Design of turbine blade fixture for fatigue test simulation

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Designing a fixture for fatigue test simulations of a turbine blade

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Preface

This thesis is written at the department of Mechanical and Marine Engineering at Western University of Applied Sciences (WNUAS). The supervisor of this project's name is Saeed Bikass. Thanks to Runar Blom Sørlid, maintenance specialist at Equinor, for literature references and a lot of knowledge about gas turbines.

A lot of research has been done surrounding gas turbines, while in this project the focus will mainly be to design a fixture that will fit a standard blade which will have a longer fatigue life than the blade.

Abstract

Gas turbines work under severe operational conditions and research shows that fatigue failure is the most common blade failure. The purpose for this paper is to design a fixture for a standard turbine blade which can be used for performing fatigue test and simulations on the blade. There are plenty of research paper about how fatigue is a problem to turbine blades, but hardly little or no work is done on designing a fixture for fatigue test of a turbine blade.

Nine different design ideas is brainstormed and the idea with the best score is taken for futher processing. Different design improvement is conducted with manufacturability, simplicity and the cost in mind. Ansys fatigue tool is used to estimate the fatigue life of the whole assembly, and the results shows that the fixture outlast the blade.

Sammendrag

Gas turbiner er utsatt for svært vanskelige driftsforhold, og forskning viser at brudd relatert til utmatting er den mest vanlige årsak for feil av turbine blader. Hovedmålet med denne forskningen er å designe en armatur til en turbine blade som skal brukes til å utføre utmattelsestest og andre type simuleringer av bladen. Det er mye forskning relatert på hvordan utmatting er til hinder på turbine blader, og lite forskning på det å designe en armatur til en turbine blade som kan brukes for å simulere utmattelsens levetid.

Ni ulike ideer er brainstormet, and det beste ideen fra bestlutningsmatrisen er valgt for videre arbeid. Ulike forbedringer er gjort underveis med tanke på produserbarhet, enkelhet og kostnaden. Simuleringen er gjort i flere trinn bestående av statisk og dynamisk analyser, og resulater er I tråd med forskning og det bekreftet at holderen har bedre levetid enn selve bladen.

Table of contents

Nomenclature (optional)

(V_b)=velocity of the blade

(V_1)=Absolute velocity of the gas at inlet

(V_2)=Absolute velocity of the gas at outlet

(V_{r1})=Relative velocity at inlet

(V_{r2})=Relative velocity at outlet

(a_1)=Absolute inlet blade angle

(a_2)=Relative outlet blade angle

(B_1)=Relative inlet blade angle

(B_2)=Absolute outlet blade angle

(V_{a1})=axial velocity component at inlet

(V_{a2})=axial velocity component at outlet

(V_{w1})=Tangential velocity component at outlet

1. Introduction

1.1 Motivation

Gas turbines are crucial in many applications and produce incredibly great amounts of power. They are primarily used in many large-scale electricity producing stations, in jet engines to provide the required torque for it to fly and in many other applications like in military tanks. Gas turbines are considered favorable due its high power to weight ratio, high fuel flexibility and low fuel usage and environmentally friendly. Most gas turbines have easy design configuration compared to for example reciprocating engines and hence require low maintenance. The demand for more electricity, the shift of low carbon economy and the evergreen aviation industry would mean more gas turbines [1].

Many countries in the world are using today nuclear plant as an effective means of electricity production, and as a result this activity is considered harmful to the environment and could endanger our existence. A better, safer, and a more reliable alternative which makes the job done are the so-called gas turbines. However, gas turbines work under severe conditions that are worth studying to maximize performance and lifetime of the blade. Under operations temperature values can reach over 1500 degrees which can be higher than the melting point of the blade itself, however this can be prevented by for example thermally coating the blade with a better material [2] like a ceramic. In addition to the risk of a blade meltdown, these higher temperatures would overtime also cause creep and oxidation of the blade. When the incoming gas mixtures from the nozzle hits the blade, they induce tensional and compressional forces thereby loading the blade with a cyclic force. This cyclic loading would diminish the fatigue life of the blade, and it is usually the biggest contributor of the fatigue failure of the blade. [3]

Fatigue failure is often triggered in two ways. The low cycle fatigue (LCF) and high cycle fatigue (HCF), and creep rapture [4]. LCF involves applying higher stresses resulting in relatively lower number of cycles usually below 10000 number of cycles, and strain life method is usually used to estimate the remaining life. HCF is the most common type, and the stresses is much lower resulting in higher number of cycles usually above 10000 number of cycles, and the stress life method is typically used to estimate the remaining life [5]. Stresses caused by fatigue loading is usually much lower than the materials yield stress, but they are considered more dangerous than the static stresses. This is because the cyclic loading of the material causes surface defects and overtime forms a nucleation, which causes the crack initiation, and this stage is followed by the fatigue propagation and the final overload would breaks the part. The Surface finish of the part, the type of material and the method of production and among others are the factors influencing the fatigue life of the part.

Gas turbine blades have complex shapes and is usually not an easy task to produce. The most common production method is so called investment casting method [6]. However, this method is expensive and quite time consuming, and it is ideal for large and simple design manufacturing. A new manufacturing method is the metal AM also called 3D-printing. This method is usually much cheaper, and it is ideal for low volume production of small and complex designs. Gas turbine blades have complex shapes and is usually not an easy task to produce. The most common production method is so called investment casting method. [7]

1.2 Requirements

Most of engineering designs have some criteria they must go through to satisfy customer's needs. In this design project a general standard design requirement is considered to evaluate the best suited design variants for the job. Manufacturability is one of the most important of all as the there is no point to design a part that is either hard or expensive to manufacture. Design ideas with an easy geometric configuration is considered favorable than those with advanced geometry, and that ensures that all surfaces to be machined can easily be accessible without the need for advanced or expensive equipment. Tolerances and fits is known cost contributor, and by minimising the number of surfaces and edges in contact of each other, and by integrating a clamping system to hold the part in place instead of using tolerances and fits, the parts manufacturing cost is greatly minimized. The last criteria is the principle of locating and clamping. The fixture should constrain all 6 degrees of freedom of the blade, as this would ensure the right values are feeded to the fatigue machine for further analysis. The tangential- and clamping forces must be aligned in such way that these forces are compensated by the locating elements and this eliminates unnecessary stress caused by the bending of the part to be fixed.

A decision matrix has been used in the evaluations prosses for comparing different ideas. On the vertical column a list over different ideas is presented and on the horizontal column the different evaluation citerias and their respective score is given and the best idea with the highest score has been taken for further analysis.

1.3 Objectives

The main objective of this project is to design a fixture that can be used for simulating the fatigue life and other fatige tests of a turbine blade. It is required that the fixture should not fail under the test, and that fatigue life of the fixture should outlast compared to that of the blade. The following steps summarizes the overall steps used in this study

- The blade type, dimensions
- The blade boundary conditions and loads
- Design of first version (V1) of the fixture
    - Positioning
    - Clamping
    - Material
- Simulation model preparing
- Analyzing the V1 design
- Improving V1 design to V2
- Final optimization
- Full simulation
- Final design and results

2. Litterature review

2.1 General mechanical properties

Understanding and analyzing quite number of engineering terms and their relationships are crucial before engineering anything at all. It is vital to understand under what condition the part would be working under. Mechanical properties usually comes first on the list, and is fundamental in all engineering fields. There are several mechanical properties in materials and in this paper we go through the most relevant ones for our project. The first one is deformation, and is defined as a change in a materials size or volume due to an applied force. When the material is deformed, the atoms are displaced from their atomic position which causes internal forces on neighboring atoms. If the force is not greater than the interatomic forces, the atoms returns to its original position and this is called elastic deformation. However when the interatomic forces are smaller it is termed as plastic deformation [8]. Deformation is a quick process and happens in a very short time, however when it extends over a period of time and the load/stress is kept constant, then a time-dependent permanent deformation takes place and this phenomenon is called creep. Creep deformation is possible in all temperatures over absolute zero, and a given stress level is extremely sensitive to temperature and as a result the higher the temperature the more pronounced creep phenomena is [9]. Stress is another mechanical property, and it is a measure of the ratio of the applied force against the average of the cross-sectional area. A Stress- strain graph is usually presented to show characteristic behavior of materials. Recent studies confirm that the disc-blade connection is the most critical part where highest stress and strain values are observed [10].

2.2 Loads on turbine blades

Understanding the type of loading the material is under during operation is crucial, as this determines the type of stress, magnitude and their direction. Different loading conditions are presented in the figure below to give a better understanding the loading types in turbine blades. Figure (1) shows an overview of the different forces acting on the blade and their corresponding names.

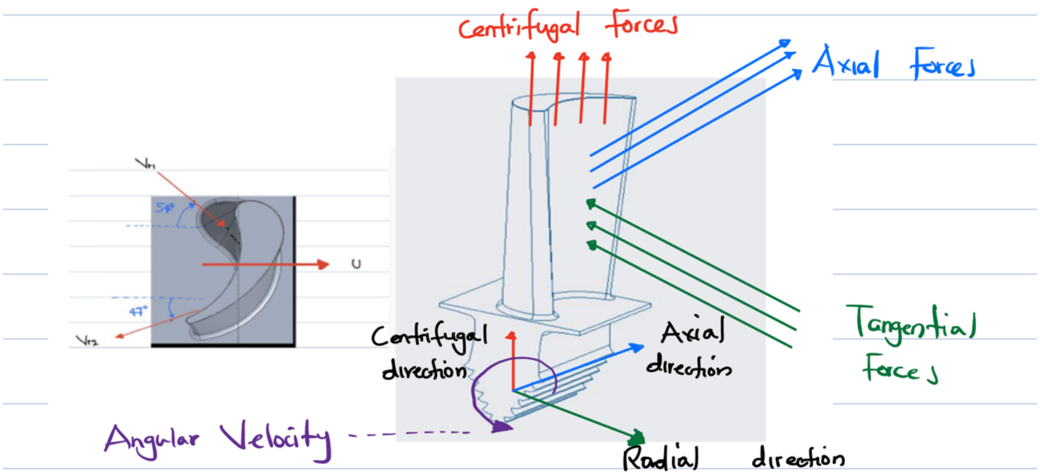


Figure 1: An overview of forces acting on a turbine blade and their directions

Turbine blade has a complex shape and therefore finding which force contribute most to failure of the blade is not easy task. However, a recent study [10] found that the stress caused by the airflow constitute 10% of the centrifugal stress. Another type of bending stress is observed in the study which can be generated when the gravity center of the blade is not aligned with the gravity center of the blade root, the blade is designed in such way that the centrifugal bending is compensated with that of the airflow bending. It is also founded that bending loads (tangential bending) contribute most to the fatigue failure even in smaller quantities than centrifugal forces. Due to the rotational effect the blade experiences centrifugal forces. This is because of the inertia since the blade has mass. So, the blade experiences a tensile force at the tip and a bending stress will also affect the blade [11]. However, this force is constant under normal operations and contribute less on fatigue failure.

2.3 Fatigue, fatigue types and testing methods

The definition of fatigue is the process progressive localized permanent structural changes occurring in a material subjected to conditions that produce fluctuating stresses at some point or points and that may culminate in cracks or complete fracture after enough fluctuations [10]. Low stresses which result in elastic deformation is called high cycle fatigue. While high stresses which result in plastic deformation is called low cycle fatigue. These are both load based. Environment based fatigue is affected by elevated temperatures and surroundings. Fatigue is calculated to estimate the fatigue life of the blade which is tested. This is important to figure out if it can be used and meet the requirements. In a fatigue machine the designed fixture will be attached to the machine, holding the blade horizontally and simulates as if the blade were used in a gas turbine.

There are multiple types of fatigue testing. Material type testing, Structural type testing and Service type testing. Material testing investigates the various environments and geometrical factors etc. When structural testing stress concentrations, fatigue life or fabrication processes is in focus. Last, Service type testing is for reliability or quality verification. Loads are produced by one of the following techniques: mechanical deflections, dead weights or constant springs, centrifugal forces, electromagnetic forces, hydraulic forces, or pneumatic forces. Load choice depends on factors such as frequency, control systems, required forces, costs, and simplifications of working loads [12]. In our case study the only one force affecting the blade during the fatigue testing in this project is the tangential force [13].

All research on the topic is overall about strain/stresses and how different relations cause fatigue. The relation between forces and how they all individually and uniformly affect the blade and tables/curves comparing rotational speed and stress. Three basic factors are essential for fatigue failure to occur. A sufficiently high value of the maximum tensile stress in the applied stress cycle, A high stress amplitude, in the applied stress cycle, and a sufficiently large number of oscillations in the applied stress cycle [7] With a high value of the maximum tensile stress [7]. The material sufficiently also needs a high tensile strength tested three different alloys, titanium alloy, stainless steel alloy and aluminum 2024 alloy. As shown in the tables, aluminum is too deformable. This leaves the titanium alloy and stainless-steel alloy [9].

These three researches have a focus on maximum tensile stress, maximum alternating stress and mean stresses. These are the foundation for fatigue to appear. While strain occurs due to iteration because of the speed of the rotation in the gas turbine [14]. The axial, tangential and centrifugal forces cause stress and is going to be simulated in Ansys. This is different from the research, because in the research temperature and/or modal analysis is also accounted for. Both factors play a vital role in calculating the fatigue life, but for the sake of this study, it is negligible. Therefore creep is not accounted for. The reason being that creep happens due to environmental fatigue like heat exposure. Exposed to a too high temperature, the material may culminate cracks or complete fracture. This is creep

Fatigue is the main issue surrounding turbine blades, which causes a regular maintenance check and eventually switching out the blade. The tangential force causes stress, which later causes fatigue, as well as fatigue properties of the blade material, loading history and environment of operation [14]. As mentioned above, there are High cycle fatigue and Low cycle fatigue. This research contains no thermal stress or modal analysis. Therefore, relevant research to read would be elevated temperature fatigue failure or modal analysis of turbine blade.

