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Abstract

The production of a HVAC cabin unit is about 4,1 times higher in Norway than in the current production site in China. This is the result of a product development for manufacturing process that have been conducted. Even with higher shipping costs from China to Norway there is no immediate economical benefit of moving the production from a project standpoint. There are several non economic benefits of moving the production, including but not limited to: Shipping costs, Carbon Footprint and sustainability, economic benefits of the Norwegian society, Lean project execution and quality control. There still are work to be done to improve the manufacturing process, and reduce manufacturing costs. This thesis only covers the process to the point of including the manufacturers and a purchaser to decrease costs.

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1 | Introduction

AF AeronMollier is an engineering company and a total supplier of HVAC (Heating Ventilation Air Conditioning) systems for ships and offshore industry. Due to the increase in shipping cost the last few years the interest in moving manufacturing from China to Norway have increased. This sparked the will to check what the production cost of a HVAC Cabin Unit in Norway would be, which now is produced in China. To meet a higher production cost as a function of the cost of manual labour in Norway a reengineering would need to be performed and a product development for manufacturing as well. This thesis only covers the process to a certain point, the product development must not be considered a finished product. Also there are necessary tests and certifications to be applied to the product before it is approved for use.

2 | Methodology

2.1 Action Research

The methodology approach is in the form of action research. Action research is a method where you gather data and progress the project side by side. Instead of gathering all the data in beforehand, you gather data as you progress the project, and do educated actions based on what you learn. The methodology has five steps cycles during the project lifespan. The five different steps in the cycle are as following:

1. Problem Identification

First step is to identify the problem. This means that there must be established a understanding of what the project is trying to achieve.

2. Action Planning

In the second step evaluation of the problems identified in the first step are used to plan actions to solve the problems. This may require more research if the problems need solutions that are not easily identified.

3. Action

In the third step you put your planned action in to motion. This is where the actual production or changes are done.

4. Evaluation

In the fourth step you evaluate the effect of the actions you have taken in the cycle. Did the actions solve the problems identified in the first step?

5. Learning

In the fifth step you specify what you have learned from the evaluation. The learning will then specify if the cycles are to stop or if they are to continue. [1]



Figure 2.1: Action Research Cycle

2.2 Product Development: Concept Generation

"A product concept is an approximate description of the technology, working principles, and form of the product. The degree to which a product satisfies customers and can be successfully commercialized depends to a large measure on the quality of the underlying concept." [2, p. 140]

In general, concept generation has five steps:

1. Problem Identification

The problem that the concept generated sets out to solve must be identified. What are the main purposes of the product?

2. External Search

Gather information from external sources, for example: Similar products, patents, users and experts.

3. Internal Search

Use the internal team knowledge, often in the form of a brainstorming. In this step there is normally generated a lot of ideas.

4. Systematic Exploration

In this step you analyze the information which has been identified in the two previous steps. Which concepts can be generated from the information gained?

5. Reflection

In this step you check if there is any room for improvement, this step is last but should in reality be done continuously in each step. If there is need for a new iteration any of the steps, this should be identified. [2, p. 117-141]

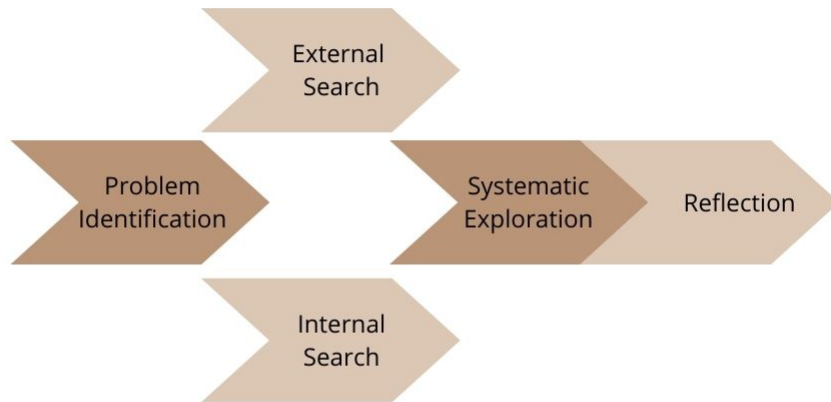


Figure 2.2: Concept Generation Process

2.3 Product Development: Concept Selection

The concept selection process is a way of identifying which concept to use in the further product development. To choose the right concept the benefits and downsides of each concept must be identified and a systematic comparison must be performed.

For the selection to be as systematic as possible, a matrix which compares the pros and cons of all the concepts must be established. The matrix creates a rating that shows which product is the better choice. Once you have rated and ranked the concepts you select one or more concepts to continue the product development with. [2, p. 145-161]

2.4 Product Development: Design for Manufacturing

Design for manufacturing is a product development process which is aimed at improving the manufacturing process while still maintaining better or similar quality and functionality as the base concept. With improving the manufacturing process, most often the a reduction in cost is the improvement you are after. There are numerous ways of improving the manufacturing process, here are a few listed:

1. Reduction of the components cost.
2. Reduction of the assembly cost.
3. Reduction of the assembly or parts production support cost, for example shipping.

Even though you can spend a lot of time developing a product to decrease the cost of the manufacturing, the cost of development it self must not be neglected. If there is a big production volume, there may be more resources to spend on the manufacturing optimization compared to a small volume. There will have to be a continuous estimation of manufacturing costs during the product development process to help determine when the product is at a "good enough" state. [2, p. 255-277]

3 | Case: Industrial Challenge

AF AeronMollier AS have over a period manufactured their HVAC Cabin Units in China. But due to the increased cost of transport there is an interest in checking the cost of manufacturing in Norway. There is also an increase in global political instability which might have an impact on global trade. The way the Cabin Units are manufactured in China are very manual labour intensive and will not be a feasible method of manufacturing in Norway due to the higher cost of manual labour. Therefore the design itself will have to be reviewed and changed to suit a less manual labour manufacturing process. All the components originate from China which also is the place of assembly. This makes competing directly on price tough to achieve in a Norwegian factory, thus there are other benefits that must be explored before making a decision on where the production should be located. [3]

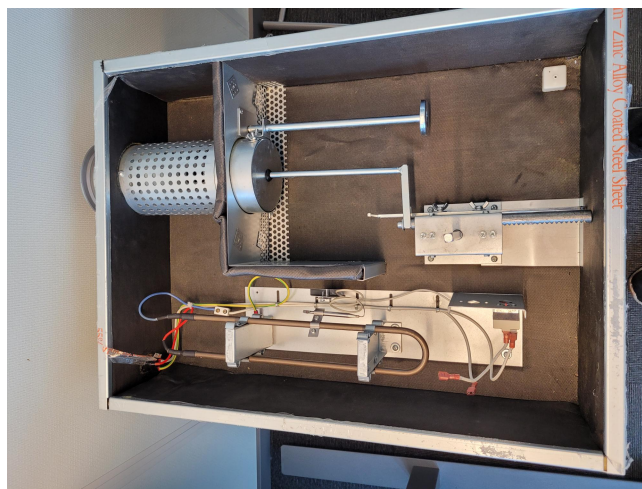


Figure 3.1: Original Cabin Unit

4 | Specifications

A HVAC(Heating Ventilation and Air Conditioning) Cabin Unit is a unit that is placed in ship cabin to control the airflow in to a cabin, and alternatively the temperature. The cabin unit is connected to the ducting network on one side and the damper inside the unit is regulated to fit the specified airflow that the cabin requires. There is also a heater option which is connected to a in room thermostat, which can control the temperature of the cabin.

The basic specifications of the cabin unit is the same as the original design (CABIN UNIT ACU1 - 30C)

Description: Single pipe unit form mounting above ceiling.

Material: Galvanized sheet steel.

Insulation: Rockwool 10mm.

Connection:Ø100mm.

Recommended airflow: 75-250m³/h

Heating Element: 500W

Outlet Connection: Ø200mm

Power Supply: 1 ph 230V AC

Overheat Thermostat Set Point: 60C

Fire Thermostat Set Point: 110C With manual reset

The cabin units also have to be DNV certified to be used in a class B-15 Ceiling. They must also be able to fit a standard diffuser model, for example ACU - SD 200 Diffuser [4]

5 | Concepts

The basis for the concept development is to develop a concept that cuts down on manufacturing costs while keeping the same or better functionality and quality. The concept development have been an ongoing process throughout the project and there have been developed many smaller concepts which have been compressed into 3 main concepts.

5.1 Concept A: Unchanged design

The cabin units which are produced in the Chinese factory have a more complex design that does include more manual labor than necessary. There are more parts and components than what is required. The basis of this design is that the air comes in through the circular damper and then flows over the heating element and out through the exit hole. The damper works by having a circular plate inside the perforated tube which slides inside the tube, making the area the air can escape from the tube and into the cabin unit smaller. There is a fine adjustment option on the side of the slider which slides a separate perforated tube over the inner perforated tube. Having two types of adjustment makes the concept more complex. Using this design would make sense from an engineering cost standpoint as there will be little to no engineering on the concept level.

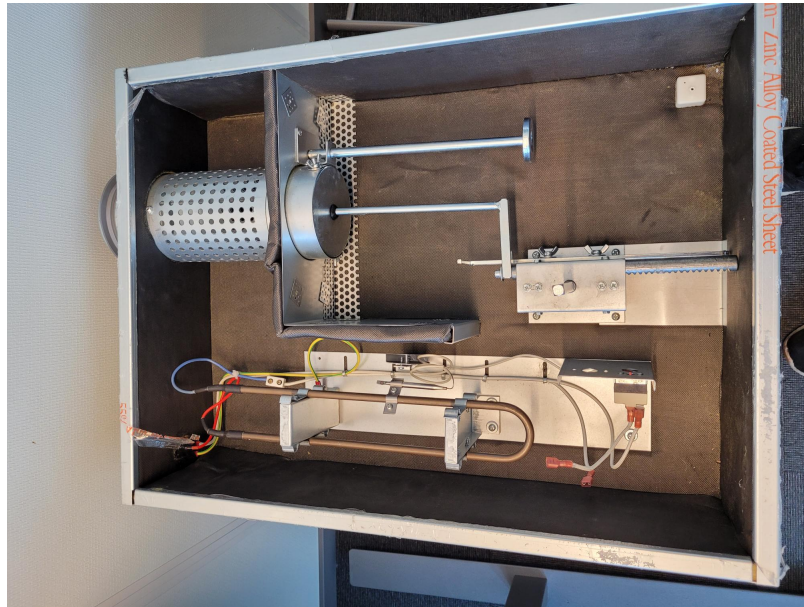


Figure 5.1: Original Cabin Unit

5.2 Concept B: Revised design with flat damper

Instead of the round damper, a concept of making a flat damper was explored. This damper works in a similar way as the round damper by having perforated plates that slide over each other. This concept does not present any real benefits over the round damper design. There would be a bigger increase in engineering cost as the concept is moving further away from the original tried concept. There was conceptualized a handle mechanism that works as a slider mechanism, transferring rotating motion to a slide motion. A slider mechanism could have worked with two perforated plates sliding above each other, as the length of the motion is relative short.

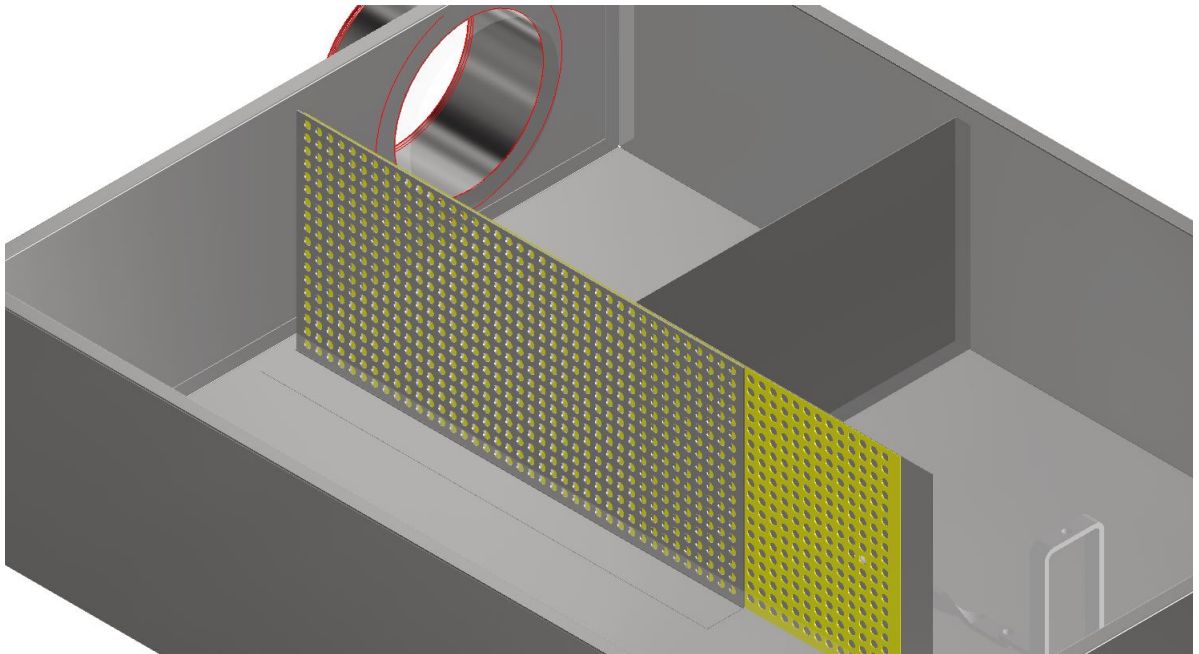


Figure 5.2: Concept B

The yellow perforated plate slides between the perforated plate and a holder, this makes the airflow being restricted as the holes are getting smaller as shown on figure 5.3 and 5.4.

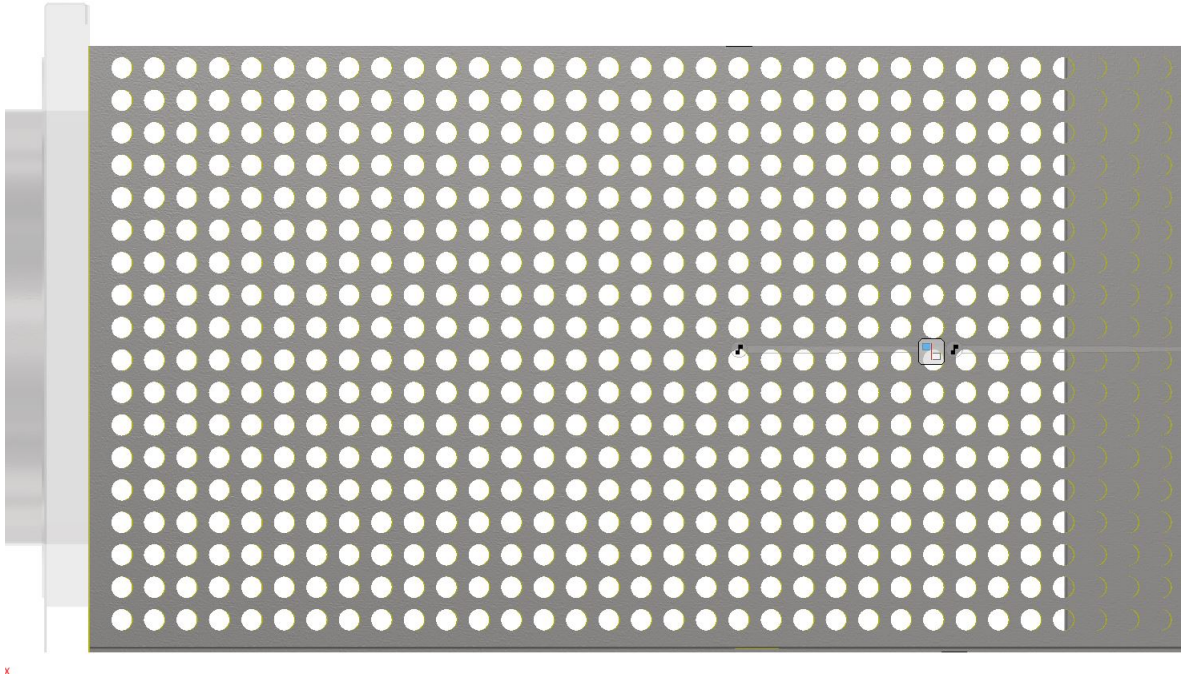


Figure 5.3: Flat damper fully open

In this figure you can see that the airflow is not restricted more than the area off the perforated plate, this would be the maximum airflow of the damper.

