UNIVERSIDAD DE VALLADOLID

ESCUELA DE INGENIERIAS INDUSTRIALES

Grado en Ingeniería Mecánica

Design and development of a kayak trailer

Autor:

Andrés Rubio, Sergio

Carmen Quintano

Hochschule Magdeburg - Stendal

Valladolid, marzo, 2018.

TFG REALIZADO EN PROGRAMA DE INTERCAMBIO

TÍTULO: Design and development of a kayak trailer

ALUMNO: Sergio Andrés Rubio

FECHA: 28/03/2018

CENTRO: Campus of Magdeburg

TUTOR: Prof. Dr.–Ing. Christian-Toralf Weber

Resumen y palabras clave

El propósito de este Trabajo Fin de Grado (TFG) es diseñar y desarrollar un remolque para canoas. Dicho remolque tiene la particularidad de que puede transportar hasta 18 canoas de forma segura y que además puede ser cargado y descargado fácilmente y sin necesidad de una escalera. El concepto inicial del remolque fue diseñado en una tesis anterior de la misma universidad. La tarea fue encargada por una compañía alemana que organiza actividades con canoas en el río Elba. Se pretende que, partiendo del diseño inicial, el remolque pueda ser fabricado y comercializado en un futuro.

El objetivo del presente trabajo es la creación de un modelo en CAD del remolque objeto de estudio, para lo que se ha utilizado el software de diseño asistido por ordenador CATIA V5.

Finalmente se realiza un análisis por el método de los elementos finitos (FEM) para comprobar la viabilidad de la estructura diseñada.

Palabras clave: remolque, canoas, acero, CAD, FEM

Abstract and keywords

The aim of the present thesis is to design and develop a kayak trailer. The main feature of the trailer object of the work is its capacity to transport up to 18 kayaks. In addition, kayaks can be loaded and unloaded on an easy way and without a ladder. The initial concept of the trailer was designed in another thesis from the same university. This work was proposed by the company "Feriendorf & Paddelabenteuer". Starting from the initial design, the intention is to manufacture and market the trailer.

The object of the work is to create a CAD model of the kayak trailer. This has been achieved with the use of CATIA V5.

Finally, a finite element analysis (FEA) was carried out in order to verify the performance of the structure designed.

Keywords: trailer, kayaks, steel, CAD, FEM

Table of Contents

List of Figures

List of Tables

Nomenclature

- Paddlebox: part of the kayak trailer with shape of box, placed on the chassis that allows transporting paddles and other accessories for kayaks.
- Boatbox: each of the two structures of steel bars that support kayaks.
- Rib: part of the boatbox made of a curved beam that joins with the paddlebox. The reason of the name is the command used in CATIA for its 3D creation.
- Central frame: it is a vertical frame placed on the paddlebox, which supports boatboxes by means of cables during loading and unloading. During driving, it keeps boatboxes closed by buckles.
- Side frames: are placed on the paddlebox on both sides of the central frame and support kayaks.

List of symbols

Symbol	Description	Unit
V	Volume	mm^3
m	Mass per meter	kg/m
M	Mass	kg
l	Length	mm
ρ	Density	kg/mm^3
σ	Stress	MPa

1. INTRODUCTION

The process of construction of a product is complex and requires a collective work of many disciplines. One of these disciplines is engineering. Engineering is the creative application of scientific principles to design, develop, construct or operate structures, machines, manufacturing processes or other works. The present thesis is an example of how does engineering take part of a manufacturing process, especially in the tasks of design.

Methodology and resources to carry out the process of design of a product have involved and improved during the last 50 years with the development of computers and software. Especially, manufacturing has been influenced by CAD software. Computer-aided design has become an important tool for engineers, which provides benefits such as lower product development costs and a greatly shortened design cycle.

The process of design of this trailer requires knowledge about steel construction because it is the main material used to manufacture it. Its good mechanical properties and low cost make steel the world's most important engineering and construction material. Steel applications cover a wide range of fields. It is a major component used in construction of buildings but also is very common in other fields such as automobile engineering.

The engineering design process is a series of steps that guides engineers as they solve problems. The design process is iterative, meaning that engineers repeat the steps as many times as needed, making improvements along the way as they learn from failure. [1]

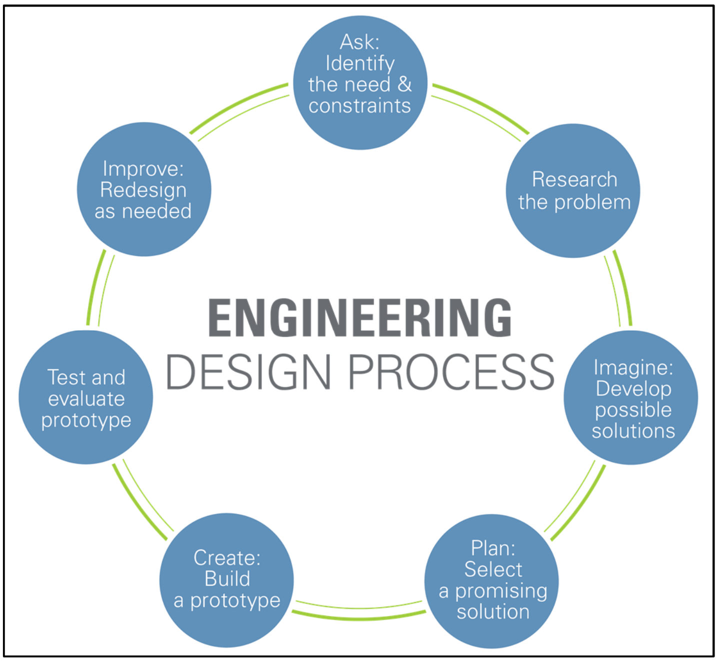


Figure 1. Engineering design process [2]

Design and development of a new product is a recurrent topic in final thesis of engineering. An engineer must be able to apply his knowledge in the elaboration of a project such as the design and development of a product or system. The present work is about this topic focused on a new model of kayak trailer.

1.1. Problem statement

The corporation “Feriendorf & Paddelabenteuer”, which is dedicated to organizing different activities on the Elbe, was interested in the creation of a kayak trailer with a large cargo capacity. The main complication to get this purpose is solving the problem with the height and the difficulty to load and unload kayaks on the trailer. For that reason, they proposed to design and develop a prototype that complies with these requirements. The company mentioned provided data about kayak models and types of frames used to transport them. This exercise was the topic of a final thesis carried out by two students of the Hochschule Magdeburg – Stendal and it was incomplete.

The present work is based on the mentioned thesis. The task to be done consists of creating a 3D model as part of the design of the kayak trailer. Starting from the initial design it is necessary to take decisions and change some aspects of the original idea in order to improve it. The final purpose of the creation of this model is to make the trailer manufacturable. Therefore, the model must be analysed by simulations to prove its performance.

After the process of design, manufacture would be carried out by “Arco-Trailer GmbH”, a German company specialized in the manufacture and marketing of trailers. Arco-Trailer provides data about steel commercial profiles used in the construction of the chassis and other parts of their kayak trailers.

Despite the fact that the main task is the creation of a CAD model, this thesis does not include the process carried out in CATIA V5, but it deals with the topic of the work from the point of view of construction. Nevertheless, pictures obtained from CATIA V5 as well as the drawings of the trailer are included in order to make the understanding of the explanation easier.

1.2. List of demands

As it mentioned above, the company “Feriendorf & Paddelabenteuer” proposed the design of a new model of kayak trailer. They provided a list of demands with the purpose and requirements of this trailer:

Purpose:
• Constructive solution for a kayak trailer with a cargo capacity of 18 kayaks and easy loading and unloading of kayaks between 2 people without ladder
Geometry:
• Length of the trailer: approx. 5500 mm • Width of the trailer: approx. 2400 mm • Permissible max. height: 3.6 m • Permissible max. width: 2.5 m
Requirements:
• Safe driving on the highway • Safe transport of kayaks on the trailer • Support the weight of at least 18 kayaks • Good handling system for 2 people • Cost-effective production

Table 1. List of demands

In addition, they supplied data about kayaks models used in their activities:

“Sunny classic” model		
Length/width (mm)		Weight (kg)
4250/830		31
“Summerwind classic” model		
Material	Length/width (mm)	Weight (kg)
Classic	4950/830	39
Touring	4950/830	40.5

Table 2. Kayak models

Data provided by “Feriendorf & Paddelabenteuer” about types of frames used to transport kayaks were used to design compartments of the boatboxes.

2. STATE OF THE ART

In view of the need to transport goods and the limitation of space in cars and other automobiles, trailers were conceived and developed as vehicles with the ability of transport merchandise. Over the years, engineering have played a leading role in the process of evolution of vehicles and in particular of trailers. Advances in technology and new needs of the society have driven this development. Nowadays there is a wide range of types and models according to current needs.

The European Conference of Ministers of Transport (ECMT) defined a trailer as "a vehicle without own propulsion to transport goods, intended to couple with an automobile, except semi-trailers". [3] The difference between a trailer and a semi-trailer is that a semi-trailer has not a front axle. A large proportion of its weight is supported either by a road tractor or by a detachable front axle assembly known as a dolly. [4] In order to couple the trailer with the car, trailers incorporate a tow bar. Tow bars transmit the forces of traction from the automobile to the trailer. There are different types of tow bars according to the type of both vehicles (automobile and trailer). In the European Union, tow bars must be a type approved to European Union directive 94/20/EC.

In Germany, trailers are named and defined according to DIN 70010 (System of road vehicles; vocabulary of power-driven vehicles, combinations of vehicles, towed vehicles). This is done in accordance with ISO 3833 (Road vehicles – Types – Terms and definitions). Trailers must comply with the standards included in the Road Traffic Licensing Regulation in Germany (StVZO). Vehicle measurements, weight and loads and other features cannot exceed the maximums that includes that legislation.

Trailers are very popular vehicles in Germany. At the present time, there is a wide range of types of trailers according to their use. They are used both for private uses and in construction sectors. In the current market can be found a lot of trailer models from different manufacturers.

Some of the most popular types of trailers are the following:

- Trailers for machinery: special trailers for transporting light and medium-weight construction machinery. This type of trailers usually have two ramps for an easier load of the machines on the trailer. They are normally used in the construction sector.

Figure 2. Trailer for machinery [5]

- Domestic trailers: is the most popular type of trailer. It is very common to see a car with one of this trailers. They are light and versatile, suitable for carrying some furniture, accessories for the car, tools, etc. They can also be covered with a tarpaulin to protect the goods from the elements (wind, rain, humidity...).

Figure 3. Domestic trailers [6]

- Trailers for vehicles: used to carry small and medium sized vehicles like bicycles, motorcycles and even cars. Vehicles must be correctly fixed to the trailer for safety reasons. They are provided of ramps to load the vehicles and some models can tilt its platform automatically.

Figure 4. Trailers for vehicles [7]

- Dump trailers: thanks to hydraulic cylinders, these trailers can tilt their box backwards and sideways. They are mainly used in the construction sector.

Figure 5. Dump trailers [8]

- Horse trailers: are designed to transport horses safely. Their appearance is completely different to the other trailers because they need a design that allows transporting a horse in an efficient way. It must be covered to protect the horse and that entails a design of the trailer body. Despite its size, an aerodynamic design is sought to reduce fuel consumption.

Figure 6. Horse trailer [9]

- Boat trailers: this group covers all the trailers that allow transporting different types of boats, from surfboards or canoes to sailing boats or motor boats. There is a variety of models according to the boat that is going to be transported.

Figure 7. Boat trailer [10]

To the group of boat trailers belongs the object of the present work, which is a kayak trailer. Kayak trailers are designed to transport usually more than one kayak. The weight and the space available are not a problem because kayaks are light and relatively small, but their instability and the number of kayaks that is going to be transported require a special design.

Figure 8. Kayak trailers [11]

Kayaks are usually supported by load bars on both sides of a frame. It is also necessary to tie the kayaks to the bars in a safe way. The existing kayak trailers in the current market usually have a cargo capacity from one or two kayaks to ten or even twelve. There are few models with a greater capacity. The capacity is the most influential factor of the appearance of the trailer because it determine its size, weight and structure. Furthermore, some trailers can be provided with a box to transport paddles or other accessories, which usually is placed on the chassis.

One limitation in the number of kayaks that a trailer can transport is the height and the problems that entails, like more instability of the trailer and difficulty in loading and unloading kayaks. The trailer object of this work was devised to have a cargo capacity of 18 kayaks and designed to avoid these problems.

3. OBJECTIVES OF THE WORK

3.1. Aim

The objective of this project is to design and develop a kayak trailer. The concept of the trailer was conceived previously by two students of the Hochschule Magdeburg – Stendal as topic of their final thesis. The scope is to improve the manufacturability of the trailer designed with potential for a future market introduction.

In order to improve the design of the trailer have been taken decisions to modify some aspects of the original idea. This has been achieved with the help of CAD software. A 3D model of the trailer was created using CATIA V5. Once the model was made, simulations were carried out with ANSYS to analyse the structure and performance.

The objective of this thesis is not to explain the process carried out in CATIA but to describe the parts of the trailer and their functions from the point of view of the construction.

3.2. Description of the trailer

The trailer object of the present work has a cargo capacity of 18 kayaks, more than most of the kayak trailers in the current market. Capacity is its main advantage compared to other models. Nevertheless, this feature entails some difficulties in the design of the trailer. In the first place, the dimensions of the trailer must not exceed the maximum dimensions allowed. Most of the trailers with a similar capacity have a problem with the height. Due to the height of the trailer, it is necessary to use a ladder to load and unload kayaks and more than one person. In order to solve this problem in this kayak trailer, has been designed a mechanism with pulleys and cables that allows to roll down the compartments of the kayaks to load and unload easily the kayaks that are on top of the trailer. Height also involves a problem related to the instability of the structure. The large cargo capacity and the instability involved by the height require a special design that provides security to the trailer while driving.

In addition to loading and unloading, transport must be considered. The structure of the trailer and its compartments must be able to support the load and protect kayaks during driving. For the construction of the trailer steel has been chosen as material for its good mechanical properties. The structure of the kayak trailer is mainly built by steel tubes of rectangular or square section.

As the rest of vehicles in Germany, the trailer designed in this thesis must comply with the StVZO. Therefore, these legal requirements such as security elements and maximum dimensions must be considered in the process of design and development.

3.3. Description of the model

The 3D model created in CATIA V5 represents the structure of the kayak trailer. On the one hand, the trailer has been created with the least possible simplifications. It includes small mechanical components such as screws, bolts, washers and cotters according to the standards. Steel frames are made of beams with commercial profiles. On the other hand, this model does not include some elements of the trailer such as the wheels and their axle, the pulleys mechanism, lights or brakes. In fact, a CAD model of a trailer does not require to include these kind of elements. The main scope of the creation of a CAD model is to use it in order to simulate the performance of its structure. If the design of the model is satisfactory, it is pretended to use this model for a future manufacturing of the kayak trailer.

Pictures obtained from the model are included in the work in order to facilitate the explanation of the different parts of the trailer.

4. METHODOLOGY

Nowadays the majority of product design processes need the support of computer programs. This work is an example of this. In order to design the 3D model of the kayak trailer object of the present work has been used CAD and FEM software. The 3D model was created with a CAD software, CATIA V5. This model was analysed by the finite element method with ANSYS software.

4.1. Computer Aided Design (CAD)

Computer aided design (CAD) can be defined as the use of computer systems to assist in the creation, modification, analysis or optimization of an engineering design. It involves any type of design activity, which makes use of the computer to carry out all those tasks.

There are many reasons for implementing CAD:

- To increase the productivity of the designer: CAD helps the designer to visualize the product and its component sub-assemblies and parts. This reduces the time required to synthesize, analyse and document the design.
- To improve the quality of design: a CAD system permits a thorough engineering analysis within a short time and a larger number of design alternatives can be investigated. Design errors are also reduced by the accuracy of the system.
- To improve communications through documentation: the use of CAD system provides better engineering drawings with more standardization, fewer drawing errors and greater legibility.
- To create a database for manufacturing: in the process of creating documentation for the product design much of the required database to manufacture is also created which can be applied for computer integrated manufacturing (CIM) application like computer numerical control (CNC) programming.

The CAD software consists of the computer programs to implement computer graphics on the system plus application programs to facilitate the engineering functions of the user. Modern CAD systems are based on interactive computer graphics (ICG), which denotes a user-oriented system in which the computer is employed to create, transform and display data in form of pictures or symbols. [12]

CAD is mainly used for detailed engineering of 3D models or 2D drawings of physical components, but it is also used throughout the engineering process from conceptual design and layout of products, through strength and dynamic analysis of assemblies to definition of manufacturing methods of components.

4.1.1. CATIA V5

CATIA is a multi-platform commercial software suite for computer-aided design, computer-aided manufacturing (CAM) and computer-aided engineering (CAE) developed by the French company Dassault Systemes. It is used to design, simulate, analyse and manufacture products in a variety of industries.

CATIA V5 is the CAD software used for creating the 3D model of the kayak trailer. In this process have been used different applications of this software, all of them contained in the Mechanical Design module:

- Sketcher: makes it possible for designers to sketch precise and rapid 2D sketches. These sketches are used to generate 3D mechanical parts by tools of the Part Design application.
- Part Design: this application makes it possible to design precise 3D mechanical parts of various complexities, from simple to advance.
- Assembly Design: its workbench allows assembling mechanical parts that make up a product. The different components of the trailer have been assembled with this application. In the process of assembly it is necessary to set several constraints to place correctly all the mechanical components and fix them together.
- Structure Design: it is an application enabling to create linear, curved structures and plates, using standard or user-defined sections and materials. This application has been used in order to create the steel frames of the trailer. It is possible to design a frame from a sketch or from a grid created in this application.
- Drafting: it is the application used to create drawings of mechanical components or assemblies. Its workbench provides a simple method to create and modify views on a predefined sheet. The drawings of the kayak trailer and some of its components have been created with this application. Drawings are an important part of an engineering project because they provide information about the product in order to manufacture it.

Figure 9. CATIA applications

4.2. Finite Element Method (FEM)

The finite element method (FEM) is a numerical method for solving problems of engineering and mathematical physics. For physical systems involving complicated geometries, loadings and material properties, it is generally not possible to obtain analytical mathematical solutions to simulate the response of the physical system. Analytical solutions generally require the solution of differential equations, which are usually not obtainable because of the complexity of the system.

