02

List	Name	Remarks
Scheepsromp-configuratie	H4004	safety rectangle (-0.6,1.5) (0.6,1.5) because of large beam of model 1.5 instead of 2.0 max rpm = 793.16 = 100 % rpm based on estimation of self-propulsion point at 12 knots and 100% UKC
Modules	H400401	Appendages have been added : 2 propellers, 2 ducts, 2 rudders X,Y,Z,PSI positions added ; X,Y,Z propellers : most outward point of hull (middle point circle) as measured on model + PSI 2° rotation (measured on GA) {as defined in manual} X,Y duct = X,Y propeller + Z measured top contact point hull – duct ship side at PS. Z SB taken as same value. {manual definition not 100% clear} X,Y,Z rudder measured where rudder cone enters the hull + psi 4° as measured on GA + confirmed by JDN {as defined in manual}
Ladingscondities	H40040101	
Ijkingswaarden	H4004010101	
Omgevingsfiles	H4006A01(A02)	

3.6.4 Appended, T_M = 0.145 m , trimmed , FH test matrix

Table 3-9 : Description lists to generated SHP file H4004010101 used in ENV H4006A01 and H4006A02

List	Name	Remarks
Scheepsromp-configuratie	H4005	safety rectangle (-0.6,1.5) (0.6,1.5) because of large beam of model 1.5 instead of 2.0 max rpm = 924.1 rpm = equivalent max rpm of full scale ship
Modules	H400501	Appendages have been added : 2 propellers, 2 ducts, 2 rudders X,Y,Z,PSI positions added ; X,Y,Z propellers : most outward point of hull (middle point circle) as measured on model + PSI 2° rotation (measured on GA) {as defined in manual} X,Y duct = X,Y propeller + Z measured top contact point hull – duct ship side at PS. Z SB taken as same value. {manual definition not 100% clear} X,Y,Z rudder measured where rudder cone enters the hull + psi 4° as measured on GA + confirmed by JDN {as defined in manual}
Ladingscondities	H40050101	
Ijkingswaarden	H4005010101	
Omgevingsfiles	H4007A02	

3.6.5 Appended, T_M = 0.200 m , even keel

Table 3-10 : Description lists to generated SHP file H4002010101 used in ENV H4003A01 and H4003A02

List	Name	Remarks
Scheepsromp-configuratie	H4002	safety rectangle (-0.6,1.5) (0.6,1.5) because of large beam of model 1.5 instead of 2.0 max rpm = 793.1 = 100 % rpm based on estimation of self-propulsion point (12 kn, 100% UKC)
Modules	H400201	Appendages have been added : 2 propellers, 2 ducts, 2 rudders X,Y,Z,PSI positions added ; X,Y,Z propellers : most outward point of hull (middle point circle) as measured on model + PSI 2° rotation (measured on GA) {as defined in manual} X,Y duct = X,Y propeller + Z measured top contact point hull – duct ship side at PS. Z SB taken as same value. {manual definition not 100% clear} <u>2024/08/01 mistake duct psi = 0,</u> X,Y,Z rudder measured where rudder cone enters the hull + psi 4° as measured on GA + confirmed by JDN {as defined in manual} <u>2024/08/01 mistake in signs of all angles Change to file has not been made as the tests have already been performed</u>
Ladingscondities	H40020101	
Ijkingswaarden	H4002010101	
Omgevingsfiles	H4003A01(A02)	

3.6.6 Appended, T_M = 0.200 m, even keel, FH test matrix

Table 3-11 : Description lists to generated SHP file H4003010101 used in ENV H4005A01 and H4005A02

List	Name	Remarks
Scheepsromp-configuratie	H4003	safety rectangle (-0.6,1.5) (0.6,1.5) because of large beam of model 1.5 instead of 2.0 max rpm = 924.1 rpm = equivalent max rpm of full scale ship
Modules	H400301	Appendages have been added : 2 propellers, 2 ducts, 2 rudders X,Y,Z,PSI positions added ; X,Y,Z propellers : most outward point of hull (middle point circle) as measured on model + PSI 2° rotation (measured on GA) {as defined in manual} X,Y duct = X,Y propeller + Z measured top contact point hull – duct ship side at PS. Z SB taken as same value. {manual definition not 100% clear} <u>2024/08/01 mistake duct psi = 0,</u> X,Y,Z rudder measured where rudder cone enters the hull + psi 4° as measured on GA + confirmed by JDN {as defined in manual} <u>2024/08/01 mistake in signs of all angles Change to file has not been made as the tests have already been performed</u>
Ladingscondities	H40030101	
Ijkingswaarden	H4003010101	
Omgevingsfiles	H4005A01(A02)	

3.6.7 Bare hull, T_M = 0.200 m, even keel

List	Name	Remarks
Scheepsromp-configuratie	H4002	safety rectangle (-0.6,1.5) (0.6,1.5) because of large beam of model 1.5 instead of 2.0
Modules	H400202	Appendages removed
Ladingscondities	H40020201	Ok
Ijkingswaarden	H4002020101	Calibration redone of hull forces, not of sinkages
Omgevingsfiles	H4004A01(A02)	Ok

3.7 Q&A

This section gives a list of questions and answers which were raised, most of them have also been discussed via email.

(1) The actual hull model is deformed with respect to the CAD. The bow and stern section are lower than middle (hogging), approx.. +4 mm bow and stern and – 2 mm middle. This is more than ITTC would recommend. Before BSHC sent out the ship, they checked model – CAD and showed agreement with ITTC. FH only checked after transport and painting (heating of model) so difficult to point at BSHC. E&O suggested to try and correct bow and stern manually at their workshop. Due to the risk of this action and the delay, there was decided not to take any action and to proceed with preparations. Memo was written WL2024M23_074_2_GeometricalMeasurements_ShipHull_WL_2023_20.docx

(2) Turbulence strips? Turbulence strips will be applied in accordance with ITTC.

(3) Inclined propeller and rudder axis in the horizontal plane, propeller and rudder are inclined with respect to ship centreline (approx.. 2° for propeller and 4° for rudder). The propeller axis are of course installed with this inclination. If the rudder is installed with mechanical 0 at centreline, then the maximum reach becomes 41° (45° capacity rudder steering – 4° = 41°). Jan De Nul however indicated that the rudder is used at ± 45° with respect to the neutral position (4° of centreline). In order to make this possible, the rudder's mechanical zero was put 4° of the centreline (=neutral position rudder). This choice has led to some complications in practice, which is discussed in section 4.10.

(4) Nozzles fixed to hull BSHC – upon request of FH – attached nozzles to hull, as this alignment is crucial for propeller system. This means that for bare hull tests, the nozzles will remain attached to the hull.

(5) Definition midship The L_{pp} is taken from the GA – 3.23 m scaled to model scale and is used to define midship and the position of the turbulence strips.