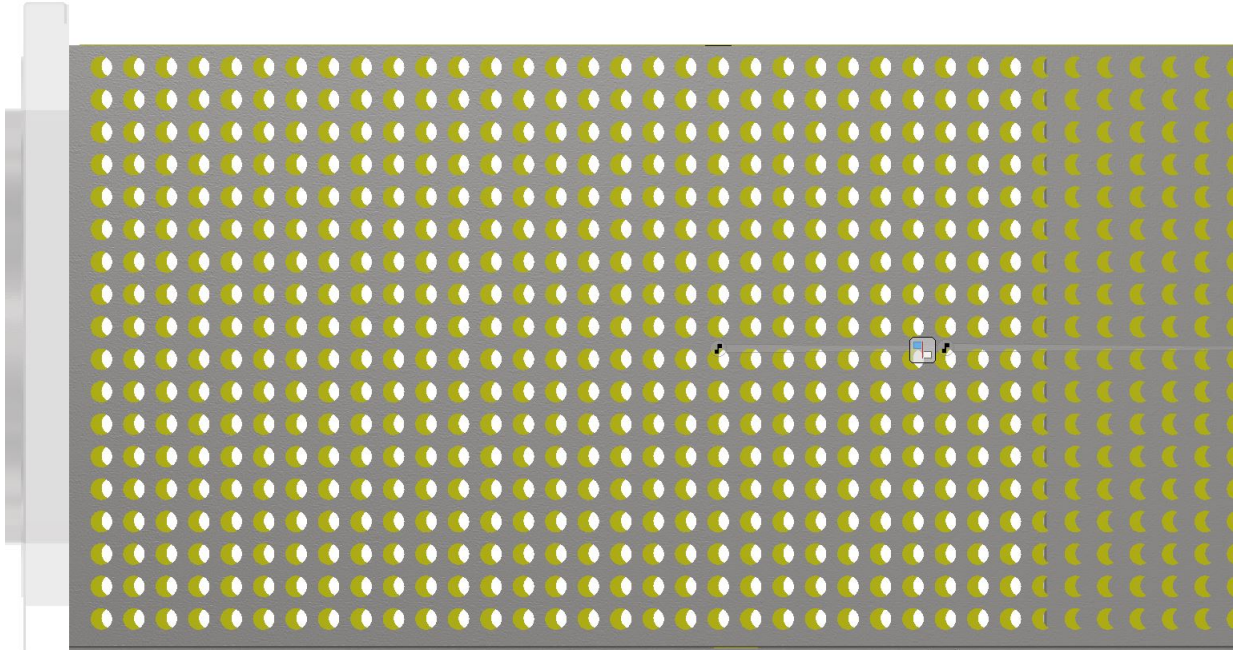


Figure 5.4: Flat damper restricted

Here the flow have been restricted by moving the inside perforated plate (yellow) to make the flow area smaller.

5.3 Concept C: Revised design with round damper

There was conceptualized a revised round damper design. The fine adjustment of the original design was removed to minimize the complexity. The slider mechanism conceptualized in concept B would not work for this type of damper as the length of the motion required is too long. Therefore a similar design as the original is implemented (This design of handle mechanism should be subject of a further product development, as it could be simplified).

The overall length of the unit has been reduced due to the heating element requiring less space than in the original concept, as a result the unit is physically smaller and has benefits as a result. Less weight, less storage space and confines less space on the installation site.

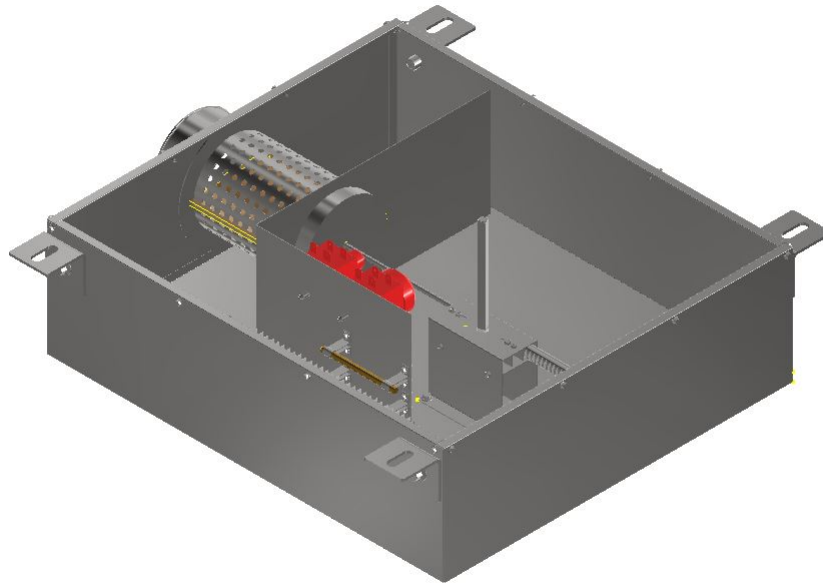


Figure 5.5: Concept C

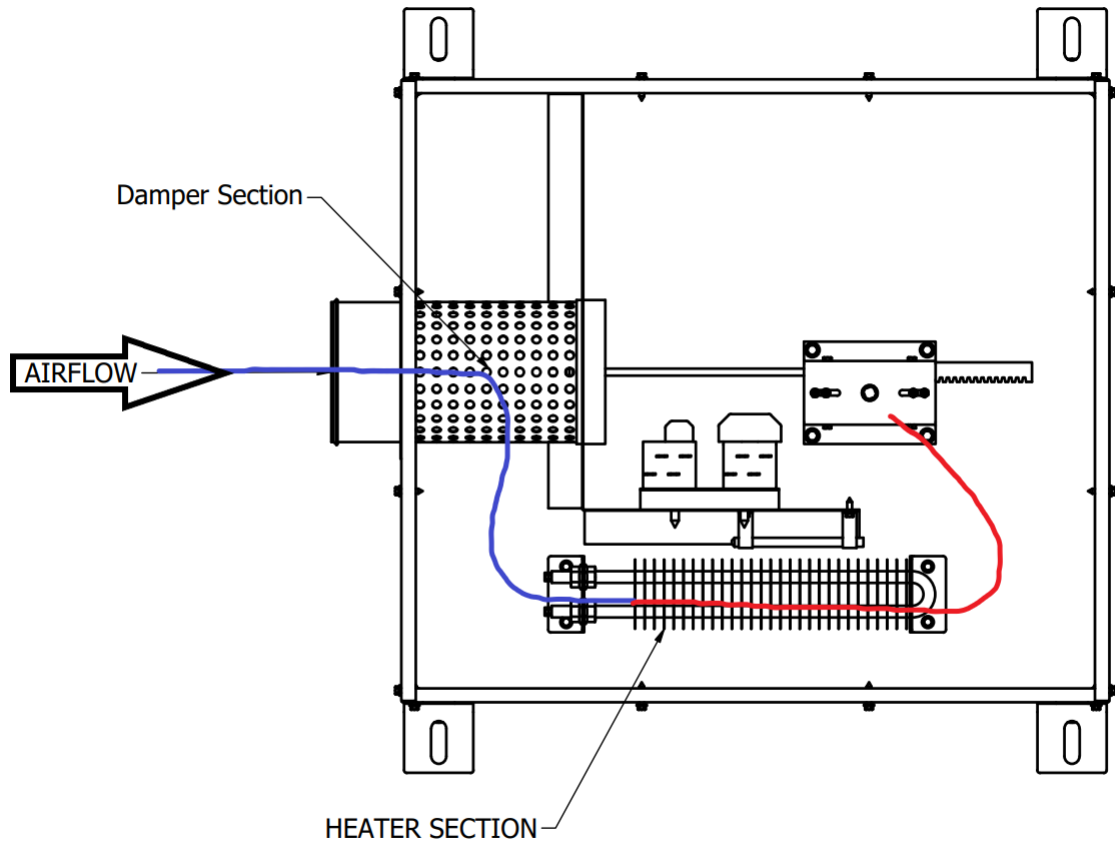


Figure 5.6: Concept C Airflow

As shown in figure 5.6 the airflow enters the circular damper and flows over the heating elements before exiting the unit.

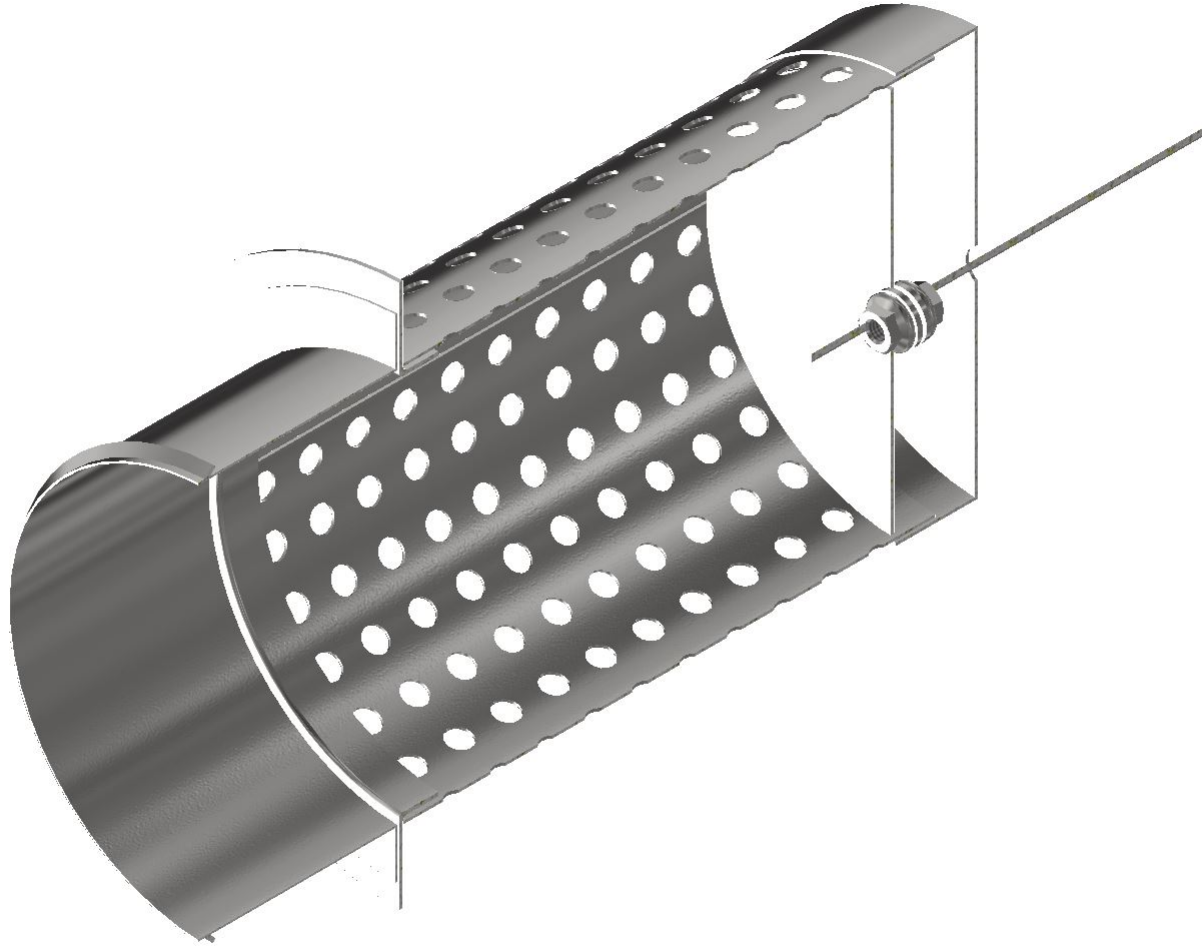


Figure 5.7: Round damper fully open

In figure 5.7 you can see that the slider is in the fully open position, in this state the only restriction on the airflow is the perforation in the tube.

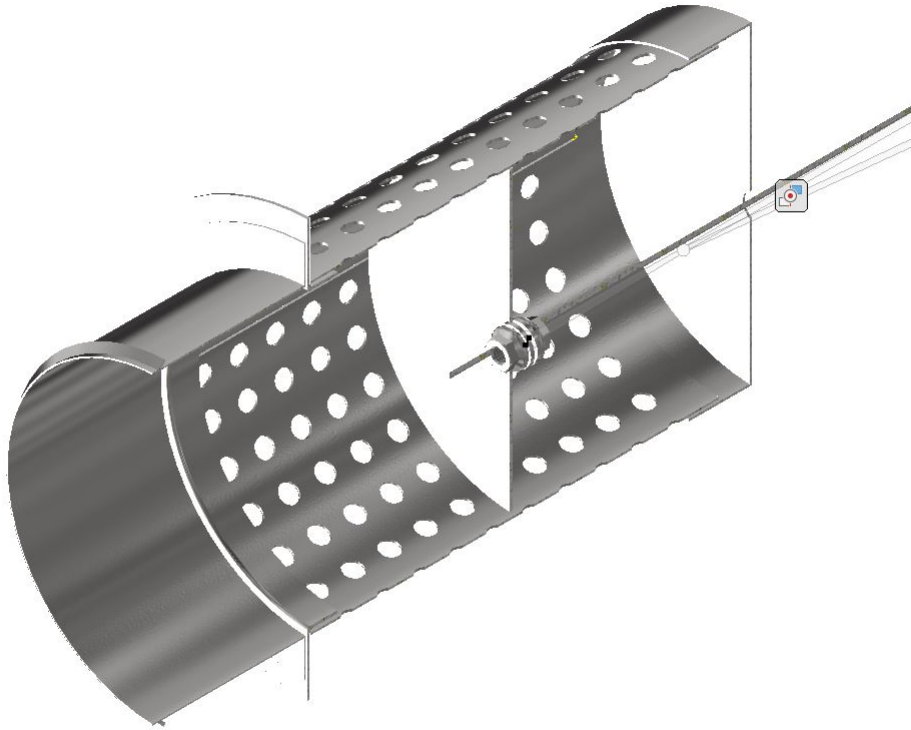


Figure 5.8: Round damper halfway open

Figure 5.8 shows how a restriction in airflow is achieved, since the slider is in the halfway position only half of the available airflow area is available. This will restrict the airflow as a function of the available air pressure in the HVAC system.