The finite element formulation of the problem results in a system of simultaneous algebraic equations for solution, rather than requiring the solution of differential equations. These numerical methods yield approximate values of the unknowns at discrete numbers of points over the domain. This method divides a given domain into a set of simple subdomains (finite elements) interconnected at points common to two or more elements (nodes). The process mentioned is called discretization. [13]

The practical application of this method is known as finite element analysis (FEA). FEA is applied in engineering as a computational tool for performing engineering analysis. It includes the use of mesh generation techniques for dividing a complex problem into small elements, as well as the use of software program coded with FEM algorithm.

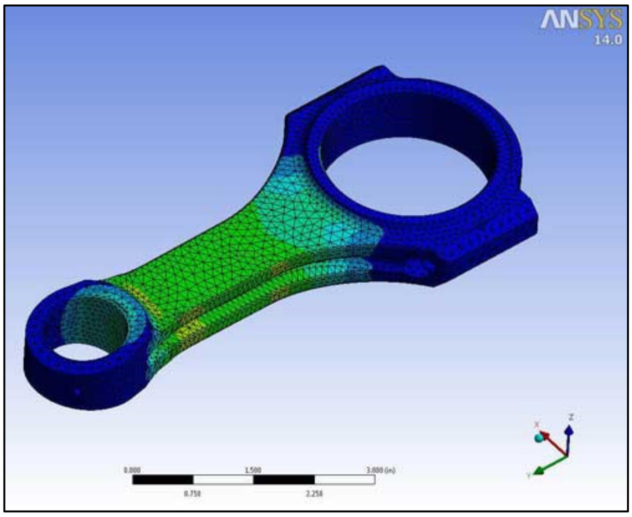


Figure 10. Example of FEA [14]

Figure 10 shows an example of finite element analysis in ANSYS software. The software creates a mesh that divides the mechanical part object of simulation into small elements. Each of these elements is analysed independently. The results of the simulation can be visualized thanks to the colours. Colours indicate the different degree of magnitude of a physical property or effect.

4.2.1. ANSYS

ANSYS Workbench is a finite element analysis software developed by the company ANSYS, Inc. and used to simulate engineering problems. The software creates simulated computer models of structures, electronics, or machine components to simulate strength, toughness, elasticity, temperature distribution, electromagnetism, fluid flow, and other attributes. A user may start by defining the model object of the analysis and then adding materials, loads and other physical properties. Finally, ANSYS software simulates and analyses movement, fatigue, fractures and other effects.

The ANSYS application used in the present work was Static-Mechanical Analyse.

5. DESIGN

5.1. Structure and construction of the trailer

The trailer object of the present work has a structure made up mainly of steel bars. In the process of fabrication of the trailer are used steel profiles according to DIN 2395 – 1 or EN 10305 – 5 (Steel tubes for precision applications - Technical delivery conditions - Part 5: Welded cold sized square and rectangular tubes).

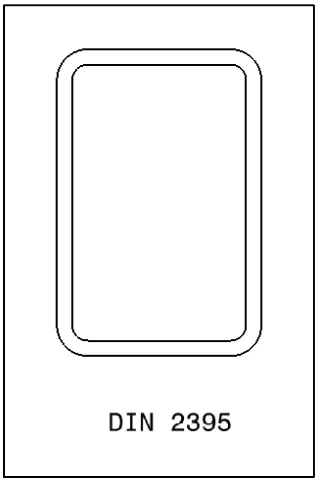


Figure 11. Cross section

Figure 11 shows this type of section. The external radius has a value of 2*t, where “t” is the thickness of the section. The internal radius has a value equal to the thickness. All the profiles used in the trailer have a thickness of 3 mm.

Steel tubes are suitable for trailers and other constructions of the automotive sector because of their good performance against torsion and bending forces, as well as their lightness.

Steel beams are joined together by welding process. In steel construction, welding is the method most used to join beams. In addition, steel tubes used as beams are also manufactured by welding. Welding is a manufacturing process that joins materials, usually metals, by a heat transfer that causes fusion. There is a great variety of types of welding with different methods and applications. One of them is MIG welding, where MIG stands for "Metal Inert Gas." The technical name for it is "Gas Metal Arc Welding" (or GMAW). It is an arc welding process in which a continuous solid wire electrode is fed through a welding gun and into the weld pool, joining the two base materials together. A shielding gas is also sent through the welding gun and protects the weld pool from contamination. [15] GMAW is one of the most popular welding methods, especially in industrial environments. It is used extensively by the sheet metal industry and, by extension, the automobile industry. Therefore, MIG welding is a suitable process for the construction of the trailer.

The kayak trailer has a complex structure and it is necessary to differentiate several parts, which are built separately and have specific functions. After building each part, all of them are assembled to form the trailer.

5.1.1. Chassis

A chassis is the framework that a vehicle is built on. It is a rigid structure that forms a skeleton to support the components and body of the vehicle. It also has the function of withstand static and dynamic loads, like the weight of the vehicle and other forces acting during driving. These forces are absorbed and transmitted to the chassis. The frame is made of steel sections so that it is strong enough to withstand the load and at the same time is light in weight to reduce dead weight on the vehicle. The trailer frame is made of steel box sections. This type of steel section is good in bending and torsion.

The chassis frame of the trailer is a conventional frame, also known as non-load carrying frame. This type of frame is not much suited to resist torsion. Use of tubular or box sections improve the torsional strength. [16]

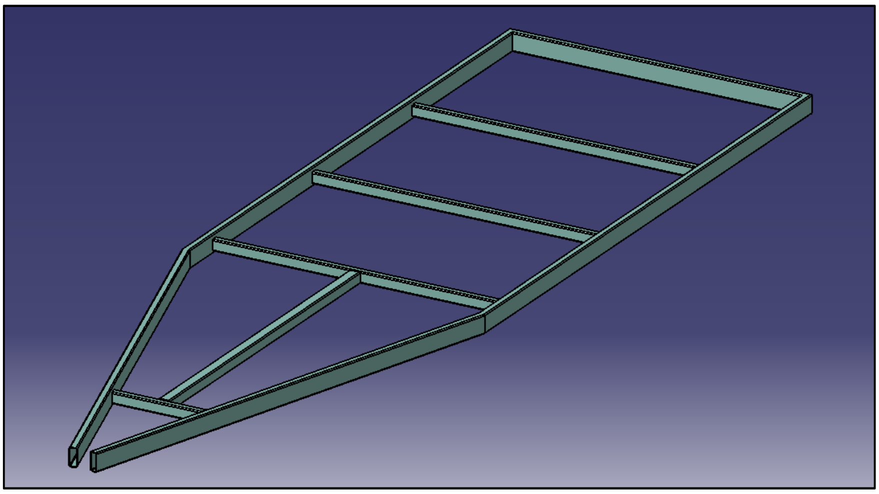


Figure 12. Chassis

The profiles that are used in the frame are the followings: 100x40x3, 60x40x3 and 60x60x3. Rectangular tubes are arranged so that the direction of the vertical load coincides with that of the highest moment of inertia for a better resistance to bending. For this reason profiles 100x40, which have a high moment of inertia, are used for exterior beams and they withstand most of the bending forces. Profiles 60x40 and 60x60 are used for cross members to increase the torsional rigidity of the frame. The complete frame is fabricated by the welding process.

The section of each beam of the frame is represented in Figure 13.

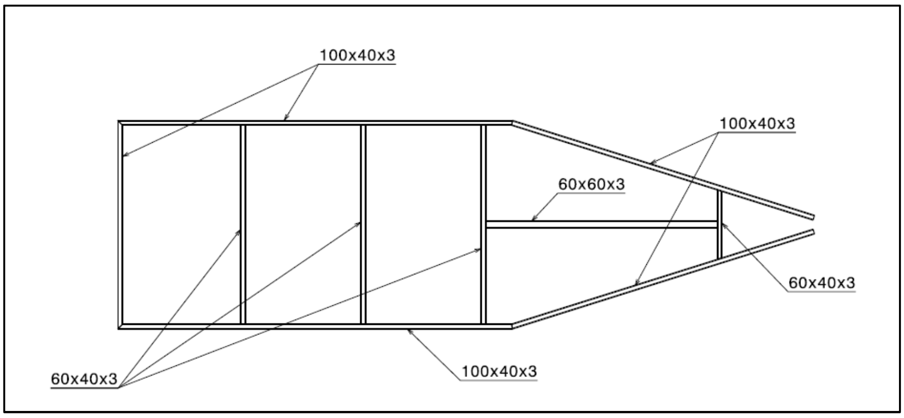


Figure 13. Profiles used in chassis

5.1.2. Paddlebox

On the chassis was designed a box with the function of carrying kayak paddles or something else. Furthermore, this part works as the joint between the chassis and the rest of the trailer. This box has been called as “paddlebox”.

The paddlebox consists of a frame and four plates of steel that shape the box. The frame is made up of steel bars with profile 40x40x3. It is composed of four horizontal beams that delimit the box and ten vertical beams that support the other four. All the beams are welded together. Steel plates have 15 mm of thickness and they have two different sizes. Two of them are 1680x340 mm and the other two are 2910x340 mm.

Steel plates are joined to the frame with screws. The type of screws chosen are self-drilling screws with washer rounded head like the figure, according to DIN 7504. They have a length of 19 mm and a diameter of 4.2 mm. These screws are made of galvanized steel and drill their own holes as they are driven into the material without pre-drilling. Therefore, it is not necessary to make holes on the plates before putting the screws and they are created while drilling.

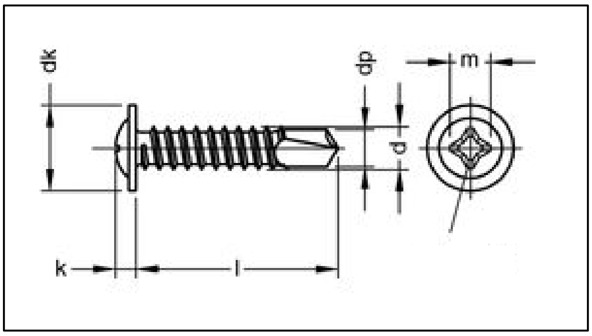


Figure 14. DIN 7504 screws [17]

The paddlebox is joined to the chassis by welding between both frames. Vertical beams of the paddlebox frame are welded to the chassis by their base.

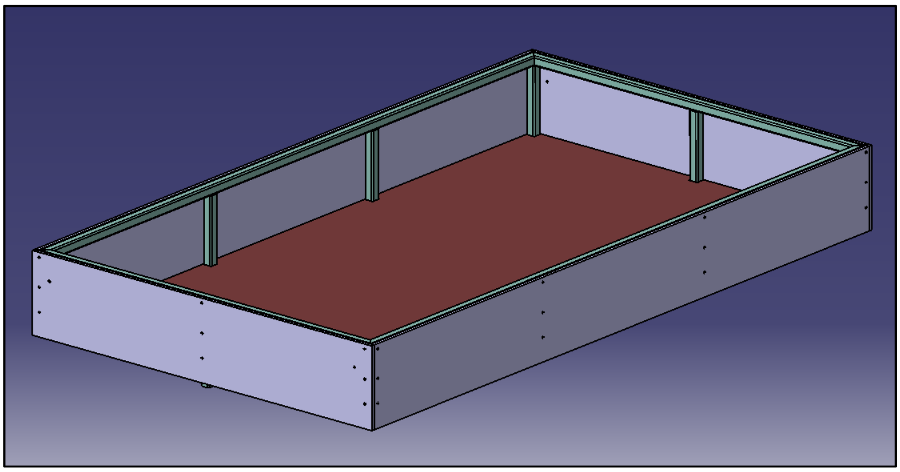


Figure 15. Paddlebox

5.1.2.1. Plywood plate

The floor of the box consists of a plywood plate 18 mm thick with a coating of phenolic resin. This plate is composed of at least three layers. These are glued and pressed with high pressure and heat. The surface that works as floor of the paddlebox is rough, anti-skid and waterproof. It is very common to find this type of plate in trailers and trucks with this application because they are weatherproof. [18]

Figure 16. Plywood plate [19]

Figure 17 shows this plate created in CATIA in order to form the floor of the paddlebox. Its outline is due to the vertical bars of the frame.

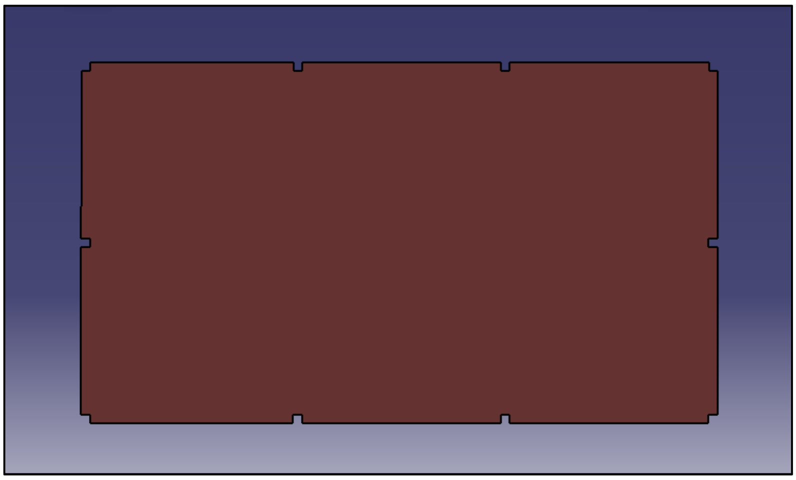


Figure 17. Paddlebox floor

5.1.3. Central frame and side frames

On the paddlebox are placed three frames of steel bars, built by welding process. Two of them are equal and are on both sides of the other frame. These frames are called "side frames". The other frame is called "central frame".

Central frame is a vertical and large frame made of three 100x40x3 steel beams. It supports boatboxes by means of cables during their movement for loading and unloading kayaks. In addition, central frame has buckles to limit cables movement.

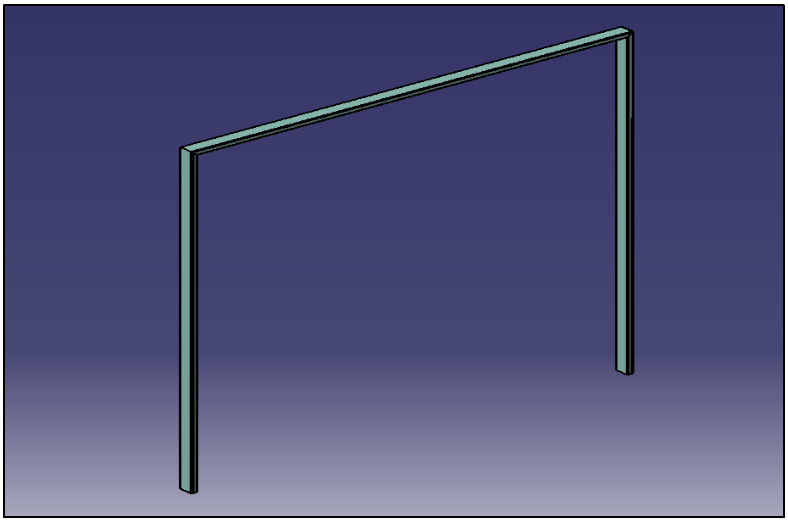


Figure 18. Central frame

Side frames are composed of five 40x40x3 steel beams. These frames have the function of supporting the first level of kayaks. On this level are supported up to six kayaks. The open ends of the frame bars are closed by plugs of plastic. There are commercial types of plugs for different profiles of beams.

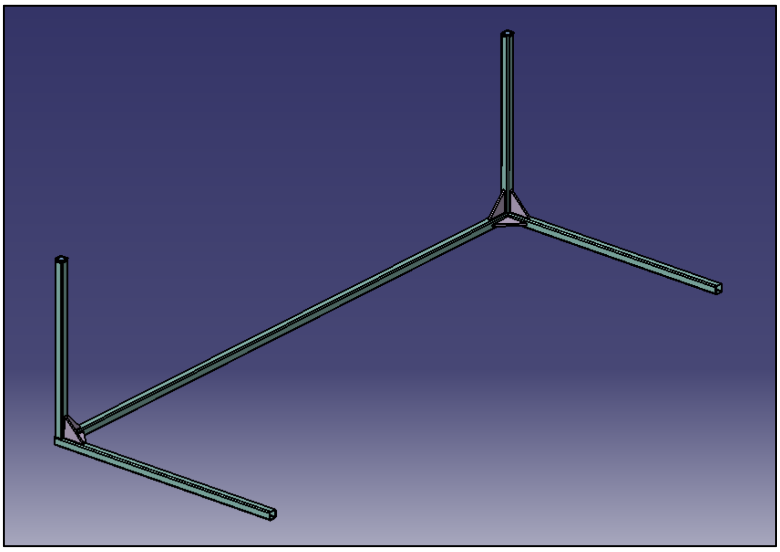


Figure 19. Side frames

5.1.3.1. Brackets

Brackets are elements often used in steel construction. They are pieces of steel or metal sheet (normally with triangular shape) that are welded to plates or beams to reinforce the joint with other beams, forming a right angle.

Physically, the most important function of a bracket in a structure is that it ensures the point-to-point coincidence of the medium lines of the beams. These elements are used in the points of joint between bars of the side frames, called nodes. They are made of steel, with triangular shape and 10 mm thick. They are welded to the bars to give more stability to the joint.

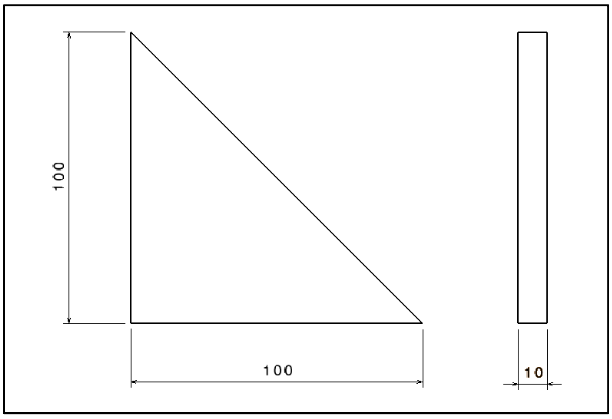


Figure 20. Bracket

5.1.4. Boatboxes

The part of the structure responsible for transporting kayaks is called "boatbox". There are two boatboxes that are able to transport up to six kayaks each one. Their structure consists in steel bars with profiles 60x20x3, 40x20x3 and 20x20x3. These bars form the compartments to transport kayaks. Boatboxes are an important part of the kayak trailer because of their two main functions. On the one hand, boatboxes support most of the kayaks transported by the trailer. Their structure must support the weight of the kayaks and be as light as possible. Compartments design must consider kayaks dimensions and are based on data provided by "Feriendorf & Paddelabenteuer". On the other hand, boatboxes are not fixed parts, but they can rotate with respect to the paddlebox. This movement solves the problem with the height and allows an easy load and unloading of the kayaks on the trailer. When the boatboxes are in position to load and unload kayaks it is said to be "open", while they are "closed" during driving.

