LiftWEC

DEVELOPMENT OF A NEW CLASS OF WAVE ENERGY CONVERTER BASED ON HYDRODYNAMIC LIFT FORCES

Deliverable D4.1

Design of the 2D scale model

Deliverable Lead	Ecole Centrale Nantes
Delivery Date	03/03/2021
Dissemination Level	Public/Consortium Only/Confidential
Status	Final
Version	2.0

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

Document Information

Project Acronym	LiftWEC
Project Title	Design of the 2D scale model
Grant Agreement Number	851885
Work Package	WP04
Related Task(s)	T4.1
Deliverable Number	D4.1
Deliverable Name	Design of the 2D scale model
Due Date	31st August 2020
Date Delivered	3rd March 2021
Primary Author(s)	Grégory Payne (ECN)
Co-Author(s)	Florent Thiebaut (ECN), Sylvain Haquin (ECN), Matthieu Weber (ECN)
Document Number	LW-D04-01-2x0

Version Control

Revision	Date	Description	Prepared By	Checked By
1.0	19/12/2019	Draft for internal review	GP	JR, JF, AE
2.0	03/03/2021	Final	GP	FT

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

EXECUTIVE SUMMARY

Experimental testing of a two-dimensional LiftWEC concept, with one or two foils, is necessary for the validation of numerical models developed as part of WP3 (Numerical Modelling) and analytical models suitable for control design developed by WP5. The specifications of the physical model were derived through discussions with the partners involved in the numerical modelling work package, through considerations of the testing facilities available at Ecole Centrale de Nantes (ECN) and ECN physical model design and testing know how. The model allows testing of configurations with one or two foils, with adjustments of the foil angle of attack and of the foils radial position, between tests. The model is to be tested in the ECN towing tank, in a narrow "sub-channel" made of partition walls, which locally reduces the flume width. The idea behind this approach is to use a tank capable of generating large waves while keeping the width of the device and hence loads on the device more manageable, thus reducing complexity and costs. The motion of the rotor is controlled using a power take-off (PTO) system consisting of an electrical machine which can be operated in speed and torque control. The quantities measured are: the PTO torque, radial and tangential loads on the axis of each foil, absolute angular position of the rotor and wave elevation upstream and downstream of the model. From those measured quantities, rotor velocity and acceleration as well as captured power can be inferred. The details of the various components as well as technical drawings of the parts of the model are provided herein.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

TABLE OF CONTENTS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

1 INTRODUCTION

This document describes the design process and the detailed design of the 2D wave tank model of the two LiftWEC concepts, including one or two foils, which will be tested at ECN.

The document starts by detailing the purpose of the model and is then followed by the description of the design criteria. Finally, the detailed design is provided and includes technical drawings.

2 MODEL PURPOSE

The main purpose of this experimental model is the validation of the numerical models developed within WP03 and analytical models suitable for control design developed by WP05. At this stage, the aim is not to build an experimental model corresponding to a finalised LiftWEC concept, optimised in terms of power production and load performances but to focus on features which are the most relevant for the validation of numerical and analytical models.

One of the key aspects of that model is that it is placed in a narrow channel whose width is equal to that of the span of a foil, so that all hydrodynamic characteristics are considered in 2D. This approach makes the hydrodynamic interactions between the device and the wave field simpler and corresponds to the configuration investigated at this stage of the project by the numerical models developed in WP03 and the analytical models developed in WP05. The experimental model will nevertheless make it possible to derive estimates of the wave energy captured by the system.

3 DESIGN CRITERIA

The design criteria described in this section is the outcome of discussions with the other relevant partners of the project (mainly those involved in numerical modelling), the full-scale wave climate at a realistic site, the constrains associated with the ECN testing facilities and the experience of the ECN team in model design and testing.

3.1 REALISTIC DEPLOYMENT SITE

In order to quantify realistic wave conditions that a LiftWEC device would experience when deployed at full-scale, we have been using the open access hindcast wave climate database HOMERE developed by the French research institution IFREMER. More details on the database can be found in [1]. The site considered is south-west of Brittany (47.84° N, 4.83° W) as shown Figure 3-1. From the HOMERE database, it was possible to quantify the wave climate for the 2001-2010 period in terms of a scatter diagram, which is presented in Figure 3-2.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

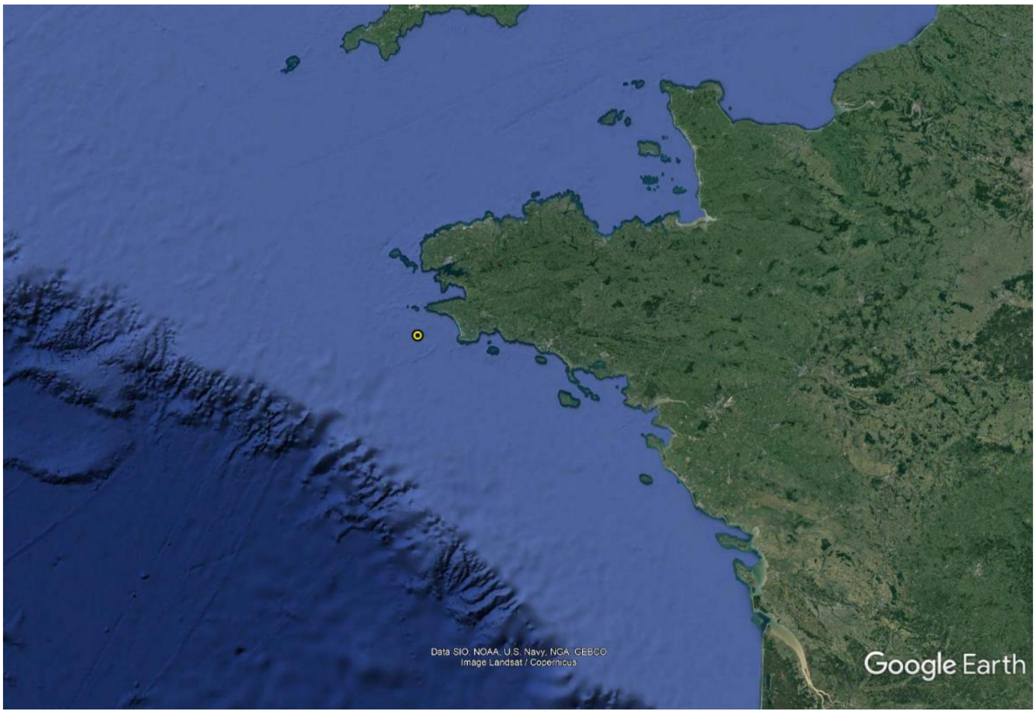


Figure 3-1: Location of the deployment site (yellow dot)

Significant wave height (metres) \ Wave energy period (secs)	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	Total
Total	0.00	0.02	1.23	7.12	16.12	20.17	18.91	14.60	10.58	6.30	2.98	1.32	0.49	0.11	0.05	100.00
8.00								0.00	0.01	0.11	0.11	0.08	0.05	0.01		0.37
7.50								0.00	0.04	0.09	0.09	0.03	0.03	0.00		0.30
7.00								0.04	0.10	0.13	0.07	0.05	0.02	0.00	0.01	0.43
6.50							0.00	0.08	0.18	0.21	0.11	0.05	0.02	0.00	0.00	0.66
6.00							0.03	0.27	0.40	0.34	0.16	0.08	0.02	0.00		1.31
5.50							0.14	0.49	0.48	0.38	0.12	0.07	0.02	0.01		1.72
5.00						0.02	0.46	0.75	0.69	0.55	0.19	0.08	0.06	0.01		2.80
4.50						0.15	0.85	0.97	0.87	0.39	0.24	0.10	0.02	0.01	0.01	3.61
4.00					0.03	0.53	1.16	1.14	0.94	0.58	0.33	0.11	0.03	0.01	0.00	4.86
3.50					0.26	1.07	1.44	1.19	1.01	0.58	0.27	0.14	0.05	0.00	0.00	6.02
3.00				0.04	0.94	2.07	1.81	1.75	1.29	0.77	0.36	0.14	0.04	0.01	0.00	9.22
2.50			0.00	0.37	2.61	3.27	2.90	2.18	1.52	0.84	0.47	0.18	0.08	0.01	0.00	14.42
2.00			0.06	1.36	3.90	4.28	4.39	2.92	1.85	0.93	0.33	0.14	0.03	0.01		20.19
1.50			0.56	3.22	4.93	5.87	4.30	2.28	0.95	0.30	0.11	0.07	0.01	0.01	0.02	22.63
1.00		0.02	0.60	2.08	3.38	2.85	1.39	0.53	0.23	0.08	0.02	0.01	0.00	0.00	0.00	11.19
0.50			0.00	0.06	0.08	0.07	0.04	0.01								0.26

Figure 3-2: Scatter diagram for the deployment site for the period 2001 – 2010

3.2 Testing Facility

Given that the LiftWEC concept relies on lifting surfaces, and that these are affected by Reynolds numbers, it is desirable to have water particle wave induced velocities as high as possible and therefore to carry out the experiments in as large waves as possible, implying a large wave tank facility. The 2D nature of the tests implies that the most appropriate testing facility is a flume rather than a wide tank. From a model design perspective, one of the advantages of 2D tests is that the width of the model can be limited, thus reducing loads on the model and hence structural, PTO and instrumentation costs. However, flume facilities capable of generating large waves often have a width

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

which is larger than what would be ideal to limit the loads on the model. The approach adopted here therefore consists in using the towing tank of ECN, which is capable of generating large waves, but to carry out the experiments in a narrow "sub-channel" built within the towing tank.

The ECN towing tank is 140 m long, 5 m wide and has a depth of 3 m (Figure 3-3).

Figure 3-3: ECN towing tank

An estimation of the largest wave conditions which can be generated in the ECN towing tank were derived from past physical experiments (mainly for regular wave) and from a virtual tank simulation tool developed by ECN which allows for the virtual generation of wave spectra, taking into account the tank dimensions and physical limits of the wavemaker.

In terms of regular waves, Table 3-1 gives an overview of the maximum wave generation capability of the towing tank, depending on the wave period. For wave periods below 2 seconds, wave generation is limited in height by wave breaking. At the longer wave end, height limitation comes from the stroke of the wavemaker and period limitation comes from the absorbing capacity of the beach.

Table 3-1: ECN towing tank regular wave generation capacity

Wave period (s)	2	3	4	5
Max wave height (cm)	46	42	29	20

3.3 Scaling considerations

The scatter diagram in Figure 3-2 shows that sea states with $H_{m0} \leq$ 4m and $T_E \leq$ 11s cover just under 90% of the sea states encountered at the site. (i.e. 88.8% in terms of H_{m0} and 88.75% in terms of T_E). T_E = 11s corresponds to T_P = 12.83s for a JONSWAP spectrum with γ = 1.

From there, we have applied a range of Froude scales and tried the scaled-down sea state parameters in the ECN virtual tank simulation tool. Through this approach, it is predicted that the largest scale that can be run in the towing tank is 1/16. This corresponds to H_{m0} = 0.25m and T_E = 3.21s at tank scale.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

3.4 Comparison with numerical model

The main objective for this test campaign is to provide experimental data to help the development of numerical models. The model design includes recommendations from LiftWEC partners to ensure the measurements can be used for comparisons and validation with the numerical models. These requirements are:

- To place the model in a channel so that the hydrofoils have a constant section from one wall to the other. The idea is to simplify the numerical modelling, assuming a 2D configuration.
- Tests with 1 or 2 hydrofoils in order to characterise the behaviour of a foil on its own and the behaviour of a foil subjected to the wake of another foil. In the case of the two-foil configuration, they are 180° separated from each other.
- Test with hydrofoils placed at different diameters.
- Tests with hydrofoils at different pitch angles (angle between the foil and the tangent of the motion circle).

4 Design considerations and details

4.1 Overall model design and assembly

The overall model assembly, illustrated in Figure 4-1 includes:

- A narrow sub-channel composed of two vertical walls at a distance equal to the model width (i.e. 0.49m).
- An electrical power take off located outside the sub-channel, so that it does not interact with the model hydrodynamics. Its shaft is directly coupled to the model rotor and is aligned with its horizontal axis of rotation, which is perpendicular to the wave propagation direction and located at 0.755m below the still water level.
- The model rotor fitted with a central shaft for rigidity and connection to the power take-off, one or two hydrofoils and a disk on either side connecting the central shaft with the hydrofoils. The discs are flush with the sidewalls of the narrow sub-channel and designed to allow adjustment of the foils pitch angle and of the distance from the central axis.

The main dimensions of the experimental setup are summarised in Table 4-1.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

Table 4-1: ECN 2D experimental setup main geometry

Description	Unit	Dimension
Tank length	m	140
Tank width	m	5
Tank depth	m	3
Sub-channel width	m	0.49
Sub-channel length	m	17.3
Sub-channel height	m	3.3
Rotor diameters	m	0.5, 0.6 or 0.75
Pitch angles	degrees	[-12, -8, -4, 0, 4, 8, 12]
Hydrofoil profile		Curved NACA0015/NACA3515
Depth of rotor axis	m	0.755
Hydrofoil chord length	m	0.3
Hydrofoil chord curve radius	m	0.3
Number of hydrofoils		1 or 2

Figure 4-1 provides an overview of the testing setup installed in the towing tank. It includes the sub-channel made of partition walls as well as the model itself in the middle of that sub-channel. Figure 4-2 shows a close-up of the central unit of the model where the rotor is located. The sub-channel is installed in the flume for the whole duration of the project while the central unit of the model can be easily lifted to change the model configuration. Figure 4-3 shows the core of the model, containing all the moving parts and instrumentation. Figure 4-4 focuses on the rotor, including shaft and the foils. Figure 4-5 shows the PTO assembly protected by a waterproofing sleeve. Finally, Figure 4-6 shows the details of the rotary encoder and slipring arrangement.

Detailed technical drawings are provided in appendix A.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