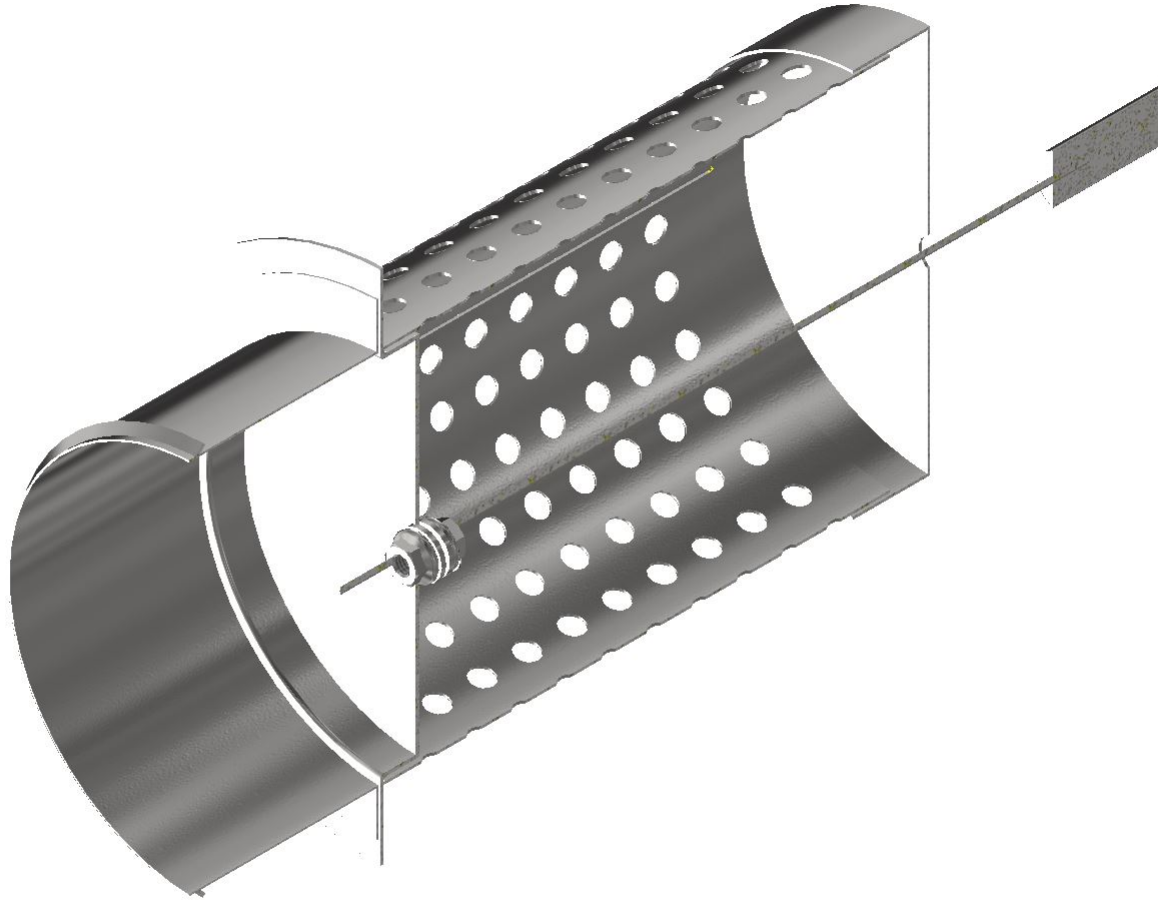


Figure 5.9: Round damper closed

Figure 5.9 shows that the slider can be put in a fully closed position, this will restrict the airflow completely.

5.4 Concept Selection

Concept Selection Matrix			
Selection Criteria	A Unchanged Design	B Flat Damper	C Revised Circular Damper
Ease of Engineering	+	0	0
Ease of Manufacturing	-	+	+
Function	0	0	0
Durability	-	+	+
Complexity	-	-	+
Weight	0	0	+
Confined Space	0	0	+
Sum +	1	2	5
Sum 0	3	3	2
Sum -	3	1	0
Net Score	-2	1	5
Rank	3	2	1
Continue?	NO	NO	YES

Table 5.1: Concept Selection Matrix

The pros and cons of each concept were identified and the selection matrix shows which concept are the most suited. Weight and space containment are big improvements to the design as these will have more benefits than just less material use. There will also be an decrease in storage space and shipping space required, as well as shipping costs will go down. Also simplifying the circular damper design makes for a less complex system and therefore more durable. You will find that the pricing is not shown in the matrix, but the price is a function of complexity. The more complex the higher the price. The complete drawings off concept C can be found in Appendix A.

6 | Components

6.1 Sourcing Components

Due to the project being focused on the product development process, the sourcing of components have mainly been a secondary objective. The sourcing of the components is something to be reconsidered by the purchasing team at AF AeronMollier, if there is any interest in doing further development of the concepts. That being said, all the components have been sourced and priced, but there has not been a broad outreach to suppliers.

Due to the sensitivity of the pricing, the source of the prices and the prices themselves have been redacted in this document.

6.2 Component Selection

The components have mainly been selected to fit the specifications of the unit, as shown in chapter 4. The components that had to be selected are the standard components that needs to be purchased, and wont be a part of the product development.

6.2.1 Heater

There was a few heater elements in question when selecting the heater, but a size decrease was wanted to reduce the overall size of the unit. A cheap heater of 500W that stil reduced the size was the goal, and the heater was selected on these conditions.

6.2.2 Thermostats

The thermostats are mainly selected to fit the specifications, and are standard components sourced in Europe. The main criteria of the selection are the specifications in chapter 4, 60C automatic reset for thermostat 1 and 110C manual reset for thermostat 2.

6.2.3 Fasteners

The fasteners are standard components taken out of the Inventor library, and then sourced afterwards. These are primarily cheap components and are not a big cost of the cabin unit.

6.2.4 Components for the handle mechanism

All the components that are used for the handle mechanism except the sheet metal parts, are standard components where suppliers have been sourced.

No	Description	Qty
Top Assembly (Sheet 03)		
1	Casing 01	1
2	M5 Bolt	4
3	Self Tapping Screw 4.2 x 16mm	24
4	Bracket	4
8	Heating Element 500W	1
10	Casing 03	1
11	M10 Bolt	4
Casing 02 (Sheet 6)		
1	Casing 02	1
2	Rockwool Insulation	1
3	POP Rivet M5	8
4	POP Rivet M10	4
Temperature Switch (Sheet 7)		
1	Din Rail	1
2	Thermostat High High 110C	1
3	Thermostat High 60C	1
Balancing Damper Assembly (Sheet 7)		
1	Casing 04	1
2	Damper 01	1
Slider 01 (Sheet 13)		
1	Teeted Rod	1
2	M5 Threaded Rod	1
3	Circular Plate	1
4	M5 Washer	2
5	M5 Hex Flange Nut	2
Handle Mechanism (Sheet 15)		
1	Plate 01	1
2	Plate 02	1
3	Rectangular Rod 8x8	1
4	Spur Gear	1
5	Split Pin	1
6	Spring Mounted Ball	2
7	Plate 03	2
8	Self Tapping Screw	8
Bottom Assembly (Sheet 21)		
1	Casing 05	1
Assembly Cost		
1	Work Hours	1

Table 6.1: Material Take Off List (PRICES REDACTED)

7 | Benefits of moving the production to Norway from China

7.1 Shipping

The main reasoning of this study is due to a increase in shipping cost. In the last three years we have seen an increase in shipping costs across the global market of approximately 1500 USD per standard 40' container to 8000 USD. [5] That is an increase of about 5 times the cost in just three years.

7.2 Carbon Footprint and sustainable development

There is an environmental benefit by moving the production from China to Norway. Since the production will be located in Norway, there will be less emissions from shipping. Also since Norway is part of the EU commitment to reduce the emissions from production of metals, there is a lesser carbon footprint from the raw material production if the steel is sourced from Norway or inside the EU.

7.3 Economic benefits in Norway, society

The economic benefits of moving a production from China to Norway has the potential to create jobs outside of the biggest industries in Norway. In Stavanger particular we are heavily invested in oil and gas which is a quite

volatile business segment. If there is room to start up traditional manufacturing facilities which can compete with Chinese industry, there could be massive benefits for the Norwegian society. This would create job and income opportunities which is not directly involved in the oil and gas sector. But for this type of industry to be successful there must be a high focus on efficiency and automation.

7.4 Lean Manufacturing

Lean manufacturing is often thought about as a way to improve the production it self, but there are benefits of a lean manufacturing that extends to the project execution. Lean manufacturing is aimed at reducing waste, and within waste there are different types of waste. The waste reduction that can be done by moving the production to Norway are:

Defects

Since the quality control will increase, the chance of having defect products delivered to the projects are minimized.

Overproduction

The lead time of the product would likely go down, which means that you can order the exact number of units required for a project, instead of ordering for storage.

Waiting

If there are delays in shipping this might create waiting in the project, this is wasted time.

Transportation

Transportation does not add any value to a product, this is adds cost and is a waste.

Inventory

This is a byproduct of overproduction, if you have too much product you will have to store it. This means you have to have a warehouse, which is a waste.

Motion

There is unnecessary movement of people when doing quality control in China, this ties down resources and has a cost.

Extra Processing

If the quality is poor, there will be modifications to some of the products coming out of China, this will cause extra processing in the form of repairs.
[6]

7.5 Quality Control

Due to production being located closer to the company, a higher level of quality control could be performed. Inspections could be performed more often and cheaper, making the risk of having a bad batch of units shipped reduced. Also, the time zones of the factory and the company would make contact easier than with a factory in China.

8 | Conclusion

The cost of producing the cabin unit is 4,1 times higher than the current Chinese price (Including Shipping). Table 6.1 shows the material take off list, which is the basis of the cost of producing and procurement in Norway (The prices have been redacted due to company sensitivity). At this price there is no economical benefit of moving the production to Norway. As long as the economic benefits of a shorter time of delivery, better quality control or a more Lean project execution is not bigger then the economic benefit of keeping the production in China, there is no economical benefit of moving the production.

If the customers require a product that is produced in Norway, with components sourced in Europe there certainly would be a market for these kinds of products.

The product must also go through more iterations of product development to improve the design for manufacturing, there is a requirement to include the production facilities them selves to get input on improvements.

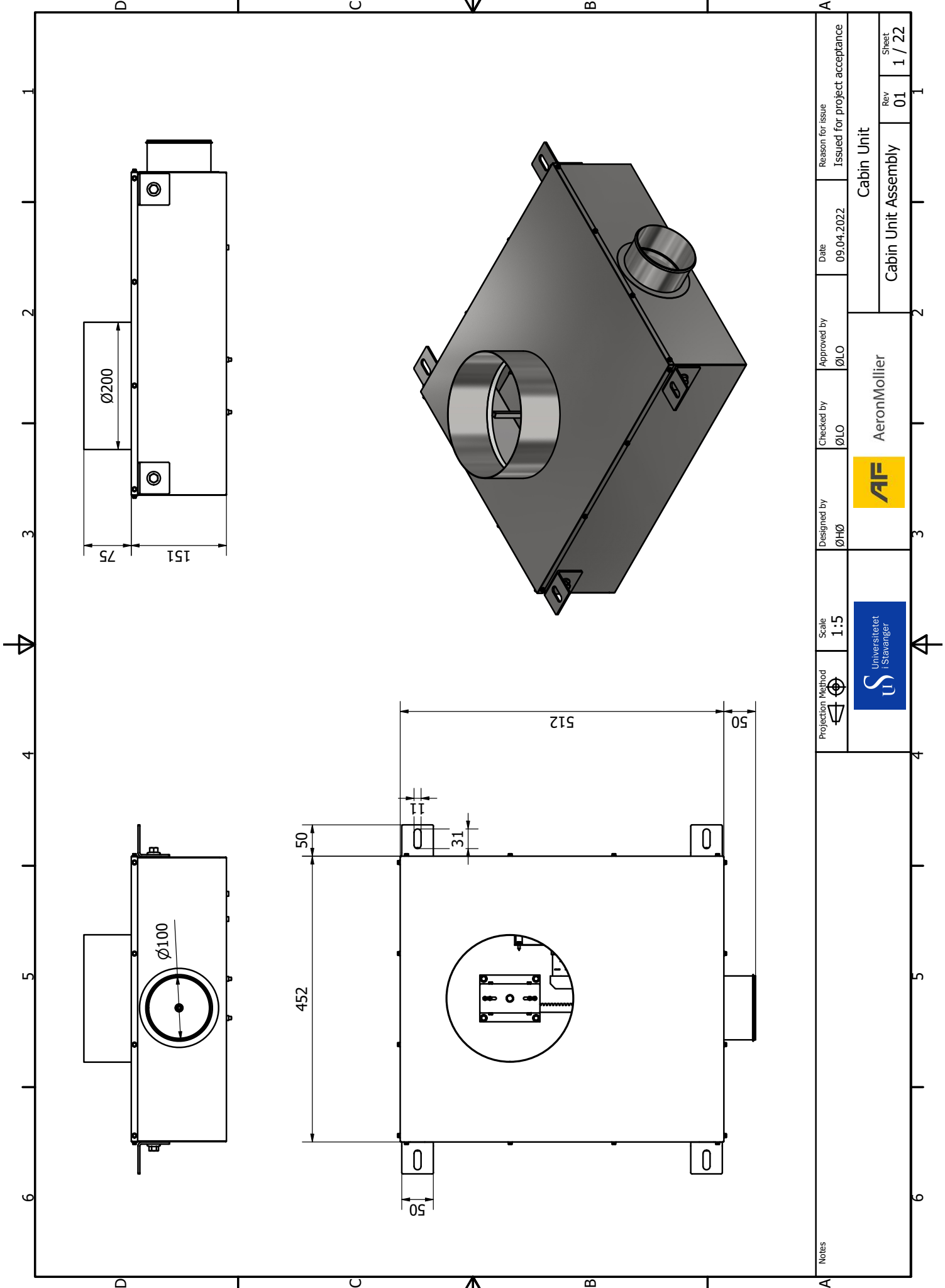
This thesis is merely a case study to show that the possibility of production is there, now there must be done further work to improve the design and manufacturing process to reduce the cost.

The cost of the product is largely driven by single components cost and labour costs, if a purchaser could get the prices of the singe components down, and the product development continues to improve the manufacturing process, the cost would be greatly reduced.

