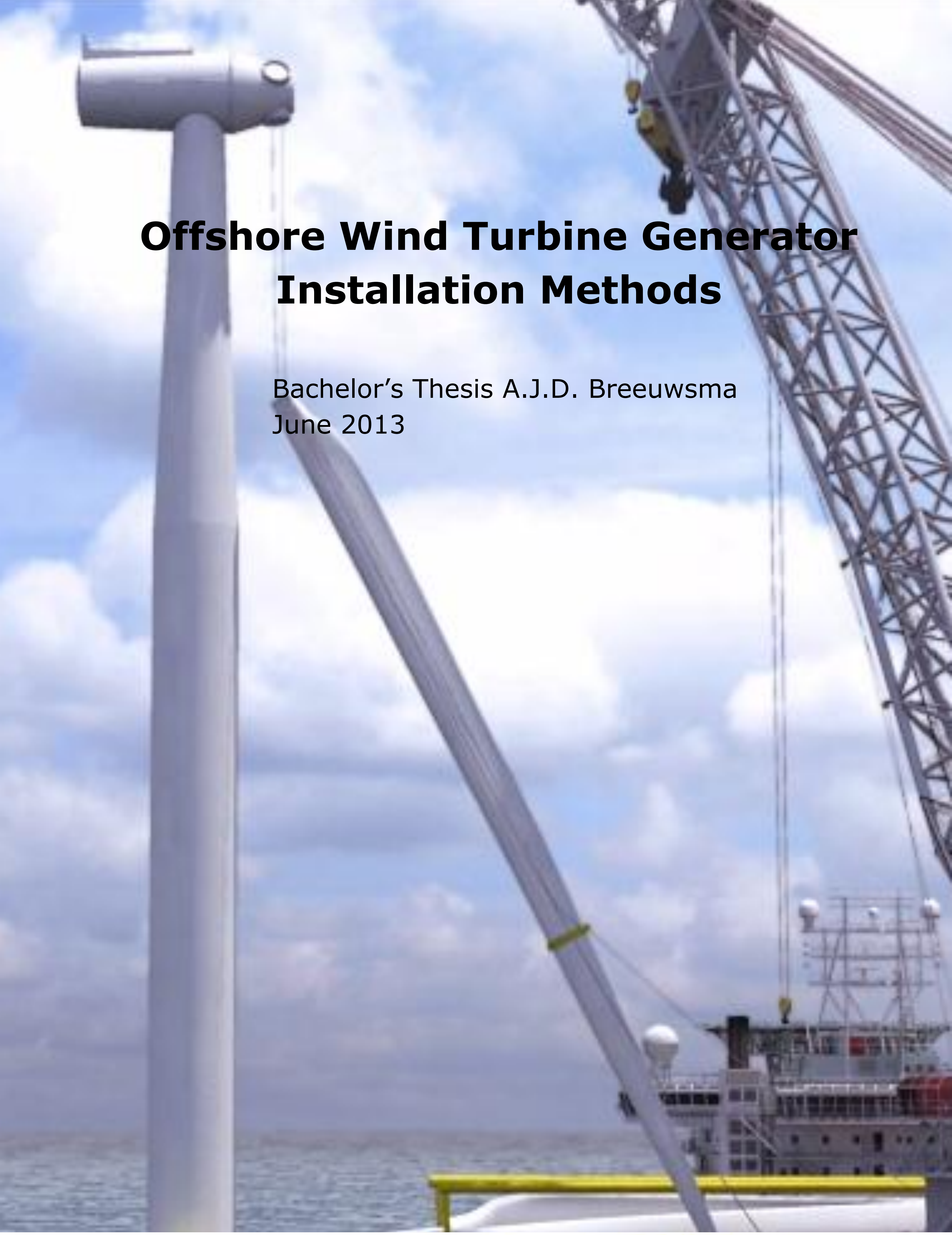
Offshore Wind Turbine Generator Installation Methods



Bachelor's Thesis A.J.D. Breeuwsma
June 2013

Seaway Heavy Lifting
offshore installation

THE HAGUE UNIVERSITY OF PROFESSIONAL EDUCATION

Offshore Wind Turbine Generator Installation Methods

Designing a blade installation system for offshore wind turbines

Bachelor's thesis project for the studies of Mechanical Engineering
June 2013

Author:
A.J.D. Breeuwsma

Seaway Heavy Lifting B.V.:
Ir. J.P. Breedeveld

The Hague University:
Ir. A.F. Le Mair

Signature	
Signature	
Signature	

Seaway Heavy Lifting
offshore installation

THE HAGUE UNIVERSITY OF PROFESSIONAL EDUCATION

Seaway Heavy Lifting
Albert Einsteinlaan 50
2719 ER Zoetermeer
The Netherlands
Tel.: +31 79 363 77 00
Fax: +31 79 363 77 99
http://www.seawayheavylifting.com.cy/

The Hague University, Location Delft
Rotterdamseweg 137, 2628 AL Delft
Postal address: PO Box 13336, 2501 EH The Hague
Delivery Address: Stamkartplein 40, 2521 EP The Hague
Phone: 015-260 6200
Fax: 015-260 6201
http://www.thehagueuniversity.com/

Foreword
This report is made by Jasper Breeuwsma for the Final thesis project, the last project of the bachelor mechanical engineering. This research was conducted during 17 weeks which is a very limited time period for such a elaborate subject. Similar concept and products design usually take more than 3 years to develop.

I would like to thank the following people for helping me to realize this final thesis for my Bachelor in Engineering:

Joep Niermeijer; he guided me through the whole project and was always available for questions concerning the wind turbine subjects.
Jan-Peter Breedeveld; even when he was extremely busy he managed to find the time to guide me Every week he checked if we were on schedule and if there were any problems or hiccups.
Niels Koorn; for accompanying me during the project. Every week at least one of us had some questions the other might be able answer. So we were a good team working towards our goals.
Seaway Heavy Lifting(SHL); for giving me the opportunity to do my final thesis project. Eversince I was in high school I am interested in sustainable energy in an offshore environment. My final high school paper was about energy from waves. This project gives me a next step towards the work field I would like to be in. I am also thankful that Seaway gave me the chance to visit AREVA Wind in Bremerhaven, Germany where we went to finalize the subject of this thesis.

During the period that I worked on my final thesis project with Seaway, some challenges emerged. There were different problems and obstructions that I needed to overcome. It took a lot of effort and energy to keep the project growing. There were days when I had the feeling that I didn’t make any headway. My way to handle this blockage was just accepting that I had lost a day, and work a bit harder the next day. With this attitude I worked my way towards the end of this paper.

During this period I also discovered that I am more of a team worker than a solo worker. I am good in motivating others, but when it comes to motivating myself, the task is much harder. Even with this great project. Working in a team makes brainstorming possible and decision making much better. I managed to find a group of engineers and other people in the work field to assist me in checking my arguments and discussing my decisions. In the end it was always my who made the last choice in every issue for this report.

Zoetermeer, May 2013

Summary

Seaway Heavy Lifting (SHL) has a business growth objective of gaining more orders in the wind turbine generator installation field. For this purpose the company is interested in finding alternative solutions for their installation methods. The main subject of this report is finding alternative solutions for installing blades on an offshore wind turbine.

In this research concepts are developed for new systems for lifting and installing the blades with SHL's vessels that will work more efficient and cheaper.
The investigation led to the development of an A frame that can be installed on top of a nacelle. With this lifting device it will be possible to eliminate the heave of the lifting vessel and control the blades better during the installation.

The main problems for innovating the existing lifting system lie in different working methods between installation companies and wind turbine fabricators. The fabricators of WTG's focus in their design on efficient energy generation and less on the installation process.
Seaway wants to install WTG's from AREVA Wind as well as from other fabricators in the future. This choice led to further research into a system that can install different wind turbines. With the information that was obtained from AREVA Wind, an example of the M5000 from AREVA was used as a first model.
After testing, a number of results emerged leading to the following proposed advantages:

- No relative movement of vessel during installation
- Easier handling of the blade during installation
- Line up of the blade into the hub
- Saving installation time
- Saving installation costs

Research method
In order to give a systematic overview, the research goal of the project is formulated first. The goal is categorized into a main question and several sub-questions. The answers to these questions can be found in this report. The answers will be categorized into chapters. After each question the chapter(s) where the answer(s) can be found are given.
The main objective of the thesis is:
To design a system (within the available period of time) that makes it possible to install blades on a wind turbine offshore from a floating vessel.

Sub-question 1: Current state of the art
The first sub-question is focused on finding out all the necessary information on currently used methods. *What are the technical specifications for a WTG that needs to be installed by SHL?* Additional sub-questions are: *What are the currently used methods for installing wind turbines offshore?* And: *Which types of vessels are used for installing a WTG and which installation methods are used by these vessels?* (See Chapter 3.3, 3.4 and 3.6)

Sub-question 2: Boundaries and constraints
The second sub-question is focused on the context, conditions and boundaries of the project and the system. *What are the boundaries and constraints for a blade installation process (from a floating vessel offshore)?* All boundaries and constraints are divided into three categories: constraints, demands and assumptions. The boundaries and constraints that are followed during this project can be found in the Chapter 4.

Sub-question 3: Brainstorming and solutions
The next sub-question signals the creative phase. In Chapter 5 ideas are listed of finding new ways of lifting and installing the blades.
Sub-question 3 is: *Based on the assembled knowledge of the existing systems, what improvements, combination of existing systems and other innovative methods can be developed for installing a WTG offshore from a floating vessel?*

With each system advantages and disadvantages are given.

Sub-question 4: Evaluation of the ideas
After finding different concepts for the problem, the sub-question 4 is asked: *Which sets of criteria can be used to evaluate and compare the concepts?* The criteria can be found in Chapter 6: Evaluation of the concepts.
The following question arises: *Which concept(s) are worth studying and which design should be elaborated on based on the weight of the arguments?* Each criterion is based on an importance factor. (Chapter 6)

Sub-question 5: Design: technical development of a new system
Last but not least the technical specifications of the new system will be listed in answer to the following question: *What are the technical specifications of the chosen concept (for installing WTG blades offshore from a floating vessel)?* (Chapter 7)

Technical specifications are:
- Sizes
- Internal forces
- Material
- Drive train
- Lifting plan
- Construction and economical considerations

An overview of each question and de reference chapter

Question	Chapter
What are the technical specifications of a WTG that need to be installed by SHL?	Chapter 3.3
What are the methods currently used for installing wind turbines offshore?	Chapter 3.4
Which types of vessels are used for installing a WTG and which installation methods are used by these vessels?	Chapter 3.6
What are the boundaries and constraints for a blade installation process (from a floating vessel offshore)?	Chapter 4
Based on the assembled knowledge about the existing systems, what improvements, combination of existing systems and other innovative methods can be developed for installing a WTG offshore from a floating vessel?	Chapter 5
Which sets of criteria can be used to evaluate and compare the concepts?	Chapter 6
Which concept(s) is best for elaboration in detail?	Chapter 6.3
What are the technical specifications of the chosen concept (for installing WTG blades offshore from a floating vessel)?	Chapter 7
Within the available period of time the object is for the student to design a system that makes it possible to install blades on a wind turbine offshore from a floating vessel.	Chapter 8

Table 1, Overview research question

Glossary & symbol list

To understand the report better a glossary and symbol list is added.

Glossary
Alpha Ventus project: Alpha ventus (also known as Borkum West) is Germany's first offshore wind farm. It is situated in the North Sea 45 kilometres (28 mi) north of the island of Borkum.
Barge: A barge is a flat-bottomed boat, built mainly for river and canal transport of heavy goods.
COG: Centre of Gravity
Crane vessel: A vessel equipped with a (heavy lifting) crane for installing offshore installations.
D/d: The ratio gained by dividing the drum diameter over the wire diameter.
Decommissioning: Uninstalling / removing offshore structures.
DNV: A global provider of services for managing risk
DP(3): Dynamic positioning (DP) is a computer-controlled system to automatically maintain a vessel's position and heading by using its own propellers and thrusters.
Drive train – power train: In a motor vehicle, the term power train or power plant refers to the group of components that generate power and deliver it to the road surface, water, or air.
Drum: The spool can also be called the winch drum
Gripper: In robotics, a gripper is the device at the end of a robotic arm, designed to interact with the environment. The exact nature of this device depends on the application of the robot.
Heave: The motion of moving up and down of the vessel.
Hinge: A hinge is a type of bearing that connects two solid objects, typically allowing only a limited angle of rotation between them.
Hub: The hub is the part that connects the blades together and to the nacelle. The hub is fixed to the rotor shaft that drives the generator through a gearbox.
Hull: A hull is the watertight body of a ship or boat.
Jack up vessel: A jack-up rig or a self-elevating unit is a type of mobile platform that consists of a buoyant hull fitted with a number of movable legs, capable of raising its hull over the surface of sea.
Lifting appliances: The lifting appliances are certification services for crane manufacturers and ship owners world-wide.
Main, auxiliary & whip hoist: A hoist is a device used for lifting or lowering a load by means of a drum or lift-wheel around which rope or chain wraps. The main hoist is the hoist that can handle the heaviest loads, which is also closest to the centre of the crane. The auxiliary and whip are smaller hoists that can lift less mass but lifts faster.
Mono hull: A mono hull is a type of boat with only one hull; a hull is the watertight body of a ship or boat.
Mooring: In oceanography a mooring is a collection of devices, connected to a wire and anchored on the sea floor.
Nacelle: The nacelle is the whole 'box' on top of the tower of a WTG. Inside the nacelle often generators, transmissions and a breaking mechanism are placed.
Non disclosure agreement: A non-disclosure agreement (NDA), also known as a confidentiality agreement (CA), confidential disclosure agreement (CDA), proprietary information agreement (PIA), or secrecy agreement, is a legal contract between at least two parties that outlines confidential material, knowledge, or information that the parties wish to share with one another for certain purposes, but wish to restrict access to or by third parties.
Pulley: A pulley is a wheel on an axle that is designed to support movement of a cable or belt along its circumference. Pulleys are used in a variety of ways to lift loads, apply forces, and to transmit power.
RSI: Rotor star installation: installing three blades and the hub at once.
SACS: An integrated finite element structural analysis suite of programs that uniquely provides for the design, fabrication, installation, operation, and maintenance of offshore structures, including oil platforms and wind farms.
SBI: Single blade installation: installing wind turbine blades piece by piece
Reevings: are multiple reefing. On one ring a wire can be passed multiple times.
SHL: Seaway Heavy Lifting
Suction pads/cubs: A suction cup, also sometimes known as a sucker, is an object that uses negative fluid pressure of air or water to adhere to nonporous surfaces, and in the process creates a partial vacuum. It exists both as an artificially created device, and as anatomical traits of some animals such as octopi and squid.
Tensioner: A device that applies a force to an object to maintain it in tension. In this example, tensioners are used to obtain the force on pipes.
Tower: The tower creates the height of the WTG and is often built up in three parts.
Tugger winch: A winch used for pulling with a tugboat. A tugboat (tug) is a boat that manoeuvres vessels by pushing or towing them.
WIVs: Wind turbine Installation Vessels
WTG: Wind Turbine Generator.

Symbol list

Symbol	Meaning	S.I.-Unit
a	acceleration	m/s
v	speed	m/s
m	meters	m
A	Area	m²
V	Volume	m³
cm	Centimetres	m
s	Time (seconds)	sec
W	Width	m
H	hight	m
t	Thikness	m
d	(circle) diamter	m
Rad	Radial	-
RPM	Rotations per minute	-
MPa	presure	Pa
T or m	Tonne	Kg
N	Newton	N
kN/m	torque	N/m
kW	Power	W

Table 2, Symbol list

List of tables

List of figures

1.1 Introduction

I think the cost of energy will come down when we make this transition to renewable energy.
Al Gore

One of the main future goals of Seaway Heavy Lifting is to bring in as many orders as possible for installing wind turbine generators (WTG) offshore. SHL is planning to execute its first offshore wind turbine installation approx. winter of 2014/2015 with its two vessels.

Seaway Heavy Lifting's mono hull crane vessels, Stanislav Yudin and Oleg Strashnov, are the pride of the company. These fully owned vessels have significant lift capacities. The vessels offer a most efficient operational execution as they can handle lifts from cargo barges offshore. They are equipped with the latest generation hydraulic pile hammers, pile lifting tools and leveling devices.
SHL's crane vessel Stanislav Yudin has a 2,500 tons revolving crane, a 500 tons auxiliary hook and a 30 tons trolley hoist. With 78.4 m. lifting height on the main hook and 100.7 m. on the auxiliary, the Stanislav Yudin is ideal for a broad range of offshore installation tasks. This Light Ice Class crane vessel has 2,500 m². of deck space (5,000 tons load capacity), with 20 m. clearance between deck and boom at rest. It has an eight-point mooring system and combines high transit speed with shallow draft (5.5 m.). There is accommodation for 148 persons and the helicopter deck is equipped for a S61 or equivalent.

The second crane vessel owned by SHL is the Oleg Strashnov. It is a self-propelled crane vessel built in 2011. This large DP3 vessel has a unique hull shape and is outfitted with the latest technology. Its 5,000 tons revolving crane has a main hook lifting height of 102 m. There are 800 tons and 200 tons auxiliary hooks and a 30 tons trolley hoist. With generous deck space totaling 3,700 m². (8,500 tons load capacity), the Oleg Strashnov represents the ideal vessel for the installation of large, heavy structures.

With Seaway Heavy Lifting's focus on project execution, chartered assets are deployed as required to meet the specialized needs of clients with challenging project timelines within different industries. One of these industries is offshore wind turbine installation.

Installing wind turbines offshore will always be a big and risky task. The main reason being the affects of the environment, due to wind and waves. These wind and wave effects will be higher and extremer than in onshore situations and will also mostly be higher on site than on the transport routes. This is due to the fact that the wind farms will be installed on positions where the most wind occurs.

Offshore wind turbine generators are all high tech generators and are designed to convert wind energy into electric energy. These WTG's, are built as light weight as possible which creates constraints for installing them. For example, the nacelle is not designed to handle extra forces beyond wind power. All the technical challenges that fabricators try to meet will affect the methods contractors use to install the wind turbines. Wind turbines will continue to become bigger and heavier. This will make it more complicated to handle these machines. Possibilities for installing bigger and heavier wind turbines must be researched.

In general offshore contractors use different methods to install wind turbines offshore. The method mainly used is by means of jack-up’s. A jack-up or a self-elevating unit is a type of mobile platform that consists of a buoyant hull fitted with a number of movable legs, capable of raising its hull above the surface of sea.

For assembling WTG’s, there are also different methods. One of the methods used for installing blades offshore is single blade installation. Offshore single blade installation is mostly done by jack-ups. Wave effects are often avoided by using jack up’s. First all the tower parts will be installed (together or separately). Once the nacelle and hub are installed the last part is installing the blades.

Figure 1, Single Blade installation

There are also a lot of different sequences possible for installing the WTG offshore. At the moment horizontal blade installation is the most commonly used method for single blade installation (Figure 1). This method, however, has a lot of risks, such as dealing with the affects of waves and wind.

As there are not yet proven solutions for installing wind turbine blades from a floating vessel, the research goal for his final thesis is:

To design a system (within the available period of time), which makes it possible to install blades on a wind turbine offshore from a floating vessel.

The project is focused on one method of installing the blades. This method is called single blade installation. Each blade will be installed separately. In chapter 3, 7 arguments can be found why this option is chosen.

Within this task different disciplines are researched, such as market research, technical part development, economical arguments and chosen a detailed design.

The study contains possible lifting plans, technical specifications and of course a design concept that will take all boundaries into account.

2 Backgrounds

Below is information on the company and the department involved in the research:

2.1 Company: Seaway Heavy Lifting

Seaway Heavy Lifting was established on October 15th, 1991 as a joint venture of Stolt Nielsen Seaway (later Stolt Comex Seaway → Stolt Offshore → Acergy → Subsea 7) and the Russian state oil company Morneft Kaliningrad (now Likoil Kaliningrad Morneft). SHL is active in the field of offshore projects, such as the installation and decommissioning of oilrigs and wind farms. The company is in possession of two heavy lift crane vessels, the Oleg Strashnov and Stanislav Yudin, with a lifting capacity of 5,000 mt and 2,500 mt respectively. The headquarters of SHL Engineering is located in Zoetermeer, other offices are located in Hamburg (Germany) and Limassol (Cyprus). SHL works on projects in the North Sea, the Mediterranean, the Middle East and along the coast of India.

2.2 Engineering Department

The Engineering Department is located at the headquarters in Zoetermeer and provides for elaborating, designing and calculating the performance of the offshore projects. This department also develops adjustments for the vessels. Engineers regularly travel to the projects and are directly involved in the implementation of the work on site.

3 Research report

The report was made to assemble all the information needed to work on the research goal.

3.1 Problem definition

Offshore wind energy is one of the most upcoming green energy sources worldwide. One of the major growth inhibitors in this industry are the installation costs of WTGs. For installing offshore wind turbines, offshore crane vessels are mainly used. These vessels cost between €100.000 – €300.000 per day. This makes installation time crucial.

3.2 Research Question[1]

The following research questions are posed:

- *What are the technical specifications of a WTG that needs to be installed by SHL?*
- *What are the current used methods for installing wind turbines offshore?*
- *Which types of vessels are used for installing a WTG and which installation methods are used by these vessels?*
- *Under which circumstances will it be possible to install wind turbines offshore?*

3.3 Technical specifications AREVA M5000-135

Wind turbines can be categorized according to their make, size, and power ratings. The primary function of a wind turbine is to convert kinetic energy of wind into mechanical energy, which is then used to generate electrical energy. The figure (2) gives an overview of the different parts of a wind turbine.
SHL will probably install the WTG M5000-135 from AREVA[2]. AREVA Wind has been developing, planning and producing the M5000-135 since 2000, the first 5MW wind turbine designed exclusively for large-scale offshore wind farms.

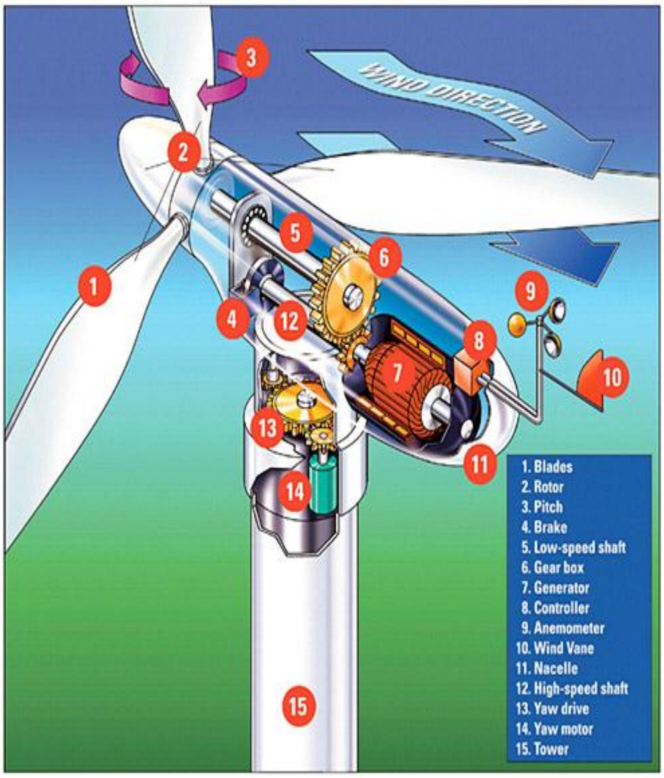


Figure 2, standard components of a wind turbine

[1] Source 1)
[2] Source 2)

The tables below show the technical specifications of the AREVA M5000-135 WTG.

General	Units
Rated power	5,000 kW
Cut-in wind speed (WTG starts working)	3.5 m/s
Rated wind speed (Highest efferent working speed)	11.4 m/s
Cut-out wind speed (WTG Stops working)	25 m/s
Design life time	20 years

Generator and converter	Units
Generator type	synchronic, permanent magnet
Rated voltage	3,300 V
Speed range	66.1 - 133.5 min^{-1} ± 10%
Converter type	full size converter

Masses	Units
Nacelle without hub	235 t
hub	64 t
rotor blade	23,3 t
Tower	348,9 t
Total	717,8 t

Rotor	Units
Rotor diameter	135 m
Number of blades	3
Rotor area	14,326 m^2
Rated speed of rotor	13,5 min^{-1}
Blade length	64 m

Pitch system	Units
Principle	electrical pitch
Power control	blade angle and
	rotor speed control

Table 3, Technical specifications WTG AREVA M5000-135

Drawings from the AREVA M5000 can be found in appendix (X).

The important specifications for the installation process are:

- All masses, especially the mass of the blade: 23.3 metric tons
- Blade length: 64 meter
- Installation height: 100 meter

The choice of foundation structure for the AREVA Wind M5000-135, depends on the specifications of the wind park. For the Alpha Ventus project, three-legged foundation structures or tripods were recommended, fastened to the bed of the North Sea using piles of approx. 30 meters, in view of the depth of water.

Figure 3, tripod installation

Other foundation structures are possible, but are outside the range of this project.

3.4 Current used methods[3]

Currently SHL and AREVA signed a non-disclosure contract to start working on methods for installing wind turbines offshore with SHL's fleet. SHL's fleet has not yet been used for installing offshore wind turbines. At the moment other companies use jack-up vessels to install the WTG's (-blades).
The graph on the next page shows different methods for installing wind turbines offshore.

Installation components

A M5000-135 tower from AVERA is built in 3 components. Other parts of the WTG are the nacelle, the hub and the blades. Together they form a complete wind turbine.

3.5 Blade Installation methods:

(A)Tower in parts, nacelle with blades onshore (RSI)

While the 3 components of the tower are loaded on the ship in the harbour, the nacelle and the blades are being assembled onshore. After assembling the nacelle and the blades, they will be loaded on the vessel. The 3 building parts of the tower will be assembled on location, thereafter the hub and blades will be added on the tower. This is called: Rotor Star Installation (RSI)

(B)Tower and nacelle onshore, blades offshore (SBI)

In this case the assembly of the tower, nacelle and hub will take place onshore. This means that only the blades need to be installed offshore. This is also called: Single Blade Installation (SBI)

(C) All parts Assemble offshore

All the parts will be assembled separately offshore. So first the 3 tower parts, then the nacelle, the hub with the blades. Nothing will be assembled onshore.

