Concept design of an installation vessel to install fully assembled next generation offshore wind energy turbines

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Master of Science Thesis

TU Delft Delft University of Technology

Seaway Heavy Lifting Engineering B.V.

Challenge the future

Concept design of an installation vessel to install fully assembled next generation offshore wind energy turbines

Master of Science Thesis

For the degree of Master of Science in Offshore and Dredging Engineering at Delft University of Technology

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"Natural selection is not the wind which propels the vessel, but the rudder which, by friction, now on this side and now on that, shapes the course."
— Asa Gray

The magnificence with which these mechanical beasts tame the wild oceans is what drove me to be part of this study. Ship building being the oldest form of art, has evolved from being merely wood carved elegance to the majestic engineering entity that it is today. Here is my small attempt to be part of this journey and to contribute to the campaign of carbon footprint reduction. The idea of pursuing such a topic was basically sparked off in class where the immense problems associated with the installation of wind turbines and their working was discussed. After a successful meeting with Jan-Peter Breedeveld, Engineering Director at Seaway Heavy Lifting, I was convinced I was going to design a ship.

I would like to first of all show my appreciation and thank my Delft University of Technology thesis committee comprising prof.dr. R.H.M.Huijsmans, dr. ir. Lex Keuning and ir. Klaas Visser for their continuous support and guidance throughout the thesis period. Their timely advice was important for the completion of the thesis.

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To conclude I would say thanks to all my friends for being there, for their timely advice and help. Without all the morale boosting and fun this could have been a harder task.

Delft University of Technology, Rishab Krishnakanth
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Executive Summary

This study is aimed at improving the efficiency and safety of wind turbine generator (WTG) installation in the North Sea region. For this the wind energy scenario in Europe is studied with emphasis on the installation market, the commonly used procedures and techniques and the different vessels used. The different configurations possible during installation of wind turbines are also studied. Apart from this the transportation methods used to carry the wind turbine and its different parts to the site of installation are looked at. The idea of the study is to optimize both these processes and reduce the time consumed by them. In this way one can reduce the costs incurred by these two processes. Finally in the later stages as the study progresses the best possible methods and solutions are presented, which will help to reduce the number of vessels used during these phases and in turn reducing the costs involved. Also this will improve the general outlook of the offshore wind industry, which presently is seen as a very costly affair by investors. This is because of the huge costs which are mostly incurred by the delays in installation and the large number of technical and other issues associated with installation and transportation.
The end result of the thesis is to be able to either propose a complete new design for a wind turbine installation vessel (WTIV) or a solution based on optimized configurations for carrying and installing wind turbines using the present crane vessels in the market.

The first part of the report will be about:

- The basis and necessity of such a study, the growing demands of energy as such.
- The inclination of the EU (European Union) and the governments involved to produce clean energy.
- What is the current market scenario with respect to the wind turbine producers and what does the future hold for this market.

The next part will show the common problems which are prevalent in the existing solutions for installation and transportation, the technical and the non-technical issues which cause loss of both money and time to the contractors and finally to the clients. This part also discusses the general practices, technology, procedures and different configurations which are currently used with their advantages and disadvantages.

The subsequent parts of the report will establish the goals for the new vessel to be designed, the specific problems SHL wants to counter, basic details of the vessel and also alternative possibilities for optimizing the transportation and installation processes as such, reducing the time involved and also improve the workability of vessels and operability in sometimes harsh North Sea conditions.

The next chapters discuss the boundary conditions and the testing criteria, which the vessel has to be subjected to in order to achieve the said workable condition. While applying these boundary conditions the most important ones are prioritized and the vessel's parameters (main dimensions) are tuned to satisfy these criteria. The pre-selection of hull shapes is based on existing vessels and research conducted previously on these hull shapes.

From a multi-criteria analysis the SWATH (small water plane area twin hull) appears to be the most promising hull shape and is therefore selected for further analysis. Because Seaway Heavy Lifting has more than two decades experience with mono hull heavy lift vessels, a dual draft mono hull vessel dedicated for WTG installation is also analysed for reference.

Once the rough hull shapes are designed the power requirements and still water resistance have been estimated and the sensitivity of all these parameters is presented to understand which of the parameters would cause unfavourable results.

Once the ship and its important dimensions are established the new WTIV is subjected to a frequency domain analysis. The hull shapes are modelled in solid works and imported into AQWA- ANSYS and the relevant RAO's for the vessels have been generated for different loading conditions and arrangements of the WTG's on deck. The workability is analysed at different working conditions during installation and transportation. The location and the weather data is chosen appropriately based on scenario analysis and speed consideration of the vessel.

Furthermore a sensitivity analysis is done on the main dimensions to check which ones affect the operability of the selected hull shapes. The initial stability estimates are verified with the help of recognized stability software. Different speed scenarios are evaluated for a given location to check the dependence on vessel speed, resistance and power requirements which could limit the workability. Based on the derived dimensions the two selected hull shapes are subjected to multi-body frequency domain motion analysis using a recognized hydrodynamics program. Subsequently the workability of both vessels is investigated using very detailed 2D wave spectral data available for an important North Sea wind farm development area.

The results of this thesis are the first steps towards establishing the SWATH hull shape as a viable option for operating as a WTG installation vessel. In certain important operational conditions the motion behaviour of the SWATH is better than that of a dual draft mono hull vessel. There are some significant advantages which the SWATH exhibits over the mono hull and other hull forms which can be utilised for the purpose of WTG installation in order to avoid complex installation systems and techniques to get safe and fast operation.

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SYMBOLS

GW	Giga watt
TWh	Terawatt hour
$	United States dollar
Km	Kilometres
m	Metres
GM	Metacentric Height
GZ	Righting lever arm
KB	Distance between Keel and centre of buoyancy
BM	Distance between Centre of buoyancy to the metacentre
KG	Distance between Keel and centre of Gravity
L	Length of the ship
B	Breadth of the ship
D	Draft of the ship
m/s	Speed in Metre per second
m/s^2	Acceleration in Metre per second square
MT	Metric Tonnes
Hr	Hours - time
Θ	Theta angle in degrees
^{o}	Degrees
∇	Displacement
I	Area Moment of Inertia
i	Area moment of inertia for free surface correction
w	displacement of ship in tonnes
ρ	Density of sea water in Kilograms per metre cubed
n	Number of longitudinal beams in a tank
T1	draft at lower pontoon level
T2	draft at strut level
T3	draft at upper pontoon
RL1	Net righting lever(GZ) curve for the condition before the loss of crane load
RL2	Net righting lever(GZ) curve for the condition after the loss of crane load
ΘF	down flooding angle
ΘL	static angle before the loss of crane load
Θe	static angle After the loss of crane load
Φ	Angle of trim
P	load in the crane
Y_d	crane radius
C_t	Total resistance coefficient
V	ship speed in m/s
S	wetted surface area
KN	Kilo Newton's
MW	Mega Watt
W_t	wind force

ρ_{air}	Density of air
V_{rw}	relative velocity of the ship with respect to wind speed
C_w	coefficient of wind resistance
A	area used for wind resistance calculation
Rpm	rotation per minute
KNm	Kilo Newton metre
Knots	speed in nautical miles per Hr
Hs	Significant wave height in metres
Tp	Time period
K	Radius of Gyration

Abbreviations

EWEA	European Wind Energy Association
EU	European Union
WTG	Wind Turbine Generator
NREAPs	National renewable energy action plans
WTIV	Wind turbine Installation Vessel
T&I	Transportation & Installation
EPCI	Engineering Procurement Construction and Installation
SHL	Seaway Heavy Lifting
SWATH	Small Water plane Area Twin Hull
CAT's	Catamaran's
HLV	Heavy Lift Vessel
AHC	Active Heave Compensation
PHC	Passive Heave Compensation
CAPEX	Capital Expenditure
OPEX	Operational Expenditure
SOLAS	Safety of life at sea
RAO's	Response amplitude operators
IMO	International Maritime Organization
SEMI	Semi-submersible vessel
3D	3 Dimensions
PA	Parametric Analysis
SS	Shipshape
COG	Centre of gravity
FSE	free surface effect

Chapter 1

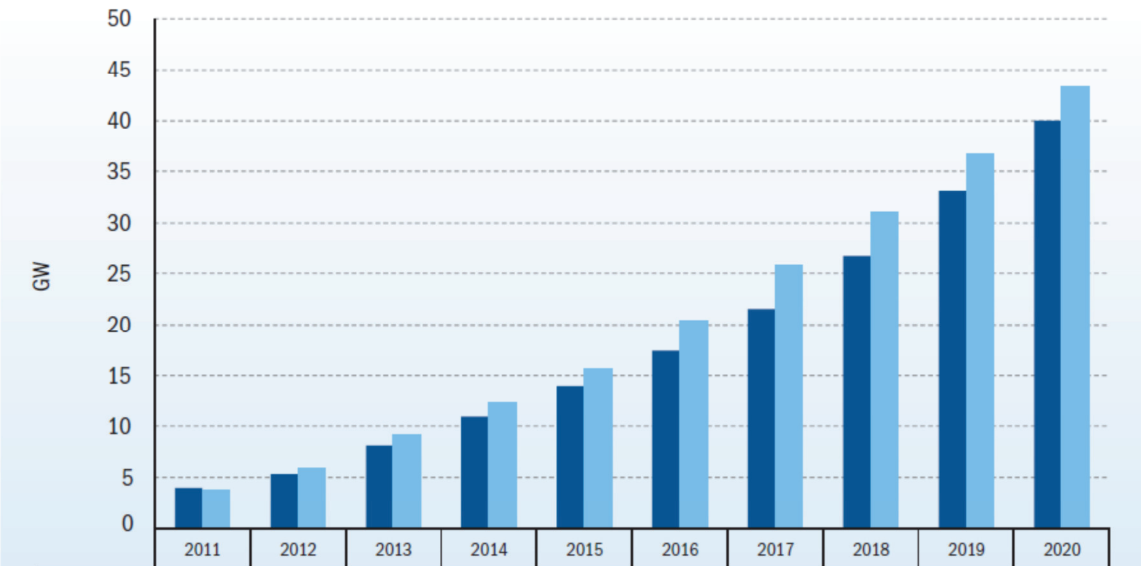
Introduction

1-1 Wind energy for the future

Wind energy seems to have become the answer to the ever increasing energy demand of the world. One of the main reasons for this is its clean nature, in the sense that there seems to be little or no pollution. Since people are now reluctant to have wind farms on land and also the amount of land available for such installations reducing gradually, the focus has shifted towards developing offshore wind farms. The EWEA is the organisation which keeps tabs on all the developments and also chalks out the future plan of action for the EU nations with respect to this industry. There are annual meetings to review and track the plans which have been chalked out by this organisation when it comes to wind energy. Some salient features from their recent report in 2012 are as follows:

- It (EWEA) estimates that by 2020, the offshore wind installations will produce 40 GW of the energy demand of the European region which is approximately 148 TWh, 4% of the total energy required by the European region.
- The EWEA believes that this capacity has to be tripled to 110 GW by 2030.
- It is also projected to generate about 40% of the total jobs which will come up in the energy sector in the above said period.
- The annual expected investment between the periods of 2011 to 2020 is 10.4 billion euros and this could increase to about 17 billion euros between the period 2020-2030.[1]

The industry is projected to have a cumulative investment of about 150 billion euro by 2030. The foreseen growth of the sector will push offshore wind power to the forefront of the EU's climate and energy strategy. (NREAPs- National Renewable Energy Action plans)



	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
EWEA	3.9	5.3	8.1	10.9	14.0	17.4	21.6	26.7	33.1	40.0
NREAPs	3.7	5.8	9.1	12.4	15.6	20.4	25.8	31.1	36.8	43.3

FIGURE 1-1: THE PROJECTED CUMULATIVE OFFSHORE WIND CAPACITY. SOURCE: EWEA [1]

1-2 Wind energy

It is a form of energy which is harnessed from the wind through devices called wind turbine generators. Man's need for energy is growing continuously and the conventional forms of energy like coal, nuclear, oil and gas are continuously being depleted at a very high rate and moreover the pollution caused by these processes is a huge problem to the environment. With all the big countries like Germany, USA and UK consciously reducing the use of nuclear and coal power plants they have to come up with alternatives. Wind energy seems to be a viable alternative, even if it is not able to cater to the complete energy demand of the world. It could make some significant contributions to plug this deficit.

Wind energy involves the process of harnessing the kinetic energy which is present in the wind and utilizing it to generate either mechanical energy or electrical energy, which can be used for day to day energy requirements. With the backing of the governments the wind energy sector has started growing tremendously over the last few years. The improvement is also in terms of the construction, materials used and new age gearboxes etc. have considerably contributed in increasing the efficiency of these devices and also improved the output energy which can be effectively harnessed from them. The improvement of technology has also facilitated the growth in the size and capacity of the wind turbines, and also facilitated the use of these devices offshore which could be advantageous in reducing the use of land considerably [1].

1-3 Wind farm development cycle and methodology

The development of a wind farm is a very elaborate process. Without getting into much details of the pre-bid stage let us have an overview of the post bid processes involved in a project.

- The main component of course is the WTG (wind turbine generator), produced by many companies like Areva, Vestas and Siemens, to name a few. Most of these companies have developed offshore compatible WTG's in the range between 3 MW to 6 MW. The next generation will be bigger and taller, having ratings between 7-10 MW. Some prototypes are already successful and some have started full scale production.
- Fabrication, transportation and installation of foundations, which come in different types and change from project to project (Gravity based jacket, mono-pile etc.) depending on the soil conditions at the location.
- Transportation and installation of the WTG's themselves. The procedure and the configurations of how they are carried and installed are very project specific. It also depends on the size and make of the WTG, site conditions, workability criteria etc. The dependencies will be elaborated on in the next chapters.
- Fabrication, transportation and installation of the substation.
- Subsea cabling within the farms and from the farms to the onshore location, following which the commissioning and grid connections will take place[1][2].

If one looks at the procedures involved carefully, a large chunk of the work takes place offshore where the workability is dictated by the weather conditions. All the steps involve transportation of parts to offshore and installation of these parts, which accounts for a large part of the whole cost of the project. This happens because of the scarcity of vessels which are available for such operations and the weather related downtimes.

As a result of the makeup of the project the number of vessels used for such a project is high. The vessels used are as follows:

- Site Survey vessels and sometimes site development vessels if the sea bed is uneven
- *Transportation vessels*: small and big based on which components they are carrying. They vary from flat top barges to complicated heavy transportation vessels.
- *Installations vessels:* two types are mainly required

- *Heavy lift vessels:* for installation of foundations and substations etc.
- Installation Vessels for lifting & installing the WTG's. Currently, apart from a few heavy lift vessels, many jack up's are being used for this operation.

- Cable installation vessels.
- Other support vessels like supply vessels.

The highlighted vessels are the ones involved with the most critical phases of the project when it comes to planning and costs. These phases and vessels involved are also known historically to cause heavy losses in projects. In the next few sections the discussions will be based only on these vessels and their functionality. The idea is to optimize these two processes, because by doing so one could avoid huge delays and losses. As it has been seen consistently in many projects, the availability of vessels and workability is a major issue. Also with the whole process of installation not optimized, it is a time consuming and risky endeavour [5][3].

FIGURE 1-2: OFFSHORE WIND FARM. SOURCE: EVWIND.ES

FIGURE 1-3: TRANSITION PIECES AND WTG BLADES BEING TRANSPORTED TO SITE. SOURCE: CENTRAL INDUSTRY GROUP

1-4 Need to optimize installation procedure

A few examples of projects which have incurred losses due to delays in installation and transport activities.

- Rodsand 2: 90 turbine project went into loss, as weather reduced the workability. The required installation window was eventually twice than what was predicted by the project team.
- Denmark's Horn's Rev 2 – world's largest wind farm project, 2 months delay due to weather issues and installation delays.
- The London array the company involved went bankrupt due to delays and weather window problems.
- Alpha Ventus – one year delay and costs increased from 270 to 357 Million $ because of installation and weather delays.[3]

This illustrates that installation and transportation can be considered as the most time consuming and risky events in the wind farm development. They are always on the critical path in a project management cycle and can make or break the profits. Moreover, it is also a precision job (e.g. installing blades) that requires an almost stable platform for the cranes to operate and to do it right. The tolerances are much smaller than with heavy lifts in the oil industry. This in turn causes issues with available weather windows etc. As a result there are always losses associated with this event if not properly planned and executed [3]. Let us look at why in the future it will be important to plug these loopholes:

- The availability of shallow water areas for development of wind farms is becoming scarce and therefore, the whole industry will have to look at moving to deeper water. This usually means harsher weather conditions will be encountered in the future, where the installation would become more difficult.
    - At present the WTG's are typically installed at a distance of 20 Km from shore and at 20-40 m water depth [1].
    - The future projects being planned are at a distance of 60 Km from shore and up to 60 m water depth (next 5 years as predicted by EWEA) [1].
    - And finally at a distance greater than 60 Km from shore and at more than 60 m water depth (next 15 years as predicted by EWEA) [1].
- Going to deeper waters away from the coast, especially in the North Sea, means encountering worse weather conditions. Therefore, getting a stable platform to do installations will be a major problem.
- The positioning system used makes that existing vessels will be limited by the water depth.
- The availability of enough vessels will always be a problem. Only in recent times there have been developmental plans and some vessels have been introduced for this specific function [1].
- The turbine itself will get bigger and heavier and occupy more space on the deck. (the new VESTAS 7 MW has a blade length of 80 m and the tower height of 135 m)[6].

These above mentioned general issues, together with some inherent problems which are prevalent in the installation vessel, will make the whole process risky and problematic for all future projects.[2]

Optimization has to take place at two levels

1. *By improving the process and devising new methods of installation. Having devices which will make the process efficient and fast, without safety issues.*

2. *By designing a completely new vessel which can carry and install WTG's fully assembled or in parts depending on the size. The vessel can be improved on major issues like stability and motion behaviour during deep water installation etc.*

Limitations of the vessels that are currently operating and the problems associated will be discussed in the later chapters.

1-5 Need to optimize transportation procedure

Transportation of the WTG parts have also become a problem, considering the increase in size of the WTG's. This will definitely cause issues considering the fact that the installation vessel will be on charter and any issue with transportation will directly cause delays in the installation. If the parts do not reach the sites on time the weather window may be lost as well. Hence it is imperative that we include this aspect also in our optimization plans of the process.

It would be really advantageous to look at improving these following aspects

- Speed of the vessels in transit.
- The ability to pick up the WTG parts from the manufacturers yard, transport it and then install in one go.
- Deck space-considering the parts are going to become bigger in the future.
- Improve on vessel stability and motion behaviour during transit
- Try to carry as many as possible on deck, either in a fully assembled configuration or in parts.
- Be able to carry different types of configurations and arrangements. Improve on deck capacity
- What is the maximum acceleration that the different parts of the WTG's can be subjected to during transportation.
- Can they be made less sensitive to these accelerations

From this one can see that the above mentioned issues and explanations for both the procedures of installation and transportation are very crucial and can make or break a wind farm project. The importance is shown in the above paragraphs. So it is a good thing if some research is done into the workings of these two processes and improvements suggested, with the future requirements in mind. This can go a long way in reducing the costs involved and also improving the outlook of the wind industry in general.

1-6 Seaway Heavy Lifting

Seaway Heavy Lifting is a leading offshore contractor in the global oil & gas and renewables industry, offering tailored T&I and EPCI solutions. The company services a diverse client portfolio including the major operators in the offshore Oil & Gas and offshore renewables industry. They operate globally focussing on the North Sea, Mediterranean, America's, Africa, India, Asia Pacific and Middle East. The company's goal is to strive to provide their clients with the most effective and added value solutions. This goal is supported by their highly skilled and motivated workforce, quality assets and the continuous focus on new technologies. The company utilizes their experience and proven solutions from both the offshore oil & gas and offshore renewables industry [4].

In 1991 the Norwegian subsea offshore company Stolt Nielsen Seaway and the Russian state oil company Kaliningrad Morneft, established a joint venture. Operations began with the crane vessel Stanislav Yudin. In 2011 a new build larger crane vessel Oleg Strashnov with 5000 Mt ton lifting capacity was delivered. Both vessels are owned by Seaway Heavy Lifting. Over the years they have grown steadily to become the global offshore contractor they are today. The current parent companies are Subsea 7 and K&S (a private investment fund). The ownership of both companies has been consistent and supportive of Seaway Heavy Lifting's growth strategy [4].

Now SHL owns and operates two heavy lift vessels 'Stanislav Yudin' and 'Oleg Strashnov'. The Stanislav Yudin has a heavy lift capability of 2500 MT and is positioned with a 8 point catenary mooring system while the Oleg Strashnov has and lifting capacity of 5000 MT and can be positioned with either its 8 point catenary mooring system or its DP 3 dynamic positioning system.

SHL has immense experience with installing wind turbine foundations for many wind farm projects. They have also explored options of installing completely assembled wind turbines in a single lift using the Oleg Strashnov. They want to play an important role in the future of this industry and believe that the wind farm projects will become the answer to the European energy demand because of the increased legislation towards making energy environmental friendly in the EU. Also the wind farms will become more financially viable if the transportation and installation is optimised and the costs involved with these functions reduced.

Being at the fore front of research and technology SHL would like to develop a Wind Turbine Installation Vessel (WTIV), which will cater to the wind farm industry specifically and address the issues currently faced by the industry with respect to installation. This way SHL wants to provide an optimal and viable solution to the industry based on the experience it has acquired over the past years. The following research thesis will be the basis for providing a solution to this problem.

1-7 Objectives of the thesis

The problem statement can be stated as follows

"Design of Wind Turbine Installation Vessel (WTIV), with improved motion characteristics to handle the North Sea weather conditions, with over 80% workability in the extended summer season (April-Aug) to perform its function, that provides safe, fast and precise installation of WTG's offshore, with an aim to reduce time required for the same and the costs involved."

The primary objectives of this research proposal are as follows:

- Design a vessel for the function stated above which involves transportation and installation of the next generation WTG's.
- The floating vessel has to have highly motionless platform both during transit and installation
- It is envisioned to try to achieve a workability of 80% in the extended summer season (April-Aug)
- The vessel should be able to carry the next generation wind turbines of 7-10 MW apart from the already existing models
- The vessel should be able to either carry it fully assembled or in parts, whichever is a more feasible option.
- The number of WTG's to be carried is to be decided based on the other requirements.
- The installation process has to be simplified so as to facilitate faster, quicker and safer installation. Single lift and installation of fully assembled WTG's to be considered.
- The speed of the vessel has to be improved, which will help it transit between the manufacturer ports and the field faster.
- Fast and motionless transportation which will improve fatigue life of WTG's.

Some of the concept vessels already in market are shown below.

FIGURE 1-4: WIND TURBINE INSTALLATION SHUTTLE. SOURCE: HUIJSMAN B.V.

FIGURE 1-5: WIND LIFTER CONCEPT. SOURCE: ULSTEIN

Chapter 2

Design Basis

2-1 Building blocks – mission profile

After the initial concept studies based on the immediate needs of the industry it was decided to continue working on the crane vessel aspect and the transportation would be optimised subsequently. Firstly the building blocks and the functional requirements of the crane vessel will be established based on a simple kite model. All the possible configurations are considered in the below mentioned table, so that one has the widest choice available. Then the options are eliminated based on the prioritization of functions and the performance of each of the ship shapes towards these functions. The whole process of design is based on the design spiral which is generally used for this purpose. But to have a more effective design, wherever possible, for this given situation some parts are also designed based on functional blocks to have a better sense of clarity during the process of reducing the options.

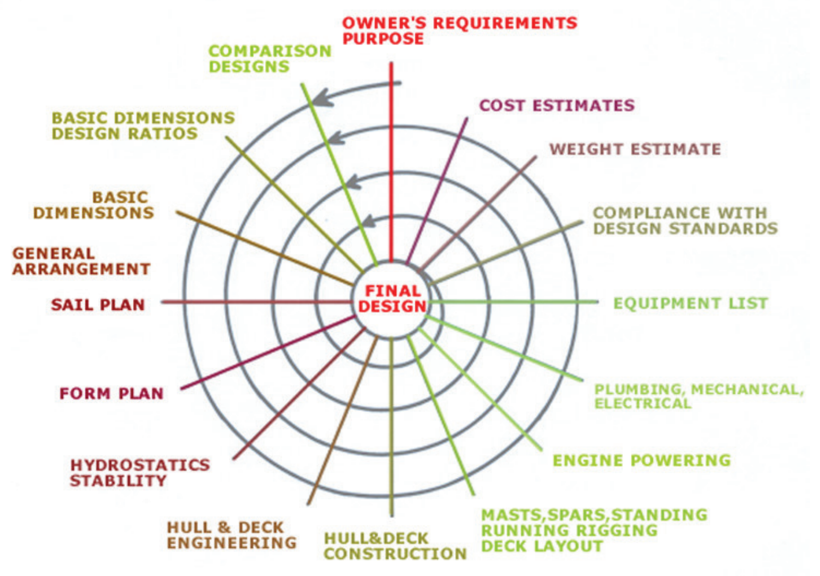


FIGURE 2-1: DESIGN SPIRAL FOR VESSELS SOURCE: ALFAMARINEDESIGN.

MISSION PROFILE AND FUNCTIONAL REQUIREMENTS OF THE CRANE VESSEL

It is important to define the mission profile as one can see in the design spiral. The mission profile basically has the following main criteria:

- The vessel should be able to transport at least 8 WTG's of the VESTAS 7 MW to the site of installation. A higher number of smaller WTG's can also be envisioned. They have to be transported fully assembled in the upright condition.
- The speed is of quite some importance and the motion behaviour has to be good during transit.
- Once at the location the vessel has to install these WTG's in the least possible time, with the help of the crane and systems defined in the single lift chapter.

- Finally once all the WTG’s have been installed it has to be back in less time to pick up the next set of turbines.

Based on the above definition of the mission profile some of the features which are important for the crane vessel are the following.

- Good motion behaviour in transit and in the installation phase with all the WTG’s in vertical position
- Stability during the installation operation
- Speed of transit has to be considerably good
- It has to be able to accommodate the required number of WTGs and the crane and provide ample access for the cranes activities. This dictates that the vessel has large deck spaces
- The possibility of having a stable platform during installation

  Apart from these main criteria some other relevant but secondary concerns are:
    - Fuel efficiency and cost of maintenance
    - Construction and design cost
    - Economic feasibility of operating such vessel

To name a few which have to be looked into later to assess the completeness of the design assignment. Based on the above mentioned criteria the main functional blocks which have to be addressed are as shown in Table 1.

The main functional blocks which are the most important at this stage of the project are looked into initially. To reduce the huge number of possibilities which arise from this analysis of building blocks, a multi criteria analysis based on data available from previous research and experiments conducted on these shapes over the years is used. Apart from this also the operational data from existing vessels is also used in the multi criteria analysis based on the building blocks and the functional requirements of the hull shapes. It is also good to study these parameters with the overall feasibility of actually having to match the lifting capabilities with the particular needs of the vessel, and also the carrying configuration.

The result of such an exercise is a reduced pool of options to choose from to go ahead with further design and analysis. The shapes chosen are still not the best but the idea is to use as many advantages as possible of the shape and leave out as many disadvantages with respect to this given mission profile. The reasoning behind the choices are explained in the APPENDIX II and in the following sections.

Hull Shapes / Vessel types	Lifting Mechanism	Transportation of Wind turbines	Carrying and lifting configurations
• Monohull crane vessel • Monohull dual draught • Catamaran • Catamaran with dual draught hulls • SWATH vessel o Single strut o Double strut • Semi- SWATH • SWATH with controllable fins • Semi-submersible • Flat barges • Cathedral hull	• Offshore lifting crane • Lifting tower single side • Lifting tower dual side • Lifting tower with offshore crane • Reel type tilt over board	• From port • Mid sea transfer from barge/supply vessel • Submersible type vessel	• Full turbine • Tower + bunny configuration(nacelle+ 2 blades)+1 blade • Tower + bunny configuration(nacelle+ 2 blades)+1 blade (install through winch) • Tower & nacelle(one piece)+blades separate

TABLE 1: FUNCTIONAL BLOCK FOR DEVELOPMENT OF CRANE VESSEL

2-2 Hull shape selection

The choice will be made based on some basic requirements which were defined earlier as the boundary conditions for the vessel design based on the mission requirements [7].

- Pay load – the number and configuration in which the WTG's will be carried
- Speed during transit, with and without payload
- Stability during the installation procedure
- Crane capacity and hook height
- Deck spacing and area available
- Ease of installation
- Cost and time for design
- Cost and time for construction and also the complexity of construction

These will be the main criteria under which the hulls mentioned below are assessed. They will be subjected to a multi-criteria analysis and the best possible alternatives are chosen for the further design. It is also taken care that some inherent problems of the hull be addressed in the new design by adding accessories or making design changes to the original shape e.g. *adding controllable fins in the SWATH which reduces the pitching moments of the swath considerably, adding a retractable heave plate to the semi-sub reduce considerable amount of heave and improves stability.*

The detailed comparative study of all the different hull shapes possible and their salient features with respect to motions, speed, stability etc. is done. In Appendix II all the features will be listed where in first the advantages and then the disadvantages will be discussed and following which the best shapes are picked for analysis in the next phase of the study. The detailed literature study is attached in the Appendix II, here the conclusions and the choices are presented.
The comparisons are purely based on motion responses and other parameters like design and construction or maintenance cost etc. are not considered. Some highlights are shown below

- In head seas the CAT's have the worst pitching motion, Monohull have better pitch motion behaviour and do not exhibit any peaks in the vicinity of the resonance frequencies[8]
- The major drawback with respect to the swath is the pitch resonance which is exhibited. But this can be reduced considerably as explained [8][9].
- This can also be reduced by altering its encounter frequency by making small changes in the speed and the heading [8].
- Vertical accelerations are lesser in the wider deck models and higher for the Monohull[10]
- During transit the Swath has the best motion behaviour compared to all the other shapes considered here [11].
- In order to reduce the ship motion it has been observed that the Swaths have to increase the speed and the Catamaran's and Monohull have to reduce the speed to have favourable motion behaviour again [8].

Although absolute motions of the vessels are important the relative motion also becomes important based on the mission profile.

Now it is important that based on these highlighted issues a choice is made considering all the requirements of the vessel. If we look critically at the available options it can be noticed that each vessel type has certain properties which are useful and some which make it incapable for the mission. But it is better to see how these problems can be handled and develop a vessel with the least issues and maximum benefits. Based on this argument the following can be said about all the shapes in conclusion.

SWATHs- even though it has features which match the mission profile the best, when compared to all other shapes some of the questions which need to be answered are:

- What are the effects of second order wave drift forces on the SWATH?
  This is something which has not been studied much. But considering the small water plane area the low frequency waves will not be much of a problem because the waves have a small water plane area to interact with. At this point not much can be discussed about this. Further detailed studies have to be done on them.
- Can a dynamic positioning system be used and will it be possible to weather vane in all directions while doing turbine installation?
  There are many SWATH vessels already working with DP 2 and functioning well, considering that the possible arrangement and location of the thruster is comparable to that of a Semi-Submersible. A careful design with due consideration to issues like thruster wash-hull interaction and thruster-thruster interaction, it is possible for a swath to work on DP and have heading and directional control.
- Will parametric pitch and diving be an issue?
  Active and passive fins have been used effectively to reduce these effects and it is seen that there is 23-33% reduction in pitching and bow diving, 5-10% reduction in heave motions and 12% reduction in vertical accelerations [11].
  A critical wave height can be established during design, beyond which slamming would become an issue. The higher this value the better for the ship performance and the ship can avoid working above this. It is possible to reduce these motions by using a bilge keel [8][9].
- Could the small water plane area be a problem and cause heel excursions during installation also during the shifting of weights on the deck?
  A solution would be to use a semi-SWATH which has a larger area at the waterline at higher draft. The other solution would be to ballast completely to a new working draft which is above the thin struts and has more stability for this purpose, as shown in the concept design.
- Will design and building be costly and complex?

The design and building will be complex, time consuming and costly. But if one looks at the overall economics this type of installation vessel will:
- Reduce the time needed for installation of each turbine
- Have increased workability with potentially higher profits
- Have considerably reduced travel times due to increase velocity

In the long run these advantages are expected to give profits that will be much higher than the extra cost spent on design and construction.

The Ideal SWATH vessel considering all that has been said is the one with the following features, apart from being a SWATH
- *Controllable fins at the fore and aft of the submerged hull*
- *ballast to higher water plane area to do the installation work*
- *working on DP and movable crane carrying 8 WTG's as shown in the sketch*
- *with "u" cuts in the deck in the aft and fore to allow for easy installation within the applicable crane radius.*
- *Angular or straight struts can be analysed.*

Catamaran- The second best candidate is the catamaran. It has similar or comparable advantages and disadvantages as the SWATH except that it has more motion than a SWATH because of the increased water plane area. Some of the main issues are:
- Effectiveness in beam seas could be a problem
- Effectiveness of DP system
- Weathervaning could be a problem
- Slamming & bow diving due to pitching

All these issues can be tackled in the same way as with the SWATH and can be reduced considerably [10][11].

The ideal Catamaran would have the following properties
- *Wave piercing hull shape*
- *Semi-SWATH type construction so it can work at two drafts one for transit and another for installation*
- *With fins to avoid pitch and slamming and also u shaped cuts on the fore and aft to allow for easy installation*

In both these cases the crane will traverse along the deck to facilitate installation from both sides. For all the WTG's it is decided to do it this way considering the clearances and space which is available and simultaneously keeping in mind the crane radius which is around 35 m for such a wind turbine installation crane. These are based on the layout considerations as shown in APPENDIX III.

FIGURE 2-2: WAVE PIERCING CATAMARAN DESIGN SOURCE: CATSAILINGNEWS.

The ideal monohull would be with the following properties:

- *A dual draft to facilitate faster transport and better installation platform*
- *A vessel with DP*
- *With axe bow or wave piercing type design in the bow like the present operational fast ships*
- *Complex sliding system for the WTG to move the WTG's along the deck to a point where it can easily be lifted by the crane which will be placed at the aft.*

FIGURE 2-3: MONOHULL WITH COMPLEX INSTALLATION SYSTEM SOURCE: IHC.

FIGURE 2-4: SWATH DESIGN WITH FINS SOURCE: MCKEESON.US

Since all the data about these ships is theoretical and based on research previously done, there is a necessity to compare the results between different shapes. The comparison has to be under similar conditions. The comparison can be made purely on the motion and stability characteristics to start off after picking the ideal scenarios from all the shapes. The comparison can be made by keeping the payload range (which drive the displacement), the length and maybe also the ship coefficients the same for all the cases. Then this would require modelling of the following 4 shapes: SWATH (ideal), SEMI SWATH, wave piercing CATAMARAN and a dual draft mono hull. Before conducting further analysis a multi-criteria analysis has to be performed to choose the best option.

2-3 Single lift concept of fully assembled WTG

The research presented here revolves around this concept. The time which is consumed for installing the wind turbine in parts is quite high. There are many methods in which the WTG parts can be combined during the installation; each of these methods have their advantages and disadvantages but the goal at the end is to be able to install as many as possible in a given time and weather condition. The parts can either be transported on the vessel or with the help of transport vessels [13].

The identified WTG installation options are as follows:

- Installation of the four components separately, i.e. starting with the foundation, then the tower, next the nacelle and finally the rotor
- Installation of foundation first, followed by the tower together with the nacelle and finally the rotor

- Installation of foundation first, followed by the tower and finally the nacelle together with the rotor
- Installation of the pre-assembled foundation and tower (one component), followed by the installation of the nacelle and finally the rotor
- Installation of pre-assembled foundation and tower, followed by the pre-assembled nacelle and rotor
- Installation of pre-assembled foundation, tower and nacelle (one component), followed by
- the rotor
- Installation of foundation first, followed by the pre-assembled wind turbine tower, nacelle
- and rotor
- Installation of complete assembled offshore wind turbine

Apart from the last option all the others have an extensive offshore program and lot of offshore installation and commissioning work has to be done. The time and cost also depend on other aspects like.

- The type of vessel used, jack up, HLV etc.
- Water depth
- Number and size of WTG's
- Weather and sea state
- Transport strategy either carry on own deck or use feeder ship
- Distance from manufacturer yard to site

All these effects contribute and influence installation. Hence a careful consideration of these topics is necessary to have a successful offshore installation campaign [14].
Based on the assessment presented above it can be seen that single lift Installation can easily alter the time required, the amount of work done offshore and the cost.

Advantages of a single lift installation

- Time required for installation of one WTG drastically reduced
- The complexity and number of lifts reduced
- Feeder vessel not required
- The production can be started immediately and revenues increased
- No extra offshore commissioning required
- Working at height's and the number of people required for blade installation etc. can be negated
- Costs associated with people, vessel chartering etc. can be reduced considerably
- More turbines can be installed in given period and weather condition

SHL as such has been working on this concept for a while now along with manufacturers of the WTG's because cost and time wise this could be very advantageous for all parties involved in wind farm development.

FIGURE 2-5: IMPRESSION OF OLEG STRASHNOV MAKING A SINGLE LIFT. SOURCE: SHL

As explained above it involves picking up the WTG from the deck and installing the assembled WTG in one go. The crane and the weights of the WTG have been explained in the design chapter and the reasons for choosing the same also have been explained. In this section the other important mechanisms and processes required for completing this will be dealt with. The completely assembled WTG will be placed on the deck and appropriate sea fastening and foundation mechanisms will be in place. Once at the site the process of installation will start and each component involved is explained and conceptualised.

Rigging

The rigging used is simple in construction and something SHL has been planning to use for some time now. Some analyses and studies have been done on this kind of system previously. It basically has a spreader frame in place which in turn is attached to a hydraulic collar which is remotely operated to hook on to the tower just below the nacelle. There are also lines running from the collar to the bottom of the tower, so all the vertical forces involved because of the weight can be balanced. The main advantages of this system will be:

- Fast hooking on and unhooking system
- No working at height for people involved
- Different diameters of towers can be handled easily

From the lifting frame, slings will be used to hold it in the main hook. Once the installation is complete the collar can be removed and used again [15][13].

Heave Compensation

One of the most important considerations which cannot be overlooked during the installation of big objects offshore is the relative motion between the vessel which is installing the piece and the seabed or a fixed structure on the seabed. This effect can also be prevalent when objects are transferred from one vessel to another. This relative motion has to be compensated or the movement has to be nullified. The heave motion of the ship is the main contributor and affects the operations the most, as the heave motion of the ship will be transferred to the object being lifted through the crane. It becomes critical when the operation involves for example a deck to be installed on a fixed jacket, Subsea modules that to be installed on fixed seabed’s etc. The relative motion can damage the lower

section of the object to be installed or the upper part of the fixed structure, due to collision or contact during the process in high wave conditions. As a result of which the installation will fail as the base on which the object has to be placed gets damaged. When the objects are being installed the speed in which they come to rest on the fixed structure is also important, because if the impact loads increase beyond a value they will tend to damage the resting or contact surface. By now it is good to visualise that the speed at which the object is lowered is also influenced by this relative motion. So the speed control during the set down process is also important.
The other important factor in this kind of installation is the method in which the contact is made with the foundation. This process of set down cannot be really fast and the accelerations associated have to be under control because all the holes have to align and the impact has to be as small as possible to avoid the integrity of the joints is compromised. They may not be damaged structurally during the installation. Hence, it is imperative that the wind turbine installation vessel has to have a mechanism to counter these effects. Therefore, it is important to study the different options to perform heave compensation. There are many different methods to perform this action. The two main methods are active heave compensation and passive heave compensation using winches either in conjunction with the crane or to have a separate AHC or PHC to perform this function. The detailed study on the heave compensation is attached in Appendix II.

FIGURE 2-6: RIGGING ARRANGEMENT ENVISIONED FOR SINGLE LIFT. SOURCE: SHL

The two concepts that have been established and the other important criteria for the installation process have been studied and presented in detail in Appendix II. These results and ideas will also be used for establishing the basic dimensions of the ship, the different possibilities of storage of the fully assembled WTG's on the deck can be envisioned. This study about the installation process as a whole will help in understanding and also predicting some basic details (hook height required, placement of WTG on deck etc.) which will aid in the further design of the vessel. As this method will reduce the amount of time and commissioning work involved later, this will definitely have a significant impact in the economics of the wind farm development, including the time required for installation. It will also reduce the risks associated with working at heights and also offshore commissioning etc..

There are some advantages and disadvantages with the 2 concepts proposed.

Concept one, active heave compensation:

- The cost of the complex crane is expected to be high
- The design and the operation would be complicated
- The installation would be easy and fast because it is actively compensated
- There is no requirement of calculating for each and every load case
- The vessel could be used for subsea-lowering also which could be an added advantage

Concept two, passive heave compensation:

- Costs of operation very minimal
- Costs and ease of design and construction of the crane much lesser than first option
- Downside being that for every load case the crane master has to be calculated and adjusted accordingly
- The installation process could be a little more time consuming than concept 1

So the final ship design, layout etc. will be done with the target that it can do single lift installation. Hence the choice of crane, deck layout profile etc. will be done around this concept to achieve little or no intervention using the heave compensation systems. Based on the final results of motion analysis a choice is to be made either to use or not use the heave compensation systems as described above.

Chapter 3

MCA, Scenario's & Weightages

3-1 Multi criteria analysis

As presented in the previous chapters it is seen that there are multiple options to choose from. The most important factor now would be to study the mission requirements of the vessel in further detail and establish which of the details are important to successfully design a WTIV which will satisfy all the objectives.
The most important features have been listed under the heading mission profile As discussed earlier each of the vessel have certain features which are useful and some which go against the needs of the current mission. To get the best set of variables for the WTIV it is considered that a weighted multi criteria analysis be performed to choose the best option. So, one can deal with fewer options while carrying out the further analysis to check the design feasibility. The extensive Multi criteria analysis is attached in the APPENDIX III. The ideology and the procedure adopted are elaborated here.

The parameters are broadly classified as General, Transit mode & Installation mode; this is done to better understand the limitations of the ship shapes in these different modes as each of these shapes behave differently in the transit and the stationary phases.
So, each of the following criteria has been weighed and factors given based on the extensive research previously done on the ships but to some extent they are subjective. But nevertheless they give enough details for one to get a clear understanding and this helps in constructively reducing the number of alternatives.
The analysis basically follows a simple methodology in which the governing parameters or variables which are important are defined and then each of these parameters are associated with a weightage, based on how much influence these parameters have on the mission profile and the project requirements. Then each of the vessels is weighed against these parameters and a final score is generated.
There are two kinds of weightages pointed out in the sheet attached

- **Design weight-** it is the weightage given based on how the factor under consideration can influence the design of the ship.
- **Project/ Mission-** it is the weightage given based on how the factor under consideration can influence the whole mission profile and the whole project of WTG installation.

General Parameters

1) Principal dimensions

The length, width and the draft are important parameters which will influence the design and also the project

- The harbour and port entry could limit these values
- The entry requirements of the panamax and the suezmax can influence the design
- The project is affected by the fact that these parameters also dictate the number of WTG's that can be carried

2) Speed

The speed is also an equally important parameter which could alter the voyage time which is important in the overall project and can influence the number of WTG's installed in a given period. At the design level some shapes will have better speed and others not. This is further analysed in the next sections

3) CAPEX , ease of design and availability of yard

They pose a significant amount of influence but not to the extent of others hence the weightages are given appropriately. The Swath and the CAT variations obviously will cost more and it will be more difficult to both find a yard to construct them. Also the duration and ease of design could be more and complicated. Compared to the Mono hull which score's better on this parameter.
The other parameters used speak for themselves and the scores are given based on the literature review and the studies conducted previously on these shapes.

Transit mode

This is the behaviour of the ships when it is travelling from a given location to the port or vice versa.

1) Intact stability will be based on the limits as prescribed by the SOLAS standards for special purpose ships.
2) Directional independence the ability of the ship to keep its heading in rough seas
3) Manoeuvrability in harbours and canals and draft available, is an important factor to be able to access most of the manufacturer yards
4) The allowable motions and accelerations of the nacelle (as this is the most sensitive part of the WTG) which are defined by the manufacturer which are directly influenced by the RAO's of the ship.
5) The rolling and pitching can also induce unnecessary motions and accelerations on the nacelle and other parts of the WTG. Also on the people on the ship the roll period can cause sea sickness. The shapes are given higher scores for a better behaviour with respect to the others the shapes which exhibit these phenomenon, which are given smaller scores accordingly
6) The deck loading complexity is defined in the sheet itself
7) The projected workability is based on the criteria as explained in the mission profile

Installation Mode

This is based on how the shape makes it easier or difficult to install the turbines in one piece. The motions and the behaviour when the WTG is hooked and picked up by the crane when it is at zero speed.

1) Intact stability as defined by the SOLAS code
2) Motions and accelerations of the nacelle in the hook of the crane and the limits as prescribed by the manufacturer
3) The drop load analysis is crucial for a heavy lift crane vessel
4) Set down velocities, this is the speed with which the WTG is landing on the foundation piece (the details already explained in the previous documents) the exact values of which again are defined by manufacturer. The heave motion of the vessel has the highest influence apart from all the others also.
5) The roll and the pitch in stationary state are different for different shapes hence this also has to be accounted for.
6) The projected workability is again based on the ability to easily install the WTG's

The detailed analysis on the weightages and the variables are presented in the APPENDIX III.

Conclusion

The Semi-SWATH and the variable draft catamaran score the highest. The next step is to establish the exact testing criteria which are required for the working of the WTIV. Since the field of choice has considerably reduced it is decided to model the Semi-SWATH shape and subject it to further analysis with respect to stability, speed scenario & workability to understand the limitations and advantages of this shape. Because SHL has extensive experience with Monohull forms, a monohull with dual draft is also considered for reference. If the lowest and the highest scoring designs are analysed, a clear idea of everything in between can be established.

3-2 Boundary limits for design

For the next step both these shapes have to be assessed based on a frequency domain analysis, in AQWA to find the RAO's and from this data conduct a motion analysis. Based on this one has to check if different points of interest on the ship are within the acceleration limits prescribed by the manufacturer of the Wind turbine. Apart from these major limits which will be with respect to the wind turbines, the ship also has to be analysed for all the parameters with respect to the Special Purposes ship code as prescribed by the IMO (the elaboration about each of these topics will be given below). These are checked for two different conditions which are TRANSPORT & INSTALLATION conditions. This is done because the limits have considerable changes and the configurations are quite different in both these modes. Also later on it will be easy to analyse as well, as one can differentiate between the applicability of the vessel in those particular modes. This document will consider each limit and elaborate on all the factors which are involved.

Wind turbine selection

The first and the foremost limits to be established are the size and the shape of the wind turbine to be carried and also the number to be transported in each voyage of the ship. The major considerations which drive this choice are

- The future market of renewables
- The developmental strategies of the major manufacturers (SIEMENS, VESTAS etc.)

Based on these details a comprehensive list is made by collecting all data available in the market and the sizes and weights compared and the 7 MW version of the Vestas was chosen for the reasons established below APPENDIX III. The driving forces which lead to the choice are as follows

- Water depth of the new fields
- The point where the JACK up's will be missing out because of hook height and depth considerations
- As the distance from the coast increases, the time for the jack ups to be pulled into location also increases etc.
- And this means that the 5 and 6 MW can also be accommodated, which are in huge demand for the most of the fields for seen in the near future.

the major dimensions and their ranges are as follows [1][6]

Sl no	Description	Range
1	Power	5 - 7 MW (lower ratings are also possible)
2	Rotor diameter	120-164 m
3	Tower Heights	65-106 m
4	Blade lengths	55-80 m
5	Total weight	800-1000 m (each turbine fully assembled)

TABLE 2: MAIN DIMENSIONS OF THE WTG CHOSEN FOR STUDY [6]

These dimensions are important because they will be the input for the next step which is the estimation of the crane requirements.

Crane capacity and selection

Based on the above details one can estimate the weights which the crane has to install. Based on the weight associated with the WTG, the maximum lifting capacity of the crane which would be required would be in the range of 1200-1600 MT. The other major criteria to be defined for the crane is the hook height at which this capacity has to be handled, again from the above considerations it is seen the range of maximum hook height is between 120-140 m considering that the foundation is above the sea level where the WTG has to be placed. Apart from this the major dimensions that are affecting the choice some other aspects which have to be taken into consideration are.

- The functionality of the crane with respect to heave compensation
- The total weight (hook capacity) which is included has to account for slings, any passive heave compensation devices used and the spreader frame and the collar.

There are some cranes in the market already which have almost all the properties of this ideal crane and this whole system can be designed as a package by companies like Huisman or Liebherr. For now these dimensions are more than sufficient to go ahead with the design. The ideal characteristics of the crane are as follows.

Sl no	Description	Range
1	Maximum Hook capacity	1400 - 1600
2	Maximum hook height for above capacity	135 from top of deck
3	Maximum radius	35
4	Boom length	106

TABLE 3: MAIN DIMENSIONS AND CAPACITY OF CRANE CHOSEN FOR STUDY [16][17]

The crane radius is also an important input in the layout design and also influences the number of WTG's that can be carried(in this case a value of 35 m is assumed based on previous data). In the swath the crane has to be moved from the aft to bow to complete all installations. In the Monohull the wind turbines will be transferred towards the crane at the aft part of the ship. Based on these inputs preliminary concept sketches of layout are presented in the APPENDIX III.

Location of site and port for study

As explained previously the biggest and largest fields envisioned in the European zone will be mainly in the north sea waters belonging to Germany and England apart from the other countries[19]. Based on this, the region called the DOGGER BANK is chosen for the analysis mainly because of the following reasons

- It has in the pipeline almost 10000 MW planned to be installed in the next 20 years[18][19].
- It is one of the most open areas in the north sea hence an analysis of this location will also mean that the ship will also satisfy the conditions in the more calmer regions.
- Just south of the Dogger bank in the territorial waters of Germany there are also plans of setting up wind farms of combined capacity of another 10000 MW [19]. This region can also be associated to the above analyses then.
- It has depths of 50 M which means the jack up's will be pushed to their limits (w.r.t capacities) and also in the German part the soil conditions are not ideal for the working of the jack up's.

Some of the salient features of the Dogger bank region are [19][1]

- 100 Km from the east coast of England (from Yorkshire)
- 17600 Km^2 area and has dimensions of approximately 260 Km long and 97 Km broad
- Shallow sand bank with depths varying between 15-30 Km
- Planned 9 zone development of wind farms of total capacity 32 GW

After this the next step is to fix some possible locations of port facilities which will have the basic functionalities

- The depth for entry of the vessel in the channels should be sufficient to accommodate the ship
- The quay side should have the same depth properties to accommodate the ship when fully loaded
- There should be facilities to assemble the WTG and keep them ready for the ship to pick them

Based on these requirements many ports are studied and the inputs from the EWEA statistics of 2011[1], which also performed studies on the different possibilities of port facilities are used. Based on characteristics like maximum length and allowable beam in the harbours, the max depth and also the distance and accessibility to the manufacturing facilities of VESTAS and SIEMENS [6], the following ports are seen as feasible for mobilization and assembling centre for the WTG's:

1) Vlissingen port Netherlands 16.5 m draft(max)
2) Esbjerg or Aalborg both with 10 m draft(max)
3) Newcastle- Tyne side 13.5 m draft(max)

Now for the transit case the transit analysis of RAO's, motion and workability will be based on the travel of the ship in these routes. This will give a clear understanding of the conditions which the vessel has to undergo during the transit. Three different ports will also give realistic results for most of the routes which it will travel in its lifetime.

Also to find out if there was any influence of the speed of the vessel on the whole project duration, a scenario analysis was done to find the sensitivity of vessel speed with respect to the time and project duration. The assumptions and the results are presented below, the detailed sheet can be found in the APPENDIX III.

Important assumptions for speed analysis

- The onshore travel and delivery is not considered
- The distance between the turbines is a thumb rule used in wind farm development feasibility studies (5-7 times the diameter of the wind turbine) [20]
- The choice of ports has been dealt with previously and the reasons for the same explained in the weightage report [1][14]
- The times indicated for the installation of turbines and also the time required to take the fully assembled turbine on board are based on previous reports of the Thanet wind farm (vestas), Report on Kentish Flats wind farm with A2sea vessels working, report on Glosten Associates on vessel data. Apart from in-house data available with Seaway heavy lifting.[14][21][22]
- The components for delay in weather and also some force majeure case have also been accounted for
- The time involved for installing the foundation is not accounted for because it is not relevant at this stage

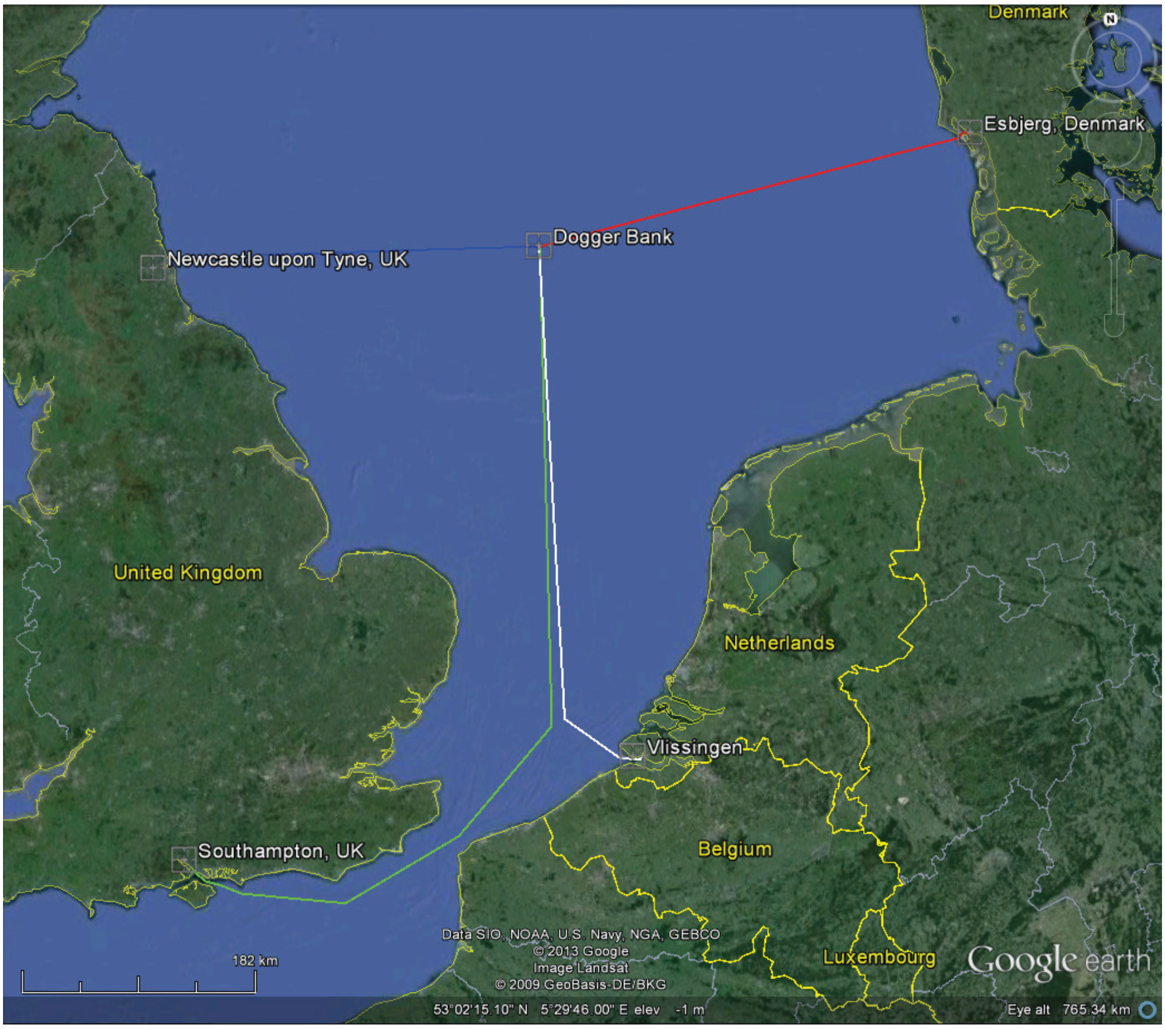


FIGURE 3-1: LOCATION AND PORTS. SOURCE: GOOGLE EARTH

	15 knots (25% reduction from 20 Knots)		10 knots (50% reduction from 20 Knots)		5 knots (75 % reduction from 20 Knots)	
	% Increase of total days	***Total No of days***	***% Increase of total days***	***Total No of days***	***% Increase of total days***	***Total No of days***
Vlissingen	8.9	64.66306695	26.9	75.32793377	80	107.3225342
Esbjerg	8.08	61.6075114	23.9	70.74460043	72.1	98.15586753
New castle (Tyne)	7.11	59.03806695	21.37	66.89043377	64	90.4475342

TABLE 4: SENSITIVITY OF TOTAL PROJECT DURATION BASED ON VESSEL SPEEDS APPENDIX III

Important conclusions:

- The reduction in speed by 25% increases the number of days only by 9 % (4 days approximately).
- The % increase in the days for the same speed reduction decreases with the reduction in distance between ports and site.
- The % increase in the days for the same speed reduction decreases or remains same with the increase in the number of turbines.

- The % increase in the days is not significant enough with respect to the total number of days the vessel is chartered for the project.
- But the reduction of power could have significant effect on the CAPEX of the vessel.

Also the data is helpful to get a feeling for the time involved for different shapes because 20 Knots (associated with High speed swaths), 15 knots (associated with SWATHs and Catamarans), 10 knots (high speed Monohull) and 5 knots (when the vessel is towed or a self-propelled semi). The shapes being suggested at the lower speed have the better motion characteristics (semi, swath etc.) so this it is very interdependent.

3-3 Testing criteria for the ship

To analyse the ship better the ship mission will be divided into two as mentioned above the motions of different criteria will be analysed separately for the transport part and differently for the installation phase. Before this some other general criteria have to be satisfied by the ship. The method to calculate and the calculated upper limits will be explained in the following sections.

Some general considerations which can be adopted for ship design are as follows [7]

- A larger L/B value is favourable for speed, but unfavourable for manoeuvrability & Stability
- L/D values usually vary between 10-15
- B/D ratios vary between 1-2 if this value becomes greater, then the tendency of the deck to be immersed in water increases.
- A larger water plane coefficient with a smaller block coefficient is favourable for the stability both in the transverse and longitudinal direction
- To have the crane on the centre line is the best position because it avoids the unnecessary roll motions if it is placed on the side towards port or starboard side
- When designing make sure the period of roll is between 15-20 seconds which is generally considered ideal

Transportation limits

In the transport condition the configuration of the WTG's is such that the tower will be fixed on a foundation 10 m below the deck and will also be held on the top with grillage to fasten it further. In the case of the Monohull these foundations are movable on rails and they are fixed in the actual transport condition. Based on some previous joint studies conducted by Seaway and Siemens and also with Areva have, yielded these following limits during transport. It is seen that the nacelle is the most sensitive part of the system. It houses the bearings and all the other important equipment, and when the hub is also assembled the system becomes more sensitive. During transport different permissible transport accelerations for different parts are determined, but the absolute accelerations as defined by SIEMENS and AREVA are as follows.

Longitudinal	ax	5	m/s^2
Transverse	ay	10	m/s^2
Vertical[1]	az	20	m/s^2

TABLE 5: LIMITS FOR ACCELERATIONS OF THE NACELLE [23]

Similarly AREVA defines the acceleration for simultaneous transport of both nacelle and hub as 4.5 m/s2 (longitudinal direction). This is comparable to the above values from Siemens, hence these values will be used as the upper limit for the motion accelerations allowed at the COG of the nacelle. The nacelles are also allowed to tilt around the longitudinal and transverse axes which must be taken into account in case of transport. The locations of the COG's of all the wind turbines can be estimated and then after finding the motion spectrum these limits can be applied to check the workability. But it is seen that these values are a little on the conservative side, hence the limits in the final step are based on operational data and more stringent values shown in later chapters.

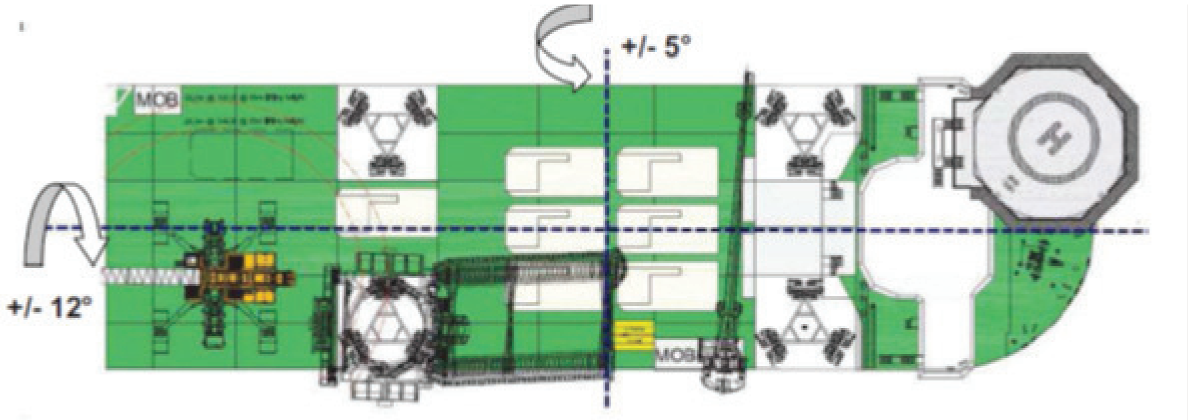


FIGURE 3-2: PERMISSIBLE TILTS ABOUT THE AXIS. SOURCE: [24]

Installation phase

The installation can be split in the free hanging and set down cases. The motion and acceleration limits of the nacelle still hold good from the previous conditions except that now there are certain other conditions also which could be limiting. A main hook will be subjected to a load equivalent to the weight of the WTG in case 1 and in case 2 it will also be fixed to the constant tension winch in the foundation.

The other important criterion which could limit the process is the set down velocity which is dependent on the vertical motions of the tower base, usually provided by the WTG manufacturer. This can be estimated in a slightly different way usually the maximum allowable free fall height is also given by the WTG manufacturer from this the impact velocity can be estimated and this can be used to estimate the significant vertical motion of the crane block. From previous experience by SHL the limit is about 2 m/s. when the 3 hr. maximum approach is considered then the maximum will be twice this value and the relative speeds of the lowering by the crane operator (again prescribed by crane manufacturer) have to be accounted for and a maximum value can be set up. In this case the maximum value therefore can be around 4 m/s . This value can be used for compliance check.

The next step is to fix the dimension for the swath model and the Monohull (dual draft) in 3D software, in this case solid works. Before it is modelled a parametric analysis is done to check the sensitivity the details are given in the next chapter. Then check for the compliance of the intact stability conditions. This model is then imported into ANSYS workbench and the RAO's are generated and these are used to generate the motion spectrum in conjunction with the wave spectrum for the major headings.

Then check the compliance of the motion w.r.t the nacelles in transport and also the different installation modes. If they are not solved then tweak the design and change the arrangements until the designs satisfy all the conditions. Then the workability in the months of April to August for the Doggerbank case is tabulated.

Chapter 4

Ship Parameter's and Design Methodology

4-1 Introduction

Ship design can be based on two methods. The first one involves the selection of a basic vessel type by the client belonging to a particular series, and retro fitting it according to the requirements of the mission. This way the design is proven to be good and the amount of time required to do such a type of design is much less. This is because it is just a case of altering some details in the already existing set up. The second method is concept design where in a completely new design is required, based on the situation either the hull shape is pre decided or not, before the start. The clear understanding of mission profile usually comes in handy in such a situation because the only details with which one can start of are the payload and broadly the working conditions etc. Once this information is present one design's the whole vessel based on a regression analysis based on previously available data of similar kind of vessels. Once that is done then the main dimensions are fine-tuned if necessary with the help of model testing and then the detailed designing takes place after this step. Based on the design spiral shown in the previous chapter there are always changes which one keeps inputting and the design and parameters keep changing about some centrally fixed parameters.
In this case it is clear that the second method has to be adopted for the initial design. The major reasons contributing to this choice are as follows

- The design of a SWATH vessel for this mission profile has never been done previously
- The current swath vessels most of them are made of aluminium and are high speed crafts used for roles as ferries.
- As a result most of the available data for comparison is scanty; this might not lead to the right results.
- There is no design methodology or rules to follow prescribed by any organisation like the IMO or any other agency for SWATH's, as the vessel development for such roles is in a nascent stage.
- Model testing is not within the scope of this research, because at this stage there is not enough proof with respect to the motions of the ship weather it is possible to use such a shape for crane vessel.
- Regression analysis can also not be performed to fit the SWATH into a particular set of vessel like for the Monohull or the Catamaran.

As a result the design methodology which was adopted is slightly different from conventional methods and it is elaborated in the next sections. It was also important to satisfy the important criteria and also look at the show stoppers without going too much into detail at each section of design like Layout design, intact Stability, accidental loads, power, speed and resistance estimation. But also enough study had to be done to get a well optimised solution to subject it to frequency domain analysis. It is also good to model and check for the similar mission profile for the Monohull so at the end of the research it is possible to verify how much difference is present between both the designs.

4-2 Preliminary design considerations

Hence the design has to be approached in a slightly different manor. After the multi criteria analysis of the shapes the Semi swath was chosen as the design favourable for further study. The mission profile has been fixed so based on the number of WTG's to be carried a preliminary layout was established based on parameters like

- The size and locations of the WTG's on the deck
- The location and functionality of the crane, which included the swinging radius and also the crane radius limitation (already established in previous chapter 35 m)
- The amount of space approximately required for accommodation
- The availability of space and location for the helipad
- The complete layout configuration is attached in APPENDIX III. The Monohull has also been considered at this stage.

The results are as shown below in figures below.

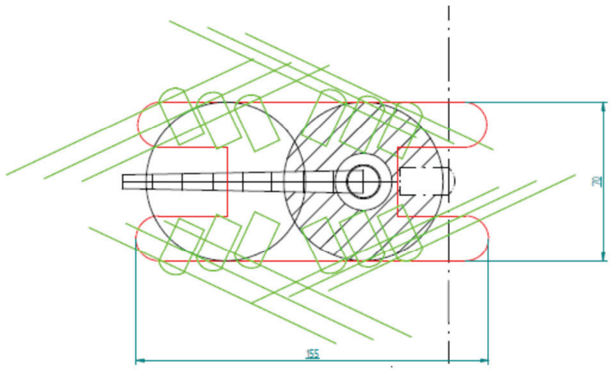


FIGURE 4-1: SWATH LAYOUT DESIGN WITH WTG'S AND CRANE ARRANGEMENT

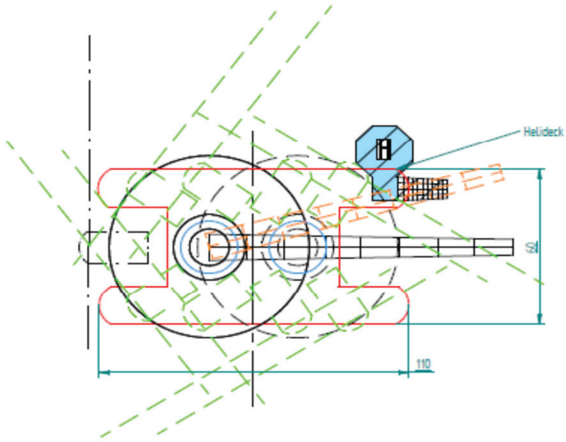


FIGURE 4-2: SWATH ARRANGEMENT SHOWING HELIDECK CRANE PEDESTAL

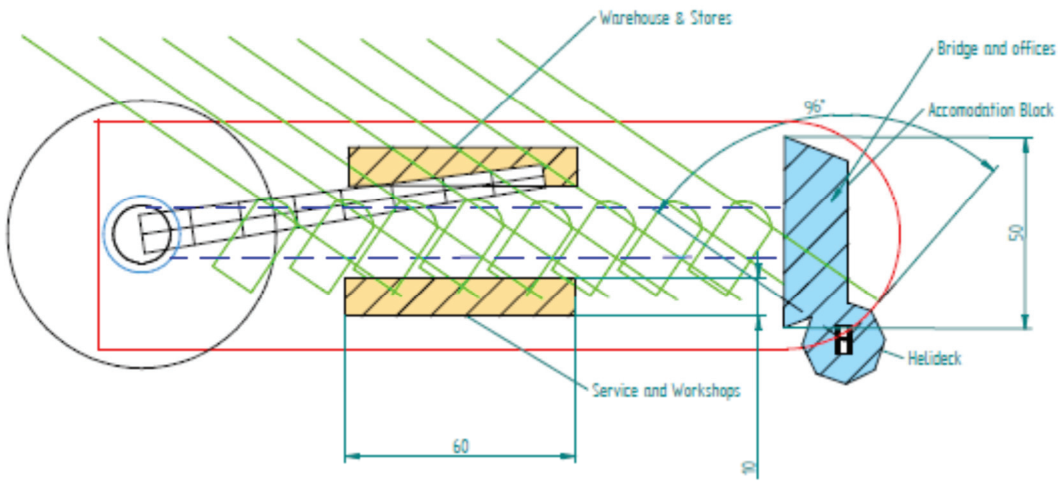


FIGURE 4-3: MONOHULL SHOWING ACCOMMODATION, HELIDECK, WTG'S & CRANE ARRANGEMENTS

The most important result from this was that the main dimensions of the vessel could be visualised based on the requirements of the mission. Once the length and breadth were established, this was checked against some rules based on port entry limitations, harbour draft and depth considerations and this was used in the further design.

4-3 Metacentric height – intact stability

The Intact stability criterion for the vessel is the most basic criteria the vessel has to satisfy for it to get certified by IMO or any agency which follows the IMO. The expansion is as follows based on the section 3 of the SOLAS code [25].

- The initial metacentric height should not be less than 0.15m
- The maximum righting arm should occur at an angle of heel preferably exceeding 30º but not less than 25º
- The righting lever has to be at least 0.20 m at an angle of heel equal to or greater than 30º
- The area under the righting lever curve (GZ curve) should not be less than 0.055 metre-radian up to θ = 30º angle of heel & not less than 0.09 metre-radian up to θ = 40º or the angle of flooding if this is less than 40º
- Additionally the area under the righting lever curve (GZ curve) between the angles of heel of 30º and 40º or between 30º and the flooding angle if it is less than 40º should not be less than 0.03 metre-radian[25]

The swath cross section was established as shown in the figure below. These parameters are defined based on the layout above. The extensive excel sheet with all back ground data is attached with the APPENDIX V.

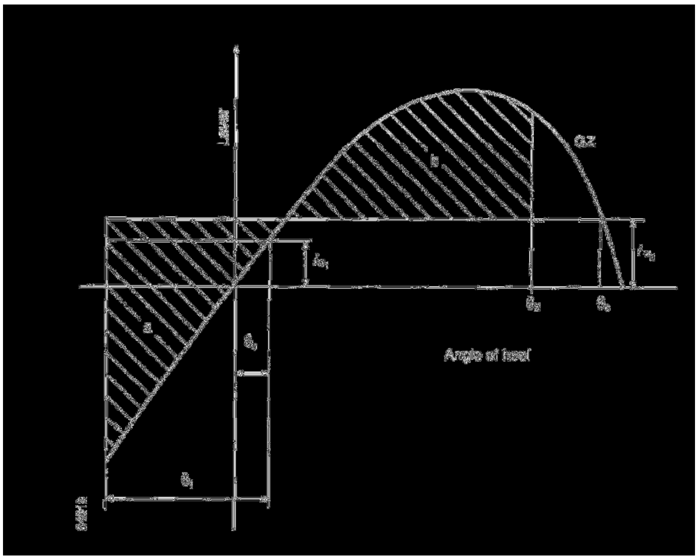


FIGURE 4-4: EXAMPLE GZ CURVE SOURCE:[25]

The idea is to establish important parameters like draft, length, breadth of the vessel and then lead into the calculation of displacement based on the water plane area. Since the displacement was not available directly certain approximations were made to facilitate the calculations and are presented as below.

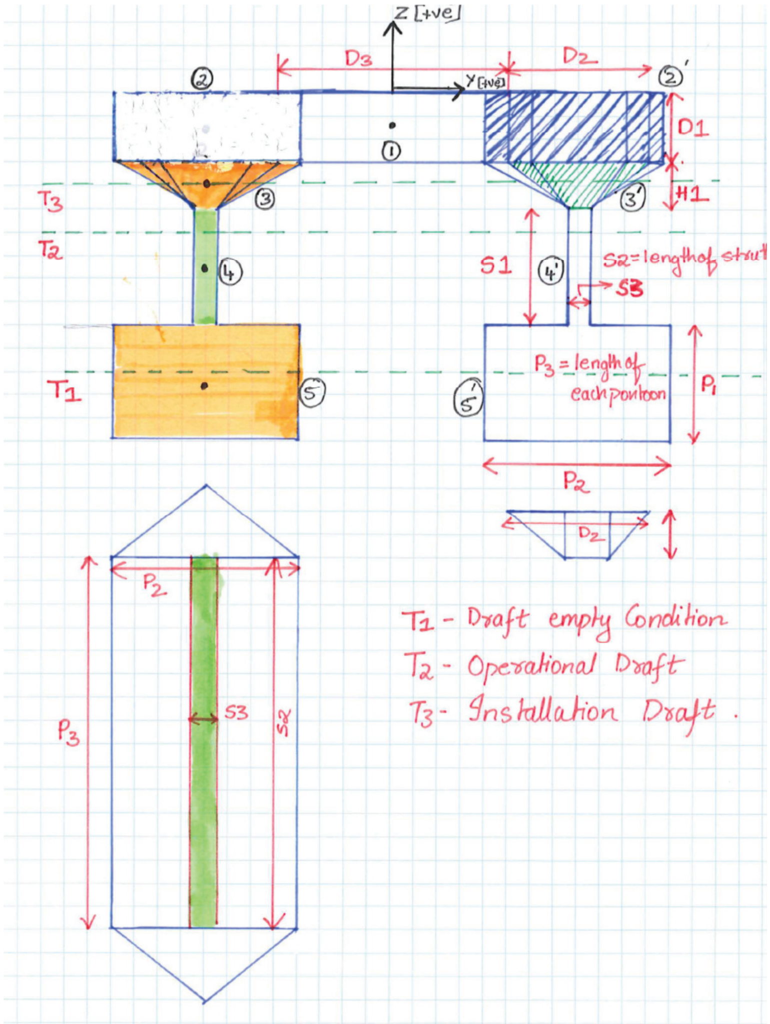


FIGURE 4-5: THE DIFFERENT PARAMETERS ESTABLISHED AND TUNED IN STEPS

- The SWATH will be operated at 3 different drafts which are established to lie between
  - 0-10 m draft at the lower pontoon level will be referred to as T1
  - 10.01-18 m draft at the small cross-section at the strut will be referred to as T2
  - 18.01-22 m draft at upper pontoon will be referred to as T3
- The payload to be carried is fixed at 10000 MT which includes the WTG's and the crane based on the values from chapter 3.
- The displacement is established based on the water plane area at different drafts assumed above and the volume of submerged spaces
- After negating the payload from the displacement value the rest of the weight required to balance the buoyancy is distributed in the form of ballast water in the lower pontoon
- From here on the GM values can be estimated at all the drafts. Following this the GM and GZ curve can be easily drawn [27] assuming the Scribanti condition of vertical walls see fig. 4-7
- To estimate the areas under the curves Simpson's rule of areas are utilised [27]
- Sign curve is used to replicate the GZ curve.