The first step in the construction of boatboxes is building the frontal frame. It defines the compartments of the kayaks and the profile of the boatbox. For the external-side beam is used 60x20x3 profile and the frame of compartments is made of 40x20x3 profile. To separate the compartments have been used 20x20x3 bars. The reason of the use of different profiles is the different magnitude of loads that each beam must withstand. Horizontal beams that define the two levels of kayaks have the function of withstanding the weight of kayaks because they are supported directly by them. These beams are arranged so that the direction of the weight of kayaks coincides with that of the highest moment of inertia for a better resistance to bending. Bars with 20x20x3 profile basically only have the function of defining the compartments for the kayaks. Therefore, these bars withstand less loads than the rest of beams and they do not require such a strong profile.

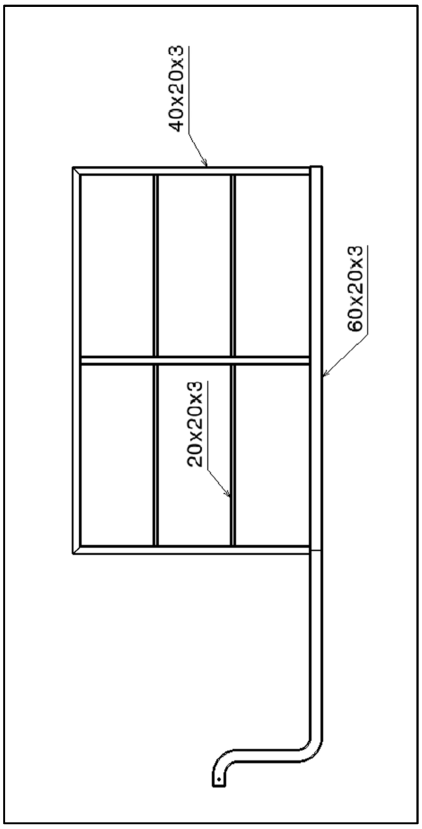


Figure 21. Frontal frame of boatbox

5.1.4.1. Ribs

Boatboxes include an important part that requires a special design. There is a curved beam assembled to the frontal frame that has the function of joining the frames of the boatbox with the rest of the trailer. These curved beams are named as “ribs”. Ribs are made of profile 60x20x3 and have a hole of 10 mm diameter in order to form the paddlebox-boatboxes joint. This hole also set the axis of rotation of the boatbox.

Rib shape requires a special design for some reasons. In the first place, it is necessary to avoid collisions with paddlebox and chassis during boatbox movement. Moreover, this movement cannot intercept with the kayaks supported by the side frames. In addition, the height from the ground to the chassis must be considered because of the boatbox position when it is open. In order to solve these problems, the design of this part has been modified respect the thesis that the present work is based on.

The following figure shows the comparation between the first design of the rib and the new one.

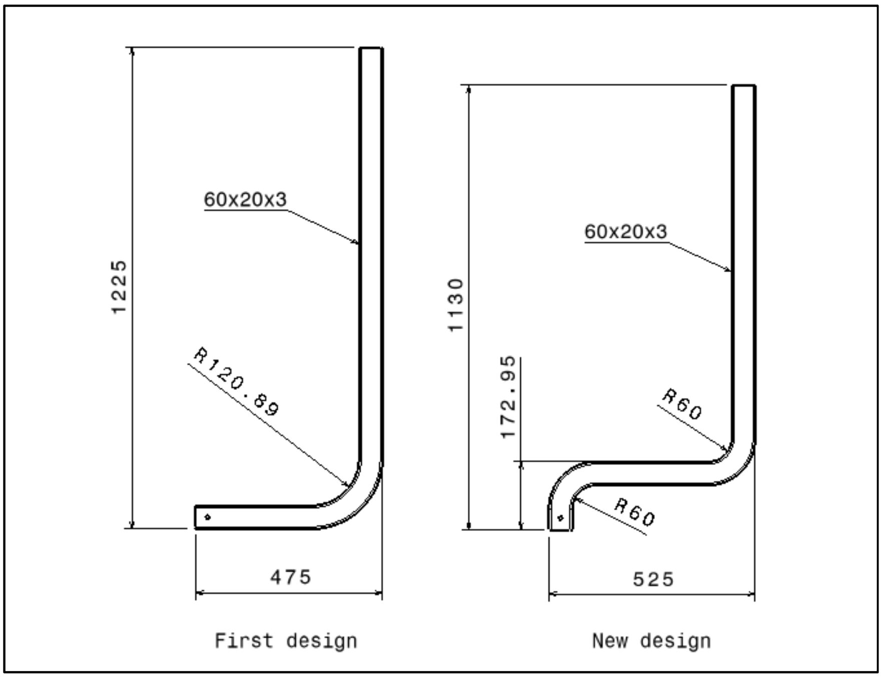


Figure 22. Redesign of the rib

Two frontal frames are joined with 40x20x3 beams to form boatbox body. These beams are arranged with their highest moment of inertia as vertical direction, in the same way that the horizontal beams of the frontal frame that support kayaks. Kayaks are not supported directly by these beams but they also withstand their weight. In addition, three beams are assembled on the external side of the boatbox to increase security and avoid possible falls of kayaks. Other function of these bars is related with the mechanism designed to open and close boatboxes. These bars are made of 20x20x3 steel tubes. The design and the profiles used for the security bars are not definitive. These aspects can be discussed in the future because they depend on the mechanism that allows to open and close boatboxes. In the original design this mechanism was made up of pulleys and cables and the bars mentioned were connected with these cables. Nevertheless, this mechanism was not developed in detail and can be discussed in the future. At first sight, it would be a better solution to connect the cables of the mechanism with both frontal frames for a better stability when boatboxes open.

In the present work the mechanism has not been considered and it is pending for the future.

Figure 23 shows a boatbox after assembling the mentioned parts.

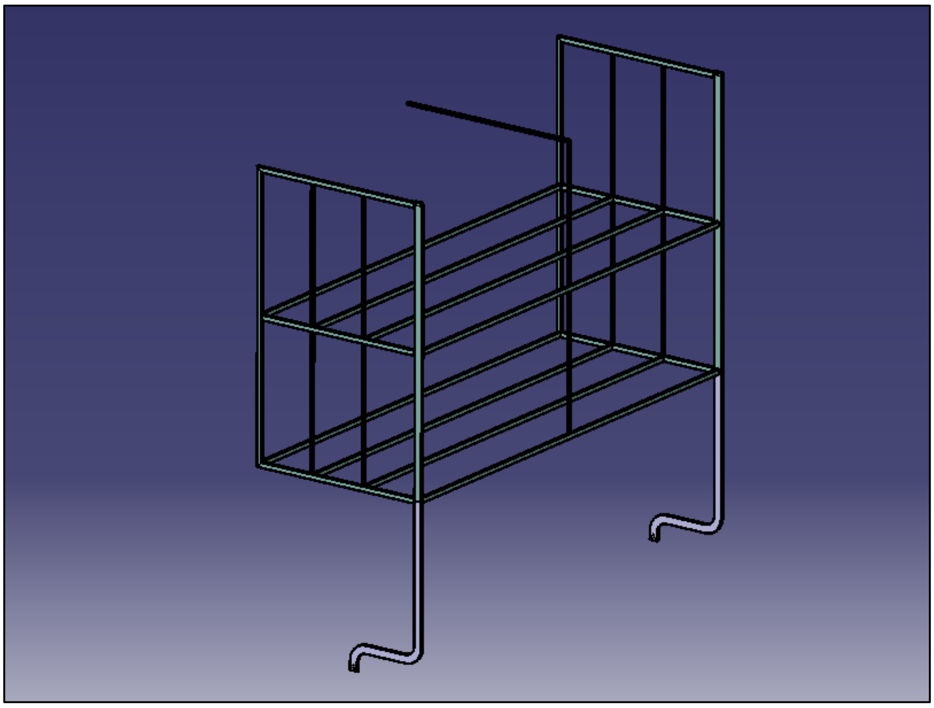


Figure 23. Boatbox

In comparison with most of the kayak trailers existing in the current market, the structure used to support kayaks is quite different. In other models, kayaks are only supported by two load bars, as seen in the pictures of the State of Art of this thesis. In the trailer object of the work, the load bars of the boadboxes are reinforced with the horizontal bars that join both frontal frames. This structure is more resistant and it is necessary in order to support such a high number of kayaks transported.

5.1.5. Paddlebox-boatboxes joint.

Boatboxes form a joint with the paddlebox with one degree of freedom. The only movement allowed is a rotation, which permits to load and unload boatboxes.

This aspect of the work has been modified respect to the thesis that is based on. In the original idea, there was a problem with the position of the boatboxes. They caused collisions with the chassis and the paddlebox during their movement. To solve this problem, has been designed a different procedure to join these parts of the trailer. Boatboxes are placed on the external side of paddlebox plates. In this way and considering the design of the rib explained in the previous section, collisions with other parts of the trailer are avoided during the movement of the boatboxes.

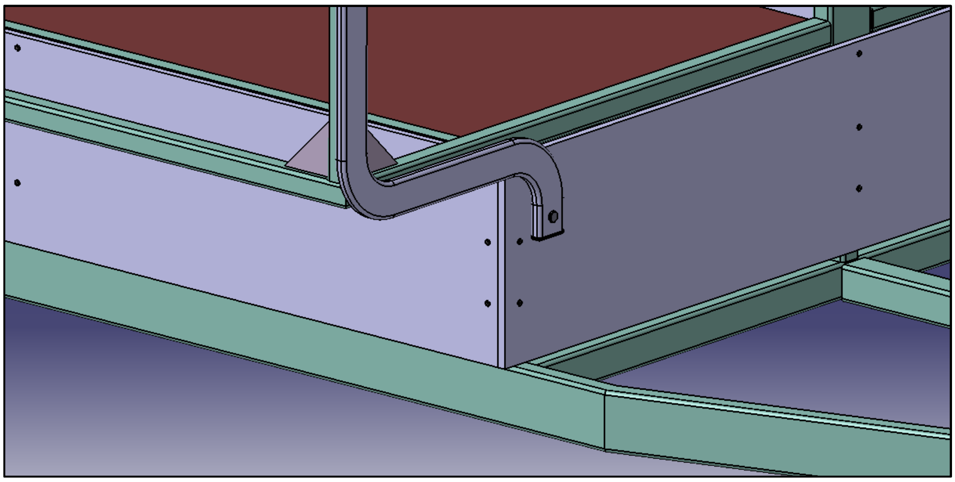


Figure 24. Paddlebox-boatbox joint

Boatboxes are joined to paddlebox in two points. Joint points are placed on the 1680x340 plates. To make possible this joint are made two 10 mm diameter holes on each plate. The exactly placement is represented in Figure 25.

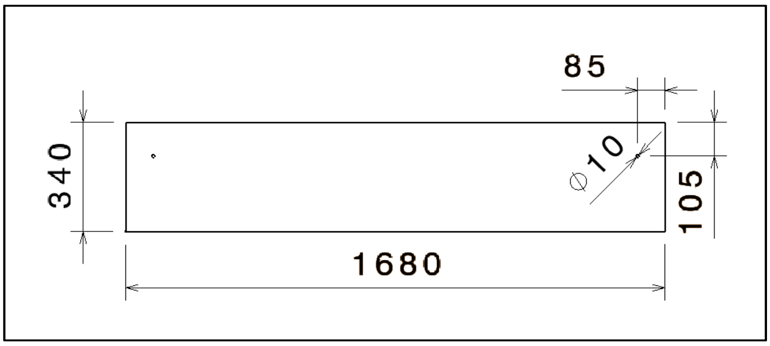


Figure 25. Joint points on paddlebox plates

The position of the joint points has been object of study. Their position has been designed simultaneously with the design of the rib shape, previously explained. The use of a CAD software makes possible this simultaneous design. Changing the dimensions of the rib and the place of the joint points it is possible to verify instantly the correct performance of the boatboxes when they open and close. CAD software like CATIA V5 permits not only create parts and structures, but it also simulates movements between the parts of an assembly.

The joint is composed of the following mechanical components. Commercial components comply with ISO or DIN standards.

5.1.5.1. Bolts

Due to the rotation allowed by the joint, it is necessary a mechanical component that does not fix parts together. The bolts chosen for the joint have been bolts with split pin hole according to ISO 2341 or DIN EN 22341 (Clevis pins with head – type B) with this features:

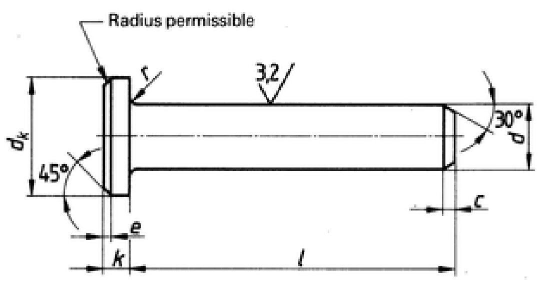
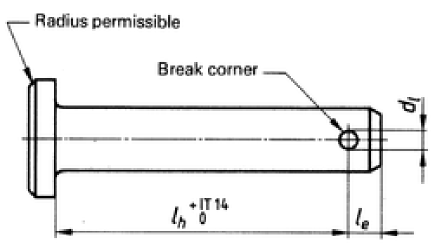
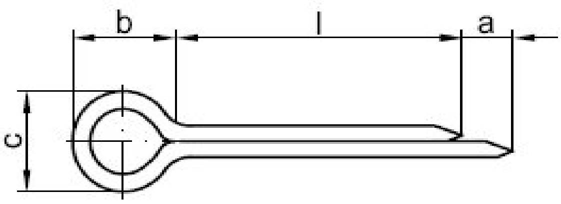
Type A Without split pin hole	Type B With split pin hole
	
l (nominal length)	60 mm
d (nominal diameter)	10 mm
d_l (hole diameter)	3,2 mm
d_k (head diameter)	18 mm
l_e	4,5 mm
k	4 mm

Figure 26. ISO 2341 bolts

5.1.5.2. Cotters

Cotters are known in mechanical engineering as pins passing through a hole to fix parts tightly together. Cotter pins are formed from half-round wire folded on itself and allowing a loop that acts as a stop and facilitates its extraction. Once inserted in its corresponding hole, its ends are bent in the opposite direction, producing its fixation. The ISO 2341 standard used for bolts is related with ISO 1234 for the choice of the pin. According to this standard have been used cotter pins with the suitable diameter to the bolt hole diameter. Figure 27 shows the measures and shape of cotter pins:

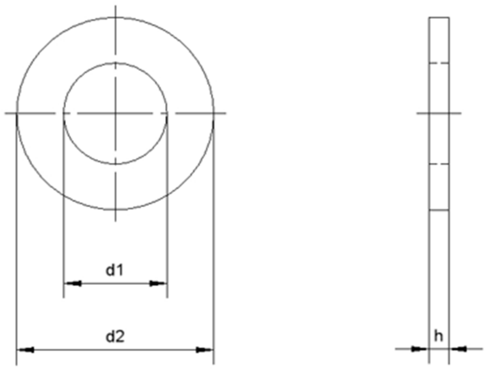


d (diameter)	3,2 mm
$a_{min.}$	1,6 mm
b	6,4 mm
$c_{max.}$	5,8 mm
l	14 mm

Figure 27. ISO 1234 cotters

5.1.5.3. Washers

When two pieces of steel in contact have a relative movement, appears the problem of the friction. This phenomenon causes erosion, fatigue and even fracture of the pieces involved. In addition, friction increases the forces needed to cause the movement. For this reason, washers are used in the joint paddlebox-boatbox. They are made of plastic and according to DIN 6340 standard. Plastic has been chosen as material of the washers to avoid friction between both steel parts. On each joint point, one washer is placed between rib and paddlebox and other is placed between the joint plate and the cotter pin.



D (thread diameter)	10 mm
d_1	10,5 mm
d_2	28 mm
h	4 mm

Figure 28. DIN 6340 washers

The choice of the thickness is important because it has to be thicker than the head of the screws used in the paddlebox. Otherwise, there would be collisions between rib and screws during paddlebox movement. For that reason, has been chosen a type of washer with a thickness of 4 mm. In addition, thicker washers provide more resistance to friction.

5.1.5.4. Joint plates

As part of the joint between paddlebox and boatbox, four triangular plates are fixed to the paddlebox plates. These plates are called "joint plates" and they serve to give more consistency to the joint. A hole of 10 mm is made to hold the bolt used in the joint. They are made of steel and are welded to the frame of the paddlebox. The measures of the plates and the position of the hole are calculated in order to match the holes with those of the paddelbox plates.

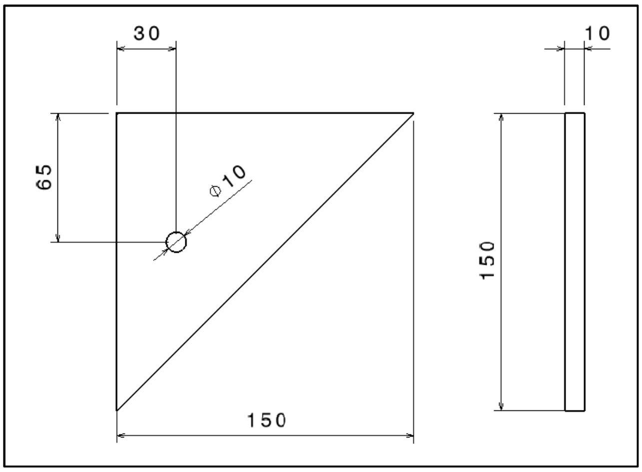


Figure 29. Joint plate

5.1.6. Assembly

The parts mentioned in the previous sections must be assembled together to get the structure of the kayak trailer. This process must follow a specific order to facilitate the construction. Obviously, the manufacturing of the different parts can be carried out simultaneously.