(D) Full Assemble onshore

The whole wind turbine will be assembled onshore, loaded on the vessel in its entirety and installed on location in one lift.

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[3] Source 3)

Each method has different ways of handling. Our research concerns the assembling of blades on the nacelle offshore **(B)**.

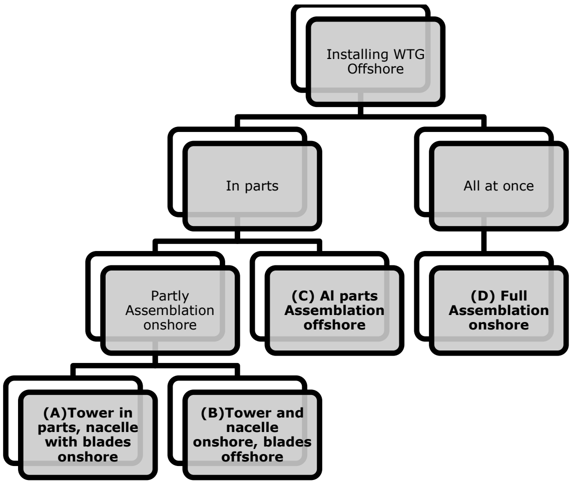

Figure 4, Overview current methods used

Blades on the Nacelle (B)

One way of installing the blades on the nacelle is to lift the blade horizontally, with one hoist as shown on figure 5 & 6**(I)&(II)**. A second method for installing blades is using more hoists to lift one blade. One can use different connection points / grippers **(III)&(IV).** Another way is to lift the blade without a crane. This can be done by adding a lifting device to or into the nacelle. SHL made a concept with one hoists from the hub **(V)**. A two crane concept is also possible. Installation methods without a crane are not yet used offshore.

Figure 5, One connection, horizontal blade installation

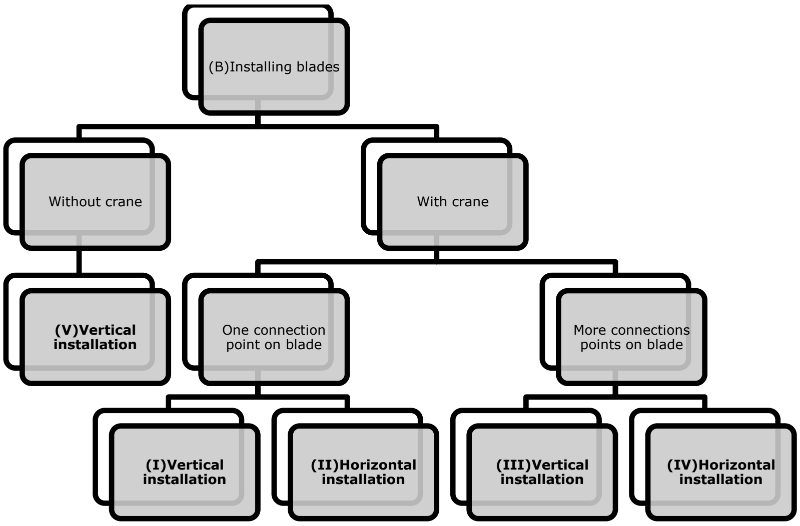

Figure 6, Overview for methods used for blade installation

The following figures (7-10) give an overview of the different clamps / grippers used for installing wind turbines. Clams are excluded from this project.

Figure 7, Jack-up blade installation with special clamp

Figure 8, Special blade rotatable

Figure 9, clamp Blade installation with special clamp and one hoist

Figure 10, Blade installation with special clamp and two hoists

3.6 Wind farm Installation Vessels (WIVs)[4]

On the table below the wind farm installation SHL vessels are listed with their specifications:

Name	Year	Deck Space m2	Capacity (tonne)	Speed knots
Oleg Strashnov	2011	3700	5000	14
Stanislav Yudin	1985	2560	2500	12

Table 4, SHL's WIV's Vessel

In Appendix (IV) a list of other WIVs can be found and more specifications of SHL's Fleet.

3.7 Rotor star versus single blade installation

Another way of installing wind turbine blades is installing them together with the hub as a three-point star. This is called rotor start installation (RSI). The blades and the hub are assembled onshore and transported to the location of the WTG. RSI is only performed by jack-up rigs offshore. The main reason to use a jack-up rig is to clear out the relative motion of the waves, which makes it easier to install the rotor star at 100m height. The rotor star for the AREVA M5000 weights about 135 tons and has a diameter of 135 meters. The weight is not the biggest concern, it is the size that makes it difficult to install and to transport the rotor star with a floating vessel.

Figure 11, jack up RSI

Advantages of SBI from a floating vessel in comparison to RSI are:

- Transportation (space on deck), RSI needs more space than SBI
- Transportation forces (moments) on rotor star due to vessel motions
- Single blades are better controlled during installation
- Lifting weight can affect the type of crane vessel needed and radius of the crane(hook choice)

Disadvantages of SBI from a floating vessel in comparison to RSI are:

- Speed of installation (RSI uses one lift, SBI uses three)

Because of the above arguments single blade installation from a floating vessel is chosen to work with instead of rotor star installation.

[4] Source 4) & Source 5)

4 Scope of the project

To map the project constraints and boundaries must be made.
Because of the time pressure the scope of the project is limited. The project was subject to the following:

Constraints
The project is focused on an AREVA M5000-135 WTG. The installation of the wind turbines must be done by SHL's floating vessels. Furthermore, the blade must be lifted up to the nacelle, which is a 100 meters above sealevel.

Demands
Maximum added weight on top off the WTG = 10 mt
An installation farm of 100 turbines must be possible.

Assumptions
Certain prerequisites for installation are assumed to be in place:
A certain amount of equipment is available on the crane vessel, such as:
- Tugger winches
- Guiding lines
- Deck space

Factors of success
Points of attention during every step of the product development are:
- Safety
- Robustness
- Environmental affects
- Installation time
- Costs

These factors must be balanced during the search for the best concept.

5 Concepts

The results from multiple brainstorm sessions concerning different methods for installing wind turbine blades offshore led to 10 proposals.

The assumption is that the status of the wind turbine is the same in every concept, i.e. the foundation, tower, nacelle and hub are fully installed.

5.1 SHL Concept: Blade pull in

The blades are pulled in (by a winch system) from the hub. The basic idea is to guide the blade inside the hub. At this time the idea is to glide the blade in vertically, but a horizontal concept is also possible.

Explanation of the concept

The extra task in this concept is finding a way to install a winch inside the hub or nacelle. So that it is possible to lift the blade to the height of the hub.

The winch and a crane vessel together lift one blade from the storage horizontally. Slowly the winch takes over and lifts the blade vertically. The crane vessel still needs to be around so that the blade is controlled in the wind and will not hit the tower. After this action the blade will be pulled in by the winch and installed vertically. The hub turns 120 degrees and another blade will be installed. This action will be repeated for the third blade. For a wind farm of 100 WTGs an option can be to install the winch system in each WTG.

Figure 12, Blade pull in concept

Advantages

- Easy handling of the blade due to multiple connection points
- Speed of installation because of better handling due the extra connection points
- Less problems of waves, because pull in from hub (no heave)

Disadvantages

- New non engineered forces on wind turbine due to adding a winch
- High tech, low weight winch needed
- People that control the winch can be on an "un-safe" location to handle the winch

5.2 Vertical blade installation concepts

These concepts are grouped because of their vertical installation method.

5.2.1 Concept 1: Up ending tool [5]

This idea is copied from a concept for installing entire wind turbines. On a barge the blades will be transported and installed in a similar way as compared to the windflip (Figure (13)). The idea is to slide each blade into a gripper and then use a flipping system to lift them high enough to install them.

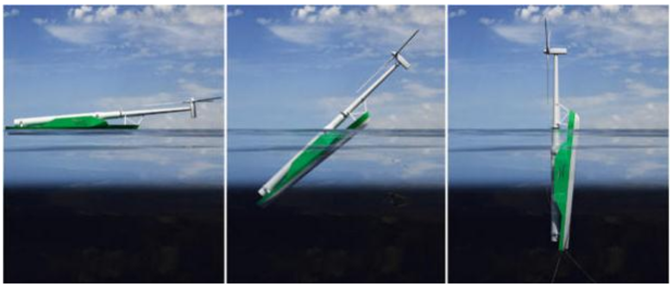

Figure 13, Windflip

This gripper is attached with two cylinders, one to make the 90 degrees angle and one to lift the blade up in the air for the last meters. When the frame is vertical the gripper extends to reach for the hub.

Advantages

- Fixed connection, so less effect from the wind
- Safe, due to better control of blade

Disadvantages

- Slow installation process, due to multiple handlings (two, one 90 degrees and one towards the hub)
- Extra space needed on vessel
- Height not easy to accomplish
- Heave compensation problems
- High building and usage costs

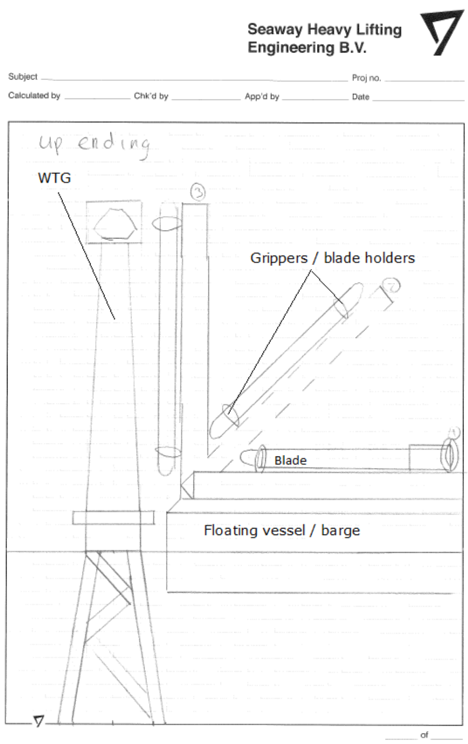

Figure 14, Up ending concept sketch

[5] Source 5)

5.2.2 Concept 2: Robot arm[6]

This concept is basically the same as the IHC Merwede / Vuyk Engineering Rotterdam B.V. designed for installing entire wind turbines (picture (15). The idea is to make the same type of robot arm, but not for installing a whole wind turbine. Only the blades need to be installed. This idea will be designed from scratch; the similarity with the already existing concept is only made to show that no crane vessels are needed for this operation. It can also be designed as an add on for an existing floating vessel.

Figure 15, IHC's Robot arm

Advantages

- Fixed connection, so less wind effects
- Modular, build up in parts
- No crane vessel needed

Disadvantages

- Setup and installation time
- High costs in building the product, usage and maintenance

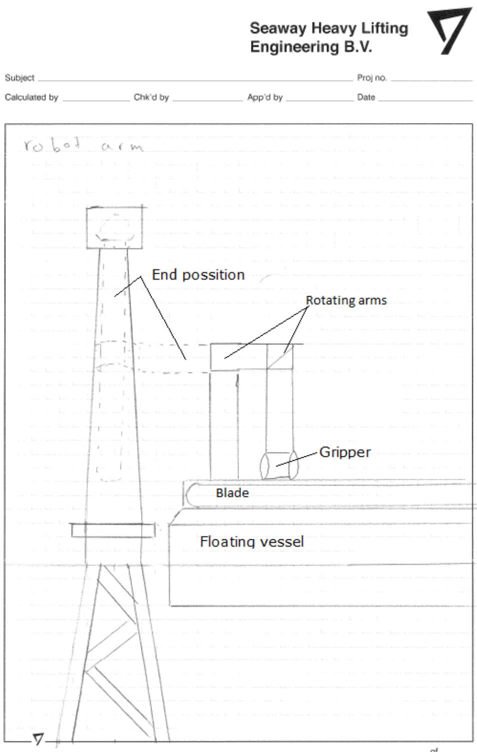

Figure 16, Robot arm concept sketch

Figure 17, Robot arm example

[6] Source 6)

5.2.3 Concept 3: Transformer

The basic idea is to make a frame that builds itself up from the foundation, around the tower and nacelle. A barge with blades comes and a lifting system pulls the blades on the hub. It is a similar concept as the lifting concept of SHL, but now the goal is to find an alternative for the lifting vessel. The transformer is positioned with a hook around the foundation and one around the turbine. Above these hooks a frame and a bridge with lifting device is built or is already installed. To lower the forces on the jacket a floating area can be added. The lifting system is positioned above the nacelle. After installing the first blade, the nacelle twists 120 degrees and the other two blades can be installed afterwards. The blades move over a rail on the barge.

Advantages

- Blade control during installation. Extra connection points possible because blade is close to frame.
- Specialized concept with only one focus: SBI

Disadvantages

- WTG dependent
- Complex and huge concept, no growing possibilities
- Forces on turbine

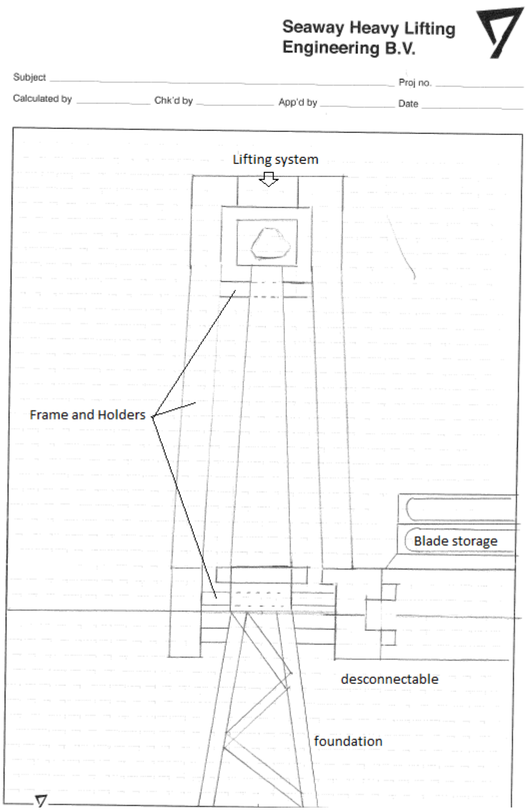

Figure 18, Concept transformer sketch 1

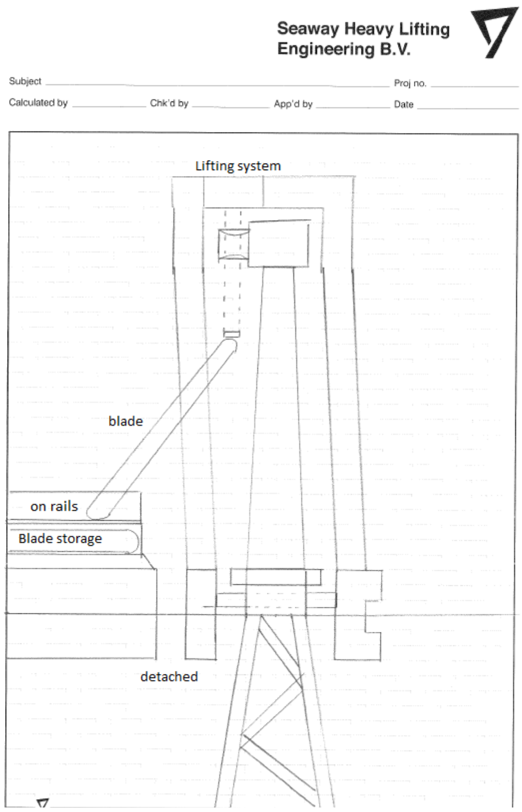

Figure 19, Concept transformer sketch 2

5.2.4 Concept 4: A frame winch

By adding a winch on top of the nacelle, it will be possible to lift the blades up vertically to the nacelle.

The blades will travel horizontally to the wind turbine. After installing a frame winch on top of the nacelle the blades will be lifted with two connection points. By pulling faster with the A - frame winch the blade will be transitioned into a vertical position. After lifting the blade to its necessary height the blade will be installed into the hub. A floating vessel with guiding lines needs to be around to control the blade during the whole lifting procedure. Then the hub twists 120 degrees and the other blades can be installed.

Advantages

- Open frame on top of WTG, easy access
- A frame can be installed onshore on nacelle
- Low building costs
- Blade control during installation

Disadvantages

- Extra forces on turbine
- Complex concept due to not allowed effects on nacelle

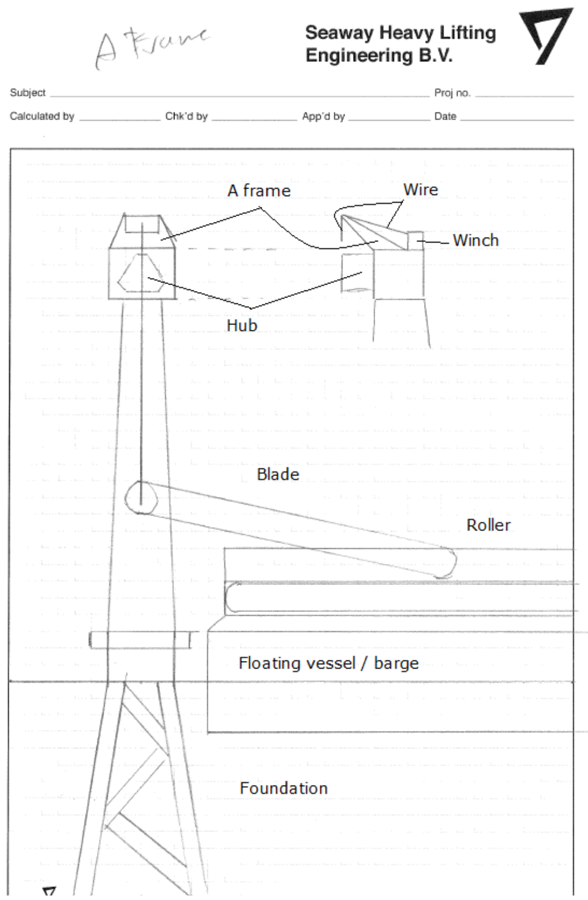

Figure 20, Concept A frame sketch

5.2.5 Concept 5: Combination of concept 1 & 2

Another possibility is to combine two concepts to create an upending robot arm. The main advantages are limited space and avoiding the effects of wind. The big difference compared to concept 2 is that there are less rotating parts. The main idea is that with the upending tool the height will be created to lift the blades high enough. The robot arm will be necessary to compensate the heave and control the blade more accurate for the final (centi)meters.

Advantages

- Little space on vessel
- Speed of installation due to direct handling and fixed connection
- Accurate
- Fixed connection has positive effect on the wind effects
- Vertical as well as horizontal installation possible

Disadvantages

- Complex, a lot of moving parts
- Heave compensation is possible, but limited
- High building and usage costs

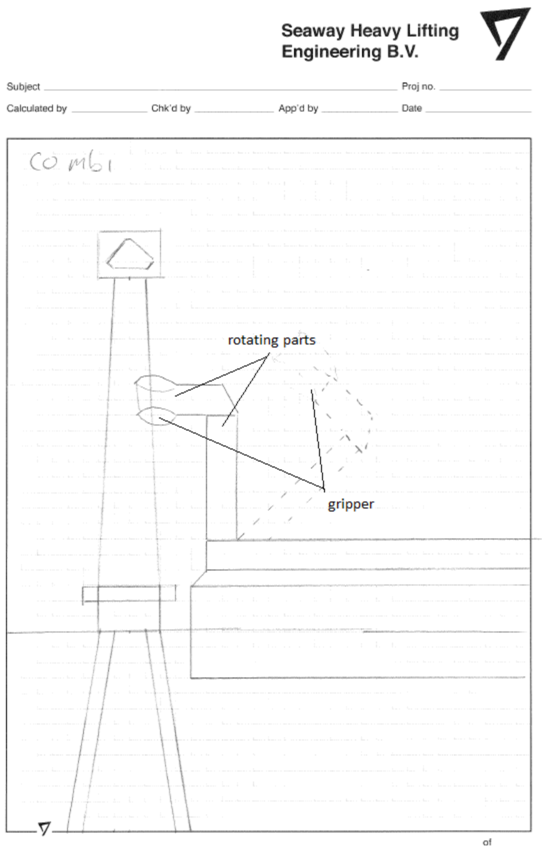

Figure 21, Concept combination sketch

5.3 Alternative concepts

These are totally different concepts, with no use of a crane vessel or barge.

5.3.1 Concept 6: Semi-sub lifting unit

Blades will be lifted by a submersible vessel or installation device. The whole vessel/barge will be sunken first with ballast and then lifted. There are various choices available for installing the blades. There is a possibility not to use the whole floating vessel as a lifting unit, but use the idea of underwater air as an up-force. This method is also a search for an alternative on a lifting crane vessel. Installing the blade (step 4, see figure (22)) is still a question; using an extended gripper or a little winch is an option.

Advantages

- Good control of the blade because it is close to the vessel

Disadvantages

- Slow installation process
- Length = height = depth, to get the necessary height the vessel needs to sink the same meters or another system must be thought of with the same lifting method (lifting on a controllable air bubble under water)
- Nearly the whole vessel under water or above water, effects of wind, waves and current
- Getting close to hub is complex

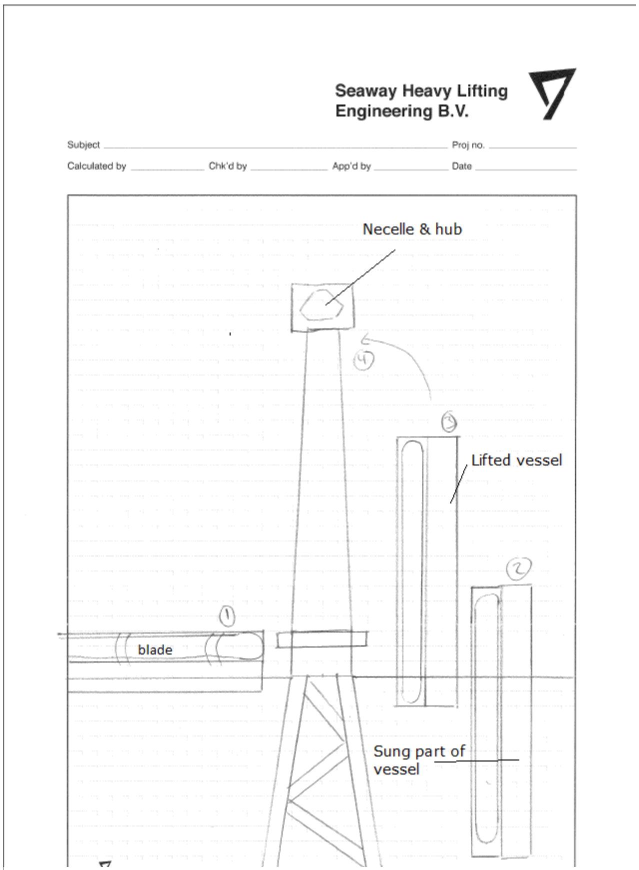

Figure 22, Concept semi-sub sketch

5.3.2 Concept 7: Kites

Skysail uses kites for wind energy, to propel cargo ships, large yachts and fishing vessels. The idea is to use wind energy to lift the blades into the hub. Doing so by using techniques from the kite surf industry, an industry that has developed kites with an extreme lifting capacity. The blades need to be installed vertically. They will be guided by rails into the turbine. With a system that makes it possible to lift the blades, and when there is a wind-dip, the blades will not fall. The use of guiding lines is necessary.

Advantages

- Works in heavy winds
- Accurate by guiders
- No heave

Disadvantages

- New concept, complex
- Many operations per blade
- Installation on the wind turbine, but assumed that reaction forces are not as big as adding a whole winch
- Dependent on wind
- Building costs expensive, usage free

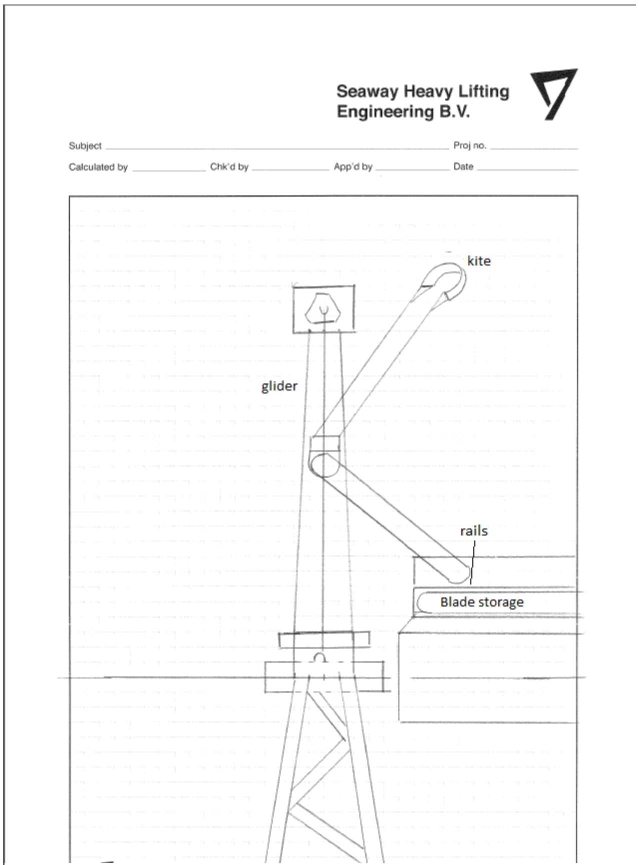

Figure 23, Concept kite sketch

5.3.3 Concept 8: (small) Wind turbine lift

Concept 8 uses a smaller wind turbine to pull up an elevator with the blades to the installation place instead of a kite. It resembles an elevator used in construction sites for people, but this one is driven by wind energy. The use of only wind to install a wind turbine is a big commercial advantage.