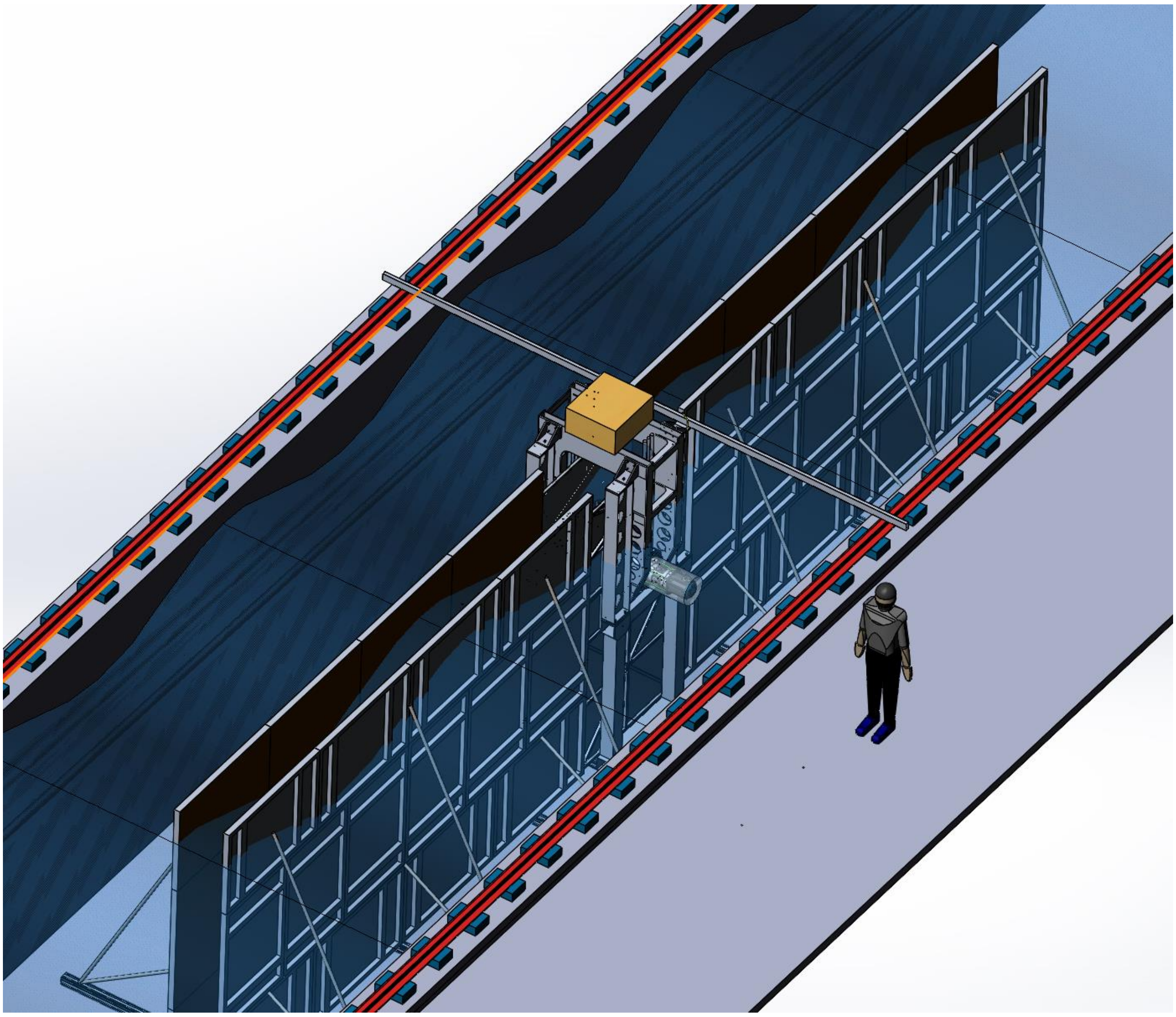


Figure 4-1: Overall CAD view of the experimental set-up

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

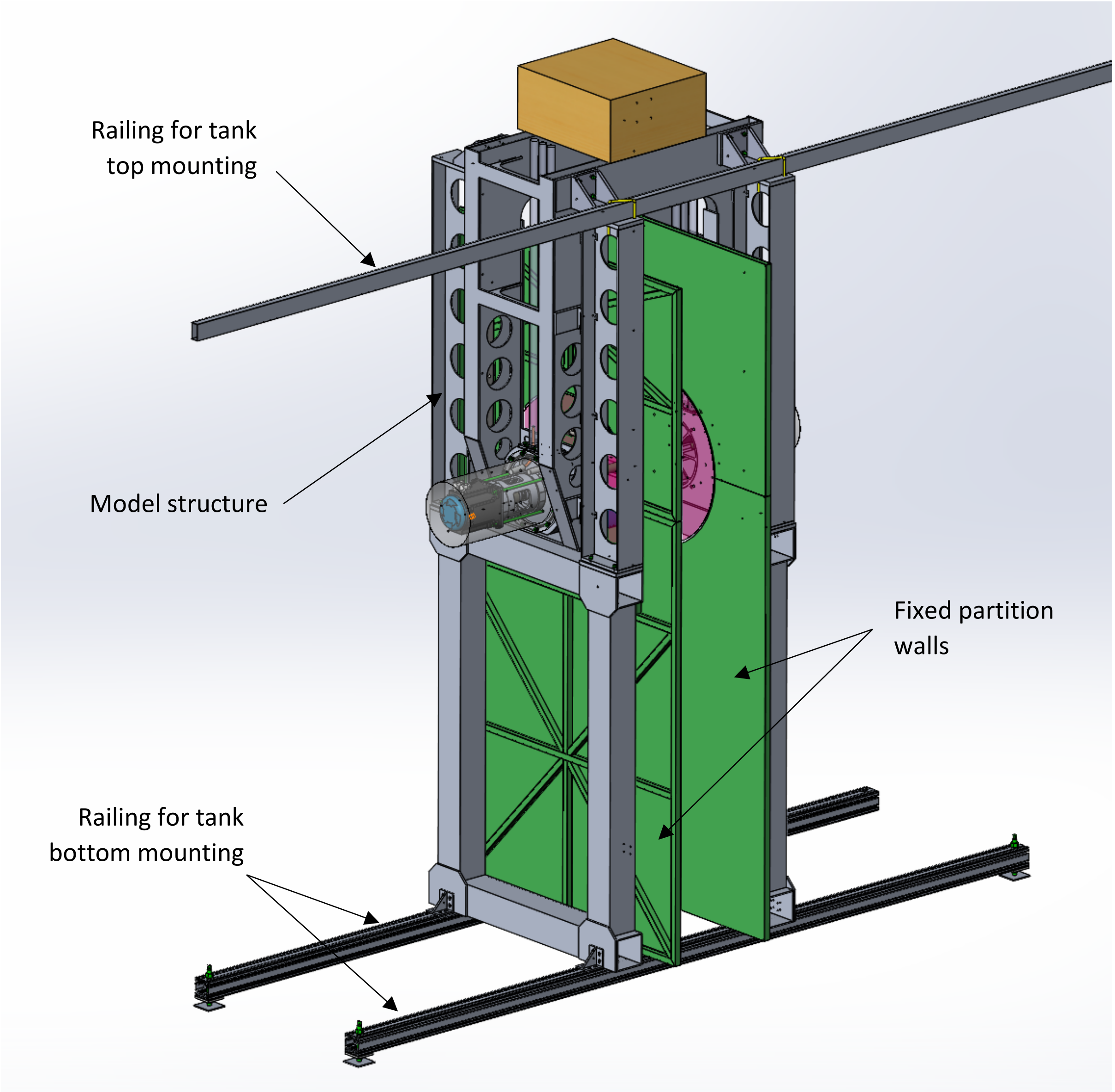


Figure 4-2: Central part of the experimental set-up

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

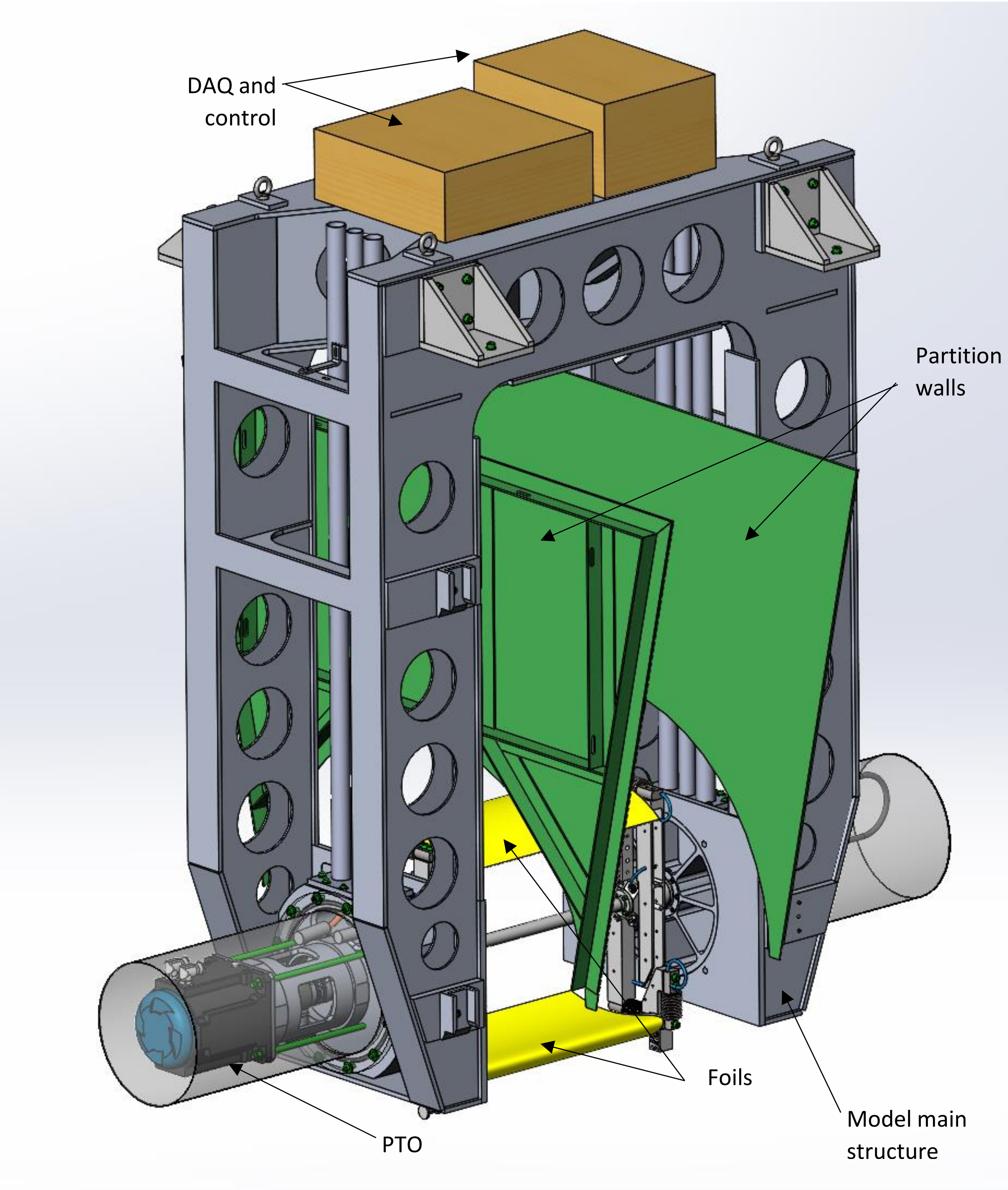


Figure 4-3: Core part of the model

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

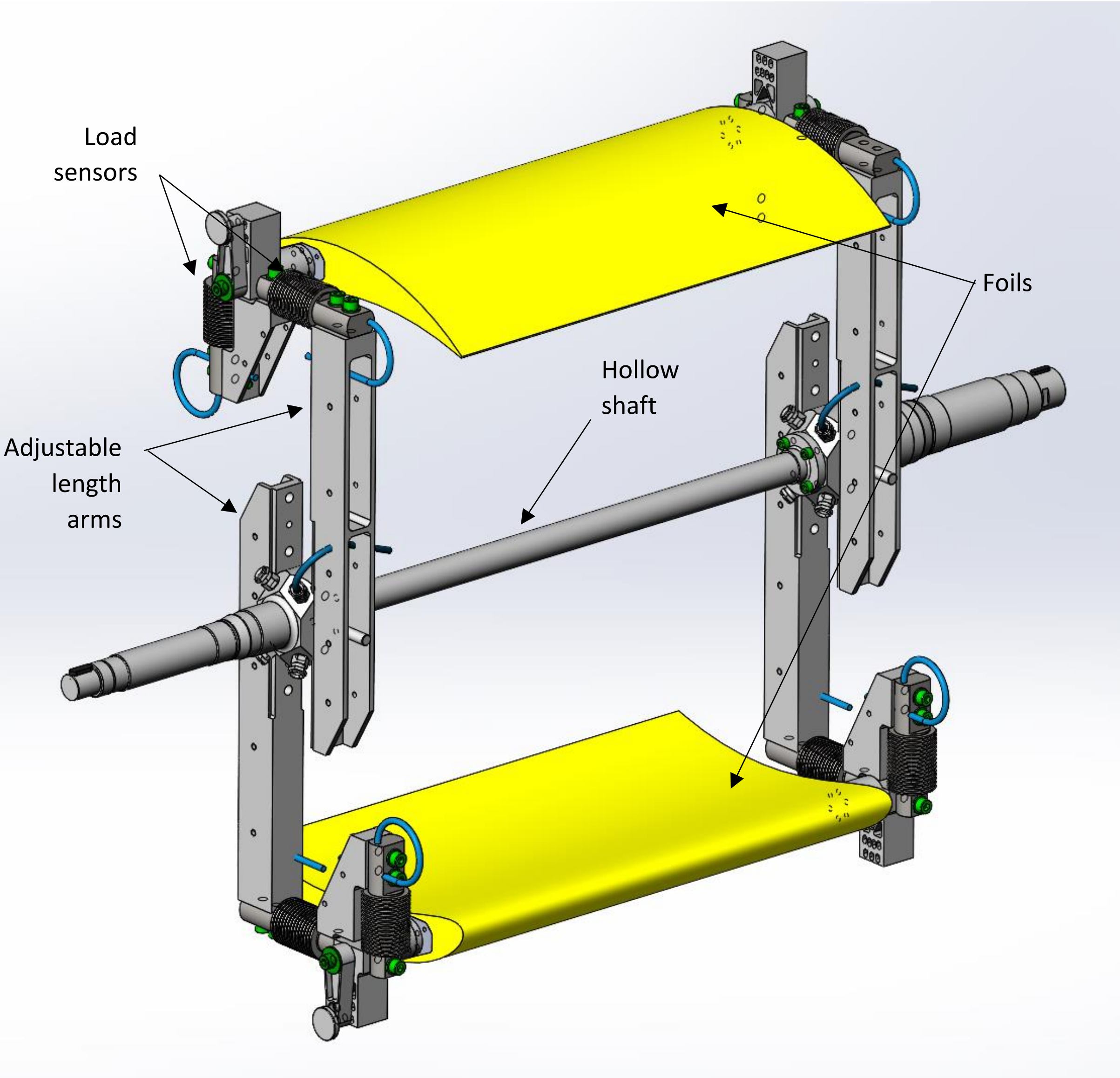


Figure 4-4: Rotor with foils

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

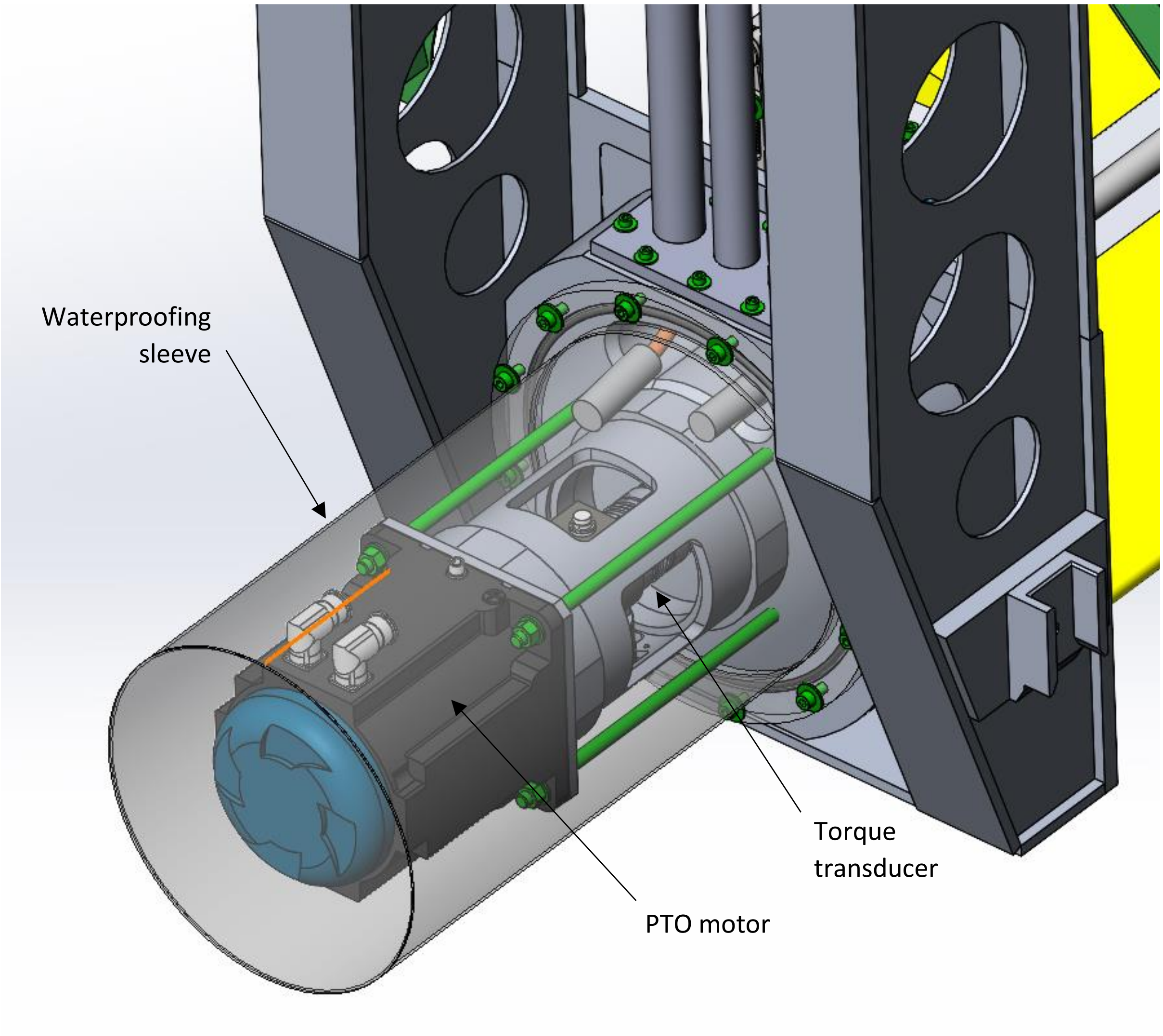


Figure 4-5: Details of the PTO

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

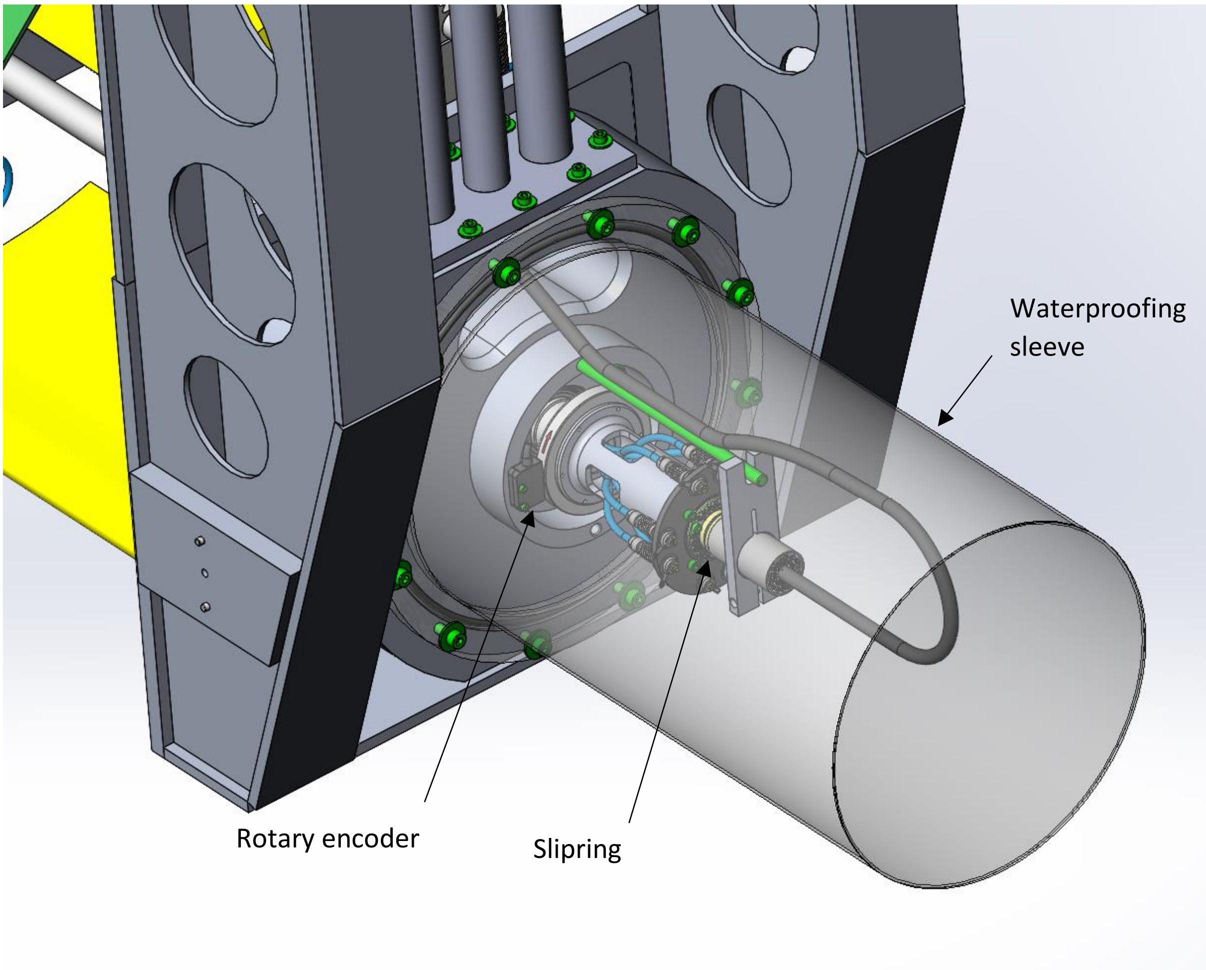


Figure 4-6: Details of the rotary encoder and slipring

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

4.2 HYDROFOILS

The nominal foil profile retained for the model is the NACA0015 with a chord length equal to the rotor radius (see Table 4-1). Compared to a standard NACA0015 profile, the chord is not straight but curved, with a radius corresponding to the rotor radius. Given that three rotor radii are considered, this would imply the manufacturing of three different types of foils. This was deemed too costly and instead, only one type of foil will be manufactured, corresponding to the middle radius configuration i.e. 0.3 m. For the two other radii, given that the chord curvature will not correspond to the path of the foils, these will have effectively a camber and their profile corresponds approximately to NACA3515.

The foils are made of a urethane machinable tooling block material, the one used here is Labelite, produced by the company Sika. The idea is to have foils, which are structurally strong enough to minimise deformation while keeping the mass down, ideally as close as possible to the density of water.

Due to manufacturing considerations, the trailing edge of the foil cannot be as sharp as that of the theoretical profile and it is therefore truncated perpendicularly to the chord line at a thickness of 3mm.

4.3 POWER TAKE-OFF AND CONTROL SYSTEM

The model power take-off is a brushless permanent magnet electrical machine, connected to the rotor main shaft through a torque meter. It is composed of:

- Motor Kollmorgen Catridge C061B-13-3105 with the following specifications:
  - High Resolution Sine-Cosine-resolver, Singleturn, Heidenhain ECN, EnDat
  - Stall Torque = 32.60Nm Peak Torque = 75.6 Nm
  - Voltage Supply = 230 VAC Rated Speed = 1950 rpm
- Drive AKD-P02406-NBCC-x069
- Dump load regen external resistor BAF(U) 200-33 (200W)

It should be noted that although the name plate voltage supply of the motor is up to 230 VAC, the drive used to control it is run at 48 V, to reduce the risks associated with the presence of water. This approach lowers the maximum speed of the motor to 200 rpm.

The motor control system will allow the following control modes:

- “Fixed position” mode: the rotor can be placed and held in position at any angle.
- “Constant speed” mode: from its starting position, in “fixed position” mode, the motor accelerates up to the required speed. The acceleration starts at a time (delay after the wave generation starts) that must be set before the wave starts. It will be used to control the phase angle between the wave and the rotor position. Once the rotor reaches the required speed, the controller modulates the rotor torque to follow that target speed. This is illustrated in Figure 4-7 where t0 is the time when the wavemaker starts and t1 is the chosen delay when the rotor speed control starts. This speed control mode can also be used in the absence of incoming waves. In this configuration, the PTO drives the rotor at a constant speed. This approach can be used to investigate the wave radiation characteristics of the device.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

- "torque control" mode: at negative or zero speed, the rotor torque is set to zero. For positive rotational speeds, a damping torque (proportional to the rotational speed) is applied to the rotor, resisting its motion. The value of the torque applied is capped i.e. as the rotor speed increases, there is a point where the torque applied by the PTO is no longer proportional to the rotational speed but becomes constant. If the rotational speed goes down, in such a way that the damping torque falls below the torque cap, then the torque becomes again proportional to the rotational velocity. This control strategy is illustrated in Figure 4-8. The damping coefficient and the torque limit can be set (within the limits of the motor capabilities). The system might not be self-starting with this control configuration, in which case, the torque control sequence will be preceded by a short speed control sequence to get the rotor spinning.

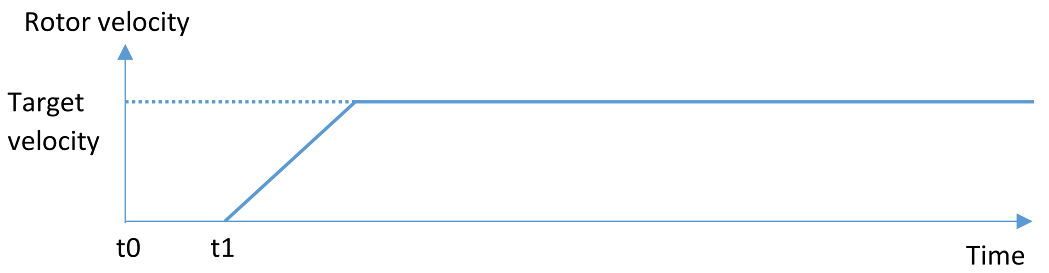


Figure 4-7: Constant speed mode

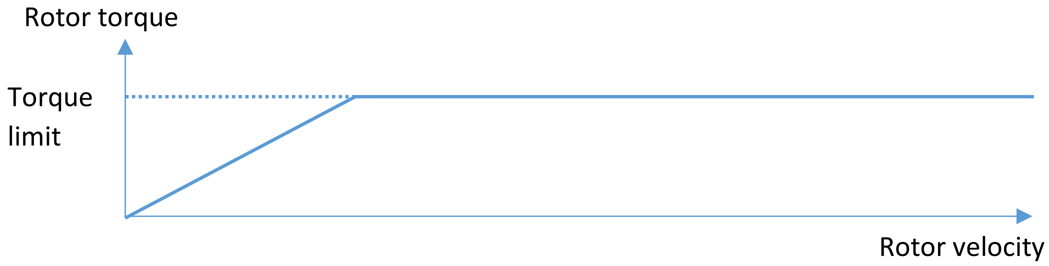


Figure 4-8: Torque mode

The control of the PTO will be implemented using a National Instruments CompactRIO connected to the motor drive. The control algorithms will be programmed in LabVIEW.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

4.4 INSTRUMENTATION

4.4.1 General considerations

The instrumentation is designed to measure the following quantities:

- Wave elevation upstream and downstream of the model, with resistive wave gauges (see picture in Figure 4-9) and ECN built signal amplifiers.
- 1 additional wave gauge at the model location during wave calibration only
- Radial and tangential forces on each foil.
- Torque on the PTO shaft
- Absolute angular position of the rotor
- Underwater video

Measurements from all the above instruments will be synchronised.

The choice for each sensor range was based on a basic numerical analysis considering hydrodynamic forces estimated using a quasi-static approach, at each of the rotor position, pitch angle and phase of a regular wave cycle, taking into account water particle wave induced velocity and the velocity experienced by the foil as it spins. On top of that, an estimation of the worst case centrifugal force (in the radial direction) and inertial force (in the tangential direction) were computed based on mass properties estimated using CAD. These estimates are summarised in Table 4-2 for one hydrofoil (0.49m span). As a worst case scenario, the sum of the hydrodynamic load and acceleration load was used for the choice of sensor. Therefore, 100 N range was chosen in the tangential direction and 300N in the radial direction with, in each direction, one sensor on each side of the foil.

Table 4-2: Numerical model results for extreme loads on one 0.49m long hydrofoil

Parameter	Unit	Minimum value	Maximum value
Hydrodynamics			
Torque	Nm	0	22.8
Tangential force	N	0	60.1
Radial force at optimal tangential force	N	-240	173
Radial force (overall)	N	-254	309
Inertial and centrifugal			
Inertial tangential force	N	0	76
Radial centrifugal force	N	0	148
TOTAL for load cell selection			
Tangential	**N**	**0**	**136.1**
Radial	**N**	**-254**	**457**

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

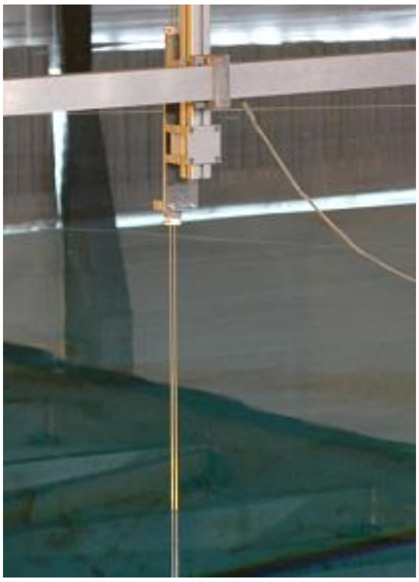


Figure 4-9: Picture of a resistive wave gauge in the ECN wave tank

4.4.2 Detailed instrumentation specifications

- PTO torque transducer
    - DRBK II 100 A produced by the German company ETH-messtechnik, with a torque rating of 100Nm
- Rotor angular position
    - The rotor angular position is measured by the motor built in resolver, coupled to the rotor in a direct drive manner. However, the resolver signal cannot be directly connected to the data acquisition system and has to be first processed by the motor drive. To avoid uncertainty and delay associated with this processing, it was decided to mount on the shaft an encoder, which is exclusively dedicated to measurements and directly connected to the data acquisition system. We went for a contactless magnetic type encoder with a resolution of 4096 pulses per turn. The encoder is produced by the German company Automation Sensorik Messtechnik (ASM). The magnetic disk model is PMIR5-50-64-M-83-AB and that of the reader head is PMIS4-50-64-20KHZ-TTL-Z3-3M-S
- Foil loads are measured by two orthogonal load cells mounted between the axis of the foil and the arms of the rotor on each side of the foil. For each foil, there are four load cells, two on each side (see Figure 4-4). The load cells selected are manufactured by the German company HBM. The models details are:
    - K-Z6-F-C3-0030-N-S3-N (300N capacity) for the radial direction
    - K-Z6-F-C3-0010-N-S3-N (100N capacity) for the tangential direction
- Underwater video
    - Underwater video will be captured using a bespoke camera system developed by ECN and based on an off-the-shelf PTZ CCTV camera with HD resolution and an optical zoom of x25. The camera and its waterproof housing are shown in Figure 4-10.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

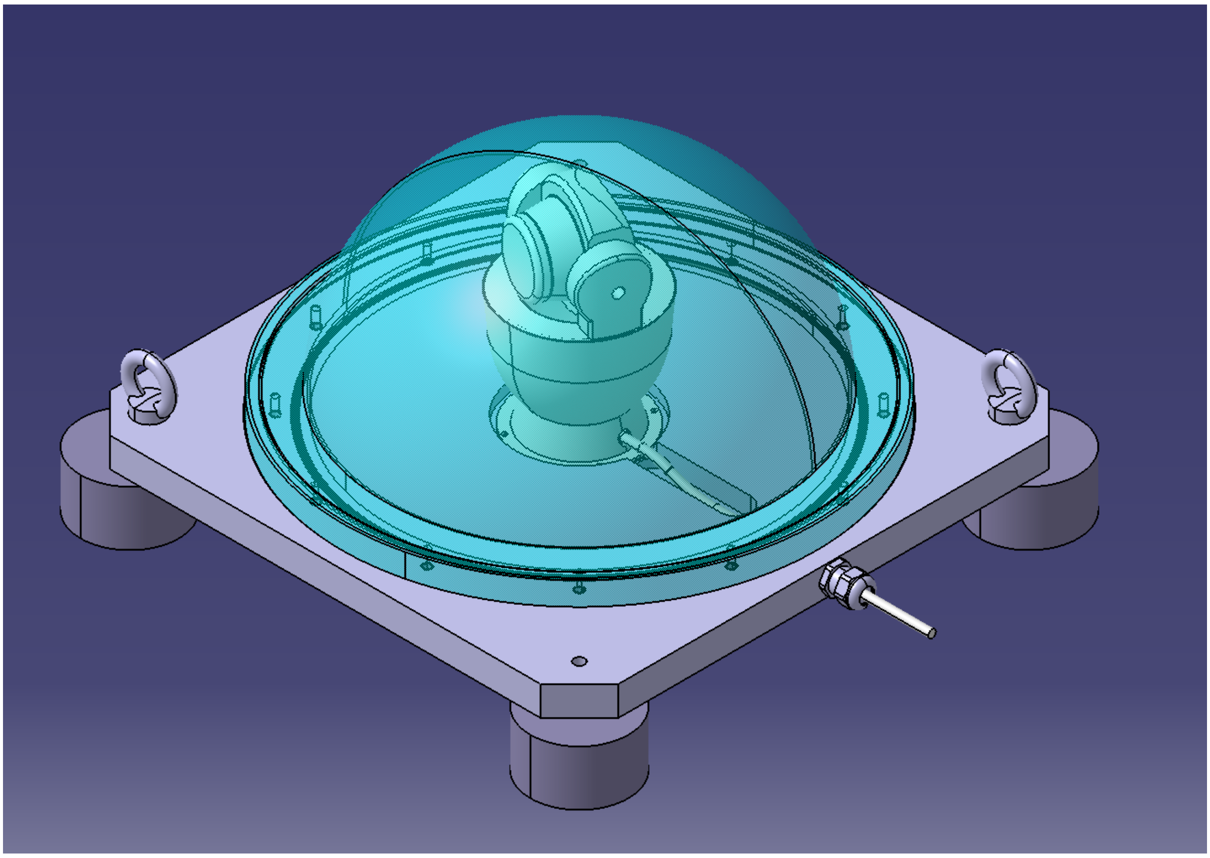


Figure 4-10: CAD view of the underwater camera system

4.4.3 Instrumentation signal wiring

All the foil load measurements are carried out within a rotating assembly and the corresponding signals need to be transferred to a fixed location. The load cells are waterproof and their cables are in the water up to the centre of the rotating shaft, entering the shaft through IP 68 cable glands and then run through the shaft up to a dry housing at the opposite side of the motor. They are then connected to the fixed section of the housing through a slip ring. The slip ring used is specially designed for weak instrumentation signals such as those coming out of strain gauge bridges. The model used is a SR36M 36 ways made by the US company Michigan Scientific.

For the torque transducer, this is achieved by a contactless process built-in the transducer.

For all instruments, the wires are then running through dry vertical tubes and connected to the data acquisition system placed directly above the model to reduce cable length.

4.5 DATA ACQUISITION SYSTEM

All sensors measurement time series will be recorded at 128 Hz, in a synchronous manner using a combination of National Instrument (CompactRIO) and HBM (Quantum) hardware.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

5 MANUFACTURING

ECN carried out all the model design but does not have capabilities in-house for the manufacturing of its large mechanical parts. The elements not manufactured at ECN are:

- The structure for the narrow sub-channel. It will be rented from a civil engineering company for the duration of the test campaign
- The structure holding and protecting the PTO system.
- All rotor parts except for the foils.

The parts listed above will be manufactured by subcontractors with which ECN has an established relationship.

Technical drawings of all the parts can be found in appendix A.

6 MODEL SETUP AND ASSEMBLY

This section describes the broad plan for model setup and assembly. As the model is being built and commissioned, this plan is likely to be refined and/or updated.

6.1 NARROW SUB-CHANNEL

The narrow sub-channel will be assembled in the tank and will remain in place for the duration of the test campaign. It will be installed first and will require divers for laying the base structure at the bottom of the tank, which will be used to support the channel walls and the model.

6.2 MODEL ASSEMBLY

The model structure, including PTO, rotor, foils, sensors, and control and acquisition cabinets (as shown in Figure 4-3), will be assembled outside the tank. It can be easily put in place and removed within the sub-channel from above, using the tank overhead crane and thanks to a guiding system visible in Figure 4-3. This process is to be used for changing foil configuration.

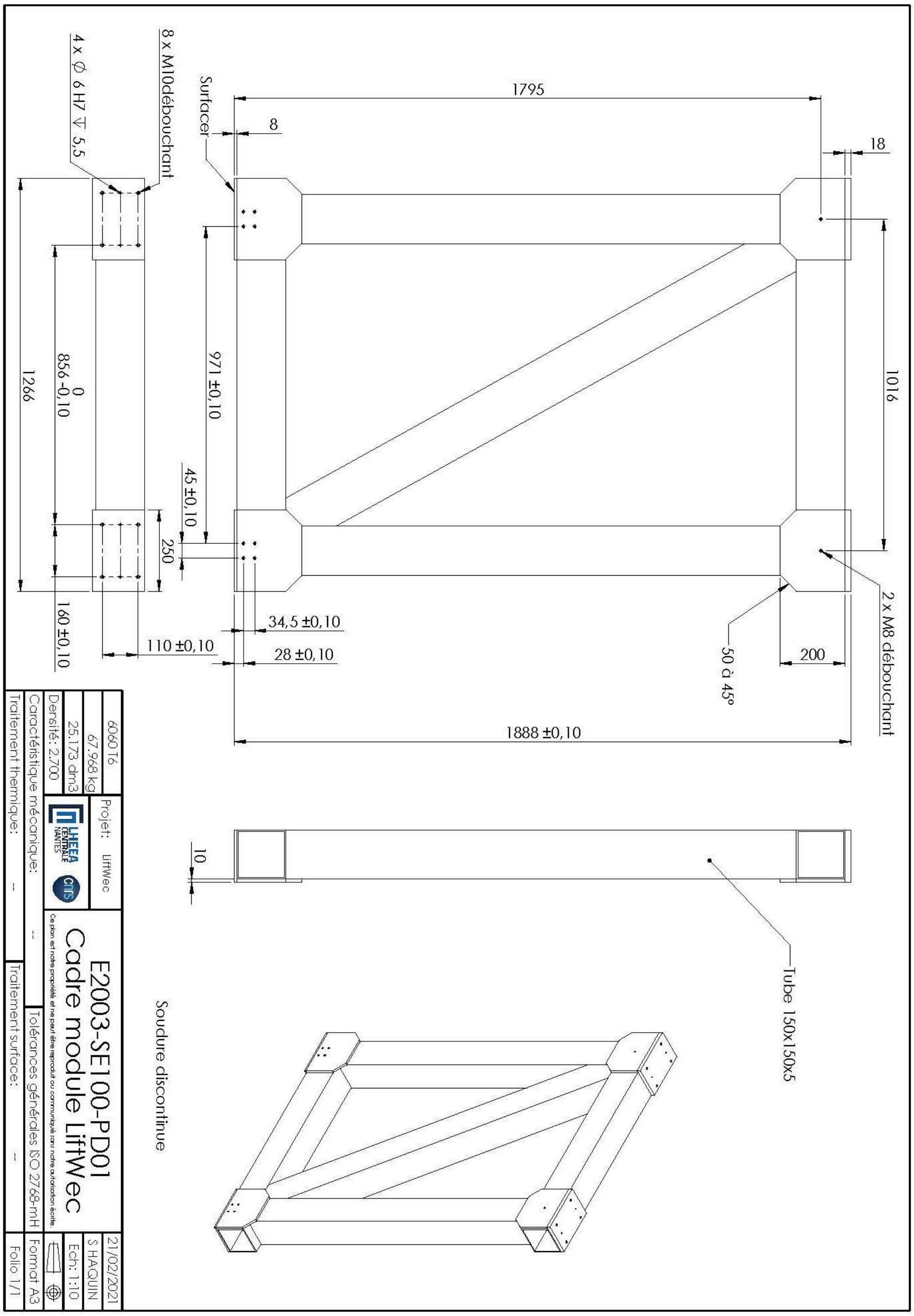
7 REFERENCES

[1] E. Boudière, C. Maisondieu, F. Ardhuin, M. Accensi, L. Pineau-Guillou, and J. Lepesqueur, “A suitable metocean hindcast database for the design of Marine energy converters,” *Int. J. Mar. Energy*, vol. 3–4, pp. 40–52, 2013.