4 Test execution (May-August 2024)

This section gives the reader an overview on how the ship model H40 was tested in the towing tank in the period May – August 2024 and how observations were made. This chapter is a must-read for persons who work with the acquired test data. Most sections end with a a "take-away message" which summarizes the content of the section.

4.1 Test matrix

The test matrix is made in the excel sheet on the ScientificSupport subsite of Pegagus projectsite 23_074 TestPlanning.xlsx. It is constructed based on a back-and-forth discussed between FH and VTT.

- VTT defines parameters from their experience with their mathematical model and the fact that they use CFD calculations to support their mathematical modelling (and their rich physical model test matrix from the past).
- FH transforms these definitions to the available predefined Zeeman test definitions.

This was not always an easy process, certainly as at the start of the discussion VTT was still learning about the Zeeman test definition structure and FH was learning about their approach to building the mathematical model. However, in the end the excel sheet is believed to be complete and gives as much information as possible to whoever wants to use the dataset.

4.2 Diary

Excel file Towing Tank Schedule diary on Pegasus 23_074. It can be used if one is interested in a specific test environment and when/how it was tested and which notes were taken during the experiments. It contains a day-to-day overview.

4.3 Data quality control

The appended tests feature rudder and propeller steering and measurement. These are included in the test definition by N1,2 [%] for propeller and Roer1,2 [°] for rudder. The propeller [%] is linked to the max. rpm which is defined in the SHP file. When generating tests with rudder and propeller there is in the test definition header a button 'N actief tijdens ijkfase', with 'false' as default setting. Past tests have been consulted (T0104) where the default value 'false' was indeed kept. There seems to be no reason within this project to change this approach.

When reading the theoretical Zeeman manual (WL2020R16_100_1), it mentions IJKK tests which should be executed 'every 60 tests' . It also mentions that bollard pull "PAAL" tests should be put at the end of the batch and that an IJKK needs to close the batch. The manual does not further elaborate on why this type of tests exists and why it must be repeated so often. It seems that – implicitly - there have been some issues in the past where performance of propeller / rudder steering and or measurement changed over the batch. It is unclear whether improvements to equipment have been made since which could make these IJKK tests obsolete.

For now, there is assumed that the Zeeman manual suggestions are followed and multiple IJKK tests during are included in a batch. That leaves us with the question on the definition of the IJKK test, as multiple parameters can be selected in the test definition. In a pragmatic approach, the last IJKK test definition made is taken (T0103A03_IJKK) and slightly tweaked in the following way

- Rudder amplitude from 35° to 45°
- Add second propeller with same settings as first propeller
- Add second rudder with same settings as first rudder

Take-away message

IJKK tests were (and should be) executed at least once per day when performing appended tests.

4.4 Propeller duct fitting

When the propellers were fitted (2024/06/1) after the (first) bare hull tests, it was observed that the propeller touched the duct at one side. After confirmation from BSHC on the position of the ducts and proof that they rotated well at BSHC prior to shipping, the decision was made to slightly sand the ducts down to allow free rotation of the propellers.

Take-away message

Propeller ducts have been sanded slightly to make propeller fit in duct.

4.5 PIOC 7 during H4002A01

On 2024/06/25&26 , the error "PIOC was geïnitialiseerd (PIOC7)" appeared at following occasions

- At the end of test H4002A01_CO0100 (data might have been removed from system…)
- During test H4002A01_AS1500 (3rd test in batch) - 2024/04/25 evening
- During test H4002_AS1501 when performed 2024/04/26 morning after resetting the system.

An analysis of the DOC file H4002A01_AS1500 shows that

- From the start of the test, many channels give zero values (ANIN 01,02,03,04,07,08,09…)
- At time 45.3 s the last data row is given and afterwards the error code is included as “info”

Analysis of H4002A01_CO0100 shows the same zero channels and error as info, this time at 74.8 s. This was solved by adding propeller ramping for propeller 2. This is standard for propellers and was already present for propeller 1.

Take-away message

Propeller ramping functions need to be defined for all propellers.

4.6 Self-propulsion point forward speed and crabbing setpoints

VTT asked to define the “100% rpm” for all appended tests and the “thrust killing rpm” for crabbing tests. An example of how this was done for H4002A01 is given here. A similar approach is followed for the other cases. Bear in mind that the excel sheet [TestPlanning.xlsx] gives elaborate details on the values which are adopted as well.

All test results (ZIP) are kept at W:\sleept\vanwagen\23_074\H4002A01\@tryouts

- \crabbing_setpoint_determination
- \self_propulsion_setpoint

This is done to separate from the ZIP files for which systematic DOC/KRT need to be delivered to VTT.

4.6.1 Self-propulsion point

In meeting with VTT on 2024/06/27 the definition for 100% rpm was elaborated on. This definition is

“ an rpm which is around the self-propulsion point for the speed of 12 knots full scale at 100% UKC”

The word “around” is important as for determination of self-propulsion point, one could discuss about resistance scaling effects etc., which can be omitted here. We do the following model tests

- H4002A01_CL01 : 25% 50% 75 % rpm* PS and SB
- H4002A01_CL02 : 35% 60% 100 % rpm PS and SB
- H4002A01_CL03 : 35% 60% 90% rpm PS and SB
- H4002A01_CL05 : 70% 80% 90% rpm PS and SB

* 100% rpm = 924.4 rpm = 130.7 rpm * sqrt(50)

In the end, the test H4002A01_CL05 was selected to determine the self-propulsion point. The analysis (data input, Python scripting, data output) can be found in

P:\23_074-WetschapOnderzOostende\3_Uitvoering\Data_analysis

Based on these tests, the self-propulsion rpm (rpm where X = 0) is 796.15 rpm. This value is set as the MAXTOER in the SHP file “scheepsrompconfiguratie”. All values in the test_planning excel are then relative to this rpm value. This is valid for all tests with this loading condition (100% and 20% UKC). A new rpm value will be determined for the other loading condition.

4.6.2 Crabbing setpoints

After the self-propulsion tests and the update of the SHP file, max rpm = 796.15 rpm =100% rpm, the crabbing tests were repeated in batch on night 2024/06/27-28. Tests AS01 – AS15 were ran. For three predetermined PS propeller rpm points (60,80,100% rpm), the SB setpoints needs to be sought. This is done through, for example PS rpm of 60%

- Test AS05 where four rpm of SB propeller are tested in one PAAL test with 30s test time for each propeller setting.
- Test AS01 ,AS02, AS03, aS04 where the four rpm settings are tested separately with 2000s waiting time between each test , to verify procedure AS05

Based on AS05, AS10 and AS15, the SB rpm needed to get X = 0 are calculated. The analysis (data input, Python scripting, data output) can be found in

P:\23_074-WetschapOnderzOostende\3_Uitvoering\Data_analysis

- PS = 60 % rpm -> SB = -400.52 rpm
- PS = 80% rpm -> SB = -540.92 rpm
- PS = 100% rpm -> SB = -692.03 rpm

The same exercise is done for the other ENV, see excel [TestPlanning.xlsx]

Take-away message

For all SHP files – except FH test matrix related – the MAXTOER definition in the scheepsrompconfiguratie is defined based on self-propulsion tests.