Advantages

- Works in heavy winds
- Accurate by guiders
- No heave

Disadvantages

- Extra moving parts in elevator
- New concept, complex and expensive
- Installation on the wind turbine
- Dependent on wind

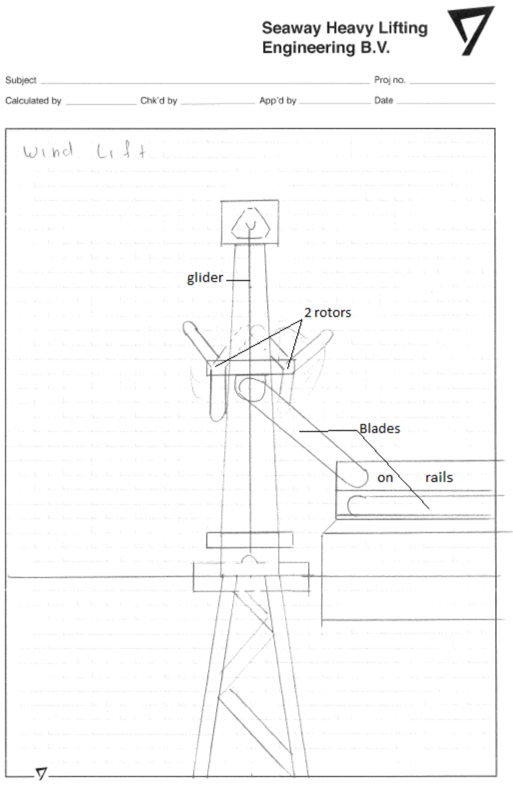

Figure 24, Concept wind lift sketch

5.3.4 Concept 9: Balance principle

First a pulley will be attached to the hub of the wind turbine. This pulley will lift one blade at a time. In this concept the counterweight of the blade will be a water bag as a counterbalance. The water bag will be filled by a water pump slowly and lift the mass of the water bag high enough to lift the blade. Water bags up to 35 tons are available. [7] Only the pulley needs to be installed on the wind turbine. The pump can be placed on a barge on the floating vessel.

Advantages

- Uses only kinematic energy for installing the blade
- Accurate by guiders
- No heave
- Safety brake is always the water level
- Low energy consumption
- Cheaper than a heavy lift vessel
- No engine needed, only a brake

Disadvantages

- Pulley installation on the wind turbine
- Extra forces on hub

Figure 25, Test load water bag

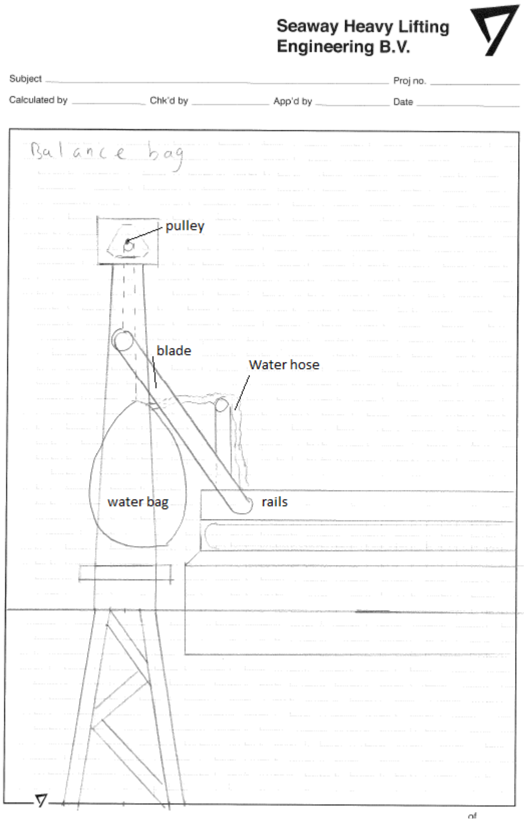

Figure 26, Concept balance principle sketch

[7] Source 7)

5.3.5 Concept 10: Caterpillar lift

In this concept lifting the blades with a lifting device around the tower will be explained. The main idea is to create a lifting device with similar equipment that is installed on a tensioner. A tensioner is a device that applies a force to an object to maintain it in tension. In this example, tensioners are used to obtain the force on pipes.
This tensioner is placed on the bottom of the tower, and crawls up to the hub to install the blades.

Advantages

- Accurate
- Higher speed possible
- No heave and wind effects
- Blade connection next to tower

Disadvantages

- Installation on wind turbine tower
- Extra forces on wind turbine (tower)
- Heavy lifting equipment
- Complex moving parts
- Loss of estimated lifetime of WTG

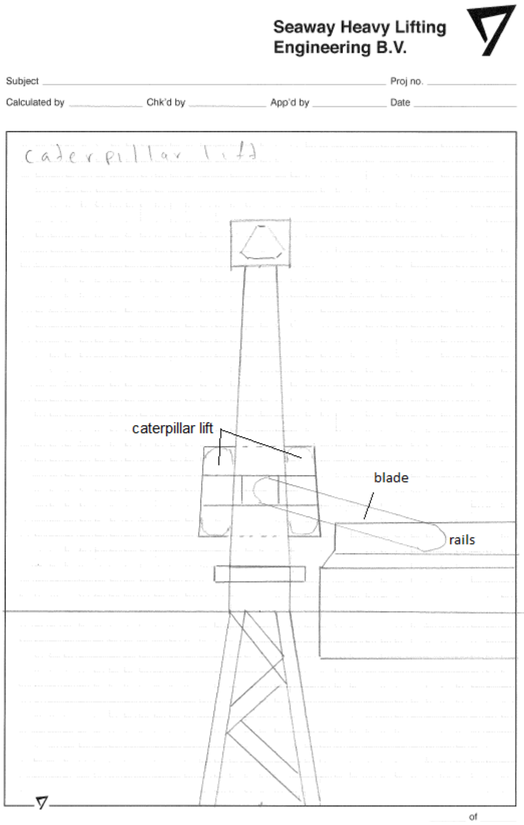

Figure 28, Concept tensioner sketch


Figure 27, pipelay tensioner

6 Evaluation of the Concepts

Finding the concept with the best chances of success.
The evaluation is an important part in the process. The SHL concept is the 'null' measurement. The other concepts are compared to this concept. There are multiple methods used to measure each concept, together they must form an overview of the best (highest chance of succeeding) concept. The best concept can be the most efficient one, but it is possible that a more safe or other type of concept will be preferred.

6.1 Evaluation: Grading by arguments

Each concept will earn grades on different criteria. The grades that are given are between 1 and 10, each grade is multiplied by an importance factor.

Positive criteria effect the grading of the concept in a positive way, negative criteria do the opposite. Each criterion is explained and graded:

1. Safety, if the grade is higher than 5 from the SHL concept, the risk for a dangerous situation during the installation is lower than the SHL's concept.
2. Robust, offshore conditions are harsh. The more robust the concept is, the higher the grade is.
3. Time is the most important factor of them all. Time is divided into three factors:
    1. Speed: divided into two factors:
        i. Speed indication in hours, graded very high because it is related to costs. A high score means a faster concept than the SHL concept.
        ii. The many different handlings and overtakings of a blade, more overtakings or different ways of installing will make it more complex.
    2. Environment: how much does the environment affect the installation method? This factor is divided into two factors:
        i. Wind will affect the methods continually. The grade is high because of high importance during the installation.
        ii. Wave affects the concept in a particular way. The concept is affected by waves on a different level than wind, although the grade is high.
    3. Starting time, each concept takes its own time from the drawing table to 'being offshore' and having a workable installation method.
4. Costs are negative grades because they affect the concepts in a bad way. There is a difference between operational and building costs for each concept.

The table on the next page shows the score per concept. Each score is explained in the tables in the Appendix IV: Grading table.

6.2 Evaluation tables

The method used to compare the concepts can be viewed by looking at the tables below. Each concept gets a grade for each factor. The grades are further explained by a second table.

		Safety	Robust	installation hours	Handlings	Wind effects	Wave effects	Start time	Operational costs	Building costs	Complexit y
comment		10 = high	10 = high	10 = fast	10 = 1 single movement	10 = high	10 = high	10 = fast	10 = expensive	10 = expensive	10 = high
Factor		2	1	3	3	-3	-3	2	-1	-1	-1
SHL Concept		5	5	5	5	5	5	5	5	5	5
Concept 1	Up ending tool	6	4	5	4	3	6	4	6	7	6
Concept 2	Robot arm	6	6	6	6	3	4	1	6	7	8
Concept 3	Transformer	4	4	4	5	2	2	2	7	8	7
Concept 4	A frame	7	7	7	7	5	7	7	3	3	6
Concept 5	Combi 1& 2	6	5	6	5	3	5	2	6	7	7
Concept 6	Semi sub	3	3	4	1	7	7	2	8	8	8
Concept 7	Kite	4	6	7	2	3	4	3	3	2	8
Concept 8	Wind lift	2	3	4	2	3	4	2	3	7	8
Concept 9	Balance concept	4	7	6	7	7	4	6	3	3	6
Concept 10	Caterpillar lift	4	3	5	5	6	6	2	6	7	7

Table 5, input evaluation table

comment		Safety 10 = high	Robust 10 = high	installation hours 10 = fast	# Handlings 10 = 1 single movement	Wind effects 10 = high	Wave effects 10 = high	Start time 10 = fast	Operational costs 10 = expensive	building costs 10 = expensive	Complexity 10 = high	Total score	From Zero
Factor		2	1	3	3	-3	-3	2	-1	-1	-1		
SHL Concept		10	5	15	15	-15	-15	10	-5	-5	-5	10	0
Concept 1	Up ending tool	12	4	15	12	-9	-18	8	-6	-7	-6	5	-5
Concept 2	Robot arm	12	6	18	18	-9	-12	2	-6	-7	-8	14	4
Concept 3	Transformer	8	4	12	15	-6	-6	4	-7	-8	-7	9	-1
Concept 4	A frame	14	7	21	21	-15	-21	14	-3	-3	-6	29	19
Concept 5	Combi 1& 2	12	5	18	15	-9	-15	4	-6	-7	-7	10	0
Concept 6	Semi sub	6	3	12	3	-21	-21	4	-8	-8	-8	-38	-48
Concept 7	Kite	8	6	21	6	-9	-12	6	-3	-2	-8	13	3
Concept 8	Wind lift	4	3	12	6	-9	-12	4	-3	-7	-8	-10	-20
Concept 9	Balance concept	8	7	18	21	-21	-12	12	-3	-3	-6	21	11
Concept 10	Caterpillar lift	8	3	15	15	-24	-24	4	-6	-7	-7	-23	-33

Table 6, Output evaluation table

6.3 Concept evaluation conclusions

From the evaluation tables (table 5), the highest score is 29 for the A frame concept. Grading this with a zero line by subtracting the score of the ’null concept‘ from every other concept we get a score of 19. Another concept that will probably have a good chance of succeeding is the balance concept. Concepts that have a negative grade will probably not succeed.

The A frame scores positive on installation hours, costs and environmental effects. These are also the three grades that affect the final score the most by their high factor.

Concept’s that will probably not succeed are:

- Concept 1: Upending tool, due to effects of waves and costs
- Concept 2: Robot arm, due to building costs
- Concept 3: Transformer, due to safety reasons, building costs and complexity
- Concept 5: Combination of 1 and 2: very complex solution
- Concept 6: Semi sub, scores low on every grading
- Concept 7: Kite, scores low on safety and complexity
- Concept 8: Wind lift, scores low on safety, robustness and starting time
- Concept 9: Balance concept, only scores low on safety
- Concept 10: Caterpillar lift, scores low on every grading.

The balance concept is the other concept that will have a good chance of succeeding. Due to similarity to the SHL concept the preferred choice is Concept 4: A frame.

7 Technical specifications of the chosen concept

Elaboration of the chosen concept.

To find out what the possibilities for a lifting device are, some extra research must be done. This lifting device positioned on top of the nacelle must lift wind turbine blades from a floating vessel to the nacelle.

Wind turbine research

Before finding the best options for the parts of the lifting device, the possibilities and boundary conditions of the WTG must be reviewed.

Boundaries conditions

It will not be possible to add heavy masses on top of the WTG, because it is advised not to change the COG(centre of gravity). With the chosen maximum weight of 10 tons of the A frame, the added mass is less than 2% of the total weight of the tower, hub and nacelle. It is assumed that the WTG can handle this 2% extra weight of the A frame. If the A frame must handle the blade all by itself the extra down forces become approx. 102% of the normal down forces. Whether the WTG can handle this is not clear, but a crane vessel can accompany the A frame to reduce the down forces on the nacelle. Calculations concerning these extra forces can be found in Appendix (VII)

Assumed Strong points

The assumption is that the strong points of the construction are located where the connections are made to connect the A frame to the nacelle. The problem of these connection points is that they are calculated to lift (pulling force) 235 tons. This is the weight of the nacelle; it is not calculated on a pressure force of 40 tons (30 tons for the blade with a safety factor and 10 for the A frame). But for this research it is assumed that together these strong points on the nacelle can handle at least 235 tons of pulling force and approx. 100 tons of pressure force in total. Another strong point in the WTG is the hub, assuming that the hub can handle the gravity of 3 blades, which is 70 tons (down force = 700kN).

7.1 Lifting appliances according to DNV certification[8]

The requirements of the A frame are according to the DNV certification for lifting appliances 2011. In Appendix (XI) called 'Lifting appliances', the relevant sections are mentioned.
For this research the following was used:

SECTION 3
MACHINERY AND EQUIPMENT
B. Components
B 100 Winches
D/d ratio higher than 18
B 500 Steel wire rope with fittings and anchorages

$$S_F = \frac{10^4}{0{,}885 * SWL + 1910} = \frac{10^4}{0{,}885 * 30{,}29 + 1910} = 5{,}8$$

SECTION 6
OFFSHORE CRANES
A. Material and fabrication
B. Structural strength
B 100 General
offshore frame safety factor of 1.3
B 200 Loads due to operational motions

7.2 Frame type

In the concept phase, the first idea was to make an A Frame, but in this section other possibilities will be elaborated. Possibilities for the following structures are:

Frame types	weight compensation
A frame	contra weight
upside down U frame	extra connection points
rectangular frame	none

Table 7, Possible Frame types

Figure 29, possible Frame types

The upside down U frame will probably be complicated to fabricate. Also it is not the best option for guiding the reaction force. This frame is designed to convert horizontal forces into a vertical force.
Rectangular frames will not be the most efficient in catching all the forces. The stresses will become too large or the frame will become too large so the A frame will be the best option. A triangular frame will guide the vertical forces into horizontal forces. Triangular frames are mainly used in lifting equipment.

[8] Source (8)

7.3 Hub rotating solution

There are three main modifications possible to accomplish rotation of the hub. This is necessary because after the installation of the second blade, one blade must cross over vertically at the spot where the A frame is located. This section of the product must be decided upon first in order to find out which parts need to be designed.

Possibilities for making the hub twist are:

1. Making the device flip/lift, like a rocker (figure (30 & 31))
2. Fold the lifting device into a linear frame.
3. Rotate the lifting device.

Ad. 1) Lift the A frame

In figures (30 & 31) the four steps that are globally needed to install three blades are made visible. Between step 1 and 2 and during step 3 the hub twists 120 degrees. Step 3 is the part where the A frame must be lifted to make place for a passing blade. This can be done by cylinders or by blocking the wire and pulling the frame towards the winch.

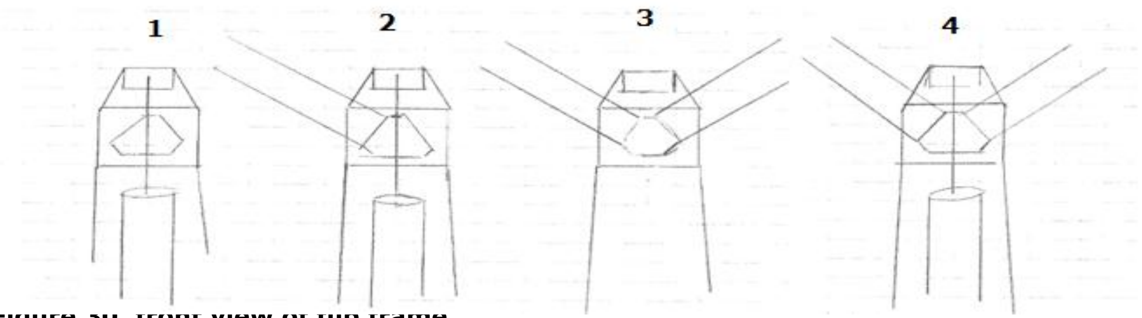

Figure 30, front view of flip frame

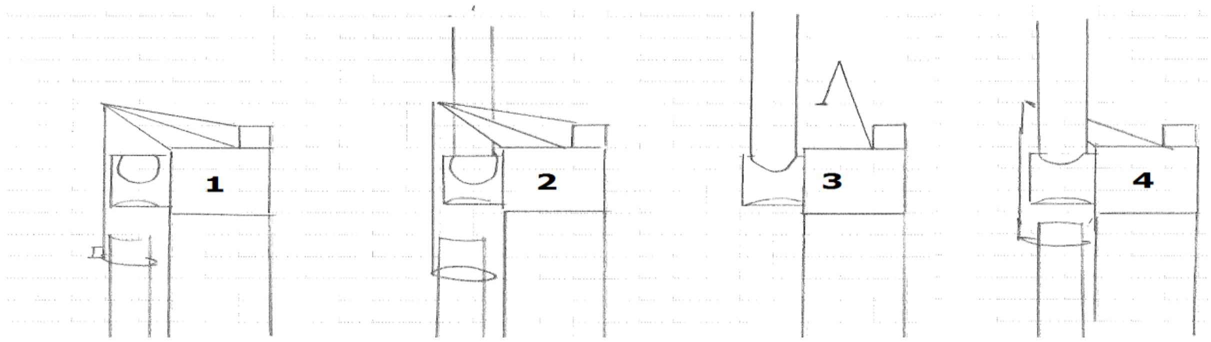

Figure 31, side view of flip frame

Made by: Jasper Breeuwsma

Ad. 2) Folding the A frame

Option 2 (Figure (32) is folding the A frame. In the middle of the upper beam a node or hinge must be added, so that the folding process is possible. This process is much more complicated than option 1. It is assumed that only a pulling force acts on the upper beam. The movement can be realised by cylinders or an extra wire circuit.

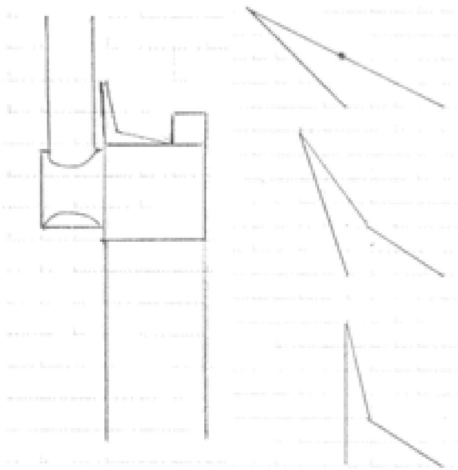

Figure 32, Folding the A frame

Ad. 3) Rotating the A frame

Figure (33 shows a sketch of a top view and front view of a rotating A frame. When the second 120 degrees twist of the hub is needed the A frame rotates 90 degrees to make place for the blade. After this action, the A frame rotates back to its normal position to lift the third blade.

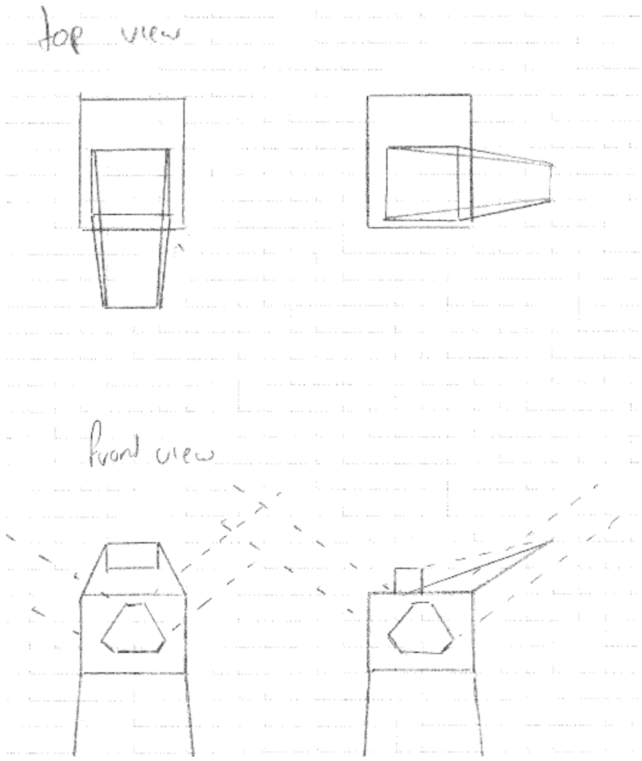

Figure 33, rotating the A frame

Conclusion:

Lifting the A frame and rotating the A frame are the best solutions. However, rotating the A frame will cost extra equipment and space and therefore the choice of a lifting A frame is made. A hinge will be designed that will handle all the reaction forces.

In appendix(VII) calculations were put to calculate if it were possible to pull the A frame up. This would be possible with an hook stopper or hook storage device. The maximum forces from the lifting of the A frame are lower than forces the winch delivers during a blade lift, so it is possible to lift the frame with the winch. The ideal position can be created due to a movement stop in the hinge.

7.4 Nacelle space layout

Secondly the layout on top of the nacelle must be considered. In order to find out the available space on top of the WTG a small research is done. Figure (33) shows that there is space on top of the nacelle. Drawings from AREVA (included in Appendix (X)) show that this space is approx. 4 meters length by 6,5 meters width. The possibility for using the hub as a connection point must be considered. Because the drawings from AREVA do not show the length and diameter of the hub; a few assumptions are made.

Figure 34, space layout

Figure 35 shows a sketch from the hub. The front circle has a diameter of 4 meters(red); a back circle diameter of 5 meters (blue) and a length of the hub of 5 meters (green).

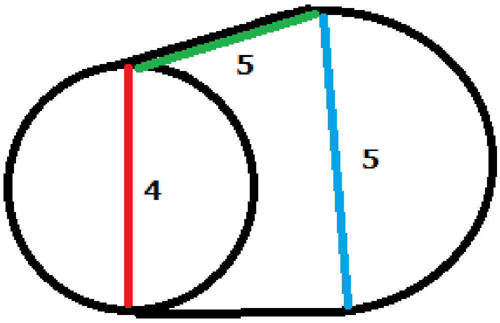

Figure 35, sketch hub

All parts of the A frame need to be mapped. There are two layout options which are explained further in this report.

Option 1

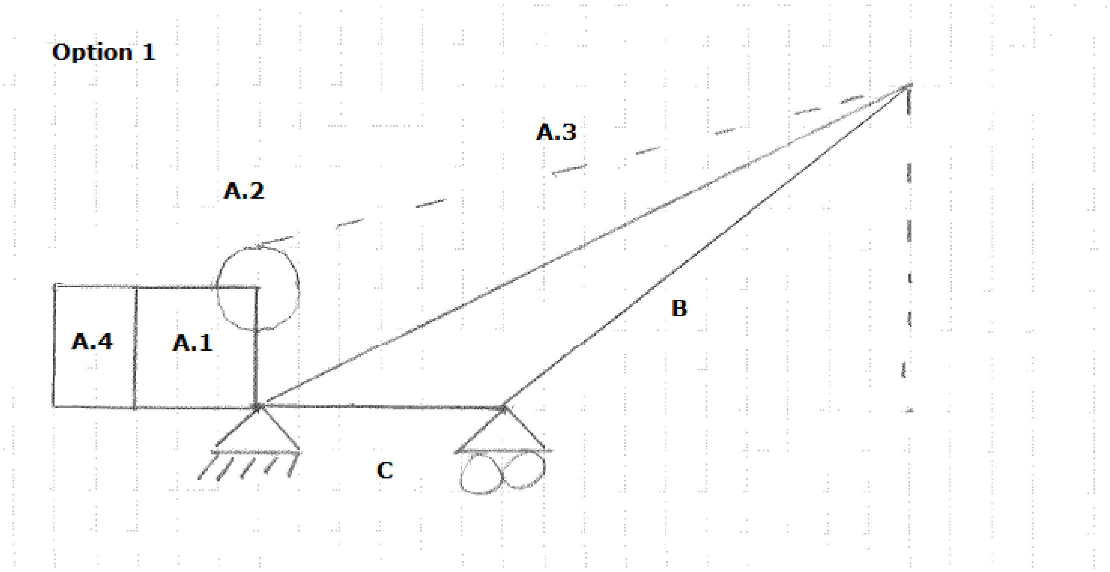

Figure 36, Frame layout option 1

A.1: The winch, consisting of an engine and a shaft to guide the forces from the motor to the drum and gearbox
A.2: Drum, this is where the wire is stored
A.3: The wire
A.4: The power supply for the engine
B: The frame
C: Connection points to the WTG

Option 2

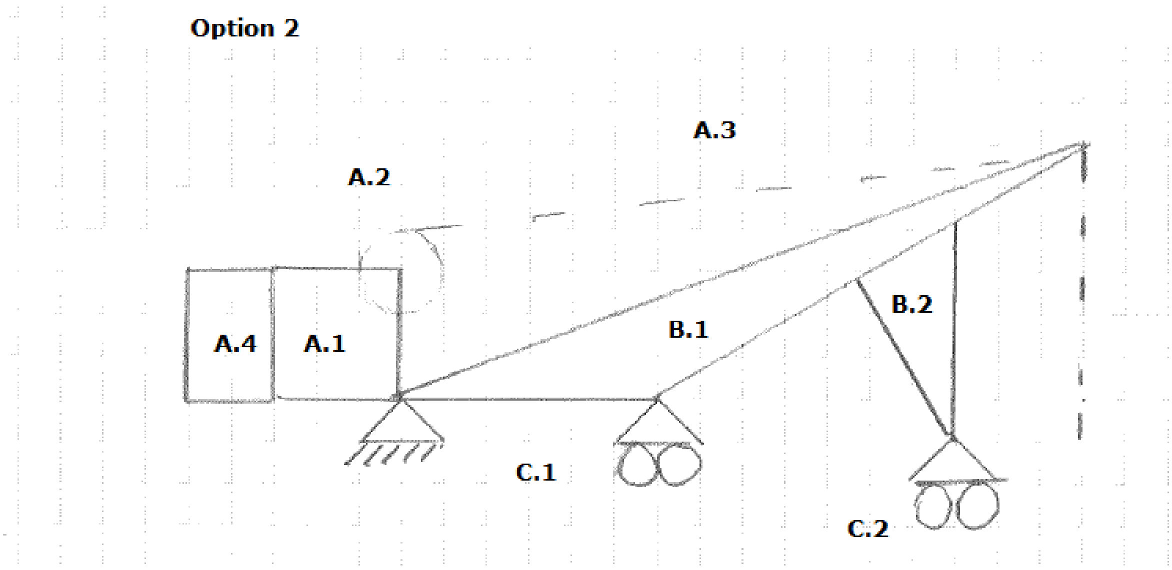

Figure 37, Frame layout option 2

A.1: The winch, consisting of an engine and a shaft to guide the forces from the motor to the drum and gearbox
A.2: Drum, this is where the wire is stored
A.3: The wire
A.4: The power supply for the engine
B1: The basic frame
B2: A supporting point that connects to the hub
C.1: Connection points to the nacelle
C.2: Connection points to the hub

The main difference between option 1 and option 2 are the frame adjustments. These frame adjustments can have an effect on all the other parts.