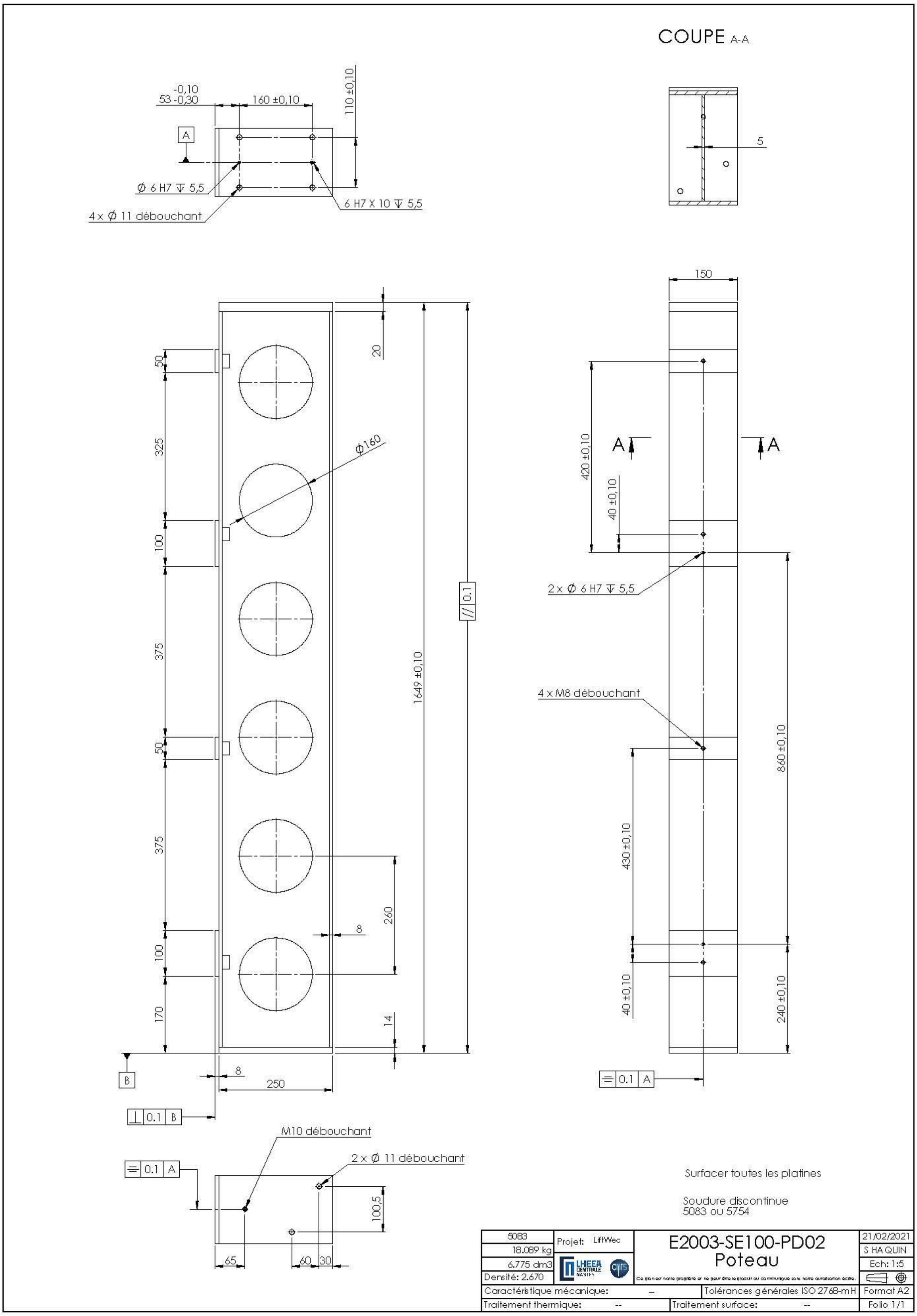
This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

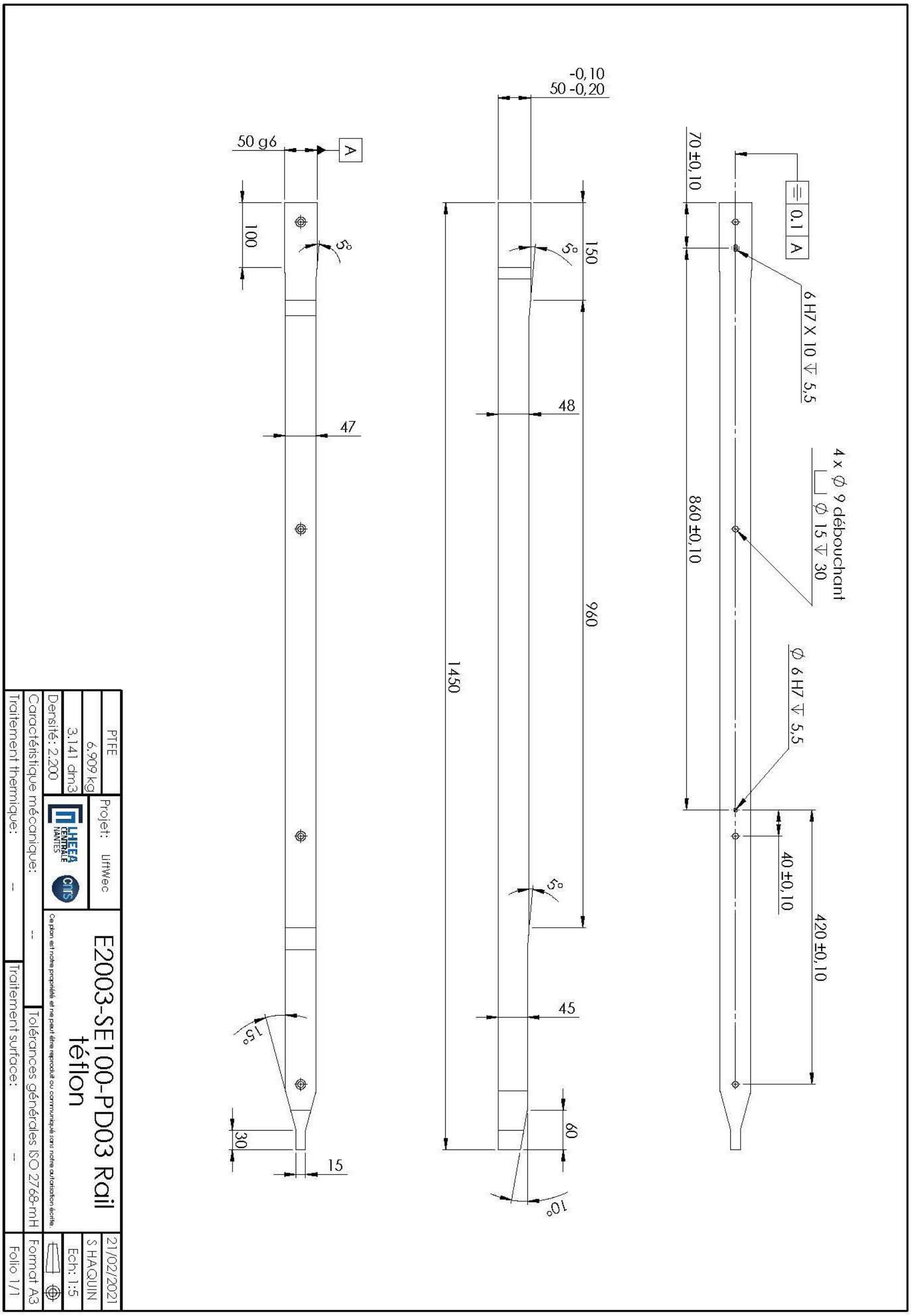
APPENDICES

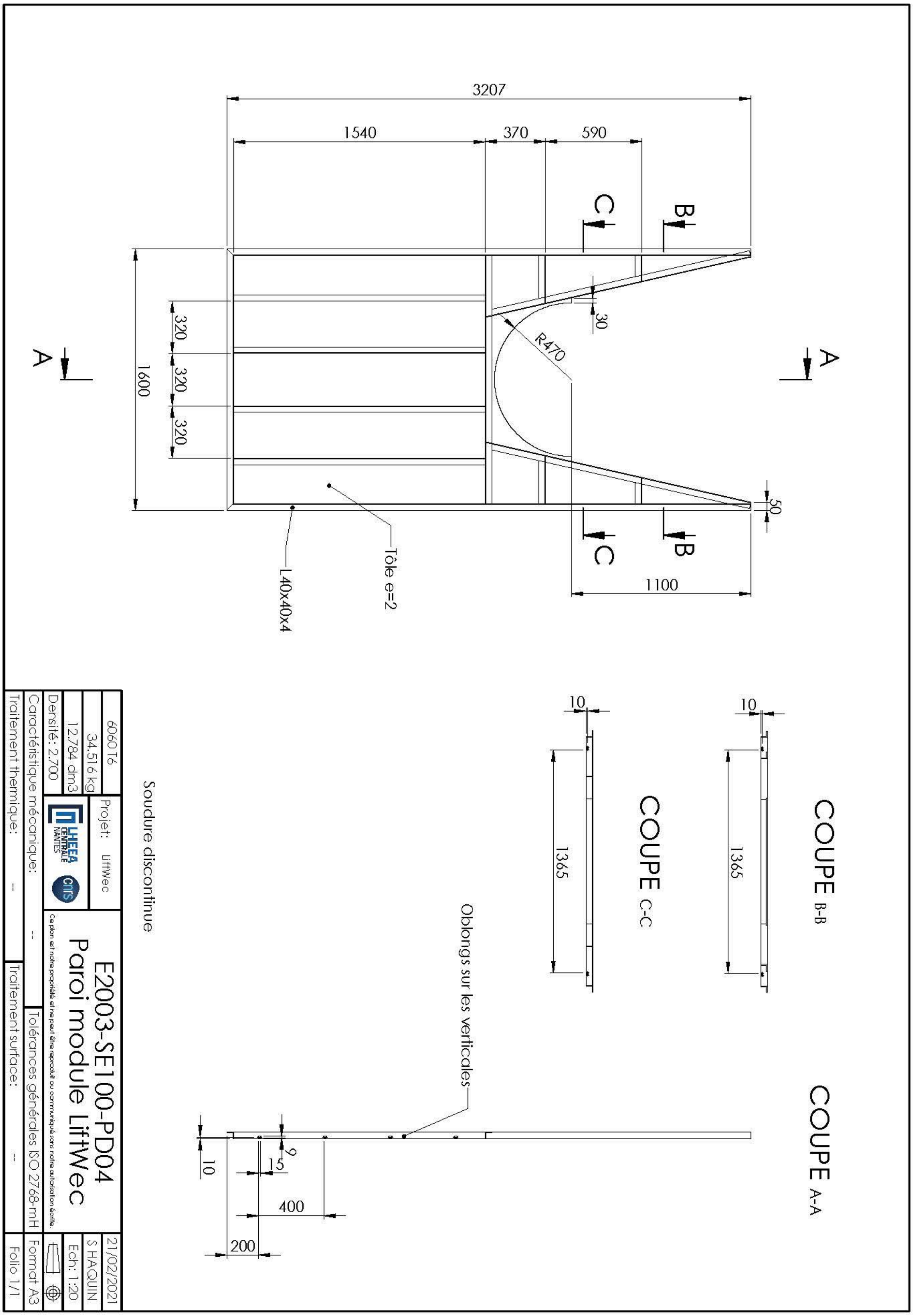
A. TECHNICAL DRAWINGS

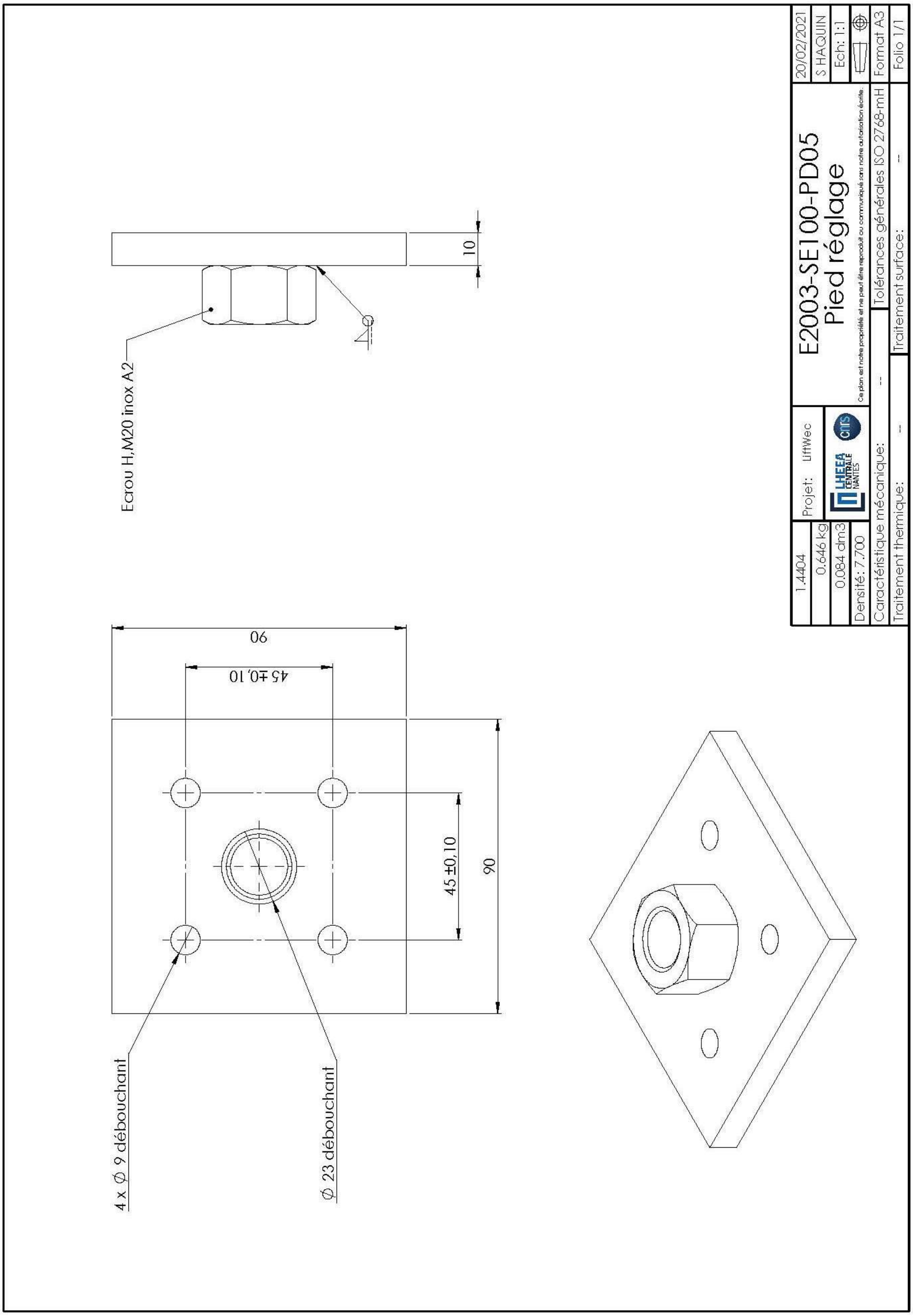


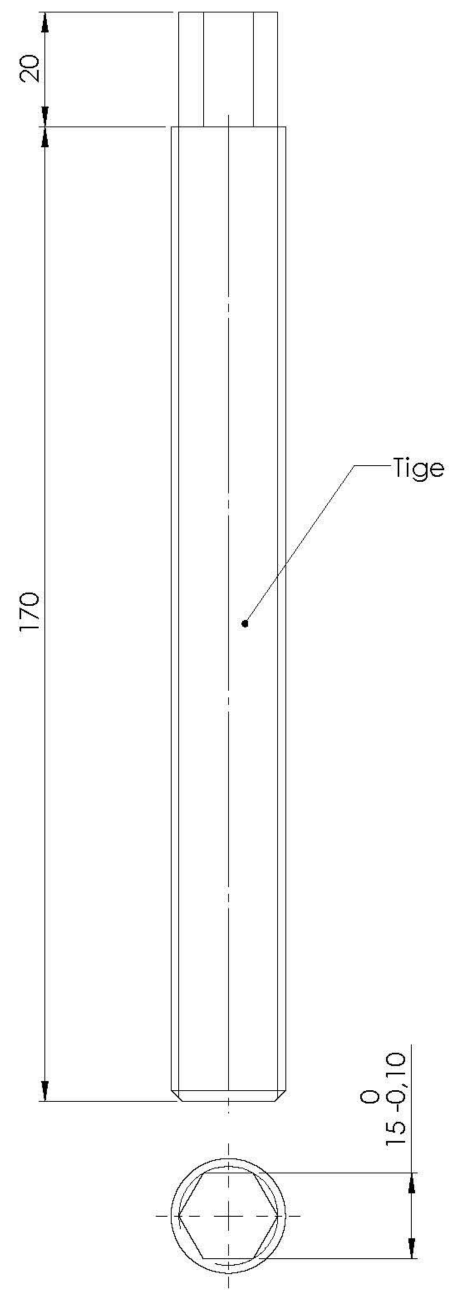
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.


COUPE A-A
53 -0,10 -0,30
160 ±0,10
110 ±0,10
A
Ø 6 H7 ⊽ 5,5
4 x Ø 11 débouchant
6 H7 X 10 ⊽ 5,5
5
150
20
Ø160
1649 ±0,10
// 0.1
420 ±0,10
40 ±0,10
2 x Ø 6 H7 ⊽ 5,5
4 x M8 débouchant
860 ±0,10
430 ±0,10
40 ±0,10
240 ±0,10
50
325
100
375
50
375
100
170
260
8
14
B
8
250
⊥ 0.1 B
= 0.1 A
M10 débouchant
2 x Ø 11 débouchant
100,5
65
60
30
Surfacer toutes les platines
Soudure discontinue
5083 ou 5754
5083
18.089 kg
6.775 dm3
Densité: 2.670
Projet: LiftWec
E2003-SE100-PD02
Poteau
21/02/2021
S HAQUIN
Ech: 1:5
Caractéristique mécanique: --
Tolérances générales ISO 2768-mH
Format A2
Traitement thermique: --
Traitement surface: --
Folio 1/1


E2003-SE100-PD03 Rail
téflon
PTFE
6.909 kg
3.141 dm3
Densité: 2.200
Projet: LiftWec
Caractéristique mécanique: --
Traitement thermique: --
Tolérances générales ISO 2768-mH
Traitement surface: --
21/02/2021
S HAQUIN
Ech: 1:5
Format A3
Folio 1/1
4 x ∅ 9 débouchant
∅ 15 ↧ 30
6 H7 X 10 ↧ 5,5
∅ 6 H7 ↧ 5,5
50 g6
1450
960
860 ±0,10
420 ±0,10
70 ±0,10
40 ±0,10

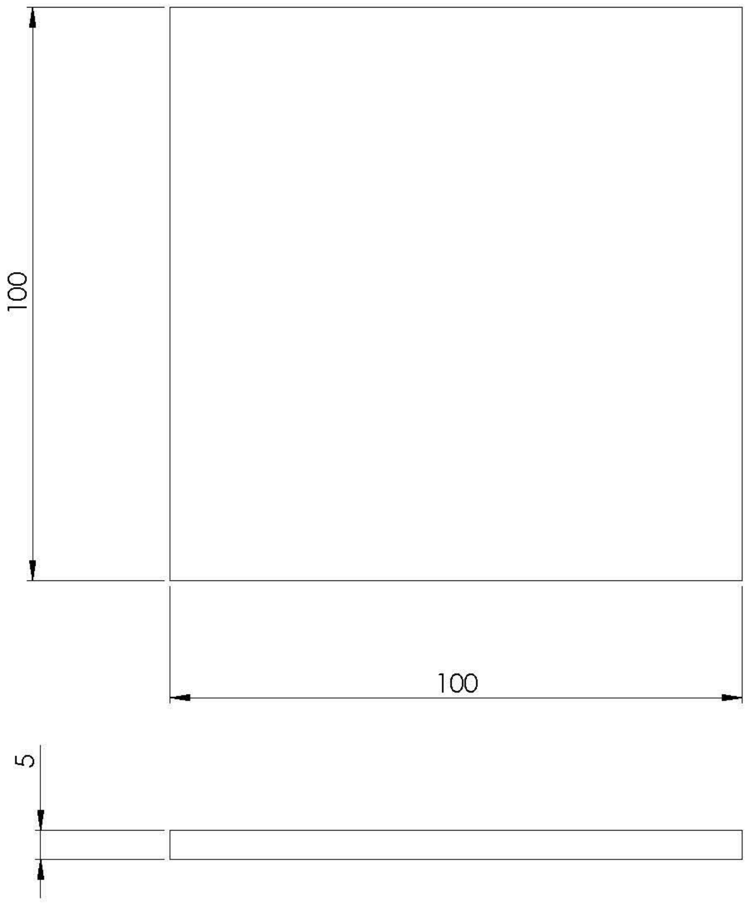

3207
1540
370
590
C
B
A
1600
320
320
320
R470
30
50
1100
Tôle e=2
L40x40x4
10
1365
COUPE C-C
COUPE B-B
COUPE A-A
Oblongs sur les verticales
Soudure discontinue
9
15
400
200
6060 T6
34.516 kg
12.784 dm3
Densité: 2.700
Projet: LiftWec
E2003-SE100-PD04
Paroi module LiftWec
Caractéristique mécanique:
Traitement thermique:
Tolérances générales ISO 2768-mH
Traitement surface:
21/02/2021
S HAQUIN
Ech: 1:20
Format A3
Folio 1/1


E2003-SE100-PD05
Pied réglage
20/02/2021
S HAQUIN
Ech: 1:1
Format A3
Folio 1/1
1.4404
0.646 kg
0.084 dm3
Densité: 7.700
Projet: LiftWec
Caractéristique mécanique: --
Traitement thermique: --
Tolérances générales ISO 2768-mH
Traitement surface: --
Ecrou H,M20 inox A2
4 x ∅ 9 débouchant
∅ 23 débouchant
90
45 ±0,10
10



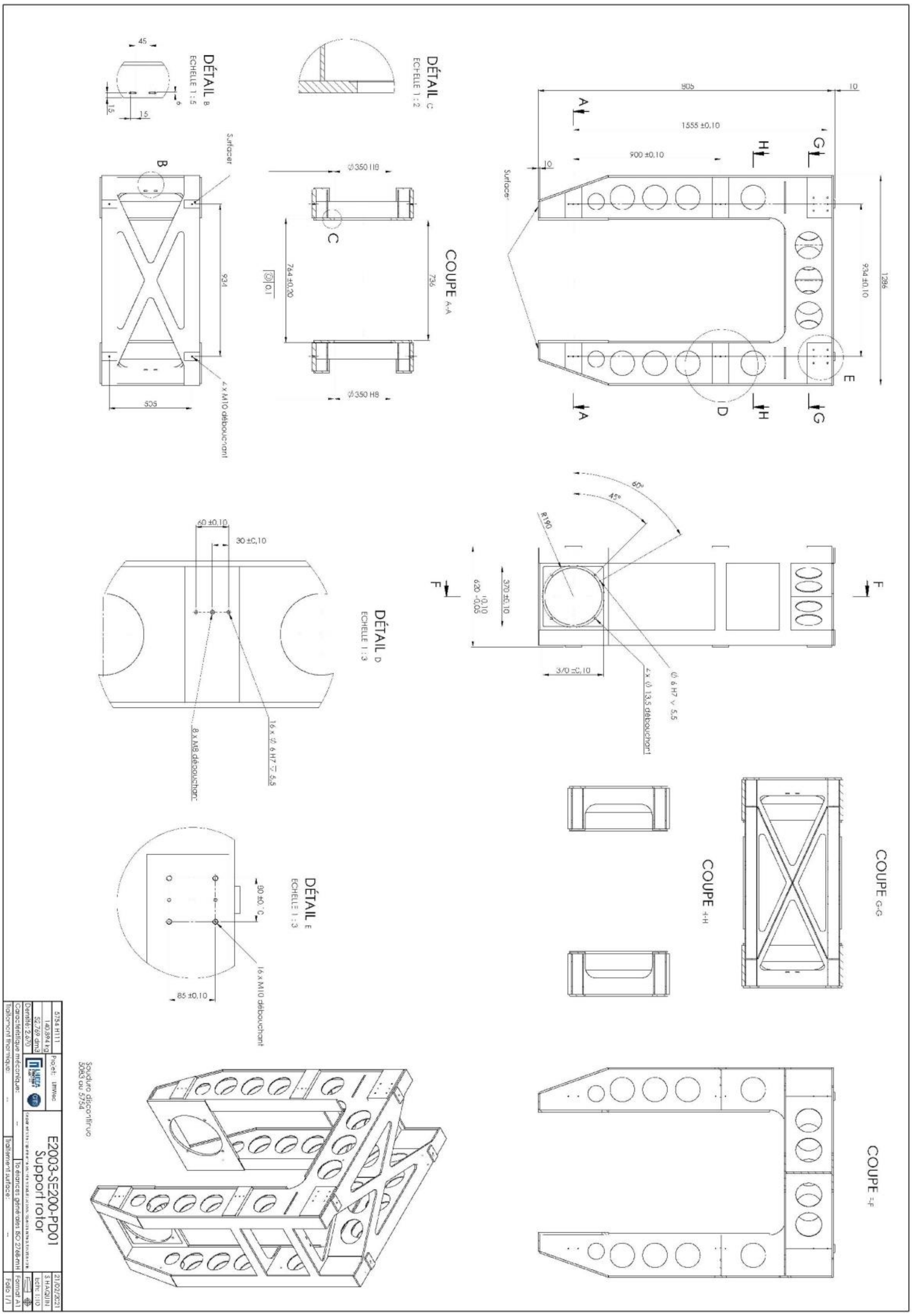
INOX A2 70	Projet: LiftWec	E2003-SE100-PD06 Vis calage	20/02/2021
0.452 kg			S HAQUIN
0.057 dm3	LHEEA CENTRALE NANTES / CNRS		Ech: 1:1
Densité: 7.900		Ce plan est notre propriété et ne peut être reproduit ou communiqué sans notre autorisation écrite.	
Caractéristique mécanique: --		Tolérances générales ISO 2768-mH	Format A4
Traitement thermique: --	Traitement surface: --		Folio 1/1