After this procedure is established now the values were tuned in order to satisfy the GM and GZ requirements of intact stability as established above.

$$\mathrm{V} = Volume\ of\ water\ displaced\ by\ the\ vessel\ (m^3) \quad (4.1)$$

$$\nabla = V * Density\ of\ water \quad (4.2)$$

$$\mathrm{GM} = KB + BM - \mathrm{KG} \quad (4.3)$$

KB is calculated using the cross sectional areas of the submerged region and finding the combined Centre of buoyancy using the method of combining areas.
KG is calculated first for the empty ship and then combined with the Centre of gravity of the crane and the WTG's to get a combined COG for the system.

$$\mathrm{BM} = \frac{I}{\nabla} \quad (4.4)$$

Where I is the Area moment of inertia at the water line and ∇ is the displacement

Draft (m)	Displacement (tons)	GM (m)
10 – T1	34440	100.276
18 – T2	42902	8.22
22 – T3	47601	105.926

TABLE 6: PRELIMINARY CALCULATED VALUES OF GM WITH 8 WTG'S ON BOARD

Description	*Parameter*		*Unit*
Height of deck box	D1	6	Meter
Width of Deck above pontoon	D2	15	Meter
Distance between two pontoons	D3	60	Meter
Height of struts	S1	8	Meter
Length of struts	S2	86	Meter
Thickness of struts	S3	6	Meter
Height of pontoon	P1	10	Meter
width of pontoon	P2	15	Meter
length of the pontoon	P3	100	Meter
height of dual draft shape	H1	4	Meter
Draft at lower case	T1	10	Meter
Draft at transport case	T2	18	Meter
Draft at installation case	T3	22	Meter
Total depth of vessel	D4	28	Meter
Angle of slope at strut	A1	48.36646	Degrees
Overall length of the top pontoon	TP1	120	Meter
Length of Triangular projection from pontoon	TP2	12	Meter

TABLE 7: PRELIMINARY PARAMETERS OF SHAPE WHICH GIVE RISE TO THE VALUES IN TABLE 5

A sensitivity analysis was conducted on all the parameters, to check how the changes in each parameter affects the GM, both with and without the WTG's. The results of such an analysis for the draft at strut level is shown in APPENDIX IV and the dark red colours signify highest reduction and the dark green colours show the highest increase in the values of GM the gradation of colour (red & Green) in between shows the relative reduction & increase in effect of the value on GM compared to the highest ones

- The highest increase in GM (up to 800%) is seen when the values of *distance between the pontoon* (D3 in Fig 4-6) and also *length of the struts* (S2 in FIG 4-6) are changed by 25% and 16 % respectively
- The highest decrease in GM up to (60%, 800% & drastic respectively) is seen when the values of *distance between the pontoon* (D3 in Fig 4-6) , *length of the struts* (S2 in FIG 4-6) & also *height of deck box* (D1 in Fig 4-6) are changed by 25%, 16 %, 30% respectively

This is helpful later to tune the GM value to fit it according to the rules of impact stability one knows which value has to be increased or decreased based on the change required in the GM.

4-4 Free surface effects

As can be seen from the shape the concept will involve a lot of ballasting and de ballasting in its lifetime of operation. Since stability is one of the most important criteria it is also important to see what are the other operational features which will affect the stability and the GM.

When a Ballast tank is completely full then the water cannot move within the tank. As a result of which the water can be considered as a static weight having its COG at the COG of the water in the tank [27].

But when the liquid is half filled in the tank or any level between full and empty. When the ship heels the liquid inside these tanks also shifts by flowing to the low side of the tank as shown in the figure below. This results in the changing of the COG because of the shift of the mass of water, which in turn effects the moment of stability. It is seen that this effect contributes to the reduction of the effective GM calculated above [27].

If the free surface effect is at any point larger than the GM and contributes to reduction so much that the GM becomes negative, then it is dangerous for the ship. Hence this has to be investigated

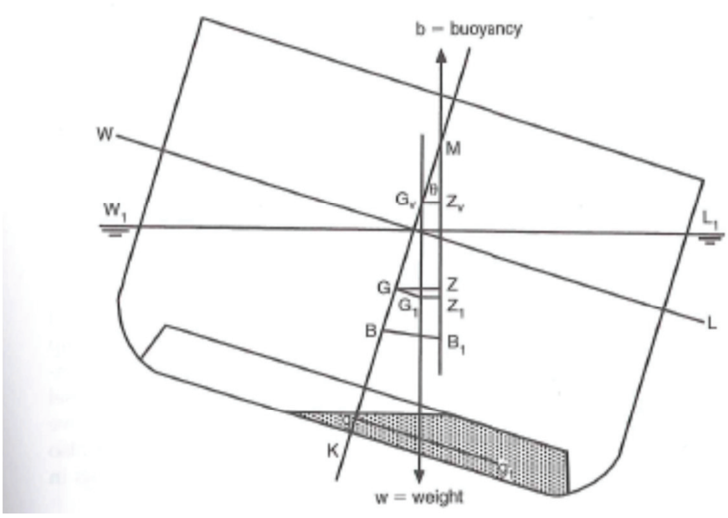


FIGURE 4-6: FREE SURFACE EFFECTS IN SHIP. SOURCE: [27]

Different possible configurations of filling up the tanks have been tested and the free surface effect calculated based on the following formula where the Virtual loss of GM is given by FSE

$$\text{FSE} = \frac{i}{w} * \rho * 1/n^2 \tag{4.5}$$

Where,
i = the area or second moment of inertia of the free surface about the centre line
w = the ship's displacement in tonnes
ρ = density of liquid in tank tonnes/m3
n = no of longitudinal compartments into which the tank is equally subdivided

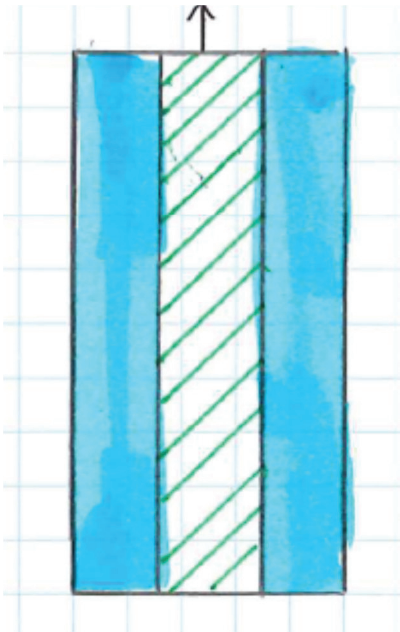


FIGURE 4-7: MOST FAVOURABLE CONFIGURATION OF WATER FILLING IN LOWER PONTOON

Many configurations for filling the tank are worked and the one chosen in Figure 4-8. Is the one which has

- The least FSE and least reduction of GM
- The best possible configuration to also avoid also trim and heel effects
- To also accommodate the necessary machinery for propulsion

The FSE is worked out for the worst case when the highest amount of ballast water has to be taken in, which is during the empty ship condition.

Draft (m)	Displacement (tons)	GM (m)	FSE (m)	Changed GM
10 – T1	34440	100.276	12.76	87.51
18 – T2	42902	8.22	10.24	-2.022
22 – T3	47601	105.926	9.23	105.926

TABLE 8: CHANGED VALUES OF GM DUE TO FREE SURFACE EFFECT

The following things can be inferred from the values shown above

- The highest case leads to negative GM in the middle draft scenario which is not good for the ship
- In case of the T1 and T3 draft cases the GM is reduced by 10% but in the T2 case it reduces by almost 100 %.

But it should be considered that at this stage the parameters can be tuned to adjust this value to have a favourable outcome. Also the free surface can always be reduced by increasing the number of longitudinal bulkheads (n in 4.5).

4-5 Drop load analysis

The drop load criteria as specified by IMO and other certifying authorities are a very important boundary condition to be tested for crane vessels. So any vessel which is equipped with a crane is to be subjected to the drop load analysis.
Accidental drop load is the case when the load in the hook of the crane is dropped and what effect this has on the ship, because for any lifting operation counter ballasting is done. As a result when the load is dropped instantly there will be unnecessary excursions in the ship but this should not be too dangerous so as to affect the stability of the ship. Hence the drop load criterion has to be tested for.

— The restoring energy represented by area A2 in Fig.1 is to be at least 40% in excess of the potential energy represented by area A1.
— The angle of static equilibrium Θ_e after loss of crane load shall not be more than 15 degrees from the upright.

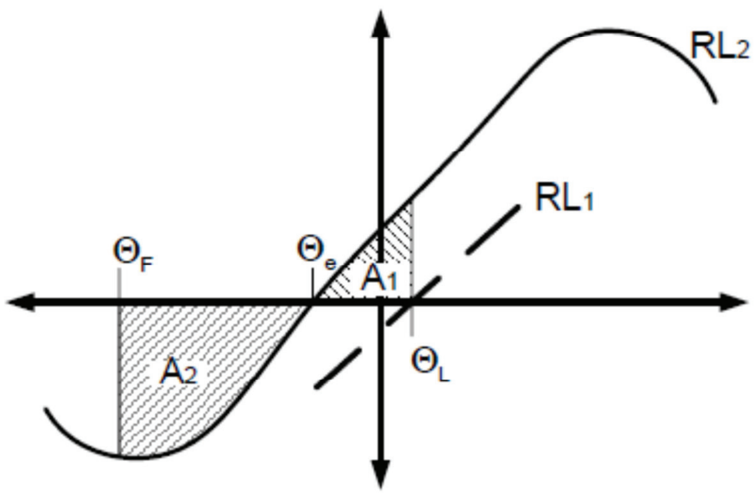


FIGURE 4-8: DROP LOAD CRITERIA SPECIFIED BY DET NORSKE VERITAS. SOURCE:[28]

Where,
RL1 is the Net righting lever (GZ) curve for the condition before the loss of crane load
RL2 is the Net righting lever (GZ) curve for the condition after the loss of crane load
Both of them corrected for the moment provided by counter ballasting
ΘF is the down flooding angle
ΘL is the static angle before the loss of crane load
Θe is the static angle after the loss of crane load

The analysis is done with the following boundary considerations

- The first case is when 7 WTG's are on the deck and the 1st WTG is in the hook and the crane drops the load
- The second case is when the last WTG is in the crane hook and the rest have been installed
- Two considerations for the position at which the installation is done over the side or at the bow in the centreline.

- Also to calculate the areas Simpsons rules are used

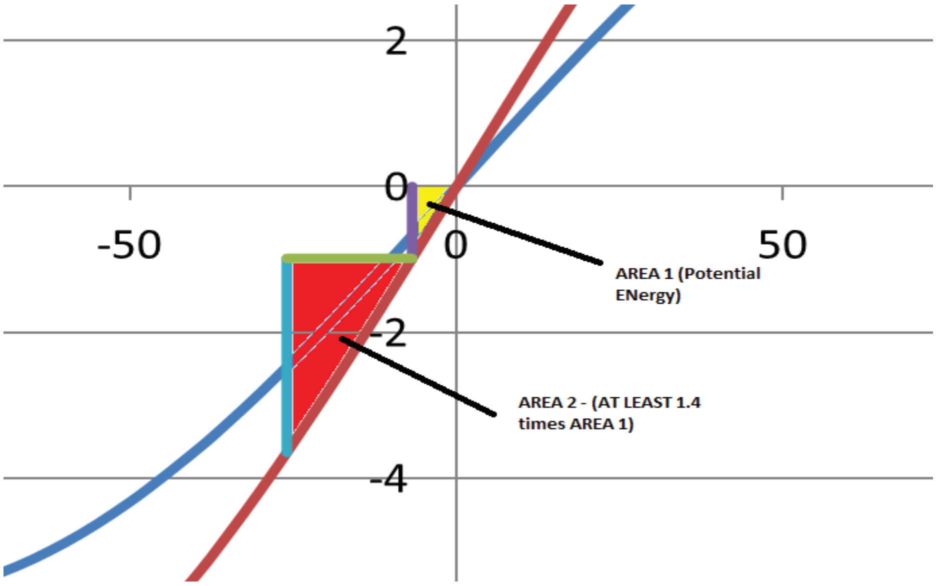


FIGURE 4-9: EXAMPLE OF THE PLOT FOR THE DROP LOAD CASE

Because the installation is done over the side, it is seen that the drop load is more important in the case of the monohull. So, if at the farthest point of outreach the load is dropped it will have the highest effect on the stability. 1400 tons is dropped either on the bow in case of the SWATH or starboard in case of the monohull. Both at a distance of 35m, which is the maximum crane radius. For the SWATH as one can see based on the layout the installation is done in the centre line of the vessel. But nevertheless the drop load analysis is carried out based on the same assumptions because the crane will swing in this direction and 35 m will be the farthest point on either side of the crane. The final drop load graphs are presented in the next section.

4-5 Moment – related to heel angle

For a crane vessel another level of check can be performed based on the tangents of the heel angle. This criteria is mostly useful in the operations side of the vessel. It is a check based on the amount of counter ballasting to be done for the vessel in the lifting conditions. It is also a good to check this as a basis of comparison to the currently operating crane vessels. The value of the heel angle can be calculated based on the following formula

$$\tan\phi = (P * y_d)/(GM * Displacement) \qquad (4.5)$$

Where,
P = Load in tons
Yd = Crane radius at that lift in meters
GM = metacentric height at this condition in meters
Displacement of the ship in tons

This is important that the vessel is also easily operable. The method adopted here is to first find this ratio (1/tanΦ) for already present vessels and try to fit the SWATH concept in that same league.

Firstly for different loads, GM and displacement are correlated to operational data from the Oleg strashnov and then the swath parameters are tuned to the same ratio value.

Data from the oleg strastnov for lifting loads under different Conditions					
Draft	***Displacement***	***GM***	***Radius***	***Load***	***Ratio***
13.458	74037.71	3.63	38	4500	1.571677704
9.474	46577.45	2.43	72	800	1.964986172
12.91	69764.11	4.877	43	3800	2.082249477
13.166	71898.44	2.796	32	5000	1.256425239
14.903	77017.09	1.823	32	5500	0.797739517
					1.534615622
Tan Φ = (P*Yd)/(GM*Displacement)					
The reciprocal of the above mentioned formula is used as an extra check to further tune the parameters of the SWATH where P= load in the crane & Yd= Radius at which the load is held					

FIGURE 4-10: DATA TO FIND THE RATIO FOR OLEG STRASHNOV. SOURCE: SHL

Conclusion

Based on all these criteria presented above the parameters of the SWATH will be tuned and set to satisfy all the conditions or fall within the limits. The final parameters and also the related values of GM, the GM curves, drop load curves & the heel angle ratio will be presented in the next section after fitting the vessel parameters to match all the requisite rules.

Chapter 5

Final design - speed, resistance and power

5-1 Final parameters of the concept semi-SWATH

Now that the design criteria have been established in the previous chapter, the vessel parameters are tuned to fit the description of the rules and also satisfy the mission criterion at the same time.

The concept SWATH will carry 8 WTG's based parameters as specified in table 3.
The detailed excel sheet and calculation are performed and attached in the APPENDIX V. The results are presented here.

Description	Parameter		Unit
Height of deck box	D1	6	Meter
Width of Deck above pontoon	D2	15	Meter
Distance between two pontoons	D3	47	Meter
Height of struts	S1	8	Meter
Length of struts	S2	96	Meter
Thickness of struts	S3	8	Meter
Height of pontoon	P1	10	Meter
width of pontoon	P2	15	Meter
length of the pontoon	P3	100	Meter
height of dual draft shape	H1	4	Meter
Draft at lower case	T1	10	Meter
Draft at transport case	T2	18	Meter
Draft at installation case	T3	22	Meter
Total depth of vessel	D4	28	Meter
Angle of slope at strut	A1	41.18593	Degrees
Overall length of the top pontoon	TP1	120	Meter
Length of Triangular projection from pontoon	TP2	12	Meter

Figure 5-1: Final Dimensions of the ship after all the checks.

Draft (m)	Displacement (tons)	GM (m)	FSE (m)	Changed GM
10 – T1	34440	57.694	10.365	47.32
18 – T2	47035.2	8.22	7.589	1.8772
22 – T3	51373	9.4621	6.94	66.41

Table 9: Values of Displacement, GM , Virtual loss of GM

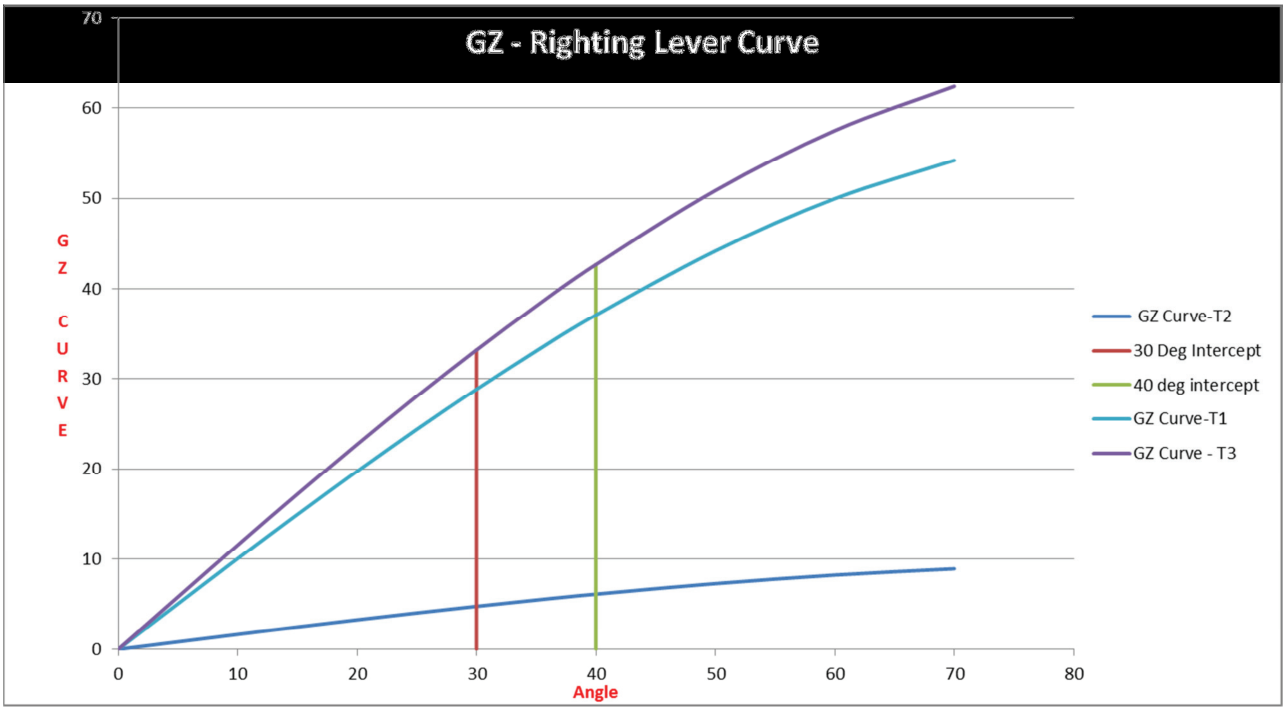


FIGURE 5-2: GZ CURVES AT ALL DRAFTS

Draft (m)	GM (m)	Changed GM	Lifting Moment Ratio	Average lifting moment value for Oleg Strashnov is 1.5354
10 – T1	57.694	47.32	33.265	
18 – T2	8.22	1.8772	1.797	
22 – T3	9.4621	66.41	62.341	

TABLE 10: VALUES OF GM, GM AFTER FSE & LIFTING MOMENT RATIO'S

The values shown above clearly indicate that the T-2 draft is the most interesting and can be tuned to the exact values as required in the criteria mentioned previously. These values need to be validated before moving on so the final results one gets with respect to the workability is true for the most sense.

5-2 Final parameters validated with ship shape

For the further validation of the concept parameters it is good to develop the shapes and design the hull, and confirm the values presented above in the parametric analysis with another source. In this section the basic working of the software used and back ground information are presented here. The results which are obtained from the software for stability calculations are compared with the stability calculation values as obtained in the parametric analysis conducted previously.

Ship shape is an interactive ship design, hydrostatics and stability software. The software was first developed for educational purposes by the Norwegian Institute of technology in congruence with the Norwegian Maritime Technology Research Institute (Marintek) in Trondheim, Norway [29]. It has come far from its initial days and now includes some special functions for offshore vessel, barge grounding, submersion calculations and more in addition to the standard applications one would find in it. It is very popular to use nowadays because of its intuitive configuration combined with powerful

and flexible functionalities which help creative designers and also help in performing standard calculations.
The model was created in ship shape with the exact dimensions of the results of the parametric analysis. The results and the full details are attached in the APPENDIX V. The important results are presented below and compared to the values established earlier.

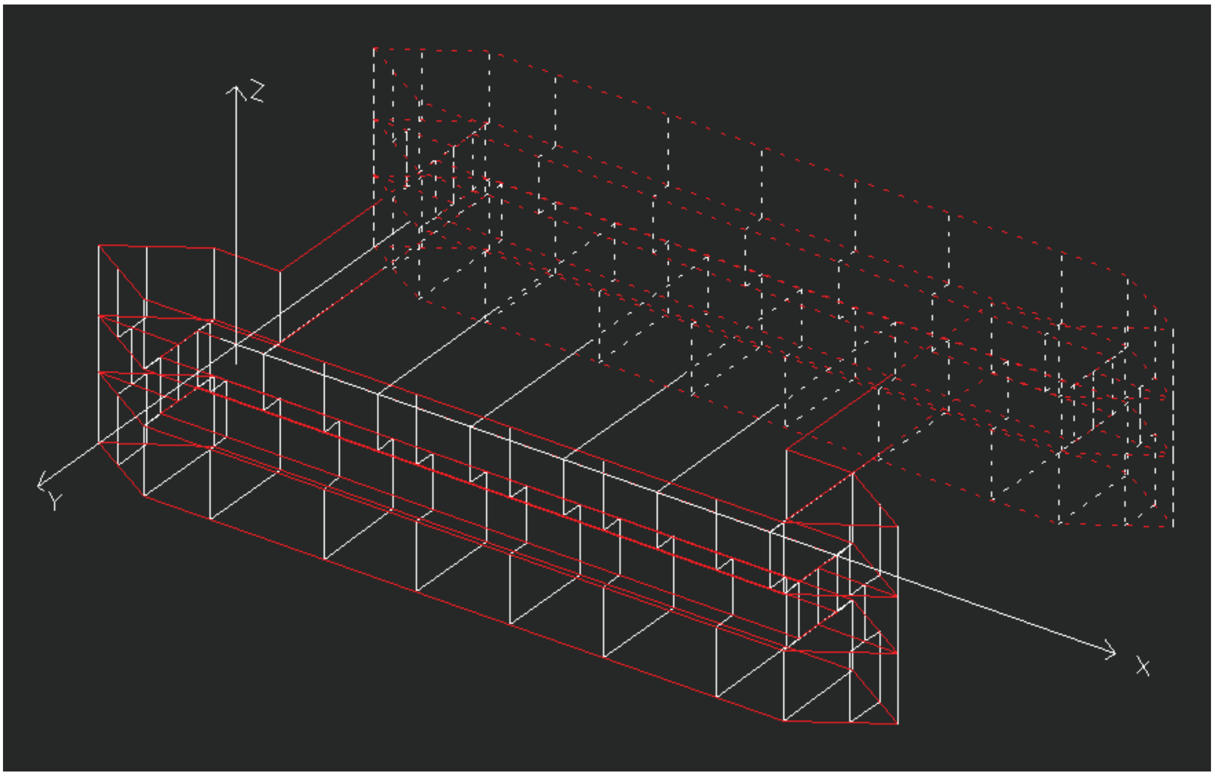


FIGURE 5-3: SEMI SWATH MODEL IN SHIP SHAPE

Sl no	Description	GM (PA) m	GM (SS) m	% difference
1	T1- lower pontoon	57.694	49.539	16%
2	T2- Strut level	9.4621	9.003	4%
3	T3- lower pontoon	59.46	52.897	12%

FIGURE 5-4: COMPARISON BETWEEN THE VALUES IN SHIPSHAPE AND THE PARAMETRIC ANALYSIS.

The important observations are:

- The values are almost similar in the case of T-2 which is the draft of interest
- The difference in T-1 and T-3 could be due to the exact shape – triangle which may be better defined in ship shape
- The Parametric analysis values can therefore be used in the further workability analysis.
- The GZ curves represented below for the Draft T-2 gives a clearer idea, compared to the GZ curves established in the previous section where it is assumed to be a sine curve. The GZ

curves established earlier also give an idea of where the 30 degree and 40 degree intercept are present.

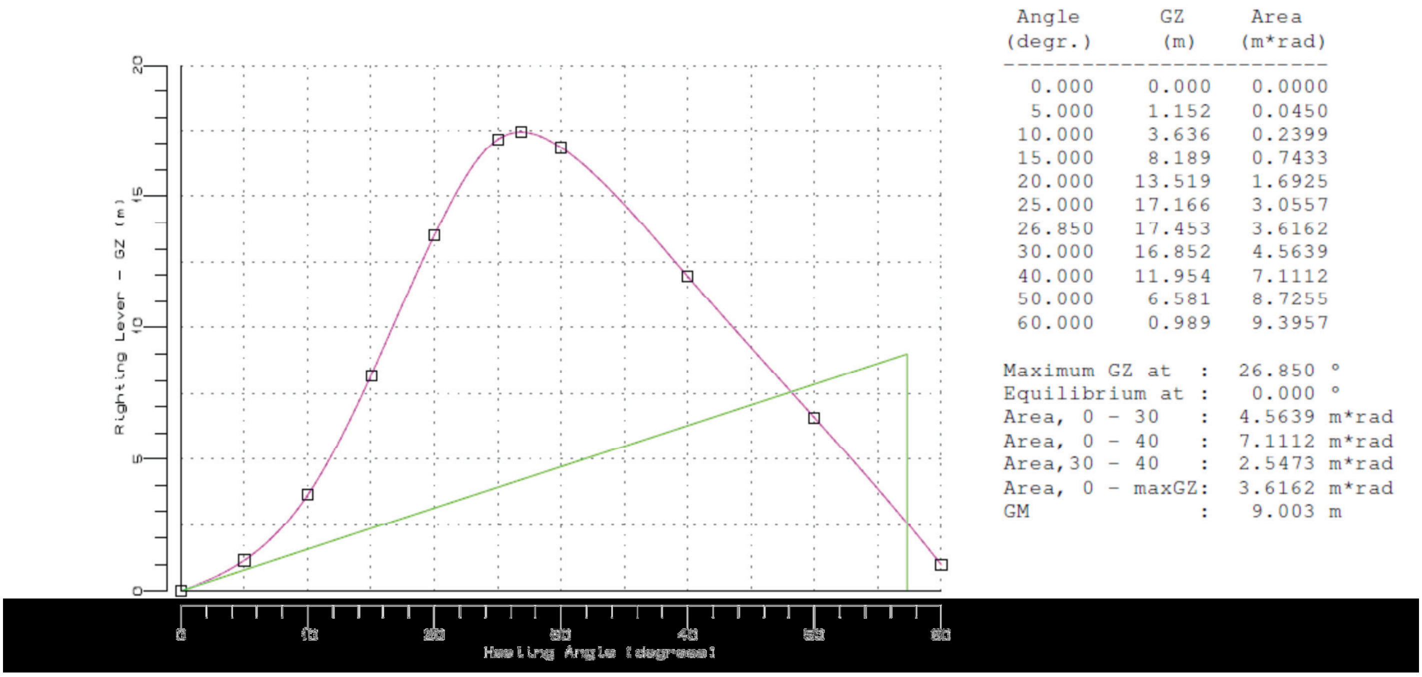


FIGURE 5-5: GZ CURVE FOR THE T-2 CONDITION AT STRUT SOURCE: APPENDIX V SHIPSHAPE REPORT

5-3 Longitudinal stability of the SWATH

The longitudinal stability of the SWATH type vessel is a very important parameter which has to be evaluated, to check if this does not limit the operational capabilities of the vessel. Especially during and just after installation the trim excursions in the vessel will lead to difference in drafts at the aft and bow. This could lead to stability issues especially in the strut level draft where the water plane area is small and small changes in weight could pose a problem. The detail calculations are attached in APPENDIX V.

Description	loaded ship with 1st turbine in aft side hook (m)	loaded ship with 8th turbine in aft side hook(m)
Change in draft aft side – lower pontoon draft 9m	0.488639418	0.244319709
Change in draft aft side – Strut level draft 18m	4.493278412	2.695330442

TABLE 11: LONGITUDINAL STABILITY CHANGE IN DRAFT VALUES

The important conclusions and suggestions are as follows:

- As expected the excursion are more at the strut level draft (18m)
- The excursions are not very significant at the lower pontoon draft (9m)
- The excursion reduce in value as the number of WTG's reduce on the dec

The installation operation at the strut level has to be assisted with a quick ballast system which can take in equivalent quantity of water at the other end of ship from where the installation is taking place. Since there are a lot of empty spaces in the deck they can be used as ballast tanks. The quantity of water also will be not much considering the moment arm is quite large.

5-4 Resistance estimation and calculation

The resistance calculations are important to predict the power requirements of the vessel and also helps with getting more clarity on the speeds at which the vessel can be operated. Based on the power requirements the speed can be adjusted so as to bring about a balance between CAPEX, OPEX and total project costs. It gives clear indications of the final design speed of the concept.

$$\mathrm{Rt} = 0.5 * \rho * V^2 * C_t * S \tag{5.1}$$

Where,
Rt = Is the total ship resistance in newton's
V = the ship's speed in m/s
ρ = density of liquid in tank kg/m3
S = Wetted surface area in m2
Ct = Coefficient of total resistance

This relation is for the total hull resistance which comprises of frictional resistance, form resistance & wave resistance. The other contribution is from the resistance due to wind, and at this stage estimating total resistance based on these two is sufficient for the concept design, to predict the power requirements.
The most important step is to get the right value for the coefficient of resistance as pointed out in equation (5.1). There are many methods to predict this value using parametric analysis, numerical methods, structural methods and finally by conducting experimental model tests. The last method gives more accurate predictions [30], although some of the parametric and numerical methods in recent years have been developed to the same level of accuracies. For a monohull design the data from existing vessel is readily available. But for the new design vessel it is always based on model tests. Since this is not part of the scope of this research, for the SWATH concept case three methods are used to predict the coefficient. The sensitivity of these methods with respect to each other is also established and the most conservative value is used in the power calculations.

- Method 1 - is based on regression analysis using parameters of already operating Swath vessels. The method involves listing all the main data available for these SWATHS. Then to establish some simple ratios based on the main dimensions and then match the concept SWATH to one or more of these SWATHS and use the Ct value from these SWATHS.
- Method 2 - is based on directly predicting resistance based on the most simplistic relations based on Reynolds number predictions as shown in APPENDIX V it is a very conservative approach [31].
- Method 3 – is to use the parametric method developed by Jan p. Michalski which is also expanded in the APPENDIX V. It is a method specifically developed for SWATHS [30].

Based on these methods the Ct calculated is seen in the table below and also the power calculations based on these resistances are also shown below.

Method	Ct	Resistance (KN)	Power required (KW)	Sensitivity (%)	This is calculated for the speed of 10 knots
Method-1	0.005615	702.809	27485.54	2%	
Method-2	0.004798	822.373	26870.5	0%	
Method-3	0.0114	1669.64	31843.91	18.5%	

TABLE 12: COMPARISON AND SENSITIVITY OF RESISTANCE FROM DIFFERENT METHODS

It is seen that the Ct from the third method is higher and as a result both the resistance and the power are also higher, but it is good to have a higher value for the power prediction to be conservative. The first method is more realistic because it is calculated based on the operational data available from the different swaths. The third method is also reasonable because it accounts for most of the effects which make the SWATH different from other vessels, and is also based on rigorous calculations and closely fits to the values of resistance for SWATH's predicted from other structural & numerical methods involving experiments [30].
The total resistance also includes the resistance which is offered from wind and also currents during the operation of the vessel. Hence it is also important to find the wind resistance component because of the WTG's on the deck, there will be a significant component which will contribute to the power estimation. The wind resistance can be estimated based on the following equation

$$\mathrm{Wt} = 0.5 * \rho_{air} * V_{rw}^2 * C_w(\alpha) * A \tag{5.2}$$

Where,
Wt = Is the total Wind resistance in newton's
Vrw = Relative wind velocity in m/s
ρ = density of air in tank kg/m3
A = Corresponding area based on direction in m2
Cw = Coefficient of total wind resistance
α = the relative wind direction

The wind resistance is calculated in the direction when α is 0 and the wind direction is just opposite to the direction of the ship motion, this will have the maximum resistance during sailing. The areas used are based on SHL results of wind tunnel testing for wind turbines, on Oleg Strashnov and the coefficients used are also from these tests [32]. The elaborated calculation methods are attached in APPENDIX V. The transverse area of projection is used accordingly in the equation (5.2).
The total resistance due to wind at different vessel speeds is presented below in the table 11.

Speed	Resistance (KN)	This is calculated for the Cw = 1.15 at α of 0 degrees and wind speed of 50 knots
20	6153.378847	
15	5305,719516	
10	4520.849765	

TABLE 13: WIND RESISTANCE FORCE ON THE SHIP AT DIFFERENT SPEEDS

The total power requirements after tabulating the total resistance (wind and hull resistances) are shown below for different vessel speeds.

	SPEED (Knots)				Ct value used
	20	15	10	5	
Estimated Power (KW)	97148.29	55216.16	27485.54	10299.22	Method 1
	88346.26	52177.42	26870.5	10284.68	Method 2
	132015.2	69925.66	31843.91	10844.02	Method 3

TABLE 14: POWER REQUIREMENTS OF OPERATING VESSEL AT DIFFERENT SPEEDS

It is seen that it is not viable to have a design speed of 15 or 20 knots for the vessel because the power requirements are quite large and the effect of reducing the speed to 10 Knots on the whole project duration is 18 %, which amounts to about 25 days in a total project duration of 60 days Appendix III (Table 4). So it is an important consideration and based on the workability study a balance has to be established on speed, Power requirements and the CAPEX an OPEX. Moreover the idea is to increase the workability of the vessel by adopting the SWATH design, hence from this point onwards the speed of the vessel is taken as 10 Knots for further calculations.

5-5 Power estimation and calculation

For power calculation the total resistance values from the previous section is used and the basic power requirements are calculated. It is seen since most of the data is unavailable at this point of time; hence most of the values used are based on previously existing Twin-Skeg ships [33]. The idea is to get a feel for the engine power required for the propulsion alone. The formulas used in the calculation are presented in APPENDIX V.

Power Estimation				
No	**Description**	**Symbol**	**Value**	**Unit**
1	Velocity of the ship	V	10	Knots
			5.144	m/s
2	operating draft of ship	D	18	m
3	Arriving water velocity to propeller (speed of advance of propeller)	Va	3.6008	m/s
4	Wake fraction	w range 0.2-0.45	0.3	
5	Resistance of the ship	Rt	6190.496	KN
6	Thrust reduction factor	t range 0.12-0.3	0.2	
7	Thrust	T	7738.12	KN
8	Effective (Towing) Power Pe=T*V	Pe	31843.91	KW
9	Thrust power (Pt=T*Va)	Pt	27863.42	KW
10	Hull efficiency	ηh	1.142857	
11	Open water efficiency	ηo range 0.35-0.75	0.55	
12	Rotational efficiency	ηr range 1 to 1.07	1	
13	Propeller efficiency behind hull	ηb	0.55	
14	propulsive efficiency	ηd	0.628571	
15	Shaft Efficiency	ηs range 0.96-0.995	0.99	
16	Total Efficiency	ηt	0.622286	
17	Thrust power delivered by propeller	Pi	27863.42	KW
18	Power delivered to propeller	Pd	50660.77	KW
19	Power delivered by main engine	Pb	**51172.49**	KW

TABLE 15: POWER DELIVERED BY MAIN ENGINE BASED ON THE EFFECTIVE TOWING POWER

The values in the yellow background are inputs from the previous section of resistance and speed calculations. The ones in the orange and green background are values based on existing data [33] and general limits for these values. Hence it is seen that the total power needed to be delivered by the engine is about 51172.49 KW. Hence it is good to split these into 2 engines with 30000 KW rating, on both the pontoons. Apart from these important considerations the other important conclusions are

- If dynamic positioning and heading control is used then the power has to be diverted to the thrusters involved.
- So while the propulsion is not being used the power can be diverted to the dynamic positioning and also the lifting operations and the crane.
- It proposed to use a diesel electric drive.
- Apart from this the other power requirements are also important for the whole ship to operate but these details are not worked out at this conceptual stage.

It should also be noted that these propulsion needs are at full capacity with 8 turbines of the limit size and weight. But at empty condition and lesser weight cases the draft will be lower and as a result the wetted surface will reduce, reducing resistance and power requirements as well.
Based on these values the propeller characteristics are estimated as follows based on previously existing open water curves for controllable pitch propellers [33].

Propeller details & matching the values				
No	**Description**	**Symbol**	**Value**	**Unit**
1	Propeller diameter	d range 5-10	9	m
2	diameter by design draft	d/D	0.5	
3	No of blades	usually 4, 5 or 6 blades	5	
4	n rpm of the blades	Based on fig	65	rpm
5	Advance Number	J	3.693054	
6	Torque	Q	74426.73	KNm
7	Thrust Coefficient	Kt	0.098043	
8	Torque coefficient	KQ	0.104777	
9	Open water efficiency	ɳo range	0.54999	
10	Power delivered to propeller	Pd	50661.68	

TABLE 16: PROPELLER CHARACTERISTICS

Conclusion

It is seen that the open water efficiency based on towing power requirements and the power delivered by the engine is in close congruence with the values calculated based on open water characteristics based in table 14 [33]. As a result of this the final design parameter is established for the concept swath the next step is to perform the frequency domain analysis and predict the workability of the vessel.

Chapter 6

Motion and workability analysis

At this stage all the pre-requisites for carrying out a motion analysis have been established. Since the vessel has satisfied all the initial testing criteria the last testing criteria are the motions at the different points on the ship. For the WTG's and also for the people working on board the vessel there are certain maximum motion conditions which are allowed and prescribed for safe operation. The vessel has to be now subjected to frequency domain analysis in congruence with the weather criteria at the site chosen to establish the motions. Finally these motions have to be correlated to testing criteria for motion and the final workability of the vessel has to be established.

6-1 Pre-requisites for motion analysis

Before the analysis is started there are some details which are required. It is assumed that the motion is harmonic and therefore the solution is based on frequency domain analysis. Some of the important requirements or details required before the analysis is started are as follows

- The spectral wave data for the location of Dogger bank
- The motion characteristics of the vessels in Installation and Transportation conditions.

The weather data is available directly but the Rao's have to be generated and the procedure for the same is explained below.

Motion analysis

This is done using ANSYS-AQWA suite of programs, along with the in-house Mat lab program to calculate the motions for a given 2D spectrum (including wave spreading).

AQWA LINE – computes the linearized hydrodynamic fluid wave loading on a fixed or floating rigid body using 3 dimensional radiation/ diffraction theory [34].

- The fluid forces comprise reactive and active forces.
- The reactive forces are due to the body motion and are calculated by investigating the radiated wave field arising from the body motions.
- The active forces are comprised of diffraction and Froude Krylov forces. They are calculated based on the scattering of incident wave fields and the undisturbed pressure fields in the incident wave respectively.
- The incident wave is considered harmonic and also having small amplitude compared to the length of the vessel.
- The fluid is considered to be ideal and hence the potential theory is used [34].

AQWA FER - uses spectral techniques to evaluate the significant response of a moored floating structure in irregular seas. Since it is a frequency domain program, no non linearity's can be accounted for. The significant motions of a point and differential significant motions between two points can be estimated using this program.

AXIS SYSTEM - The equations of motion are defined in a moving axis system with the origin at the centre of gravity. All 2-dimensional potential coefficients are defined in an axis system with the origin in the water plane.
The coordinate system in which the waves are defined is earth-bound and positioned in the still water surface the positive x-axis is in the direction of the wave propagation.

The ship motions are defined by three translations of the ship's centre of gravity in the direction of the X-, Y-, and Z-axes and three rotations about these axes, as given below [34].

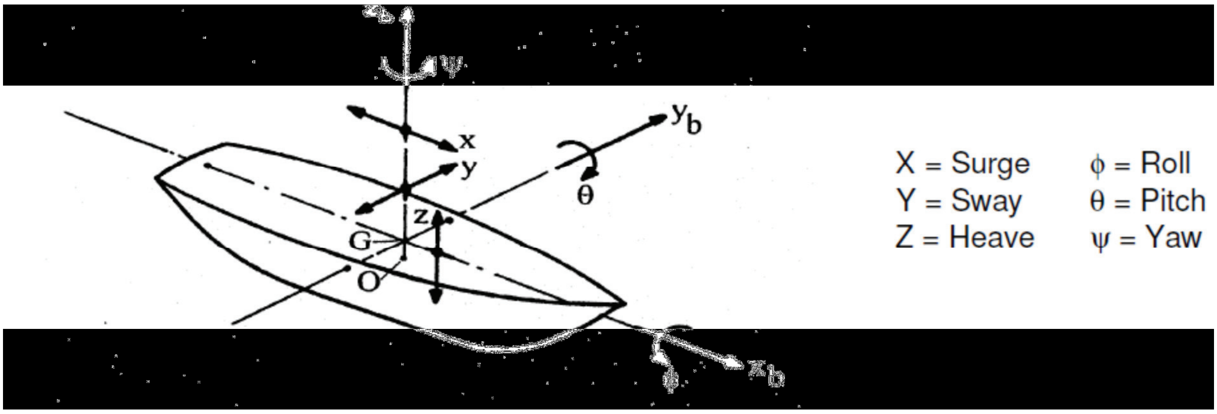


FIGURE 6-1: AXIS SYSTEM FOR THE AQWA CALCULATIONS

ADDED ROLL DAMPING - Total roll damping depends on the beam/draught ratio, bilge and bilge keel shape and roll amplitude. the radiation damping part is already computed by the AQWA program. Added (viscous) damping has to be input in the AQWA dat file. This data is usually available from model test or operational data.
Since this data is not available for the SWATH's the value is taken and assumed after relating it to the available data of a semi-submersible. Tuning this value based on general considerations to accommodate all the anomalies which differentiate the SWATH's from the Semi's. For the Monohull the values are used from the operational data available from Oleg Strashnov.

MODEL- The SWATH and the Monohull which are designed in SOLID WORKS based on the design parameters previously established, is taken into ANSYS. The axis system is adjusted and then the water line is defined based on the draft. The whole model is meshed and then saved as a DAT file (example attached in APPENDIX VI) which is the format in which the AQWA suite can process the model.

ENVIRONMENTAL CONDITIONS – To determine the Hs-Tp limits for the installation, the theoretical 3-hour wave spectra are set up using JONSWAP spectrum definition, associated with an Hs and Tp dependant gamma factor and a COS^4 wave spreading which is typical for the North Sea conditions. To evaluate the workability, 11 year (200-2010) 2D wave spectra data (source: Met Ocean Solutions) at the location Dogger bank 55.25N, 2E is used. The water depth is around 40 m for the installation purposes at the given location. Find attached below an example of the theoretical Jonswap Cos^4 Spectrum and also the 2D wave spectrum at the Dogger bank location.

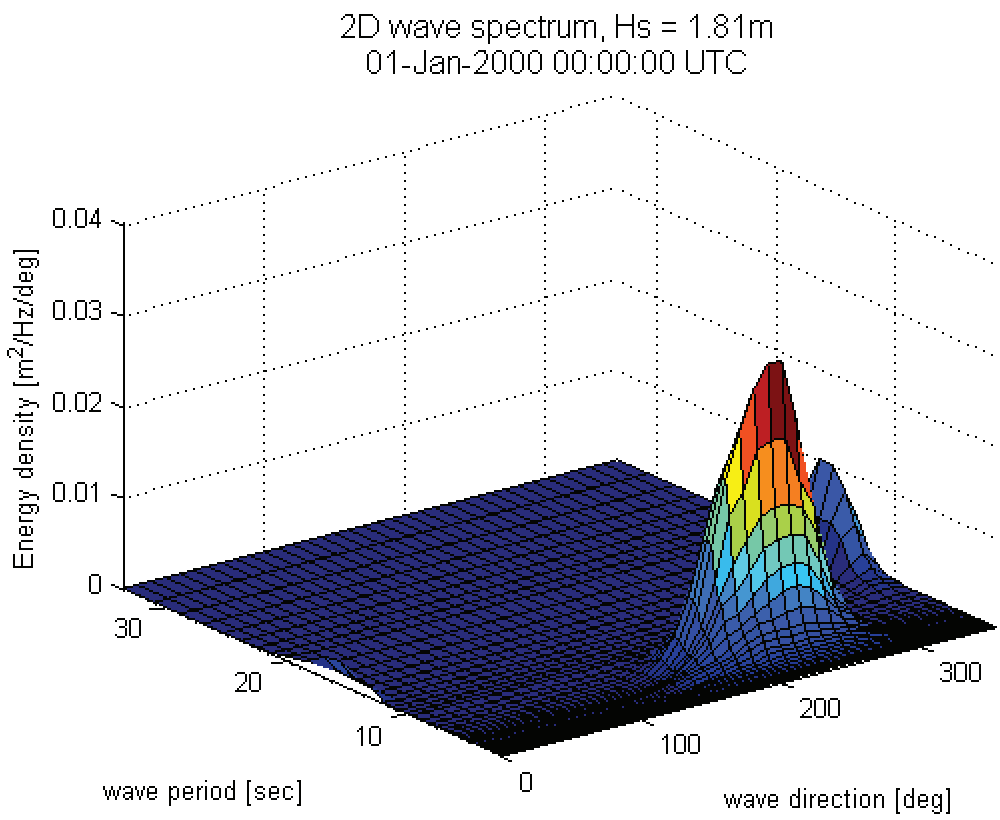


FIGURE 6-2: EXAMPLE OF 2D WAVE SPECTRUM AT THE DOGGER BANK LOCATION FOR A PARTICULAR HS

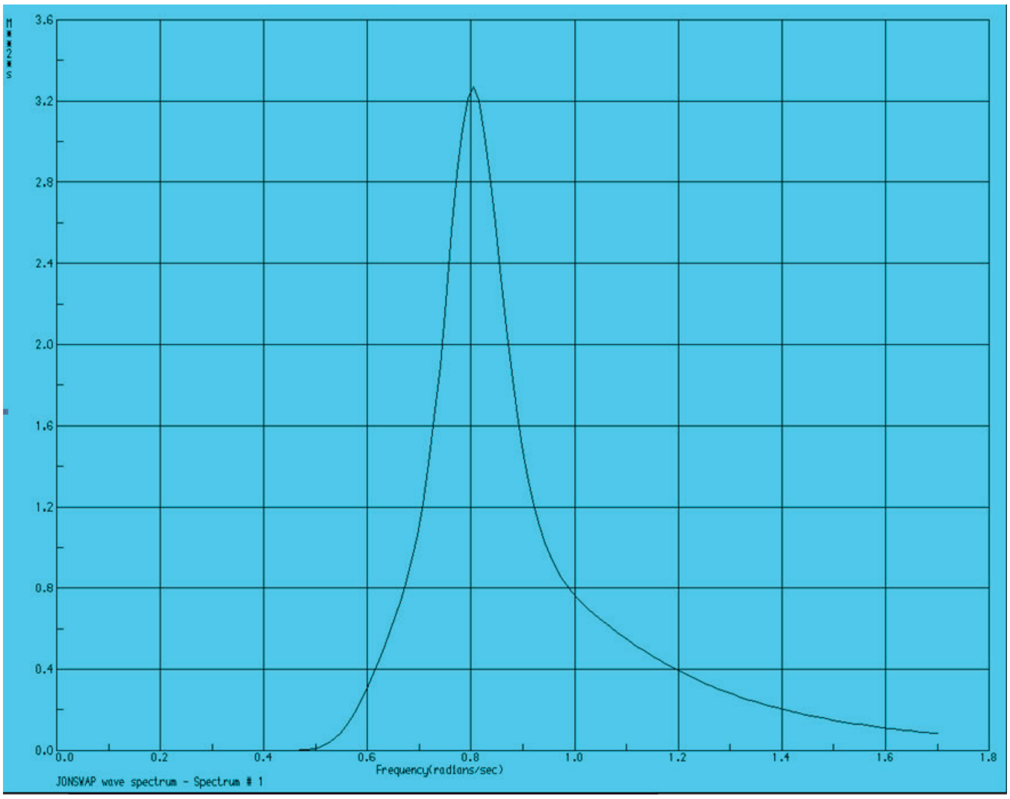


FIGURE 6-3: EXAMPLE OF THEORETICAL JONSWAP SPECTRUM USED

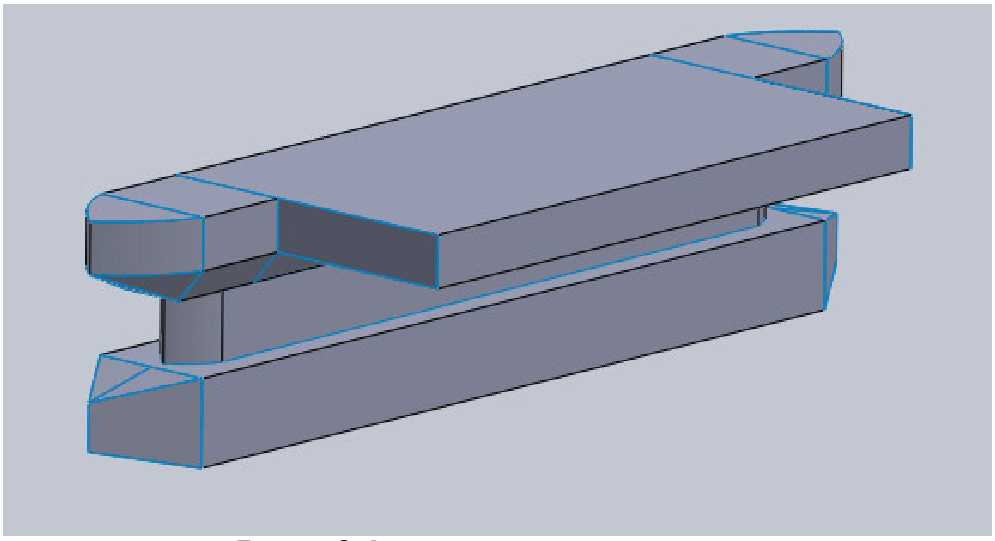


FIGURE 6-4: SWATH MODELLED IN SOLID WORKS

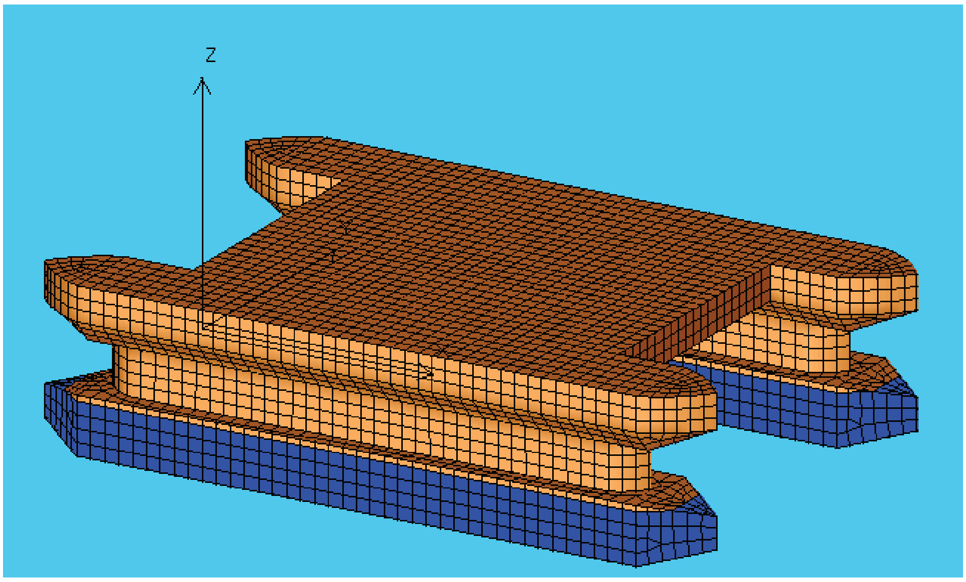


FIGURE 6-5: SWATH MESHED AND MODELLED IN ANSYS-AQWA

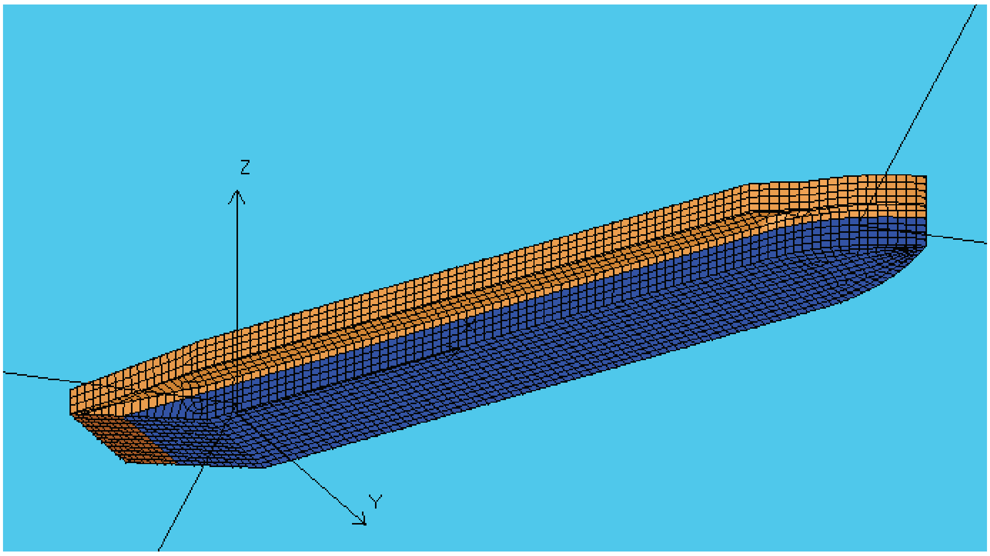


FIGURE 6-6: MONOHULL MESHED AND MODELLED IN ANSYS-AQWA

6-2 AQWA- calculations

The basic AQWA files generated have to be altered and some other data has to be added some of the main data are as follows

- Displacement – Calculated in the parametric analysis
- GM Metacentric height – Calculated in the parametric analysis
- Water depth
- The mass moment of inertia of the combined system (I_{xx}, I_{yy}, I_{zz}) including the ship and the WTG's
- COG – Centre of Gravity – Calculated in the parametric analysis
    - COG of the ship and combined system with WTG's
    - COG of the ship
    - COG of the ship and combined system during Installation with WTG in crane

All the above data except the mass moment of inertia have been established previously.

Calculations of mass moment of inertia

- Firstly the weight of each of the components of the WTG are calculated based on the data available and also comparing with other WTG's
- The nacelle and tower dimensions and weights are available
- Considering the nacelle to be a rectangular parallelepiped and the tower as a thin walled cylinder the moment of inertia for the individual components about their own axis's are found. Detailed sheet attached in APPENDIX VI.
- The mass moment of inertia of the ship is estimated based on the radius of gyration data obtained from operational SWATHS and Monohull. 40% of the breadth and length of the vessel [35]. Then I can be estimated based on a simple relation

$$K = \sqrt{(I/\Delta)} \qquad (5.1)$$

Where K is the radius of Gyration and Δ is the displacement

For 8 turbines with respect to the ship axis								
		Value	***Kg.m2***				***Value***	***Kg.m2***
		Ixx	155459968				Ixx	2762936578
		Iyy	156383792				Iyy	1475868396
		Izz	29943296				Izz	186915063.5
Draft T2				Total deck with WTG's			Ship	
				Value	***Kg.m2***		Ixx Ship(roll)	44619472128
				Ixx	2918396546		Iyy Ship(pitch)	60957619200
				Iyy	1632252188		Izz ship (yaw)	60957619200
				Izz	216858359.5			

FIGURE 6-7: EXAMPLE CALCULATION OF THE MOMENT OF INERTIA FOR ONE SITUATION

Following this the AQWA-Line program is run followed by the AQWA-Librium program. The second one finds the combined equilibrium position and also helps define points of interest where the motions have to be estimated. Followed by this the AQWA-FER program is used and the spectral analysis is done.

The same procedure has to be repeated for all the different drafts of both the vessels. Also for the installation the WTG has to be modelled and all the above parameters have to be re calculated for this condition and these new values used for analysis. These values have already been estimated during

the drop load analysis etc. attached in Appendix V. From the final run's the RAO's for all the situations can be outputted and used in the next step.
By performing the analysis in ANSYS AQWA, linearized response RAO's are calculated and used to calculate the Hs-Tp limits. The Hs-Tp limits are derived for the sea states based on the limiting criteria established previously.

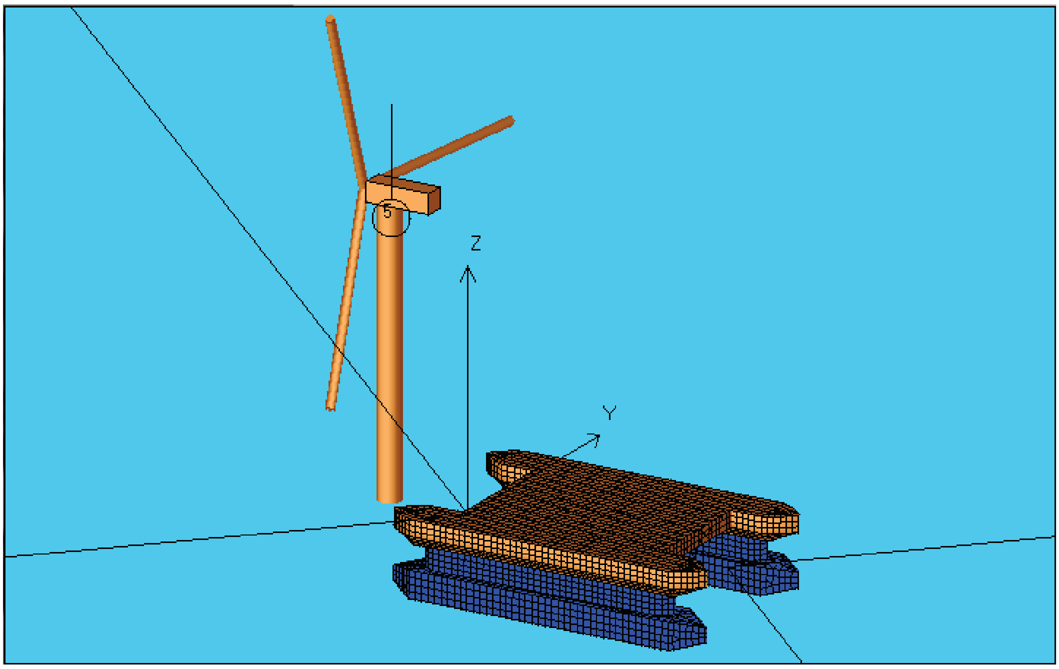


FIGURE 6-8: MODEL IN AQWA FOR THE INSTALLATION PHASE ANALYSIS FOR THE SWATH

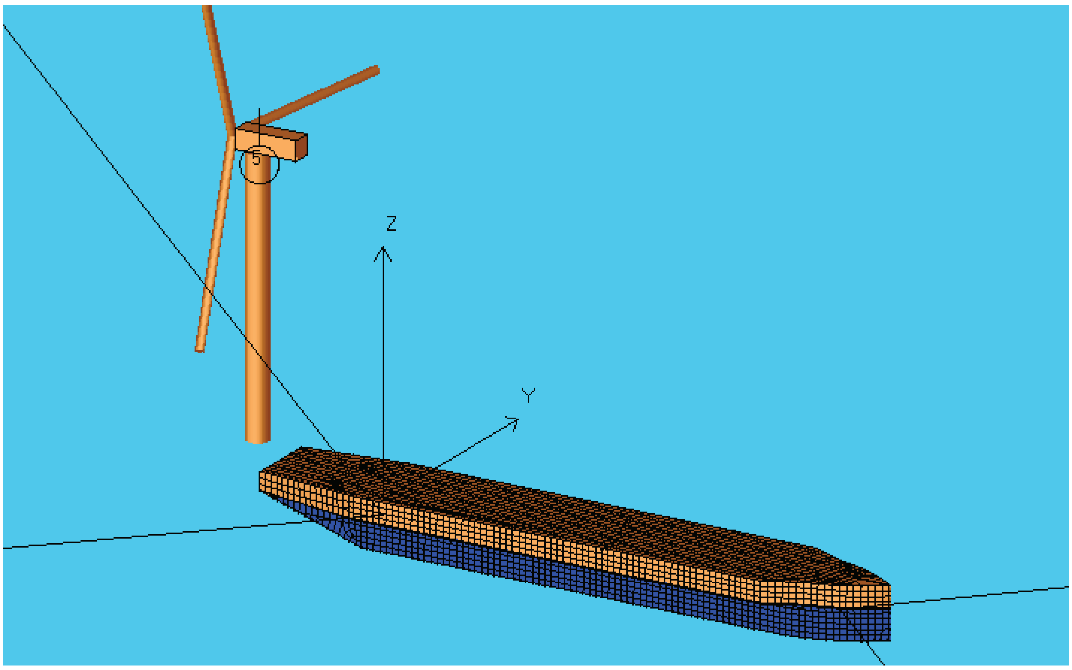


FIGURE 6-9: MODEL IN AQWA FOR THE INSTALLATION PHASE ANALYSIS FOR THE SWATH

Wave scatter diagram 2000 - 2010 Doggerbank 55.25N, 2E [ALL YEAR] for 0 degrees																							
		TP	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0	21.0
			2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0	21.0	22.0
HS																							
0.0	0.2																						
0.2	0.4			5	38	31	12	32	30	43	7	3	37	34	36	12	6						
0.4	0.6				54	240	413	218	187	152	108	41	70	84	103	71	48	11	5	7	2		
0.6	0.8				26	215	518	762	380	278	175	129	33	22	152	122	95	41	27	3			
0.8	1.0				4	109	327	709	954	316	310	171	43	26	62	72	134	55	21	16	5		
1.0	1.2					64	381	449	839	835	396	296	87	49	52	38	36	17	34	16	9		
1.2	1.4					7	254	303	514	776	667	319	106	46	23	30	22	11	5	1	2		
1.4	1.6					5	96	183	387	596	912	424	184	49	24	17	13	7	4	1	1		
1.6	1.8						44	176	261	331	672	583	221	91	34	9	4	2	7		4		
1.8	2.0						12	122	267	293	356	612	300	82	48	9	5	6	6	3	1		
2.0	2.2							85	225	232	242	446	374	81	37	3	4	4	4				
2.2	2.4						1	47	186	194	176	308	416	110	37	2	3	4					
2.4	2.6							11	143	160	147	222	314	111	55	5	9	7				2	
2.6	2.8							2	91	119	119	132	223	79	41	6	2	7				5	
2.8	3.0							1	55	103	95	71	147	118	71	18	6	2					
3.0	3.2							1	25	102	72	52	126	85	73	32	1						
3.2	3.4								10	85	91	58	85	54	83	31	2						
3.4	3.6								3	36	97	65	61	39	64	39	1						
3.6	3.8									27	114	63	40	41	58	13	5						
3.8	4.0									23	70	53	38	18	30	13	3						
4.0	4.2									11	68	77	33	15	32	19	6	1					
4.2	4.4									1	35	77	26	9	14	6	3	4					
4.4	4.6										11	50	27	5	12	6	2	8					
4.6	4.8										12	66	26	6	3	13	3	5					
4.8	5.0										7	50	23	4	6	12	5	7					
5.0	5.2										4	51	26	5	8	6							
5.2	5.4										1	19	27	11	3	4							
5.4	5.6											16	35	13	5	3							
5.6	5.8											11	33	12	1								
5.8	6.0											2	33	9	2								
6.0	6.2											3	13	10	3								
6.2	6.4												9	9	1								
6.4	6.6												7	3									
6.6	6.8												5	3	1								
6.8	7.0													3									
7.0	7.2												4	2	1								
7.2	7.4												1	3	2								
7.4	7.6													1	5								
7.6	7.8														3								
7.8	8.0														1								
8.0	8.2														1								
8.2	8.4																						

FIGURE 6-10: WAVE SCATTER DIAGRAM OF THE DOGGER BANK AREA FOR 0 DEGREES. SOURCE: SHL

Chapter 7

Results and recommendations

The analysis is done for the Vessels in two different modes the first being transport in all directions and the installation of the WTG again in all directions. The resulting RAO's are outputted from the ANSYS AQWA program and in conjunction with the wave spectra details the workability is worked out, with the in house Matlab program developed at SHL. The limits for the workability are based on the limitations of accelerations, set down velocity and general parameters associated with vessel motions as mentioned in the table below. The results can be presented in two forms the

- Hs-Tp curves for each direction which basically gives a relation between the periods and the wave height for the given direction of the vessel operation with respect wave spectrum direction. Also they give an indication of the maximum Hs at which the vessel can operate for a given period satisfying the limiting criteria.
- The workability for the complete operation which is in two phases, transport for a given time and then installation of the first wind turbine

			Vessel		point on nacelle					
No.	Description	Duration	roll	pitch	ax1	ay1	az1	ax2	ay2	az2
		Hours	[deg]	[deg]	m/s2	m/s2	m/s2	m/s2	m/s2	m/s2
1	Transportation	18			4.905	4.905	2.943	4.905	4.905	2.943
2	Installation	9	1	1						

FIGURE 7-1: LIMITING CRITERIA USED FOR THE SHIPS FOR TRANSPORTATION CONDITION

			Crane tip							
No.	Description	Duration	x	y	z	x	y	z	Vz	Az
		Hours	m/s2	m/s2	m/s2	m	m	m	m/s	m/s2
1	Transportation	18								
2	Installation	9	4.905	4.905	2.943	1.3	1.3	1	0.63	0.39
Note : Wind speed according to SS7is 12 m/s for the installation process										

FIGURE 7-2: LIMITING CRITERIA USED FOR THE SHIPS FOR INSTALLATION CONDITION

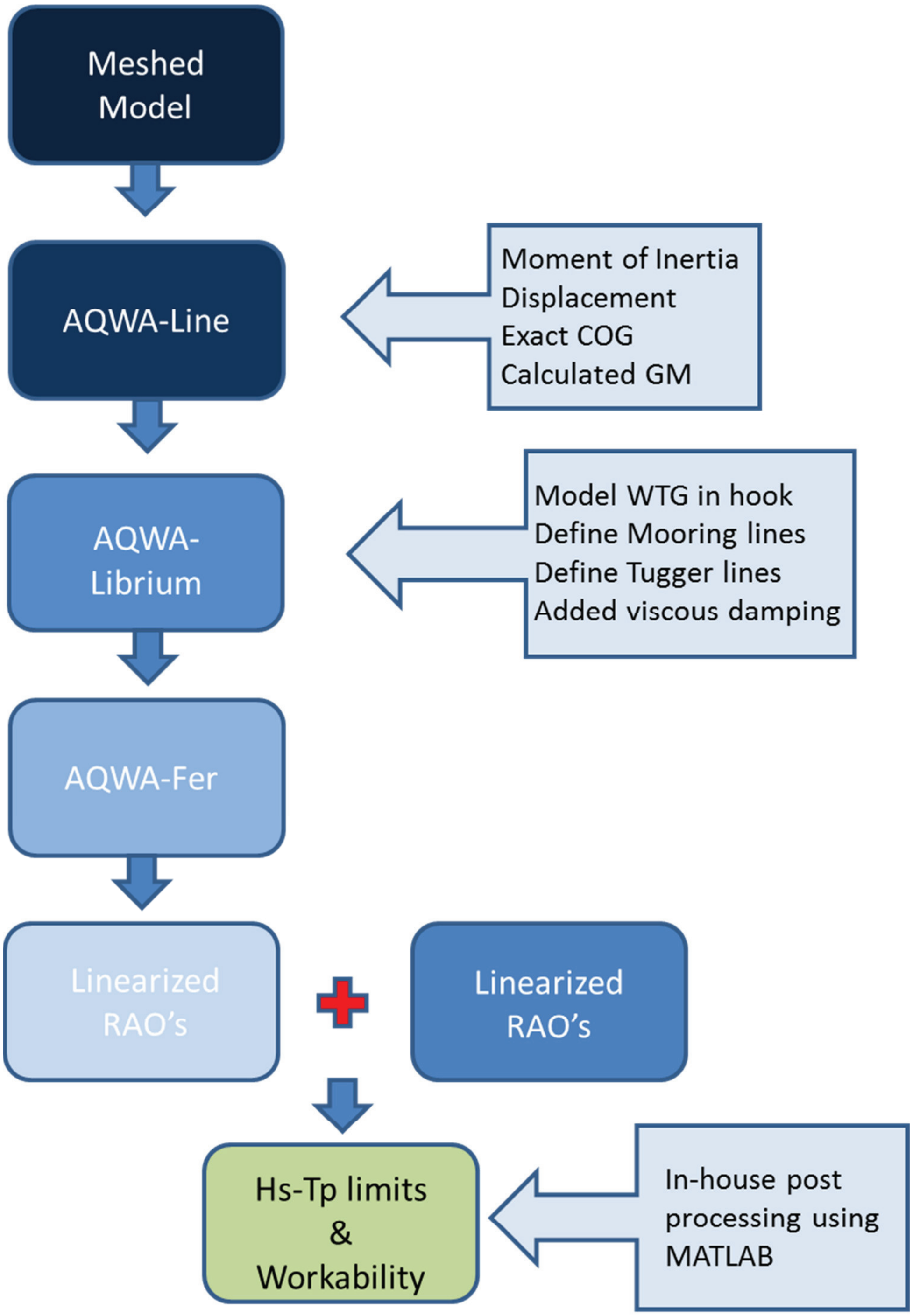


FIGURE 7-3: FLOW CHART FOR THE ANALYSIS

7-1 Observations

The RAO's which are got from the ANSYS AQWA are first analysed for anomalies. The Sheets are attached in Appendix VII. The Pitch, Heave and Roll are analysed at 90º & 180º directions for the transport conditions (SWATH- 9m & 18m draft, Monohull- 8m draft) & Installation mode (SWATH- 9m & 18m draft, Monohull-1 2m draft) . That is the direction perpendicular to the starboard side & form bow to aft directions. This is the case for the installation at the centreline at the aft of the ship

HEAVE

- @ 90º
  - There are two pronounced peaks one each for the SWATH at the draft 9m the peak is at 8 seconds and for the 18m draft at 15 seconds
  - For the lower and the higher draft of the Monohull the peaks are not as pronounced as the 18 m draft SWATH but they lie in the lower period zone where the wave energy is present
- @ 180º
  - The observations are similar and the peak for the 18m draft is more pronounced in this case
  - There are secondary peaks at the longer periods in all cases

Conclusions

- Even though there is a pronounced peak at the 18m SWATH case it is in the longer period as result not much wave energy exists here
- The other draft (9m) for the Swath and the Monohull have smaller peaks but in the region where there is quite a bit of wave energy
- Hence the best case here is the 18 m draft SWATH in the lower periods. But in the region of 12-15 seconds and for the others of the PHC and AHC type compensation systems have to be considered.

PITCH

- @ 90º
  - For the transport case the SWATH does not exhibit any peaks at either drafts, but with forward speed this might change. But the monohull has a predominant peak in the lower period zone
  - For the installation modes the there are multiple peaks for the pitch motion in the SWATH this may be attributed to the dynamic modes in which the WTG oscillates, dude to normal pitch and heave induced pitch but the peaks are not significantly high and occur in the long periods
- @ 180º
  - The SWATH (9m draft) at 12 seconds has a high peak so one should avoid operating at this period in both the modes of operation

Conclusions

- As predicted the swaths do have a significant problem with pitch but if operated at the draft near the struts this problem is not as significant during installation
- The pitch could be a significant problem when the vessel has forward speed and could cause some problems but that is not studied in detail here
- Hence the best case here is the 18 m draft SWATH because the peaks are moved away from the high energy area

ROLL

- @ 90º
  - Small peak at 12 seconds for the 9 m, for the 18 m draft no significant peaks except a small peak at 60 seconds multiple peaks are present due to motion of the WTG.
  - The Monohull also has a peak but at longer periods
- @ 180º
  - The Monohull at both drafts have pronounced peaks at 10 and 40 seconds
  - The swath has a peak at 25 seconds

Conclusions

- The Monohull has a significant roll problem
- The SWATH at 9 m has a higher tendency to roll than the 18 m draft SWATH

From just looking at the RAO's it is seen that the SWATH operated at the 18m draft behaves much better than the Monohull and the 9m lower pontoon draft of the SWATH. Mostly because the peaks at this draft are steered away from the high frequency zone of the wave energy and this will have better workability.

OBSERVATIONS FROM THE Hs-Tp CURVES FOR TRANSPORTATION (Appendix VII)

- @ 9m draft – SWATH
  - The limitations are caused mostly due to the roll and pitch of the vessel itself
  - At 8 seconds the Hs is 4m and beyond that reduce to 2m
- @ 18m draft – SWATH
  - The limitations are caused by the roll and the pitch but the they occur at higher periods and hence the vessel can operate at higher Hs values than the above case
  - AT 8 seconds the Hs is 7m and at 10 seconds it is 6.5m
- @ 8m draft – Monohull
  - The Monohull is bad at the higher periods it can operate only at the Hs of 2m beyond 8 seconds period

Conclusions and recommendations

- The 18 m draft is the best solution for the purely transport compared to the others, the SWATH at lower draft and the Monohull have similar behaviour
- The pitch could increase at forward speed for the SWATH but this will also mean the same effect on the Monohull because of its huge length
- Slamming is also not considered

OBSERVATIONS FROM THE Hs-Tp CURVES FOR INSTALLATION (Appendix VII)

The analysis for the installation of the first turbine on the aft side of the vessels yielded the following results

- @ 9m draft – SWATH
  - The limitations are caused mostly due to the roll and pitch of the vessel itself and also the allowable accelerations of the nacelle in the hook of the crane
  - Also the set down velocity limits are also quite significant and the allowable displacement of the main hook is also breached
  - At 6 seconds the maximum Hs is 1m as a results it can operate only below this period beyond this the maximum Hs is well below 1m
- @ 18m draft – SWATH
  - The limitations are caused by the y acceleration of the nacelle but otherwise the vessel can in significantly higher Hs even in longer periods up to 10 seconds making it suitable even for regions of swell
  - At 4-6 seconds there occurs a small peak where the nacelle acceleration limits in x and y direction are reached and in this zone the Hs is 2m but this can always be controlled with effective tugger wire system at the base of the WTG.
- @ 12m draft – Monohull
  - The Monohull is bad at the higher periods it can operate only at the Hs of 1m and lesser beyond 8 seconds period. Also at the lower periods the maximum allowable Hs is not as good as the SWATH(18m draft)

7-2 Workability and observations from combined operations

The combined operation involves two stages of the operation, and the phases are as follows

- SWATH
  - The first phase is to analyse the motions with the wind turbines on the deck transport phase
  - The next phase is installation, where the WTG will be installed from the aft side of the vessel
  - The combination of transport and installation is analysed at the 18m and the 9m draft
- Monohull
  - The transport is similar but the draft for the transportation is 8m draft
  - The installation is at 12m draft

The workability is also calculated by an in house program developed at seaway in Matlab which works on the principle of workability calculation for irregular sea states. The combined RAO's from ANSYS AQWA are used as transfer functions and the motion response spectrum for each motion type is found in conjunction with the wave spectrum from the location [36]. Then each cell in the spectrum is checked for concurrence with the limiting conditions and then the total operational workability is calculated. Find attached the workability of the vessel shapes in the table below and the detailed sheet in APPENDX VII.

