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MASTER'S THESIS

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Construction and Analysis of Atex Nitrogen Generator Frame with Components

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Abstract

This Master thesis will include the design and structure of a nitrogen generator that shall be approved for internal lifting on offshore platforms. The generator shall be in accordance with the harmonized standards: NORSOK R-002 – Lifting equipment and NORSOK Z-015 – Temporary equipment.

NORSOK R-002 requires a safety factor higher than 2.52 for the frames to be approved for internal lifting on offshore platforms. There have been performed finite element analyses of a lifting test of the different prototypes, to ensure which of the prototypes will be approved.

It has been performed additional finite element analysis to simulate how the different forces will be distributed on the prototypes via an impact test. The impact test will simulate what happens to the frame if it collides into a fixed element.

A research regarding certification of the nitrogen generator according to DNV 2.7-3 – Portable offshore unit have been performed, and if it will be beneficial to fulfill the changes that are required.

A description of the components in the nitrogen generator and the purpose of each component have been presented.

It has also been made a comparison of the current nitrogen generators on the market today, and how the unit presented in this Master thesis stands out.

Acknowledgements

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Notations & Abbreviations

E	Elastic modulus
I_z:	Moment of inertia of the beam cross-sectional area about a centroid axis parallel to the z axis.
PSA	Pressure Swing Adsorption
CO_2	Carbon dioxide
Ar	Argon
N	Nitrogen
D.o.f	Degree of freedom
R_e	Specified minimum yield stress at room temperature in N/mm^2
R_m	Specified minimum tensile strength at room temperature in N/mm^2
R_p	Proof stress at room temperature in N/mm^2
Y	Deflection of structural member, in N/mm^2
g	Standard acceleration of gravity (9.81m/s^2)
σ_e	Von Mises equivalent stress, in N/mm^2
ν	Angle of sling leg from vertical in degrees
RSL	Resulting sling load
C	For steel: R_e For aluminum: $R_{p0.2}$ but not to be taken greater than 0.7 x R_m
MGW	Maximum Gross Weight

PO unit	Portable Offshore unit
T	Tare weight
P	Maximum allowable payload for the PO unit
DF	Design Factor
SKL	Skew Load Factor
PL	Percent Loading of F
PL_{SKL}	Percent Loading of F in the pad eye considering all skew loads effects
CoG	Center of Gravity
MBL	Minimum Breaking Load
RSF	Pad eye in line design load [N]
WLL	Working Load Limit
HP	High-Pressure
LP	Low-Pressure
DAF	Dynamic Amplifying Factor
P1	Prototype 1
P2	Prototype 2
P3	Prototype 3
CST	Constant Strain Triangle
LST	Linear Strain Triangle

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1. Introduction

1.1 Background

Nitrogen is one of the most common gasses we have around us. The air we breathe consist of approximately 78% nitrogen. The natural gas has therefore been developed as one of the most common gasses used in a wide broad of industries.

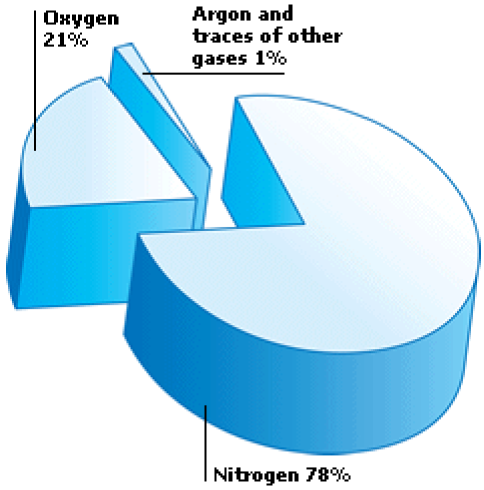

Figure 1: Gases in the atmosphere [1].

Nitrogen is today essential in many industries where the gas is applicable in a variety of operations from aerospace & aircraft industries. In these operations, the nitrogen can have different operational tasks, from being used in high Reynolds number wind tunnels to welding and laser-cutting applications, where the nitrogen is used as an assist gas [2].

The oil and gas industry used nitrogen to increase the reservoir reserves, and fracture hydrocarbon bearing to increase the production of oil and gas, and to optimize the operating efficiency [2].

Nitrogen can be used in a wide range of operations:

- Aerospace & Aircraft
- Automotive & Transportation Equipment

Chemicals

- Energy
- Food & Beverage
- Healthcare
- Metal Production

- Oil & Gas
- Pharmaceutical & Biotechnology
- Refining
- Welding & Metal Fabrication [2].

In the market today, there are two main sources for nitrogen supply in the industry:

- Nitrogen generator
- Liquefied nitrogen

1.1.1 Nitrogen Generator

A nitrogen generator is mounted onsite/onboard that produces a desired volume of nitrogen.

Nitrogen that is produced onsite is mainly designed for limited specific applications. These generators are mainly fixed generators mounted on a skid. These generators will receive compressed air from an external compressor, or from a "platform airline". [2]

Generally, there are two ways to make on-site nitrogen:

- PSA (Pressure Swing Absorption)
- Nitrogen Membrane Generators

These generators are normally mounted on a stationary skid in the process area or in the utility area of the installation. Normal practice for stationary nitrogen generators is that they receive compressed air from "platform" airline or having an external compressor that supply compressed air.

Produced nitrogen is then supplied to different users around the installation, maintaining a low pressure in pipes. Figure 2 illustrates a typical overview of a nitrogen membrane generator:

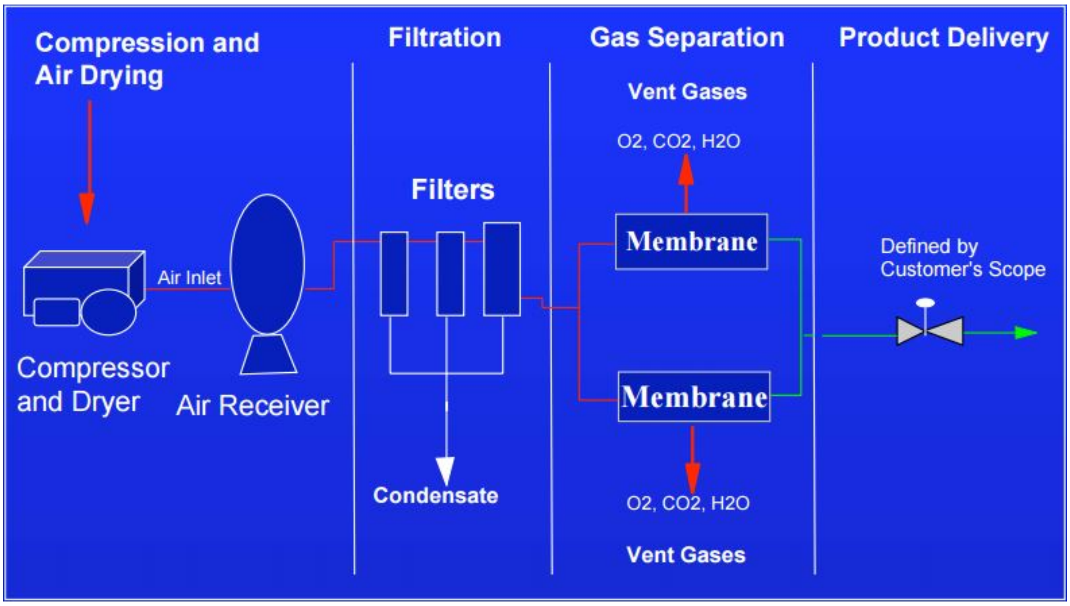

Figure 2: Overview of a nitrogen membrane generator [4]

Main Components:

- Air Compressor: Low-pressure air compressor that can supply continually air to the generator.
- Air treatment system: Due to the specified cleanness of the inlet air to the nitrogen generator, filtration system is an essential part of the system. Water, oil and dust filtration is the main function for the air treatment.
- Nitrogen membrane/ PSA: Flow and purity of the specified nitrogen is the key factors for choosing between PSA or membrane solution.

1.1.2 Liquefied Nitrogen

Before nitrogen generators were common, nitrogen had to be shipped with supply boats to the installation, causing high logistics impact and expensive to use.

Liquefied nitrogen is transported to offshore installation, as cooled liquefied nitrogen or high-pressure nitrogen in bottle rack.

1.2 Description

Nitrogas AS is a daughter company of E innovation, and is developing portable nitrogen generators for both onshore and offshore use. The generator will be approved for use in Atex zone 1.

E innovation is a company that develops portable, mobile air compressors that generates oil-free breathing air for use in Atex zone 1.

1.3 Objectives

The objective for this Master thesis will be to design a cost-efficient frame for the nitrogen generator. The frame shall be innovative, service friendly and easy to disassemble by only using bolts, nuts and washers.

There will be performed a comprehensive finite element analysis that will cover the different aspects of the prototypes that have been designed, and if they will be approved according to the harmonized standards that are valid to get the frame approved for internal lifting on offshore platforms. This Master thesis will describe the components and their operational task in the nitrogen generator. This thesis will cover the design for the main structure using 3-D modelling, calculation and analyzing.

It will be important to design a prototype that will meet the criterions for Nitrogas and the harmonized standards.

There has also been made a comprehensive research on what improvements that are needed to get the prototypes approved on offshore lifting – from vessel to offshore platform, and if it will be beneficial for Nitrogas to perform such changes.

It has also been performed a finite element analysis regarding an impact test for the different prototypes that has been designed for this Master thesis. The impact test will give a clarification if the frame will be able to withstand rough behavior that may occur on a daily basis.

1.4 Organization of the work

This chapter contains a brief introduction about nitrogen generators, and different methods to generate nitrogen. Chapter 1 also describes the state of art technology, beam theory, High-Pressure booster concept, definition of Atex standards and material theory.

Chapter 2 contains the different design criterions that are applicable for the nitrogen generator frame that has been designed in this Master thesis. It also covers the different harmonized standards, and the applicable requirements for the frame to be in conformity for offshore use.

Chapter 3 contains a review of the design criterions and what has been done on the prototypes to fulfill them. Chapter 3 also contains a presentation of the different prototypes that has been designed, as well as the different advantages and disadvantages of each frame.

Chapter 4 contains the description of the main components, the structure of the air regulation plates, and a system overview of generator.

Chapter 5 contains a research regarding certification for the nitrogen generator according to DNV 2.7-3 – Portable offshore units. The chapter contains the critical demands from DNV 2.7-3, and a discussion regarding if this will be applicable or not.

Chapter 6 contains the experimental procedure and result from the performed analyses. The results has also been discussed according to the criterions from NORSOK R-002 – Lifting equipment.

Chapter 7 is the conclusion of the research that has been performed, along with margins of error that may occur, as well as a further progress of the nitrogen generator.

1.5 Theory

1.5.1 Generating Nitrogen

Membrane Systems

Nitrogen can be generated in different forms. Some of the generators uses the air in the atmosphere as input, and then multiple filters and a membrane will filter out the oxygen molecules. The fibers in the membrane will filter out the oxygen molecules, leaving "only" nitrogen left. Compressed oxygen and nitrogen are separated by the relative speed of each molecule, and oxygen molecules will permeate the fiber sidewalls in the membrane at a faster speed than nitrogen molecules will. Which will enable the oxygen molecules to be selective exhausted. The purity of nitrogen gas will increase as the flow proceeds down the fibers. Membrane systems is the most robust nitrogen separation system, but uses more energy than PSA. With the membrane purifier system, it is possible to achieve a nitrogen purity up to 99% as Figure 5 illustrates [4].

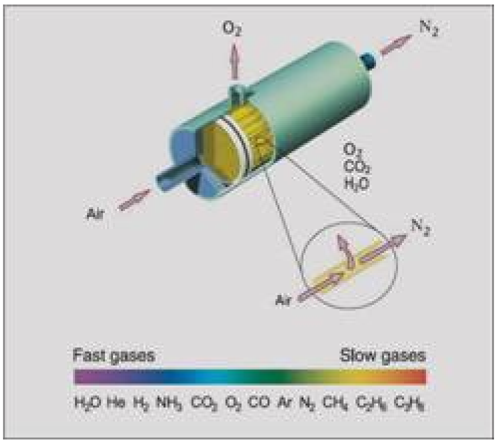

Figure 3: Membrane system [4]

PSA System

Pressure Swing Adsorption is used in onsite nitrogen generators, and can generate a purity higher than 99%. PSA generates nitrogen by using the concept of a pressure swing dryer, by using two-container system containing carbon molecular sieve (CMS). The CMS will separate nitrogen gas from air by absorbing the oxygen, carbon dioxide and water molecules onto the surface of the carbon molecular sieve with pressurized clean air. This will continue until it remains a purity of 99 – 99.995% nitrogen. Figure 4 illustrate the concept of PSA system [4].

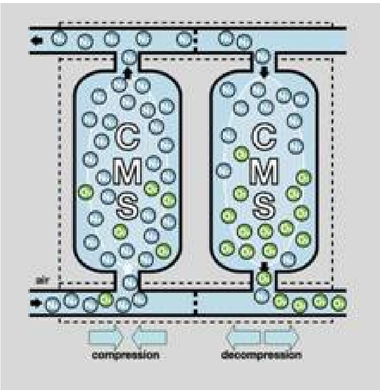

Figure 4: PSA system [4]

Cryogenic Nitrogen Plants

Cryogenic air separation plant generates nitrogen by compressing air, and then cooling it by multi-stage refrigeration until it liquefies at approximately -190C. The liquid will then be heated and separated into its components nitrogen, oxygen and argon by fractional distillation in a rectification column. This method has the lowest cost for producing liquid nitrogen in larger quantities. When the liquid nitrogen has been bottled up, it will be transported to the preferred destination. A disadvantage of a cryogenic nitrogen plant is that it requires full time monitoring as well as an operational staff. It is also highly expensive to transport the liquid nitrogen, and store it in specific areas offshore [4].

Membrane technology will be used on the nitrogen generator that is presented in this Master thesis.

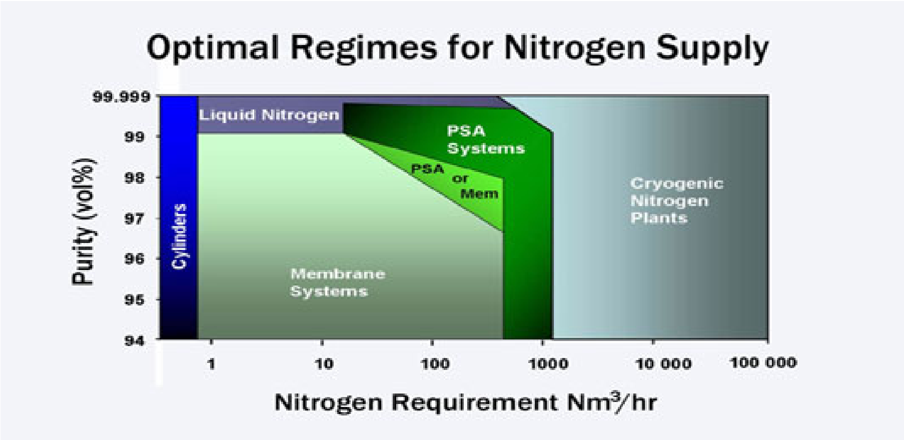

Figure 5: Optimal regimes for nitrogen supply [4]

1.5.2 State of Art

On the market today, several manufacturers and producers supply nitrogen generators for the oil and gas industry. The common factors are that the generators are mounted in stationary skids or containers and then transported in bottles to the desired work area. It has not been found any other supplier that can deliver a manual portable unit that will generate nitrogen in Atex zones without air supply from the platform/vessel.

The nitrogen generator on the market that can be compared to the nitrogen generator that is presented in this Master thesis is Atlas Copco’s NGM 2 [5]. The generator is stationary and generates nitrogen with the membrane system, it is not Atex approved. The NGM 2 unit is illustrated in figure 6.

Figure 6: Stationary nitrogen generator [5]

Portable nitrogen generators do exist. However, these are not Atex approved. The nitrogen generator that is illustrated in figure 7 shows a portable generator, but this generate nitrogen from an external compressor. [6]

Figure 7: Portable nitrogen generator from Zhuhai EST [6]

Figure 8: Atex approved nitrogen generator from JB well solution [7]

Figure 8 illustrates an Atex approved nitrogen generator. This generator generates nitrogen via the membrane system, the generator is diesel driven, stationary and geometric large. A crane or truck is required to transport it [7].

As mentioned, there are different types of nitrogen generator in the oil & gas industry today. However, they are either large, stationary machines that are expensive to operate, and demands planning and a logistic structure that are yesterday's news. The industry is in need of a portable nitrogen generator that can provide nitrogen on-site, whether the customer is onshore or offshore. The nitrogen generator that will be described in this Master thesis will bring a revolution in the oil and gas industry.

Since the oil-price in the world today, is low, due to comparison with earlier years. The industry is now in need to save as much money as possible, but the demand for nitrogen is still in need. Therefore, it is vital to come up with a new dimension of thinking, which will bring a cost-efficient unit that can be revolutionary for this industry, and it is here Nitrogas` nitrogen generator comes in.

1.5.3 Beam Theory

1.5.3.1 Finite Element Analysis

General purpose of finite element analysis software can be divided into three steps:

- Preprocessing: Input data describes geometry, material properties, loads and boundary conditions. Software can automatically prepare much of the FE mesh, but must be given direction as to the type of element and the mesh density desired, it is important to choose one or more element formulations, that suits the mathematical model, and state how large or how small elements should be in selected portions of the FE model.

- Numerical analysis: Software automatically generates matrices that describe the behavior of each element, combines these matrices into a large matrix equation that represents and solves the equation to the FE structure. Values of field quantities at nodes is also determined.
- Post processing: The FEA solution and quantities derived from it are listed or graphically displayed. This step is also automatic, except that the analyst must tell the software what to display. In stress analysis, typical displays include the deformed shape, with deformations exaggerated, and stresses of various types on various planes [8].

1.5.3.2 2D Beam Element

Beams are the most common type of structural components. The primary function of a beam is to resist transverse loads generally through bending. Beam is a bar-like structural member with, where the longitudinal dimension is considerably larger than the other two. The longitudinal dimension can also be called beam axis. The intersection between the planes that are normal to the longitudinal dimension with the beam members are called cross-sections [9].

Since beams is actually three-dimensional bodies, all bodies necessarily involve some form of approximation to the underlying physics. The best-known models for straight beams are based on the Bernoulli – Euler theory, also called classical beam theory [9].

Bernoulli-Euler Beam Model

The Bernoulli-Euler model assumes that the internal energy of beam member is entirely due to bending strain and stresses. The Bernoulli- Euler model neglects transverse shear deformations and cross-sections remain plane during deformation and perpendicular to the longitudinal axis [9].

Beam in a Local System

A beam is exposed to transverse load that will lead to a considerable greater bending deformation compared to axial and distortion deformation. Figure 9 illustrates the axial condition of a beam element and shows that each element will have six degrees of freedom in a local system.

Displacement field in a beam

The difference between a bar element and a beam element is the degrees of freedom.

- Bar element has 1 DOF at each node: axial displacement
- Beam element has three DOF at each node: axial displacement, transverse displacement and rotation.

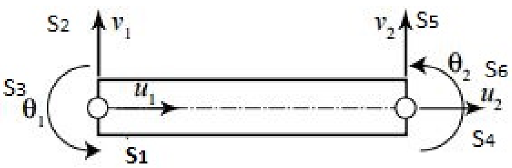

Figure 9: Degrees of freedom in a beam

Figure 9 above illustrates the number of DOF in a beam. Where u_1 and u_2 is representing the axial conditions of the beam element. In addition, v_1, θ_1, v_2 and θ_2 is representing the bending conditions. The stiffness matrix for the bending condition can be set up from the definition on the elements in the stiffness matrix. Equation 1,2,3,4 and 5 are found in reference [10].

$S_a = k_a \text{ x } v_a$ (1)

$S_b = k_b \text{ x } v_b$ (2)

Where $v_a = [u_1\ u_2]^T$ is axial conditions and $S_a = [S_1\ S_4]^T$ is the corresponding axial forces in node 1 and node 2.

$V_b = [v_1\ \theta_1\ v_2\ \theta_2]^T$ (3)

$S_b = [S_2\ S_3\ S_5\ S_6]^T$ (4)

In equation (3) v_1 and v_2 are transverse displacements in node 1 and 2, and θ_1 and θ_2 are angular deflection. The load vector S_b contains matching forces and moments [10].

When only looking at bending deformation and its four degrees of freedom, the stiffness matrix K_b has a size of 4x4 as illustrated below:

$$K_b = \begin{bmatrix} k_{22} & k_{23} & k_{25} & k_{26} \\ k_{32} & k_{33} & k_{35} & k_{36} \\ k_{52} & k_{53} & k_{55} & k_{56} \\ k_{62} & k_{62} & k_{65} & k_{66} \end{bmatrix} \qquad (5)$$

Figure 10 below illustrates how each column can be found and calculated [10] (the notations in figure 10 and formula 5 are not related).

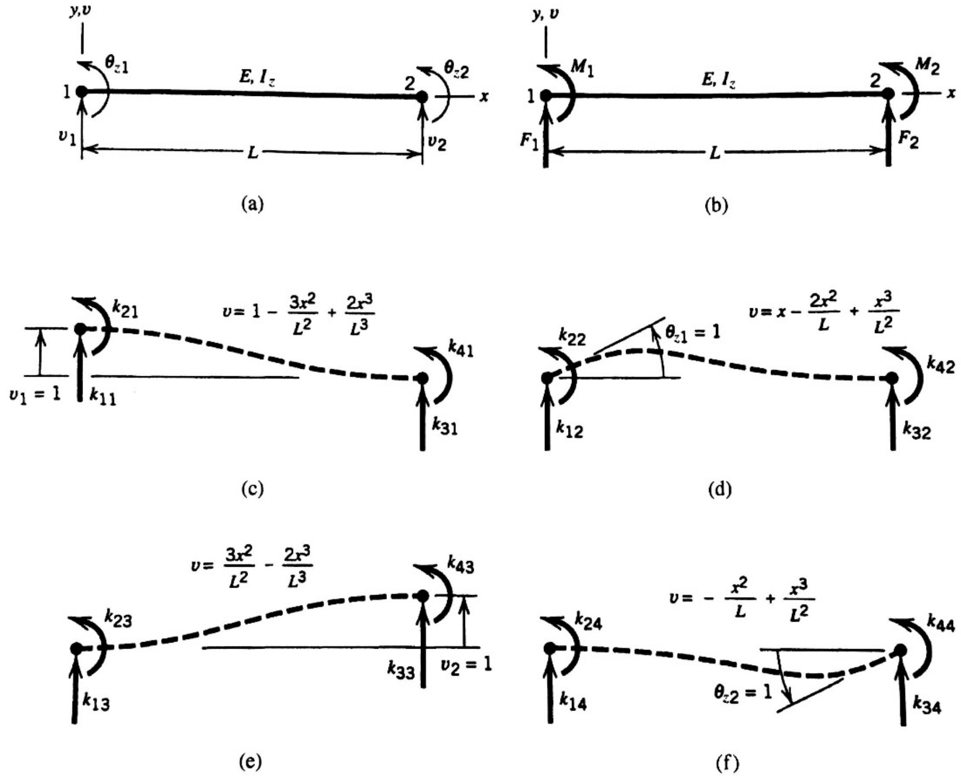

Figure 10: (a) Beam element in the x y plane and its nodal d.o.f. (b) Nodal loads associated with nodal d.o.f. (c-f) Dashed lines show lateral displacements due to bending associated with activation of each d.o.f. in turn. Formulas are obtained from beam theory [8].

Figure 10 – illustrates beam elements in the x y-plane and its nodal degree of freedom. Each node has two degree of freedom, namely, latterly translation and rotation. Nodal rotations contain subscript z to denote that their vector representations point along the z-axis, which is normal to the x-y plane. Nodal loads, each positive if acting in the same direction as its corresponding D.o.f, as Figure 10 b. illustrates [8].

The stiffness matrix can be explained and obtained by looking at the 4 x 4 matrix. Where the j_{th} column is the right number in the k_{ij} notation in the matrix. The matrix can be constructed column by column, where the j_{th} column is the vector of nodal loads associated with unit value of the j_{th} degree of freedom and zero values for all other degree of freedom. The load vector will contain moments as well as forces. The loads from figure 10 are named k_{11}, k_{21}, k_{31}, and k_{41}, to indicate that they will appear in rows 1, 2, 3 and 4 and in column 1 of the element stiffness matrix [k]. To obtain k_{11} and k_{21} one can apply the formulas of elementary beam theory by regarding figure 10 – c as a cantilever beam fixed at node 2 and loaded at node 1 by force k_{11} and moment k_{21} such that $v_1 = 1$ and $\theta_{z1} = 0$. Thus

$V_1 = 1: \frac{k11*L^3}{3*E\,Iz} - \frac{k21*L^2}{2EIz} = 1$ (6)

$\Theta_{z1} = 0 - \frac{k11*L^2}{2EIz} + \frac{k21*L}{EIz} = 0$ (7)

From equation (1) and (2) it is possible to determine k_{11} and k_{21} from the following formulas:

$K_{11} = \frac{12EIz}{L^3}$ (8)

$K_{21} = \frac{6EIz}{L^2}$ (9)

Now that it is possible to determine k_{11} and k_{21}, it is possible to determine k_{31} and k_{41} from considerations of static equilibrium, by sum y-direction forces and moments about node 2[8]:

$K_{11} + k_{31} = 0$ (10)

$k_{21} + k_{41} - k_{11}L = 0$ (11)

From equation 8, 9, 10 & 11 we obtain

$K_{31} = -\frac{12EIz}{L^3}$ (12)

$K_{41} = \frac{6Eiz}{L^2}$ (13)

By doing a similar analysis of the latter three parts of figure 11 provides terms in the latter three columns of [k] [8]. The equations 6 – 13 are from reference [8].

The complete 2-D beam element stiffness matrix is:

$$[\mathbf{k}] = \begin{bmatrix} \frac{12EI_z}{L^3} & \frac{6EI_z}{L^2} & \frac{-12EI_z}{L^3} & \frac{6EI_z}{L^2} \\ \frac{6EI_z}{L^2} & \frac{4EI_z}{L} & \frac{-6EI_z}{L^2} & \frac{2EI_z}{L} \\ \frac{-12EI_z}{L^3} & \frac{-6EI_z}{L^2} & \frac{12EI_z}{L^3} & \frac{-6EI_z}{L^2} \\ \frac{6EI_z}{L^2} & \frac{2EI_z}{L} & \frac{-6EI_z}{L^2} & \frac{4EI_z}{L} \end{bmatrix} \begin{matrix} v_1 \\ \theta_{z1} \\ v_2 \\ \theta_{z2} \end{matrix}$$

Figure 11: Illustration of complete 2D beam element stiffness matrix [8]

The column of symbols on the right is appended merely to indicate that [k] operates on the column vector of element d.o.f {d} =[$v1 \quad \theta z1 \quad v2 \quad \theta z2]^T$. A different ordering of d.o.f in {d} would change the ordering of coefficients in [k] but not their numerical values. If the left end of the beam element is fixed so that *v1* = 0 and *θz1* = 0, it will be obtained a structure with "active" d.o.f *v2* and *θz2* [8]. The stiffness matrix of this one-element cantilever beam is the lower right 2 by 2 in figure 11.

The effect of axial displacement in a first order analysis is independent of the effect of the other two DOF.

A frame construction is characterized by multiple beams that has rigid nodes (welded joint ends). In addition, beams can be affected by transverse loads, and from there be a victim of buckling in the element. This will create stresses in the beam elements by rotations and accompanying bending moments. [8]

1.5.4 3D Beam Element

As seen from the figure 12 below, there are six degree of freedom per node is six. Three translations and three rotations. *W* and *θy* d.o.f account for lateral deflection is the z-x plane. Θ*x* d.o.f account for twist about the x-axis, for which the stiffness coefficient is $\frac{GK}{L}$, where K is a property of the shape and size of the cross section [8].

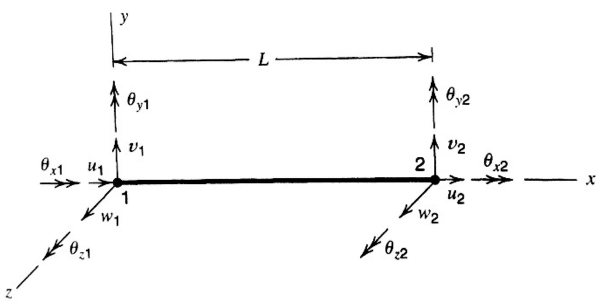

Figure 12: Beam element on the x-axis of a rectangular coordinate system, with nodal d.o.f. used to defined axial displacement, twisting, and lateral deflection in the y and z directions [8]

1.5.5 Mesh

1.5.5.1 Linear Triangle (CST)

A linear triangle is a plane triangle whose field quantity varies linearly with Cartesian coordinates *x* and *y*. In stress analysis, a linear displacement field produces a constant strain field, so the element may be called a *constant – strain triangle* (CST). For convenience, at node 1 at x = y = 0 and side 1-2 along a local axis, from figure 13 [8].

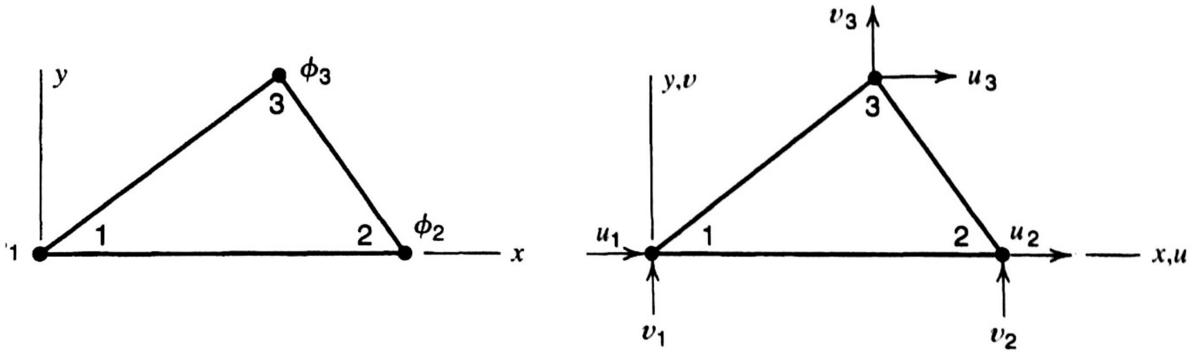

Figure 13: Linear triangles. (a) Scalar field element. (b) CST element for 2D stress analysis [8]

The linear triangle was the first element devised for plane stress analysis, and it does not work very well. When the beam is affected of bending, a mesh of these elements is undesirably stiff, and the correct results are approached as a mesh is refined, but the convergence is slow [8].