Initially section A is researched, further for both options section B and C will be researched. Arguments will determine the choice between the two.

7.5 Section A: The power train of the A frame

To determine the sizes of the drum, wire and engine a study concerning the reevings must be conducted.

Available space for drum

The drum can have a maximum width of 6 meters because the nacelle has a maximum width of 6.5 meters. The remaining 0.5 meters will be necessary for the transmission. It is possible that these sizes will be influenced: the transmission can be a direct shaft, (v-) chain or a gearbox. The diameter of the drum can be determined when the balance between the line pull and the delivered torque on the shaft of the drum is found.

Reevings

Using reevings will make it possible to choose the sizes of the winch and drum. The following table shows the line pull per number of reevings:

Line pull									
min	23,3	ton	23300	kg	233000	N	233	kN	
safety factor	1,3	ton							Required wire
# reevings	30,29	ton	30290	kg	302900	N	302,9	kN	meters
1	30,29	ton	30290	kg	302900	N	302,9	kN	100
2	15,145	ton	15145	kg	151450	N	151,45	kN	200
4	7,5725	ton	7572,5	kg	75725	N	75,725	kN	400
8	3,78625	ton	3786,25	kg	37862,5	N	37,8625	kN	800
16	1,893125	ton	1893,125	kg	18931,25	N	18,93125	kN	1600
32	0,946563	ton	946,5625	kg	9465,625	N	9,465625	kN	3200

Table 8, Winch power per number of reevings

The maximum number of reevings will be put at 8, because more reevings will have a negative effect on the required drum space and lifting speed.

Wire[9]

There are different factors involved in selecting the right wire.
In table (9) wires from a diameter of 12mm till 28mm are listed with their weight per 100m and minimum breaking load. There are many different types of wires on the market. The table below shows three different types from one fabricator.

18x7+FC **19x7** **35Wx7**

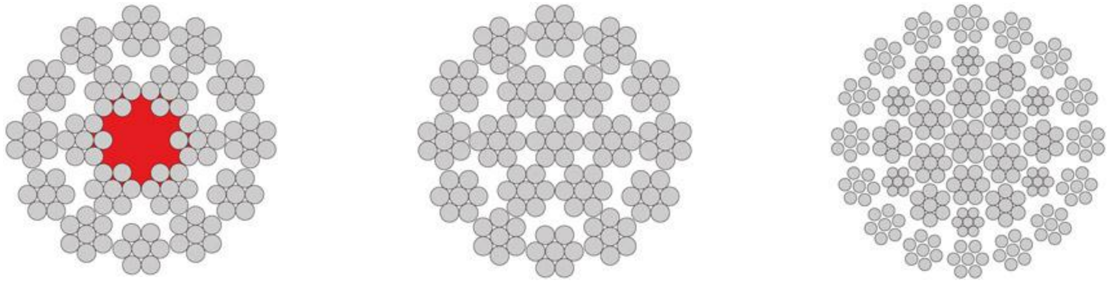

Figure 38, three types of wires

These wires are just an example of different types sold by one fabricator. Other wires can have better specifications but these wires were used for further calculations.

Nominal diameter	Weight 100 m	Minimum breaking load		
mm	kg	kN	kg	
12	55	92,6	9442	18x7+FC
18	124	208	21244	
24	220	370	37766	
12	57,7	92,6	9440	19x7
18	130	208	21200	
24	231	370	37800	
14	89	148	15100	35Wx7
16	116	194	19800	
18	147	245	25000	
20	182	302	30800	
22	220	366	37300	
24	262	435	44400	
26	307	511	52100	
28	356	593	60500	

Table 9, Possible wire diameters and their braking load

From the information on the line pull and the different types of wires the sizes of the drum can be chosen. The calculations will determine a torque needed to act on the shaft of the drum.

[9] Source (9)

Drum

In order to find a realistically required torque, a balance must be made between the necessary space for wire storage and the diameter of the drum.

There are three factors that affect the choice of the drum:

- D/d ratio
- Fleet angle
- Layers

The relation between the wire rope diameter as it is bent around the drum diameter is expressed as a (D/d) ratio (drum diameter divided by wire diameter). The smaller the ratio the sharper the bend a wire must make as it spools around a drum. A minimum D/d ratio of 18 is handled, however, a higher ratio is recommended.

The angle between the center line and the lead sheave and the center line of the rope leading to the drum is called the fleet angle. The higher the fleet angle is, the higher is the friction between the layers and inside the wire. An option to lower the fleet angle is to choose a smaller drum width or to change the position of the drum during the lifting operation. Figure 40 shows three ways of moving the drum. Movement A rotates the drum to eliminate the fleet angle. Movement B moves the drum longitudinally to eliminate the fleet angle, and movement C moves the drum widthwise. This last method cannot eliminate the fleet angle totally.

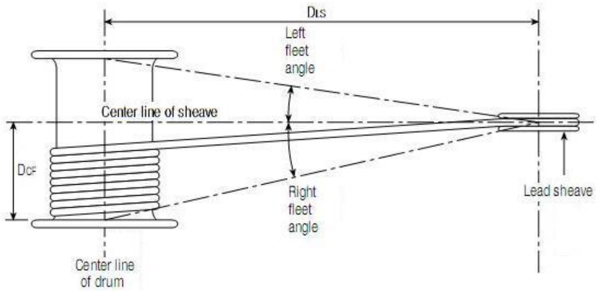

Figure 39, Fleet angle

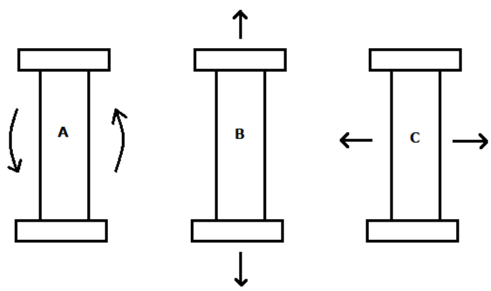

Figure 40, Drum movement

Because of space constraints option B is the best method for erasing the fleet angle.

Due to the extra movement of the drum, the maximum width of the drum is again limited. To fully eliminate the fleet angle the wire must continually move over the center line of the drum and lead sheave.

The frame width is 6 meters, assumed is that on both sides empty space of 0,5 meters is needed for maintenance. 5 meters is left for the drum, but to eliminate the fleet angle the drum needs to move longitudinally over these 5 meters. So the maximum drum diameter is now 2.5 meters. Assuming that the mechanism that moves the drum will take 1 meter in total the drum width is limited to 2 meters.

So 0,5m for the movement of the drum, 0,5m for the transmission, 1m maintenance and 2m for the drum. Then 2m is free for the movement of the drum.

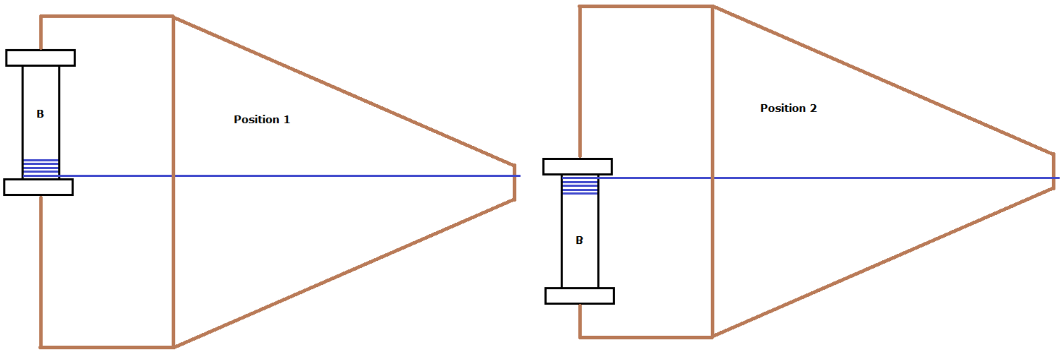

Figure 41, Drum positions

Figure 41 shows two drum positions. The fleet angle is eliminated and the maximum drum width is 2 meters, but 1 meter will also work.

In order to determine which wire diameter, drum length and drum diameter will function best, the following table(10) is made.

Width [m]	1,00	drum diameter				Lebus factor	1,20
Wire		0,25	0,50	0,75	1,00	1,25	1,50
mm	possible windings	D/d					
8	104	31	63	94	125	156	188
12	69	21	42	63	83	104	125
16	52	16	31	47	63	78	94
20	42	13	25	38	50	63	75
24	35	10	21	31	42	52	63
28	30	9	18	27	36	45	54
32	26	8	16	23	31	39	47
36	23	7	14	21	28	35	42
40	21	6	13	19	25	31	38
44	19	6	11	17	23	28	34
48	17	5	10	16	21	26	31
52	16	5	10	14	19	24	29
56	15	4	9	13	18	22	27
60	14	4	8	13	17	21	25
64	13	4	8	12	16	20	23
68	12	4	7	11	15	18	22

Table 10, Wire diameter, windings and D/d

Drum diameters with a diameter lower than 0,75 meter have a very low D/d ratio. Also listed are the possible number of windings and the wire size. In this calculation a space factor (Lebus factor) of 1.2 is calculated to accomplish that the wires in one layer are not touching each other. For example: With a wire diameter of 10mm, on both sides of the wire 1mm extra space is implemented to erase fraction.

It is important to check if there is enough wire storage and how many layers are needed. Calculations concerning this storage can be viewed in table:

Width [m]	**1**	**Wire diameter [m] →**	**0,008**	**0,012**	**0,016**	**0,020**	**0,024**	**0,028**	**0,032**	**0,036**
% layers		Windings→ Drum diameter V	**104**	**69**	**52**	**42**	**35**	**30**	**26**	**23**
Layer	1	1	329	219	165	132	110	95	83	74
Layer	2	1	657	439	330	264	221	190	166	148
Layer	3	1	987	660	496	398	332	286	251	223
Layer	4	1	1318	882	664	533	445	383	336	300
Layer	5	1	1651	1105	833	669	560	482	423	378
Layer	6	1	1984	1330	1003	806	675	582	512	457
Layer	7	1	2320	1556	1174	945	792	683	601	538
Layer	8	1	2656	1783	1347	1085	911	786	692	620
Layer	9	1	2994	2012	1521	1227	1030	890	785	703
Layer	10	1	3333	2242	1696	1369	1151	995	878	787
Layer	11	1	3673	2473	1873	1513	1273	1102	973	873
Layer	12	1	4015	2706	2051	1658	1397	1210	1069	960
Layer	13	1	4358	2940	2231	1805	1521	1319	1167	1049
Layer	14	1	4702	3175	2411	1953	1648	1429	1266	1139
Layer	15	1	5047	3411	2593	2102	1775	1541	1366	1230

Table 11, wire storage on drum

Safety factor calculations according to DNV Lifting appliance:

$load = 30{,}29\ tonne = 302{,}9\ kN\ S_F = 5{,}81\ \#\ of\ reevings = 4$

$$\frac{302{,}9}{4} * 5{,}81 = 440{,}0\ kN\ wire\ strength$$

Out of the calculations the following sizes were chosen:
Drum: own build
Diameter: 1 meter
Width: 1 meter
Layers: 6
Windings: 35
Flange diameter: 1,3 meter
Storage: 675 meter
Maximum number of reevings: 4
Line pull First layer needs to be minimum 8 tonne
Required torque drum shaft = 78 kN/m
Wire: 35Wx7
Diameter: 24mm
D/d ratio: 42
Weight per 100m: 262 kg
Total weight inclusive storage: 1768,5 kg
Minimum breaking load: 444 kN = 44400 kg

Engine and transmission

For choosing the engine and transmission, the preferred hook speed must be calculated. The auxiliary hoist from the Oleg Strashnov can lift masses up to 200 tons with a speed of 24 meters / minute. This is not a criterion for the A frame. For further calculations the criterion will be set on a maximum speed of 6 meters / minute.
With the chosen drum and wire the requirements of the engine with or without transmission can be calculated:

$$6\frac{m}{min} = 0{,}1\, m/s$$

With the drum diameter of 1 meter the rotational speed will be:

$$v = \pi * d * \frac{n}{60} \;\&\; v = \omega * \frac{d}{2}$$

$$1{,}9\, RPM = \frac{1}{\left(\frac{10\pi}{60}\right)}$$

$$0{,}2\frac{Rad}{s} = \frac{0{,}1}{0{,}5}$$

Because of the 4 reevings, the drum speed is 4 times higher. This results in a drum speed of 7,6 RPM.

$$power = toqure * \frac{speed(RPM)}{9{,}5488} = 78000 * \left(\frac{7{,}6}{9{,}5488}\right) = 62{,}8\, kW$$

Between the drum and the engine a transmission can be placed. This is necessary in this case, because of space, energy supply and mechanical possibilities there is no option of finding a motor with a torque with 78kN/m and a rotational speed of 8RPM.

The following transmissions are possible:

1 on	RPM	Nm
100	763,9437	785,12
200	1527,887	392,56
400	3055,775	196,28
800	6111,55	98,14
1600	12223,1	49,07

Table 12, Transmissions with RPM and torque

Engine and power supply

Four types of engines and their power supply are possible:

- Electric engine driven by:
  - Batteries
  - (on fuel) Electric generator
- Hydraulic engine with hydro pump, the hydro pump can be driven by
  - Batteries
  - Electric generator
- Pneumatic engine driven by
  - Pressure tanks
  - Air compressors
- Fuel driven engines supplied by
  - Fuel tank

Fuel driven engines have a higher torque on high rotation speeds. For lifting on lower rotation speeds a high torque is needed. This can be accomplished with the other three possibilities. Hydraulic engines can deliver enough torque and rotational speed, but there is a chance that there is no space for also adding a hydraulic power supply on top of a WTG. Pneumatic engine's can handle high rotational speeds but not very high torques. Due to limited space double transmission and transmission above 1:800 are not recommended. The best option will be an electric power train.

Electric option
The HVH250 series electric motor from Remy is a possibility. The specifications are listed in Appendix (V)
The HVH250 high Torque delivers:
Continuous power output of 60 kW
Continuous torque output of 243 Nm
A peak efficiency of 93% between 1500 rpm and 8000 rpm

To create the power supply for the HVH250 a 60kW generator can be selected. Examples of possible generators are:

- Generac Guardian Series™ 60 kW Standby Generator (LP - Steel)
- PM0601250
- Movie Quiet® 60KW Generator 500 Amps Prime Power @ 120 Volts

There are many different 60 kW generators on the market with different specs.

Another easy solution is bringing the power supply for the A frame from the vessel to the nacelle. The vessel also needs to bring a power supply to the WTG to twist the hub, the same power can be used to drive the A frame.

For now the option of using the power of the vessel connected to the tower is used.

Brake
The breaking force must be 78kNm on the drum. With a transmission this is 196 Nm on the motor shaft. An option can be the M100 from TWG.
Multiple brakes are needed due to the DNV lifting appliance. Brakes are always on when there is no power delivered to the brake.

Parts:
Engine: HVH250 high Torque
Transmission: gearbox with ratio = 1:400
Brake: M100 TWG
Frame: Own design

7.6 Section B: The frame

Appendix (VII) presents the calculations concerning the reaction forces of the frame. Different inputs were chosen to calculate the best option. Differences in input are:

- Two fixed points
- Roller support on front connection points
- Frame height

The three different calculations are checked with the program SACS. The results for the roller support are correct. It is assumed that with the two fixed points, the calculation with the ratios is incorrect. This ratio only has effect on the horizontal reaction forces. In SACS 2D and 3D simulations were made. All SACS simulations can be found in Appendix (XII). The 2D simulations were made to check the hand calculations and the 3D simulations were made to find the correct reaction forces and stresses.

Calculations lead to the following conclusions:
For the frame with a fixed connection:

- The higher the frame is constructed, the lower the overall horizontal reaction forces are. If the frame is too high, the beam AC changes from a pressure beam to a traction beam. This is a result of the moment which is created by the horizontal forces of the wire.

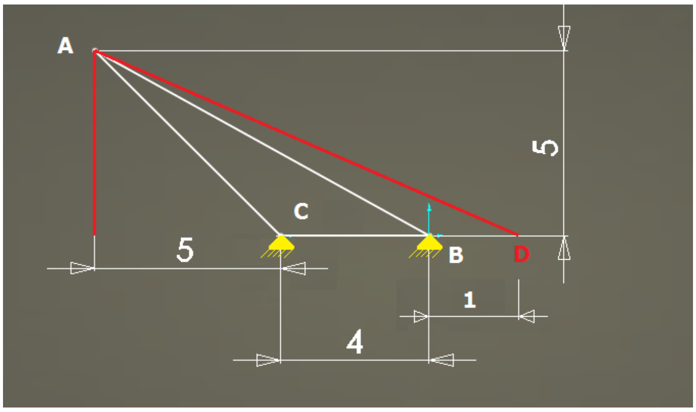

Figure 42, A frame with fixed connection points

Optimal frame sizes for two fixed type of frame are:

  - ACh (horizontal) = 5 meter
  - Acv (vertical) = 4 meter
  - CB = 4 meter
  - BD = 1 meter

For the frame with one roller (on point C) the conclusions are:

- The higher the frame is constructed, the more forces will come on point C, reacting into a negative force (up) in point B.
- Because C will not catch the horizontal forces, all forces from the horizontal line pull will be caught up by connection point B.

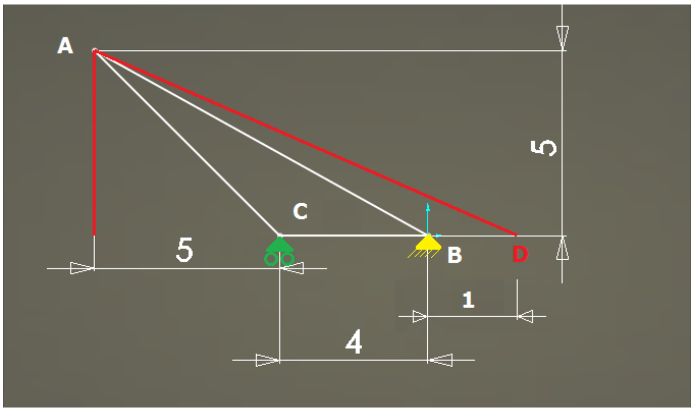

Figure 43, A frame with roller on nacelle

- Optimal frame sizes for the roller positioned frame fixed are:
    - ACh (horizontal) = 5 meter
    - ACv (vertical) = 4 meter
    - CB = 4 meter
    - BD = 1 meter

For the frame with one roller located on the hub (on point E) the conclusions are:

- Adding an extra connection point on the hub will have an effect on the forces in C and B, all forces are lower.
- Because C will not catch the horizontal forces, all forces from the horizontal line pull will be caught up by connection point B.
- The increase of the distance between E en C (horizontally) will have little effect on the reaction forces in B, the highest distance is the best option to catch the vertical reaction forces.

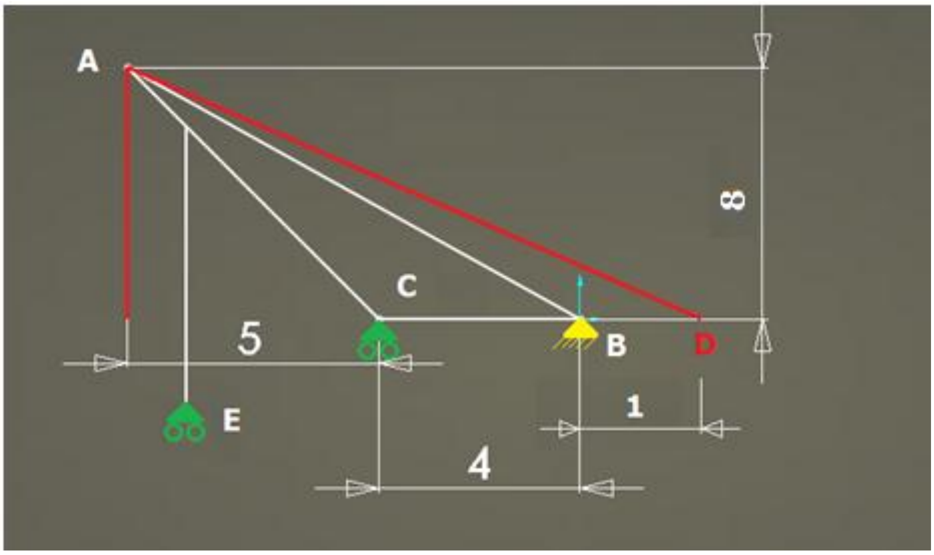

Figure 44, A frame with roller on nacelle and hub

- Optimal frame sizes for the hub connection type frame are:
    - ACh (horizontal) = 5 meter
    - ACv (vertical) = 8 meter
    - CB = 4 meter
    - BD = 1 meter
    - EC (horizontal) = 4 meter

Calculating the last option with fixed points in B and C is a subject for further research. The reaction forces of a 3D frame are different than the ones calculated in the 2D calculations. The program SACS will give the correct reaction forces for a 3D frame.

Option 1 versus Option 2:
Calculations show that the best option for the design of the frame will be the one with the roller on the hub. Adding an extra connection point will lower all the stresses in the construction. The hub is designed to handle 70 tons of vertical forces and the flipping mechanism will work with this type of frame.

Material
Most of the offshore constructions are made of steel. Structures in harsh working conditions like in the offshore industry require a specific range of steels to promote greater safety, longer working life and reduce the risk of failure.

Offshore Steel Characteristics:
Characteristics for offshore steel are:
High yield strength
Excellent weld ability
Good internal soundness
Good resistance to brittle fracture (longitudinal and transverse)
Low phosphorus and sulphur contents
High resistance to lamellar tearing

For structural steel, the choice is more limited, the four best choices are:
EN10225:2001 – S355 Offshore Structural Steels
EN10225:2001 – S420 Offshore Structural Steels
EN10225:2001 – S460 Offshore Structural Steels
EN10225:2001 – S460 Offshore Structural Steels
EN10225:2001 – S690 Offshore Structural Steels

The number following the S in all the structural steel types shows the yield strength in MPa, so the S355 has a yield strength of 355 MPa. The higher the yield strength, the less frame thickness is needed to handle the same forces.

S355 steel is often used for offshore constructions; this is the main reason it is selected for the A frame. A higher yield strength is not necessary and higher steels are harder to modify and weld.

Frame profile and stresses[10]

Different profiles are possible. The following profiles have been checked for maximum stress and buckling:

- Rectangular (HxWxt): 15 x 5 x 0,4 cm
- Rectangular (HxWxt): 30 x 20 x 1 cm

Both options are with S355 steel quality.

Conclusions per profile:

With the maximum force acting on the top of the A frame(in point A): The smaller frame will handle these stresses. It is calculated that the rectangular (HxWxt): 15 x 5 x 0,4 cm will have a maximum stress of 14,9 MPA which is less than the yield strength of 355 MPA (S355 steel).
The Rectangular (HxWxt): 30 x 20 x 1 cm has a lower maximum stress due to a higher area. The maximum stress will be 2,4 MPA, which is much lower than 355 MPa These results are also checked in SACS. According to SACS the bending of the bigger A frame will be less and it will not have a big affect on the space requirements the rectangular (HxWxt): 30 x 20 x 1 cm is selected.

The stresses out of the SACS simulation are not much different. For the fixed connection the maximum stress is 51,6 MPa, The hub connection is 18,6 MPa, which is more likely. Out of the 3D simulations the stress with one roller connection point is 23MPa and with two roller connection points is 22,6 MPA. The A Frame with two roller connection is has the best 3D solution.

Hinge

A hinge is added to create the flipping movement needed to twist the hub. This is necessary to install the third blade (see Chapter 8.5: Hub rotation solution). The reaction forces from calculations on the hinge are:

- Horizontal reaction forces: 116,1 kN
- Vertical reaction forces: 51,3kN

There are hinge's in the offshore industry that can handle these forces.

[10] Source(10)

7.7 Section C: Connecting to the WTG

There are some options for connecting the A frame to the nacelle:

1. Using the connection points that are used for lifting
2. Using (vacuum) suction pads

Ad 1) The drawings from AREVA, which can be viewed in the Appendix (X), show that some connection points can be found in the lifting points on the nacelle.
Possibilities to connect to these points are:

- hydraulic clamp
- bolted connection
- welding

Welding will not be a good idea, due to the speed of the connecting process. The hydraulic clamp needs a hydraulic power supply. This power supply is not available. So for this situation the best option is a bolted connection. This can be a hole – pin connection.
One of the benefits of connecting the A frame to these lifting points, is that these points are located above the centre of gravity (COG) of the nacelle. This is for reasons for better transport. This does not mean that the COG of the tower and nacelle is located in the same place.