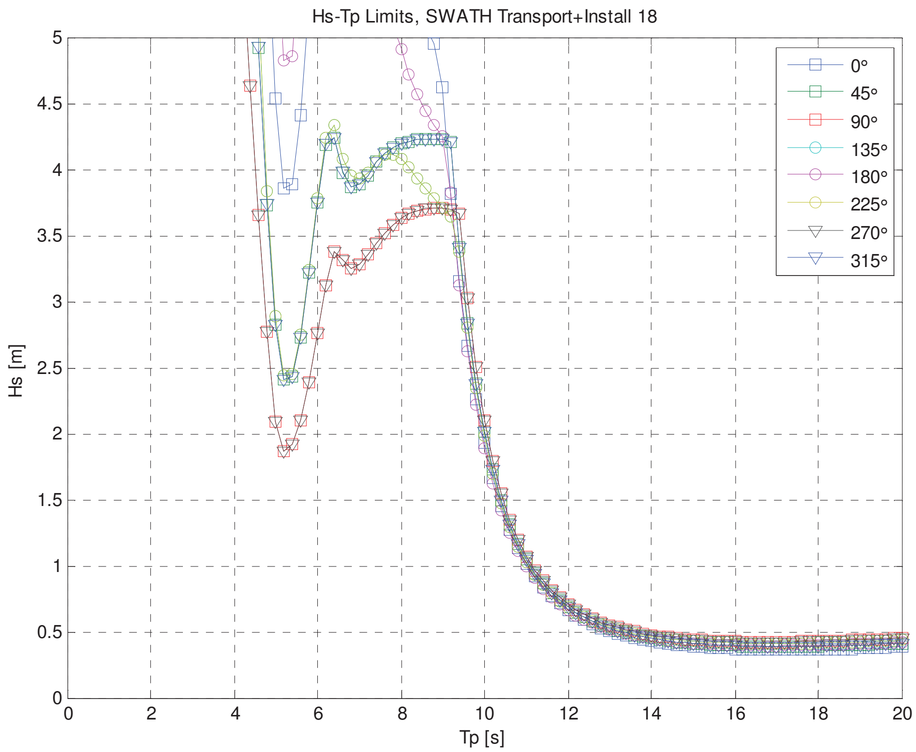


FIGURE 7-4: HS-TP CURE FOR THE COMBINED OPERATION OF SWATH AT 18M

OBSERVATIONS FROM THE Hs-Tp CURVES FOR COMBINED OPERATION (Appendix VII)

- @ 9m draft – SWATH
  - It is seen that the vessel can operate beyond 8 seconds only at maximum Hs of 0.5m or less

    - These observations will reduce the workability of the vessel at this draft
- @ 18m draft – SWATH
    - The Hs-Tp clearly shows a higher Hs for the operations at this draft and hence this is the preferred design choice
    - Between 4 and 6 seconds small peak and this interval maximum Hs is 2m
    - This obviously means the swath has better workability when operated at the strut level
- @ 12m draft (Installation) & 8m draft (transport) – Monohull
    - The observations are similar and comparable to the SWATH performance at the 9m draft

Operation and vessel type	Workability in the most favourable direction in %		
	Jan - April	May - Sep	Oct - Dec
SWATH Transportation + Installation @ 9m Draft	11.25	57.6	8.67
SWATH Transportation + Installation @ 18m Draft	48.25	92.6	46.33
Monohull Transportation @ (8m) + Installation @ (9m) Draft	32.75	79	40.3

FIGURE 7-5: WORKABILITY OF THE VESSELS THROUGHOUT THE YEAR APPENDIX VII

7-3 Conclusion and recommendations

It can be clearly deduced from the above observations and results, that for these given set of parameters the SWATH operated at the strut level is definitely a better choice. For the preliminary boundary conditions chosen in this design basis, for both the transportation and installation the SWATH is the better solution. Mainly because of the following reasons

- The workability is observed to be good year round
- There is less interaction with the waves and as a result lesser energy transfer to the vessel and the reduced water plane area also adds to this effect
- The SWATH has more directional independence compared to the Monohull in this case
- It has reduced Length and breadth (100mx70m) compared to the Monohull (240mx35m) making the SWATH access a larger number of ports and harbours
- The Monohull will envisage a complex transfer system of the WTG's towards the aft of the ship from the bow, which is not required for the SWATH
- The power requirements of the Monohull will be more than that of a SWATH because the size and the wetted surface area at the water line for the Monohull are higher for the same given payload
- The SWATH if operated at the lower draft at the lower pontoon has a lesser workability compared to the Monohull as well, which makes it a less interesting choice
- The SWATH at 18 m draft can be used in swell conditions at a higher Hs as well (Appendix VII). This can be seen from the curves (Hs – Tp, combined case). The other cases don't comply with this.
- The RAO's and the motion analysis for transport operation show a large difference between the Monohull and the SWATH. Hence even if the installation phase does not

work out the SWATH design can definitely be designed or conceptualised to operate purely as a high speed transport for fully assembled WTG's

- The deck space on the SWATH is higher so even mono piles can be accommodated for the same initial conditions so increasing the scope of operability
- The Swath will also have the flexibility of operating at both deep water locations and shallow water locations and can also operate at different draft modes giving it more operational flexibility

From all the above conditions and observations, it is seen that the goal to increase workability for a vessel to install WTG's in high seas is possible through this different design concept, mostly based on the preliminary design conditions as listed in the thesis. The overall requirements of installing wind turbines in one piece, and to improve the workability in the extended summer season for the North Sea operability is more or less achieved. But there are some important parameters which will still contribute to reduce these results and the aim would be to spend more time to include these parameters as well.

RECOMMENDATIONS

After all that is said and done there are still certain boundary conditions which will still govern the choice for the vessel, and these need to be evaluated if SHL wants to pursue the design. Some of the more important ones are as follows:

- A very quick ballasting system has to be incorporated for the changes which are required to be made to the displacement
- A good sea fastening system has to be established to hold the blades and the WTG itself in place
- The power has to be used for both purposes in phases. During transit no power is required for DP operation and lifting. When installing no propulsion other than used for DP is required. This has to be kept in mind during the detailed design of the dynamic positioning system.
- The viscous damping component which was added into the AQWA files is based on the values of that of an operational semi sub. Hence it is not exact it could either be small or more as well. To get an exact value for this model tests are recommended
- The parametric pitch condition is present in all the operational SWATH's but in the results they could not be comprehended. Mainly because the transport analysis was not done at forward speeds and this effect shows up only during higher speeds. Again model tests are recommended. But in this case the SWATH is not being operated at high speed so this problem might not even manifest.
- The effect on the fatigue life of the WTG's can also be further studied based on this design and approach of calculating motions.
- The concepts with the PHC an AHC can be tested with the same vessel to see if the heave RAO's and workability for installation improves.
- There are more detailed analyses required to confirm the feasibility and workability figures presented above like damage stability, structural interactions between the two hulls, strength of the deck box, slamming and all possible dynamic interactions.

Based on all the recommendations it can be seen that even though some of the major limiting criteria seem conservative and some boundary conditions are not tested for, on an even comparison between the SWATH and the monohull, the SWATH is a better equipped to perform the role of floating installation solution for the wind farm development. So it will be interesting to perform more studies in this direction, since there will be huge demand for these kind of vessels even if the floating foundations come into play. As seen, the SWATH can be employed to act with a less complicated compensation system. The time required for installing WTG's can be improved this way. Also for SHL to be able to give a complete solution to the industry with one vessel to install all the wind turbines including the foundations and mono piles can be envisaged.

APPENDIX-I

CONCEPT AND PROBLEM DEFINITION

1. Solution-1
2. Solution-2
3. Initial concept Sketches
   - Concept-1
   - Concept-2

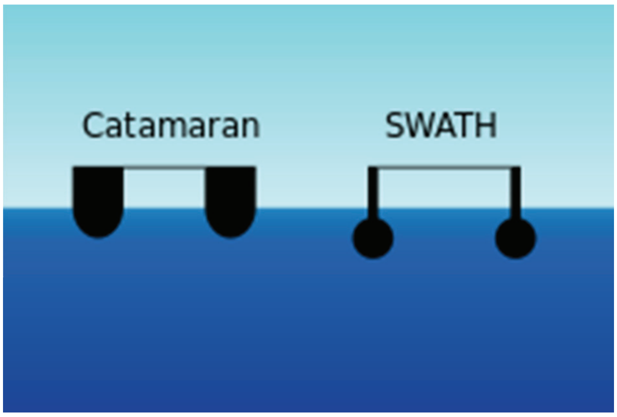
Solution 1 – Possibilities

Concept

One of the options to handle the problem at hand would be to develop a completely new vessel. The vessel will be dedicated for transportation and installation of the WTG's either in one piece or in a few possible configuration after checking the fatigue characteristics of the WTG's during transit and installation.

Looking ahead

- Establish all the functional requirements of the operation (like speed, carrying capacity, crane capacity etc.)
- Design basis for the vessel based on the functional blocks
- Establish some basic dimensions of the vessel and make a model or line diagram to import into AQWA for this we need the following
    - Proper understanding of possible hull shapes, advantages and dis-advantages of each form (SWATH's, Catamaran etc.).
    - Feasibility of using the hull form for the above purpose as a crane vessel has to be studied
    - Multi criteria analysis has to be done for the hull shapes and a couple of feasible and possible solutions should be chosen.
- Model the WTG's and try to place them and integrate with the vessel, try different configurations and choose most feasible ones for analysis in AQWA.
    - Design and study different concepts for best configurations for transportation.
    - Design concepts and configurations for lifting and installation.
- Establish basic capacities of cranes and other possible material handling (possible J lay type tower for installing the tower part).
- Use these shapes in AQWA then make a mesh subject to diffraction analysis and check the motions
    - First for the hull shape chosen
    - Then for the WTG's kept at different places or in different configurations
    - During free lift calculate accelerations of the different locations
    - Calculate the motions during set down as well
- Analyse the workability based on these results. Also then based on the results look at improvements to systems like hull shapes, heave compensation systems and check if the response can be improved.



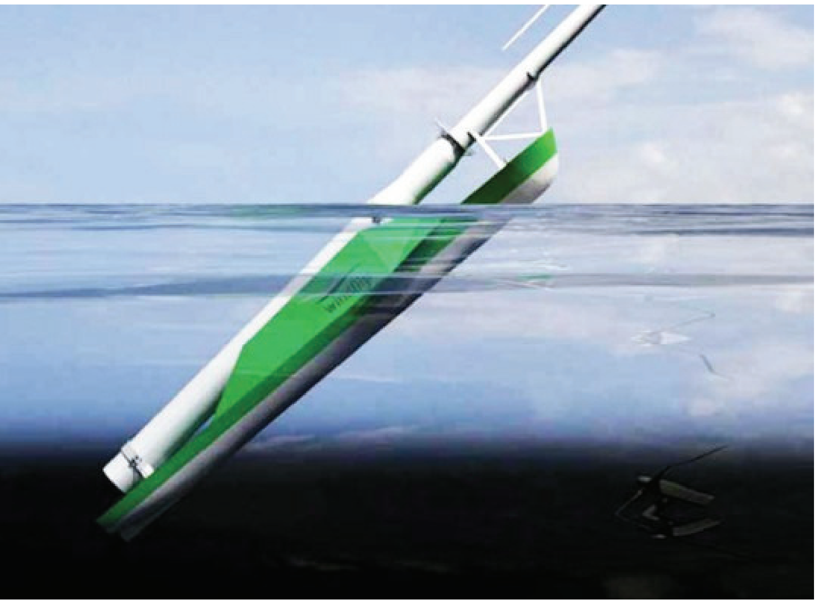
Solution 2 – Possibilities

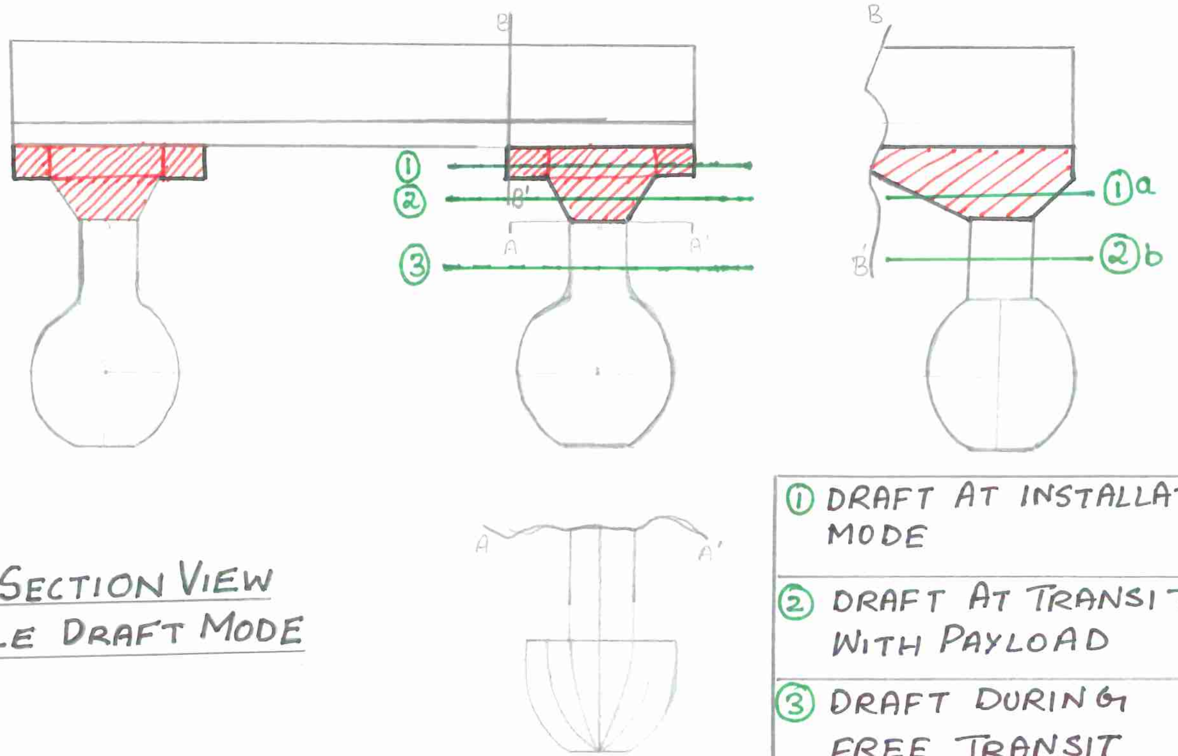
Concept

The second possibility is a slightly a different approach, with the installation taking the back seat but the priority being the transportation of a number of pre-assembled WTG's. The WTG's will be of the next generation larger modules. The installation will be done using the Oleg strashnov. The idea is to develop a high speed transit transport vessel/barge. This vessel will bring the assembled WTG's in one piece from the manufactures load out yard. Then the HLV will lift in one piece and install.

Looking ahead

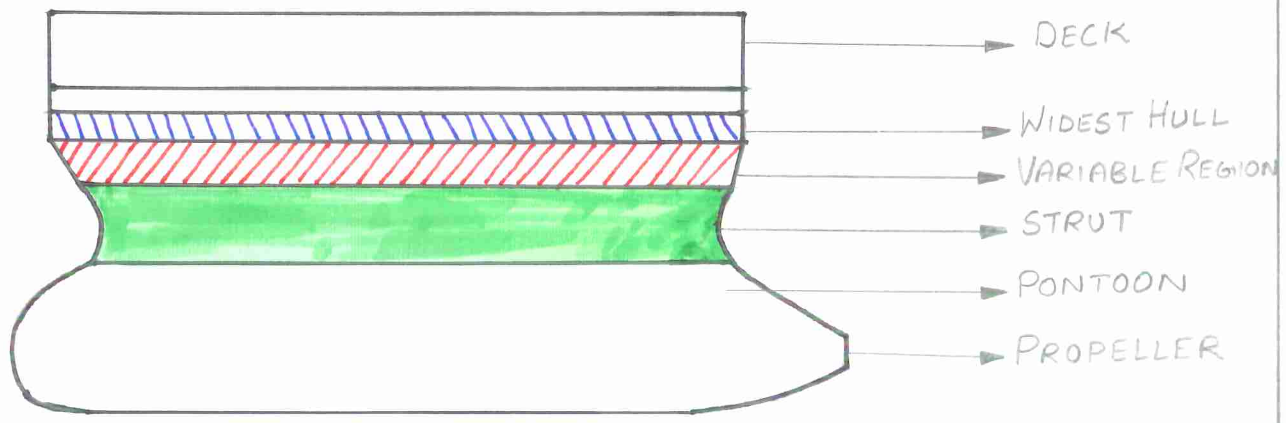
- Model the WTG's
- Establish a design for this specialised vessel which will be self-propelled bearing in mind the functionalities and the size of these turbines
- After which a design basis can be developed for the vessel and some basic design parameters and sizes established.
- Design or establish concepts for carrying these WTG's in a completed form.
- Place them on the specialised vessel which should be modelled in AQWA and check all possible motions.
- The motions and stability during transit and also high seas during the installation phase to be established.
- The mooring mechanism (mooring on anchors is still possible up to approx. 350 m) or DP based on the vessel type has to be conceptualised for the installation phase.
- Installation approach and mid sea lift of by the HLV to be established and conceptualized.
- Then it is possible also to use these results in a suitable analysis to check for the workability of the whole process.
- Based on the above results improvements can be made.



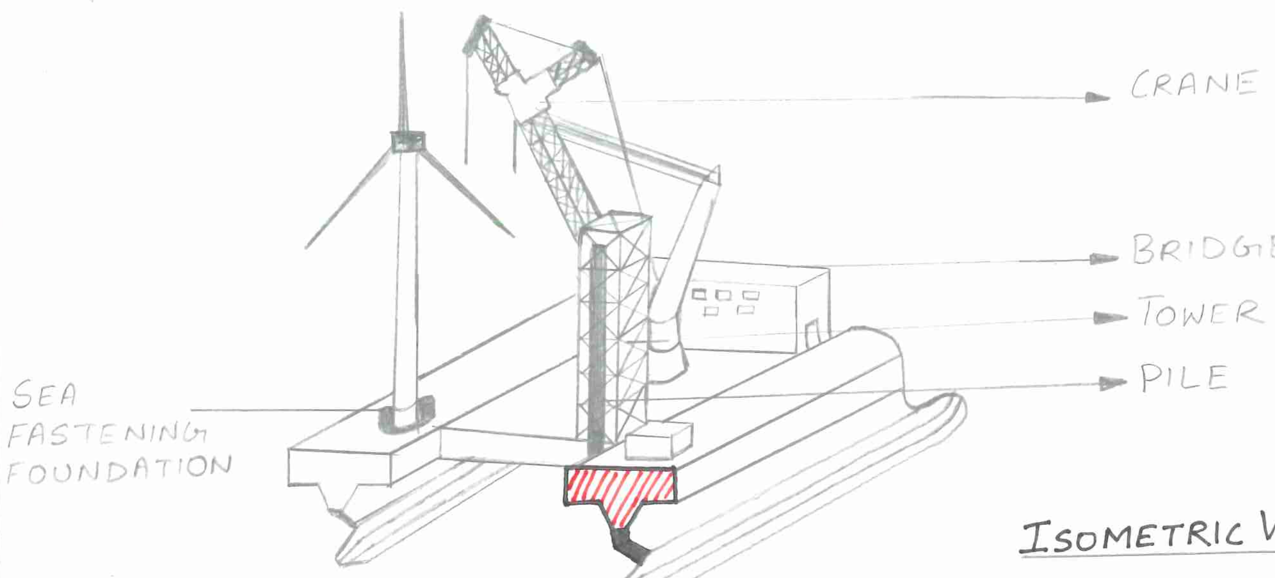


FRONT SECTION VIEW
MULTIPLE DRAFT MODE

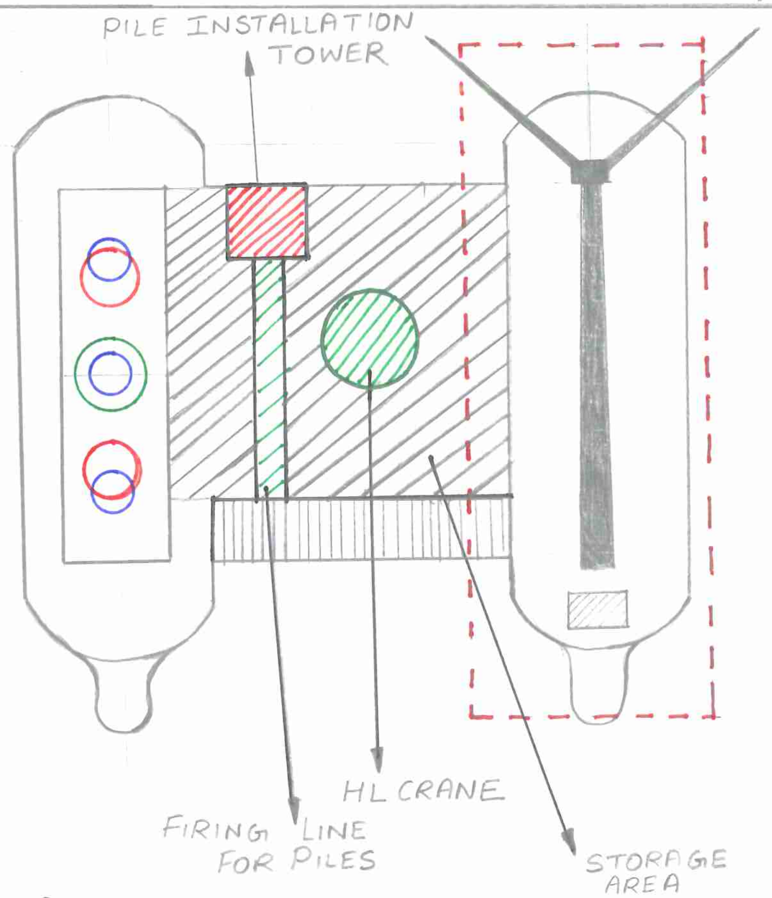
①	DRAFT AT INSTALLATION MODE
②	DRAFT AT TRANSIT WITH PAYLOAD
③	DRAFT DURING FREE TRANSIT



SIDE VIEW HULL



ISOMETRIC VIEW

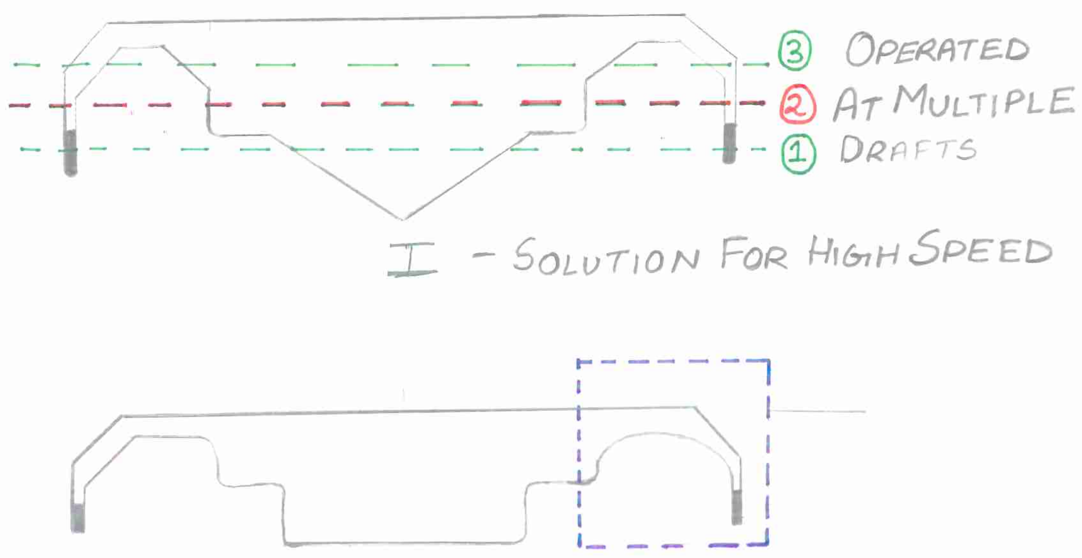


TOP VIEW

SL NO	DESCRIPTION
1	3MW≤ WTG'S IN UPRIGHT POSITION 7MW≥ 3MW-5MW
2	ALTERNATE CARRYING CONFIGURATION
3	WINCH SYSTEM FOR HOLDING THE BOTTOM PART OF WTG, WHEN CRANE LIFTS FROM TOP
	BRIDGE

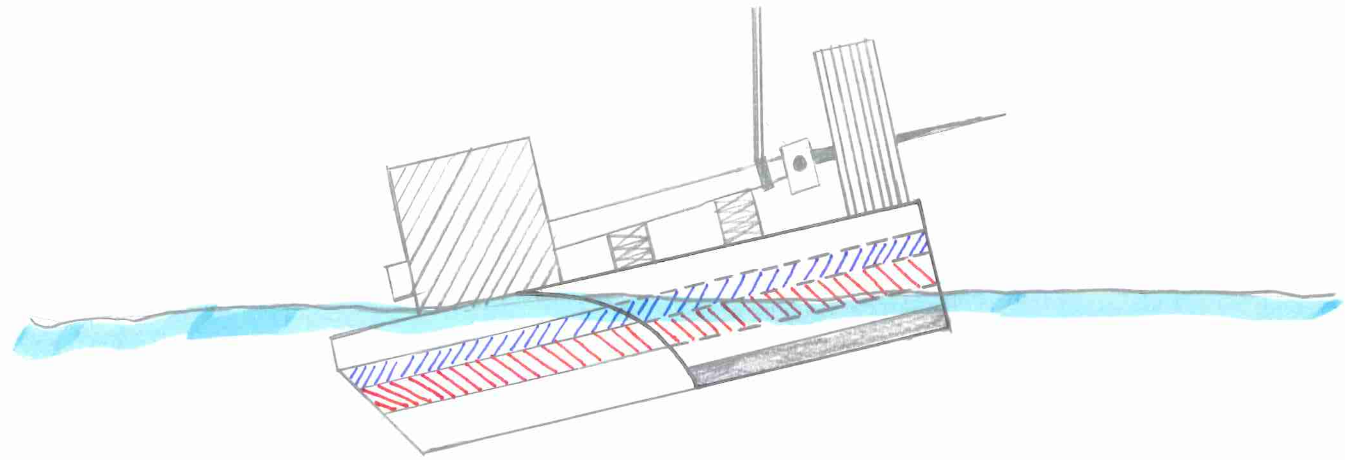
TITLE - CONCEPT I - DUAL DRAFT SWATH CRANE VESSEL	
PROJECT - THESIS STUDY WIND TURBINE INSTALLATION VESSEL [WTIV]	
DATE - 18-09-2013	TU Delft
SCALE - 1m :1mm	FOR INTERNAL STUDY ONLY

Front View - Looking From Aft To Bow



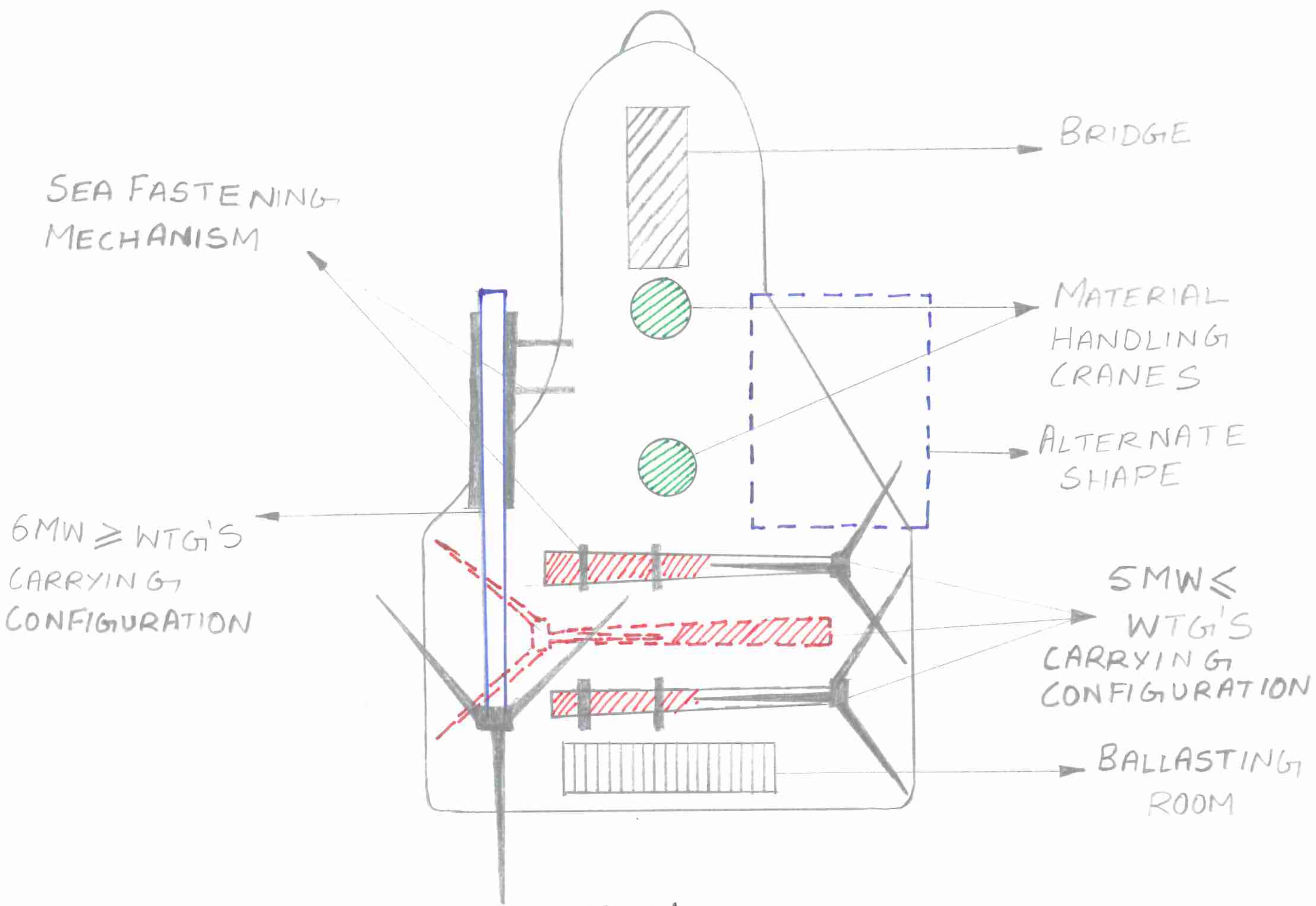
I - Solution For High Speed

II - Solution For Higher Stability

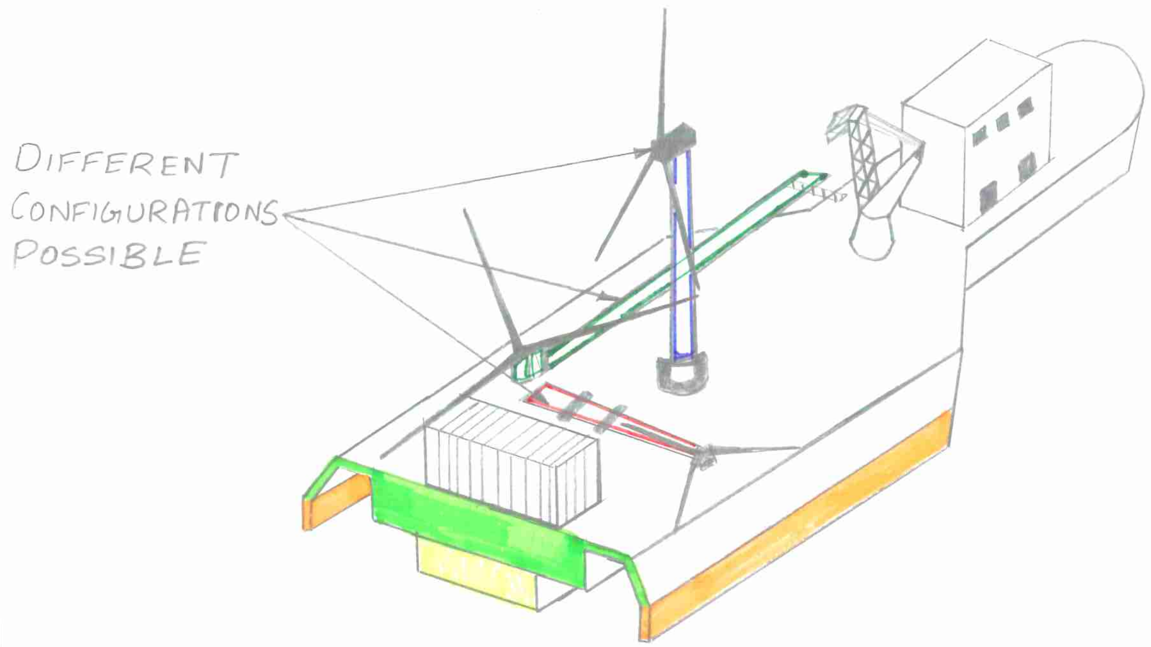


Side View

During Operation



Top View



Isometric View

Title - Concept II - High Speed Shuttle Transport Barge		
Project - Thesis Study Of High Speed Transport Of WTG's		
Date - 20-09-2013		TU Delft
Scale - 1m : 1mm	For Internal Study Only	

APPENDIX-II

HULL COMPARISON

The Monohull is the most conventional shape but it has some inherent issues with still water stability in high seas and cannot perform precision installations like the blades of the wind turbine easily. So the Monohull will not be considered in detail here all the other possible hull shapes will be explored.

Mono-hull dual draft

The Monohull with dual draft is a relatively new technology which is intended at improving on the drawbacks of a conventional Monohull. Some of the major issues with the conventional Monohull are neutralised in his new design.
The ship has two sections in the hull the lower section which is a narrower section, extending from the keel to a particular height. Then as this section ends a wider section starts which is much wider than the lower section hence it is called dual draft. It uses a ballasting system, which can take the vessel from either operating at the lower cross section or the wider cross section.

Lower cross section(D1):

- this draft is used during transit and this helps with achieving speeds of up to 15 knots which is not common for conventional Monohull crane vessels as they have a very wide cross section
- the roll motions are considerably reduced during transit because of the smaller cross section at the water line. (slightly less excitation)
- the smaller cross section at the water line also moves the natural roll period away from that what the ship would encounter in the form of wave periods in high seas
- lower draft also helps in harbour conditions. But smaller width of the waterline does not help because this means at the same displacement the draft is deeper.
- The pre lift operations and preparation also can be done at this mode making it operable at high seas in different locations.
- For pipe laying not much stability is required , lack of stability results in long roll periods which are beneficial for vessel motions

Wider cross section (D2): once the ship is ballasted down about 2-4 meters this lowers the centre of gravity and increase the cross section (transverse moment of inertia) at the water line

- which make a good platform for crane operations, due to increased stability
- it can be used for pipe laying, heavy lifting (presently up to 5000 MT) or general offshore construction activities.

Advantages and disadvantages

- *Has higher transit speeds up to 15 knots*

- *Better sea keeping characteristics compared to conventional Monohull*
- *It is self-propelled can be DP operated It has higher operating window compared to other Monohull heavy lift vessels*
- *Reduced downtime and mobilization times making it less costly for the operators to employ in the field*
- *The motions especially roll and pitch are still large and make it difficult to operate for precision lift especially in beam and bow quartering waves reducing workability. Motion compensation may be required.*
- *At higher hook heights the motions are considerable*
- *Deck capacity is not as large when compared to SWAT's and CAT's of same length to breadth ratios*
- *Resistance is considerable due to wide shapes and the length is also an important factor to decide the resistance and the resulting hull speed.*
- *Bad performance in beam waves depending on the natural period*
- *There is not much flexibility with respect to the location and placement of the crane*
- *It has to be evaluated If weather vanning is possible for WTG installation.*

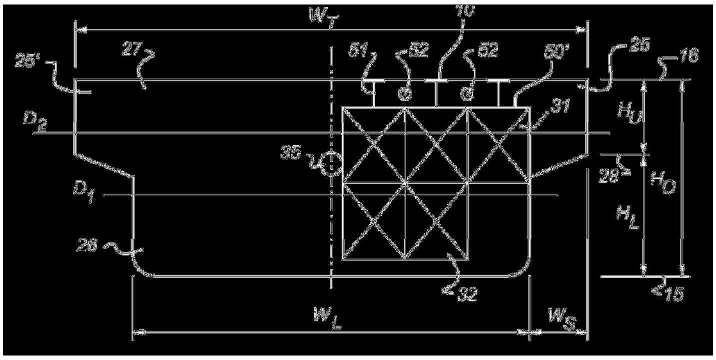


Figure 1 : Dual Draft Hull sectional view

Figure 2 Oleg Strashnov Dual Hull crane ship

Small water plane area twin hull vessel (SWATH)

The SWATH is extensively used as a ferry to transport people and also cargo in rough seas at very high speeds. It is also extensively used as research vessel because it provides a very stable platform for working in high seas.

It is a multi-hull type of vessel it basically consists of two submerged pontoons which give the vessel all its primary buoyancy, and they are connected to the deck box or the superstructure via struts. This is the basic configuration but there are many variations like:

- Double struts configuration
- Deck box separated from the struts by a middle structure, called cross structure etc.

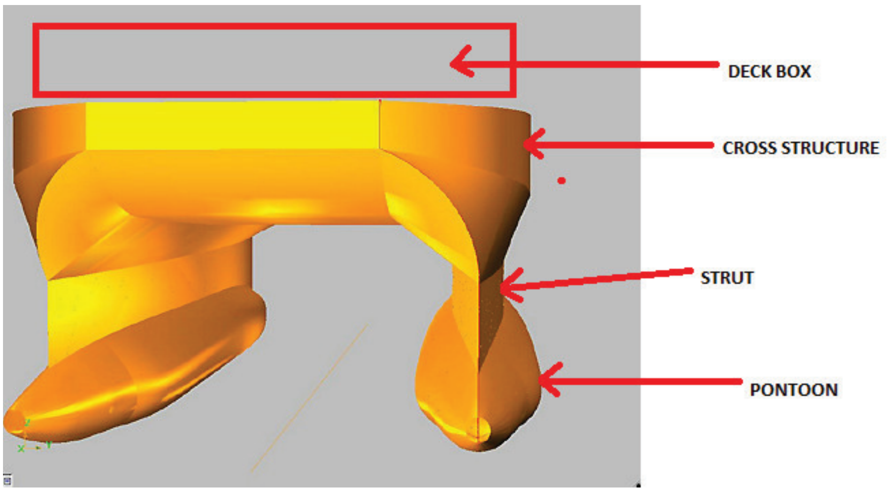


Figure 3 Swath vessel with basic Configuration

The main advantage of the SWATH is its flexibility during design to choose different types of hulls, and the hulls are designed to have the secondary or reserve buoyancy. They have high operational stability and can operate both in the open seas and also in the coastal regions. The most important feature of this vessel is the small water plane area which helps in almost negating the wave excitation giving it superior sea keeping characteristics and minimal motions during operations at sea, because the deck is kind of de-coupled from actions of the waves.

Some of the significant advantages are as follows

- *Allows for a larger deck space and higher usable volumes*
- *Reduced motions roll, pitch and heave accelerations on the deck both during transit and stationary operating modes, even in high sea states (it has almost ½ the amount of motions of a Monohull of the same size)*

Can this be done at different headings?

- *It works independently of the direction in which the wave acts and does not have any directional limitation even in high sea states, hence they have directional stability*
- *It can attain high speed , even in high sea states and maintain it*

The effects of parametric pitch slamming and current and wave drift forces have to be evaluated?

- *Flexibility in that the natural frequency of the deck is can be designed in such a way that the natural periods can be veered away from the wave frequencies likely to be encountered by the vessel*
- *It is transversely limited design limiting some negative effects of the same*

And disadvantages

- *Because of the configuration and design of submerged pontoons they operate only at high drafts, but this can be accounted for by designing a system which has smaller drafts at the harbour and can be ballasted down to deeper draft during operations*
- *The amount of power required for propulsion is higher compared to Monohull of same size because the wetted area is higher*
- *Increased trim and heel excursions because of the small water plane area*
- *Increased sensitivity to draught changes by weight shifting on the top of the deck*
- *Pitch motions are higher for particular conditions and subjected to bow diving*
- *Slamming induced forces are higher as the vessel is susceptible to a lot of slamming*
- *Design is complicated and construction is costly and complicated as well*

Figure 4 Swath working in the Germany

Figure 5 : Swath cruise ship

CATAMARAN

A catamaran is also a multi hull type of vessel. The basic configuration is simple to understand and visualize unlike the SWAT. It consists basically two parallel Monohull connected to each other by some beam structure in the centre. As a result of its geometry it has better motion characteristics. It has considerably less heeling excursions as compared to a Monohull and also better sea keeping characteristics. There is a bridging structure which supports both the hulls. Initially these were used only for recreational purposes now more vessels have been constructed for the military, passenger ferries etc. because they have better speed ,stability and comfort.

Figure 6 : Catamaran Basic configuration

The CAT has many superior qualities compared to a corresponding Monohull of the same L/B ratios or displacements but at the same time there are some drawbacks as well :

- *Because of the geometry as we have discussed it will have much less heel*
- *Highly stabilised for doing activities in high seas as well as coastal region because of the spread out configuration and large area at water line*
- *Increased speed compared to Monohull because of the lesser resistance offered by the two hulls operating at shallow drafts. As they have wide beams instead of a deep ballasted keel like in the mono hull. This offers less drag*
- *Wave piercing catamarans are even faster*
- *Large deck areas and increased safety from capsizing because of the spread geometry*
- *Low fuel consumption because of all the above features*
- *Pitching motions are reduced considerably in comparison to Monohull*
- *The bow diving motion is considerably less than the SWATH*

Some disadvantages

- *The cross structure is subjected to heavy slamming loads when the CAT is subjected to slamming in transit, sometimes it also cause the whole structure to vibrate.*

- *They have Larger roll motions especially in beam waves compared to even a Monohull*
- *Vertical deck edge acceleration more compared to the Monohull as the bow might experience crest at slightly different phase*
- *The geometry gives rise to some unique motions, like the cork screw motion in quartering waves when the roll and pitch periods can become close hence the hydro dynamics is slightly complicated*
- *Design is difficult and construction as well is equally difficult and costly*

Figure 7 Simple Catamaran shape

SemiSubmersible

They are a class of specialised vessels, which execute multiple roles in the offshore industry. They are used as Crane vessels, Production platforms, installation and heavy lift vessel, pipe laying and also some times for accommodation and maintenance. They exhibit superior motion behaviour and sea keeping characteristics with considerable stability. The basic design consists of a submerged buoyancy pontoon(usually more than one) which is water tight. The operating deck is always above the water line decoupled from the waves and it is connected to the pontoon with the help of columns. This structure means it has a reduced waterline area and this results in good stability during operations. The decks are made in different shapes rectangular, square and sometimes in triangular, the columns can also be square, triangular, rectangular or circular and each having their advantages and disadvantages.

Some of the advantages of using the semi are as follows

- *Have good sea keeping characteristics*
- *Have good stability in rough seas- damage stability can be an issue*
- *Motion behaviour also is considerably better- one of the most important features of the design.*
- *The wave forces at water line are lesser than Monohull as a result of the small area*
- *Can be used for heavy lifting because of the stability and motion characteristics- a lot of ballasting has to be done to avoid heel during lifts*
- *Have huge deck spaces*

Disadvantages

- *Construction costs are high*
- *Slow transit speeds*
- *Limited payload*
- *Very sensitive to load shifts on the decks*

Figure 8 : Multi legged Semi- Submersible

Other shapes

There are many other possible shapes like the ones presented above they are also subjected to many advantages and some drawbacks. There is a lot of research going to explore the different possibilities and make use of some features unique to certain shapes, because these aspects help specific tasks to be performed offshore. The other shapes also considered in this research are as follows. The idea is to bring along the most advantages and counter the drawbacks with accessories and design changes

Semi-SWATH - It's a bridge between the SWATH and the catamaran. It basically tries to draw out the advantages of the SWATH and the catamaran and try to avoid all their disadvantages

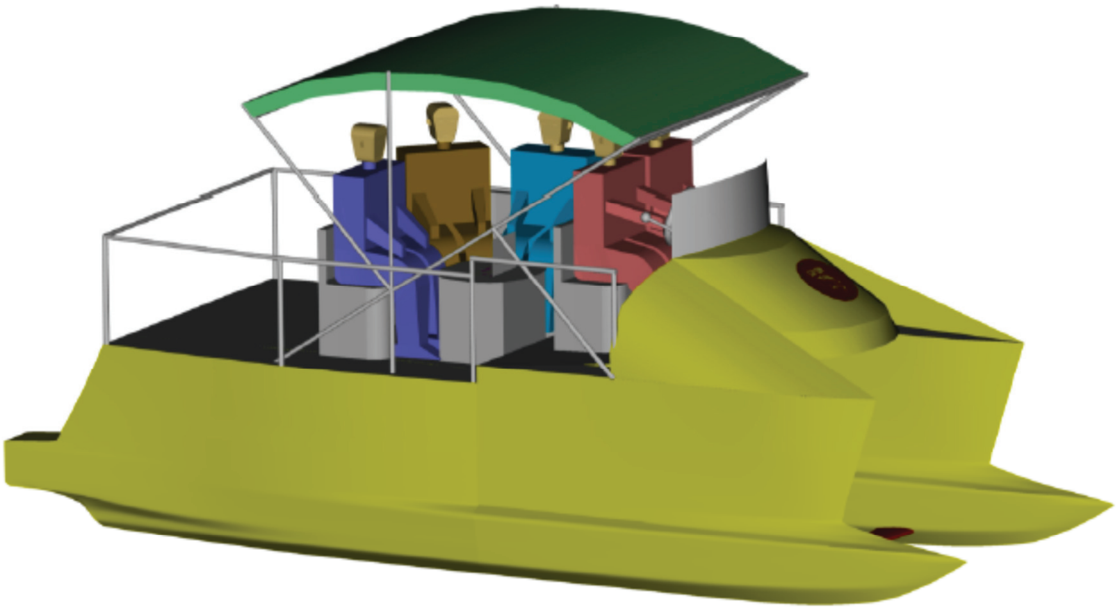


Figure 9 Semi Swath design

This vessel has better motion characteristics than the normal swath , but the most important point is it reduces the slamming and the huge pitch motions which a normal swath would encounter. It also has some controllable fins which further reduce the pitch and roll motions making it better. The different drafts at which it is allowed to work also gives it the flexibility to perform different roles.

Trimaran – The Trimaran is unique in that there are only few ships built in this class. They have some real advantages over all the conventional shapes in that

- High speeds
- The fuel consumption reduces by 20% compared to a catamaran of the same size and by 50% compared to a Monohull of the same size
- Very low draft are possible because of the spread out geometry hence working in the coastal regions and in shallow drafts is possible
- Manoeuvrability is very high compared to any other shape mentioned above

There is basically three hulls at the bottom with a central hull and one on each side as shown in the figure below. There are only few ships in this class called the Littoral class ships and the USS independence is the fully commissioned and built and is working fine.

Figure 9 : LCS ship USS Independence

SWASH - small water plane area single hull ship it is a variation of the SWATH it exhibits mostly the same operational features as the SWATH.

Figure 10 SWASH Vessel

Tri-SWATH, Tri-SWASH, HYSWAS are the few other shapes for the hull which are possible. There is not much data on such shapes and these shapes were conceptualized based on the particular needs or functionalities, mostly by the different naval administrations of different countries. Hence most of the data is confidential, but there is some information available to start the design and also to understand what outcomes one can expect from such designs.

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- http://www.gizmag.com/ship-design-austal-102-trimaran/12433/ (Trimaran Vs. Swath vs. Catamaran)
- http://www.globalsecurity.org/military/systems/ship/offshore-drillrig-comp.htm (tri swath)
- http://www.maritimejournal.com/news101/vessel-build-and-maintenance/ship-and-boatbuilding/a-and-r-makes-waves-with-new-swash-design (SWASH)
- DEVELOPMENT OF A SEMI-SWATH CRAFT FOR MALAYSIAN WATERS-OMAR BIN YAAKOB
- Small SWATH Research Vessels- Robertson Dins more
- ON THE ADDED RESISTANCE OF CATAMARANS IN WAVES-Tony Armstrong and Anton Schmieman- Austal Ships100, Clarence Beach Road, Henderson, Australia
- DUAL DRAFT CRANE VESSEL- US PATENT Pub. No.:US2008/0295756 A1
- Hull construction for a SWATH- Nelson W. Hall, Poway; Paul ,Kotzebue, San Diego, both of Calif.
- Oo, Khin Maung (1974) The design of semi-submersibles for minimum vertical motion.
- SWIV concept Leenars BV
- Sea worthiness of resonance swath and fast ocean going ship -Yoshida, Iwashita, Kihara, Kinoshita
- PREDICTION OF MOTION CHARACTERISTICS ON SWATH TYPE FLOATING STRUCTURE USING TWO-DIMENSIONAL FRANK CLOSE-FIT TECHNIQUE – Mas Murtedjo, Eko B. Djatmiko
- SWATH Technology-Advanced SWATH Design Methods- Gregor Schellenberger
- EXPERIMENTAL STUDY OF SWATH MODEL ROLLING IN BEAM WAVES by-0 4 Edward Numata
- Swath developments and comparison with other vessel by T.G. LANg
- COMPARATIVE ANALYSIS OF CONVENTIONAL AND SWATH PASSENGER CATAMARAN Serđo Kos, Ph. D. David Brčić, B. Sc. Vlado Frančić, M. Sc.
- A SEAKEEPING COMPARISON BETWEEN THREE MONOHULLS,TWO SWATHS, AND A COLUMN-STABILIZED CATAMARAN DESIGNED FOR THE SAME MISSION-David W. Taylor Naval Ship Research and Development Center Bethesda, Maryland July 1975
- How Hull Design Impacts the Performance of Wind Farm Support and Maintenance Vessels Mark Willbourn, Ed Dudson and Rob Sime BMT Nigel Gee, United Kingdom
- STUDY ON DIFFERENT CONCEPTS FOR DESIGN OF A COASTAL RESEARCH VESSEL By Premchand Mallampalli, SMDR (IMU Visakhapatnam), India.
- IHC Merwede website

HEAVE COMPENSATION AND CONCEPTS OF SINGLE LIFT

Passive heave compensation

A simple ***PHC*** works on the principle that it absorbs the energy form the disturbance causing mechanism, in this case the waves and then either damp the energy away or reapply it appropriately into the system. A simple layout of a PHC system is shown below in the fig. A soft spring can be a simple PHC, but there are much more complex hydraulically and mechanically operated systems as well. The PHC system can be described as a reactive system and moreover does not require power hence it is a fail proof device compared to the AHC.

Advantages

- Closed loop system rarely requiring external power
- Easy to construct and visualise
- Compensates the heave motion to a large extent
- They are fail safe as they do not require any external source of energy
- Cheap and easy to operate

Disadvantages

- The reaction time is large
- Not as effective as the AHC
- It is based on a load by load system, hence the accumulator's pressure has to be calculated for each scenario. So every new load case has new values and new calculations
- Limited motion range and hysteresis effects are present

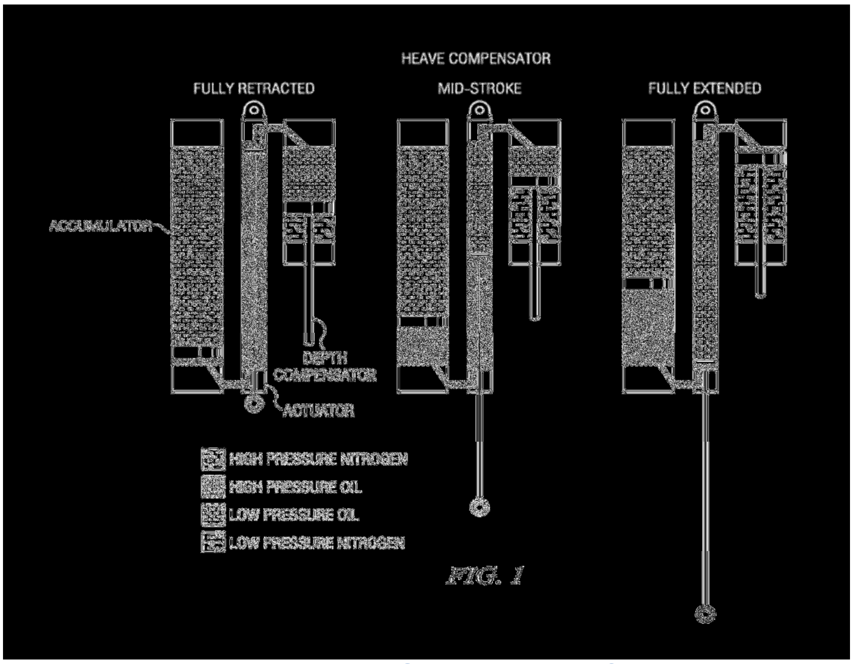


Figure 6.1 & 6.2 Schematics of PHC

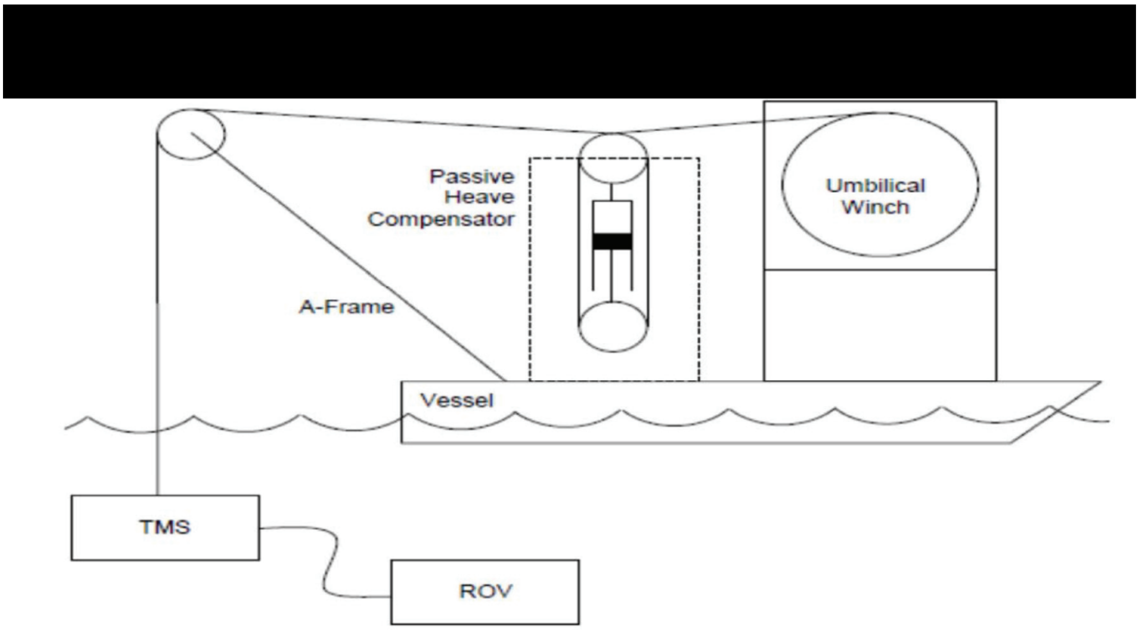
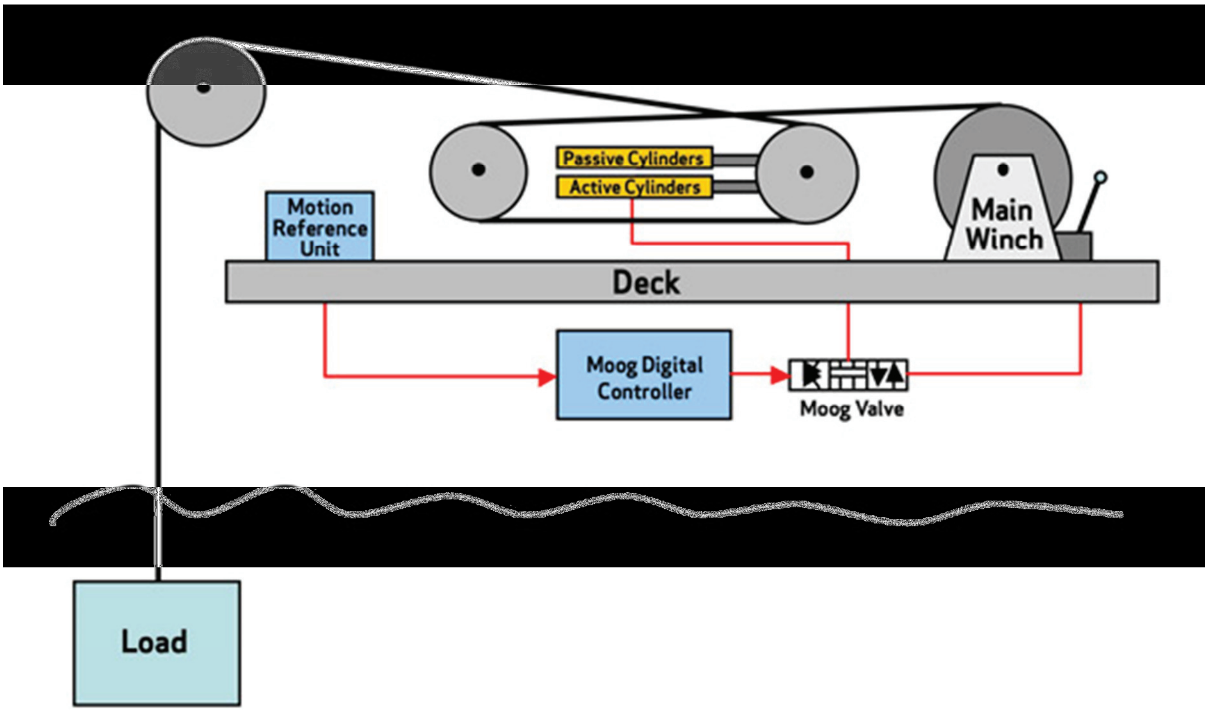


Figure 6.3 Basic arrangement of AHC



Active heave compensation is more a proactive system, in that it uses external power and also a control unit. It measures the vessel motion using some instrumentation continuously and tries to keep the load motionless during the operation. They come in many different types and sizes.

It is a complex system compared to the PHC system but it is very effective and has much better response than the PHC. The motion reference unit measures the vessel motion in heave and inputs the signal to the controller. The controller or control unit is the heart of the system it will send an error signal to cylinders, motors etc. to make the compensation. The actual system which brings about the compensation can be any of the following types

- Electrical winches – use an electric motor to run the winch in the opposite direction of the motion which the vessel undergoes.
- Hydraulic winches – similarly these use hydraulically operated winches to compensate for heave
- Hydraulic Cylinders – They are the oldest kind of system to be in operation, they have pressurised cylinders either filled with gas or fluid and in conjunction with accumulators. The piston within moves to compensate for the motion.

Advantages

- The response is really fast
- The fact that it is continuous and gives real time compensation is really advantageous
- The error is very minimal and the accuracy levels are high
- Easy to operate and is very adaptable and one dos not have to reset and calculate the different load cases every time

Disadvantages

- It is a complex and costly system to design and install
- The design criteria and loads on the cranes or winches becomes complicated and one has to account for fatigue loads, design of sheaves, power consumption, cooling etc. extended design is always a problem.
- They consume power and this leads to operational costs
- To make them redundant it becomes costly because all the systems have to be installed in double

They can also be used in conjunction with the crane, in that the whole system will be working in close relation to the crane wires and they themselves will be compensated using one of the systems as mentioned above. Sometimes both the passive and active system are used in combination in something called hybrid systems which also have its advantages and disadvantages.

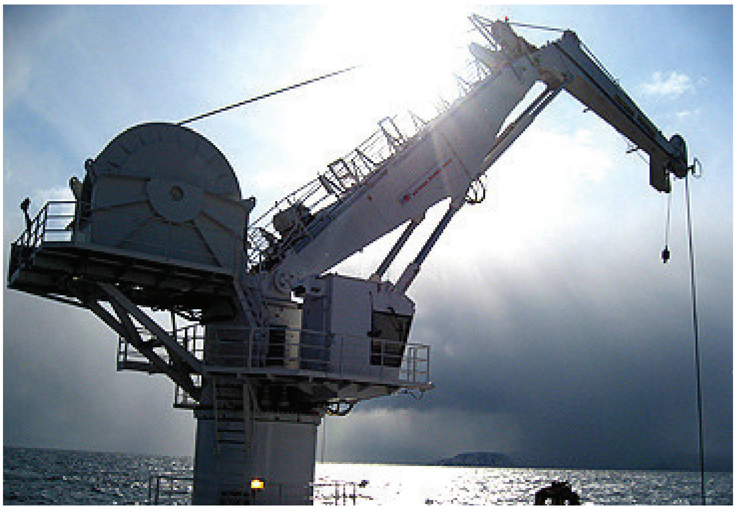


Figure 11 Actively heave compensated knuckle boom crane

They two concepts proposed in the next sections will use one of these systems in conjunction with the crane or without.

2.2.1 Concept I – Actively Heave compensated crane and tugger lines

This concept can be visualised based on the diagram attached in the appendix. This method employs an Active heave compensation system in conjunction with the crane. The motion sensors of the vessel will be used to develop a signal of error (Heave, roll etc). This will be sent to the controlling unit which will analyse the error and send the signal for operating the winches to which the main load lines are attached. Based on the motion which the vessel is experiencing the winches will either pull in or give slack, thus keeping the object in this case the WTG motion less with respect to the foundation on which it has to be installed.

Tugger lines or steering lines will be connected to the bottom of the WTG , where the vertical lines coming down from the clamp is also hooked on. These will be connected to constant tension winches. They can be used to also move, align or steer the load to the exact location for setting down.
The continuously acting heave compensation system and the tugger lines can be used to do the installation, depending on what the set down force and accelerations are a suitable dampers need to be used. For the fixing and aligning of the wind turbine with the bottom part, without going into details it is reasonable to say that the use of positioning guides/stabs already prevalent and previously used by SHL in the in-house studies is sufficient. Apart from this a quick lock system also previously studied for this single lift concept can be used, it helps in holding the WTG till the time all the bolts are tightened. This particular step is useful in the sense that the crane can already disconnect from the WTG immediately after set down and continue its work. Whereas the bolts can be put in while the crane is already picking up the next turbine it is advantageous in that one could save quite a bit of time. To smoothen the

landing even further the end of the positioning stabs, there will be some dampers or springs which will reduce the impact and also the accelerations with which the set down takes place.

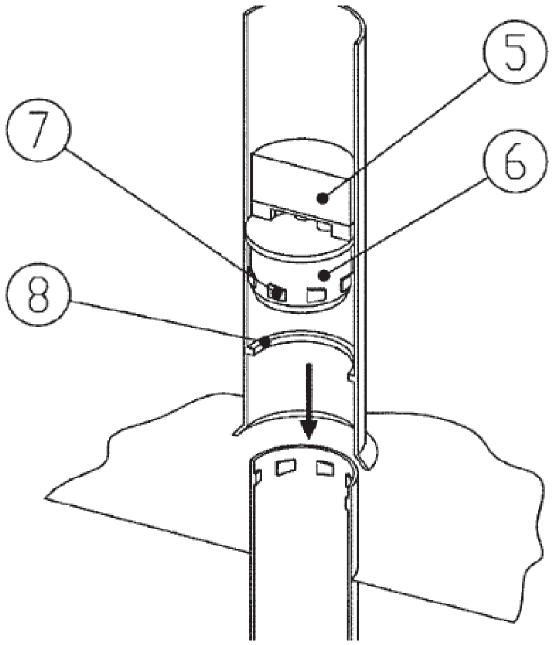


Figure 12 Quick Lock System

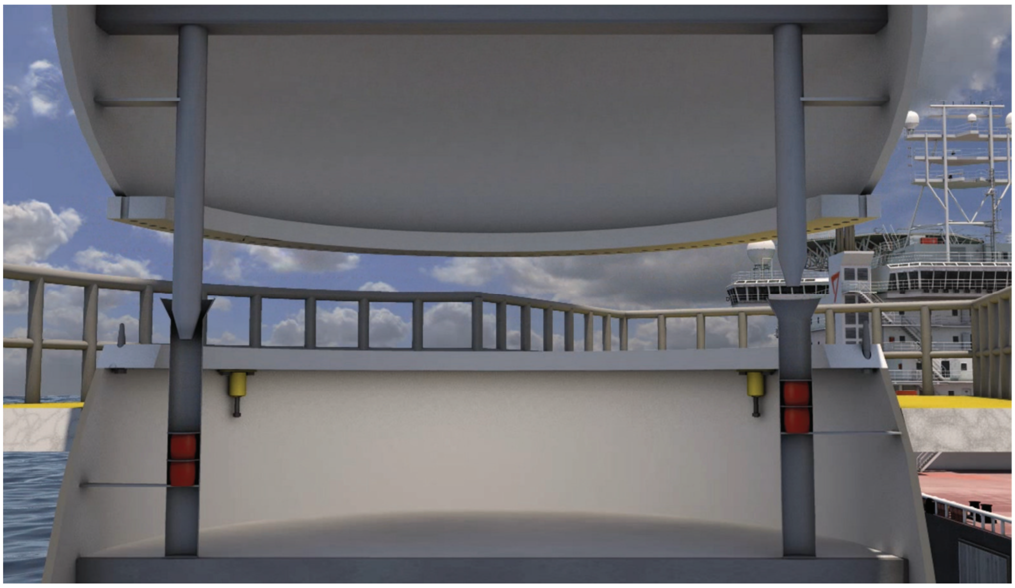


Figure 13 Positioning Stabs

2.2.2 Concept II – Normal crane with passive heave compensator and winch system inside the foundation

The second possibility is to use a crane which works without active heave compensation. In this case for the installation a passive heave compensation system has to be used like the Cranemaster (alternative products from IHC are also available). But to also have a smooth landing of the WTG the positioning stabs, the dampers etc. will be functioning in the same way as explained previously.

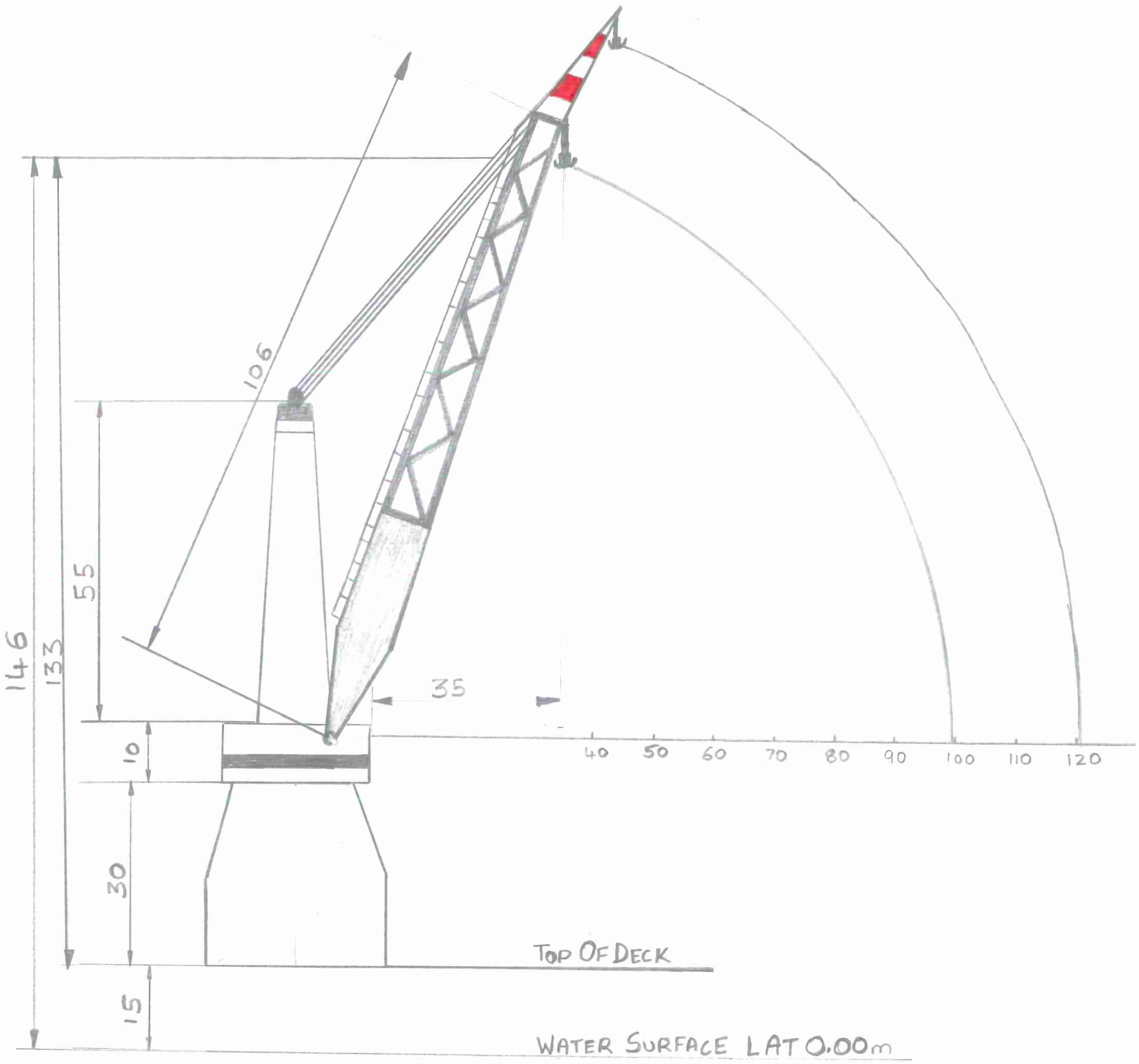
Apart from the PHC system which will be explained further, there will also be a winch system within the foundation and the wires form the winch system will be connected to the inner part of the tower, this is necessary because the PHC cannot be used alone in such single lifts (because their use is generally limited to transfer lifts, subsea lowering etc. where there is some damping present) unless there is some force from below is pulling on it to make it perform better. It is also useful in the sense that the winch can also perform the function of pulling the WTG towards itself , hence it will help in aligning the Tower with the foundation effectively.

Cranemaster

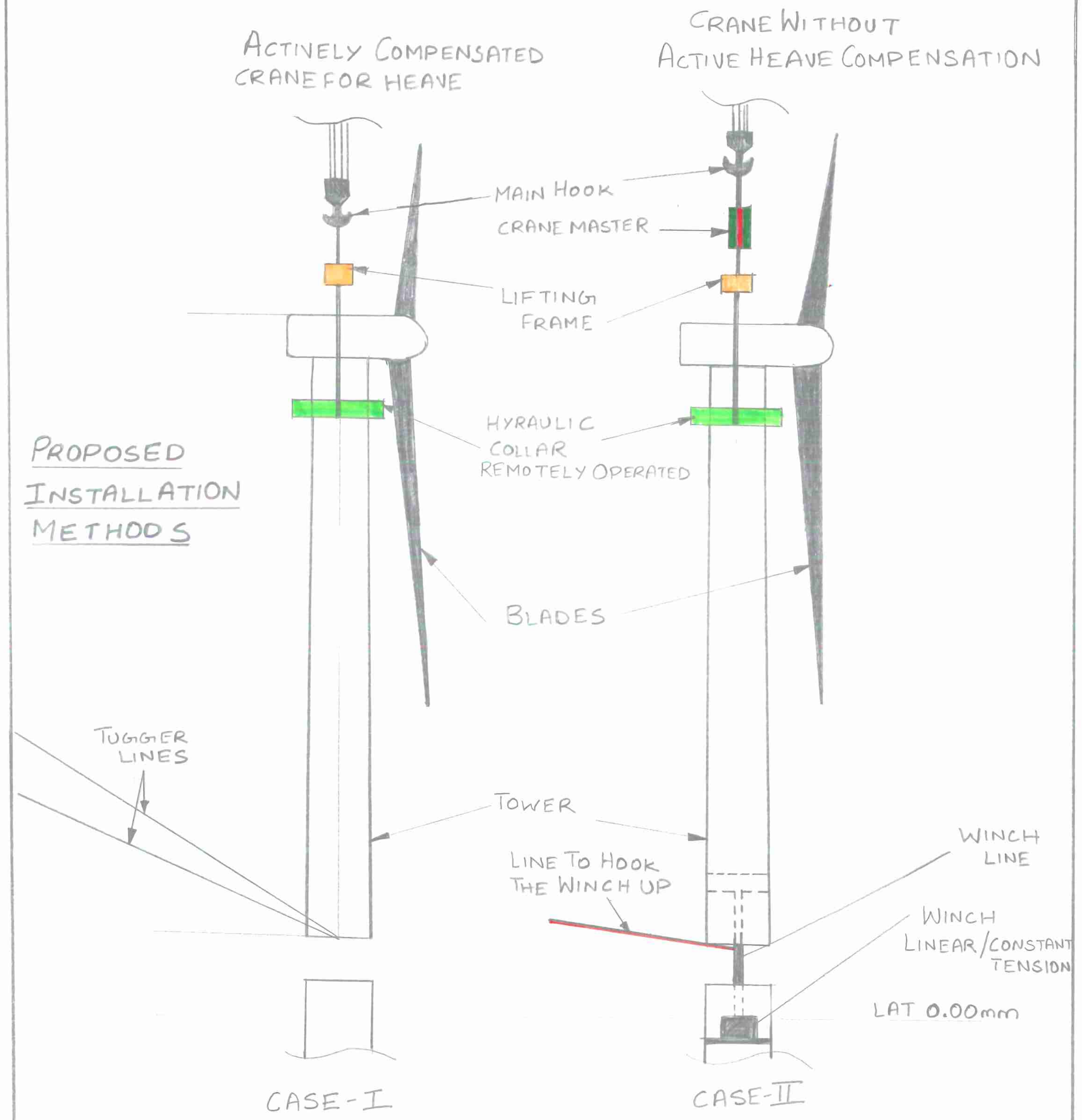
It is basically a passive heave compensator system housed in one unit. It does not require any external power to act it usually reduces the dynamic loads on the crane wire when lifting an object. The main effect given by using Cranemaster during the lifting operation in transfer lifts is to enable the crane to maintain its lifting capacity at increasing wave height. This is possible through an improved and formally approved load chart for the crane. It improves the weather window in which a particular crane vessel can operate.

For stiff cranes, the dynamic amplification factor (DAF) resulting from wave induced movements, may be very high even for small wave heights. With a Cranemaster unit mounted, the DAF is typically reduced to 1.3 or below for sea states up to Hs = 2.0-2.5 m. The first applications of Cranemaster units back in the early 1980s were related to shock absorption. Since then small units with SWL of a few tons up to large units with SWL of 500 tons have been developed. In the current concept it will be used in conjunction with the winch. Cranemaster has been used in many projects for offshore wind installations, typically resulting in reduced downtime for the installation and reduced risk of damaging equipment, Used frequently for tension control during installation of transition pieces.

Note * for the visual arrangement of the system explained in both concepts look at the sketch attached.