1.5.5.2 Quadratic Triangle (LST)

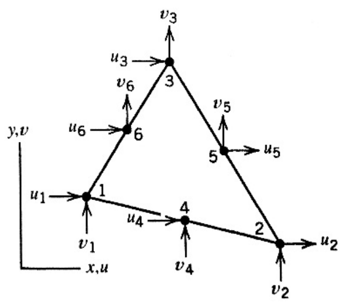

Figure 14: Quadratic triangle (LST and its 12 nodal d.o.f [8]

A quadratic triangle is illustrated in figure 14. The triangle has side nodes, as well as vertex nodes. In stress analysis, the nodal d.o.f. are u_i and v_i at each node (where i = 1,2,…,6) for a total of 12 d.o.f. per element. In terms of generalized d.o.f. a_i, the element displacement field is the complete quadratic:

$$u = a_1 + a_2x + a_3y + a_4x^2 + a_5xy + a_6y^2 \quad (14)$$

$$v = a_7 + a_8x + a_9y + a_{10}x^2 + a_{11}xy + a_{12}y^2 \quad (15)$$

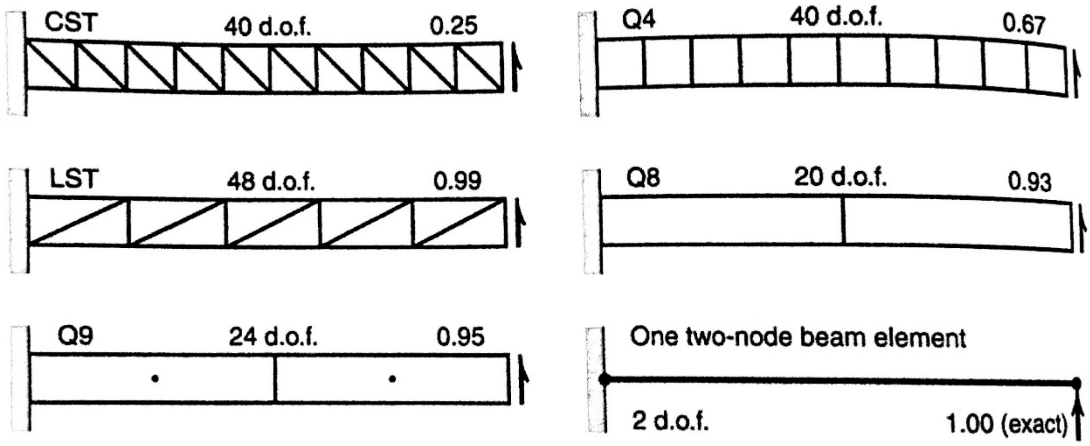

Figure 15: Tip-loaded cantilever beams [8]

Equation (14) and (15) are from reference [8].

Figure 15 illustrates tip-loaded cantilever beams of aspect ratio 10 and Poisson's ratio v = 0.30. Transverse tip displacement is reported as the ratio of computed value to exact value.

As figure 15 illustrates it is possible to detect that LST is the most exact mesh.

An LST element may be called "linear-strain triangle." Because displacement functions are quadratic in x and y directions, all lines in the element, including its sides can deform into quadratic curves.

Both CST and LST are used to find strains and displacement [8].

1.6 Material

There are six different main aluminum alloy series: 1xxx, 2xxx, 3xxx, 5xxx, 6xxx and 7xxx series. The two most commonly used alloys in marine operations are the 5xxx and 6xxx alloys. The 5xxx series aluminum alloy have magnesium as the main component while the 6xxx series has magnesium and silicone as the main components. These components form precipitates of magnesium silicide, which allows the alloy to be heat-treated [11].

For this thesis, there have been used two different aluminum alloys. The exterior parts, such as the frame, consist of an aluminum 6082 alloy. While the interior parts, such as air regulation, and retaining wall will be an aluminum 5082 alloy.

The two aluminum alloys has been selected due to different design criterions, which is to keep the weight as low as possible, and maintain a frame with minimum welding due to economic (the design criterions is covered in chapter 2).

I have personally contacted Tom Rosland, technical supervisor at Lie CNC, and asked him about forming aluminum 6082 by buckling. He said it was not possible to form aluminum 6082 plates by buckling [12], and aluminum 5052 have therefore been chosen as the suitable aluminum alloy for the interior plates.

Both of the alloys have the required mechanical properties, and are capable of withstanding corrosion. The selected alloys are suited for use in the offshore technology due to the high corrosion resistance. The chemical properties are found in reference [31][32].

1.6.1 Aluminum 6082

Aluminum 6082 is a structural alloy that has a very good corrosion resistance. 6082 alloy have been chosen for the frame, due to its high corrosion resistance, low weight, physical properties and low cost. The addition of magnesium and silicone to aluminum produces the compound magnesium-silicide. Formation of the 6xxx series provides the heat-treatability [11].

1.6.2 Aluminum 5052

Aluminum 5052 alloy has been chosen as the suited material for the interior parts in the nitrogen generator unit. The interior aluminum plates are going to be formed by buckling, and work as air regulation (the specific task for the interior plates are presented in chapter 4).

Aluminum 5052 has good forming characteristics and has a good corrosion resistance; the corrosion resistance is including salt water [13].

Aluminum 5052 possesses high magnesium content, making it the highest strength non-heat treatable alloy available [14].

1.6.3 Stainless Steel

The four threaded rods in the frame are going to be stainless steel. It is assumed that it will be 316 alloys. 316/316L stainless steel has a high resistance to many chemical corrodents and marine atmosphere. These alloys are more resistant to general corrosion and pitting/crevices than conventional austenitic stainless steel [15].

1.7 High Pressure Booster

Nitrogas is also developing a high-pressure unit that will boost the nitrogen from the chosen pressure in the LP-unit and up to 300bar. The high-pressure unit has not been dealt with in this Master thesis, but the frame shall be applicable for both LP and HP unit.

1.8 Atex

The Norwegian offshore platforms have very high security standards regarding equipment in an explosive atmosphere. On offshore platforms, there are several dangerous chemicals and gases. In 2003, EU made a directive on how companies should protect their employees from explosion risk in areas with an explosive atmosphere. When the directive was published in 2003, it was clear that the equipment must be approved into different classes, and its size and location will depend on the likelihood of the explosive atmosphere occurring and its persistence if it does explode. Equipment that is used in these areas with gases is divided into three different zones: 0, 1 and 2. Where area 0 is the zone with highest risk of an explosive atmosphere [16] [17].

All types of lifting appliances, fixed, mobile or temporary, electrical and non-electrical, installed or used in hazardous areas, shall comply with ATEX requirements, i.e. Zone 0, Zone 1 or Zone 2as relevant for the hazardous area classification [18].

Table 1: Defining different Atex zones [16]

European and IEC Classification	Definition of zone or division	North American Classification
Zone 0 (gases/vapors)	An area which an explosive mixture is continuously present or present for long periods	Class | Division 1 (gases)
Zone 1 (gases/vapors)	An area in which an explosive mixture is likely to occur in normal operation	Class | Division 1 (gases)
Zone 2(gases/vapors)	An area in which an explosive mixture is not likely to occur in normal operation and if it occurs it will exist only for a short time)	Class| Division 1(gases)

The areas, which are classified into these zones, must be protected from sources of ignition.

2. Design Criterions

Designing the frame for the nitrogen generator indicates that many fundamental aspects have to be considered to get the preferred result. Nitrogas` goal is to design and produce a low-pressure nitrogen generator that can generate and deliver low-pressure nitrogen in the range of 450 l/min. The unit shall be portable, and be able to be moved by hand by the operator. It shall be possible to operate in all working areas, including Atex zone 1.

Design Criterions for the frame:

- The frame shall be compatible with the low-pressure unit and the high-pressure unit.
- The frame shall be service friendly
- The frame shall be easy to disassemble
- The frame shall be approved according to:
  - NORSOK Z-015 – Temporary equipment
  - R-002 – Lifting equipment
- The frame shall have a maximum weight of 450kg.
- The frame shall be able to transport through doors (0.80 m).
- The frame shall be able to withstand sea-water, and be applicable in fluid conditions
- The frame shall be portable with wheels

The design criterions that have been set for the generator frame is defined by Nitrogas AS.

2.1 Harmonized Standards

The nitrogen generator shall be designed and produced in accordance with the harmonized standards that is necessary to make the nitrogen generator approved for offshore use.

2.1.1 NORSOK Standards R-002, Lifting equipment, edition 2, September 2012

The main purpose of NORSOK R-002 standard is to contribute to an acceptable level of safety for humans, the environment and material assets in the petroleum industry by giving technical requirements for lifting equipment [18].

This standard is valid for technical requirements to lifting appliances and lifting accessories on all fixed and floating installations, mobile offshore units, barges and vessels, as well as on land based plants where petroleum activities are performed. The standard is also valid for material handling and for the following equipment:

- Launching and recovery appliances for life saving equipment with and without lifting functions.
- Means of connection and release systems that are integrated parts of life saving equipment, as well as their anchorage in the life saving equipment.
- Portable units.
- Foundations and suspensions for lifting appliances.
- Lifts [18].

NORSOK R-002 is a standard that applies for internal lifts in offshore operations.

In Annex F in NORSOK R-002, the Nitrogen generator can be referred to as a portable unit and type A in DNV 2.7-3 (This is validated in chapter 2.1.3).

Table 2: Overview of object groups [18].

Group no.	Group	Description	Subject to NORSOK R-003 or R-003 Annex H and E
F1	Offshore containers	Portable unit with a maximum gross mass not exceeding 25 000kg, for repeated use in the transport of goods or equipment, handled in open seas, to, from or between fixed and/or floating installations and ships	Unit and lifting set
F2	Offshore service containers	Portable unit built and equipped for a special service task, mainly for temporary installation, e.g. are laboratories, workshops, stores, power plants, control stations.	Unit and lifting set
F3	Offshore portable units	Portable unit built or package with a primary structure frame and maximum gross weight not exceeding 100 tons, for repeated or single use, as defined in DNV Standard for Certification No. 2.7-3 clause 1.1.5 Type A	Unit and lifting set

F4	Heavy lift units and units for subsea lifting	Heavy lift units are portable units with a maximum gross weight equal to or exceeding 50tons planned to be lifted as suspended load onshore or offshore. Units for subsea lifting are portable units intended for lifting through wave zone and lowering in deep water to landing on seabed.	Lifting set only
F5	Lifted objects	This group includes any loads not belonging to the other groups, which are not in themselves lifting equipment, but fitted with attachment points for lifting accessories for lifting onshore, internally on an offshore installation or between installation and vessel. Lifted objects also includes objects with detachable transport skid/cradle Examples of lifted objects may be • Machines, components or equipment with fixed or detachable dedicated lifting points, • Modules or structures with lifting point for intended for lifting during installation, maintenance, and decommissioning. Typical unit weights from 2 tons to 50 tons but may be used for lifts up to 100 tons	Lifting set only

From table two, the nitrogen generator unit will be categorized into group F5 - Lifted Objects, and will be designed by the respective design criterions.

Group F5 includes objects and lifting sets that do not belong in any of the groups F1 to F4. This group of lists often have the typical characteristics, e.g.:

- Permanent structure or equipment to be installed as a new part of the installation, or moved/removed as part of platform modification or removal.
- Objects that cannot be lifted with the aid of a load carrier.
- Often unsymmetrical lifting sets due to defined location of the center of gravity (CoG) or unsymmetrical configuration of lifted object;
- If a transport cradle is required, the cradle is often designed with defined supports for the machine or equipment to be transported and sometimes bolted or locked to the equipment;
- In some special cases, the lifting lugs may partly be located on the lifting cradle and partly on the equipment to be transported [18].

Offshore portable units and their dedicated lifting sets shall be designed and manufactured in accordance with DNV standard for certification No. 2.7-3 May 2011. Only units designed for operational class R60 is acceptable for use on the Norwegian continental shelf, even if their use is intended to less severe sea states [18].

Certification requirements given in DNV standard for certification No. 2.7-3 are not mandatory requirements of NORSOK R-002 (the different criterions regarding DNV 2.7-3 has been reviewed in chapter 5)

According to NORSOK R-002, the design factor is defined as:

$DF = \gamma_p \times \gamma_c$

Where

γ_p = partial load factor

γ_c = consequence factor

γ_p and γ_c is found in table 3

Table 3: Design factors (DF) [18]

Element category	γ_p	γ_c	DF (γ_p x γ_c)
Lifting points including attachments to object **Single critical elements supporting the lifting point**	1.34	1.25	1.68
Lifting equipment (spreader bar, shackles, slings etc)	1.34	1.25	1.68
Main elements which are supporting the lift point	1.34	1.10	1.48
Other structural elements of the lifted object	1.34	1.0	1.34

The design factor in the frame must be greater than 1.48 (Main elements, which are supporting the lift point)

$DF = \gamma_p \times \gamma_c = 1.34 \times 1.10 = 1.474$ (1.48)

Safety factor is defined as DF x DAF

Standard dynamic amplifying factor (DAF) to be used when designing lifted objects and their corresponding lifting accessories shall be:

"The DAF for lifting accessories shall never be selected for less than 1.5 for loads up to 50 tons in order to comply with safety factors according to machinery directive and NMD" [18].

Onshore lifts and onboard lifts on fixed or floating installations:

DAF = 1.5 for WLL $\leq$ 50 tons [18].

SF = DF x DAF

1.48 x 1.5 = 2.22

According to this formula, the safety shall be above 2.22 to be approved for internal lifting on offshore platforms. All of the equations that are submitted in chapter 2.1.1 are found in reference [18].

2.1.2 NORSOK Z-015

This standard defines how the temporary equipment should be handled, and what requirements that is necessary to fulfill for the units.

The definition of temporary equipment is equipment that has a planned time limit, that demands connection by offshore device (Containers, diesel motors etc.) [19].

A gas detector shall be placed in all air-intakes for compressor, and shall be able to close down the equipment, if necessary [19]. The gas detector has been placed at the inlet for the compressor. As shown in Figure 16.

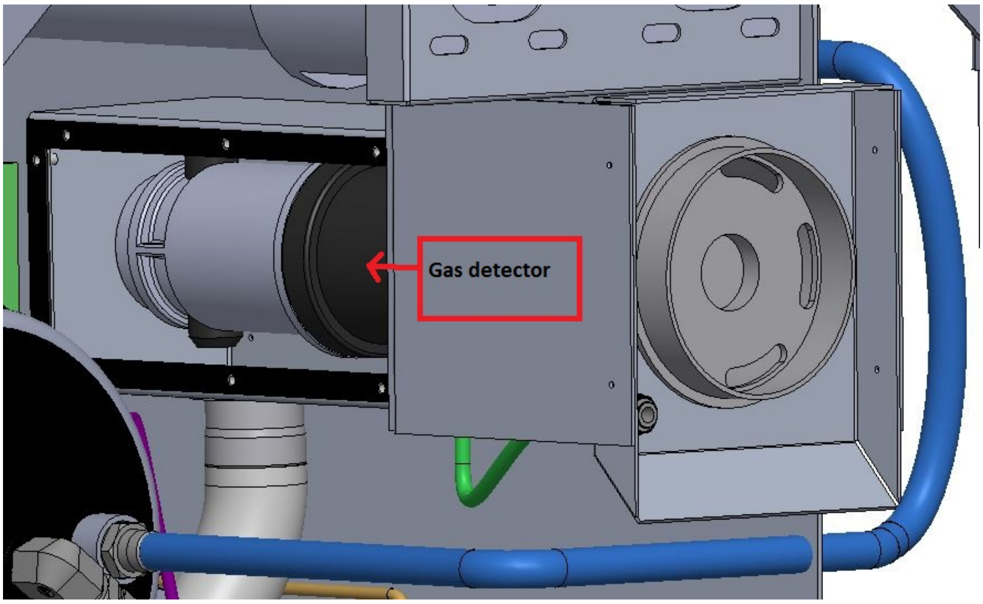

Figure 16: Inlet and gas detector

3. Design of Frame

The purpose and main challenges of the frame is to have a design that is innovative, with a combination of minimum welding, minimum cost and maximum strength.

3.1.1 Review of Design Criterions

In this Master thesis, there has been designed three different prototypes for the nitrogen generator frame. As a starting point, the frame was designed to fulfill the design criterions as good as possible.

The different prototypes have been designed in accordance with the design criterions, and the harmonized standards.

There have been designed three frames, which is compatible for the low-pressure unit and the high-pressure unit. The idea is to disassemble the four corner beams, and then lift the corner beams with the top cover plate of the bottom structure, which will enable an easy access to perform service maintenance by the mechanic.

Dimensions of the frame are:

L: 1260mm

W: 800mm

H: 1108mm

The width of the frame is 800mm (0.8m); it will therefore be able to being transported through doors.

The chemical properties for the materials that has been chosen for the frame, and its corrosion resistance properties, is suitable for operations within Atex zone 1 area.

The frame has also been designed with wheels, and handlebar, meaning it is possible to transport it by an operator.

3.2 First Prototype

In this chapter there has been designed various prototypes of the nitrogen generator frame. It started with a concept of a frame with zero welding, and an easy way to disassemble the frame. The idea was to design the frame with an approach that would make it easy for the mechanic to perform service maintenance on the unit. It should be easy to access the interior parts by disassembling the bolts, nuts and washers in the bottom frame for the corner beams. By doing this, one can lift off the top/corner frame in one piece, leaving only the bottom frame, which will make it easy for the mechanic to perform service maintenance on the interior parts.

On the first prototype, there were designed two bottom plates with a thickness of 3mm and these plates should carry the load of the components. The concern with this prototype is the lack of supporting structure. The maximum gross weight of the nitrogen generator will be approximately 450 kilos, and all the components will have an approximately weight of 400kg (The exact weight of this frame is unknown, and the numbers of the frame are assumed). The bottom plates will not be strong enough to withstand a weight that high, and will fail. Therefore, it has not been made an analysis of prototype 1.

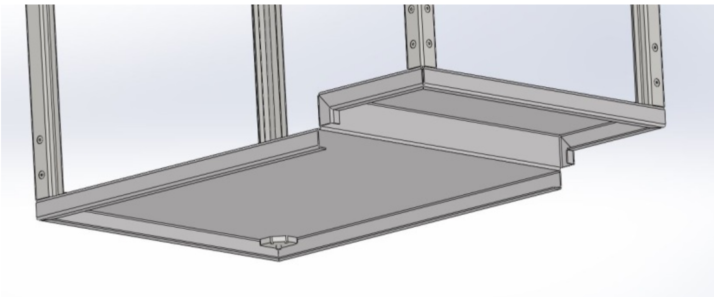

Figure 17: Bottom base plate in P1

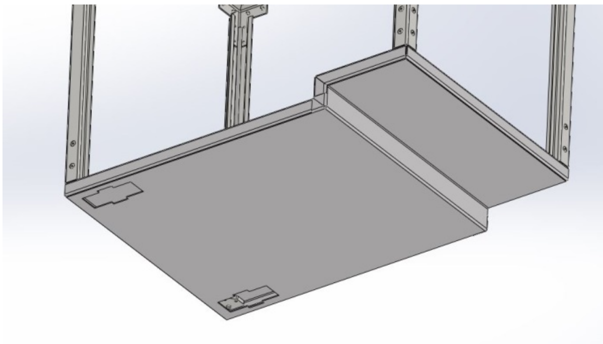

Figure 18: Bottom base plate of P1

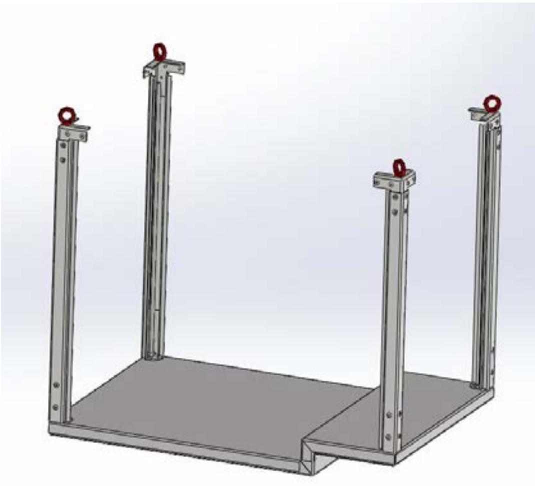

Figure 19: Prototype 1

Figure 17, 18 and 19 illustrates prototype 1, it shows that the frame is simple with no reinforcements, but the plot is to have two bottom plates of 3mm thickness, that will carry the load of the components.

The two bottom plates in the structure were designed as a base, where all the components should be mounted. Since this is a starting point of the design, it has not been designed any support structure to help the bottom plate in carrying the load of the components.

Figure 20 illustrates how the cover plates can be mounted into slots that has been implemented in the bottom plate. The cover plates will be fastened into the top frame on top, which will lead to a mounting in an easy and innovative procedure.

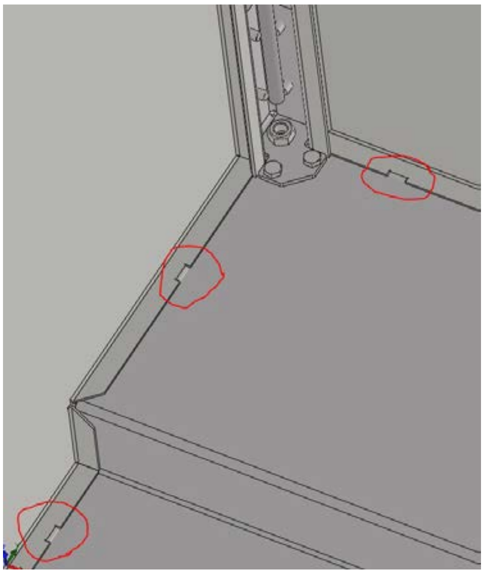

Figure 20: Slots for cover plates

Figure 22 illustrate how the corner beams are mounted in the bottom plate. There are no welding, and instead of rectangular beams, it has been designed a beam that will be formed by buckling. By using these corner beams instead of rectangular beams, it will result in an innovative method to mount the cover plates on, as well as the minimum welding design criterion is fulfilled. Figure 21 illustrates how the top of the corner beam, and how the cover plates can be fastened at the top via the top cover plate, and a lock at the top of the cover plate.

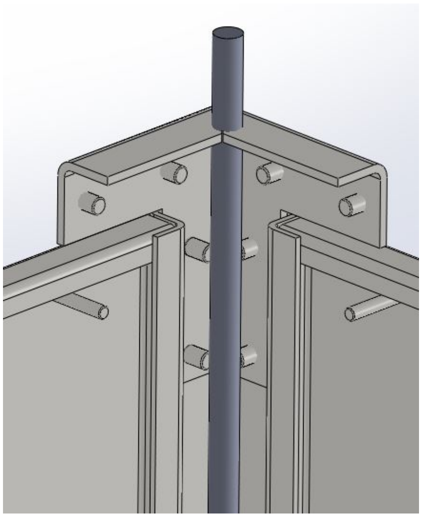

Figure 21: Top view of corner beam

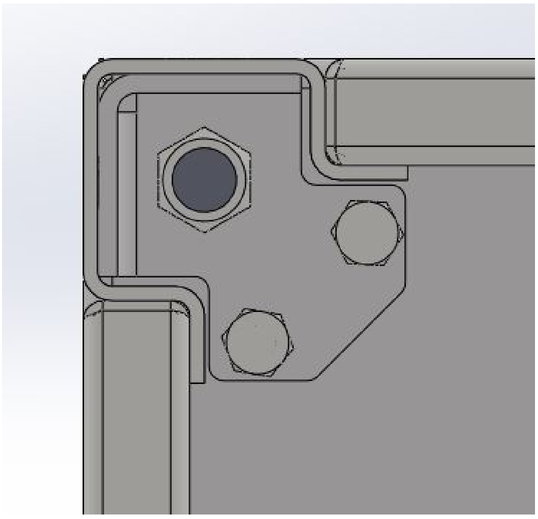

Figure 22: Top view of corner beam formed by buckling

3.3 Prototype 2

The second prototype that was designed is an extended development of the first prototype. A major change that has been included in prototype 2 is a reinforced frame. The bottom plate has been replaced with a welded frame that shall be capable of supporting the structure with all the components mounted on. The reinforced frame contains multiple 30 x 30 x 3mm square beams. This is illustrated on figure 24. The reinforced frame will be welded internally, and the corner beams shall be fastened by bolts, nuts and washers.

Results from the analyses is presented and discussed in chapter 6.

It has been made structural reinforcements to withstand the load of the different parts inside

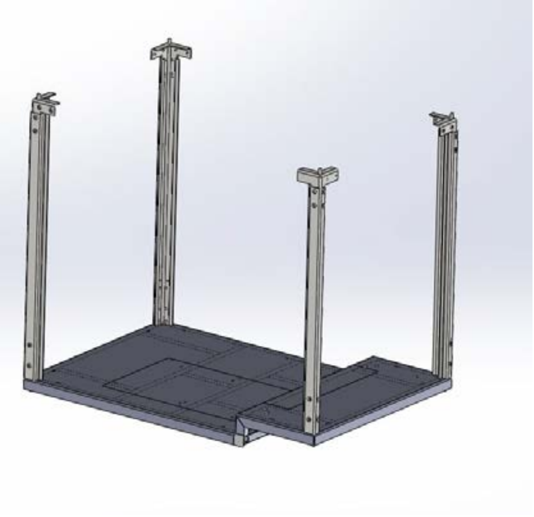

Figure 23: Prototype 2

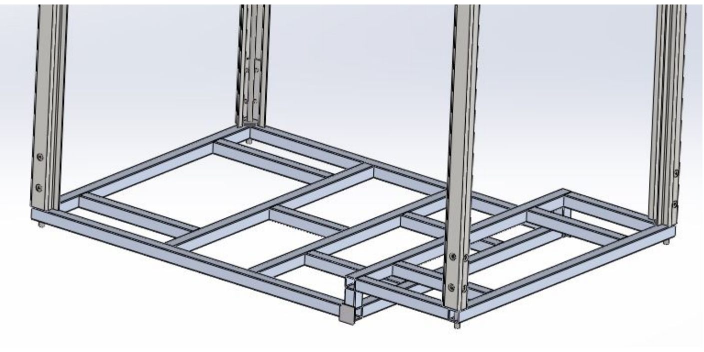

Figure 24: Reinforced welded frame

the unit.

The structural members in the reinforced frame has been designed at specific locations to withstand the load of the components.

3.4 Prototype 3

From the second prototype to the third there have been made significant changes. The reinforced frame has been changed frame 30 x 30 x 3mm square beams to 40 x 40 x 4mm square beams. The placement of the beams in the reinforced frame has been changed. This change has been made due to a desire of reducing the cost by using fewer beams.

The final prototype is illustrated below in figure 25. The concept of an entirely weld-free frame, which was planned in prototype one has been abandoned due to lack of supporting structure and strength issues. Prototype 3 has been designed with multiple weldments in bottom frame, corner brackets and top frame. The 40 x 40 x 4mm square beams that have been chosen for prototype 3 are highlighted in Appendix 1. The drawings for prototype 3, as well as an explanation of the different views of the frame are illustrated in Appendix 4.

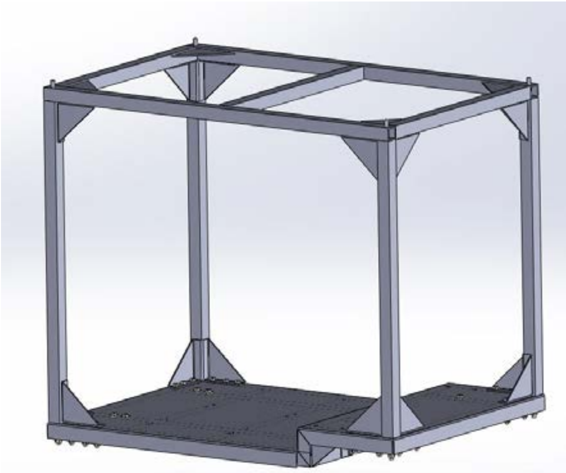

Figure 25: Prototype 3

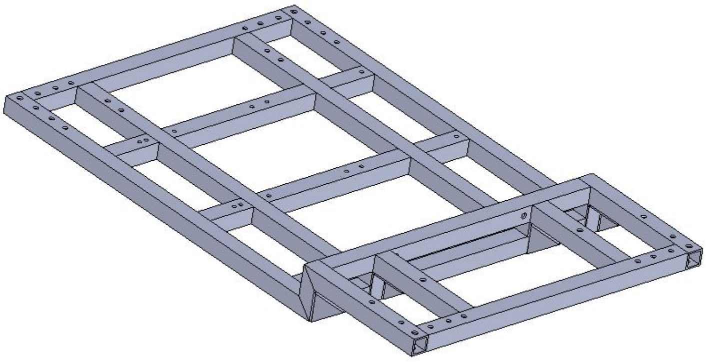

Figure 26: Reinforced frame for P3

Figure 27: Corner beam P2

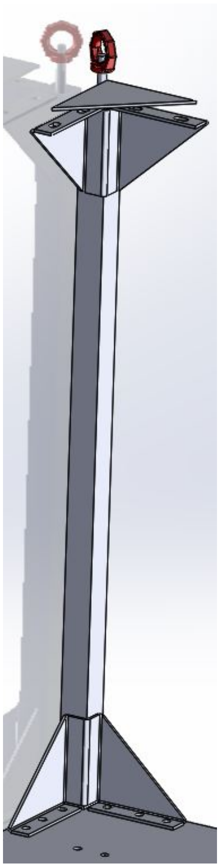

Figure 28: Corner beam P3

Figure 27 and 28 illustrates the one of the major changes in the prototypes. One can see that the corner beams in prototype 3 has been added structural support in the corner brackets. The corner brackets is mounted with bolts, nuts and washers for both of the prototypes, as seen, prototype 3 is more solid. The corner beams on prototype 3 will also protect the threaded rods.

Figure 29: Final version of P3

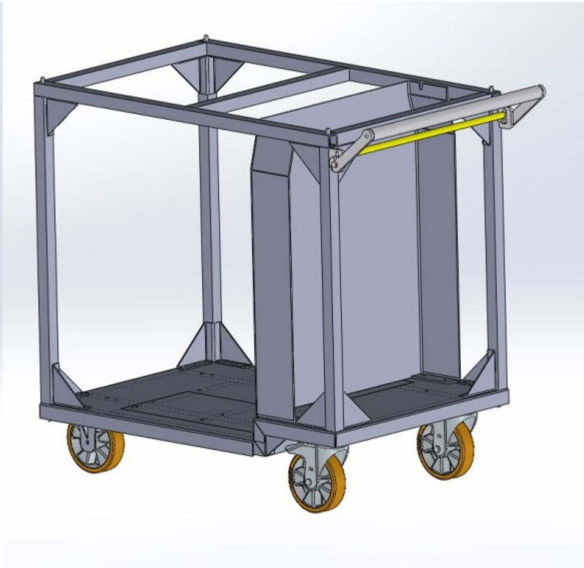

Figure 30: Different view of P3

Table 4: Advantages and disadvantages of frames

First Prototype	Second Prototype	Third Prototype
Weld free Cost efficient Easy to disassemble	Reinforced frame Innovative Easy to disassemble	Reinforced frame Solid Easy to disassemble
First Prototype Too weak Lack of support structure	**Second Prototype** Too weak	**Third Prototype** Expensive Considerable amount of welding

Table 4 illustrates the main advantages and disadvantages for the different frames, where the blue color is the advantages, and the red color is the disadvantages of the frames.

Other aspects are worth including as advantages and disadvantages, such as the result, and a detailed discussion why one frame is more suitable than the others, is explained in chapter 6.

4. Description & Components

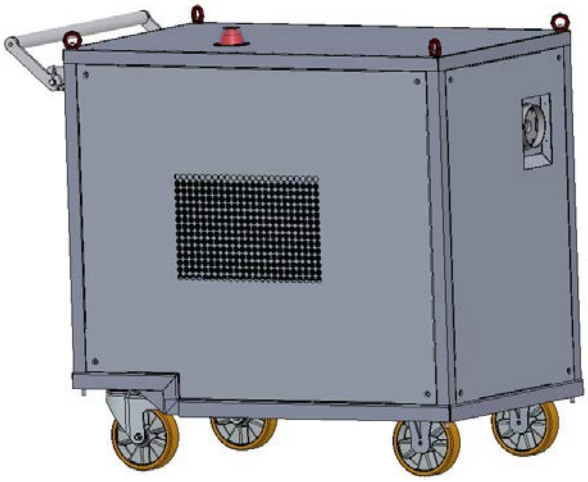

Figure 31: Nitrogen generator

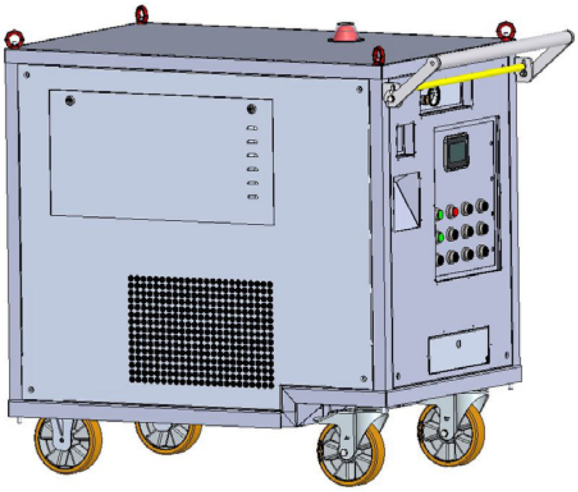

Figure 32: Nitrogen generator with different view

In figure 31 & 32, the final design of the nitrogen generator is illustrated, with all of the cover plates mounted. On figure 32, one can notice a hatchet, this hatchet is designed to the purpose that the customer itself can change filters inside the filter package, this can be unlocked by using a square lock, if necessary.