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

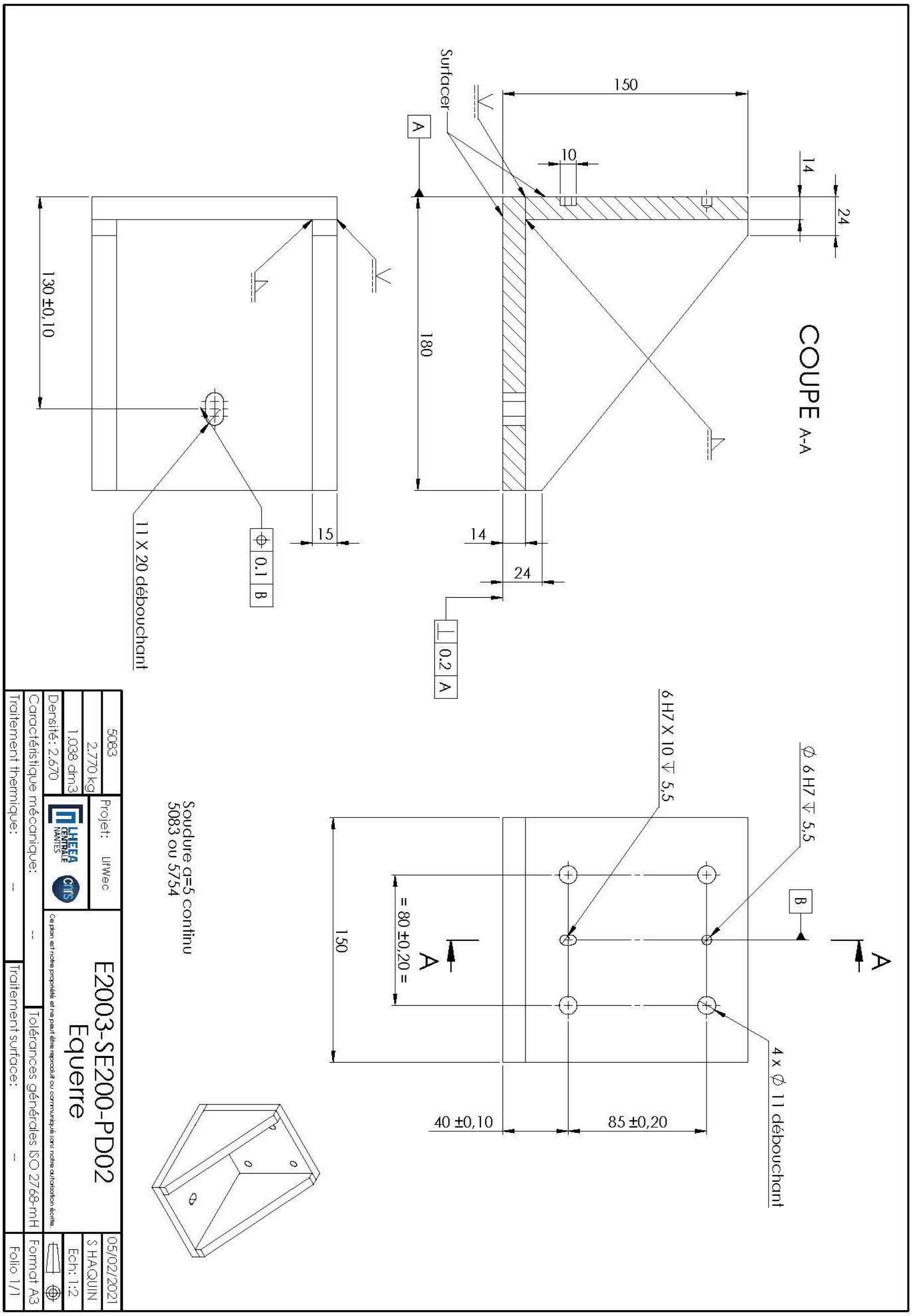


6060 T6	Projet: LiftWec	E2003-SE100-PD07 Cale	20/02/2021
0.135 kg			S HAQUIN
0.050 dm3	LHEEA CENTRALE NANTES, cnrs		Ech: 1:1
Densité: 2.700		Ce plan est notre propriété et ne peut être reproduit ou communiqué sans notre autorisation écrite.	
Caractéristique mécanique: --		Tolérances générales ISO 2768-mH	Format A4
Traitement thermique: --		Traitement surface: --	Folio 1/1

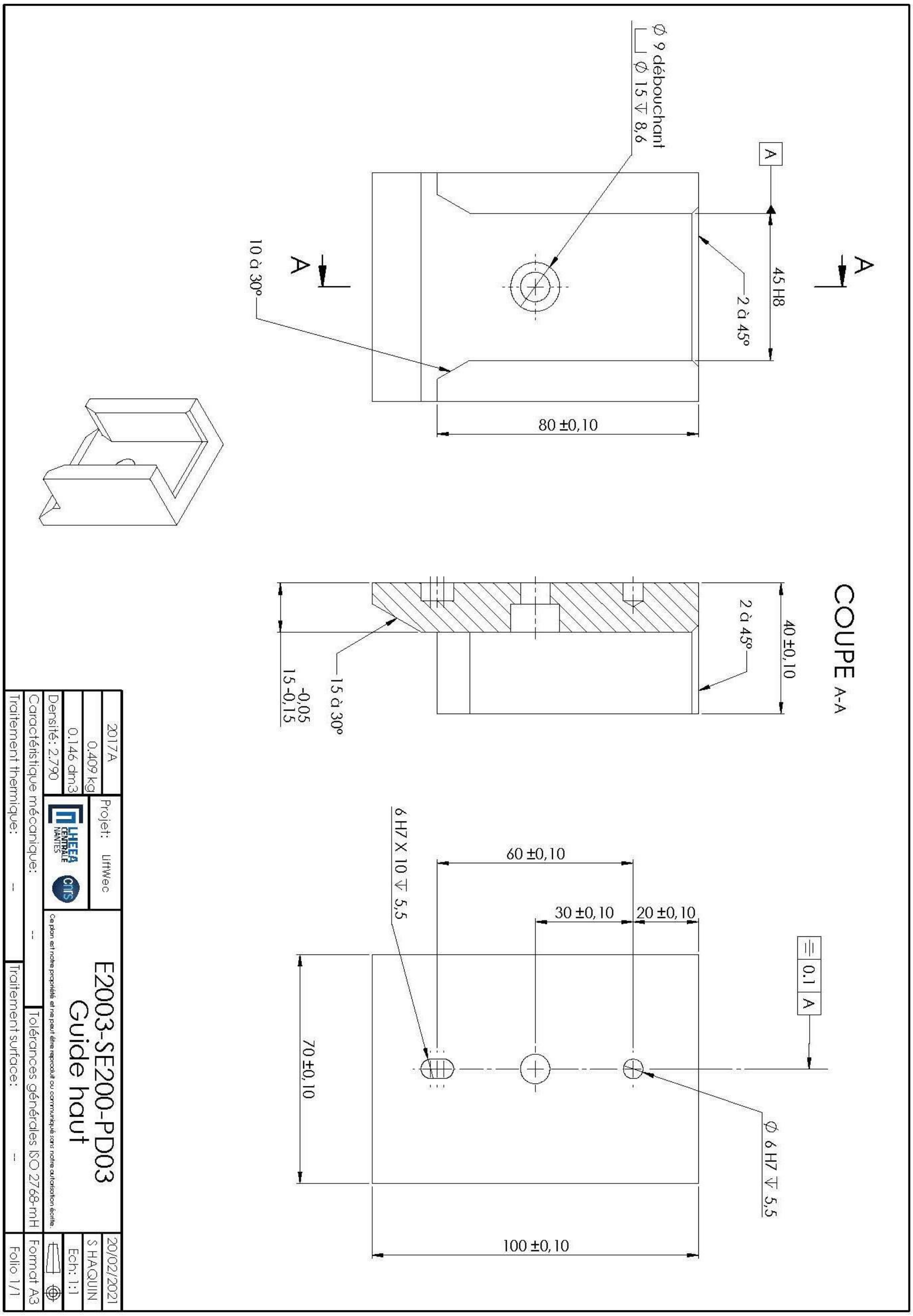
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.



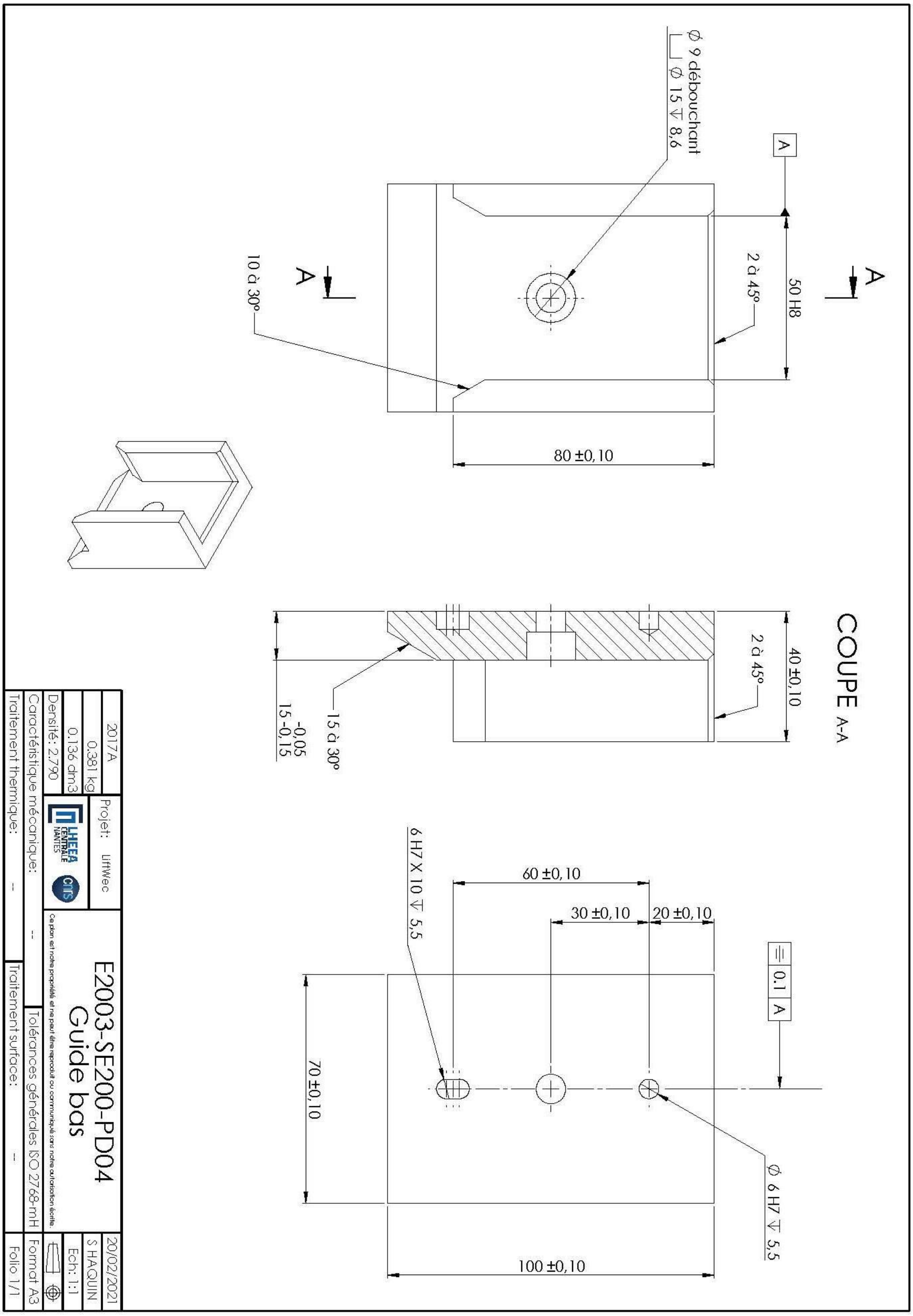
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.



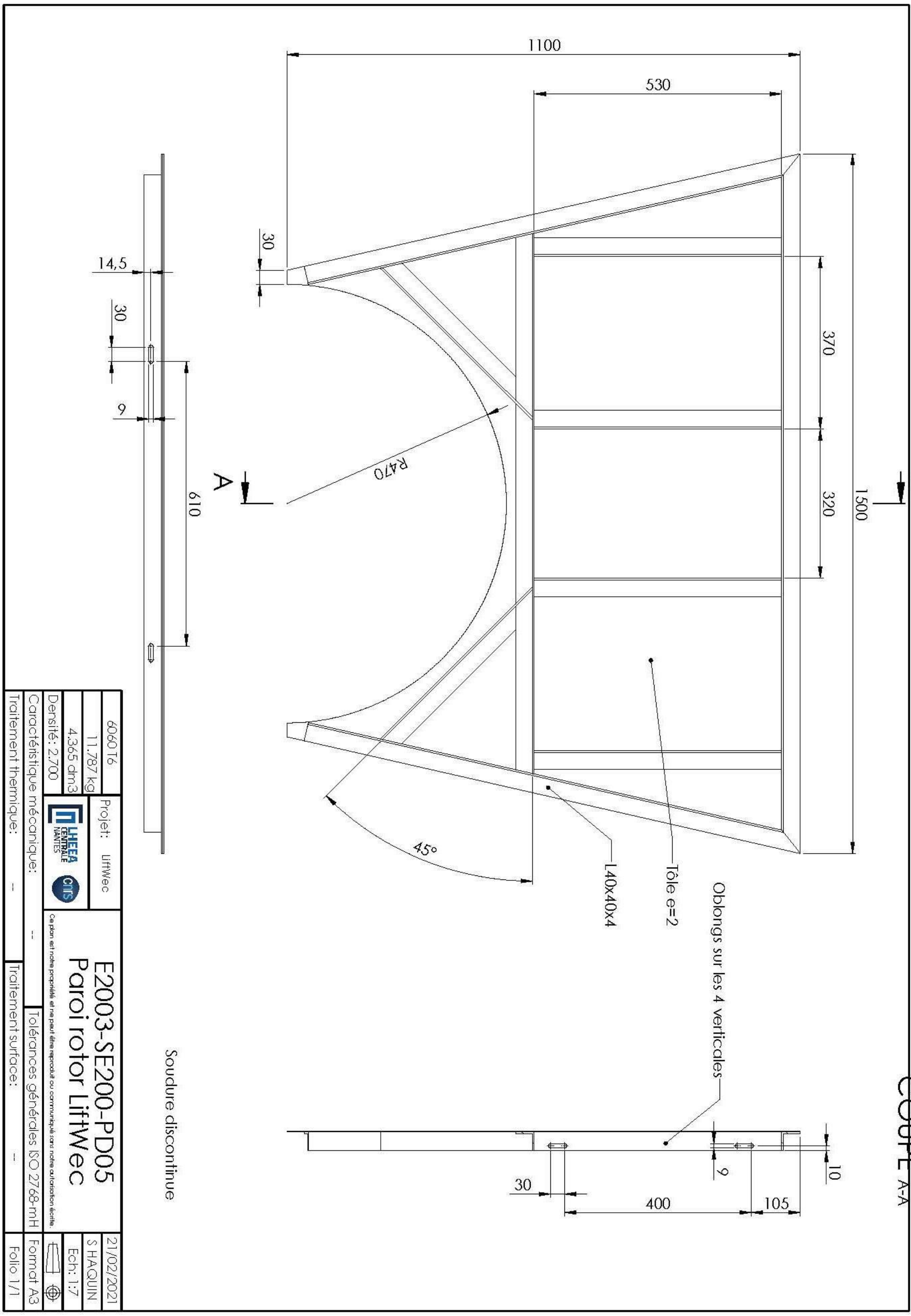
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.



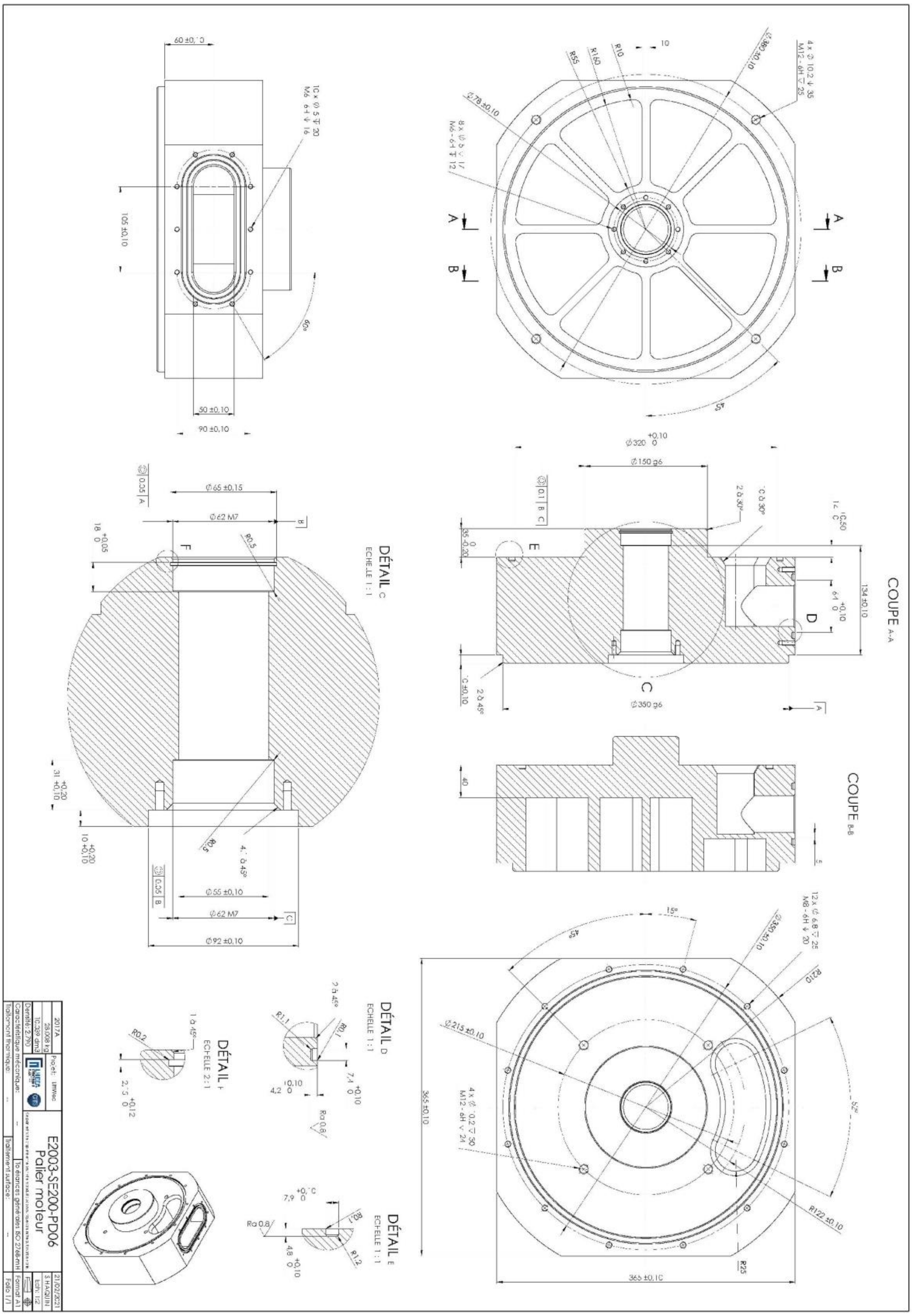
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.



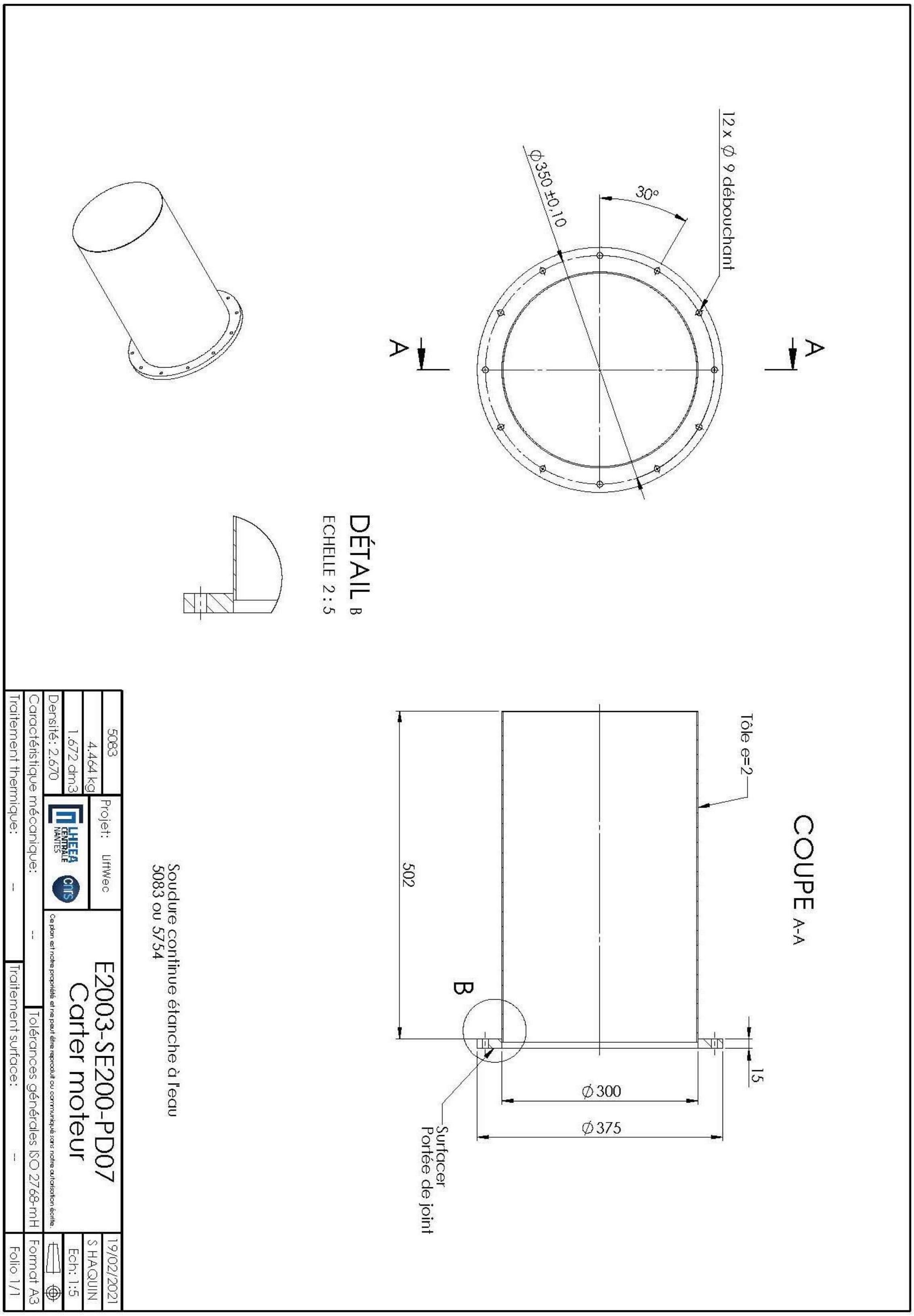
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.



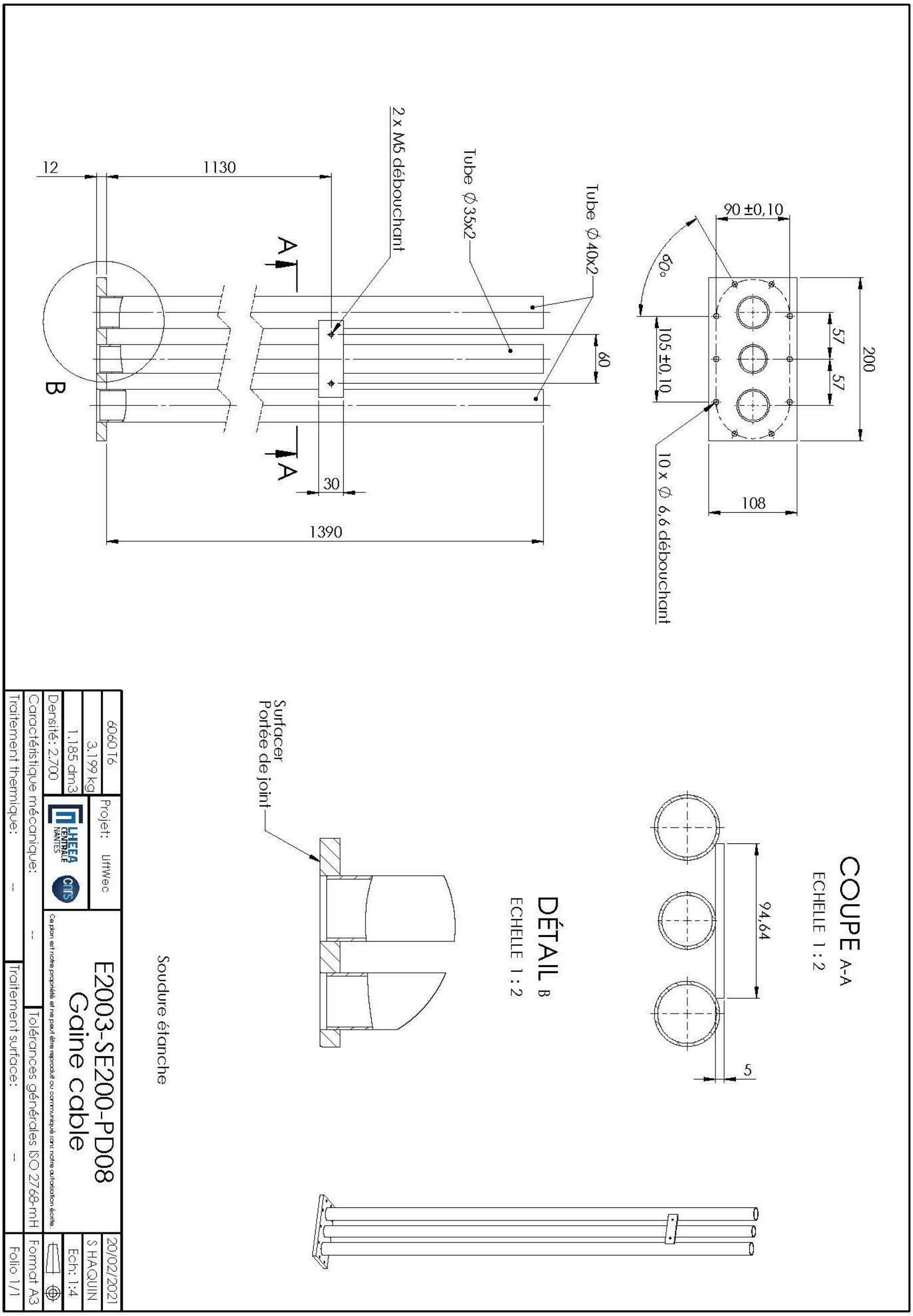
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.