Ad 2) Another possibility is connecting the A frame with suction pads. Using suction pads will make it possible to install the A frame on different types of WTG's. Further research will determine if suction pads are a possibility. These suction pads can be located on the four corners of the A frame. The arm of the suction pad must have multiple angles of freedom to make a connection to the WTG. A drawing concerning this idea can be found in the Appendix (IX): Drawings and ideas.

Because suction pads are less reliable option 1 is selected. Suction pads can slip so accurate positioning is not always guaranteed. For option 1 the best solution would be if the A frame is implemented to the frame of the nacelle or to the whole WTG. This way the forces will be guided by the whole frame of the WTG and not only by the nacelle.

7.8 COG & affects A frame on WTG

To find out if there are changes into the Centre Of Gravity by adding the A frame on the WTG, different calculations were made. The first one is to find out how much effect the A frame has on the total weight of the WTG. The following table gives an overview of all the masses.

part	mass [mt]	[kg]
Nacelle	235	235000
hub	64	64000
S1	85,8	85800
S2	88,5	88500
S3	174,6	174600
A frame	10	10000
mass 1 blade	23,3	23300
Total mass WTG (with 3 blades)		717800
total mass with A frame (2 blades installed and 1 in clamp)		727800
Mass gain only A frame in %		101,39%

Table 13, WTG parts and masses

The effect of added mass to the WTG because of the A frame is nihil. The added mass is less than 2%. Assuming that the WTG (frame) is built with safety factors above 2% of its weight, this will not be a problem. It is assumed that wind turbine generators are designed on a higher safety factor than 1.02. The maximum forces on the WTG during the last (third) lift are calculated to be the A frame and one blade (727800 kg).

The AREVA drawings (Appendix (X)) also show that the COG (Schwerpunkt) is located right under the middle of the tower. Even if the COG of the A frame is out of the range of the nacelle, the effect will be over calculated by safety factors.

7.9 Lifting plan and schedule

There are two main options for the A frame:

- Keep the A frame on the WTG (for the whole lifetime of the WTG)
- Re-use the A frame to install multiple WTG blades

Each method has its own possibilities. First the methods will be explained after which the advantages and disadvantages will be listed. Also a costs overview is made which will be used as an argument to choose the best method.

In all schedules the plan is to install a WTG farm of 100 WTG's.

7.9.1 Price of the product

To give a better price indication a part list has been made. A budget is given to each part. Also the weight per part is given and summed.

Part	Type	Price budget	Weight [kg]
Winch		€20,000.-	
Engine	Purchased		100
Brake(s)	Purchased		100
Drum	Purchased		500
Wire	Purchased	€5,000.-	1768
Frame	Purchased	€15.000-	5877
Guiding lines	Added		
Total		€50.000.-	8345

Table 14, Part list

7.9.2 Method 1: Keep the A frame on the WTG

The A frame will be installed on the nacelle onshore. This is a cheap operation in comparison to installing the A frame offshore. Together with the A frame the nacelle will be installed on the tower parts as normal. This installation procedure is out of the scope of this project. It is assumed that installing the nacelle with an A frame will take the same amount of time as installing the nacelle without an A frame. After installing the A frame and nacelle the three blades can be installed. The A frame is left behind on top of the WTG so that it can be used for maintenance of the WTG.

Advantages

- No decommissioning costs
- Cheaper maintenance A frame and WTG due to use of A frame
- Strongpoints are no temporary points and have to be implemented in the fabrication of the nacelle.

Disadvantages

- A frame must be engineered to keep it working for 20 years
- Continuous extra forces on the wind turbine
- Loss of efficiencies of the WTG

7.9.3 Method 2: Re-use the A frame

There is a possibility that the whole installation process of multiple WTG's can be done with one A frame. After installing all the blades the A frame will be transferred from the installed WTG on top of the second waiting nacelle on deck. This way it will be possible to only bring one A frame offshore. But a second frame will be necessary in case the first one stalls. The position of the A frame is explained in figure (45).

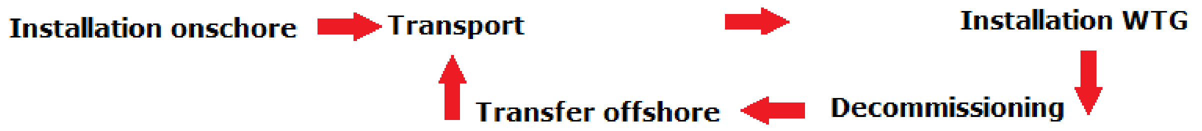

Figure 45, Diagram of position A frame,

The assumption is that four WTG's will be installed from one vessel. Onshore the A frame will be put on one of the four nacelles. The nacelle will be installed first. After installing the blades using the A frame the A frame will be decommissioned and transferred to the next nacelle. The same way the third and fourth nacelle will be equipped with the same A frame offshore. After installing the last blade of the fourth WTG, the nacelle will be decommissioned and stored on deck. If the lifting vessel needs to go back into the harbour to load four entire WTG's (in parts), the same A frame can be used for the installation for the next four WTG's.

Advantages

Design life A frame for max 1 wind farm of for example 10 operations
Less A frames needed for the installation of 1 wind farm

Disadvantages:

Extra lift needed for decommissioning of the A frame

7.10 Economic considerations for installation methods

The following two subjects have an effect on the feasibility of the project:

1. Price of the product
2. Installation method

To find the cheapest method a calculation has been made concerning the installation of a wind farm of 100 turbines. The different aspects per method are reviewed.

First the costs of the use of a lifting vessel must be mapped out as well as the time that it will cost to install one WTG. All factors are discussed with engineers from SHL to check if the time and price indication correct.

In table (15) the inputs and calculation concerning the installation of one WTG are listed.

per 1 WTG			**normal installation hours**	**25**	**hours**
costs heavy lifting vessel	300000	per day	**decommissioning hours of the A frame**	2	hours
	12500	per hour	**Sail time vessel**	40	minutes
			Extra decommissioning time	1,6	Hours
costs installation	332500	euro		80	Minutes
costs decommission a frame	20000	euro			
			total ship used	26,6	hours
total costs for the installation of 1 WTG	332500	euro	**lifetime WTG**	20	years
total WTG in farm	100	WTG's			

Table 15, Installation price wind farm

Useful conclusions are:

- Number of hours it will take to install one WTG with one A frame: 26.6 hours
- Costs of installation of one WTG: €332,500

This information makes it possible to calculate the costs for installing a 100 turbine wind farm.

For method 1 the results are as follows:

The total costs of the installation procedure of a wind farm of 100 WTG's with using and keeping the A frame offshore is 36,3 million euro.

Difference between method 1 and 2 are:

- The purchase costs
- Installation hours of the decommissioning of the A frame

The total costs of the installation procedure of a wind farm of 100 WTG's with the use of 10 A frame is 33,5 million euro. After installing more than 10 WTG's with one A frame more profit can be made.

Bringing two A frames on board for the installation of 100 WTG's is the cheapest option.

keep A frame on WTG	
Construction price of 1 A frame	50000
A frames needed	100
Total purchase costs	€ 5.000.000,00
Time loss due to decommissioning of the A frame	0
Time of installation	€ 2.500,00
Total costs of installation wind farm	€ 31.250.000,00
Total costs: installation and purchase	€ 36.250.000,00
Difference in euro	€ 2.800.000,00

re-use A frame	
Construction price of 1 A frame	50000
A frames needed	2
Total purchase costs	€ 100.000,00
Time loss due to decommissioning of the A frame	1,6
reduction Time in hours	€ 160,00
reduction Time in euro	€ 2.000.000,00
Total costs: installation	€ 33.350.000,00
Total costs installation and purchase	€ 33.450.000,00

Table 16, Installation costs method 1 & method 2

The method: re-use of the A frame is 2,8 million euro cheaper and is advised to use for installing 100 wind turbine blades.

7.11 Detailed lifting plan

On the Oleg Strashnov there is enough space on deck to bring four WTG's in parts.

To find out how many A frame's are needed to install a wind farm of 100 WTG's a calculation has been made regarding two situations.

- Method 1: install four A frames onshore
- Method 2: transfer one A frame each time from nacelle to nacelle.

The difference between the methods is the time needed to switch the A frame from one nacelle to the other. Extra time is needed to position the A frame above the next nacelle. In both situations the A frame must be connected to a solid underground. In method 1 it is the deck. In method 2 it that the nacelle. Therefore this time can be spent during the sail time from WTG to the next foundation. In the following example is it assumed that the vessel moves with 0,25 m/s between the foundations and these foundations are positioned 800 meters from each other. It will take the vessel 40 minutes to get there. It will not take more than 40 minutes to connect an A frame to a solid underground with its hole – pin connection. (see the above calculation in Table 15)

In appendix (VIII) a overview is made to give an indication which steps are needed to install the blades with an A frame. Step 11 and 12 are divided into separate steps to show the difference between bringing four or two A frames offshore.

8 Conclusion & recommendations

The answer to the main research question; proposal of future research and concluding remarks.

Seaway Heavy Lifting (SHL) has a business growth objective of gaining more orders in the wind turbine generator installation field. To accomplish this, Jasper Breeuwsma has worked on a system for offshore single blade installation. Within the available period of time he managed to design a system, which makes it possible, to install blades with Seaway Heavy Lifting's fleet.

With the information gained on the technical specifications of one of the Wind turbine generators AREVA wind produces, a start was made for a concept research. Ten concepts were thought of, each with its constraints and benefits. Out of a customized selection method one concept emerged as being the 'best', this was the concept called A frame. The criteria used for selecting the best concept were safety, time and environmental factors.

The A frame concept is an alternative lifting device that makes it possible to eliminate the relative movement of a floating vessel. With the A frame wind turbine blades can be installed vertically. The use of the A frame will speed up the line up process because the A frame is positioned right above the hub. It is a triangular frame on top of a wind turbine with a small winch on the back of the frame. Calculations were made to check if the A frame can handle lifting one blade at a time.

For installing a wind farm of approx. 100 turbines the most cost efficient method is to bring two A frames on board. After installing the blades on the WTG, the A frame will be decommissioned and installed on a nacelle on board.

Further research must be conducted before physical building and using the A frame:

- Affects of wind on the whole installation process
- Affects of usage on different WTG's
- Product description and construction manual
- COG study on installation process
- Gripper
- Hinge to flip the frame design

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10 Appendixes

The appendixes are structured as follows:

I. Process description

This was the first project I did as a student that i had to do fully on my own for 17 weeks. This brought some complications and challenges. One of them was creating your own schedule and keeping yourself motivated during the project.

The first 4 weeks went fast, I worked hard and I managed to produce a lot of work. Between week 4 and 10 there were period’s were collecting and organizing information became hard and I cost me a lot of energy to keep going forward.
Around week 10 I managed to get everything back on track and started working towards my end goal. The first version of the final report was made around this week. The table of content approved in week 12 and from then on only filling each chapter was put on the schedule. Finalization cost a lot of effort in the last two weeks. The last two weeks it was necessary to work every evening.

II. Meetings

On Wednesday 20-3-2013 the second meeting with AREVA Wind was scheduled. The objective of this meeting was to identify all obstacles encountered while installing WTGs and to specify subsequent actions.

Beneath is shown the agenda of this meeting, underneath the agenda a short description of the meeting.

Agenda

Item		Time
1.0	**Introduction** The objective of this meeting is to develop the project plan and identify open issues to be solved.	9:00
2.0	**Fatigue lifetime estimations** AREVA developed a MBS method to estimate the fatigue damage during sea transport and installation. This should be a good start to define installation and transportation forces.	9:30
3.0	**Tower lift points and installation aids** • Lift method • Lift point design • Lift rigging design • Guiding system design • Landing and locking system	10:30
4.0	**Blade/Rotor installation** • Relative motions during installation due to a floating vessel • Method development for installation • Other obstacles	11:30
Lunch		12:30
5.0	**Miscellaneous** • Hub and Nacelle bearings during transport and installation • Flange tolerances and their fabrication	13:00
6.0	**Qualification plan for demonstrator project**	13:45
7.0	**A.O.B.**	14:30
Finish		15:00

After a short introduction round, the subject: fatigue lifetime estimations started. The main point in this discussion was that the fatigue on the lowest tower part was the one where the problem lays during transport.
Yvan Radovcic gave a presentation about how AREVA Wind calculates all the forces on the WTG during transport and installation. Out of this presentation the discussion started and SHL and AREVA Wind will combine forces to find the best way of handling the WTG.

III. WIV's (Wind Turbine Installation vessels)

Name	Year	Deck Space m2	Capacity (tons)	Speed knots	Leg Length (m)	Water Depth (m)	Jacking speed (m/min)
Oleg Strashnov	2011		5000	14	-	10	-
Stanislav Yudin	1985	2560	2500	12	-	6.5	-
Sea Energy	2002	1020	2386	7.8	32	24	Semi jack up
MPI Resolution	2003	3200	8950	11	71.8	35	0.5
Leviathan	2009	900	1300	8	85.6	41	0.8
Wind Lift 1	2009	2000	2600	8	71	45	0.35
MPI Adventure	2011	3730	3750	12.5	71.5	40	0.35
MPI Discovery	2011	3730	3750	12.5	71.5	40	0.35
Zaratan	2012	2000	2850	9.1	85	45	0.4
Windcarrier 1 & 2 (sister)	2012	3200	5300	12	81.5	45	0.4
Seafox 5	2012	3500	7000	10	106	65	1
Sea Installer	2012	3350	5000	12	83	45	0.5
Van Oord	2012	3300	6500	12	81	45	0.5
Pacific Orca	2012	4300	8400	13.5	105	75	1.2 to 2.4
Pacific Osprey	2013	4300	8400	13.5	105	75	1.2 to 2.4

Stanislav Yudin			**Oleg Strashnov**		
General			**General**		
Name		**Stanislav Yudin**	**Name**		Oleg Strashnov
Flag		Cyprus	Flag		Cyprus
Built Wartsila, Finland		Built Wartsila, Finland	Accommodation	POB	220
Accommodation	POB	143			
Helicopter deck					
Equipped for S-61					
Classification Russian Maritime of Shipping		KM* L32 A2			
Certification crane vessel		DNV 1A1			
Dimensions			**Dimensions**		
Length overall	m	183.2	Length overall	m	183.0
Length of vessel	m	173.1	Breadth	m	47.0
Breadth	m	36.0	Depth from deck	m	18.20
Depth from deck	m	13	Draught	m	8.5 - 13.5
Draught	m	5.5 - 8.9			
Gross tonnage	t	24,822			
Deck load	t	5t/m2 - 10t/m2			
Stanislav Yudin			**Oleg Strashnov**		
Deck space	m2	2,56			
Free deck height	m	20			
Propulsion / power			**Propulsion / power**		
Main engines (three)	kW	4,095	Main engines (six)	kW	4,5

Generators (three)	kVA, V, Hz	4,860, 600, 50	Main thrusters (two)	kW	5
Main thrusters (two)	kW	2,800, fixed pitch, 360°	DP thrusters (two)	kW	3,5
Bow thrusters (two)	kW	880, tunnelled	Bow thrusters (two)	kW	1,012
			Transit speed	knots	14
Emergency power	kVA, V, Hz	200, 380, 50			
Transit speed	knots	12	**Positioning system**		
Ballast system			DP3 positioning system		
Ballasting tanks	m3	24,1	Eight-point mooring system		
Anti-heeling tanks	m3	11,8	Anchors		15 t
Ballast pumps (six)	m3/h	850			
Anti-heeling pumps	m3/h	12,8			
Mooring system					
Eight-point system					
Anchors		10 t Delta Flipper			
Maximum pull	kN	1,8			
Maximum braking capacity	kN	2,59			
Crane			**Crane**		
Make		Gusto	Main hoist		
Main hoist			Maximum revolving capacity	mt	5,000 @ 32 m
Maximum revolving capacity	mt	2,5	Maximum lifting height above water level	m	102
Maximum lifting height above water level	m	78.3	Auxiliary hoist I		
Auxiliary hoist			Maximum capacity	mt	800 @ 72 m
Maximum capacity	mt	500	Maximum lifting height above water level	m	134
Maximum lifting height above water level	m	100.3	Auxiliary hoist II		
			Maximum capacity	mt	200
			Maximum lifting height above water level	m	110

IV. Grading table

All arguments are given in short sentences to explain the grade.

0	comment	Factor	SHL Concept	
			all arguments	Grade
Safety	10 = high	2	crane vessel, controllable due 2 connection points	5
Robust	10 = high	1	crane vessel	5
installation hours	10 = fast	3	pull in from hub, faster	5
Handlings	10 = 1 single movement	3	1 or 2, vertical and installation	5
Wind effects	10 = high	-3	High and new	5
Wave effects	10 = high	-3	medium, but no heave used	5
Start time	10 = fast	2	depends on possibilities of nacelle, extra change on wind turbine	5
usage costs	10 = expensive	-1	crane = expensive, installation of extra winch in turbine	5
building costs	10 = expensive	-1	crane no new, high tech winch	5
Complexity	10 = high	-1	possibility winch inside hub	5

1	comment	Factor	Concept 1	
			Up ending tool	
Safety	10 = high	2	close by & gripper, no wind effects	6
Robust	10 = high	1	less than crane, steel construction	4
installation hours	10 = fast	3	2 moves, different methods	5
Handlings	10 = 1 single movement	3	2, upending and connecting	4
Wind effects	10 = high	-3	gripper, on whole system	3
Wave effects	10 = high	-3	last installation must have heave compensation	6
Start time	10 = fast	2	slower then SHL	4
usage costs	10 = expensive	-1	lower then crane vessel, new only blade in stallion concept	6
building costs	10 = expensive	-1	new concept	7
Complexity	10 = high	-1	2 moves, last move complex	6

2	comment	Factor	Concept 2	
			Robot arm	
Safety	10 = high	2	close by & gripper, no wind effects	6
Robust	10 = high	1	moving parts, but solid system	6
installation hours	10 = fast	3	totally calculated and shortest distance	6
Handlings	10 = 1 single movement	3	1, it can be done in 1 move	6
Wind effects	10 = high	-3	gripper, on whole system	3
Wave effects	10 = high	-3	heave compensation possible in arm	4
Start time	10 = fast	2	to complex, so very long	1
usage costs	10 = expensive	-1	due to a lot of moving parts no long lifetime	6
building costs	10 = expensive	-1	complex, combination of different systems	7
Complexity	10 = high	-1	very complex	8

3	comment	Factor	Concept 3	
			Transformer	
Safety	10 = high	2	external parts, out of range	4
Robust	10 = high	1	maximal construction methods possible	4
installation hours	10 = fast	3	after setting up, same as SHL concept	4
Handlings	10 = 1 single movement	3	same as SHL concept	5
Wind effects	10 = high	-3	Low, but frame makes it extra possible to control blades	2
Wave effects	10 = high	-3	medium, but no heave used	2
Start time	10 = fast	2	extra vessel, to complex, so very long	2

usage costs	10 = expensive	-1	New concept, vessel add-on	7
building costs	10 = expensive	-1	new concept	8
Complexity	10 = high	-1	new concept	7
4	comment	Factor	Concept 4	
			A frame winch	
Safety	10 = high	2	open frame and easy installation	7
Robust	10 = high	1	possibilities depend on effect on wind turbine	7
installation hours	10 = fast	3	together with nacelle	7
Handlings	10 = 1 single movement	3	same as SHL concept	7
Wind effects	10 = high	-3	probably high	5
Wave effects	10 = high	-3	medium, but no heave used	7
Start time	10 = fast	2	little add-on on wind turbine	7
usage costs	10 = expensive	-1	Adding extra frame winches. Different vessel possible	3
building costs	10 = expensive	-1	not a lot of expensive parts	3
Complexity	10 = high	-1	medium complex	6
5	comment	Factor	Concept 5	
			combi 1& 2	
Safety	10 = high	2	combination of 1 and 2, crane vessel, controllable	6
Robust	10 = high	1	combination of 1 and 2, crane vessel, OK	5
installation hours	10 = fast	3	combination of 1 and 2, pull in from hub, faster	6
Handlings	10 = 1 single movement	3	combination of 1 and 2, 1 or 2, vertical and installation 3	5
Wind effects	10 = high	-3	combination of 1 and 2, high	3
Wave effects	10 = high	-3	combination of 1 and 2, medium, but no heave used	5
Start time	10 = fast	2	combination of 1 and 2, depends on possibilities of nacelle, extra change on wind turbine	2
usage costs	10 = expensive	-1	combination of 1 and 2, crane = expensive, installation of extra winch in turbine	6
building costs	10 = expensive	-1	combination of 1 and 2, crane no new, high tech winch	7
Complexity	10 = high	-1	combination of 1 and 2, possibility winch inside hub	7
6	comment	Factor	Concept 6	
			semi sub	
Safety	10 = high	2	partly under water method	3
Robust	10 = high	1	under water method, solid object	3
installation hours	10 = fast	3	slow installation because of change of ballast	4
Handlings	10 = 1 single movement	3	4, and difficult ones	1
Wind effects	10 = high	-3	big area above sea level, whole system effected	7
Wave effects	10 = high	-3	floating installation	7
Start time	10 = fast	2	total new concept	2
usage costs	10 = expensive	-1	total new concept, submersible	8
building costs	10 = expensive	-1	total new concept, difficult	8
Complexity	10 = high	-1	very complex	8
7	comment	Factor	Concept 7	
			kite	
Safety	10 = high	2	wind reliable, storm problems	4
Robust	10 = high	1	2 installations	6
installation hours	10 = fast	3	after installing equipment, fast installation is possible	7
Handlings	10 = 1 single movement	3	3, speed dependency	2
Wind effects	10 = high	-3	works on wind, guided	3

Wave effects	10 = high	-3	little heave problems	4
Start time	10 = fast	2	alternative concept	3
usage costs	10 = expensive	-1	no expensive offshore equipment needed	3
building costs	10 = expensive	-1	no expensive offshore equipment needed	2
Complexity	10 = high	-1	very complex	8
8	comment	Factor	Concept 8	
			wind lift	
Safety	10 = high	2	wind reliable, storm problems and high moving parts	2
Robust	10 = high	1	moving parts, alternative concept	3
installation hours	10 = fast	3	depends on wind	4
Handlings	10 = 1 single movement	3	3, depends on wind	2
Wind effects	10 = high	-3	works on wind	3
Wave effects	10 = high	-3	little heave problems	4
Start time	10 = fast	2	alternative concept	2
usage costs	10 = expensive	-1	no expensive offshore equipment needed	3
building costs	10 = expensive	-1	no whole vessel, but complex and more then add-on	7
Complexity	10 = high	-1	very complex	8
9	comment	Factor	Concept 9	
			balance concept	
Safety	10 = high	2	extra safety (water hits sea level)	4
Robust	10 = high	1	less than crane, but pulley must be perfect engineered	7
installation hours	10 = fast	3	higher than crane	6
Handlings	10 = 1 single movement	3	1 or 2, vertical and installation	7
Wind effects	10 = high	-3	big area above sea level, with water bag other way is possible	7
Wave effects	10 = high	-3	little heave problems	4
Start time	10 = fast	2	little modification on nacelle or hub	6
usage costs	10 = expensive	-1	way cheaper than crane	3
building costs	10 = expensive	-1	not a lot of expensive parts	3
Complexity	10 = high	-1	medium complex, different method	6
10	comment	Factor	Concept 10	
			Catapillar lift	
Safety	10 = high	2	extra complex & moving parts	4
Robust	10 = high	1	a lot of moving parts	3
installation hours	10 = fast	3	same as SHL	5
Handlings	10 = 1 single movement	3	one extra, installing lift	4
Wind effects	10 = high	-3	extra area around WTG	6
Wave effects	10 = high	-3	same as SHL	5
Start time	10 = fast	2	big lift installation around WTG	2
usage costs	10 = expensive	-1	extremely expensive	6
building costs	10 = expensive	-1	extremely expensive	7
Complexity	10 = high	-1	very high, difficult to not affect the WTG	7

V. Part specifications:

A POWERFUL LEGACY | *Engineering the Future*™

Remy

HVH250 Series Electric Motors

Patented Hairpin Stator technology. Highest output, efficiency and power density available.

With the HVH250, Remy combines award-winning, patented hairpin stator technology with a smaller footprint and lighter weight to introduce a customizable motor assembly platform that **boasts the highest efficiency and power density available.**

- 160 kW peak output
- 440 N-m peak torque
- Suited for traction motor, generator, or motor/generator applications

With the largest hybrid motor production and testing facility in North America, Remy stands poised to provide the market with scalable solutions that are available quickly and at lower cost to help reduce dependence on fossil fuels and spur the adoption of hybrid motor technology for transportation.

HVH250, back
Shown with optional spun steel housing

HVH250, front
Shown with optional spun steel housing

HVH250, rotor and stator

"Remy continues to develop several high technology products for the electrification of the powertrain and has secured major production programs for these products, including multiple awards to produce high power electric motors and traction drives for producers of light duty and heavy duty HEVs."

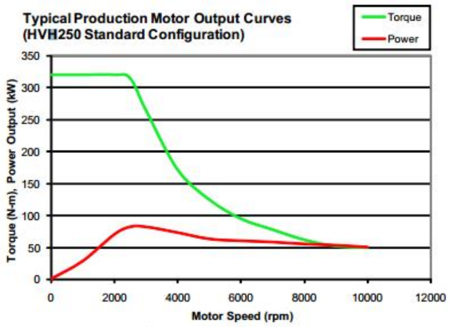
JOHN H. WEBER
President and Chief Executive Officer of Remy International, Inc.