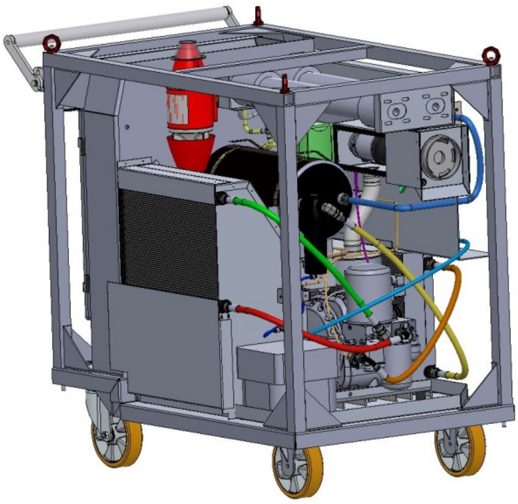

Figure 33: Nitrogen generator without cover plates

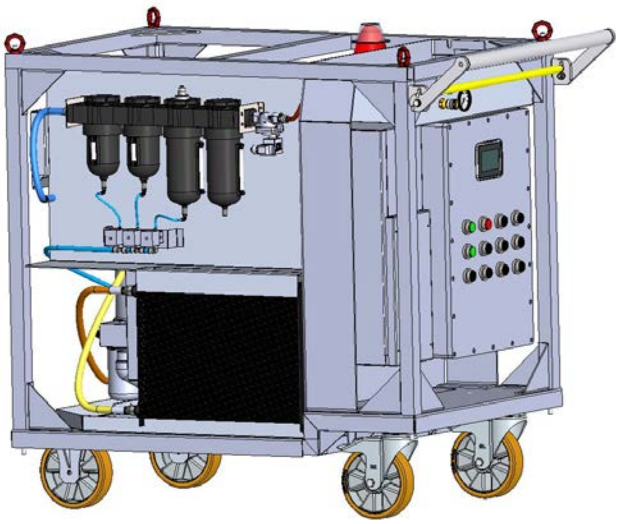

Figure 34: Different view of nitrogen generator without cover plates

These figures illustrate the final version of the nitrogen generator with components and hoses. On figure 34, one can notice the filters that can be manually changed (behind the hatchet on figure 32). Information about the filter package is located in chapter 4.1.4 and in Appendix 3. As illustrated, there are two different radiators in the nitrogen generator. The radiator illustrated in figure 32 is the oil radiator, and is cooling down the oil in the compressor. The radiator illustrated in figure 33 is the air radiator. Air is sucked into the generator and into the motor that is mounted behind the air radiator. The air regulation plates will make the air go straight from the motor and out through the oil radiator, and cool down the motor.

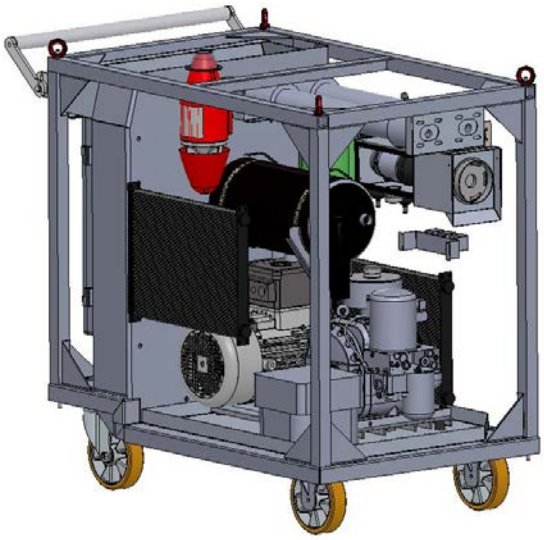

Figure 35: Nitrogen generator without hoses and interior plates

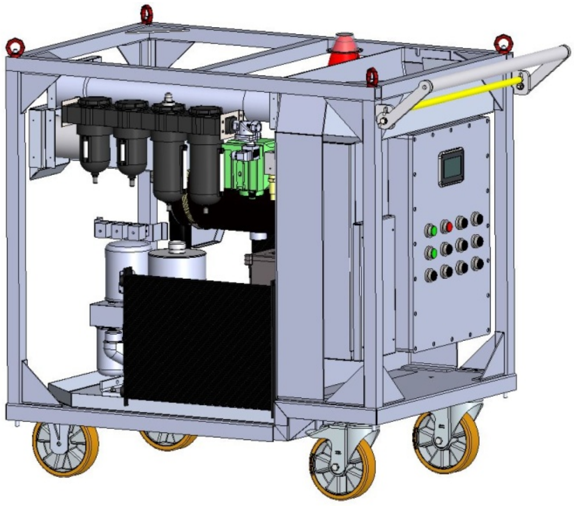

Figure 36: Different view of nitrogen generator without hoses and interior plates

As illustrated above, figure 35 & 36 gives an indication on how the final nitrogen generator will look like, without any interior plates or hoses. The wall that is mounted between the electrical cabinet and the motor is the torpedo wall. The torpedo walls purpose is to be a mounting/bearing wall in the nitrogen generator. The components can only be mounted either on this wall, or on the base plate.

The design criterions specified that it shall be easy to disassemble the frame, no components can therefore be mounted onto the frame.

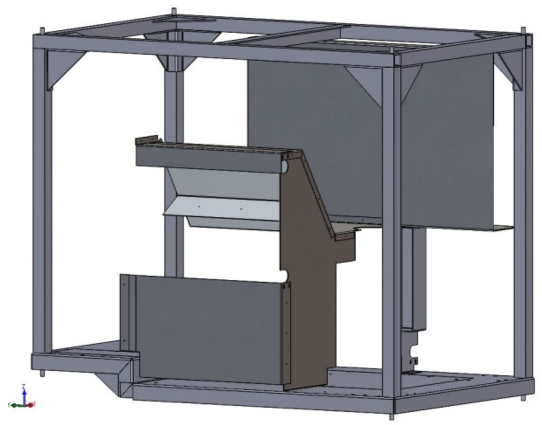

Figure 37: Interior air regulation plates

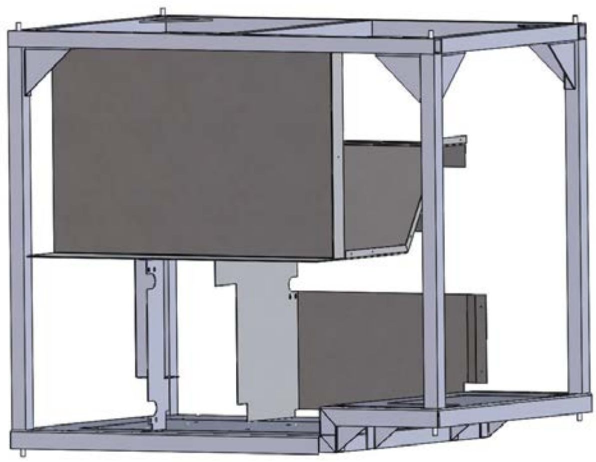

Figure 38: Different view of interior air regulation plates

Illustrated in figure 36 & 37, the machined and formed air regulation plates, these plates are made of aluminum 5052. The purpose for each interior plates are described on the next page.

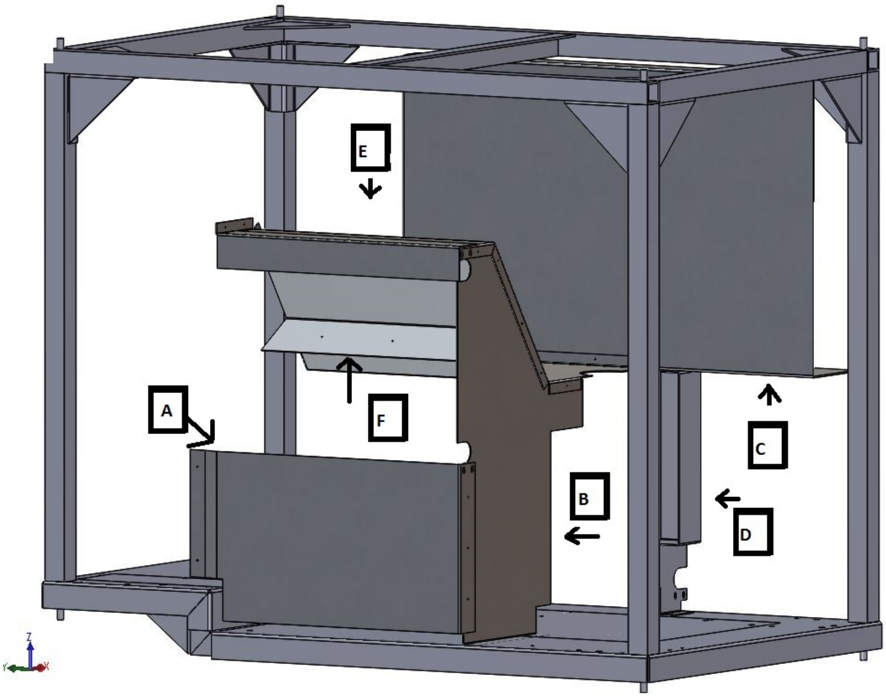

Figure 39: Explanation of air regulation plates

All of the plates are important supporters for most of the components in the nitrogen generator, where all of the plates have important specific roles:

- Plate A is placed below one of the radiators for the role as an air regulator, and work as a shield, so the air that is sucked in, into the air radiator, is transferred out via the oil radiator.
- Plate B is designed for air regulation, and helps transfer the air from the air radiator to the oil radiator. It is also used to support the oil radiator.
- Plate C is working as a component wall, with many components mounted to it (Filter package, membrane assembly, miscellaneous valves). It is only mounted in the torpedo wall, and in no frame structure, so it will be easy for the mechanics to disassemble the plate.
- Plate D is mounted on the bottom plate, and its role is to support plate C, and be a cover for the transmission belt. The transmission belt is mounted on the motor and compressor, behind the air radiator.
- Plate E is mounted on top of plate B and onto the torpedo wall. It is an air regulator plate, the aluminum tank is mounted on top of this plate.
- Plate F is mounted onto plate E. The purpose of the plate is to reduce the noise from the motor, which will be led out through the oil radiator, and the intention is that the sound waves that comes from the motor shall hit this plate and lead to a detour for the sound waves,

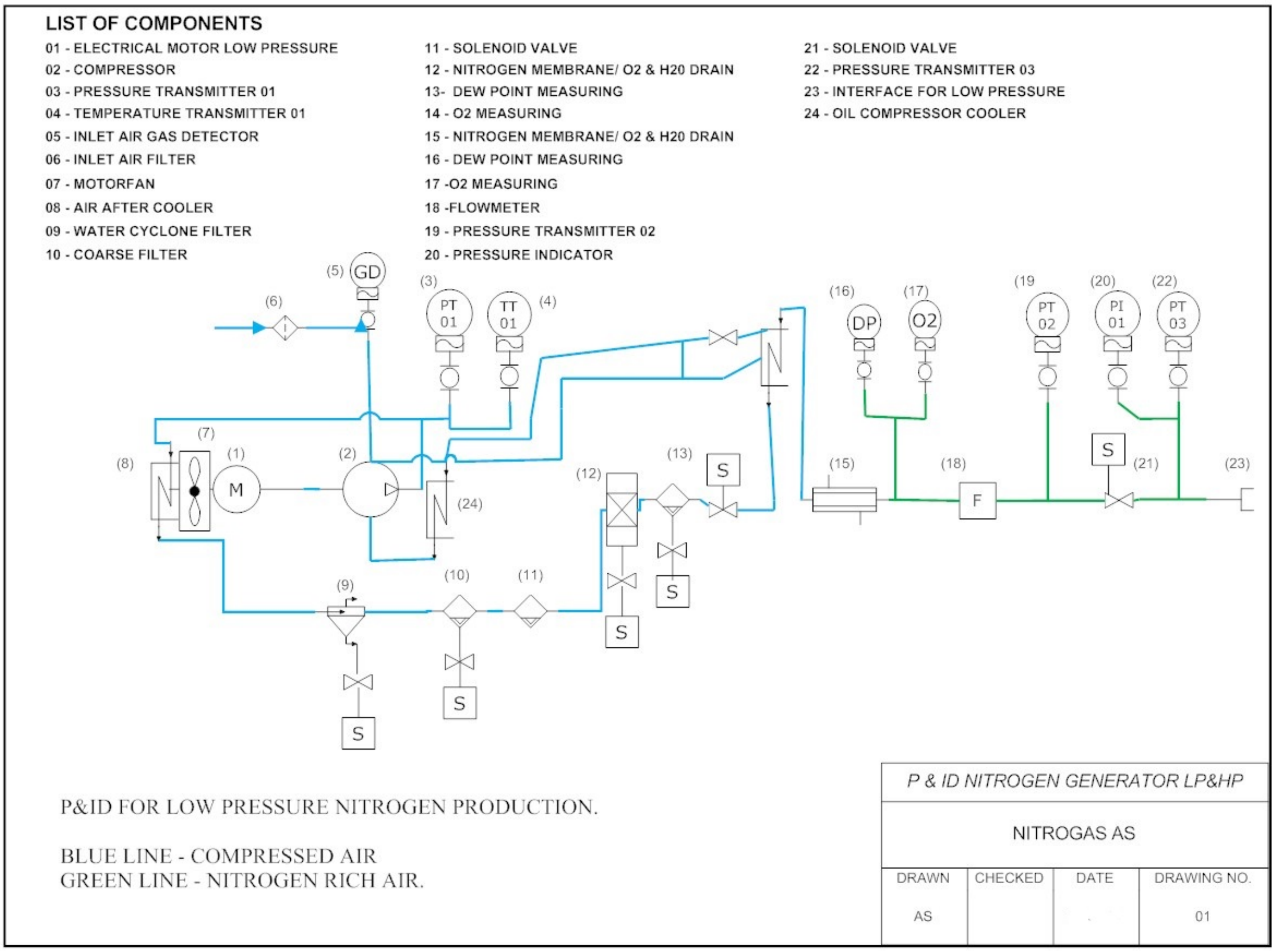

Figure 40: Overview of system

Figure 40 illustrates the specific path of the air, with each components and its purpose.

The nitrogen generator uses an electrical motor to generate power for the compressor that will suck in the air in the atmosphere, and uses the membrane technology that is mentioned above to filter out oxygen molecules.

The air will be sucked in, at point 6, and through an inlet air filter. The air will then pass through gas detector (required from NORSOK Z-015), and from there through the compressor. The compressor will pressurize the air, up to a desired pressure between 8-10 bar.

The compressor has many vital operations; they are discussed in chapter 4.1.2.

After the compressor, the air will pass through a filter package. The filter package consists of a water cyclone and three filters. The water cyclones purpose is to filter out the humidity in the air.

After the air has passed through the water cyclone, it will go through to a filter package that will eliminate the oil in the air (oil from the compressor). From here, the air will pass through two membrane filters, which will filter out the oxygen molecules. Leaving nitrogen gas with a purity of 99% left. The nitrogen gas is now consumer ready.

The process in general is a quite simple but brilliant method to generate nitrogen, and all of this is mounted inside a frame with a size of 1260mm x 800mm x 1108mm.

If the nitrogen generator is going to be approved for offshore use, all of the components that has been presented in this chapter shall be Atex approved.

4.1.1 Motor

The motor that has been selected for the nitrogen generator is an electric bevi motor with 5,5kW. The primary work for the motor is to generate electricity for the compressor.

4.1.2 Compressor

The compressor is from Rotorcomp. The main purpose for the compressor is to compress the air up to 10 - 12 bar. The aim is to have an outlet of nitrogen within the area of 8-9 bar, and due to all the hoses and components in the unit, there will be a pressure loss of approximately 1-2 bar. Therefore, it is necessary to set the inlet pressure a couple of bar higher than the outlet pressure. The desired pressure can be set manually by an operator.

4.1.3 Filter Package

After the air has been compressed, it is sent through to a filter package, containing four different filters with different operational tasks.

- Water cyclone
- Coarse filter (water & oil) x 2
- Oil filter
- Oil steam filter

The water cyclone´s purpose is to filter out the humidity from the air. The water will be transported from the water cyclone and to an oil separator.

After the water cyclone, the air passes through two coarse filters. The purpose for these filters is to filter out large particles of oil and the remaining H_2O particles in the air.

The air then passes through an oil filter. This filter is finer than the previous ones. The oil filter will filter out the remaining oil particles in the air.

The final filter before entering the membrane is the oil-steam filter. Nearly all oil particles are already filtered out, but the oil-steam filter will filter out the oil gas/ steam that remains in the air.

The filter package that has been chosen for this project is Norgren filters.

4.1.4 Membrane

After the air has progressed through the filter package, the air is being transported directly through a hose to a membrane assembly. The purpose of the membrane is as mentioned in chapter 1.1 is to filter out the oxygen molecules from the air, which will remain a purity of 99% nitrogen in the system.

Data sheets for each component is presented in Appendix C.

4.1.5 Accessories

4.1.5.1 Wheels

The wheels that have been selected for this frame is the “Blickle ALTH”

These wheels are made for heavy load with polyurethane plastic on an aluminum rim.

Polyurethane

Polyurethane is a plastic material that exist in various forms. The material is a very common material, which is used in for example: shoe soles, sportswear, wheels and many other applications [20]

Table 5: Information about rear wheel [20]

Wheel	Diameter[mm]	Width [mm]	Load Capacity [kg]	Wheel Bearing	Shaft hole – diameter	Hub
ALTH 200/20K	200	50	800	Bearings	20	60

These wheels have a good rolling resistance, silent, and are gentle to the floor surface.

Table 6: Front wheel information [20]

Fork	Diameter [mm]	Wheel Width	Load Capacity [kg]	Wheel bearing	Building height [mm]	Plate size [mm]	Bolt hole spacing [mm]	Bolt hole diameter [mm]
LEX - TPA 200G -FI	200	40	250	Bushings	235	140 x 110	105 x 75-80	11

The fork to support the wheels has a stop-fix implemented, making it easy to have control over the generator, and make it stop, when needed [20].

Figure 41: Rear wheel [20]

Figure 42: Front wheel with fork [20]

5. Review of DNV 2.7-3

5.1 Configuration of DNV 2.7-3

NORSOK R-002 applies to internal lift on offshore platforms, while DNV 2.7-3 applies for lifts from vessel to offshore platforms. The intention is that this thesis will cover the aspects and requirements for approval of the nitrogen generator frame for internal lifting on offshore platforms. However, it would also be interesting to investigate and see what the requirements would be for getting the frame approved from lifts from vessel to platform.

The different demands from DNV 2.7-3 will be tested on prototype 3; because it is more solid.

When the nitrogen generator is transported to the offshore platform, it will be transported inside a type “A “container illustrated in figure 44, where this container is lifted from the vessel and onto the platform. However, what is required from DNV 2.7-3 to make the nitrogen generator approved for lifting from vessel to platform and make the nitrogen generator certified as a portable offshore unit?

In the following subchapter, the normal font is cited from DNV 2.7-3, while the font written in *italic* is my own thoughts and aspects regarding the nitrogen generator. A further discussion has been made in chapter 5.2.

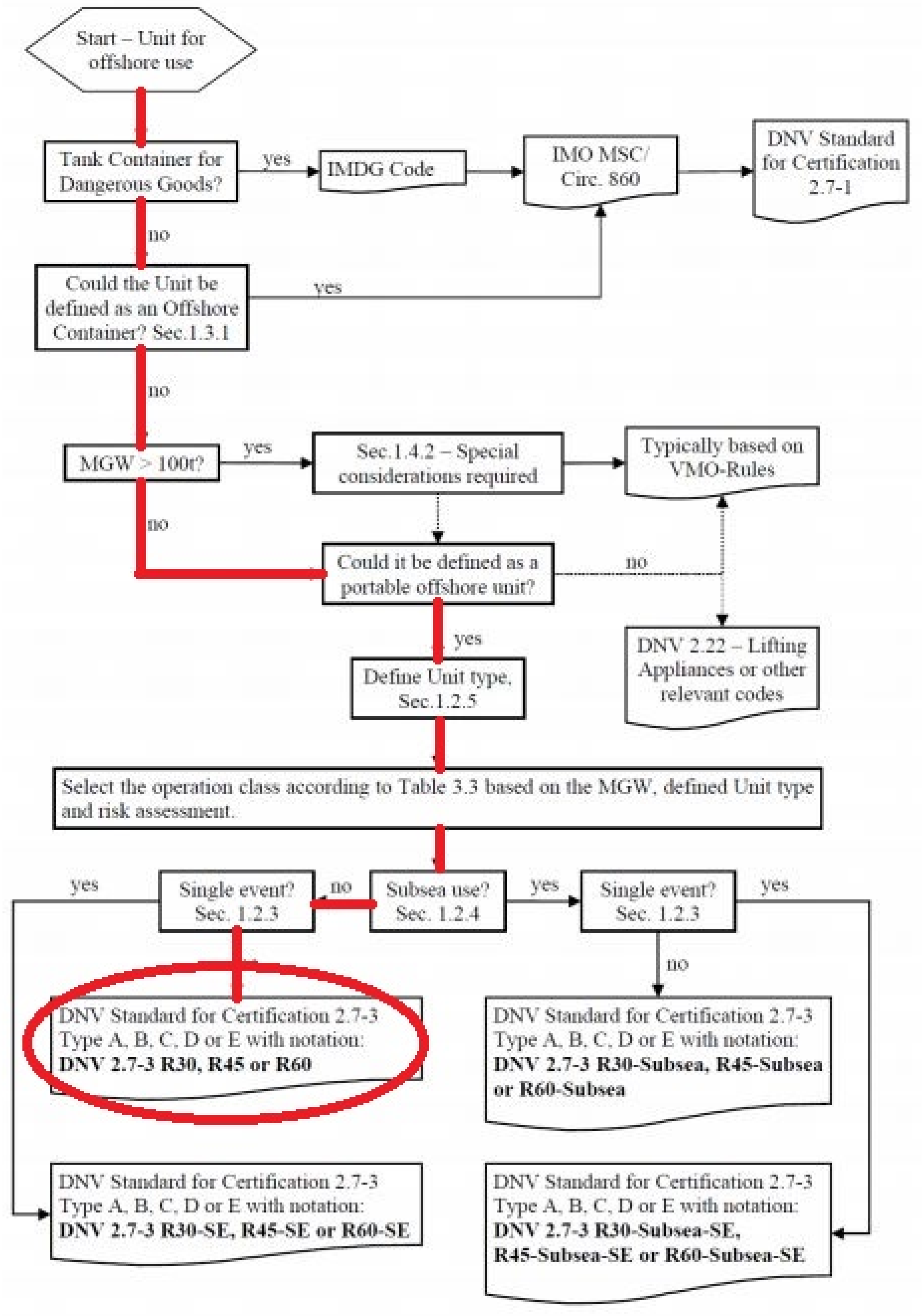

Figure 43: Flowchart to find the PO Units appropriate design basis [21]

The path on figure 43, helped to clarify and determine how to select the correct standard.

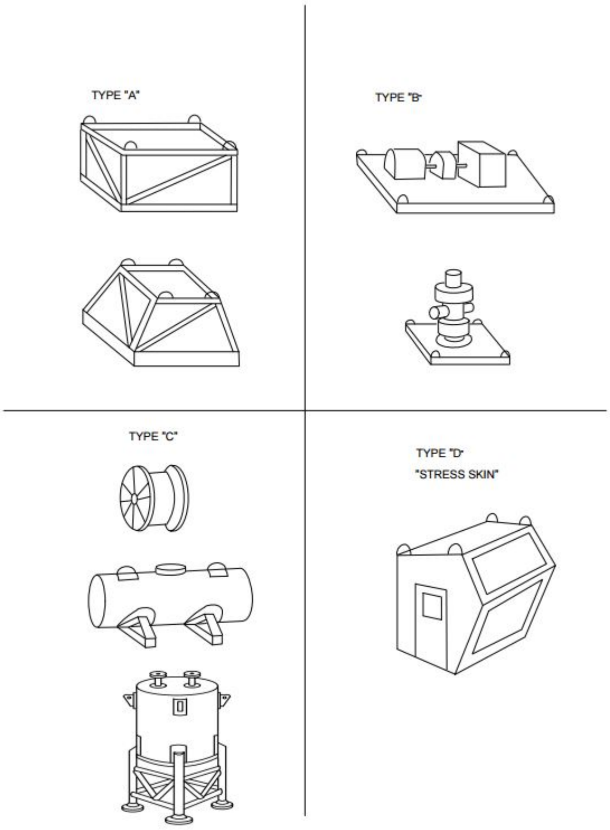

Figure 44: Different types of PO Units [21]

Figure 43 and Figure 44 helped to infer to select the correct type of portable offshore unit.

The following headlines and notations are in conformity with DNV 2.7-3.

2.1.3 Lifting Sets

To include the lifting set in the certification process is optional [21].
The lifting set has not been included.

2.2 Design Verification

2.2.2 Content

The design verification will include at least:

- Applied design loads
- Strength of main structure, including lifting points
- Design details
- Material specifications
- Welding and other joining methods [21].

3. Design

3.1 Design Condition

PO Units shall be designed in accordance to a set of main principle and pre-established criteria to promote means for safe handling and transportation.

These principles and criteria shall be selected to ensure the structural integrity of the PO Units during its exposure to dynamic conditions that are common for an offshore transportation involving:

- Sea voyages,
- Lifting to and from vessels offshore, and
- If, applicable, lifting into (and out of) the sea [21].

3.1.3 Offshore Lifting

PO Units designed in compliance with this Standard for Certification shall have sufficient strength and integrity to withstand dynamic forces generated when handled in a sea state of up to the significant wave height defined by the PO Units Operational Class

The PO Units should to the degree possible be designed to facilitate safe lifting. E.g., the following should be duly considered:

- Design details of protruding parts, if such parts are not possible to avoid.
- For PO Units to be mixed with other frequent handled goods details and parts that may catch or damage other structures should normally not be allowed. Of allowed such parts should be clearly marked.
- Door handles, hinges, hatch cleats and similar details should be arranged in a recessed or protected fashion to avoid becoming catch points or containing points that may complicate lifting and handling operations.
- Avoid elements that the lift accidentally could hook on to.
- Safe handling and tensioning of lift sling set. Normally this imply that use of “loose” spreader bars is not allowed [21].

The nitrogen generator will not have any protruding parts, except the pad eyes.

The nitrogen generator is one whole unit, and it will have a logo from Nitrogas on it, mixing of other frequent handled goods will be difficult.

The unit has been designed with no doors, hinges or hatch cleats; two square lock hatches has been implemented, these locks will not complicate lifting nor handling operations.

The handlebar on the nitrogen generator is the only component that the lift can accidentally hook on to, but the handlebar is a collapsible object that is designed to be folded when it is not being used.

There is no need for spreader bar when lifting the nitrogen generator, due to small geometric dimensions on the nitrogen generator.

3.2 Materials

The design temperature shall not be taken higher than the (statistically) lowest daily air temperature for the area where the PO Unit shall operate. In the absence of a design temperature designation, the design temperature shall be -20 °C [21].

The design temperature shall be -20 °C.

3.2.2 Minimum Material Thickness

The following minimum material thicknesses apply:

Table 7: Minimum material thickness [21]

MGW	**Single events**		**Multiple events**	
	Corners	Other	Corners	Other
0-1t	3mm	3mm	4mm	4mm
1-25t	5mm	4mm	6mm	4mm
>25t	6mm	5mm	8mm	6mm

By assuming that the minimum material thickness applies for the whole frame, the base plate, which has been designed with a 3mm plate, needs to be changed to a 4mm plate. Assuming that the nitrogen generator applies for multiple events.

3.2.3 Wrought Steel

Steel shall comply with the material requirements of a recognized code. The chemical composition, mechanical properties, heat treatment and weld ability shall be satisfactory for the service as well as the fabrication process [21].

Steel shall possess adequate fracture resistance energy to avoid the initiation of brittle fracture. Austenitic stainless steels are exempt from the Charpy testing requirement.

Threaded rods are the only parts that are made of stainless steel, it is therefore not necessary with a Charpy test. There are no wrought steel on the unit.

3.2.6 Aluminum

The chemical composition, mechanical properties, heat treatment and weldability shall be satisfactory for the service as well as the fabrication process.

Aluminum alloys and tempers listed in Section 3.2 of DNV's "Standard for Certification 2.7-1, Offshore Containers" or in "DNV Rules for Ships/High Speed, Light Craft and Naval Surface Craft, Pt 2 Ch2 Sec." Are acceptable for use [21][22].

In section 3.2 of DNV 2.7-1, the standard clarifies that it is acceptable to use:

- *Aluminum 5052 for rolled products*
- *Aluminum 6082 for extruded products*

3.3 Operational Class

PO Units shall be assigned to an Operational Class for the offshore lift. The class should be selected based on the following:

- Weight/mass
- Risk evaluation
- Type of structure (figure 44)[21]

3.3.2 Risk Evaluation

The operational risk involved in offshore lifting of PO Units is in this standard defined as "Low" or "High". Both possible consequences and probability of an incident will define the risk. The following elements are considered to increase the risk and should at least be included in the risk evaluation:

A) Installed/transported equipment especially sensitive to impact loads.

B) Protruding parts where the crane hook and/or sling set could catch during tensioning.
C) Protruding parts that may damage and/or get stuck on other (transported) items or on the transport vessel
D) Lack of roof protection so it is considered possible for the crane hook to accidentally hook onto items inside the PO Unit.
E) Lift points in positions where they could be damaged by impacts.
F) Lack of proper crash framing and there is installed/transported equipment that could be damaged due to impacts.
G) PO Units of exceptional geometry or unhandy (big) size.
H) Sling sets including (loose) spreader bar(s) [21].

If one of the elements above is clearly applicable or at least two elements are partly present the risk level should normally be defined as "High".

Review of risk evaluation:

A) All of the installed equipment is not sensitive to impact loads, and are well covered.
B) There are no protruding parts where the crane hook and/or sling set could catch. All of the parts are in cover by the cover plates.
C) There are no protruding parts that may get stuck or get damaged on the transport vessel.
D) There are roof protection; it is not possible for the crane to hook accidentally onto items inside the PO Unit.
E) The lifting points are placed on the top side of the nitrogen generator, unless an object is dropped onto the top of the nitrogen generator the lifting points cannot be damaged by an impact. It is also possible to substitute the lifting points with another pad eye. The conclusion is no, the lifting points are not in a position that can be damaged by impact.
F) The installed equipment may be damaged due to impact. It is many factors involved, such as location of impact, how great the impact is. It is difficult the exact answer for this, but some of the installed equipment may be damaged (filter package).
G) The geometry to the unit is not exceptional or unhandy.
H) Sling set with spreader bar(s) is not necessary.

Only one element partly present the risk level, which implies that the frame cannot be defined as "High" risk.

Type	*Risk*	*MGW*	**Class**
A	Low	MGW ≤ 25 t	**R60**
A	Low	MGW > 25 t	**R45**
A	High	MGW ≤ 25 t	**R45**
A	High	MGW > 25 t	**R30**
B	Low	MGW ≤ 15 t	**R60**
B	Low	MGW > 15 t	**R45**
B	High	MGW ≤ 15 t	**R45**
B	High	MGW > 15 t	**R30**
C	High [a)]	MGW ≤ 15 t	**R45**
C	High [a)]	MGW > 15 t	**R30**
D	High/Low [b)]	MGW ≤ 10 t	**R45**
D	High/Low [b)]	MGW > 10 t	**R30**
E	Low	MGW ≤ 15 t	**R60**
E	Low	MGW > 15 t	**R45**
E	High	MGW ≤ 15 t	**R45**
E	High	MGW > 15 t	**R30**
[a)] Type C have normally no requirements to impact load calculations, see notes in 3.6.2 and 3.6.3, and should be considered as *"High"* risk PO Units			
[b)] R60 (R45 for MGW > 10 t) could be applicable if it is documented that the evaluated risk is *"Low"* and the PO Unit global structural integrity is not sensitive to substantial local skin damage.			