3. Presenting and evaluating design ideas

3.1 Description of ideas

Model 1

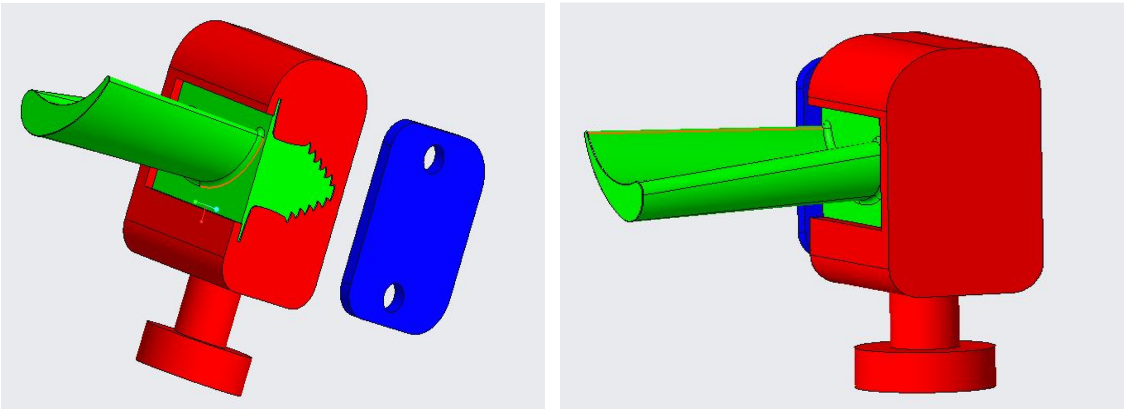


Figure 2: Picture showing design idea 1

Description:	Advantages:
Developed in the first stages of idea making.	1. Simple and easy to install Disadvantages: 1. Difficult to produce 2. No clamping device 3. Requires big investment in tolerencing and fit. 4. Not all degrees of freedom are constrained

Idea 2

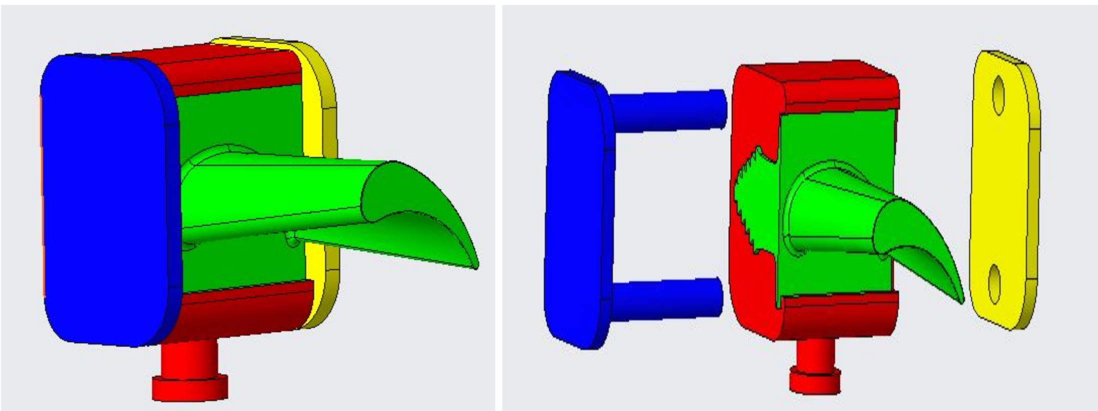


Figure 3: Illustration of design idea 2

Description:	Advantages:
This model is created after improving the first model.	1. Manufacturable 2. Easy to install Disadvantages: 1. No clamping device installed

Idea 3

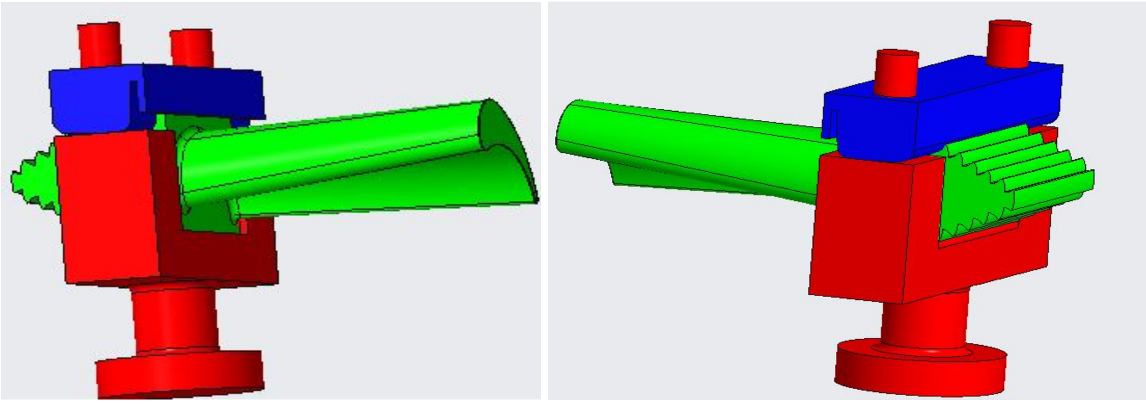


Figure 4: Illustration of design idea 3

Description:
A clamping device was a concern in the previous ideas, and this model is intended to the solve that concern

Advantages:

1. The blade can be firmly held to position by the clamping device.
2. Easy geometric shape

Disadvantages:

1. Small spaces makes it hard to produce the part.

Since the fixture will not hold the blades root, it is not always clear the position of the blade at all times.

Idea 4

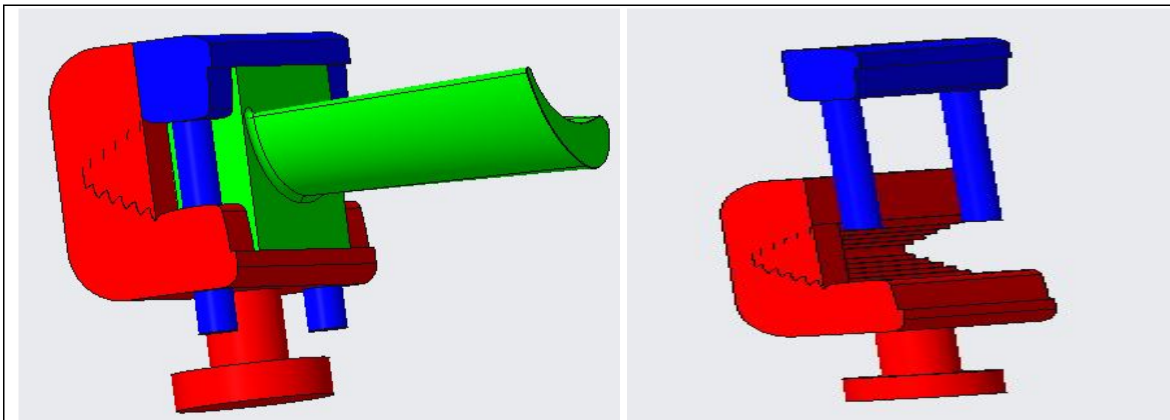


Figure 5: Illustration of design idea 4

Description:
Model two and three is combined in this model, and now we have a precise locating element and a clamping device integrated in this model

Advantages:

1. Easily Manufacturable
2. Easy geometry

Disadvantages:

	No axial forces holding the blade into place

Idea 5

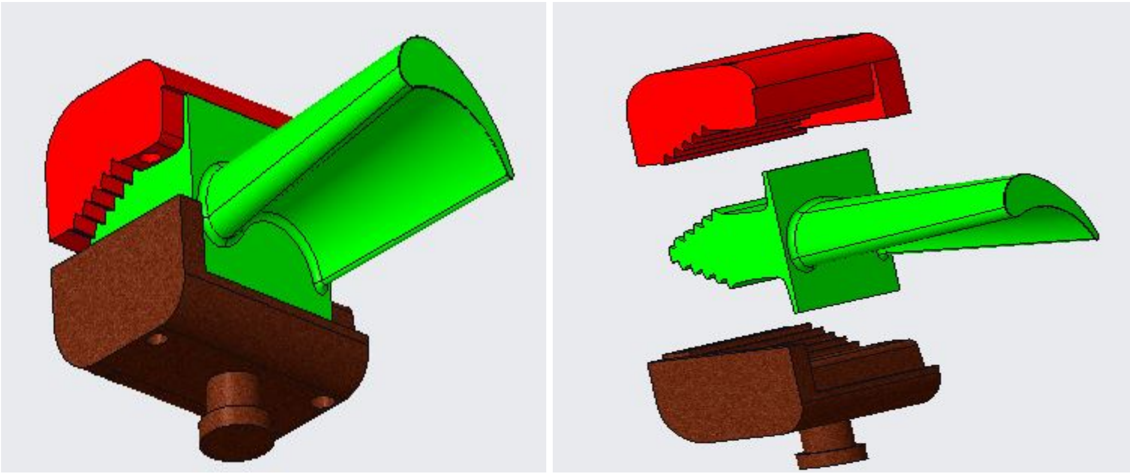


Figure 6: Illustration of design idea 5

Description: Further simplifications of model 4 is done by making the clamping device and the locating element as a one sine part.	Advantages: 1. Easy to install 2. All in one solution Disadvantages: Only the clamping forces hold the whole part in place.

Idea 6

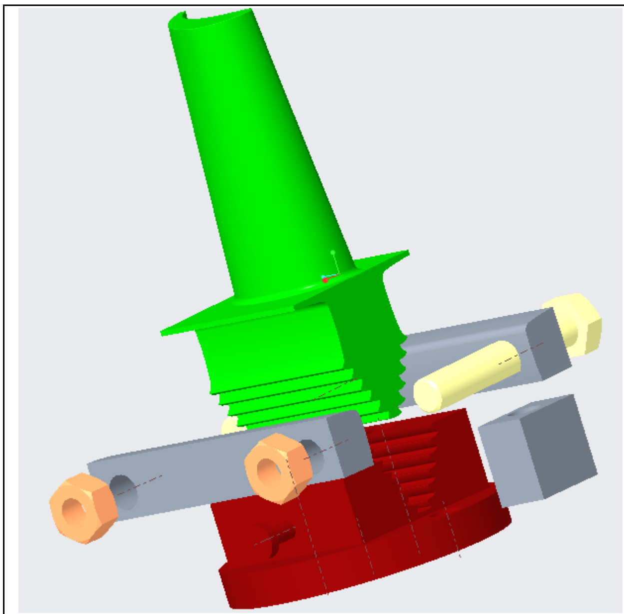


Figure 7: Illustration of design idea 6

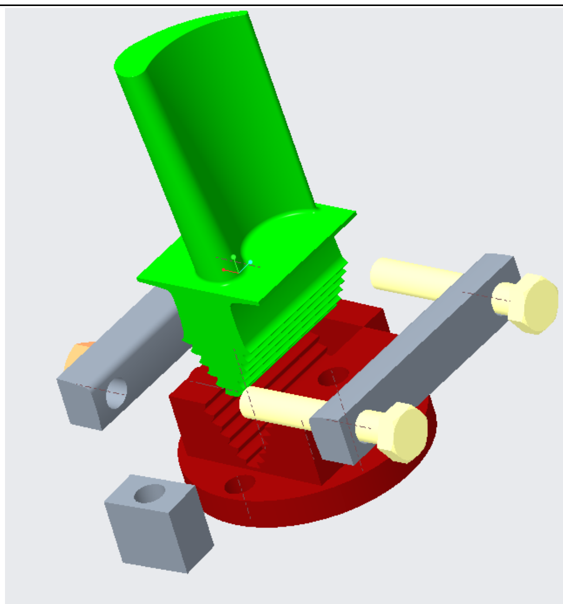
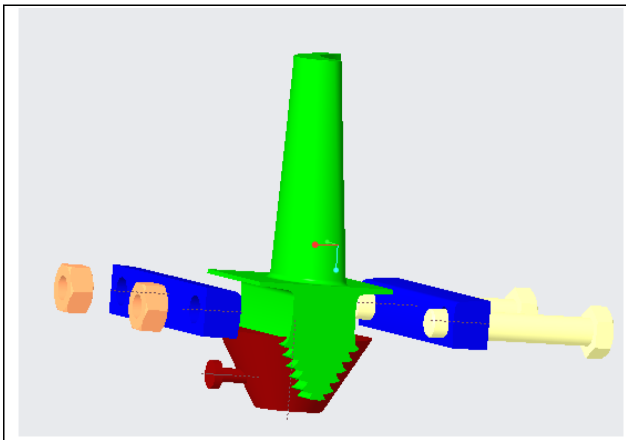
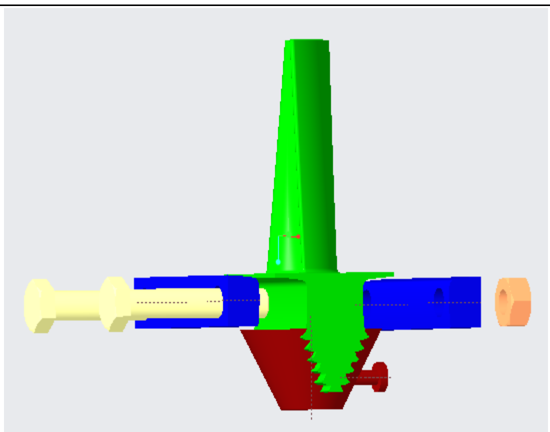


Figure 8: Illustration of design idea 6

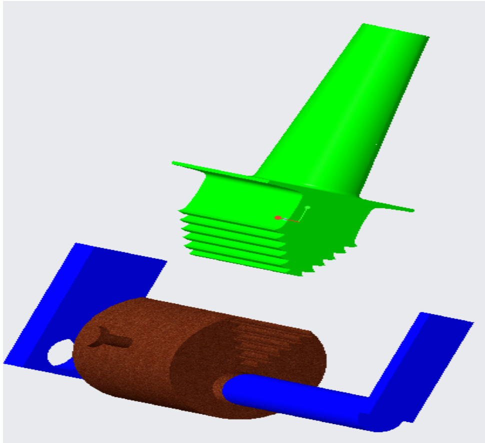
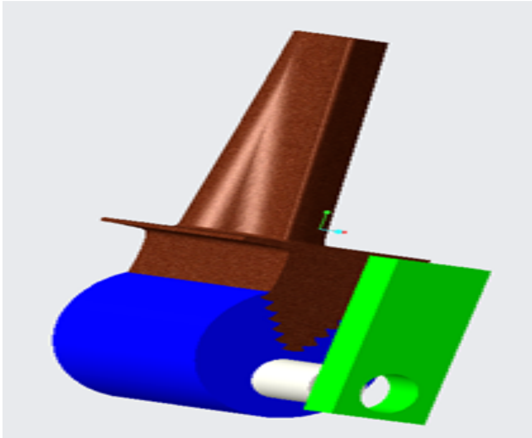
Description:	Advantages:

The circular base is to attach the wall where the blade is inserted and for the screws that is holding the blade in position. In the middle there is a rectangular base for holding the blade, with one clamp on each side in the direction of the forces.	1. Small size Disadvantages: 1. Only tolerance holding the blade No clamping