Specifications

	HVH250 Standard	HVH250 HT High Torque	HVH250 High Flow Cooling	HVH250 HT High Flow Cooling
Measurements				
Overall Length (mm)	147	180	147	180
Stator Outside Diameter (mm)	242	242	242	242
Rotor Inside Diameter (mm)	132	132	132	132
Mass - Complete Motor (kg)	33.5	43	33.5	43
Performance				
Continuous Power Output (kW)	60	60	100	100
Peak Power Output (kW)	82	87	150	150
Continuous Torque Output (N-m)	200	243	300	440
Peak Torque Output (N-m)	325	440	320	460
Max. Input Current Peak/ Continuous (Amps)	200/300	200/300	300 continuous	300 continuous
Peak Efficiency (%)	93 @ 2,500-10,000 rpm	93 @ 1,500-8,000 rpm	93+ @ 3,000-7,000 rpm	93+ @ 1,500-8,000 rpm
Max. Operating Speed (rpm)	10,600	10,600	10,600	10,600
Base Speed (rpm)	2,500	1,400	4,000	2,600
Operating Voltage (VDC nom.)	320	320	650	650
Temperature Limits	160° C			
Internal Oil (ATF) Cooling	90C Oil Inlet Temperature		70C Oil Inlet Temperature	
Flow Requirement	5 l/min	7 l/min	25 l/min	30 l/min
Conductor Type				
	High Voltage Hairpin			
Rotor Types				
Permanent Magnet	Internal	Internal	Internal	Internal
AC Induction	Not Available	Optional	Optional	Optional

Optional Content Available: Resolvers, Housings

Standardized and scalable solutions for seamless customer integration.



The HVH250 assembly offers the highest power density among today's conventional electric motors.

Remy International, Inc.
World Headquarters & U.S. Technical Center
600 Corporation Drive, Pendleton, IN 46064
For more information, contact 1.800.372.3555
www.remyinc.com

HVH250 SPECS, r4 09/09

A POWERFUL LEGACY | *Engineering the Future™*

VI. Materials

S355 offshore steel in accordance with EN10225:2001 which covers technical delivery conditions for material in offshore structures.

The chemical and mechanical properties of these steels are engineered specifically for marine/offshore use.

S355G7+M / S355G7+N
S355G8+M / S355G8+N
S355G9+M / S355G9+N
S355G10+M / S355G10+N

The material can be delivered as normalised (N) or thermo-mechanically rolled (M).

As part of the EN10225:2001 specification, Masteel UK Limited supply high quality S420 steel to the offshore Industry.

The standard relates to technical delivery conditions for this steel and is supplied quenched and tempered. Mesteel UK can supply this steel on a global basis, ex–stock from our UK warehouse. As a specific offshore steel product, the material is chemically and mechanically engineered specifically for this purpose.

Good tensile and yield strength are characteristics of this steel range. S420 is used commonly in the construction of offshore structures in some of the world's harshest and most unforgiving environments.

S420G1+Q / S420G1+M
S420G2+Q / S420G2+M

The material can be delivered as quenched (Q) or thermo-mechanically rolled (M).

The offshore industry places heavy demands on material product which are required to operate in some of the harshest natural environments.

Steel is no exception with products being developed specifically for the offshore market under the EN10225:2001 specification for steels used in fixed offshore structures.

Masteel supply Grade S460 under this specification – it is used specifically in the building of offshore platforms. The material is quench and tempered and offers good tensile and yield strength.

S460G1+Q / S460G1+M
S460G2+Q / S460G2+M

VII. Calculations

Frame calculations

The frame and sizes are chosen on their reaction forces. The calculation done for this is divided into three methods.

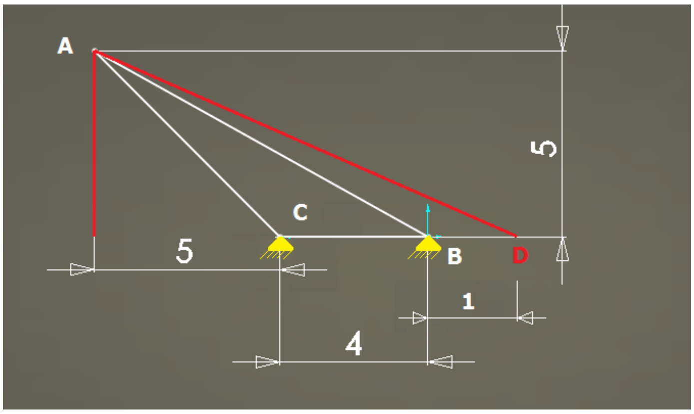
- Fixed connection
- One roller connection
- Two roller connections

The calculations were as follows:

Fixed connection

Standard equilibrium calculations:

Light gray is the wire with has a tension(with safety factor) in this case of 30mT.



Yellow, fixed connection

D = assumed position winch

2 fixxed	Ton → A frame 1	30,29	mt	15,145	mt	gravitatie	9,814
ACv	4	m	1	2	3	4	5
ACh	5	m	5	5	5	5	5
CB	4	m	4	4	4	4	4
BD	1	m	1	1	1	1	1
D +/- of B	+	#	+	+	+	+	+
AC	**6,4**	m	**5,1**	**5,4**	**5,8**	**6,4**	**7,1**
AB	**10,8**	m	**10,0**	**10,2**	**10,4**	**10,8**	**11,2**
Ax	**138,0**	kN	147,9	145,7	142,4	138,0	132,9
-Ay	**203,8**	kN	163,4	177,8	191,3	203,8	215,1
Bx	**127,3**	kN	241,5	194,6	156,9	127,3	104,2
By	**116,8**	kN	167,3	149,4	132,4	116,8	102,7
Cx	**10,7**	kN	***-93,6***	***-48,9***	***-14,5***	10,7	28,8
Cy	**320,6**	kN	330,7	327,1	323,7	320,6	317,8

Because there are two triangle's the forces is divided into two. So the actual load is 15,145 mt.

First the forces in A are calculated. These are:

$$Ax = \left(\frac{m * g}{Lab}\right) * Ladh = 15.15 * \frac{9.814}{10.8} * 10 = 138$$

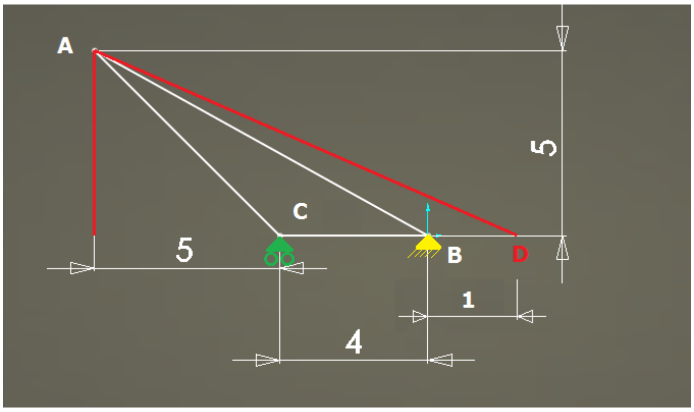
$$Ay = (m * g) + \left(\frac{m * g}{Lab}\right) * ACv = 15.15 * 9.81 + \frac{9.814}{10.8} * 4 = 203.8$$

These are the x and y component of the force in A.
Reaction forces in B and C are calculated as follows:
By is a result of the moment around point C
Cy is a result of the moment around point B
Bx and Cx are calculated by a catch ratio of point B and C
These ratio is the moment of B + the moment of C and than in % how much C is and how much B is:

M C	125		-576	-373	-138	125	411
M B	1486		1486	1486	1486	1486	1486
Sum M	1612		910	1113	1349	1612	1897
% C	0,92		1,63	1,34	1,10	0,92	0,78
% B	0,08		-0,63	-0,34	-0,10	0,08	0,22

These % C and % B are then multiplied by Ax

Roller connection



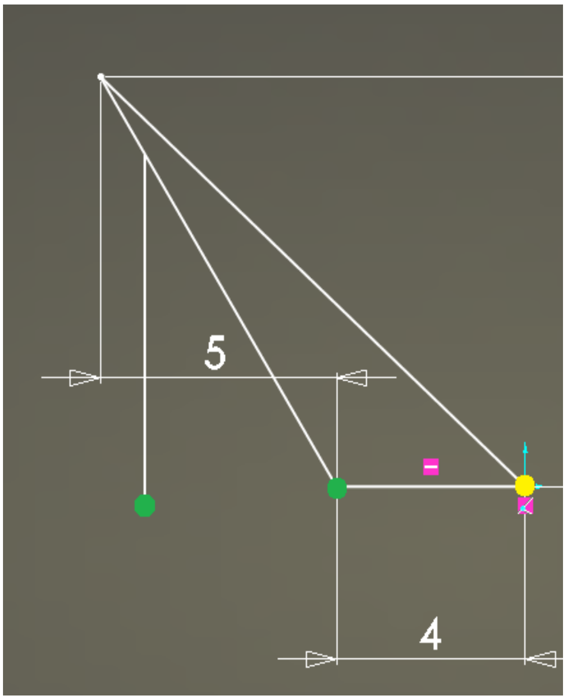
Green, roller connection
Yellow, fixed connection
D = assumed position winch

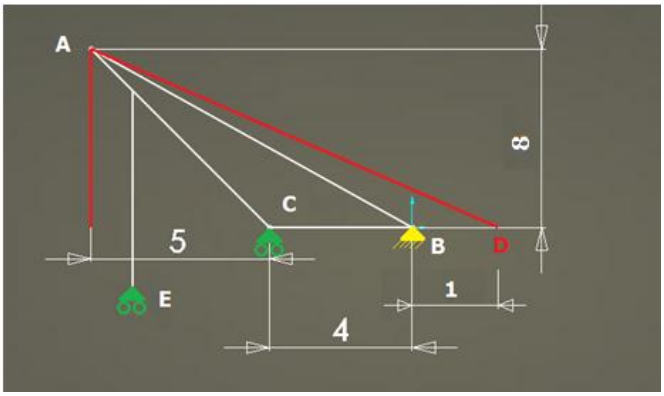
roller	aantal ton A frame 1	30,29	mt	15,145	mt	gravitatie	9,814
ACv	4	m	2	3	4	5	6
ACh	5	m	5	5	5	5	5
CB	4	m	4	4	4	4	4
BD	1	m	1	1	1	1	1
D +/- of	+	#	+	+	+	+	+

B							
AC	**6,4**	m	**5,4**	**5,8**	**6,4**	**7,1**	**7,8**
AB	**10,8**	m	**10,2**	**10,4**	**10,8**	**11,2**	**11,7**
Ax	***-138,0***	kN	***-145,7***	***-142,4***	***-138,0***	***-132,9***	***-127,5***
Ay	***-203,8***	kN	***-177,8***	***-191,3***	***-203,8***	***-215,1***	***-225,1***
Bx	138,0	kN	145,7	142,4	138,0	132,9	127,5
By	***-31,3***	kN	93,3	34,4	***-31,3***	***-102,7***	***-178,3***
Cx	0,0	kN	0,0	0,0	0,0	0,0	0,0
Cy	235,2	kN	84,5	156,9	235,2	317,8	403,4

This one is much easier than the two fixed connection because of the only use of the static balance principle.
Bx = Ax
By is a result of the moment of C
Cx = 0
Cy is a result of the moment of B

Roller connection on hub





Green, roller connection
Yellow, fixed connection
D = assumed position winch
E = roller connection on hub

met hub	aantal ton A frame 1	30,29	1	15,145	mt	gravitatie	9,814
ACv	4	m	5	5	5	5	5
ACh	5	m	5	5	5	5	5
CB	4	m	4	4	4	4	4
BD	1	m	1	1	1	1	1
AEh	1		1	2	3	4	0,5
D +/- of B	+	#	+	+	+	+	+
AC	**6,4**	m	**7,1**	**7,1**	**7,1**	**7,1**	**7,1**
AB	**10,8**	m	**11,2**	**11,2**	**11,2**	**11,2**	**11,2**
CE	4	m	4	3	2	1	5
Ax	**-138,0**	kN	***-132,9***	***-132,9***	***-132,9***	***-132,9***	***-132,9***
Ay	**-93,4**	kN	***-82,2***	***-82,2***	***-82,2***	***-82,2***	***-82,2***
Bx	**138,0**	kN	132,9	132,9	132,9	132,9	132,9
By	**52,2**	kN	52,5	54,5	56,2	57,7	51,4
Cx	**0,0**	kN	0,0	0,0	0,0	0,0	0,0
Cy	**20,6**	kN	14,8	13,8	13,0	12,2	15,4
Ex	**0,0**		0,0	0,0	0,0	0,0	0,0
Ey	**20,6**		14,8	13,8	13,0	12,2	15,4

met hub	aantal ton A frame 1	30,29	2	15,145	mt	gravitatie	9,814
ACv	5	m	6	7	8	9	10
ACh	5	m	5	5	5	5	5
CB	4	m	4	4	4	4	4
BD	1	m	1	1	1	1	1
AEh	1		4	4	4	4	4,0
D +/- of B	+	#	+	+	+	+	+
AC	**7,1**	m	**7,8**	**8,6**	**9,4**	**10,3**	**11,2**
AB	**11,2**	m	**11,7**	**12,2**	**12,8**	**13,5**	**14,1**
CE	4	m	1	1	1	1	1
Ax	**-132,9**	kN	***-127,5***	***-121,8***	***-116,1***	***-110,5***	***-105,1***
Ay	**-82,2**	kN	***-72,2***	***-63,4***	***-55,8***	***-49,2***	***-43,5***
Bx	**132,9**	kN	127,5	121,8	116,1	110,5	105,1
By	**59,7**	kN	55,7	53,6	51,3	49,1	46,9
Cx	**0,0**	kN	0,0	0,0	0,0	0,0	0,0

Cy	11,2	kN	8,2	4,9	2,2	0,1	***-1,7***
Ex	0,0		0,0	0,0	0,0	0,0	0,0
Ey	11,2		8,2	4,9	2,2	0,1	***-1,7***

This method is again calculated with ratio's. To make this hand calculation possible the two rollers have been calculated as one. And then dived into two forces. That's why they are the same amount of reaction force. Assumed is that this isn't the real reaction force. The ratio table is as follows:

Between which points							
AE	0,11		0,11	0,22	0,33	0,44	0,06
AC	0,56		0,56	0,56	0,56	0,56	0,56
new p	0,33		0,33	0,39	0,44	0,50	0,31
C2	3,00		3,00	3,50	4,00	4,50	2,75
smb- C2 =	41,27		29,67	27,69	25,96	24,43	30,77

SACS check

In the appendix(XXX) SACS models have been made to check these results. The results from the SACS models are:

2D	**roller**	**hub**		**3D**	**roller**	**hub**
	kN	kN			kN	kN
Bx	0	0		Bx	138,1	138,1
By	320	128		By	7	7
Cx	138	138		Bz	21,6	24,3
Cy	117	48		Ex	138,1	138,1
Ey		26,8		Ey	7	7
				Ez	21,6	24,3
				Cy	182,2	176,9
				Fy	182,2	176,9
Displacement		cm		Displacement		cm
Ay	0,7	0,8		Ay	0,4	0,23
Ax	1,2	0,2		Ax	0,4	0,69
max stress	51,8	18,6	Mpa	Mpa	23	22,7

The 2D roller models matches. The hub is lower, so that's in our advantage. The stresses in the 30 x 20 x 1 frame are still under 10% of the yield stress.

```
                         MEMBER INFORMATION REPORT

  MEMBER   GRUP      RELEASES  REF. BETA  SEGMENT  LENGTH OD/SEC     WT     FY
   A    B BOX                                      12.298 BOX               35.5
   A    D BOX                                       1.0   BOX               35.5
   A H1.1 BOX                                       1.952 BOX               35.5
   C    B BOX                                       4.0   BOX               35.5
   D    E BOX                                      12.298 BOX               35.5
   E    B BOX                                       6.0   BOX               35.5
   F    C BOX                                       6.0   BOX               35.5
   F    E BOX                                       4.0   BOX               35.5
 H1.1    C BOX                                      7.808 BOX               35.5
 H1.1 H1.2 BOX                                      6.705 BOX               35.5
 H2.1    D BOX                                      1.952 BOX               35.5
 H2.1    F BOX                                      7.808 BOX               35.5
 H2.1 H2.2 BOX                                      6.705 BOX               35.5
```

Lifting the A frame calculations

If the A frame is considered as a triangle of 9m by 8m high the following table can be followed. Also assumed is, is that the COG of the A frame is located on 2/3 of the triangle:

mass A frame	**10,0**	**mt**	**98,1**	**kN**			**0,7**				
					COG - C	extra Hight AC	kN	mt	kN		
degrees	radialen		cos	sin			smc		linepull 1 line	4 revings	mt
0,0	0,0		1,0	0,0	6,0	0,0	73,6	7,5	110,4	27,6	2,8
5,0	0,1		1,0	0,1	6,0	0,5	68,8	7,0	103,6	25,9	2,6
10,0	0,2		1,0	0,2	5,9	1,0	64,1	6,5	97,7	24,4	2,5
15,0	0,3		1,0	0,3	5,8	1,6	59,5	6,1	92,5	23,1	2,4
20,0	0,3		0,9	0,3	5,6	2,1	55,0	5,6	87,9	22,0	2,2
25,0	0,4		0,9	0,4	5,4	2,5	50,7	5,2	83,8	21,0	2,1
30,0	0,5		0,9	0,5	5,2	3,0	46,4	4,7	80,3	20,1	2,0
35,0	0,6		0,8	0,6	4,9	3,4	42,2	4,3	77,2	19,3	2,0
40,0	0,7		0,8	0,6	4,6	3,9	38,0	3,9	74,5	18,6	1,9
45,0	0,8		0,7	0,7	4,2	4,2	34,0	3,5	72,1	18,0	1,8
50,0	0,9		0,6	0,8	3,9	4,6	30,0	3,1	70,1	17,5	1,8
55,0	1,0		0,6	0,8	3,4	4,9	26,2	2,7	68,4	17,1	1,7
60,0	1,0		0,5	0,9	3,0	5,2	22,3	2,3	66,9	16,7	1,7
63,6	1,1		0,4	0,9	2,7	5,4	19,6	2,0	66,0	16,5	1,7
65,0	1,1		0,4	0,9	2,5	5,4	18,5	1,9	65,7	16,4	1,7
70,0	1,2		0,3	0,9	2,1	5,6	14,8	1,5	64,8	16,2	1,6
75,0	1,3		0,3	1,0	1,6	5,8	11,0	1,1	64,0	16,0	1,6
80,0	1,4		0,2	1,0	1,0	5,9	7,4	0,7	63,5	15,9	1,6
85,0	1,5		0,1	1,0	0,5	6,0	3,7	0,4	63,2	15,8	1,6

The required angle to flip the frame till its right above point C is in this case 63,6 degrees. And the maximum line pull will be 27 kN. But this isn't the best method for calculating the flipping frame. Because it isn't a fully triangle, the position must be calculated that the frame is fully out of the way for the hub. This is when the frame is flipped 32 degrees. This is drawn in the next figure:

Blue rest position
Green lifted position
Red wire: D wire is (Blue – green) = 12,35 – 12,04 = 0,31 m = 31 cm

The following table shows the line pull till 40 degrees.

mass A frame	**10,0**	**m t**	**98 ,1**	**kN**				**0,7**				
						COG - C	extra Hight AC	kN	mt	kN		
graden	radialen		cos	sin	smc			smc		linepull 1 line	4 revings	mt
0,0	0,0		1,0	0,0		6,0	0,0	73,6	7,5	110,4	27,6	2,8
5,0	0,1		1,0	0,1		6,0	0,5	68,8	7,0	103,6	25,9	2,6
10,0	0,2		1,0	0,2		5,9	1,0	64,1	6,5	97,7	24,4	2,5
15,0	0,3		1,0	0,3		5,8	1,6	59,5	6,1	92,5	23,1	2,4
20,0	0,3		0,9	0,3		5,6	2,1	55,0	5,6	87,9	22,0	2,2
25,0	0,4		0,9	0,4		5,4	2,5	50,7	5,2	83,8	21,0	2,1
30,0	0,5		0,9	0,5		5,2	3,0	46,4	4,7	80,3	20,1	2,0
32,0	0,6		0,8	0,5		5,1	3,2	44,7	4,6	79,0	19,8	2,0
35,0	0,6		0,8	0,6		4,9	3,4	42,2	4,3	77,2	19,3	2,0
40,0	0,7		0,8	0,6		4,6	3,9	38,0	3,9	74,5	18,6	1,9
50,0	0,9		0,6	0,8		3,9	4,6	30,0	3,1	70,1	17,5	1,8
55,0	1,0		0,6	0,8		3,4	4,9	26,2	2,7	68,4	17,1	1,7
60,0	1,0		0,5	0,9		3,0	5,2	22,3	2,3	66,9	16,7	1,7
63,6	1,1		0,4	0,9		2,7	5,4	19,6	2,0	66,0	16,5	1,7
65,0	1,1		0,4	0,9		2,5	5,4	18,5	1,9	65,7	16,4	1,7
70,0	1,2		0,3	0,9		2,1	5,6	14,8	1,5	64,8	16,2	1,6
75,0	1,3		0,3	1,0		1,6	5,8	11,0	1,1	64,0	16,0	1,6
80,0	1,4		0,2	1,0		1,0	5,9	7,4	0,7	63,5	15,9	1,6
85,0	1,5		0,1	1,0		0,5	6,0	3,7	0,4	63,2	15,8	1,6

The line pull on the first layer of the drum is maximum on the first degrees. These are 27,6 kN. The drum is designed to lift 80 kN on the first layer so flipping the frame will not be a problem.
The 31 cm is with the drum of 1 m diameter a twist of 0,005 radial

Weight frame
Total length: 78,526m
Density: 7849 ton/m3
Area = 96cm^2

$$96\ mm^2 = 0{,}0096m^2$$
$$0{,}0096 * 78 = 0{,}7488\ m^3$$
$$0{,}7488 * 7849 = 5877\ kg$$

Mass frame = 5877kg

VIII. Detailed lifting plan

Here the detailed lifting schedule with assumed hours per operation are given.

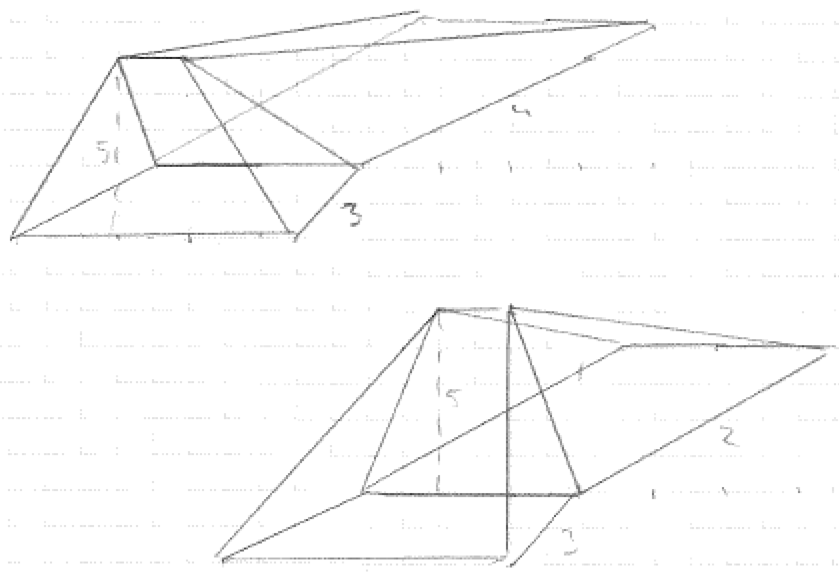
installation of 4 wind turbines	all four installed on nacelle onshore	deck space layout
Offshore part	bring 4 A frames	
sailing to location		
installing tower parts		
installing necelle en hub		
installation of rotor blades		
decomissioning A frame		
installing A frame on next nacelle		

		critical / non critical	Quarters of an hour		hours		minutes
	installation rotor blades						
1	transfer people to WTG	simultaneously	1		0,25		15
2	bringing energy to WTG	simultaneously	1		0		0
3	lowering winch A frame		1		0,25		15
4	connecting hooks to blade		2		0,5		30
5	pulling blade into the hub		6		1,5		90
6	connecting the blade to the hub		16		4		240
7	disconnecting the blade from the gripper / wires		2		0,5		30
8	lifting the A frame	simultaneously	2		0,5		30
9	change position hub	simultaneously	2		0		0
10	positioning A frame		2		0,5		30
					0		0
3	lowering winch A frame		1		0,25		15
4	connecting hooks to blade		2		0,5		30
5	pulling blade into the hub		6		1,5		90
6	connecting the blade to the hub		16		4		240
7	disconnecting the blade from the gripper / wires		2		0,5		30
8	lifting the A frame	simultaneously	2		0,5		30
9	change position hub	simultaneously	2		0		0
10	positioning A frame		2		0,5		30
					0		0
3	lowering winch A frame		1		0,25		15
4	connecting hooks to blade		2		0,5		30
5	pulling blade into the hub		6		1,5		90
6	connecting the blade to the hub		16		4		240
7	disconnecting the blade from the gripper / wires		2		0,5		30
					0		0
11	disconnecting the a frame from nacelle		4		1		60
12	lifting the A frame from nacelle to next nacelle on deck		4		1		60
13	transfering people from WTG to vessel	simultaneously	2		0		0
14	disconnecting power supply WTG	simultaneously	1		0		0
15	connecting the A frame on next nacelle on deck	simultaneously	4		1		60
16	sailing to next WTGm installing A frame on nacelle			total	25,5	u	
X	**Detailed faces 11 & 12**						
11	disconnecting the a frame from nacelle		1		0,25		15
11,1	connection hook to hook connection points on A frame		2		0,5		30
11,2	disconnecting the A frame from nacelle		1		0,25		15
12	lifting the A frame from the naccelle to the deck		2		0,5		30
11	disconnecting the a frame from nacelle		1		0,25		15
11,1	connection hook to hook connection points on A frame		2		0,5		30
11,2	disconnecting the A frame from nacelle		1		0,25		15
12	lifting the A frame from the naccelle to the next nacelle on deck		2		0,5		30
12,2	connection the A frame to the next nacelle		16		4		240

IX. Drawing and ideas

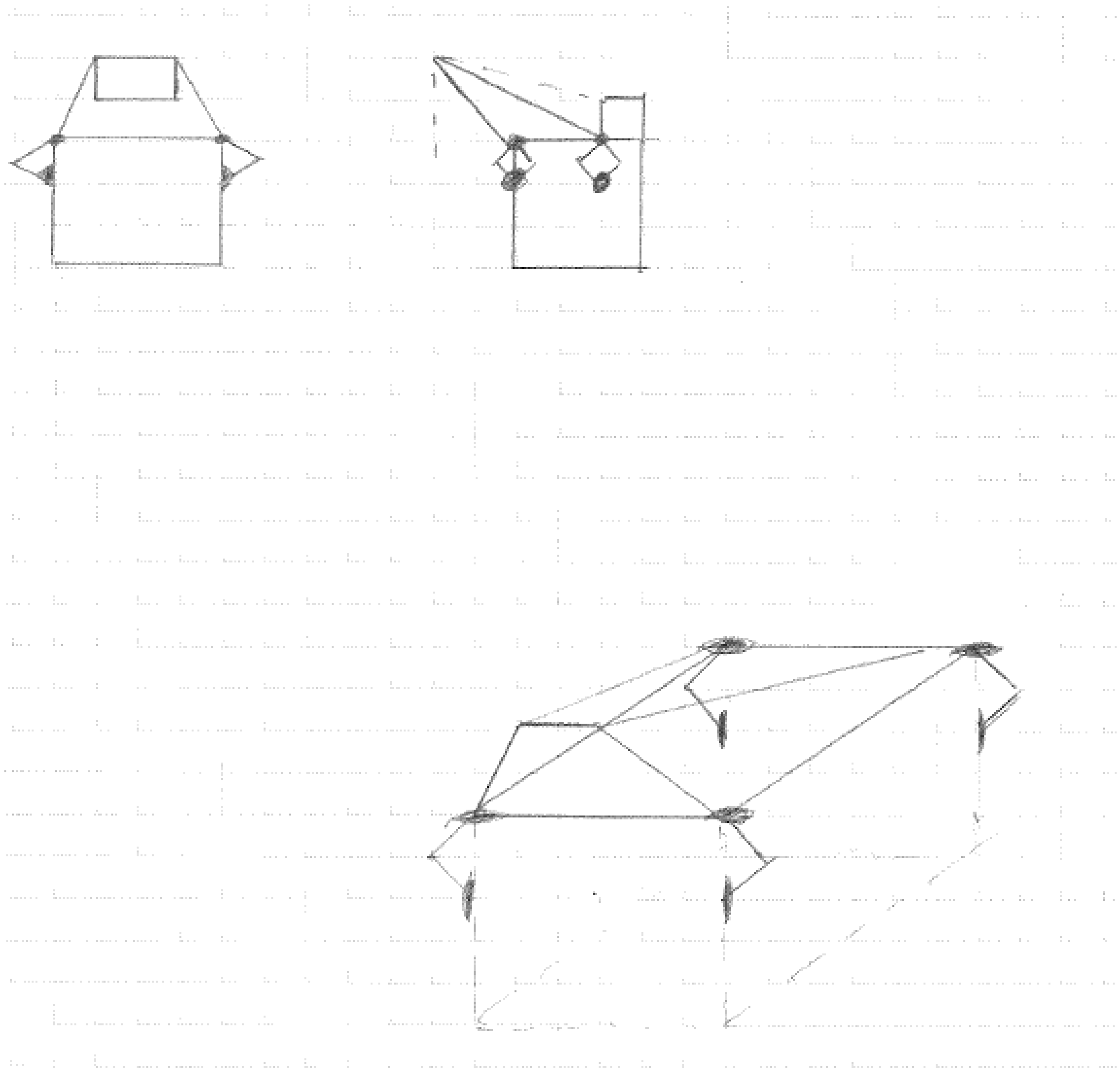
Newer versions of the A frame

During the end of the project some changes ware thought of, but due to deadline problems everything that is worked out is put into the appendix.