4.7 Rudder angle measurement (rudder 1)

When performing the test batch over the weekend of 2024/06/29-30, it was observed that when comparing IJKK at beginning (H4002A01_IJKK0101) and end (H4002A01_IJKK0102), the measurement rudder angle of rudder 1 was deviating from the steered signal (Table 4-1). Steered values in orange, measured values in blue. When studying the rudder 1 in detail, the following was assessed:

- Actual rudder position (physical) was 0.5° off the true zero in 'rest'. This was adjusted by Joeri at the model itself. Such small differences can be accepted as well as it is hard to put the initial position more accurate with the current method.
- The rudder measurement (blue) was indeed deviating from the steered value (orange). This was adjusted by changed Bcal of the rudder as follows : New Bcal = Old Bcal + 2.3.

This needs to be checked at the start and end of every batch – at least – even better can be a daily check. Of course, when the test is analysed, the calibration time of 10 s is used to 'correct' for this offset, so the measurement data should still be ok, if the error is in the measurement (drift in signal, offset, Bcal).

This issue continued to arise. In weekend batch 2024/07/06-07 it even caused tests to be stopped as ANIN limit for rudder was reached. By then, the measurement was around 5° off the steered value (see diary as well). A new correction to Bcal was made on 2024/07/08 (New Bcal = Old Bcal + 5). On 2024/07/12 this was done again (New Bcal = Old Bcal + 2.2).

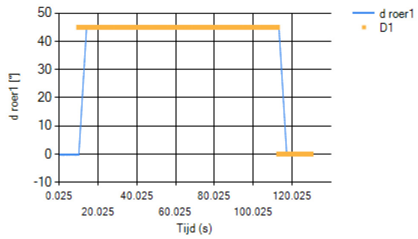
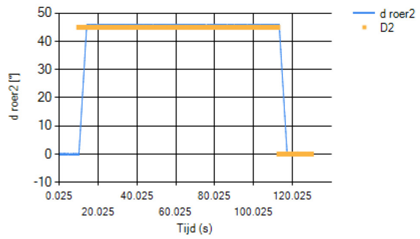
Finally, in the week of 2024/07/15, E&O addressed this and changed some components in order to get rid of this issue. This upgrade really helped and the issue – in this magnitude – did not occur afterwards. For the post-processing, there is no issue, one or two of following approaches can be taken

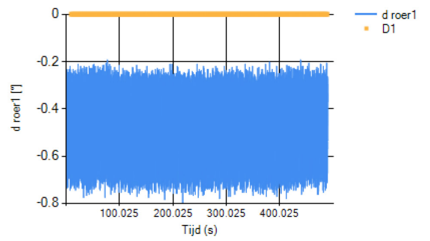
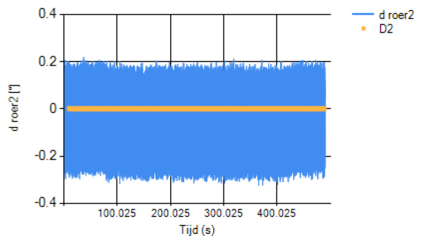
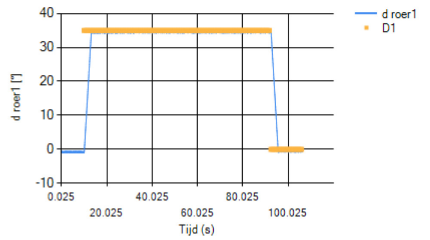
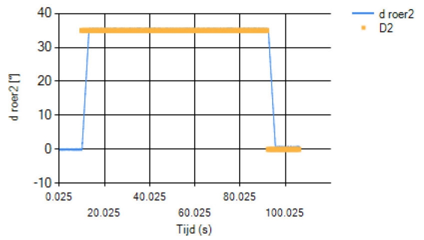
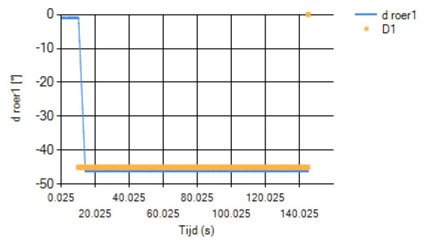
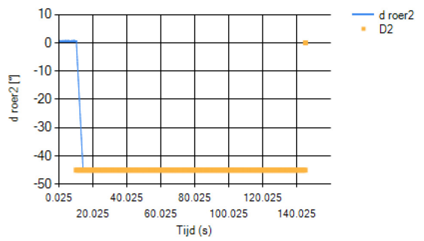
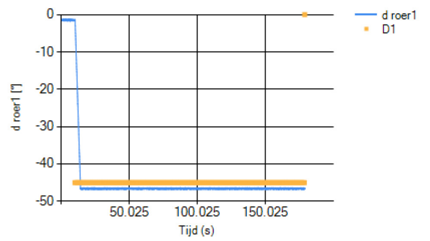
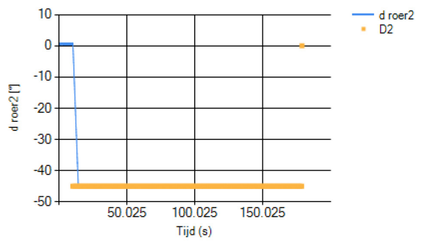
- Take the ANUIT (steering) of rudder 1 for the mathematical model input instead of the ANIN (measured) rudder angle.
- Use the calibration time (10s) at the start of the test to correct the rudder angle offset. This is in fact general towing tank procedure when post-processing DOC files to KRT/RES/DPT.

Take-away message

Rudder position measurement (ANIN) should be monitored. In this case, the measurement system showed some deviation over time. The steered (ANUIT) value and actual physical position was ok.

Table 4-1 : Analysis deviation in measured rudder angle rudder 1.

5 PM 06/28 CH		

5 AM 06/29 CB06		
5 PM 06/29 CJ19		
5 AM 06/30 GG12		
5 PM 06/30 GE06		

4.8 Brief analysis Crabbing tests

Crabbing tests (see [test planning]) are not usually part of FH's manoeuvring test matrix hence little internal references on what results to expect is available.

When analysing H4002A01_AS16 (XLS of test), the X-force (X_voor + X_achter) seems to go up (trend) during the first ten seconds, Figure 4-1. The only active component in this test is the rudder 1 angle (0 -> -45°). This rudder motion seems to cause the initial X-force measurement. It can only be seen that when the same regime is repeated four times for 30 s (with 10 s stop in between; 10s->40s, 50s->80s, 90s->120s, 130s->160s), the average X-force over the 30s shows some variation.