- The first step is to assemble paddlebox with the chassis. Chassis is the framework that the trailer is built on. Both parts are assembled by welding between their frames. Vertical bars of the paddlebox frame are welded to the 100x40x3 beams of the chassis. One of the bars of the paddlebox frame has a greater length than the rest. The reason is that this bar is welded to a 60x40x3 beam, whose upper surface is at a different height than the beams of the contour.
- The next stage consists of placing the central frame and side frames on the paddlebox. This is also achieved by welding. These frames are welded to the horizontal bars of the paddlebox frame.
- Finally, boatboxes must be joined to the rest of the trailer. As explained above, each boatbox is joined to the paddlebox in two points. The elements that have been used in the joint are the following: bolts, cotters and washers. In addition, a triangular sheet of steel called joint plate is fixed to the paddlebox in each point of joint. Joint plates and paddlebox plates have a hole of 10 mm in diameter. This is the nominal diameter of the chosen bolt. Bolts have a small hole near their end to hold a cotter pin. A bolt with a pin permits to keep the parts of the joint united but allowing a rotation in the bolt axis. Bolts are fixed and cannot rotate on its axis. Boatboxes can rotate because bolts are not threaded. Washers are placed between boatbox and paddlebox and on the joint plate.

Creating the 3D model in CATIA has been followed the same sequence of operations in order to understand the reason of this specific order.

5.1.7. Final result

The kayak trailer object of the present work is the result of assembling all the mentioned parts. Final measures of the trailer are shown in the following Table:

Large	5.545 m
Width (boatboxes closed)	2.5 m
Height (without wheels)	3.275 m

Table 3. Trailer measures

The 3D model of the kayak trailer is represented in the following figures.

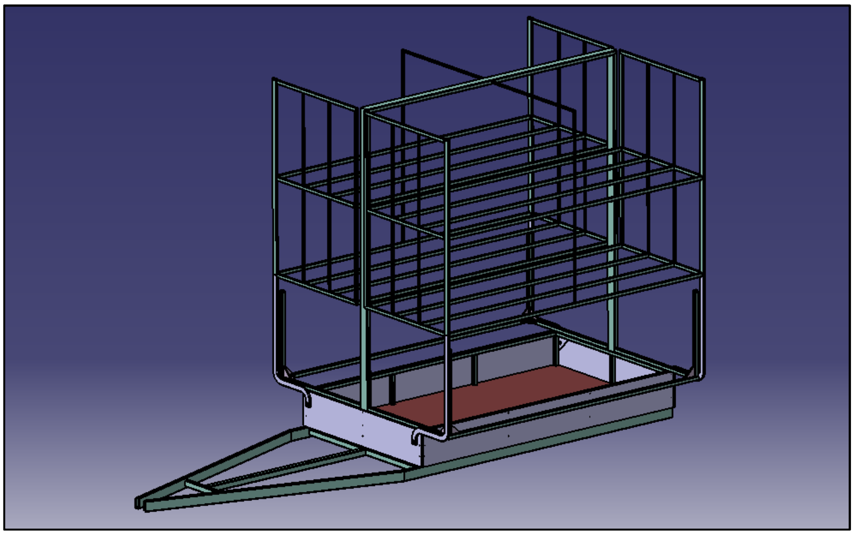


Figure 30. Trailer with boatboxes closed

In Figure 31 can be appreciated the position of a paddelbox when it is open. In this position kayaks can be loaded and unloaded in a safe way and without a ladder.

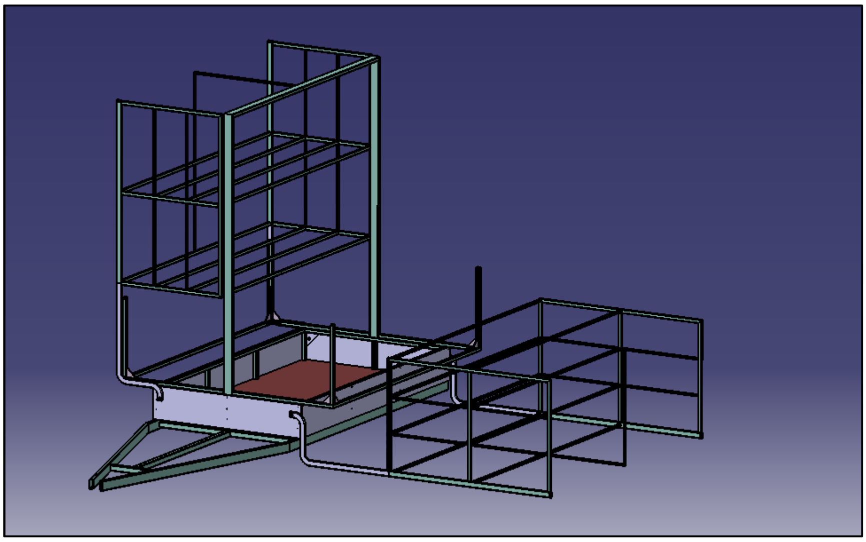


Figure 31. Trailer with one boatbox open

5.2. Steel used in manufacturing

Steel is the main material used in the manufacturing of the kayak trailer. In the present section is calculated the mass of steel employed in the construction of the trailer structure, except mechanical components such as fasteners.

Table 4 contains the mass per length of each commercial profile according to DIN 2395 standard.

Dimensions	Mass per length (kg/m)
20x20x3	1,60
40x20x3	2,39
40x40x3	3,33
60x20x3	3,33
60x40x3	4,28
60x60x3	5,22
100x40x3	6,16

Table 4. Mass per length DIN 2395 [20]

The density of steel has a value of 7,86 g/cm^3.

- The mass of the chassis frame is calculated by the following formulas:
  - Mass per unit of length: m
  - Mass: $M = m \cdot l$
  - Mass: $M = \rho_{steel} \cdot V$

$$m_{100x40x3} = 6{,}16\ kg/m$$

$$M_{100x40x3} = m_{100x40x3} \cdot l_{100x40x3} = 6{,}16 \frac{kg}{m} \cdot (2500\ mm \cdot 2 + 3095{,}102\ mm \cdot 2 + 1610\ mm) = 78{,}85\ kg$$

$$m_{60x40x3} = 4{,}28\ kg/m$$

$$M_{60x40x3} = m_{60x40x3} \cdot l_{60x40x3} = 4{,}28 \frac{kg}{m} \cdot (1570\ mm \cdot 3 + 535{,}39\ mm) = 22{,}45\ kg$$

$$m_{60x60x3} = 5{,}22\ kg/m$$

$$M_{60x60x3} = m_{60x60x3} \cdot l_{60x60x3} = 5{,}22 \frac{kg}{m} \cdot 1827\ mm = 9{,}54\ kg$$

$$M_{chassis} = M_{100x40x3} + M_{60x40x3} + M_{60x60x3} = 78{,}85\ kg + 22{,}45\ kg + 9{,}54\ kg = 110{,}84\ kg$$

The mass of the chassis is 110,84 kg.

- The mass of the paddlebox is calculated by the following formulas:

$m_{40x40x3} = 3{,}33\ kg/m$

$$M_{paddlebox\ frame} = m_{40x40x3} \cdot l_{paddlebox\ frame}$$
$$= 3{,}33 \frac{kg}{m} \cdot (2870\ mm \cdot 2 + 1610\ mm \cdot 2 + 300\ mm \cdot 9 + 320\ mm)$$
$$= 39{,}89\ kg$$

The mass of the frame is 39,89 kg.

$$M_{plates} = \rho_{steel} \cdot V_{plates}$$
$$= \frac{7{,}86\ g}{1000\ mm^3} \cdot 2 \cdot (1680\ mm \cdot 340\ mm \cdot 15\ mm + 2910\ mm \cdot 340\ mm \cdot 15\ mm)$$
$$= 367{,}98\ kg$$

$$M_{paddlebox} = M_{paddlebox\ frame} + M_{plates} = 39{,}89\ kg + 367{,}98\ kg$$
$$= 407{,}87\ kg$$

The paddlebox has a mass of steel of 407,87 kg.

- The mass of the frames is calculated by the following formulas:

$$M_{central\ frame} = m_{100x40x3} \cdot l_{central\ frame}$$
$$= 6{,}16 \frac{kg}{m} \cdot (2815\ mm\ \cdot 2 + 2870\ mm) = 52{,}36\ kg$$

$$M_{bracket} = \rho_{steel} \cdot V_{bracket} = \frac{7{,}86\ g}{1000\ mm^3} \cdot (0{,}5 \cdot 100\ mm \cdot 100\ mm \cdot 10\ mm)$$
$$= 0{,}393\ kg$$

$$M_{side\ frame} = \left(m_{40x40x3} \cdot l_{side\ frame} + M_{bracket} \cdot 6\right)$$
$$= 3{,}33 \frac{kg}{m} \cdot (1130\ mm \cdot 2 + 800\ mm \cdot 2 + 2870\ mm)$$
$$+ 0{,}393\ kg \cdot 6 = 24{,}77\ kg$$

The mass of the central frame is 52,36 kg and side frames together have a mass of 49,54 kg.

- The mass of the boatboxes is calculated by the following formulas:

$m_{60x20x3} = 3{,}33\ kg/m$

$$M_{60x20x3} = m_{60x20x3} \cdot (l_{rib} + l_{60x20x3}) = 3{,}33 \frac{kg}{m} \cdot (53\ mm + \pi \cdot 90\ mm + 285\ mm + 897\ mm + 1840\ mm) = 11{,}18\ kg$$

$m_{40x20x3} = 2{,}39\ kg/m$

$$M_{40x20x3} = m_{40x20x3} \cdot l_{40x20x3} = 2{,}39 \frac{kg}{m} \cdot (1120\ mm \cdot 2 + 1100\ mm + 1820\ mm) = 12{,}33\ kg$$

$m_{20x20x3} = 1{,}60\ kg/m$

$$M_{20x20x3} = m_{20x20x3} \cdot l_{20x20x3} = 1{,}6 \frac{kg}{m} \cdot (870\ mm \cdot 4) = 5{,}57\ kg$$

$$M_{frontal\ frame} = M_{60x20x3} + M_{40x20x3} + M_{20x20x3} = 11{,}18\ kg + 12{,}33\ kg + 5{,}57\ kg = 29{,}08\ kg$$

$$M_{horizontal\ bars} = m_{40x20x3} \cdot l_{horizontal\ bar} \cdot 8 = 2{,}39 \frac{kg}{m} \cdot 2948\ mm \cdot 8 = 56{,}36\ kg$$

$$M_{safety\ bars} = m_{20x20x3} \cdot l_{safety\ bars} = 1{,}6 \frac{kg}{m} \cdot (870\ mm + 890\ mm + 1170\ mm) = 4{,}68\ kg$$

$$M_{boatbox} = M_{frontal\ frame} \cdot 2 + M_{horizontal\ bars} + M_{safety\ bars} = 29{,}08\ kg \cdot 2 + 56{,}36\ kg + 4{,}68\ kg = 119{,}2\ kg$$

The mass of one boatbox is 119,2 kg.

- The mass of steel used in the manufacturing of the trailer is the sum of the mass of the different parts:

$$M_{trailer} = M_{chassis} + M_{paddlebox} + M_{central\ frame} + M_{side\ frames} + M_{boatboxes} = 110{,}84\ kg + 407{,}87\ kg + 52{,}36\ kg + 49{,}54\ kg + 2 \cdot 119{,}2\ kg = 859{,}01\ kg$$

The mass of steel of the trailer is 859,01 kg.

This is not the total mass of the kayak trailer, but it is the mass of steel used in the manufacturing of its structure, except joint plates, bolts and screws. They are small parts in comparison with frames and plates. Therefore, these calculations do not provide the total mass of the structure, but it gives an idea of its approximate weight. The parts that have not been considered such as small mechanical components and the plywood plate of the paddlebox are light in comparison with the parts considered.

The weight of the mechanism for the boatboxes as well as the axle and wheels would be added to the calculated weight of the structure.

As the structure has a weight of 859 kg, the trailer object of the work is classified as trailer heavier than 750 kg and it must comply with the requirements of this type of vehicle. Some of these legal requirements are dealt in the next section.

5.3. Legal requirements and safety devices

As mentioned at first of the present thesis, trailers are considered vehicles and therefore, they must comply with some stipulations. In Germany, this legislation is included in the Road Traffic Licensing Regulation (Straßenverkehrs-Zulassungs-Ordnung). Trailers requirements are discussed in the section "Motor vehicles and their trailers" of StVZO.

5.3.1. Dimensions

The maximum dimensions allowed to motor vehicles and trailers to be authorized to circulate are:

Dimension	Characteristic	Authorized dimension
Length	For trailers	12 m
Width	As a general rule	2.55 m
Height	As a general rule (load included)	4 m

Table 5. Maximum dimensions allowed [21]

The trailer object of work comply with these maximums as seen in Table 3.

5.3.2. Braking system

Due to the weight of the kayak trailer, it is possible to increase security by incorporating breakes. According to StVZO, trailers with a weight less than 750 kg do not need any type of breakes. The trailer object of the work is heavier than this weight. Trailers with weight from 750 to 3500 kg can incorporate a type of brakes called overrun brakes. [22]

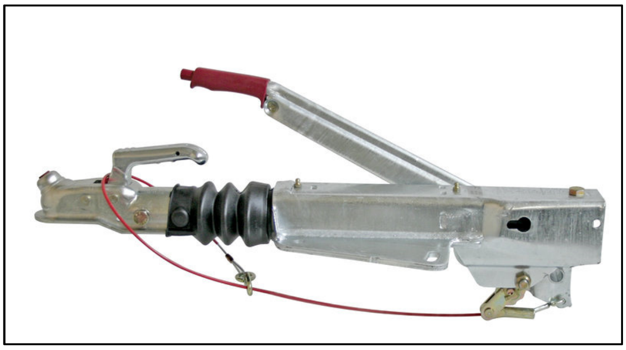


Figure 32. Overrun brake [23]

Overrun brakes are used on trailers up to 3.5 tons of maximum permissible mass that do not have their own hydraulic braking system. The task of the overrun brake is to convert the kinetic energy occurring during braking of the towing vehicle as synchronously as possible into braking force. [24] Braking the towing vehicle produces a drawbar force on the coupling point. After overcoming the response threshold the drawbar is pushed in, this operates the overrun lever and the brakes via the transmission unit. [25] In other words, the inertia of the trailer provides the force to apply the brakes.

The mechanism that allows this process of braking in trailers is represented in Figure 33.

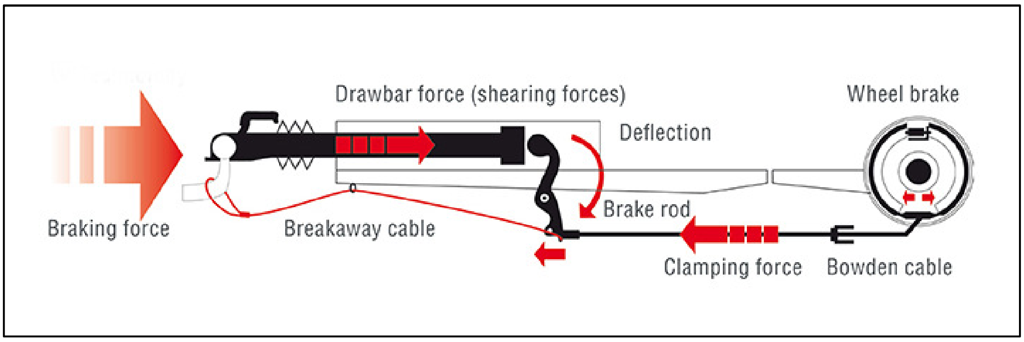


Figure 33. Overrun brake mechanism [26]

5.3.3. Lighting devices and reflectors

Motor vehicles and their trailers may only be fitted with the prescribed and approved lighting equipment. As lighting devices also apply phosphors and retroreflective agents. The lighting equipment must be installed correctly and firmly and must be ready for use at all times. Lighting equipment for motor vehicles and trailers must comply with the technical requirements set by the United Nations Economic Commission for Europe (ECE). [27] These requirements are specified in the Road Traffic Licensing Regulation in Germany (StVZO).

- Trailers must have rear lights, brake lights and indicators, as well as one or two rear fog lights. In addition, one or two reversing lights can be fitted. [28] Lighting is powered by the towing vehicle.
- All trailers must have two non-triangular white reflectors on the front. Distance between the point of the luminous area of the lights and the outermost point of the reflector surface can not exceed 150 mm. [29]
- Trailers must be equipped on the long sides with yellow, non-triangular reflectors acting to the side. [30]
- Trailers over 2.1 m wide must have red front and white rear safety lights. [31]
- All trailers must be equipped with two triangular red reflectors. The length of the reflectors sides must be at least 150 mm, the top of the triangle must be oriented upwards. The outermost point of the illuminating surface of the reflectors shall not be more than 400 mm from the outermost point of the vehicle outline and its highest point of the illuminating surface not more than 900 mm from the roadway. [32]

In Figure 34 can be appreciated the yellow reflectors on the long side and rear lighting of a model of domestic trailer.

Figure 34. Rear and lateral lighting [33]

In current models of trailers it is very common to find multi-function rear lighting. A single lighting device incorporates different reflectors as is represented in Figure 35. These devices are usually placed on the license plate holder.

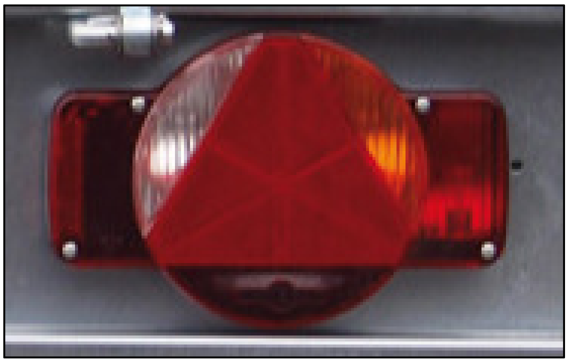


Figure 35. Multi-function lighting [34]

5.3.4. Coupling

The coupling creates a safe connection between towing vehicle and trailer. For trailers (with or without overrun brake) the ball coupling is the current coupling standard.