CRANE ARRANGEMENT ON DECK - LOAD CAPACITY - 1600MT



TITLE - CRANE ARRANGEMENT & INSTALLATION CONCEPTS	
PROJECT - HIGH SPEED WTIV	
DATE - 17 - 10 - 2013	TU Delft
SCALE - 1m : 1mm / FOR INTERNAL STUDY ONLY	

APPENDIX-III

DESIGN BASIS AND BOUNDARY CONDITIONS

1. Multi-criteria analysis based on previous research done on shapes
2. Crane selection sheet
3. WTG – Size and Choice
4. Scenarios for speed and transport options
5. Accommodation layout
6. General arrangement of WTG on decks – Monohull and SWATH

Mode of operation based on mission profile	*Description*	*Remarks/Detail criterion*	*Weight (D)*	*Weight(P)*	*Monohull*	*Design*	*Project*	*Monohull with dual draft*	*Design*	*Project*	*Catamaran*	*Design*	*Project*	*Catamaran Dual draft*	*Design*	*Project*	*SWATH*	*Design*	*Project*
General	Principal Dimensions	Length (longer is '-ve')	5	7	5	25	35	6	30	42	6.5	32.5	45.5	7	35	49	8	40	56
		Draft (larger is '-ve')	3	7	5	15	35	6.5	19.5	45.5	7	21	49	7	21	49	8	24	56
		Breadth (wider is '-ve')	7	7	5	35	35	6.5	45.5	45.5	6	42	42	6	42	42	8	56	56
		Air Draft (higher is '-ve')	6	8	5	30	40	6	36	48	6	36	48	6	36	48	6	36	48
	Speed		0	8	6	0	48	6.5	0	52	6.5	0	52	7.5	0	60	8	0	64
	Design complexity & Time		4	0	9	36	0	8	32	0	5	20	0	5	20	0	4	16	0
	CAPEX	cheapest has higher value	6	0	9	54	0	8	48	0	6	36	0	5	30	0	4	24	0
	Availabilty of yard	Including ease of construction & Dry docking in later years	5	0	9	45	0	8	40	0	6	30	0	6	30	0	4	20	0
	Deck Space		8	8	4	32	32	6	48	48	9	72	72	9	72	72	8	64	64
	OPEX	Fuel Efficiency	7	0	5	35	0	7	49	0	9	63	0	9	63	0	8	56	0
		others	7	0	7	49	0	7	49	0	5	35	0	7	49	0	8	56	0
	Ease of Installation	Crane movement- and placement	7	7	4	28	28	6	42	42	8	56	56	8	56	56	8	56	56
	Expected time for Installation	Time for one WTG to be installed in same weather conditions	6	8	5	30	40	6	36	48	8.5	51	68	9	54	72	9	54	72
	Accomodation and other aspects	No of people accomodated	6	7	6	36	42	6	36	42	8.5	51	59.5	9	54	63	9	54	63
		Ease of locating the Helideck and accomodations	5	6	5	25	30	6	30	36	5	25	30	5	25	30	6	30	36
Transit Mode	Intact Stability	Based on IMO	7	8	6	42	48	7	49	56	9	63	72	9	63	72	8	56	64
	Directional Independence	Ability to handle harsh sea conditions and maintain the direction	0	8	5	0	40	6	0	48	7	0	56	8	0	64	8	0	64
	Maneouverability	Specially in Harbours	0	6	6	0	36	6	0	36	6	0	36	6	0	36	6	0	36
	Motion of the nacelles (accelerations)	Approximately at 80 M from the deck in all three directions	0	9	6	0	54	7	0	63	8	0	72	8	0	72	8	0	72
	pitch and Roll (Parametric)	based on previous experiments carried out	8	9	7	56	63	7	56	63	7	56	63	7	56	63	5	40	45
	Deck loading complexity	Slamming	7	6	6	42	36	8	56	48	6	42	36	6	42	36	7	49	42
		Torsional - cork screw loading	6	5	6	36	30	8	48	40	7	42	35	7	42	35	8.5	51	42.5
		Relative movement of the hulls (split force)	5	5	9	45	45	9	45	45	7	35	35	7	35	35	8.5	42.5	42.5
	Projected open sea characteristics and workability		0	9	5	0	45	6.5	0	58.5	7	0	63	7	0	63	8	0	72
Installation Mode	Intact stability with one WTG in hook		7	8	6	42	48	7.5	52.5	60	9	63	72	9	63	72	5	35	40
	Motions and accelerations of nacelles and crane tip	The upper limits as defined by manufacturer	4	9	6	24	54	7.5	30	67.5	8	32	72	8	32	72	8	32	72
	Set down velocities	Heave motion in stationary condition	8	8	6	48	48	6	48	48	7	56	56	7	56	56	8	64	64
	Parametric roll and pitch		0	7	7	0	49	7	0	49	7	0	49	7	0	49	6	0	42
	Projected open sea characteristics and workability		0	9	6	0	54	7.5	0	67.5	7	0	63	8	0	72	9	0	81
	Total					810	1015		925.5	1198.5		959.5	1302		976	1338		955.5	1350

Note : The dual draught vessels have a considerable advanatage w.r.t the acceleration during transit, as they have shallow draft which is just enough for transit & deeep draft jus enough for Installation of 1st WTG. But they

SEMI-SWATH	Design	Project	Semi sub	Design	Project
8	40	56	6	30	42
8	24	56	7	21	49
8	56	56	6	42	42
6	36	48	6	36	48
9	0	72	5	0	40
4	16	0	5	20	0
4	24	0	6	36	0
4	20	0	8	40	0
8	64	64	8.5	68	68
8	56	0	5	35	0
8	56	0	5	35	0
8	56	56	8	56	56
9	54	72	8	48	64
9	54	63	8	48	56
7	35	42	8	40	48
8	56	64	6	42	48
9	0	72	4	0	32
9	0	54	4	0	24
9	0	81	8	0	72
5	40	45	6	48	54
6	42	36	7	49	42
8	48	40	6	36	30
8	40	40	6	30	30
8	0	72	8	0	72
6	42	48	5	35	40
8	32	72	7	28	63
8	64	64	6	48	48
7	0	49	6	0	42
9.5	0	85.5	8	0	72
	955	1407.5		871	1182

need a really quick ballasting system.

SL No	Manufacturer	Type	Lifting Capacity	Max Hook Height	Max radius	Boom length	Diameter of the base	Foot print
			Mt	m	m	m	m	m x m
1	Huijsman	Offshore Mast crane crane	1600	125	30			12 x 12
2	Huijsman	Offshore pedestal mounted crane	500-1200	125				
3	Huijsman	Wind turbine installation cranes	1500	125	32			
4	Huijsman	Heavy lift rigger cranes	1200-1600	140				
5	Liebherr	Offshore heavy lift crane BOS 45000	1200	120	27.5	51-105		
6	Liebherr	Offshore heavy lift crane Cal 64000	1500	120	31.5			
7	Liebherr	Offshore heavy lift crane MTC 78000	2000/1600	120	35	87		

Note 1 : The capacities as given by the website of the companies

Note 2 : 90 % of the boxes in yellow the details can be modified based on request and the sizes can only be got after formal enquiries

Note 3 :	IDEAL	Offshore Wind Installation Crane	1200-1600	120-140	32-35	75-100	15	

			Dimensions				Weights						
Manufacturer	***type***	***Power***	***Rotor Diameter***	***Tower Heigth***	***Blade***	***Nacelle***	***Rotor***	***Blade***	***Nacelle***	***Tower***	***Total***	***Remarks***	***Reference***
		MW	***m***	***m***	***m***	***hxlxw [m]***	***Mt***	***Mt***	***Mt***	***Mt***			
Siemens	SWT-3.6-107	3.6	107	80+	52.0		95.0	16.0	125.0	250.0	470.0		http://www.4coffshore.com + Siemens Brochure
	SWT-3.6-120	3.6	120	66.0	58.5	4.3x14.1x4.2	100.0	18.4	125.0	262.0	487.0	90 m Hub height	http://www.4coffshore.com + Siemens Brochure
	SWT-4.0-120	4.0	120	Site specific	58.5		100.0		140.0	Site specific		90 m Hub height	http://www.4coffshore.com + Siemens Brochure
	SWT-4.0-130	4.0	130	Site specific	63.5		100.0		140.0	Site specific		90 m Hub height	http://www.4coffshore.com + Siemens Brochure
	SWT-6.0-120	6.0	120	Site specific	58.0		100	18.0	190.0	180.0	470.0	180 is minimum	http://www.4coffshore.com + Siemens Brochure
	SWT-6.0-154	6.0	154	88.0	75.0	8.4x16.2x6.5	90.0	27.0	218.0	370.0	678.0		http://www.4coffshore.com + Siemens Brochure
REpower	5M	5.1	126.0	85/95	61.5	6x18x6	130.0	19.5	325.0		455.0		http://www.4coffshore.com + Repower Brochure
	6M	6.2	126.0	85/95	61.5	8x20x6.5	135.0	23.0	325.0		460.0		http://www.4coffshore.com + Repower Brochure
Vestas	V90-3.0 MW Offshore	3.0	90.0	65-105	44.0	5.4x9.65x3.65		7.0	91.0		91.0		http://www.4coffshore.com + Vestas brochure
	V112-3.0 MW Offshore	3.0	112.0	84-119	54.7	3.4x12.8x4		11.9	119.5		119.5		http://www.4coffshore.com + Vestas brochure
	V164-7.0 MW	7.0	164.0	105.0	80.0	7.5x24x12		35.0	390.0		800.0		http://www.4coffshore.com + Vestas brochure
Areva Wind	M5000-116	5	116	90.0	56.0		112.0	16.5	233.0	350.0	695.0		http://www.4coffshore.com+20120815_ Summary M5000_135er weigths and dimensions (Internal document)
	M5000-135	5.0	135.0	90.0	66.0		134.0	23.3	221.0	355.0	710.0		http://www.4coffshore.com+20120815_ Summary M5000_135er weigths and dimensions (Internal document)
XEMC -Darwind	XE/DD115	5.0	115.0	100.0	55.5					225.0	225.0		http://www.4coffshore.com
	XE/DD128	5.0	128.0	100.0	62.0						0.0		http://www.4coffshore.com
Nordex	N150/6000	6.0	150.0	100.0							0.0		http://www.4coffshore.com
Alstom Power	Haliade 150-6MW	6	150.0	100.0	73.5			26.0			0.0		http://www.4coffshore.com
Gamesa	G128 - 5 MW	5	128.0		62.5						0.0		http://www.4coffshore.com
	G14X - 7 MW	7.0	140.0								0.0		http://www.4coffshore.com
Samsung	SHI 7 MW	7	172.0				105.0	35.0			105.0		http://www.4coffshore.com
GE	GE 4.1	4.0	113.0		54.0						0.0		http://www.4coffshore.com
Bard	Bard 6.5	6.5	122.0			8x15x8			280.0		280.0		http://www.4coffshore.com
IDEAL CASE	XXXX	5 to 7	120 -164	65 - 105	55 - 80	?	?	?	?	?	500 - 1000		

Note 1 : the ideal case is highlighted in the red an cranes have been searched and the design data established on this criteria

Note 2 : Assuming that 1000 Mt apart from the weight of the slings(5%), SHL contingency(10%), DAF(10%), and if a crane master (heave compensation) is used another 10% - looking at 1400 MT hence the cranes of this capacity researched in the next sheet

Location used for study	Dogger bank
percentage used for weather delay component (%)	20
Speed Of ship (Knots)	20
No of turbines to be carried in one trip	8
Time needed for installing 1 WTG (Hrs)	8
Time needed for loading 1 WTG on the ship (Hrs)	6
Distance between each turbine to be installed (NM)	0.566954644 Assuming 7 D (rotor diameter)
Total number of turbines to be installed	100
% correction needed for other unforseen events	10

Sl NO	***Port***	***Distance form Port***	***Time needed for Travel both ways in one operation***	***Total time required for installing All turbines***	***Total time for one complete operation***	***Total time required for the whole field development***
	Name	***NM***	***Hrs***	***Hrs***	***Hrs***	***Days***
1	Vlissingen	234	23.4	64.22678186	87.62678186	59.33063355
2	Esbjerg	190	19	64.22678186	83.22678186	57.03896688
3	New castle (Tyne)	153	15.3	64.22678186	79.52678186	55.11188355

	15 knots (25% reduction from 20 Knots)		10 knots (50% reduction from 20 Knots)		5 knots (75 % reduction from 20 Knots)	
	% Increase of total days	***Total No of days***	***% Increase of total days***	***Total No of days***	***% Increase of total days***	***Total No of days***
Vlissingen	8.9	64.66306695	26.9	75.32793377	80	107.3225342
Esbjerg	8.08	61.6075114	23.9	70.74460043	72.1	98.15586753
New castle (Tyne)	7.11	59.03806695	21.37	66.89043377	64	90.4475342

Important Assumptions

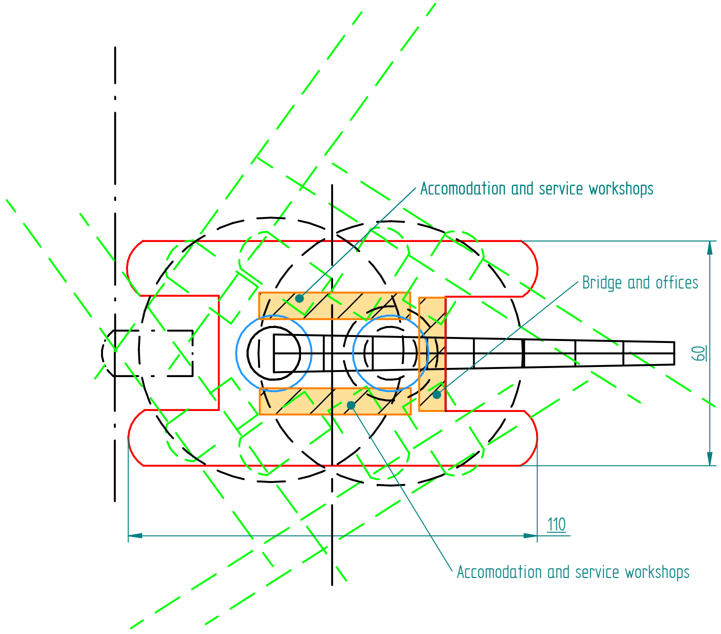
• The onshore travel and delivery is not considered
• The distance between the turbines is a thumb rule used in wind farm development feasibility studies (5-7 times the diameter of the wind turbine) [20]
• The choice of ports has been dealt with previously and the reasons for the same explained in the weightage report [1][14]
• The times indicated for the installation of turbines and also the time required to take the fully assembled turbine on board are based on previous reports of the Thanet wind farm (vestas), Report on kentish flats wind farm with A2sea vessels working, report on Glosten Associates on vessel data. Apart from in-house data available with Seaway heavy lifting.[14][21][22]
• The components for delay in weather and also some force majeure case have also been accounted for
• The time involved for installing the foundation is not accounted for because it is not relevant at this stage

Important conclusions

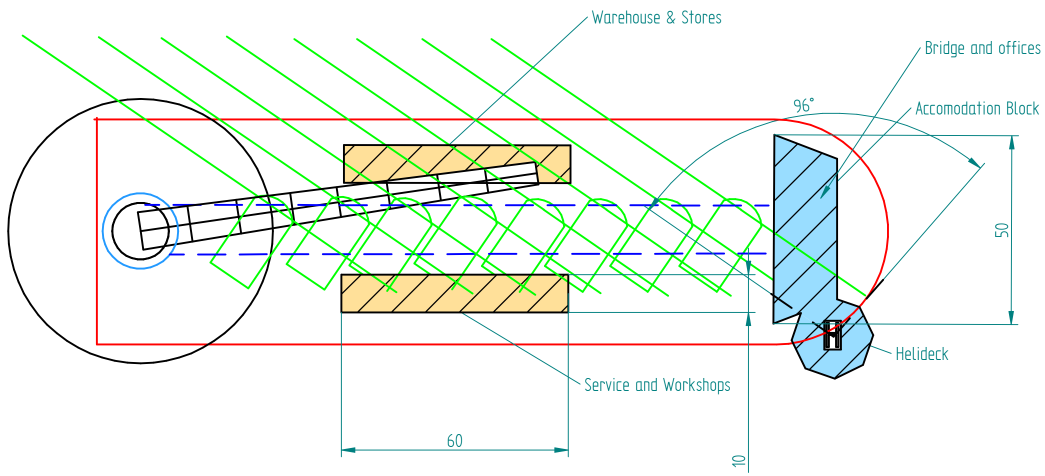
• The reduction in speed by 25% increases the number of days only by 9 %(4 days approximately).
• The % increase in the days for the same speed reduction, decreases with the reduction in distance between ports and site.
• The % increase in the days for the same speed reduction, decreases or remains same with the increase in the number of turbines.
• The % increase in the days is not significant enough with respect to the total number of days the vessel is chartered for the project.
• But the reduction of power could have significant effect on the CAPEX of the vessel.

Also the data is helpful to get a feeling for the time involved for different shapes because 20 Knots (associated with High speed swaths), 15 knots (associated with Swaths and Catamarans), 10 knots (high speed Monohull) and 5 knots (when the vessel is towed or a self-propelled semi). Hence it gives a good idea of number which can be used in the power calculations later. The shapes being suggested at the lower speed have the better motion characteristics (semi, swath etc.) so this it is very interdependent.

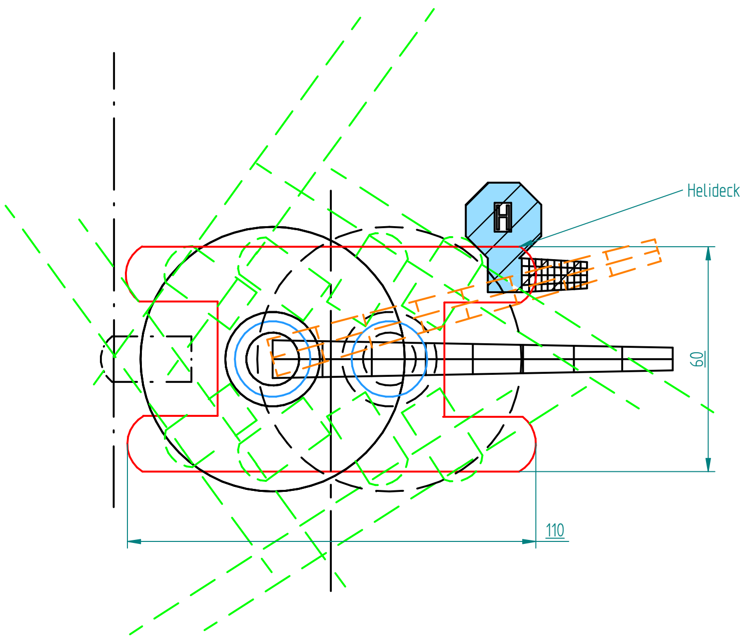
REVISION HISTORY			
REV	DESCRIPTION	DATE	APPROVED



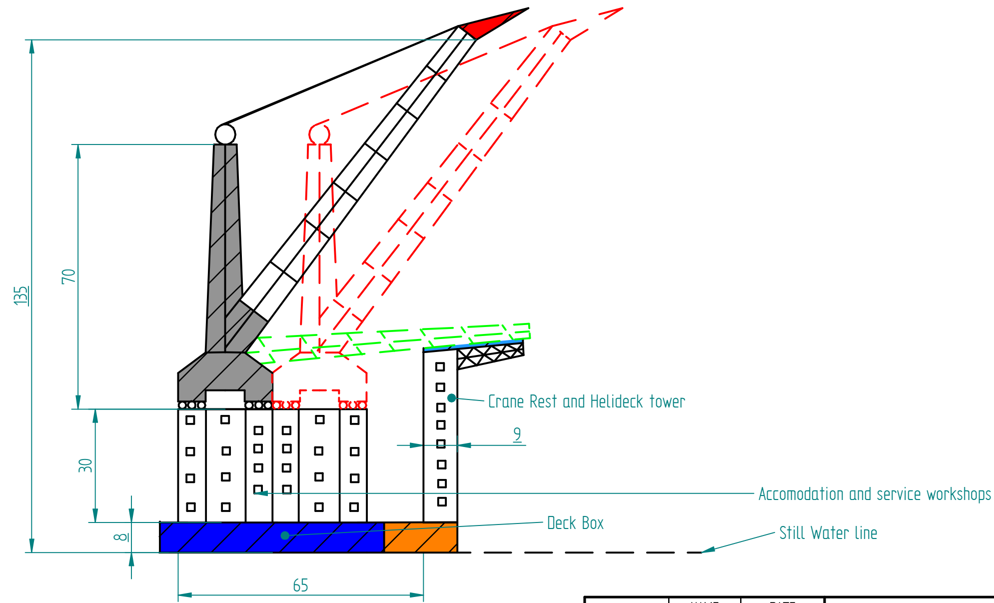
Top View - SWATH/CAT-showing the Accomodation and Bridge



Top View - Monohull - Showing Accomodation and Helideck, Bridge



Top view - SWATH/CAT Showing Helideck and crane rest



Side View - Sliding crane arrangement alternative on top of accomodation for SWATH Case

	NAME	DATE
DRAWN	RIK	11/04/13
CHECKED		
ENG APPR		
MGR APPR		

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN MILLIMETERS
ANGLES ±X.X°
2 PL ±X.XX 3 PL ±X.XXX

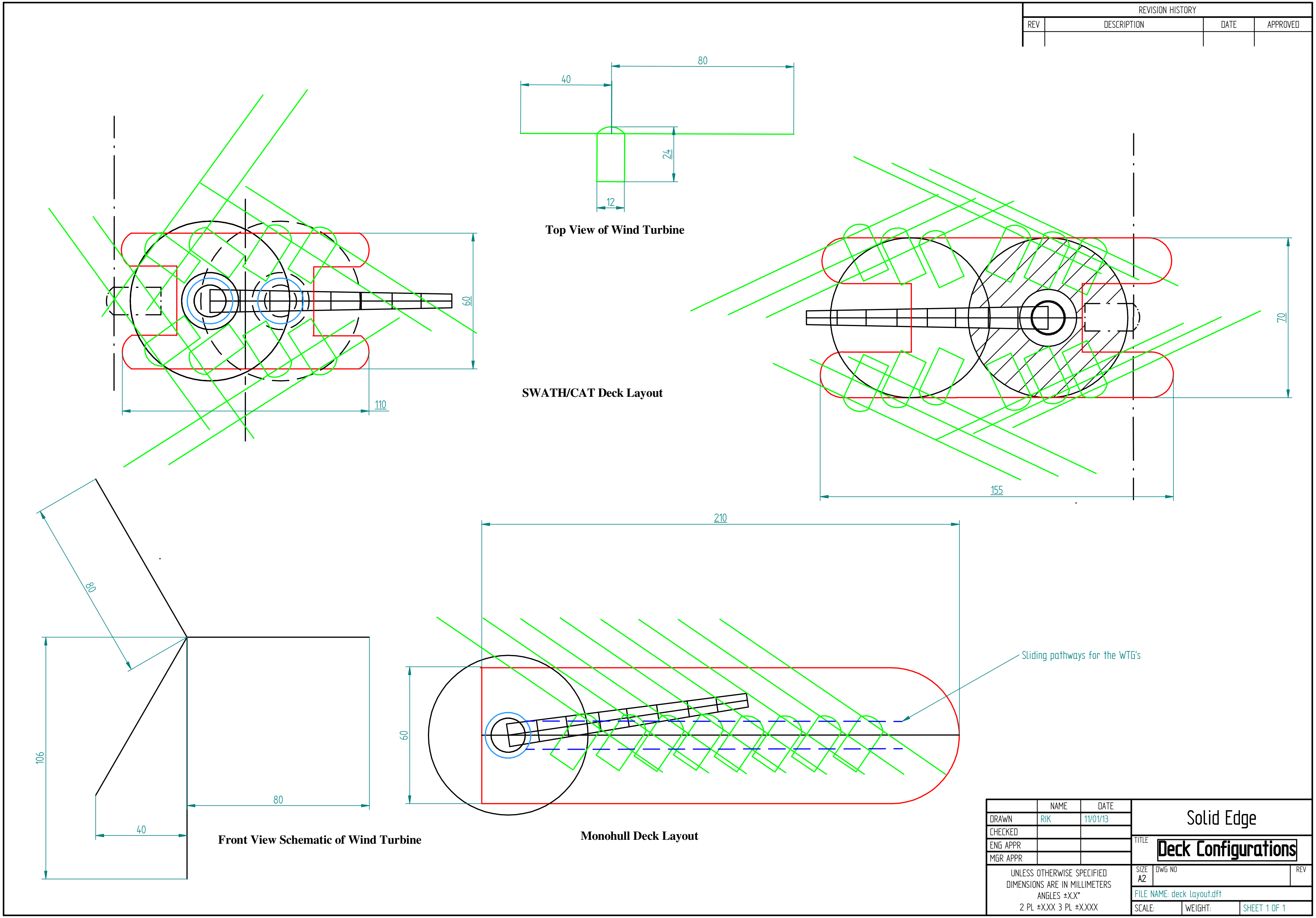
Solid Edge

TITLE
Accomodation Layout

SIZE A2 | DWG NO | REV

FILE NAME: Accomodation.dft

SCALE: | WEIGHT: | SHEET 1 OF 1


REVISION HISTORY
REV
DESCRIPTION
DATE
APPROVED
40
80
24
12
Top View of Wind Turbine
60
110
SWATH/CAT Deck Layout
70
155
80
106
80
40
Front View Schematic of Wind Turbine
210
60
Sliding pathways for the WTG's
Monohull Deck Layout
NAME
DATE
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RIK
11/01/13
CHECKED
ENG APPR
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UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN MILLIMETERS
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Deck Configurations
SIZE
A2
DWG NO
REV
FILE NAME: deck layout.dft
SCALE:
WEIGHT:
SHEET 1 OF 1

APPENDIX-IV

SENSITIVITY ANALYSIS AND INITIAL DESIGN

1. Sensitivity analysis of the main parameters of the SWATH vessel

Description	***Parameter***	***Value original & changed by***	***Unit***	***% Change***	***GM without WTG , Mid draft Change in (%)(2)***	***GM with WTG , Mid draft Change in (%)(2)***	***Operation***	***Remarks***
Height of deck box	D1	5	Meter		Increase by 20	Increase by 600	Reduced	Height of the deck if increased raises the cg even more so the High GM's are reduced but the mid draft GM is decreased
		5		100	Decreases by 30	Decreases Drastically	Increased	
Width of Deck above pontoon	D2	15	Meter		Increase by 3	Increase by 100	Reduced	The increase or decrease has not much drastic effect on any values
		5		33	Decreases 3	Decreases by 100	Increased	
Distance between two pontoons	D3	80	Meter		Decrease by 60	Decrease by 100	Reduced	The reduction in this value also helps drop the values of the other high value GM's can be used to increse values of (2) upto 10 m
		20		25	Increase by 90	Increase by 800	Increased	
Height of struts	S1	5	Meter		Increase by 30	Increase by 60	Reduced	Reduction of value is better but the strut height reduces hence not much change can be done here
		2		40	Decreases by 30	Decreases by 60	Increased	
Length of struts	S2	60	Meter		Decreases by 61	Decreases by 800	Reduced	The reduction of this value has a drastic effect on the mid draft GM
		10		16	Increase by 61	Increase by 800	Increased	
Thickness of struts	S3	3	Meter		Decreases by 30	Decreases by 300	Reduced	
		2		33	Increase by 30	Increase by 370	Increased	
Height of pontoon	P1	10	Meter		Increase by 10	Decreases by 100	Reduced	
		2		20	Decreases by 50	Decreases by 300	Increased	
width of pontoon	P2	15	Meter		Increase by 50	Decreases by 400	Reduced	
		5		33	Decreases by 20	Increase by 300	Increased	
length of the pontoon	P3	96	Meter		Increase by 25	Decreases by 100	Reduced	
		10		10	Decreases by 17	Increase by 200	Increased	
height of dual draft shape	H1	4	Meter		Increase by 13	Increase by 200	Reduced	
		2		10	Decreases by 8	Decreases by 100	Increased	

APPENDIX V

RESISTANCE AND POWER CALCULATION

1.0 The First method based on regression analysis and operational data of SWATHS

For the first method the following steps have been taken to estimate the ct for the resistance calculation.

- First the data collected on the swaths [31] is tabulated in an excel sheet.
- The main hull dimensions and the submerged part dimensions are used in the form of simple ratios as established [30] which are elaborated below.
- The concept ship is also subjected to the same evaluation.
- The closest fit to the concept ship with the calculated ratios are highlighted as shown in the Table 2.
- Then the average Ct value is calculated for the concept based on the Ct values of these different operational SWATHS in Table 2.

Main ship dimensions						Submerged sections			
Name of the ship	***Loa***	***B***	***T***	***Δ***	***v***	***Lp***	***Dp***	***b***	***S***
	m	***m***	***m***	***tons***	***Kn***	***m***	***m***	***m***	***m2***
Skrunda	25.71	13	2.7	132.9	20	23.82	2.15	11	300
Jokob Prei	26.1	13	2.7	132.9	20	23.75	2.08	11	300
Perseus	25.2	13	2.7	125	18	23.63	2.05	11	300
Ad hoc 24 m	26.93	9.8	2.03	75	25	22	1.5	8.3	220
Ad hoc 41 m	48	16.9	3.7	375	28	41.25	2.72	14.2	670
MC-ASD	20	9.6	1.5	60	14	18.06	1.53	7.6	190
FOB SWATH	25	10.6	2.49	100	22.85	24.63	2.47	8	310
planet	73	25	6.8	3500	15	69.37	6.16	20	2400
Swath OPV	49.35	19	4.55	900	20	46	3.5	15	1100
MV China Star	131	32.3	8.4	12880	14	122.63	7	24.2	6000
Silver cloud	41	17.8	4.1	600	14	38	3.2	14.6	770
Elbe	49.9	22.5	5.9	1500	14	46.49	4.23	18.3	1400
Dose, duhnen	25.2	13	2.7	125	15	23.5	2	11	300
Kilo Moana	57	27	7.6	2588	15	52.61	6.52	20.5	1800
Sea Fighter	79.9	22	3.6	950	55	71.46	2.57	19.4	1000
Concept swath	120	74	15	47000	10	120	15	59	10800

TABLE 1: THE TABULATED DATA FROM OPERATIONAL SWATHS

Ratios					Resistance and coefficients		
Loa/B	*B/T*	*Lp/Dp*	*S/Δ*	*Lp/b*	*Rt (Kn)*	*Ct*	*Cr*
1.977692	4.814815	11.07906977	2.257336	2.165455	94.36	0.00579	0.00386
2.007692	4.814815	11.41826923	2.257336	2.159091	94.36	0.00579	0.00386
1.938462	4.814815	11.52682927	2.4	2.148182	84.36	0.00639	0.00443
2.747959	4.827586	14.66666667	2.933333	2.650602	83.98	0.0045	0.00267
2.840237	4.567568	15.16544118	1.786667	2.90493	299.93	0.00421	0.00254
2.083333	6.4	11.80392157	3.166667	2.376316	56.32	0.0114	0.00908
2.358491	4.257028	9.971659919	3.1	3.07875	91.88	0.00418	0.00227
2.92	3.676471	11.26136364	0.685714	3.4685	296.53	0.00405	0.00232
2.597368	4.175824	13.14285714	1.222222	3.066667	406.3	0.0068	0.00508
4.055728	3.845238	17.51857143	0.465839	5.067355	944.79	0.00592	0.00432
2.303371	4.341463	11.875	1.283333	2.60274	136.64	0.00667	0.0048
2.217778	3.813559	10.99054374	0.933333	2.540437	152.74	0.0041	0.00228
1.938462	4.814815	11.75	2.4	2.136364	84.35	0.00639	0.00443
2.111111	3.552632	8.069018405	0.695518	2.566341	213.84	0.00389	0.00214
3.631818	6.111111	27.80544747	1.052632	3.683505	950.09	0.00231	0.00088
1.621622	4.933333	8	0.229787	2.033898	822.3739	0.005615	0.003715

TABLE 2: RATIOS CALCULATED AND CORRESPONDING VALUES OF RESISTANCE COEFFICIENTS

The highlighted values in the last row are the values used for the concept. The ratios are based on the following equations

Loa = Length overall of the vessel
B = is the breadth of the vessel
T = is the draft of the ship
Lp = is the length of the submerged pontoon
Dp = is the equivalent diameter of the submerged pontoon
S = is the total surface area of the wetted surface under water
Δ = is the displacement at the given draft
b = is the spacing between the hulls

Once these ratios are established the ships which exhibit the closest match to the ratios of the concept ship are also highlighted. The vessels which have the highest highlighted sections are chosen as seen in the above table 1 and 2. The values of the Ct and Cr of these vessels are averaged and the Ct for the concept is calculated. The values of the Ct for the vessels are from operational data hence these values are more realistic compared to any of the numerical or structural methods.

1.1 The second method based on Reynolds number

This is a very simple method in which the resistance coefficient is tabulated based on very simple formulas based on the Reynolds number which can be calculated for the ship given a particular speed. The formulas used are as follows [31].

$$C_t = C_f + C_r + \Delta C_t \qquad \text{(E1)}$$

Ct = total resistance coefficient
Cf = the frictional resistance coefficient
Cr = residuary resistance coefficient
ΔCt = the correlation coefficient

$$C_f = 0.075/(\log R_n - 2)^2 \qquad \text{(E2)}$$

Where,

$$R_n = \frac{V*L}{\nu} \qquad \text{(E3)}$$

V = velocity of the ship in m/s
L = length of the Vessels
ν = Dynamic viscosity of water in Ns/m2

$$\Delta C_t = \frac{14.77 - 0.738(lnR_n)}{1000} \qquad \text{(E4)}$$

Cr is got from the earlier method and then the Ct is calculated from these values.

This Ct value is very conservative but is essential in understanding how far away the resistance of a Mono hull of similar dimensions is away from the SWATH resistance.

1.2 The third method based on parametric analysis

is a method presented by Jan P. Michalski from the polish Naval University. The method was elaborated on the basis of numerical calculation results obtained by using structural methods based on ship hydrodynamic theory and performed for sufficiently large series of body forms with systematically changing ship parameters[30].Also, the results of verifying investigations dealing with features of the method in question are presented by comparing the obtained resistance characteristics with those achieved by other authors as well as with ship model experimental test results. The obtained results of the verification indicate that the elaborated method can be useful in preliminary designing the SWATH ships.

The first step in this method is to establish that the concept vessel fits the range of applicability of this method. To check this the following parameters of the ship and their ratios are checked if they fall in a set of applicable limits. If these ratios satisfies the limits, then the elaborate formulas used here can be used to calculate the Ct.

Description	*Symbol*	*Value*	*Unit*
Length of lower pontoon	Lp	120	m
Diameter of equivalent circle	Dp	15	m
Length of struts	Lk	96	m
Thickness of struts	Bk	8	m
Spacing of the axis of the floats	Yp	59	m
Ratio of Float volume to volume of cylinder of equivalent dia Cylindrical Coefficient	ϕ	0,848826	
Speed of Hull	V	20	Knots m/s
Acceleration due to Gravity		9,8	m/s2
Column water plane coefficient	αk	0,666667	
Draught of columns above pontoon	Tk	5	
Dynamic viscosity coefficient of water	0,000798	N S/m2	
Density of water	1025	kg/m3	

TABLE 3: DIMENSIONS OF CONCEPT SWATH USED IN THE PARAMETRIC STUDY

The limits for the ratios are as follows [30]. Lower hull Slenderness (8-16), Upper hull length, Breadth of struts(0.7-0.9), Dimensionless spacing of hulls(0.4-0.6), Block coefficient of lower hulls(2-4) & Froude number related to float length(0.3-0.5). The values are in green means the ratios are satisfied and the further calculations are based on the same dimensions and follow the following formulas[30].

Ratios to check, for which the method is valid		
Lower hull Slenderness	X1= Lp/Dp	8
Upper hull length	X2= Lk/Lp	0,8
Breadth of struts	X3= Bk/Dp	0,533333
Dimensionless spacing of hulls	X4= Lp/Yp	2,033898
Block coefficient of lower hulls	X5=ϕ	0,848826
Froude number related to float length	X6	0,300028

TABLE 3: RATIO CHECK FOR APPLICABILITY OF METHOD

Step1 – Calculation of the wetted surface area

$$\Omega\ (x) = 2\left(L_p * D_p * \varphi^{C0} - L_k * B_K * \alpha_k^{c1}\right) + 2 * L_k * T_k * B_k^{c2}$$

Tab. 1. The structural constants in the formula (3) for wetted surface area of SWATH ship hull

i =	0	1	2
C_i	0.66666	1.50	0.002

Step 2 – calculation of Cv viscosity resistance coefficient

$$C_v(x,c) = \frac{0.075}{\left(\log\left(v * \frac{L_P}{\frac{\mu}{\rho}}\right) - 2\right)^2} * (\left(1 + \left(\frac{D_p}{L_p}\right)^{C1}\right)\left(\frac{2\left(L_p * D_p * \varphi^{C2} - L_k * B_K * \alpha_k^{c3}\right)}{2 * \left(L_p * D_p * \varphi^{C2} - L_k * B_K * \alpha_k^{c3}\right) + (4 * L_k * T_k * B_k^{c4})}\right) + \left(1 + \left(\frac{3.2 * \sqrt{(2 * B_K * T_k)}}{L_k}\right)^{1.43}\right)\left(\frac{\left(4 * L_k * T_k * B_k^{c4}\right)}{2 * \left(L_p * D_p * \varphi^{C2} - L_k * B_K * \alpha_k^{c3}\right) + (4 * L_k * T_k * B_k^{c4})}\right)$$

Tab. 2. The structural constants in the formula (8) for viscosity resistance characteristics of SWATH ship hull

i =	1	2	3	4
C_i	1.250	0.6666	1.50	0.002

Step 3 - to calculate the coefficient of wave resistance Cw

Tab. 3. The structural constants in the formula (10) for wave resistance coefficient characteristics of SWATH ship hull

		i = 0	i = 1	I = 2	i = 3
$C_{i,0}$	j = 0	−12.1397304	92.9980695	−233.111006	191.37337
$C_{i,1}$	j = 1	−1.04586444	6.80487275	−18.1580215	15.9779735
$C_{i,2}$	j = 2	3.55241531	−29.5798224	88.3886875	−77.6752057
$C_{i,3}$	j = 3	31.0710348	−238.120645	598.284408	−492.059972
$C_{i,4}$	j = 4	−19.1679792	147.631585	−372.719428	307.847798
$C_{i,5}$	j = 5	−1.06797869	7.76205472	−19.4101477	15.9798061
$C_{i,6}$	j = 6	0.380383693	−2.99449204	8.25988137	−7.33575198
$C_{i,7}$	j = 7	−1.43530796	10.0595466	−22.915595	16.9069877
$C_{i,8}$	j = 8	0.853411164	−5.32492704	10.4095064	−6.21579753
$C_{i,9}$	j = 9	0.83038227	−6.91822075	18.3849983	−16.0594273
$C_{i,10}$	j = 10	−0.72083999	5.99518048	−16.053947	14.1285268
$C_{i,11}$	j = 11	20.2259023	−147.264231	371.04320	−301.57430
$C_{i,12}$	j = 12	−2.51608454	−1.20224482	−4.0574586	37.0598212

$$C_w(x,c) = \Bigg(C_{0,0} + C_{0,1} * \left(\frac{D_p}{L_p}\right) + C_{0,2} * \left(\frac{D_p}{L_p}\right)^2 + C_{0,3} * (\varphi) + C_{0,4} * (\varphi)^2 + C_{0,5} * \left(\frac{B_k}{D_p}\right) + C_{0,6} * \left(\frac{B_k}{D_p}\right)^2 + C_{0,7} * \left(\frac{Y_p}{L_p}\right) + C_{0,8} * \left(\frac{Y_p}{L_p}\right)^2 + C_{0,9} * \left(\frac{L_k}{L_p}\right) + C_{0,10} * \left(\frac{L_k}{L_p}\right)^2 + C_{0,11} * \left(\frac{D_p}{L_p}\right) * \frac{B_k}{D_p} * \frac{L_k}{L_p} + C_{0,12} * \left(\frac{D_p}{L_p}\right)^2 * \frac{B_k}{D_p} * \frac{L_k}{L_p} \Bigg)$$

$$+ \Bigg(C_{1,0} + C_{1,1} * \left(\frac{D_p}{L_p}\right) + C_{1,2} * \left(\frac{D_p}{L_p}\right)^2 + C_{1,3} * (\varphi) + C_{1,4} * (\varphi)^2 + C_{1,5} * \left(\frac{B_k}{D_p}\right) + C_{1,6} * \left(\frac{B_k}{D_p}\right)^2 + C_{1,7} * \left(\frac{Y_p}{L_p}\right) + C_{1,8} * \left(\frac{Y_p}{L_p}\right)^2 + C_{1,9} * \left(\frac{L_k}{L_p}\right) + C_{1,10} * \left(\frac{L_k}{L_p}\right)^2 + C_{1,11} * \left(\frac{D_p}{L_p}\right) * \frac{B_k}{D_p} * \frac{L_k}{L_p} + C_{1,12} * \left(\frac{D_p}{L_p}\right)^2 * \frac{B_k}{D_p} * \frac{L_k}{L_p} \Bigg) * F_n$$

$$+ \Bigg(C_{2,0} + C_{2,1} * \left(\frac{D_p}{L_p}\right) + C_{2,2} * \left(\frac{D_p}{L_p}\right)^2 + C_{2,3} * (\varphi) + C_{2,4} * (\varphi)^2 + C_{2,5} * \left(\frac{B_k}{D_p}\right) + C_{2,6} * \left(\frac{B_k}{D_p}\right)^2 + C_{2,7} * \left(\frac{Y_p}{L_p}\right) + C_{2,8} * \left(\frac{Y_p}{L_p}\right)^2 + C_{2,9} * \left(\frac{L_k}{L_p}\right) + C_{2,10} * \left(\frac{L_k}{L_p}\right)^2 + C_{2,11} * \left(\frac{D_p}{L_p}\right) * \frac{B_k}{D_p} * \frac{L_k}{L_p} + C_{2,12} * \left(\frac{D_p}{L_p}\right)^2 * \frac{B_k}{D_p} * \frac{L_k}{L_p} \Bigg) * F_n^2$$

$$+ \Bigg(C_{3,0} + C_{3,1} * \left(\frac{D_p}{L_p}\right) + C_{3,2} * \left(\frac{D_p}{L_p}\right)^2 + C_{3,3} * (\varphi) + C_{3,4} * (\varphi)^2 + C_{3,5} * \left(\frac{B_k}{D_p}\right) + C_{3,6} * \left(\frac{B_k}{D_p}\right)^2 + C_{3,7} * \left(\frac{Y_p}{L_p}\right) + C_{3,8} * \left(\frac{Y_p}{L_p}\right)^2 + C_{3,9} * \left(\frac{L_k}{L_p}\right) + C_{3,10} * \left(\frac{L_k}{L_p}\right)^2 + C_{3,11} * \left(\frac{D_p}{L_p}\right) * \frac{B_k}{D_p} * \frac{L_k}{L_p} + C_{3,12} * \left(\frac{D_p}{L_p}\right)^2 * \frac{B_k}{D_p} * \frac{L_k}{L_p} \Bigg) * F_n^3$$

The Cv and Cw are combined to form the Ct and the resistance is calculated based on this value of Ct. Then estimate the resistances with different Ct values using formula 5.1 in chapter 5.

2.0 Wind resistance calculations

To find the total resistance caused due to forces from the wind acting on the ship are calculated as follows.

The position and the layout of the wind turbines have been established early in the report. The data for the area of cross section of the wind turbines has to be estimated first. This is done by using data from wind tunnel tests performed on a model of the Oleg starshnov[32]

- The area of the ship with the wind turbines on the ship is given then also the test is performed without the wind turbines, from these values one can get the data for the relevant area from the report

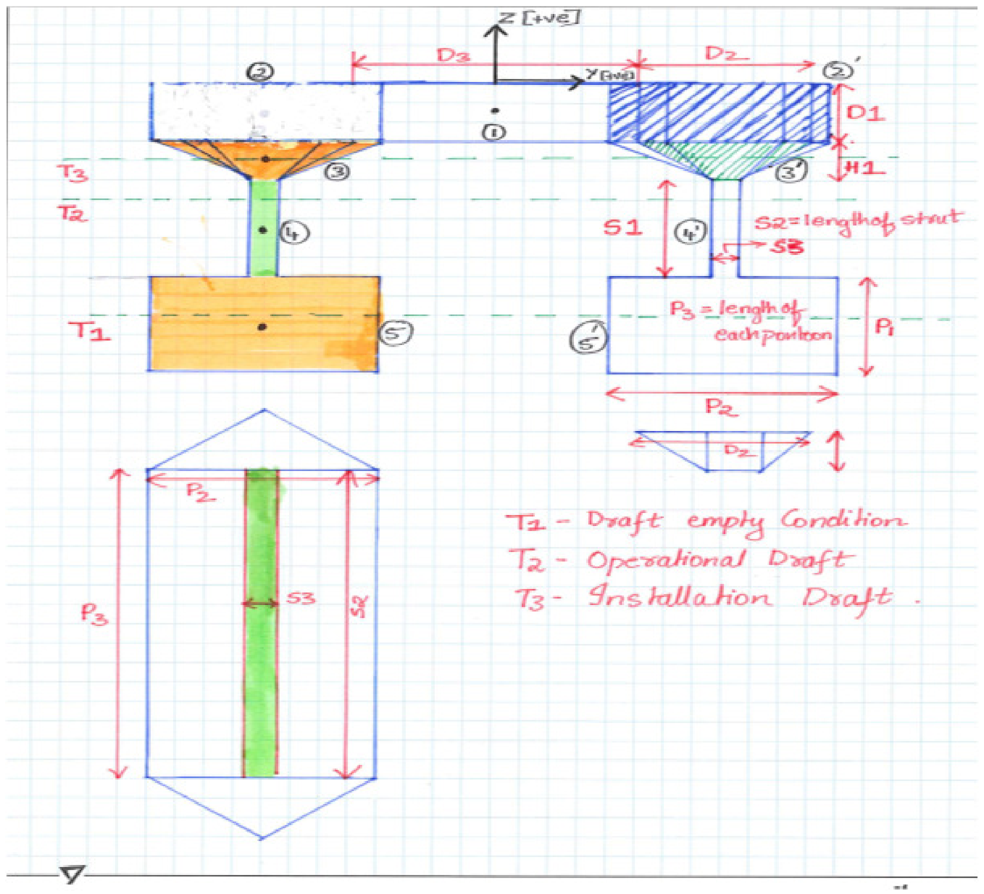
- The next step is to extrapolate the values based on the difference between the WTG's used on the Oleg and the ones being used in the concept.

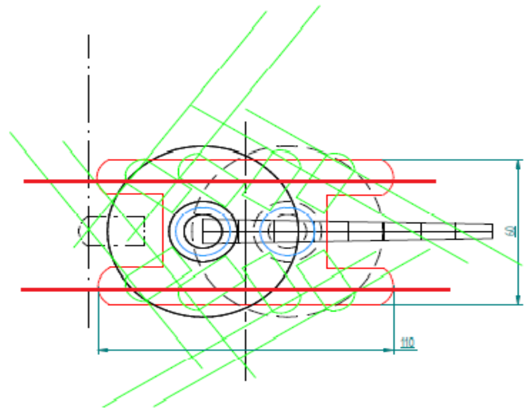
Once the areas are known the rest of the details are pretty much straight forward. The coefficient for wind resistance in that direction is also estimated from the report and incorporated in the calculation shown below to estimate the wind resistance based on formula 5.2 in chapter 5 of the main report.

Description	***Symbol***	***Value***	***Unit***	***Note***
The no of turbines on deck	N	8		
Transverse area of projection of ship	At1	348	m2	
Lateral area of projection of ship	Al1	2976	m2	
Surface area of one turbine in particular configuration from front	WS1	750	m2	Combination of SHL results and size extrapolation 50 % increase in length of tower and 36 % increase in blade length
Surface area of one turbine in particular configuration from Side	WS2	1059.45	m2	
Transverse area of projection of combined system	At	6348	m2	
Lateral area of projection of ship	Al	11451.6	m2	
Wind speed	Vw	50	Knots	25.722
Coefficient of wind resistance	Cxw	1.15		
Total wind resistance	Rw	4520.85	KN	

Files attached

1. Ship shape report generated for draft at lower pontoon
2. Ship shape report generated for draft at strut level
3. Ship shape report generated for draft at upper pontoon level
4. Power calculations in detail
5. Mono hull parametric study (excel sheet)-1
6. Mono hull parametric study (excel sheet)-2
7. SWATH parametric study (excel sheet)-1 main dimension
8. SWATH parametric study (excel sheet)-2 GM, Free surface and drop load
9. SWATH parametric study (excel sheet)-3 GZ curve – Intact stability
10. SWATH parametric study (excel sheet)-4 Drop load calculations
11. SWATH parametric study (excel sheet)-5 Drop load GZ curves
12. Longitudinal Stability calculations sheet





Description	*Parameter*		*Unit*
Height of deck box	D1	6	Meter
Width of Deck above pontoon	D2	15	Meter
Distance between two pontoons	D3	47	Meter
Height of struts	S1	8	Meter
Length of struts	S2	96	Meter
Thickness of struts	S3	8	Meter
Height of pontoon	P1	10	Meter
width of pontoon	P2	15	Meter
length of the pontoon	P3	100	Meter
height of dual draft shape	H1	4	Meter
Draft at lower case	T1	9	Meter
Draft at transport case	T2	18	Meter
Draft at installation case	T3	22	Meter
Total depth of vessel	D4	28	Meter
Angle of slope at strut	A1	41.18593	Degrees
Overall length of the top pontoon	TP1	120	Meter
Length of Triangular projection from pontoon	TP2	12	Meter

COG	*X*	*Y*	*Z*	*Mass*
WTG 1	-48	-31	66.5	1000
WTG 2	-16	-31	66.5	1000
WTG 3	16	-31	66.5	1000
WTG 4	48	-31	66.5	1000
WTG 5	-48	31	66.5	1000
WTG 6	-16	31	66.5	1000
WTG 7	16	31	66.5	1000
WTG 8	48	31	66.5	1000
	0	**0**	**66.5**	**8000**
Crane At the centre Location	0	0	35	1800
Note : Crane has same dimensions as established previously (liebherr 1600 MT capacity) comparable boom length to oleg strashnov and hence approximated to 35				
When the WTG 1 is in the hook on Aft side	-35	0	86.5	1400
When the WTG 1 is in the hook on Bow side	35	0	86.5	1400
When the WTG 8 is in the hook on Aft side	-35	0	86.5	1400
When the WTG 8 is in the hook on Bow side	35	0	86.5	1400

Finding out the geometric CG								
	x(m)	y(m)	z(m)	Area(m2)				
COG of Shape 1	0	0	-3	282				
COG of Shape 2	0	-31	-3	90				
COG of Shape 2'	0	31	-3	90				
COG of Shape 3	0	-33.83333333	-7.555555556	21				
COG of Shape 3'	0	33.83333333	-7.555555556	21				
COG of Shape 4	0	-31	-14	64				
COG of Shape 4'	0	31	-14	64				
COG of Shape 5	0	-31	-23	150				
COG of Shape 5'	0	31	-23	150				
Final CoG	0	0	-11.15379113					
	0	25.83333333	-7.333333333	7	0	25.83333333	-7.333333	7
	0	44.66666667	-7.333333333	7	0	36.16666667	-7.333333	7
	0	31	-8	7	0	31	-8	32
	0	33.83333333	-7.555555556	21	0	31	-7.797101	
		KG only ship	16.84620887					

Centre of Buoyancy and Displacement for T1 (valid for T1 between 0 and 10)				
	x(m)	y(m)	z(m)	Area(m2)
COB of shape 5	0	-31	-23.5	135
COB of shape 5'	0	31	-23.5	135
Combined COB	0	0	-23.5	
KB (m)			4.5	
Volume of submerged part (m3)	30240			
Displacement (tons)	30996			

Description	Value	Unit
I shape 1	22792.5	m4
I shape 1'	146767.5	m4
I shape 3	2939250	m4
I-Area Moment of Inertia	3108810	m4
BM	100.29714	m
GM	87.950926	m
Without WTG's at the level of the pontoons		

Description	Value	Estim
		Volume of ballast water
Light Weight (tons)	18597.6	
Dead weight (tons)	24176.9	583.804878
Weight of WTG's (tons)	8000	
Weight to be distributed in tanks (tons)	598.4	
Loss in GM due to free surface effects case 1	12.0334	
Loss in GM due to free surface effects case 2	24.0668	
Loss in GM due to free surface effects case 3	4.63325	
Loss in GM due to free surface effects case 4	11.5172	

Centre of Buoyancy and Displacement for T2 (valid for T2 between 10 and 18)				
	x(m)	y(m)	z(m)	Area(m2)
COB of shape 5	0	-31	-23	150
COB of shape 5'	0	31	-23	150
COB of shape 4	0	-31	-14	32
COB of shape 4'	0	31	-14	32
Combined COB	0	0	-21.41758242	
KB(m)			6.582417582	
Volume of submerged part (m3)	45888			
Displacement (tons)	47035.2			

	Value	Unit
I-Area Moment of Inertia	1484288	m4
BM	31.556962	m
GM	21.29317	m
Without WTG's at the level of the struts		

Description	Value	Estim
		Volume of ballast water
Light Weight (tons)	18597.6	
Dead weight (tons)	24176.9	16231.80488
Weight of WTG's (tons)	8000	
Weight to be distributed in tanks (tons)	16637.6	
Loss in GM due to free surface effects case 1	7.92997	
Loss in GM due to free surface effects case 2	15.8599	
Loss in GM due to free surface effects case 3	3.05329	
Loss in GM due to free surface effects case 4	7.58977	

Centre of Buoyancy and Displacement for T3 (valid for T3 between 18 and 22)				
	x(m)	y(m)	z(m)	Area(m2)
COB of shape 5	0	-31	-23	150
COB of shape 5'	0	31	-23	150
COB of shape 4	0	-31	-14	64
COB of shape 4'	0	31	-14	64
COB of shape 3	0	-31	-7.797101449	46
COB of shape 3'	0	31	-7.797101449	46
Combined COB	0	0	-18.09487179	
KB(m)			9.905128205	
Volume of submerged part (m3)	50120			
Displacement (tons)	51373			

	Value	Unit
I-Area Moment of Inertia	4269600	m4
BM	83.109805	m
GM	76.168724	m
Without WTG's at the level of the dual draft shape		

Description	Value	Estim
		Volume of ballast water
Light Weight (tons)	18597.6	
Dead weight (tons)	24176.9	20463.80488
Weight of WTG's (tons)	8000	
Weight to be distributed in tanks (tons)	20975.4	
Loss in GM due to free surface effects case 1	7.26039	
Loss in GM due to free surface effects case 2	14.5208	
Loss in GM due to free surface effects case 3	5.59096	
Note: Case 3 the length is 96 instead of 48 because the height of the pontoon is not enough		
Loss in GM due to free surface effects case 4	6.94891	

ation of the New KG and GM with the WTG's on board					
height of water in each pontoon	***x (m)[LCG]***	***y(m)[TCG]***	***z(m)[VCG]***		
0.389203252	0	31	-27.805398		
	0	-31	-27.805398		
0.194601626	0	31	-27.902699		
	0	-31	-27.902699		
0.778406504	0	27.25	-27.610797		New GM After
	0	-27.25	-27.610797	***GM***	loss due to FSE
Case 1	0	0	12.792368	***64.005***	51.97134694
Case 2	0	0	12.79036	***64.007***	39.93993483
Case 3	0	0	12.796384	***64.001***	59.36750449
case 4	0	0	12.792655	***64.004***	52.487312

Estimation of the New KG and GM with one WTG's on hook							
Case 4	***New Weight***	***height of water in each pontoon***	***x (m)[LCG]***	***y(m)[TCG]***	***z(m)[VCG]***		New GM After loss due to FSE
						GM	
Weight 1	598.4		-1.666893	0	14.4759771	62.32	50.80398985
Dropped			0	0	10.8742614	65.92	54.40570553
Weight 2	7198.4	5.01630662	0	36.75	-25.491847		
			0	25.25	-25.491847		
			0	-36.75	-25.491847		58.09400888
			0	-25.25	-25.491847		31.2714846
			-1.361262	-2.02E-16	7.18595802	69.61	
Dropped			0	-2.1E-16	3.97634827	42.79	

T1-4	33.2019739

ation of the New KG and GM with the WTG's on board					
height of water in each pontoon	***x (m)[LCG]***	***y(m)[TCG]***	***z(m)[VCG]***		
10.82120325	0	31	-22.589398		
	0	-31	-22.589398		
5.410601626	0	31	-25.294699		
	0	-31	-25.294699		
10.82120325	0	27.25	-22.589398		New GM After
	0	-27.25	-22.589398	***GM***	loss due to FSE
Case 1	0	0	0.7459567	***9.3934***	1.46344893
Case 2	0	0	-0.2534773	***10.393***	-5.467090532
Case 3	0	0	0.7459567	***9.3934***	6.340132376
Case 4	0	3.231E-16	0.4033032	***9.7361***	2.146310352

Estimation of the New KG and GM with one WTG's on hook							
case 3	***New Weight***	***height of water in each pontoon***	***x (m)[LCG]***	***y(m)[TCG]***	***z(m)[VCG]***		New GM After loss due to FSE
						GM	
Weight 1	16637.6		-1.078459	3.203E-16	1.60146403	8.538	0.948149482
Dropped			0	0	-1.0976937	11.24	3.647307209
Weight 2	23237.6	16.19344948	0	36.75	-19.903275		
			0	25.25	-19.903275		
			0	-36.75	-19.903275		2.940466153
			0	-25.25	-19.903275		5.342889639
			-0.94167	3.305E-16	-0.3908526	10.53	
Dropped			0	0	-2.7932761	12.93	

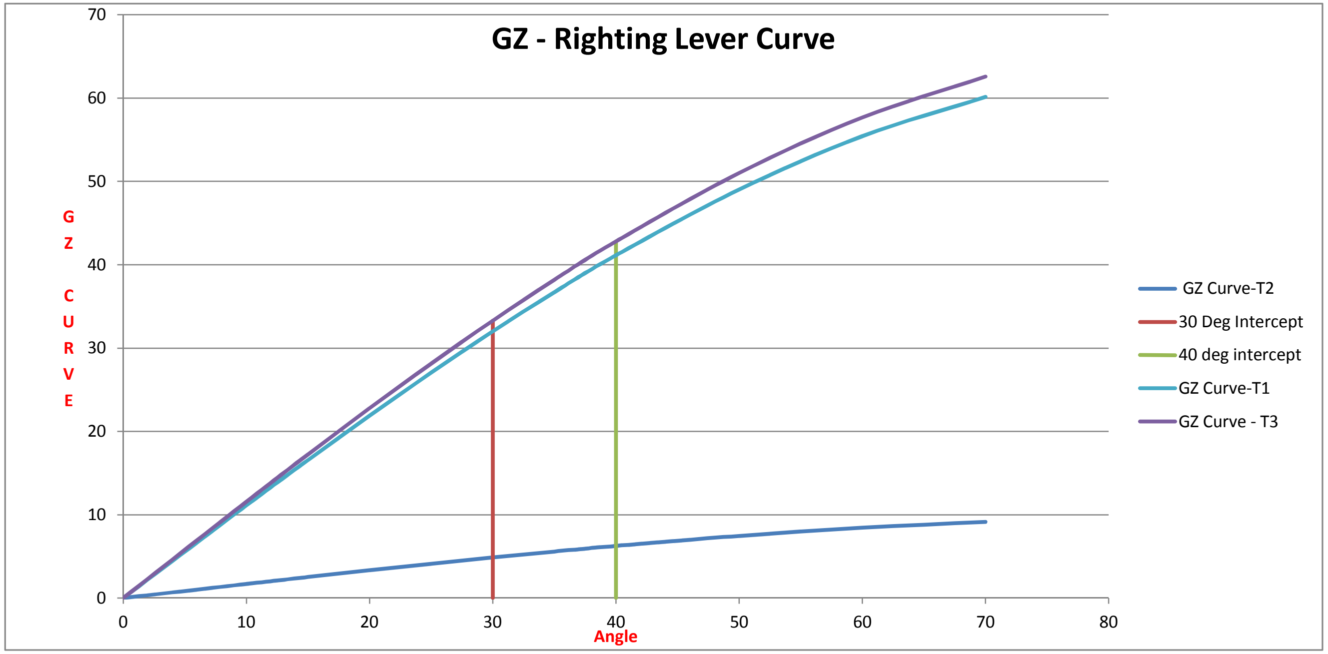
	With FSE case 1 , Case 2 , case 3 as shown previously
	with FSE
	1.40476761
	-5.2478714
	6.08590601
T2-4	2.06024769

ation of the New KG and GM with the WTG's on board					
height of water in each pontoon	***x (m)[LCG]***	***y(m)[TCG]***	***z(m)[VCG]***		
13.64253659	0	31	-21.178732		
	0	-31	-21.178732		
6.821268293	0	31	-24.589366		
	0	-31	-24.589366		
13.64253659	0	27.25	-21.178732		New GM After
	0	-27.25	-21.178732	***GM***	loss due to FSE
Case 1	0	0	-1.1477146	***66.163***	58.90226004
Case 2	0	0	-2.5966729	***67.612***	53.09083071
Case 3	0	0	-1.1477146	***67.612***	62.02064915
case 4	0	0	-1.582829	***66.598***	59.64885603

Estimation of the New KG and GM with one WTG's on hook							
Case 3	***New Weight***	***height of water in each pontoon***	***x (m)[LCG]***	***y(m)[TCG]***	***z(m)[VCG]***		New GM After loss due to FSE
						GM	
Weight 1	20975.4		-0.984469	0	-0.4731283	65.49	59.89710461
Dropped			0	0	-2.9902842	68.01	62.41426046
Weight 2	27575.4	19.21630662	0	36.75	-18.391847		
			0	25.25	-18.391847		
			0	-36.75	-18.391847		60.57694444
			0	-25.25	-18.391847		62.80920674
			-0.86921	0	-1.1529682	66.17	
Dropped			0	0	-3.3852305	68.4	

T3-4	62.5375649

Angle (DEG	GZ= GM SIN(θ) (T2-4)	GZ (T1-4)	GZ (T3-4)
0	0	0	0
10	1.690651857	11.11426	11.56458
15	2.519881897	16.56558	17.23677
20	3.329934113	21.89082	22.77778
25	4.114643521	27.04946	28.14543
30	4.868038006	32.00224	33.29888
35	5.584383784	36.71146	38.19891
40	6.258229028	41.14129	42.80822
50	7.458266927	49.03028	51.01685
60	8.43168916	55.42951	57.67535
70	9.148918785	60.14454	62.58143



Area Under 30 Deg LINE	8.5752	Limit as Given by IMO is that the area under the curve at 30 deg intercept should be more than 0.055 radian-metre
	1.304421	
	8.922643	
Area Under 40 Deg LINE	14.97546	Limit as Given by IMO is that the area under the curve at 40deg intercept should be more than 0.09 radian-metre
	2.278	
	15.58222	

Stactic angle of equillibrium before loss of load This angle should be less than 15 deg (DNV code)	***Degrees***	
Case 4 FSE and 1st turbine installation	7.218034273	-7.218034273
Case 4 FSE and last turbine installation	5.116872115	-5.116872115
Case 4 FSE and 1st turbine installation -t1	1.532297792	-1.532297792
Case 4 FSE and last turbine installation-t1	1.12036056	-1.12036056

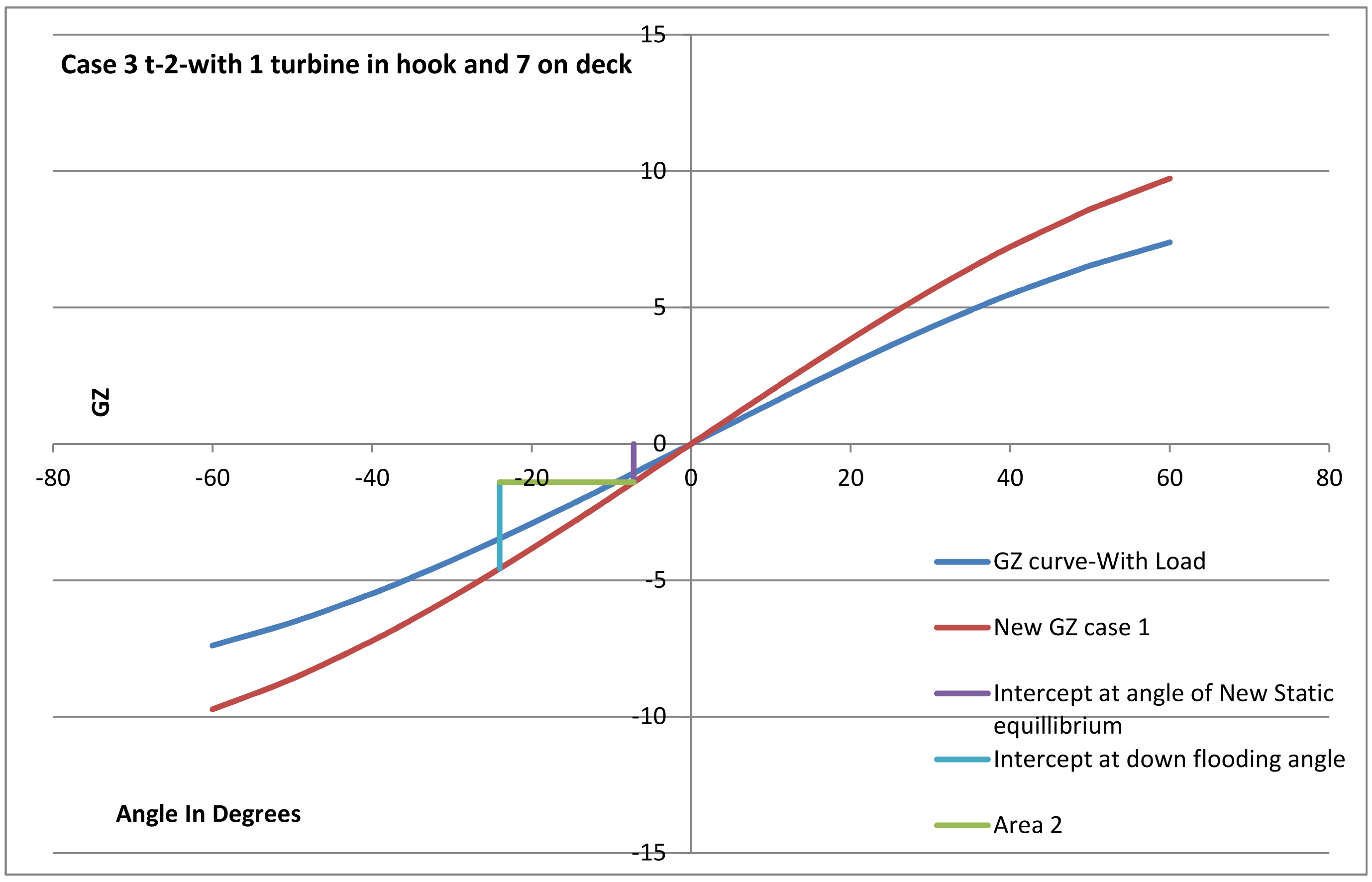
Angle	*last t2*	*last t2 dropped*	*First t2*	*First t2 dropped*
-60	-9.119448259	-11.20000803	-7.39405141	-9.73159057
-50	-8.066625566	-9.906988727	-6.540422451	-8.60809723
-40	-6.768702537	-8.312950587	-5.488066067	-7.22305121
-35	-6.039892838	-7.41786634	-4.897146942	-6.445320212
-30	-5.265115907	-6.46632765	-4.268957572	-5.618536435
-25	-4.450268265	-5.465576303	-3.608278857	-4.748992204
-20	-3.601551394	-4.423228619	-2.920138961	-3.843305274
-15	-2.725424543	-3.347217495	-2.209775045	-2.90836847
-10	-1.828555565	-2.245732025	-1.482593406	-1.951297226
0	0	0	0	0
10	1.828555565	2.245732025	1.482593406	1.951297226
15	2.725424543	3.347217495	2.209775045	2.90836847
20	3.601551394	4.423228619	2.920138961	3.843305274
25	4.450268265	5.465576303	3.608278857	4.748992204
30	5.265115907	6.46632765	4.268957572	5.618536435
35	6.039892838	7.41786634	4.897146942	6.445320212
40	6.768702537	8.312950587	5.488066067	7.22305121
50	8.066625566	9.906988727	6.540422451	8.60809723
50	8.066625566	9.906988727	6.540422451	8.60809723
60	9.119448259	11.20000803	7.39405141	9.73159057

	Corresponding angle of static equillibrium	***Mid point***	***Area Under curve***	
Intercept case1	-1.411887671	-0.707346621	0.089051534	Potential Energy
Intercept case2	-1.153432503	-0.577291687	0.051538635	
Intercept case1	-4.570529297	-1.639796112	0.198697655	This value must be 1.4 times the potential Energy
Intercept case2	-5.260184803	-2.121493544	0.438276641	
Angle of down flooding	24	-24		

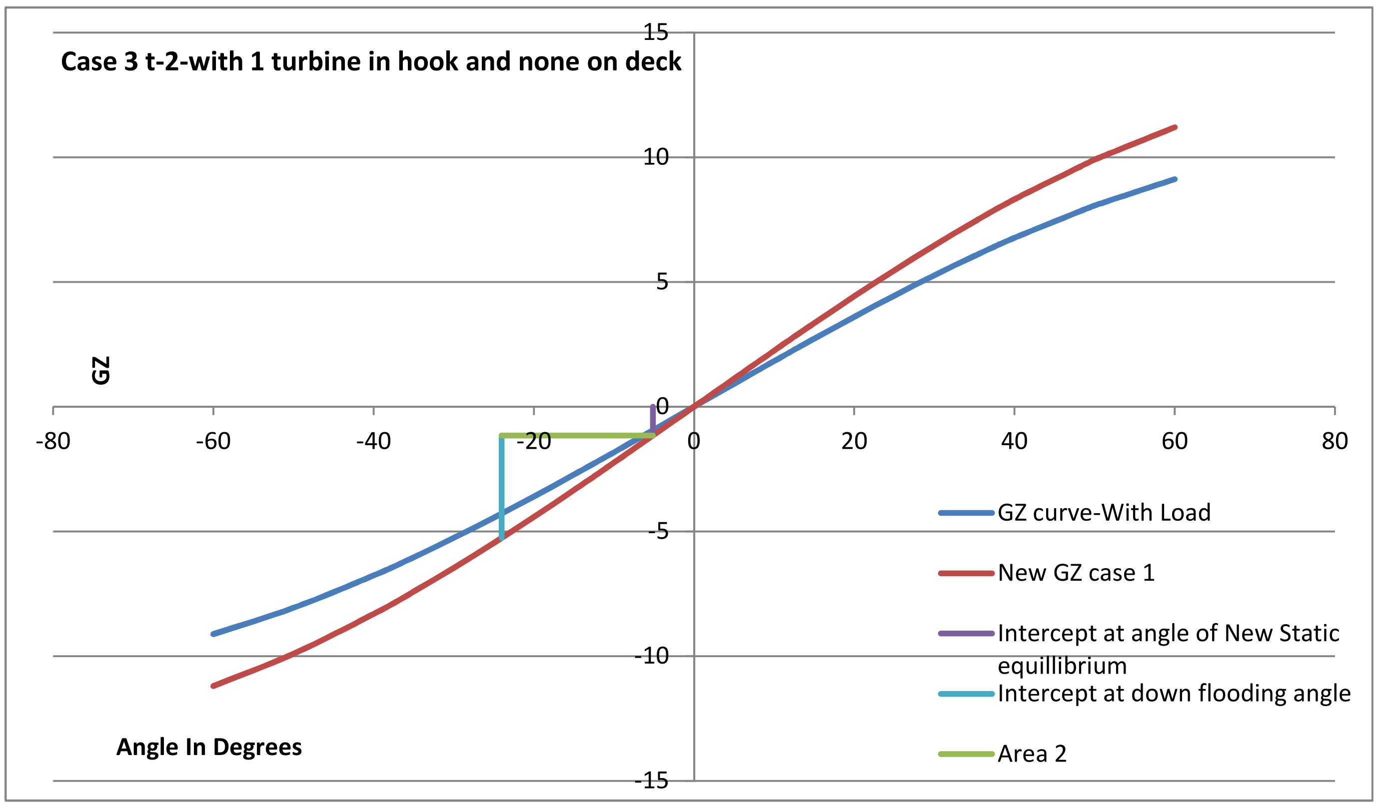
For Draft T-2

	Corresponding angle of static equillibrium	***Mid point***	***Area Under curve***	
Intercept case1	-1.762807557	-0.881482584	0.023573352	Potential Energy
Intercept case2	-0.836635168	-0.418337578	0.008180035	
Intercept case1	-26.81324837	-12.84269072	4.533736804	This value must be 1.4 times the potential Energy
Intercept case2	-17.403713	-8.486640063	3.139167176	
Angle of down flooding	24	-24		

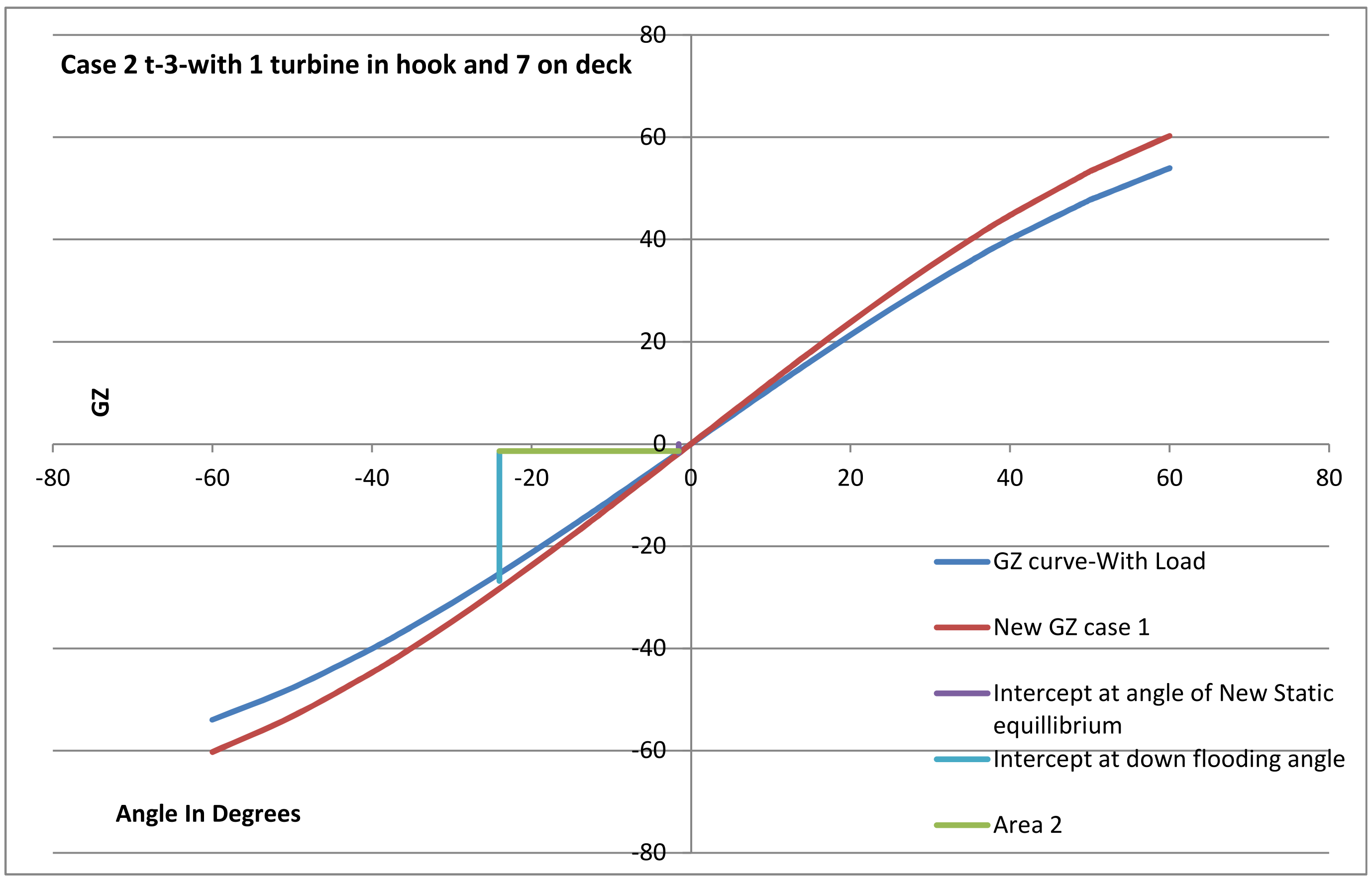
Angle	*last t1*	*last t1 dropped*	*First t1*	*First t1 dropped*
-60	-60.28504775	-37.05606032	-53.97170607	-60.28504775
-50	-53.32525539	-32.77800971	-47.74077682	-53.32525539
-40	-44.74520213	-27.50401586	-40.05926822	-44.74520213
-35	-39.92733089	-24.54256299	-35.74594775	-39.92733089
-30	-34.80558855	-21.3943264	-31.16057903	-34.80558855
-25	-29.41895466	-18.08326607	-26.33805949	-29.41895466
-20	-23.80842477	-14.63458117	-21.31509141	-23.80842477
-15	-18.01669838	-11.07451826	-16.12990262	-18.01669838
-10	-12.08785405	-7.430171584	-10.82195553	-12.08785405
0	0	0	0	0
10	12.08785405	7.430171584	10.82195553	12.08785405
15	18.01669838	11.07451826	16.12990262	18.01669838
20	23.80842477	14.63458117	21.31509141	23.80842477
25	29.41895466	18.08326607	26.33805949	29.41895466
30	34.80558855	21.3943264	31.16057903	34.80558855
35	39.92733089	24.54256299	35.74594775	39.92733089
40	44.74520213	27.50401586	40.05926822	44.74520213
50	53.32525539	32.77800971	47.74077682	53.32525539
50	53.32525539	32.77800971	47.74077682	53.32525539
60	60.28504775	37.05606032	53.97170607	60.28504775



Case 3 t-2-with 1 turbine in hook and 7 on deck
15
10
5
0
-5
-10
-15
GZ
-80
-60
-40
-20
0
20
40
60
80
GZ curve-With Load
New GZ case 1
Intercept at angle of New Static equillibrium
Intercept at down flooding angle
Area 2
Angle In Degrees



Case 3 t-2-with 1 turbine in hook and none on deck
15
10
5
0
-5
-10
-15
GZ
-80
-60
-40
-20
0
20
40
60
80
GZ curve-With Load
New GZ case 1
Intercept at angle of New Static equillibrium
Intercept at down flooding angle
Area 2
Angle In Degrees



Case 2 t-3-with 1 turbine in hook and 7 on deck
80
60
40
20
0
-20
-40
-60
-80
GZ
-80
-60
-40
-20
0
20
40
60
80
GZ curve-With Load
New GZ case 1
Intercept at angle of New Static equillibrium
Intercept at down flooding angle
Area 2
Angle In Degrees

Loading Condition no. : 2

CONDITION DRAFT AT STRUT BETWEEN 10M AND 18M

FLOATING CONDITION DATA

Mean Draught (moulded) :	16.328	m
Trim over Lpp (aft +) :	0.000	m
List (starboard +) ... :	0.000	°
Draught, AP (moulded) :	16.328	m
Draught, LCF (moulded) :	16.328	m
Draught, FP (moulded) :	16.328	m

Displacement .... :	42983.004	MT
LCB (rel. AP) .... :	60.000	m
VCB (rel. BL) .... :	6.899	m
LCF (rel. AP) .... :	60.005	m
TPC - Immersion ...... :	15.747	MT/cm
Trim Moment .... :	100.776	MT*m/cm

WEIGHT SUMMARY

Miscellaneous Mass Loads :	22319.0	MT
Total DEADWEIGHT :	22319.0	MT

STABILITY DATA/CONTROL

KG (incl. FSC) .... :	30.050	m
Free Surface Correction:	0.000	m
KM (metacentre) ...... :	39.053	m
GM (incl. FSC) .... :	9.003	m
KGmax, intact, calc. . :	38.903	m
Stability Margin ......:	8.853	m
Stability Conclusion . :	OK	

Water Density = 1.025 t/m3

Please note !
-Floating data are based on hydrostatic for upright vessel (zero heel). List is found by use of GM.