Figure 45: Selection of Operational Classes [21]

The nitrogen generator has been defined as a "Low" risk, and the maximum gross weight is less than 25 tons. The nitrogen generator can be defined as a Class R60.

3.4 Analysis and Acceptance Criteria

3.4.1 Calculation Methods

When performing design analyses for verification of structural strength alternative approaches are acceptable. It is assumed that the calculation approach covers critical details in an acceptable way and is representative for the true (planned) load (mass) distribution within the PO Unit and the support conditions for the PO Unit.

Only the primary structure shall be included in the design calculations. Strength of frame members may be calculated using manual calculation, 3-dimentional beam analysis or finite element modelling [21].

The design calculations on the nitrogen generator has been performed with finite element modelling, and are assumed to be covering critical details in a representative way.

3.4.2 Load Combinations

The PO Unit shall be calculated/analyzed for all relevant load combinations. Guidance on relevant load combinations is included in the design load sections [21].

It has only been performed calculations regarding a lifting load analyze, additional relevant load combinations would be required.

3.4.3 Allowable Stresses

Design loads defined in this section shall not produce Von Mises equivalent stresses,

σ_e exceeding: 0.85 x C [21]

For aluminum: C = $R_{p0.2}$ but not to be taken greater than 0.7 x R_m [21].

Proof stress for aluminum 6082 = 290Mpa [Aalco source, see appendix 4]

Von Mises shall not exceed 0.85 x 290Mpa = 246.5MPa.

The equivalent stress that has been analyzed in chapter 6, regarding prototype 3 and the lifting load analysis is not exceeding 246.5MPa.

3.4.4 Buckling Resistance

All plates and members subject to compression stress should be verified for buckling. The allowable buckling stress/capacity should be calculated based on a recognized code applying elastic stress distribution.

The maximum allowable utilization factor shall be taken as 0.85[21]

3.4.5 Welding

Weld strength shall be based on the nominal weld area and the stress intensity produced by the design load. The allowable stress for the weld shall be as designated in 3.4.2 multiplied by the following reduction factor:

A. 0.5 for fillet weld
B. 0.75 for partial penetration weld plus fillet weld where the throat area of the fillet weld is equal to or less than the stress area of the partial penetration weld
C. 1.0 for full penetration welds [21].

The nominal weld area for the nitrogen generator will be on the strengthened base frame. The stress intensity produced by the design load will be needed for additional calculations.

3.4.6 Deflections

It should be documented that the deflections of PO Units and single members in PO Units for any load condition will not:

A. Be greater than specified (if applicable) by the owner of the PO Unit
B. Complicate safe handling of the PO Units.
C. Introduce unacceptable loads in equipment due to relative deflection of their supports.
D. Members deflected due to impact loads will not damage the cargo [21].

It has been performed an impact test for prototype 3, where the analysis illustrates that the impact load will not destroy the frame, but additional calculation and analysis would be necessary to investigate this subject before prototype 3 could be approved for lifting from/to vessel from/to offshore platform.

3.4.8 Stability Against Tipping

The sea transport design loads should not cause uplift in any corner of the PO Unit. If required uplift could be prevented by lashings

IN order to ensure adequate stability before lift (and after removal of lashing) the PO Unit should normally be stable considering the following tilting angles:

- Operational Class R60: 30°
- Operational Class R45: 23°
- Operational Class R30: 15°

The nitrogen generator is an operational class R60, and should be able to withstand a tilting angle of 30°. This seems difficult, and would most probable lead to design modifications. There has been made no analysis or testing of stability against tipping.

3.4.9 Maximum Gross Weight – MGW

Maximum gross weights is defined as MGW = T + P, where;

- Tare weight of the PO unit. The weight should be found by weighing or documented by a reasonable conservative weight estimate.
- P is maximum allowable payload for the PO Unit. Normally this will be known equipment for which the weight should be found by weighing or documented by a reasonable conservative weight estimate [21].

MGW = T + P

T = Weight of frame (this is unknown)

P = Weight of all components inside of frame

MGW = 450kg

Both the tare weight and maximum payload is unknown for the nitrogen generator at this point, but due to the design criterions made by Nitrogas, where the maximum weight should be 450 kg. We can assume that MGW = 450kg.

3.4.10 Load Application

The design loading should be applied as exactly as possible. I.e. the loading shall be distributed to members and joints according to the mass distribution in the PO Unit. Loads from equipment needs to be carefully evaluated [21].

When performing the finite element analysis for the prototypes, the design load has been set as: the weight of the whole unit x (g x a) = 450kg x (9.81 x 1.3) m/s^2 = 5738.85N.

This is assumed to be as exactly as possible.

3.4.11 Equipment and Supports for Equipment

Mounting of equipment or outfitting details installed in a PO Unit shall be designed to withstand maximum dynamic loadings during transport and lifting calculated according to the relevant equations in sections 3.5, 3.6 and 3.7. MGW should be substituted with the equipment weight in the equations.

Applied equipment weights shall include relevant weight contingency. Both vertical and horizontal loads shall be applied to the equipment CoG in order to obtain ‘correct’ support reactions.

The weight contingency has been included in the analyses, but the calculation regarding dynamic loadings during transport has not been performed, and needs additional calculations to determine if the equipment will be displaced

3.5 Design Loads – Lifting

The design loading on all elements in a lift with lifting slings shall be calculated based on F (in kN) where F is the greater of F_{air} and F_{sub} (if applicable). The following definitions apply:

For all PO Units: F_{air} = DF x MGW x g

Table 8: Design Factors [21]

Operational Class	MGW < 50 tons	MGW ≥ 50 tons
R60	$1.4 + 0.8 \text{ x} \sqrt{\frac{50}{MGW}}$	2.2
R45	$1.4 + 0.6 \text{ x} \sqrt{\frac{50}{MGW}}$	2.0
R30	$1.4+0.4 \text{ x} \sqrt{\frac{50}{MGW}}$	

Operational class is R60, and maximum gross weight equal to 450kg

$$DF = 1.4 + 0.8\, x \sqrt{\frac{50}{MGW}} = 2.467$$

F_{air} = *2.467 x450x 9.81 = 10890.57N*

This implies that the design factor cannot be less 2.467 with a lifting force of 10890.571N for a lifting load test.

There is no F_{sub} applicable for this test.

Additional lifting tests has to be applied, since the criterions from DNV 2.7-3 are more strict, and another lifting force will be needed.

3.5.2 Design Load Application

For the normal lift condition, the design loading for the PO Unit global strength calculation/analysis shall be calculated based on F.

Normally there are many criterions from DNV 2.7-3 regarding lifting, and how the pad eyes and slings should be handled. However, for the nitrogen generator, the pad eyes are mounted on manually and are already certified from the supplier. Further calculations about pad eyes and slings have not been included.

3.6 Design Loads – Impact

3.6.1 General

Impact loads may occur during lift off or set down of PO Units and they are a result of the relative velocities between transport vessel deck and the hanging load. Impact loads occur randomly and are of very short duration. Due to the inherent uncertainties in the input parameters, it is not considered feasible to calculate these loads accurately. Hence, in this standard, impact loads are considered adequately described by requirements in 3.6.2 and 3.6.3 [21]

3.6.2 Horizontal Impact

The primary members shall be capable of withstanding a local horizontal impact at any point. Where relevant, the impact stress shall be combined with a lifting stress based on the MGW of the PO Unit. The impact force may act in any horizontal direction on the corners of the PO Unit. On all sides of the PO Unit, the load is considered to act perpendicular to the surface.

The following values shall be used for the static equivalents of impact load for corner posts and bottom rails/edge:

- R60 & R45: F_{HI} = 0.08 x The minimum value of F and 2.5 x MGW x g (from table 9)

F = 450kg x 9,81x 1.3 = 5738.85N

2.5 x 450 x 9.81 = 11036.25N

F_{HI} = 0.08 x 5738.85 = 459.108N

F_{HI} = 459.11N

The horizontal impact test load shall be performed with a force equal to 459.108N

Table 9: Test load [21]

MGW	Test load
Less or equal to 25 tons	Minimum of F and 2.5 x MGW x g

The impact test that has been performed on the nitrogen generator is a horizontal impact test. The primary members are capable of withstanding a local horizontal impact. The full impact results are illustrated and discussed in chapter 6.

3.6.3 Vertical Impact

Vertical impacts shall be calculated according to both of the points below:

- PO Units in Operational Class R45, R60 and R60-SE (Single Event) shall be capable of withstanding an impact from lowering on one corner of the structure on a flat surface. Inertia forces acting on elevated part of the structure shall be addressed.
- PO Units shall also be verified for an impact load acting on any other point on the bottom outer edge that could hit it the PO Unit is set down on a not flat surface: $F_{VI} = 0.08 \times F$

It has not been performed a vertical impact test of the unit, nor a simulation of lowering on one corner of the structure on a flat surface.

The vertical impact force $F_{VI} = 0.08 \times 5738.85 = 459.108N$

3.7 Sea Transport

The strength including equipment supports, and stability of all PO Units shall be checked for loads due to the maximum accelerations and wind pressure that could occur during transport. It may also be applicable to consider forces due to sea pressure. If not known, realistic assumptions regarding support conditions and sea fastening should be made.

3.7.2 Design Forces

The accelerations could, if relevant, be based on motions calculations for the actual transport vessel(s), position (and direction) of PO Unit on vessel, and maximum weather/wave conditions. Appropriate design factors considering the allowable stress given in 3.4.3 should be applied.

If no information is available a horizontal design load due to vessel motion of:

$F_H = MGW \times g$

Should be considered in any direction and in combination with both maximum and minimum vertical loads as defined below:

$F_{Vmax} = 1.3 \times MGW \times g$

$F_{Vmin} = 0.7 \times MGW \times g$

In addition, a horizontal design wind force of $1.0kN/m^2$ shall normally be considered [21].

Calculation regarding acceleration during transport, and wind pressure must be performed. There is no information available, so additional calculation regarding F_{Vmax} and F_{Vmin} needs to be calculated.

5. Testing

5.1 Extent of Testing

A test program shall be agreed with DNV for each PO Unit or series of units. The program shall include prototype testing, the extent of the testing shall be based on the guidance in the following table [21]:

Table 10: Extent of Testing [21]

Class	Lift testing?	2 point?	Drop test?
R60	Yes	Yes	See 3.6.3

Regarding the nitrogen generator and it has been defined to be a R60 Operational Class. A lift test, a two-point diagonal lifting test and according to 3.6.3, a vertical impact test is mandatory to get the prototype approved.

5.2 Discussion Regarding DNV 2.7-3

A research regarding the different criterions to acquire an approval for lifting to/from vessel from/to offshore platform where achieved, regarding both the criterions for the standard and what needs to be done from Nitrogas' point of view. There are several aspects to include if the nitrogen generator should be approved according to DNV 2.7-3.

The discussion for the advantages and disadvantages for making the nitrogen generator certified as a portable offshore unit is important. It would be necessary to perform more analyses, such as a drop test, and a two-point diagonal lifting test. It would be necessary to change the design, make it more solid, and from there perform the required analyses.

One of the differences that would be necessary to perform would be a change in minimum material thickness. From table 7, the minimum material thickness for a PO Unit with a maximum gross weight between 0-1t is 4mm. The base plate is 3mm. It would not be required to change the aluminum, since both 5052 alloy and 6082 alloy is accepted for use.

The criterions in DNV 2.7-3 would require several adjustments for the prototype to be approved. I personally think that it would be too many adjustments, which would result in too little benefits. It would result in many hours of work for the design engineer to modify the design of the nitrogen generator. It would result in a frame that most likely would not be fulfilling the design criterions that were set by Nitrogas regarding this Master thesis.

6. Experimental Procedure & Result

6.1 Finite Element Analysis

6.1.1 Software

Ansys is an engineering simulation software that provides different simulation and analysis products. These products are Ansys CFD, Ansys simulation technology: structural mechanics, multiphysics, fluid dynamics, explicit dynamics, electromagnetics, hydrodynamics and more [23].

In this Master thesis there has been performed an analysis in Ansys Workbench for structural mechanics simulation a lifting test with remote load. It has been vital to perform an analysis and see if the frame is applicable for offshore usage within the harmonized standard criterions.

6.1.2 Boundary Conditions

The two frames that have been analyzed are almost identical in design and purpose, and the same boundary conditions have therefore been implemented for both of the prototypes in the analysis.

Boundary condition 1

A fixed support has been added for both of the frames; the fixed support is representing the heavy components in the unit (motor, compressor, electrical cabinet etc.).

Fixed support in these areas is synonymous with an area that will not be lifted it will be fixed.

Boundary condition 2

A remote force has been applied to illustrate the lifting shackle, which is going to lift the frame.

Boundary condition 3

Defining the boundary conditions in Ansys Workbench:

In finite element analysis, if two independent parts are present, there is no stiffness relationship defined between them, and the resulting stiffness matrices will be uncoupled [24]. It is therefore important to choose the right boundary conditions inside the software.

Different materials in frame and in the threaded rod (aluminum & stainless steel) led to:

- Asymmetric behavior
- Multipoint Constraint contact (MPC)

Asymmetric behavior

Due to different materials in the frame, Ansys are including *Asymmetric Behavior* condition into the analysis.

Asymmetric behavior is selected because it is only the contact surface that is constrained from penetrating the target surfaces. In these analyzes the contact surfaces are the threaded rod, while the holes in the top and bottom of the frame is the target. In asymmetric behavior, the nodes of the contact surface cannot penetrate the target surface [25].

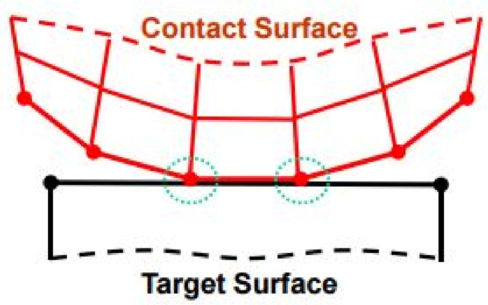

Figure 46: Asymmetric behavior [25]

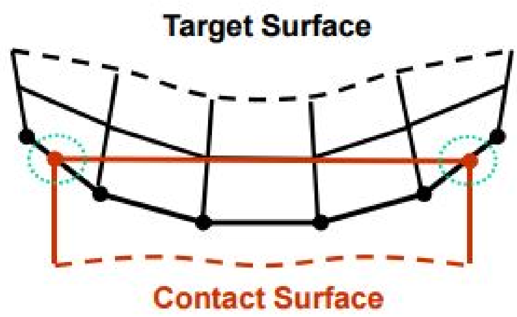

Figure 47: Symmetric behavior [25]

The illustrations above show the importance of choosing the correct behavior.

The contact surface will be of stainless steel, while the target surface will be in aluminum 6082.

Beneficial guideline for proper selection of contact surfaces for asymmetric behavior:

- If a convex surface encounters a flat or concave surface, the flat or concave surface should be the target surface.
- If one surface has a coarse mesh and the other, a fine mesh the surface with the coarse mesh should be the Target surface.

- If one surface is stiffer than the other, the stiffer surface should be the Target surface.
- If one surface is larger than the other, the larger surface should be the Target surface [25].

Due to the fourth line "If one surface is larger than the other, the larger surface should be the Target surface" The selected surfaces was chosen due to this statement.

Multi-Point Constraint (MPC)

MPC formulation for bonded contact does not have a stiffness calculated for the connection. The MPC connection uses rigid constraint equations between the solid elements on the contact and target faces for a truly bonded connection. The connection locations are still determined using the contact element.

MPC internally adds constraint equations to "tie" the displacements between contact surfaces. This approach is not penalty-based or Lagrange multiplier-based. It is a direct, efficient way or relating surfaces of contact regions, which are bonded. Large deformation effects also are supported with MPC-based bonded contact [25].

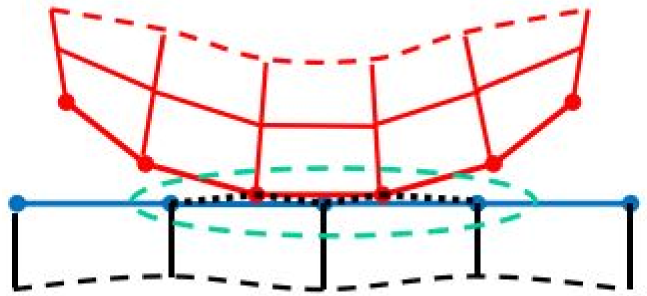

Figure 48: Multi point constraint [25]

For achieving the most exact results, the boundary conditions have to be correct. Therefore, the threaded rod and the top/bottom beam of the frame has been set to bonded, asymmetric and MPC.

Boundary condition - Impact test

The velocity on the frame has been set to 3m/s. Direction of velocity has been set as towards the fixed geometry. The "wall" has been set as a fixed support.

6.2 Second Prototype - Result

There has been made a finite element analysis for the second and third prototype. The lifting load analysis has been performed in accordance with NORSOK R-002 – Lifting equipment.

The load that has been set for the analysis is:

F = m x g = 450kg x (9.81*1.3) m/s^2 = 5738.85N

The acceleration is arbitrary, and has been set to 0.3m/s^2.

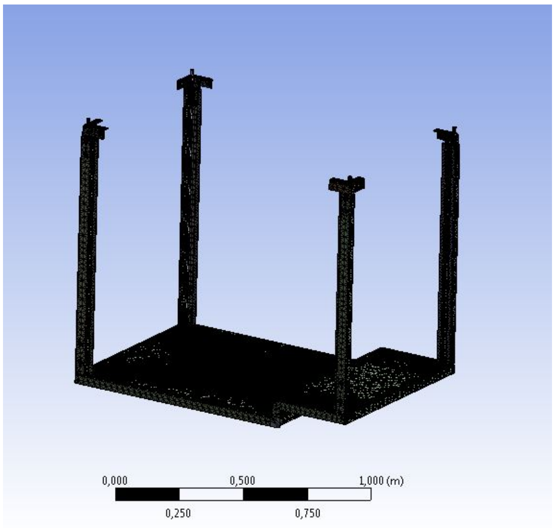

Figure 49: Meshed P2

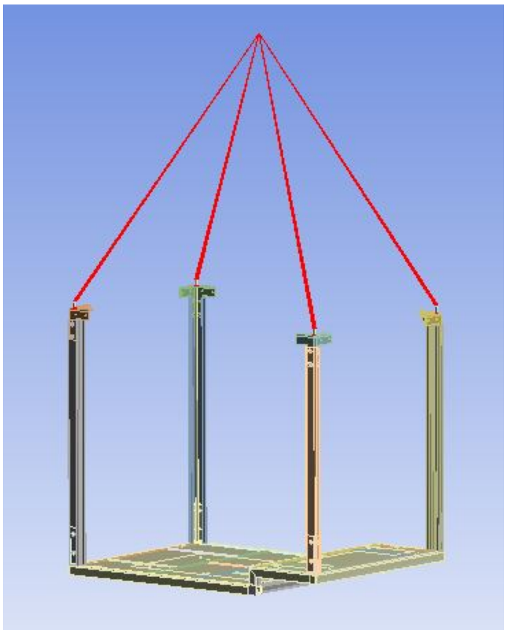

Figure 50: P2 with remote load

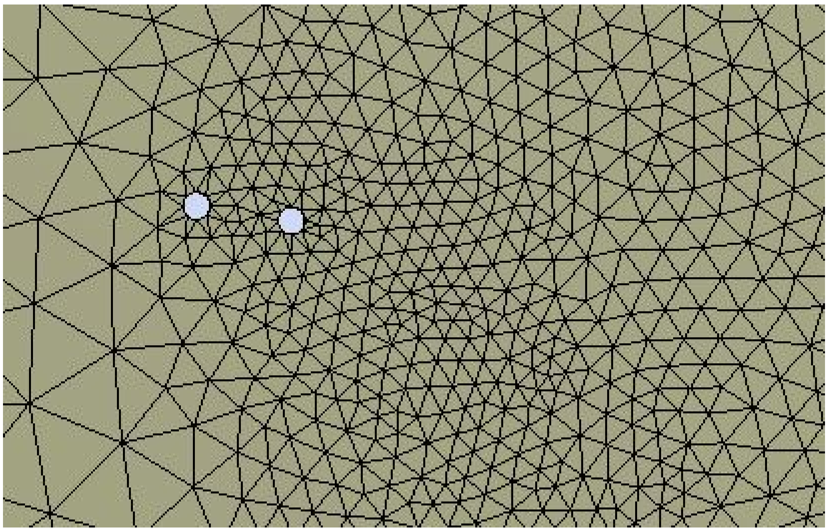

Figure 51: Mesh of bottom frame

6.2.1 Safety Factor

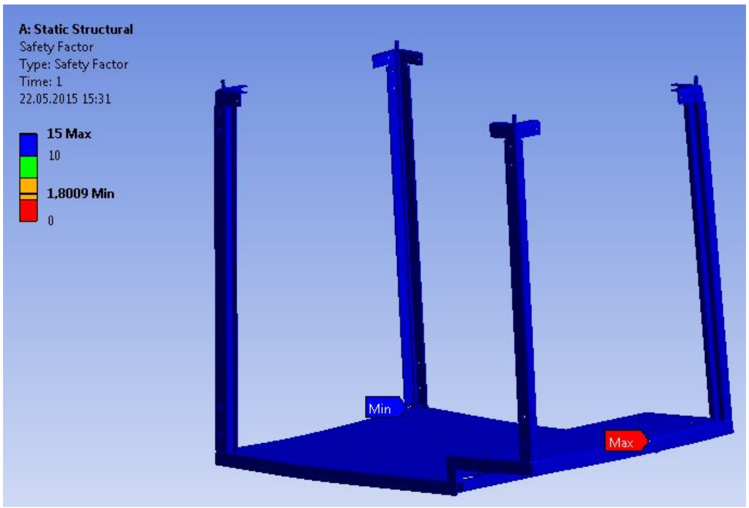

Figure 52: Safety factor on P2

Figure 52 illustrates the safety factor on the entire frame, and the safety factor is 15 on almost the whole frame. The exceptions are illustrated in figure 53, where the figure illustrates the location of the minimum safety factor. The value is 1.8009 as a minimum value. Even though the safety factor is above one, which would normally imply that the frame is solid enough, and could be used if the frame was not going to be approved according to the harmonized standards. In NORSOK R-002 the design factor must be greater than 2.52 (refer to chapter 2.1.1) to be approved for internal lifts on offshore platforms. This implies that the prototype 2 is not solid enough.

Minimum safety factor occurs in the connection of the structural reinforcement frame, approximately just below the corner post that is illustrated in figure 52 and 53.

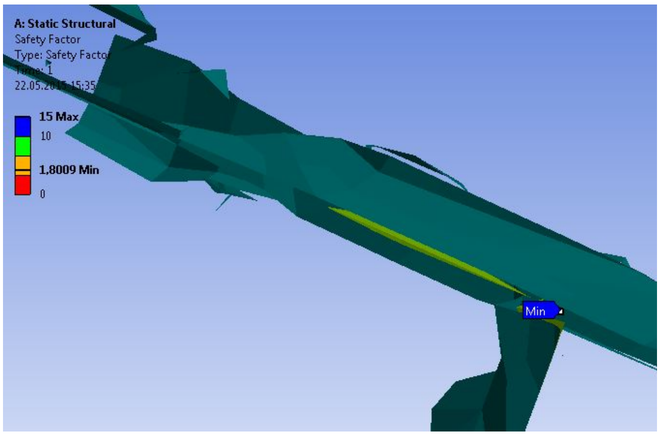

Figure 53: Minimum safety factor

6.2.2 Equivalent Stress

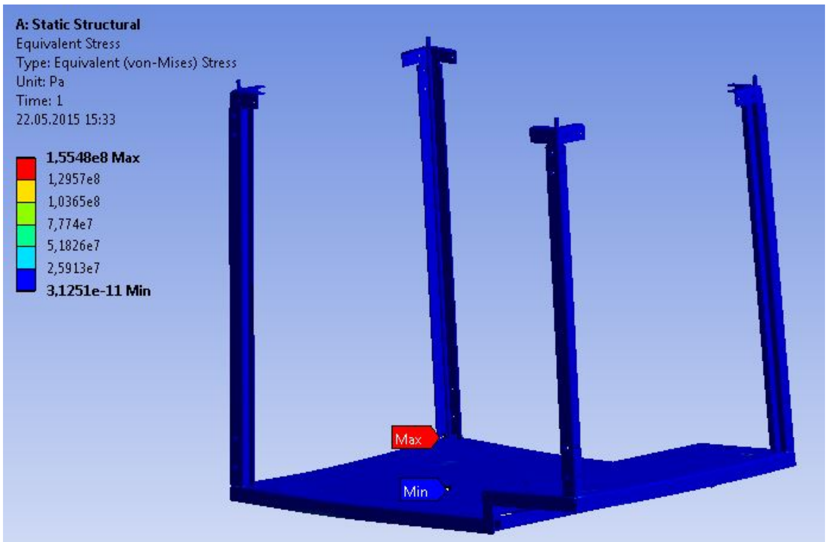

Figure 54: Equivalent stress in prototype 2

If the equivalent stress / Von Mises stress is higher than the yield strength of the material, the material will yield and fail. Figure 54 gives an overview of the equivalent stress in the frame, it indicate that the equivalent stress will vary from approximately equal to 0MPa and up to 155MPa. Yield strength for aluminum 6082 is 255MPa [32], which correspond with the safety factor that this will not yield.

Maximum equivalent stress occurs in the joint between two structural members. It is unknown if the software can estimate the correct calculation regarding the joint-area, assuming that there are no welding between the beams, which there is.

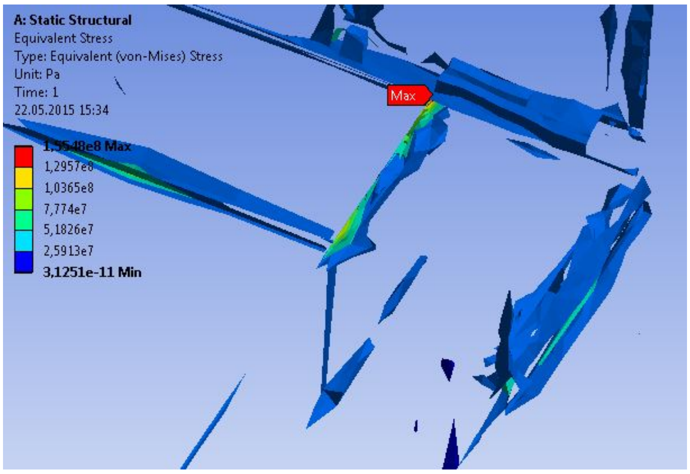

Figure 55: Maximum equivalent stress

6.2.3 Deformation

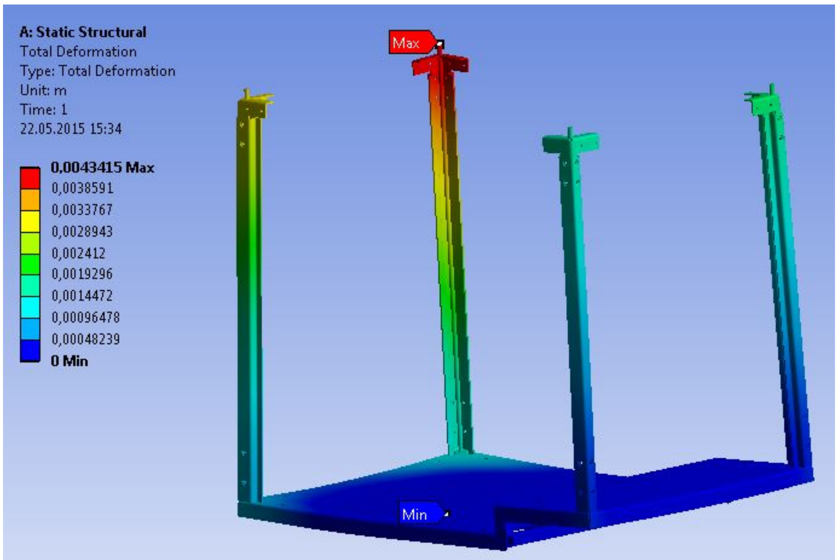

Figure 56: Variation of deformation in prototype 2

The deformation appears in the frame and varies from 0mm to 4.3mm; maximum deformation appears in the top rear-right corner beam. One could argue with that the deformation will vary greater in the rear-right corner beam because the position of the fixed support. The components will affect the left side of the frame, instead of the middle, which may lead to a greater deformation in the corner beam in the rear-right end. Due to a shortage of free space on the unit, one can either try to replace some of the components, which will lead to a decrease in the deformation, and may lead to an evenly more distributed deformation. Another possibility is to change the buckled corner beams into square beams. As it have been done in the third prototype.

The deformation is equal in the two corner beams on the front view of the frame and is approximately 1.4mm. The remote force is acting equal on each member and it can be concluded that the fixed support is the reason to a variation of deformation in the corner brackets.

6.3 Third Prototype - Result

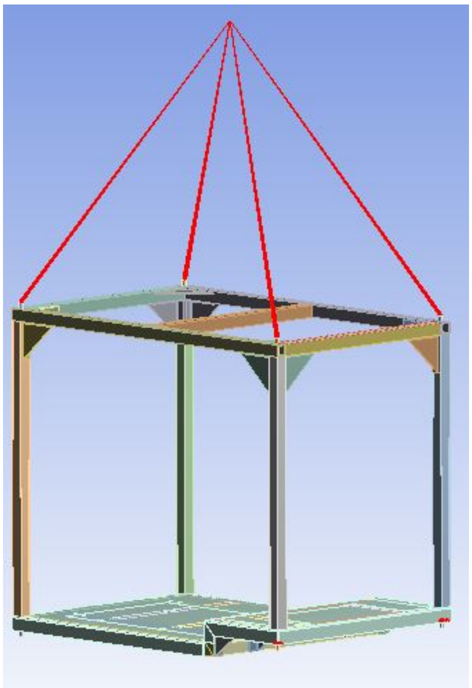

Figure 57: Remote load in prototype 3

The remote load for prototype 3 is identical to the remote load on prototype 2, which is illustrated in figure 57.

Figure 58 illustrates the mesh applied mesh on the frame. Figure 59 illustrates the fixed support.

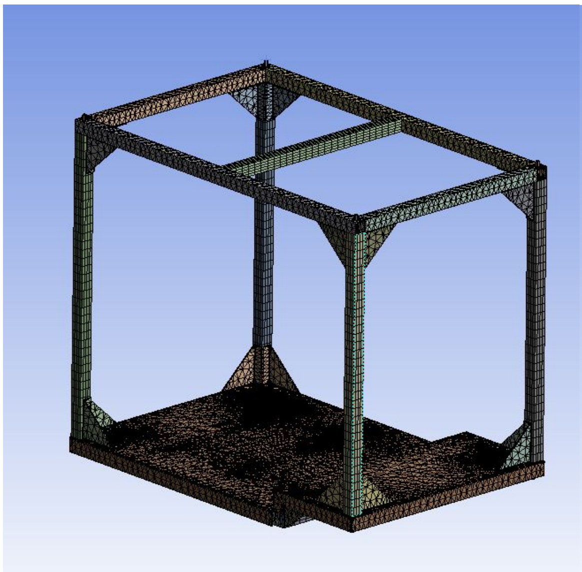

Figure 58: Meshed prototype 3

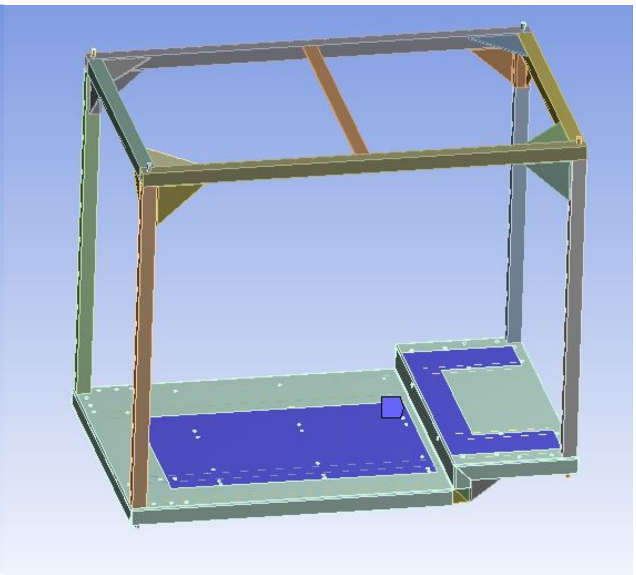

Figure 59: Fixed support for P3

6.3.1 Safety Factor

There have been made significant improvements on the third prototype versus the second. As mentioned, the base reinforcement frame has been changed from 30 x 30 x 3mm square beams to 40 x 40 x 4mm square beams. The corner beams formed by buckling has been replaced with 40 x 40 x 4mm square beams. It has also been included beams in the top frame and triangular corner brackets to increase the stiffness.