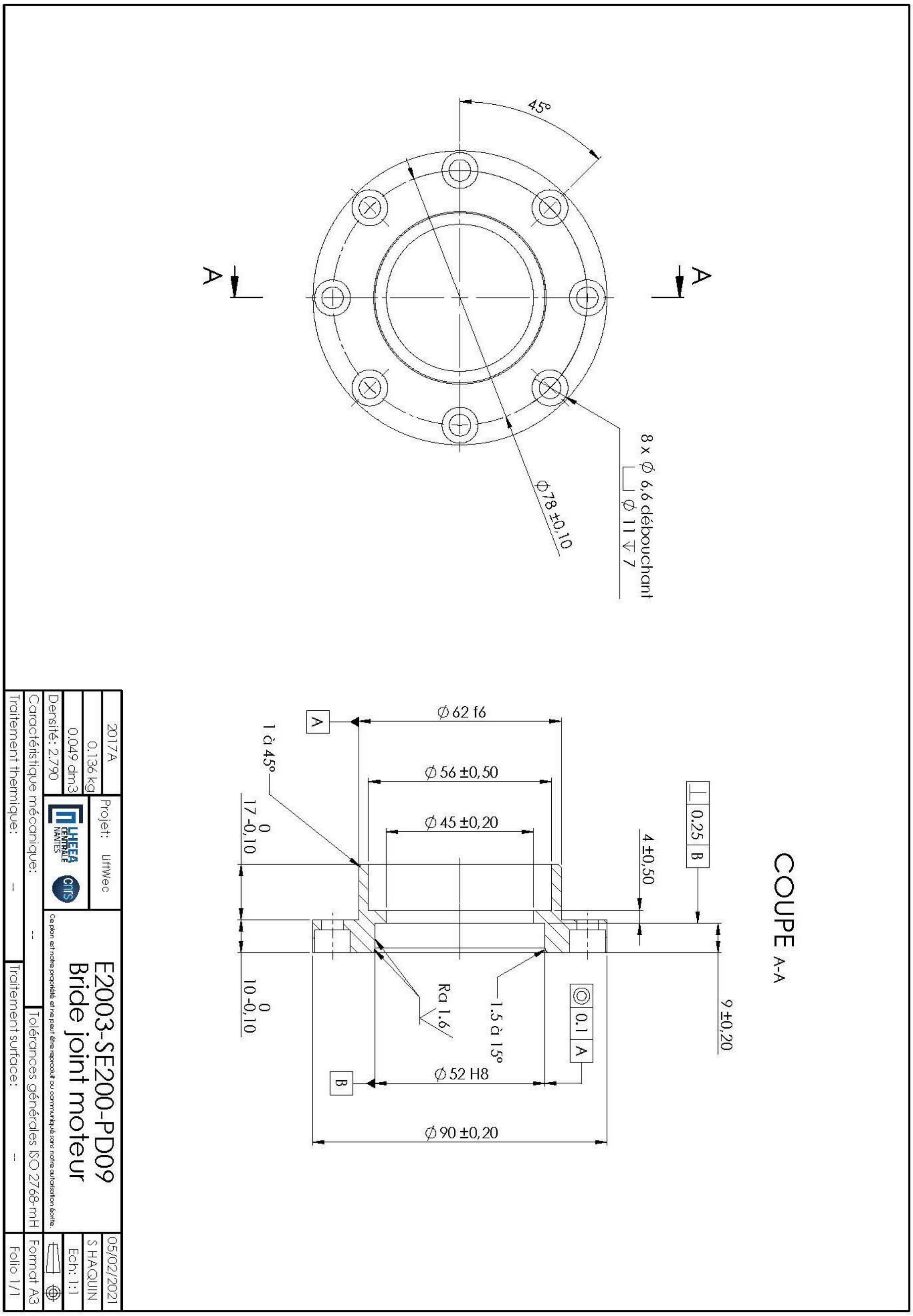
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

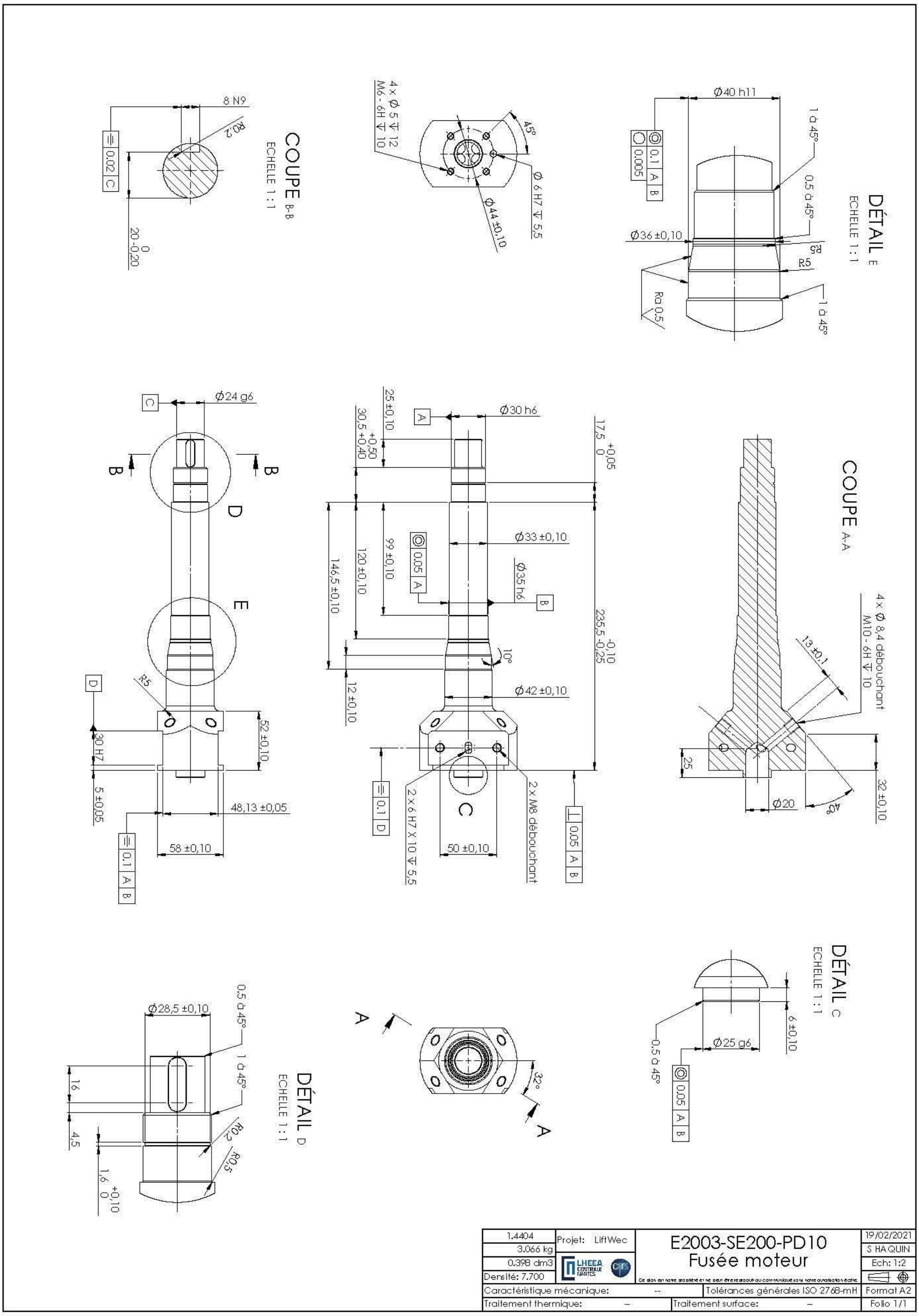


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

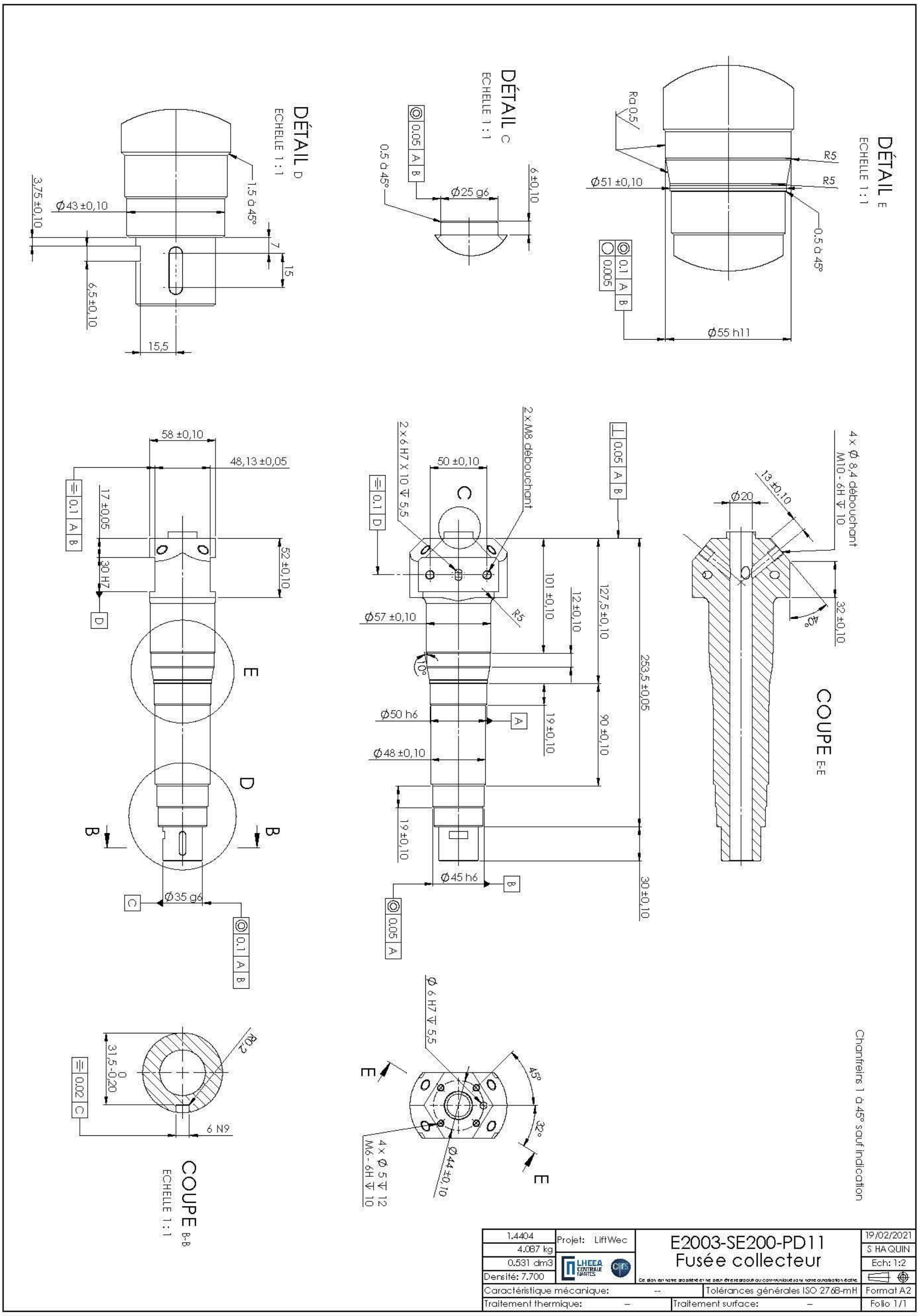


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

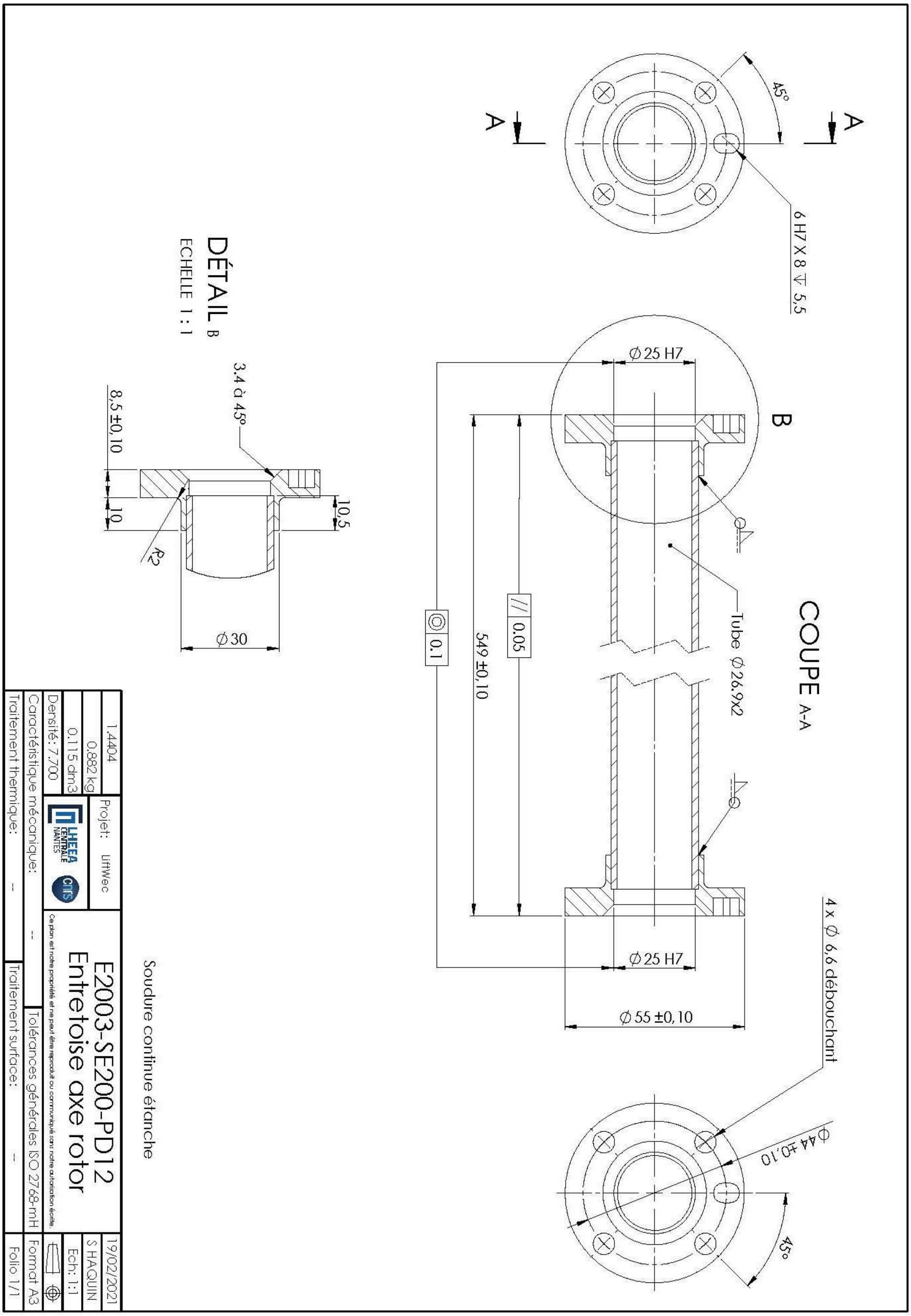

45°
A
A
8 x Ø 6,6 débouchant
⌴ Ø 11 ↧ 7
Ø 78 ±0,10
COUPE A-A
Ø 62 f6
Ø 56 ±0,50
Ø 45 ±0,20
1 à 45°
17 -0,10 0
10 -0,10 0
4 ±0,50
⊥ 0.25 B
9 ±0,20
Ra 1.6
1.5 à 15°
◎ 0.1 A
Ø 52 H8
Ø 90 ±0,20
2017A
0.136 kg
0.049 dm3
Densité: 2.790
Projet: LiftWec
E2003-SE200-PD09
Bride joint moteur
05/02/2021
S HAQUIN
Ech: 1:1
Format A3
Folio 1/1
Caractéristique mécanique: --
Traitement thermique: --
Tolérances générales ISO 2768-mH
Traitement surface: --



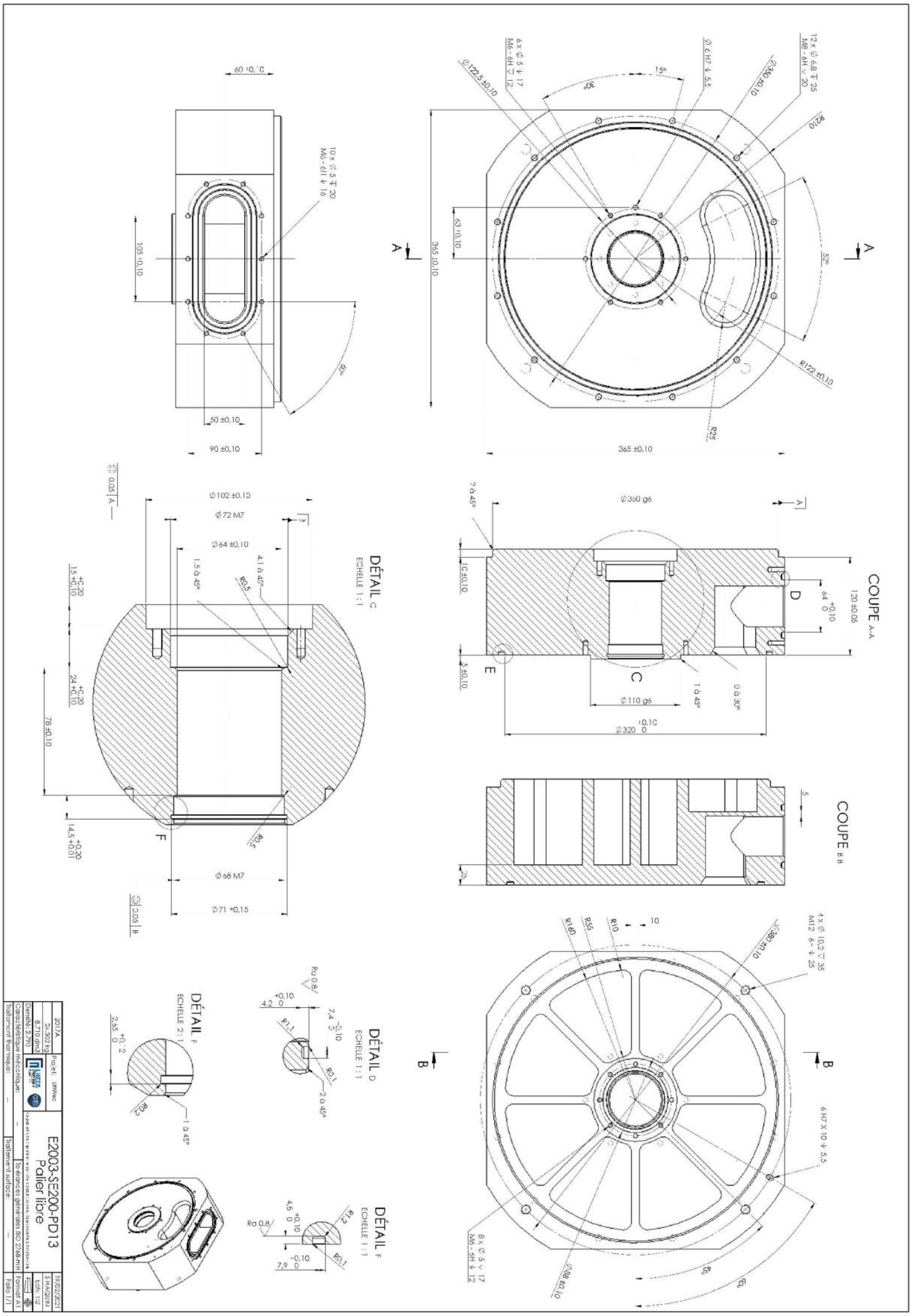
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.



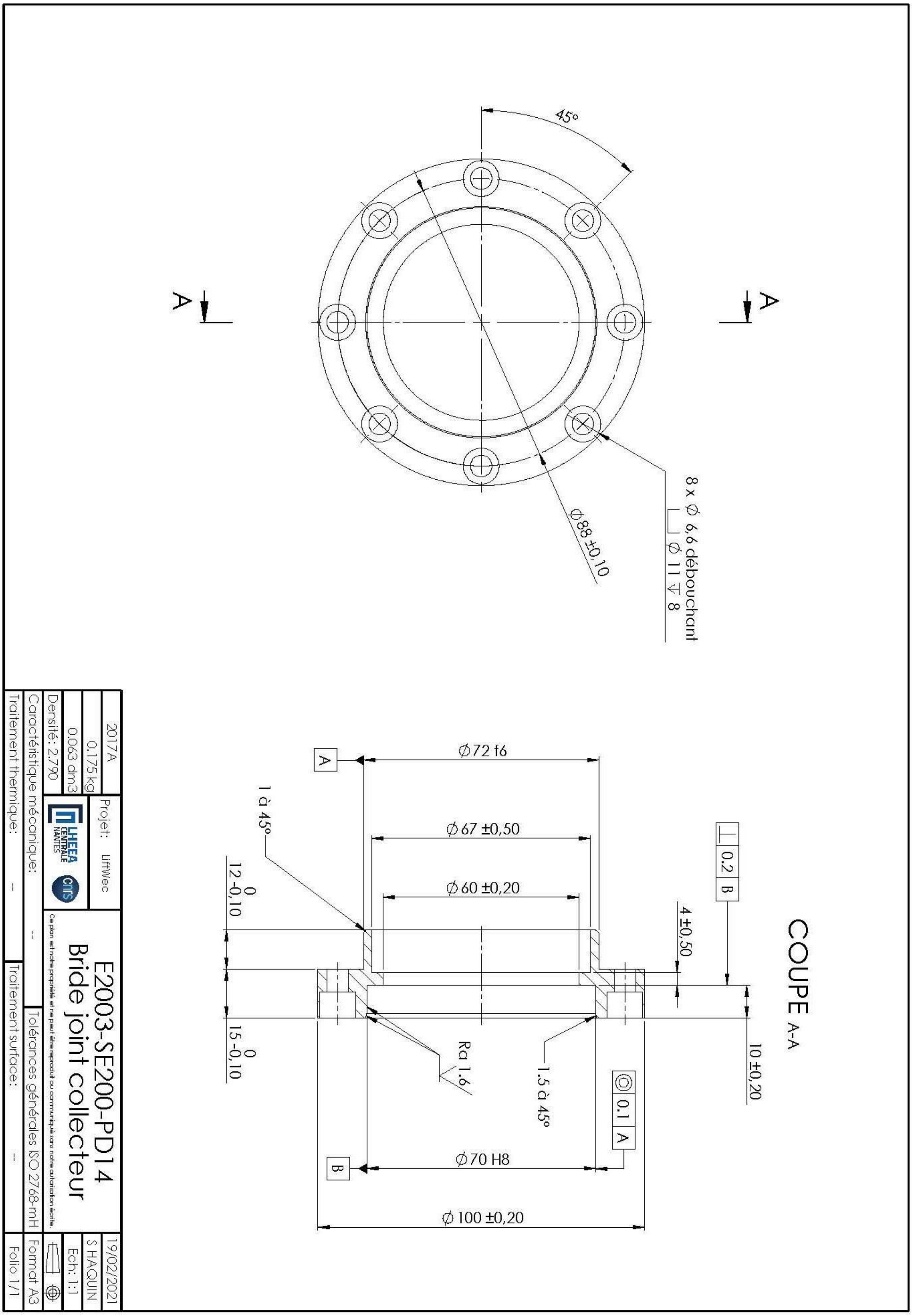
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.



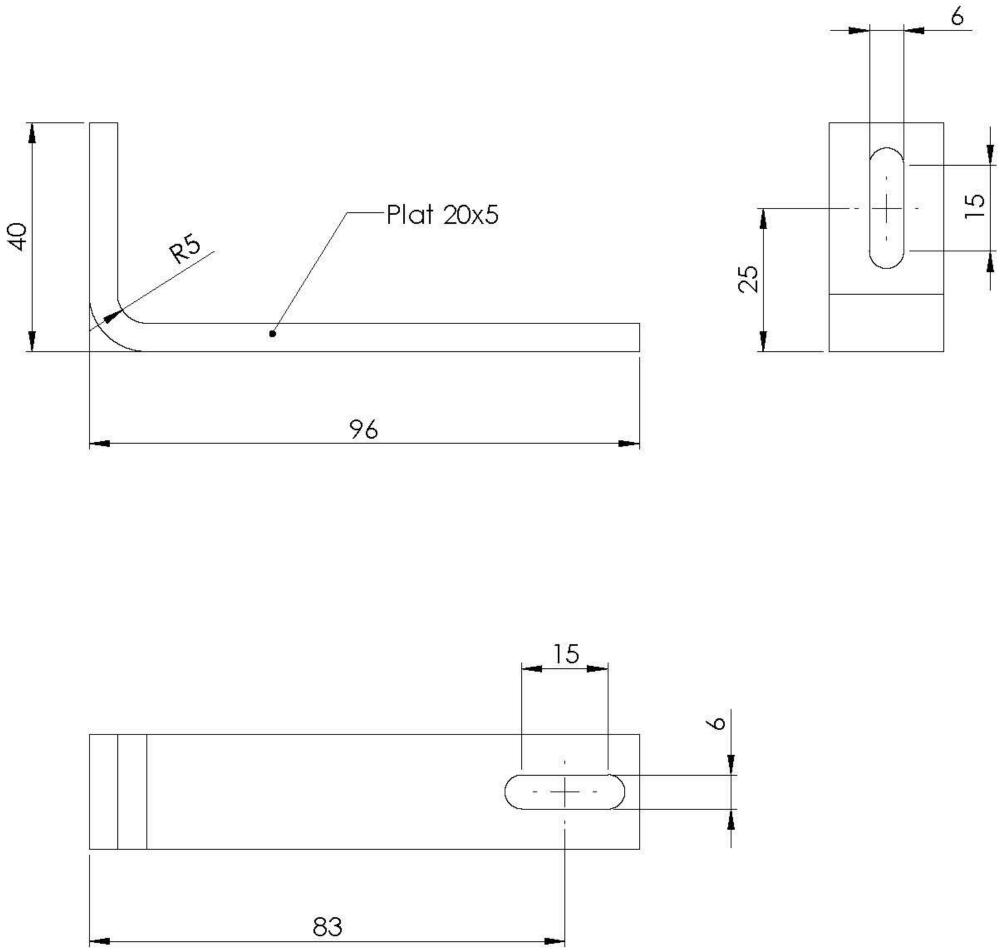
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