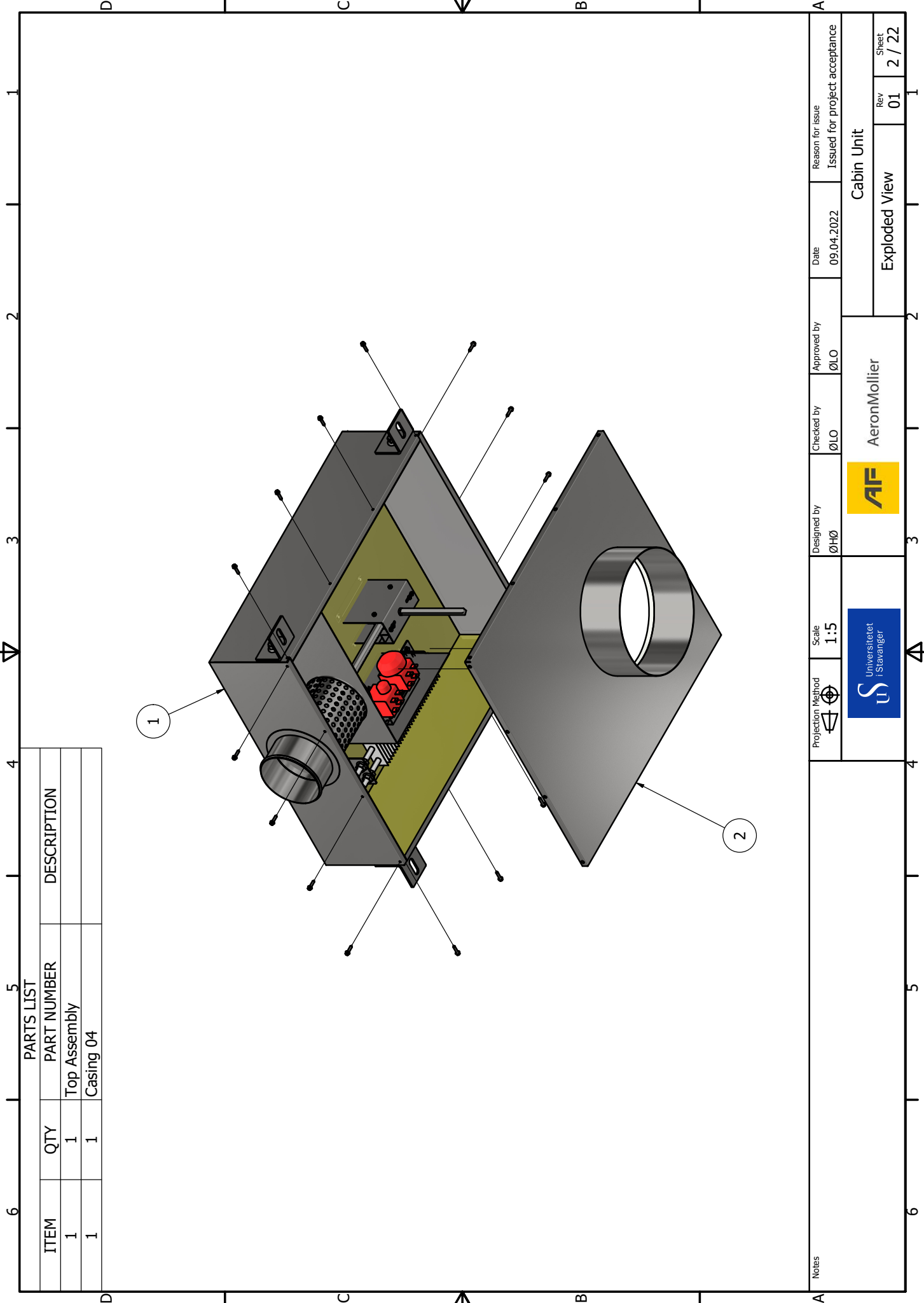
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A | Appendix



Notes	Projection Method	Scale	Designed by	Checked by	Approved by	Date	Reason for issue
		1:5	ØHØ	ØLO	ØLO	09.04.2022	Issued for project acceptance
 Universitetet i Stavanger			 AeronMollier		Cabin Unit		
					Cabin Unit Assembly		Rev
				01	1 / 22		

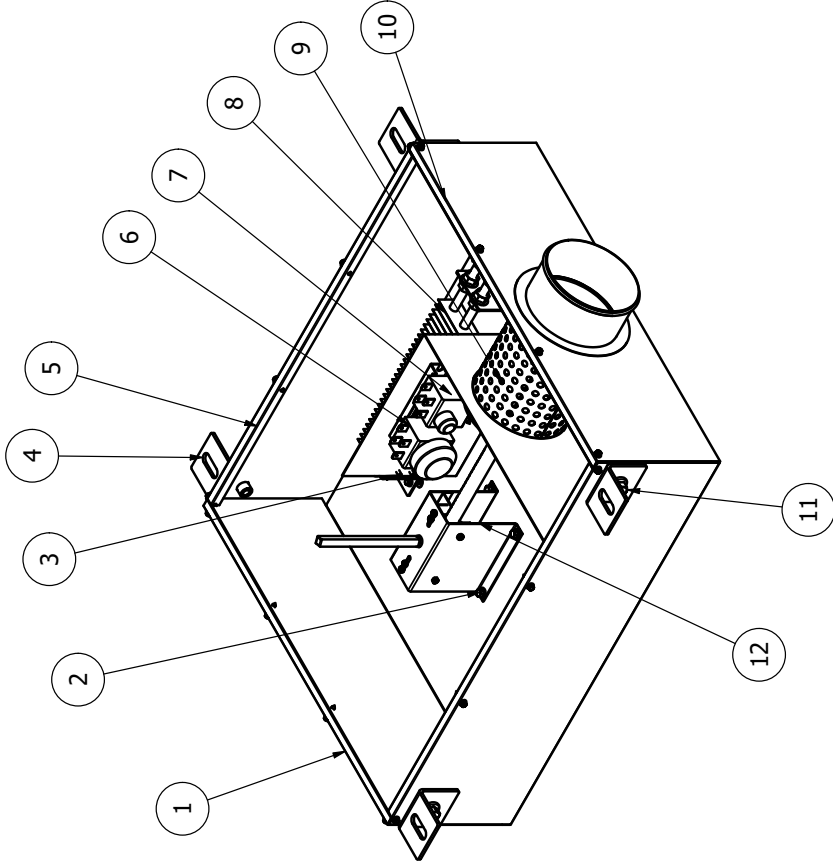


PARTS LIST		
ITEM	QTY	DESCRIPTION
1	1	Top Assembly
1	1	Casing 04

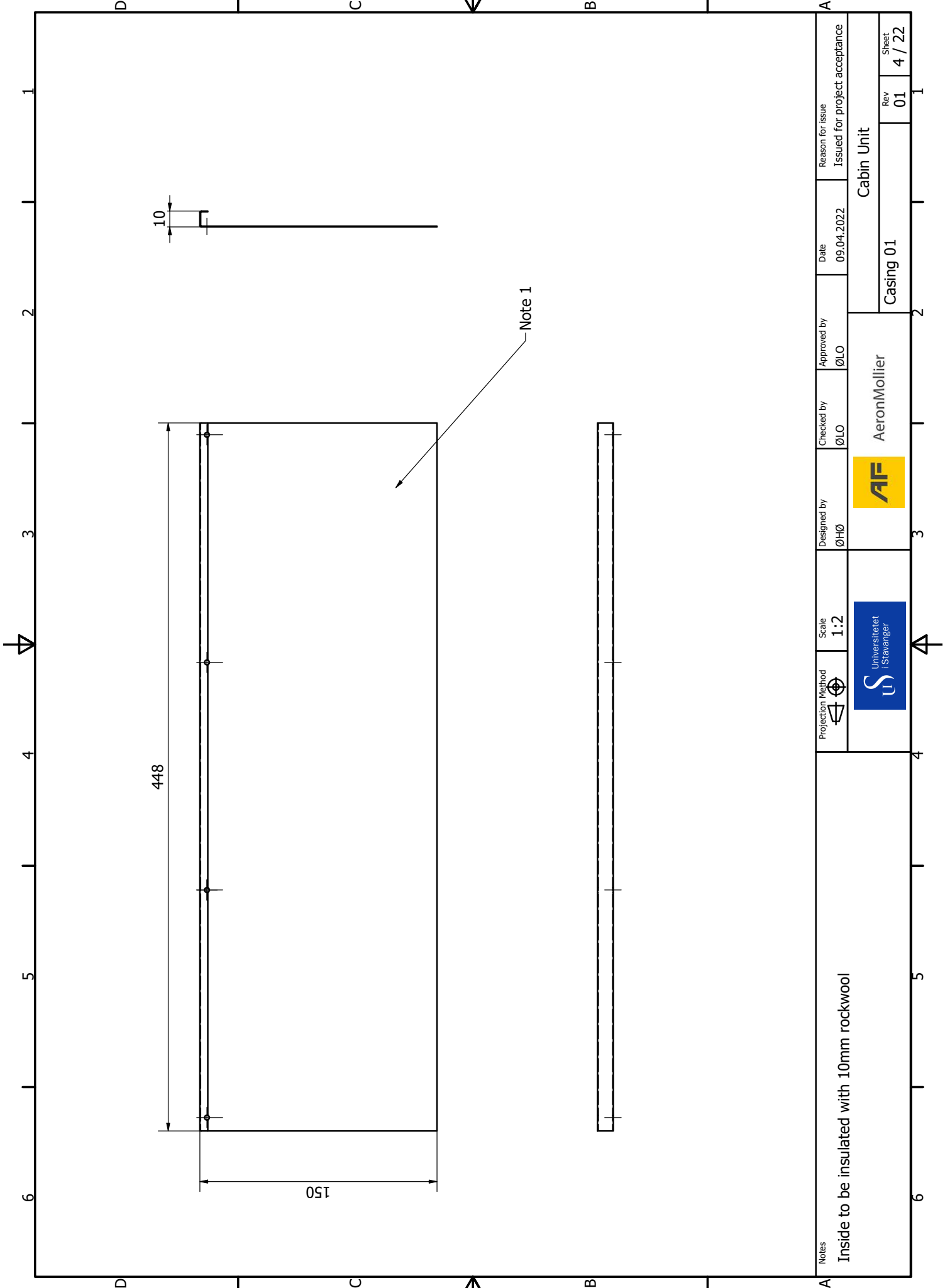
Notes	Projection Method	Scale	Designed by	Checked by	Approved by	Date	Reason for issue
		1:5	ØHØ	ØLO	ØLO	09.04.2022	Issued for project acceptance
					Cabin Unit		
					Exploded View		Rev
						01	2 / 22

ITEM QTY	PART NUMBER	DESCRIPTION	SHEET
1	Casing 02		4
2	M5 Bolt	Hex Flange Head Machine Screw	
3	IFI 502 - 3.5x1.3 x 10, HFHTSTAM	Hex Flange Head Tapping Screw - Type AB - Metric	
4	Bracket		5
5	Casing 02		6
6	Temperature Switch (High/High High)		7
7	Thermal Element		8
8	Heater Assembly	500W	9
9	Balancing Damper Assembly	Ø100	10
10	Casing 03		14
11	M10 Bolt	Hex Flange Head Machine Screw	
12	Handle Mechanism		15

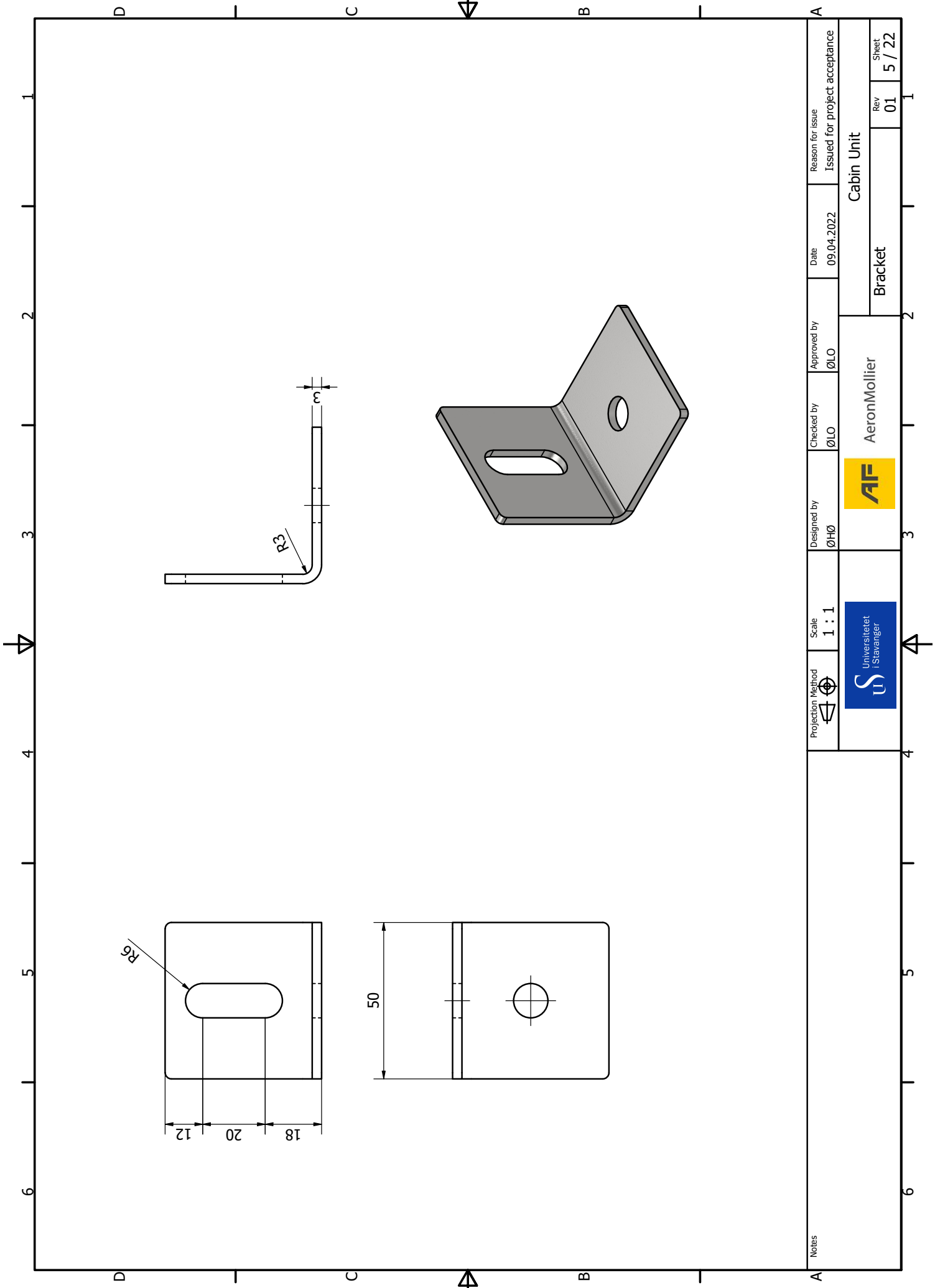
PARTS LIST



Notes	Projection Method	Scale	Designed by	Checked by	Approved by	Date	Reason for issue
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					Top Assembly		Rev
		6	5	4	3	2	1
		A	B	C	D		