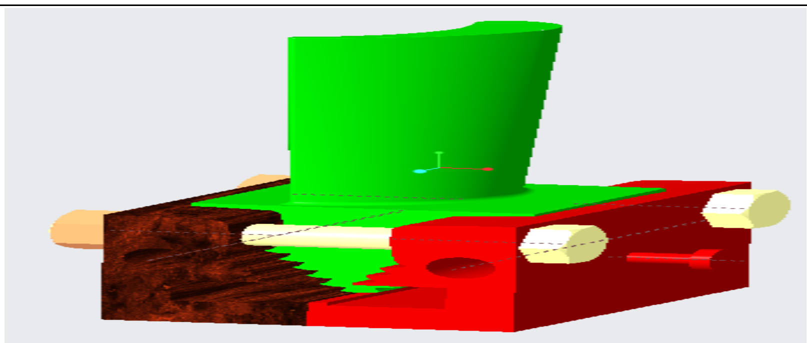
Idea 7

 Figure 9: Illustration of design idea 7	 Figure 10: Illustration of design idea 7
This idea is a cone-shaped fixture. Quite simple, the blade is inserted in the middle and attached with two plates on top, to hold the blade in position. This idea has a bad clamping solution, due to no clamping.	**Advantages**: 1. Compact and simple **Disadvantages**: 1. Only tolerance holding the blade No clamping

Idea 8

<table>
<tr>
<td>
Figure 11: Illustration design idea 8</td>
<td>
Figure 12: Illustration of design idea 8</td>
</tr>
<tr>
<td>Description:
Both where the blade is inserted, and the base of the fixture is a circle. To keep the blade in the correct position, there is a circle underneath the "Christmas tree" * which a wall will be attached on each side of the blade. For clamping there is one plate on each side, with holes to screw them together to hold the blade in the direction of the forces.</td>
<td>Advantages:
1. Simple
2. Manufacturable
Disadvantages:
1. No clamping
2. Not all degrees of freedom is constrained</td>
</tr>
</table>

Idea 9

<table>
<tr>
<td colspan="2">
Figure 13: Illustration of design idea 9</td>
</tr>
<tr>
<td>Description:
A rectangular fixture with a spot for the bottom of the Christmas tree, and two more tracks to make sure the blade is attached. There will be one clamp on each side of the blade, which will hold the blade in the correct position.</td>
<td>Advantages:
1. Easy manufacturable
2. Simple
Disadvantages:
-</td>
</tr>
</table>

3.2 Analysing different design ideas

A table of matrix is used to evaluate the nine ideas brainstormed. A scale 1-6 is used to assess the ideas, and value of 6 meaning best. Figure 14 shows the best idea having the highest score.

Proposed Variants	Simplicity	Ergonomic	Manufacturability	Need for tolerences	Locating and clumping	Total score
Idea 1	4	3	2	1	1	11
Idea 2	4	4	4	2	1	15
Idea 3	3	4	2	2	3	14
Idea 4	3	3	4	3	4	17
Idea 5	4	4	4	4	5	21
Idea 6	3	3	2	2	2	12
Idea 7	5	3	3	1	1	13
Idea 8	4	2	3	1	2	12
Idea 9	3	3	5	4	4	19

Figure 14: A decision matrix table used to asses the ideas

3.3 Idea chart

In the ideamaking prosses nine ideas are brainstormed. The figure (15) shows an overview of the ideas and which can be a candidate for engineering.

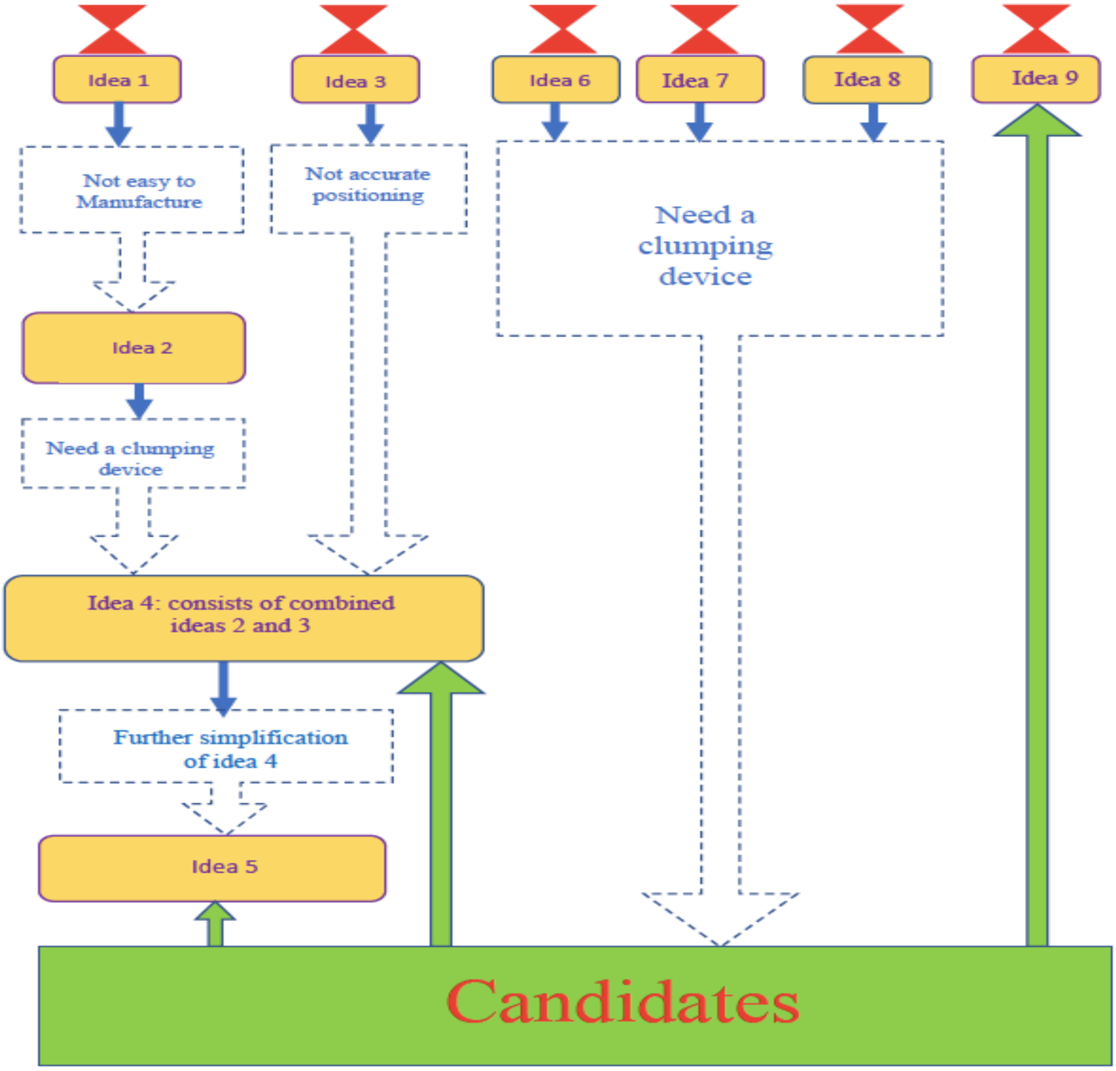


Figure 15: Idea chart and their relationship

4. Designing in Creo

Going from the idea-stage to a substantial design, it is important to notice the details, due to the small appearance of the fixture. The focus in this chapter is creating a 3D part from the proposed ideas in the table (14). The designed parts are further assembled in Creo parametric and termed as the first version of the fixture design (V1), and the dimensions of the parts are first taken relatively to the blade and then a more realistic sizes are chosen after simulations in Ansys, and the final fixture design is termed as second fixture design (V2).

After choosing the best idea (Idea 5), further design simpification is required to reduce manufacturing costs and also avoid costs related to tolerences. There are especially two flaws in the design with focus on manufacturability. The first is about the simplification of the fixture root, and the second is about diving main parts in V1 into small parts so that all surfaces can easily be accessible for manufacturing. A turbine blade has generelly a complex geometry with the root having the most advanced geometry, and the reason is that the root of the blade is designed in a such way that it is very accurate and should be used for postioning. However this doesn't necesserelly mean that the fixture should have the same root geometry so as to hold it. The complex root geometry can be simplified into a cylindrical shapes which inturn eases the cost of manufacturing, and the following picture shows cross sectional view the root contact between the blade and the fixture and the different geometric simpilifications which is considered.

The second issue with manufacturing costs in mind is braking up the fixtures main parts into small parts so that the manufacturing equipments have adequate working space. Figure (16) shows the fixture design V1 as a one parts before manufacturing considering and figure (17) shows fixture design 2 after after deviding it into small parts for easy manufacturing.

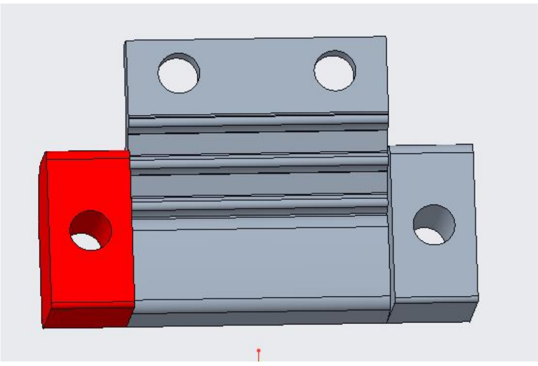


Figure 16: Fixture design V1

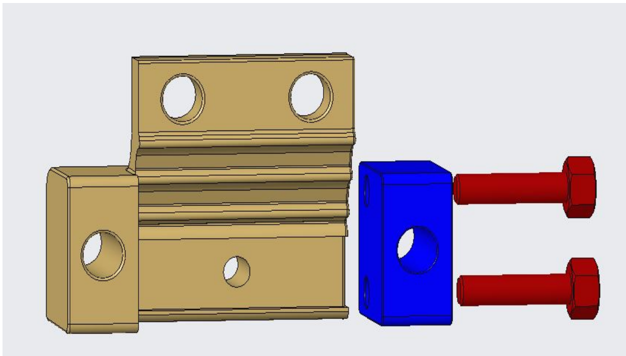


Figure 17: Improved V1 to V2 due manufacturability

Another factor influencing the cost is tolerence, and increasing the number of surfaces in contact of each other would intern increase the cost assosiciated with tolerences. On the V1 design when the two fixture parts are clamped together many unnecessery surfaces come in contact with the blade creating more investment on machining and hence tolerences, and to avoid that many mechanisms are carefully investigated, but at last the chosen solution is one where the screw is moved by a nut outside the fixture, resulting in the inner wall moving from or to the blade. By making this change, the tolerance is considerable marginalized. Figure (18) shows the blade-fixture root connection of V1, and the figure (19) and (20) shows lifting mechanism to manually adjust the hight of unwanted surfaces after the part is calmped together.

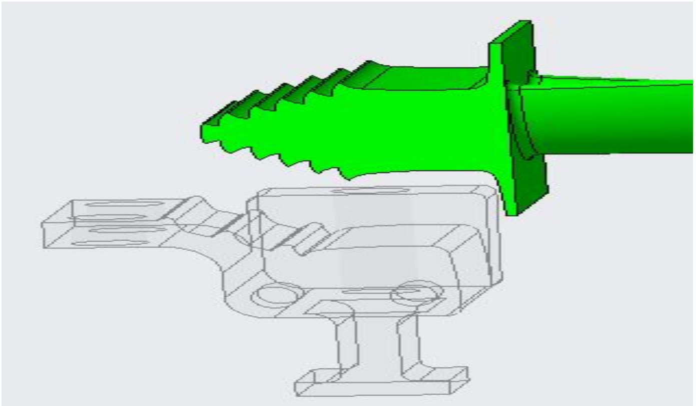


Figure 18: Fixture-blade root connection of the V1

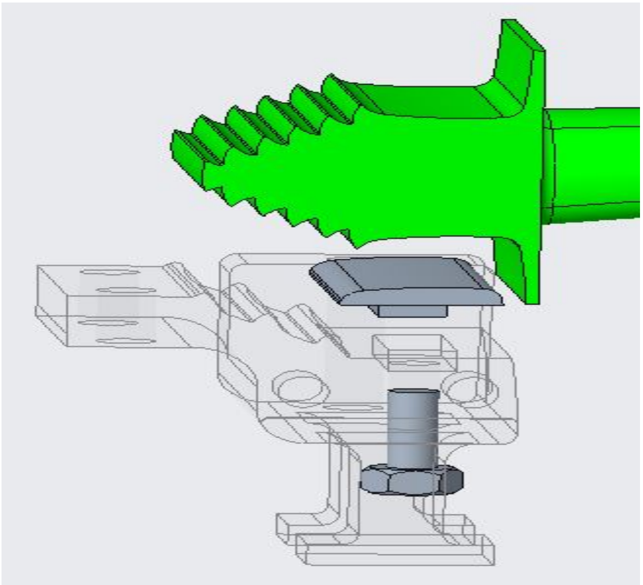


Figure 19: Fixture-blade root Lifting of V2 with mechanism 1

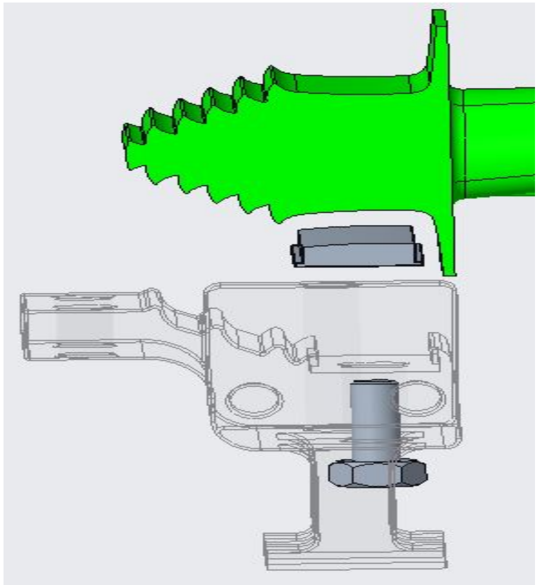


Figure 20: Fixture-blade root Lifting of V2 with lifting mechanism 2

An overview of the designing process used in this project is summarized in the picture (21). The problem is first defined and then different ideas is brainstormed and then evaluated to each other.