This will result in an increasing of the safety factor; minimum value has increased to 4.0747.

By doing these few steps to reinforce the frame, the frame has now gone from unsafe to safe, according to NORSOK R-002 – Lifting equipment.

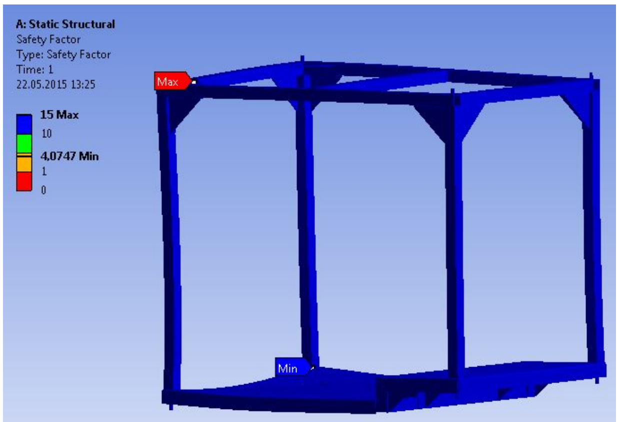

Figure 60: Safety factor in prototype 3

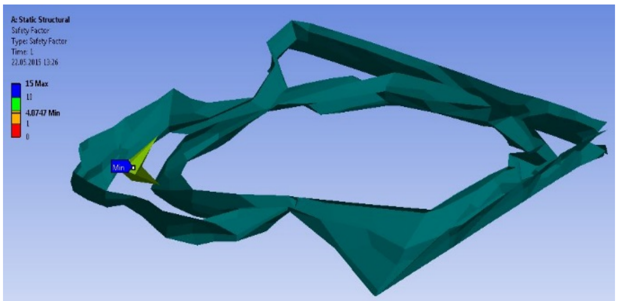

Figure 61: Minimum safety factor in prototype 3

6.3.2 Equivalent Stress

The maximum equivalent stress is 68.7MPa, which is a reduction from 155.5MPa on prototype 2. By performing these reinforcements, the frame is now significantly stronger, and much more solid.

Maximum equivalent stress is less than 255MPa, which implies that the frame will not yield.

The maximum equivalent stress is located inside one of the corner beams near the hole to the threaded rod (the same corner area as the maximum equivalent stress appeared in prototype 2). Figure 62 illustrates the whole frame, and the location of the maximum equivalent stress. Figure 63 illustrates the location where the maximum equivalent stress appears. One could argue with that the reason the equivalent stress occurs at this location, is because the location of the fixed support. The vulnerable area is located at the rear-right corner beam area. The stress concentration occurs in the same area for both of the prototypes.

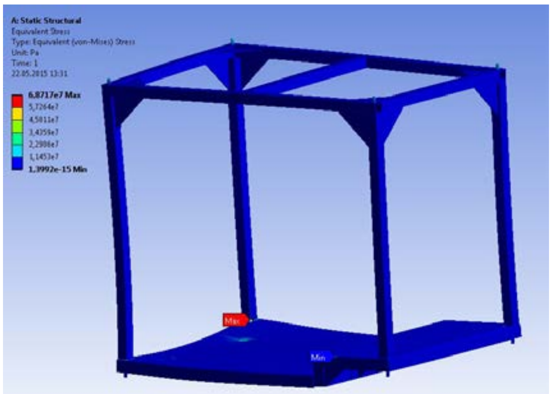

Figure 62: Maximum Von Mises stress on prototype 3

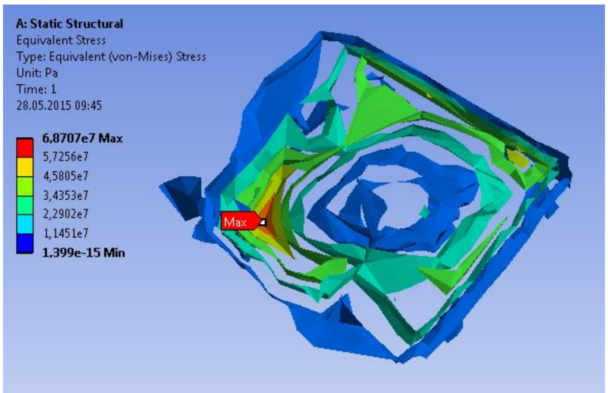

Figure 63: Exact location of maximum Von Mises stress in P3

6.3.3 Deformation

The deformation in prototype three has reduced. The deformation varies from 0mm and up to 0.5mm, which is the maximum deformation. Maximum deformation appears in the same corner beam as it did in prototype 2, as mentioned; the deformation has been reduced from 4.3mm to 0.51mm. This is a significant improvement.

The corner beam intends to bend inwards the middle of the beam.

A comparison between the prototypes is that the deformation occurs at the same areas, and one of the corner beams have a much greater deformation than the other corner beams. A possible statement is that the placement of the components has an impact on the displacement on the frame for this prototype as well.

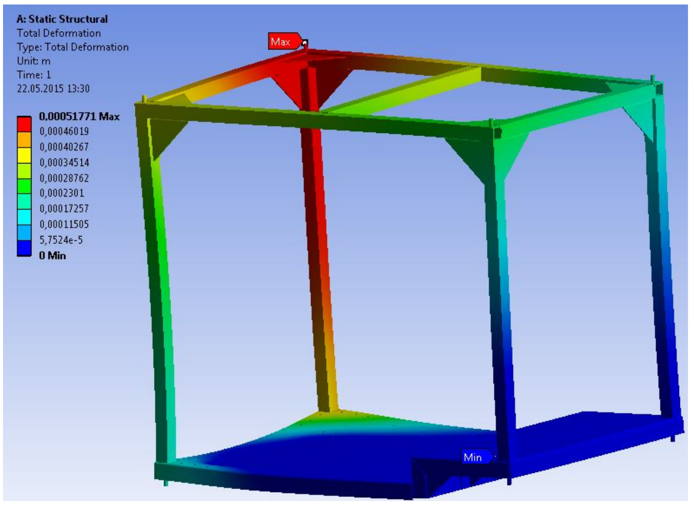

Figure 64: Variation of deformation

6.4 Impact Test – Prototype 2

A lifting load analysis will only give an indication on how the forces will react on the frame, when the frame is being lifted up. As mentioned earlier, the nitrogen generator is to be used on offshore platforms, and accidents such as rough behavior, knocks etc. may happen. What would happen if an operator would crash into a wall, or a door while transporting the nitrogen generator?

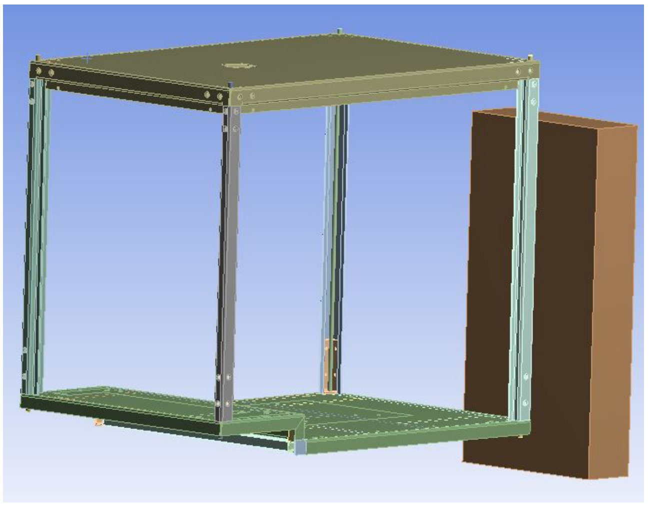

Figure 65: Prototype 2

Figure 65 illustrates the concept about the impact test for prototype 2. The weight of the frame is set to 450kg, and the velocity of the frame has been set to 3m/s.

Due to computational limitations, the velocity had to be set at 3m/s. A simulation of an average walking speed were intended, where the velocity was set to 1.38m/s (5km/h), but the simulation had a time estimate at 8500 hours. Even though the velocity is too fast to be realistic on an offshore platform, it gives an indication on how the forces would be distributed on the frame.

As seen on figure 65, where prototype 2 is illustrated, a top cover plate is mounted; this cover plate has not been included on the lifting test but will be mounted on a daily basis. On the lifting test, only the frame will be lifted, no equipment shall be mounted.

6.4.1 Safety Factor

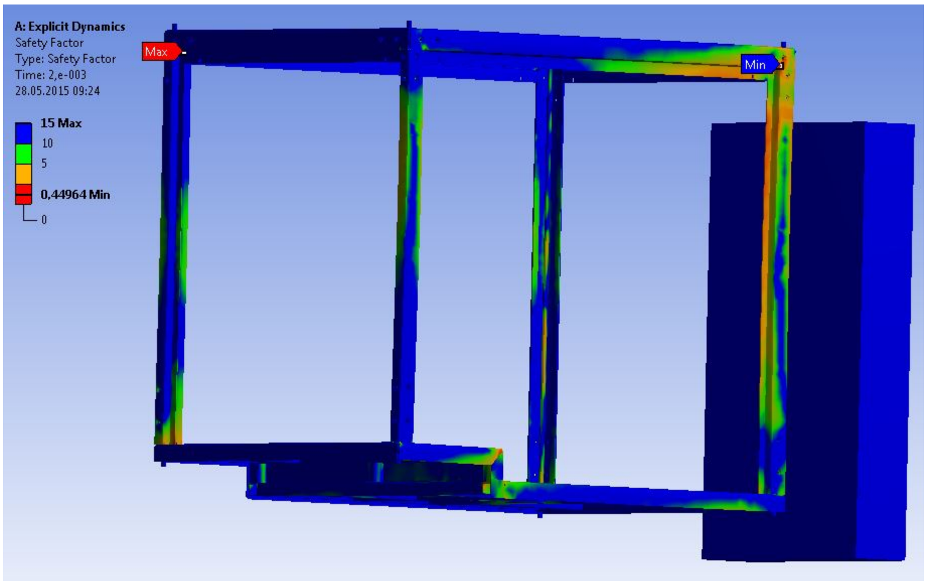

Figure 66: Safety factor - Impact test P2

Figure 66 illustrates the distribution of the safety factor on the frame, where the minimum safety factor is 0.449. The area of the minimum safety occurs in the top right corner of cover plate.

Figure 67 illustrates the iso-clipping of the minimum safety factor, and the exact location of minimum safety factor.

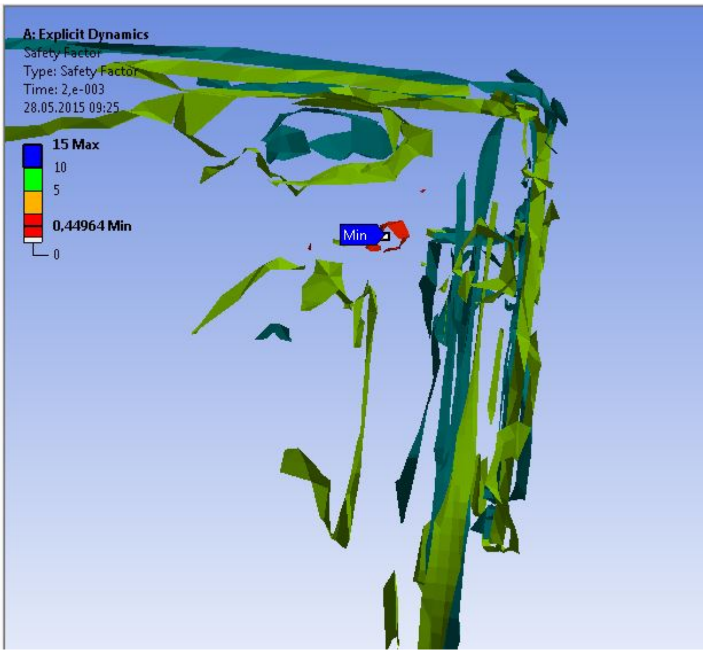

Figure 67: Minimum safety factor – Impact test P2

6.4.2 Equivalent Stress

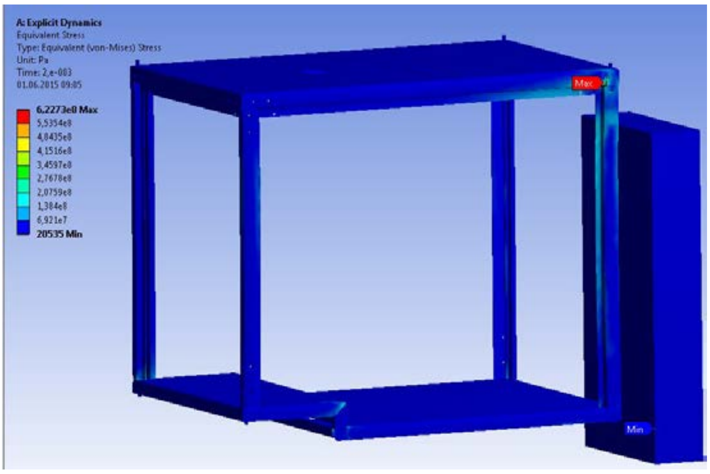

Figure 68: Equivalent stress - Impact test P2

Figure 68 illustrates how the equivalent stress is distributed through the frame. Maximum equivalent stress is 622 MPa, and is significantly higher than yield stress. The stress concentration that occurs, is illustrated in figure 70. A new design of the top plate, could decrease the stress concentration in this area, it would be recommended to perform additional analysis of an impact test with a new top cover plate.

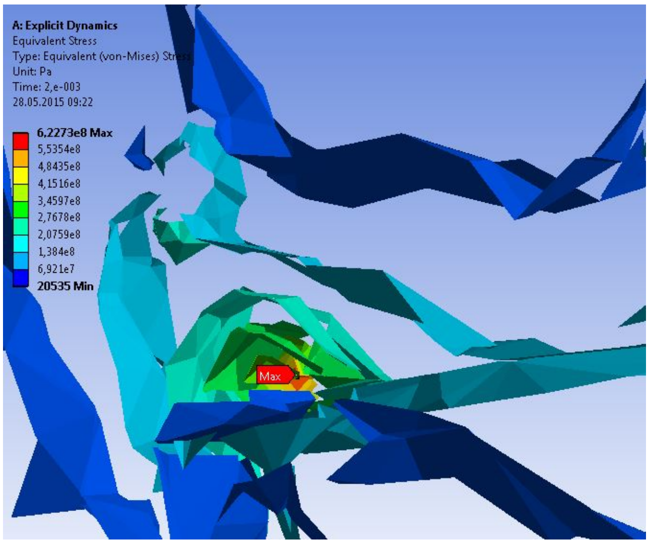

Figure 69: Maximum equivalent stress - Impact test P2

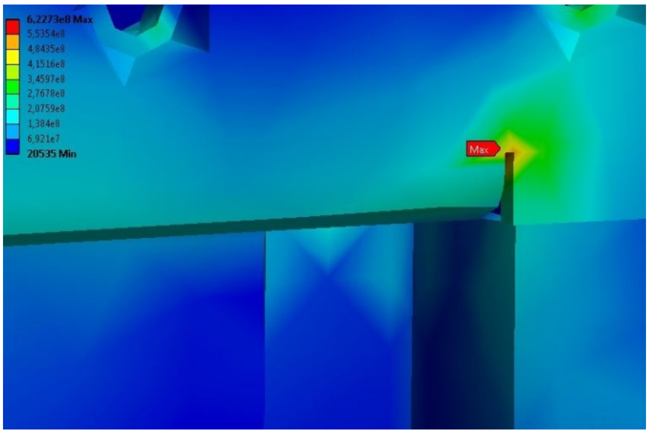

Figure 70: Stress concentration - Impact test P2

6.4.3 Deformation

Figure 71 illustrates the deformation that occurs on the prototype after the unit have crashed into the wall. Maximum deformation occurs in one of the threaded rods. The deformation affects the whole frame, especially in the threaded rods. One can see that the threaded rod that intersects with the wall will also be affected. Maximum deformation that occurs is 6.75mm.

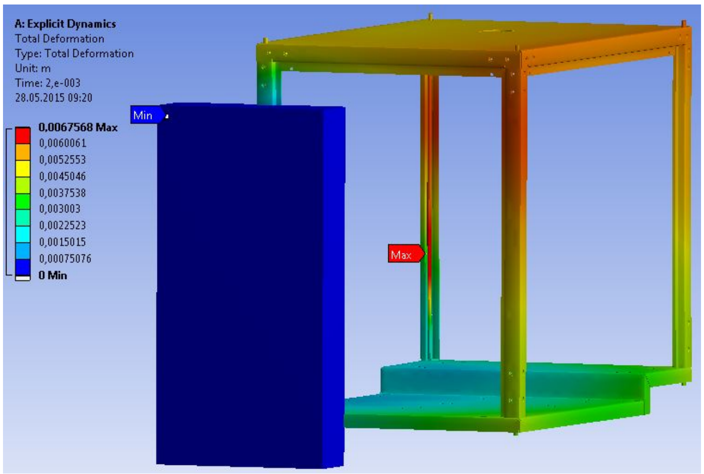

Figure 71: Deformation - Impact test P2

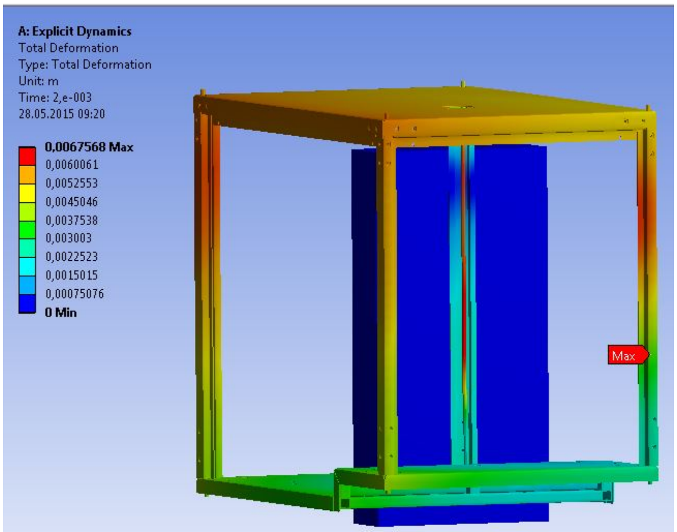

Figure 72: Deformation - Impact test P2 different view

6.5 Impact test – Prototype 3

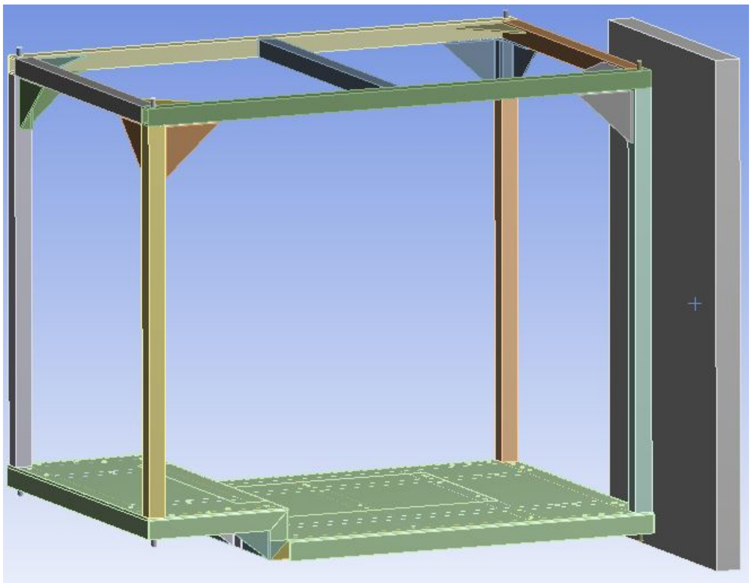

Figure 73: Prototype 3 impact test

The same boundary conditions have been selected for prototype 3, as for the first impact test. Velocity has been set at 3 m/s, and the wall has been set as a fixed support. The weight of the frame is 450 kg.

6.5.1 Safety Factor

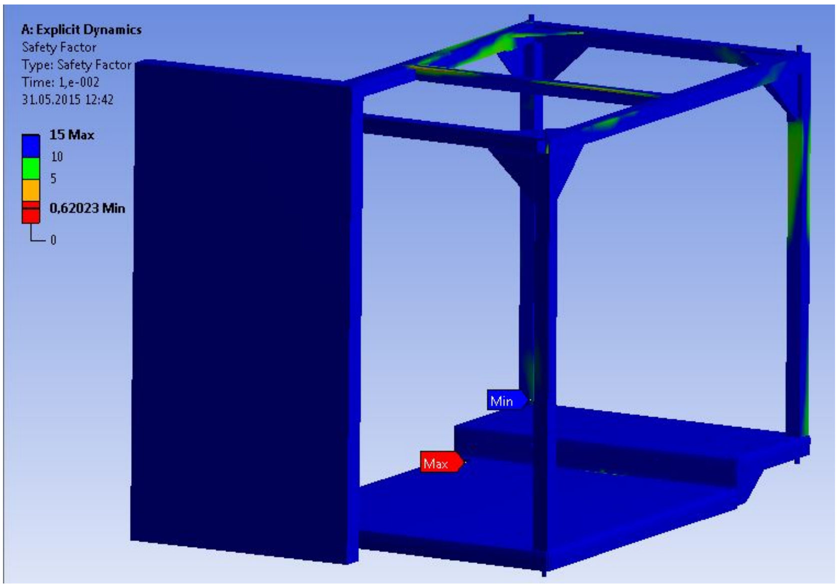

Figure 74: Safety factor – Impact test P3

The safety factor has increased from 0.449 to 0.62. The increasing of the safety factor was less than assumed, and is still too small. Even though the threaded rod is more protected in prototype 3 than it is on prototype 2, it is still vulnerable, and the threaded rod will yield.

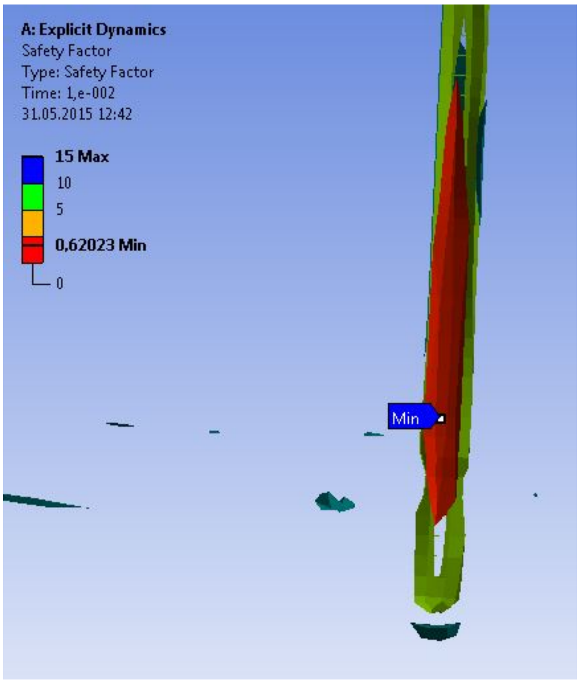

Figure 75: Minimum safety factor – Impact test P3

6.5.2 – Equivalent Stress

The distribution of Von Mises stress has its maximum value at the threaded rod, which is placed inside the corner beam at the right front of the frame. This is illustrated in figure 76. The maximum value is 333MPa, and the yield strength for 316-alloy stainless steel is 205 MPa [33]. The maximum value of equivalent stress will result in a plastic deformation in the threaded rods. Figure 77 illustrates the variation of the equivalent stress inside the exposed threaded rod.

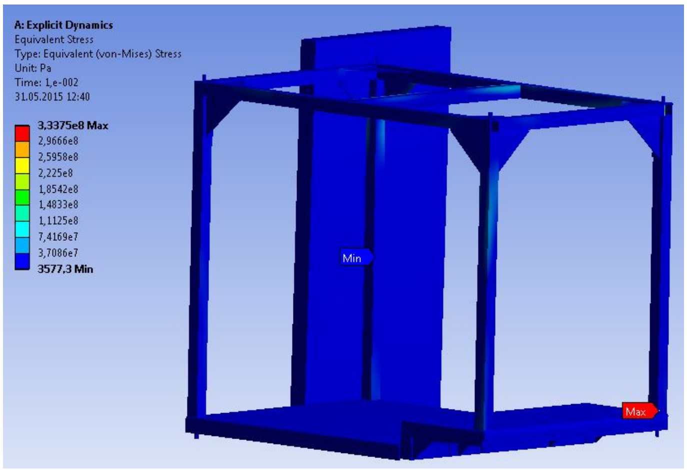

Figure 76: Equivalent stress - Impact test P3

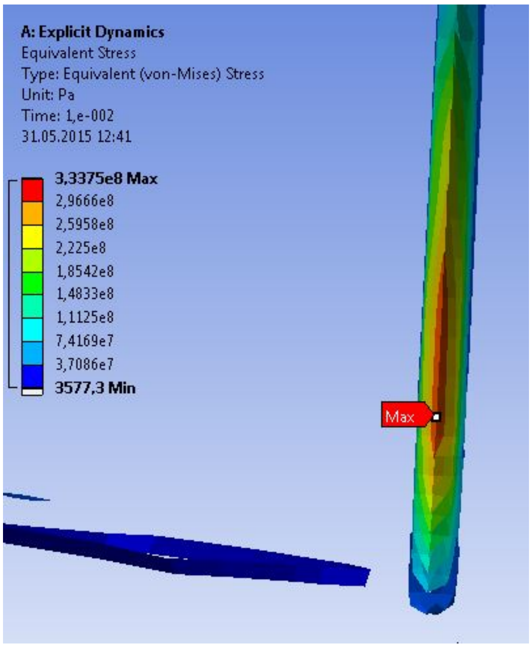

Figure 77: Maximum equivalent stress - Impact test P3

6.5.3 Deformation

Maximum deformation occurs at the rear top left corner of the frame. The result is realistic, due to the velocity that will be 3 m/s the whole time, even after the frame has intersected with the wall. This will lead to a greater deformation at the left corner beams. The deformation will vary from its maximum value at 2.3cm to 0mm.

The bottom plate is 3mm thick and will be the component that will intersect with the wall first. This is also illustrated at figure 79 (the corner that intersects with the wall).

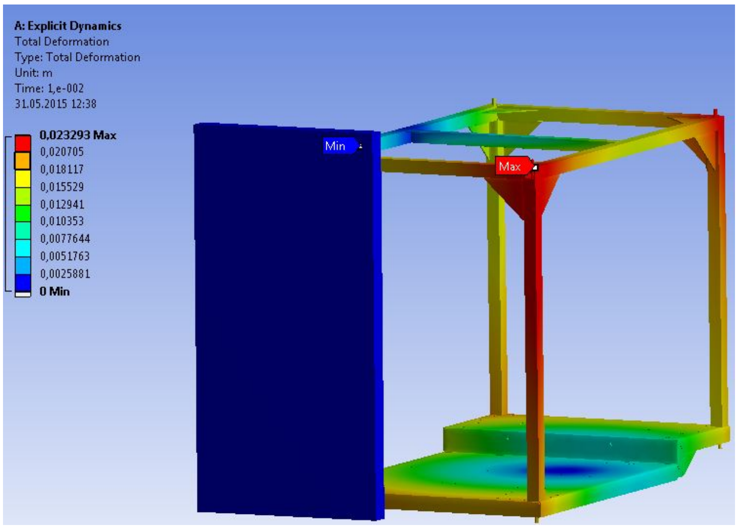

Figure 78: Deformation - Impact test P3

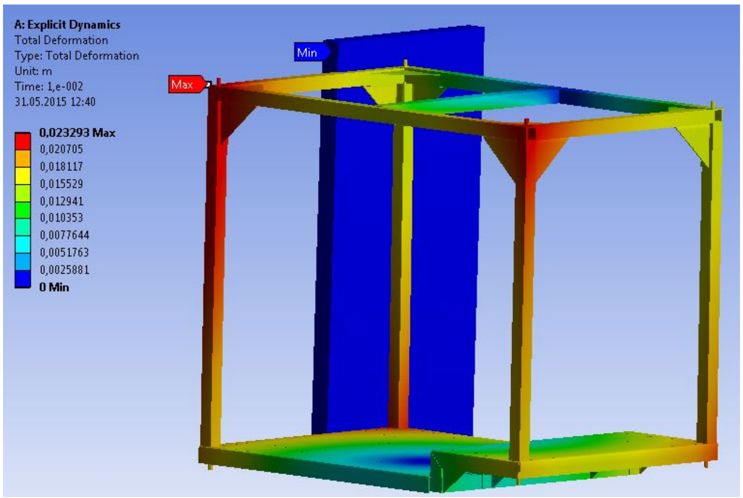

Figure 79: Different view of deformation - Impact test P3

6.6 Discussion Regarding Different Prototypes

There are several differences between prototype two and prototype three. The second prototype weighs less than prototype 3 (the exact weight for each frame are unknown, but due to more parts in prototype 3, one can conclude that that the third prototype will be heavier), will result in a more economic manufacturing, with fewer welding operations.

When the results were reviewed for prototype 2 and the calculation and simulation indicated that the frame was not solid enough, instead of developing further on the prototype, a completely new frame was designed. Although it would be interesting to see how the forces would react if the reinforced base structure were replaced from 30 x 30 x 3mm beams to 40 x 40 x 4mm beams on prototype 2.

One of the differences between prototype 2 and prototype 3 is that prototype 3 was designed and analyzed with an implemented top frame. The top frame contributes to increasing the stiffness in the frame.

The lifting test has been performed without cover plates. The cover plates will also be contributing to an increase in stiffness. According to NORSOK R-002 – Lifting equipment, the frame is the only component that shall be lift-tested, and since the cover plates are additional components, they shall not be implemented on the lifting test, even though they contribute to additional stiffness.

A lifting test analyze gives an indication on how the different forces will distribute through the frame, but it does not clarify how the nitrogen generator will react on a daily basis. It has therefore been performed an impact test which gives another aspect on how the forces in the frame would behave during accidents that may happen. If the nitrogen generator would be dropped down a ramp, or another accidental situation occur the impact test would give an indication of the vulnerable parts in the unit. As the results have shown, the threaded rods are the most vulnerable parts on the frame, and should be replaced by a greater solution to maintain a secure generator. Even though the velocity of the impact test is too situational, it gives a clear statement on how the forces will be distributed throughout the frame.

A possible solution to increase the safety factor would be to change the stainless steel alloy to 8.8 stainless steel quality. An 8.8 quality alloy will have a yield strength of 640MPa [34], and during an impact test, the threaded rods would be ok. It is also important to remember that the analyzed impact test was performed with a velocity of 3 m/s, which implies that the safety factor would e even greater with a slower velocity.