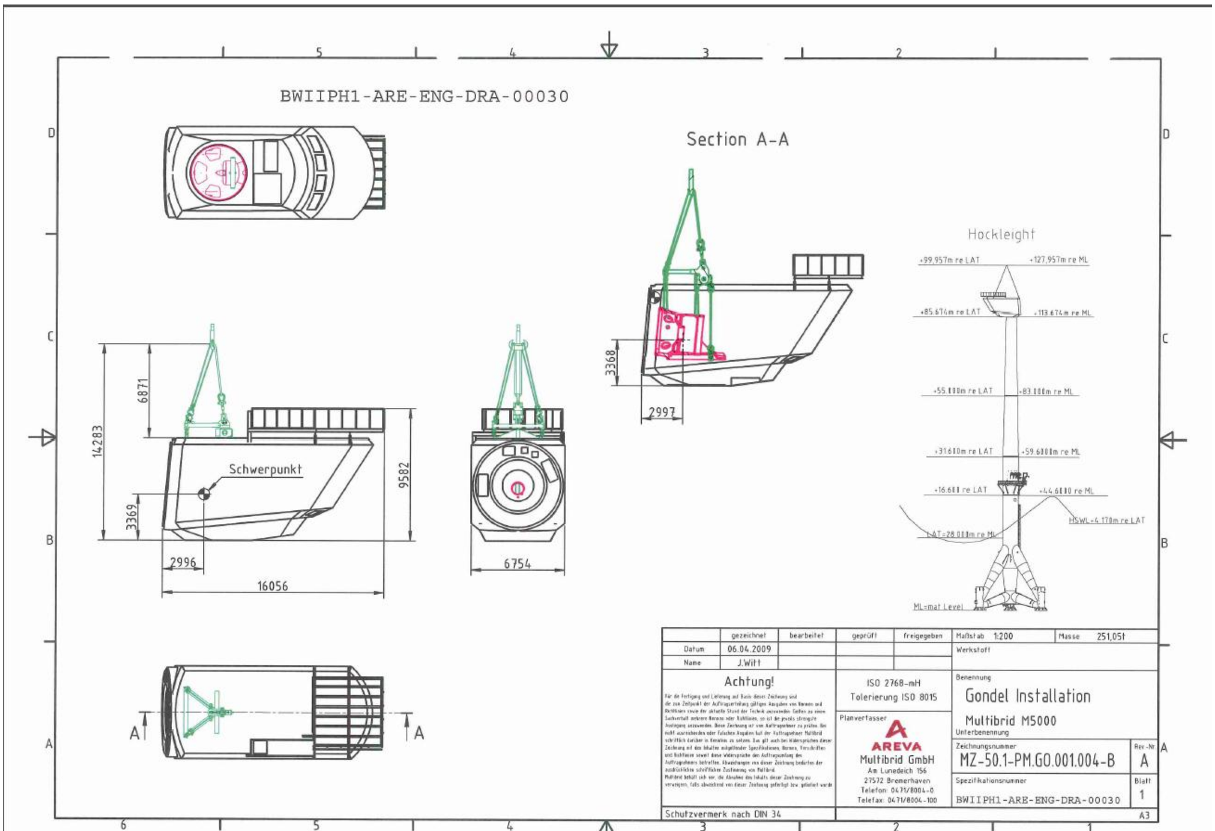


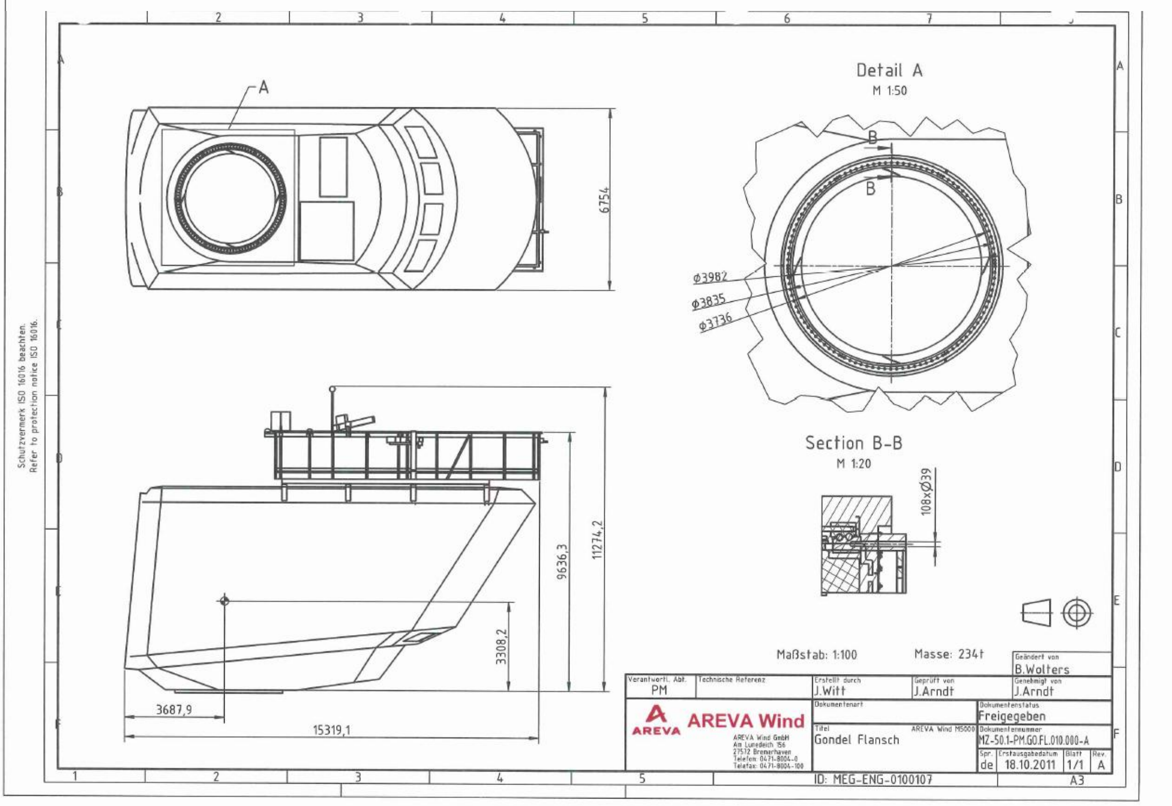
A possibility for the connection points are the use of suction cubs. Suctions cubs clamp to the WTG by sucking air out of a volume close by the WTG. This solution needs further study on different subjects:

- Area of WTG
- Type and size of suction cubs
- The arms for the suction cubs and their angle’s of freedom



X. Drawings AREVA





XI. Lifting appliances

B. Components

B 100 Winches

101 For design of the support of the winch to its foundation, relevant forces from crane operations are understood to having been evaluated at their maximum.

102 Winches shall be fitted with an operational brake, which normally absorbs energy through the winch power system. The operational brake is used to brake normal operating movements. Capacity and strength for the operational brake shall be documented through testing. In addition there shall be a mechanical brake, which satisfy requirements given in B300.

103 The direction of motion of the operating devices shall be such that the load is raised by clockwise movement of a hand-wheel or crank handle, or alternatively movement of a hand-lever towards the operator.

104 The operating device shall be arranged to return automatically to the braking position when the operator releases the control. However, for cranes operating in constant tension or active heave compensation modus – the brake shall remain off when the operator releases the control.

B 200 Drums

201 Drum diameters shall be determined with due respect to:

— type of reeving
— state of loading
— daily operating time

and shall be suitable for the selected steel wire rope, as directed by the rope manufacturer.

The ratio D_p/d shall normally not be less than 18 where

D_p = pitch diameter of drum
d = nominal diameter of steel wire rope.

202 As far as practicable and suitable for the arrangement, drums shall be designed with a length sufficient to reel up the rope in not more than 3 layers.

More than 3 layers may be accepted if the wire rope has an independent wire rope core (IWRC) and one of the following conditions is complied with:

— spooling device is provided
— drum is grooved
— fleet angle is restricted to 2°
— split drum is arranged
— separate traction drum is fitted.

However, when the number of layers exceeds 7, special consideration and approval will be required.

SECTION 6
OFFSHORE CRANES

A. Material and fabrication

A 100 General

101 Material and fabrication requirements are given in Sec.1. This section specifies supplementary information valid for offshore cranes.

A 200 Bolts for main slewing ring

201 Bolt material having yield strength exceeding 940 N/mm^2 (10.9 ISO strength class) will normally not be accepted.

B. Structural strength

B 100 General

101 General description of structural strength is given in Sec.2. This section specifies supplementary information valid for offshore cranes.

B 200 Loads due to operational motions

201 The dynamic factor ψ for design purposes shall not be taken less than:

ψ = 1.3 for 10 kN < W ≤ 2 500 kN

ψ = 1.1 for W > 5 000 kN.

Linear interpolation shall be used for intermediate values of W between 2 500 kN and 5 000 kN.

When the dynamic factor ψ is calculated by the formula given in Sec.2 A302, the following shall be taken into account when assessing the relative velocity between load and hook at the time of lift-off, V_R:

$$V_R = 0.5 \cdot V_L + \sqrt{V_{in}^2 + V_t^2}$$

Where the value $0.5 \cdot V_L$ above is less than V_H, as given in 202, then V_H shall be used instead of $0.5 \cdot V_L$.

V_L = maximum steady hoisting speed (m/s) for the rated capacity to be lifted.

V_{in} = downward velocity (m/s) of the load at the time of lift off (due to movement of the deck of a supply vessel from which the load is lifted.

V_t = velocity (m/s) from motion of the crane jib tip if the crane is located on a mobile offshore unit or other floating unit.

V_{in} is to be determined as a function of sea state and motion parameters (roll, pitch and heave response) of the vessel/offshore unit or hydrodynamic response of an underwater object to be handled.

202 Unless otherwise agreed to by the purchaser, the hoisting speed should normally not be less than

$$V_H = 0.1 \cdot (H_{sign} + 1)$$

for cranes used for cargo operations towards supply boats.

where

H_{sign} = Significant wave height (m).

The V_L used for calculation of dynamic factors for derating shall be the actual maximum available hook speed attainable, and shall normally be equal to or larger than V_H. For significant wave heights where the hoisting speed V_L is less than V_H, the derating chart will be shaded and giving information that it is dependent upon the crane driver's skill to avoid re-entry of the next wave.

203 For cranes located on crane vessels, semi submersibles units and bottom supported platforms the following values for V_L and V_{in} may be used for the calculation of the dynamic factor when lifting off loads from a supply vessel.

V_L = Available hoisting speed or 0.6 H_{sign}

whichever is the smaller.

V_{in} = 0.6 H_{sign} (m/s) for 0 < H_{sign} ≤ 3 (m)

B 500 Steel wire rope with fittings and anchorages

501 For wire and rope materials and construction of steel wire ropes, see Sec.1.

For testing of steel wire ropes, see Sec.12.

502 Length of wire rope for a lifting appliance shall be such that there is not less than 3 turns of wire rope on the drum with the hook at the lowest position and the boom in the most adverse position. Normally the ropes for hoisting and derricking shall be in one length.

503 Steel wire rope safety factor for running application or forming part of sling and for mast stays, pendants and similar standing applications shall be the greater of:

Not less than the greater of 3 and

$$S_F = \frac{10^4}{0.885 \cdot SWL + 1910}$$

but need not exceed 5.

S_F = 2.3 ψ
ψ = dynamic factor for the crane
SWL = Safe Working Load (kN).

For cranes with wire rope suspended jibs, the same safety factor will be required for hoisting and luffing.

504 For safety factor of wire ropes used for lifting people or manned objects see Sec.9 E201.

505 The minimum breaking load B of steel wire ropes shall not be less than

$$B = S_F \cdot S$$

where S is the maximum load in the rope resulting from the effect of the working load (suspended load) and loads due to any applicable dead weights. The number of parts and friction in sheaves shall be considered.

506 Where not otherwise demonstrated by testing, a combined allowance for friction and bending of the wire ropes, taken as

— 1.5% for each sheave with ball or roller bearings
— 5% for each sheave with plain bearings

shall be applied for calculation purpose of S in 505.

507 In wire ropes for running application the number of wires shall not be less than 114 (6 strands with 19 wires each).

In the case of one part hoist line (whip hoist) non-rotation wire shall be used or ball bearing swivel shall be provided for preventing accumulation of twist.

Guidance note:
A swivel should always be fitted between the hoist rope and the hook or other lifting attachment, and, except in the case of a ship's derrick, the swivel should be fitted with ball- or roller bearings that can be lubricated regularly

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

XII. SACS

What is sacs[11]:

SACS is an integrated finite element structural analysis suite of programs that uniquely provides for the design, fabrication, installation, operations, and maintenance of offshore structures, including oil platforms and wind farms. Thirty-eight years of focus on these specialized requirements have made SACS the analysis mainstay for most of the world's offshore engineers. Virtually all of the world's energy companies specify SACS software for use by their engineering firms across the lifecycle of fixxed offshore platforms.

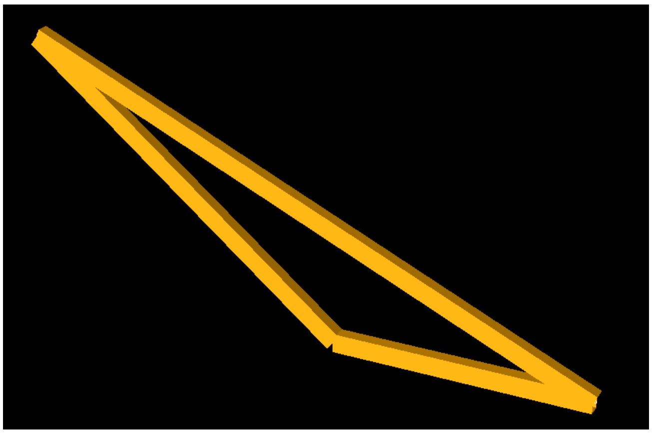
How is it implemented?

After finishing the (hand) calculation, a check by the program SACS was needed. This program makes it possible to check my calculations.

Up direction is Z positive. Down is Z negative
Left is X negative. Right is X positive

2D Review
First the 2D calculation's must be checked by SACS. Input's that are used are:

Rolled connection



```
OPTIONS      MN              1 1
SECT
SECT BOX       BOX
30.0001.00020.0001.000
GRUP
GRUP BOX BOX
20.007.72224.80 1    1.001.00
7.8490
MEMBER
MEMBER A   B    BOX
MEMBER A   C    BOX
MEMBER C   B    BOX
JOINT
JOINT A      0.000  0.000  4.000
JOINT B      5.000  0.000  0.000                 001000
JOINT C      9.000  0.000  0.000                 FIXED
LOAD
LOADCN TL1
LOAD   A       138.100       -203.80                     GLOB JOIN   1
END
 **JNCV** 0 0 0 0 0 1 1
END
```

Beneath An explanation about these input's is given, these are copies of the input file in SACS:

---

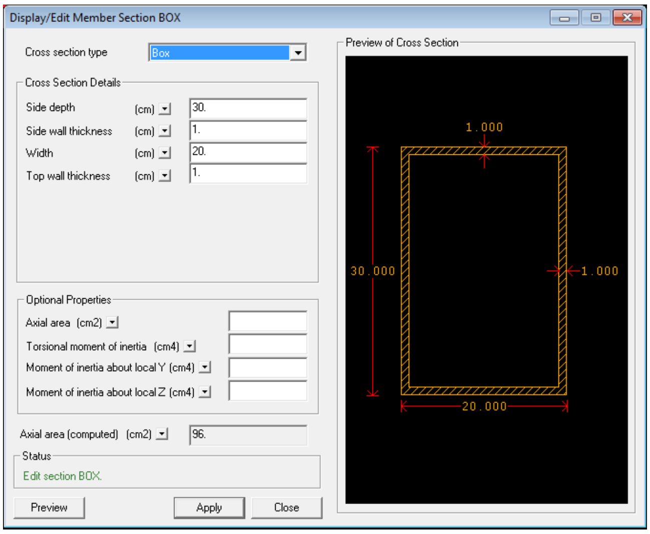
[11] Source: http://www.sacs-edi.com/

SECT BOX BOX 30.0001.00020.0001.000

Which are 30cm by 20cm, with a thinness of 1cm. Defined name: BOX

Defining the joint are done by coordinates:

	X	Y	Z
JOINT A	0.000	0.000	4.000
JOINT B	5.000	0.000	0.000
001000 (roller point)			
JOINT C	9.000	0.000	0.000
FIXED			



Joint B in SACS = Joint C in hand calculations
Joint C in SACS = Joint D in hand calculations

Connecting the joint are done by members end their property:

MEMBER A B BOX
MEMBER A C BOX
MEMBER C B BOX

At last the force needs to be defined:

		X	Y		
LOAD	A	138.100	-203.80	GLOB JOIN	1

Our force has an X and a Y component and act's op joint A.

The screenshot shows the direction of the displacement and the quantity of the displacement.

Results:

REACTION FORCES AND MOMENTS

JOINT	LOAD COND	FORCE(X) (kN)	FORCE(Y) (kN)	FORCE(Z) (kN)	MOMENT(X) (kN-m)	MOMENT(Y) (kN-m)	MOMENT(Z) (kN-m)
B	TL1	0.000	0.000	320.846	0.000	0.000	0.000
C	TL1	-138.100	0.000	-117.046	0.000	-1.584	0.000

MAXIMUM JOINT DISPLACEMENTS

LOAD COND	JOINT	DEFL(X) (CM)	JOINT	DEFL(Y) (CM)	JOINT	DEFL(Z) (CM)	JOINT	DEFL(T) (CM)
TL1	A	-0.708		0.000	A	-1.251	A	1.437

LOAD SUMMATION REPORT

Load Condition TL1

The sum of forces at the origin are:

Fx =	138.1	Fy =		Fz =	-203.8
Mx =		My =	552.4	Mz =	

The center of forces is:

For X forces:	X = 0.0	Y = 0.0	Z = 4.0
For Z forces:	X = 0.0	Y = 0.0	Z = 4.0

SACS-IV SYSTEM ELEMENT STRESS REPORT AT MAXIMUM UNITY CHECK

MEMBER	GRP	MAXIMUM UNITY CHECK	CRITICAL COND.	LOAD CASE NO.	DIST FROM END m	AXIAL N/mm2	BENDING Y-Y N/mm2	BENDING Z-Z N/mm2	SHEAR Y N/mm2	SHEAR Z N/mm2	CM VALUES Y	CM VALUES Z	NEXT TWO HIGHEST CASES UNITY CHECK	LOAD COND	UNITY CHECK	LOAD COND
A- B	BOX	0.634	C>.15A	TL1	6.40	-51.79	-24.13	0.00	0.00	-0.64	0.85	0.85	0.00		0.00	
A- C	BOX	0.258	TN+BN	TL1	9.85	28.22	-10.10	0.00	0.00	-0.05	0.85	0.85	0.00		0.00	
C- B	BOX	0.448	C>.15A	TL1	4.00	-40.19	-24.13	0.00	0.00	-1.21	0.85	0.85	0.00		0.00	

List of validated and used values:

Reaction forces:

- By = 320kN
- Cx = 138 kN
- Cy = 117 kN

Max displacement

- Ay = 0,7 cm
- Ax = 1,2 cm

Max stress is 51,8 N/mm^2 = 51,8 Megapascal [MPa]

Fixed connection

Inputs:

```
OPTIONS      MN              1 1
SECT
SECT BOX       BOX                          30.0001.00020.0001.000
GRUP
GRUP BOX BOX                 20.007.72224.80 1    1.001.00           7.8490
MEMBER
MEMBER A   B    BOX
MEMBER A   C    BOX
MEMBER C   B    BOX
JOINT
JOINT A      0.000  0.000  4.000
JOINT B      5.000  0.000  0.000                     FIXED
JOINT C      9.000  0.000  0.000                     FIXED
LOAD
LOADCN TL1
LOAD   A        138.100       -203.80                      GLOB JOIN   1
END
 **JNCV** 0 0 0 0 0 1 1
END
```

Results

REACTION FORCES AND MOMENTS

JOINT	LOAD COND	FORCE(X) (kN)	FORCE(Y) (kN)	FORCE(Z) (kN)	MOMENT(X) (kN-m)	MOMENT(Y) (kN-m)	MOMENT(Z) (kN-m)
B	TL1	-384.016	0.000	313.067	0.000	23.583	0.000
C	TL1	245.916	0.000	-109.267	0.000	5.950	0.000

MAXIMUM JOINT DISPLACEMENTS

LOAD COND	JOINT	DEFL(X) (CM)	JOINT	DEFL(Y) (CM)	JOINT	DEFL(Z) (CM)	JOINT	DEFL(T) (CM)
TL1	A	-0.604		0.000	A	-1.020	A	1.186

LOAD SUMMATION REPORT

Load Condition   TL1

```
The sum of forces at the origin are:
Fx =     138.1     Fy =                 Fz =    -203.8
Mx =               My =     552.4       Mz =
The center of forces is:
For X forces:   X  = 0.0           Y  = 0.0           Z  = 4.0
For Z forces:   X  = 0.0           Y  = 0.0           Z  = 4.0
```

SACS-IV SYSTEM   ELEMENT STRESS REPORT AT MAXIMUM UNITY CHECK

MEMBER	GRP	MAXIMUM UNITY CHECK	CRITICAL COND.	LOAD CASE NO.	DIST FROM END m	APPLIED STRESSES AXIAL N/mm2	BENDING Y-Y N/mm2	BENDING Z-Z N/mm2	SHEAR Y N/mm2	SHEAR Z N/mm2	CM VALUES Y	CM VALUES Z	NEXT TWO HIGHEST CASES UNITY CHECK	LOAD COND	UNITY CHECK	LOAD COND
A- B	BOX	0.664	C>.15A	TL1	6.40	-51.61	-29.30	0.00	0.00	-0.76	0.85	0.85	0.00		0.00	
A- C	BOX	0.238	TN+BN	TL1	9.85	28.03	-7.39	0.00	0.00	0.00	0.85	0.85	0.00		0.00	
C- B	BOX	0.000	C<.15	TL1	0.00	0.00	0.00	0.00	0.00	0.00	0.85	0.85	0.00		0.00	