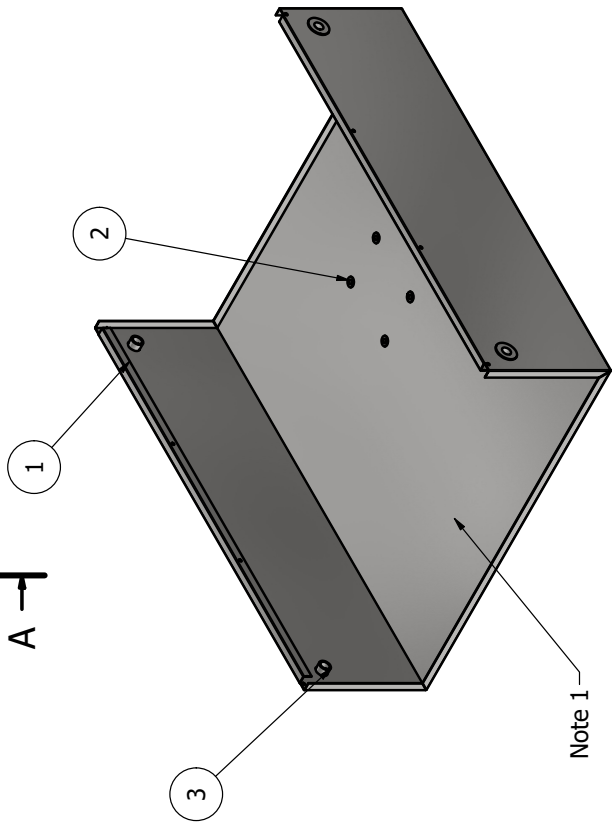
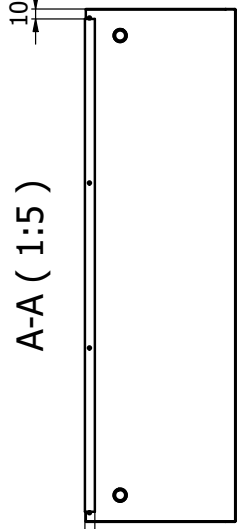
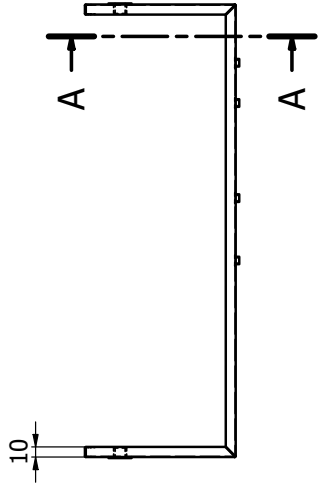
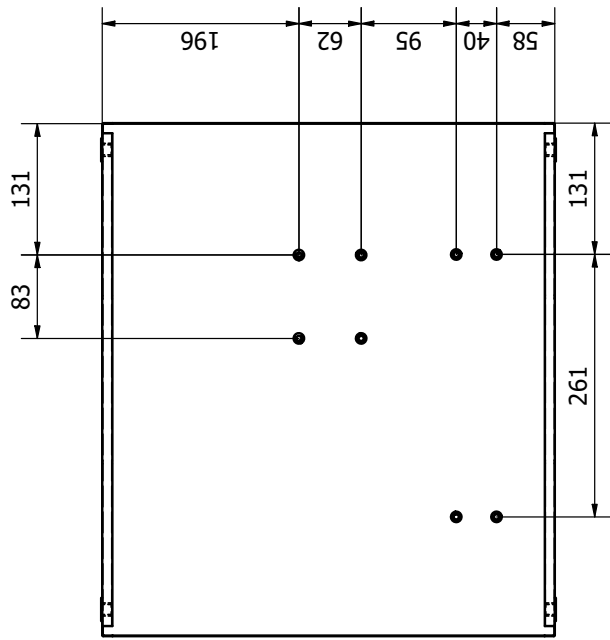
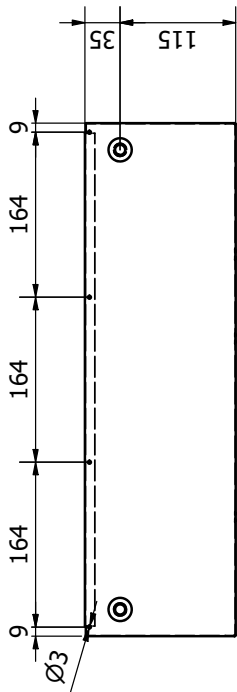


Notes	Inside to be insulated with 10mm rockwool						Projection Method	Scale	Designed by	Checked by	Approved by	Date	Reason for issue
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											Cabin Unit		
								AeronMollier		Casing 01		Rev	Sheet
												01	4 / 22



Notes	Projection Method	Scale	Designed by	Checked by	Approved by	Date	Reason for issue	
		1 : 1	ØHØ	ØLO	ØLO	09.04.2022	Issued for project acceptance	
 Universitetet i Stavanger			 AeronMollier		Bracket			
					Cabin Unit			
							Rev	Sheet
							01	5 / 22

PARTS LIST		
ITEM	QTY	DESCRIPTION
1	1	Casing 02
2	1	Rockwool Insulation 10mm
2	8	M5 Pop Nut
3	4	M10 Pop Nut

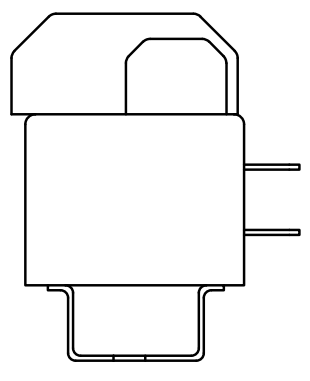
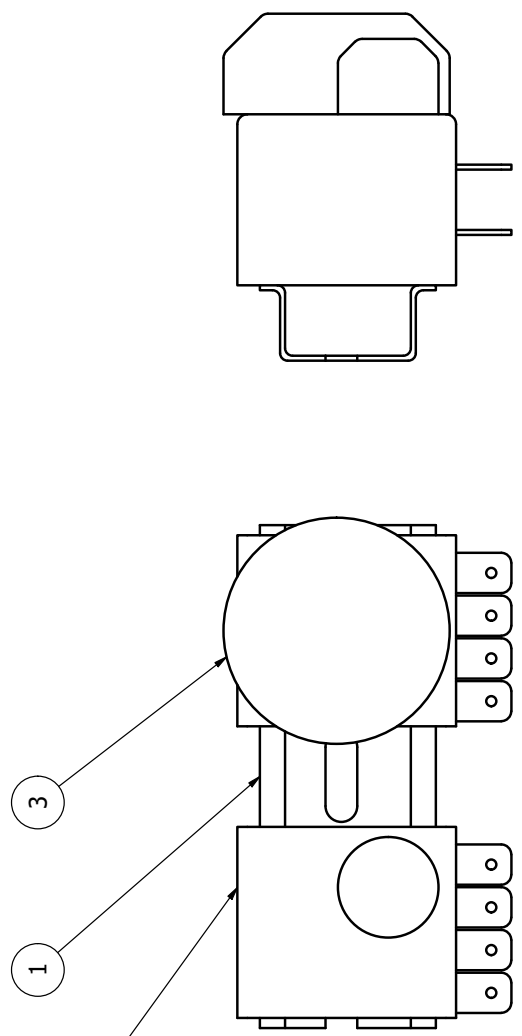


Note 1

Notes 1. Inside to be insulated with 10mm RockWool	Projection Method	Scale	Designed by	Checked by	Approved by	Date	Reason for issue
		1:5	ØHØ	ØLO	ØLO	09.04.2022	Issued for project acceptance
		AeronMollier		Casing 02		Cabin Unit	
				Rev	Sheet	01	6 / 22

1 2 3 4 5 6

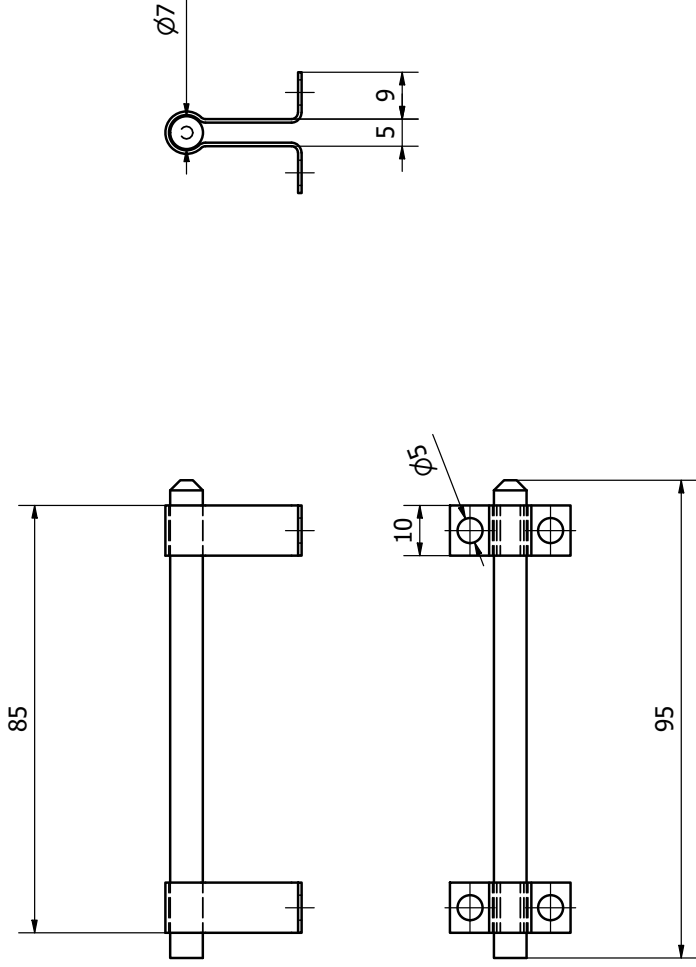
PARTS LIST		
ITEM	QTY	DESCRIPTION
1	1	Din Rail
2	1	Temperature Switch High High 110C
3	1	Temperature Switch High High 60C



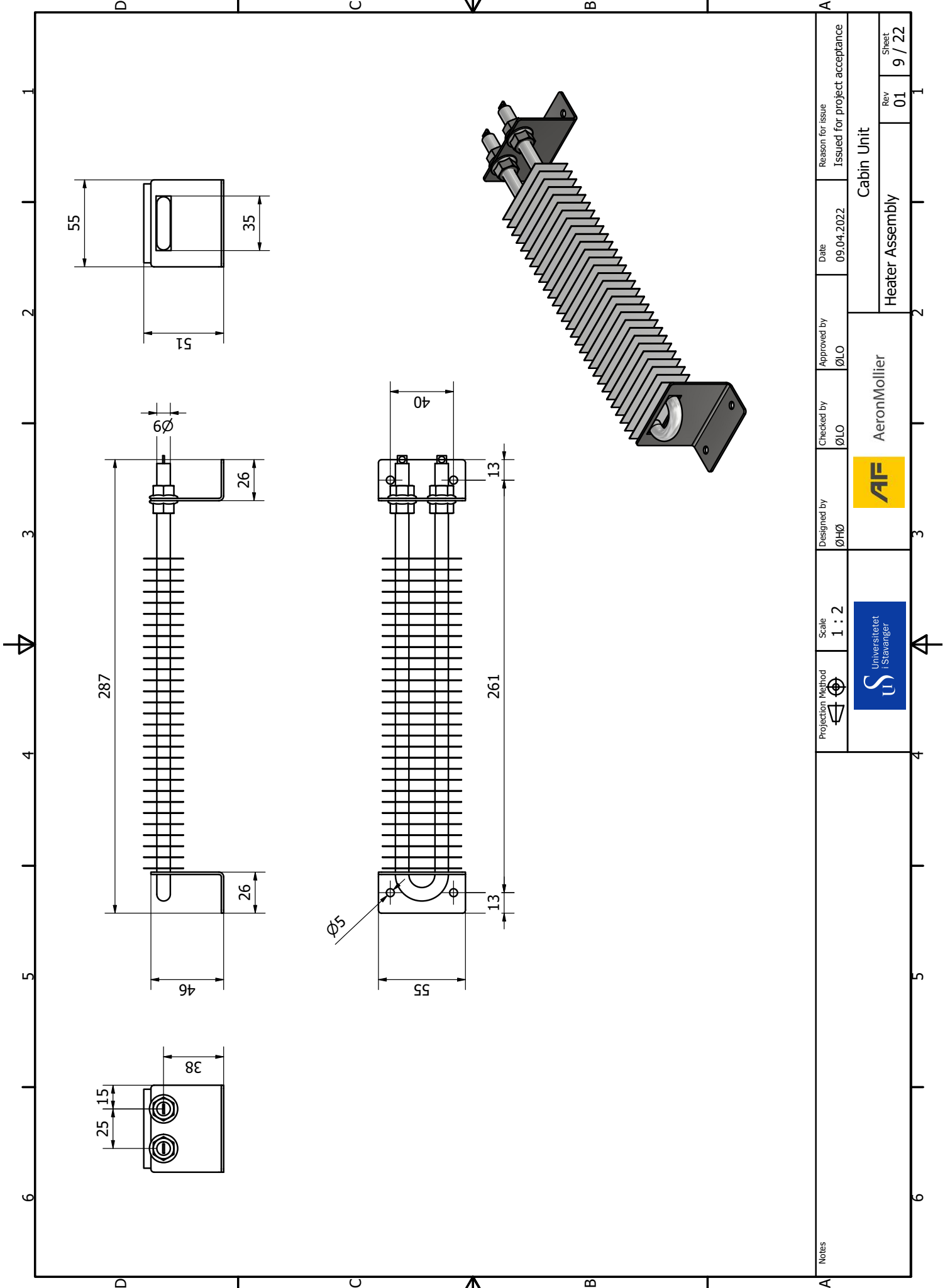
Notes	Projection Method	Scale	Designed by	Checked by	Approved by	Date	Reason for issue
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					Cabin Unit		
					Temperature Switch		Rev
					01		7 / 22

D C B A

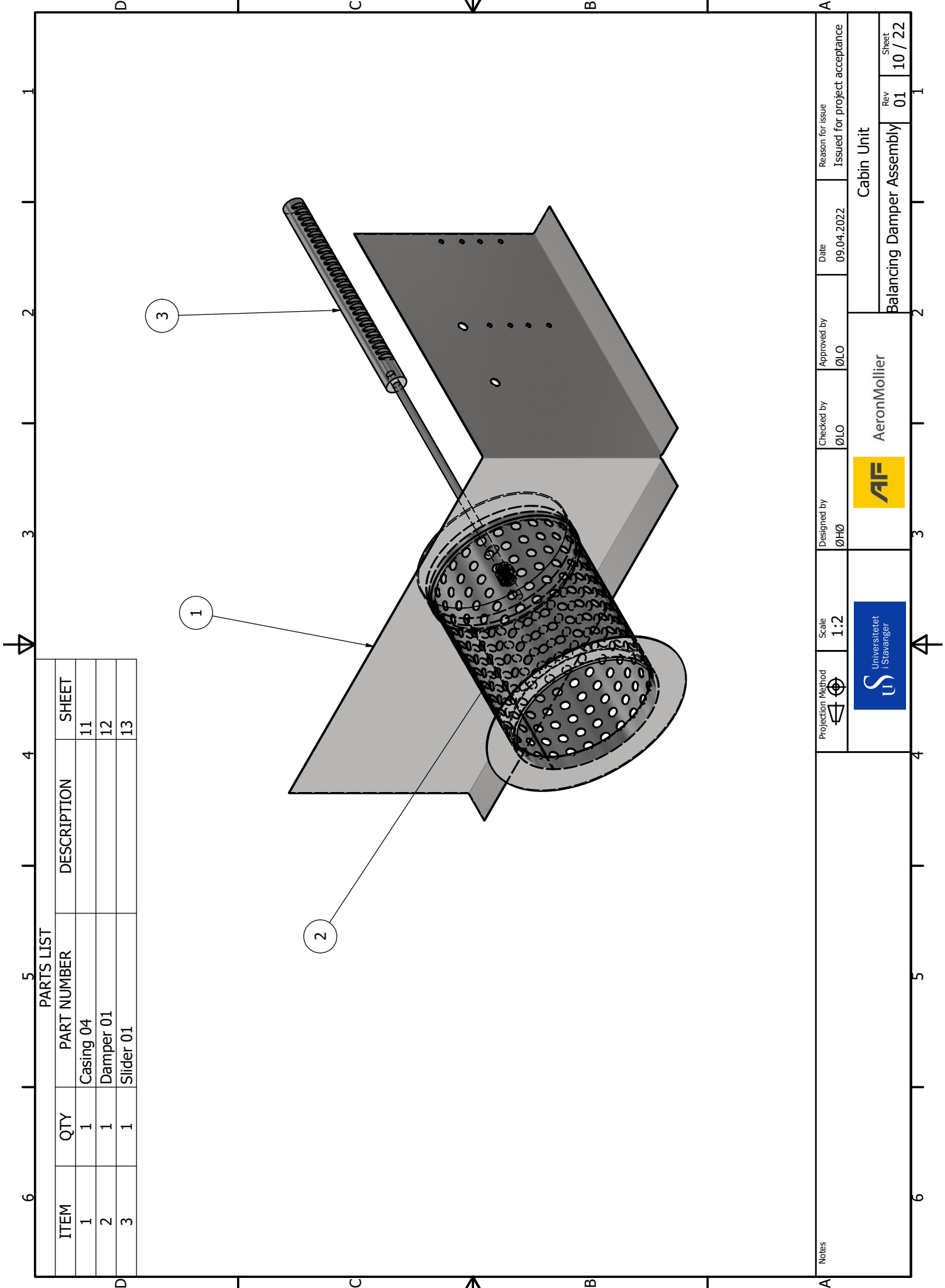
PARTS LIST		
ITEM	QTY	DESCRIPTION
1	2	Thermal Element Bracket
2	1	Thermal Element