When a customer rent a nitrogen generator for the first time from Nitrogas AS, the first impression is vital. Everything must be perfect, including the frame. Therefore, it is important to design a frame that looks solid and feels solid. Prototype 3 is a more solid frame than prototype 2, both by it looks and what the results implies. Prototype 3 contains more parts to increase the stiffness and the strength of the frame which results in a safety factor that is above the limit required from NORSOK R-002 – Lifting equipment where 4.07 > 2.52. Although the price for prototype 3 is higher than prototype 2, the first two or three nitrogen generators will be developed with the frame of prototype 3. The customer prefers something that he/she remembers, something solid, and since the nitrogen generator is not out on the market yet, it is vital that the customer is satisfied with the totality of the nitrogen generator product.

7. Conclusion

The main objective in this Master thesis was to design a cost-efficient frame with minimum welding; it should be innovative, service friendly and easy to disassemble by only using bolts, nuts and washers.

The first prototype was designed with only two 3mm plates as acting as the bottom frame. However, with a load of approximately 450kg, the plates will not have a sufficient strength to withstand the load of the components. Prototype 1 has not been analyzed due to the reason that the frame will not be strong enough and will most likely fail.

Prototype 2 is the most exciting frame that has been designed and analyzed in this Master thesis, it contributes with a further development of the design criterions. Even though the welding has increased, due to a reinforced base frame, the welding does not appear elsewhere and is still inside the design regulations. It has been performed a lifting load analysis to illustrate if the frame will be approved according to NORSOK R-002 – Lifting equipment, and what would happen to the frame during an impact test. Even though the safety factor was above one, and could be regarded as safe, the safety factor was below the criterions from NORSOK R-002, and could therefore not be approved.

The third prototype is more solid, more expensive, and have additional welding compared to the other prototypes. The formed by buckling corner beams have been replaced with 40 x 40 x 4mm square aluminum beams. This frame had a safety factor that was greater than the safety factor criterion from NORSOK R-002 (4.07 > 2.52), and will therefore be approved for internal lifting on offshore platforms.

A research regarding the steps of nitrogen generator being approved according to DNV 2.7-3 – Portable offshore unit was made. DNV 2.7-3 proved to have too many criterions and restrictions. It would lead to extensive differences on both the design, relocation of the components and further analyses. It would not be beneficial to perform the changes regarding the certification of the nitrogen generator according to DNV 2.7-3 – Portable offshore units.

During this Master thesis I have used Solid works for 3D modeling, I have learnt how to use Ansys Workbench and performing static and explicit dynamics analyses. I have gained knowledge how to perform and make system design in Smart Draw, as well as I have learned vital knowledge of the Norwegian standards and its criterions. This thesis has helped me developing my knowledge within the area of finite element analysis, as well as research and development within the technology and science of nitrogen.

7.2 Further work

By reinforcing the base structure in prototype 2 from 30 x 30 x 3mm to 40 x 40 x 4mm square beams, and still keep the corner beams formed by buckling, one will achieve a frame that is more solid. The vulnerable parts will be replaced, this could lead to a more cost-efficient and innovative frame. This hybrid would be interesting to design, analyze and develop, whereas this could result in a model that would be inexpensive compared to prototype 3, but stronger than prototype 2.

Another aspect of reducing the cost will be to change the design of the frame by make the whole platform at one level, this could contribute to reducing the cost of the frame, as well as there would be fewer welded parts.

Another aspect would be to implement a mixture of helium and nitrogen – so called Helinite. Since the helium molecules are smaller than nitrogen molecules, Helinite would be a great addition for leakage testing. Benjamin Pettersen who also writes a Master thesis for Nitrogas AS covers this topic.

7.3 Margins of error

It is assumed that the analyses are correct, and the settings and boundary conditions that have been applied in Ansys Workbench are correct.

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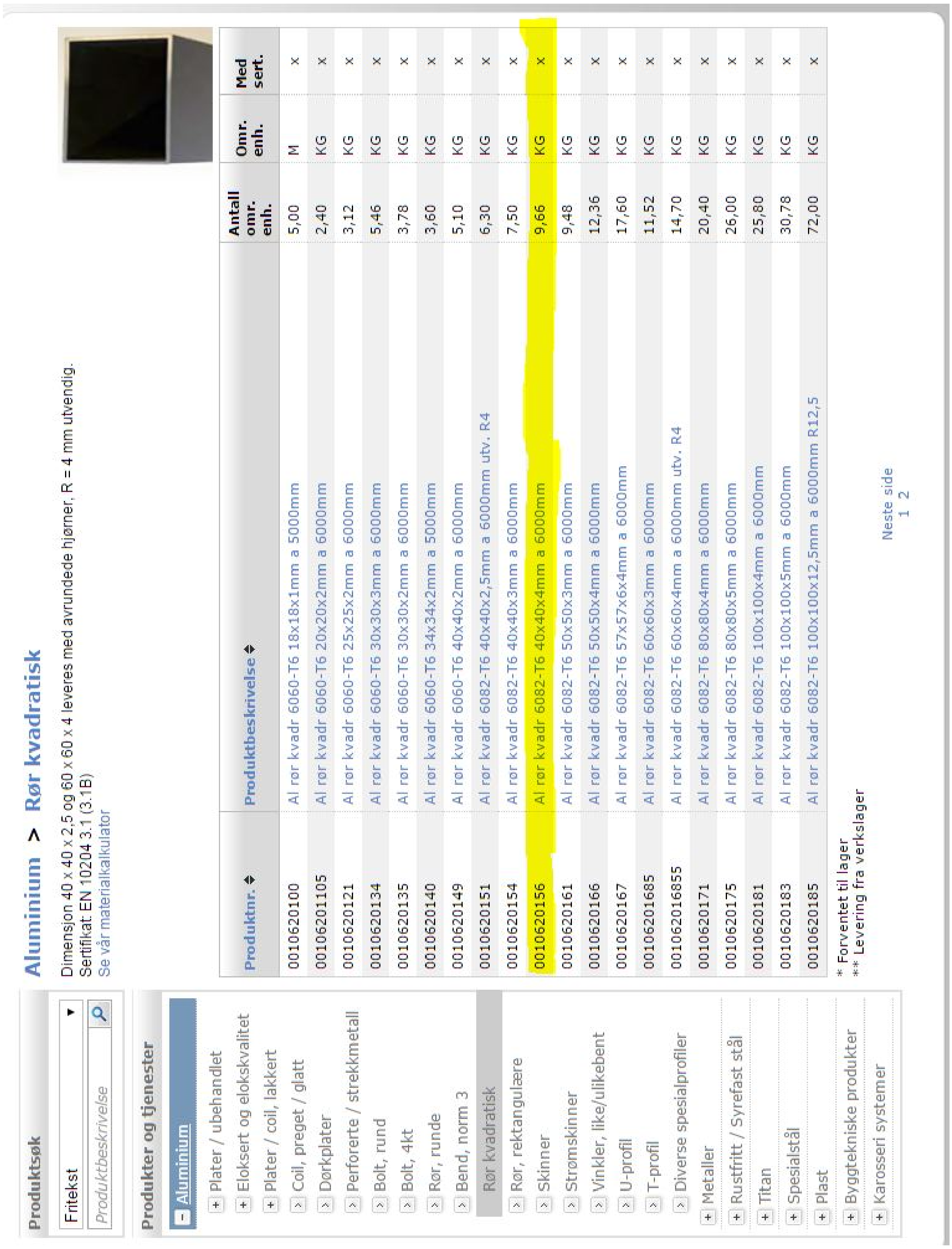
http://www.westfieldfasteners.co.uk/Ref_Strength_Spec.html

Appendix 1. Primary structure component 40 x 40 mm square pipe catalog



Produktsøk

Fritekst

Produktbeskrivelse

Produkter og tjenester

- Aluminium
  - Plater / ubehandlet
  - Eloksert og elokskvalitet
  - Plater / coil, lakkert
  - Coil, preget / glatt
  - Dorkplater
  - Perforerte / strekkmetall
  - Bolt, rund
  - Bolt, 4kt
  - Rør, runde
  - Bend, norm 3
  - Rør kvadratisk
  - Rør, rektangulære
  - Skinner
  - Strømskinner
  - Vinkler, like/ulikebent
  - U-profil
  - T-profil
  - Diverse spesialprofiler
- Metaller
- Rustfritt / Syrefast stål
- Titan
- Spesialstål
- Plast
- Byggtekniske produkter
- Karosseri systemer

Aluminium > Rør kvadratisk

Dimensjon 40 x 40 x 2,5 og 60 x 60 x 4 leveres med avrundede hjørner, R = 4 mm utvendig.
Sertifikat: EN 10204 3.1 (3.1B)
Se vår materialkalkulator

Produktnr.	Produktbeskrivelse	Antall omr. enh.	Omr. enh.	Med sert.
0010620100	Al rør kvadr 6060-T6 18x18x1mm a 5000mm	5,00	M	x
00106201105	Al rør kvadr 6060-T6 20x20x2mm a 6000mm	2,40	KG	x
0010620121	Al rør kvadr 6060-T6 25x25x2mm a 6000mm	3,12	KG	x
0010620134	Al rør kvadr 6060-T6 30x30x3mm a 6000mm	5,46	KG	x
0010620135	Al rør kvadr 6060-T6 30x30x2mm a 6000mm	3,78	KG	x
0010620140	Al rør kvadr 6060-T6 34x34x2mm a 5000mm	3,60	KG	x
0010620149	Al rør kvadr 6060-T6 40x40x2mm a 6000mm	5,10	KG	x
0010620151	Al rør kvadr 6082-T6 40x40x2,5mm a 6000mm utv. R4	6,30	KG	x
0010620154	Al rør kvadr 6082-T6 40x40x3mm a 6000mm	7,50	KG	x
0010620156	Al rør kvadr 6082-T6 40x40x4mm a 6000mm	9,66	KG	x
0010620161	Al rør kvadr 6082-T6 50x50x3mm a 6000mm	9,48	KG	x
0010620166	Al rør kvadr 6082-T6 50x50x4mm a 6000mm	12,36	KG	x
0010620167	Al rør kvadr 6082-T6 57x57x6x4mm a 6000mm	17,60	KG	x
00106201685	Al rør kvadr 6082-T6 60x60x3mm a 6000mm	11,52	KG	x
001062016855	Al rør kvadr 6082-T6 60x60x4mm a 6000mm utv. R4	14,70	KG	x
0010620171	Al rør kvadr 6082-T6 80x80x4mm a 6000mm	20,40	KG	x
0010620175	Al rør kvadr 6082-T6 80x80x5mm a 6000mm	26,00	KG	x
0010620181	Al rør kvadr 6082-T6 100x100x4mm a 6000mm	25,80	KG	x
0010620183	Al rør kvadr 6082-T6 100x100x5mm a 6000mm	30,78	KG	x
0010620185	Al rør kvadr 6082-T6 100x100x12,5mm a 6000mm R12,5	72,00	KG	x

* Forventet til lager
** Levering fra verkslager

Neste side
1 2

Figure 80: Rectangular square beams for P3 [26]

Appendix 2 - Maximum Principal Stress

Prototype 2 – Lifting Load Analysis

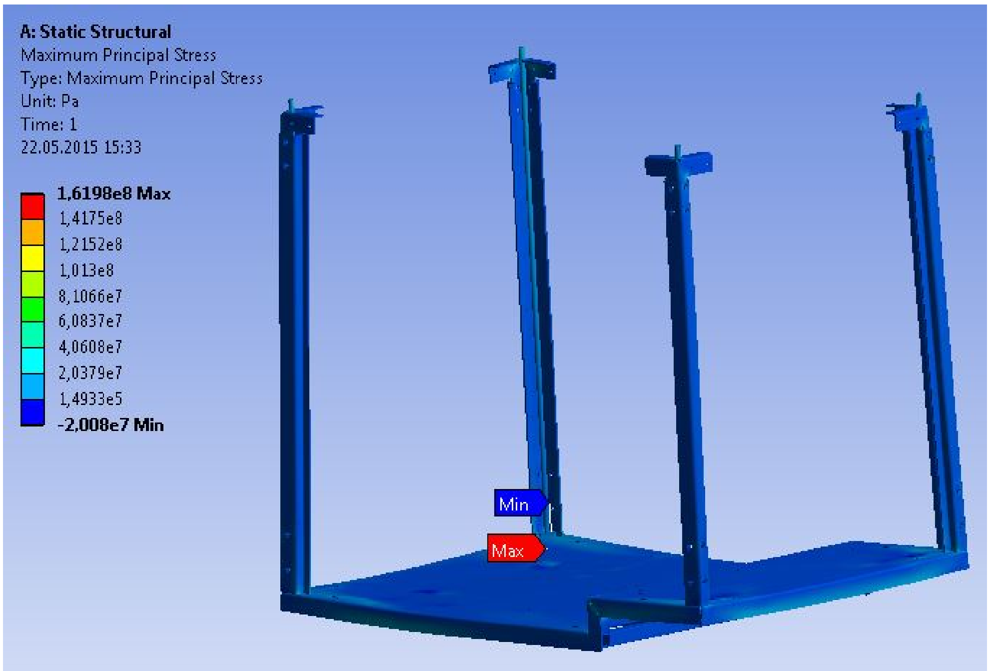


Figure 81: Maximum principal stress - P2

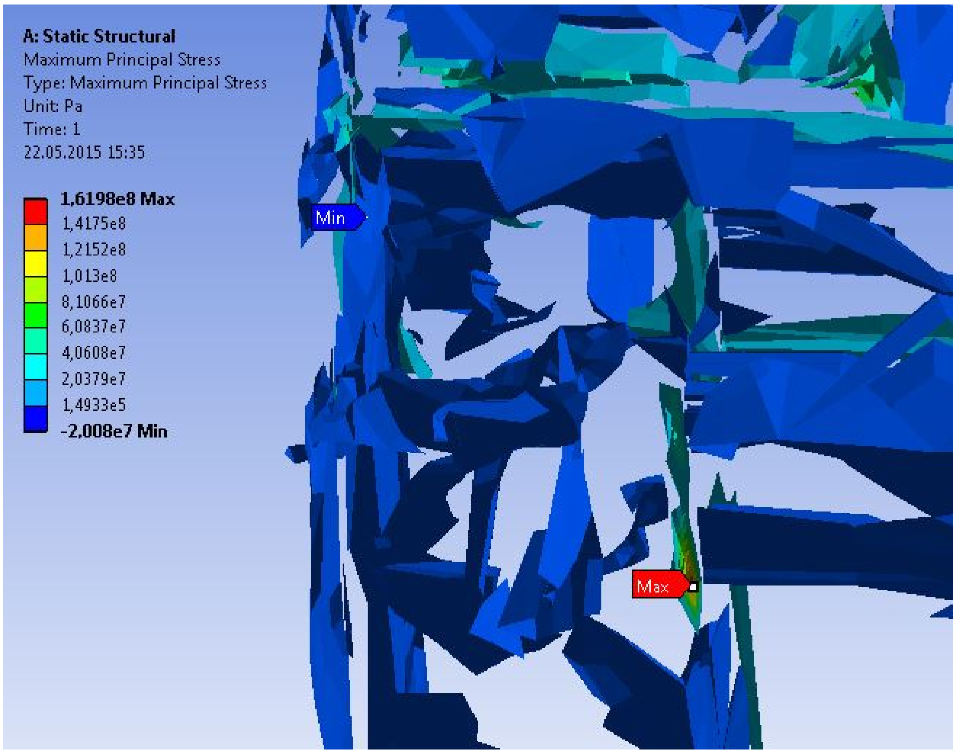


Figure 82: Maximum principal stress - iso-clipping P2

Prototype 2 – Impact test

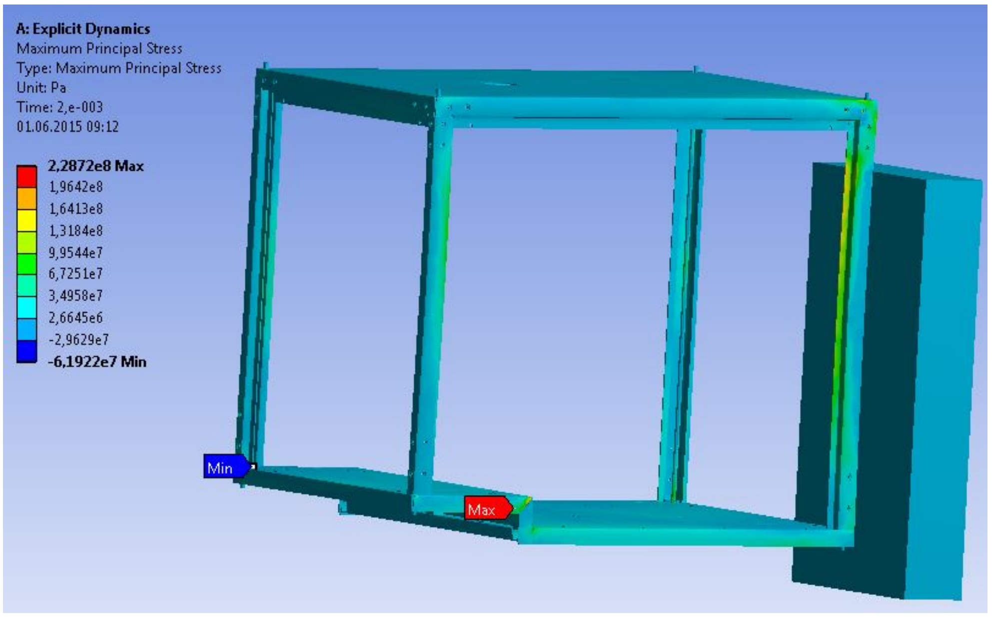


Figure 83: Maximum principal stress - Impact test P2

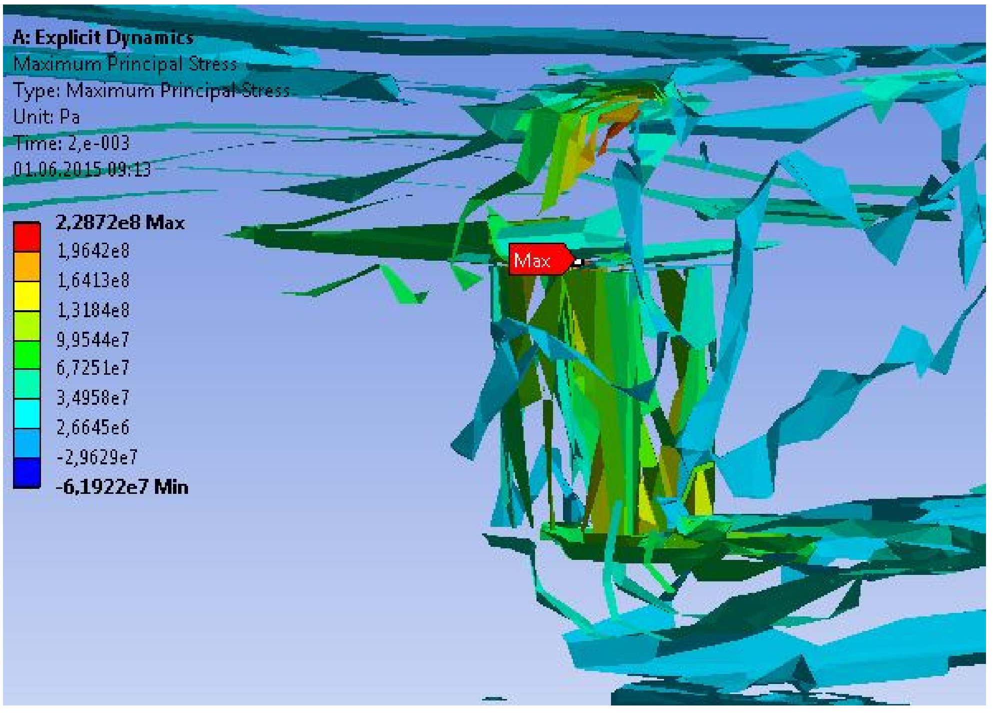


Figure 84: Maximum principal stress - Impact test - iso clipping P2

Prototype 3 – Lifting Load Analysis

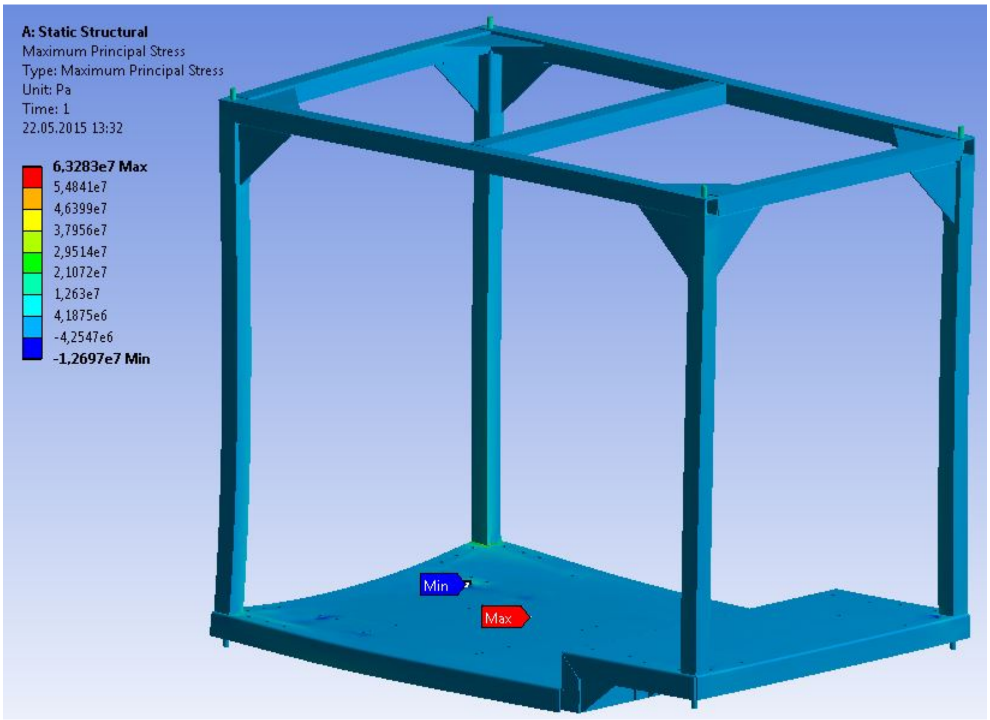


Figure 85: Maximum principal stress - P3

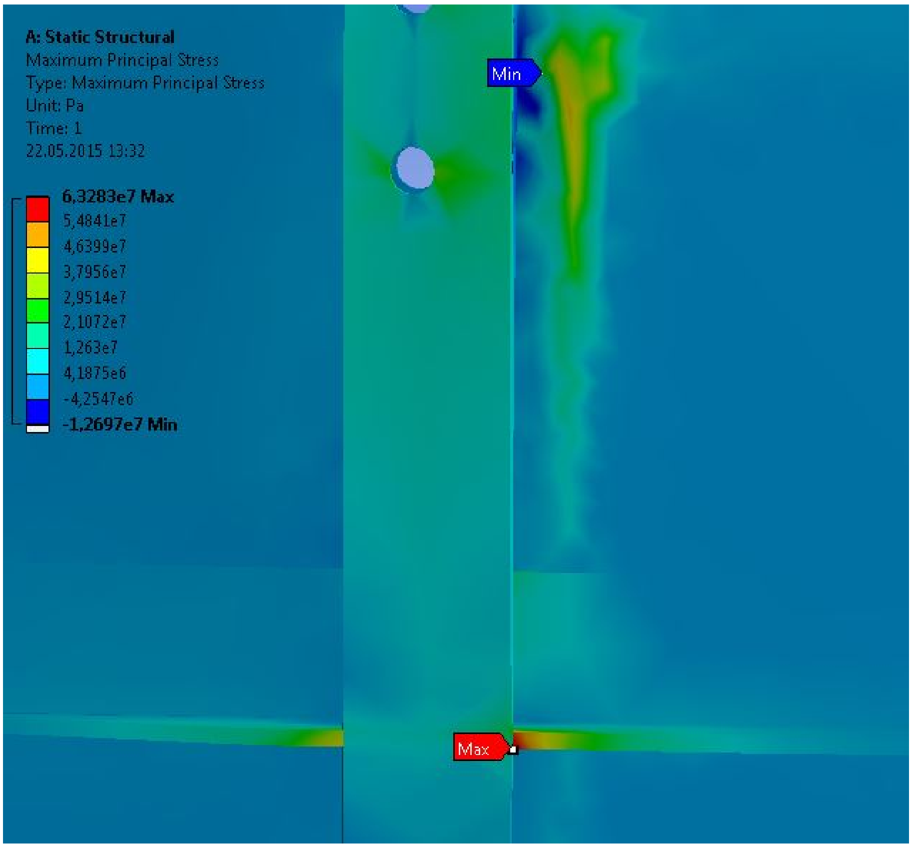


Figure 86: Maximum principal stress - iso-clipping P3

Prototype 3 – Impact test

Figure 87: Maximum principal stress – Impact test P3

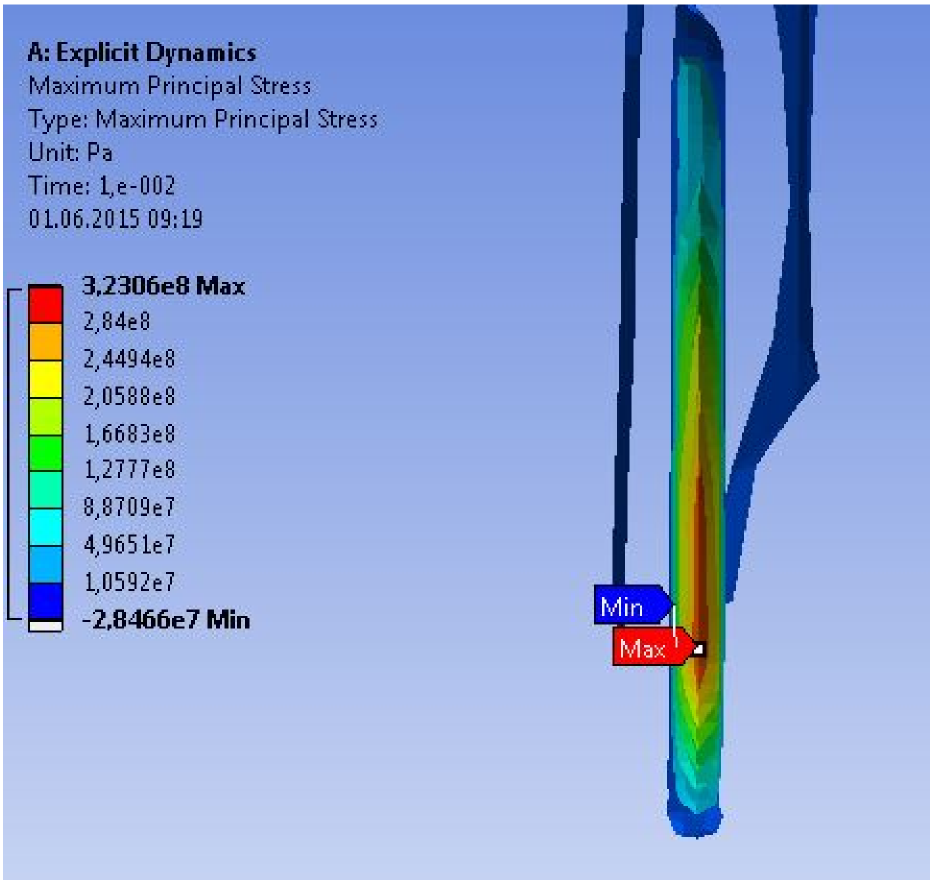


Figure 88: Maximum principal stress - Impact test iso-clipping P3

Appendix 3 - Various Components

Parker ST708 nitrogen membrane

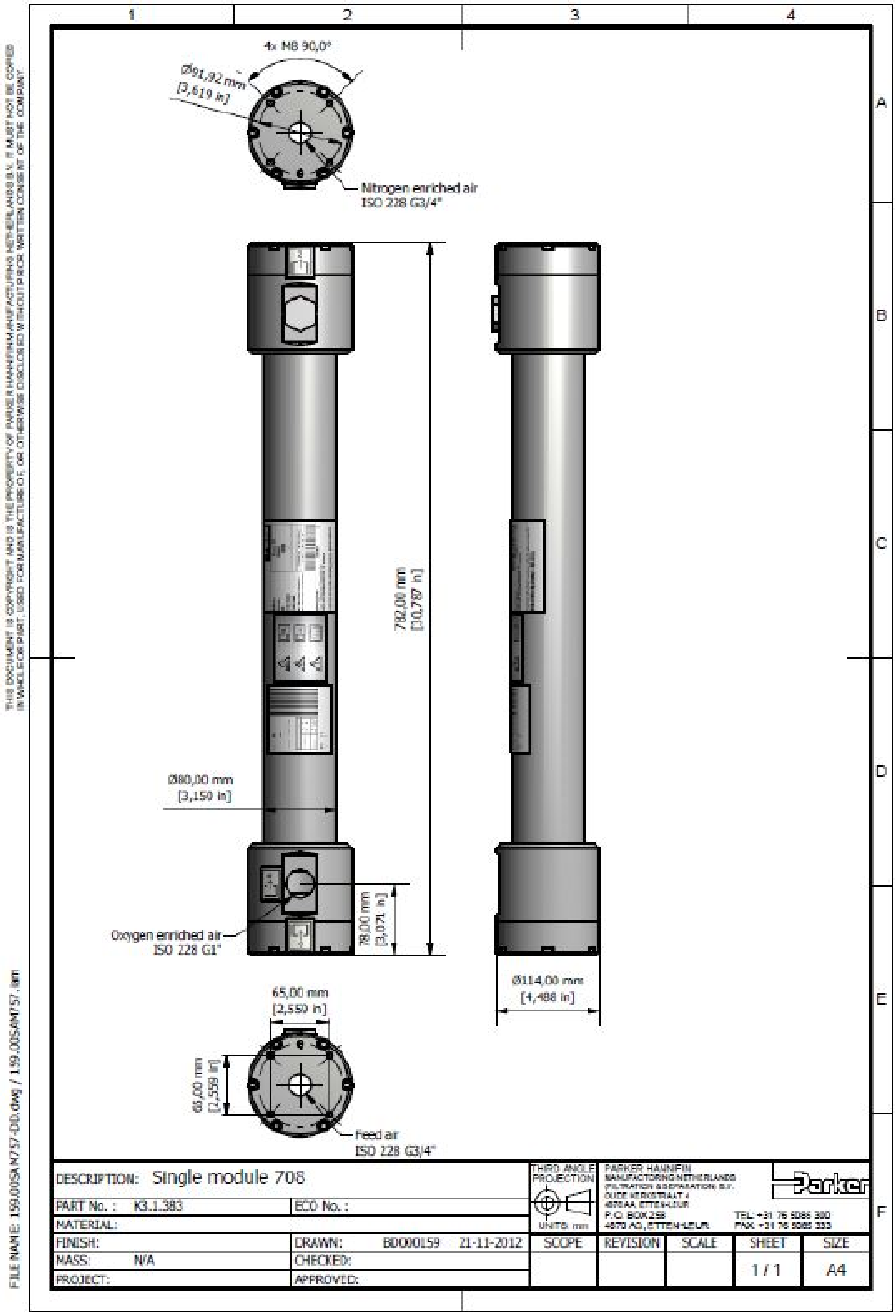


Figure 89: Parker ST708 nitrogen membrane [27]

Blickle – Front Wheel Information

Blickle

Series: L-ALTH, B-ALTH, BH-ALTH

Pressed steel castors, medium duty brackets, with top plate fitting, wheel with Blickle Extrathane® polyurethane tread

180 - 500 kg ✓RoHS

Blickle Extrathane®

Brackets: L/B/BH series - Made of pressed steel, swivel bracket with double ball bearing in the swivel head, strong central kingpin (wheel Ø 150-250 mm), swivel head seals. The special Blickle dynamic riveting process of the swivel head results in minimal swivel head play and smooth rolling characteristics with an increased service life achieved by the work hardening of the ball race grooves. Bolted wheel axle. Zinc-plated, blue-passivated, Cr6-free.
Bracket overview: Page 65
Top plate drawings: Page 77
Wheel and swivel head 'stop-fix' brake: Page 80