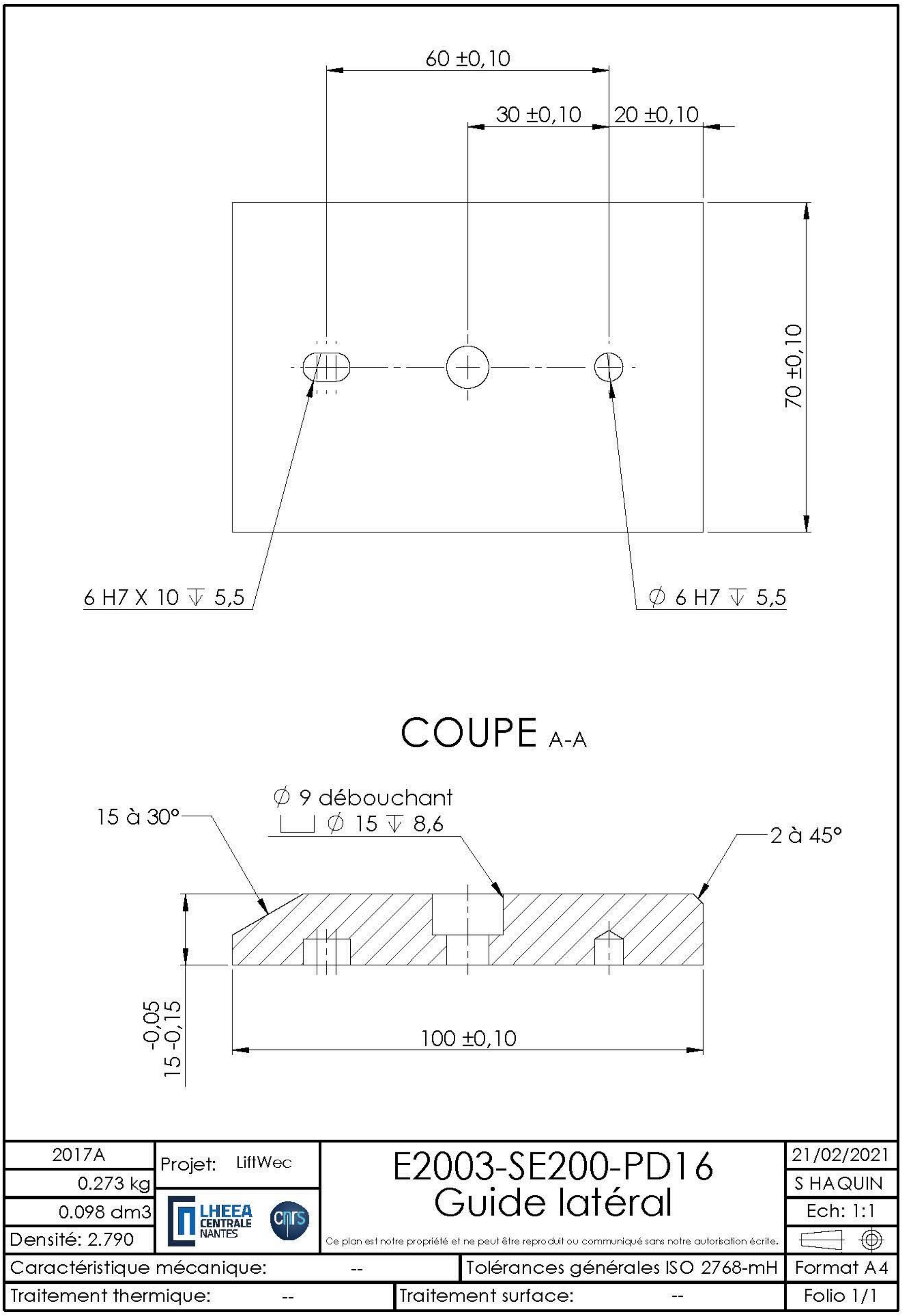


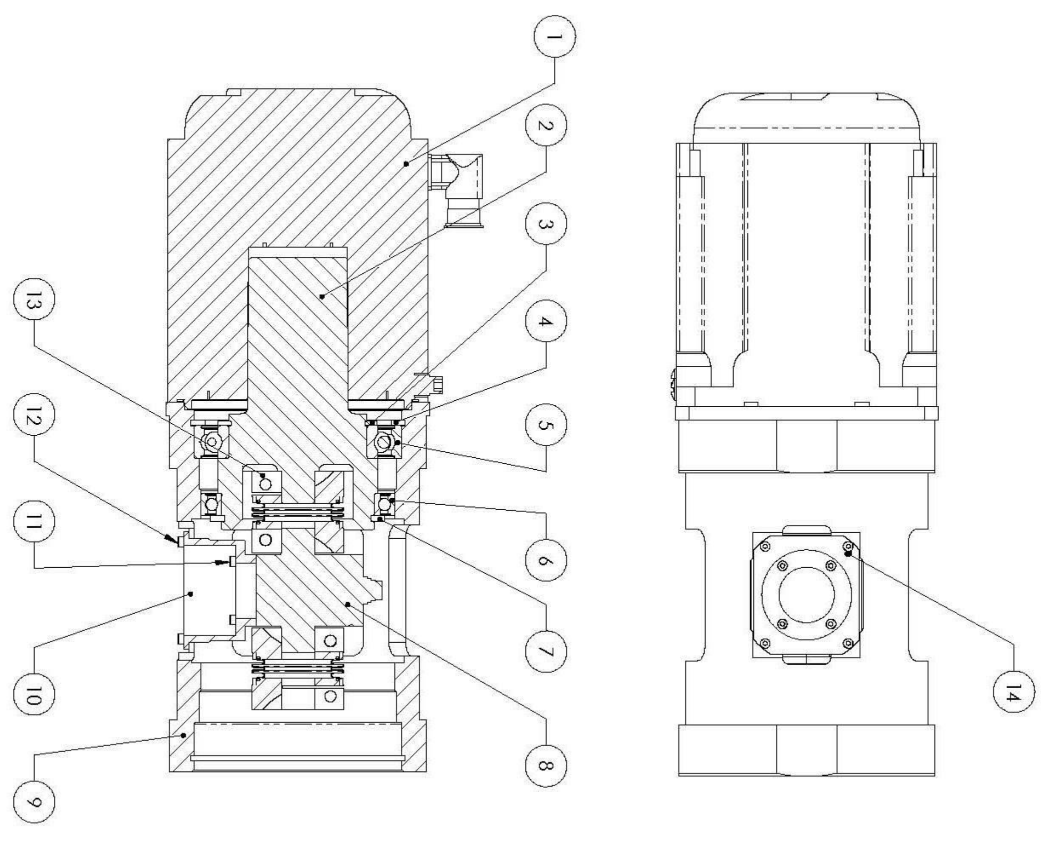
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

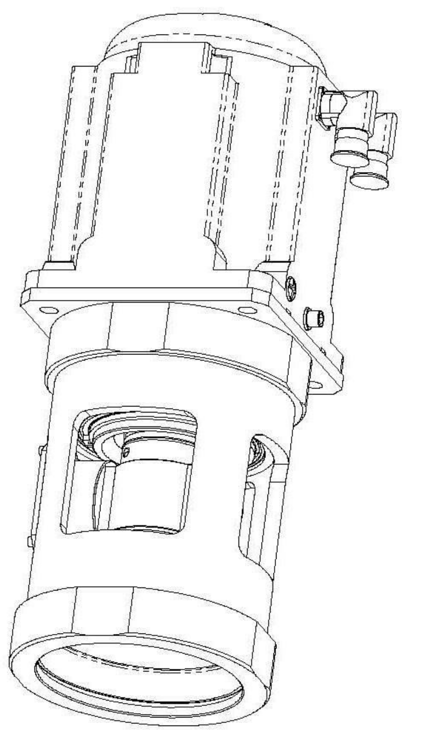


6060 T6	Projet: LiftWec	E2003-SE200-PD15 Patte de fixation		20/02/2021
0.031 kg				S HAQUIN
0.012 dm3	LHEEA CENTRALE NANTES / cnrs			Ech: 1:1
Densité: 2.700		Ce plan est notre propriété et ne peut être reproduit ou communiqué sans notre autorisation écrite.		
Caractéristique mécanique: --			Tolérances générales ISO 2768-mH	Format A4
Traitement thermique: --		Traitement surface: --		Folio 1/1

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.


60 ±0,10
30 ±0,10
20 ±0,10
70 ±0,10
6 H7 X 10 ↧ 5,5
∅ 6 H7 ↧ 5,5
COUPE A-A
∅ 9 débouchant
⌴ ∅ 15 ↧ 8,6
15 à 30°
2 à 45°
15 -0,05 -0,15
100 ±0,10
2017A
0.273 kg
0.098 dm3
Densité: 2.790
Projet: LiftWec
E2003-SE200-PD16
Guide latéral
Ce plan est notre propriété et ne peut être reproduit ou communiqué sans notre autorisation écrite.
21/02/2021
S HAQUIN
Ech: 1:1
Caractéristique mécanique: --
Tolérances générales ISO 2768-mH
Format A4
Traitement thermique: --
Traitement surface: --
Folio 1/1

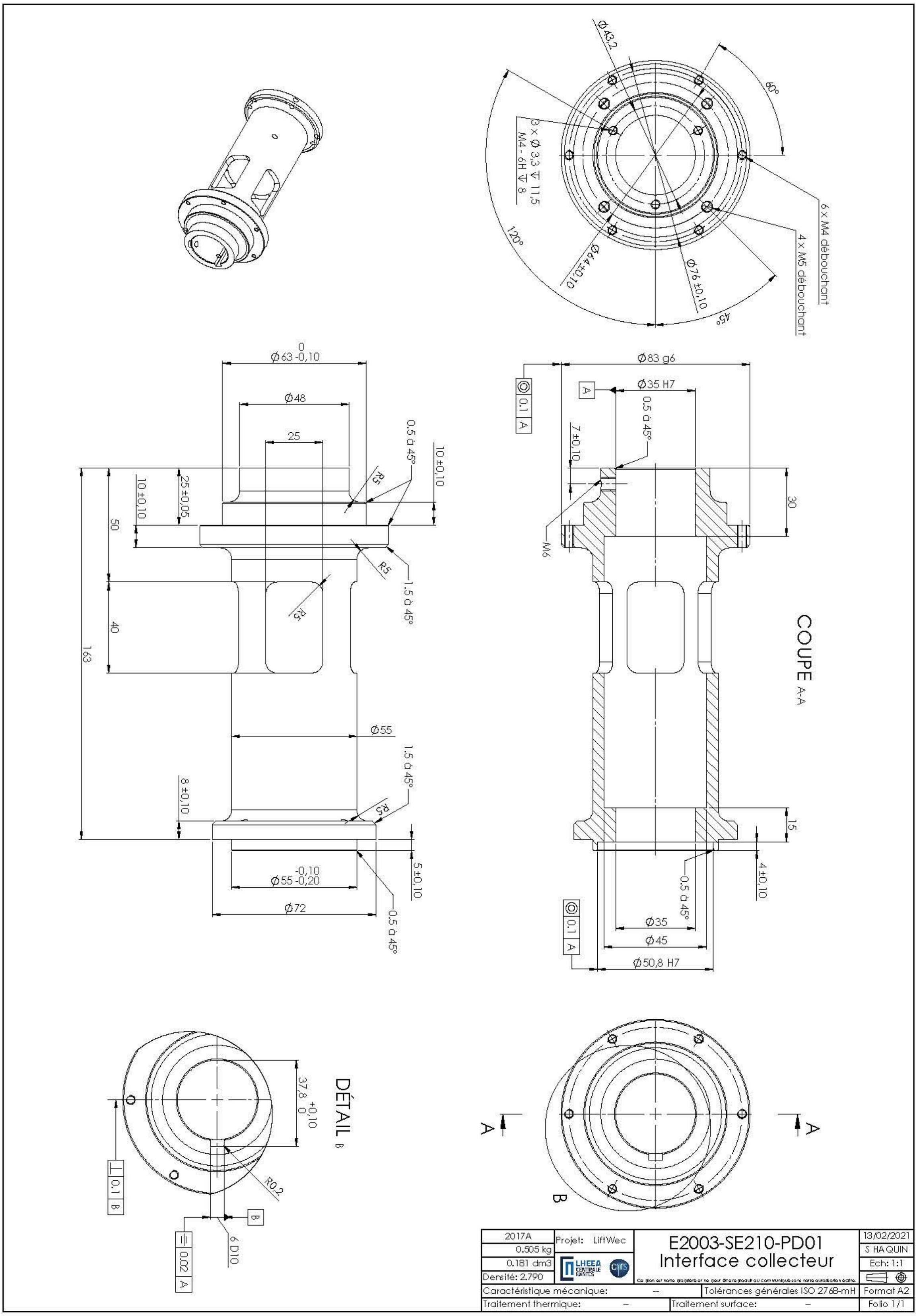




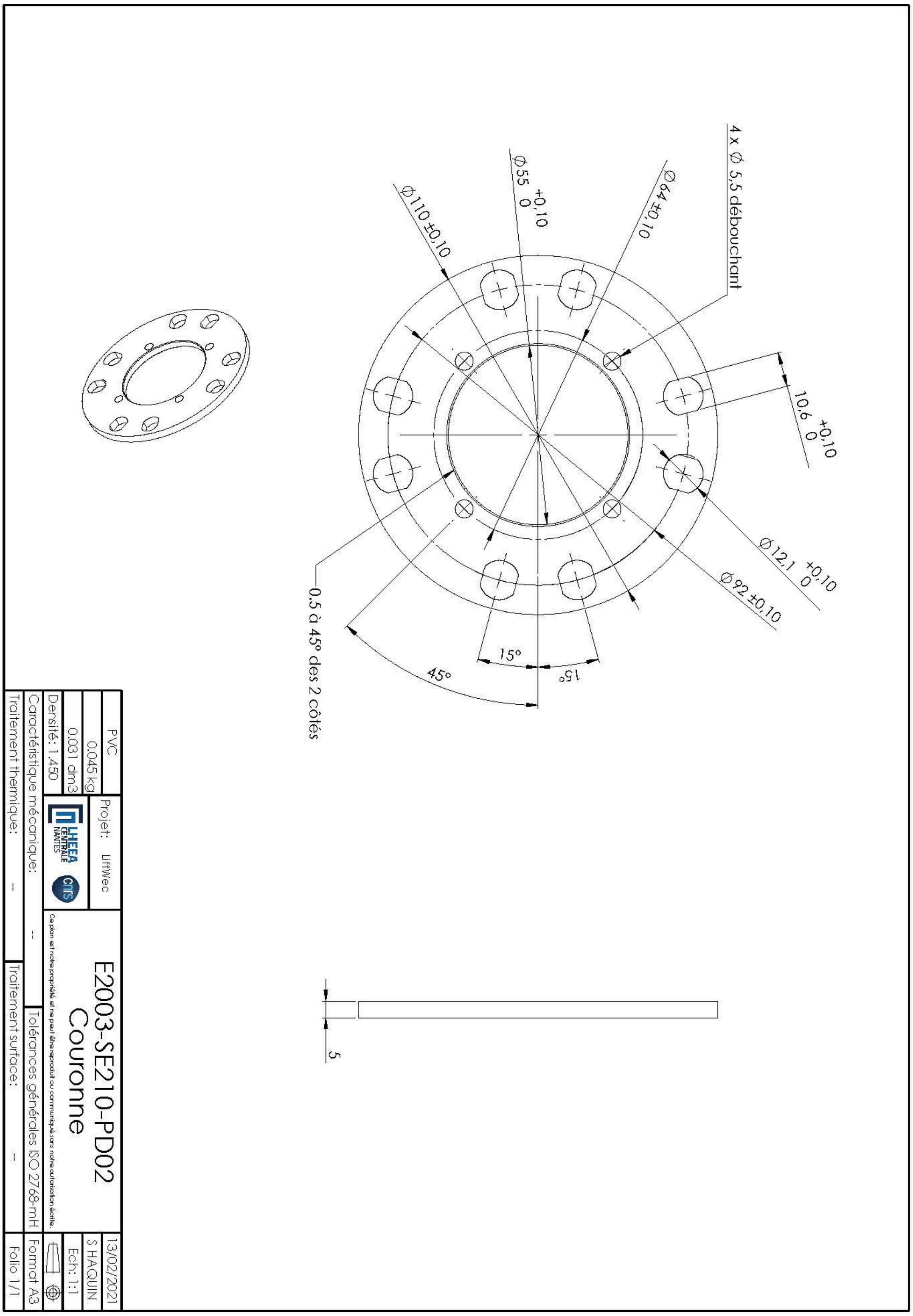
Rep	Désignation	Description	Qté
14	Pion de positionnement d4x10	316L étiré h9	1
13	BKE-200-24-24		2
12	Vis CHC.M4-12	INOX A2	4
11	Vis CHC.M4-16	INOX A2	4
10	E180402-SE300-PD02 Support couplemètre		1
9	E180402-SE300-PD01 Lanterne		1
8	DRBK-100	PM-Instrumentation	1
7	Circlips_din471_110x4		1
6	61822-2RZ	SKF	1
5	6020-2Z	SKF	1
4	Circlips_din472_150x4		1
3	Circlips_din471_100x3		1
2	E180402-SE300-PD04 Axe moteur		1
1	C061B-13-3105-xxx	Kollmorgen	1

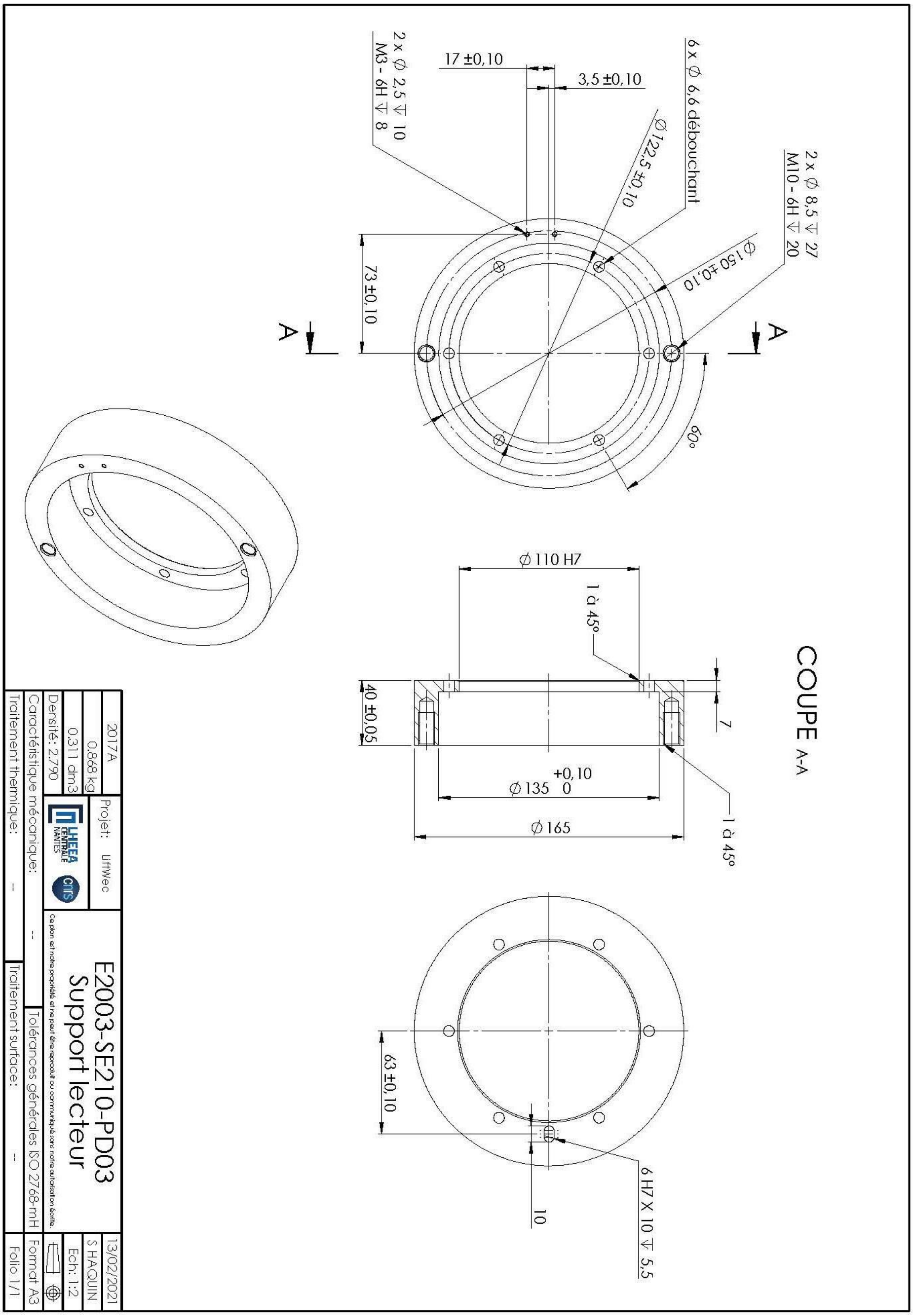
35.181 kg 9.253 dm3 Densité:	Projet: LiftWec LHEEA Centrale Nantes / CNRS	E2003-SE200-PE02 Nomenclature controle Ce plan est notre propriété et ne peut être reproduit ou communiqué sans notre autorisation écrite.
07/02/2021 S HAQUIN Ech: 1:3		
Caractéristique mécanique: --	Tolérances générales ISO 2768-mH	Format A3
Traitement thermique: --	Traitement surface: --	Folio 1/1

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

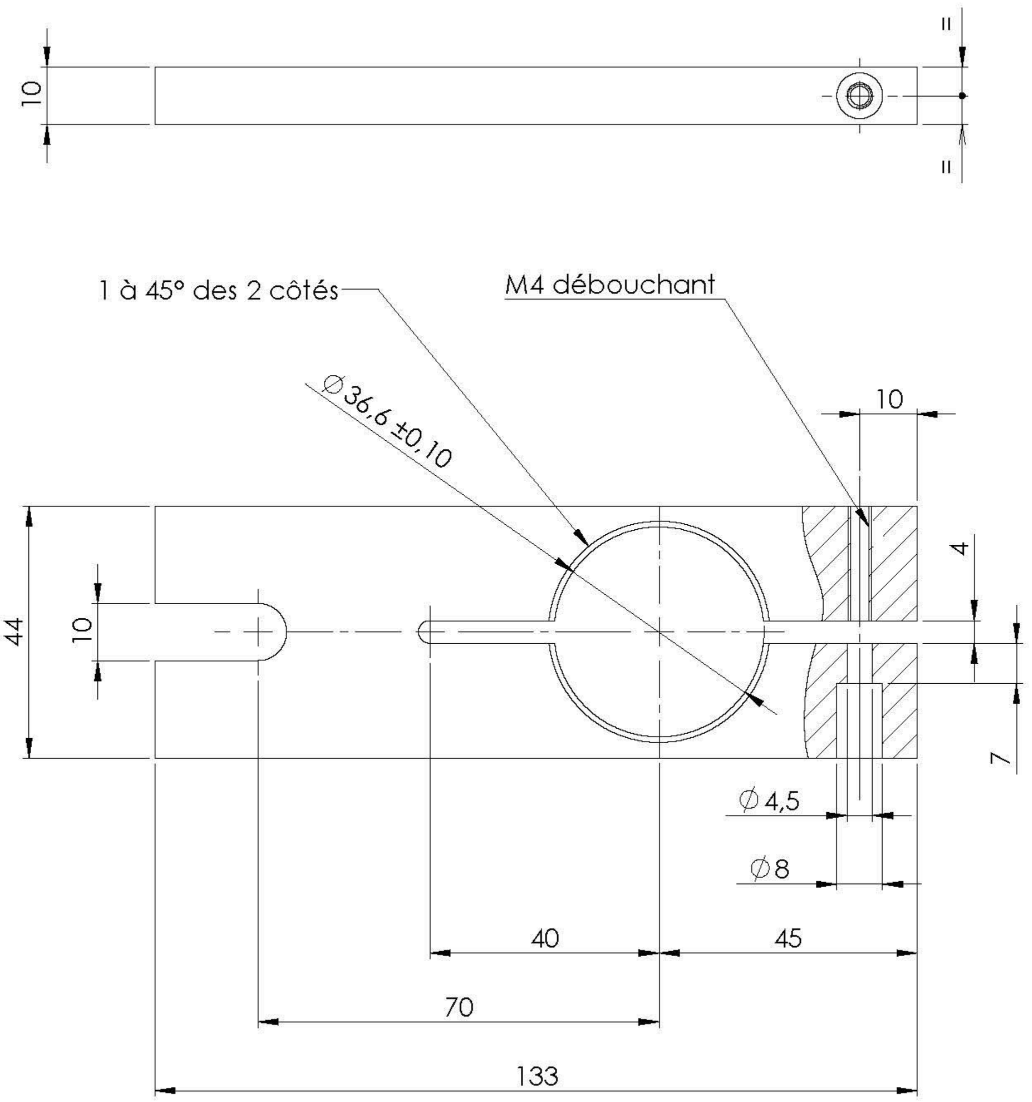


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.


4 x Ø 5,5 débouchant
Ø64 ±0,10
Ø55 +0,10 0
Ø110 ±0,10
10,6 +0,10 0
Ø12,1 +0,10 0
Ø92 ±0,10
15°
15°
45°
0.5 à 45° des 2 côtés
5
PVC
0.045 kg
0.031 dm3
Densité: 1.450
Projet: LiftWec
E2003-SE210-PD02
Couronne
13/02/2021
S HAQUIN
Ech: 1:1
Caractéristique mécanique:
Tolérances générales ISO 2768-mH
Format A3
Traitement thermique:
Traitement surface:
Folio 1/1

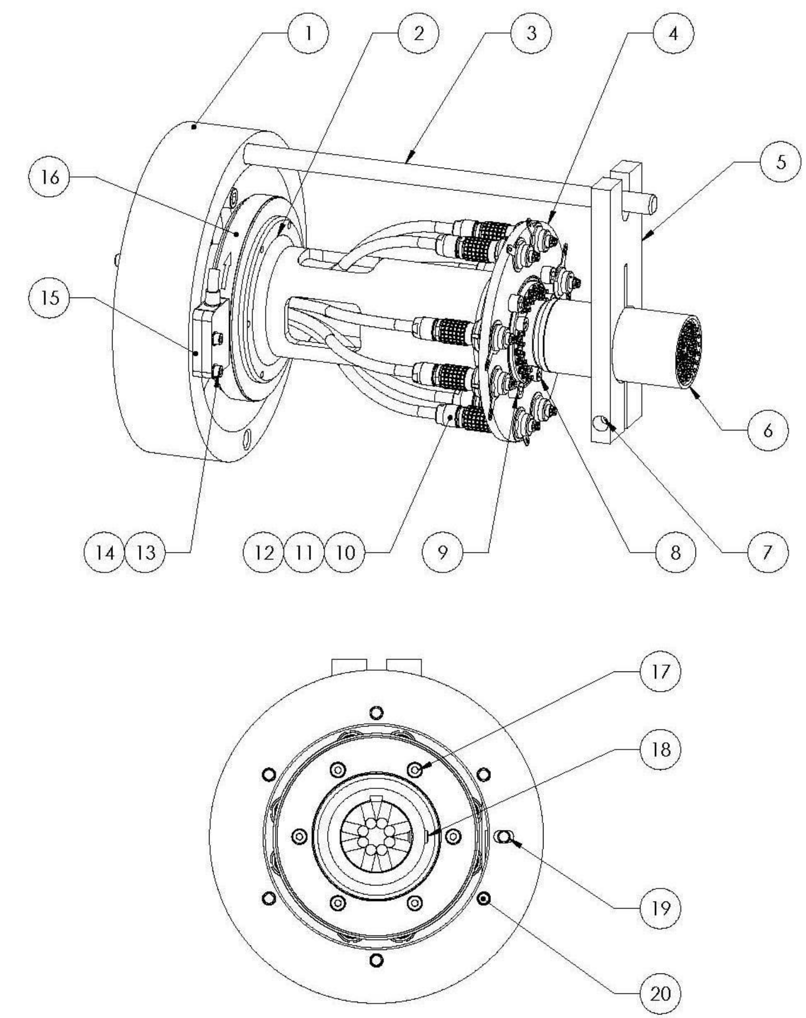


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.



