Species Recognition System

Phase 1 - Documentation

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ABSTRACT

This report documents phase 1 of the redesign and construction of a Species Recognition System (SRS). The system allows digitization of collected insect samples by individually photographing insects from two angles, while it sinks through a glass cuvette filled with ethanol. Data associated with the sample are documented, saved, and connected to the images.

The system is constructed of a simple aluminum profile frame with light proofed aluminum paneling. The system contains a custom flushing mechanism and a dispenser for refilling for an automated testing process. A lid in the plating allows for easy serviceability and inspection of the internals of the system.

The design choices and decisions are likewise documented to an extend, that makes replicating and improving the system possible. Documentation of the system consists of: physical construction, electrical design, and software. Technical Drawings and data sheets for used electrical components are available in the following Appendix. The executable, installer, source code and technical documentation are all available online (1).

The challenges that have arisen during the development of the system is discussed and used as recommendations for design improvements for the system. Additionally, the initial testing of the system yielded several recommendable design improvements.

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CONTENTS

Reading Guide

Reading this, expected a general knowledge within software and general engineering disciplines. The following method have been used in the development process for describing the requirements in this report.

MoSCoW

A modified Moscow method is used to prioritize the requirements of the requirement specification. The method uses the following categories:

Must have

Requirements marked as must have are essential critical requirements, where if only one requirement cannot be fulfilled, the entire project will be considered as unsuccessful. Ideas from the idea generation phase that do not comply with these requirements are excluded.

Should have

Requirements marked as should have are important, but not necessary for project success. The requirements should preferably be met, but it is acceptable that a selection of them will not be met.

Could have

Requirements marked as could have are desirable requirements, that could improve the user experience or customer satisfaction at small development costs. These will typically be included if time and resources allow.

1 System Description

The Species Recognition System (SRS) consists of a 600x600x260 mm box shown in Figure 1. An ethanol container is connected to a pump, which is externally connected to the case. A collection container is connected to the bottom of the case, shown in Figure 2. The connections and tubing for the Pump, ethanol container and collection container can be seen in Figure 3.

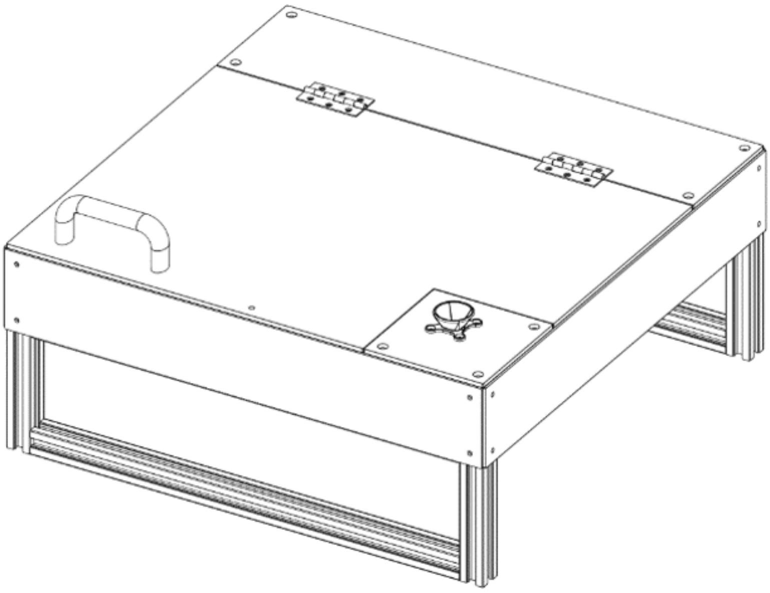

Figure 1: SRS, Case.

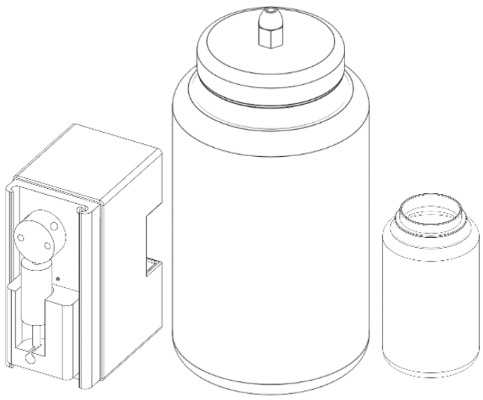

Figure 2: Shown left to right: Pump, Ethanol container, Collection container.

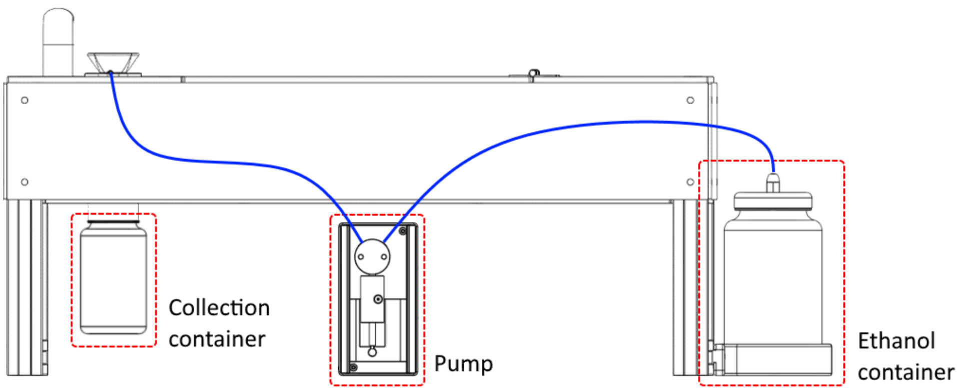

Figure 3: External tubings to SRS box, marked with blue lines.