Loading Condition no. : 2
Condition Id. text : CONDITION DRAFT AT STRUT BETWEEN 10M AND 18M

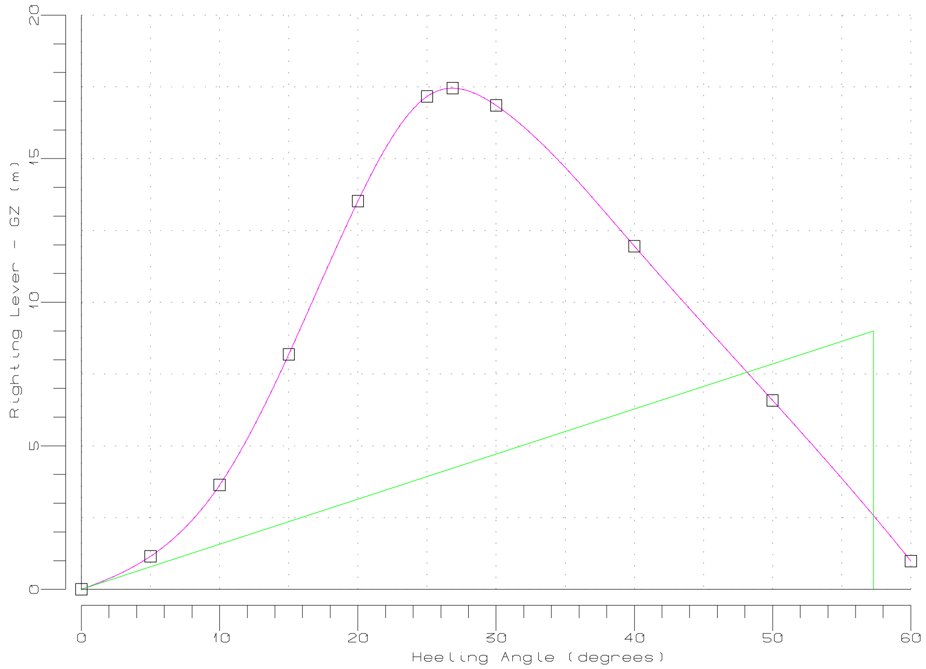
- UNIT LOADS

WEIGHT LOADS

Part no.	Id.text	Weight (MT)	Load (%)	Density (MT/m3)	Distribution Aft (m)	Distribution Fore (m)	LCG (m)	TCG (m)	VCG (m)	FSCT Moment (MT*m)
1	WTG WEIGHTON DECK	8000.000					60.000	0.000	94.500	
2	WATER BALLAST	12519.000					60.000	0.000	6.180	
3	CRANE WEIGHT ON DECK	1800.000					60.000	0.000	63.000	
	DEAD WEIGHT	22319.000					60.000	0.000	42.420	
	LIGHT WEIGHT, lSW	20664.000					60.000	0.000	16.690	
	TOTAL WEIGHT	42983.000					60.000	0.000	30.050	

Loading Condition no. : 2
Condition Id. text : CONDITION DRAFT AT STRUT BETWEEN 10M AND 18M

INTACT STABILITY DATA (GZ-curve, Areas, Particulars & Criteria Control)



Angle (degr.)	GZ (m)	Area (m*rad)
0.000	0.000	0.0000
5.000	1.152	0.0450
10.000	3.636	0.2399
15.000	8.189	0.7433
20.000	13.519	1.6925
25.000	17.166	3.0557
26.850	17.453	3.6162
30.000	16.852	4.5639
40.000	11.954	7.1112
50.000	6.581	8.7255
60.000	0.989	9.3957

Maximum GZ at : 26.850 °
Equilibrium at : 0.000 °
Area, 0 - 30 : 4.5639 m*rad
Area, 0 - 40 : 7.1112 m*rad
Area,30 - 40 : 2.5473 m*rad
Area, 0 - maxGZ: 3.6162 m*rad
GM : 9.003 m

Heel to starboard side
Applied VCG : 30.050 m
TCG : 0.000 m

Table of intact stability criteria

TYPE : IMO A.167 (ES.IV)

Code	Id. text	Req.	Actual value	Concl-usion	KGmax (m)
GZMi1	GZ at angle greater or equal to 30.0°	: 0.20 m	16.852	OK	63.355
GZAng	Angle at which max. GZ occur, ð	: 25.00 °	26.850	OK	50.998
GMMin	Minimum GM	: 0.15 m	9.003	OK	38.903
GZAr1	Area, GZ curve (0.0-30.0)°	*) : 0.055 m·rad	4.564	OK	58.272
GZAr2	Area, GZ curve (0.0-min<40.0,ß>)°	*) : 0.090 m·rad	7.111	OK	57.687
GZAr2	Area, GZ curve (30.0-min<40.0,ß>)°	*) : 0.030 m·rad	2.547	OK	60.408

ß : flooding angle
ð : angle for maximum GZ
GZarea : area of righting lever
*) : area will also be limited by angles for equilibrium and 2nd intercept

Intact Stability conclusion ...... : OK

Resulting KGmax .... (m): 38.903
KG (incl. correction) .... (m): 30.050
Intact stability margin .... (m): 8.853

Please note !

-GM is calculated based on metacentric height (KMT) for upright vessel (zero heel)

Freeboard to Deck

Loading Condition no. : 2 ,CONDITION DRAFT AT STRUT BETWEEN 10M AND 18M

No.	X (m)	Y (m)	Z (m)	Freeboard Starboard (m)	Freeboard Port (m)
1	0.000	0.000	28.100	11.772	11.772
2	0.000	0.000	28.100	11.772	11.772
3	0.000	0.000	28.100	11.772	11.772

Freeboard is vertical distance from deck point to sea at equilibrium.

Loading Condition no. : 3

CONDITION DRAFT AT UPPER PONTOON MORE THAN 18M

FLOATING CONDITION DATA

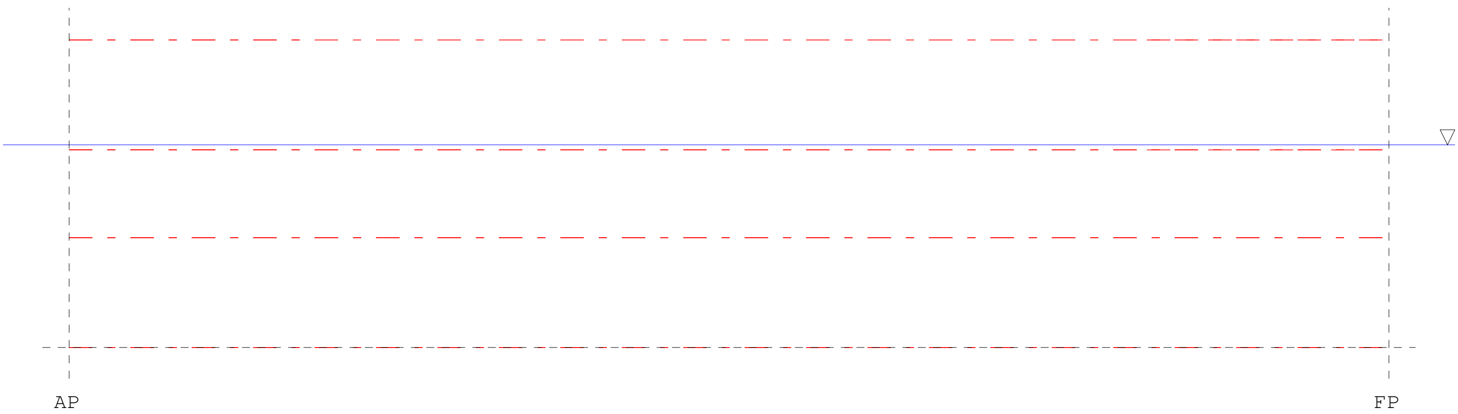
Mean Draught (moulded)	:	18.446 m
Trim over Lpp (aft +)	:	0.000 m
List (starboard +) ...	:	0.000 °
Draught, AP (moulded)	:	18.446 m
Draught, LCF (moulded)	:	18.446 m
Draught, FP (moulded)	:	18.446 m
Displacement	:	48464.004 MT
LCB (rel. AP)	:	60.000 m
VCB (rel. BL)	:	8.154 m
LCF (rel. AP)	:	59.997 m
TPC - Immersion	:	67.482 MT/cm
Trim Moment	:	408.074 MT*m/cm

WEIGHT SUMMARY

Miscellaneous Mass Loads	:	27800.0 MT
Total DEADWEIGHT	:	27800.0 MT

STABILITY DATA/CONTROL

KG (incl. FSC)	:	27.928 m
Free Surface Correction	:	0.000 m
KM (metacentre)	:	80.795 m
GM (incl. FSC)	:	52.867 m
KGmax, intact, calc. .	:	51.701 m
Stability Margin	:	23.773 m
Stability Conclusion .	:	OK



Water Density = 1.025 t/m3

Please note !
-Floating data are based on hydrostatic for upright vessel (zero heel). List is found by use of GM.

Loading Condition no. : 3
Condition Id. text : CONDITION DRAFT AT UPPER PONTOON MORE THAN 18M

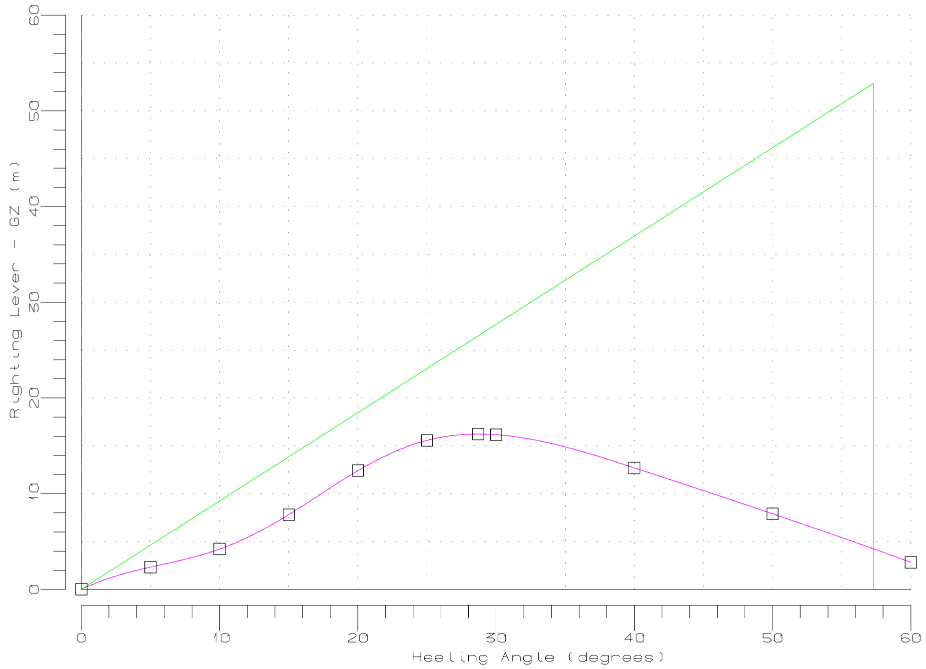
- UNIT LOADS

WEIGHT LOADS

Part no.	Id.text	Weight (MT)	Load (%)	Density (MT/m3)	Distribution Aft (m)	Distribution Fore (m)	LCG (m)	TCG (m)	VCG (m)	FSCT Moment (MT*m)
1	WTG WEIGHT ON DECK	8000.000					60.000	0.000	94.500	
2	CRANE WEIGHT	1800.000					60.000	0.000	63.000	
3	BALLAST WATER	18000.000					60.000	0.000	7.734	
	DEAD WEIGHT	27800.000					60.000	0.000	36.281	
	LIGHT WEIGHT, lSW	20664.000					60.000	0.000	16.690	
	TOTAL WEIGHT	48464.000					60.000	0.000	27.928	

Loading Condition no. : 3
Condition Id. text : CONDITION DRAFT AT UPPER PONTOON MORE THAN 18M

INTACT STABILITY DATA (GZ-curve, Areas, Particulars & Criteria Control)



Angle (degr.)	GZ (m)	Area (m*rad)
0.000	0.000	0.0000
5.000	2.334	0.1153
10.000	4.213	0.3942
15.000	7.804	0.9051
20.000	12.407	1.7883
25.000	15.571	3.0263
28.700	16.226	4.0604
30.000	16.158	4.4281
40.000	12.695	6.9996
50.000	7.898	8.7995
60.000	2.834	9.7409

Maximum GZ at : 28.700 °
Equilibrium at : 0.000 °
Area, 0 - 30 : 4.4281 m*rad
Area, 0 - 40 : 6.9996 m*rad
Area,30 - 40 : 2.5715 m*rad
Area, 0 - maxGZ: 4.0604 m*rad
GM : 52.867 m

Heel to starboard side
Applied VCG : 27.928 m
TCG : 0.000 m

Table of intact stability criteria

TYPE : IMO A.167 (ES.IV)

Code	Id. text		Req.	Actual value	Concl-usion	KGmax (m)
GZMi1	GZ at angle greater or equal to 30.0°		: 0.20 m	16.158	OK	59.843
GZAng	Angle at which max. GZ occur, ð		: 25.00 °	28.700	OK	51.701
GMMin	Minimum GM		: 0.15 m	52.867	OK	80.645
GZAr1	Area, GZ curve (0.0-30.0)°	*)	: 0.055 m·rad	4.428	OK	51.823
GZAr2	Area, GZ curve (0.0-min<40.0,ß>)°	*)	: 0.090 m·rad	7.000	OK	51.811
GZAr2	Area, GZ curve (30.0-min<40.0,ß>)°	*)	: 0.030 m·rad	2.572	OK	57.377

ß : flooding angle
ð : angle for maximum GZ
GZarea : area of righting lever
*) : area will also be limited by angles for equilibrium and 2nd intercept

Intact Stability conclusion ...... : OK

Resulting KGmax .... (m): 51.701
KG (incl. correction) .... (m): 27.928
Intact stability margin .... (m): 23.773

Please note !

-GM is calculated based on metacentric height (KMT) for upright vessel (zero heel)

Freeboard to Deck

Loading Condition no. : 3 ,CONDITION DRAFT AT UPPER PONTOON MORE THAN 18M

No.	X (m)	Y (m)	Z (m)	Freeboard Starboard (m)	Freeboard Port (m)
1	0.000	0.000	28.100	9.654	9.654
2	0.000	0.000	28.100	9.654	9.654
3	0.000	0.000	28.100	9.654	9.654

Freeboard is vertical distance from deck point to sea at equilibrium.

Loading Condition no. : 1

CONDITION DRAFT AT LOWER PONTOON LESS THAN 10M

FLOATING CONDITION DATA

Mean Draught (moulded) :	9.850	m
Trim over Lpp (aft +) :	0.000	m
List (starboard +) ... :	0.000	°
Draught, AP (moulded) :	9.850	m
Draught, LCF (moulded) :	9.850	m
Draught, FP (moulded) :	9.850	m

Displacement .... :	32464.002	MT
LCB (rel. AP) .... :	60.000	m
VCB (rel. BL) .... :	4.928	m
LCF (rel. AP) .... :	60.008	m
TPC - Immersion ...... :	33.210	MT/cm
Trim Moment .... :	270.548	MT*m/cm

STABILITY DATA/CONTROL

KG (incl. FSC) .... :	37.527	m
Free Surface Correction:	0.000	m
KM (metacentre) ...... :	87.066	m
GM (incl. FSC) .... :	49.539	m
KGmax, intact, calc. . :	13.058	m
Stability Margin ......:	-24.469	m
Stability Conclusion . :	NOT OK !!	

WEIGHT SUMMARY

Miscellaneous Mass Loads	:	11800.0 MT
Total DEADWEIGHT	:	11800.0 MT

Water Density = 1.025 t/m3

Please note !
-Floating data are based on hydrostatic for upright vessel (zero heel). List is found by use of GM.

Loading Condition no. : 1
Condition Id. text : CONDITION DRAFT AT LOWER PONTOON LESS THAN 10M

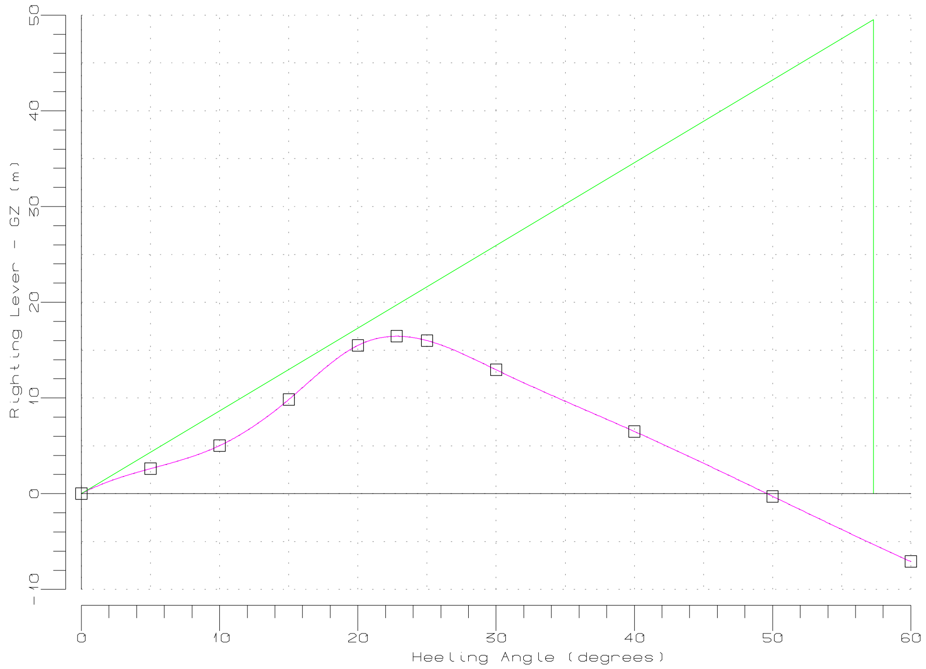
- UNIT LOADS

WEIGHT LOADS

Part no.	Id.text	Weight (MT)	Load (%)	Density (MT/m3)	Distribution Aft (m)	Distribution Fore (m)	LCG (m)	TCG (m)	VCG (m)	FSCT Moment (MT*m)
1	WTG ON DECK	8000.000					60.000	0.000	94.500	
2	CRANE WEIGHT	1800.000					60.000	0.000	63.000	
3	BALLAST WATER	2000.000					60.000	0.000	2.000	
	DEAD WEIGHT	11800.000					60.000	0.000	74.017	
	LIGHT WEIGHT, lSW	20664.000					60.000	0.000	16.690	
	TOTAL WEIGHT	32464.000					60.000	0.000	37.527	

Loading Condition no. : 1
Condition Id. text : CONDITION DRAFT AT LOWER PONTOON LESS THAN 10M

INTACT STABILITY DATA (GZ-curve, Areas, Particulars & Criteria Control)



Angle (degr.)	GZ (m)	Area (m*rad)
0.000	0.000	0.0000
5.000	2.615	0.1276
10.000	5.020	0.4503
15.000	9.835	1.0788
20.000	15.492	2.2023
22.800	16.444	2.9907
25.000	15.997	3.6163
30.000	12.943	4.8903
40.000	6.502	6.5795
50.000	-0.277	7.1304
60.000	-7.093	6.4807

Maximum GZ at : 22.800 °
Equilibrium at : 0.000 °
Area, 0 - 30 : 4.8903 m*rad
Area, 0 - 40 : 6.5795 m*rad
Area,30 - 40 : 1.6892 m*rad
Area, 0 - maxGZ: 2.9907 m*rad
GM : 49.539 m

Heel to starboard side
Applied VCG : 37.527 m
TCG : 0.000 m

Table of intact stability criteria

TYPE : IMO A.167 (ES.IV)

Code	Id. text		Req.	Actual value	Concl-usion	KGmax (m)
GZMi1	GZ at angle greater or equal to 30.0°		: 0.20 m	12.943	OK	63.013
GZAng	Angle at which max. GZ occur, ð		: 25.00 °	22.800	NOT OK	13.058
GMMin	Minimum GM		: 0.15 m	49.539	OK	86.916
GZAr1	Area, GZ curve (0.0-30.0)°	*)	: 0.055 m·rad	4.890	OK	65.352
GZAr2	Area, GZ curve (0.0-min<40.0,ß>)°	*)	: 0.090 m·rad	6.579	OK	65.351
GZAr2	Area, GZ curve (30.0-min<40.0,ß>)°	*)	: 0.030 m·rad	1.689	OK	59.674

ß : flooding angle
ð : angle for maximum GZ
GZarea : area of righting lever
*) : area will also be limited by angles for equilibrium and 2nd intercept

Intact Stability conclusion ...... : NOT OK

Resulting KGmax .... (m): 13.058
KG (incl. correction) .... (m): 37.527
Intact stability margin .... (m): -24.469

Please note !

-GM is calculated based on metacentric height (KMT) for upright vessel (zero heel)

Freeboard to Deck

Loading Condition no. : 1 ,CONDITION DRAFT AT LOWER PONTOON LESS THAN 10M

No.	X (m)	Y (m)	Z (m)	Freeboard Starboard (m)	Freeboard Port (m)
1	0.000	0.000	28.100	18.250	18.250
2	0.000	0.000	28.100	18.250	18.250
3	0.000	0.000	28.100	18.250	18.250

Freeboard is vertical distance from deck point to sea at equilibrium.

longitudinal stability								
			I (total) m^4	***BM (L) m***	***GM(L) m***			
					Empty ship	***loaded ship***	***loaded ship with 1st turbine in aft side hook***	***loaded ship with 8th turbine in aft side hook***
		44010						
Lower pontoon		2500000	2544010	75.71458333	63.86837446	43.14150875	41.59550478	47.52653914
Strut level Draft			1333333.333	26.6028199	16.33902861	4.507911552	3.31216311	5.521575674

Trimming moment		14000			***Corresponding to above GM(L)***			
MCT 1cm (tonnes m/cm)	LP				219.9626817	148.5793561	143.2549185	163.6814008
	STRUT				76.85094785	21.20305215	15.57882543	25.97084161
Change of trim (cm)	LP						97.72788361	85.53201482
	STRUT						898.6556824	539.0660883
Change in draft on aft side(m)	LP						0.488639418	0.244319709
	STRUT						4.493278412	2.695330442

Data to Be Input	***Value***	***Unit***
Speed	20	Knots
Length overall (Loa)	240	Meters
Length at waterline (Lwl)	235.2	Meters
Breadth	38	Meters
Draught (T)	10	Meters
Bilge radius	3	Meters
Depth	20	Meters
Cp	0.742759	
Cwp	0.825571	
Froude Number	0.214289	
C=1.08(Single screw)=1.09(Twin screw)	1.09	
length between perpendiculars (Lpp)	225.792	Meters
Cubic Number CN (Lpp*B*T)	85800.96	m3
Cd for general cargo ships (Scheenkluth)	0.7	
Displacement	87774.38	Tons
Deadweight	61442.07	Tons
Light weight	26332.31	Tons

Estimating the Value of Mid Ship Coefficient Cm	
Method 1	0.989835
Method 2 Kerlen (1970)	0.98916
Method 3 HSVA	0.990384
Method 4 Meizoso	0.981696
Method 5 Parson	0.989835
AVG value of Cm	0.988182

Estimating the Value KB	
KB Normand using Cb and Cwl	5.389908
KB Normand using Cm	5.442545
KB Scheenkluth	5.301473
KB Wobig	5.283371
AVG KB	5.354324

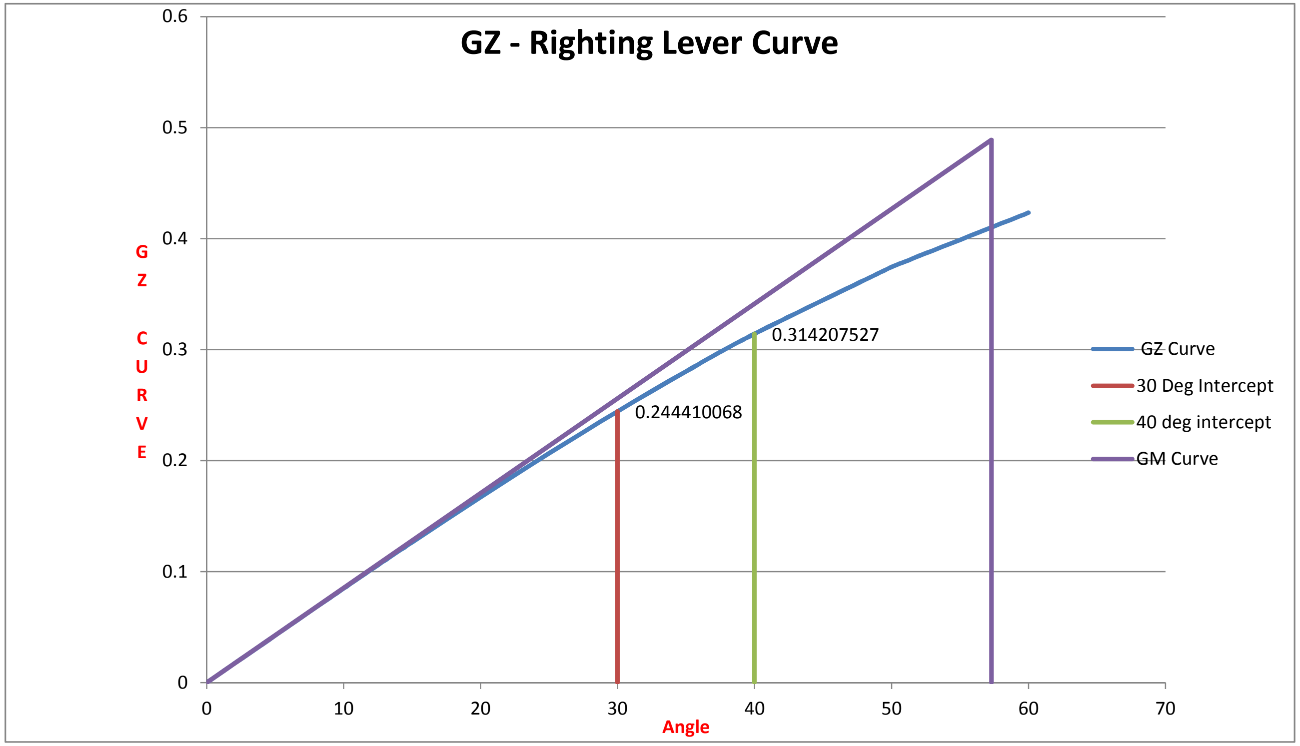
Estimating the Value KM	
(Cb/Cwp)	***0.889058***
KM - applicable for ships with 0.73 <(Cb/Cwp)<0.95	19.48882
Method 1 Schneekluth (1987)	18.15545

Estimating the Value of Block Coefficient Cb	
Method 1 Schneekluth (1987)	0.729994993
Method 2 Schneekluth (1987)	0.658085314
Method 3 Schneekluth (1987)	0.646966439
Method 4 Schneekluth (1987)	0.728847748
Method 5 Barras(2004)	0.691400482
Method 6 Alexander(1962)	0.760011344
Method 7 Katsoulis	0.911692713
Method 8 Kerlen(1970)	0.744851105
AVG Value of Cb	0.733981267

Estimating the Value of Block Coefficient Cwl	
Method 1 Schneekluth - Cwl (u shape sections)	0.813738668
Method 2 Schneekluth - Cwl (Intermediate shapesections)	0.822654178
Method 3 Schneekluth - Cwl (V Shape Sections)	0.842010254
Method 4 Schneekluth - Cwl general	0.825571476
Method 5 Torroja - U shaped vessel	0.849687894
Method 6 Torroja - V shaped vessel	0.826377239
Method 7 Parson	0.838429763
AVG Value of Cwl	0.831209925

Other General Criterion		
Common values are Passenger ships 6-8,Freighters 5-7, Tug Boats 3-5 Increased values good for speed but not for manoeuverability & Stability and vice versa	6.315789474	L/B Ratio
The customary values vary between 10-15	12	L/D Ratio
This generally varies between 2-4.5	3.8	B/T Ratio
This generally varies between 1-2 (increase will cause deck edge submergence)	1.9	B/D Ratio
BM	14.13449573	
GM (should lie between 0.3 and 0.5 for general Cargo ships) IMO & Should not be less than 0.15 (Initial)	0.488820136	
Note : Heavy lifting might require a higher GM but this can be countered using a quick ballasting system		

Angle (DEG)	GZ= GM SIN(θ)
0	0
10	0.084882726
15	0.126515961
20	0.167186333
25	0.206584316
30	0.244410068
35	0.280375712
40	0.314207527
50	0.374457949
50	0.374457949
60	0.423330656
70	0.459340675
80	0.48139386
90	0.488820136
100	0.48139386
110	0.459340675
120	0.423330656
130	0.374457949
140	0.314207527
150	0.244410068
160	0.167186333
170	0.084882726
180	5.98877E-17
GM	0.488820136



Area Under 30 Deg LINE	0.065491204	Limit as Given by IMO is that the area under the curve at 30 deg intercept should be more than 0.055 radian-metre
Area Under 40 Deg LINE	0.114371759	Limit as Given by IMO is that the area under the curve at 40deg intercept should be more than 0.09 radian-metre
Roll Period	31.44422127	Calculated based on the 3.2.2.3 of the Special purposes ship code

Power Estimation					Note
No	**Description**	**Symbol**	**Value**	**Unit**	
1	Velocity of the ship	V	10	Knots	Fill in value based on what speed in required
			5.144	m/s	
2	operating draft of ship	D	18	m	
3	Arriving water velocity to propeller (speed of advance of propellar)	Va	3.6008	m/s	
4	Wake fraction	w range 0.2-0.45	0.3		
5	Resistance of the ship	Rt	6190.496	KN	Value got from resistance calculations based on the same speed
6	Thrust reduction factor	t range 0.12-0.3	0.2		
7	Thrust	T	7738.12	KN	
8	Effective (Towing) Power Pe=T*V	Pe	31843.91	KW	
9	Thrust power (Pt=T*Va)	Pt	27863.42	KW	
10	Hull efficiency	ηh	1.142857		
11	Open water efficiency	ηo range 0.35-0.75	0.55		Choose This value as per the range given
12	Rotational efficiency	ηr range 1 to 1.07	1		Choose This value as per the range given
13	Propeller efficiency behind hull	ηb	0.55		
14	propulsive efficiency	ηd	0.628571		
15	Shaft Efficiency	ηs range 0.96-0.995	0.99		Choose This value as per the range given
16	Total Efficiency	ηt	0.622286		
17	Thrust power delivered by propeller	Pi	27863.42	KW	
18	Power delivered to propeller	Pd	50660.77	KW	
19	Power delivered by main engine	Pb	51172.49	KW	

Propeller details & matching the values					Note
No	**Description**	**Symbol**	**Value**	**Unit**	
1	propeller diameter	d range 5-10	9	m	Choose This value as per the range given
2	diameter by design draft	d/D	0.5		
3	No of blades	usually 4, 5 or 6 blades	5		
4	n rpm of the blades	Based on fig	65	rpm	
5	Advance Number	J	3.693054		
6	Torque	Q	74426.73	KNm	
7	Thrust Coefficient	Kt	0.098043		
8	Torque coefficient	KQ	0.104777		
9	Open water efficiency	ηo range	0.54999		check if values correspond to values given above
10	Power delivered to propeller	Pd	50661.68		

Results
1) There have to be two propeller systems with at 20000 KW each to move the swath at 10 Knots. This without considering any details like dynamic positioning and crane activities etc.

APPENDIX VI

MOMENT OF INERTIA CALCULATION

Rotor	*Blade*	*Nacelle*	*Tower*	*Total*		Rotor weight ratio	Blade weight ratio	Nacelle weight ratio	Tower weight ratio
Mt	*Mt*	*Mt*	*Mt*						
95.0	16.0	125.0	250.0	518.0		0.183397683	0.092664	0.241313	0.482625483
100.0	18.4	125.0	262.0	542.2		0.184433788	0.101807	0.230542	0.483216525
100.0		140.0	Site specific						
100.0		140.0	Site specific						
100	18.0	190.0	180.0	524.0		0.190839695	0.103053	0.362595	0.34351145
90.0	27.0	218.0	370.0	759.0		0.118577075	0.106719	0.28722	0.487483531
130.0	19.5	325.0		455.0					
135.0	23.0	325.0		460.0					
	7.0	91.0		91.0					
	11.9	119.5		119.5					
	35.0	390.0		800.0					
112.0	16.5	233.0	350.0	744.5		0.150436535	0.066488	0.312962	0.470114171
134.0	23.3	221.0	355.0	779.9		0.1718169	0.089627	0.28337	0.455186562
					Average Ratio	0.166583613	0.093393	0.286334	0.45368962
Weights of components in Vestas 7MW WTG in tons						133.2668901	74.71451	229.0669	362.9516963
						133	75	229	363

FIGURE A6-1: WEIGHT CALCULATIONS OF THE WTG COMPONENTS

Nacelle			
Dimension	*Meters*	*Value*	*Kg.m2*
A = width	7.5	Ixx	19072875
L = length	24	Iyy	19072875
B = height	7.5	Izz	3393750

Tower			
Dimension	*Meters*	*Value*	*Kg.m2*
Outer dia	8	Ixx	345013860.5
Height of tower	105	Iyy	345013860.5
Inner radius	7.925	Izz	23015220.94

FIGURE A6-2: MOMENT OF INERTIA OF INDIVIDUAL COMPONENT

$$I_{xx} = \frac{1}{12} * m * (A^2 + L^2) \quad (A6.1)$$

$$I_{yy} = \frac{1}{12} * m * (B^2 + L^2) \quad (A6.2)$$

$$I_{zz} = \frac{1}{12} * m * (A^2 + B^2) \quad (A6.3)$$

$$I_{xx} = I_{yy} = \frac{1}{12} * m * (r_1^2 + r_2^2) + h^2) \quad (A6.4)$$

$$I_{zz} = \frac{1}{12} * m * (r_1^2 + r_2^2) \quad (A6.5)$$

Where r 1 = Inner diameter of the cylinder
r 2 = Outer diameter of the cylinder
h = height of the cylinder

Formulas used to calculate individual moment of inertia for the Nacelle (A6.1-6.3) & Tower (A6.4-6.5)

For 8 turbines with respect to the ship axis								
		Value	***Kg.m2***				***Value***	***Kg.m2***
		Ixx	155439718				Ixx	2762924704
		Iyy	156363542				Iyy	2763851080
		Izz	29943296				Izz	186915063.5
Draft T1				Total deck			Ship	
				Value	***Kg.m2***		Ixx Ship(roll)	29404045440
				Ixx	2918364422		Iyy Ship(pitch)	40170816000
				Iyy	2920214622		Izz ship (yaw)	40170816000
				Izz	216858359.5			

For 8 turbines with respect to the ship axis								
		Value	***Kg.m2***				***Value***	***Kg.m2***
		Ixx	155459968				Ixx	2762936578
		Iyy	156383792				Iyy	1475868396
		Izz	29943296				Izz	186915063.5
Draft T2				Total deck			Ship	
				Value	***Kg.m2***		Ixx Ship(roll)	44619472128
				Ixx	2918396546		Iyy Ship(pitch)	60957619200
				Iyy	1632252188		Izz ship (yaw)	60957619200
				Izz	216858359.5			

For 8 turbines with respect to the ship axis								
		Value	***Kg.m2***				***Value***	***Kg.m2***
		Ixx	155463443				Ixx	2762938710
		Iyy	156387267				Iyy	2763865086
		Izz	29943296				Izz	186915063.5
Draft T3				Total deck			Ship	
				Value	***Kg.m2***		Ixx Ship(roll)	48734482720
				Ixx	2918402153		Iyy Ship(pitch)	66579408000
				Iyy	2920252353		Izz ship (yaw)	66579408000
				Izz	216858359.5			

For 8 turbines with respect to the ship axis for monohull								
		Value	***Kg.m2***				***Value***	***Kg.m2***
		Ixx	152650051.2				Ixx	2760177935
		Iyy	139940225.8				Iyy	2421544724
		Izz	33952700				Izz	230167409.4
Draft T1				Total deck				
				Value	***Kg.m2***		Ixx Ship(roll)	13104000000
				Ixx	2912827986		Iyy Ship(pitch)	3.276E+11
				Iyy	2561484950		Izz ship (yaw)	3.276E+11
				Izz	264120109.4			

	Draft T1 total		Draft T2 total		Draft T3 total			Monohull T2
	32322409862		47537868674		51652884873			16016827986
	43091030622		62589871388		69499660353			3.30161E+11
	40387674360		61174477560		66796266360			3.27864E+11
For all wind turbines on the deck								

FIGURE A6-3: TOTAL MOMENT OF INERTIA CALCULATIONS FOR ALL CASES IN TRANSPORT AND PRE LIFT CASE with one turbine in the crane

For 7 turbines with respect to the ship axis 1 in crane								
		Value	***Kg.m2***				***Value***	***Kg.m2***
		Ixx	155089275				Ixx	2762574437
		Iyy	157173309				Iyy	3456512362
		Izz	36383426				Izz	186569425.5
Draft T1				Total deck			Ship	
				Value	***Kg.m2***		Ixx Ship(roll)	29404045440
				Ixx	2917663711		Iyy Ship(pitch)	40170816000
				Iyy	3613685670		Izz ship (yaw)	40170816000
				Izz	222952851.5			

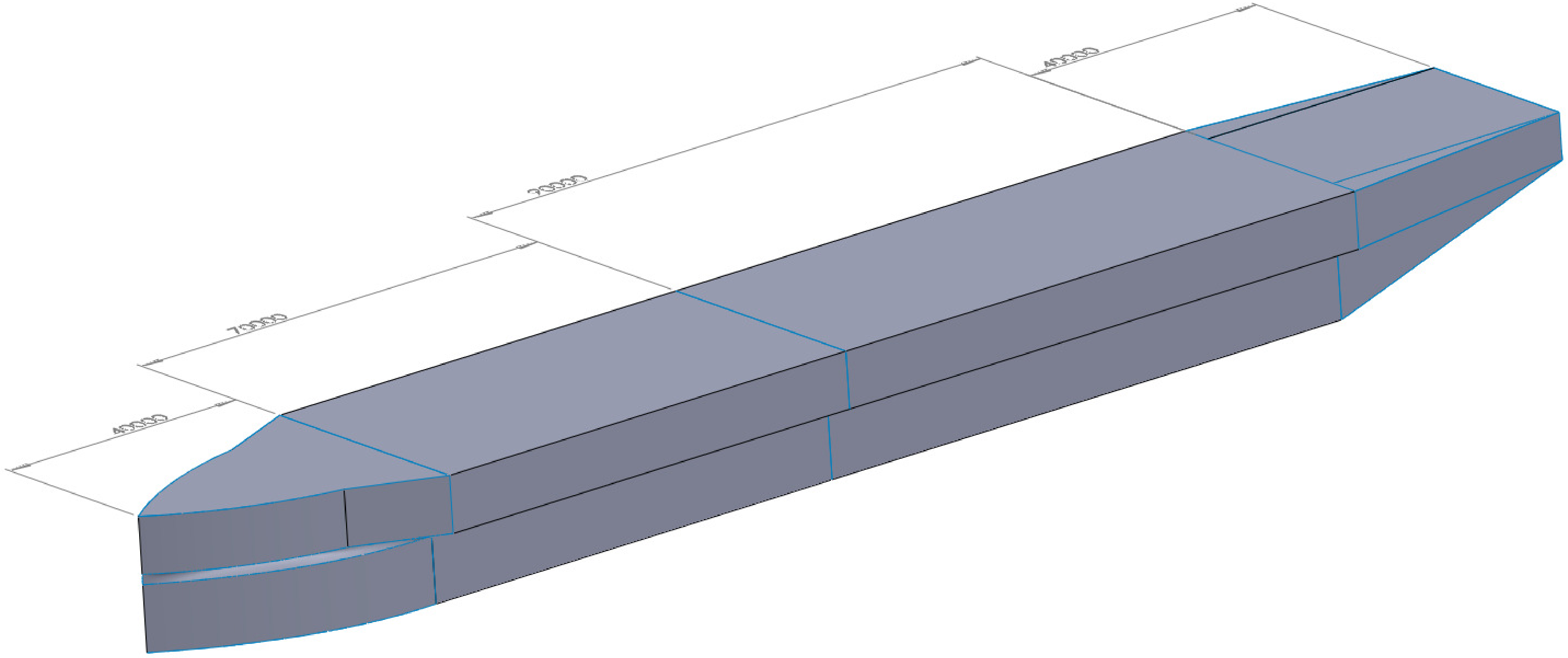
For 7 turbines with respect to the ship axis 1 in crane								
		Value	***Kg.m2***				***Value***	***Kg.m2***
		Ixx	155110020				Ixx	2762586479
		Iyy	197172766				Iyy	2168532857
		Izz	29597658				Izz	186569425.5
Draft T2				Total deck			Ship	
				Value	***Kg.m2***		Ixx Ship(roll)	44619472128
				Ixx	2917696500		Iyy Ship(pitch)	60957619200
				Iyy	2365705623		Izz ship (yaw)	60957619200
				Izz	216167083.5			

For 8 turbines with respect to the ship axis								
		Value	***Kg.m2***				***Value***	***Kg.m2***
		Ixx	155118061				Ixx	2762940259
		Iyy	156389455				Iyy	2764681207
		Izz	33339546				Izz	186569425.5
Draft T3				Total deck			Ship	
				Value	***Kg.m2***		Ixx Ship(roll)	48734482720
				Ixx	2918058320		Iyy Ship(pitch)	66579408000
				Iyy	2921070662		Izz ship (yaw)	66579408000
				Izz	219908971.5			

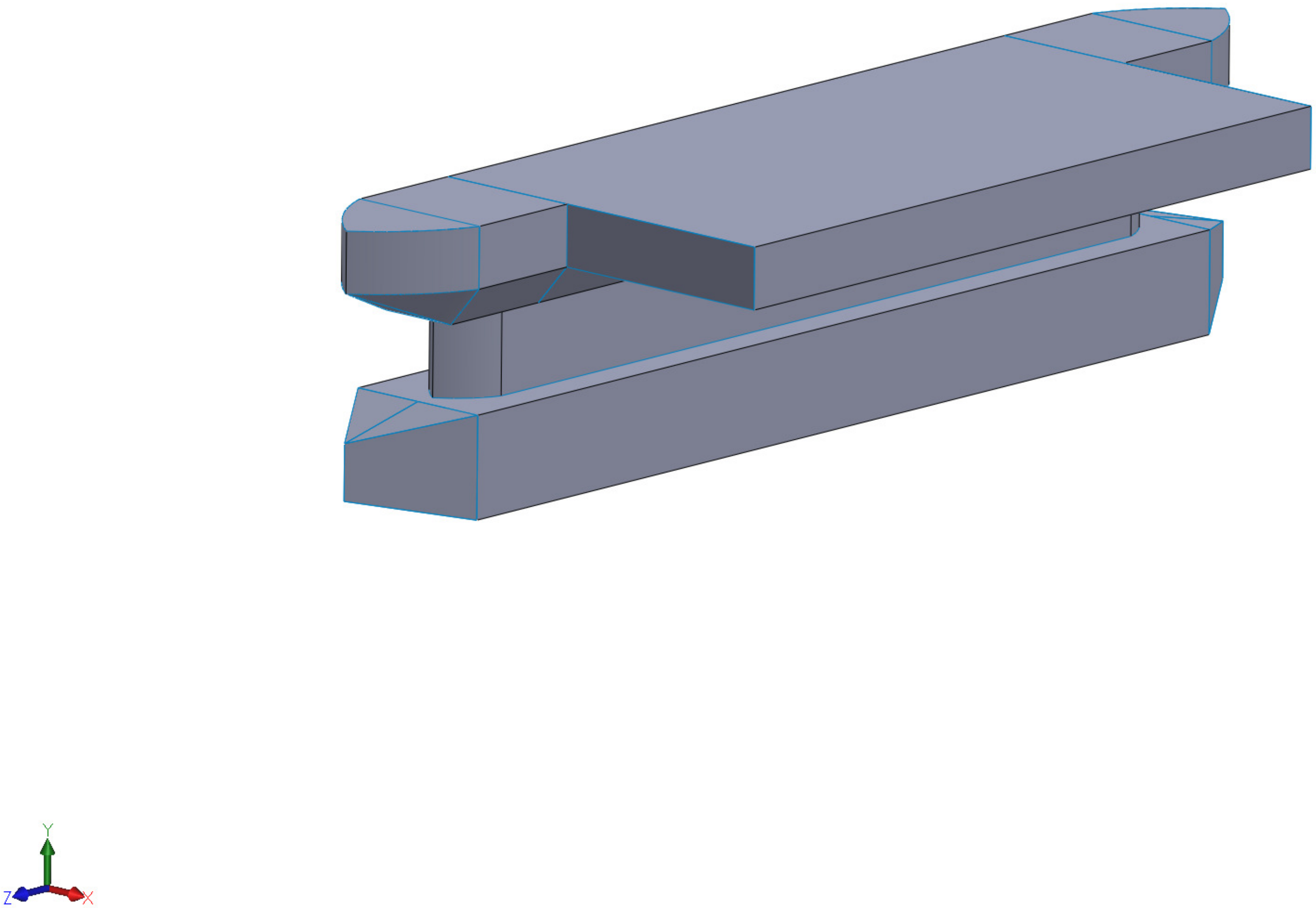
	Draft T1 total		Draft T2 total		Draft T3 total
	32321709151		47537168628		51652541040
	43784501670		63323324823		69500478662
	40393768852		61173786284		66799316972
For 7 wind turbines on the deck and 1 in crane					

FIGURE A6-3: TOTAL MOMENT OF INERTIA CALCULATIONS FOR INSTALLATION PHASE

- Monohull model from solid works
- Swath model from solidworks



40000
73000
73000
40000

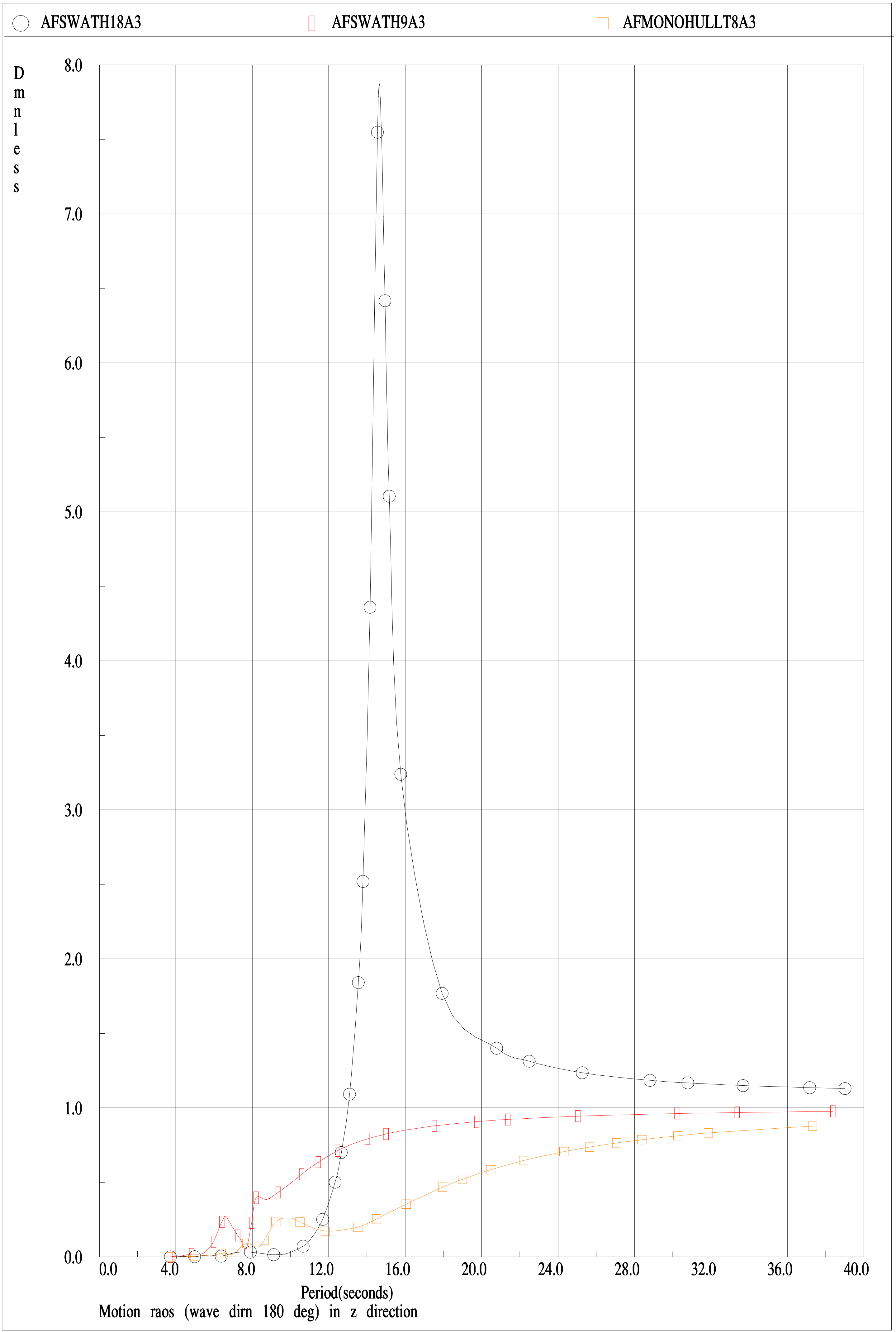


Y
Z
X

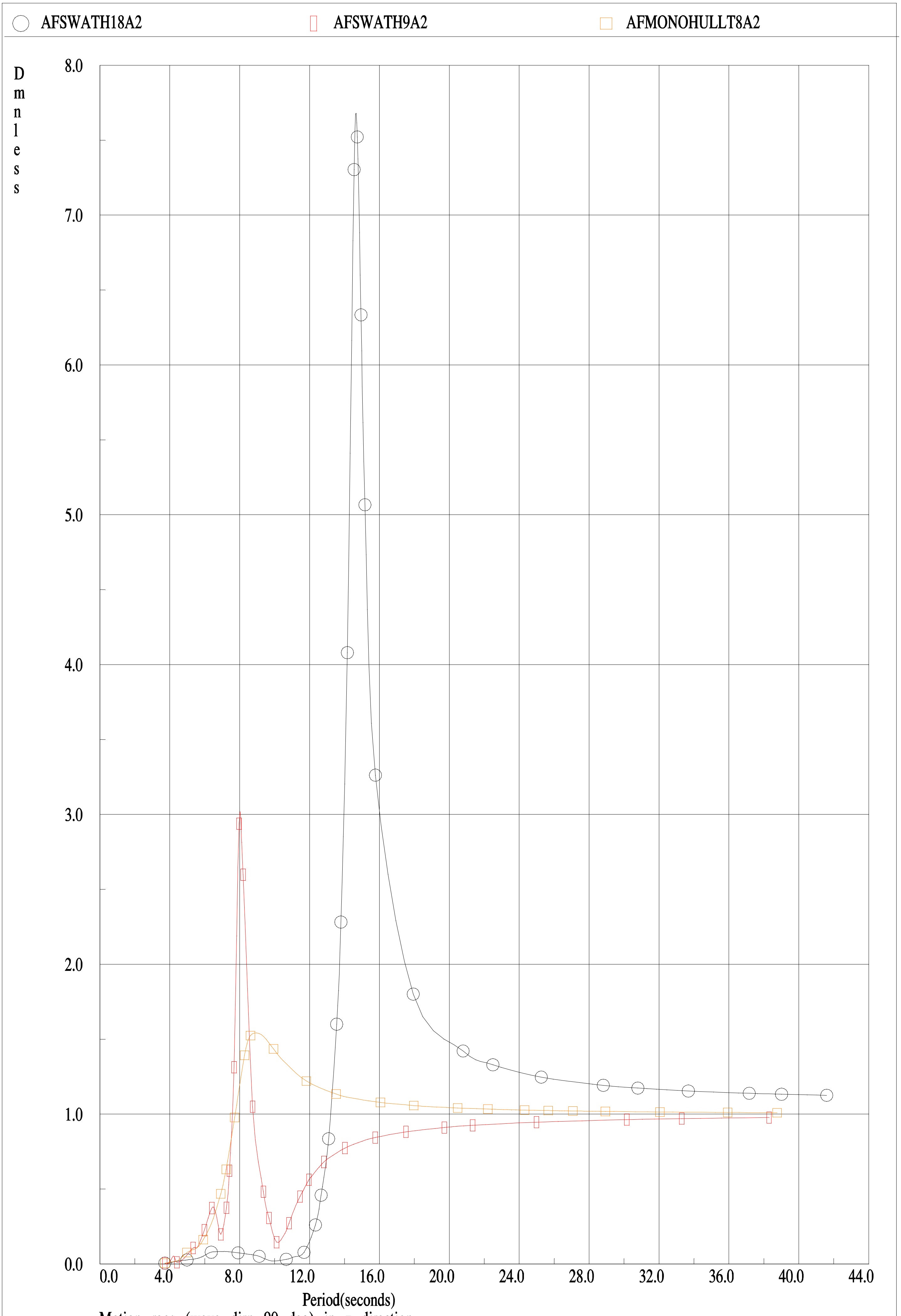
APPENDIX VII

RESULTS AND RECOMMENDATIONS

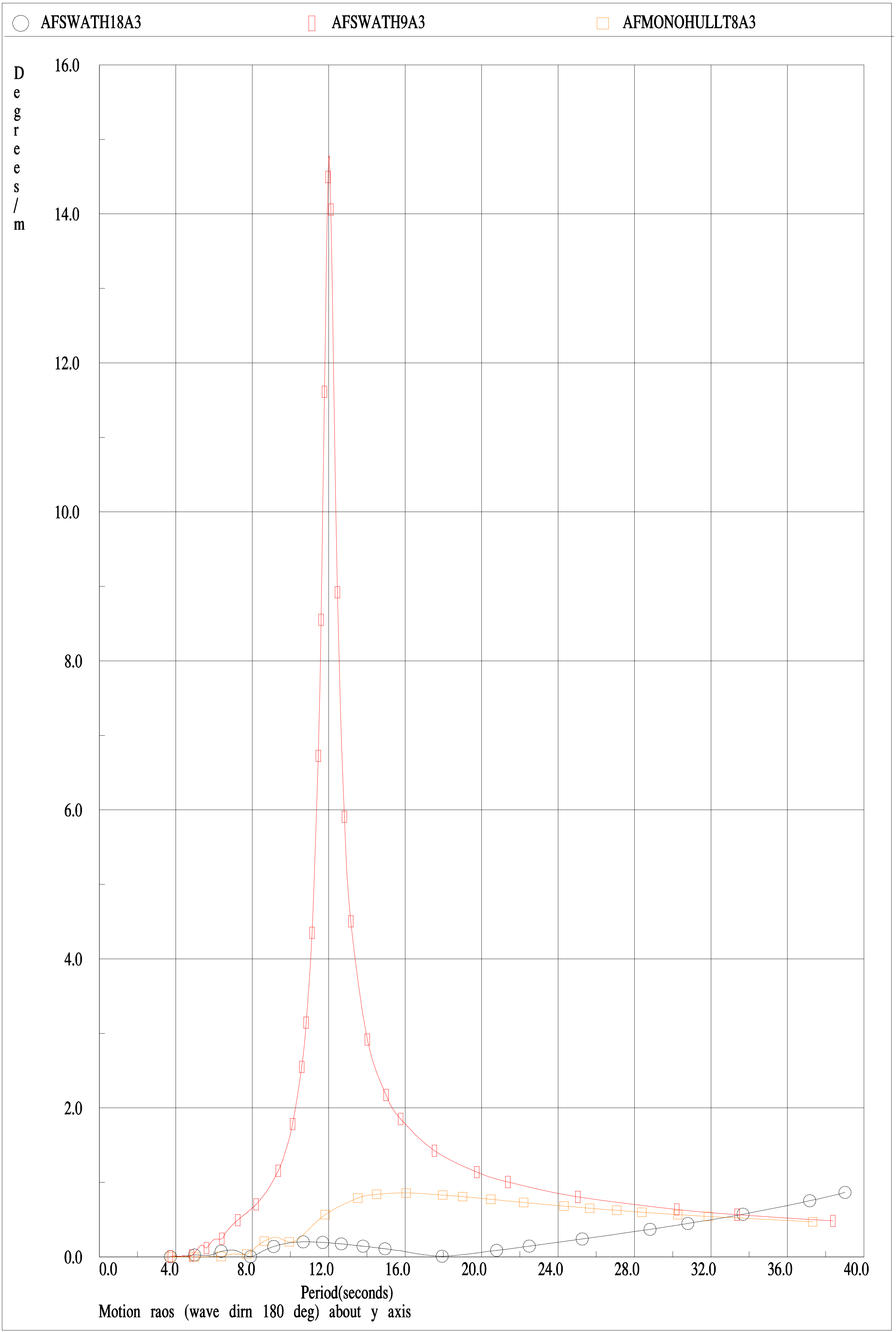
1. Heave RAO's for the 90º direction for all the different vessel and conditions
2. Pitch RAO's for the 90º direction for all the different vessel and conditions
3. Roll RAO's for the 90º direction for all the different vessel and conditions
4. Heave RAO's for the 180º direction for all the different vessel and conditions
5. Pitch RAO's for the 180º direction for all the different vessel and conditions
6. Roll RAO's for the 180º direction for all the different vessel and conditions
7. Hs-Tp curves for Installation operation Monohull
8. Hs-Tp curves for Transportation operation Monohull
9. Hs-Tp curves for Installation operation SWATH-9
10. Hs-Tp curves for Transportation operation SWATH-9
11. Hs-Tp curves for Installation operation SWATH-18
12. Hs-Tp curves for Transportation operation SWATH-18
13. Hs-Tp curves for combined operation Transportation + Installation all cases
14. Workability - Monohull
15. Workability – SWATH-9
16. Workability – SWATH-18

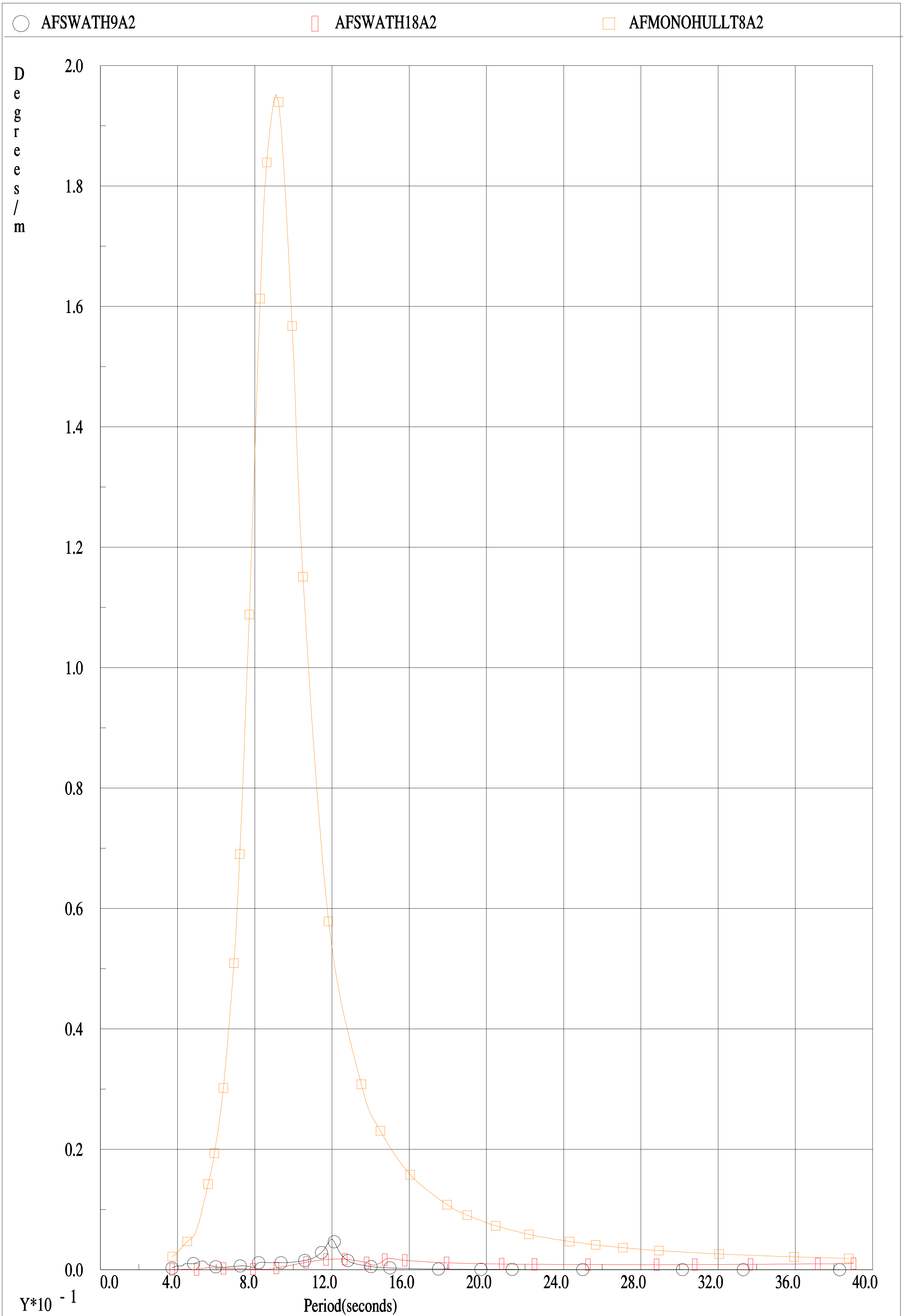


AFSWATH18A3
AFSWATH9A3
AFMONOHULLT8A3
Dmnless
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.0
4.0
8.0
12.0
16.0
20.0
24.0
28.0
32.0
36.0
40.0
Period(seconds)
Motion raos (wave dirn 180 deg) in z direction

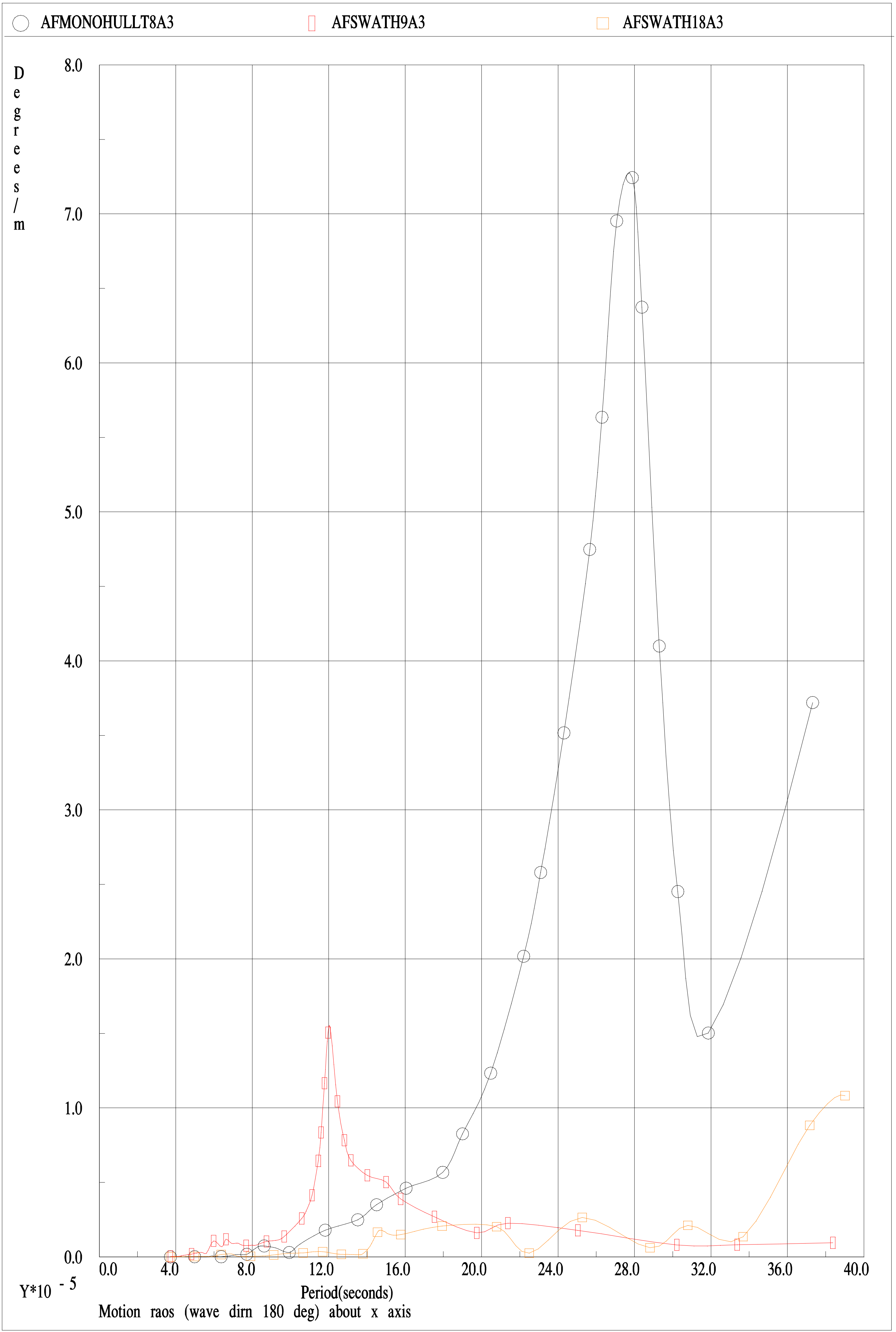


Motion raos (wave dirn 90 deg) in z direction

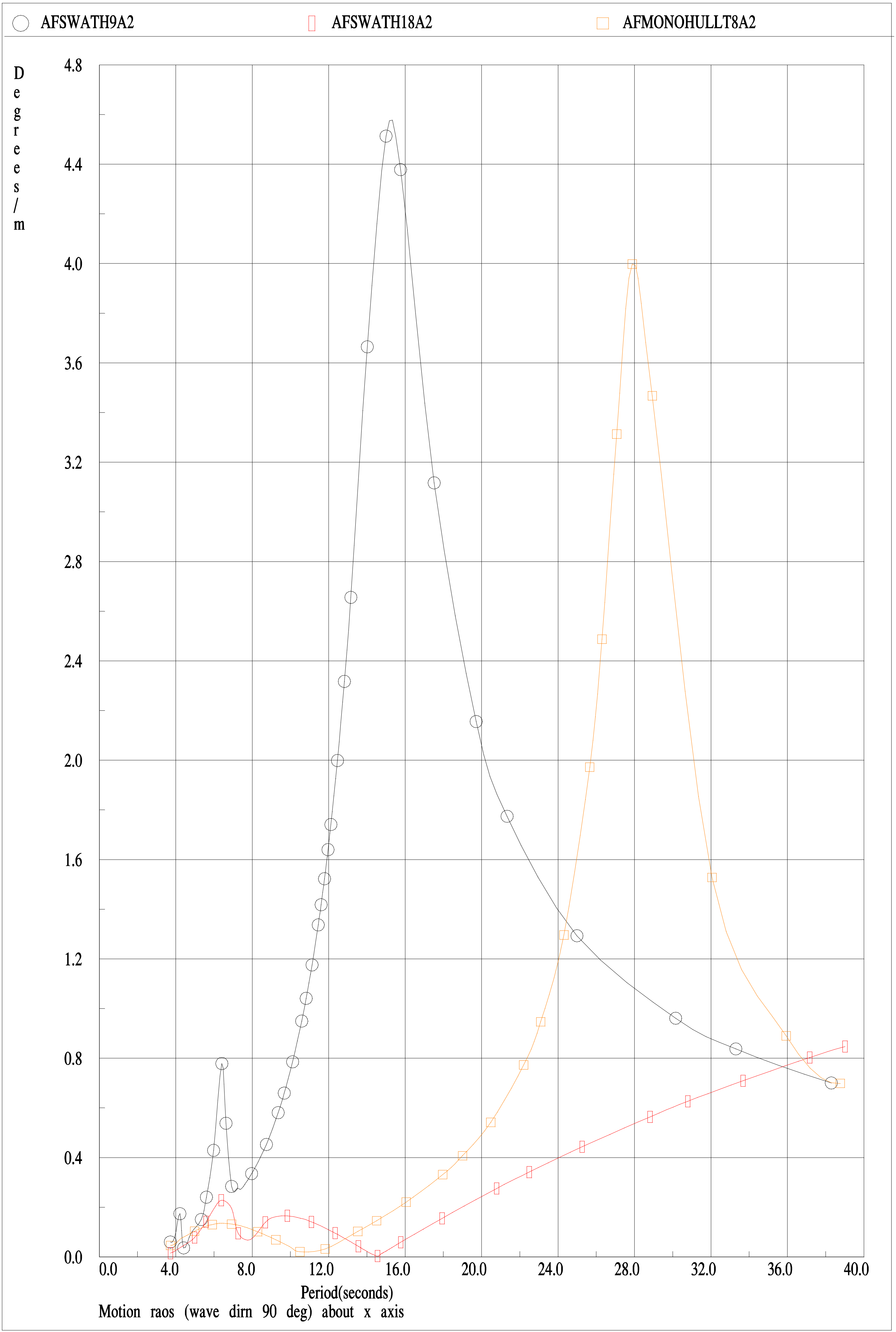

AFSWATH18A3
AFSWATH9A3
AFMONOHULLT8A3
Degrees/m
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0.0
4.0
8.0
12.0
16.0
20.0
24.0
28.0
32.0
36.0
40.0
Period(seconds)
Motion raos (wave dirn 180 deg) about y axis



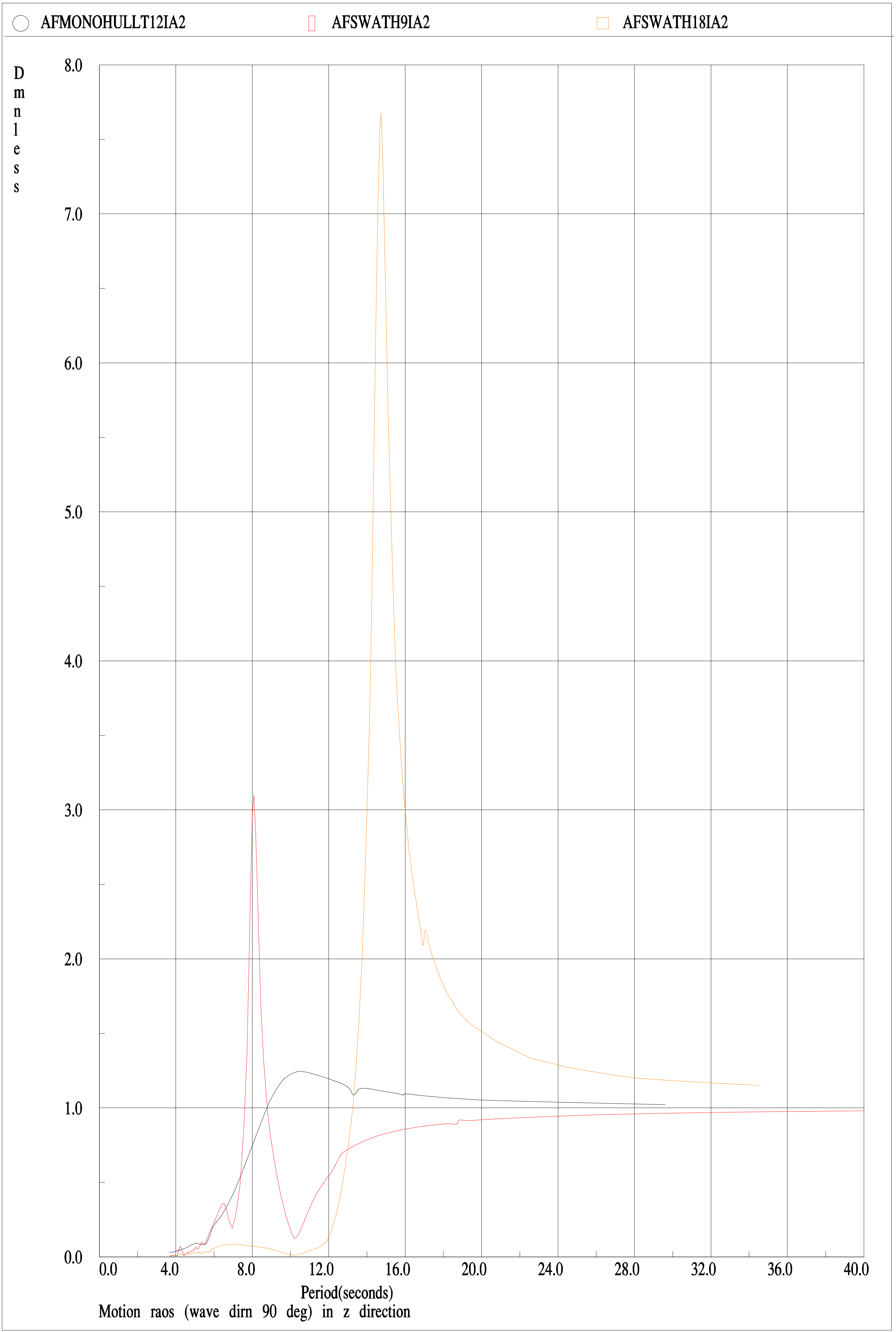
Motion raos (wave dirn 90 deg) about y axis