2017A	Projet: LiftWec	E2003-SE210-PD04 Bride collecteur	13/02/2021
0.119 kg	LHEEA CENTRALE NANTES / CNRS		S HAQUIN
0.043 dm3			Ech: 1:1
Densité: 2.790		Ce plan est notre propriété et ne peut être reproduit ou communiqué sans notre autorisation écrite.	
Caractéristique mécanique: --		Tolérances générales ISO 2768-mH	Format A4
Traitement thermique: --	Traitement surface: --		Folio 1/1

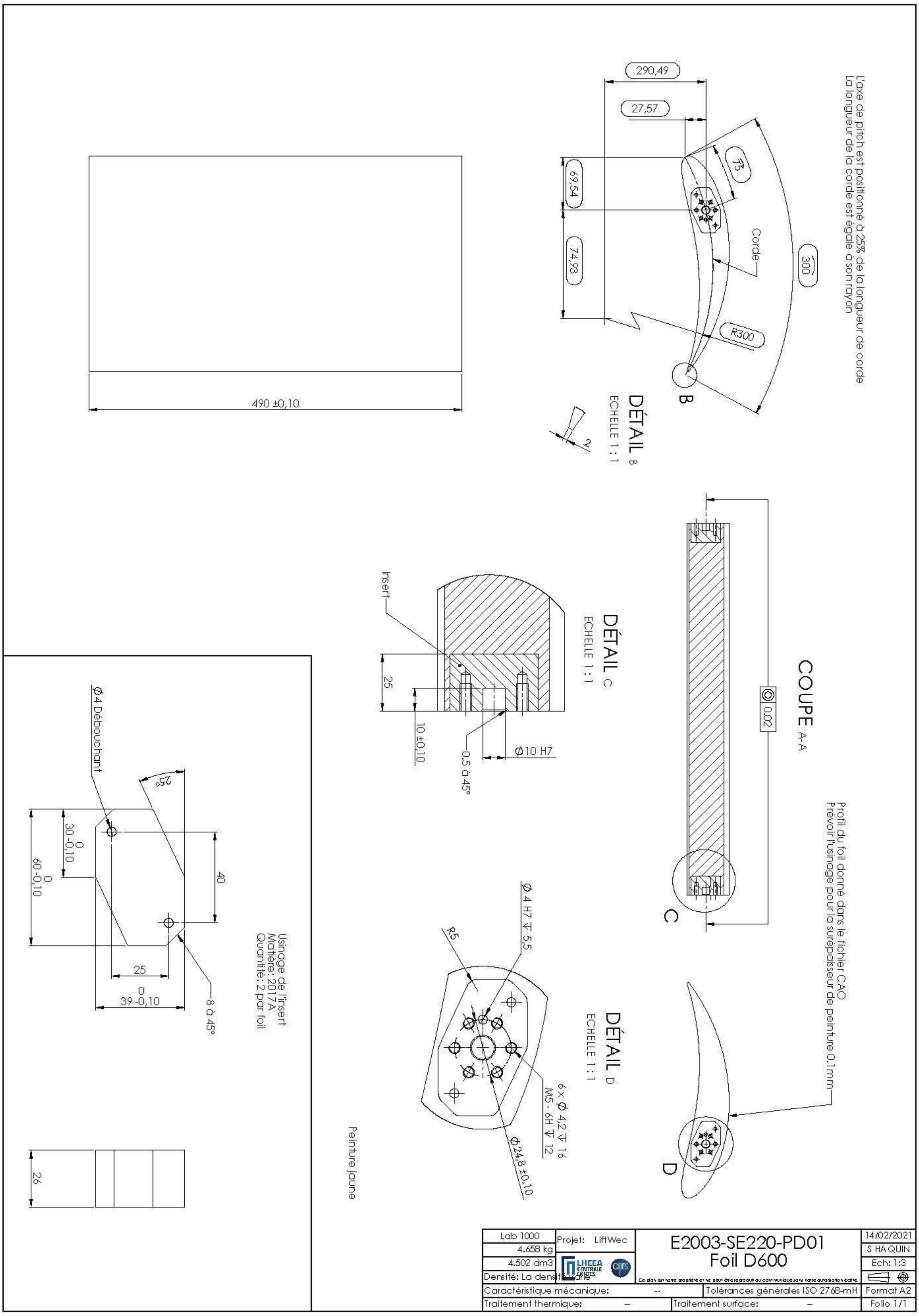
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

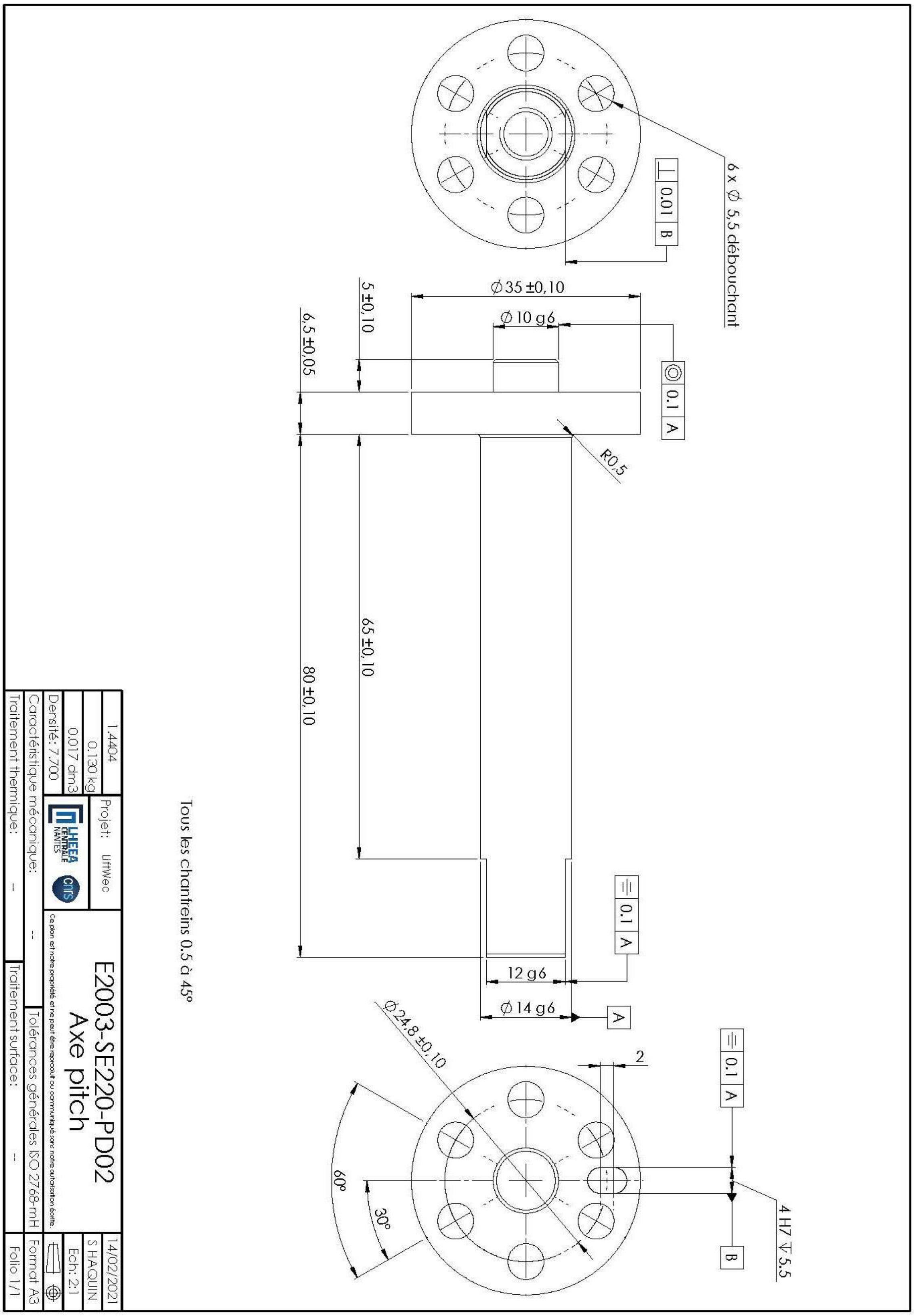


Rep	Désignation	Description	Qté
20	Vis CHC,M6-16	INOX A2	6
19	Pion de positionnement d6x10	316L étiré h9	1
18	Vis HC,M6-10 bout plat	INOX A2	1
17	Vis CHC,M4-12	INOX A2	6
16	PMIR5-50-64-M-83-AB	ASM	1
15	PMIS4-50-64-20KHZ-TTL-Z3-3M-S	ASM	1
14	Rondelle M3	INOX A2	2
13	Vis CHC,M3-16	INOX A2	2
12	GCA-1S-255-LT	LEMO	8
11	EEG-1B-306-CLL	LEMO	8
10	FGG-1B-306-CLAD62	LEMO	8
9	Vis CHC,M5-12	INOX A2	4
8	Vis CHC,M4-16	INOX A2	3
7	Vis CHC,M4-20	INOX A2	1
6	SR36M	Michigan Scientific	1
5	E2003-SE210-PD04 Bride collecteur		1
4	E2003-SE210-PD02 Couronne		1
3	Tige filetée M10-235	INOX A2 70	1
2	E2003-SE210-PD01 Interface collecteur		1
1	E2003-SE210-PD03 Support lecteur		1

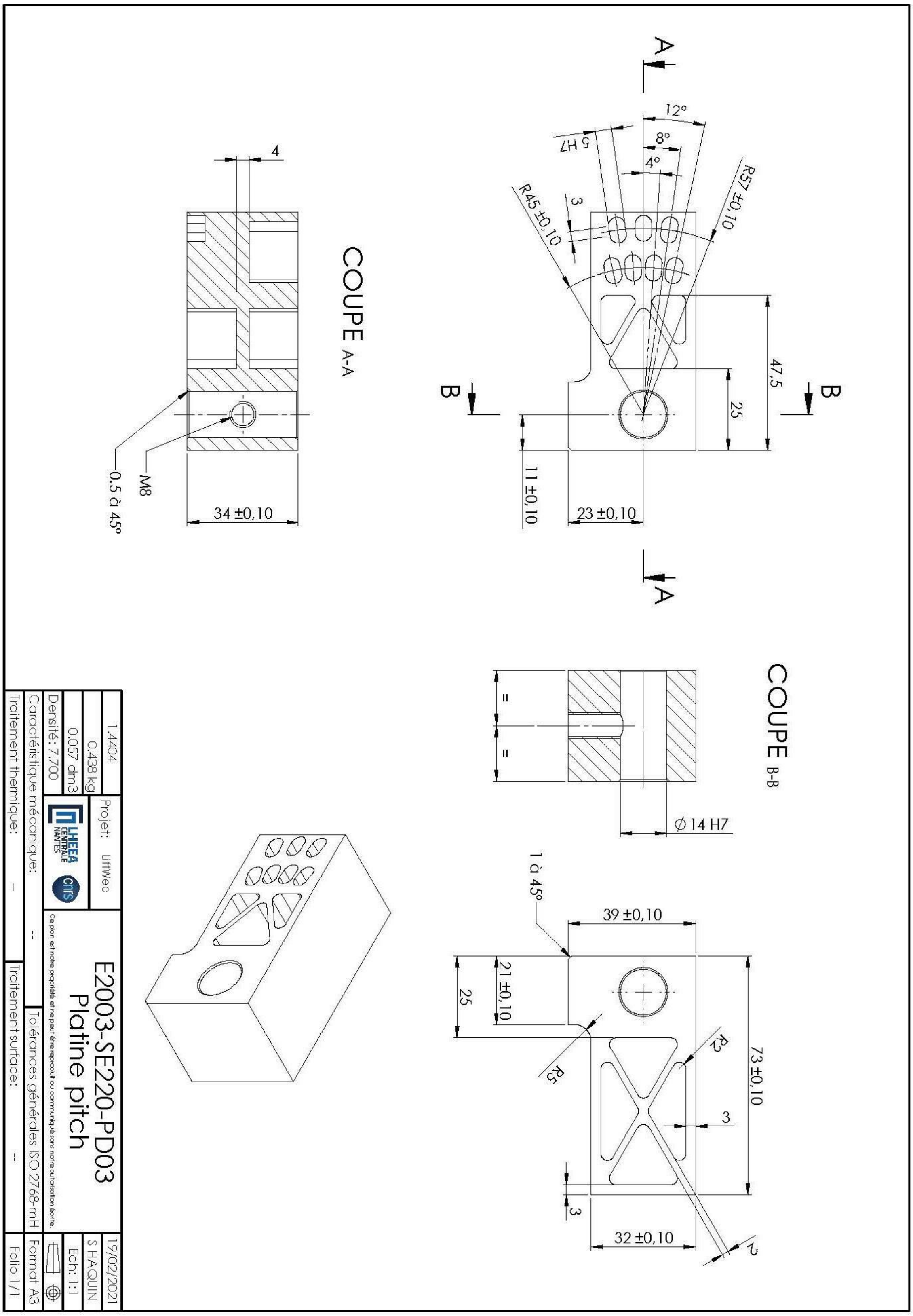
2.161 kg 0.828 dm3 Densité:	Projet: LiftWec LHEEA Centrale Nantes, CNRS	E2003-SE210-PE01 Nomenclature collecteur Ce plan est notre propriété et ne peut être reproduit ou communiqué sans notre autorisation écrite.	06/02/2021 S HAQUIN Ech: 1:2
Caractéristique mécanique: --		Tolérances générales ISO 2768-mH	Format A3
Traitement thermique: --		Traitement surface: --	Folio 1/1

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

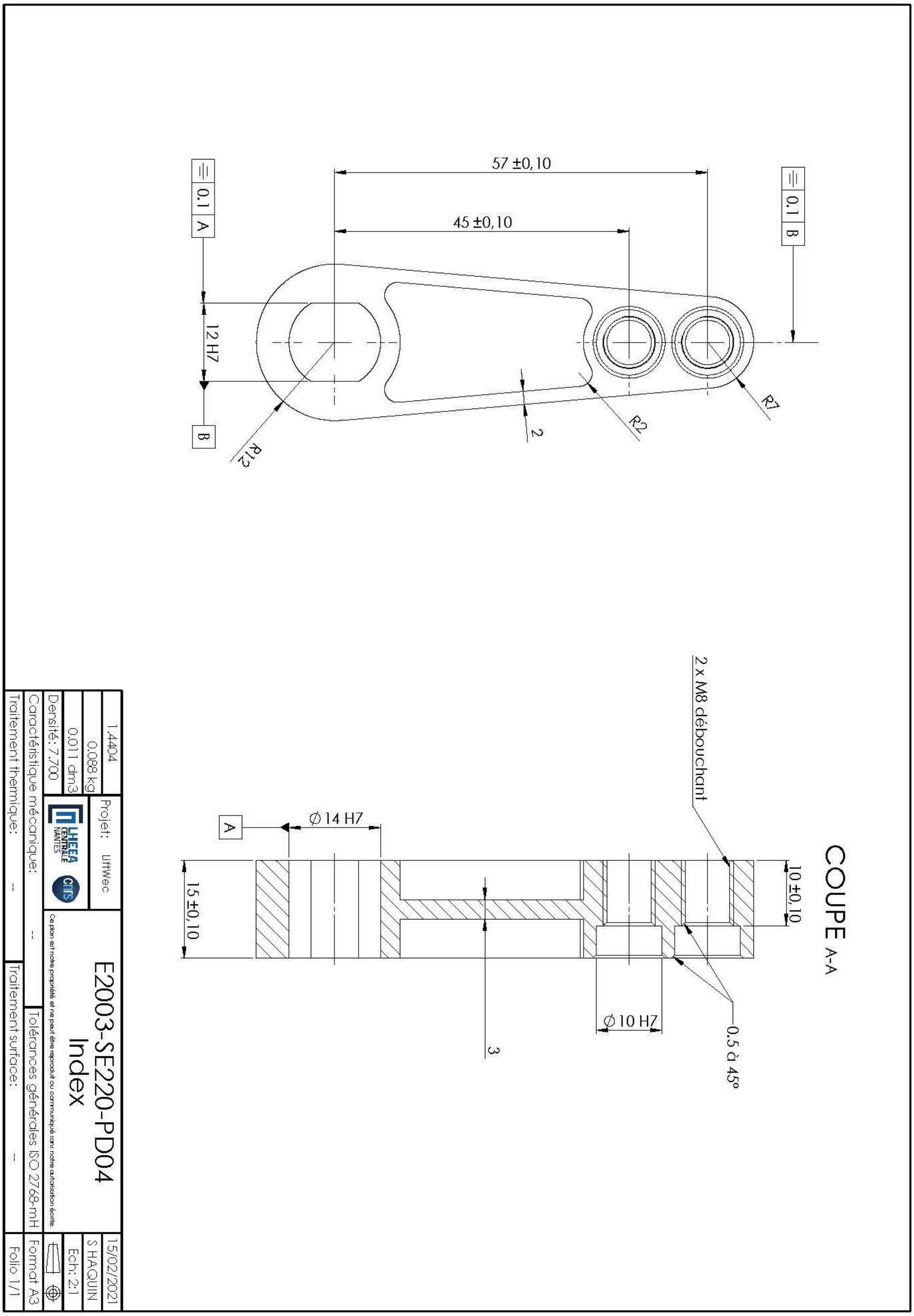

L'axe de pitch est positionné à 25% de la longueur de corde
La longueur de la corde est égale à son rayon
290,49
27,57
73
300
R300
Corde
69,54
74,93
490 ±0,10
DÉTAIL B
ECHELLE 1 : 1
COUPE A-A
0,02
DÉTAIL C
ECHELLE 1 : 1
Insert
25
10 ±0,10
0,5 à 45°
Ø 10 H7
Profil du foil donné dans le fichier CAO
Prévoir l'usinage pour la surépaisseur de peinture 0,1mm
DÉTAIL D
ECHELLE 1 : 1
Ø 4 H7 ↧ 5,5
R5
6 x Ø 4,2 ↧ 16
M5 - 6H ↧ 12
Ø 24,8 ±0,10
Peinture jaune
Ø 4 Débouchant
25°
40
25
8 à 45°
Usinage de l'insert
Matière: 2017A
Quantité: 2 par foil
26
Lab 1000
4,658 kg
4,502 dm3
Projet: LiftWec
E2003-SE220-PD01
Foil D600
14/02/2021
S HAQUIN
Ech: 1:3
Caractéristique mécanique:
Tolérances générales ISO 2768-mH
Format A2
Traitement thermique:
Traitement surface:
Folio 1/1



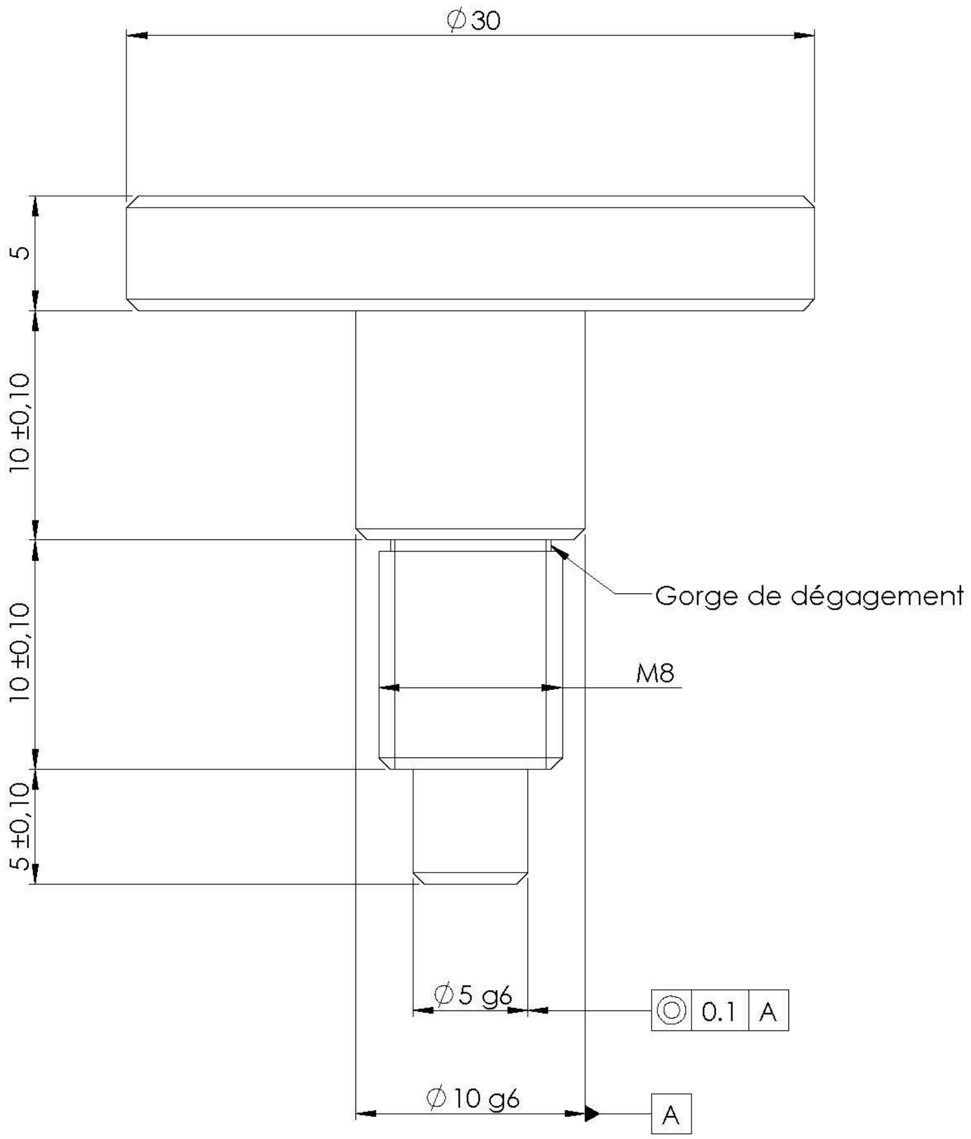
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.



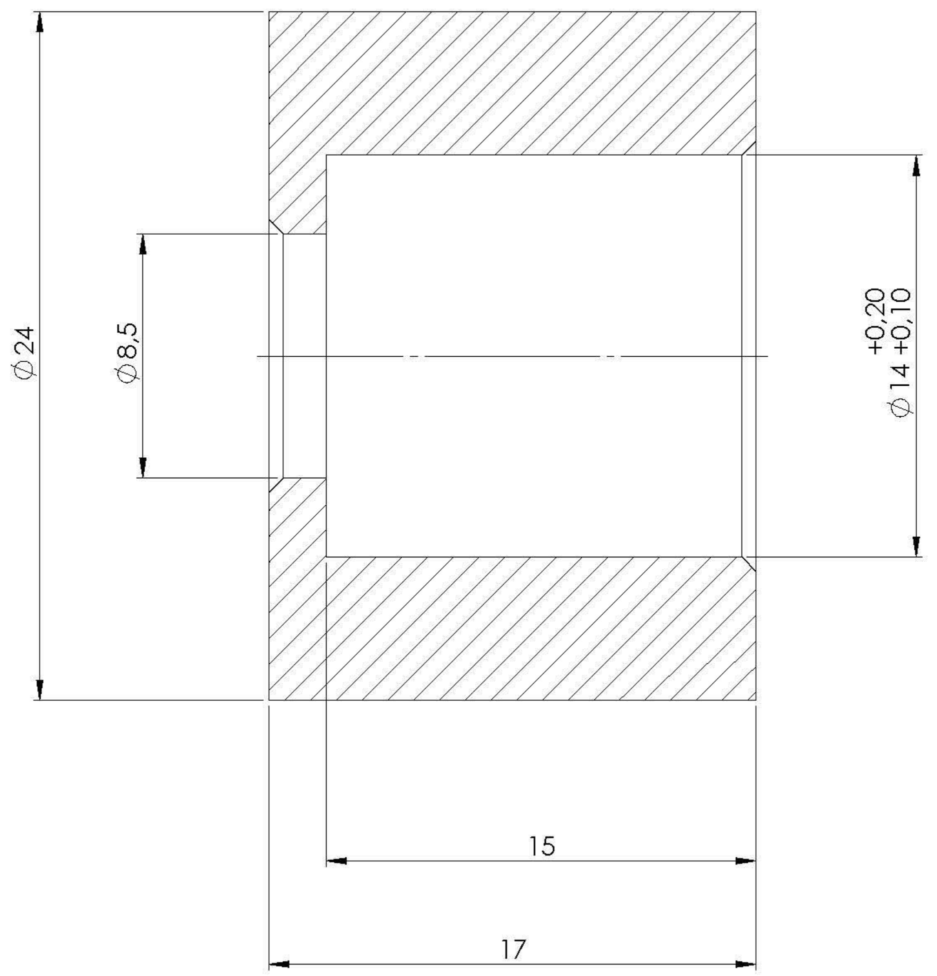
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.



Tous les chanfreins 0.5 à 45°

1.4404	Projet: LiftWec	E2003-SE220-PD05 Vis ajustée	14/02/2021
0.038 kg			S HAQUIN
0.005 dm3	LHEEA CENTRALE NANTES / cnrs		Ech: 4:1
Densité: 7.700		Ce plan est notre propriété et ne peut être reproduit ou communiqué sans notre autorisation écrite.	
Caractéristique mécanique: --		Tolérances générales ISO 2768-mH	Format A4
Traitement thermique: --	Traitement surface: --		Folio 1/1

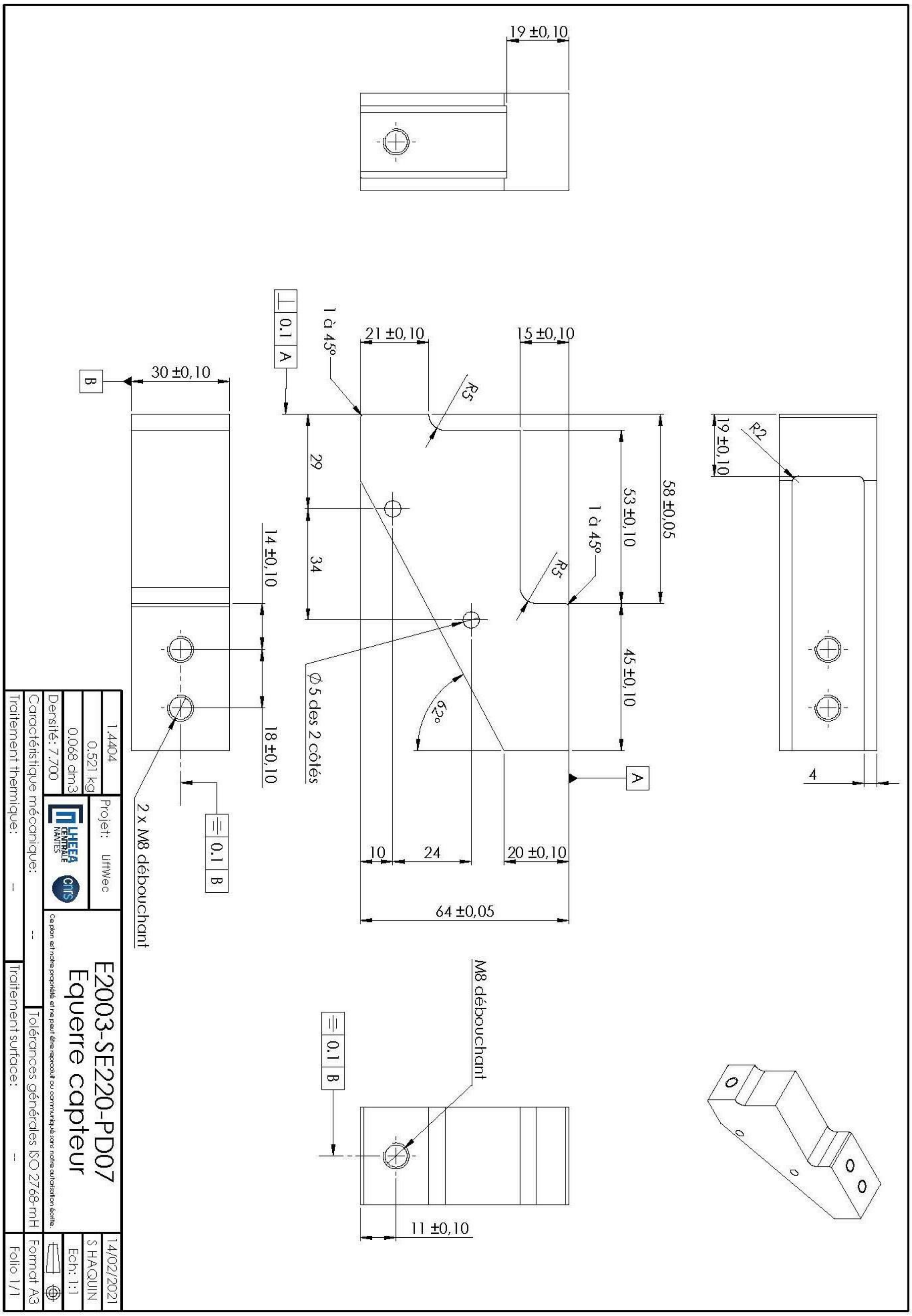
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.