Notes	Projection Method	Scale	Designed by	Checked by	Approved by	Date	Reason for issue
		1 : 1	ØHØ	ØLO	ØLO	09.04.2022	Issued for project acceptance
		AF	AeronMollier		Cabin Unit		
			Thermal Element		Thermal Element		
							Rev
							01
							8 / 22
							Sheet
							8 / 22



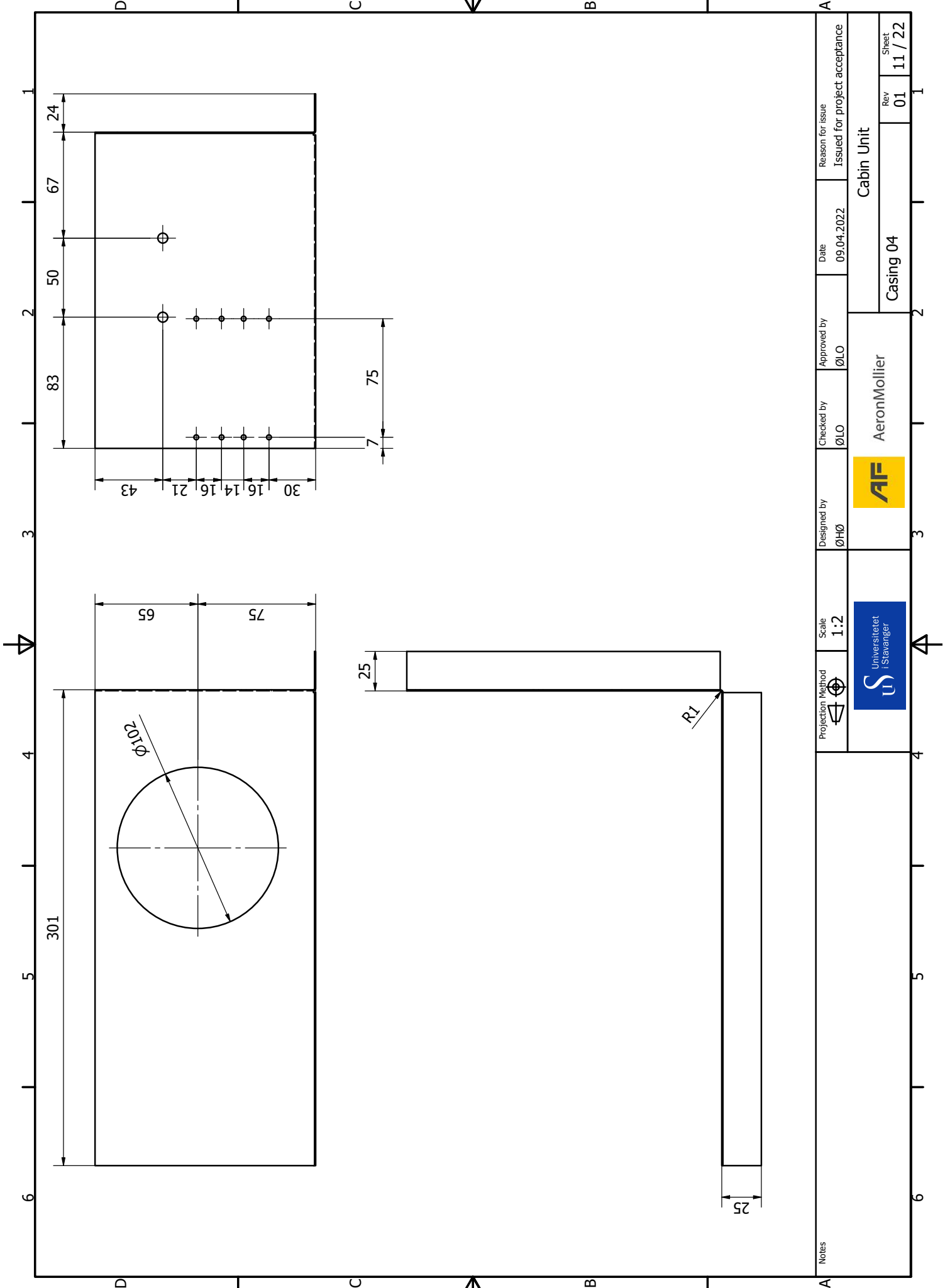
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		AF	AeronMollier		Cabin Unit		
			Heater Assembly		Rev	Sheet	01



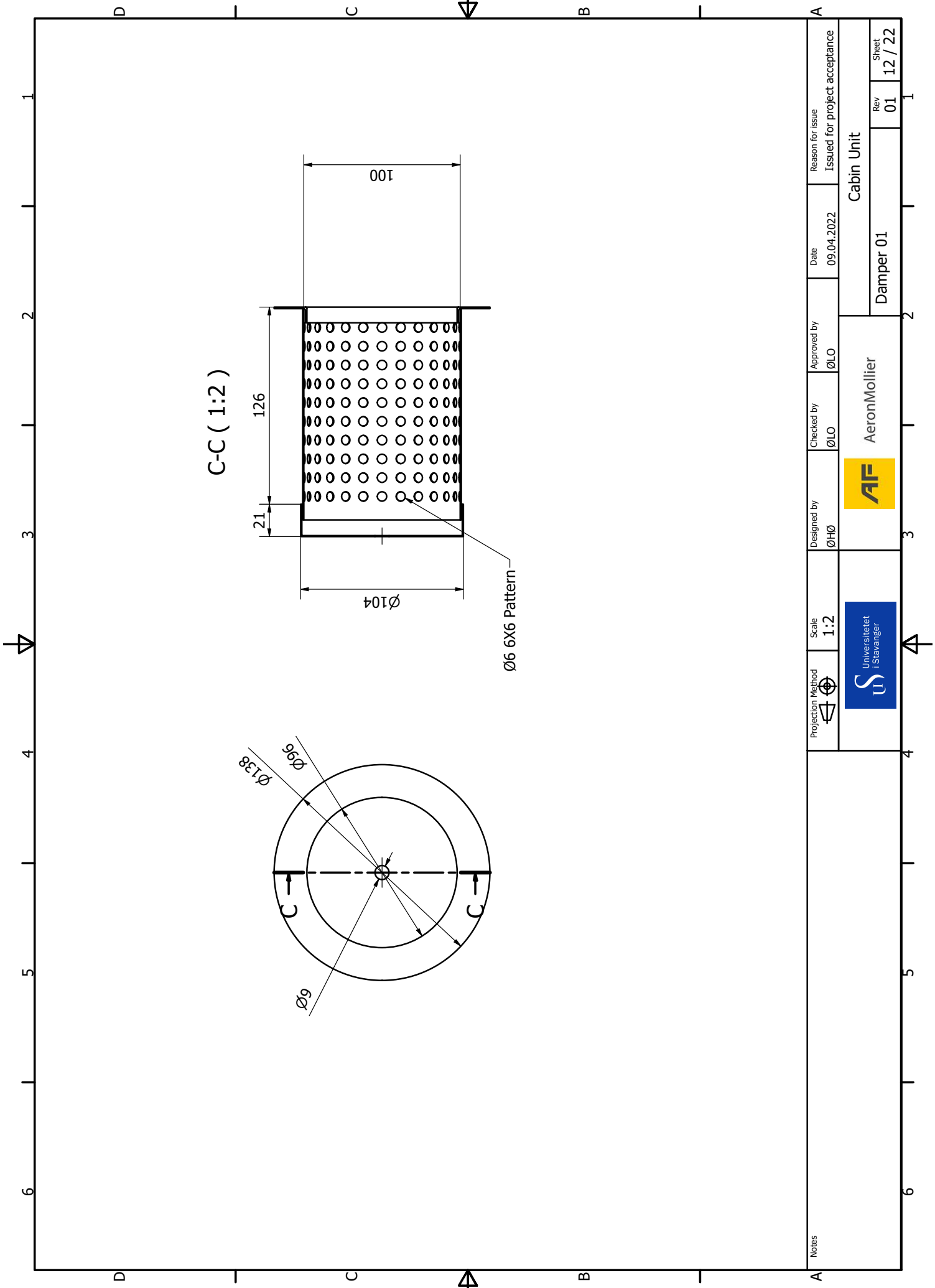
PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION	SHEET
1	1	Casing 04		11
2	1	Damper 01		12
3	1	Slider 01		13

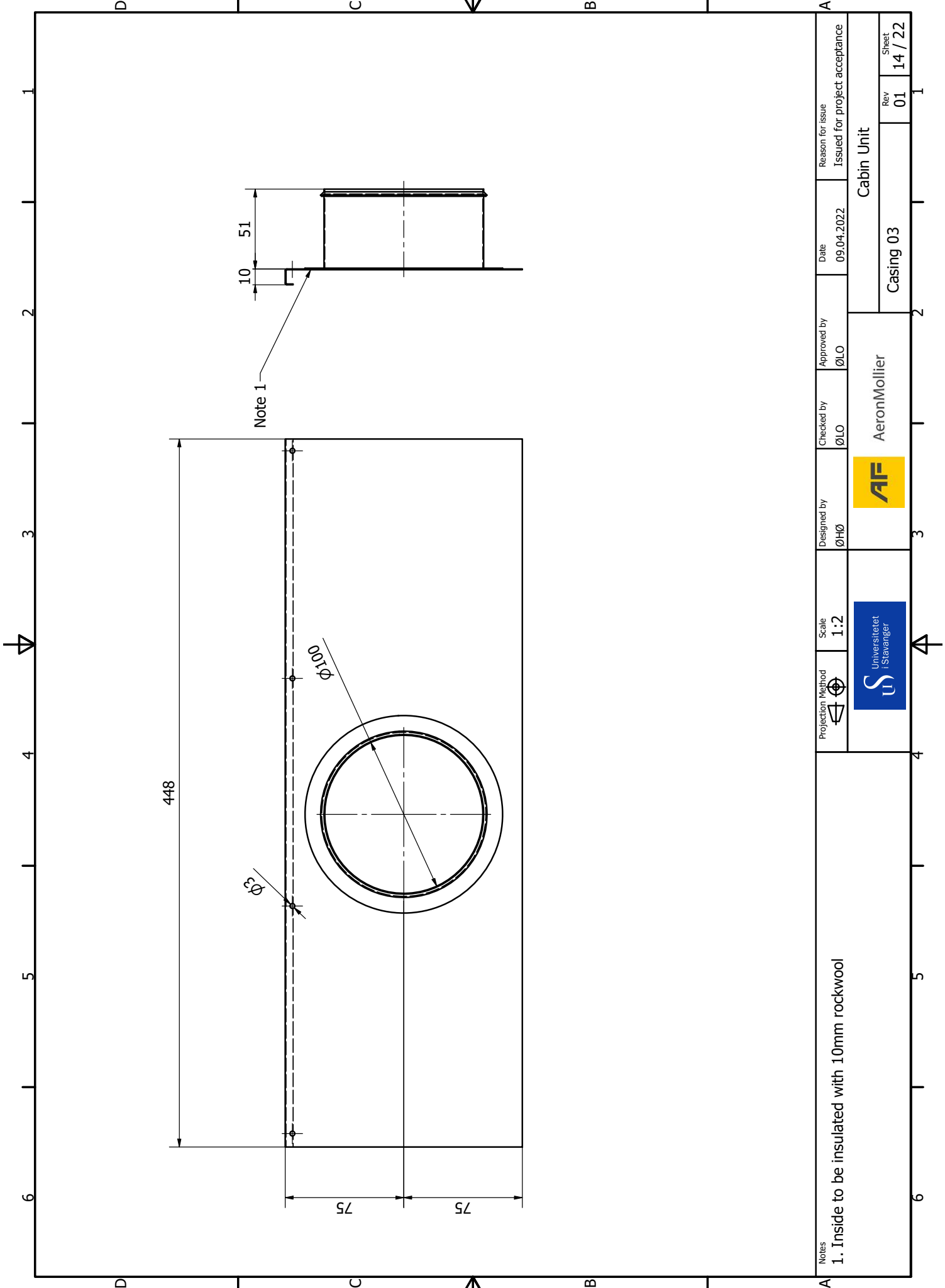
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 Universitetet i Stavanger			 AeronMollier		Cabin Unit Balancing Damper Assembly			Rev
								01
							Sheet	
							10 / 22	






Notes	Projection Method	Scale	Designed by	Checked by	Approved by	Date	Reason for issue	
		1:2	ØHØ	ØLO	ØLO	09.04.2022	Issued for project acceptance	
					AeronMollier		Casing 04	
							Cabin Unit	
							Rev	Sheet
							01	11 / 22



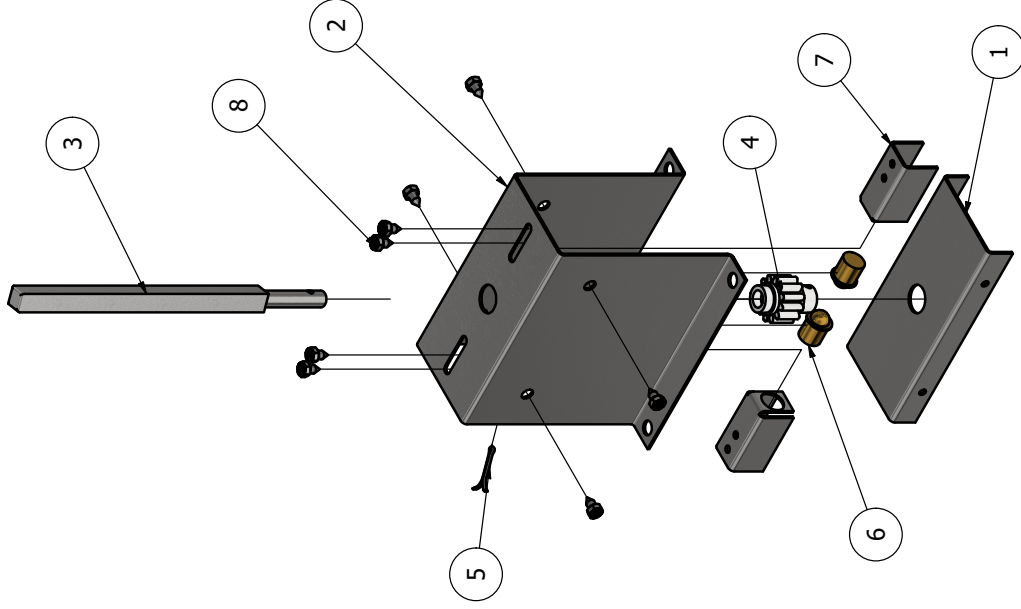
Notes	Projection Method	Scale	Designed by	Checked by	Approved by	Date	Reason for issue
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 Universitetet i Stavanger			 AeronMollier		Cabin Unit		
					Damper 01		Rev
				01	12 / 22		