Wheels: ALTH series - Tread: Made of high-quality polyurethane-elastomer Blickle Extrathane®, 92° shore A, light brown, non-marking, non-staining.
Wheel centre: Made of die-cast aluminium.
Bearing type: Two pressed-in ball bearings.
Detailed description: Page 246 and 48

Swivel castors	Fixed castors	Swivel castors with 'stop-fix' brake	Wheel Ø [mm]	Wheel width [mm]	Load capacity [kg]	Bearing type	Total height [mm]	Plate size [mm]	Bolt hole spacing [mm]	Bolt hole Ø [mm]	Offset swivel castor [mm]
L-ALTH 80K	**B-ALTH 80K**	**L-ALTH 80K-FI**	80	30	180	Ball bearing	102	100 x 85	80 x 60	9	38
L-ALTH 100K	**B-ALTH 100K**	**L-ALTH 100K-FI**	100	40	200	Ball bearing	125	100 x 85	80 x 60	9	36
L-ALTH 125K	**B-ALTH 125K**	**L-ALTH 125K-FI**	125	40	200	Ball bearing	150	100 x 85	80 x 60	9	40
L-ALTH 151K	**B-ALTH 151K**	**L-ALTH 151K-FI**	150	40	400	Ball bearing	190	140 x 110	105 x 75-80	11	60
L-ALTH 150K	**B-ALTH 150K**	**L-ALTH 150K-FI**	150	50	400	Ball bearing	190	140 x 110	105 x 75-80	11	60
L-ALTH 160K	**B-ALTH 160K**	**L-ALTH 160K-FI**	160	50	400	Ball bearing	195	140 x 110	105 x 75-80	11	60
L-ALTH 180K	**B-ALTH 180K**	**L-ALTH 180K-FI**	180	50	400	Ball bearing	215	140 x 110	105 x 75-80	11	60
L-ALTH 200K	**B-ALTH 200K**	**L-ALTH 200K-FI**	200	50	400	Ball bearing	235	140 x 110	105 x 75-80	11	65
L-ALTH 250K-3	**BH-ALTH 250K**	*	250	60	500	Ball bearing	295	140 x 110	105 x 75-80	11	77

* For the 'stop-top' brake version refer to 'Options'

11

Options

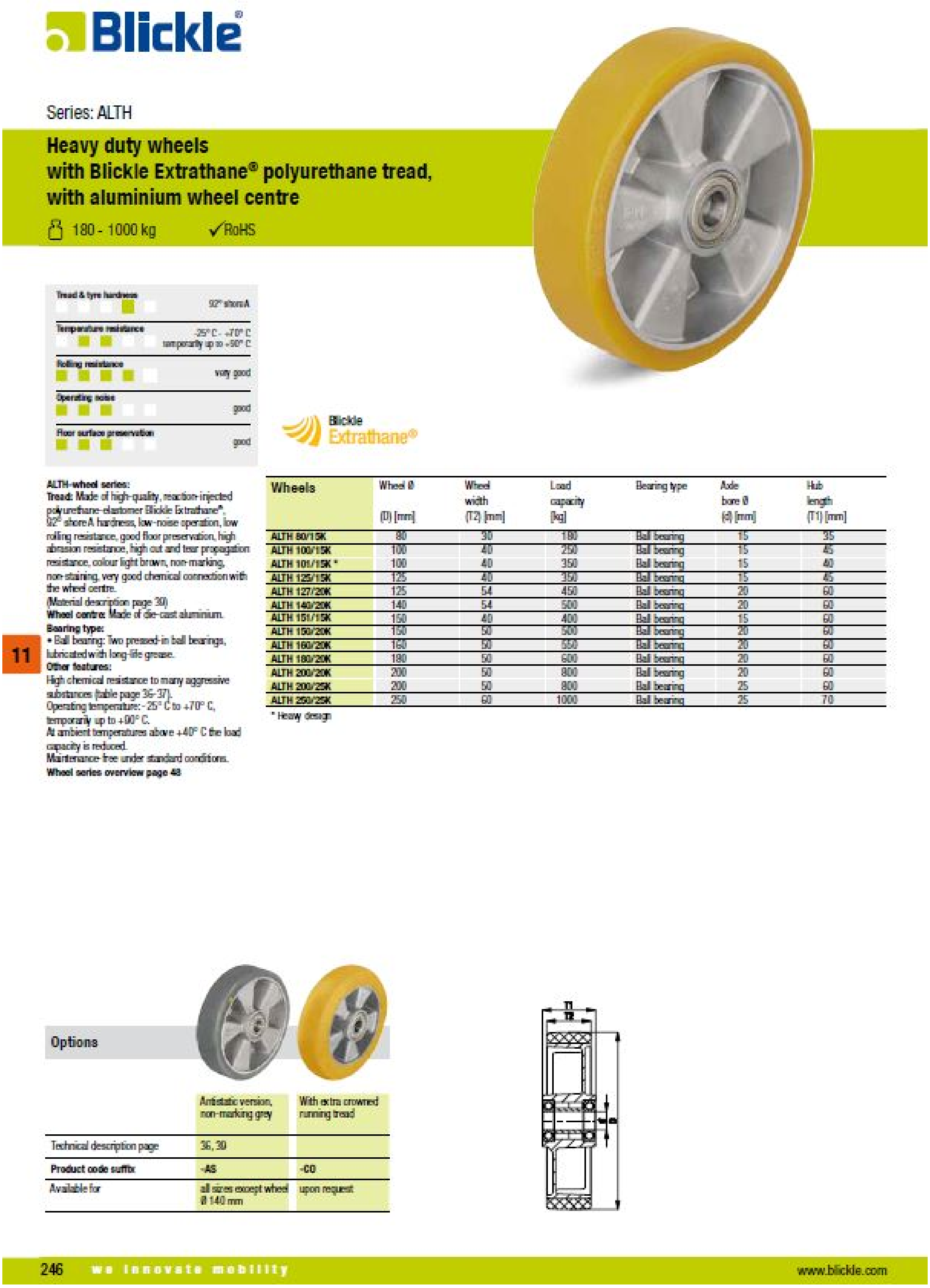
	Antistatic version, non-marking grey	With extra crowned running tread	With 'stop-top' brake	With central braking system 'central-stop'	Directional lock (retro fit) 1 x 360° **	Directional lock (retro fit) 1 x 360° **	With synthetic (-FP) or steel (-FS) foot guard
Technical description page	36, 39		80	81	83	83	84
Product code suffix	**-AS**	**-CO**	**-ST**	**-CS11**	**RI-03.01**	**RI-05.03**	**-FP / -FS**
Available for	all sizes	upon request	all sizes	wheel Ø 160+200 mm	wheel Ø 100-125 mm	wheel Ø 150-200 mm	upon request

** Only for swivel castors without brake

www.blickle.com we innovate mobility 247

Figure 90: Front wheel information [20]

Blickle – Rear Wheel Information


Blickle

Series: ALTH

Heavy duty wheels
with Blickle Extrathane® polyurethane tread,
with aluminium wheel centre

180 - 1000 kg ✓RoHS

Tread & tyre hardness		92° shore A
Temperature resistance		-25° C - +70° C temporarily up to +90° C
Rolling resistance		very good
Operating noise		good
Floor surface preservation		good

Blickle Extrathane®

ALTH-wheel series:
Tread: Made of high-quality, reaction-injected polyurethane-elastomer Blickle Extrathane®, 92° shore A hardness, low-noise operation, low rolling resistance, good floor preservation, high abrasion resistance, high cut and tear propagation resistance, colour light brown, non-marking, non-staining, very good chemical connection with the wheel centre.
(Material description page 30)
Wheel centre: Made of die-cast aluminium.
Bearing type:
• Ball bearing: Two pressed-in ball bearings, lubricated with long-life grease.
Other features:
High chemical resistance to many aggressive substances (table page 36-37).
Operating temperature: - 25° C to +70° C, temporarily up to +90° C.
At ambient temperatures above +40° C the load capacity is reduced.
Maintenance-free under standard conditions.
Wheel series overview page 48

11

Wheels	Wheel Ø (D) [mm]	Wheel width (T2) [mm]	Load capacity [kg]	Bearing type	Axle bore Ø (d) [mm]	Hub length (T1) [mm]
ALTH 80/15K	80	30	180	Ball bearing	15	35
ALTH 100/15K	100	40	250	Ball bearing	15	45
ALTH 101/15K *	100	40	350	Ball bearing	15	40
ALTH 125/15K	125	40	350	Ball bearing	15	45
ALTH 127/20K	125	54	450	Ball bearing	20	60
ALTH 140/20K	140	54	500	Ball bearing	20	60
ALTH 151/15K	150	40	400	Ball bearing	15	60
ALTH 150/20K	150	50	500	Ball bearing	20	60
ALTH 160/20K	160	50	550	Ball bearing	20	60
ALTH 180/20K	180	50	600	Ball bearing	20	60
ALTH 200/20K	200	50	800	Ball bearing	20	60
ALTH 200/25K	200	50	800	Ball bearing	25	60
ALTH 250/25K	250	60	1000	Ball bearing	25	70

* Heavy design

Options	Antistatic version, non-marking grey	With extra crowned running tread
Technical description page	36, 30	
Product code suffix	**-AS**	**-CO**
Available for	all sizes except wheel Ø 140 mm	upon request

246 we innovate mobility www.blickle.com

Figure 91: Rear wheel information [20]

Norgren Filter Package

NORGREN

OLYMPIAN PLUS PLUG-IN SYSTEM

Breathing air sets

FFB64, FFB68 - G1/4 ... G3/4

FFB64, FFB68

Pre-assembled combinations include a general purpose pre-filter and 'Ultraire®' oil/oil vapour removal filter

Activated carbon pack assists in the removal of hydro-carbon gases and odours

Pre filter extends life of oil removal filter

High quality breathing air for the supply of up to 5 masks

TECHNICAL DATA

Medium:
Compressed air only

Maximum inlet pressure:
17 bar

Note: These units will not remove carbon monoxide, carbon dioxide or other toxic gases or fumes.

Remaining oil content:
0.003 mg/m³ (at 21°C)

Particicle removal:
To 0.01 µm

Ambient temperature:
-20°C ... +65°C
Consult our Technical Service for use below +2°C

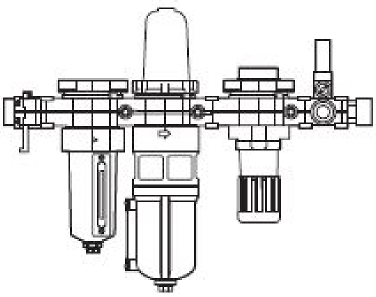
MATERIALS

FFB64
Bowls: aluminium & zinc
Body & yoke: zinc alloy
Pre-filter element: sintered bronze or plastic
Main filter element & activated carbon pack: composite materials

FFB68
Bowls & body: aluminium
Yoke: aluminium
Elastomers: synthetic rubber
Pre-filter element: sintered plastic
Main filter element & activated carbon pack: composite materials

					MODELS				ACCESSORIES		
Port size	Flow (dm³/s)	kg	Num. of masks	Primary pre-filter (µm)	Auto drain	Manual drain	Model with pressure regulator Auto	Model with pressure regulator Manual	Wall mounting bracket	Silencer (shut-off valve)	3/2 Shut-off valve*
G1/4	7	3,20	1	5	FFB64-208	FFB64-228	FFR64-208	FFR64-228	74504-50	T40B1800	T64T-2GB-P1N
G3/8	11	3,57	2	5	FFB64-308	FFB64-328	FFR64-308	FFR64-328	74504-50	T40B1800	T64T-3GB-P1N
G1/2	35	7,45	3	25	FFB68-408	FFB68-428	FFR68-408	FFR68-428	18-001-979	T40B1800	T68H-4GB-B2N
G3/4	60	7,65	4/5	25	FFB68-608	FFB68-628	FFR68-608	FFR68-628	18-001-979	T40B1800	T68H-6GB-B2N

For service kit numbers refer to individual units *Threaded exhaust port.



The addition of a pressure switch and end connector allows a low pressure warning signal to be given to an external electrical circuit.
FFR model shown (64 Series only).

6-070

For further information
i PDF CAD
www.norgren.com/info/en6-070

Figure 92: Filter Package from Norgren [28]

NORGREN

OLYMPIAN PLUS PLUG-IN SYSTEM

General purpose filters

F64G, F68G - G1/4 ... G1 1/2

F64G

F68G

Effective liquid removal and positive solid filtration

Large filter element area for minimum pressure drop

Standard options include element service indicator, manual drains and alternative filter elements

TECHNICAL DATA

Medium:
Compressed air only

Maximum inlet pressure:
17 bar

Ambient temperature:
-20°C ... +80°C
Consult our Technical Service for use below +2°C

MATERIALS

F64G
Body: zinc alloy
Bowl: aluminium
Yoke: aluminium
Filter element: sintered plastic
Elastomers: synthetic rubber

F68G
Body & bowl: aluminium
Yoke: aluminium
Filter element: sintered bronze or plastic
Elastomers: synthetic rubber

F64G

Port size	kg	Flow* (dm³/s)	MODELS Auto drain	MODELS Manual drain	ACCESSORIES Wall mounting bracket	ACCESSORIES 3/2 Shut-off valve**	ACCESSORIES Silencer (shut-off valve)	SERVICE KIT Auto drain	SERVICE KIT Manual drain
G1/4	1,42	33	F64G-2GN-AD3	F64G-2GN-MD3	74504-50	T64T-2GB-P1N	T40B1800	F64G-KITA40	F64G-KITM40
G3/8	1,42	66	F64G-3GN-AD3	F64G-3GN-MD3	74504-50	T64T-3GB-P1N	T40B1800	F64G-KITA40	F64G-KITM40
G1/2	1,32	75	F64G-4GN-AD3	F64G-4GN-MD3	74504-50	T64T-4GB-P1N	T40B1800	F64G-KITA40	F64G-KITM40
G3/4	1,72	75	F64G-6GN-AD3	F64G-6GN-MD3	74504-50	T64T-6GB-P1N	T40B1800	F64G-KITA40	F64G-KITM40

* Typical flow with 6.3 bar inlet pressure and 0.5 bar pressure drop
**Threaded exhaust port. For replacement filter (without yoke) substitute 'N' at the 5th and 6th digits eg: F64G-NNN-AD3 (F64).

F68G

Port size	kg	Flow* (dm³/s)	MODELS Auto drain	MODELS Manual drain	ACCESSORIES Wall mounting bracket	ACCESSORIES 3/2 Shut-off valve**	ACCESSORIES Silencer (shut-off valve)	SERVICE KIT Auto drain	SERVICE KIT Manual drain
G3/4	2,45	160	F68G-6GN-AR3	F68G-6GN-MR3	18-001-979	T68H-6GB-B2N	T40B2800	F68G-KITA40	F68G-KITM40
G1	2,33	190	F68G-8GN-AR3	F68G-8GN-MR3	18-001-979	T68H-8GB-B2N	T40B2800	F68G-KITA40	F68G-KITM40
G1 1/4	2,43	200	F68G-AGN-AR3	F68G-AGN-MR3	18-001-978	T68H-AGB-B2N	T40B2800	F68G-KITA40	F68G-KITM40
G1 1/2	2,30	200	F68G-BGN-AR3	F68G-BGN-MR3		T68H-BGB-B2N	T40B2800	F68G-KITA40	F68G-KITM40

* Typical flow with 6.3 bar inlet pressure and 0.5 bar pressure drop
**Threaded exhaust port. For replacement filter (without yoke) substitute 'N' at the 5th and 6th digits eg: F68G-NNN-AR3 (F68).

FLOW CHARACTERISTICS

For further information

www.norgren.com/info/en6-063

6-063

Figure 93: Filters from Norgren [28]

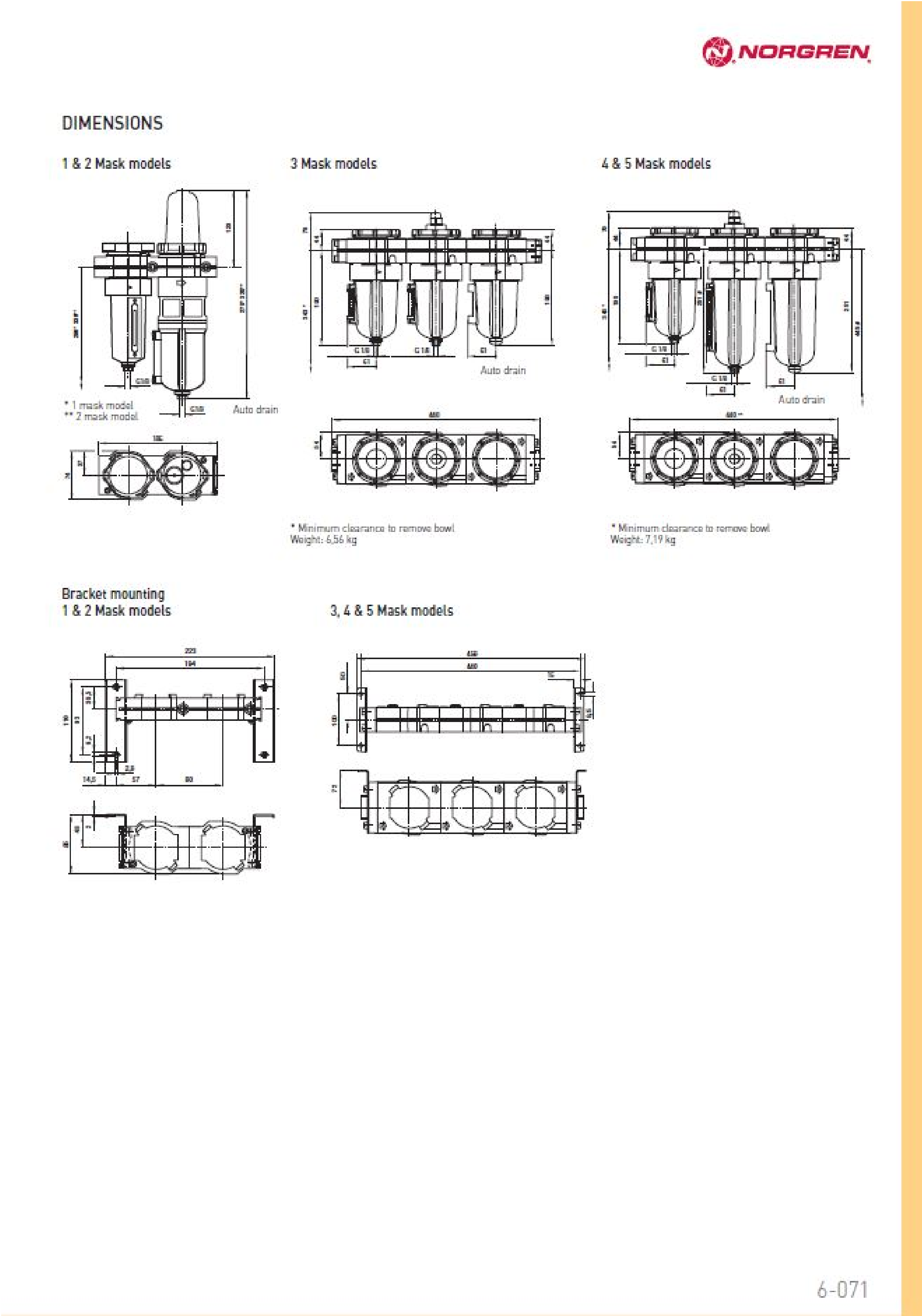


Figure 94: Dimensions regarding Norgren filters [28]

Domnick Hunter – Water Separator

Figure 95: Domnick Hunter Water cyclone [29]

Produktutvalg & Tekniske Data

Modell	Tilslutning	l/s	m³/min	m³/t	cfm	Maksimalt arbeidstrykk bar g	Maksimalt arbeidstrykk psi g	Maksimal Driftstemperatur		Minimum Driftstemperatur	
WS010A☐FX	¼"	10	0.6	36	21	16	232	80°C	176°F	1.5°C	35°F
WS010B☐FX	⅜"	10	0.6	36	21	16	232	80°C	176°F	1.5°C	35°F
WS010C☐FX	½"	10	0.6	36	21	16	232	80°C	176°F	1.5°C	35°F
WS015B☐FX	⅜"	40	2.4	144	85	16	232	80°C	176°F	1.5°C	35°F
WS020C☐FX	½"	40	2.4	144	85	16	232	80°C	176°F	1.5°C	35°F
WS020D☐FX	¾"	40	2.4	144	85	16	232	80°C	176°F	1.5°C	35°F
WS020E☐FX	1"	40	2.4	144	85	16	232	80°C	176°F	1.5°C	35°F
WS025D☐FX	¾"	110	6.6	396	233	16	232	80°C	176°F	1.5°C	35°F
WS030E☐FX	1"	110	6.6	396	233	16	232	80°C	176°F	1.5°C	35°F
WS030F☐FX	1¼"	110	6.6	396	233	16	232	80°C	176°F	1.5°C	35°F
WS030G☐FX	1½"	110	6.6	396	233	16	232	80°C	176°F	1.5°C	35°F
WS035F☐FX	1¼"	350	21	1260	742	16	232	80°C	176°F	1.5°C	35°F
WS040G☐FX	1½"	350	21	1260	742	16	232	80°C	176°F	1.5°C	35°F
WS045H☐FX	2"	350	21	1260	742	16	232	80°C	176°F	1.5°C	35°F
WS055I☐FX	2½"	800	48	2880	1695	16	232	80°C	176°F	1.5°C	35°F
WS055J☐FX	3"	800	48	2880	1695	16	232	80°C	176°F	1.5°C	35°F

Kapasitet er ved driftstrykk på 7 bar (g) (102 psi g) med referanse til 20°C, 1 bar (a), 0% relativ vanndamp trykk.

Systemtrykk bar g	Systemtrykk psi g	Korreksjons-faktor
1	15	0.25
2	29	0.38
3	44	0.50
4	58	0.63
5	73	0.75
6	87	0.88
7	100	1.00
8	116	1.06
9	131	1.12
10	145	1.17
11	160	1.22
12	174	1.27
13	189	1.32
14	203	1.37
15	218	1.41
16	232	1.46
[illegible]		
17	247	1.50
18	261	1.54
19	275	1.58
20	290	1.62

Filter koder og valg av produkt

GRAD	MODELL	Tilslutning størrelse	TILSLUTNING TYPE	DREN TYPE	MONITOR
WS	3 siffret kode vist over	Bokstav angir tilslutning størrelse	B = BSPT N = NPT	F = Flotør M = Manuell	X = Ikke tilgjengelig
WS	010	A	B	F	X

WS modeller leveres standard med flotørdrenering. For trykk fra 16 til 20 bar g (232 til 290 psi g) må manuelt dren benyttes.

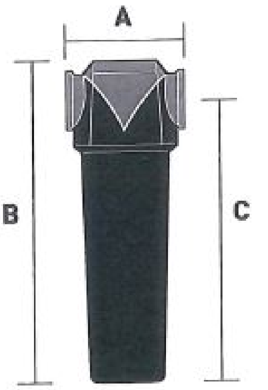
For valg av vanneseparator passende til system kapasitet og trykk.

Eksempel: Systemkapasitet på 1050 m³/t ved et trykk på 8 bar g

1. Finn riktig trykk korreksjonsfaktor i tabell. Korreksjonsfaktor for 8 bar g = 1.06
2. Del systemkapasitet på på korreksjonsfaktor for å finne kapasitet ved 7 bar g 1050m³/t ÷ 1.06 = 984 m³/t (ved 7 bar g)
3. Velg en separatormodell fra tabellen over med kapasitet større eller lik 984 m³/t. Passende vanneseparator modeller : 035 eller 040
4. Velg tilslutning størrelse og type. Systemet benytter 1 1/2" rør og BSP gjenger : Modell WS040GB
5. Velg dren type. Trykk under 16 bar g (232 psi g), automatisk flottør dren montert som standard. Modell WS040GBFX

Vekt og dimensjoner

Modell	Tilslutning	A mm	A ins	B mm	B ins	C mm	C ins	Vekt kg	Vekt lbs
WS010A☐FX	¼"	76	3	181.5	7.2	153	6	0.6	1.3
WS010B☐FX	⅜"	76	3	181.5	7.2	153	6	0.6	1.3
WS010C☐FX	½"	76	3	181.5	7.2	153	6	0.6	1.3
WS015B☐FX	⅜"	97.5	3.8	235	9.3	201	7.9	1.1	2.4
WS020C☐FX	½"	97.5	3.8	235	9.3	201	7.9	1.1	2.4
WS020D☐FX	¾"	97.5	3.8	235	9.3	201	7.9	1.1	2.4
WS020E☐FX	1"	97.5	3.8	235	9.3	201	7.9	1.1	2.4
WS025D☐FX	¾"	129	5.1	275	10.8	232.5	9.2	2.2	4.8
WS030E☐FX	1"	129	5.1	275	10.8	232.5	9.2	2.2	4.8
WS030F☐FX	1¼"	129	5.1	275	10.8	232.5	9.2	2.2	4.8
WS030G☐FX	1½"	129	5.1	275	10.8	232.5	9.2	2.2	4.8
WS035F☐FX	1¼"	170	6.7	432.5	17	382.5	15	5.1	11.2
WS040G☐FX	1½"	170	6.7	432.5	17	382.5	15	5.1	11.2
WS045H☐FX	2"	170	6.7	432.5	17	382.5	15	5.1	11.2
WS055I☐FX	2½"	205	8.1	505	19.9	444.5	17.5	10	22
WS055J☐FX	3"	205	8.1	505	19.9	444.5	17.5	10	22



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filtration purification separation

A division of Parker Hannifin Corporation

Figure 96: Technical information water cyclone [29]

RotorComp – Compressor Information

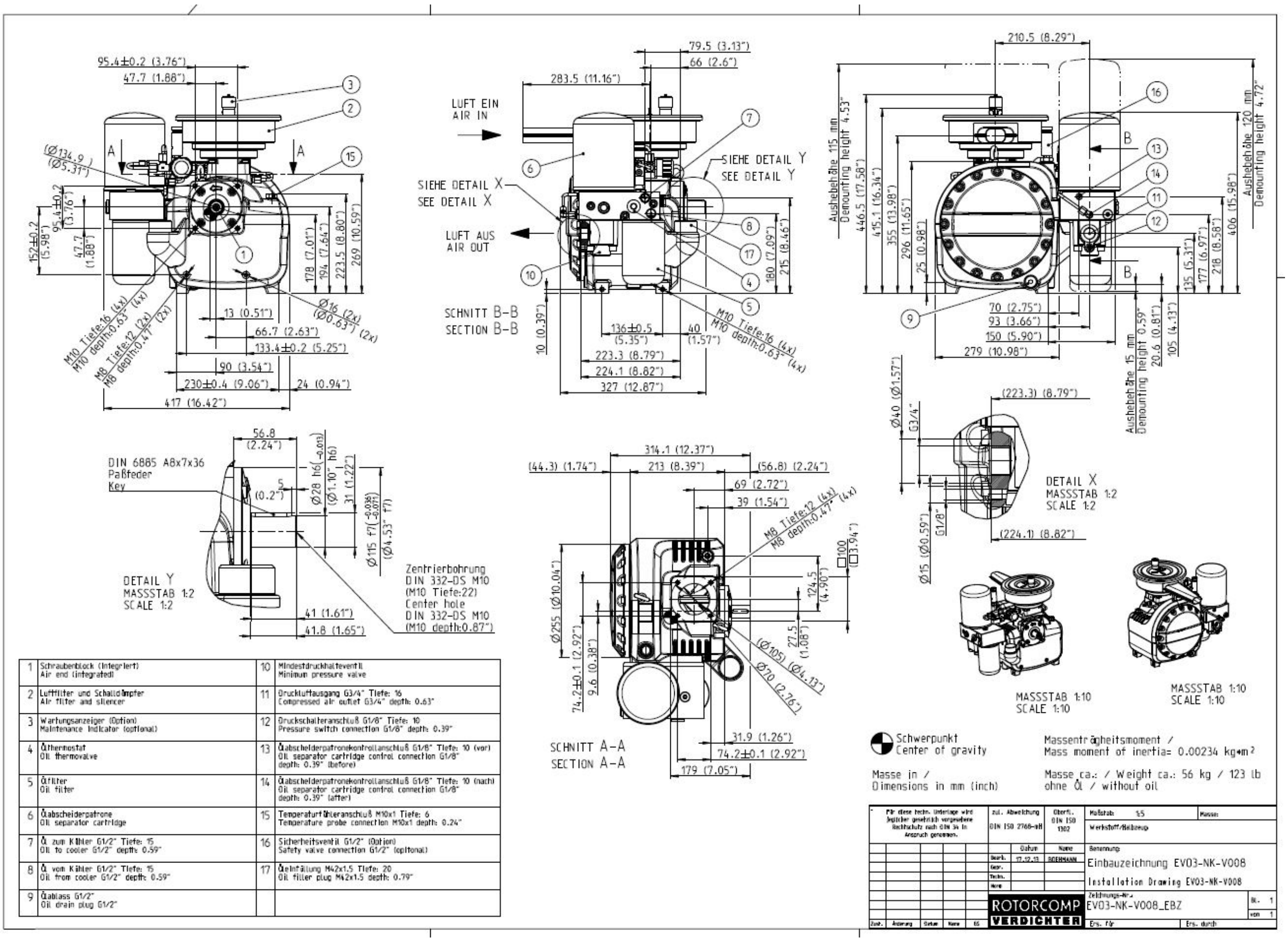

Figure 97: Technical information RotorComp compressor [30]