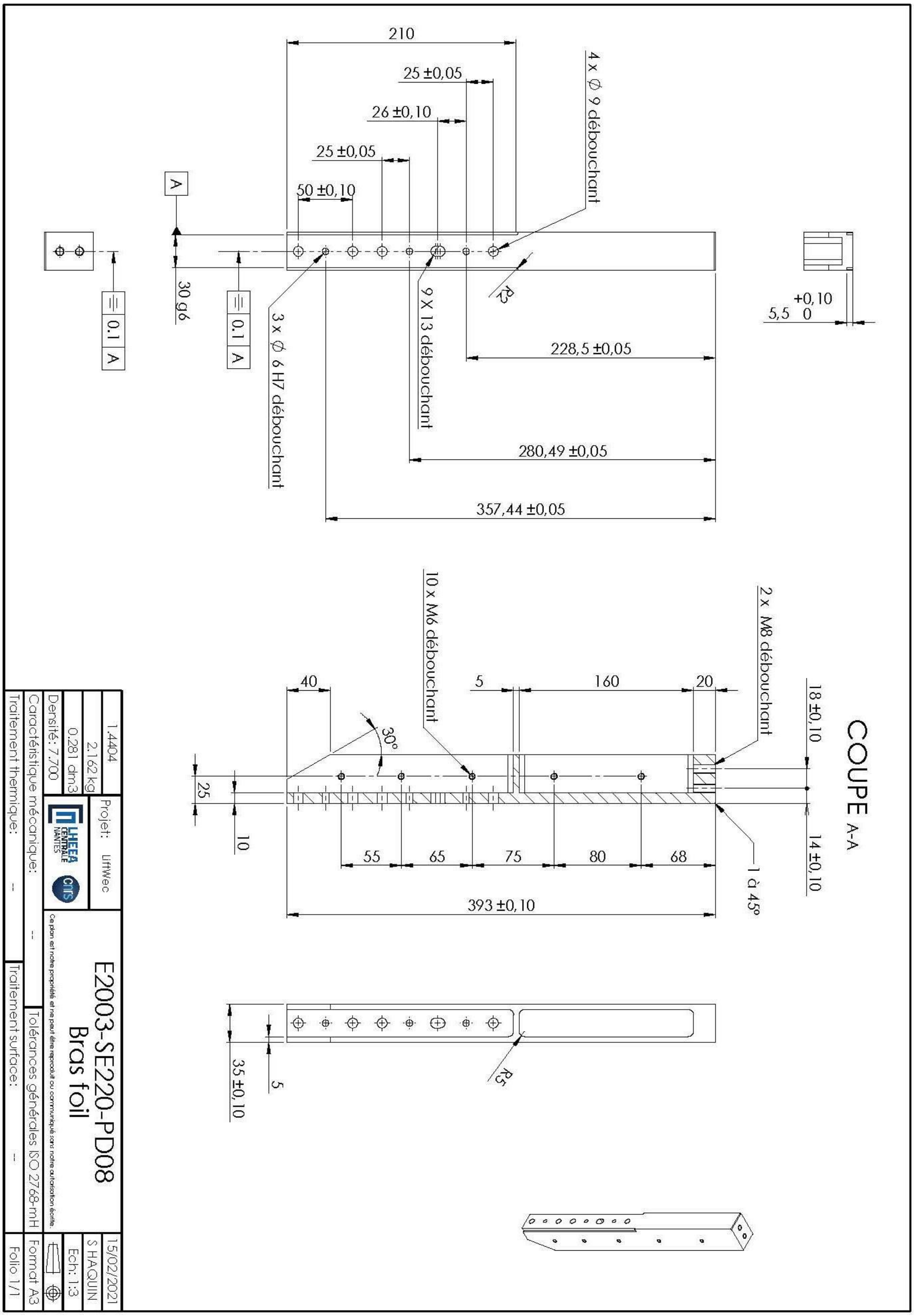
Chanfreins 0.5 à 45°

1.4404	Projet: LiftWec	E2003-SE220-PD06 Entretoise foil	20/02/2021
0.040 kg			S HAQUIN
0.005 dm3	LHEEA CENTRALE NANTES cnrs		Ech: 5:1
Densité: 7.700		Ce plan est notre propriété et ne peut être reproduit ou communiqué sans notre autorisation écrite.	
Caractéristique mécanique: --		Tolérances générales ISO 2768-mH	Format A4
Traitement thermique: --		Traitement surface: --	Folio 1/1

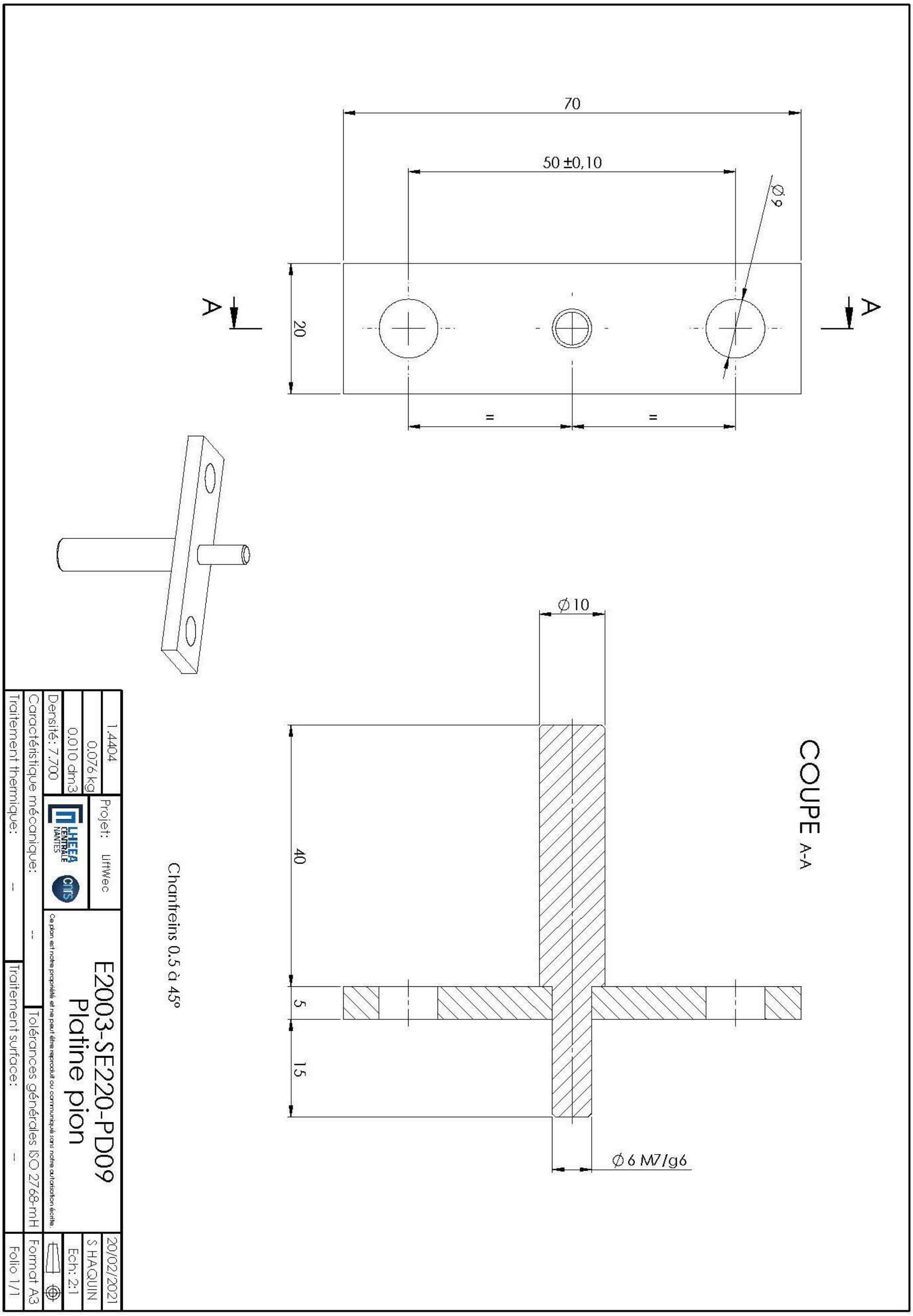
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

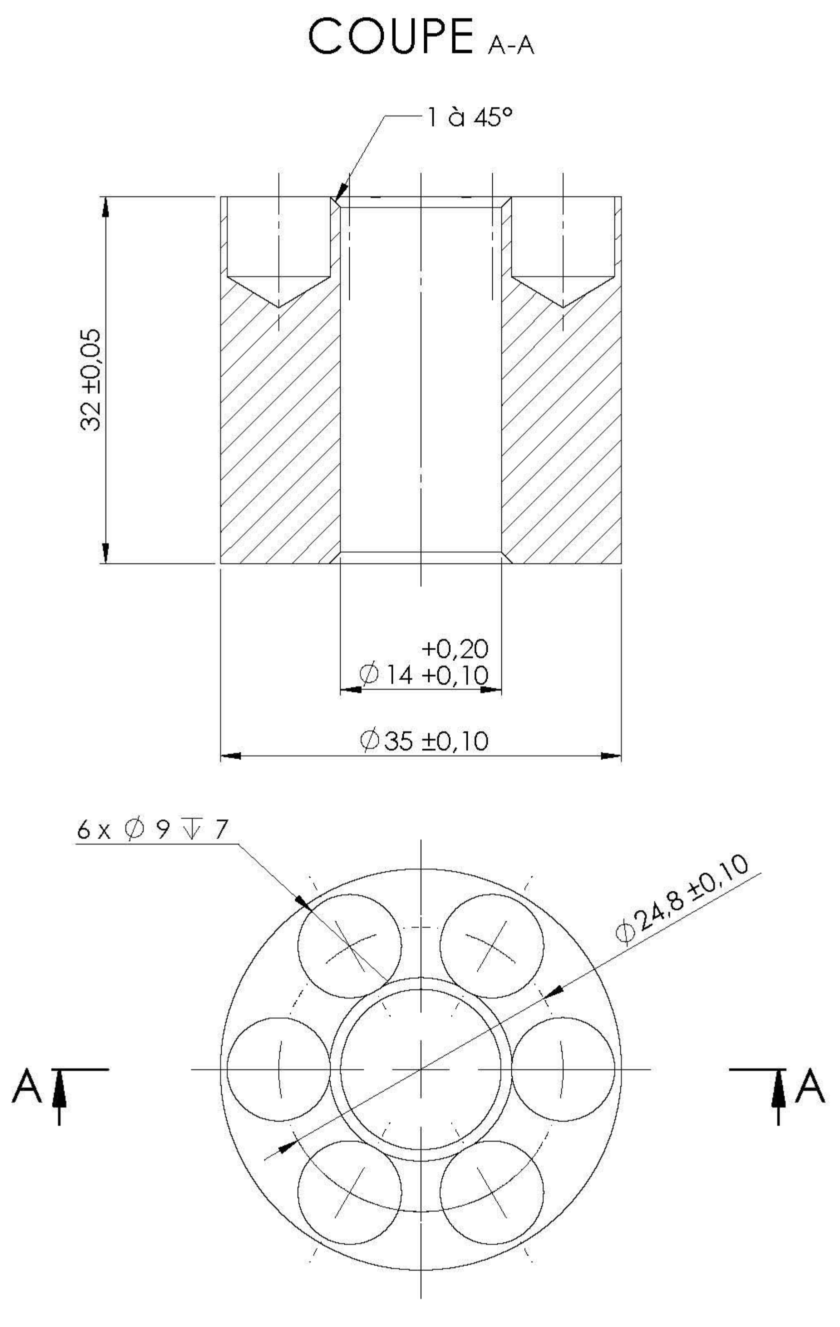


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

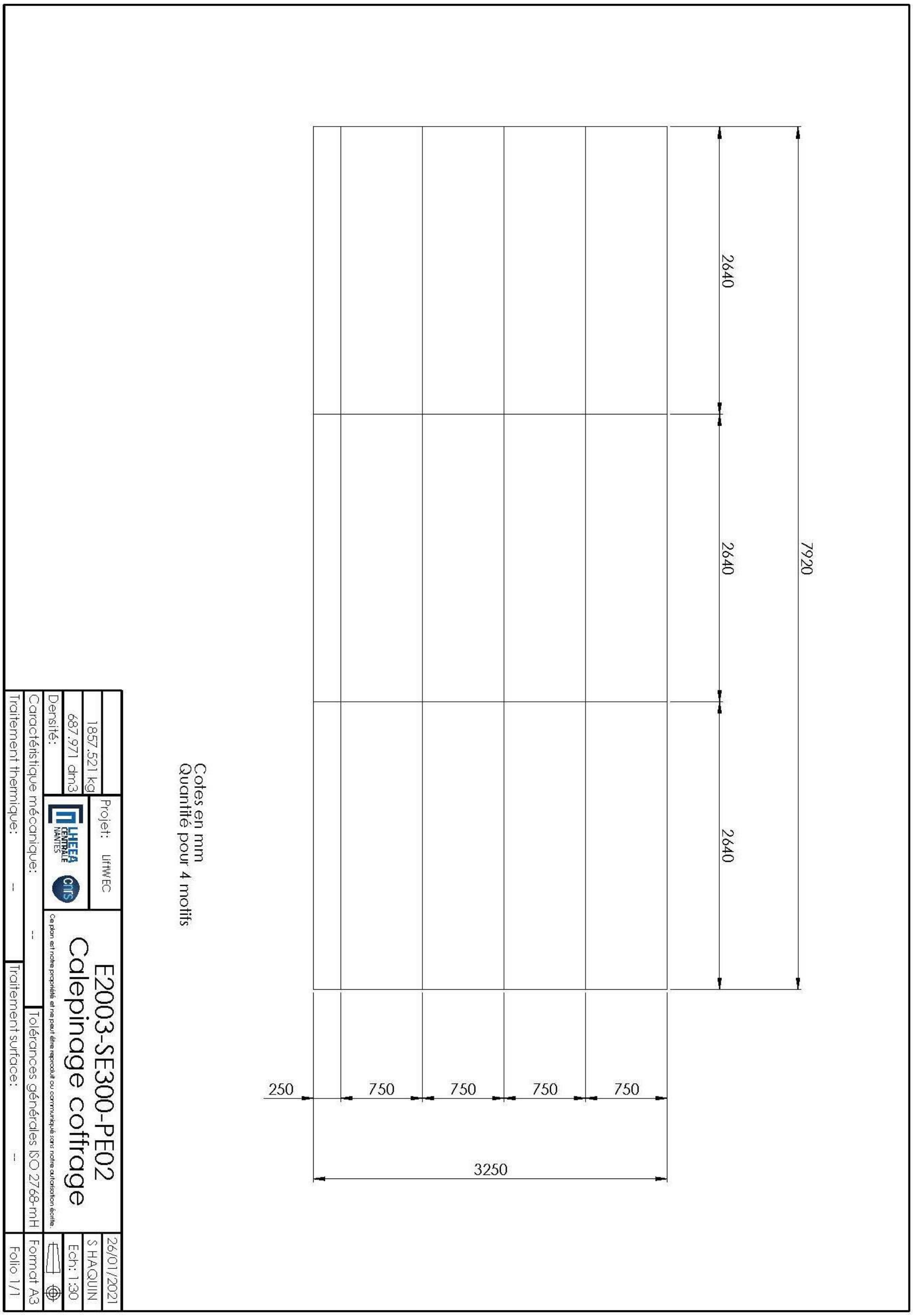


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

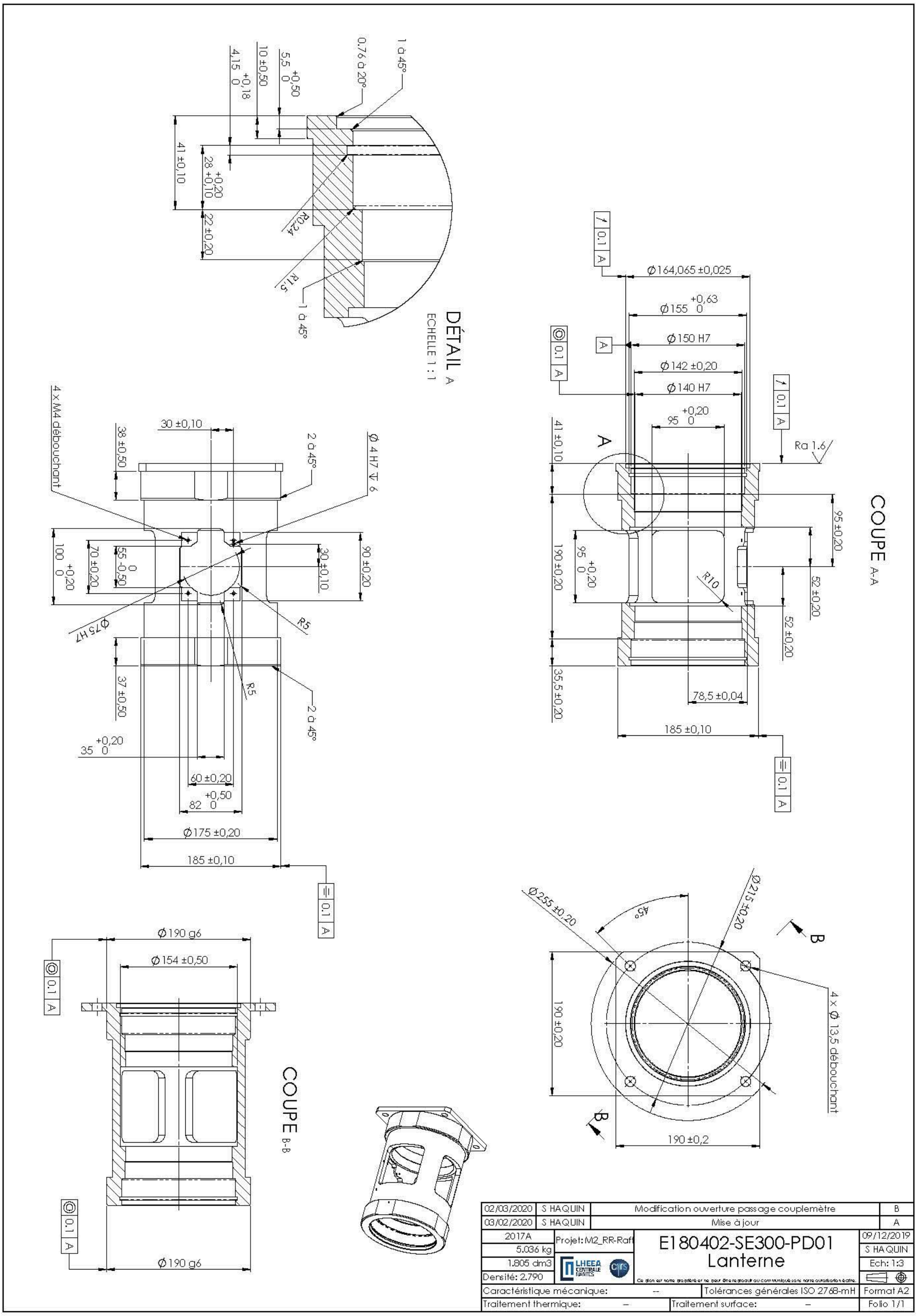

70
50 ±0,10
Ø9
20
A
A
=
=
Ø10
COUPE A-A
40
5
15
Ø6 M7/g6
Chanfreins 0.5 à 45°
1.4404
0.076 kg
0.010 dm3
Densité: 7.700
Projet: LiftWec
E2003-SE220-PD09
Platine pion
20/02/2021
S HAQUIN
Ech: 2:1
Format A3
Folio 1/1
Caractéristique mécanique: --
Traitement thermique: --
Traitement surface: --
Tolérances générales ISO 2768-mH



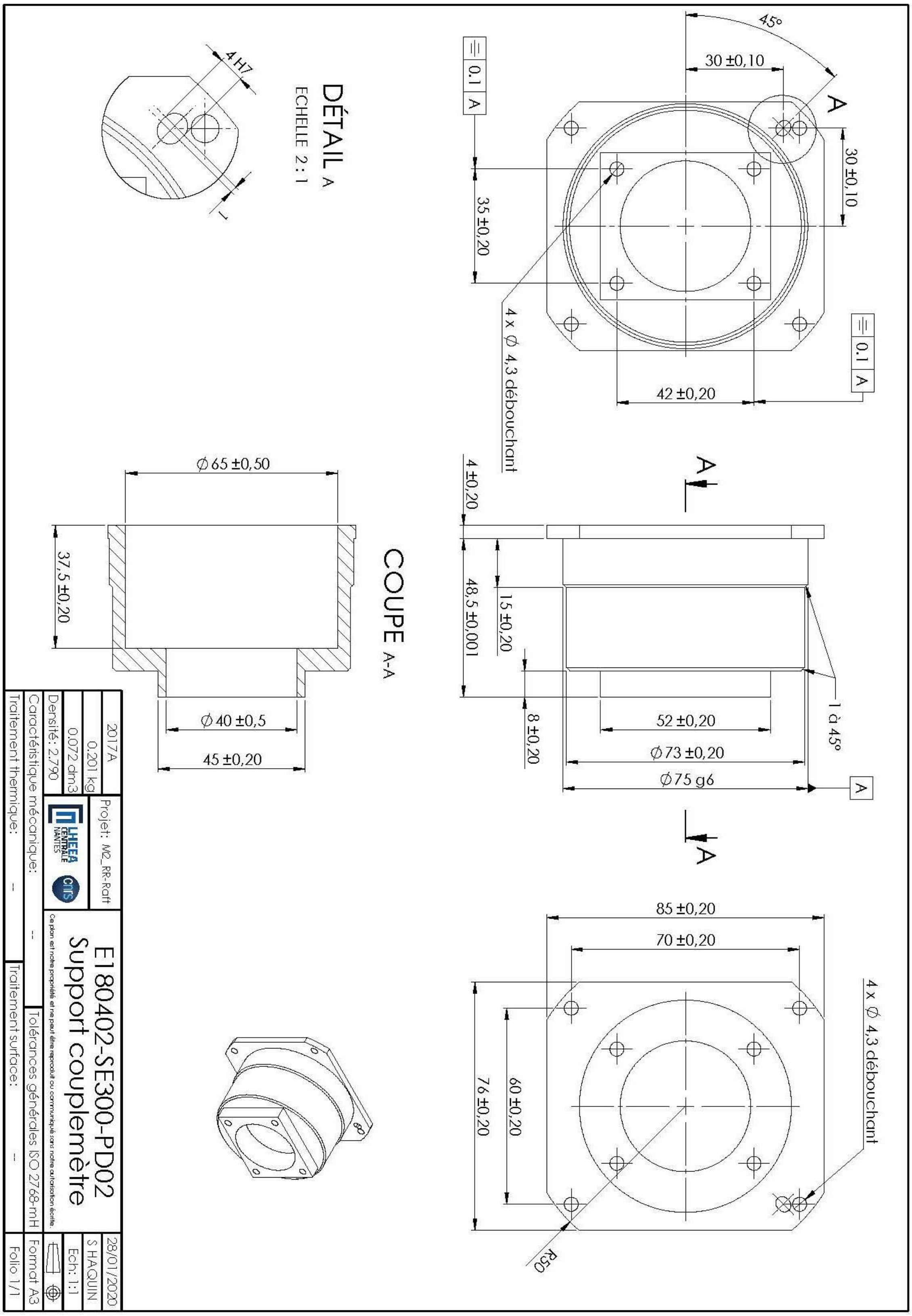
1.4404	Projet: LiftWec	E2003-SE220-PD10 Entetoise pitch		20/02/2021
0.176 kg	LHEEA CENTRALE NANTES / cnrs			S HAQUIN
0.023 dm3				Ech: 2:1
Densité: 7.700		Ce plan est notre propriété et ne peut être reproduit ou communiqué sans notre autorisation écrite.		
Caractéristique mécanique: --		Tolérances générales ISO 2768-mH		Format A4
Traitement thermique: --		Traitement surface: --		Folio 1/1

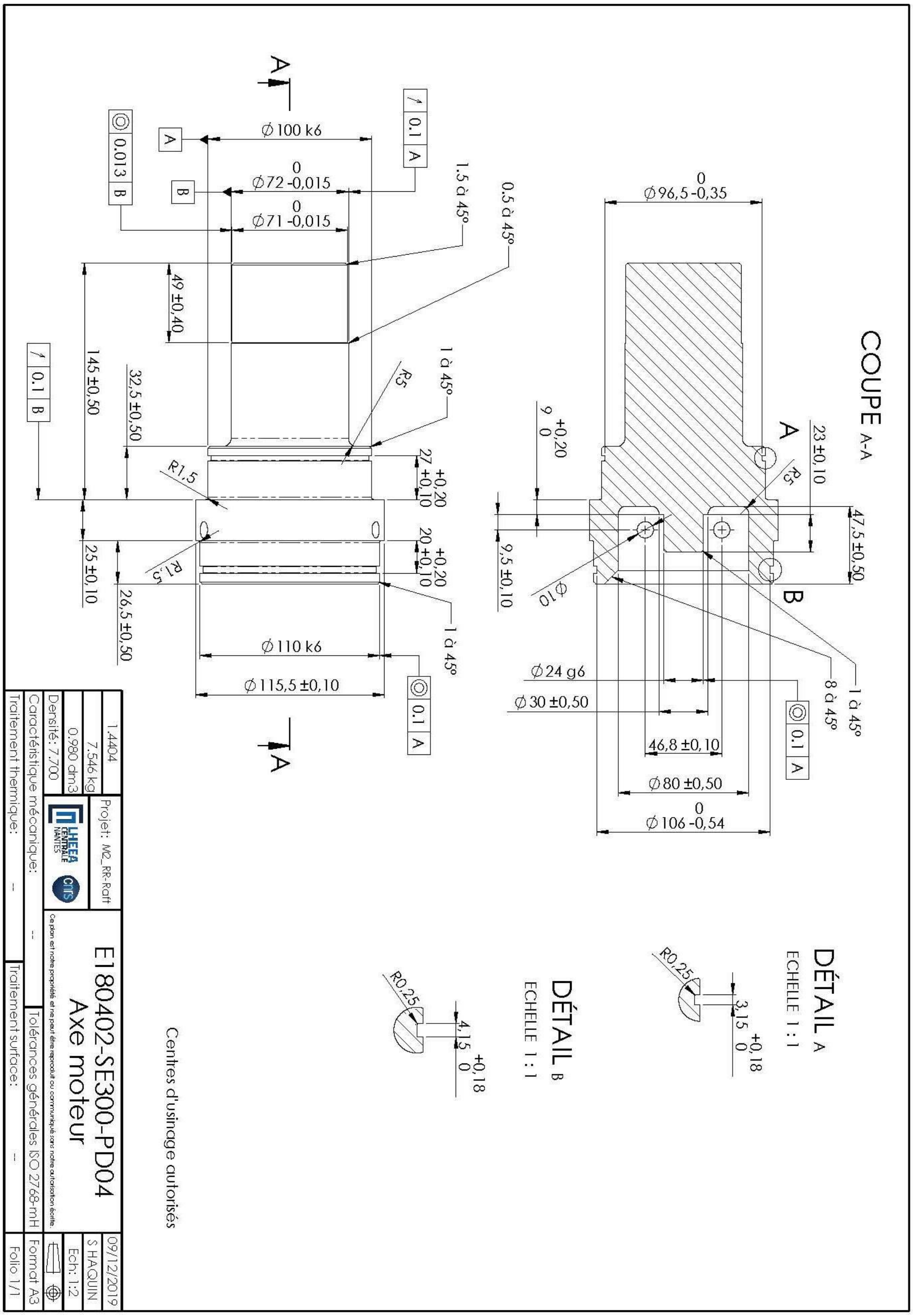


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.


E180402-SE300-PD02
Support couplemètre
COUPE A-A
DÉTAIL A
ECHELLE 2 : 1
4 x Ø 4,3 débouchant
Ø 65 ±0,50
Ø 40 ±0,5
45 ±0,20
37,5 ±0,20
Ø 73 ±0,20
Ø 75 g6
52 ±0,20
85 ±0,20
70 ±0,20
76 ±0,20
60 ±0,20
42 ±0,20
35 ±0,20
30 ±0,10
48,5 ±0,001
15 ±0,20
8 ±0,20
4 ±0,20
1 à 45°
R50
4 H7
Projet: M2_RR-Raft
2017A
0.201 kg
0.072 dm3
Densité: 2.790
Caractéristique mécanique:
Traitement thermique:
Traitement surface:
Tolérances générales ISO 2768-mH
28/01/2020
S HAQUIN
Ech: 1:1
Format A3
Folio 1/1



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.