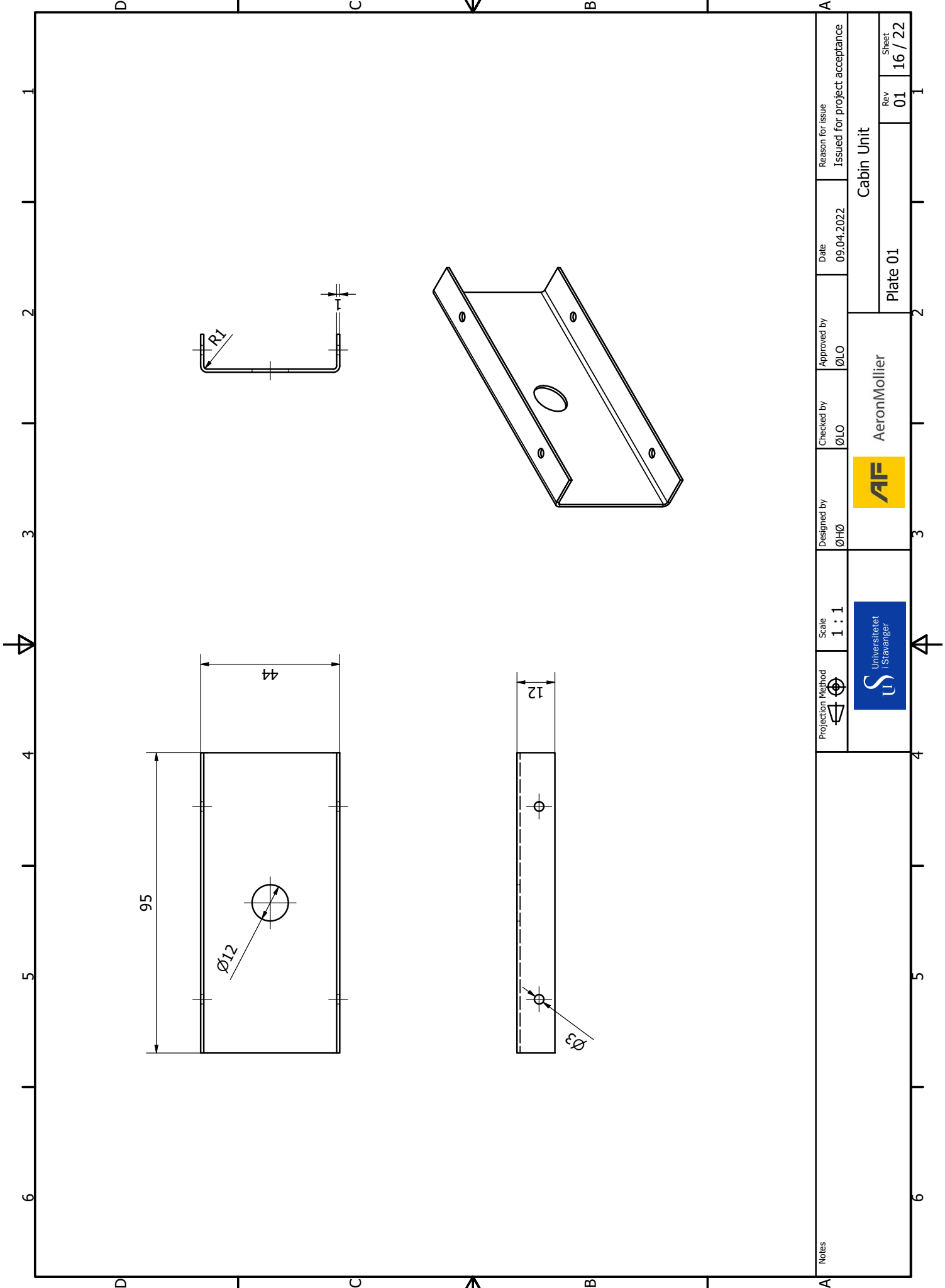
Notes	1. Inside to be insulated with 10mm rockwool									
	Projection Method	Scale	Designed by	Checked by	Approved by	Date	Reason for issue	Cabin Unit		
	1:2	ØHØ	ØLO	ØLO	09.04.2022	Issued for project acceptance	Casing 03			Rev
	 Universitetet i Stavanger	 AeronMollier		 Universitetet i Stavanger			01 / 14 / 22			Sheet
										01

ITEM	QTY	PART NUMBER	DESCRIPTION	SHEET
1	1	Plate 01		16
2	1	Plate 02		17
3	1	Rectangular Rod		18
4	1	Spur Gear		19
5	1	DIN EN ISO 1234 - 1.6x15	Split Pin	
6	2	Spring Mounted Ball	Ø10 L:9mm	
7	2	Plate 03		20
8	8	Self Tapping Screw	Cross recessed hexagon head tapping screws with identification	

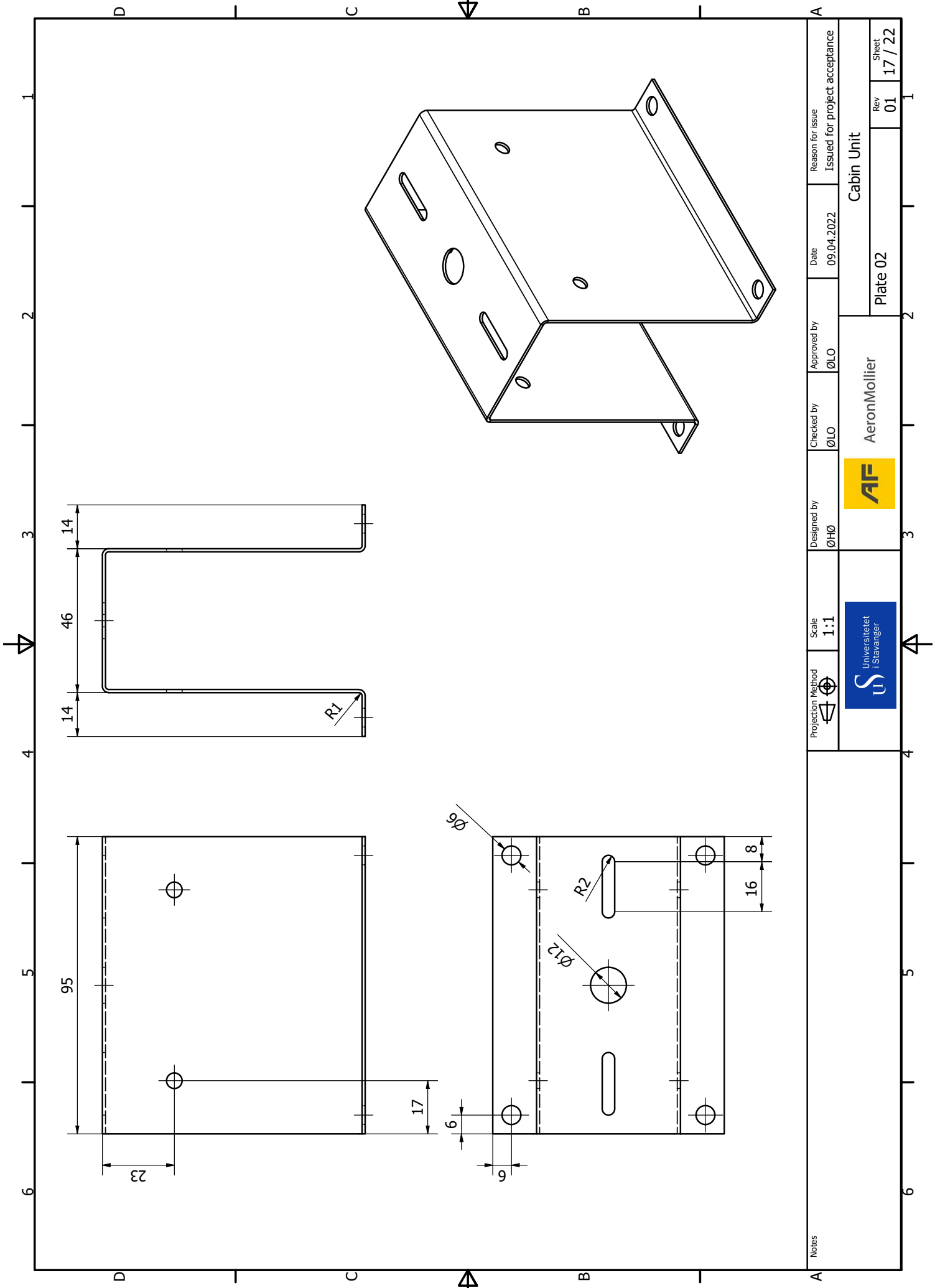
PARTS LIST



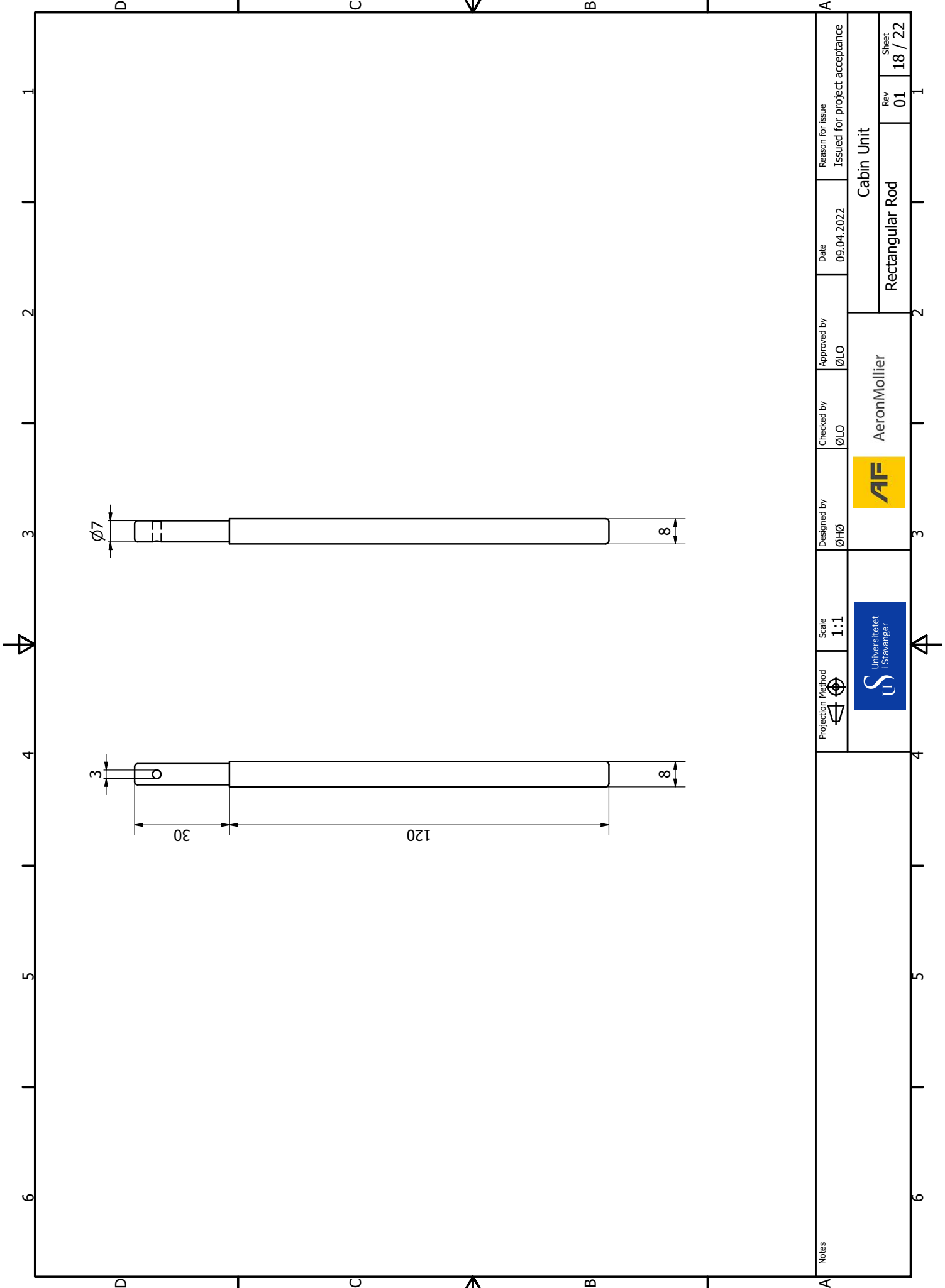
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					AeronMollier			Handle Mechanism
								Cabin Unit
								Rev
								01
								Sheet
								15 / 22