Towing vehicle incorporates tow bars that must be a type approved to European Union directive 94/20/EC. The ISO standard tow ball is 50 mm in diameter. The coupling device of the trailer must be suitable for the tow ball and can incorporate a system of braking such as an overrun brake or not. Coupling fixes the trailer to the towing vehicle with some degrees of freedom. Swaying and pitching movements of the trailer are suppressed.

Figure 36 shows a commercial model of coupling device for trailers.

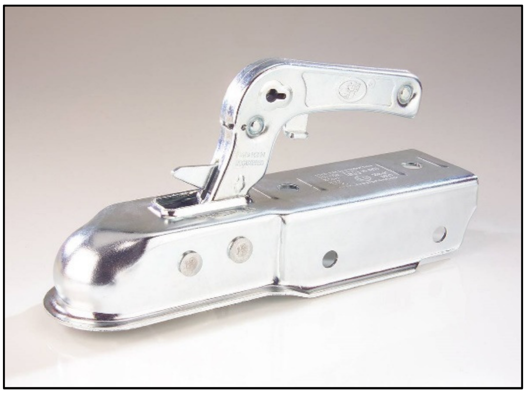


Figure 36. Ball coupling device [35]

Although the components mentioned in this section are not included in the 3D model created in the present work, are part of the design of a trailer. They must be installed after the manufacturing of the trailer in order to be authorized to circulate as well as obligatory elements such as suitable wheels, license plate and other signals.

6. FINITE ELEMENT ANALYSIS

The process of design of a product includes a step of simulation that allows proving the performance of the product and determines if the design is successful or must be changed. In this work, once the CAD model was finished, it was necessary to analyse it with a FEM software. This was carried out with ANSYS software and its module Static-Mechanical Analysis.

6.1. Preparation of the model

In order to calculate the behaviour of the loaded trailer, a Finite Element Analysis (FEA) was performed. The CAD model was generated as described before. To ensure a flawless import to the FE module, a standard file format IGES (Initial Graphics Exchange Specification) has been used. For the numerical simulation ANSYS Workbench 18.2 was used to perform the FEA.

The first step is importing the model created in CAD to ANSYS. Once the software correctly recognizes the model, it is necessary to establish a new system of coordinates. The next step is creating some constraints and boundary conditions in order to simulate the trailer hitch. One boundary condition is a fix point that simulates the fixing point of the trailer with a car. The other one must represent the wheels of the trailer. There are 6 degrees of freedom (DOF) of which three are translationally and three are rotatory. For this trailer all translationally DOF was set to be zero as well as the rotation around z-axis. Rotation around x- and y-axis was set to be free.

In this simulation all the bodies that are part of the trailer were considered made of structural steel. In fact, most of the parts are made of steel except the plywood plate of the paddlebox and some small parts. The properties of steel were taken from the ANSYS technical database:

Young Modulus (E)	200 GPa
Poisson Ratio (v)	0.3

Table 6. Steel properties

A total weight of the construction was calculated: 2.259,8 kg. This weight includes 18 x 40,5 kg for the kayaks. It has been considered the weight of the heaviest model of kayak, which is “Summerwind classic - Touring” model with a weight of 40,5 kg as seen in Table 2. To simulate the weight of the kayaks, 14 mass points were created. 12 of them simulate kayaks that are supported by the boatboxes and each one of the other 2 mass points simulate 3 kayaks supported by one of the side frames. For each mass point it is necessary to define the faces of the beams that support the kayak simulated.

The position of the mass points can be appreciated in the following figures. The system of coordinates created is also represented.

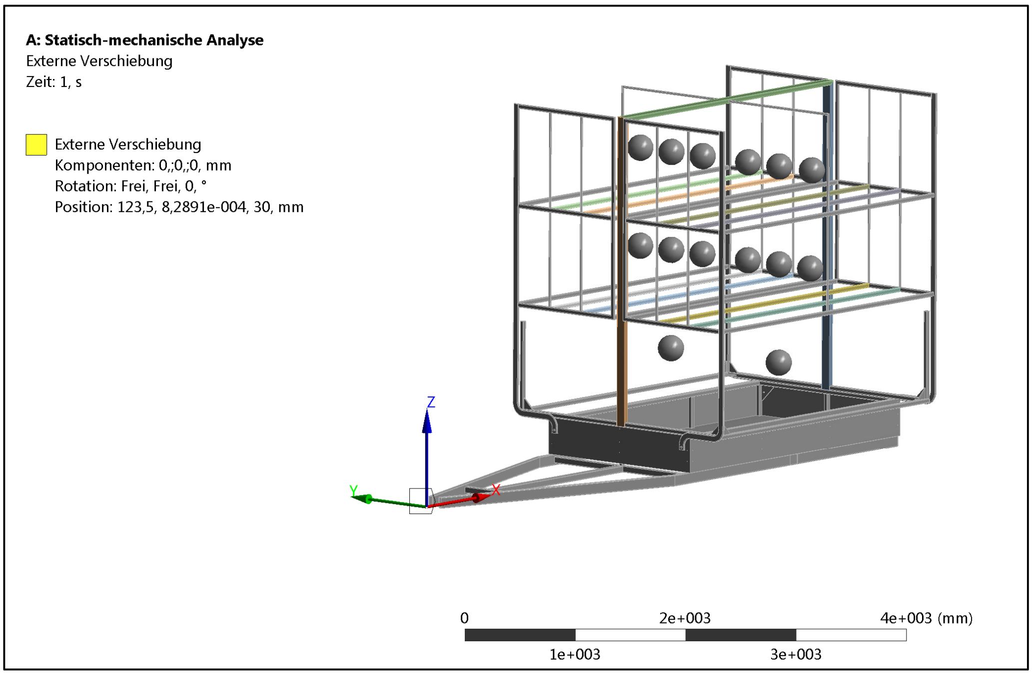


Figure 37. Mass points position 1

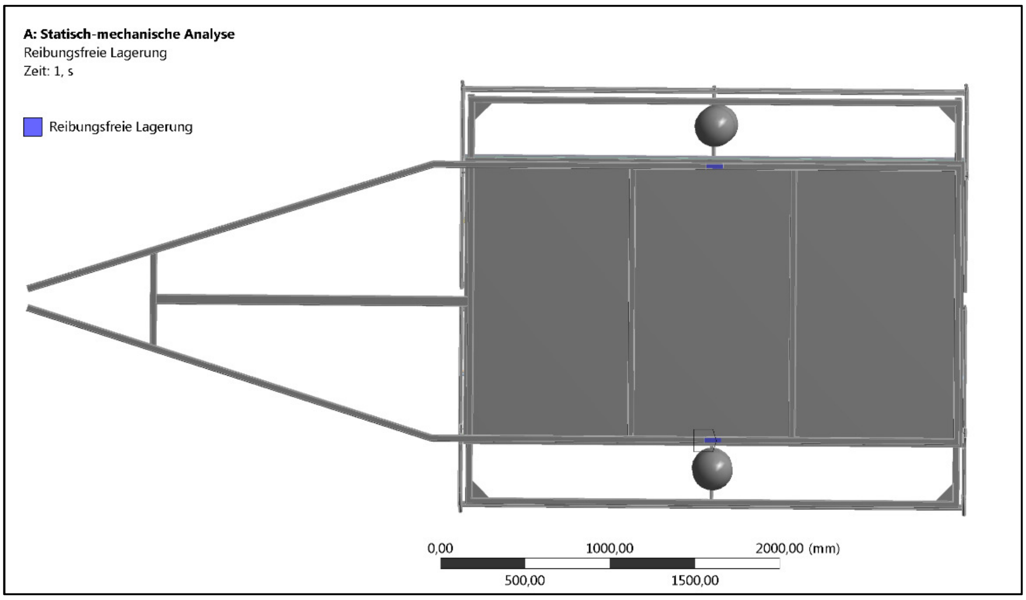


Figure 38. Mass points position 2

Besides the weight of the kayaks, was applied the g-force of 9,8066 m/s².

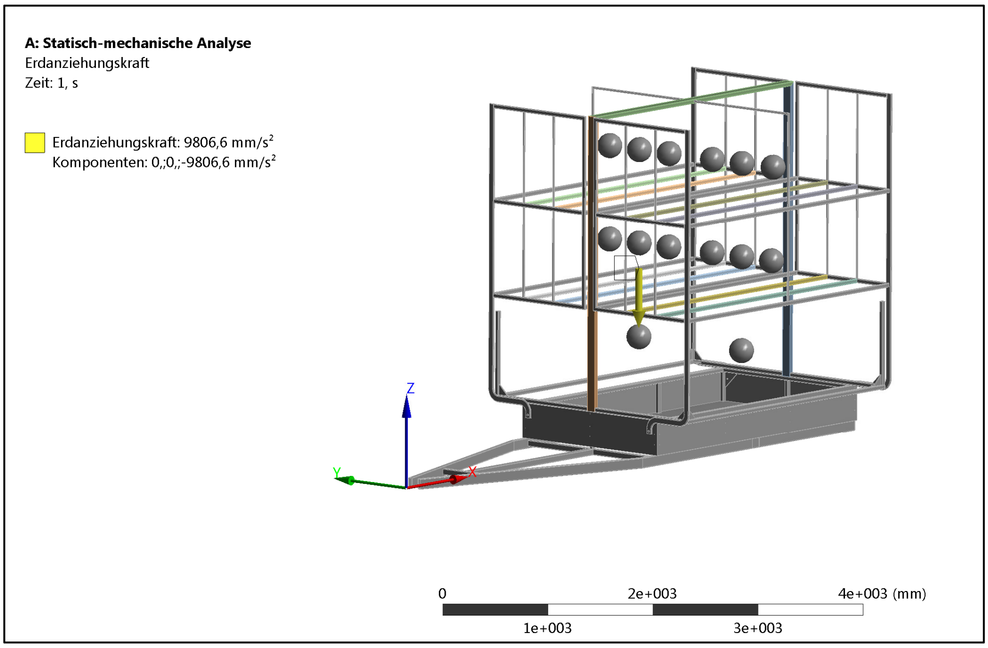


Figure 39. Force of gravity

The contacts between each of the generated parts was set to be bonded (or non free). This approach ensures less calculation time and is suitable for estimated results. It is about a volumetric model and for that reason a high number of elements is needed to get a simulation. The mesh includes 1.561.109 elements and 3.465.131 nodes.

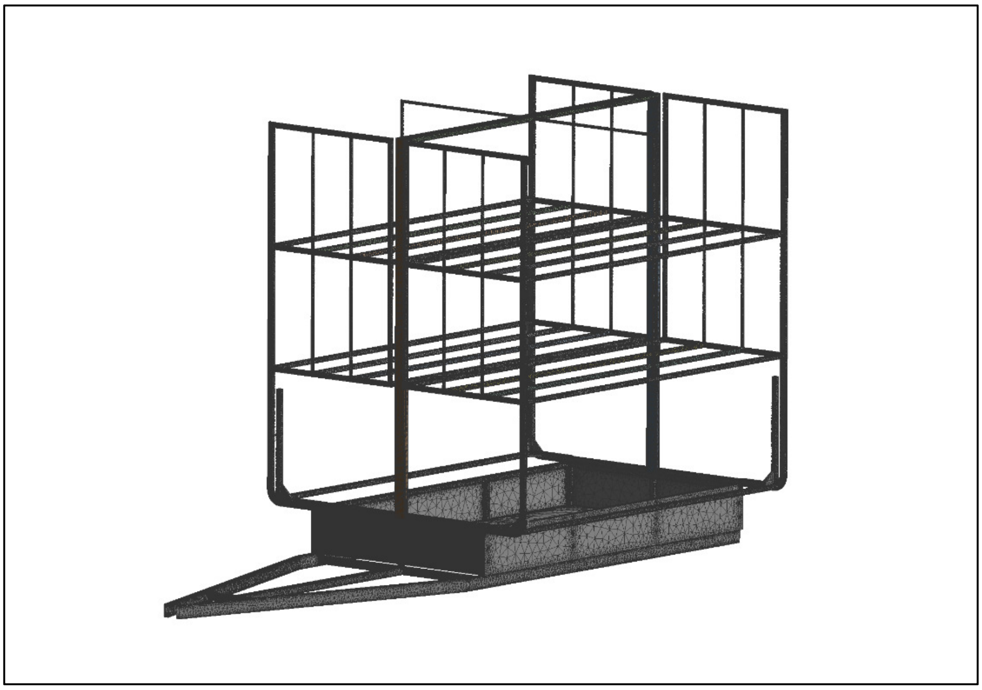


Figure 40. FEA mesh

6.2. Results of the analysis

6.2.1. Displacement analysis

Due to the loads, the structure of the trailer is deformed. Displacements of this structural deformation are represented in Figure 41 and Figure 42.

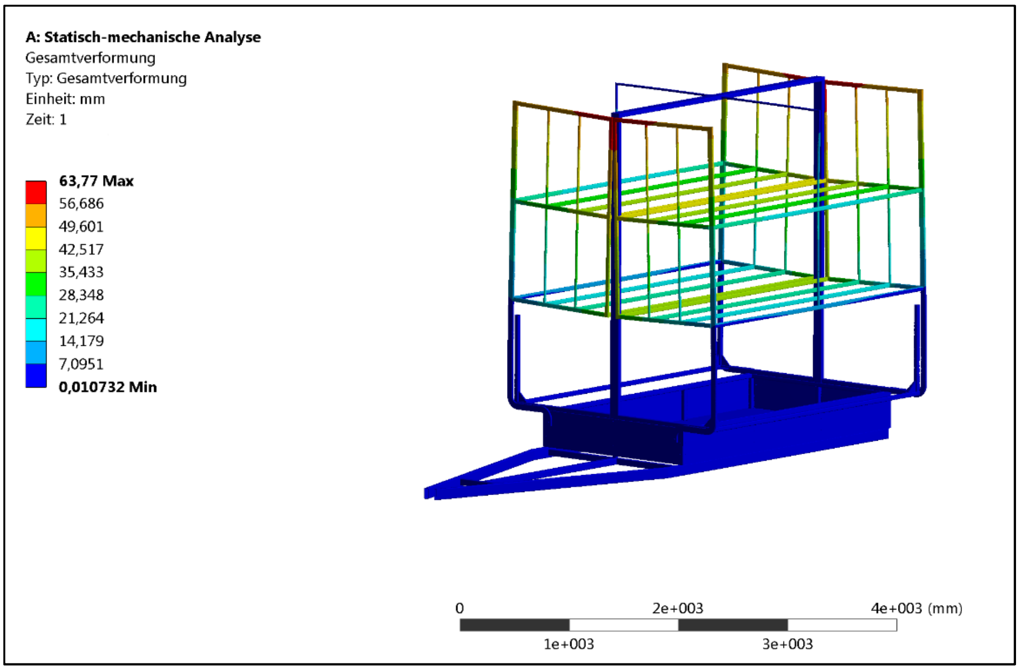


Figure 41. Displacement analysis (isometric view)

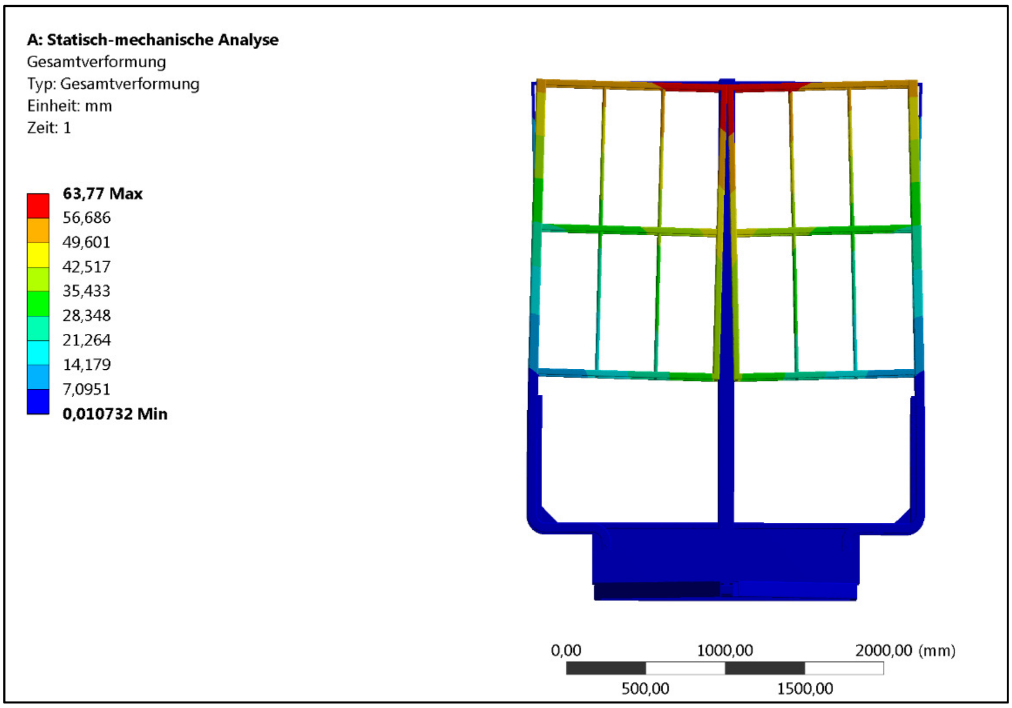


Figure 42. Displacement analysis (front view)

6.2.2. Von Mises stress analysis

In order to measure the resistance of a structure, Von Mises stress is used in mechanical engineering to check if a design is safe and will withstand a given load condition. This parameter is represented in the following figures.