Appendix 4 – Prototype 3 Drawings

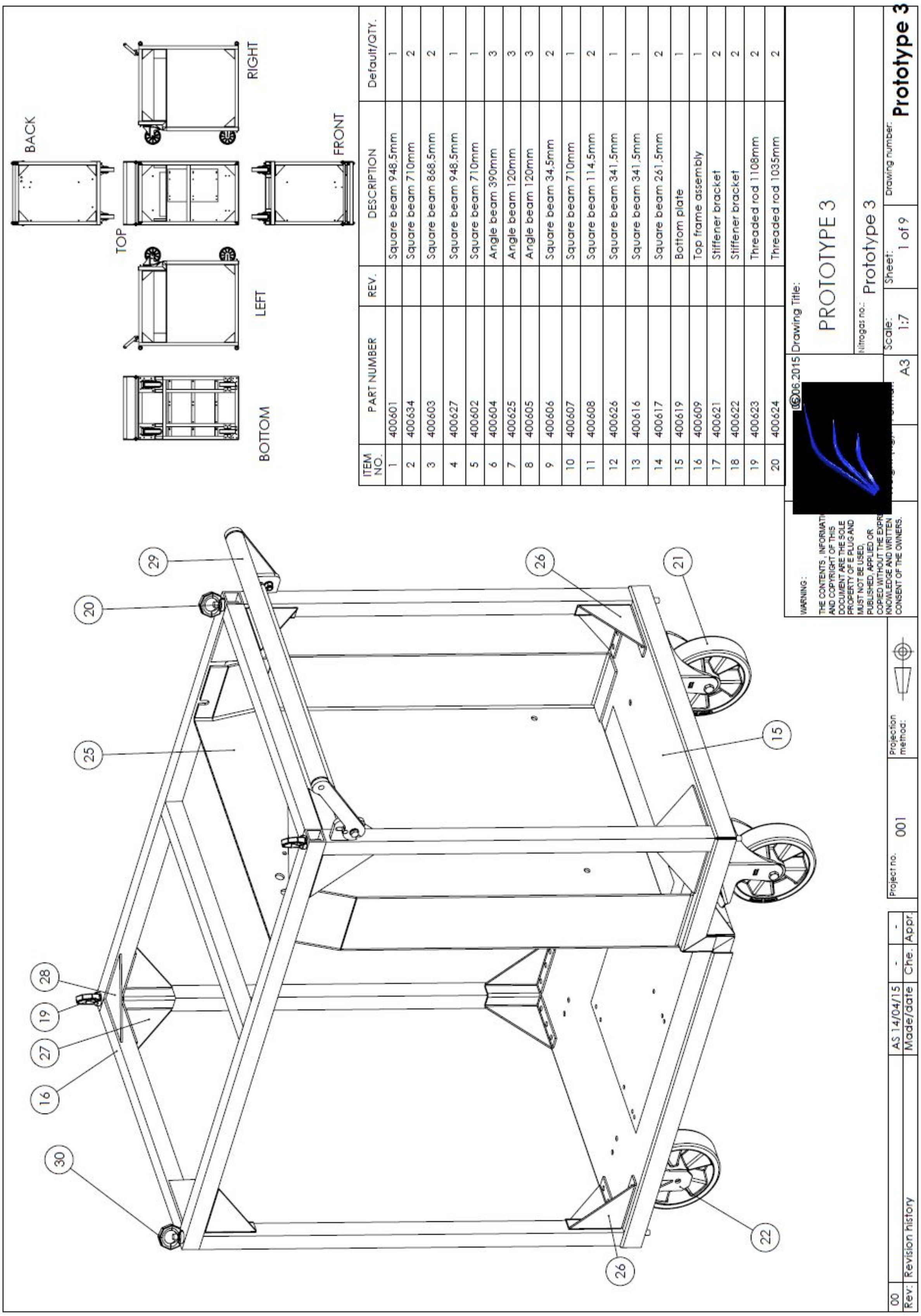

Figure 98: Prototype 3 with part number and description

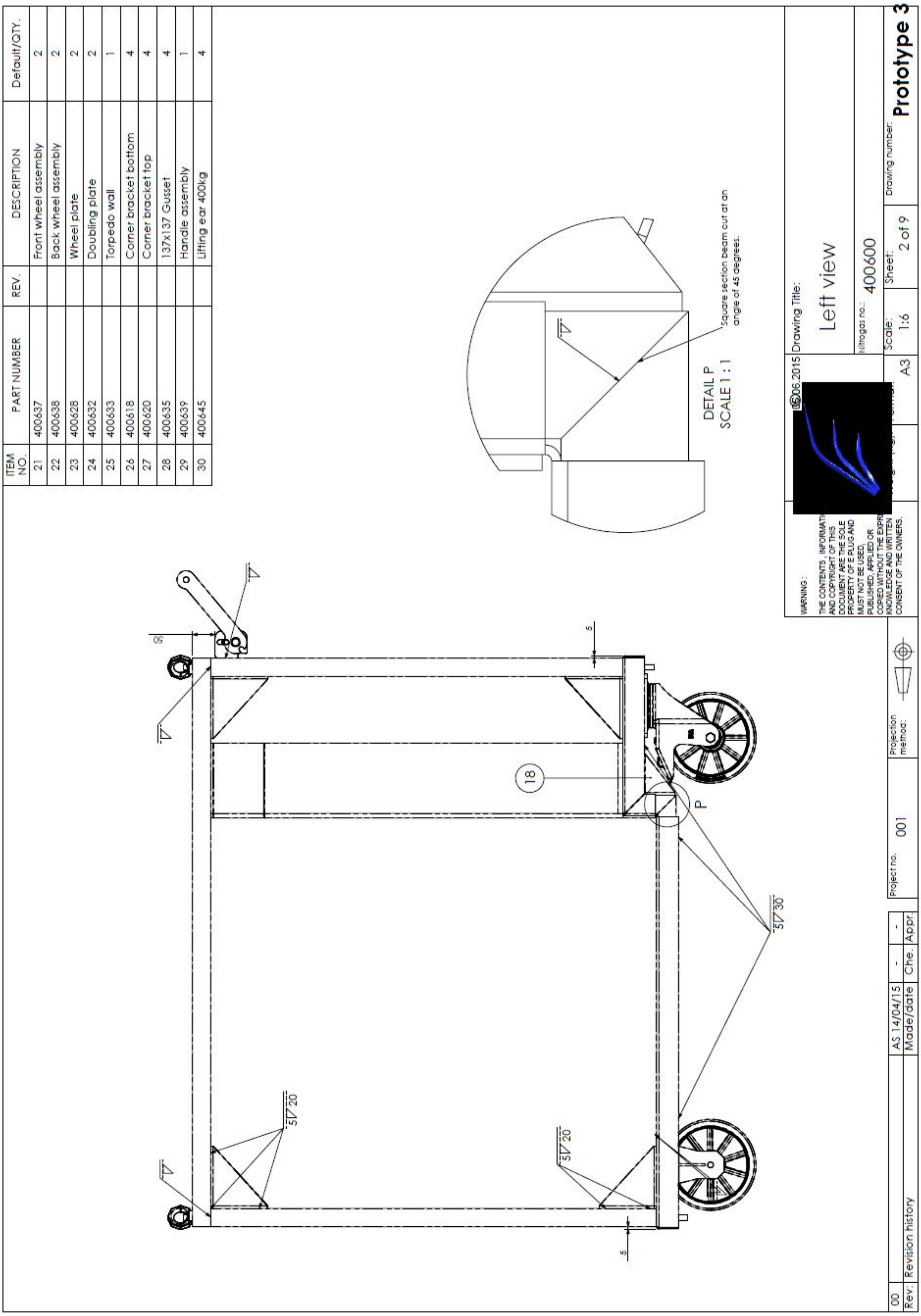

Figure 99: Prototype 3 - Left view

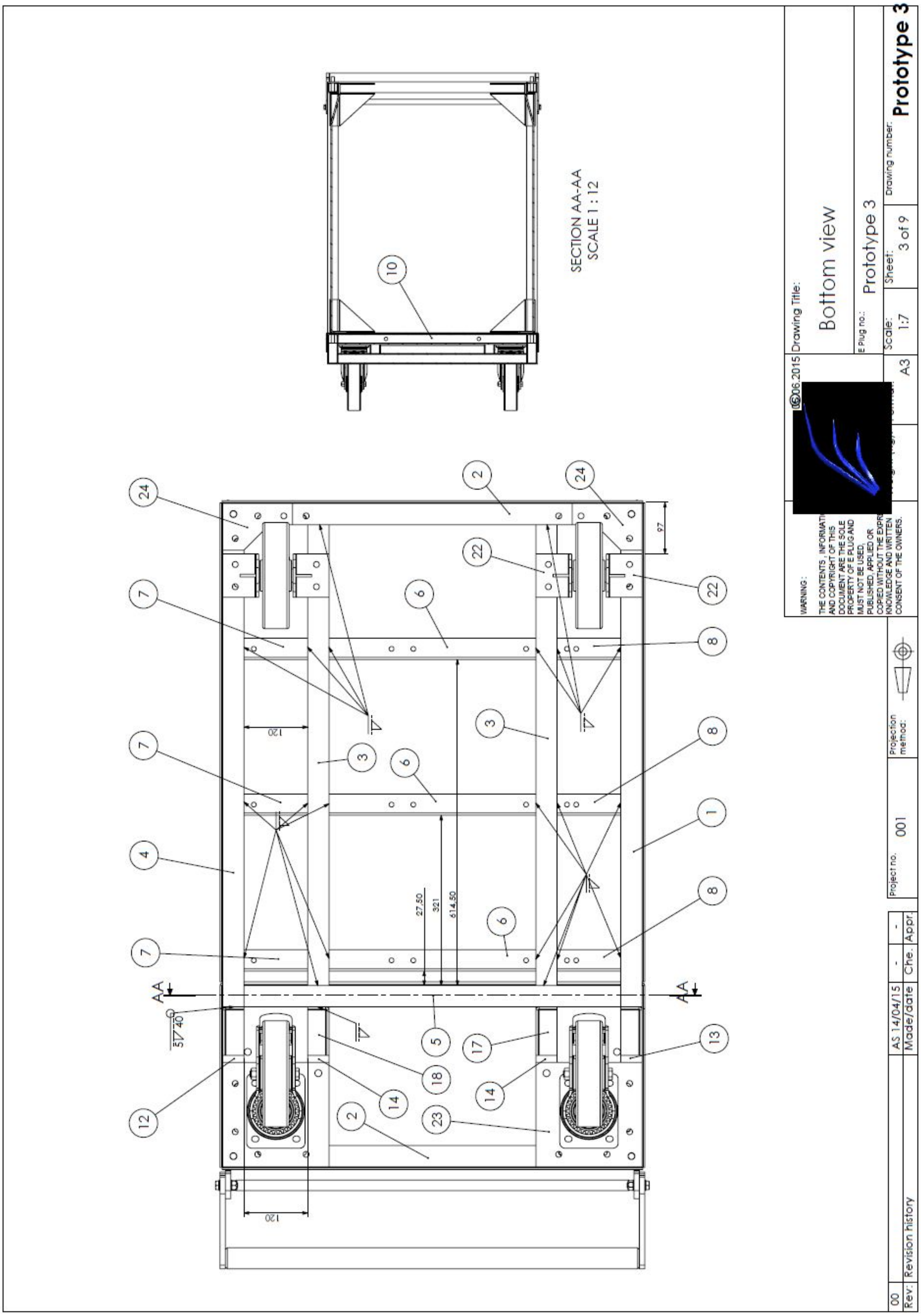

Figure 100: Prototype 3 - Bottom view

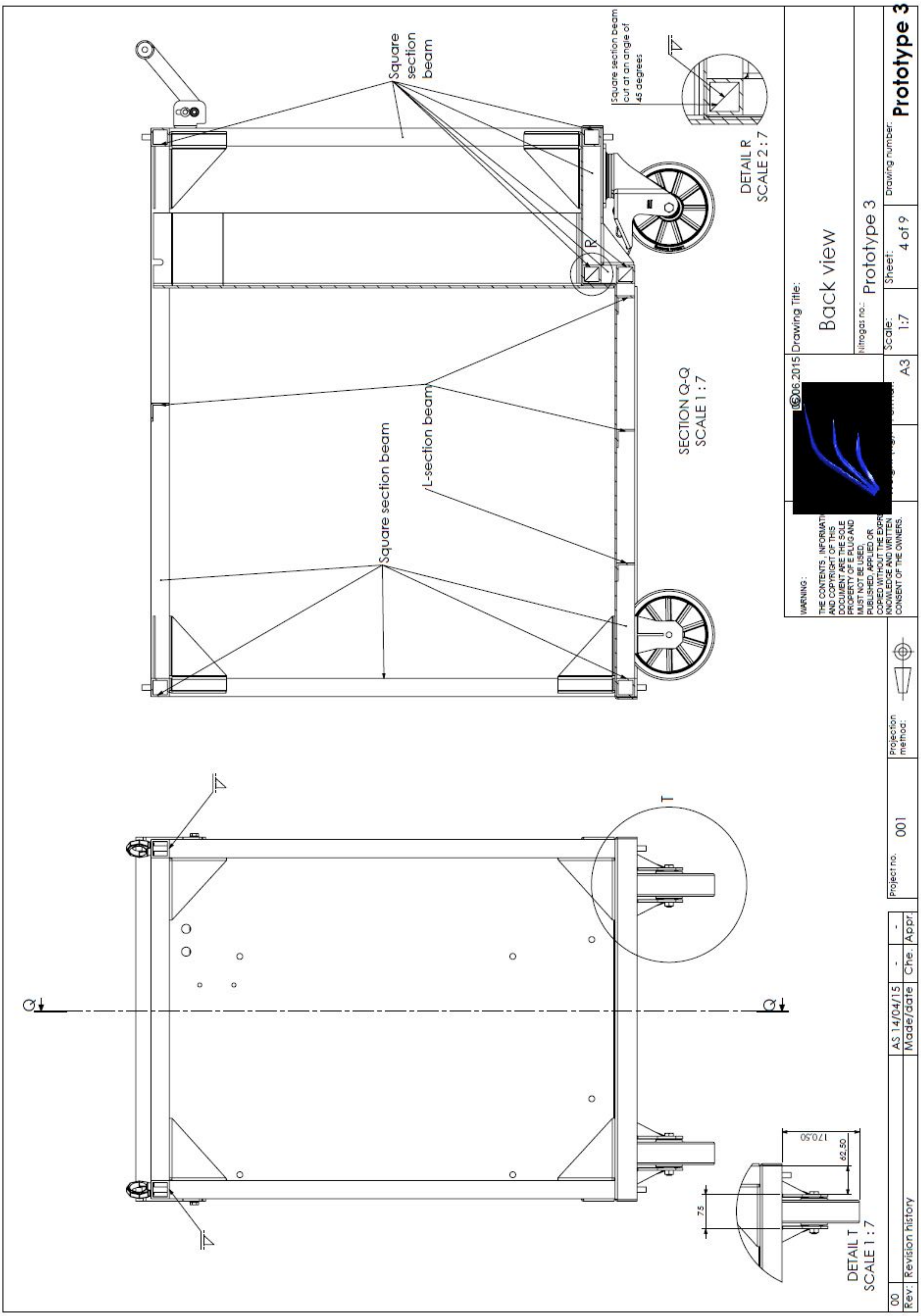

Figure 101: Prototype 3 - Back view

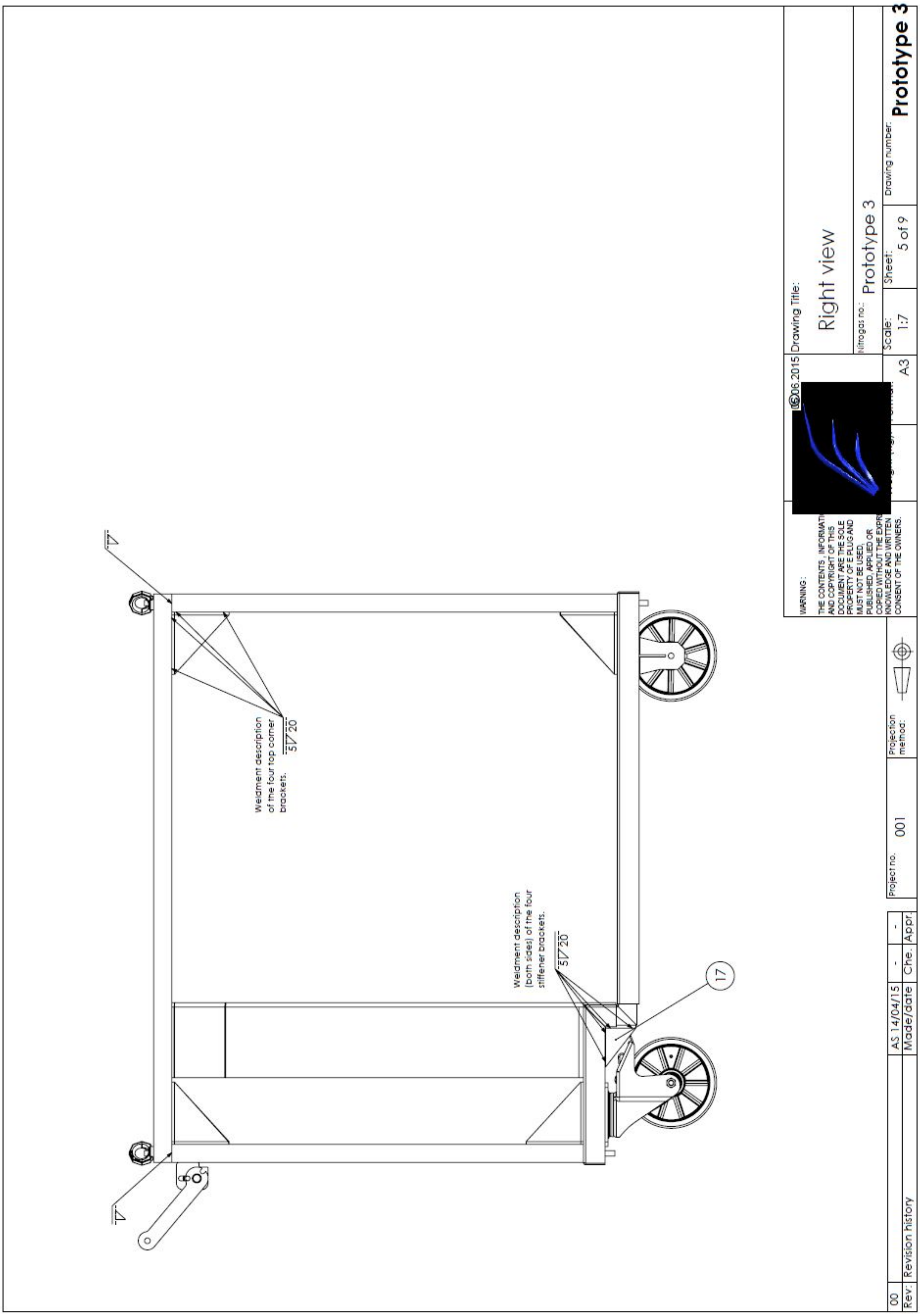

Figure 102: Prototype 3 - Right view

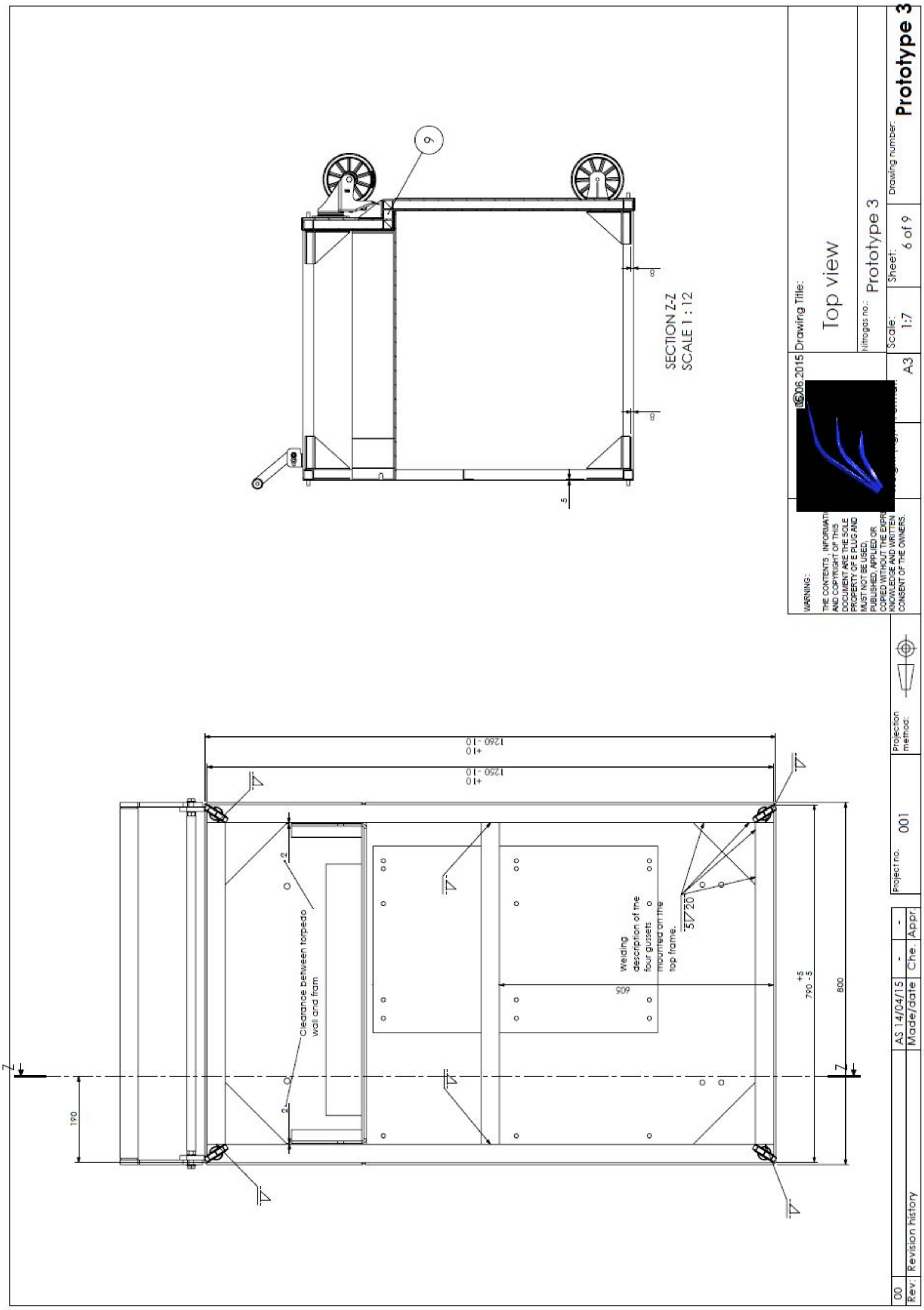

Figure 103: Prototype 3 - Top view

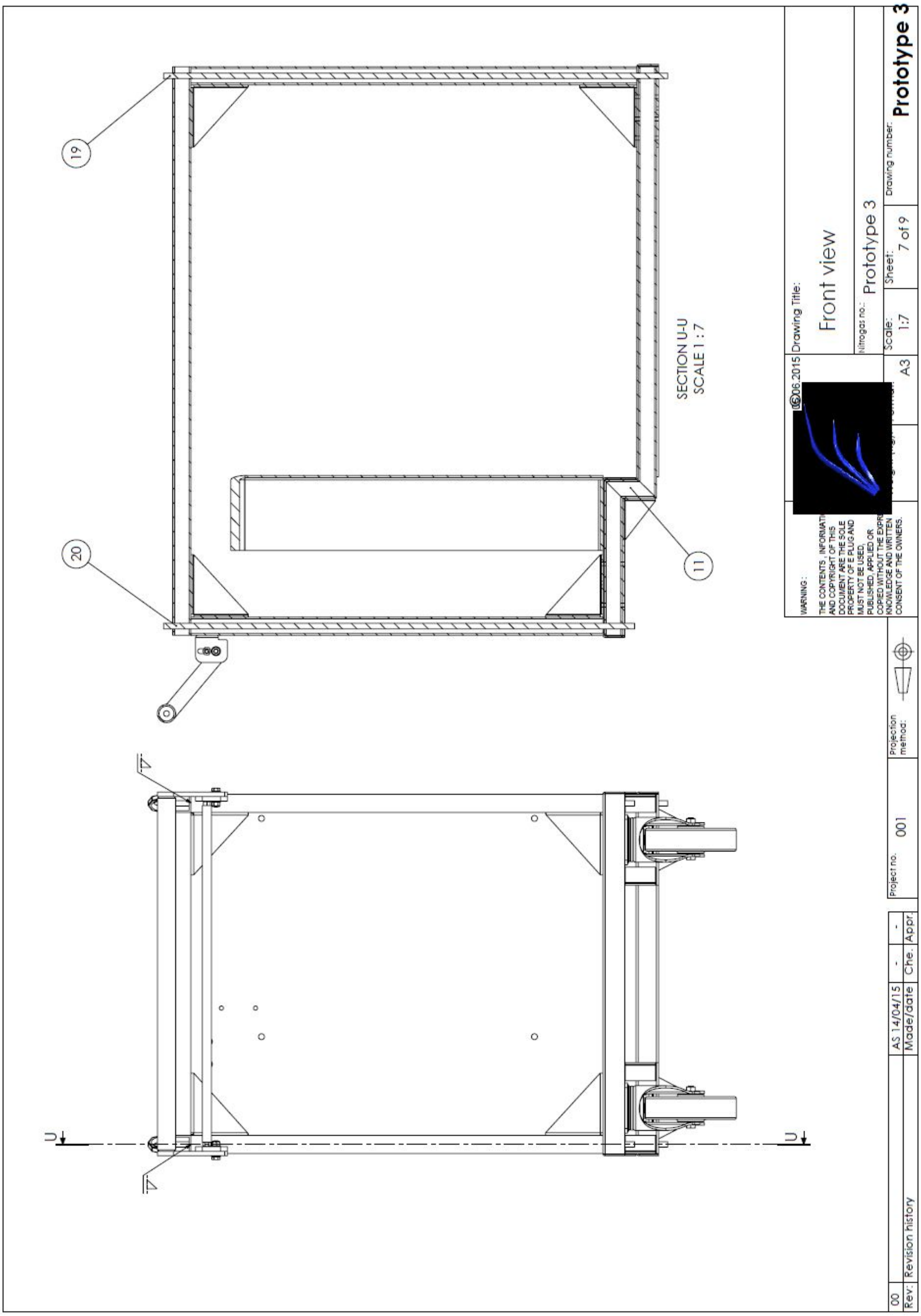

Figure 104: Prototype 3 - Front view

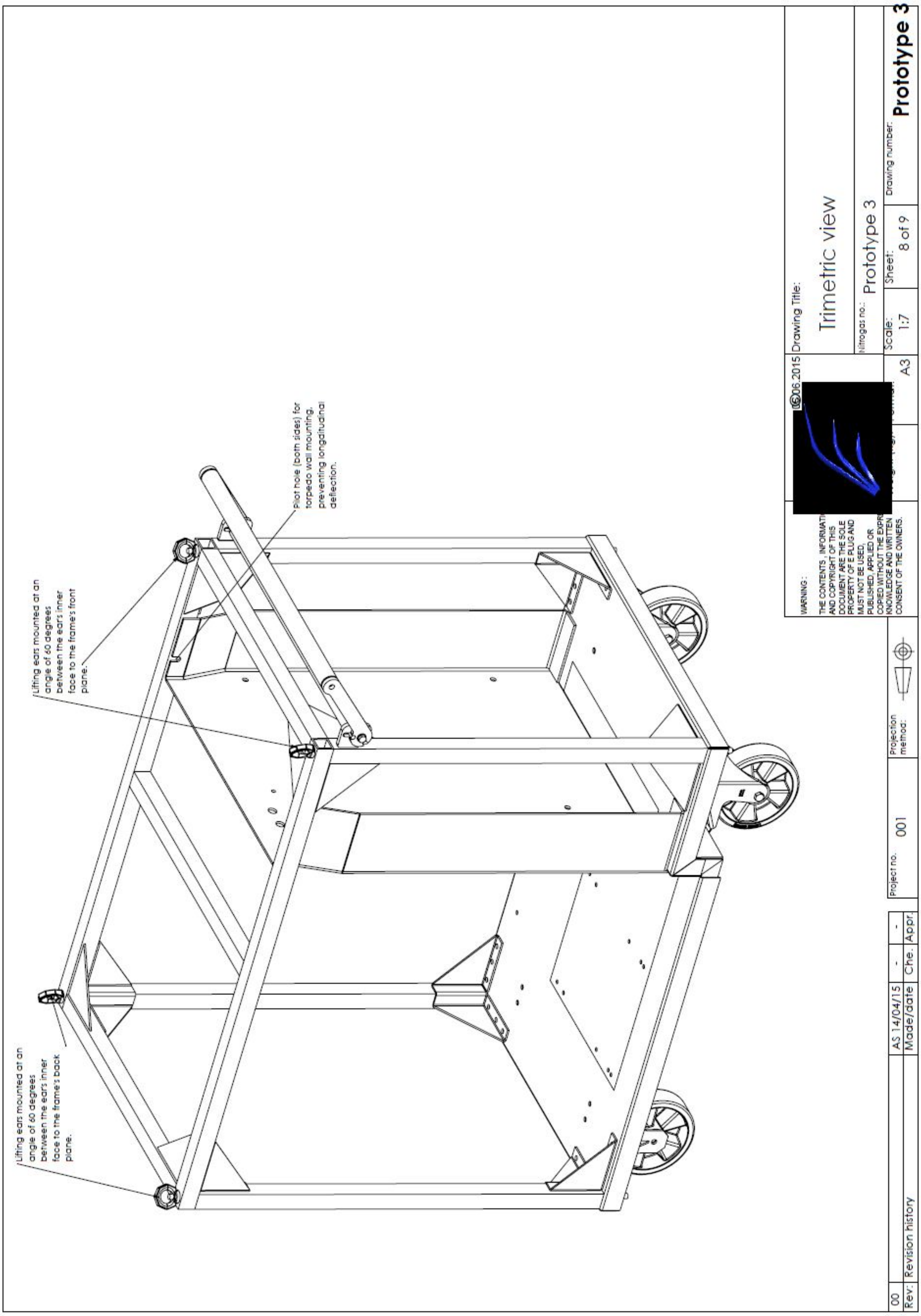

Figure 105: Prototype 3 - Trimetric view one

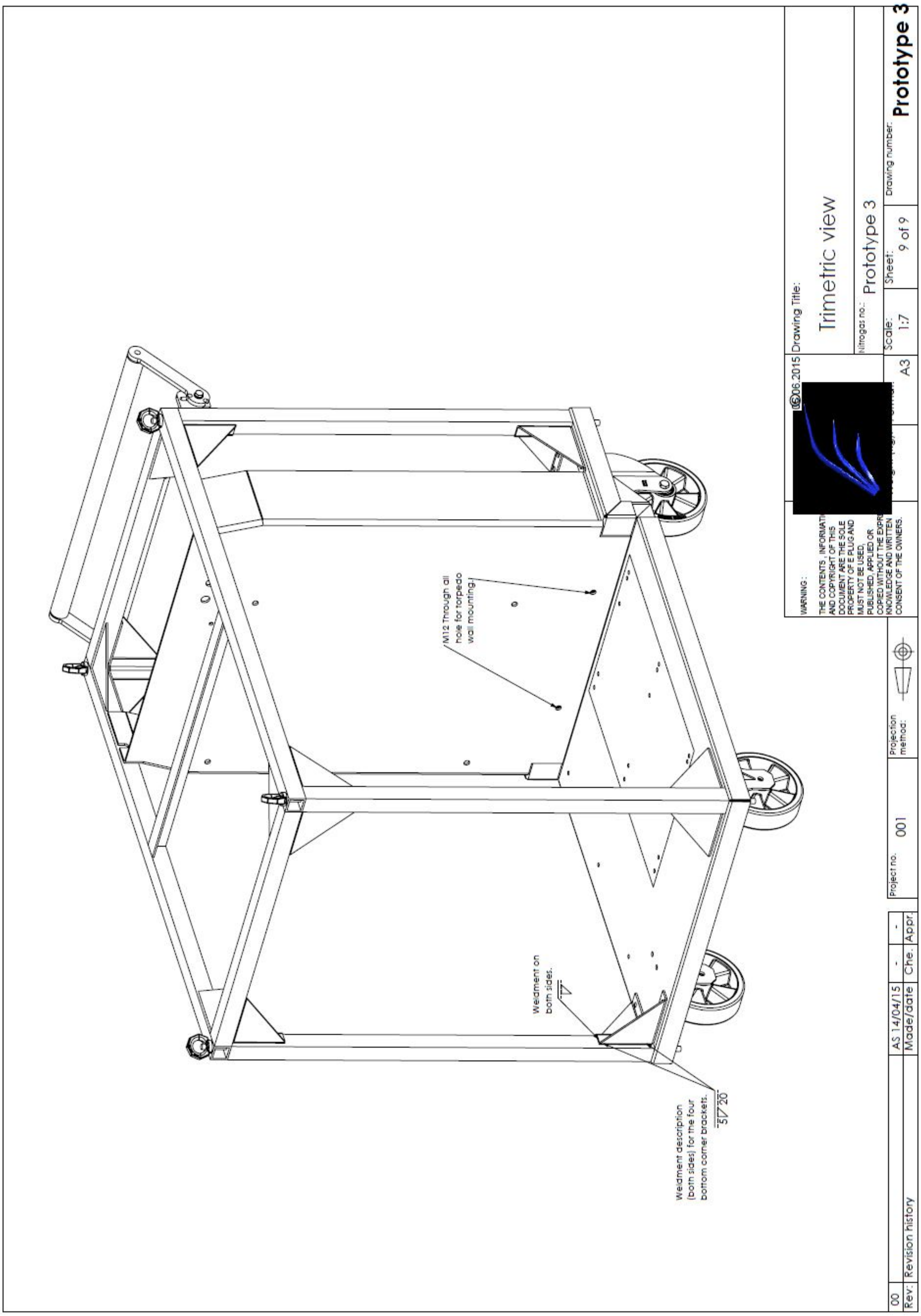

Figure 106: Prototype 3 - Trimetric view two