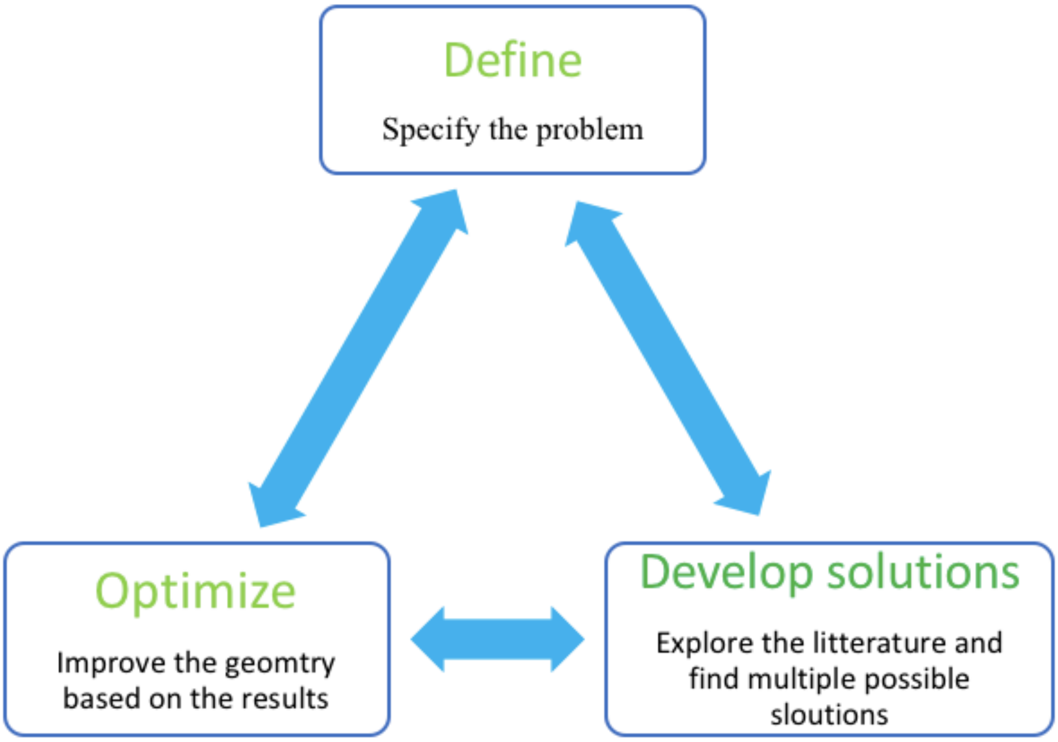


Figure 21: An overview of how the designing process is done

5. Boundary Conditions

5.1 Inlet and outlet velocity triangle

The inlet and outlet velocity triangle diagram can be used to find alle the velocity components of the blade which can further be used to calculate the forces acting on it. The figure (22) shows the setup of a velocity diagram and their corresponding angles.

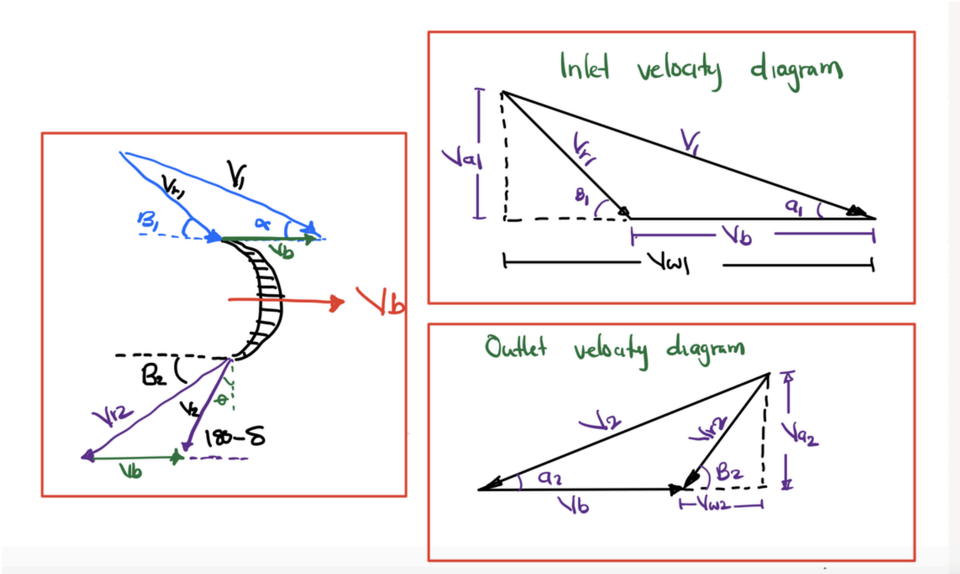


Figure 22: Inlet and outlet velocity diagram of gas turbine blades

The inlet and outlet velocity can further be constructed as combined inlet and outlet velocity diagram to better show the required components for force calculations. Figure (23) shows the combined inlet and outlet velocity diagram.

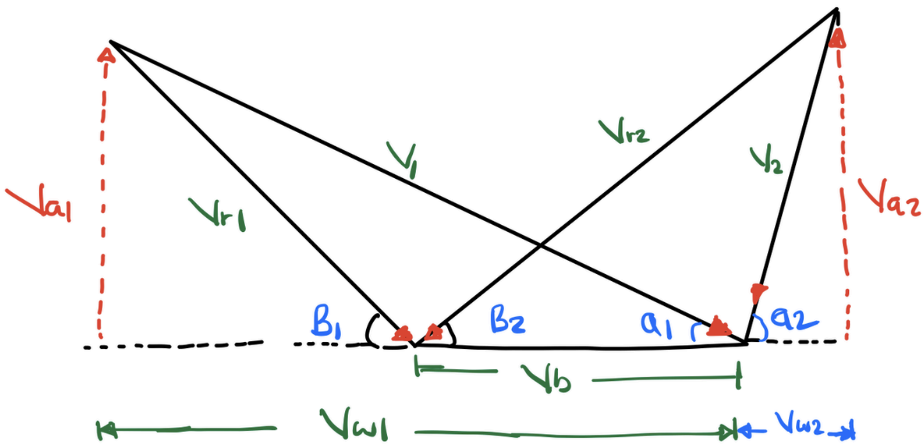


Figure 23: Combined inlet and outlet velocity diagram

1.Velocity of the blade (V_b)

$V_b=(\pi*D_m*N)/60$...............$V_b=989$ m/s

2.Maximum nozzle velocity at inlet (V_1)

$V_1=(V_b*2)/\cos(a_1)$…..........$V_1=2106$ m/s

5.2 loads and directions

As discussed in the literature review there are two forces acting on a turbine blade. The force generated due to the high velocity spinning of the blade which is termed as the centrifugal force, and the force generated due to the high velocity expanding gases hitting the blade surface and this has two component. these two components are further termed as axial force, and tangential force.

1.Axial: Which is dependent on the angle of the blades, number of rows and type of gas. And has the same direction as the axis of the rotor. This force should be as low as possible since it has no use for the turbine.

2.Tangential: The tangential component caused due to the force induced by the expanding gas, and it is the one causing the rotation of the rotor hence the torque of the machine

3.Centrifugal Force: This force is always biggest of all as it is dependent on the rotational speed of the rotor and has a radial direction. This force can be demonstrated as tension force applied on the blade.

Theoretical calculations of these forces can be calculated, and table (1) shows the equation and the procedures used for calculation.

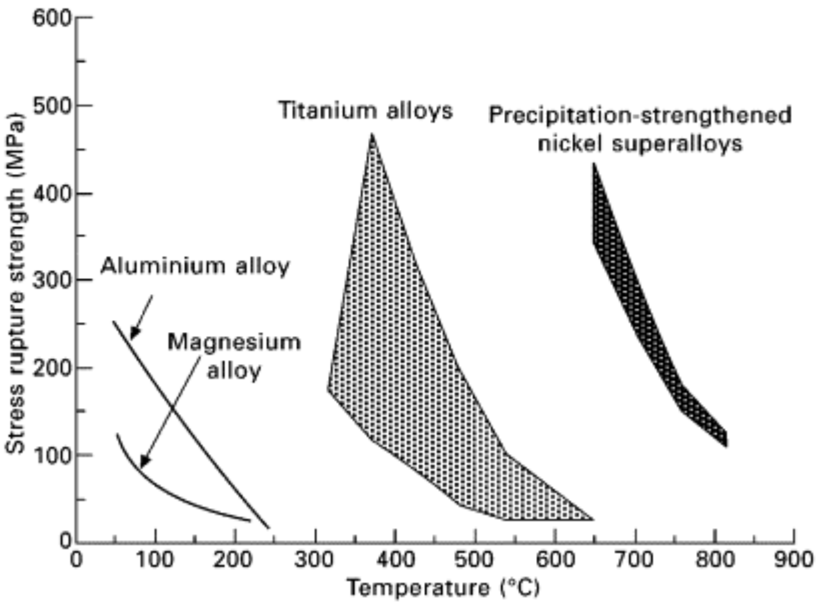
Calculation of axial forces	Calculation of tangential forces
Axial forces (F_a)=Mass flow rate * (V_{a1})-(V_{a2}) =670kg/s*(719-647)m/s =2520N F_a/Blade =28N	Tangential forces (F_t)=Mass flow rate * (V_{w2})-(V_{w1}) =670*(1978+99)m/s =72730N F_t/Blade=808N

Table 1: Calculating the tangential and axial component of the resultant force

5.3 Material selection and meshing

5.3.1 Material Selection

Due to a variety of materials that can be selected this is a choice based on fatigue life and achieving a high safety factor. Due to the forces affecting the fixture and blade from the fatigue machine, a high and an ideal safety factor is achieved between 700-1000 MPa. A safe, but sturdy choice would be the nickel-based superalloy the blade is made of. For this project, different steel alloys were up for discussion.



[15] where the picture is taken from

Nickel-based super alloys are great for withstanding elevated temperatures, but in this assignment, heat is neglected. Therefore, carbon steel alloys were taken into consideration. But the oxidation of the material with the amount of carbon required for a high yield strength, would lower the fatigue life. Next solution were the different steel alloys which looks perfect for the use of the fixture, due to the variety of yield stress and ultimate tensile strength. Steel alloys have a vast number of yield strength varieties which makes it a valid material for this field of work. Steel alloys corrode in air and sea water, so these materials need a protection- painting, plating, or tinning. [16] To conclude, ASTM A533 is the decided material for the fixture. The reason being, as shown in the simulations, the safety factor, maximum stress and deformation is within the limits for a long fatigue life. Typical material used in turbine blades is Inconnel 713 LC, and the S-N table is retrieved from a recent study [17]. The S-N diagram for ASTM A533 is generated from another recent study [18], and these data are used in ANSYS as an input for fatigue calculations. The following figures shows the properties of the different materials used in this project.

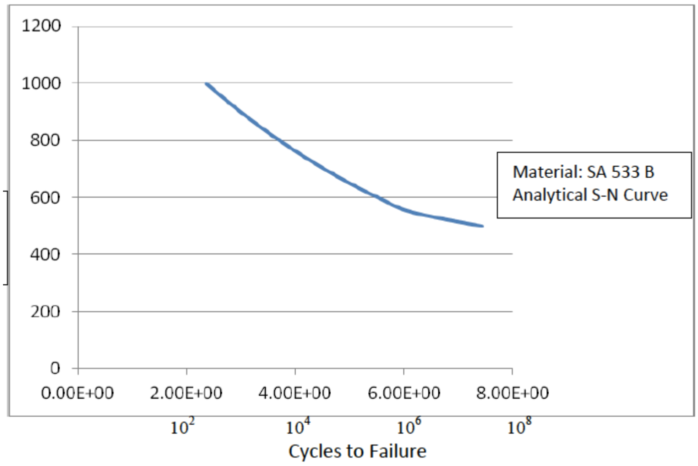


Figure 24: The S-N diagram of the fixture material (ASTM A533)

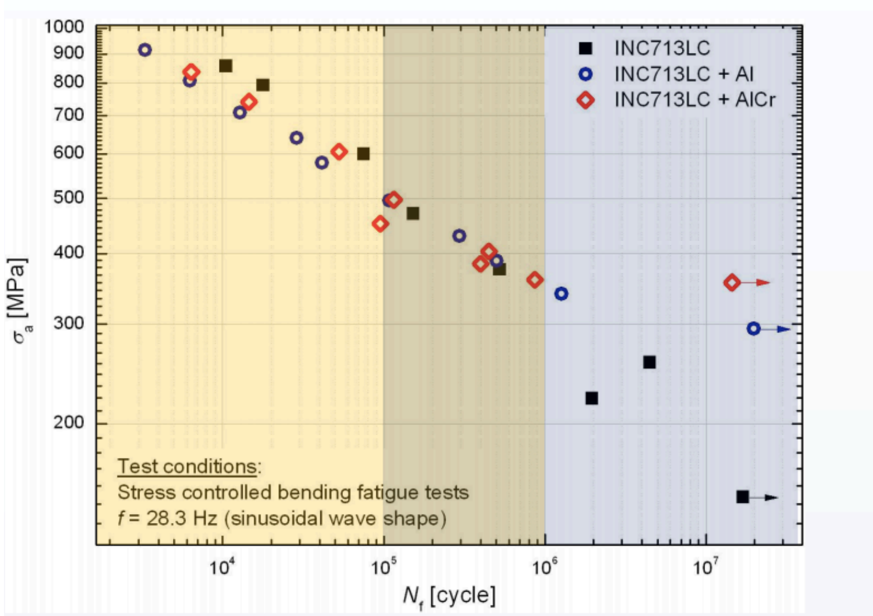


Figure 25: The S-N diagram of the blade material (Inconnel 713 LC)

Material properties of Inconnel 713 LC and ASTM A522

	Inconnel 713 LC	**ASTM A533**
Modulus of elasticity	200 Gpa	200Gpa
Density (Kg/m^3)	7850	7850
Yield strength (Mpa)	690	450
Utimate strength (Mpa)	760	690

5.3.2 Meshing

The geometrical shape of the blade as well as the fixture design is complex, and the model has many contact places. Therefore a fine mesh is chosen to give a better interpretation of the results, and a body sizing method with element size of 1mm on bolt and nuts, and 2mm on the rest is used to make a fine mesh. After generating the mesh 457969 elements and 699920 nodes are used.