H4002A01_CB08 is a test with forward speed Figure 4-2 and Figure 4-3. It is seen that the X-force is (running average 200 points) unsteady. The unsteadiness of the test is also clearly visible when looking at the sinkages. Notice that there is a heavy trim of the ship (z_achter > 0 and z_voor < 0). This can be explained as we move into second quadrant (positive speed, negative rpm).

Take-away message

Knowledge on crabbing tests needs to be extended at FH.

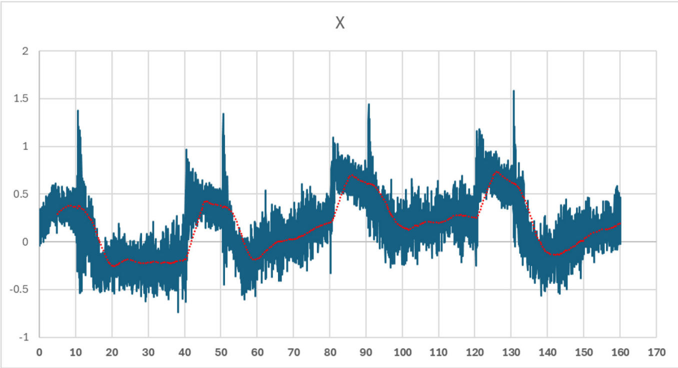


Figure 4-1 : H4002A01_AS1600 time series X_achter + X_voor [N] ;
red line = running average over 200 points.

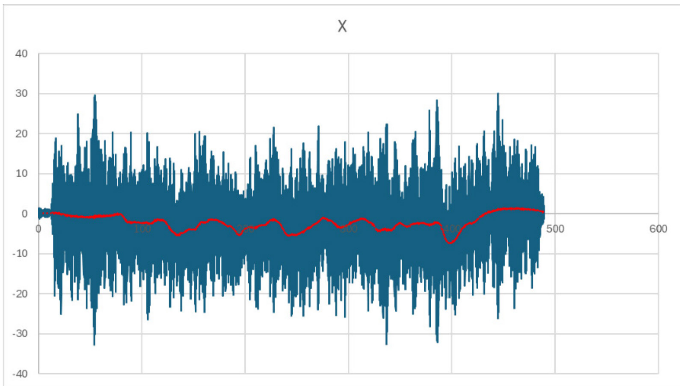


Figure 4-2 : H4002A01_CB08 XLS plot of X = X_voor + X_achter [N] in function of time [s];
red line = running average over 200 points.

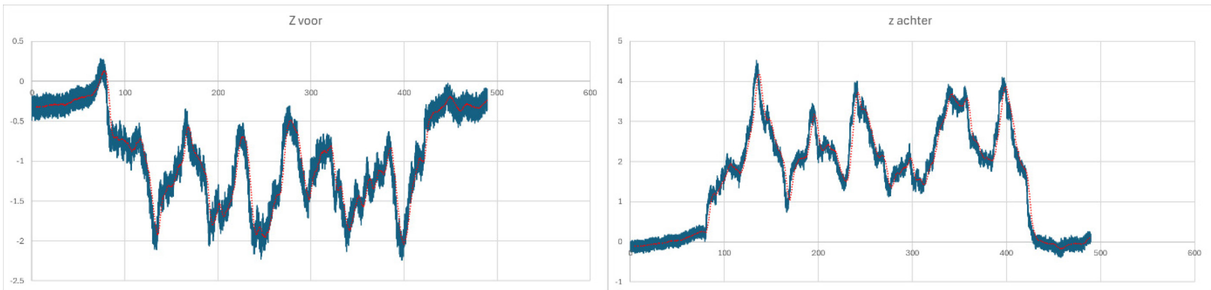


Figure 4-3 : H4002A01_CB08 XLS plot of z_voor (z_voor_BB + z_voor_SB)/2 and z_achter (z_achter_BB + z_achter_SB)/2 [mm] in function of time [s]; red line = running average over 200 points.

4.9 Acal values n schroef 1 and n schroef 2

After completion of H4002A01 – first appended test series – it was seen that the measured rpm always seemed slightly higher than the steered rpm. When looking at Acal in I/O file, it was seen that the Acal for n schroef 1 and n schroef 2 were the same for ANIN and ANUIT. The calibration file (see WLSOW database, SHP file H4001020101) showed different values. The differences are < 1%, still they are corrected before starting the tests for H4002A02. The measured rpm values will thus be between 0% and 1% lower from this point onwards with respect to what would have been measured before.

Table 4-2 : ANIN and ANUIT values before and after adjustment ; adjustment made after the completion of H4002A01.

	ANIN 'before'	ANIN 'after'	ANUIT 'before'	ANUIT 'after'
n schroef 1	100.32	99.33	100.32	100.32
n schroef 2	100.09	99.73	100.09	100.09

Take-away message

If H4002A01 would be analysed in the future – not likely as it was dismissed for rudder issue – the steered rpm (ANUIT) should be taken as basis for the analysis. I/O settings should be double checked - four eyes.

4.10 Initial deviation of rudder 2 (Port side)

On 15/07/2024 it was found that the rudder 2 (portside) had a deviation of 4° (when measurement indicates zero the real angle was + 4° in relation with the rudder axis (meaning 8 ° in relation with the centre line))

This offset occurred from the beginning of the fully appended tests (H4002A01 and H4002A02). A check of the IJKK files for H4002A02 confirmed that the rudder did not move off the neutral position during the tests (based on rudder angle measurement and force measurement) :

W:\sleept\vanwagen\23_074_H40\H4002A02\@tryout\3_IJKK\KRT

Actions:

- The rudder 2 (port side) was aligned to the correct position (measuring zero when angle is 4 deg in relation with the centre line)
- The rudder 1 (starboard) amplifier was replaced to avoid the drifting issue (Acal and Bcal were adapted), see section 4.7.

Some tests were repeated (H4002A1) to evaluate the impact on the test measurements of these actions. These differences are reported here to take further actions if necessary (to be discussed). It was decided to continue with initial the planning.

These actions were done at the beginning of the series H4003A01 (change of load condition to T=0.2m). The figures in appendix 1 show the range of differences of the rudder 2 (port-side) before and after the adaptation (blue and orange lines, respectively). A quick observation show that the maximum differences are in the order of 0.3 N specially in the X-direction.

On 2024/08/01 FH team sat together and decided that the asymmetry introduced by the portside rudder misalignment could have a major impact on the quality of the mathematical model. Therefore, it was decided to redo all tests for environments H4002A01 and H4002A02. As the ship was already at the second loading condition, the ballast needed to be changed and the calibration of the hull forces was performed again. A new SHP file, H4004010101 and ENV files H4006A01 and H4006A02 were made, copying the test matrices from H4002A01 and H4002A02 respectively. A note was added to the respective "opwagen" and "vanwagen" folders of H4002A01 and H4002A02 to warn users that the test series have been superseded. The data however is not removed.