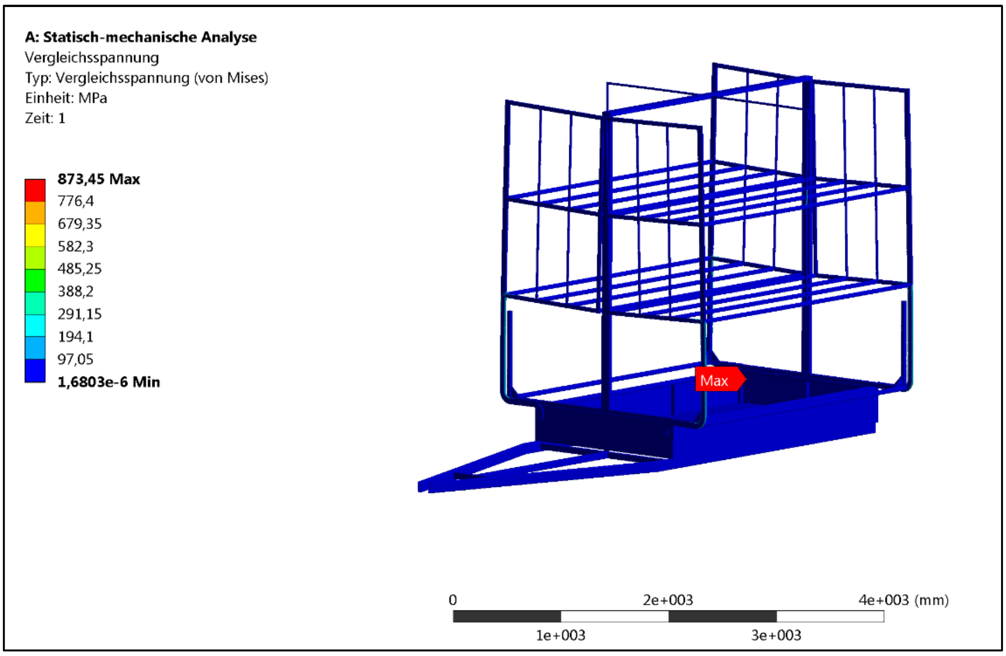


Figure 43. Von Mises stress analysis (1)

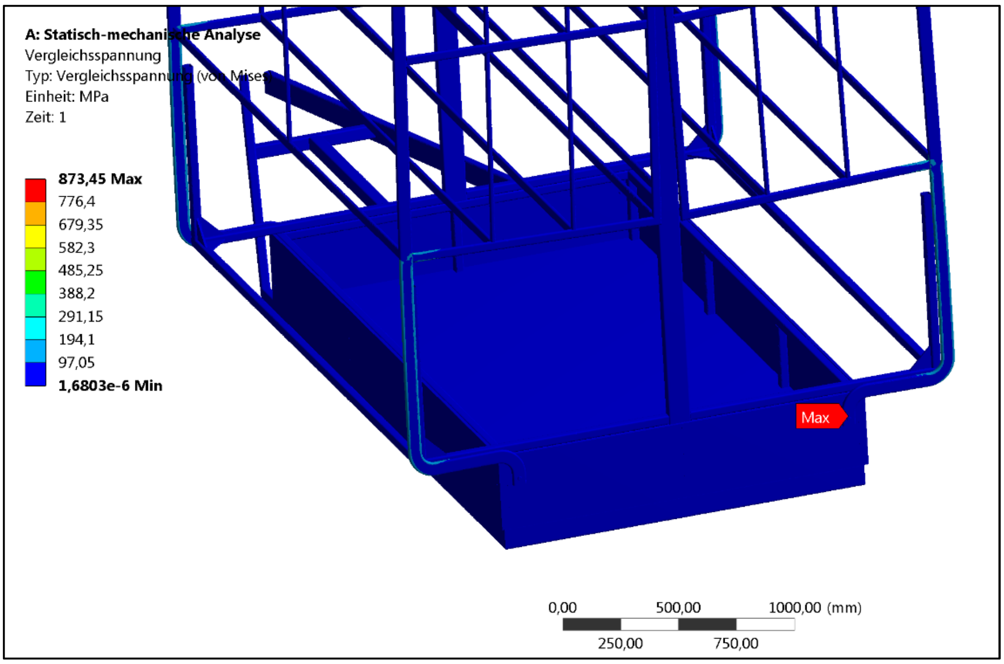


Figure 44. Von Mises stress analysis (2)

The maximum value of Von Mises stress appears in the bolts used to join the boatboxes with the paddlebox. To appreciate this maximum it is necessary a sectional view.

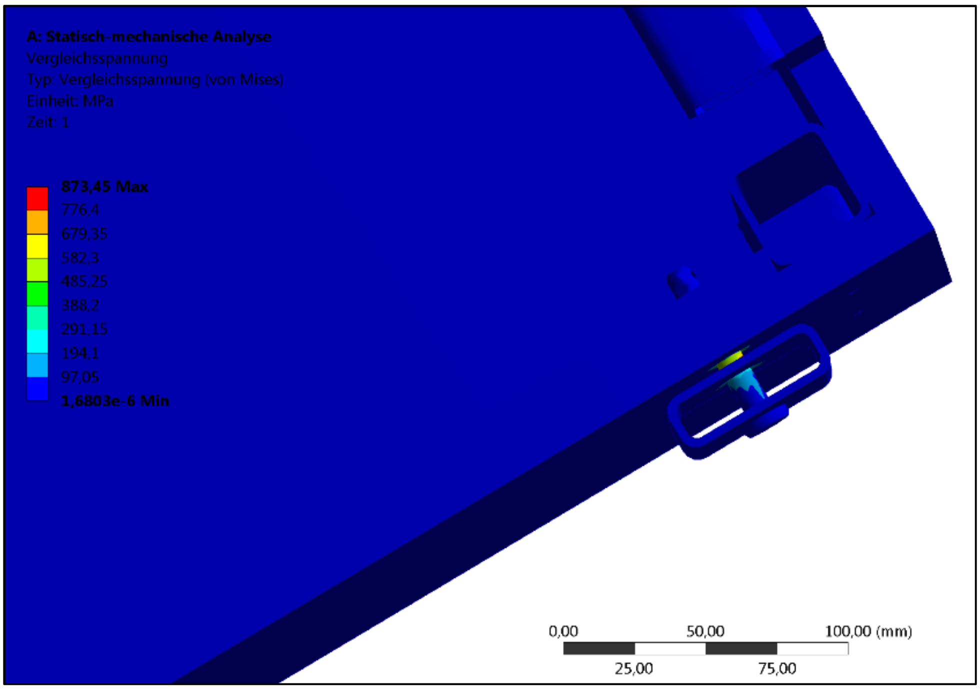


Figure 45. Von Mises stress maximum (1)

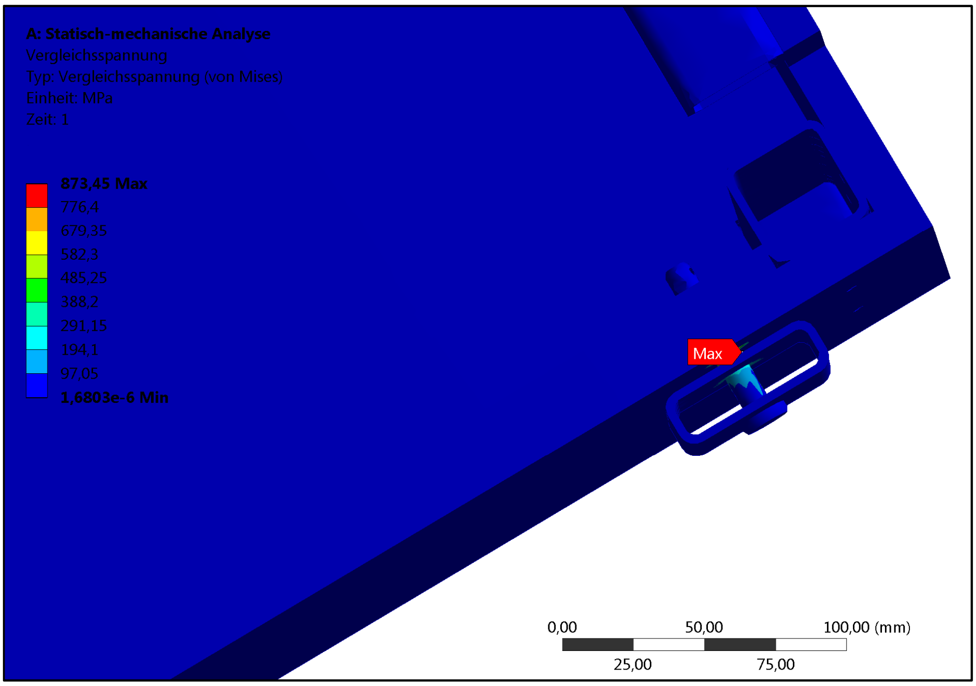


Figure 46. Von Mises stress maximum (2)

6.3. Discussion about the results

6.3.1. Displacement analysis

As expected, displacements appear in boatboxes. The weight of the kayaks is withstood by the beams of boatboxes and for that reason they present bending. Maximum displacement occurs at the top of the frontal frames of boatboxes. Both frontal frames deform inward until they collide with each other, as can be seen in Figure 48.

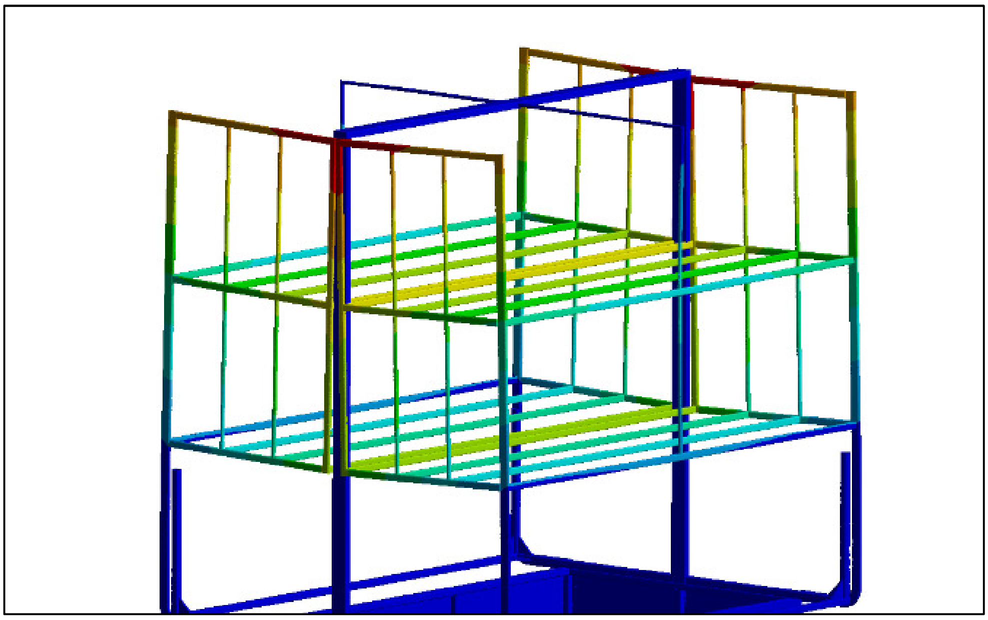


Figure 47. Maximum displacements (isometric view)

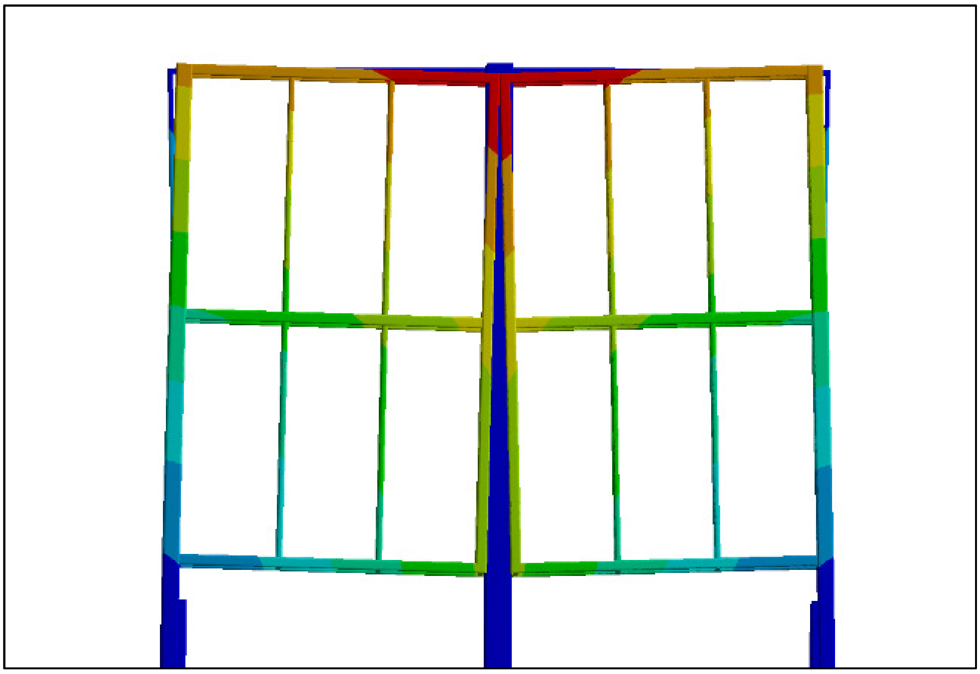


Figure 48. Maximum displacements (front view)

The maximum displacement has a value of 63,77 mm. This value is excessive and unacceptable. Nevertheless, it is necessary to explain that this deformation is due to the CAD model. In the CAD model, the rotation of the boatboxes respect to the rest of the trailer is allowed. It was created without any element that keep the boatboxes closed, only the central frame restricts the inward movement of the boatboxes. In FEA simulation the boatboxes cannot move inwards but their frontal frames can deform in that way. Obviously, the real trailer will include a system to keep the boatboxes closed on a safe way. Therefore, the deformation represented in FEA is not realistic but it gives an idea of how important is the design of a system to close boatboxes. In addition, the analysis serves to verify that it is the most critical part of the trailer.

Chassis, paddlebox, side frames and central frame do not present any deformation. This is a sign that the design is acceptable. Chassis withstands without difficulty the weight of the structure plus kayaks.

6.3.2. Von Mises stress analysis

The maximum Von Mises stress appears in one of the bolts used to join boatboxes with the rest of the trailer. This maximum has a value of 873 MPa, which is unacceptable and would cause the failure of the structure.

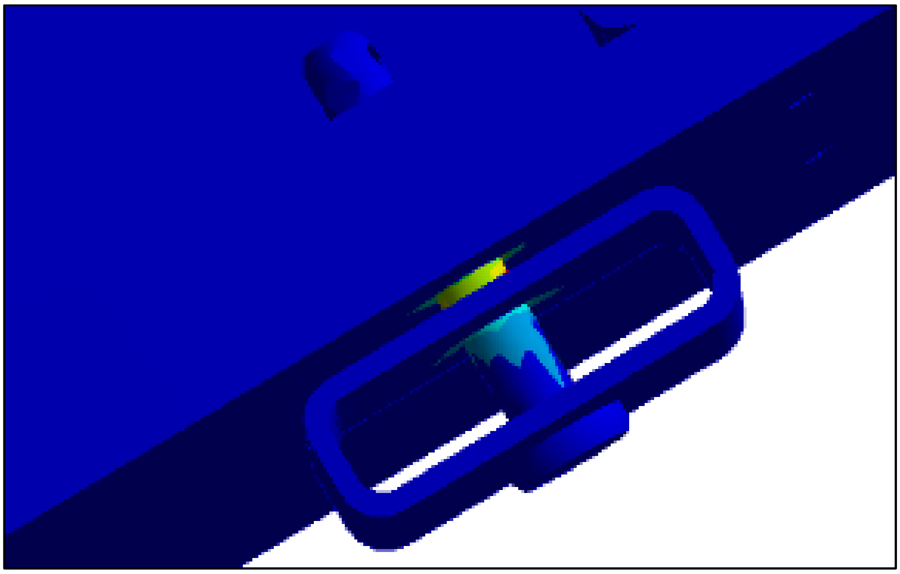


Figure 49. Detail of the maximum Von Mises stress

As in the case of the displacements, the results of the Von Mises stress analysis are not realistic. In the CAD model bolts are allowed to rotate around its axis but inside the construction they cannot move or rotate. Therefore there would not be such high values. Considering realistic stresses there would be a Von Mises stress less than 55 MPa for most of the trailer, which is uncritical for the construction. The maximum Von Mises stress criterion states that a ductile material starts to yield when Von Mises stress becomes equal to the stress limit of the material. The stress limit of any steel is higher than 55 MPa.

Maximum Von Mises stress criterion:

$$\sigma_{Von\ Mises} \geq \sigma_{limit}$$

6.3.3. Conclusion

In the first place, it was to be expected that the most critical part of the structure in terms of deformations were the boatboxes. They have the function of supporting most of the kayaks transported in the trailer and in addition they are not immobile parts. All of this causes instability and possible problems of deformation.

As seen in the previous sections, both analysis have provided some unacceptable values of displacement and Von Mises stress. Nevertheless, those results are due to the model created in CAD, which allows certain movements that in the real trailer would not exist. Therefore, these results do not indicate that the design of the structure is inadmissible. The rest of values of both magnitudes are within the range of acceptable values and therefore, the design of the kayak trailer is considered successful.

7. DISCUSSION AND CONCLUSION

The main part of the work has been the creation of the model with the help of CAD software. It has been a long process due to the high number of parts that form the trailer and the difficulties that the design of these parts entails. The creation of the model has not been a lineal process because it was necessary to modify some of its aspects more than once. In addition, there were several problems to import the CAD model to ANSYS because this software did not recognize all the bodies that form the model. In order to solve it, it was necessary to create the chassis of the trailer again but on a different way.

With a view to a future market introduction, legal requirements must be considered. Some of these aspects have been discussed in this work as part of the process of design of a vehicle, which must comply with the Road Traffic Licensing Regulation.

After the results obtained in FEA and their correct interpretation, this work is concluded. Nevertheless, it should be clarified that the initial objective of this thesis has not been completed.

At first, it was pretended to get a CAD model of the kayak trailer with all of its components so that this model would serve to the manufacturing of the trailer. Finally, the CAD model created in the present work represents the essential part of the trailer, that is, its structure. The structure of a vehicle or other product is the object of analysis in order to verify the quality of the design. Therefore, the main objective of the thesis has been achieved but the design of the kayak trailer must be completed.

In the future it is necessary to study in detail other aspects of the work that have not been discussed in the present work such as the pulley mechanism taht allows to open and close the boatboxes. This mechanism was developed in the tesis that this work is based on and probably its design must be modified.

Attached to the thesis are provided some drawings of the kayak trailer and its different parts. These drawings have been obtained from the CAD model in CATIA V5 and can serve to its future manufacturing.