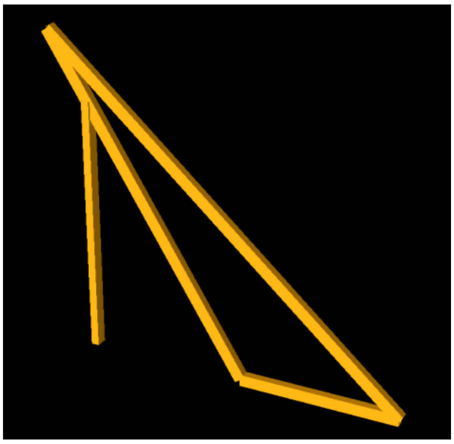
List of validated and used values:
Reaction forces:
- Bx =384 kB
- By = 313kN
- Cx =245 kN
- Cy = 109 kN

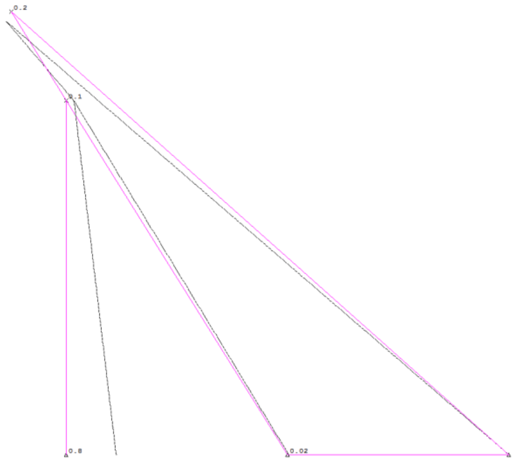
Max displacement
- Ay = 0,6 cm
- Ax = 1,0 cm

Max stress is 51,6 N/mm^2 = 51,6 Megapascal [MPa]

Made by: Jasper Breeuwsma

hub connection





```
OPTIONS      MN              1 1
SECT
SECT BOX       BOX                          30.0001.00020.0001.000
GRUP
GRUP BOX BOX                 20.007.72224.80 1    1.001.00          7.8490
MEMBER
MEMBER A   C    BOX
MEMBER A   H1   BOX
MEMBER C   B    BOX
MEMBER H1  B    BOX
MEMBER H1  H2   BOX
JOINT
JOINT A      0.000  0.000  8.000
JOINT B      5.000  0.000  0.000                    001000
JOINT C      9.000  0.000  0.000                    FIXED
JOINT H1      1.000  0.000  6.400
JOINT H2      1.000  0.000  0.000                    001000
LOAD
LOADCN TL1
LOAD   A       138.100       -203.80                       GLOB JOIN   1
END
 **JNCV** 0 0 0 0 0 1 1
END
```

Results:

REACTION FORCES AND MOMENTS

JOINT	LOAD COND	FORCE(X) (kN)	FORCE(Y) (kN)	FORCE(Z) (kN)	MOMENT(X) (kN-m)	MOMENT(Y) (kN-m)	MOMENT(Z) (kN-m)
B	TL1	0.000	0.000	128.858	0.000	0.000	0.000
C	TL1	-138.100	0.000	48.132	0.000	-0.509	0.000
H2	TL1	0.000	0.000	26.810	0.000	0.000	0.000

MAXIMUM JOINT DISPLACEMENTS

LOAD COND	JOINT	DEFL(X) (CM)	JOINT	DEFL(Y) (CM)	JOINT	DEFL(Z) (CM)	JOINT	DEFL(T) (CM)
TL1	H2	0.775		0.000	A	-0.151	H2	0.775

LOAD SUMMATION REPORT

Load Condition TL1

The sum of forces at the origin are:
Fx = 138.1 Fy = Fz = -203.8
Mx = My = 552.4 Mz =
The center of forces is:
For X forces: X = 0.0 Y = 0.0 Z = 4.0
For Z forces: X = 0.0 Y = 0.0 Z = 4.0

SACS-IV SYSTEM ELEMENT STRESS REPORT AT MAXIMUM UNITY CHECK

MEMBER	GRP	MAXIMUM UNITY CHECK	CRITICAL COND.	LOAD CASE NO.	DIST FROM END m	AXIAL N/mm2	BENDING Y-Y N/mm2	BENDING Z-Z N/mm2	SHEAR Y N/mm2	SHEAR Z N/mm2	CM VALUES Y	CM VALUES Z	NEXT TWO HIGHEST CASES UNITY CHECK	LOAD COND	UNITY CHECK	LOAD COND
A- C	BOX	0.219	C>.15A	TL1	0.00	-7.33	-10.30	0.00	0.00	0.16	0.85	0.85	0.00		0.00	
A- H1	BOX	0.236	C<.15	TL1	1.89	-18.62	-17.01	0.00	0.00	-1.94	0.85	0.85	0.00		0.00	
C- B	BOX	0.112	C<.15	TL1	4.00	-8.84	7.01	0.00	0.00	0.35	0.85	0.85	0.00		0.00	
H1- B	BOX	0.274	C>.15A	TL1	0.00	-16.26	-17.01	0.00	0.00	0.43	0.85	0.85	0.00		0.00	
H1- H2	BOX	0.026	C<.15	TL1	0.00	-2.79	0.00	0.00	0.00	0.00	0.85	0.85	0.00		0.00	

Reaction forces:
- By = 128
- Cx =138 kN
- Cy = 48 kN
- Ey = H2 = 26.8 kN

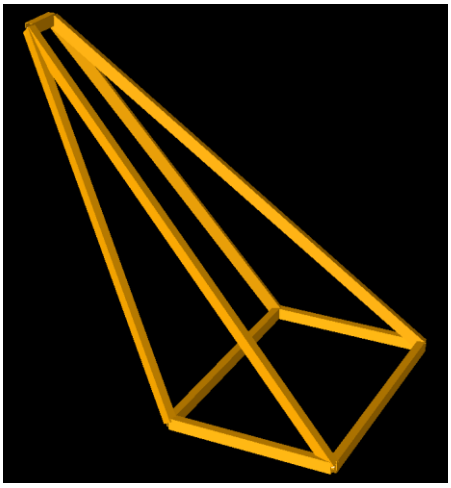
Max displacement
- Ay = 0,8 cm
- Ax = 0.2 cm

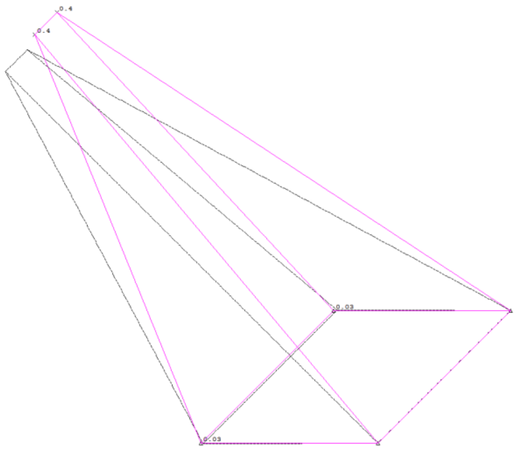
Max stress is 18.6 N/mm^2 = 18.6 Megapascal [MPa]

Made by: Jasper Breeuwsma

3D Review:
Now the 3D calculation's must be checked by SACS. The roller connection and the hub roller connection are made in 3D. Input's that are used are:

Roller connection





Inputs:

```
OPTIONS      MN             1 1
SECT
SECT BOX       BOX                        30.0001.00020.0001.000
GRUP
GRUP BOX BOX               20.007.72235.50 1    1.001.00          7.8490
MEMBER
MEMBER A   B    BOX
MEMBER A   C    BOX
MEMBER A   D    BOX
MEMBER C   B    BOX
MEMBER D   E    BOX
MEMBER D   F    BOX
MEMBER E   B    BOX
MEMBER F   C    BOX
MEMBER F   E    BOX
JOINT
JOINT A      0.000  2.500  8.000
JOINT B      9.000  0.000  0.000               FIXED
JOINT C      5.000  0.000  0.000               001000
JOINT D      0.000  3.500  8.000
JOINT E      9.000  6.000  0.000               FIXED
JOINT F      5.000  6.000  0.000               001000
LOAD
LOADCN TL1
LOAD   A      138.100      -203.80                    GLOB JOIN   1
LOAD   D      138.100      -203.80                    GLOB JOIN   1
END
```

JNCV 0 0 0 0 0 1 1
END
Results:

REACTION FORCES AND MOMENTS

JOINT	LOAD COND	FORCE(X) (kN)	FORCE(Y) (kN)	FORCE(Z) (kN)	MOMENT(X) (kN-m)	MOMENT(Y) (kN-m)	MOMENT(Z) (kN-m)
B	TL1	-138.100	7.036	21.591	0.462	0.566	-0.287
C	TL1	0.000	0.000	182.209	0.000	0.000	0.000
E	TL1	-138.100	-7.036	21.591	-0.462	0.566	0.287
F	TL1	0.000	0.000	182.209	0.000	0.000	0.000

Load Condition TL1

The sum of forces at the origin are:
Fx = 276.2 Fy = Fz = -407.6
Mx = -1222.8 My = 2209.6 Mz = -828.6
The center of forces is:
For X forces: X = 0.0 Y = 3.0 Z = 8.0
For Z forces: X = 0.0 Y = 3.0 Z = 8.0

SACS-IV SYSTEM ELEMENT STRESS REPORT AT MAXIMUM UNITY CHECK

MEMBER	GRP	MAXIMUM UNITY CHECK	CRITICAL COND.	LOAD CASE NO.	DIST FROM END m	AXIAL N/mm2	BENDING Y-Y N/mm2	BENDING Z-Z N/mm2	SHEAR Y N/mm2	SHEAR Z N/mm2	CM VALUES Y	CM VALUES Z	NEXT TWO HIGHEST CASES UNITY CHECK	LOAD COND	UNITY CHECK	LOAD COND
A- B	BOX	0.090	C<.15	TL1	12.30	-3.58	-2.09	-0.21	0.00	-0.02	0.85	0.85	0.00		0.00	
A- C	BOX	0.337	C>.15A	TL1	9.76	-23.03	-2.80	-0.57	-0.01	-0.05	0.85	0.85	0.00		0.00	
A- D	BOX	0.035	C<.15	TL1	1.00	-6.62	0.47	-0.12	0.00	0.00	0.85	0.85	0.00		0.00	
C- B	BOX	0.081	C<.15	TL1	0.00	-11.78	-2.73	0.08	-0.02	0.14	0.85	0.85	0.00		0.00	
D- E	BOX	0.090	C<.15	TL1	12.30	-3.58	-2.09	0.21	0.00	-0.02	0.85	0.85	0.00		0.00	
D- F	BOX	0.337	C>.15A	TL1	9.76	-23.03	-2.80	0.57	0.01	-0.05	0.85	0.85	0.00		0.00	
E- B	BOX	0.000	C<.15	TL1	0.00	0.00	0.00	0.00	0.00	0.00	0.85	0.85	0.00		0.00	
F- C	BOX	0.031	TN+BN	TL1	0.00	5.88	0.63	0.20	0.00	0.00	0.85	0.85	0.00		0.00	
F- E	BOX	0.081	C<.15	TL1	0.00	-11.78	-2.73	-0.08	0.02	0.14	0.85	0.85	0.00		0.00	

Reaction forces:
B & E Fixed point
C & F roller points

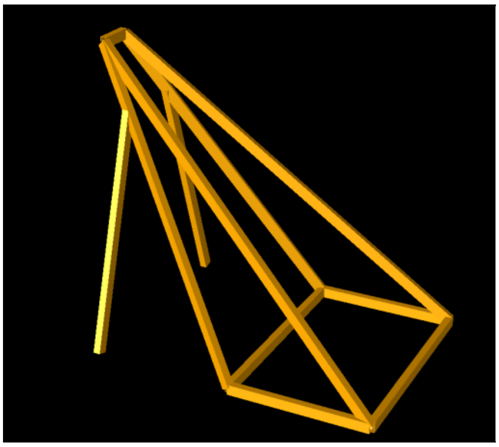
- Bx =138.1
- By = 7.0
- Bz = 21.6
- Ex =138.1
- Ey = 7.0
- Ez = 21.3
- Cy = 182.2 kN
- Fy = 182.2 kN

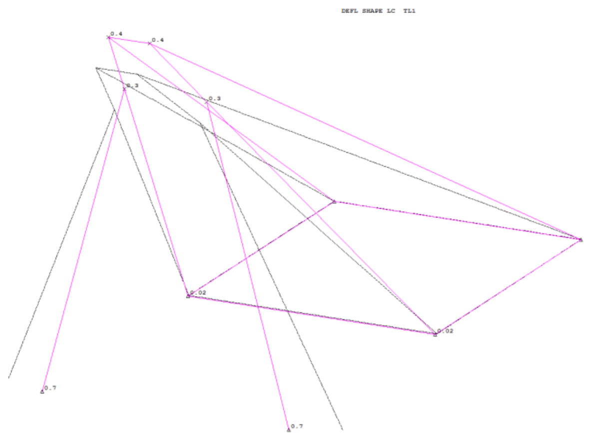
Max displacement

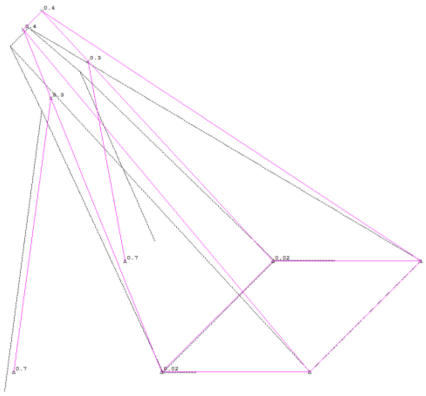
- Ay = 0,4 cm
- Ax = 0,42 cm

Max stress is 23.0 N/mm^2 = 23.0 Mega Pascal [MPa]

Hub connection







Inputs:

```
PTIONS      MN                1 1
SECT
SECT BOX       BOX                             30.0001.00020.0001.000
GRUP
GRUP BOX BOX                   20.007.72235.50 1    1.001.00          7.8490
MEMBER
MEMBER A   B    BOX
MEMBER A   D    BOX
MEMBER A   H1.1 BOX
MEMBER C   B    BOX
MEMBER D   E    BOX
MEMBER E   B    BOX
MEMBER F   C    BOX
MEMBER F   E    BOX
MEMBER H1.1C    BOX
MEMBER H1.1H1.2 BOX
MEMBER H2.1D    BOX
MEMBER H2.1F    BOX
MEMBER H2.1H2.2 BOX
```

```
JOINT
JOINT A      0.000  2.500  8.000
JOINT B      9.000  0.000  0.000                  FIXED
JOINT C      5.000  0.000  0.000                  001000
JOINT D      0.000  3.500  8.000
JOINT E      9.000  6.000  0.000                  FIXED
JOINT F      5.000  6.000  0.000                  001000
JOINT H1.1   1.000  2.000  6.400
JOINT H1.2   1.000  0.000  0.000                  001000
JOINT H2.1   1.000  4.000  6.400
JOINT H2.2   1.000  6.000  0.000                  001000
LOAD
LOADCN TL1
LOAD   A      138.100      -203.80                GLOB JOIN   1
LOAD   D      138.100      -203.80                GLOB JOIN   1
END
 **JNCV** 0 0 0 0 0 1 1
END
```

REACTION FORCES AND MOMENTS

JOINT	LOAD COND	********** kN ********** FORCE(X)	FORCE(Y)	FORCE(Z)	********** kN-m ********** MOMENT(X)	MOMENT(Y)	MOMENT(Z)
B	TL1	-138.100	7.542	24.207	0.220	0.582	0.023
C	TL1	0.000	0.000	176.981	0.000	0.000	0.000
E	TL1	-138.100	-7.542	24.207	-0.220	0.582	-0.023
F	TL1	0.000	0.000	176.981	0.000	0.000	0.000
H1.2	TL1	0.000	0.000	2.612	0.000	0.000	0.000
H2.2	TL1	0.000	0.000	2.612	0.000	0.000	0.000

LOAD SUMMATION REPORT

Load Condition   TL1

```
The sum of forces at the origin are:
Fx =      276.2     Fy =                 Fz =     -407.6
Mx =    -1222.8     My =     2209.6      Mz =     -828.6
The center of forces is:
For X forces:   X  = 0.0          Y  = 3.0          Z  = 8.0
For Z forces:   X  = 0.0          Y  = 3.0          Z  = 8.0
```

JOINT DISPLACEMENTS AND ROTATIONS

JOINT	LOAD COND	DEFL(X) (cm)	DEFL(Y) (cm)	DEFL(Z) (cm)	ROT(X) (radians)	ROT(Y) (radians)	ROT(Z) (radians)
A	TL1	-0.2272	0.0016	-0.2935	-0.0001	-0.0006	0.0000
B	TL1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C	TL1	0.0230	-0.0087	0.0000	0.0000	-0.0001	0.0001
D	TL1	-0.2272	-0.0016	-0.2935	0.0001	-0.0006	0.0000
E	TL1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
F	TL1	0.0230	0.0087	0.0000	0.0000	-0.0001	-0.0001
H1.1	TL1	-0.1472	-0.0275	-0.2073	-0.0005	-0.0004	0.0002
H1.2	TL1	0.1808	-0.6881	0.0000	-0.0013	-0.0004	0.0002
H2.1	TL1	-0.1472	0.0275	-0.2073	0.0005	-0.0004	-0.0002
H2.2	TL1	0.1808	0.6881	0.0000	0.0013	-0.0004	-0.0002

MAXIMUM JOINT DISPLACEMENTS

LOAD COND	JOINT	DEFL(X) (CM)	JOINT	DEFL(Y) (CM)	JOINT	DEFL(Z) (CM)	JOINT	DEFL(T) (CM)
TL1	A	-0.227	H1.2	-0.688	D	-0.293	H1.2	0.711

SACS-IV SYSTEM ELEMENT STRESS REPORT AT MAXIMUM UNITY CHECK

MEMBER	GRP	MAXIMUM UNITY CHECK	CRITICAL COND.	LOAD CASE NO.	DIST FROM END m	AXIAL N/mm2	** BENDING ** Y-Y N/mm2	Z-Z N/mm2	*** SHEAR *** Y N/mm2	Z N/mm2	* CM VALUES * Y	Z	* NEXT TWO HIGHEST CASES * UNITY CHECK	LOAD COND	UNITY CHECK	LOAD COND
A- B	BOX	0.095	C<.15	TL1	12.30	-3.95	-1.55	-0.18	0.00	0.00	0.85	0.85	0.00		0.00	
A- D	BOX	0.057	C<.15	TL1	1.00	-6.59	3.94	-1.49	0.00	0.00	0.85	0.85	0.00		0.00	
A-H1.1	BOX	0.140	C<.15	TL1	0.00	-22.66	2.97	-2.42	-0.09	-0.22	0.85	0.85	0.00		0.00	
C- B	BOX	0.078	C<.15	TL1	0.00	-11.49	-1.61	-0.93	0.04	0.08	0.85	0.85	0.00		0.00	
D- E	BOX	0.095	C<.15	TL1	12.30	-3.95	-1.55	0.18	0.00	0.00	0.85	0.85	0.00		0.00	
E- B	BOX	0.000	C<.15	TL1	0.00	0.00	0.00	0.00	0.00	0.00	0.85	0.85	0.00		0.00	
F- C	BOX	0.030	TN+BN	TL1	6.00	5.81	-0.06	0.53	0.00	0.00	0.85	0.85	0.00		0.00	
F- E	BOX	0.078	C<.15	TL1	0.00	-11.49	-1.61	0.93	-0.04	0.08	0.85	0.85	0.00		0.00	
H1.1- C	BOX	0.232	C>.15A	TL1	0.00	-22.44	-3.13	2.52	-0.09	0.03	0.85	0.85	0.00		0.00	
H1.1-H1.2	BOX	0.032	C<.15	TL1	0.00	-0.26	6.49	0.00	0.00	-0.13	0.85	0.85	0.00		0.00	
H2.1- D	BOX	0.140	C<.15	TL1	1.95	-22.66	2.97	-2.42	0.09	0.22	0.85	0.85	0.00		0.00	
H2.1- F	BOX	0.232	C>.15A	TL1	0.00	-22.44	-3.13	-2.52	0.09	0.03	0.85	0.85	0.00		0.00	
H2.1-H2.2	BOX	0.032	C<.15	TL1	0.00	-0.26	6.49	0.00	0.00	-0.13	0.85	0.85	0.00		0.00	

Reaction forces:
B & E Fixed point
C, F, H1.2 and H2,2 are roller points

- Bx =138.1
- By = 7.0
- Bz = 24.3
- Ex =138.1
- Ey = 7.0
- Ez = 24.3
- Cy =176.9 kN
- Fy = 176.9 kN
- H1,2y = 2.612
- H2,2y = 2.612

Max displacement

- Ay = 0,23 cm
- Ax = 0,69 cm

Max stress is 22.7 N/mm^2 = 22.7Mega Pascal [MPa]

2D	roller	hub		3D	roller	hub
	kN	kN			kN	kN
Bx	0	0		Bx	138,1	138,1
By	320	128		By	7	7
Cx	138	138		Bz	21,6	24,3
Cy	117	48		Ex	138,1	138,1
Ey		26,8		Ey	7	7
				Ez	21,6	24,3
				Cy	182,2	176,9
				Fy	182,2	176,9
Displacement		cm		Displacement		cm
Ay	0,7	0,8		Ay	0,4	0,23
Ax	1,2	0,2		Ax	0,4	0,69
max stress	51,8	18,6	Mpa	Mpa	23	22,7

Made by: Jasper Breeuwsma

Competentie set February 2013

nr.	**Taakrollen:** competentieset werktuigbouw & hbo algemeen / competenties werktuigbouwkunde	onderzoeker	ontwerper	adviseur	beheerder	projectleider	ondernemer
1	projectmanagement uitvoeren (organiseren, plannen, uitvoeren, verslag opstellen)	4	4				
2	een onderzoeksopdracht uitvoeren	3					
3	het kunnen opstellen van productdefinitie, pva en pve voor een duurzaam product of proces	3	3				
4	het realiseren van een functioneel duurzaam product of voortbrengingsproces	4	3				
5	het realiseren van een detailontwerp voor een duurzaam product of voortbrengingsproces	4					
6	het realiseren van een prototype/model van een duurzaam product of voortbrengingsproces	3	4				
7	het voorbereiden van een voortbrengingsproces	3	4				
8	het produceren van een duurzaam product	4					
9	het beheren of onderhouden van een product of proces	4					
nr.	**algemene hbo competenties**						
10	kritisch handelen (analytisch en probleemoplossend vermogen en het onderbouwen van keuzen, oordeelsvorming)	4	3				
11	systematisch een probleem aanpakken (creatieve, plan- en projectmatige werkhouding)	4	4				
12	samenwerken (sociaal communicatieve vaardigheden)	3	3	4			
13	persoonlijke en professionele ontwikkeling	4	4				
14	zelfverantwoordelijk werken	4	4				
15	kunnen functioneren in een internationale en/of multiculturele context	4	4				

overzicht competentieniveaus				
		taakrol		
		geleid	zelfstandig	sturend
context	simpel	1	2	3
	lastig	2	3	4
	complex	3	4	5

Made by: Jasper Breeuwsma

Competentie set June 013

nr.	competentieset werktuigbouw & hbo algemeen competenties werktuigbouwkunde Taakrollen:	onderzoeker	ontwerper	adviseur	beheerder	projectleider	ondernemer
1	projectmanagement uitvoeren (organiseren, plannen, uitvoeren, verslag opstellen)	4	4				
2	een onderzoeksopdracht uitvoeren	3					
3	het kunnen opstellen van productdefinitie, pva en pve voor een duurzaam product of proces	4	4				
4	het realiseren van een functioneel duurzaam product of voortbrengingsproces	4	3				
5	het realiseren van een detailontwerp voor een duurzaam product of voortbrengingsproces	4					
6	het realiseren van een prototype/model van een duurzaam product of voortbrengingsproces	3	4				
7	het voorbereiden van een voortbrengingsproces	3	4				
8	het produceren van een duurzaam product	4					
9	het beheren of onderhouden van een product of proces	4					
.	**algemene hbo competenties**						
10	kritisch handelen (analytisch en probleemoplossend vermogen en het onderbouwen van keuzen, oordeelsvorming)	4	3				
11	systematisch een probleem aanpakken (creatieve, plan- en projectmatige werkhouding)	4	4				
12	samenwerken (sociaal communicatieve vaardigheden)	3	3	4			
13	persoonlijke en professionele ontwikkeling	4	4				
14	zelfverantwoordelijk werken	3	4				
15	kunnen functioneren in een internationale en/of multiculturele context	4	4				

overzicht competentieniveaus				
		taakrol		
		geleid	zelfstandig	sturend
context	simpel	1	2	3
	lastig	2	3	4
	complex	3	4	5

XIII. Project organisation:

This chapter is an overview of all stakeholders and their contact information.

1. Graduate
Name: A.J.D. Breeuwsma
Student number: 8809702
Department: Engineering
Room number: 2.05
Email School: a.j.d.Breeuwsma@student.hhs.nl
Work Email: jbreeuwsma@shl.nl
Email private: jasper@breeuwsma.nl
Website: www.breeuwsma.nl
Mob: 06-43 53 96 77

2. Graduation Coach
Name. ir. A.F. le Mair
Position: lecturer
Email: A.leMair@hhs.nl
Tel: 015-2606251

3. Assessor
Name: Dr E. F. Erdurcan
Function: Lecturer in mechanics, strength of materials
Room: D1.069
Email: e.f.erdurcan@hhs.nl
Tel:. 015-206 62 54

4. Coach from SHL
Name: Dr J. P. Breedeveld
Position: Manager Engineering Department
Room number: 2.11
Email: jbreedeveld@shl.nl
Tel:. 079-363 77 06

5. Graduation Coordination
Name: Dr C. van Hulst
Function: Graduation coordinator
Room: D1.071
Email: c.vanhulst@hhs.nl
Tel:. 015-260 62 50
Name: Mr A. van der Vlugt
Function: Assistant graduation coordinator
Room: D1.069
Email: a.vandervlugt@hhs.nl
Tel:. 015-260 62 58