Take-away message

If inclined axes for rudder are used, a method needs to be defined prior to the tests to verify the rudder position during the tests. A (traditional) visual observation (with mirror) is not sufficient to determine straight position (you cannot detect 4° angle).

4.11 FH manoeuvring test matrix

The test matrix was built based on the previous program executed with the model T01 (one rudder, one propeller). The Excel file containing the information to construct the test program can be found in:

P:\23_074-WetschapOnderzOostende\3_Uitvoering\FH_standard_matrix\proevenprogramma_H40_H4007A02.xlsx

During the campaign, two attempts to execute the complete FH program were done:

- H4005A02. It was interrupted to perform a repetition of previous tests due to a problem in the model rudder angle.
- H4007A02. It was almost completely executed (approx. 15 tests left) due to the preparations for the next required load condition. The analysis of the obtained results and the post-processing will be presented in a separate report.

Take-away message

Next time a ship with two propellers should be used as basis to derive such matrix (propeller interaction)

4.12 Post-processing of bare hull using Zeeman

As can be read in email 2024/08/20, the bare hull test series H4001A01/A02 could not be post-processed from DOC -> RES -> DPT , only from DOC -> KRT -> DPT. The first option delivers a cleaner and more workable DPT for the purpose of the further analysis of the towing tank tests. This issue is further addressed in WL2024M23_074_5 and WL2024R16_100_2_improve_suggestions_2024.docx

Take-away message

The bare hull test DPT generation from RES – which is desired here - gives an error code. The DPT via RKT generation is possible, however less desirable.

4.13 Freeboard analysis at high speeds and large draft

For condition H4004A01, test H4004A01_CO01 (1.091 m/s) was executed successfully with sinkage measurement of around 25 mm at the bow – mechanical sinkage limits at 50 mm. The faster test H4004A01_CQ01 (1.237 m/s) showed sinkage around 40 mm, which is below the mechanical sinkage limit. However, due to the presence of the bow wave, water at bow came close to the top of the bow section. Visible observation : around 20 to 30 mm below top of bow section. Too close for comfort as water overtopping at this speed could cause major flooding of the hull.

Take-away message

Tests at high speed, large draft, large water depth, should only be executed with higher bow section to avoid overtopping of water and flooding of the hull. By all means : do not forget about the bow wave when determining max. speed.

4.14 Analysis PMMPSI2 with drift

Part of the test matrix involves performing PMMPSI tests with on top of the harmonic motion in yaw a drift angle. This causes large drift and corresponding lateral forces, yaw moments and roll moments. Due to the roll moment magnitude, the ship (and measurement structure) shows some deformation, which leads to a difference in sinkage measurement portside and starboard side. This should only occur during these drift / yaw tests and should disappear when other (straight) tests are performed. Figure 4-4 shows the test at largest draft at 100% UKC which causes the largest forces and resulting discrepancy between PS and SB sinkage.

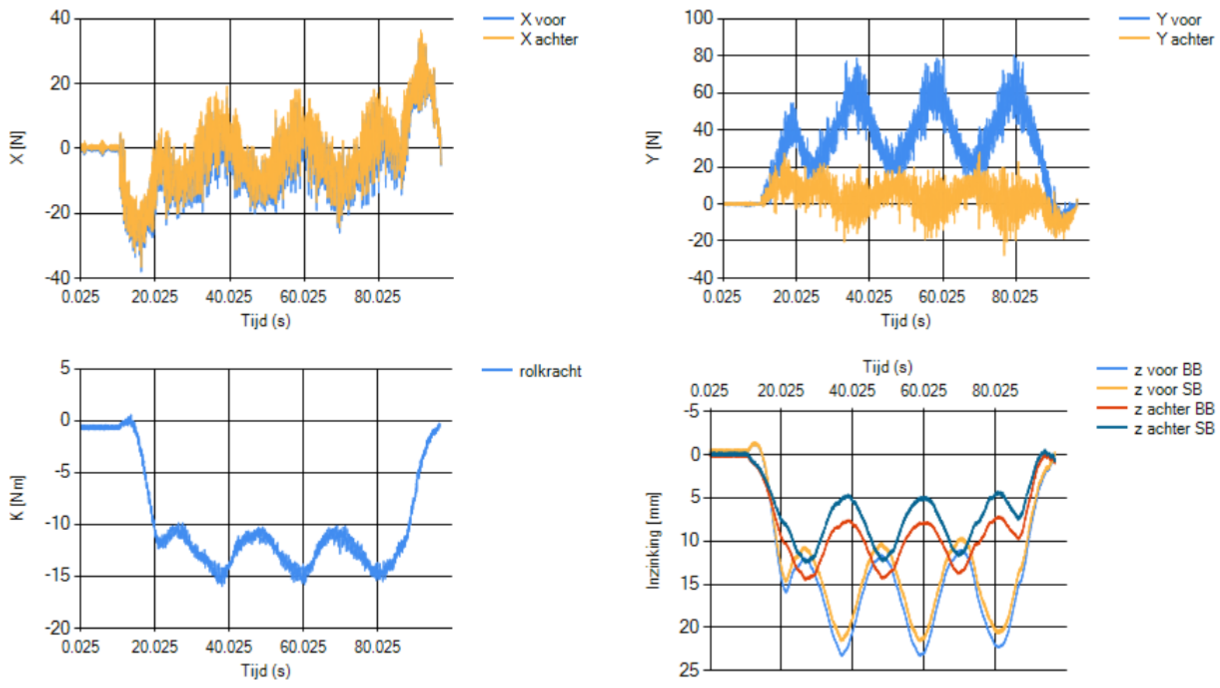


Figure 4-4 : Analysis DOC file test H4004A01_GJ0500

Take-away message

When drift angles are large and/or significant harmonic yaw moments are defined, it is possible that the system ship – measurement beam – shows some !elastic! deformation which causes differences between SB and PS sinkage measurement, despite fixed roll gauge. Should dissapear for next test (elastic deformation)

4.15 SLOW test acceleration variation

It was decided to use some weekend batch time of H4004A02 to investigate the sensitivity of smaller acceleration times for the SLOW tests (H4004A02_MS**). Larger acceleration times were also defined, but this caused non-validated tests (psi rotation outside of limits psi axis during acceleration and deceleration). The test series H4004A02_M1** and H4004A02_M2** were defined, which are copies of H4004A02_MS**, but with acceleration and deceleration times of 10 s and 15 s respectively. The tests have also been added to the test planning excel test_planning.

Take-away message

The SLOW tests have been extended for H4004A02 with smaller acceleration times. Data is available.

5 Summary test matrix

The test campaign for the ship H40 – scale model 1:50 of Charles Darwin has ran from June to August 2024 as part of the 23_074 project at the Towing Tank Antwerp of Flanders Hydraulics. A summary of the campaign can be found in Table 5-1 and Table 5-2, details can be found in the TestPlanning.xlsx excel sheet.