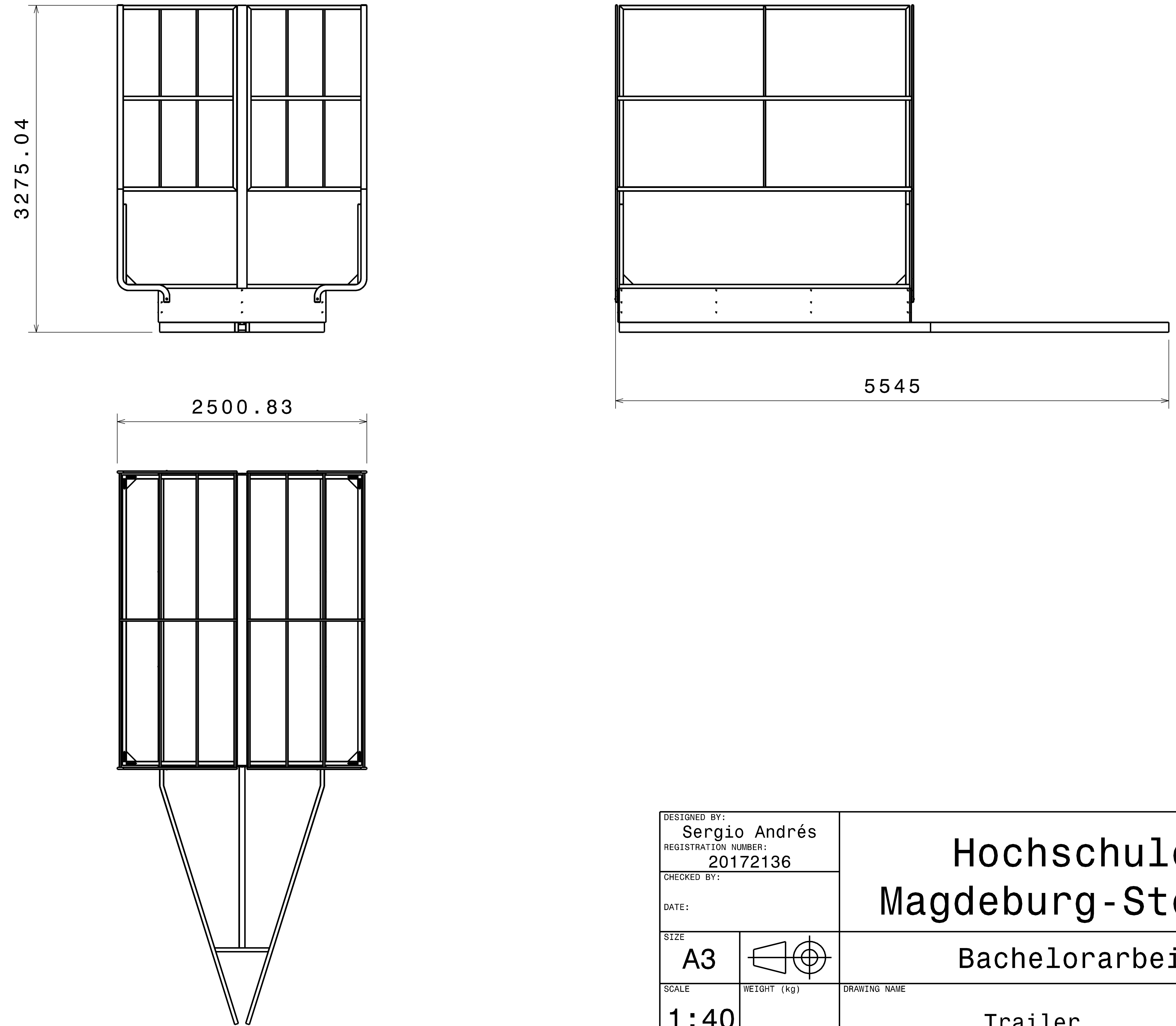
References

- [1] https://www.teachengineering.org/k12engineering/designprocess
- [2] https://www.teachengineering.org/k12engineering/designprocess
- [3] Definition of “Trailer” (Begriffsbestimmung der Europäischen Konferenz der Verkehrsminister, BGBl. 2015 II S. 69, 72)
- [4] http://www.amtrex.net/semitrailer_definition.htm
- [5] https://www.humbaur.com/anhaenger/bauanhaenger.html
- [6] https://www.humbaur.com/anhaenger/einachsanhaenger/konfigurieren/modell/startrailer-h-752010.html?no_cache=1&tx_kchumbaurproducts_trailers%5Baction%5D=show
- [7] https://www.humbaur.com/anhaenger/fahrzeugtransporter/modelluebersicht.html
- [8] https://www.humbaur.com/anhaenger/kipper-und-baumaschinentransporter/modelluebersicht.html
- [9] https://www.humbaur.com/anhaenger/pferdeanhaenger/balios-aero.html
- [10] http://www.arco-trailer.de/segelboot/
- [11] https://www.yakima.com/mount-location/trailer https://www.northwoodssporttrailers.com/1-to-24-place-canoe-kayak-sup-bike--gear-trailers.html https://www.osagian.com/index.php?route=product/product&path=2&product_id=41 https://mysportboats.com/Magneta-UKCT10-10-Kayak-Trailer-10-Canoe-Trailer-p29.html
- [12] Narayan, K. Lalit; Computer Aided Design and Manufacturing, 2008.
- [13] Daryl L. Logan; A first course in the finite element method, 2011.
- [14] http://www.3dcadportal.com/images/stories/ansys/carillo-rod-static.jpg
- [15] https://www.millerwelds.com/resources/article-library/mig-welding-the-basics-for-mild-steel
- [16] Rajput, R. K.; A Textbook of Automobile Engineering, 2007.
- [17] https://www.pegnitz-schrauben.de/LInsenkopf-m-Scheibe
- [18] https://expresszuschnitt.de/Siebdruckplatten
- [19] https://expresszuschnitt.de/Siebdruckplatten

- [20] http://richter-kiel.de/media/pdf/Richter_Stahlkatalog.pdf
- [21] StVZO § 32
- [22] StVZO § 41
- [23] https://www.et-anhaengertechnik.de/epages/63322401.sf/de_DE/?ObjectPath=/Shops/63322401/Products/247581-4D1
- [24] https://www.at-rs.de/auflaufbremse.html
- [25] http://www.al-ko.com/sites/all/modules/handmade_reddot_intergration/reddot_files/za/1157.htm
- [26] http://www.al-ko.com/sites/all/modules/handmade_reddot_intergration/reddot_files/za/1157.htm
- [27] StVZO § 49a
- [28] StVZO § 52a
- [29] StVZO § 51
- [30] StVZO § 51a
- [31] StVZO § 51b
- [32] StVZO § 53
- [33] https://www.humbaur.com/anhaenger/einachsanhaenger/tieflader-startrailer.html
- [34] https://www.humbaur.com/anhaenger/einachsanhaenger/tieflader-startrailer.html
- [35] https://www.westfalia.net/shops/farming/agricultural_equipment/trailer-accessories/tow_bars_and_accessories/1528523-ball-coupling-for-connecting-trailers-square-60-x-60-mm.htm

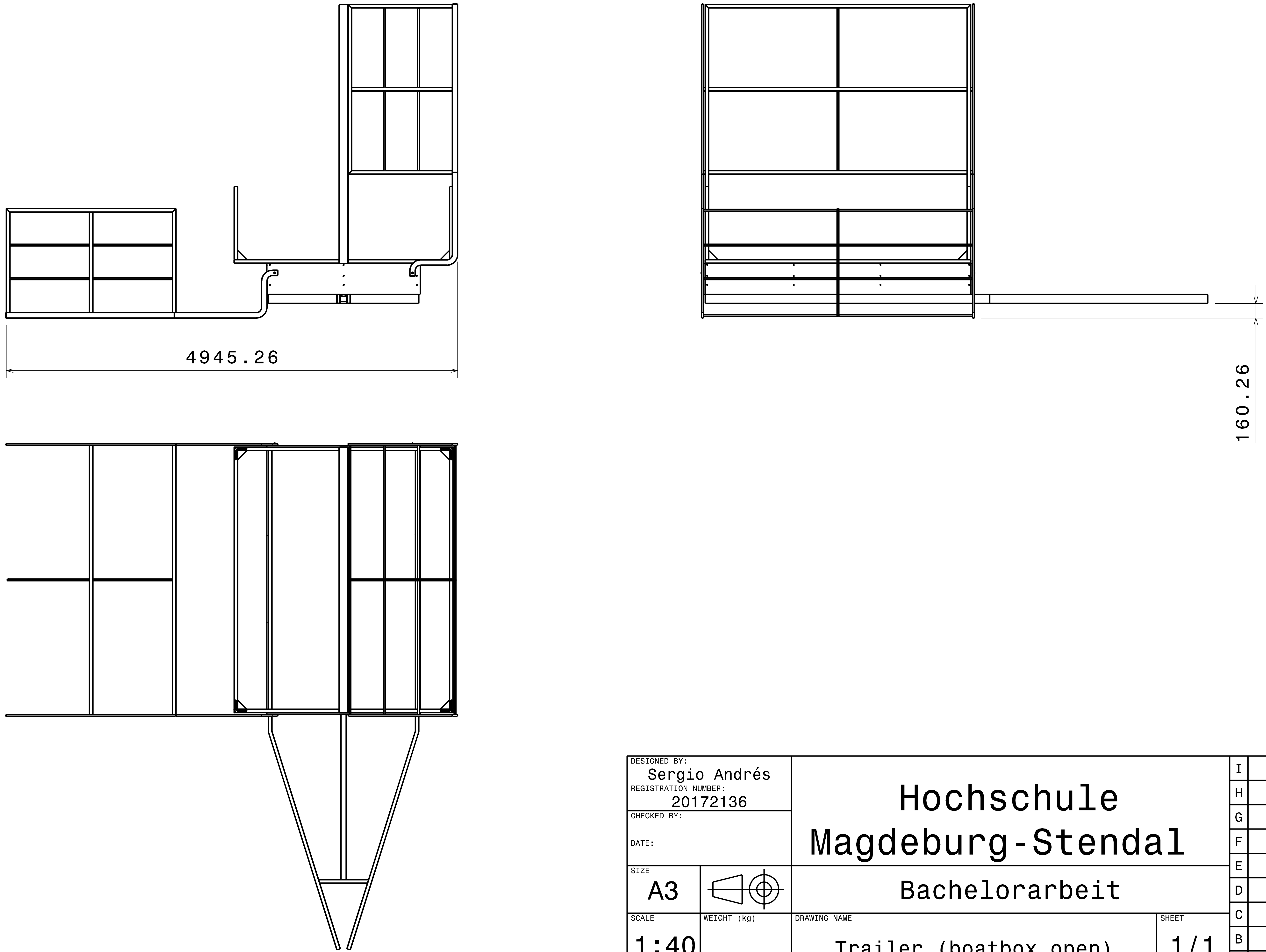
APPENDIX: Drawings

1. TRAILER
2. TRAILER (BOATBOX OPEN)
3. CHASSIS
4. PADDLEBOX
5. SIDE FRAME
6. CENTRAL FRAME
7. BOATBOX



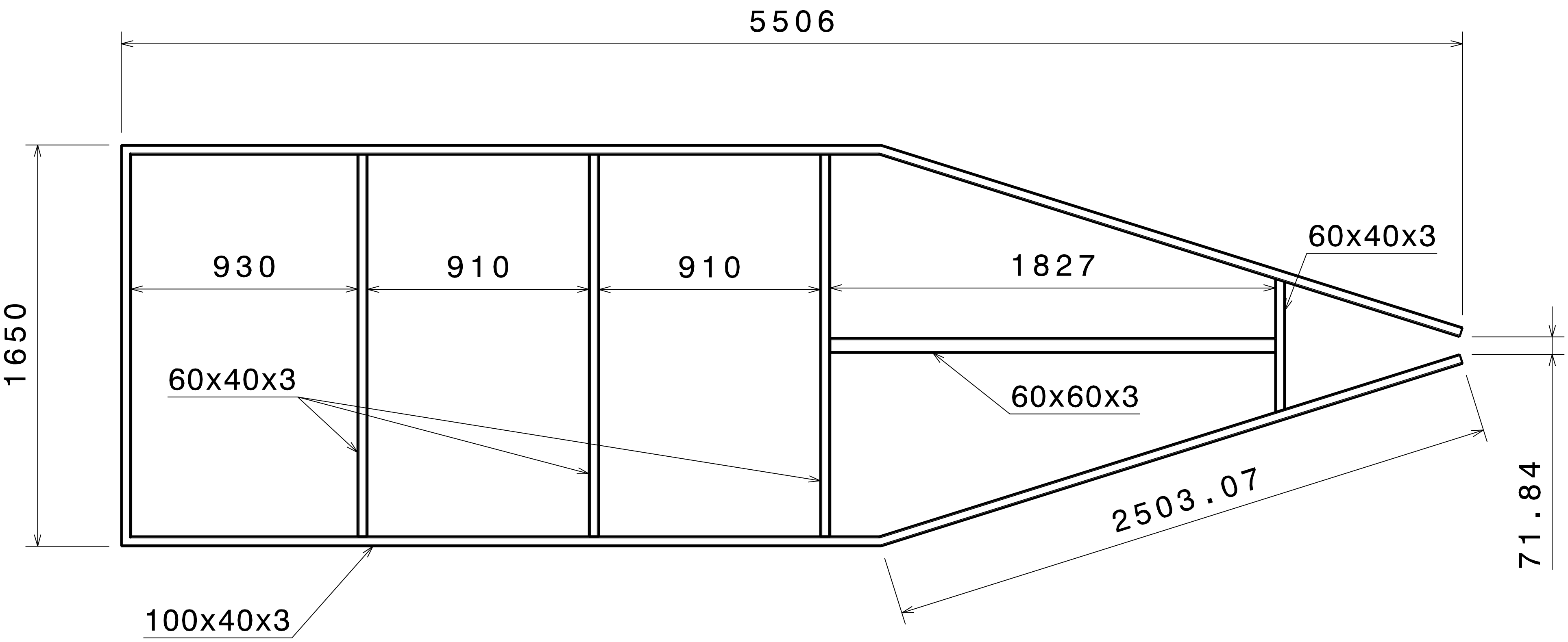
DESIGNED BY: Sergio Andrés REGISTRATION NUMBER: 20172136 CHECKED BY: DATE:	Hochschule Magdeburg-Stendal		
SIZE A3		Bachelorarbeit	
SCALE 1:40	WEIGHT (kg)	DRAWING NAME Trailer	SHEET 1/1

I	_
H	_
G	_
F	_
E	_
D	_
C	_
B	_
A	_

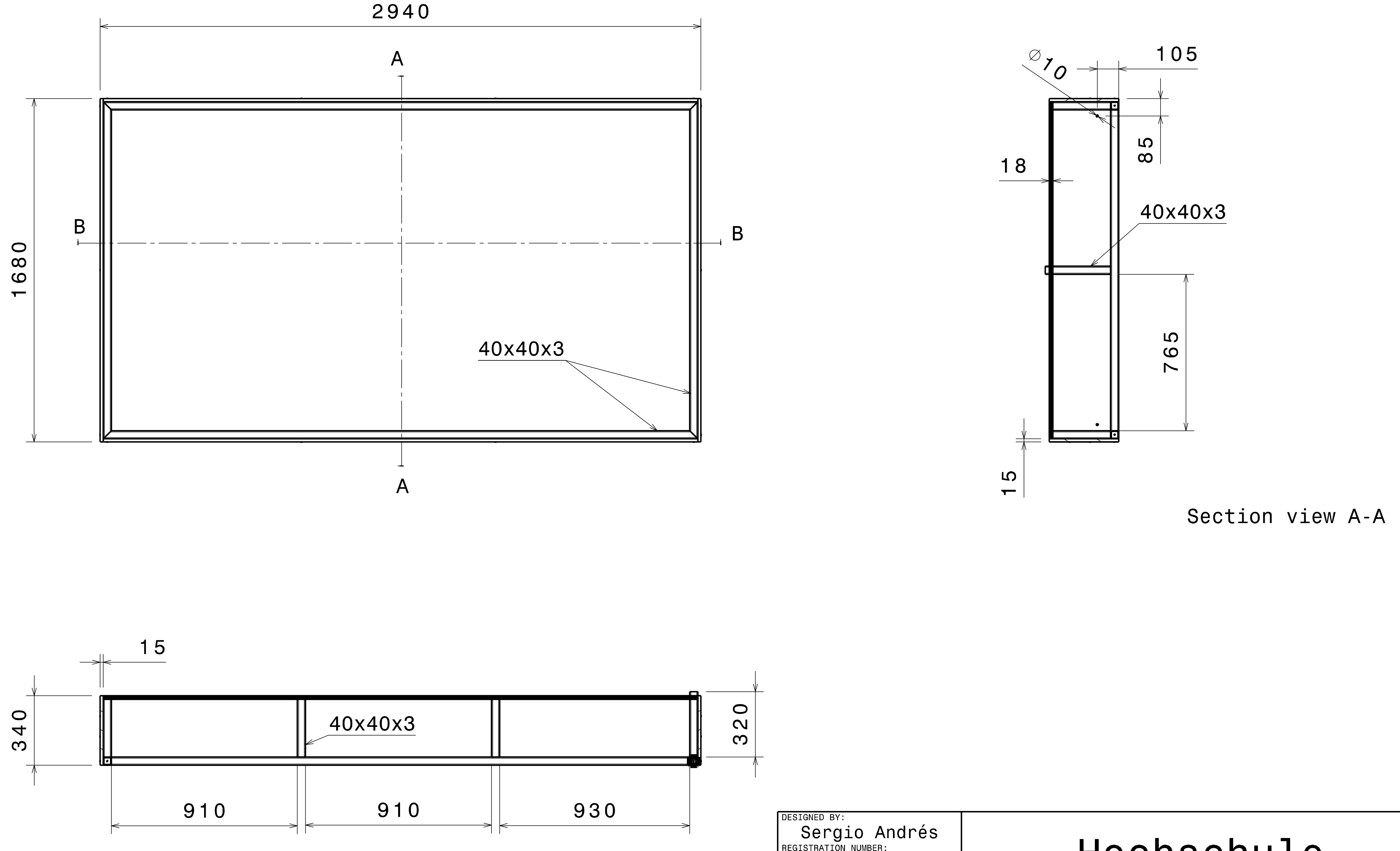


DESIGNED BY: Sergio Andrés REGISTRATION NUMBER: 20172136		Hochschule Magdeburg-Stendal	
CHECKED BY: DATE:			
SIZE A3		Bachelorarbeit	
SCALE 1:40	WEIGHT (kg)	DRAWING NAME Trailer (boatbox open)	SHEET 1/1