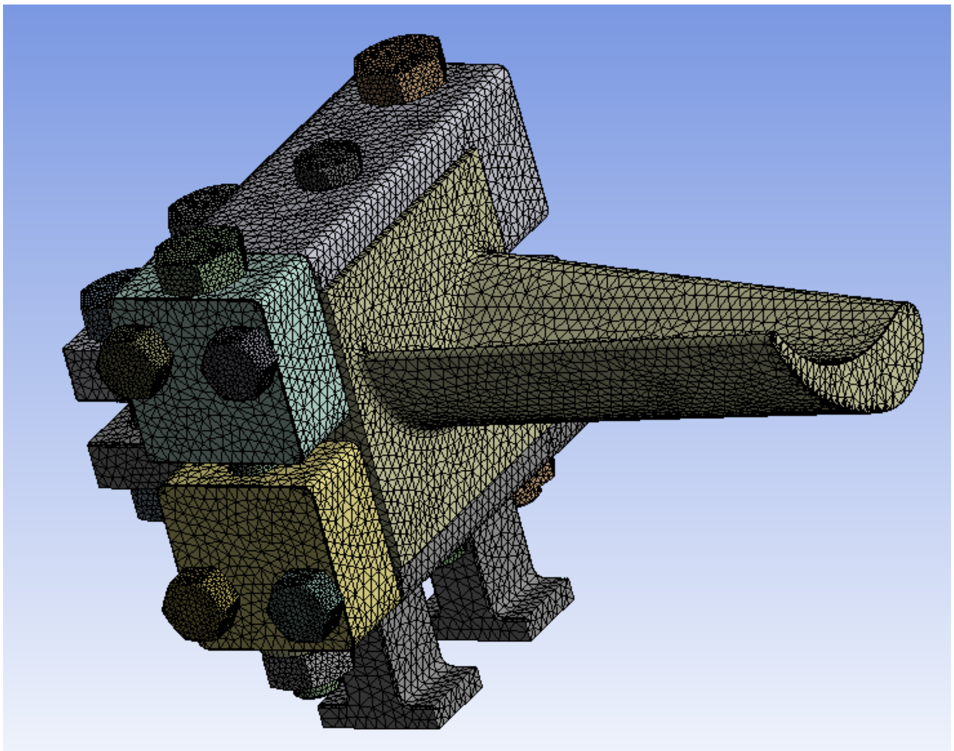


Figure 26: A picture showing the applied mesh

6. Simultions, Results and Conclusions

6.1 Simulation

The blade experiences a combination of mechanical stress, creep, thermal stress and vibrations and the choice of the material must be made in such way that the material can withstand all these stresses under its operations. However, the fixture does not operate under the same boundary conditions as of the blade. Only mechanical stresses are considered in the fixture design, and vibrations caused by fluttering of the blade is neglected as the amplitude of the frequency is considered constant. The reason being the material which the blade is made of is not necessarily the same as of the fixture. Typical material used in gas turbine blades is the Inconel 713LC, and the S-N diagram for this type of material is derived from this study. The S-N diagram is an input in ANSYS and used to compute the fatigue properties in the high cycle fatigue and the stress life method is used in this regard, however if the interest is finding the fatigue properties in a low cycle fatigue, then the strain data is required, and the strain life method is used for calculation.

Eight bolt connections hold the whole assembly together and thereby giving a special attention on modeling the bolt connection is considered a key step in this study. Three different methods can be used to simulate a bolt connection in an engineering design. The bolt can be simulated as a beam connection, line connection or as 3D bolt model. The bolt dimensions are modelled under international standards () Making a 3D model of the bolt is the most accurate and easiest, However the bolt without thread is used for simulation and gives reliable data for further analysis.

Now that the blades material, the method of bolt modeling, and the contacts are defined, and all boundary conditions are applied the first simulation is done with structural steel as the default material for the fixture. The simulation is divided into two stages. The first being running the model on ANSYS statical tools and check magnitude of Von-mises stress and factor of safety, and the second being checking the fatigue behavior by calculating the life of the part. The criteria are that the model must pass both these steps for it to be considered as the final design. After the model has passed the first step of analysis which is static analysis, the fatigue tool in ANSYS is further used to calculate the fatigue life of the part. However, it is assumed that the cyclic loading is symmetric and that the mean stress is 0.

6.2 Results

The first simulation is carried with Ansys default material assigned with M6 bolts followed by another one with M8 bolts. The results shows that both simulations give a factor of safety less than one, and therefore the setup would not proceed to the second analysis which is fatigue analysis. Figure (24) and figure (25) shows the factor of safety of both simulations.

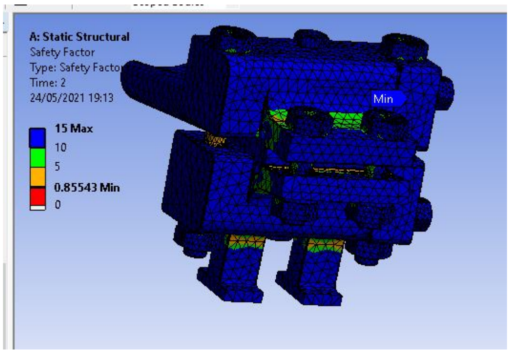


Figure 27: Factor of safety of the fixture with 9mm bolt hole and default Ansys material assigned.

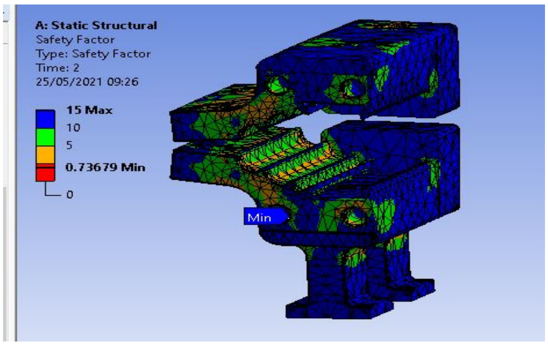


Figure 28: Factor of safety of the fixture with 7mm bolt hole and default Ansys material assigned

Further simulations are done with improved bolt quality and with a much stronger material, and this process is repeated several times until the desired results are achieved. A clearance of 1mm is also created between the bolt shaft and the fixture hole to overcome the high bending stress. The last material used for the simulation of the fixture is a steel alloy called ASTM A533 grade b, and its corresponding mechanical properties are presented on the material selection. Figure (26) and figure (27) shows the corresponding factor of safety after simulation with the new material.

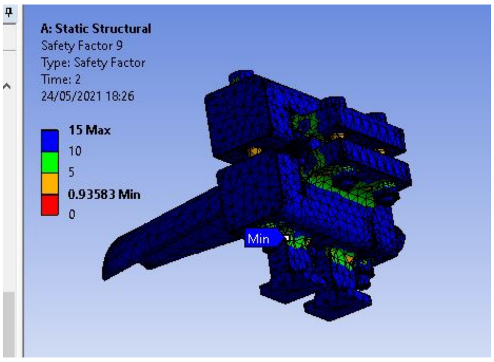


Figure 29:Factor of safety of the fixture with 7mm bolt hole and ASTM A533 assigned.

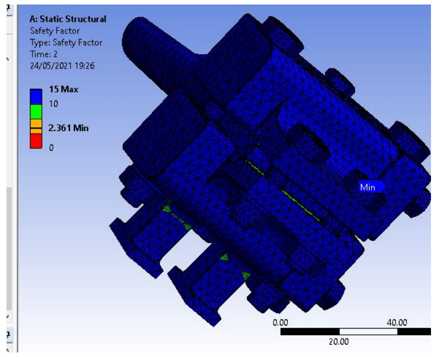


Figure 30: Factor of safety of the fixture with 9mm bolt hole and ASTM A533 assigned.

Figure (27) shows that the structure is safe and that the factor of safety is over 2, and in that regard fatigue analysis can be initiated. The life of the fixture with both the M6 bolts and M8 bolts is calculated to compare them. Figure (28) shows the fatigue life of the fixture simulated with M6 bolts, while figure (29) shows the life of the fixture simulated with M8 bolts.

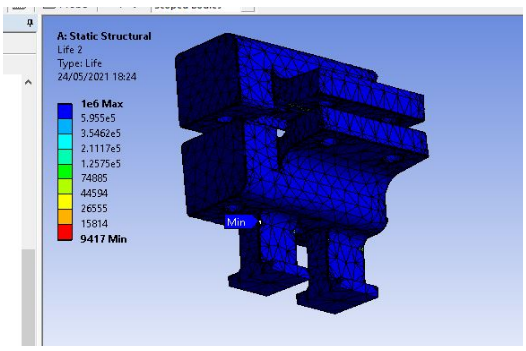


Figure (28): Life of fixture simulated with M6 bolts

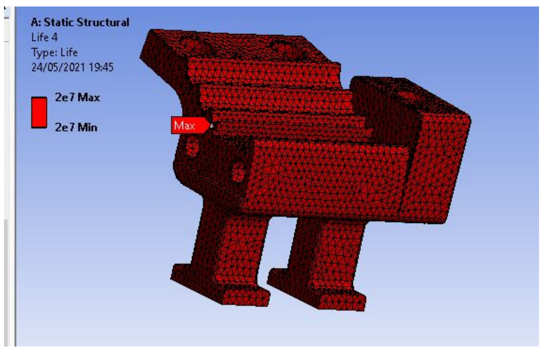


Figure (29): Life of fixture simulated with M6 bolts

At last, a stress concentration is observed on the filet edge of the bottom of the fixture as shown in figure (28), and the filet size is increased from 4mm to 5mm. After these optimizations are done results are shown on Figure (30), and the life of the fixture is better than that of the blade.

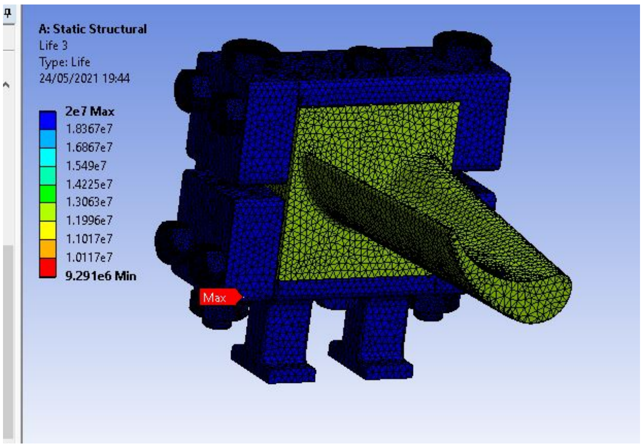


Figure 30: The minimum fatigue life of the whole assembly

6.3 Conclusion

The objective of this study is to design a fixture that can be used for fatigue test simulations of a turbine blade, and it is required that the fixture should not fail under the fatigue test. Results are in line with the question study and that the minimum fatigue life can be found on the blade and is 9.29*10^6 cycles.

As a result of the expanding gases hitting the blade surface a netto force is created which has a tangential component and axial component, and the results shows that the tangential component is the main contributor of a fatigue failure. Further studies can be done by topology optimization of the model, and there minimizing the material use and the mass.

As we found our results, we discovered there were several solutions to the problem. Hence, choosing a different material for different designs or different bolt mechanisms would possibly improve that design.

7. Bibliography

[1] Mohamad Barhm and Alsarayefi Saad, "EFFECTS OF TRANSIENT LOAD ON GASTURBINE BLADE STRESS AND FATIGUE LIFE CHARACTERISTIC," *ResearchGate*, Vol. 10, p. 3, Apr. 2018.

[2] Kauss O., Tsybenko H., Naumenko K., Hutter S., and Kruger M., "Structural analysis of gas turbine blades made of Mo-Si-B under transient thermo-mechanical loads," *ScienceDirect*, pp. 1-2, 2019.

[3] Beghini M. et al., "High temperature fatigue testing of gas turbine blades," *ScienceDirect*, Vol. 7, pp. 5-6, 2017.

[4] Ranjan Kumar Ravi and M. Pandey K., "Static Structural Analysis of Gas Turbine Blade," *Journal of basic and applied engineering research*, p. 1, 2016.

[5] Kim Younghune and Hwang Woonbong, "High-Cycle, Low-Cycle, Extremely Low-Cycle Fatigue and Monotonic Fracture Behaviors of Low-Carbon Steel and ItsWelded Joint," *Materails*, p. 2, Dec. 2019.

[6] Singh Chauhan Alok, "Selection of Manufacturing Process for Aeroengine Gas Turbine Blades," *ResearchGate*, p. 9, Nov. 2015.

[7] Pereira Tanisha, V Kennedy John, and Potgieter Johan, "A comparison of traditional manufacturing vs additive manufacturing, the best method for the job," *ScienceDirect*, pp. 2-10, 2019.

[8] Bhaduri Amit, "Tension," in *Mechanical Properties and Working of Metals and Alloys*, Spinger Link, 2018, pp. 1-2.

[9] Bhaduri Amit, "Creep and Stress Rupture ," in *Mechanical Properties and Working of Metals and Alloy*, Springer Link, 2018, pp. 2-3.

[10] Zhu Mingyu, "Design and analysis of steam turbine blades," *IOPscience*, pp. 1-4, 2019.

[11] Madan Kumara and Veerabhadraiah Nandish, "Fatigue failure analysis of rotating turbine blade with damage at the leading edge," University of Oxford, Oxford, 10.13140/RG.2.1.3949.3207, 2014.

[12] Lauren Safai, Juan S Cuellar, Gerwin Smit, and Amir A Zadpoor, "A review of the fatigue behavior of 3D printed polymers," Elsevier, Delft, https://www.sciencedirect.com/science/article/pii/S2214860418308662?via%3Dihub, 2019.

[13] Ahmed A Jabbar, A Rai, P. Ravinder Reedy, and Mahmood H Dakhil, "Design and analysis of gas turbine rotor blade using finite element method," International Journal of Mechanical and Production Engineering Research and Development, Hyderabad, 2249-6890/2249-8001, 2014.

[14] J S Ryas and N S Vao. (2013-2014, January) asmedigitalcollection. http://home.iitk.ac.in/~vyas/publication/19-Journal%20of%20Engineering%20for%20Gas%20Turbines%20and%20Power%20pp198.pdf

[15] A.K Bhargava and M.K Banerjee, "sciencedirect," 2017, https://www.sciencedirect.com/topics/materials-science/nickel-based-superalloys

[16] James Carvill, *Mechanical Engineer's Data Handbook*, 1st edition, Oxford, England, Butterworth Heinemann, pp. 240-241, 1993.

[17] Pokluda Jaroslav and Obrtlik Karel, "Fatigue life of cast Inconel 713Lc".

[18] Chattopadhyay Somnath, "Analytical Studies on S-N Curves for some steels," No. Atlanta, p. 6, 2013.

[19] B. Szabo and I. Babuska, *Finite Element Analysis*, Wiley & Sons, Inc., 1991.