Table 5-1 : Test summary H40 test campaign part of project 23_074 (June 2024 – August 2024) : part I

ENV	HULL	SHIP file	Start date	End date	h [m]	T_A [m]***	T_M[m]	T_F [m]
H4001A01	Bare	H4001010101	5/06/2024	11/06/2024	0.290	0.160	0.146	0.131
H4001A02	Bare	H4001010101	12/06/2024	17/06/2024	0.192	0.160	0.146	0.131
H4002A01**	App	H4001020101	27/06/2024	3/07/2024	0.290	0.160	0.145	0.130
H4002A02**	App	H4001020101	4/07/2024	12/07/2024	0.192	0.160	0.145	0.130
H4003A01	App	H4002010101	16/07/2024	22/07/2024	0.400	0.200	0.200	0.200
H4003A02	App	H4002010101	23/07/2024	28/07/2024	0.240	0.200	0.200	0.200
H4004A01	Bare	H4002020101	22/08/2024	26/08/2024	0.240	0.200	0.200	0.200
H4004A01	Bare	H4002020101	26/08/2024	30/08/2024	0.240	0.200	0.200	0.200
H4005A02*	App	H4003010101	29/07/2024	1/08/2024	0.240	0.200	0.200	0.200
H4006A01	App	H4004010101	2/08/2024	7/08/2024	0.290	0.160	0.145	0.130
H4006A02	App	H4004010101	07/08/224	12/08/2024	0.192	0.160	0.145	0.130
H4007A02	App	H4005010101	13/08/2024	20/08/2024	0.192	0.160	0.145	0.130

** extra test matrix H4005A02 'FH manoeuvring program', needed to be aborted due to time restrictions. H4007A02 was executed later.*

*** H4002A01 and H4002A02 were performed with rudder 2 angle offset. Superseded by test series H4006A01 and H4006A02 with correct rudder positions.*

**** realised draft as measured in the towing tank, with allowed deviation of ± 1 mm with respect to target draft.*

Table 5-2 : Test summary H40 test campaign part of project 23_074 (June 2024 – August 2024) : part II : details on tests for VTT : number of tests for each test type

ENV	SHIP file	STATX	PMMY	OSC	PMMPSI	MULTI	Zeeman folder*
H4001A01	H4001010101	28**	8	8	39	15	V:\1716781
H4001A02	H4001010101	26	9	8	24	15	V:\1717745
H4002A01	H4001020101						
H4002A02	H4001020101						
H4003A01	H4002010101	54			48	54	V:\1719120
H4003A02	H4002010101	48			37	48	V:\1719826
H4004A01	H4002020101	33	16	8	48	15	V:\1722258
H4004A02	H4002020101	30	10	8	35	42	V:\1722418
H4005A02*	H4003010101						V:\1720032
H4006A01	H4004010101	54			48	54	V:\1720526
H4006A02	H4004010101	54			43	46	V:\1720700
H4007A02	H4005010101	98	7	1	49	81	V:\1721681

** When post-processing tests in Zeeman, they are stored in a database which works in the background. Only limited people will have access to this location upon request to FH IT division. Via the Zeeman interface, the data can be accessed and the user is allowed to download the data to a local drive on a VO-computer.*

*** repetition are not counted*

Blacked out cells means that this test type was not part of the test matrix

Greyed out cells means that the data should not be considered for further analysis.

Appendix 1 background figures rudder issue

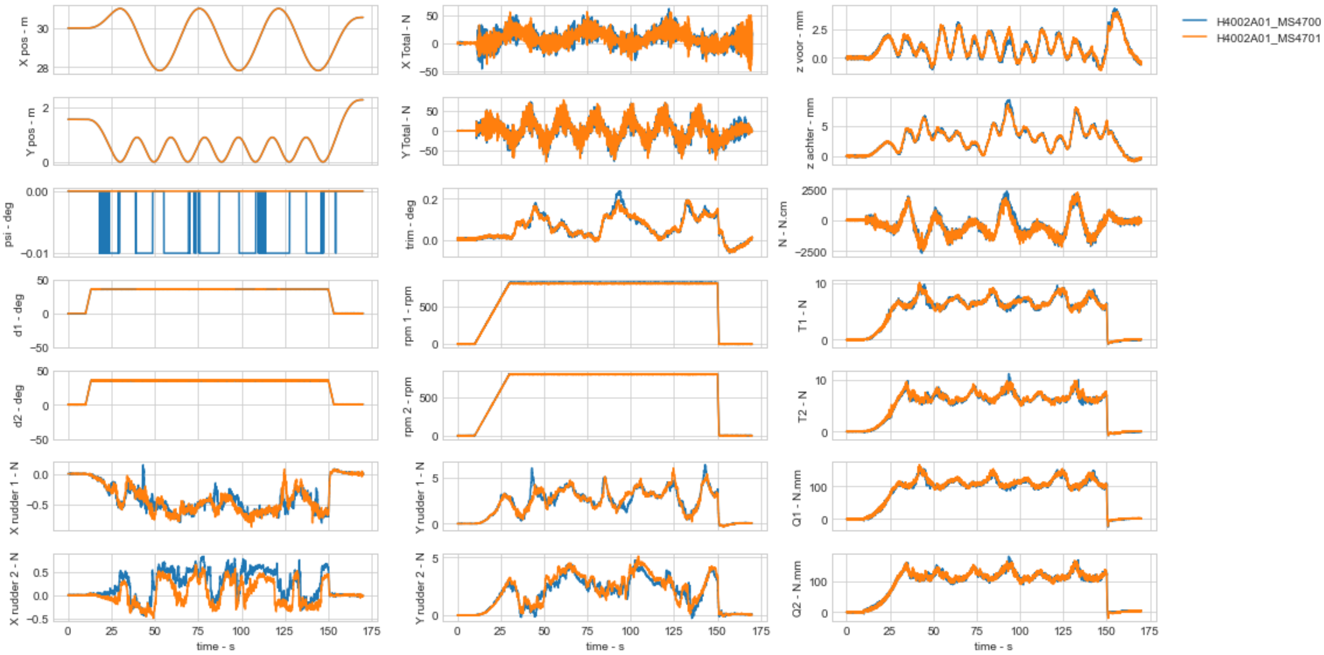


Figure 0-1 : Measured signals during test H4002A01_MS47; 00 (blue line) before the adaptation ; 01 (orange line) after adaptation