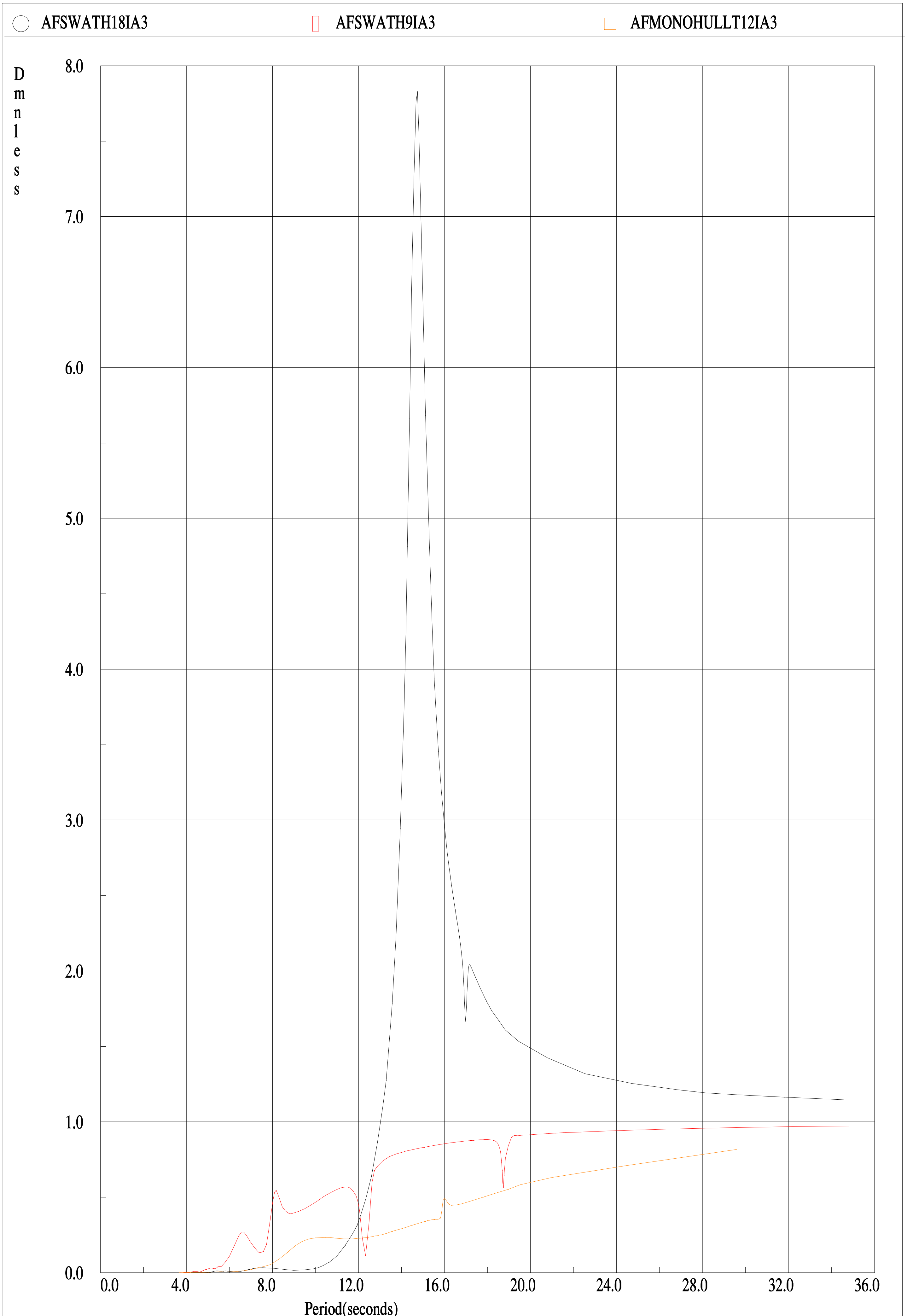


AFMONOHULLT8A3
AFSWATH9A3
AFSWATH18A3
D e g r e e s / m
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.0 4.0 8.0 12.0 16.0 20.0 24.0 28.0 32.0 36.0 40.0
Y*10 - 5
Period(seconds)
Motion raos (wave dirn 180 deg) about x axis

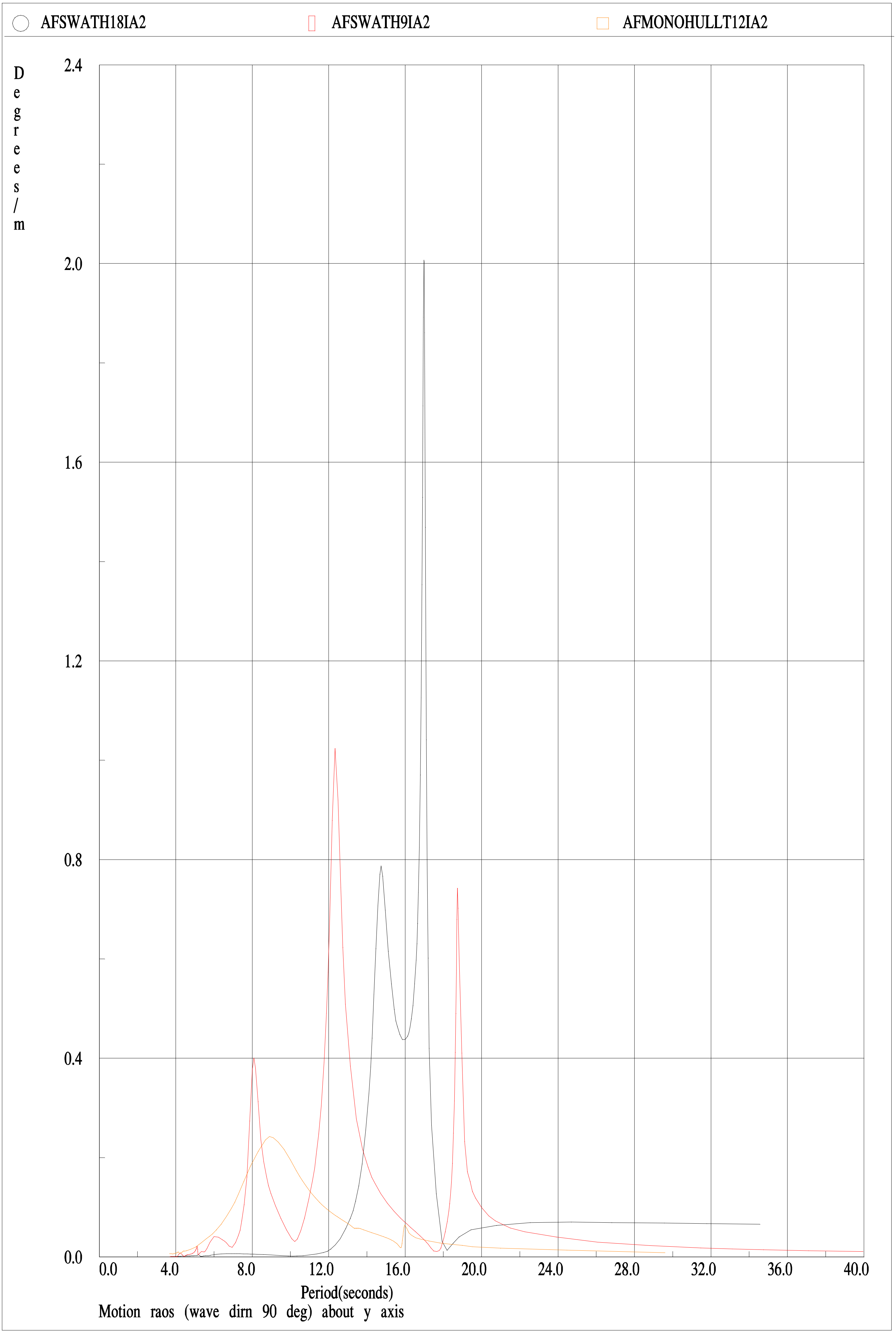


AFSWATH9A2
AFSWATH18A2
AFMONOHULLT8A2
Degrees/m
4.8
4.4
4.0
3.6
3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0.0
0.0
4.0
8.0
12.0
16.0
20.0
24.0
28.0
32.0
36.0
40.0
Period(seconds)
Motion raos (wave dirn 90 deg) about x axis

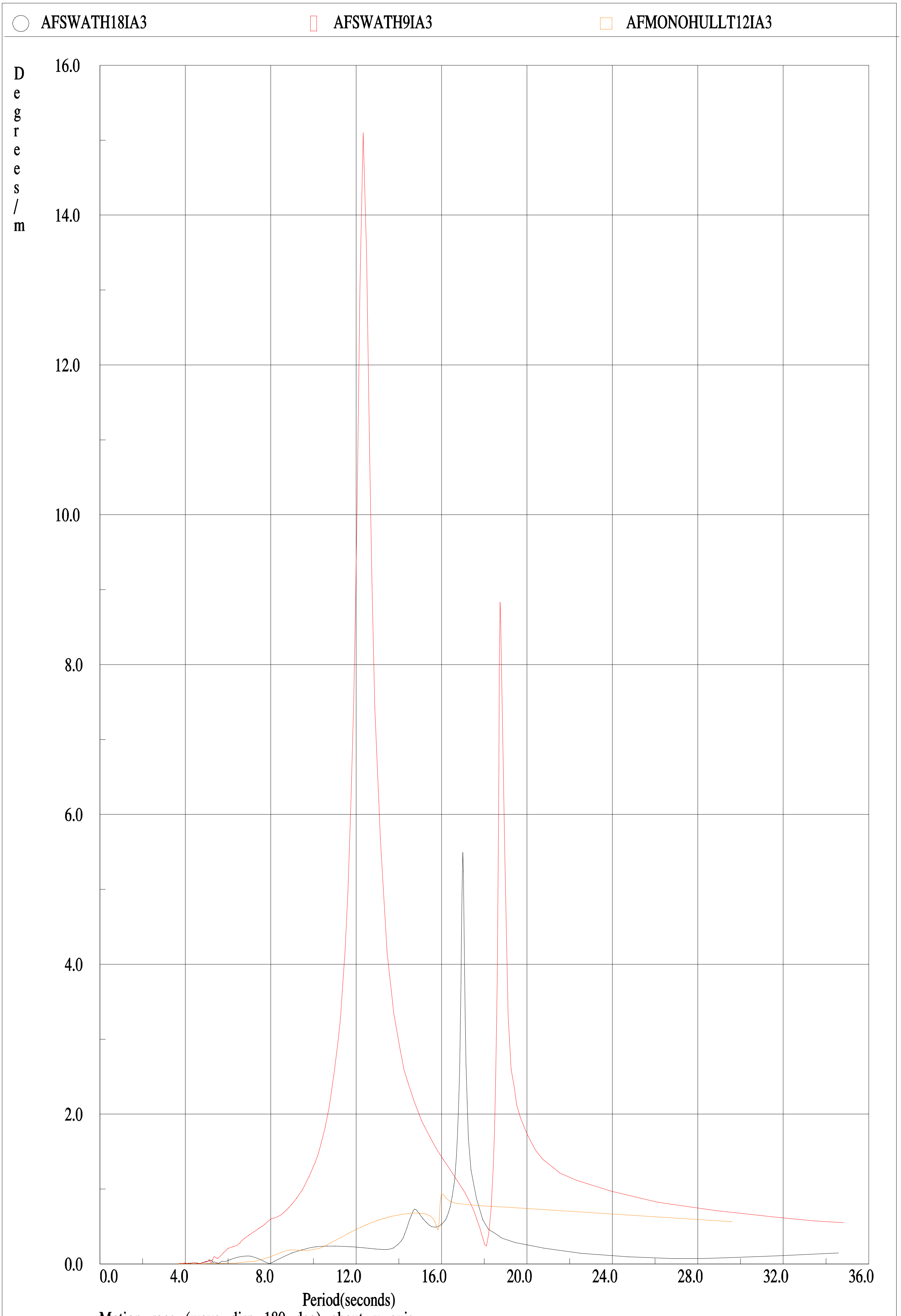

AFMONOHULLT12IA2
AFSWATH9IA2
AFSWATH18IA2
Dmnless
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.0
4.0
8.0
12.0
16.0
20.0
24.0
28.0
32.0
36.0
40.0
Period(seconds)
Motion raos (wave dirn 90 deg) in z direction



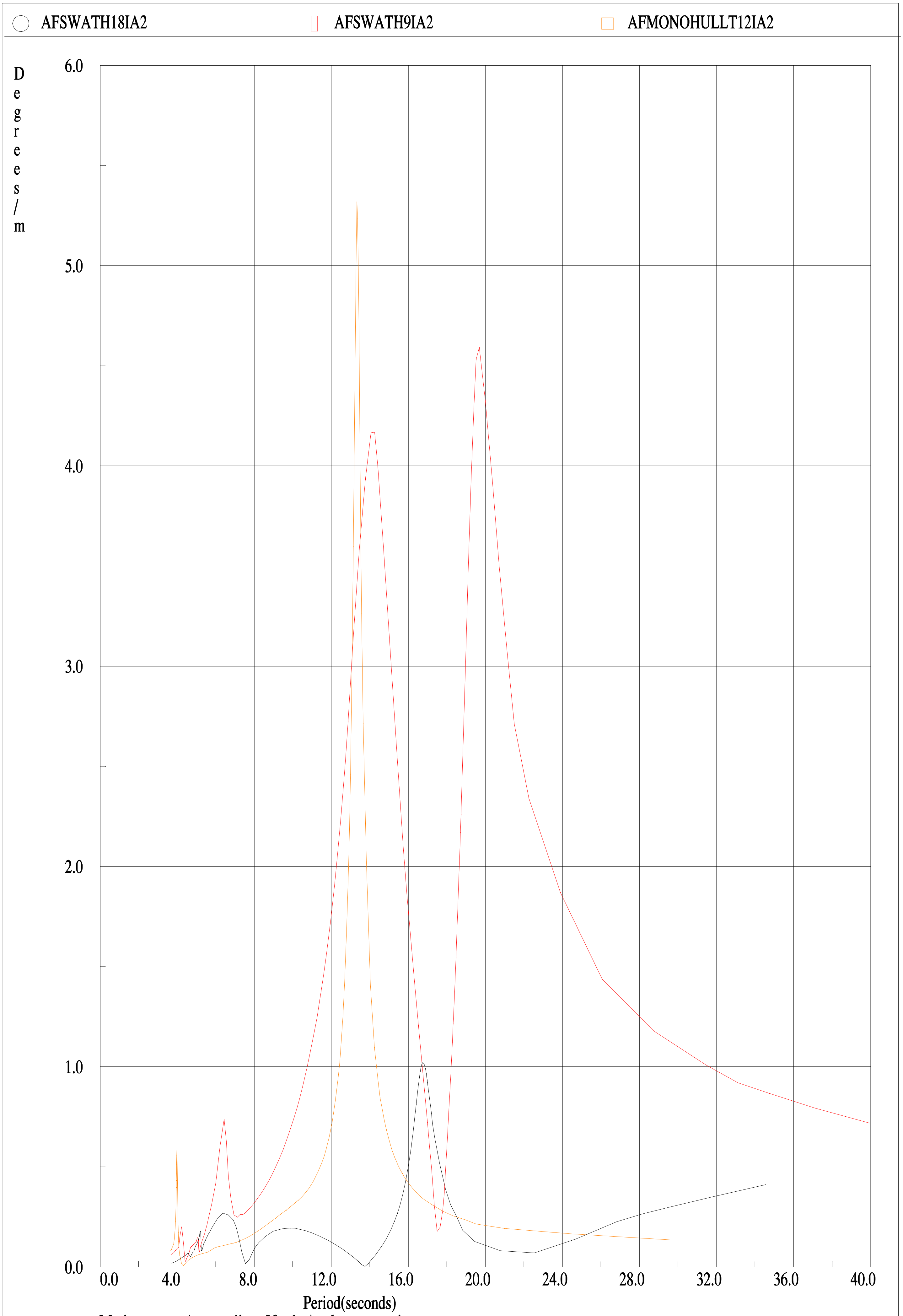
Motion raos (wave dirn 180 deg) in z direction



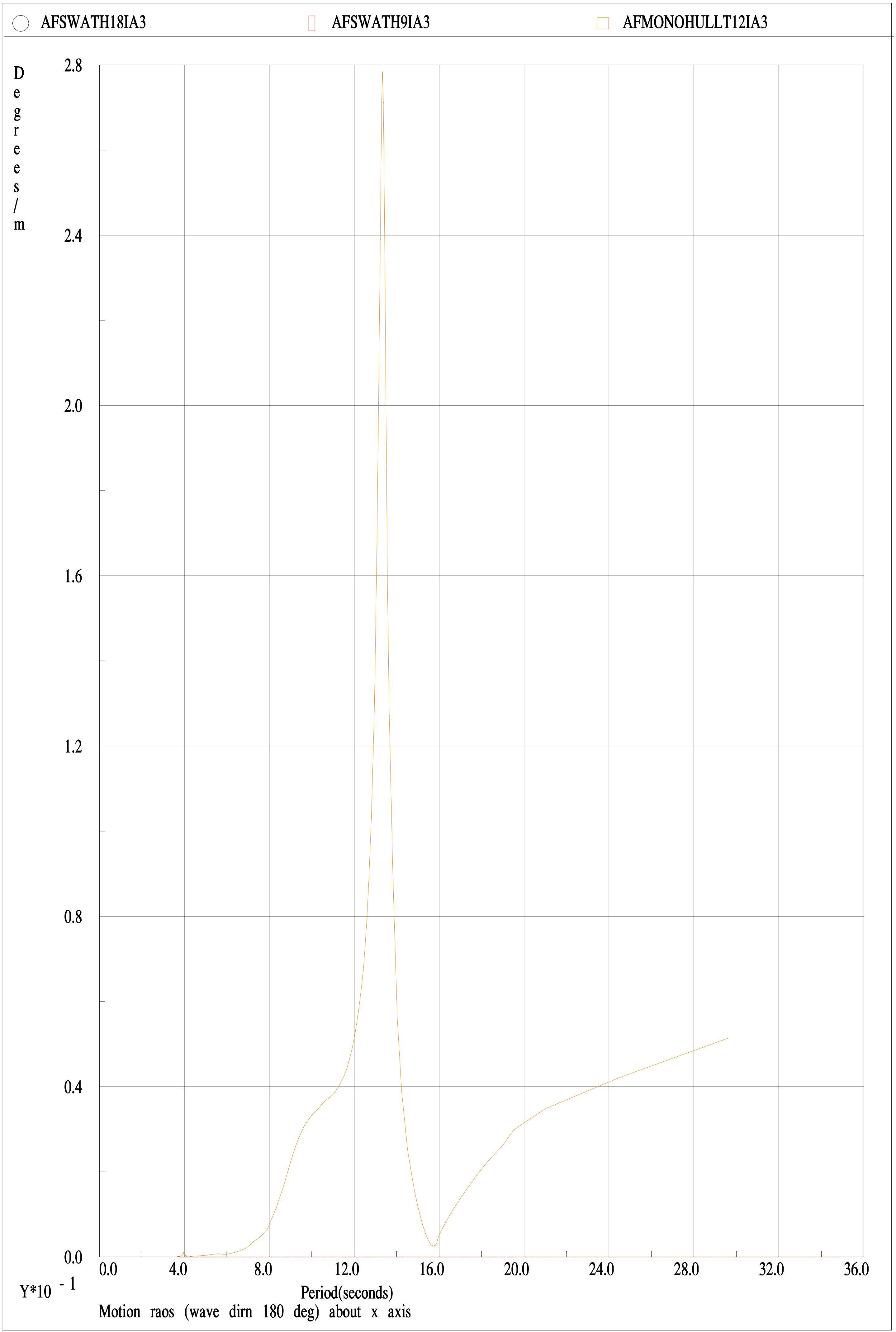
AFSWATH18IA2
AFSWATH9IA2
AFMONOHULLT12IA2
Degrees/m
2.4
2.0
1.6
1.2
0.8
0.4
0.0
0.0
4.0
8.0
12.0
16.0
20.0
24.0
28.0
32.0
36.0
40.0
Period(seconds)
Motion raos (wave dirn 90 deg) about y axis

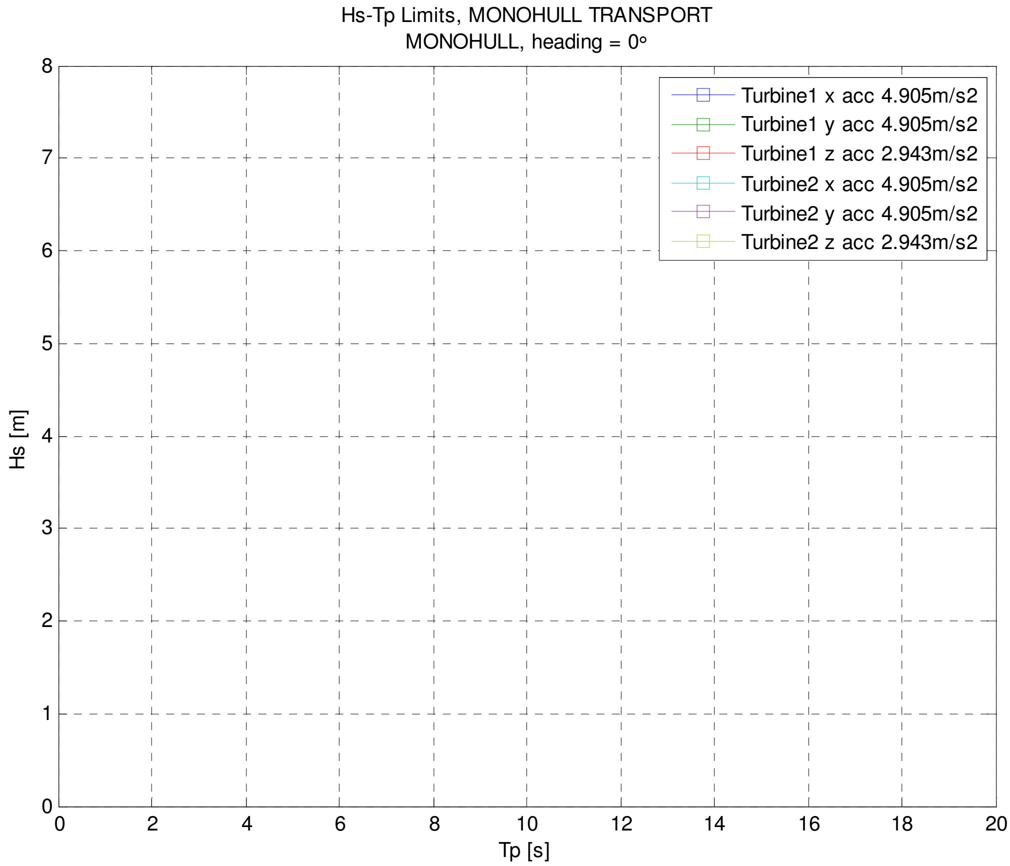


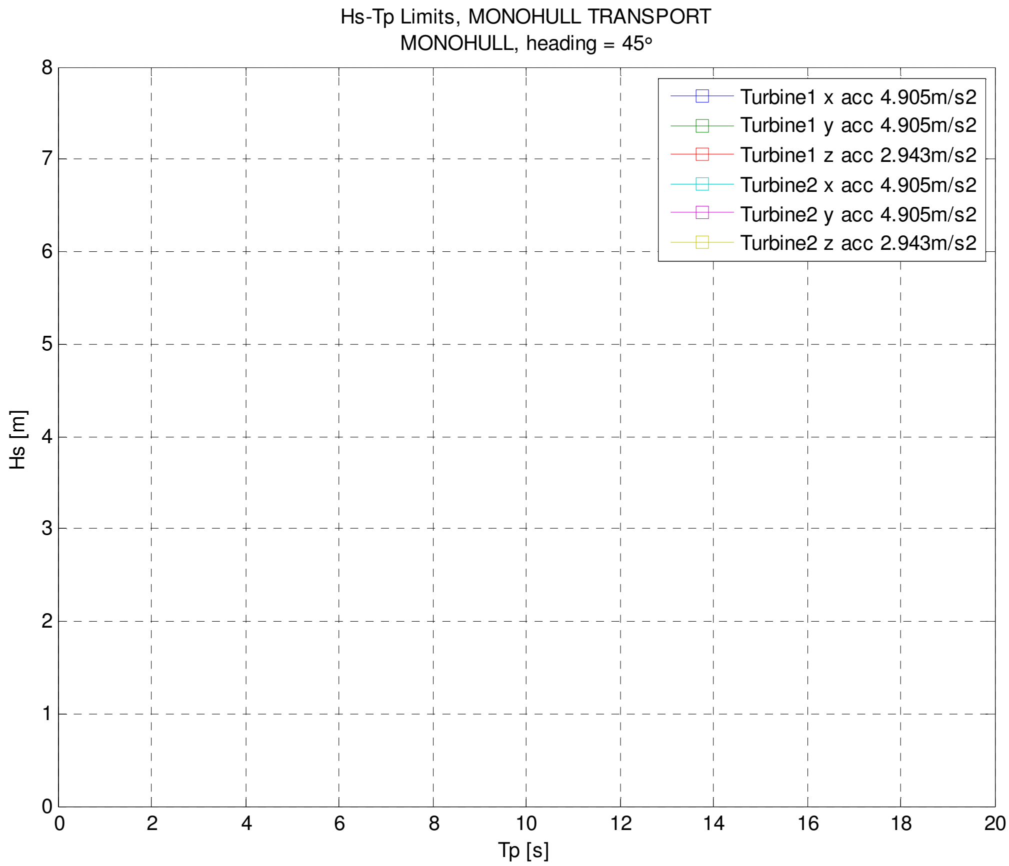
Motion raos (wave dirn 180 deg) about y axis

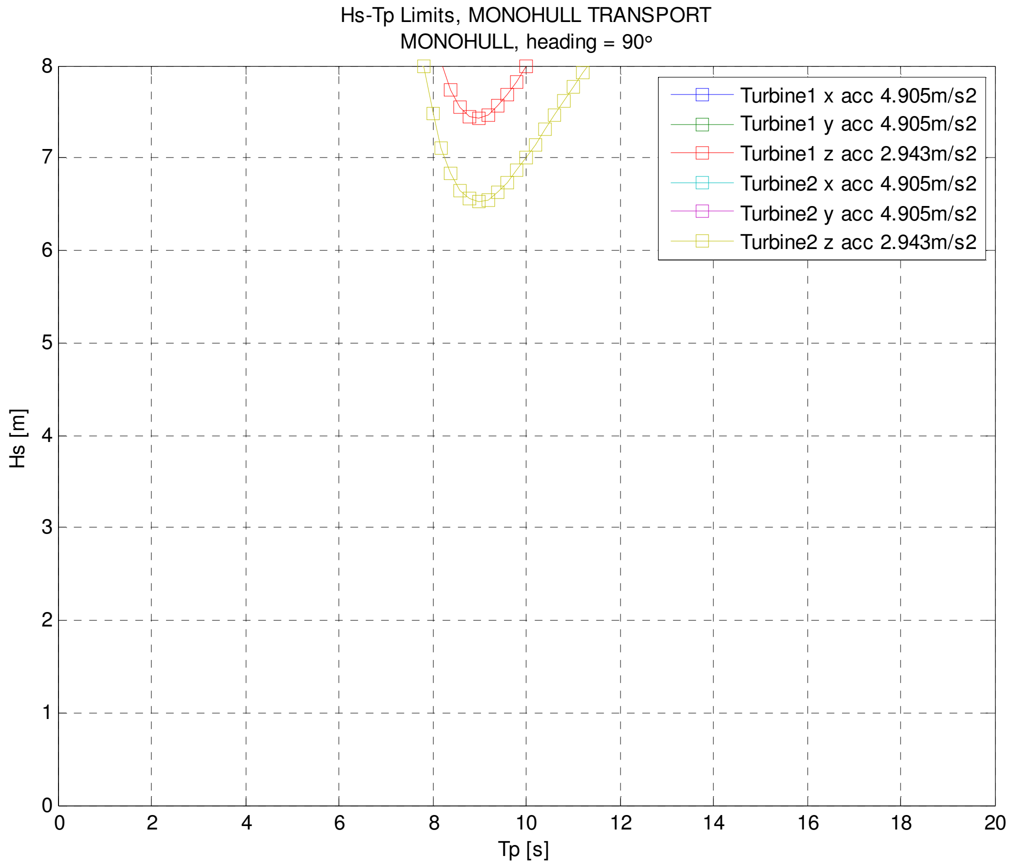


Motion raos (wave dirn 90 deg) about x axis

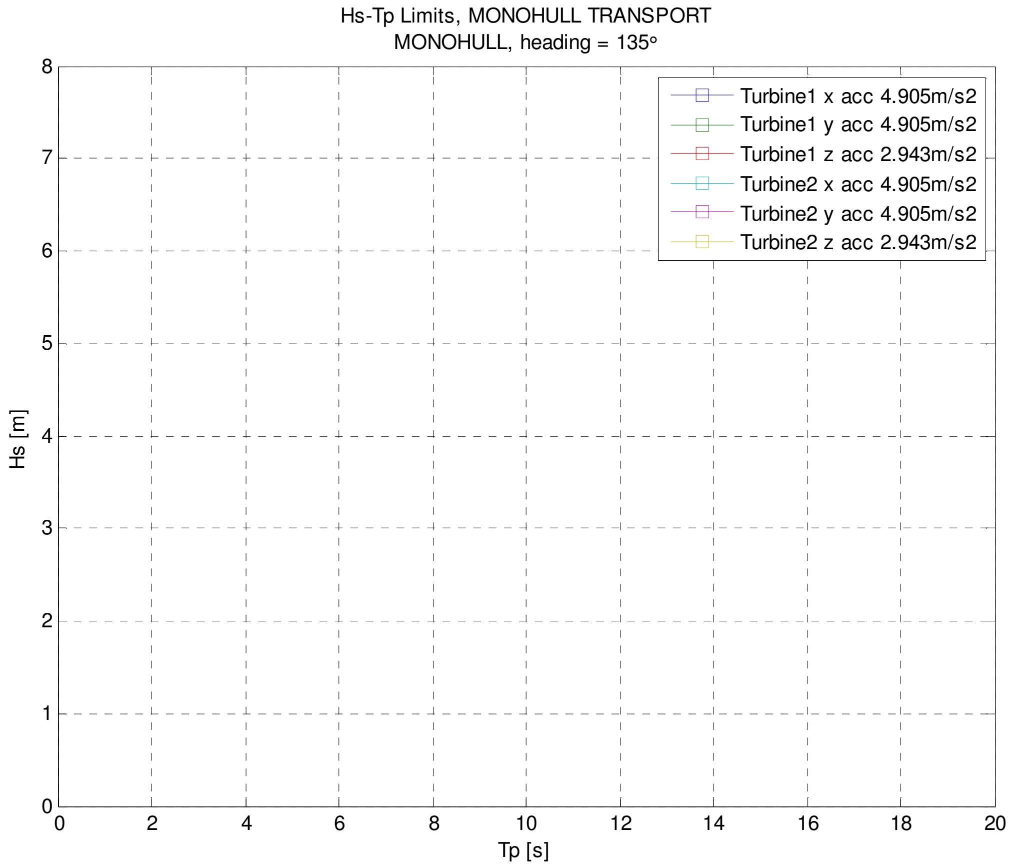

AFSWATH18IA3
AFSWATH9IA3
AFMONOHULLT12IA3
Degrees/m
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0.0
0.0
4.0
8.0
12.0
16.0
20.0
24.0
28.0
32.0
36.0
Y*10 - 1
Period(seconds)
Motion raos (wave dirn 180 deg) about x axis


Hs-Tp Limits, MONOHULL TRANSPORT
MONOHULL, heading = 0°
Turbine1 x acc 4.905m/s2
Turbine1 y acc 4.905m/s2
Turbine1 z acc 2.943m/s2
Turbine2 x acc 4.905m/s2
Turbine2 y acc 4.905m/s2
Turbine2 z acc 2.943m/s2
Hs [m]
Tp [s]

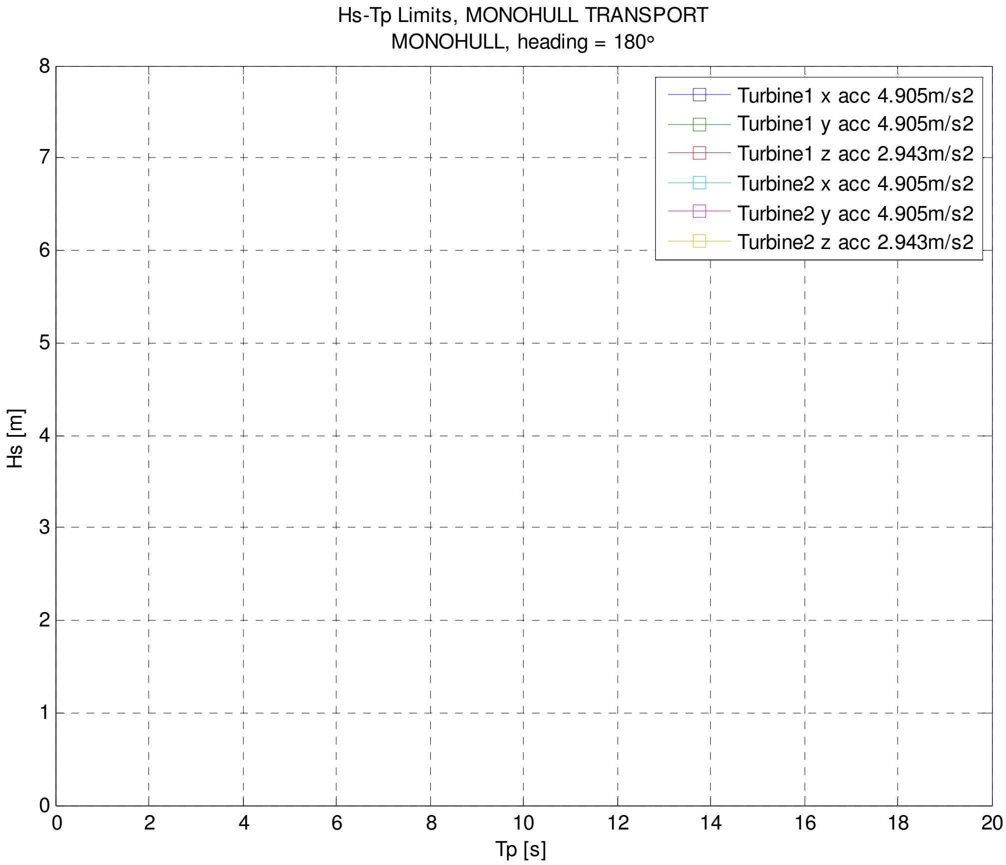

Hs-Tp Limits, MONOHULL TRANSPORT
MONOHULL, heading = 45°
Turbine1 x acc 4.905m/s2
Turbine1 y acc 4.905m/s2
Turbine1 z acc 2.943m/s2
Turbine2 x acc 4.905m/s2
Turbine2 y acc 4.905m/s2
Turbine2 z acc 2.943m/s2
Hs [m]
Tp [s]

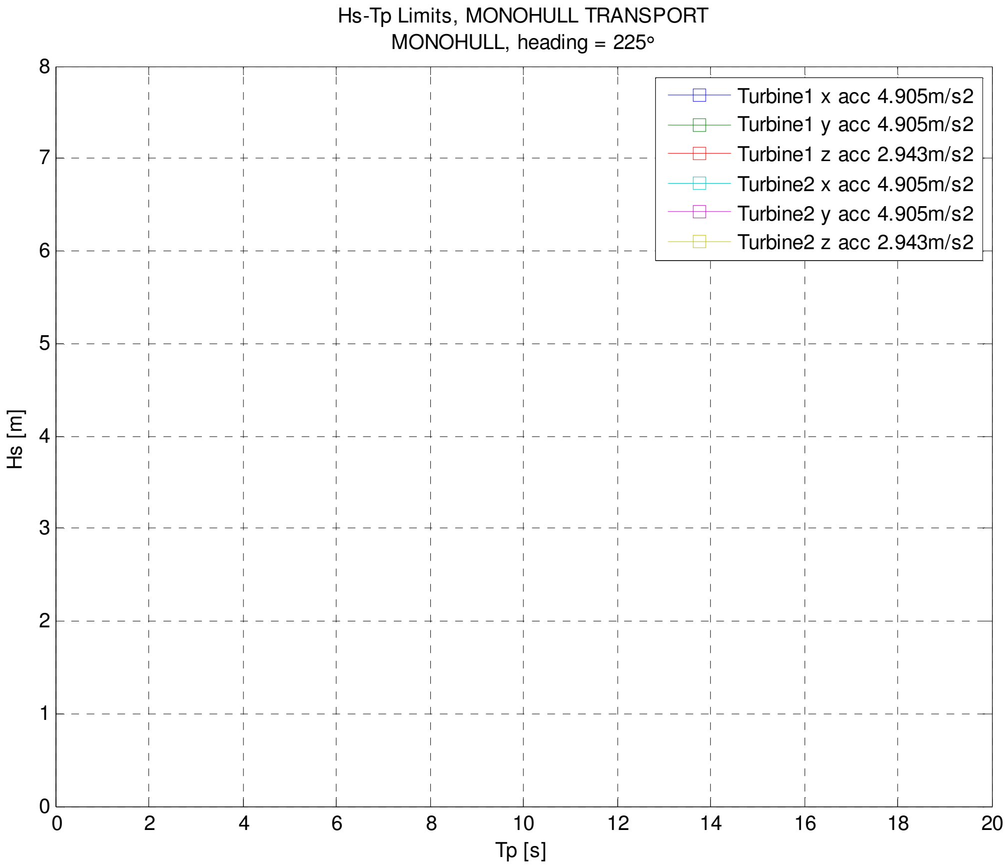


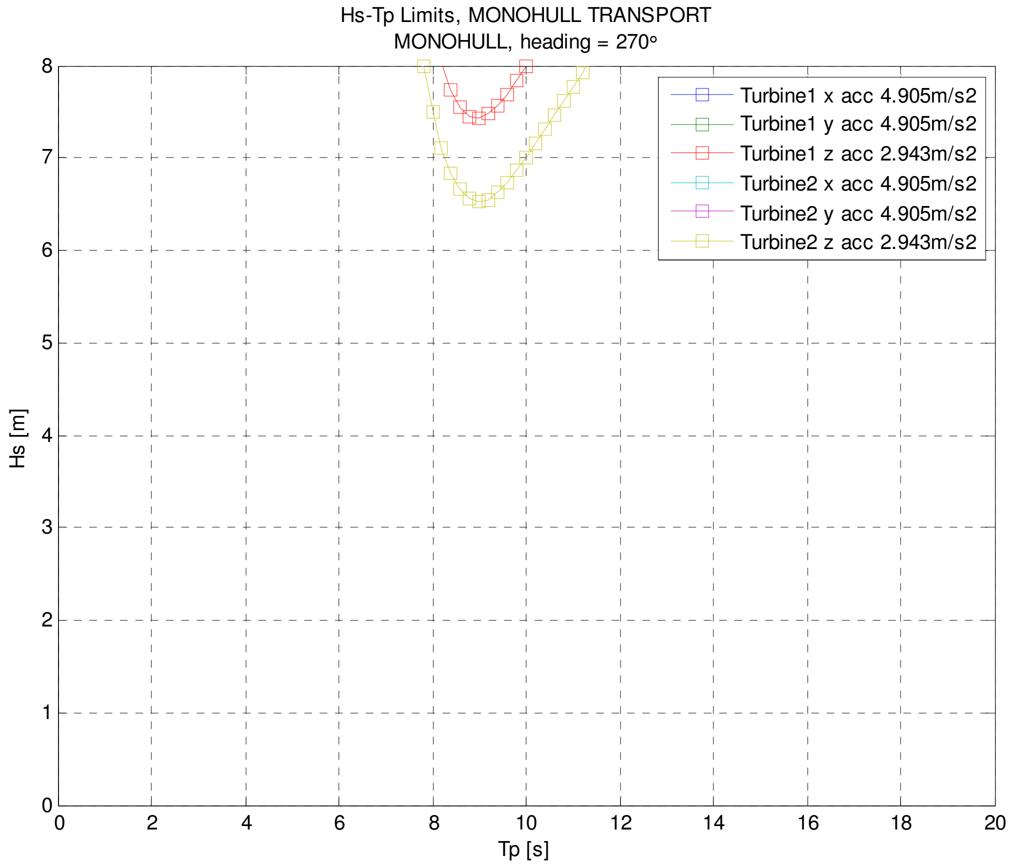
Hs-Tp Limits, MONOHULL TRANSPORT
MONOHULL, heading = 90°
Turbine1 x acc 4.905m/s2
Turbine1 y acc 4.905m/s2
Turbine1 z acc 2.943m/s2
Turbine2 x acc 4.905m/s2
Turbine2 y acc 4.905m/s2
Turbine2 z acc 2.943m/s2
Hs [m]
Tp [s]

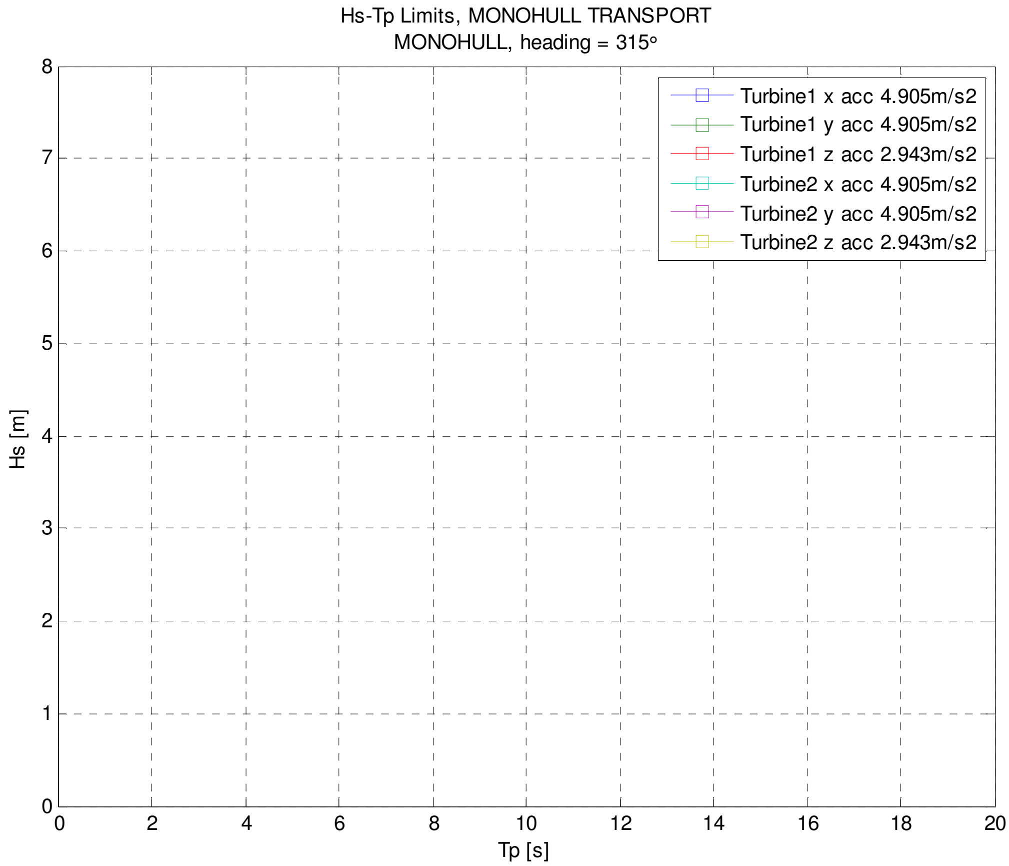


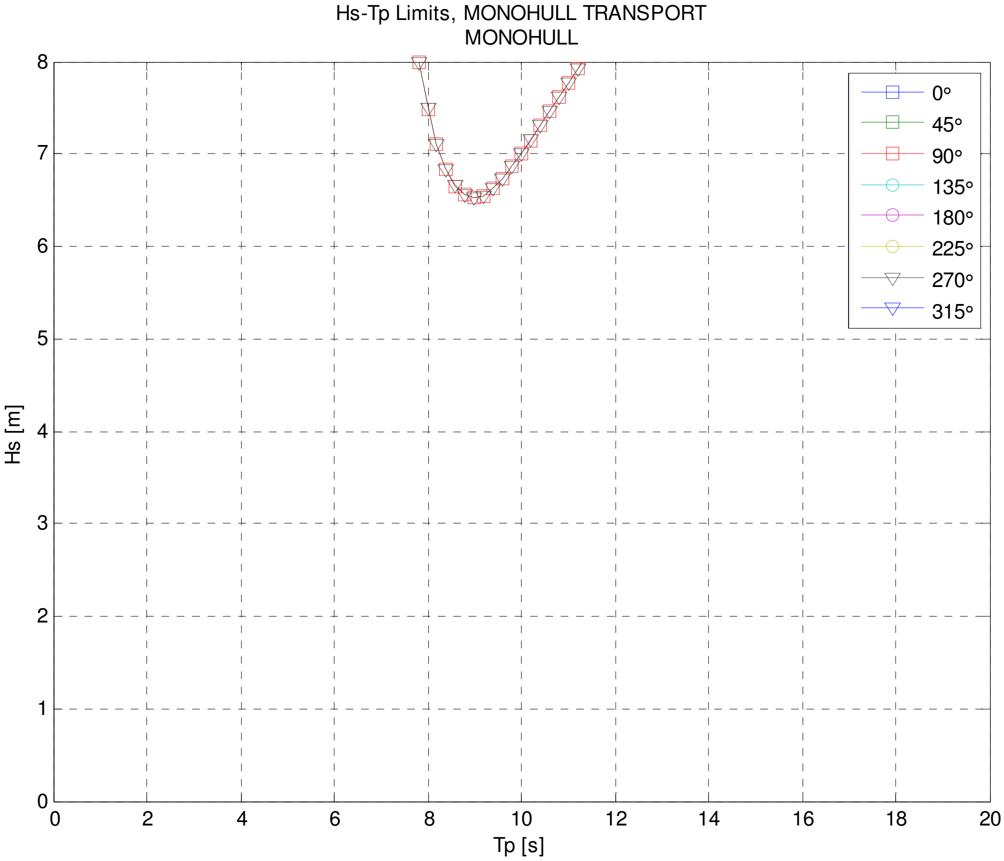
Hs-Tp Limits, MONOHULL TRANSPORT
MONOHULL, heading = 135°
Turbine1 x acc 4.905m/s2
Turbine1 y acc 4.905m/s2
Turbine1 z acc 2.943m/s2
Turbine2 x acc 4.905m/s2
Turbine2 y acc 4.905m/s2
Turbine2 z acc 2.943m/s2
Hs [m]
Tp [s]

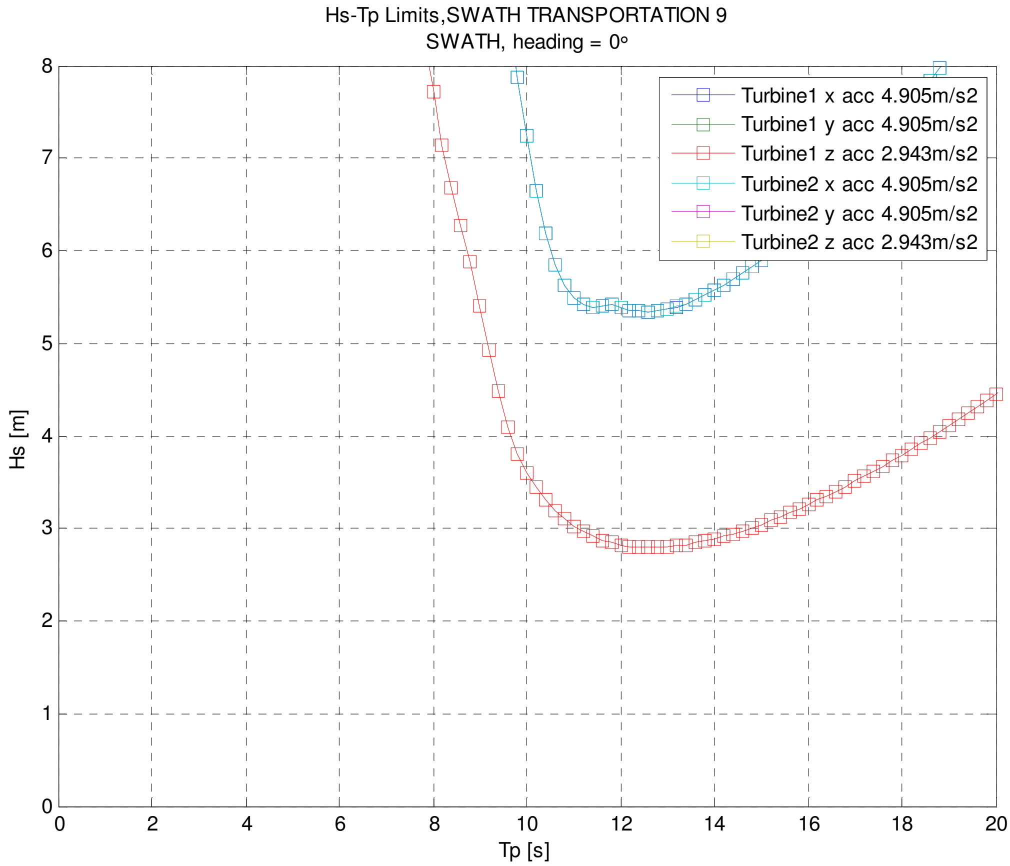

Hs-Tp Limits, MONOHULL TRANSPORT
MONOHULL, heading = 180°
Hs [m]
Tp [s]
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20
Turbine1 x acc 4.905m/s2
Turbine1 y acc 4.905m/s2
Turbine1 z acc 2.943m/s2
Turbine2 x acc 4.905m/s2
Turbine2 y acc 4.905m/s2
Turbine2 z acc 2.943m/s2

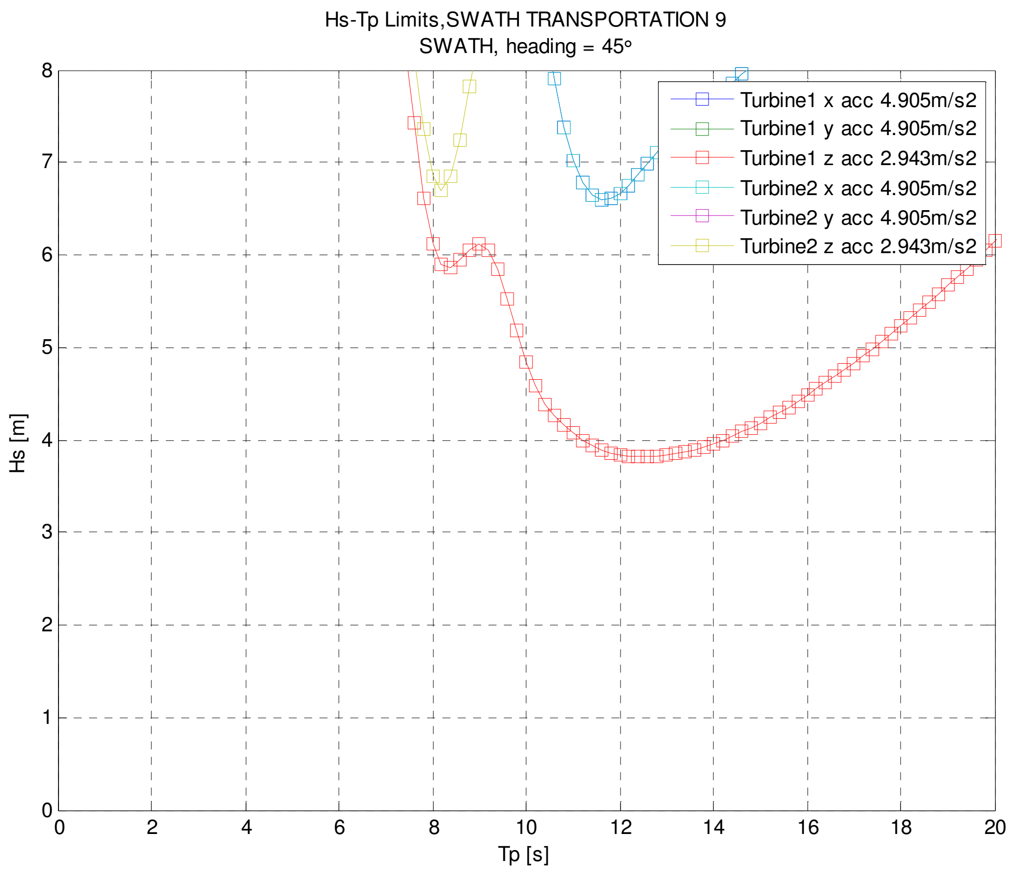

Hs-Tp Limits, MONOHULL TRANSPORT
MONOHULL, heading = 225°
Hs [m]
Tp [s]
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20
Turbine1 x acc 4.905m/s2
Turbine1 y acc 4.905m/s2
Turbine1 z acc 2.943m/s2
Turbine2 x acc 4.905m/s2
Turbine2 y acc 4.905m/s2
Turbine2 z acc 2.943m/s2

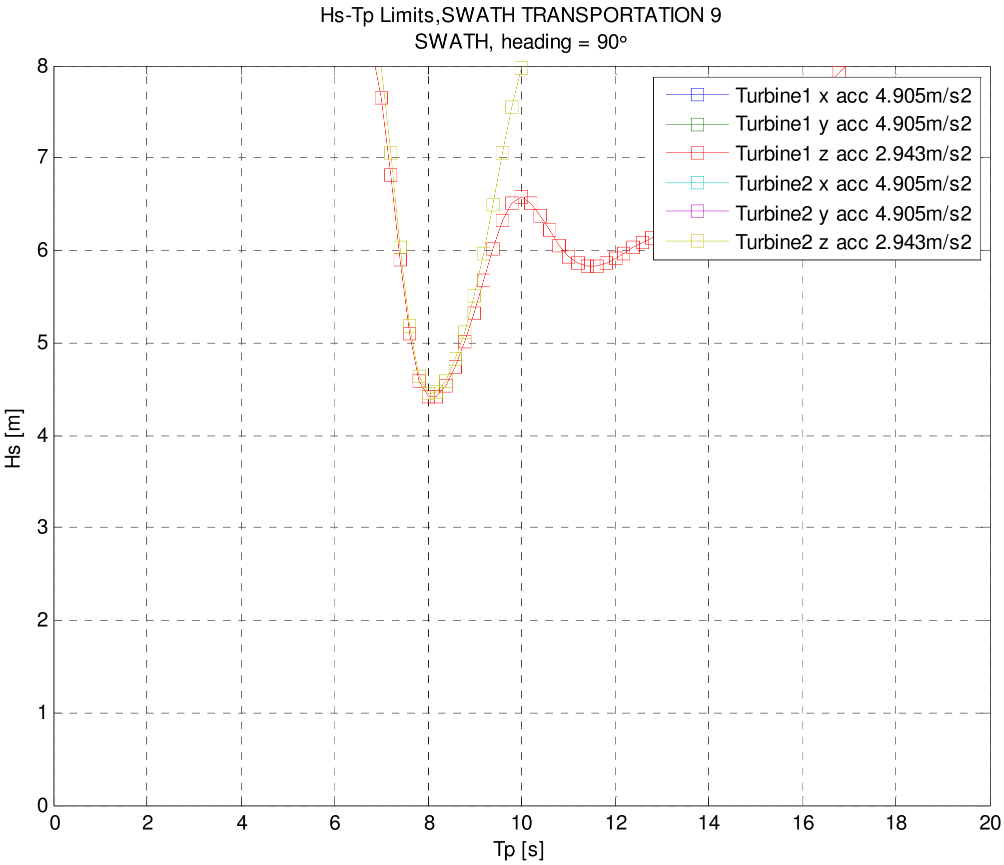

Hs-Tp Limits, MONOHULL TRANSPORT
MONOHULL, heading = 270°
Hs [m]
Tp [s]
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20
Turbine1 x acc 4.905m/s2
Turbine1 y acc 4.905m/s2
Turbine1 z acc 2.943m/s2
Turbine2 x acc 4.905m/s2
Turbine2 y acc 4.905m/s2
Turbine2 z acc 2.943m/s2

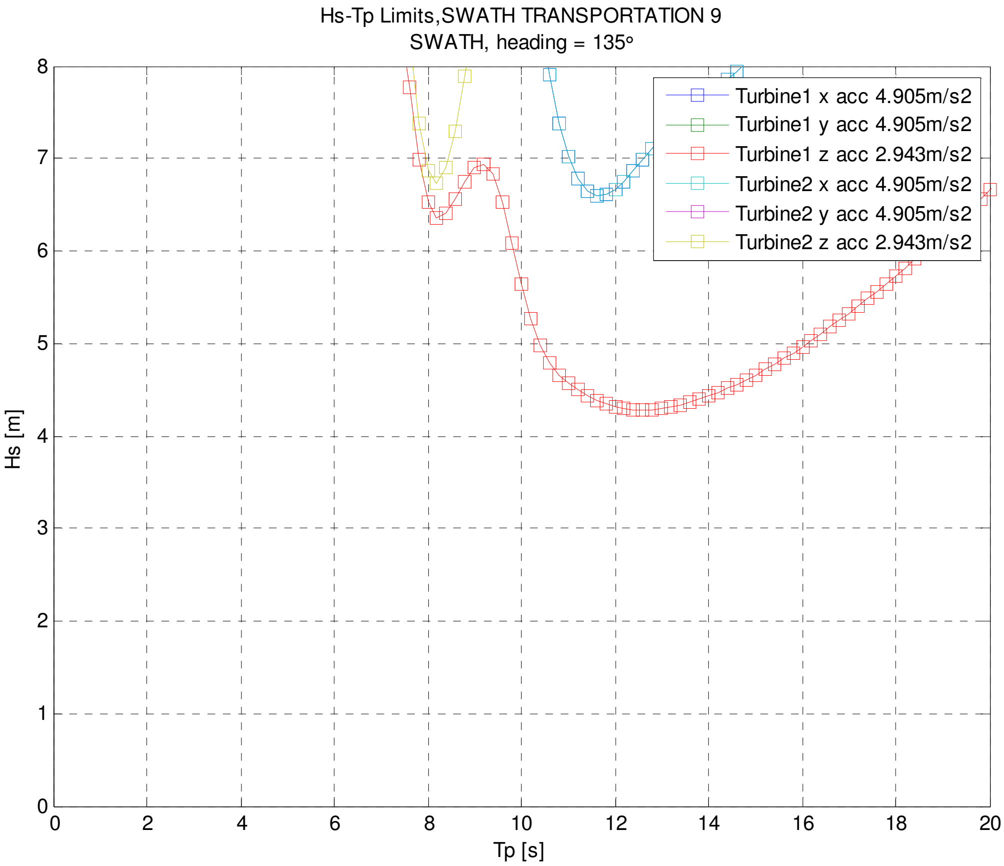

Hs-Tp Limits, MONOHULL TRANSPORT
MONOHULL, heading = 315°
Hs [m]
Tp [s]
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20
Turbine1 x acc 4.905m/s2
Turbine1 y acc 4.905m/s2
Turbine1 z acc 2.943m/s2
Turbine2 x acc 4.905m/s2
Turbine2 y acc 4.905m/s2
Turbine2 z acc 2.943m/s2

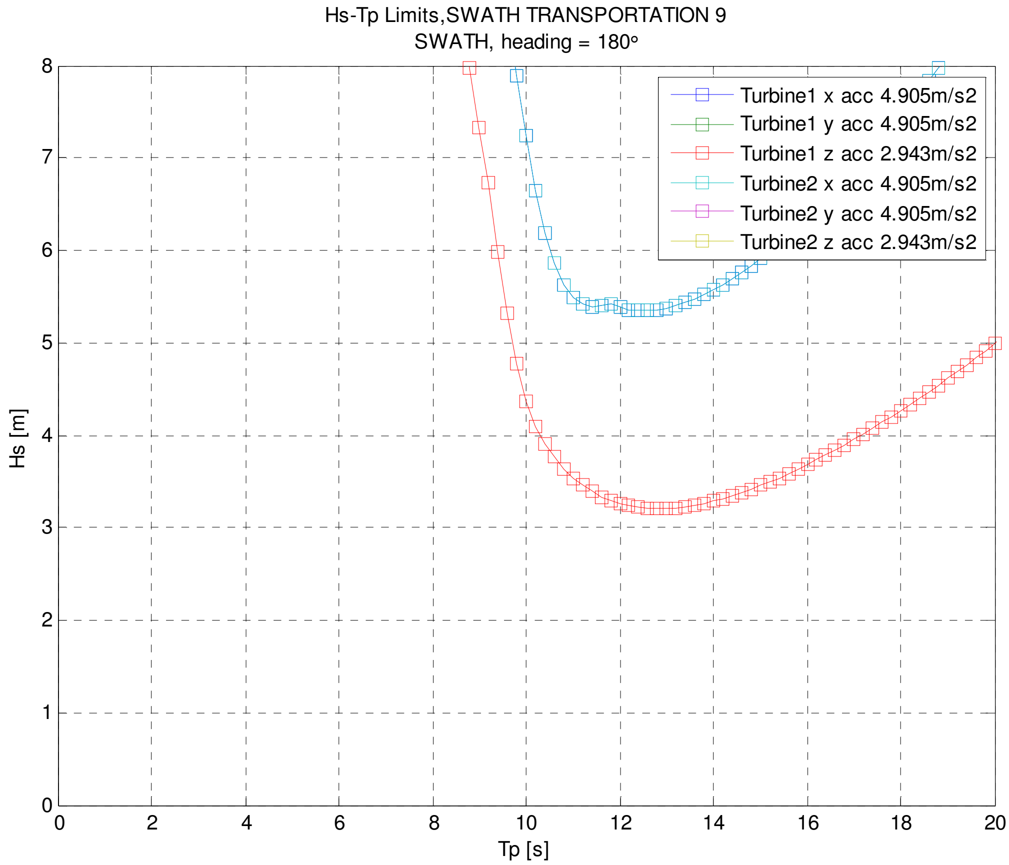

Hs-Tp Limits, MONOHULL TRANSPORT
MONOHULL
Hs [m]
Tp [s]
0°
45°
90°
135°
180°
225°
270°
315°
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20

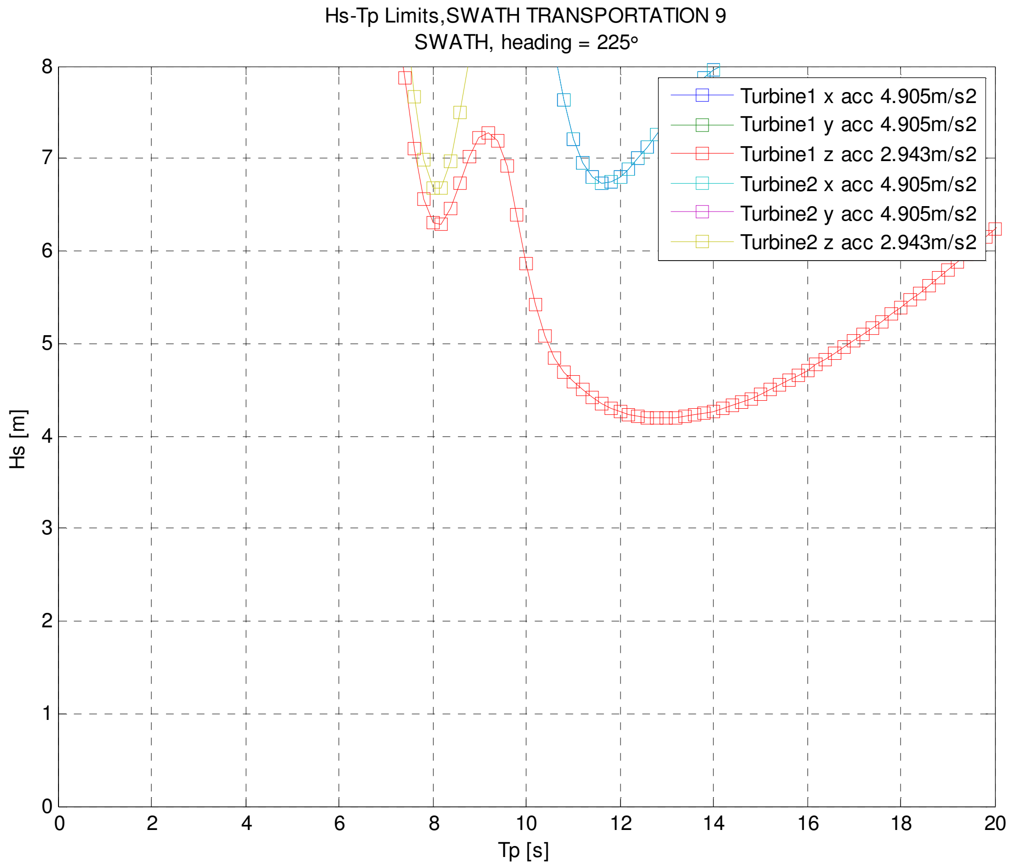

Hs-Tp Limits,SWATH TRANSPORTATION 9
SWATH, heading = 0°
Turbine1 x acc 4.905m/s2
Turbine1 y acc 4.905m/s2
Turbine1 z acc 2.943m/s2
Turbine2 x acc 4.905m/s2
Turbine2 y acc 4.905m/s2
Turbine2 z acc 2.943m/s2
Hs [m]
Tp [s]
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20

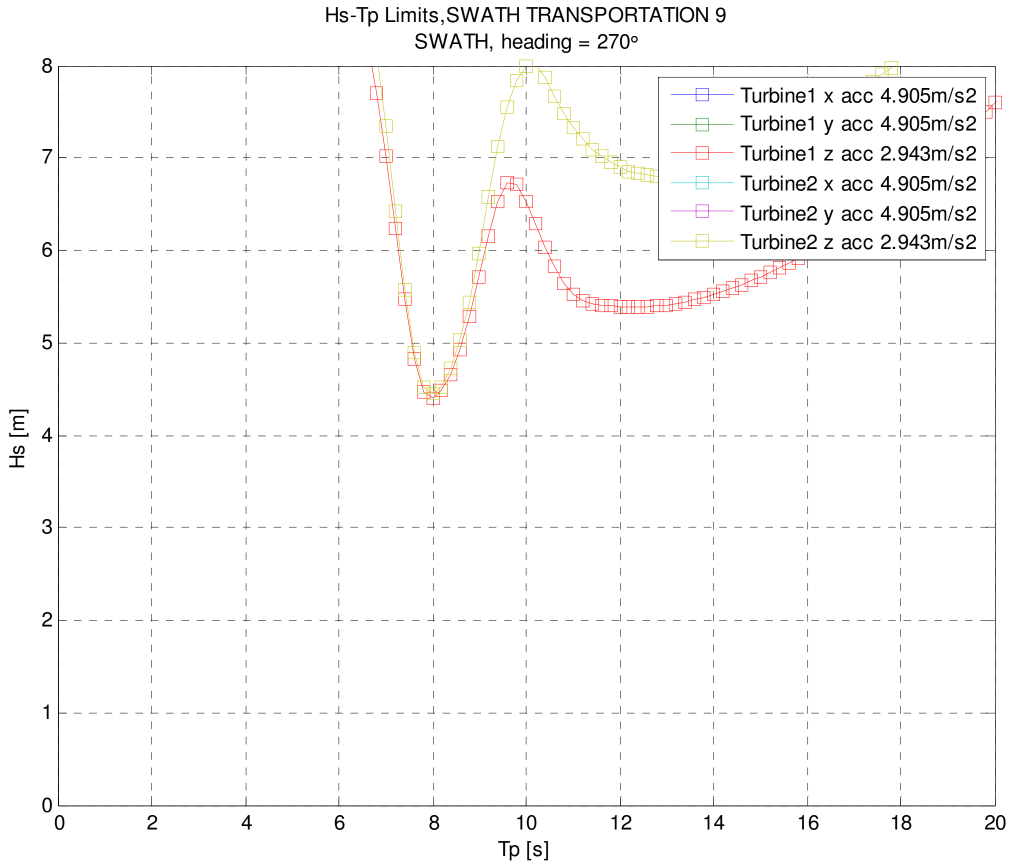

Hs-Tp Limits,SWATH TRANSPORTATION 9
SWATH, heading = 45°
Turbine1 x acc 4.905m/s2
Turbine1 y acc 4.905m/s2
Turbine1 z acc 2.943m/s2
Turbine2 x acc 4.905m/s2
Turbine2 y acc 4.905m/s2
Turbine2 z acc 2.943m/s2
Hs [m]
Tp [s]
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20


Hs-Tp Limits,SWATH TRANSPORTATION 9
SWATH, heading = 90°
Turbine1 x acc 4.905m/s2
Turbine1 y acc 4.905m/s2
Turbine1 z acc 2.943m/s2
Turbine2 x acc 4.905m/s2
Turbine2 y acc 4.905m/s2
Turbine2 z acc 2.943m/s2
Hs [m]
Tp [s]
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20

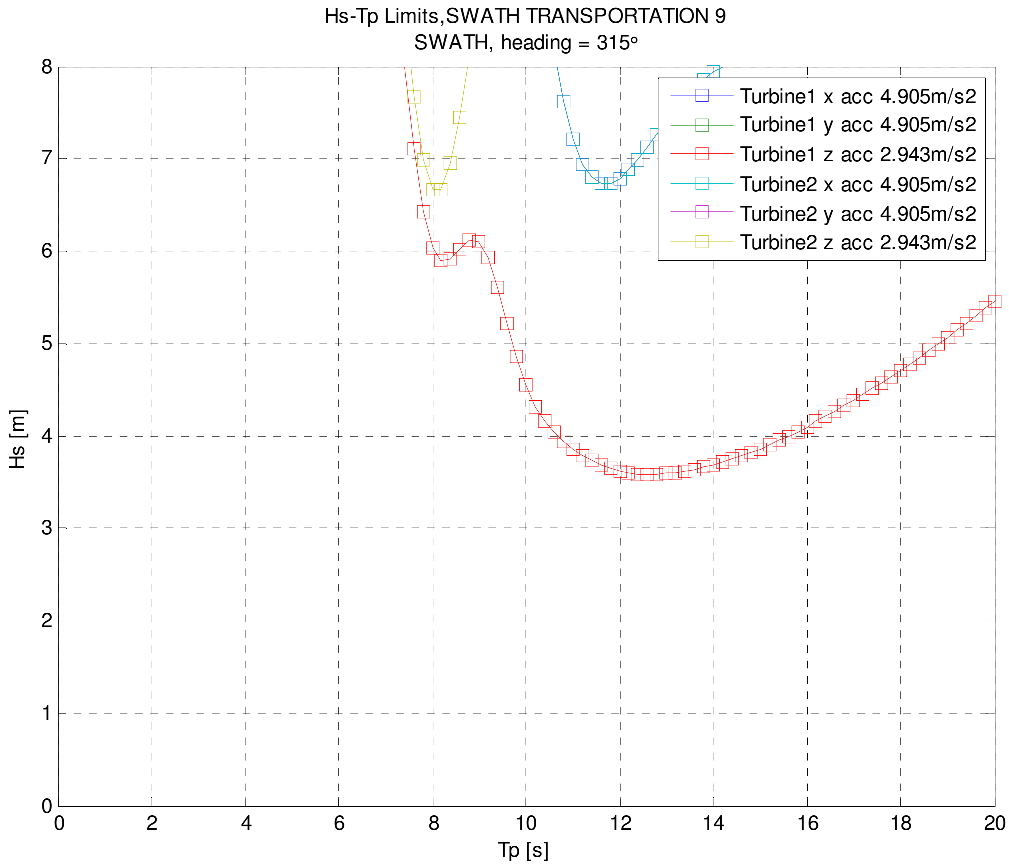

Hs-Tp Limits,SWATH TRANSPORTATION 9
SWATH, heading = 135°
Turbine1 x acc 4.905m/s2
Turbine1 y acc 4.905m/s2
Turbine1 z acc 2.943m/s2
Turbine2 x acc 4.905m/s2
Turbine2 y acc 4.905m/s2
Turbine2 z acc 2.943m/s2
Hs [m]
Tp [s]
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20


Hs-Tp Limits,SWATH TRANSPORTATION 9
SWATH, heading = 180°
Turbine1 x acc 4.905m/s2
Turbine1 y acc 4.905m/s2
Turbine1 z acc 2.943m/s2
Turbine2 x acc 4.905m/s2
Turbine2 y acc 4.905m/s2
Turbine2 z acc 2.943m/s2
Hs [m]
Tp [s]

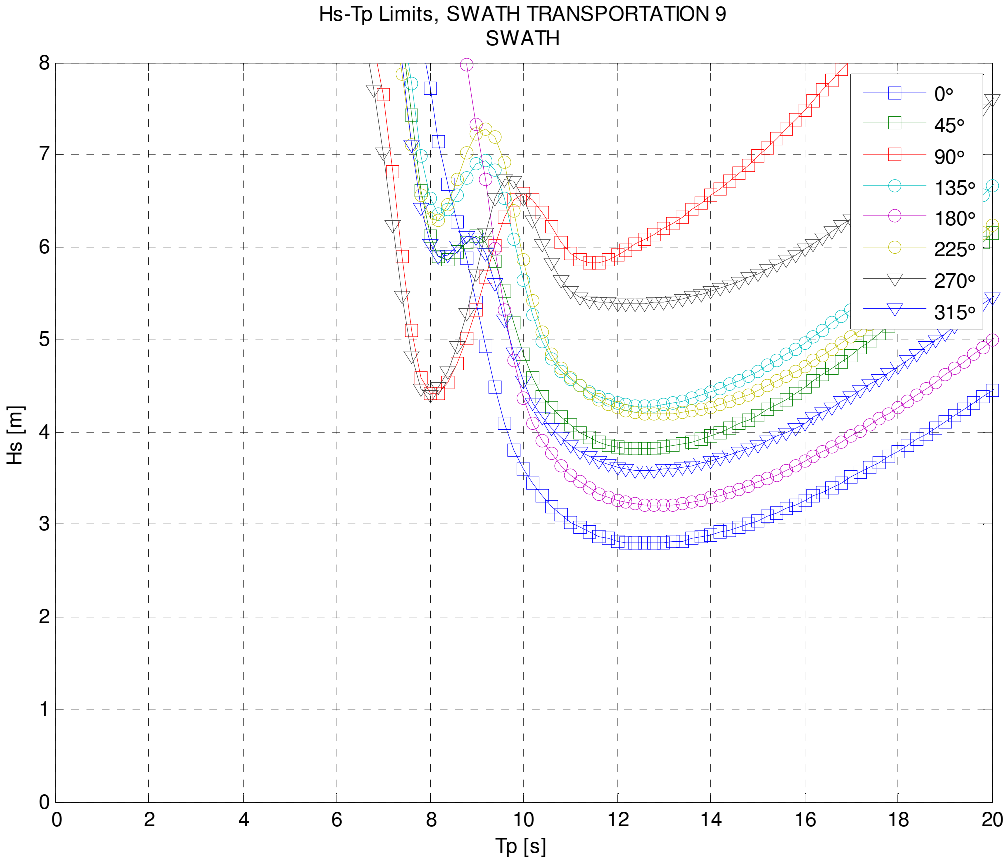

Hs-Tp Limits,SWATH TRANSPORTATION 9
SWATH, heading = 225°
Turbine1 x acc 4.905m/s2
Turbine1 y acc 4.905m/s2
Turbine1 z acc 2.943m/s2
Turbine2 x acc 4.905m/s2
Turbine2 y acc 4.905m/s2
Turbine2 z acc 2.943m/s2
Hs [m]
Tp [s]