[20] K. J. Rawson and E. C. Tupper, *Basic Ship Theory*, 5th edition, Jordan Hill, Oxford and Woburn, MA, Elsevier Butterworth-Heinemann, p. 91, 2001.

[21] K Garme and A. Rosén, "Time-domain simulation and full-scale trials on planing craft in waves," *International Shipbuilding Progress*, Vol. 50, pp. 177-208, 2006.

[22] K. Garme and A. Rosén, "Experimental pressure investigation on high-speed craft in waves," in *International Conference on Hydrodynamicd of High-Speed Craft*, RINA, UK, 2000.

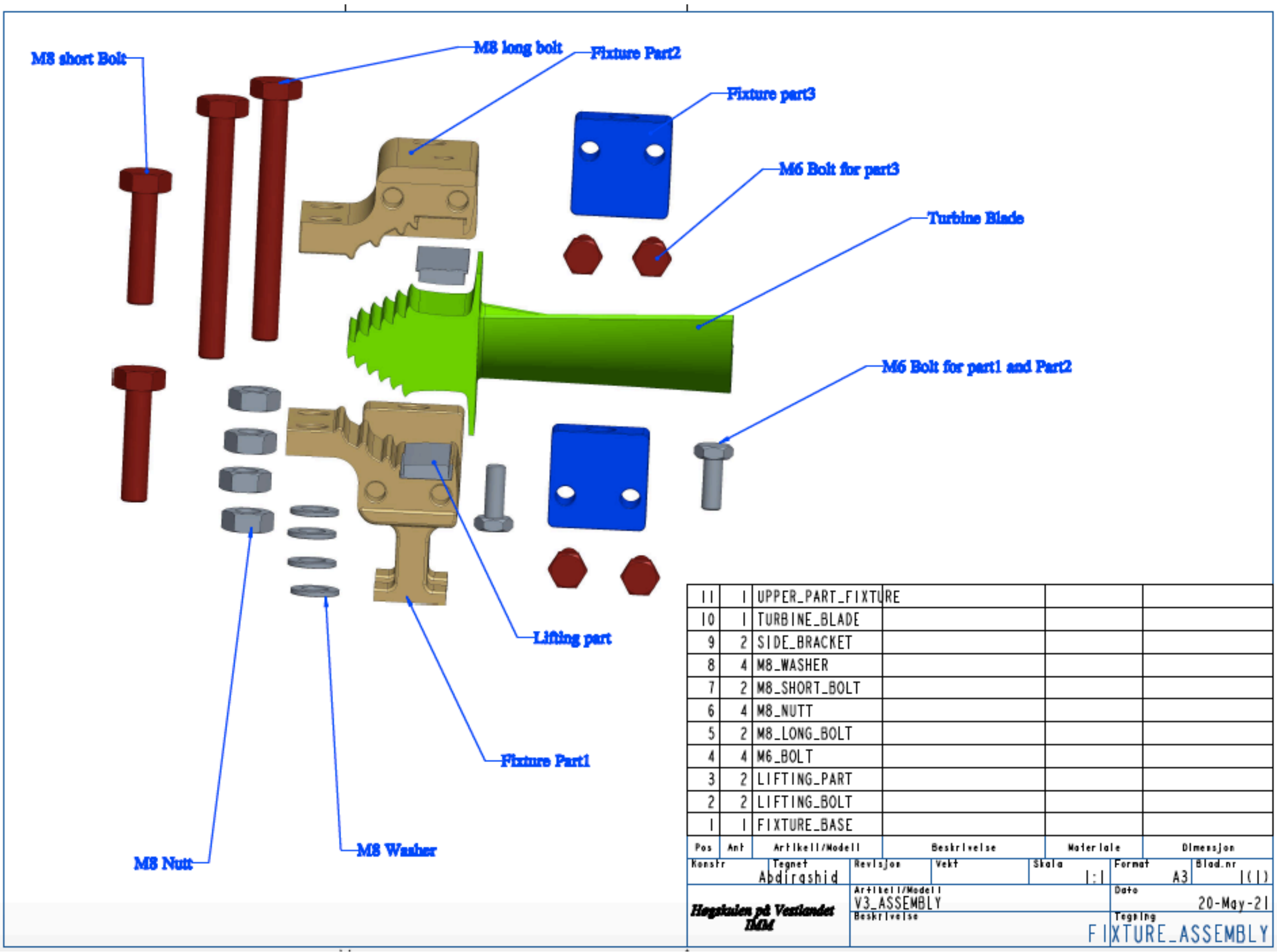
[23] A. Keller, "Loads and responses for planing craft in waves," (PhD Thesis), Royal Institute of Technology, December 2004.

[24] NASA Langley Research Center, "The X-48B blended wing body," January 2012, http://www.nasa.gov/vision/earth/improvingflight/x48b.html

[25] The MathWorks, Inc., "Matlab - Primer R2013b," Version 8.2, September 2013.

[26] Pereira Tanisha, Kennedy John V, and Johan Potgieter, "A comparison of traditional manufacturing vs additive manufacturing, the best method for the job," ScienceDirect, 2,.

[27] Zhu Mingyu, "Design and analysis of steam turbine blades," IOPscience, 1-4, 2019.


M8 short Bolt
M8 long bolt
Fixture Part2
Fixture part3
M6 Bolt for part3
Turbine Blade
M6 Bolt for part1 and Part2
Lifting part
Fixture Part1
M8 Nutt
M8 Washer
11 1 UPPER_PART_FIXTURE
10 1 TURBINE_BLADE
9 2 SIDE_BRACKET
8 4 M8_WASHER
7 2 M8_SHORT_BOLT
6 4 M8_NUTT
5 2 M8_LONG_BOLT
4 4 M6_BOLT
3 2 LIFTING_PART
2 2 LIFTING_BOLT
1 1 FIXTURE_BASE
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Beskrivelse
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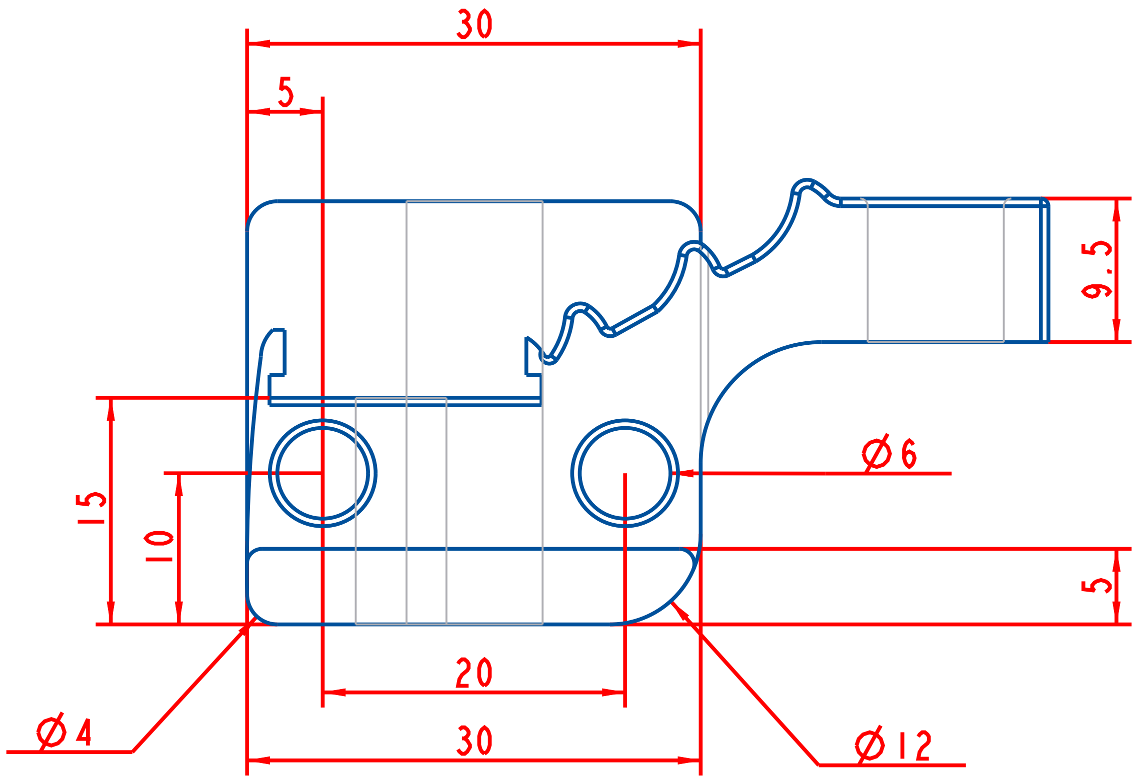