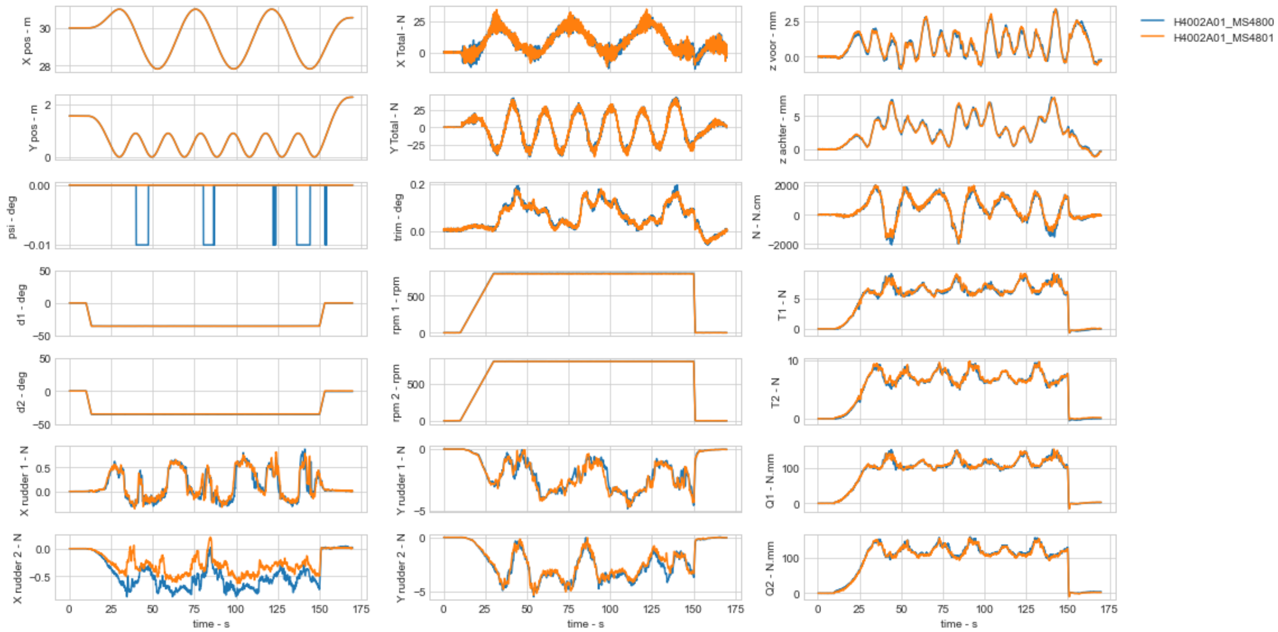


Figure 0-2 : Measured signals during test H4002A01_MS48; 00 (blue line) before the adaptation ; 01 (orange line) after adaptation

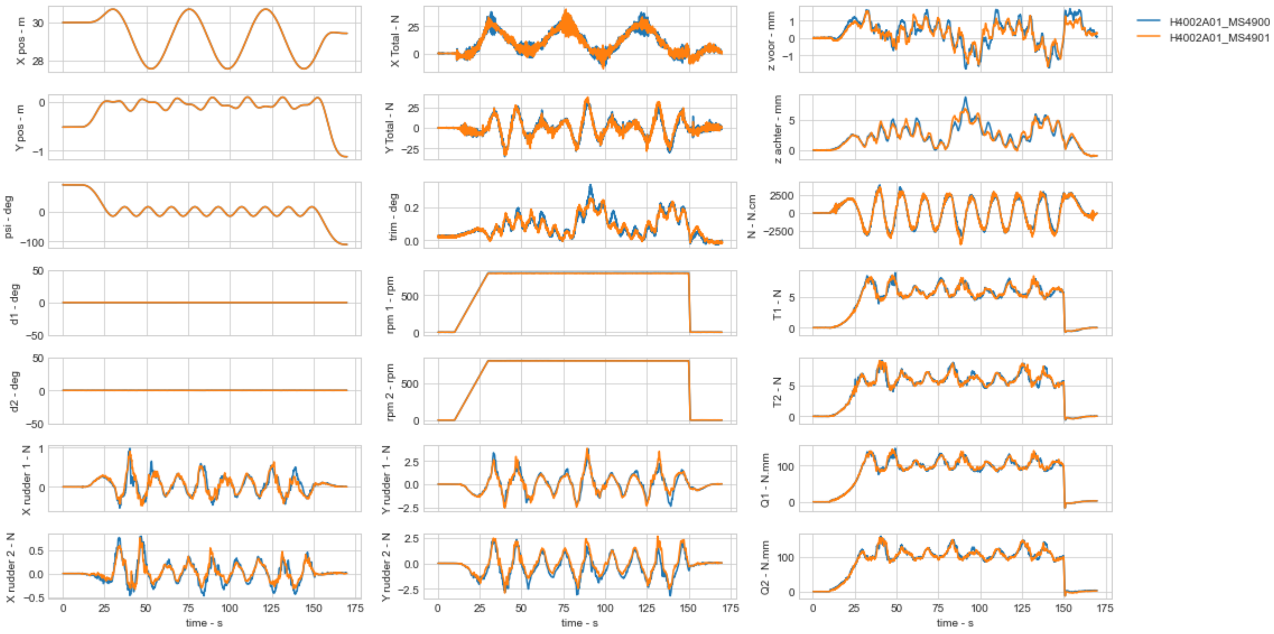


Figure 0-3 : Measured signals during test H4002A01_MS49; 00 (blue line) before the adaptation ; 01 (orange line) after adaptation

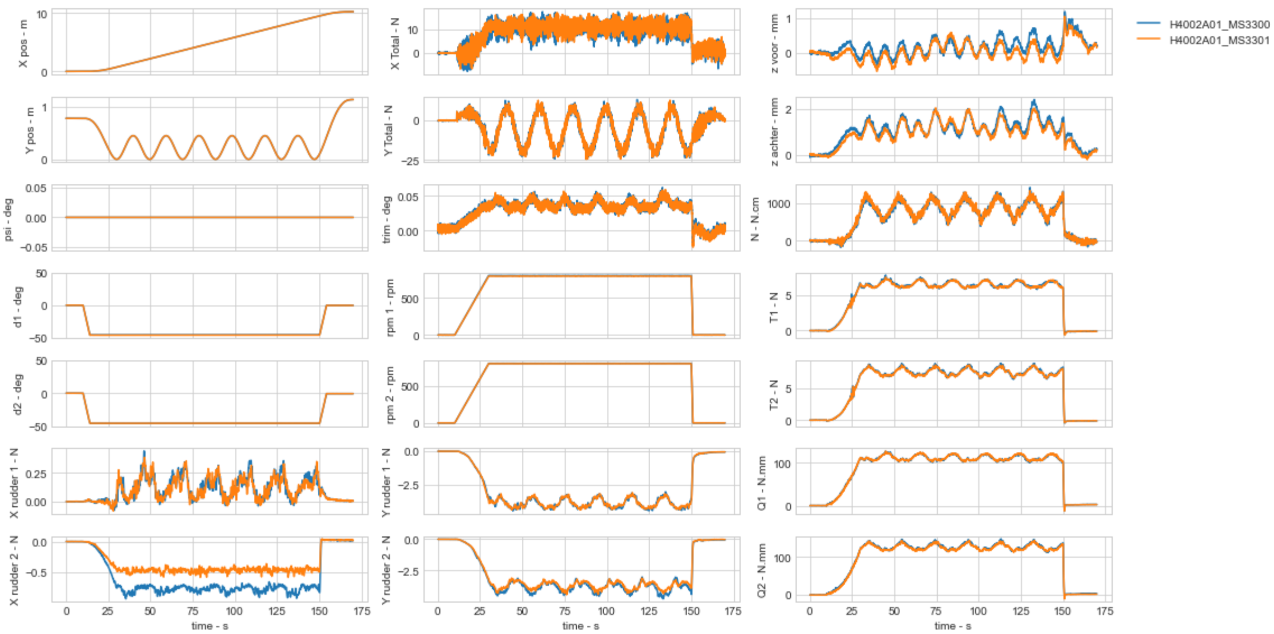


Figure 0-4 : Measured signals during test H4002A01_MS33; 00 (blue line) before the adaptation ; 01 (orange line) atfer adaptation