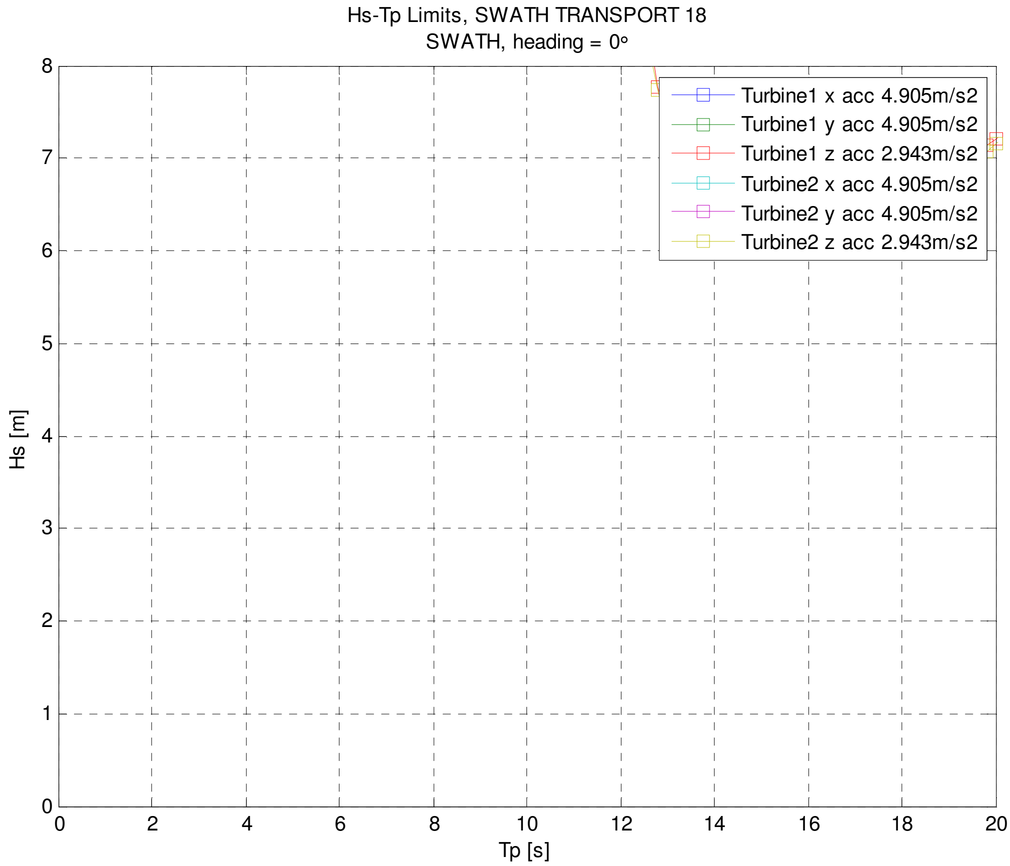
Hs-Tp Limits,SWATH TRANSPORTATION 9
SWATH, heading = 270°
Turbine1 x acc 4.905m/s2
Turbine1 y acc 4.905m/s2
Turbine1 z acc 2.943m/s2
Turbine2 x acc 4.905m/s2
Turbine2 y acc 4.905m/s2
Turbine2 z acc 2.943m/s2
Hs [m]
Tp [s]
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20

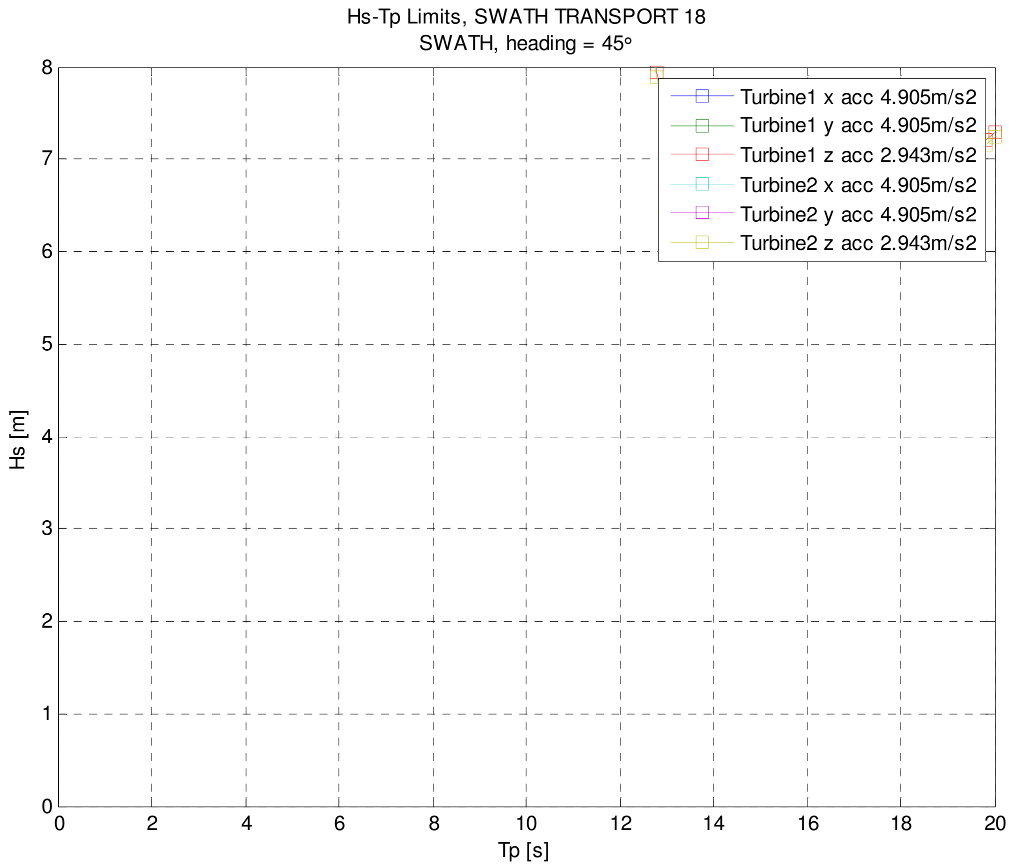


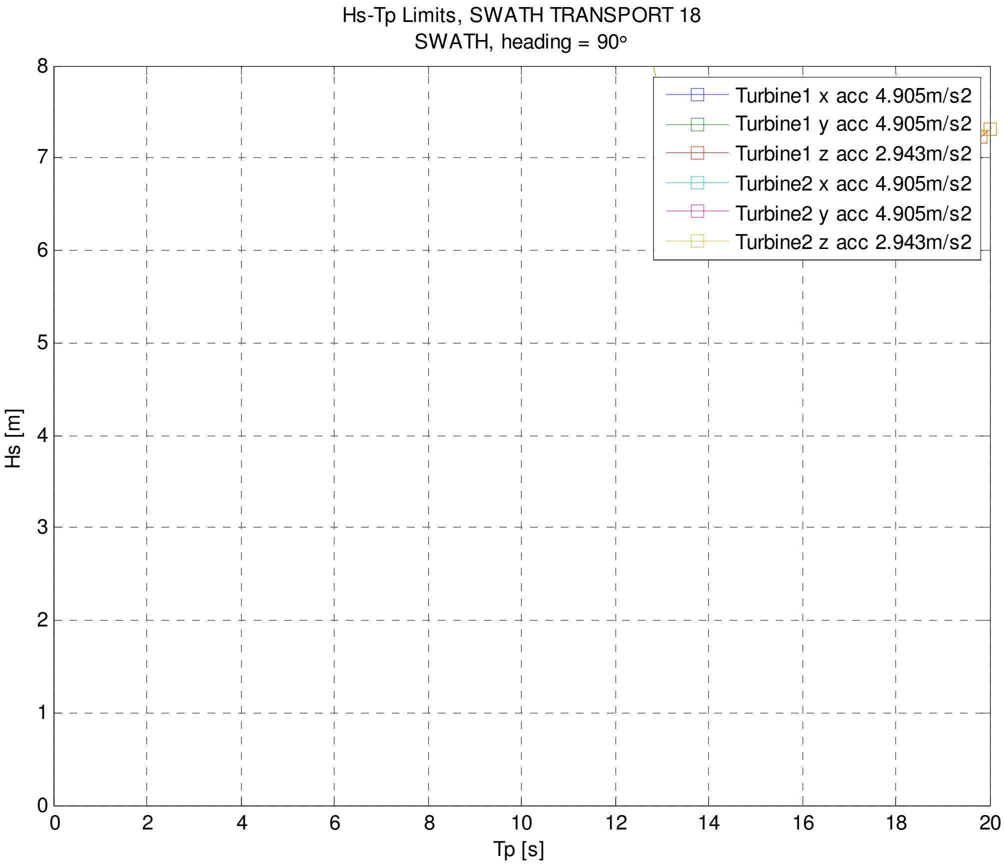
Hs-Tp Limits,SWATH TRANSPORTATION 9
SWATH, heading = 315°
Turbine1 x acc 4.905m/s2
Turbine1 y acc 4.905m/s2
Turbine1 z acc 2.943m/s2
Turbine2 x acc 4.905m/s2
Turbine2 y acc 4.905m/s2
Turbine2 z acc 2.943m/s2
Hs [m]
Tp [s]
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20

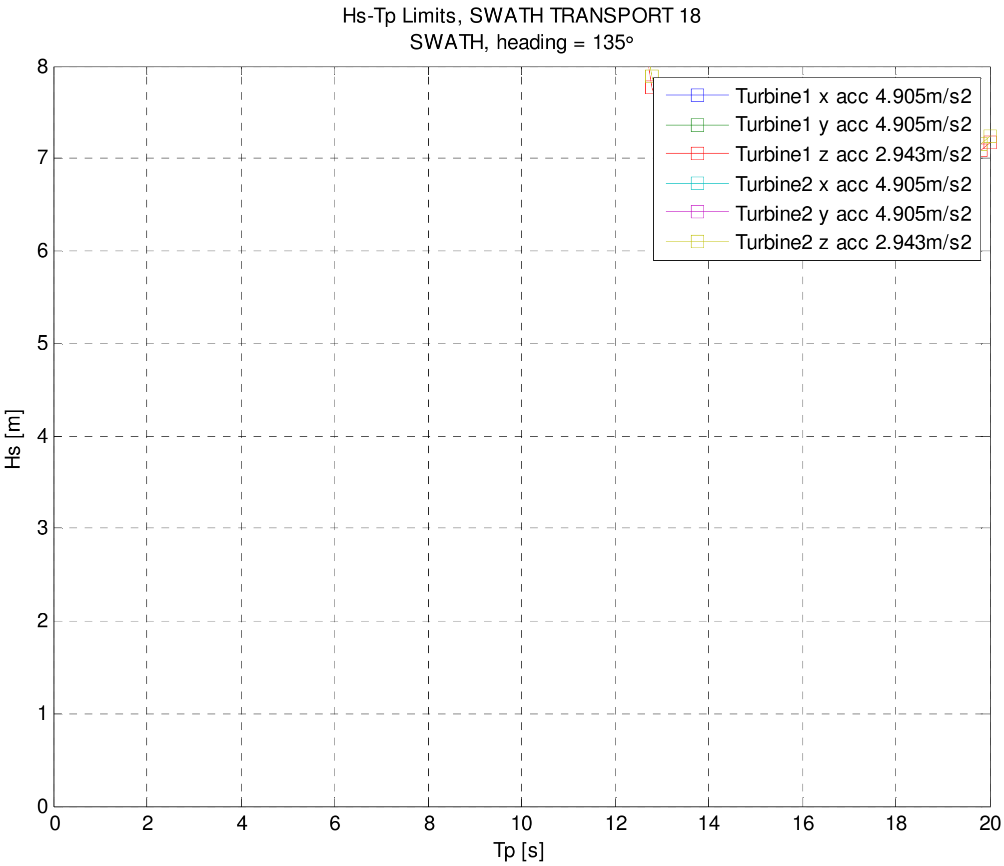


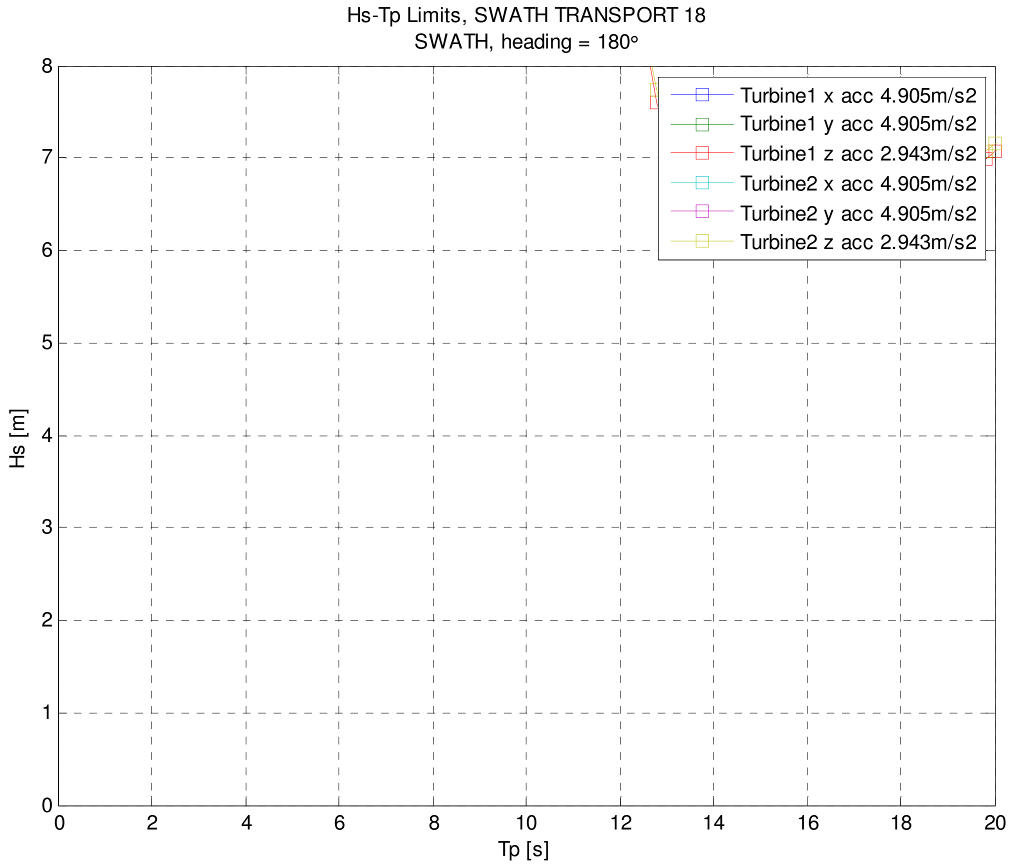
Hs-Tp Limits, SWATH TRANSPORTATION 9
SWATH
Hs [m]
Tp [s]
0°
45°
90°
135°
180°
225°
270°
315°
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20


Hs-Tp Limits, SWATH TRANSPORT 18
SWATH, heading = 0°
Hs [m]
Tp [s]
Turbine1 x acc 4.905m/s2
Turbine1 y acc 4.905m/s2
Turbine1 z acc 2.943m/s2
Turbine2 x acc 4.905m/s2
Turbine2 y acc 4.905m/s2
Turbine2 z acc 2.943m/s2

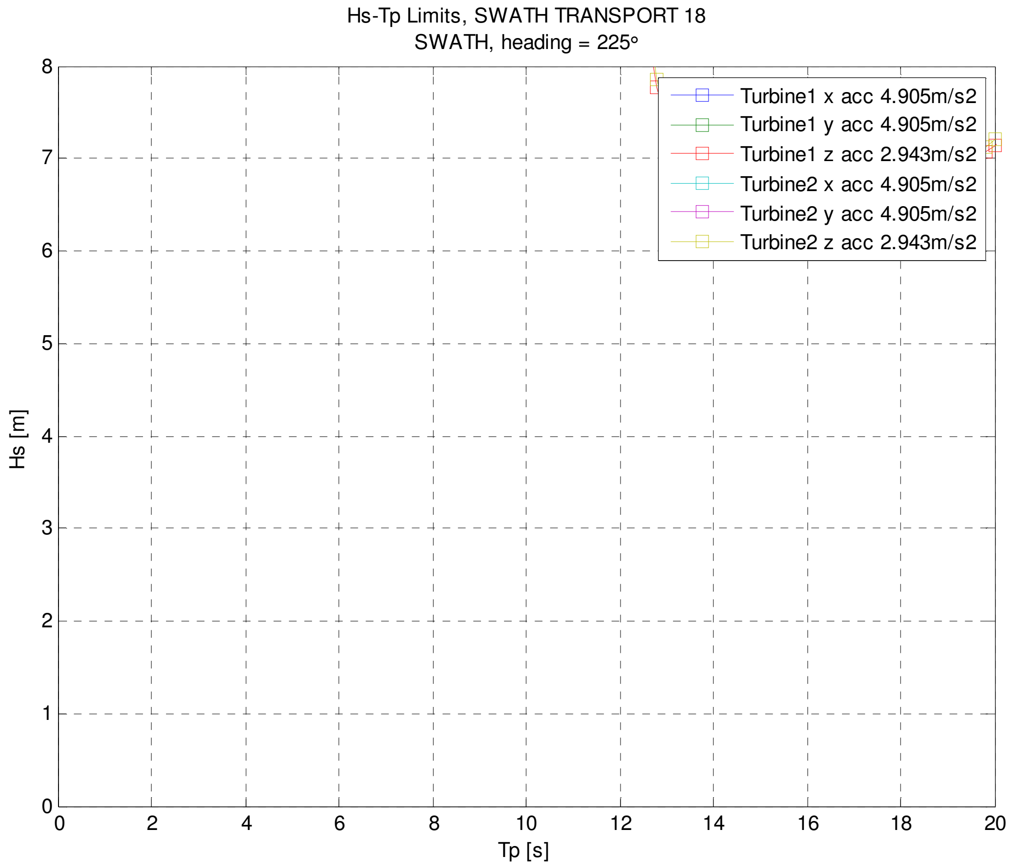

Hs-Tp Limits, SWATH TRANSPORT 18
SWATH, heading = 45°
Hs [m]
Tp [s]
Turbine1 x acc 4.905m/s2
Turbine1 y acc 4.905m/s2
Turbine1 z acc 2.943m/s2
Turbine2 x acc 4.905m/s2
Turbine2 y acc 4.905m/s2
Turbine2 z acc 2.943m/s2


Hs-Tp Limits, SWATH TRANSPORT 18
SWATH, heading = 90°
Hs [m]
Tp [s]
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20
Turbine1 x acc 4.905m/s2
Turbine1 y acc 4.905m/s2
Turbine1 z acc 2.943m/s2
Turbine2 x acc 4.905m/s2
Turbine2 y acc 4.905m/s2
Turbine2 z acc 2.943m/s2

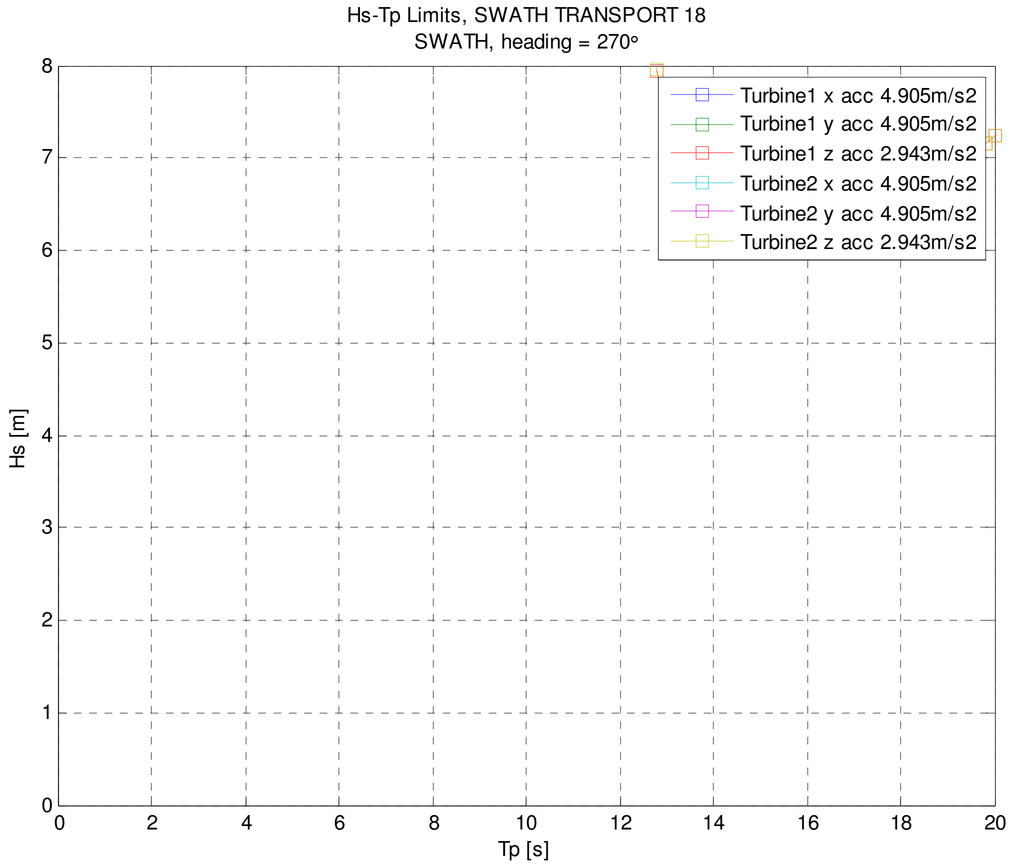

Hs-Tp Limits, SWATH TRANSPORT 18
SWATH, heading = 135°
Hs [m]
Tp [s]
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20
Turbine1 x acc 4.905m/s2
Turbine1 y acc 4.905m/s2
Turbine1 z acc 2.943m/s2
Turbine2 x acc 4.905m/s2
Turbine2 y acc 4.905m/s2
Turbine2 z acc 2.943m/s2



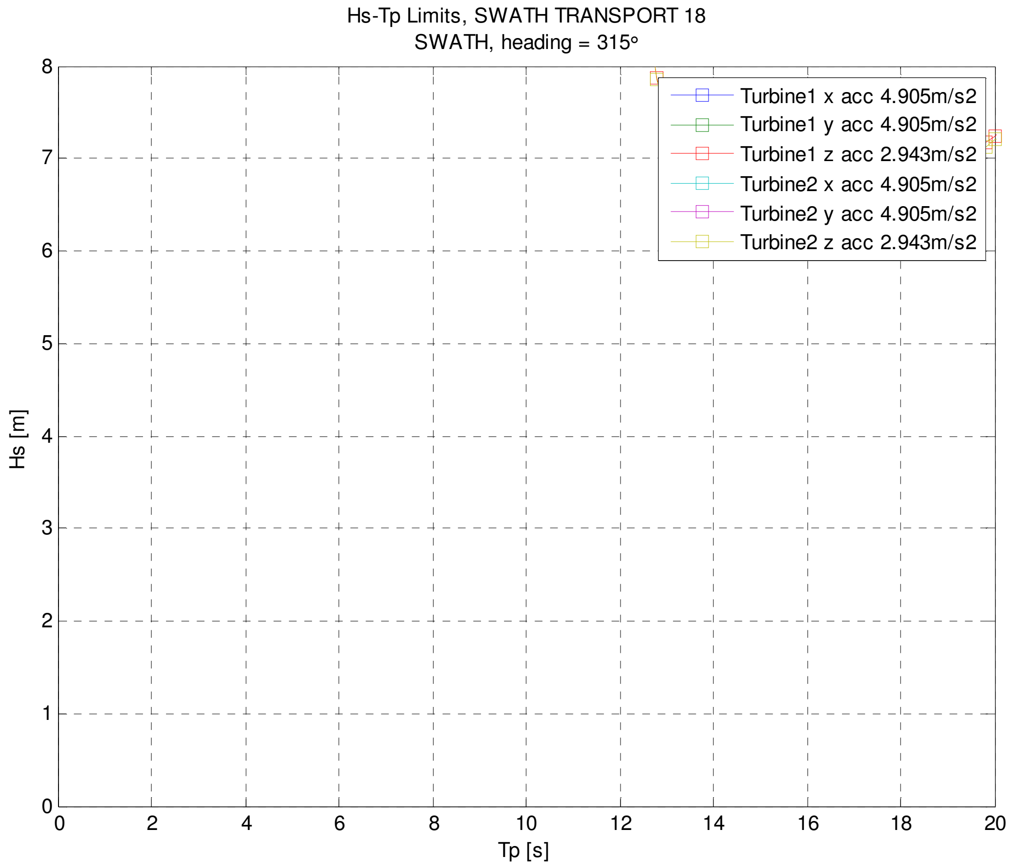
Hs-Tp Limits, SWATH TRANSPORT 18
SWATH, heading = 180°
Hs [m]
Tp [s]
Turbine1 x acc 4.905m/s2
Turbine1 y acc 4.905m/s2
Turbine1 z acc 2.943m/s2
Turbine2 x acc 4.905m/s2
Turbine2 y acc 4.905m/s2
Turbine2 z acc 2.943m/s2



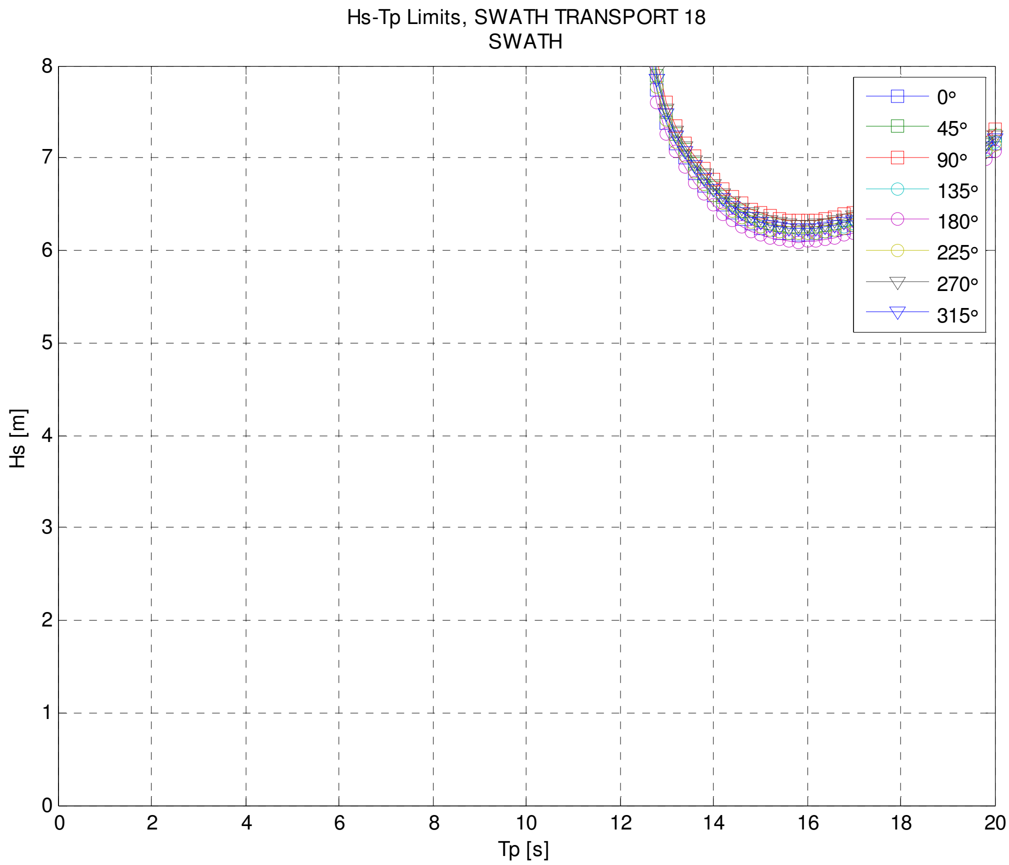
Hs-Tp Limits, SWATH TRANSPORT 18
SWATH, heading = 225°
Hs [m]
Tp [s]
Turbine1 x acc 4.905m/s2
Turbine1 y acc 4.905m/s2
Turbine1 z acc 2.943m/s2
Turbine2 x acc 4.905m/s2
Turbine2 y acc 4.905m/s2
Turbine2 z acc 2.943m/s2

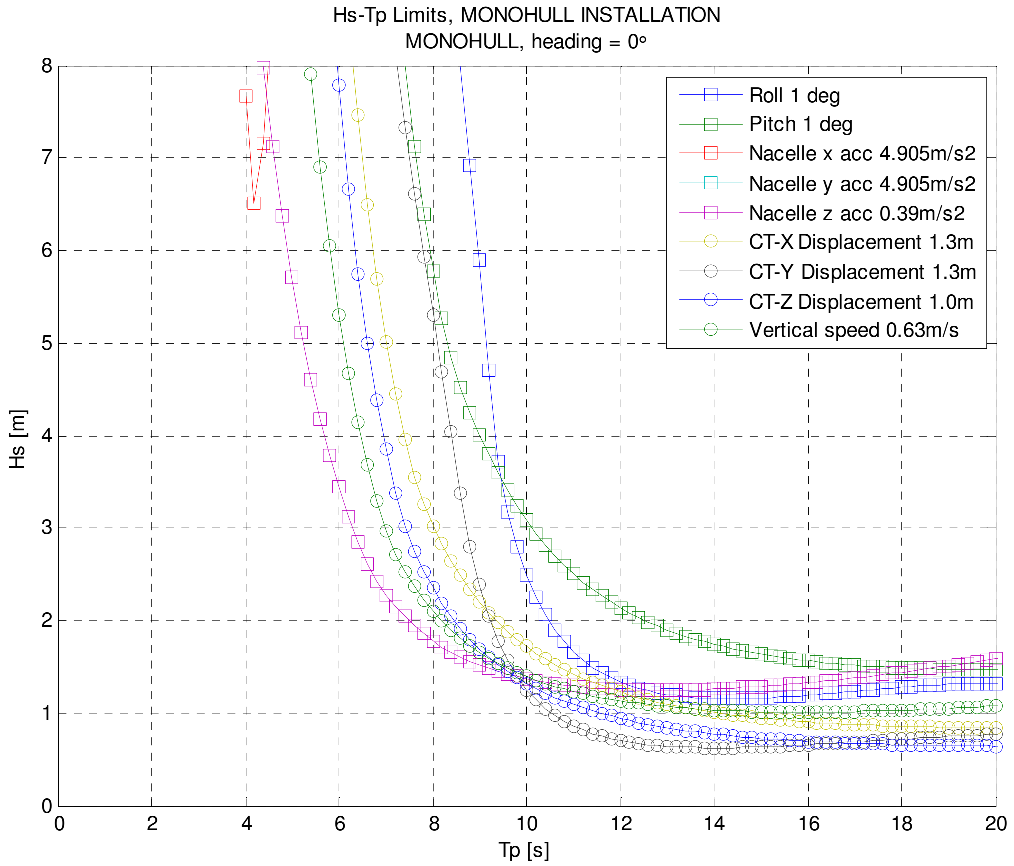


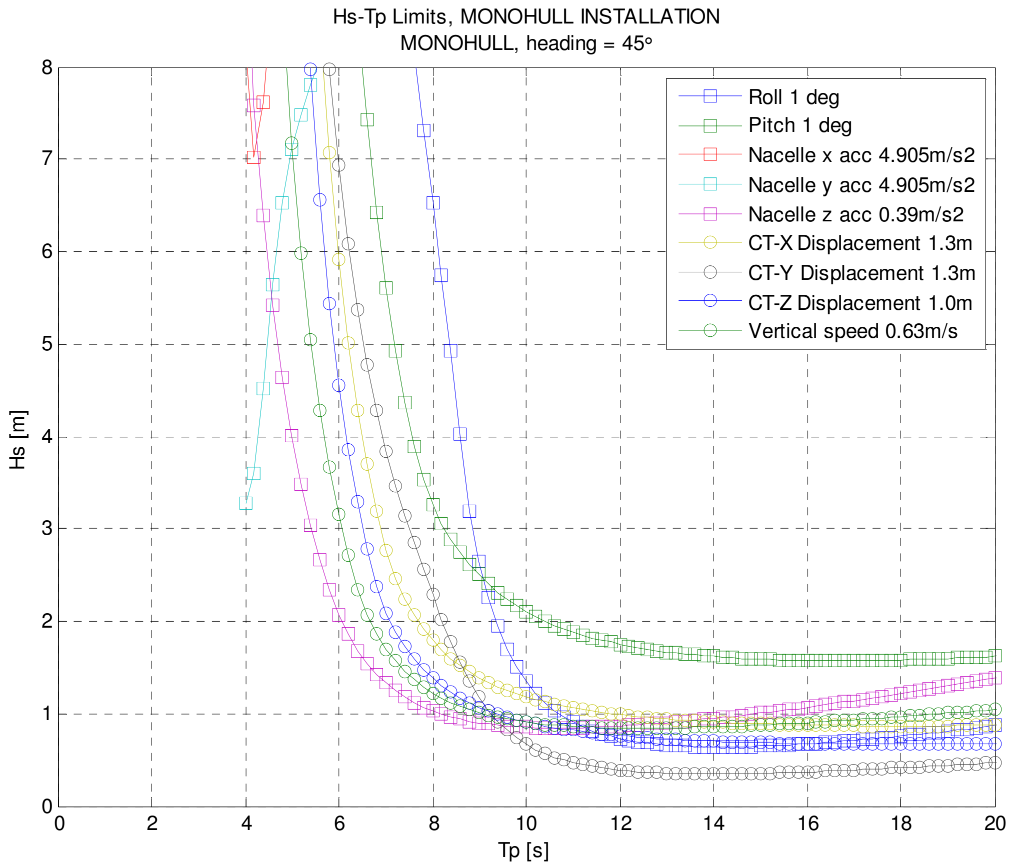
Hs-Tp Limits, SWATH TRANSPORT 18
SWATH, heading = 270°
Turbine1 x acc 4.905m/s2
Turbine1 y acc 4.905m/s2
Turbine1 z acc 2.943m/s2
Turbine2 x acc 4.905m/s2
Turbine2 y acc 4.905m/s2
Turbine2 z acc 2.943m/s2
Hs [m]
Tp [s]
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20

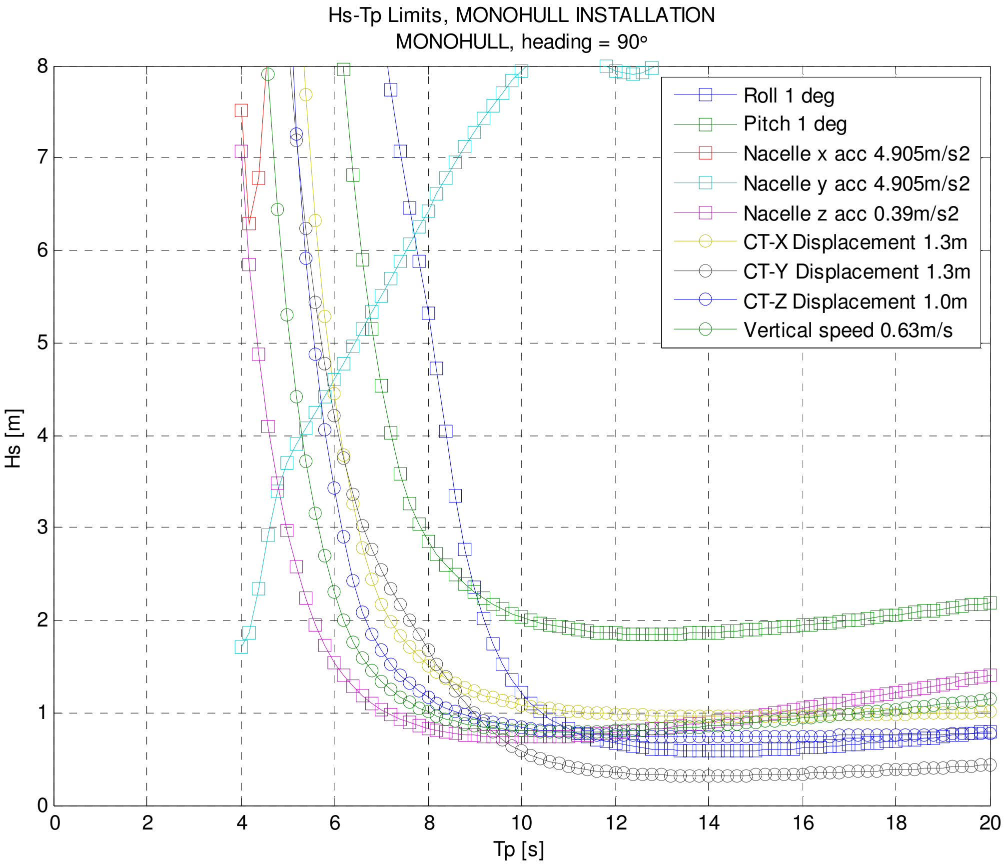


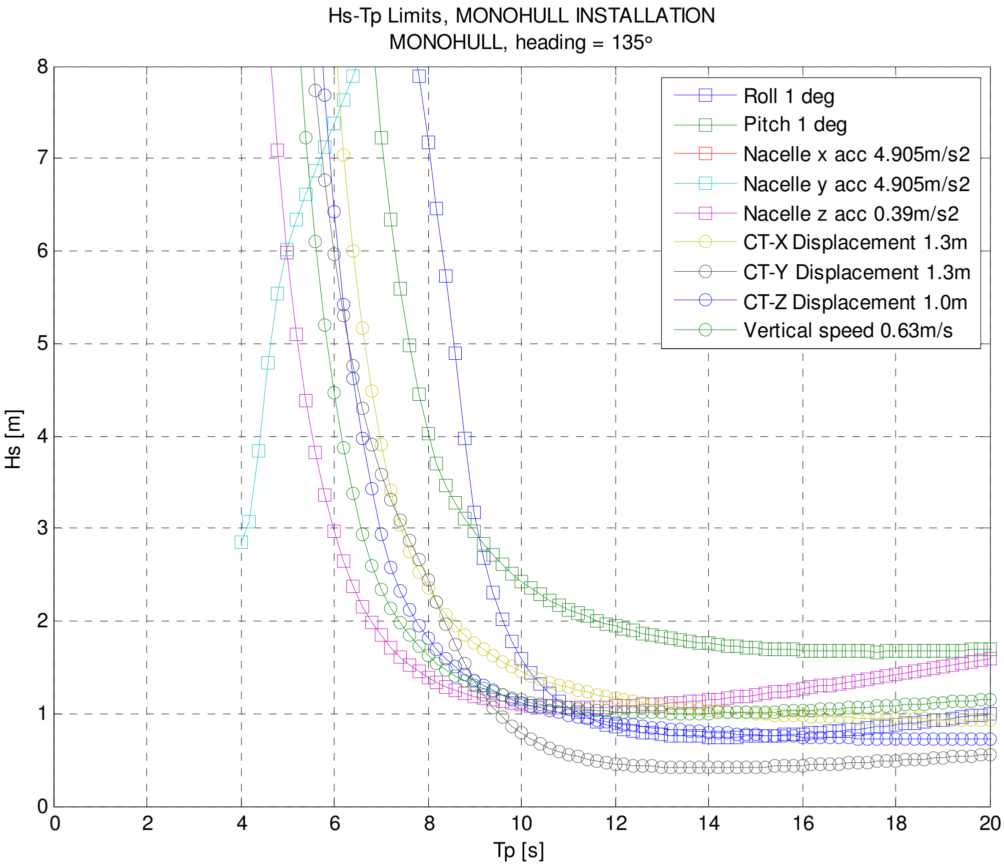
Hs-Tp Limits, SWATH TRANSPORT 18
SWATH, heading = 315°
Turbine1 x acc 4.905m/s2
Turbine1 y acc 4.905m/s2
Turbine1 z acc 2.943m/s2
Turbine2 x acc 4.905m/s2
Turbine2 y acc 4.905m/s2
Turbine2 z acc 2.943m/s2
Hs [m]
Tp [s]
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20

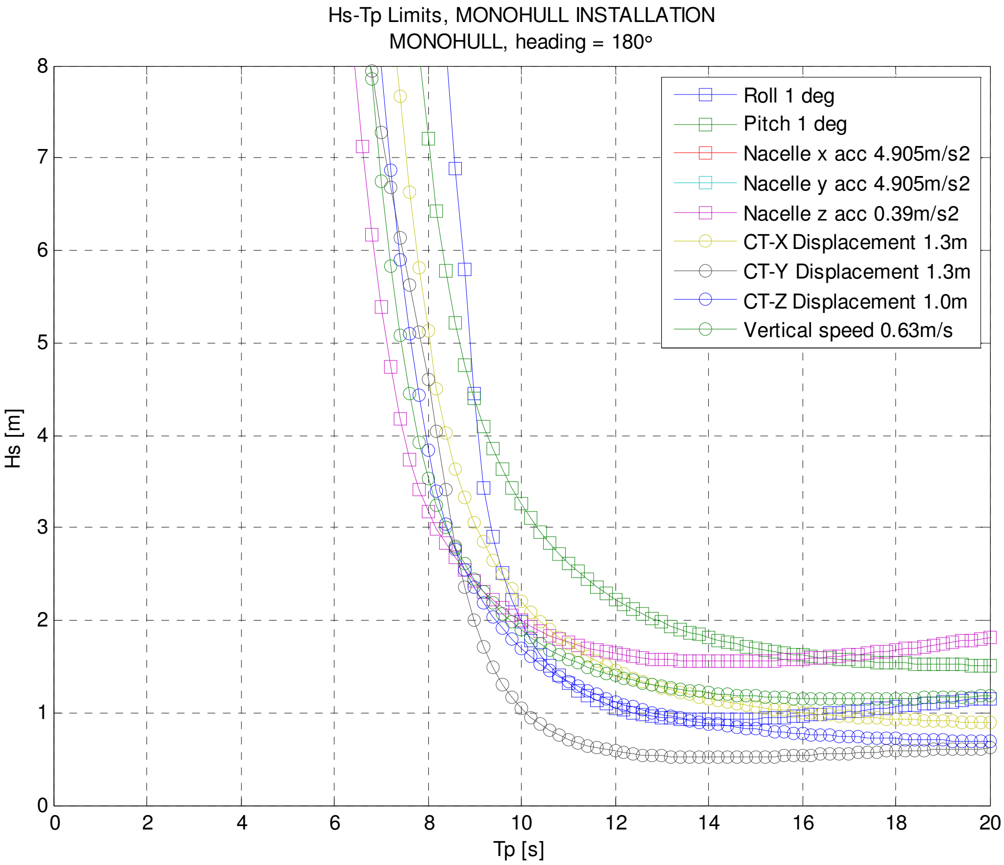

Hs-Tp Limits, SWATH TRANSPORT 18
SWATH
Hs [m]
Tp [s]
0°
45°
90°
135°
180°
225°
270°
315°
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20

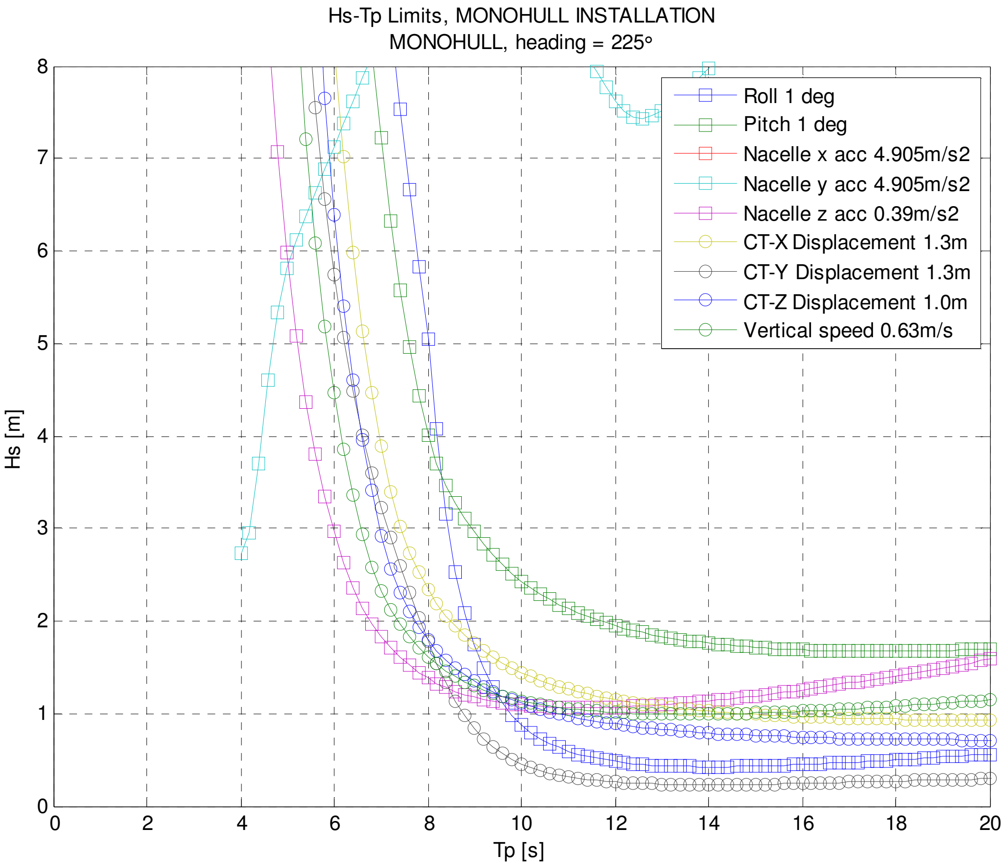

Hs-Tp Limits, MONOHULL INSTALLATION
MONOHULL, heading = 0°
Hs [m]
Tp [s]
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20
Roll 1 deg
Pitch 1 deg
Nacelle x acc 4.905m/s2
Nacelle y acc 4.905m/s2
Nacelle z acc 0.39m/s2
CT-X Displacement 1.3m
CT-Y Displacement 1.3m
CT-Z Displacement 1.0m
Vertical speed 0.63m/s

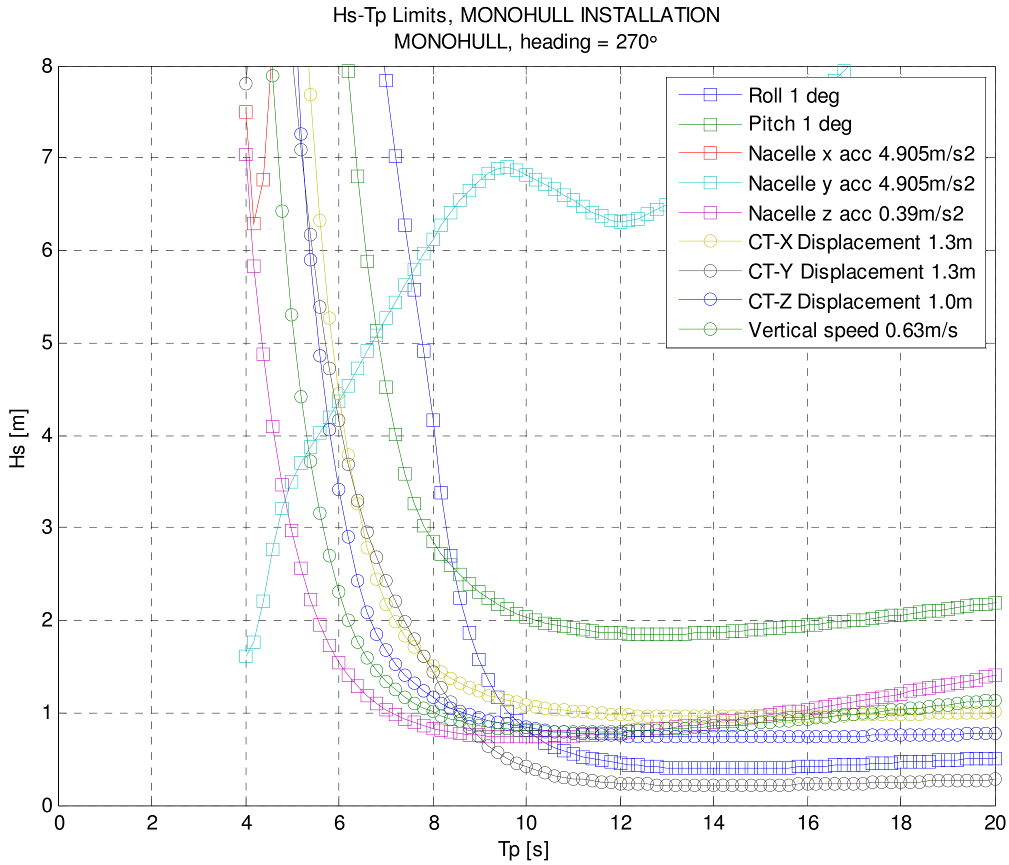

Hs-Tp Limits, MONOHULL INSTALLATION
MONOHULL, heading = 45°
Hs [m]
Tp [s]
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20
Roll 1 deg
Pitch 1 deg
Nacelle x acc 4.905m/s2
Nacelle y acc 4.905m/s2
Nacelle z acc 0.39m/s2
CT-X Displacement 1.3m
CT-Y Displacement 1.3m
CT-Z Displacement 1.0m
Vertical speed 0.63m/s

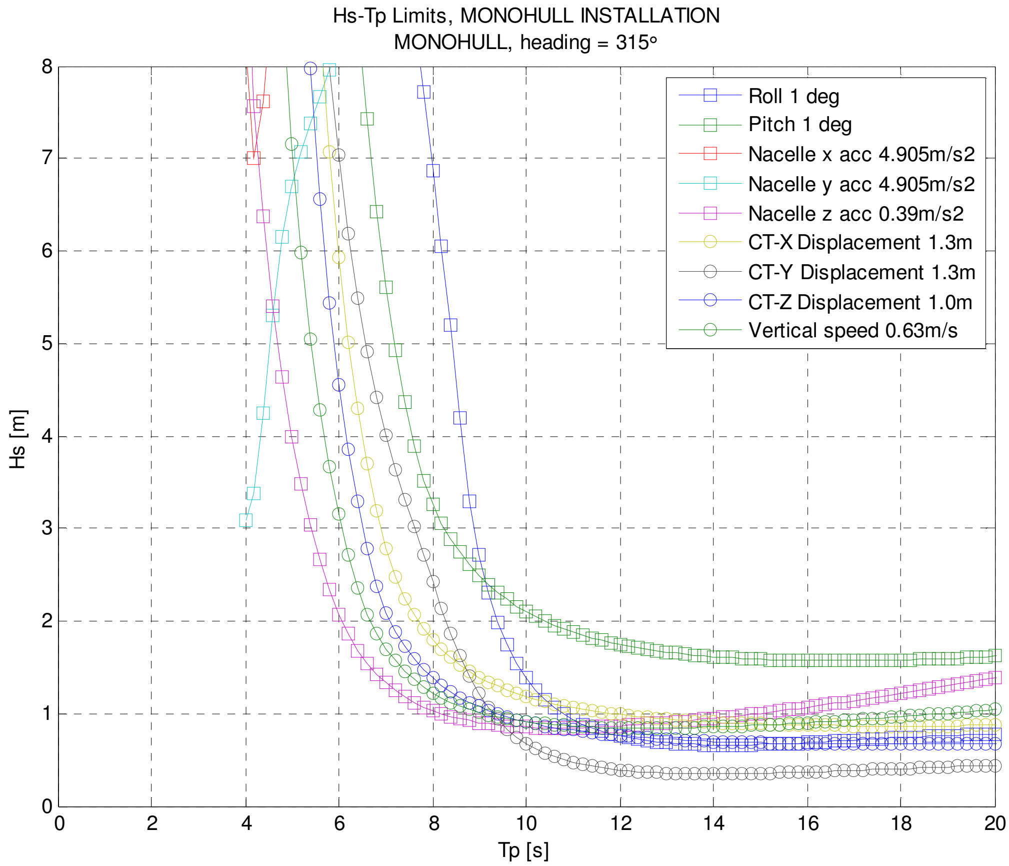

Hs-Tp Limits, MONOHULL INSTALLATION
MONOHULL, heading = 90°
Hs [m]
Tp [s]
Roll 1 deg
Pitch 1 deg
Nacelle x acc 4.905m/s2
Nacelle y acc 4.905m/s2
Nacelle z acc 0.39m/s2
CT-X Displacement 1.3m
CT-Y Displacement 1.3m
CT-Z Displacement 1.0m
Vertical speed 0.63m/s

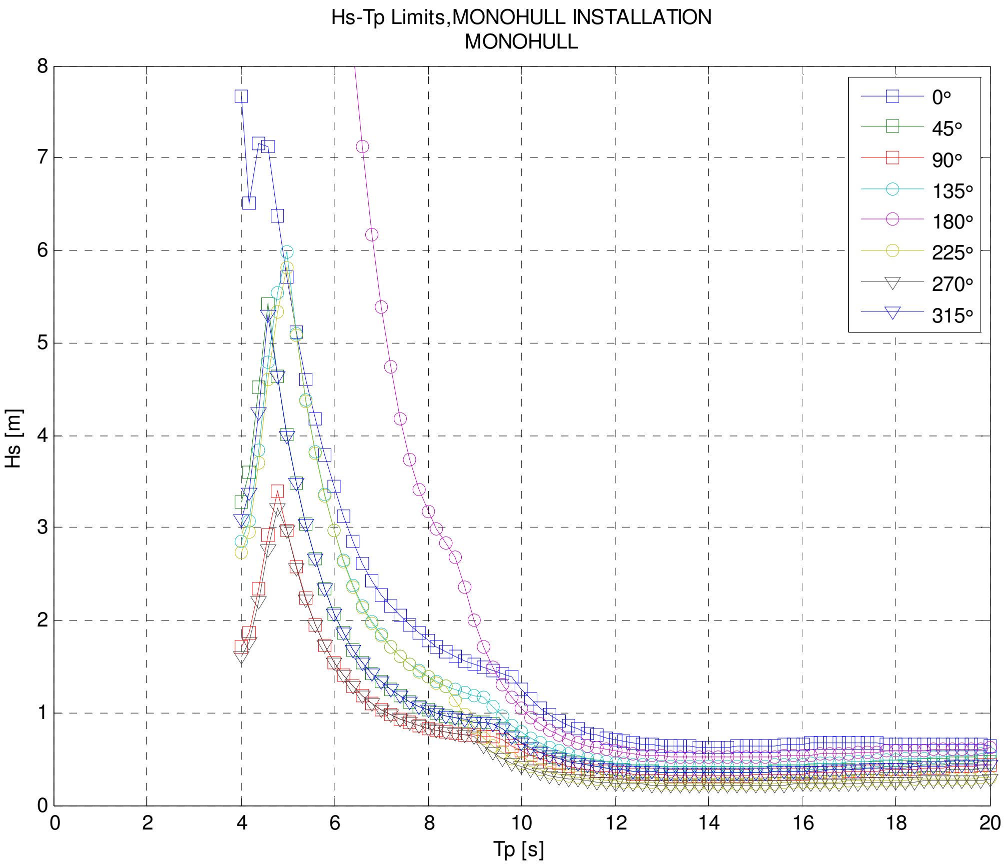

Hs-Tp Limits, MONOHULL INSTALLATION
MONOHULL, heading = 135°
Hs [m]
Tp [s]
Roll 1 deg
Pitch 1 deg
Nacelle x acc 4.905m/s2
Nacelle y acc 4.905m/s2
Nacelle z acc 0.39m/s2
CT-X Displacement 1.3m
CT-Y Displacement 1.3m
CT-Z Displacement 1.0m
Vertical speed 0.63m/s


Hs-Tp Limits, MONOHULL INSTALLATION
MONOHULL, heading = 180°
Roll 1 deg
Pitch 1 deg
Nacelle x acc 4.905m/s2
Nacelle y acc 4.905m/s2
Nacelle z acc 0.39m/s2
CT-X Displacement 1.3m
CT-Y Displacement 1.3m
CT-Z Displacement 1.0m
Vertical speed 0.63m/s
Hs [m]
Tp [s]

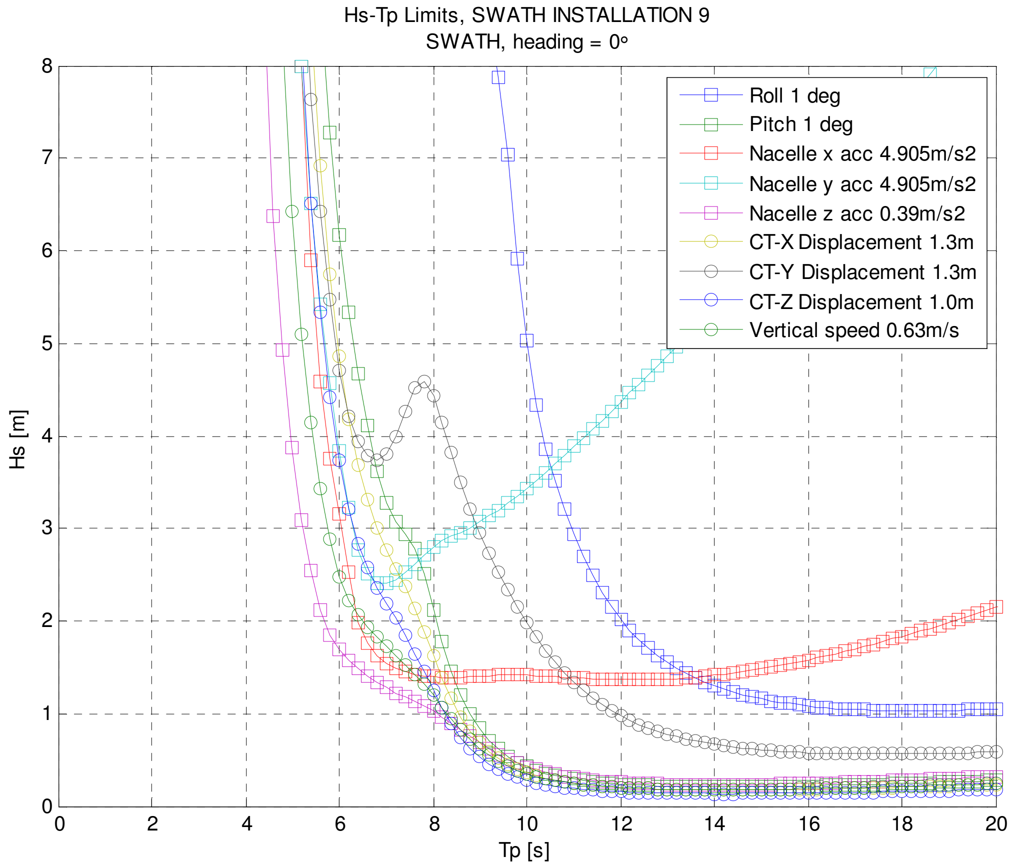

Hs-Tp Limits, MONOHULL INSTALLATION
MONOHULL, heading = 225°
Roll 1 deg
Pitch 1 deg
Nacelle x acc 4.905m/s2
Nacelle y acc 4.905m/s2
Nacelle z acc 0.39m/s2
CT-X Displacement 1.3m
CT-Y Displacement 1.3m
CT-Z Displacement 1.0m
Vertical speed 0.63m/s
Hs [m]
Tp [s]


Hs-Tp Limits, MONOHULL INSTALLATION
MONOHULL, heading = 270°
Hs [m]
Tp [s]
Roll 1 deg
Pitch 1 deg
Nacelle x acc 4.905m/s2
Nacelle y acc 4.905m/s2
Nacelle z acc 0.39m/s2
CT-X Displacement 1.3m
CT-Y Displacement 1.3m
CT-Z Displacement 1.0m
Vertical speed 0.63m/s

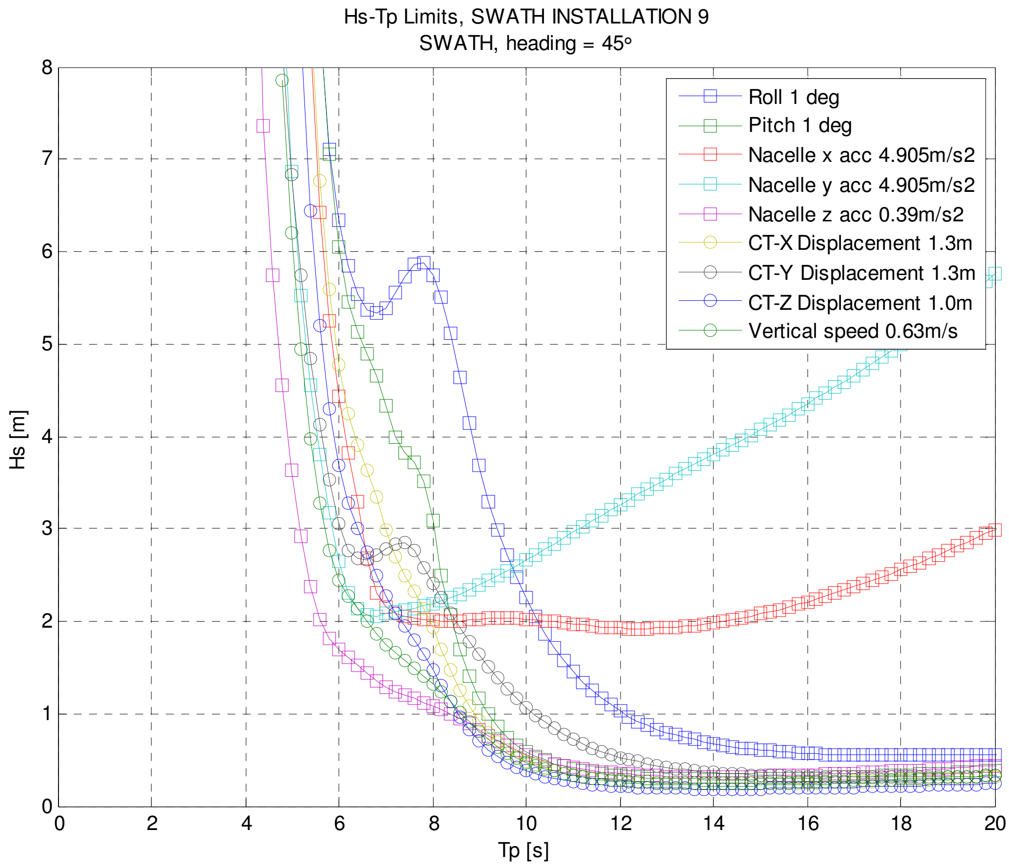

Hs-Tp Limits, MONOHULL INSTALLATION
MONOHULL, heading = 315°
Hs [m]
Tp [s]
Roll 1 deg
Pitch 1 deg
Nacelle x acc 4.905m/s2
Nacelle y acc 4.905m/s2
Nacelle z acc 0.39m/s2
CT-X Displacement 1.3m
CT-Y Displacement 1.3m
CT-Z Displacement 1.0m
Vertical speed 0.63m/s



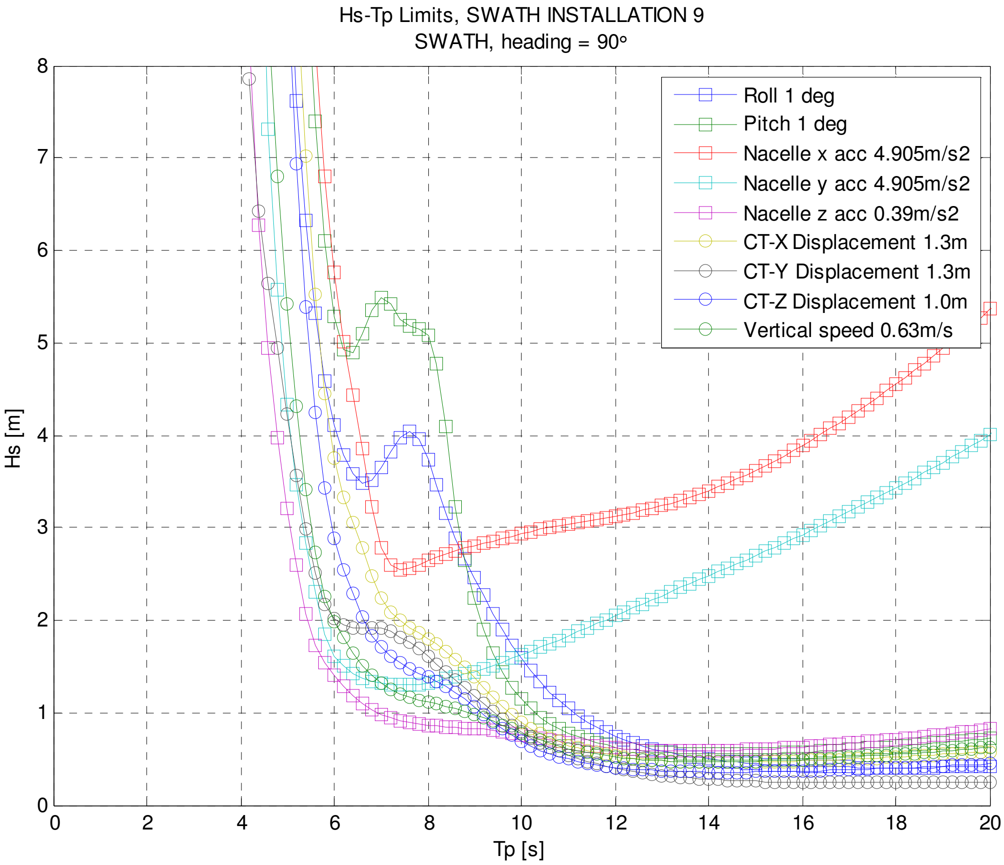
Hs-Tp Limits,MONOHULL INSTALLATION
MONOHULL
Hs [m]
Tp [s]
0°
45°
90°
135°
180°
225°
270°
315°
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20

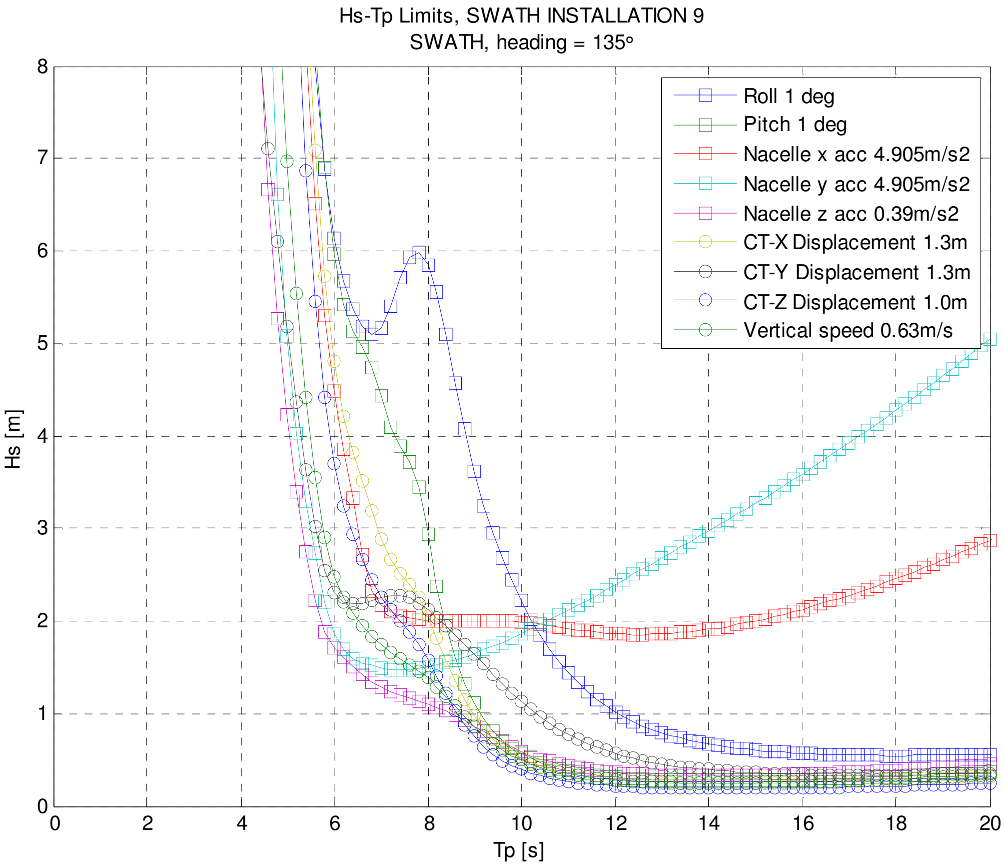


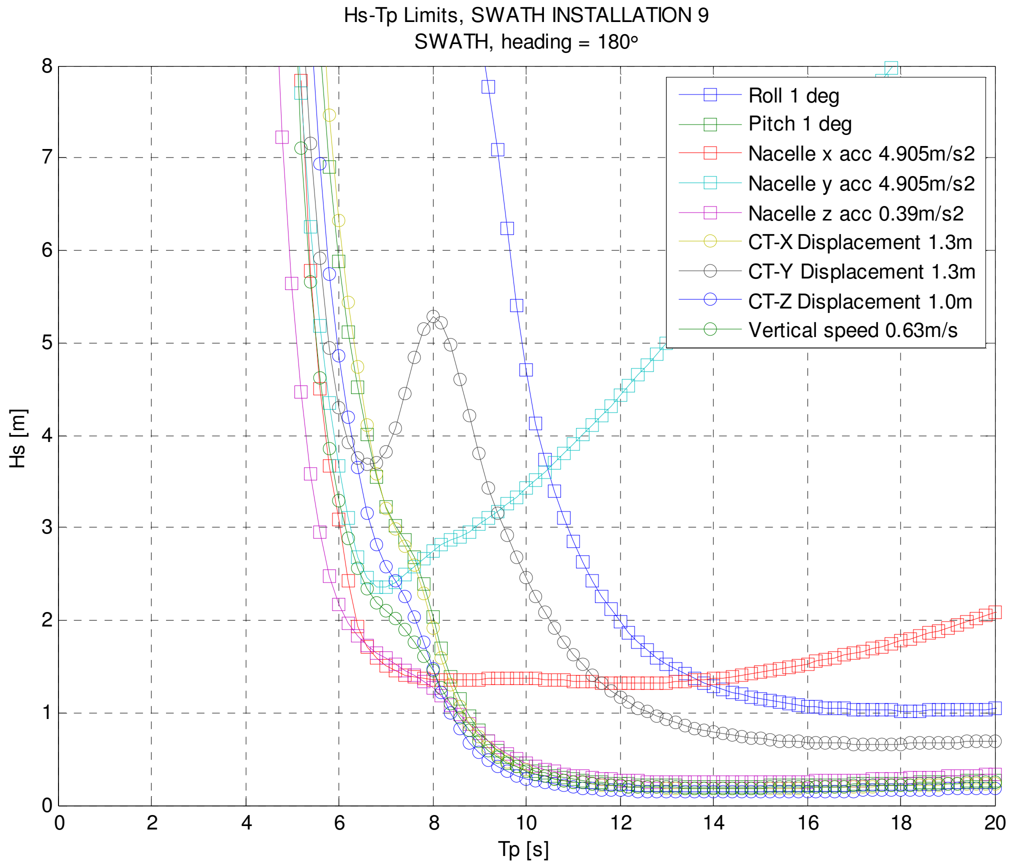
Hs-Tp Limits, SWATH INSTALLATION 9
SWATH, heading = 0°
Roll 1 deg
Pitch 1 deg
Nacelle x acc 4.905m/s2
Nacelle y acc 4.905m/s2
Nacelle z acc 0.39m/s2
CT-X Displacement 1.3m
CT-Y Displacement 1.3m
CT-Z Displacement 1.0m
Vertical speed 0.63m/s
Hs [m]
Tp [s]

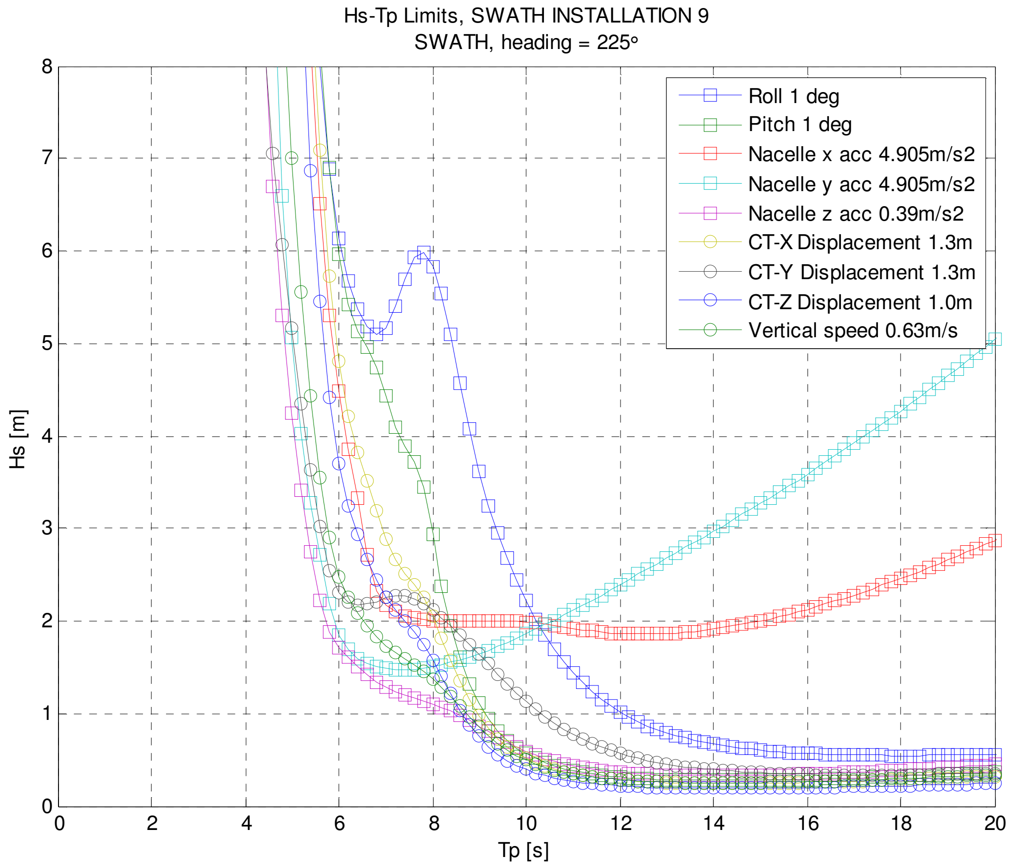


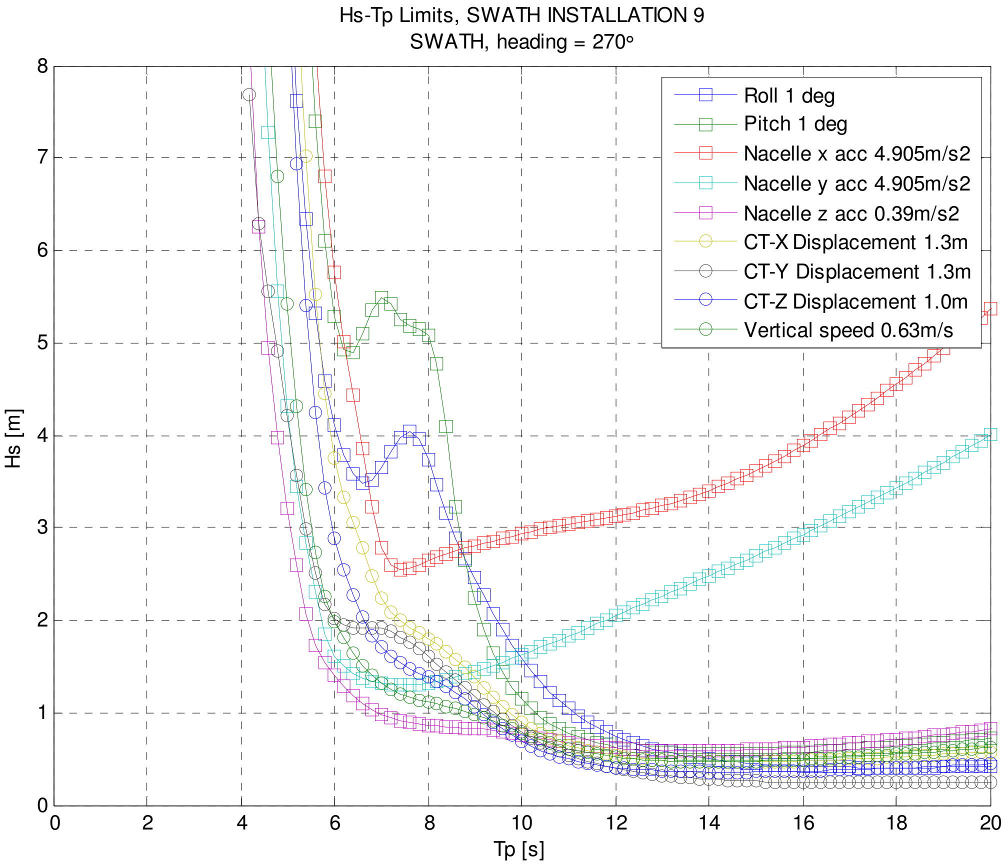
Hs-Tp Limits, SWATH INSTALLATION 9
SWATH, heading = 45°
Roll 1 deg
Pitch 1 deg
Nacelle x acc 4.905m/s2
Nacelle y acc 4.905m/s2
Nacelle z acc 0.39m/s2
CT-X Displacement 1.3m
CT-Y Displacement 1.3m
CT-Z Displacement 1.0m
Vertical speed 0.63m/s
Hs [m]
Tp [s]