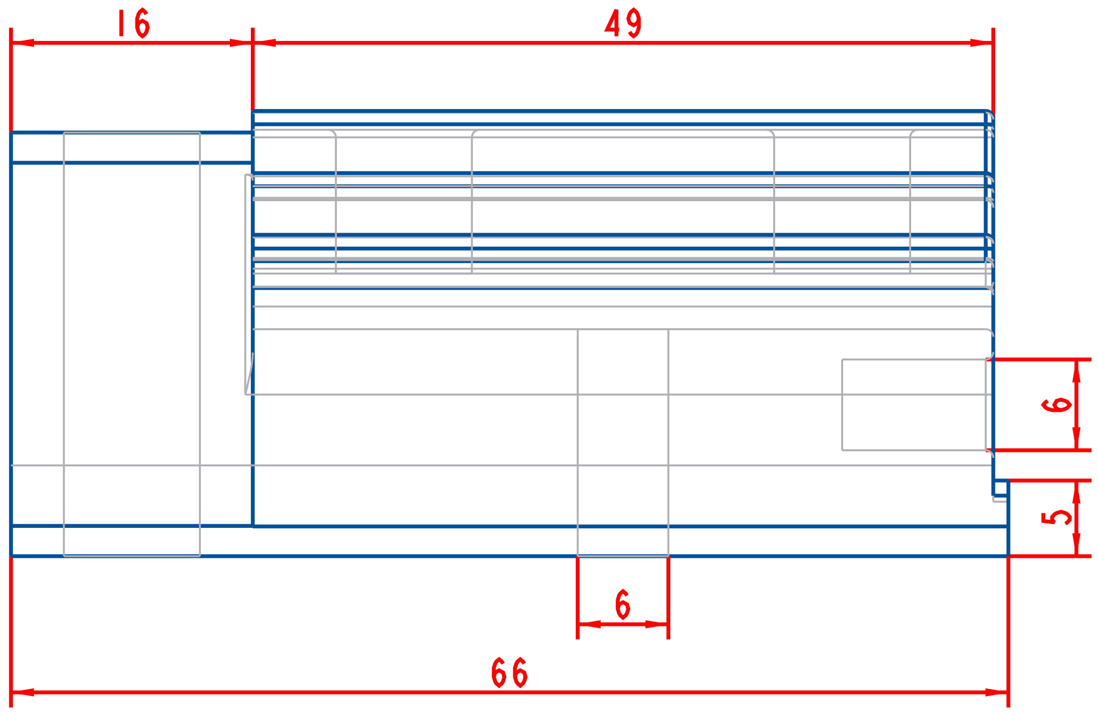

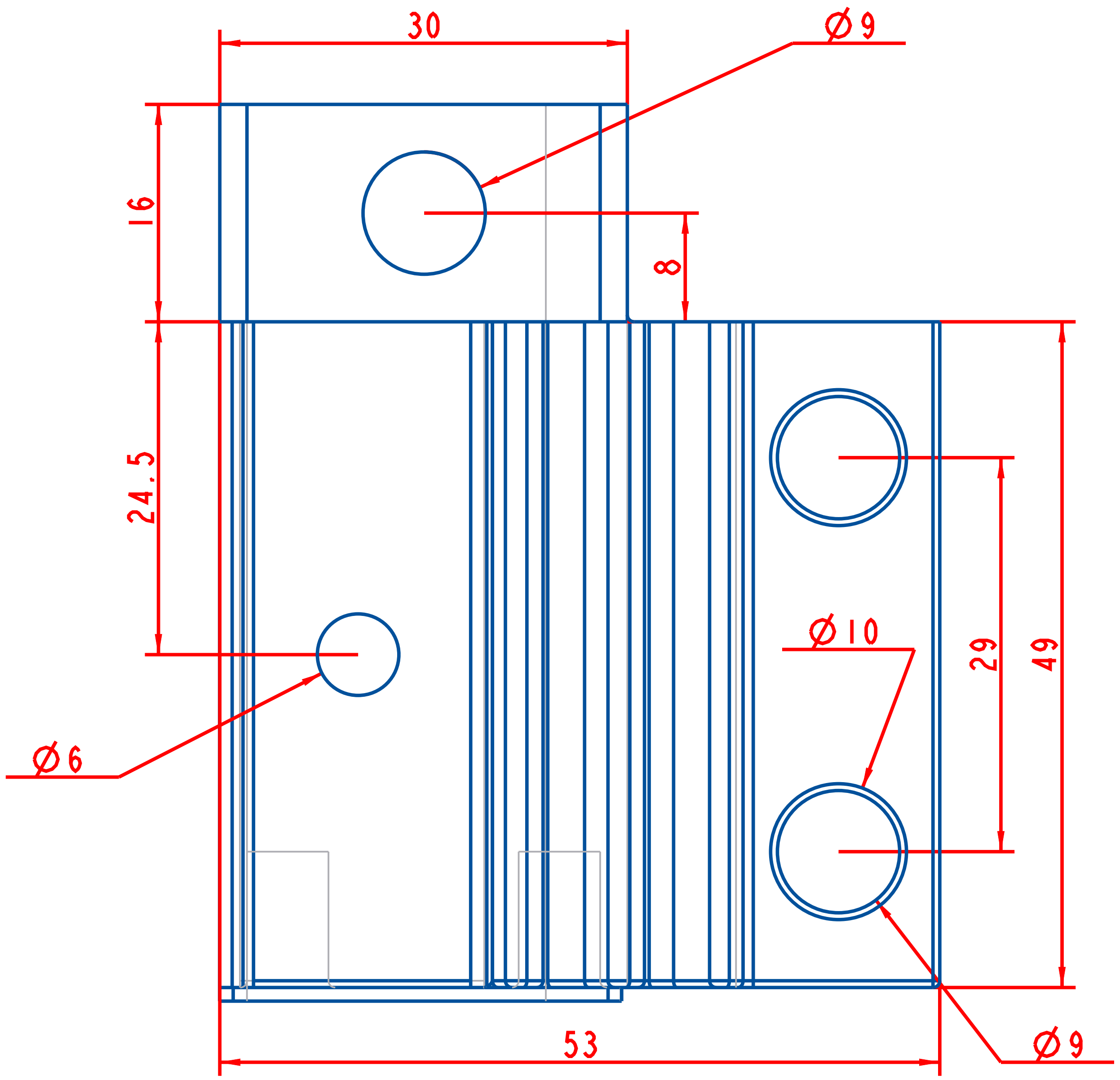

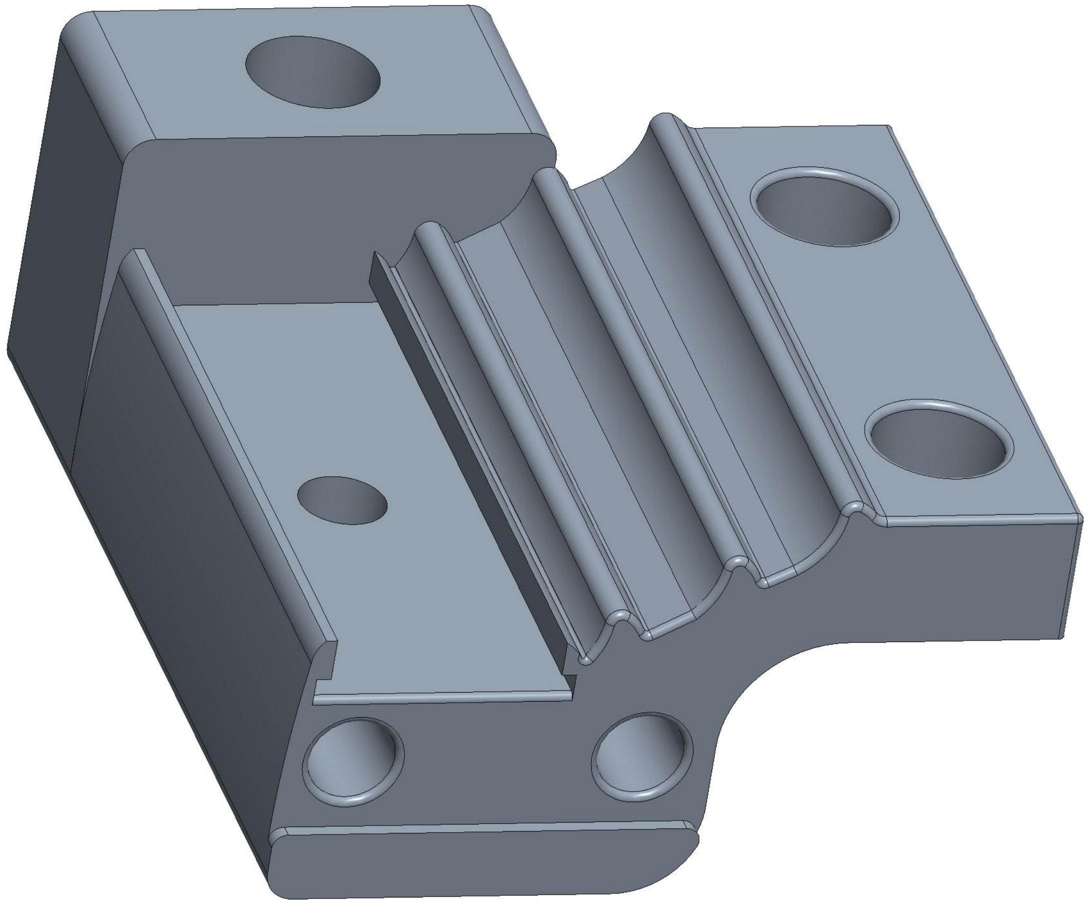

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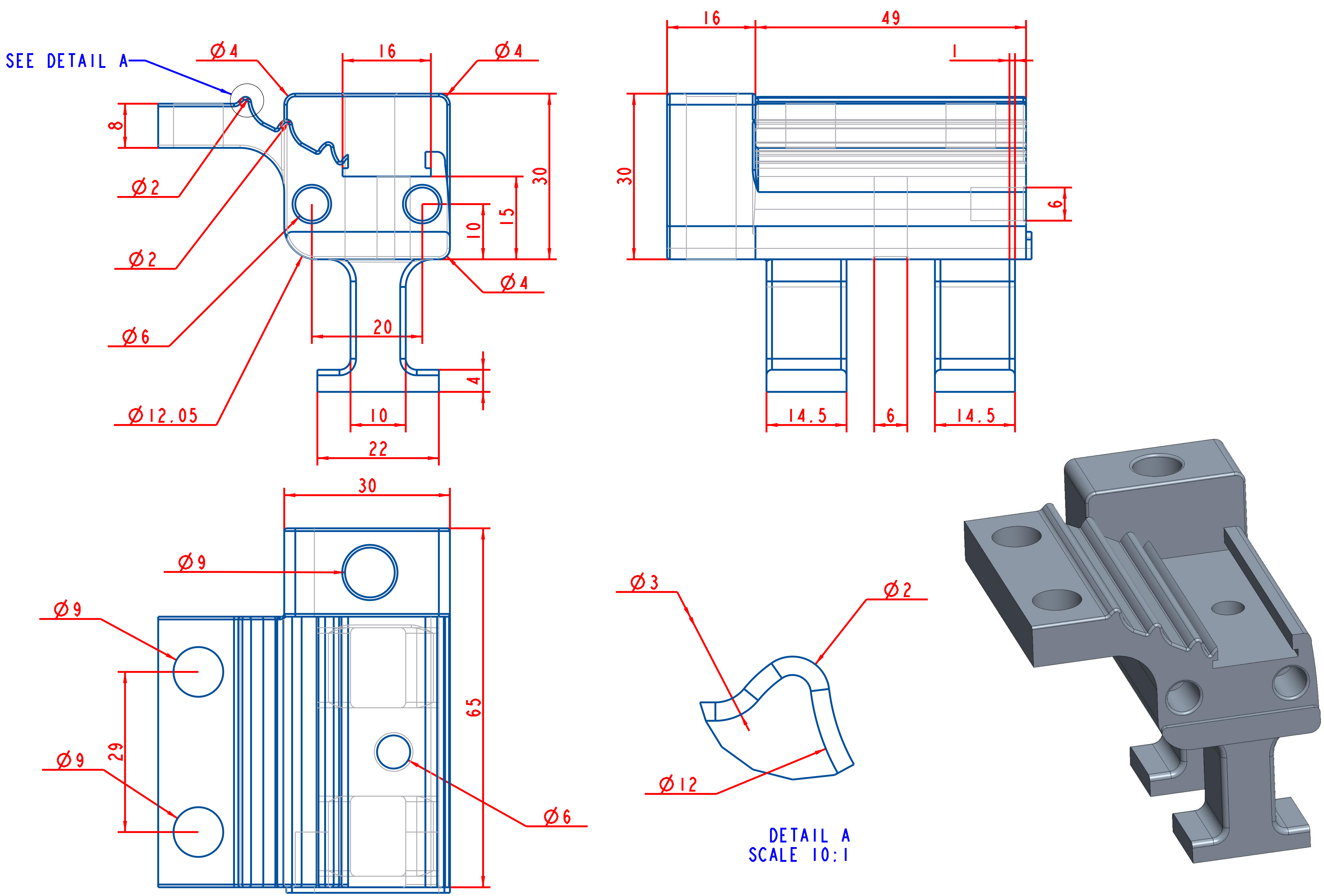

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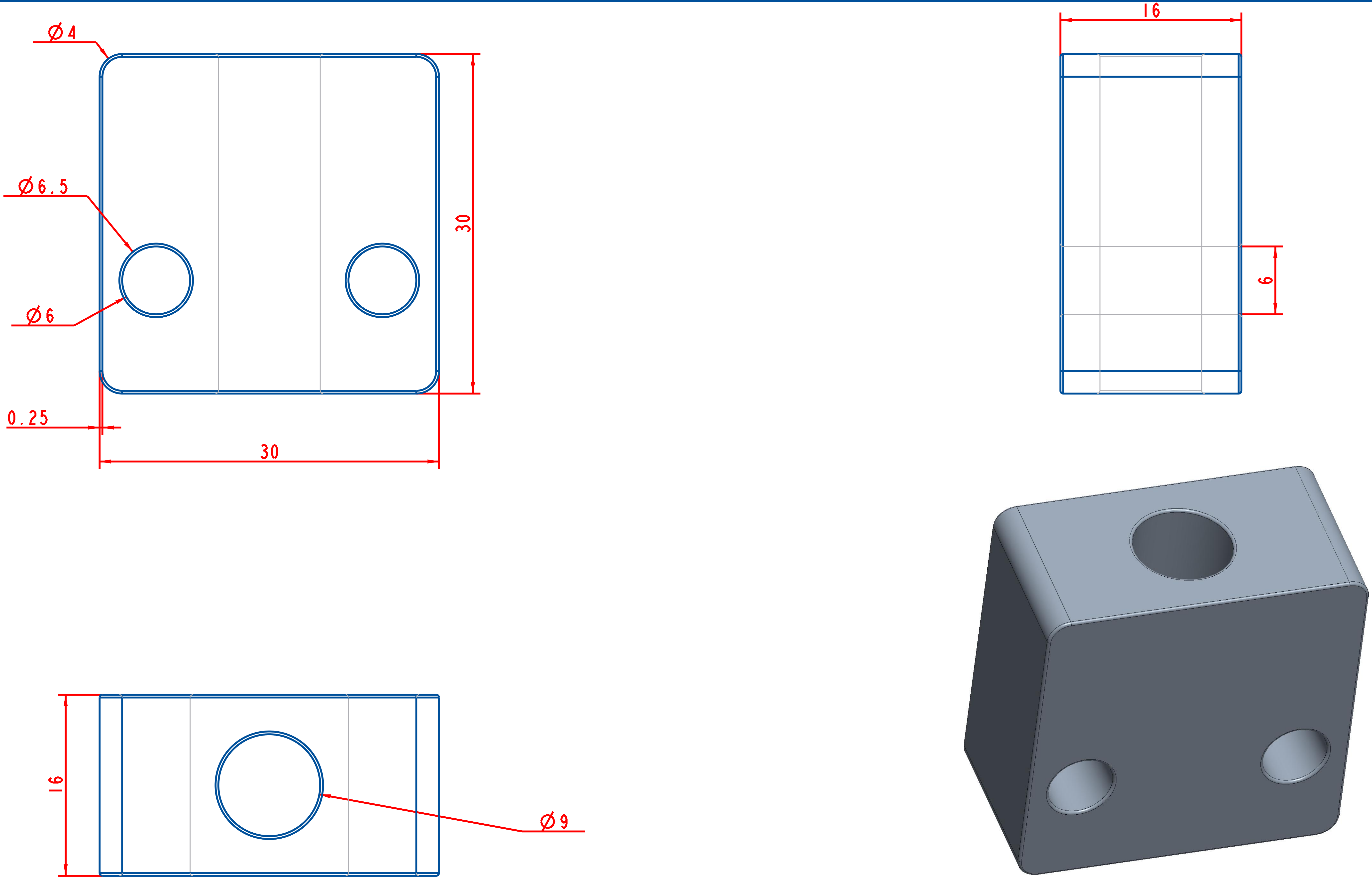

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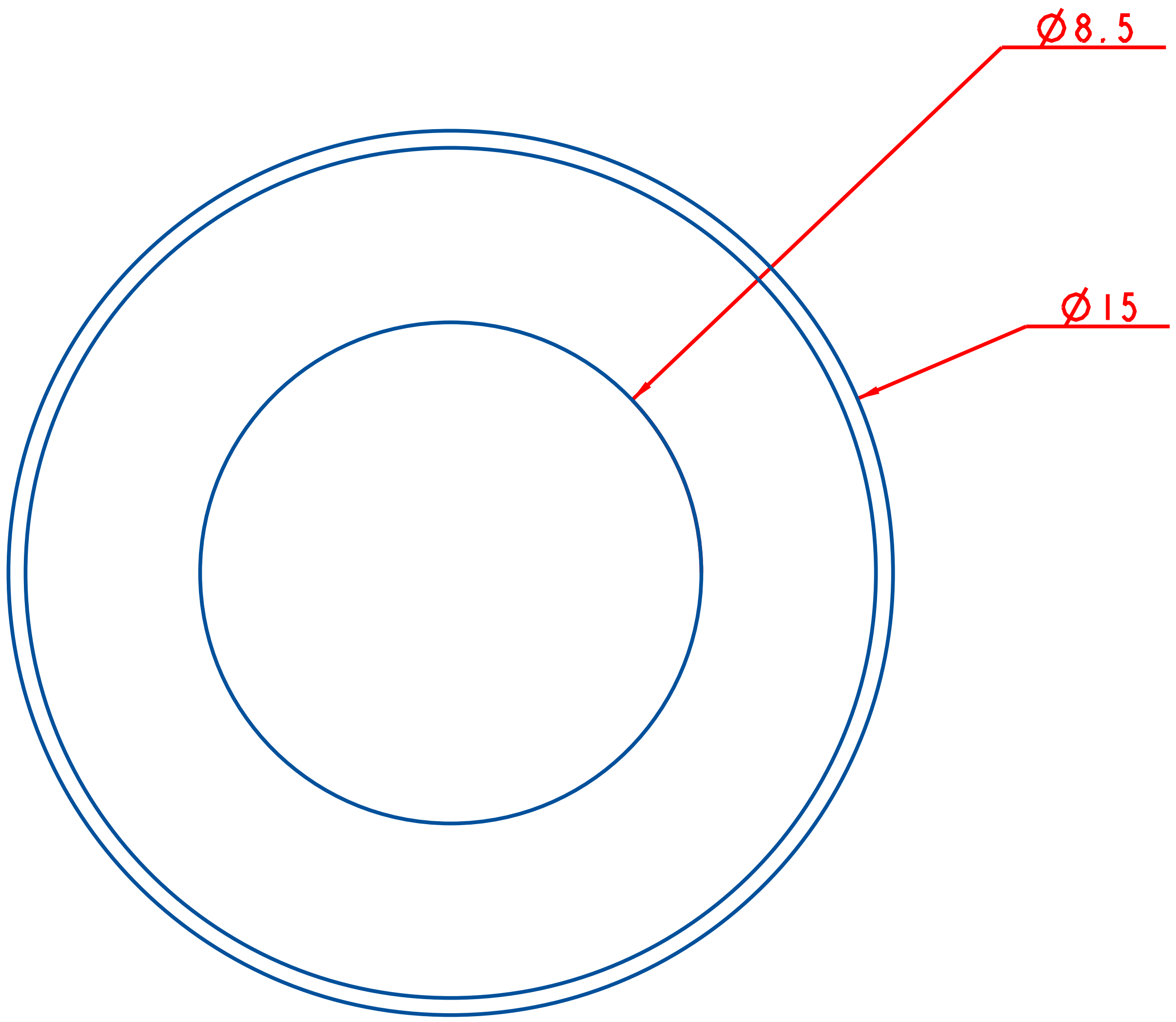