I	_
H	_
G	_
F	_
E	_
D	_
C	_
B	_
A	_



DESIGNED BY: Sergio Andrés REGISTRATION NUMBER: 20172136	Hochschule Magdeburg-Stendal			I: _ / H: _ / G: _ / F: _
CHECKED BY: DATE:				
SIZE: A4		Bachelorarbeit		E: _ / D: _
SCALE: 1:25	WEIGHT (kg): 110,84	DRAWING NAME: Chassis	SHEET: 1/1	C: _ / B: _ / A: _



DESIGNED BY:
Sergio Andrés
REGISTRATION NUMBER:
20172136
CHECKED BY:
DATE:

Hochschule Magdeburg-Stendal

Bachelorarbeit

SIZE: A3

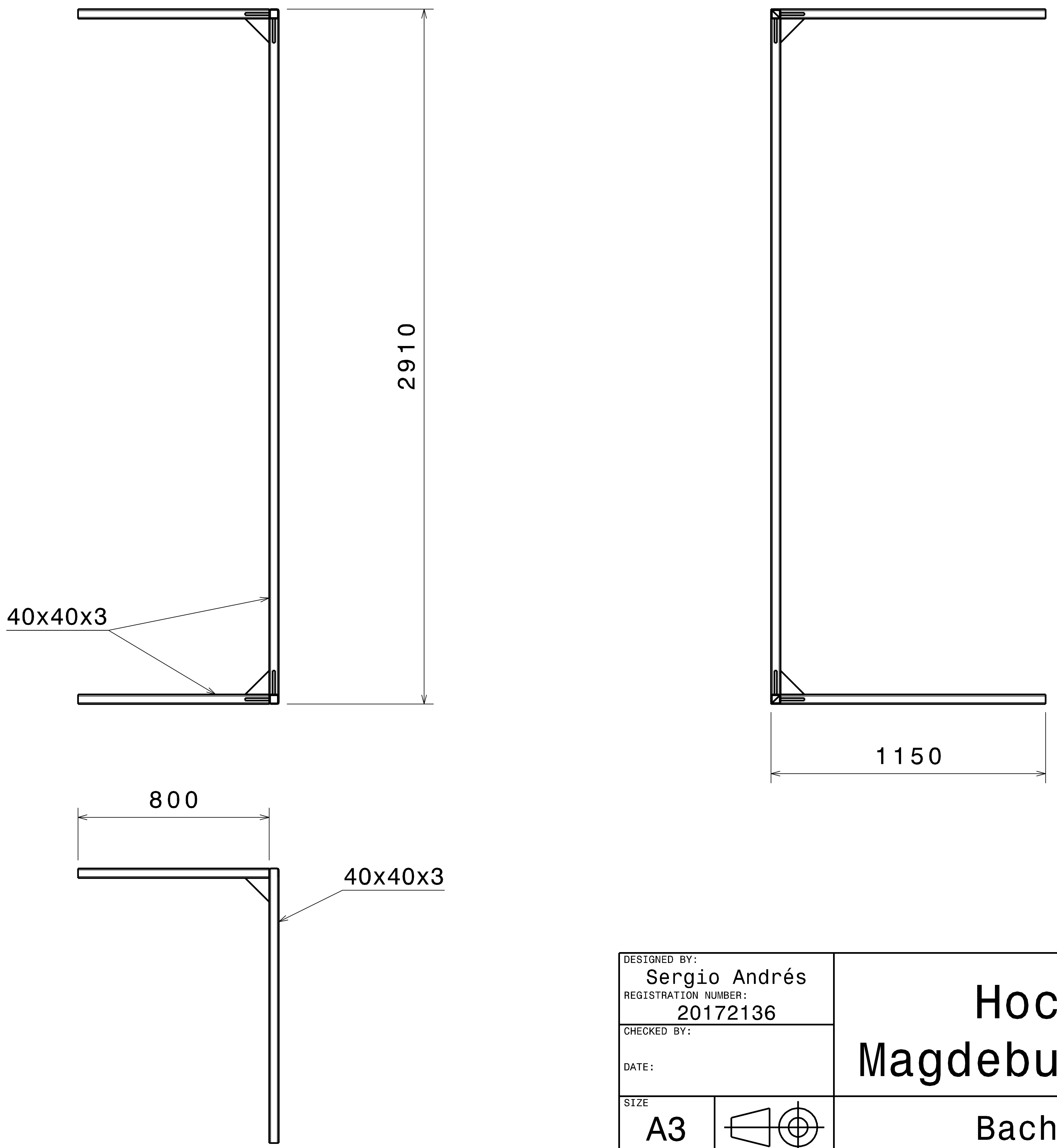
SCALE: 1:20

WEIGHT (kg):

DRAWING NAME: Paddlebox

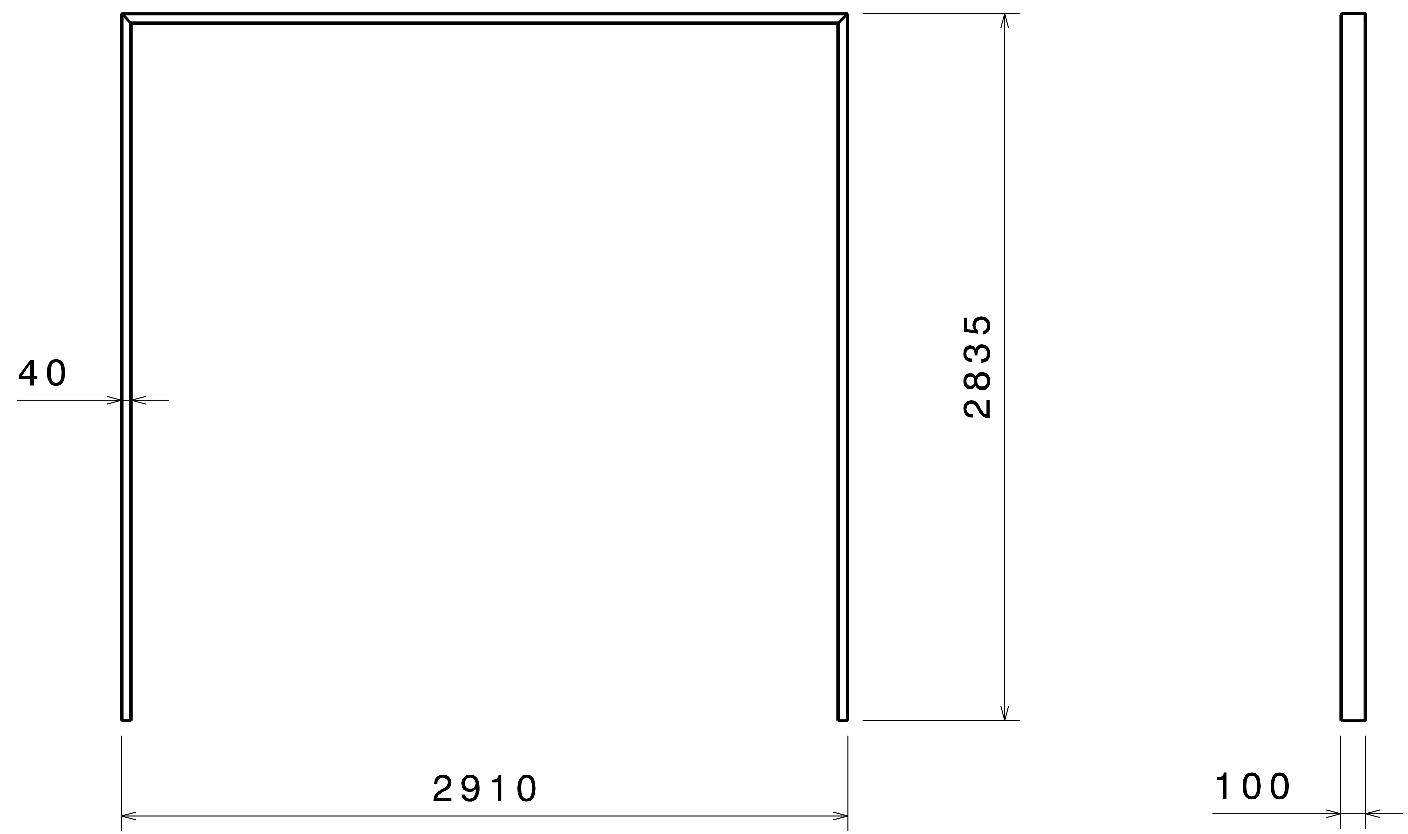
SHEET: 1/1

I	_
H	_
G	_
F	_
E	_
D	_
C	_
B	_
A	_



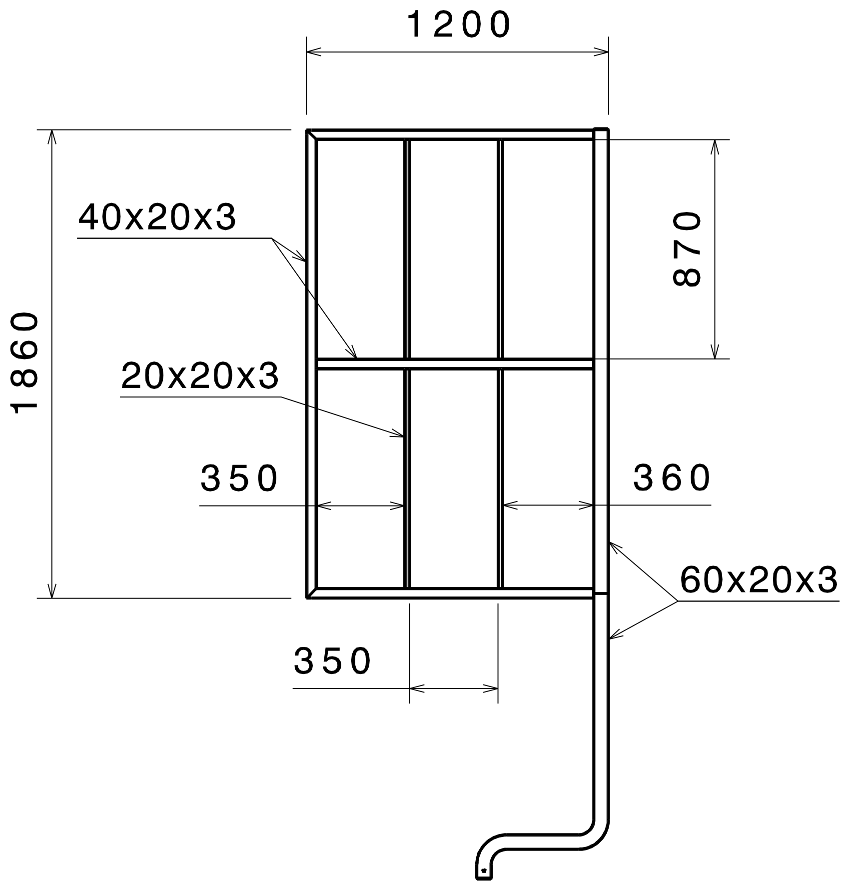
DESIGNED BY: Sergio Andrés REGISTRATION NUMBER: 20172136		Hochschule Magdeburg-Stendal		
CHECKED BY: DATE:				
SIZE A3		Bachelorarbeit		
SCALE 1:20	WEIGHT (kg) 24,77	DRAWING NAME Side frame		SHEET 1/1

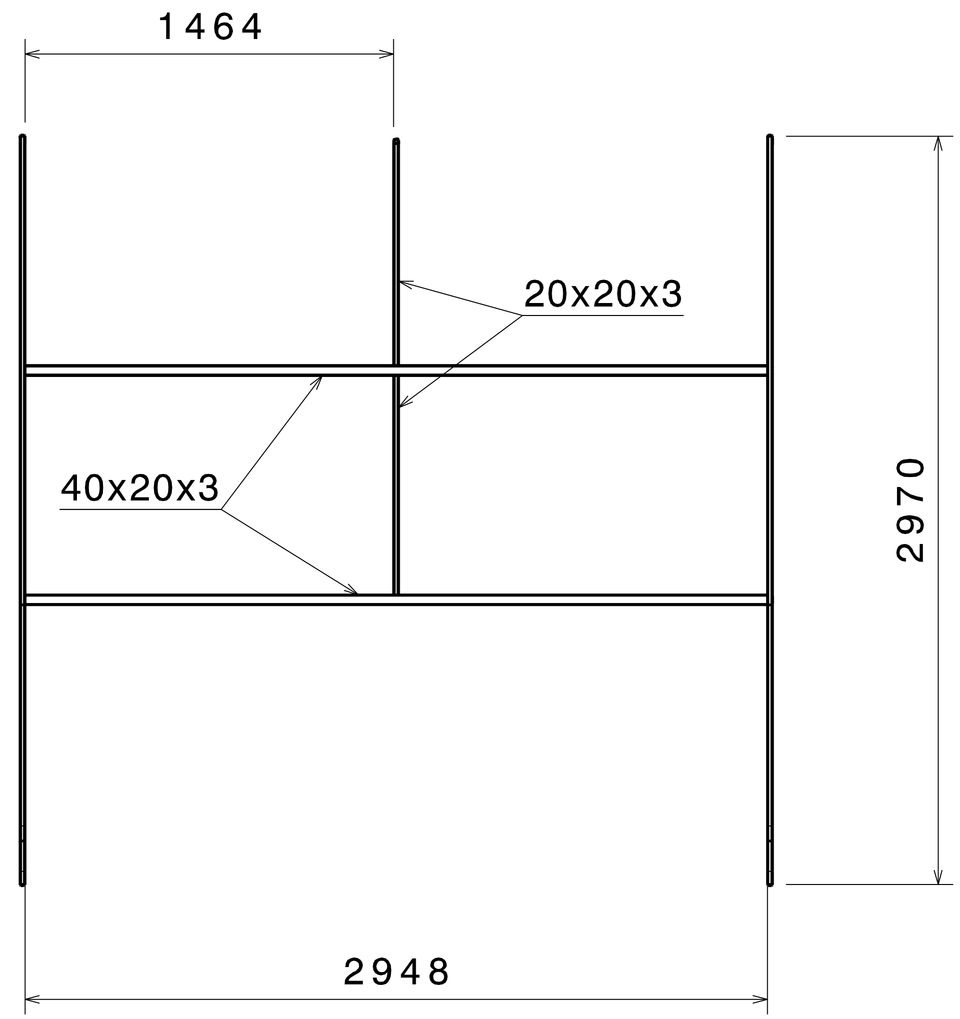
I	_
H	_
G	_
F	_
E	_
D	_
C	_
B	_
A	_

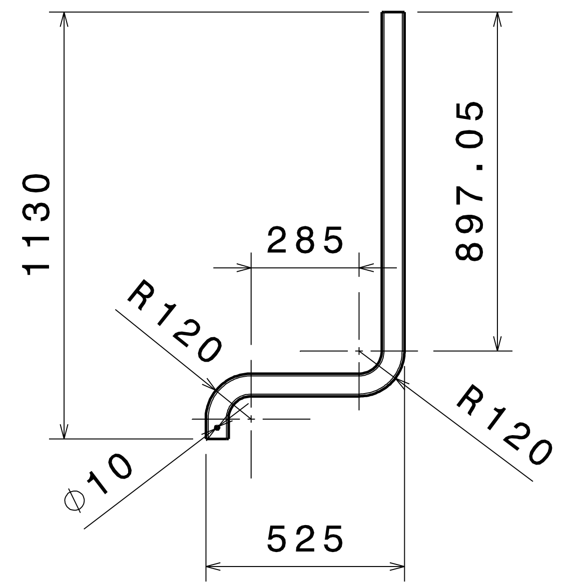


DESIGNED BY: Sergio Andrés REGISTRATION NUMBER: 20172136	Hochschule Magdeburg-Stendal		
CHECKED BY: DATE:			
SIZE A4		Bachelorarbeit	
SCALE 1:30	WEIGHT (kg) 52,36	DRAWING NAME Central frame	SHEET 1/1

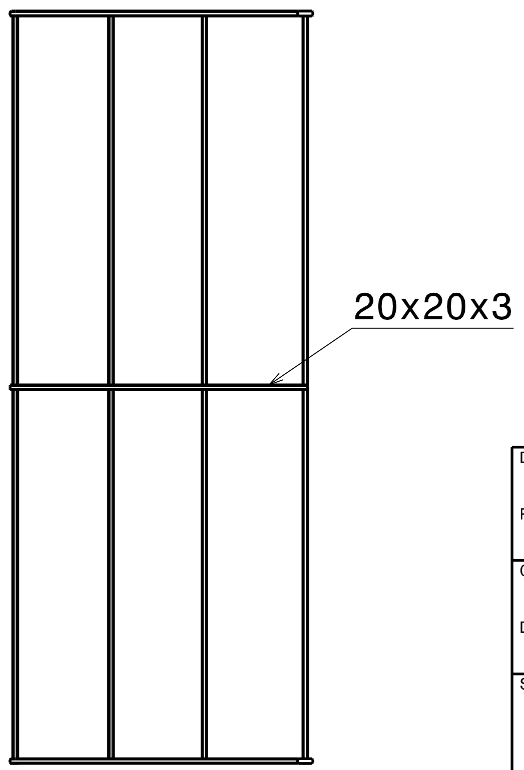
I	_
H	_
G	_
F	_
E	_
D	_
C	_
B	_
A	_







Rib
Scale: 1:20



DESIGNED BY: Sergio Andrés REGISTRATION NUMBER: 20172136 CHECKED BY: DATE:		Hochschule Magdeburg-Stendal	
SIZE A3		Bachelorarbeit	
SCALE 1:30	WEIGHT (kg) 119,2	DRAWING NAME Boatbox	SHEET 1/1

I	–
H	–
G	–
F	–
E	–
D	–
C	–
B	–
A	–