Hs-Tp Limits, SWATH INSTALLATION 9
SWATH, heading = 90°
Roll 1 deg
Pitch 1 deg
Nacelle x acc 4.905m/s2
Nacelle y acc 4.905m/s2
Nacelle z acc 0.39m/s2
CT-X Displacement 1.3m
CT-Y Displacement 1.3m
CT-Z Displacement 1.0m
Vertical speed 0.63m/s
Hs [m]
Tp [s]
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20

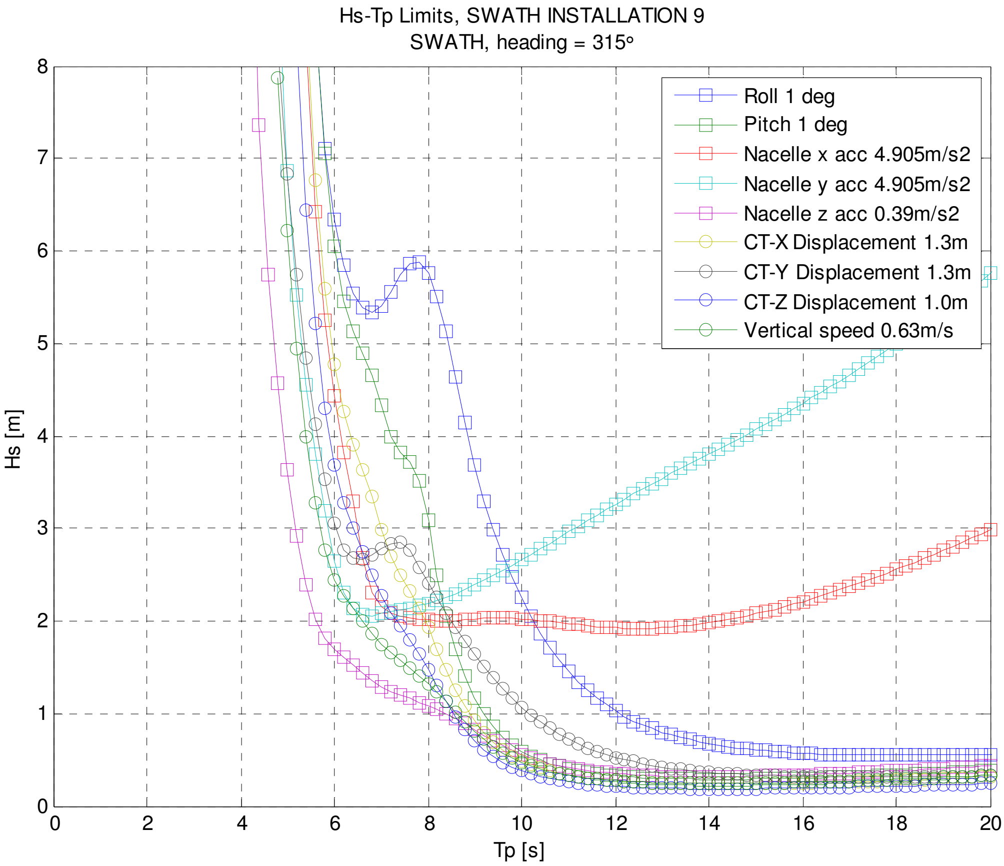

Hs-Tp Limits, SWATH INSTALLATION 9
SWATH, heading = 135°
Roll 1 deg
Pitch 1 deg
Nacelle x acc 4.905m/s2
Nacelle y acc 4.905m/s2
Nacelle z acc 0.39m/s2
CT-X Displacement 1.3m
CT-Y Displacement 1.3m
CT-Z Displacement 1.0m
Vertical speed 0.63m/s
Hs [m]
Tp [s]
0
1
2
3
4
5
6
7
8
0
2
4
6
8
10
12
14
16
18
20


Hs-Tp Limits, SWATH INSTALLATION 9
SWATH, heading = 180°
Hs [m]
Tp [s]
Roll 1 deg
Pitch 1 deg
Nacelle x acc 4.905m/s2
Nacelle y acc 4.905m/s2
Nacelle z acc 0.39m/s2
CT-X Displacement 1.3m
CT-Y Displacement 1.3m
CT-Z Displacement 1.0m
Vertical speed 0.63m/s

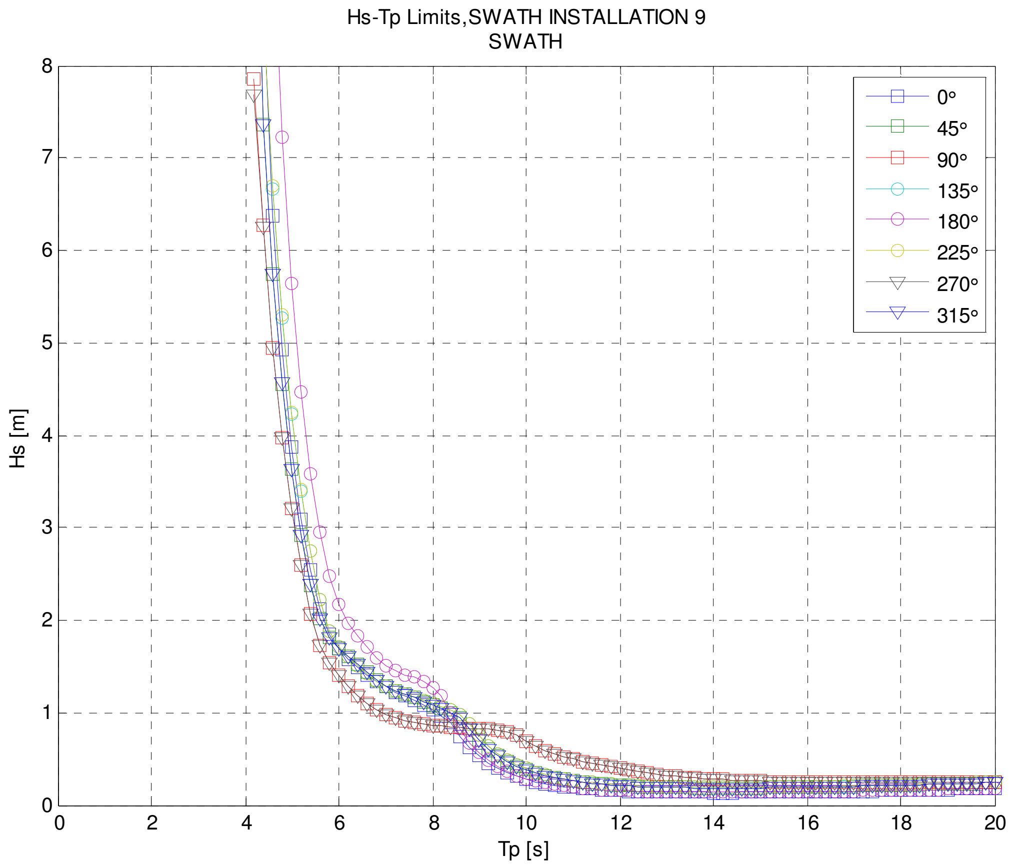

Hs-Tp Limits, SWATH INSTALLATION 9
SWATH, heading = 225°
Hs [m]
Tp [s]
Roll 1 deg
Pitch 1 deg
Nacelle x acc 4.905m/s2
Nacelle y acc 4.905m/s2
Nacelle z acc 0.39m/s2
CT-X Displacement 1.3m
CT-Y Displacement 1.3m
CT-Z Displacement 1.0m
Vertical speed 0.63m/s

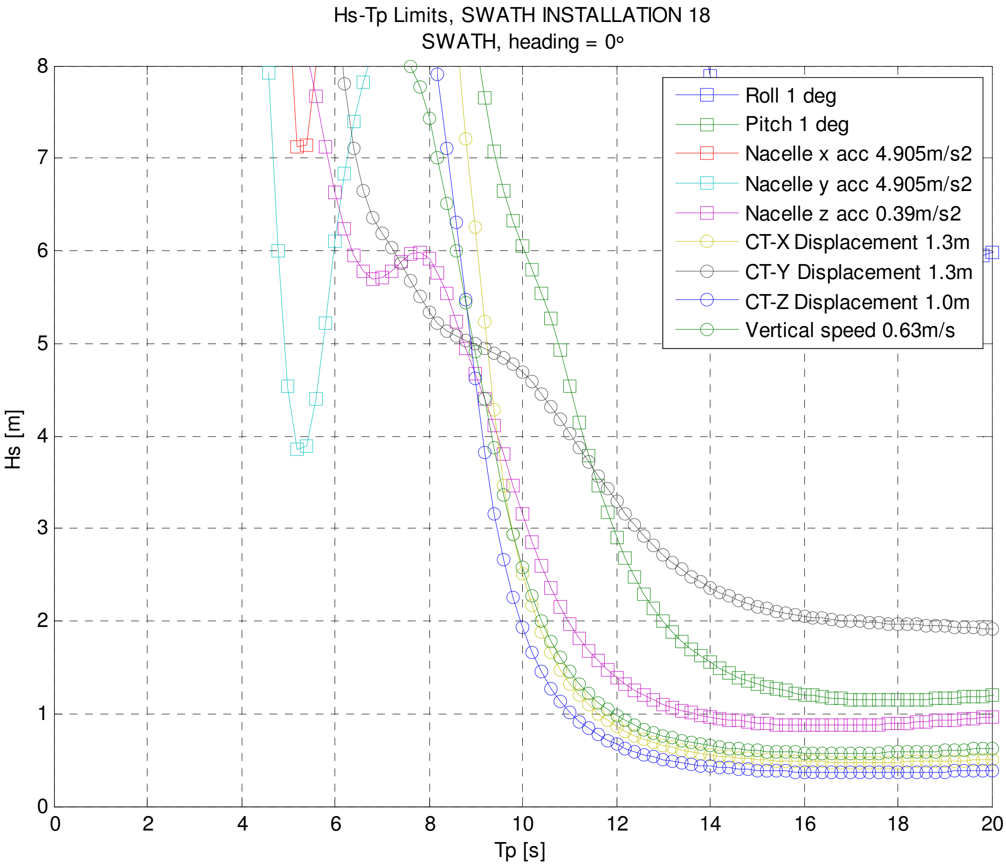


Hs-Tp Limits, SWATH INSTALLATION 9
SWATH, heading = 270°
Roll 1 deg
Pitch 1 deg
Nacelle x acc 4.905m/s2
Nacelle y acc 4.905m/s2
Nacelle z acc 0.39m/s2
CT-X Displacement 1.3m
CT-Y Displacement 1.3m
CT-Z Displacement 1.0m
Vertical speed 0.63m/s
Hs [m]
Tp [s]

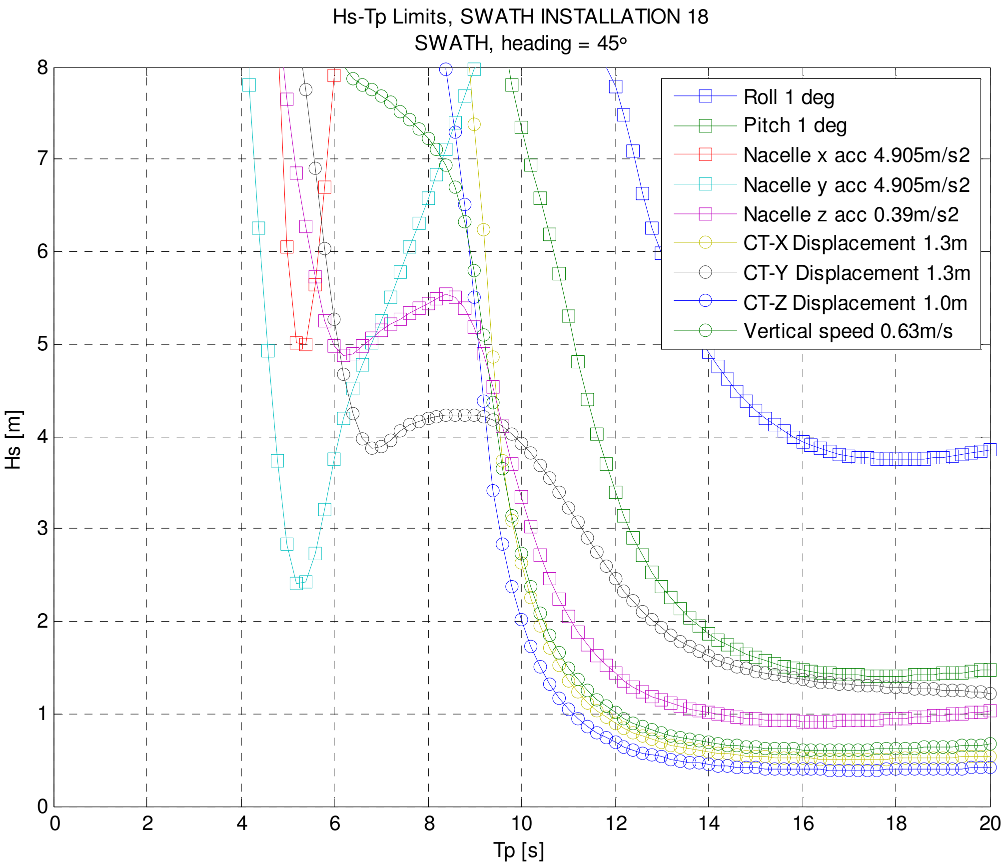


Hs-Tp Limits, SWATH INSTALLATION 9
SWATH, heading = 315°
Roll 1 deg
Pitch 1 deg
Nacelle x acc 4.905m/s2
Nacelle y acc 4.905m/s2
Nacelle z acc 0.39m/s2
CT-X Displacement 1.3m
CT-Y Displacement 1.3m
CT-Z Displacement 1.0m
Vertical speed 0.63m/s
Hs [m]
Tp [s]

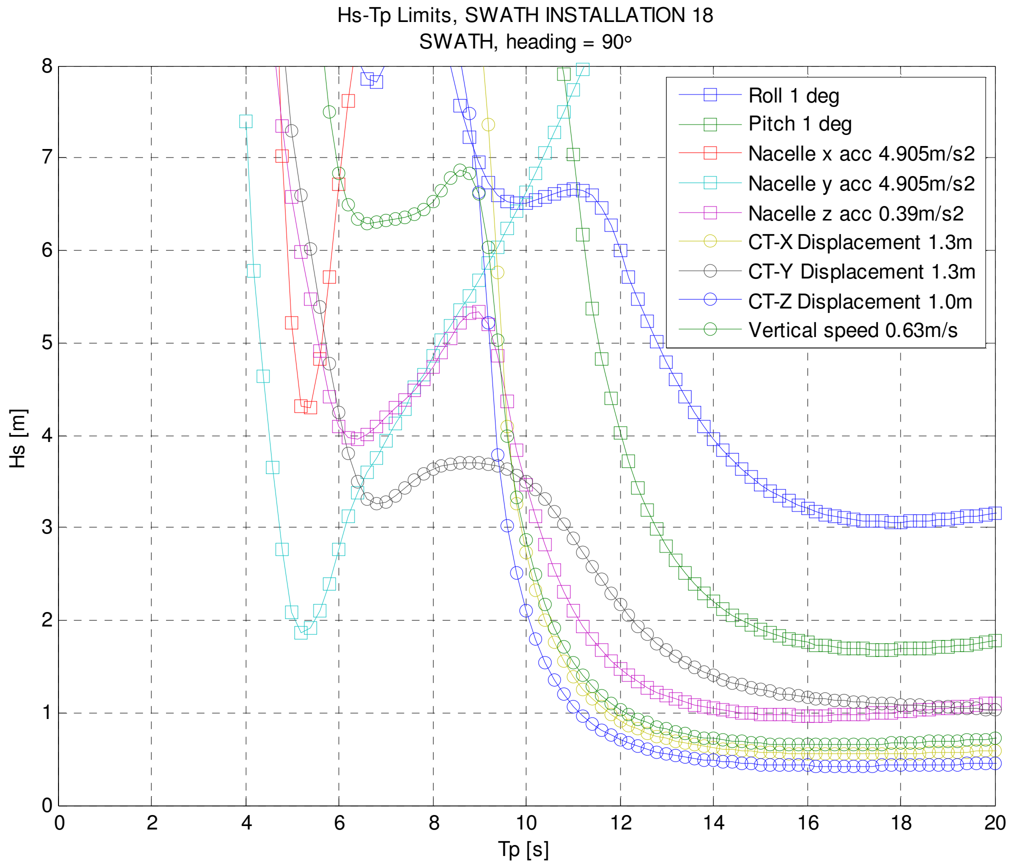

Hs-Tp Limits,SWATH INSTALLATION 9
SWATH
Hs [m]
Tp [s]
0°
45°
90°
135°
180°
225°
270°
315°
0
2
4
6
8
10
12
14
16
18
20
1
3
5
7

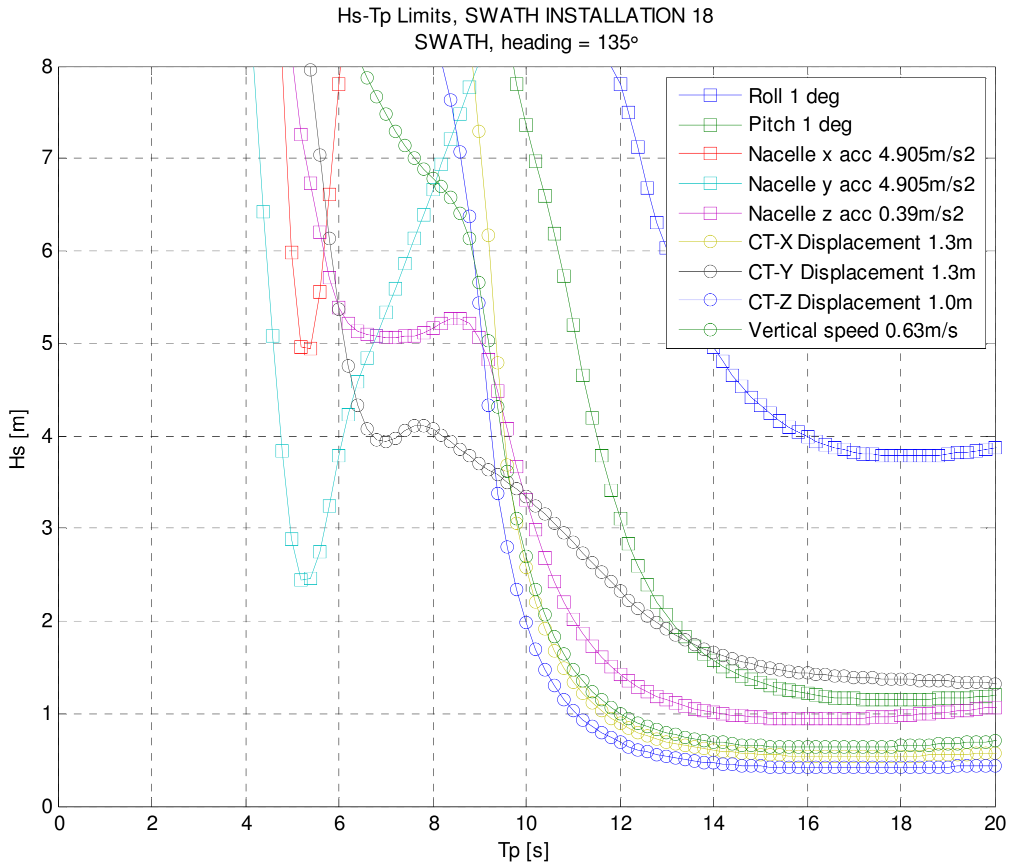


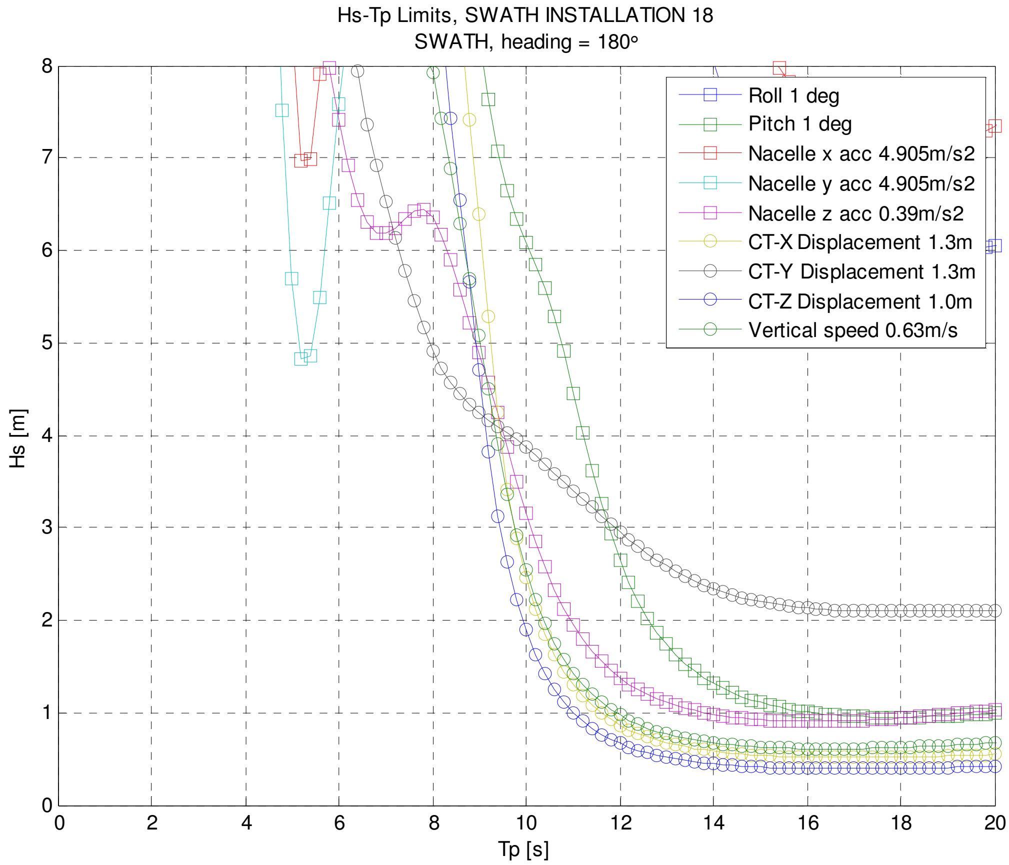
Hs-Tp Limits, SWATH INSTALLATION 18
SWATH, heading = 0°
Hs [m]
Tp [s]
0
2
4
6
8
10
12
14
16
18
20
1
2
3
4
5
6
7
8
Roll 1 deg
Pitch 1 deg
Nacelle x acc 4.905m/s2
Nacelle y acc 4.905m/s2
Nacelle z acc 0.39m/s2
CT-X Displacement 1.3m
CT-Y Displacement 1.3m
CT-Z Displacement 1.0m
Vertical speed 0.63m/s



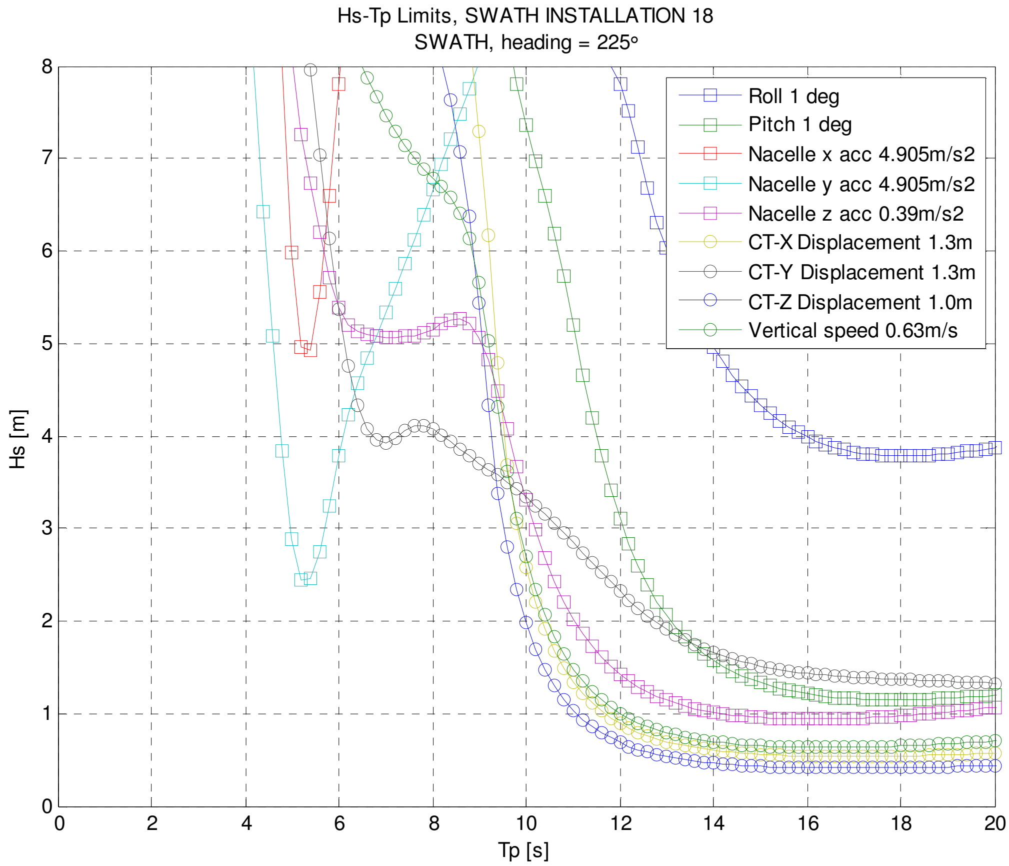
Hs-Tp Limits, SWATH INSTALLATION 18
SWATH, heading = 45°
Hs [m]
Tp [s]
0
2
4
6
8
10
12
14
16
18
20
1
2
3
4
5
6
7
8
Roll 1 deg
Pitch 1 deg
Nacelle x acc 4.905m/s2
Nacelle y acc 4.905m/s2
Nacelle z acc 0.39m/s2
CT-X Displacement 1.3m
CT-Y Displacement 1.3m
CT-Z Displacement 1.0m
Vertical speed 0.63m/s


Hs-Tp Limits, SWATH INSTALLATION 18
SWATH, heading = 90°
Hs [m]
Tp [s]
Roll 1 deg
Pitch 1 deg
Nacelle x acc 4.905m/s2
Nacelle y acc 4.905m/s2
Nacelle z acc 0.39m/s2
CT-X Displacement 1.3m
CT-Y Displacement 1.3m
CT-Z Displacement 1.0m
Vertical speed 0.63m/s

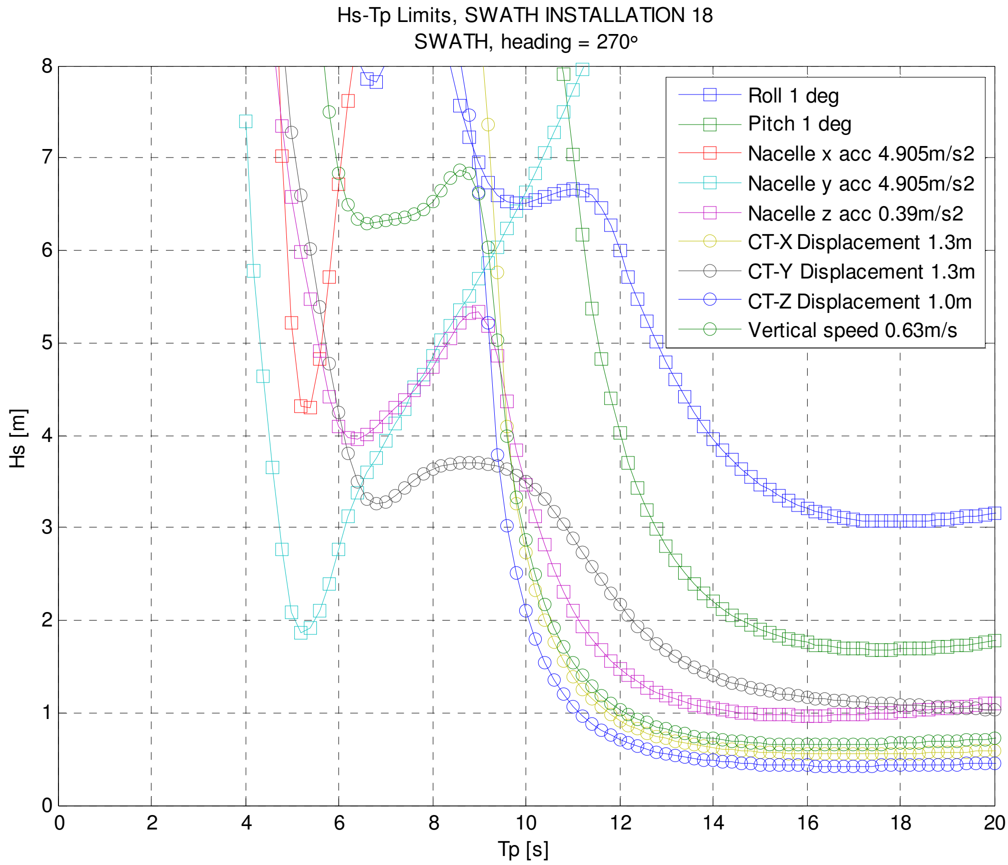

Hs-Tp Limits, SWATH INSTALLATION 18
SWATH, heading = 135°
Hs [m]
Tp [s]
Roll 1 deg
Pitch 1 deg
Nacelle x acc 4.905m/s2
Nacelle y acc 4.905m/s2
Nacelle z acc 0.39m/s2
CT-X Displacement 1.3m
CT-Y Displacement 1.3m
CT-Z Displacement 1.0m
Vertical speed 0.63m/s

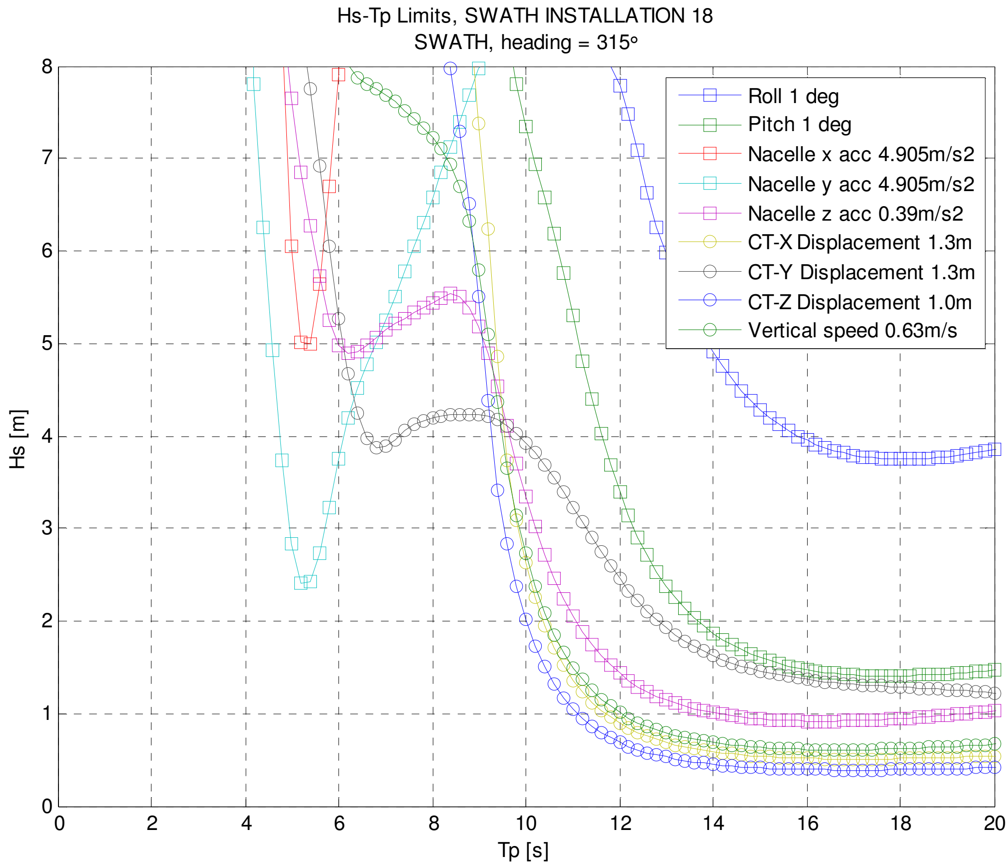


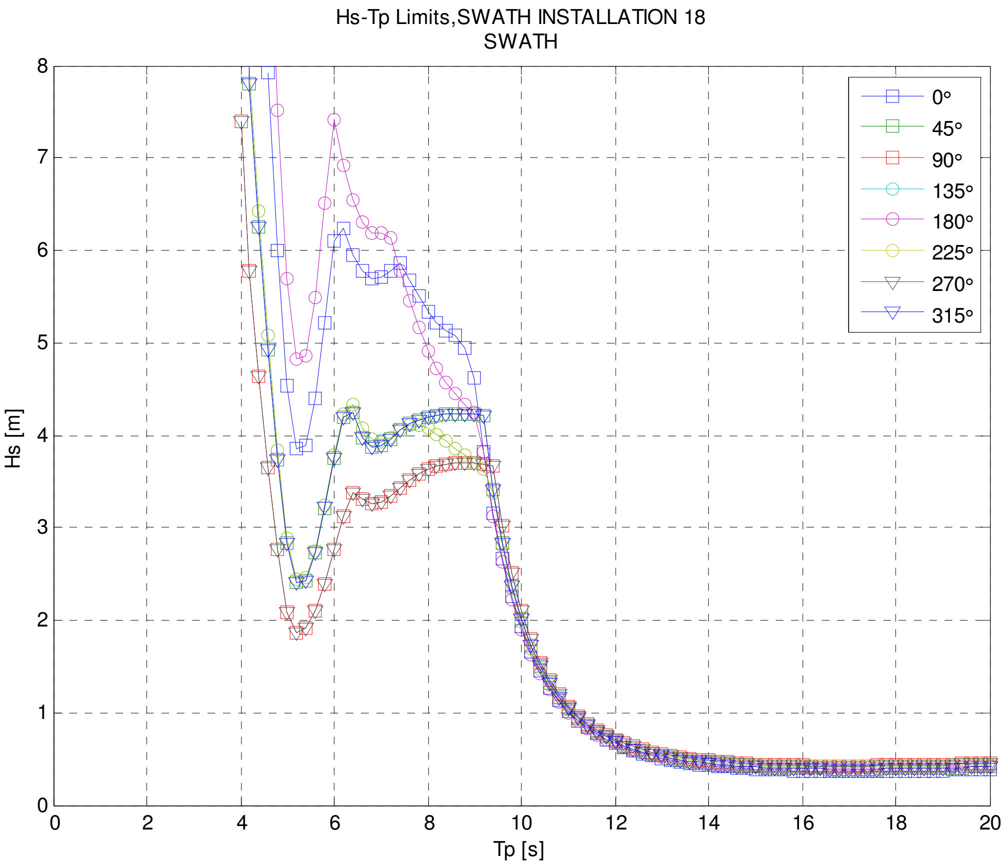
Hs-Tp Limits, SWATH INSTALLATION 18
SWATH, heading = 180°
Hs [m]
Tp [s]
0
2
4
6
8
10
12
14
16
18
20
0
1
2
3
4
5
6
7
8
Roll 1 deg
Pitch 1 deg
Nacelle x acc 4.905m/s2
Nacelle y acc 4.905m/s2
Nacelle z acc 0.39m/s2
CT-X Displacement 1.3m
CT-Y Displacement 1.3m
CT-Z Displacement 1.0m
Vertical speed 0.63m/s



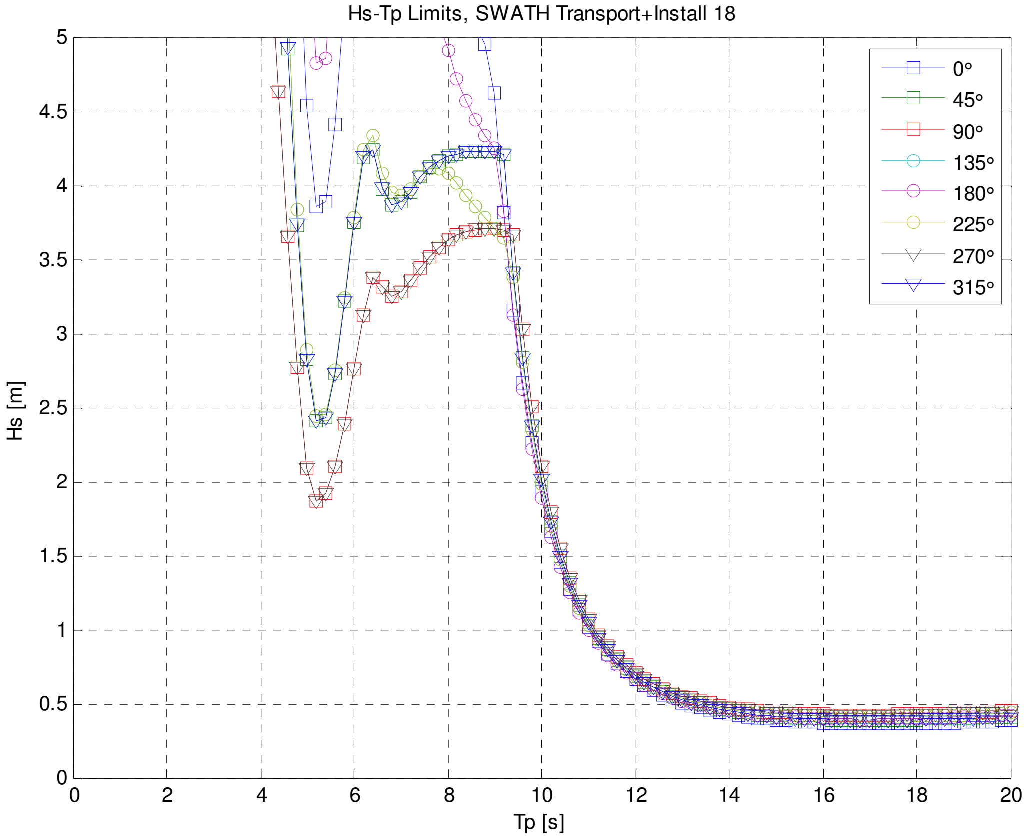
Hs-Tp Limits, SWATH INSTALLATION 18
SWATH, heading = 225°
Hs [m]
Tp [s]
0
2
4
6
8
10
12
14
16
18
20
0
1
2
3
4
5
6
7
8
Roll 1 deg
Pitch 1 deg
Nacelle x acc 4.905m/s2
Nacelle y acc 4.905m/s2
Nacelle z acc 0.39m/s2
CT-X Displacement 1.3m
CT-Y Displacement 1.3m
CT-Z Displacement 1.0m
Vertical speed 0.63m/s


Hs-Tp Limits, SWATH INSTALLATION 18
SWATH, heading = 270°
Roll 1 deg
Pitch 1 deg
Nacelle x acc 4.905m/s2
Nacelle y acc 4.905m/s2
Nacelle z acc 0.39m/s2
CT-X Displacement 1.3m
CT-Y Displacement 1.3m
CT-Z Displacement 1.0m
Vertical speed 0.63m/s
Hs [m]
Tp [s]

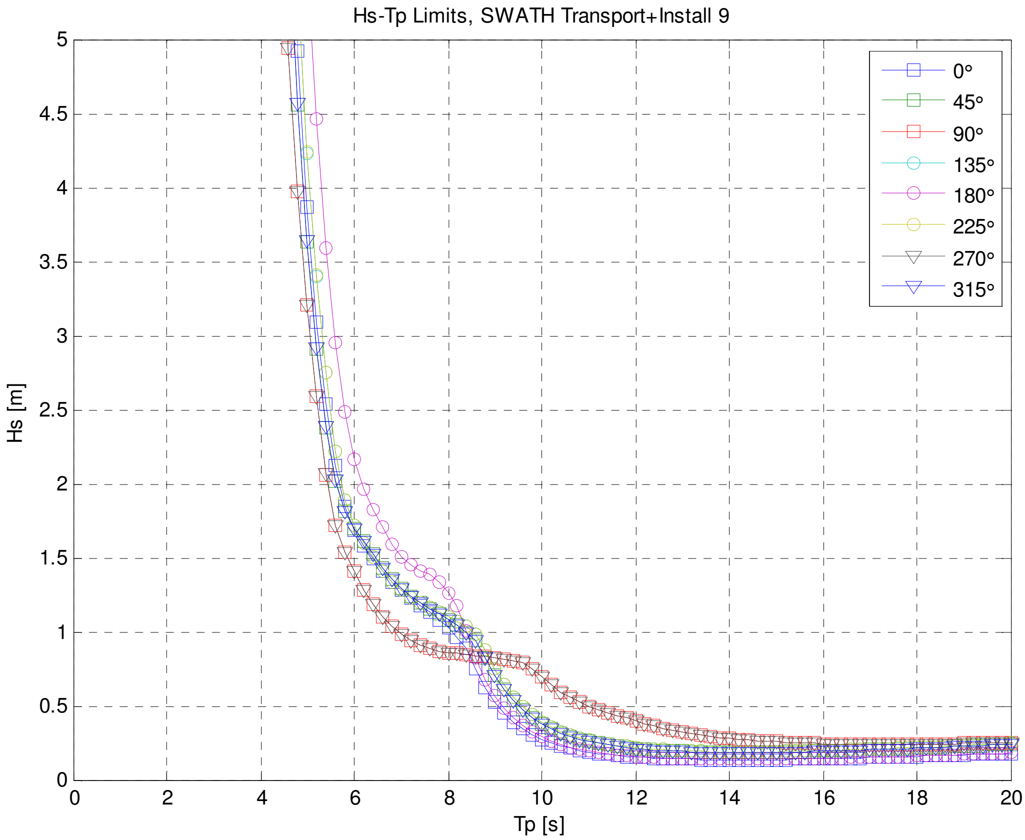

Hs-Tp Limits, SWATH INSTALLATION 18
SWATH, heading = 315°
Roll 1 deg
Pitch 1 deg
Nacelle x acc 4.905m/s2
Nacelle y acc 4.905m/s2
Nacelle z acc 0.39m/s2
CT-X Displacement 1.3m
CT-Y Displacement 1.3m
CT-Z Displacement 1.0m
Vertical speed 0.63m/s
Hs [m]
Tp [s]



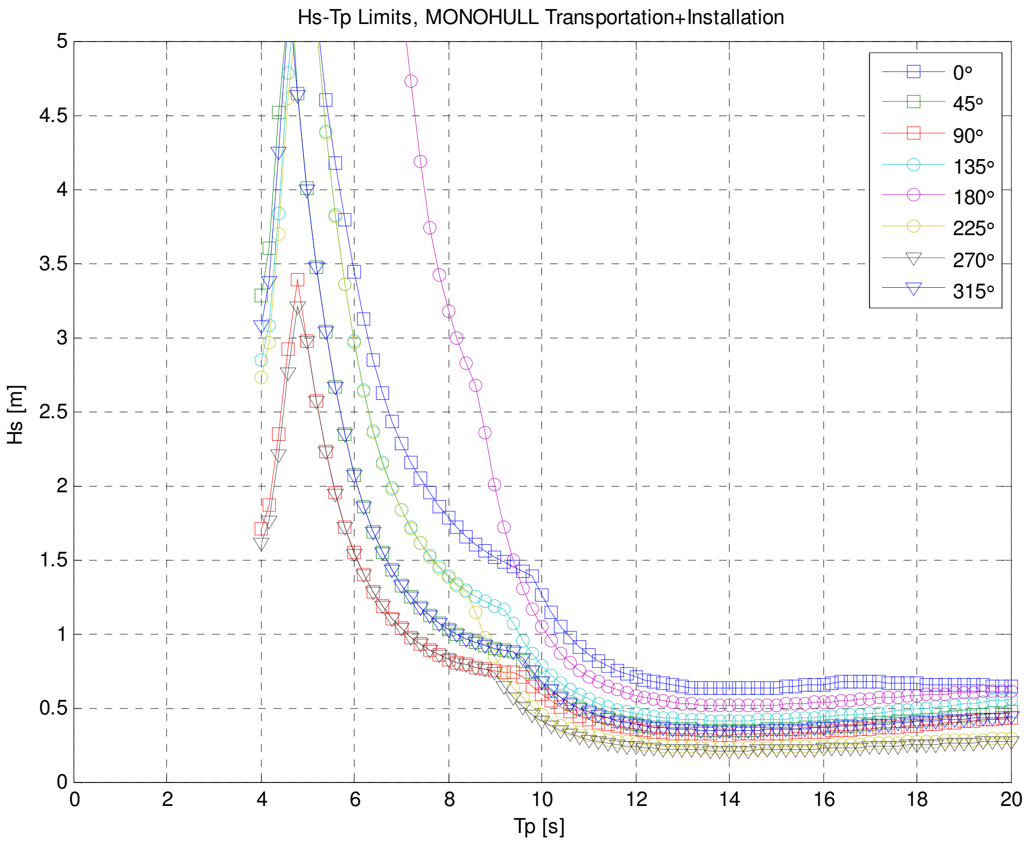
Hs-Tp Limits,SWATH INSTALLATION 18
SWATH
Hs [m]
Tp [s]
0°
45°
90°
135°
180°
225°
270°
315°



Hs-Tp Limits, SWATH Transport+Install 18
Hs [m]
Tp [s]
0°
45°
90°
135°
180°
225°
270°
315°



Hs-Tp Limits, SWATH Transport+Install 9
Hs [m]
Tp [s]
0°
45°
90°
135°
180°
225°
270°
315°


Hs-Tp Limits, MONOHULL Transportation+Installation
Hs [m]
Tp [s]
0°
45°
90°
135°
180°
225°
270°
315°
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
2
4
6
8
10
12
14
16
18
20

DSO PROJECT WORKABILITY MONOHULL
Period of analysis 2000-2010
Workability [%]

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Heading												
0	35.8	45.0	52.6	77.6	88.7	91.2	93.9	90.6	73.6	57.1	42.3	46.0
5	32.5	40.6	50.5	73.6	87.8	91.2	93.4	90.1	72.6	53.8	37.2	42.4
10	27.7	33.5	46.0	69.5	85.6	91.0	92.4	88.6	70.6	51.0	32.9	36.8
15	25.1	29.9	43.4	66.6	82.1	89.8	91.6	86.3	69.5	46.4	28.5	31.5
20	22.3	27.4	39.8	63.2	80.5	89.1	89.7	85.4	64.1	44.4	26.1	29.9
25	19.3	22.3	34.5	59.3	76.7	86.9	89.1	84.8	63.2	39.6	23.4	25.9
30	18.0	19.1	31.5	58.6	74.4	84.9	88.1	82.5	60.3	36.0	22.3	22.1
35	16.0	17.8	30.0	53.5	71.6	83.5	87.4	81.3	59.0	35.0	19.3	20.6
40	15.0	15.6	27.5	50.6	69.1	83.5	87.3	80.3	55.9	33.3	17.9	19.3
45	12.0	13.8	25.9	49.3	67.3	82.3	85.9	78.0	54.4	31.0	15.5	19.3
50	11.7	13.1	24.6	48.6	66.1	79.3	85.0	76.5	52.3	30.7	14.8	18.3
55	11.4	13.5	23.3	47.9	66.1	77.9	84.6	76.2	51.8	30.5	14.5	18.5
60	11.1	14.5	23.6	48.4	65.2	76.0	84.1	75.4	50.8	30.4	13.8	18.8
65	11.7	14.5	24.6	49.1	64.7	75.0	83.8	75.2	51.3	30.7	14.5	19.3
70	11.9	15.8	24.7	48.9	63.5	73.3	82.3	74.2	51.3	30.5	16.5	19.8
75	12.9	16.5	26.4	50.3	63.2	71.4	82.1	73.6	53.4	30.2	17.2	21.4
80	13.5	18.0	27.9	51.1	63.2	71.1	80.0	73.7	54.0	31.5	17.6	21.4
85	14.2	18.0	29.2	52.2	63.2	70.9	80.3	73.9	53.4	31.8	18.6	22.1
90	15.2	18.0	30.2	53.5	62.2	69.5	80.0	73.7	54.2	32.2	18.8	23.6
95	16.5	20.9	31.0	54.4	63.7	70.1	80.0	75.1	55.7	32.5	20.5	24.4
100	16.2	21.4	31.3	52.7	62.5	70.1	78.4	73.7	55.7	33.8	19.8	24.7
105	17.2	21.1	31.0	52.8	64.3	70.1	77.9	73.9	57.1	34.6	19.8	25.7
110	19.5	21.8	32.5	53.5	65.0	70.1	77.9	73.6	58.1	35.0	19.1	27.1
115	20.8	23.3	34.3	53.7	66.6	71.4	79.5	75.4	60.3	36.1	19.9	28.2
120	22.6	26.5	35.3	56.8	68.0	74.5	81.0	77.9	60.9	36.8	20.8	29.5
125	25.2	28.7	37.9	59.3	70.6	75.2	83.6	79.2	63.8	41.1	22.5	31.5
130	26.2	32.3	38.6	60.7	73.6	77.7	86.1	81.3	64.3	43.5	25.7	33.3
135	27.7	34.1	41.6	63.1	78.0	81.6	87.4	82.8	65.1	44.0	27.3	35.1
140	29.2	36.8	45.2	64.6	81.2	84.2	89.2	84.1	66.0	47.5	30.0	35.5
145	31.3	39.7	46.0	69.4	82.1	86.6	90.4	85.3	67.3	49.5	32.0	36.8
150	32.3	41.1	47.5	72.8	85.0	87.4	90.7	86.1	68.0	51.8	33.4	40.6
155	34.3	43.1	49.8	74.1	86.6	87.8	91.6	86.6	67.8	54.9	37.0	43.4
160	34.3	44.4	52.0	75.2	87.4	89.1	92.0	87.4	69.5	56.3	38.7	44.4
165	35.0	47.3	52.6	75.2	88.1	89.7	92.0	87.6	71.3	57.9	39.4	46.8
170	36.3	47.3	53.9	77.2	88.6	90.2	92.9	87.9	71.8	58.4	40.1	45.5
175	37.3	46.7	53.9	76.5	88.7	89.5	92.4	87.4	71.4	58.2	41.3	46.2
180	37.3	45.8	52.6	75.7	88.9	89.5	92.4	87.4	71.8	57.7	41.1	45.5
185	37.4	43.6	51.3	74.3	88.9	88.6	91.4	86.9	71.8	55.9	40.6	44.4
190	34.0	42.2	49.8	71.1	87.3	88.3	90.1	87.1	71.4	53.8	38.9	44.4
195	31.0	39.6	46.8	71.1	85.4	87.3	89.9	86.1	71.1	50.8	37.2	40.6
200	27.9	32.6	44.4	67.0	84.6	86.1	88.9	85.1	69.5	50.1	35.3	36.5
205	25.2	29.3	41.1	63.8	82.5	85.6	88.4	84.0	68.0	47.2	33.2	32.8
210	22.3	28.0	38.9	63.4	79.7	84.4	87.8	82.6	65.1	43.4	29.5	29.2
215	20.3	24.8	36.5	60.7	76.4	82.3	87.1	82.0	63.1	41.2	27.4	27.9
220	19.6	25.2	33.8	57.4	73.2	79.8	85.9	80.7	62.7	39.6	25.7	25.6
225	18.6	23.4	31.3	53.9	71.6	79.8	85.4	79.0	61.9	38.4	25.4	24.9
230	18.3	22.6	31.0	53.9	68.5	78.1	84.3	77.9	61.2	37.3	24.0	24.2
235	18.1	23.0	31.5	54.4	67.0	75.2	82.6	76.5	59.1	36.5	23.9	24.9
240	18.1	22.6	32.5	54.4	65.5	73.1	81.5	76.0	58.1	36.1	24.2	27.2
245	21.4	22.3	32.8	55.2	65.5	71.9	81.0	76.2	58.1	36.1	23.9	27.5
250	20.3	22.7	33.8	54.9	64.0	70.9	79.2	75.4	57.3	35.6	22.5	29.0
255	19.6	24.5	34.1	54.5	63.7	71.8	79.2	75.1	59.1	35.5	23.4	29.7
260	19.6	23.4	33.8	54.2	62.7	70.4	78.4	74.1	58.1	35.0	22.3	28.4
265	20.1	21.9	33.2	54.5	63.0	70.7	78.7	75.1	58.5	36.3	22.3	27.1
270	19.8	22.3	32.3	55.4	64.0	71.6	79.7	75.9	58.5	36.6	22.0	26.1
275	19.8	23.4	33.3	56.4	65.0	74.1	82.8	77.5	59.8	37.4	21.6	26.4
280	20.1	23.8	35.0	56.3	65.7	74.3	83.0	78.7	61.0	38.3	22.0	26.4
285	21.4	24.5	35.3	57.3	66.5	75.0	84.3	81.3	61.9	38.4	21.6	26.4
290	21.8	24.0	34.8	57.1	67.0	76.4	85.6	82.0	61.7	39.1	22.0	26.6
295	21.1	25.4	36.5	59.0	69.3	77.9	86.3	82.1	62.6	40.6	21.6	27.9
300	23.8	27.2	37.8	59.8	71.4	78.8	87.1	82.8	64.1	41.4	23.5	29.2
305	26.1	29.9	39.1	61.0	73.2	82.8	88.7	84.3	66.0	44.4	25.2	31.5
310	27.2	34.3	42.4	62.7	77.0	85.2	90.1	86.1	66.6	47.7	25.9	34.3

315	30.5	38.6	44.7	65.3	80.2	87.3	91.1	87.6	68.0	49.2	29.0	36.6
320	31.8	40.2	47.5	68.4	84.5	88.8	92.5	88.4	69.5	50.6	32.4	38.1
325	31.8	42.9	49.8	73.3	86.9	90.0	93.0	89.6	70.6	53.1	34.6	40.4
330	33.5	46.2	51.0	74.7	89.1	90.9	93.0	90.9	71.8	55.3	37.2	43.7
335	36.1	48.0	53.6	78.8	89.4	91.9	93.7	91.2	73.3	57.2	39.7	45.0
340	37.0	49.5	55.4	79.6	89.4	92.2	94.0	91.2	73.6	59.2	42.3	47.3
345	38.6	51.1	56.4	79.9	89.9	92.2	94.5	91.4	74.5	59.4	45.0	48.7
350	39.1	50.9	56.1	79.6	89.2	92.2	94.2	91.1	74.1	60.0	44.7	49.0
355	38.4	49.1	54.8	78.9	88.6	91.7	94.4	90.4	73.8	60.0	44.7	48.8
max	39.1	51.1	56.4	79.9	89.9	92.2	94.5	91.4	74.5	60.0	45.0	49.0

Workability at most favorable headings [%]:

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	34	31	49	75	96	96	96	98	81	62	68	40
2001	76	56	65	84	96	96	94	96	64	62	45	60
2002	56	20	62	77	94	86	100	98	96	49	66	44
2003	36	80	76	71	94	96	96	98	88	69	75	45
2004	40	47	78	83	94	92	98	78	62	58	54	51
2005	25	44	51	77	89	99	94	93	83	76	41	58
2006	71	56	47	83	80	94	100	98	86	69	34	51
2007	11	48	47	86	89	92	94	93	66	89	32	51
2008	33	47	29	83	94	90	93	98	84	49	36	58
2009	44	84	76	96	91	98	93	89	84	74	43	62
2010	44	70	82	90	96	94	96	94	58	58	47	51
max	76	84	82	96	96	99	100	98	96	89	75	62
mean	43	53	60	82	92	94	96	94	77	65	49	52
min	11	20	29	71	80	86	93	78	58	49	32	40

DSO PROJECT WORKABILITY - SWATH T9
Period of analysis 2000-2010
Workability [%]

Month Heading	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	4.9	9.1	13.9	36.8	53.4	72.6	82.3	71.4	39.0	21.3	9.2	10.6
5	4.9	9.5	14.8	38.5	55.4	73.3	82.5	71.1	40.2	22.9	9.5	11.5
10	5.3	9.8	15.8	39.9	57.1	73.0	82.5	72.1	41.9	23.9	10.9	12.7
15	6.9	10.2	17.2	40.9	58.6	73.8	83.3	72.6	43.6	25.6	11.9	13.7
20	7.9	11.3	18.5	42.3	60.0	74.3	84.0	73.4	45.0	26.2	12.6	14.7
25	9.2	12.4	20.1	44.0	60.4	74.1	84.0	73.9	47.7	27.1	14.0	15.3
30	10.7	14.5	22.1	47.0	61.7	75.5	84.0	75.7	50.5	27.4	15.0	16.0
35	11.5	15.9	24.7	50.1	63.7	76.5	83.6	75.4	52.8	28.5	15.7	17.0
40	13.4	17.8	26.7	51.5	64.2	77.2	83.8	75.7	54.2	29.0	15.3	19.6
45	14.4	18.1	27.7	52.8	65.3	78.1	83.6	75.1	56.6	28.9	16.0	20.9
50	14.0	18.1	27.7	52.8	65.2	76.9	83.1	75.2	57.3	30.4	16.7	20.6
55	14.0	18.5	28.5	52.5	64.5	75.2	82.3	72.9	56.6	30.7	15.7	21.6
60	12.7	17.0	28.9	53.2	63.3	73.1	80.8	73.1	55.4	30.7	16.0	20.1
65	12.7	16.3	27.9	51.1	61.2	71.1	79.8	72.3	54.4	31.3	16.0	20.8
70	11.7	16.7	26.9	51.5	60.7	69.0	78.5	71.1	53.7	30.2	16.0	21.4
75	11.7	16.7	26.6	51.5	59.2	68.5	77.5	71.4	53.0	29.5	16.0	21.4
80	12.0	16.7	25.9	50.8	57.6	67.2	76.4	69.1	51.1	29.4	16.0	21.1
85	11.7	16.3	25.9	50.5	56.7	67.5	75.5	69.0	51.5	28.4	16.0	21.1
90	11.7	16.3	26.6	50.5	56.7	67.3	75.4	68.6	52.0	28.4	15.7	20.9
95	12.0	16.3	25.9	50.8	58.1	67.7	76.0	69.6	51.6	29.2	14.7	20.6
100	12.0	16.0	26.7	50.5	58.1	68.4	76.4	70.1	52.0	29.5	14.7	20.6
105	11.4	14.9	26.4	49.4	59.4	69.7	78.4	71.8	51.0	28.4	14.7	19.0
110	10.1	13.8	25.2	48.4	58.7	70.6	79.3	72.7	50.3	27.4	13.6	17.7
115	9.6	12.7	24.6	46.4	59.9	70.1	81.2	73.7	49.6	26.2	14.0	16.0
120	8.9	11.6	21.6	44.3	60.9	73.6	82.8	74.6	47.9	25.7	11.9	14.7
125	7.3	10.9	19.3	42.1	62.5	75.0	84.0	74.2	46.7	26.1	11.3	13.7
130	6.9	9.1	17.7	42.1	61.4	76.5	84.3	74.2	44.5	24.6	10.6	11.1
135	6.6	8.7	16.7	40.9	58.9	75.5	83.6	73.2	43.1	22.9	10.2	10.6
140	6.6	8.4	15.2	39.5	56.9	75.5	82.3	72.6	41.1	22.6	9.5	9.6
145	5.3	8.0	14.5	38.5	56.9	74.3	81.7	71.6	39.5	21.3	9.2	9.6
150	4.9	8.0	14.2	37.5	55.1	73.0	80.8	69.9	38.9	19.6	8.9	8.9
155	4.3	8.0	13.5	36.8	54.4	72.1	80.2	68.8	38.2	19.3	7.8	8.9
160	4.0	7.6	13.2	34.1	53.4	71.4	80.5	67.8	37.5	19.6	7.8	9.2
165	4.0	8.0	12.9	33.8	52.8	70.1	80.7	67.5	37.2	19.5	8.2	9.6
170	4.0	8.7	12.9	34.4	52.1	69.2	80.0	67.1	38.0	19.8	9.5	9.6
175	4.0	8.7	13.2	34.8	51.5	68.7	79.7	68.5	38.9	20.3	9.5	9.9
180	4.3	9.1	13.9	35.1	51.5	69.4	79.2	69.8	38.9	20.3	9.5	9.9
185	4.6	9.5	14.2	35.8	53.1	69.7	80.0	70.1	39.9	22.1	10.2	10.6
190	5.3	9.8	14.5	37.8	54.1	70.6	80.7	70.6	40.9	23.8	10.6	10.9
195	6.3	10.2	16.8	39.5	56.1	70.6	82.3	71.3	43.0	24.4	10.6	13.4
200	6.6	10.9	17.5	42.3	57.2	71.4	82.8	72.7	44.5	25.1	12.3	14.4
205	8.9	12.4	19.5	44.0	58.9	73.3	83.3	73.7	46.2	26.9	13.3	14.7
210	10.2	13.8	21.4	46.0	61.5	74.5	83.8	74.1	50.1	27.5	14.7	15.7
215	11.5	16.3	23.8	47.7	63.2	76.2	83.8	75.7	52.0	29.4	15.0	16.7
220	13.5	17.4	25.4	49.8	64.8	76.9	83.8	76.2	52.3	29.4	14.7	18.6
225	14.0	17.4	25.4	51.1	66.1	78.1	83.8	74.9	53.2	29.7	15.3	20.1
230	14.0	18.1	27.2	52.7	66.0	77.9	83.5	75.1	54.9	30.4	14.7	19.5
235	13.4	17.4	27.5	52.0	66.8	76.9	83.0	75.1	55.6	31.2	15.0	20.0
240	13.0	16.3	27.9	52.5	64.5	75.3	81.8	74.1	54.9	30.2	14.0	20.0
245	12.7	16.3	27.5	52.5	63.5	73.6	80.8	72.6	54.5	30.7	14.0	20.0
250	12.0	16.7	26.6	51.1	60.2	71.4	79.5	72.6	54.2	29.2	15.3	19.6
255	11.1	15.9	25.2	50.8	59.7	69.0	79.2	70.9	53.9	29.5	16.0	19.6
260	11.1	16.3	24.9	50.1	57.9	68.5	77.5	70.3	51.1	29.7	16.0	20.0
265	11.4	16.0	24.9	49.8	58.2	68.2	76.0	69.1	50.8	28.9	15.9	20.3
270	11.7	16.7	25.2	50.1	58.2	68.2	75.2	69.9	50.8	28.7	16.4	21.3
275	12.0	17.4	26.2	50.1	57.9	68.2	76.2	70.1	50.6	28.7	16.2	21.9
280	11.7	16.3	26.2	49.1	57.7	67.8	76.4	70.3	50.3	27.9	15.5	20.3
285	10.7	16.7	25.1	48.8	59.1	68.2	76.4	71.3	50.3	28.0	15.3	19.0
290	9.4	13.8	24.1	48.4	58.4	68.5	78.2	71.9	49.9	26.7	15.0	18.0
295	8.1	13.1	23.1	46.7	59.1	70.2	80.2	72.7	48.9	26.4	14.3	16.0
300	7.9	12.4	22.8	45.3	59.7	72.4	82.0	75.1	49.9	26.6	12.6	15.0
305	7.6	11.3	20.8	43.5	62.2	75.5	83.8	74.9	47.4	25.4	11.6	14.0
310	7.3	9.8	18.1	42.8	61.9	76.4	84.3	75.5	45.9	24.9	11.3	12.7

315	6.6	8.7	17.3	41.3	60.4	77.0	84.8	74.9	43.3	22.6	9.9	11.1
320	6.6	8.7	15.7	40.2	59.2	76.5	84.3	73.9	42.3	22.9	9.2	10.2
325	6.3	8.4	14.8	39.5	56.3	76.9	83.6	73.2	40.7	22.8	8.5	9.9
330	5.3	8.0	14.5	38.2	55.9	76.7	83.6	72.9	38.5	21.1	8.5	9.9
335	4.6	8.0	14.2	37.5	55.6	74.7	83.1	72.4	38.2	20.1	8.2	8.9
340	4.6	8.0	14.2	37.5	54.9	74.1	82.8	71.3	37.5	19.5	8.5	9.2
345	4.3	8.0	13.5	37.2	55.6	73.5	81.5	70.8	37.5	20.1	8.2	9.6
350	4.3	8.7	13.5	35.8	53.9	72.8	81.8	69.9	37.3	20.5	8.9	11.2
355	4.3	9.1	13.5	36.1	53.8	72.8	82.1	71.6	38.7	20.9	9.2	10.9
max	14.4	18.5	28.9	53.2	66.8	78.1	84.8	76.2	57.3	31.3	16.7	21.9

Workability at most favorable headings [%]:

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	7	8	18	30	80	64	83	94	60	36	23	15
2001	40	16	47	53	80	86	82	89	49	40	11	44
2002	18	0	33	62	65	77	94	89	79	25	39	25
2003	11	36	40	56	65	90	85	73	71	34	41	24
2004	15	31	49	56	73	75	93	60	38	31	19	4
2005	4	12	29	71	49	88	80	73	62	33	23	29
2006	34	40	18	45	54	90	94	78	77	34	4	18
2007	0	20	33	62	67	84	85	71	36	58	8	25
2008	7	8	15	60	91	66	83	87	69	18	15	25
2009	7	24	36	75	67	88	83	80	62	36	24	29
2010	25	36	29	60	67	88	93	83	47	36	11	36
max	40	40	49	75	91	90	94	94	79	58	41	44
mean	15	21	32	57	69	81	87	80	59	35	20	25
min	0	0	15	30	49	64	80	60	36	18	4	4

DSO PROJECT WORKABILITY HLV OS
Period of analysis 2000-2010
Workability [%]

Month Heading	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	57.1	59.0	71.9	87.3	97.8	97.7	98.1	98.6	90.9	83.5	66.5	65.3
5	57.1	59.7	71.6	87.3	97.8	97.7	98.1	98.6	90.9	83.5	66.8	65.7
10	57.1	59.9	71.6	87.3	97.8	97.7	98.1	98.6	91.0	83.5	67.2	65.7
15	57.4	60.1	71.6	87.3	97.8	97.7	98.1	98.6	91.0	83.5	67.3	65.5
20	57.4	59.9	71.9	87.3	98.0	97.7	98.1	98.6	91.0	83.3	67.5	65.8
25	57.4	59.9	72.3	87.3	98.0	97.7	98.1	98.6	91.0	83.3	67.5	66.1
30	57.4	60.6	72.3	87.3	98.0	97.7	98.3	98.6	91.4	83.5	68.2	66.8
35	58.1	61.2	72.6	87.3	98.0	97.7	98.3	98.6	91.9	83.3	68.5	66.8
40	58.4	61.7	72.9	87.3	98.1	97.7	98.3	98.6	92.6	83.6	69.0	67.3
45	58.1	62.3	72.9	87.3	98.1	97.8	98.3	98.6	92.7	84.0	69.9	67.3
50	58.1	63.0	73.4	87.6	98.1	97.8	98.3	98.6	92.7	84.0	70.6	67.1
55	59.4	63.2	73.7	88.1	98.1	97.8	98.3	98.6	92.7	84.6	70.6	67.3
60	59.7	63.9	73.9	88.1	98.3	97.8	98.3	98.8	92.7	85.4	70.6	67.3
65	60.0	64.6	74.2	88.1	98.3	97.8	98.3	98.8	93.1	85.4	70.6	67.3
70	60.2	64.6	74.2	88.1	98.3	97.8	98.3	98.8	93.1	86.1	70.6	67.0
75	59.9	64.3	73.9	88.1	98.3	97.8	98.3	99.1	93.1	86.1	70.6	67.6
80	58.9	63.9	73.6	88.1	98.3	97.8	98.3	99.1	93.1	86.1	70.4	67.5
85	58.9	63.5	73.6	88.1	98.3	97.8	98.3	99.1	93.1	85.6	70.4	67.1
90	58.2	62.8	73.2	88.1	98.3	97.8	98.3	99.1	93.1	85.3	69.9	66.8
95	58.2	62.8	72.9	88.1	98.3	97.8	98.3	99.1	93.1	85.4	68.9	66.3
100	57.9	62.5	72.9	88.1	98.3	97.8	98.3	99.1	93.1	85.3	68.5	66.3
105	57.9	62.1	72.9	88.1	98.3	97.8	98.3	99.1	92.7	84.6	68.7	66.0
110	57.9	61.7	72.3	88.1	98.3	97.8	98.3	98.8	92.7	84.6	68.0	65.5
115	57.1	61.7	71.8	87.8	98.1	97.8	98.3	98.8	92.4	84.8	67.2	65.3
120	57.1	60.1	72.1	87.8	98.1	97.8	98.1	98.8	91.7	83.5	67.2	65.0
125	56.4	59.0	72.1	87.6	98.1	97.8	98.1	98.8	91.2	83.6	66.6	64.5
130	56.1	59.4	72.1	87.6	98.1	97.8	98.1	98.6	91.2	83.3	66.8	64.8
135	55.4	58.4	71.9	87.6	98.1	97.8	98.1	98.6	91.2	83.3	66.5	64.5
140	55.1	58.4	71.6	87.6	98.0	97.8	98.1	98.6	91.2	83.3	66.5	64.5
145	55.1	58.1	71.4	87.6	98.0	97.8	98.1	98.6	91.2	83.0	65.8	64.2
150	54.8	57.4	71.1	87.6	98.0	97.7	98.1	98.6	91.2	83.0	65.8	64.2
155	54.4	57.4	71.1	87.6	98.0	97.7	98.1	98.6	91.2	83.0	65.5	64.2
160	54.4	57.4	71.1	87.6	98.0	97.7	98.1	98.6	91.2	83.1	65.1	64.2
165	54.4	57.7	70.8	87.6	98.0	97.7	98.1	98.6	90.9	83.1	65.5	64.2
170	54.8	57.7	70.4	87.3	97.8	97.7	98.1	98.6	91.0	83.1	65.5	64.2
175	55.1	57.7	70.6	87.3	97.8	97.7	98.1	98.6	91.0	83.0	65.5	63.8
180	55.1	58.1	70.9	87.3	97.8	97.7	98.1	98.6	91.0	83.0	65.5	63.5
185	55.1	58.4	70.9	87.3	98.0	97.7	98.1	98.6	91.0	83.0	65.5	63.8
190	55.8	58.6	71.9	87.3	98.0	97.7	98.1	98.6	91.4	83.3	65.5	64.2
195	57.1	58.8	71.9	87.3	98.0	97.7	98.1	98.6	91.4	83.1	66.1	64.5
200	57.1	59.2	72.3	87.3	98.0	97.7	98.1	98.6	91.4	83.0	66.8	64.5
205	57.1	59.4	72.3	87.3	98.0	97.7	98.3	98.6	91.7	83.0	67.8	65.0
210	57.1	60.5	72.3	87.3	98.1	97.7	98.3	98.6	91.7	83.3	67.8	65.3
215	57.4	61.4	72.3	87.3	98.3	97.8	98.3	98.6	92.4	83.3	68.5	65.7
220	57.4	61.7	72.6	87.3	98.3	97.8	98.3	98.6	92.6	83.3	69.5	65.8
225	57.4	62.5	72.7	87.6	98.3	97.8	98.3	98.6	92.6	83.5	70.2	65.7
230	58.1	61.6	72.6	88.1	98.3	97.8	98.3	98.6	92.6	84.1	70.2	66.3
235	58.4	62.1	72.9	88.1	98.3	97.8	98.3	98.8	93.1	84.8	70.6	67.0
240	58.6	63.2	73.2	88.1	98.3	97.8	98.3	98.8	93.1	85.3	70.9	67.0
245	59.2	64.3	73.6	88.1	98.3	97.8	98.3	98.8	93.1	85.6	70.7	67.5
250	59.5	63.9	73.9	88.1	98.3	97.8	98.3	98.8	93.1	85.6	70.4	67.1
255	59.5	64.3	74.2	88.1	98.3	97.8	98.3	99.1	93.1	85.6	70.1	66.8
260	59.2	64.3	74.2	88.1	98.3	97.8	98.3	99.1	93.1	85.6	70.1	66.8
265	59.2	64.3	74.2	88.1	98.3	97.8	98.3	99.1	93.1	85.4	69.9	66.8
270	58.6	63.5	73.2	88.1	98.3	97.8	98.3	99.1	93.1	85.3	69.9	66.8
275	58.6	63.5	73.2	88.1	98.3	97.8	98.3	99.1	93.1	85.1	69.2	66.1
280	58.2	62.8	73.2	88.1	98.3	97.8	98.3	99.1	92.4	84.3	69.2	66.6
285	58.2	62.8	72.9	88.1	98.3	97.8	98.3	99.1	92.4	84.3	69.2	66.3
290	57.7	62.1	72.7	87.8	98.3	97.8	98.3	98.8	92.0	84.5	69.2	65.7
295	57.4	61.9	72.1	87.8	98.3	97.8	98.1	98.8	91.7	84.3	68.5	65.7
300	56.7	61.0	72.1	87.6	98.3	97.8	98.1	98.8	91.5	84.1	67.3	65.2
305	56.7	60.3	72.1	87.6	98.3	97.8	98.1	98.6	91.2	83.8	67.0	65.5
310	56.7	60.3	72.1	87.6	98.1	97.8	98.1	98.6	91.0	83.8	67.0	65.2

315	56.4	60.5	72.1	87.6	98.0	97.8	98.1	98.6	91.0	83.5	67.2	65.2
320	56.4	60.1	72.1	87.6	98.0	97.8	98.1	98.6	91.2	83.3	66.5	65.2
325	56.1	59.4	72.3	87.6	98.0	97.8	98.1	98.6	91.2	83.3	66.1	64.8
330	55.8	59.4	72.3	87.6	98.0	97.7	98.1	98.6	91.2	83.3	66.3	64.8
335	55.4	59.4	72.3	87.6	97.8	97.5	98.1	98.6	90.7	83.3	66.3	64.8
340	55.4	59.2	71.9	87.6	97.8	97.7	98.1	98.6	90.9	83.3	66.1	64.5
345	56.1	58.8	71.9	87.3	97.8	97.7	98.1	98.6	90.9	83.3	66.1	65.2
350	56.7	58.8	71.9	87.3	97.8	97.7	98.1	98.6	90.9	83.3	66.3	64.8
355	57.1	58.8	71.9	87.3	97.8	97.7	98.1	98.6	90.9	83.3	66.3	65.2
max	60.2	64.6	74.2	88.1	98.3	97.8	98.3	99.1	93.1	86.1	70.9	67.6

Workability at most favorable headings [%]:

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	42	50	51	68	98	98	98	100	96	94	90	73
2001	98	78	93	86	100	96	100	100	90	94	38	67
2002	67	42	69	92	100	96	100	100	99	87	92	83
2003	64	72	85	86	96	99	100	100	90	78	92	42
2004	58	70	93	92	98	99	100	96	88	93	60	47
2005	33	48	78	90	93	99	100	98	98	98	68	83
2006	78	72	69	92	100	99	96	100	99	91	71	69
2007	40	76	62	81	98	96	96	100	86	89	51	74
2008	58	58	54	90	100	99	94	100	96	60	62	65
2009	62	72	85	98	100	99	98	100	98	91	88	80
2010	73	84	80	96	100	96	100	98	84	80	69	71
max	98	84	93	98	100	99	100	100	99	98	92	83
mean	61	66	74	88	98	98	98	99	93	87	71	69
min	33	42	51	68	93	96	94	96	84	60	38	42

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