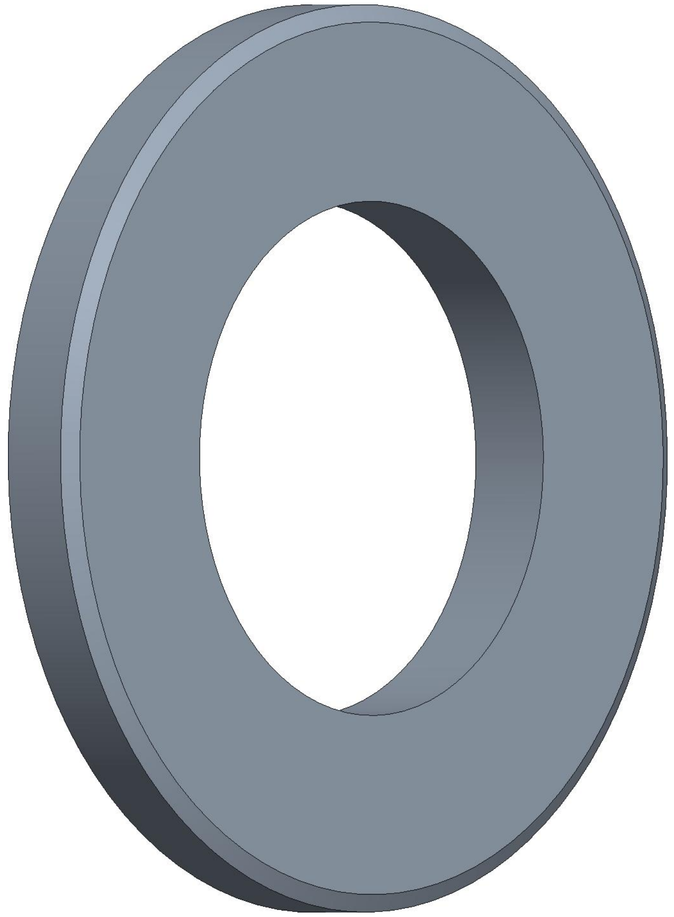

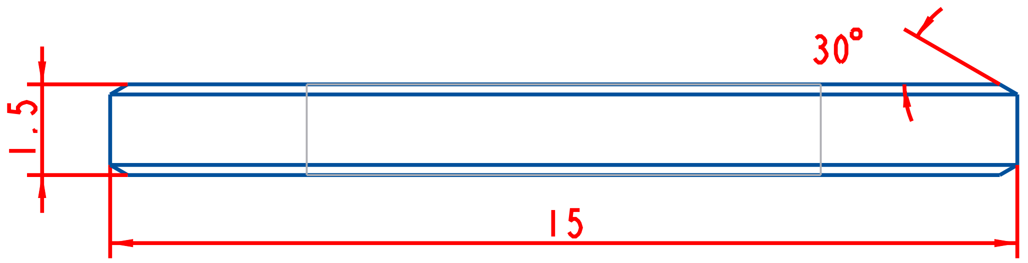

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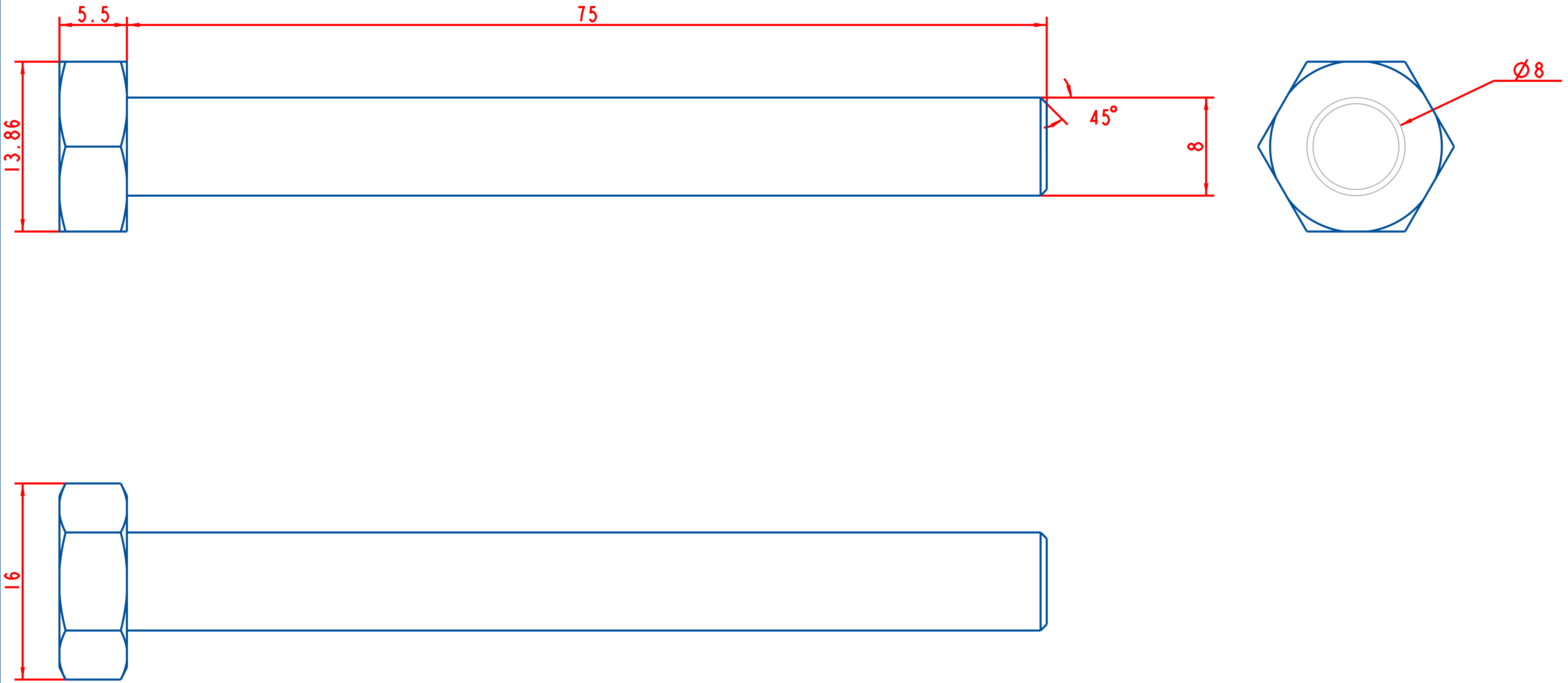

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Dato: 23-May-21

Beskrivelse:

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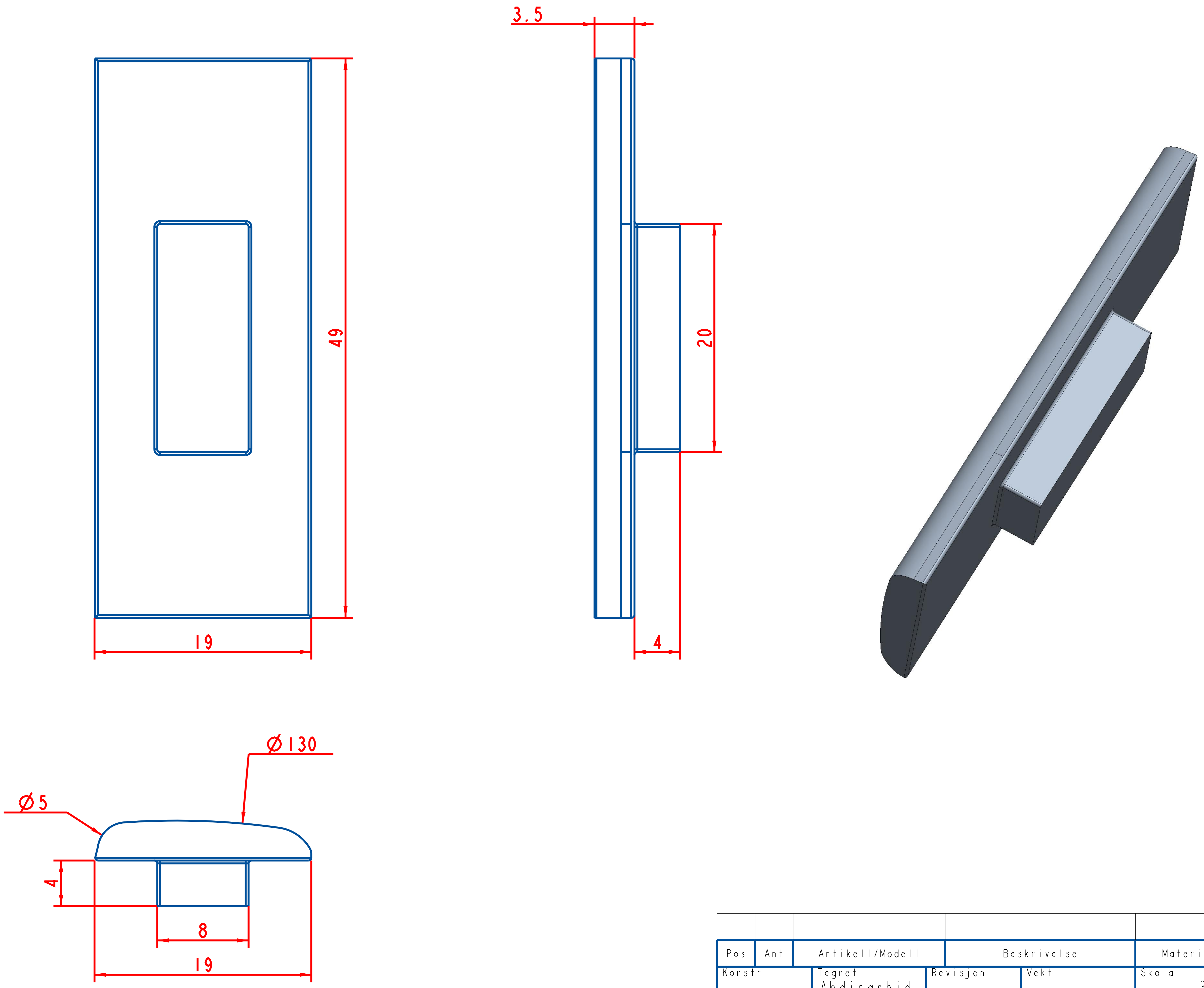

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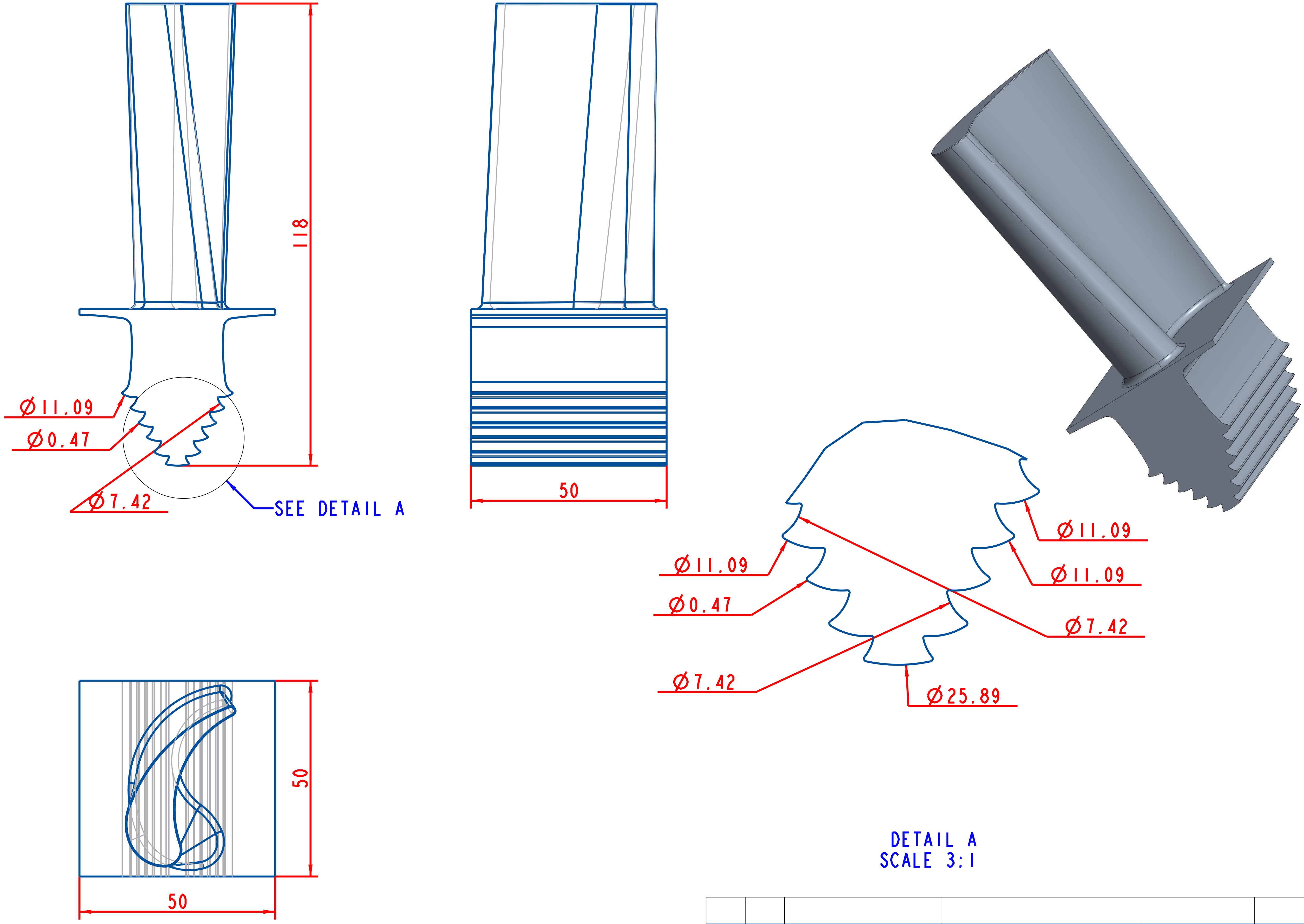

DETAIL A
SCALE 3:1

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