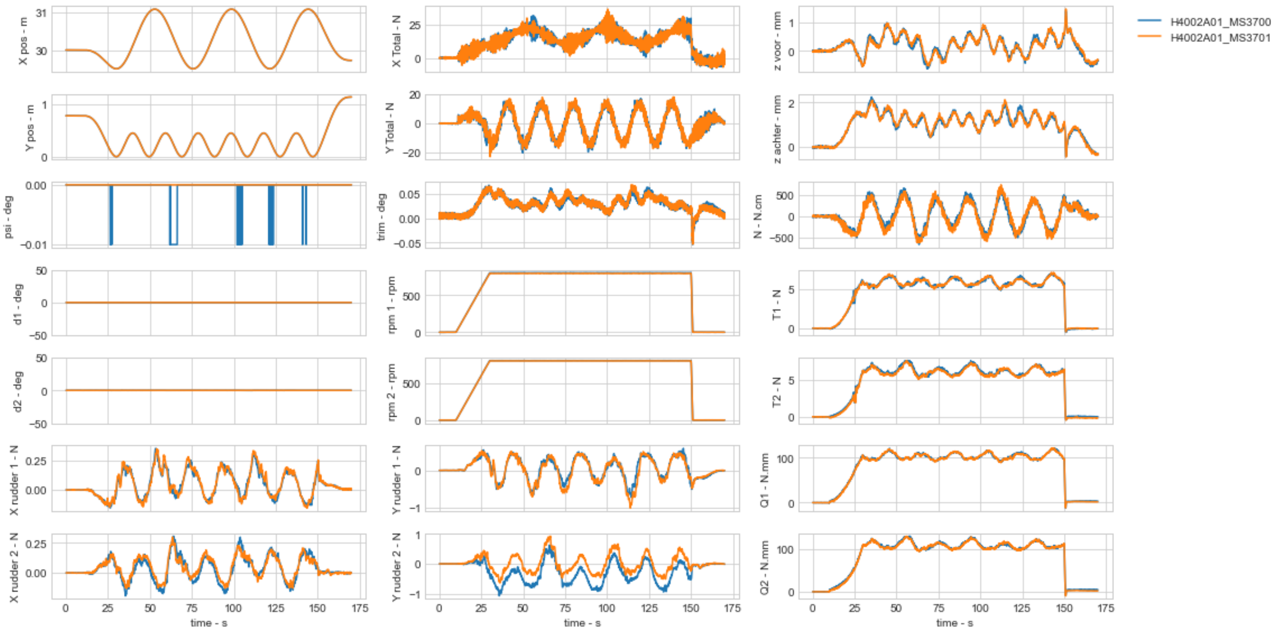


Figure 0-5 : Measured signals during test H4002A01_MS37; 00 (blue line) before the adaptation ; 01 (orange line) after adaptation

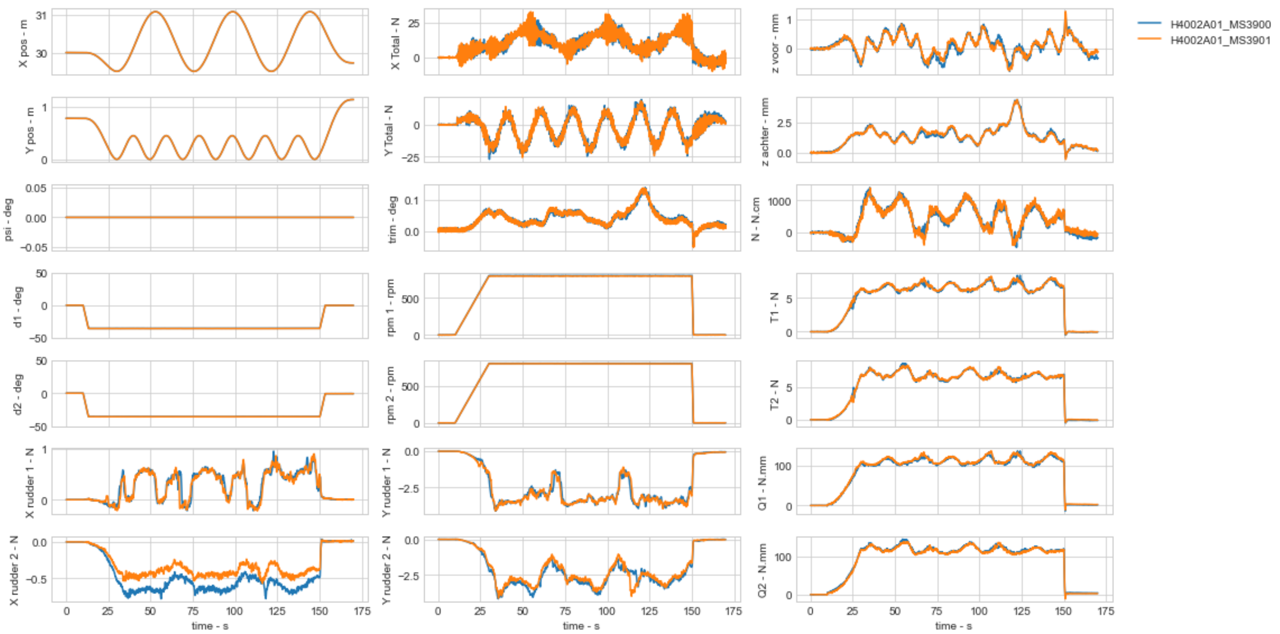


Figure 0-6 : Measured signals during test H4002A01_MS39; 00 (blue line) before the adaptation ; 01 (orange line) after adaptation

DEPARTMENT **MOBILITY & PUBLIC WORKS**
Flanders hydraulics

Berchemlei 115, 2140 Antwerp
T +32 (0)3 224 60 35
F +32 (0)3 224 60 36
flanders.hydraulics@vlaanderen.be
www.flandershydraulics.be