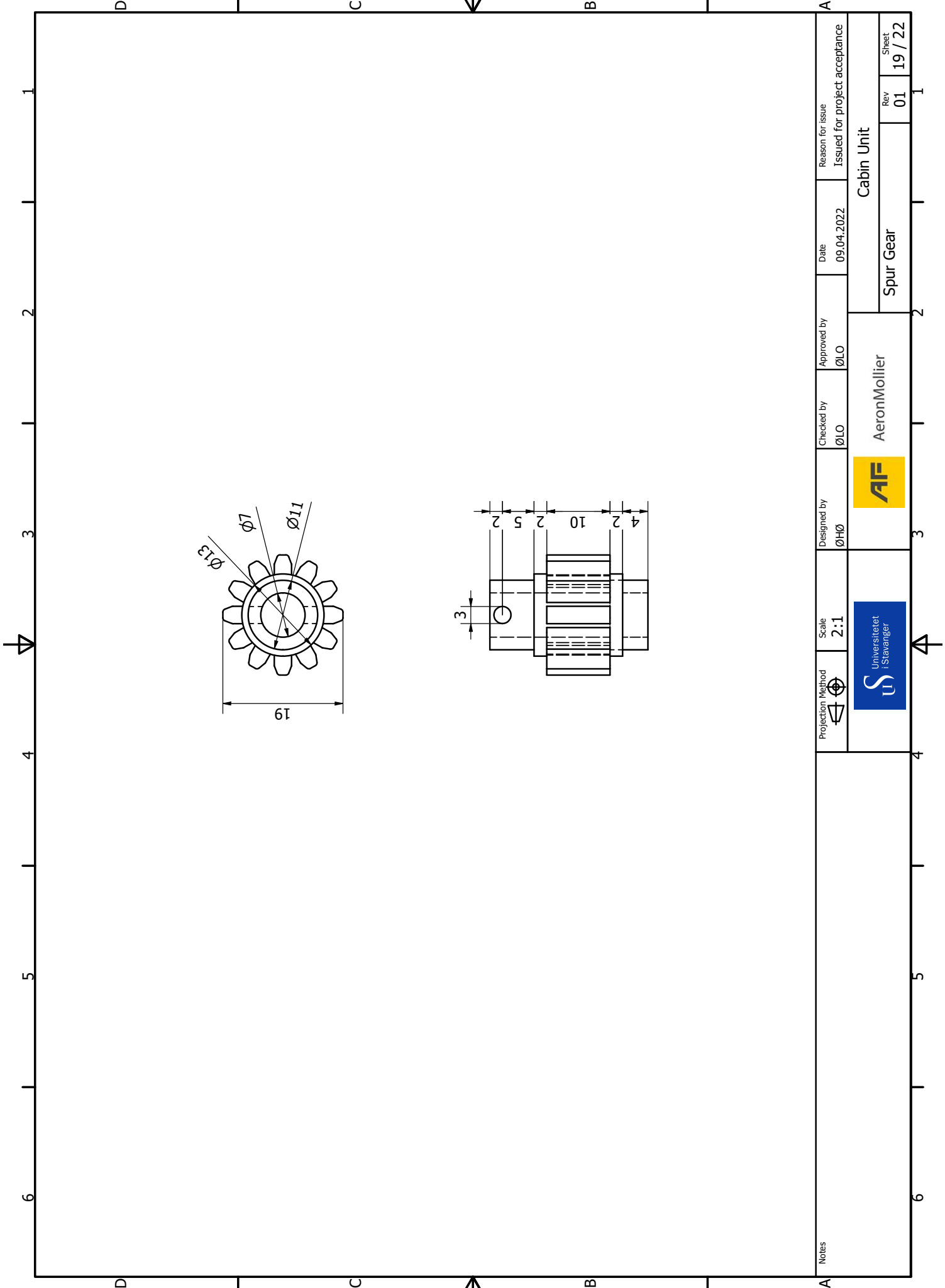
Notes	Projection Method	Scale	Designed by	Checked by	Approved by	Date	Reason for issue
		1 : 1	ØHØ	ØLO	ØLO	09.04.2022	Issued for project acceptance
 Universitetet i Stavanger			 AeronMollier		Cabin Unit		
					Plate 01	Rev 01	Sheet 16 / 22



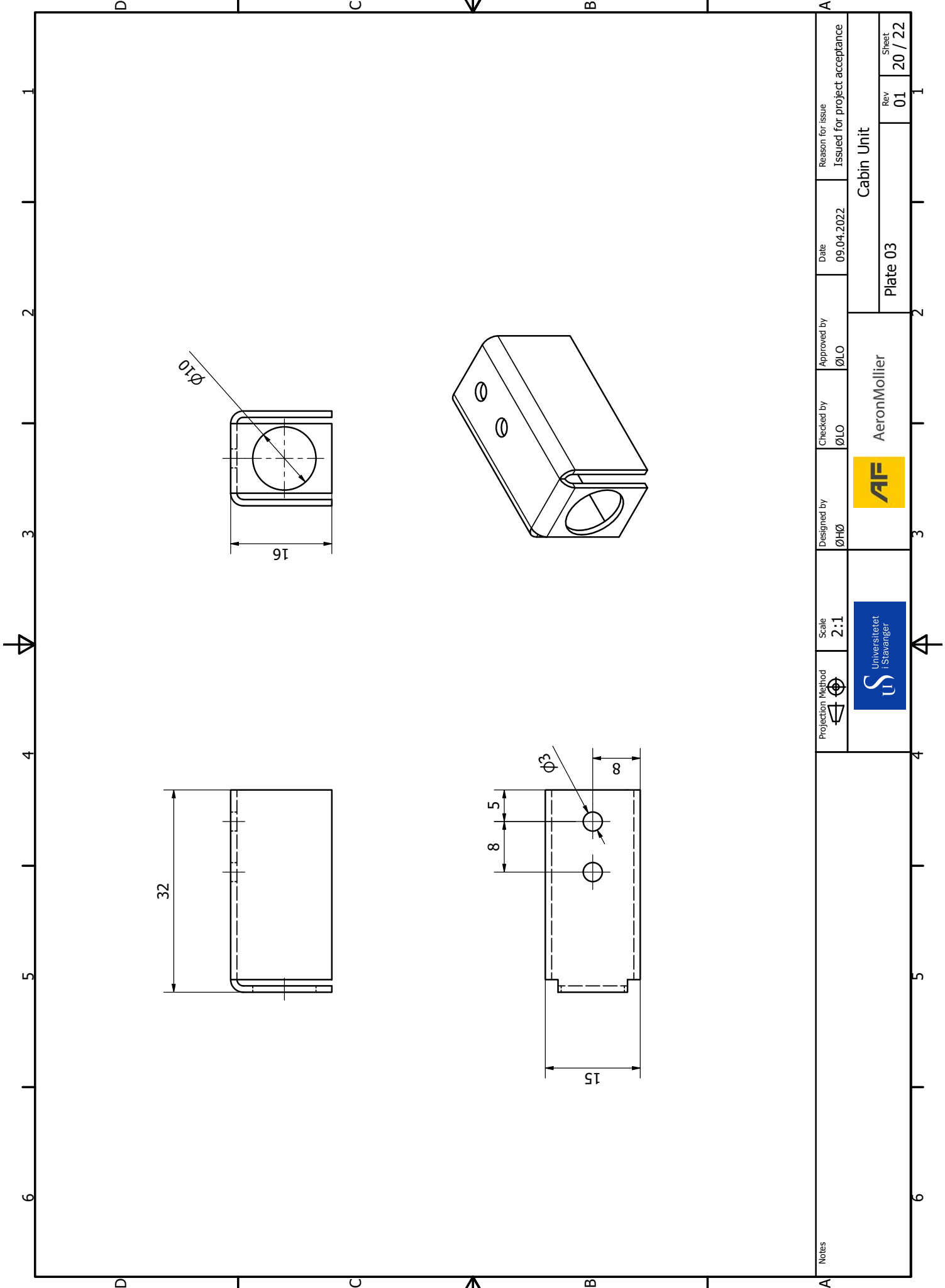
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 Universitetet i Stavanger			 AeronMollier		Cabin Unit		
					Plate 02	Rev 01	Sheet 17 / 22



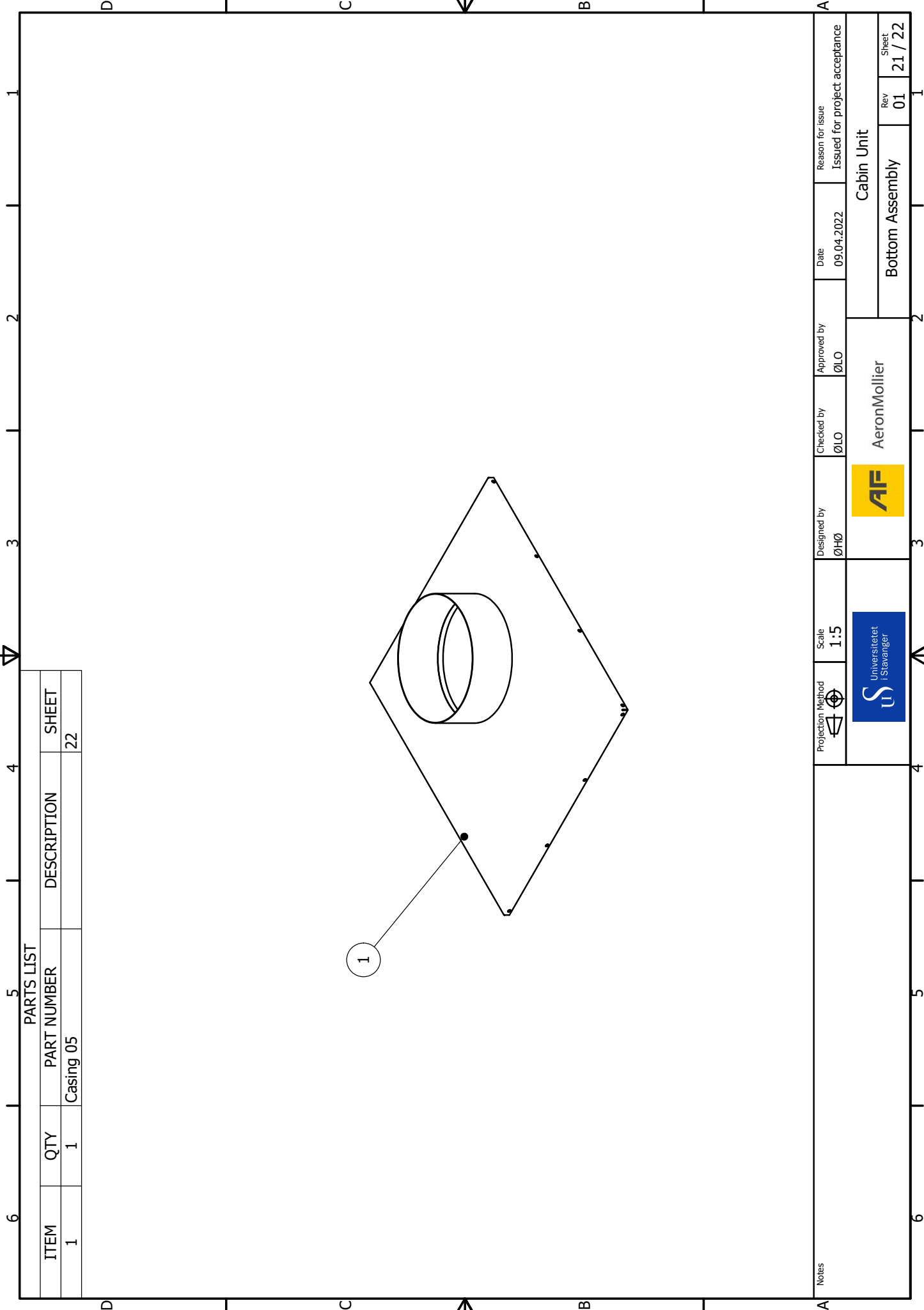
Notes	Projection Method	Scale	Designed by	Checked by	Approved by	Date	Reason for issue
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					Cabin Unit		
					Rectangular Rod		Rev
						01	18 / 22



Notes	Projection Method	Scale	Designed by	Checked by	Approved by	Date	Reason for issue
		2:1	ØHØ	ØLO	ØLO	09.04.2022	Issued for project acceptance
				AeronMollier		Cabin Unit	
				Spur Gear		Rev 01 19 / 22	



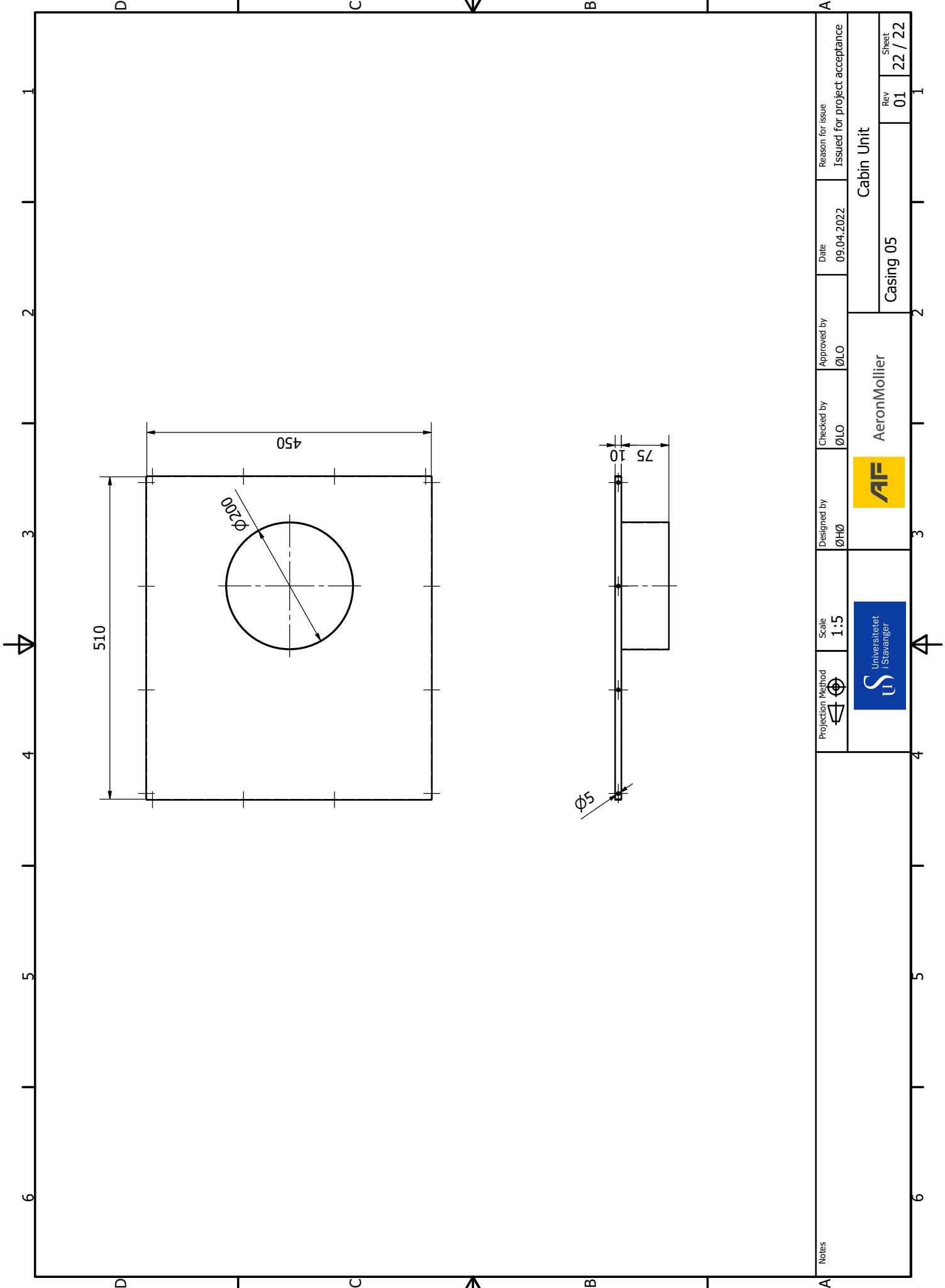
Notes	Projection Method	Scale	Designed by	Checked by	Approved by	Date	Reason for issue
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 Universitetet i Stavanger			 AeronMollier		Cabin Unit		
					Plate 03		
					01	20 / 22	1



PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION	SHEET
1	1	Casing 05		22

Notes	Projection Method	Scale	Designed by	Checked by	Approved by	Date	Reason for issue	
		1:5	ØHØ	ØLO	ØLO	09.04.2022	Issued for project acceptance	
					Cabin Unit			
					Bottom Assembly			
							Rev	Sheet
							01	21 / 22



Notes	Projection Method	Scale	Designed by	Checked by	Approved by	Date	Reason for issue
		1:5	ØHØ	ØLO	ØLO	09.04.2022	Issued for project acceptance
 Universitetet i Stavanger			 AeronMollier		Cabin Unit		
					Casing 05		Rev
				01	22 / 22		