The system is powered by a 230V 50 Hz AC connection and the pump is connected via a DB15 connector. A computer is connected to the system via a USB 3.0 cable and runs the software controlling the entire system, as illustrated in Figure 4.

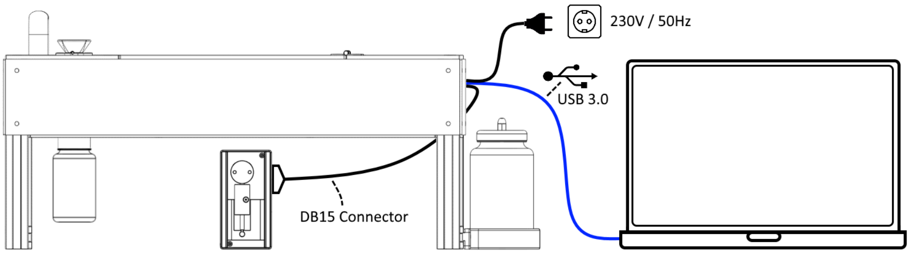

Figure 4: External connections to SRS box.

An overview of the main function of the system (image capture of insects) is shown in Figure 5.

1. An insect is dropped into the funnel making the sample fall through the glass cuvette filled with ethanol.
2. While the insect falls through the ethanol two color cameras capture images of the falling insect.
3. The insect falls down to the bottom of the cuvette out of the cameras field of view, and once the area is full or the sample of insects are all done, the valve can be opened.
4. When the valve has been opened the insects fall into a bottle below the system, accessible from the outside.

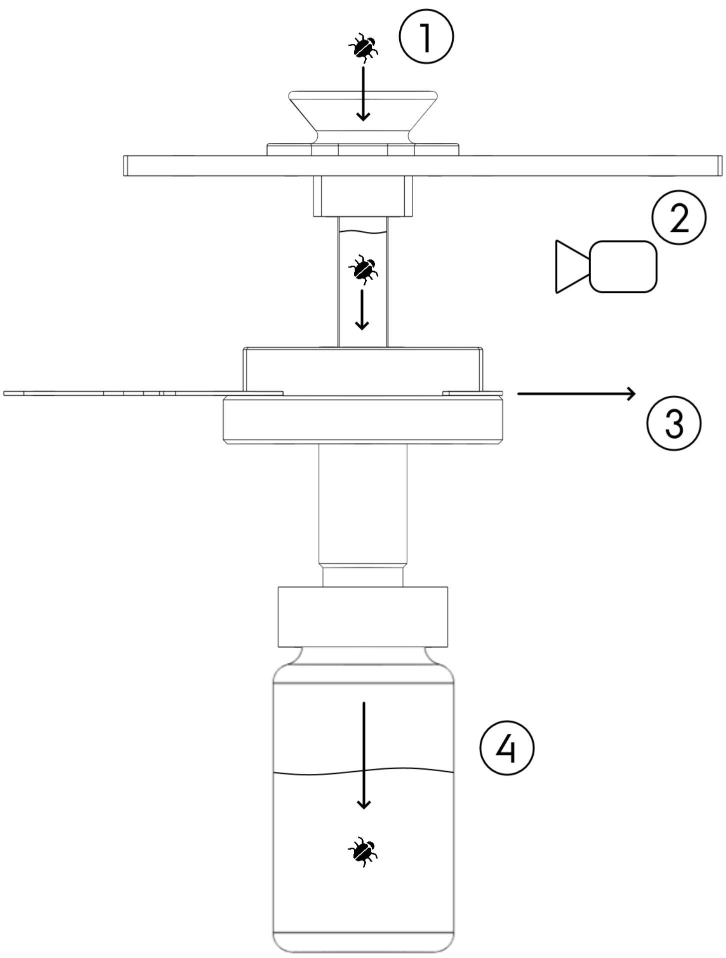

Figure 5: System overview.

1.1 Final system

The actual system can be seen in Figure 6, with an internal view in Figure 7.

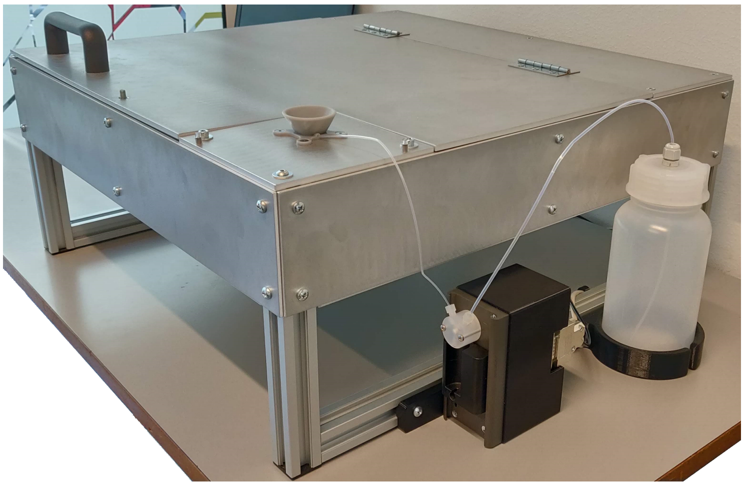

Figure 6: System overview.

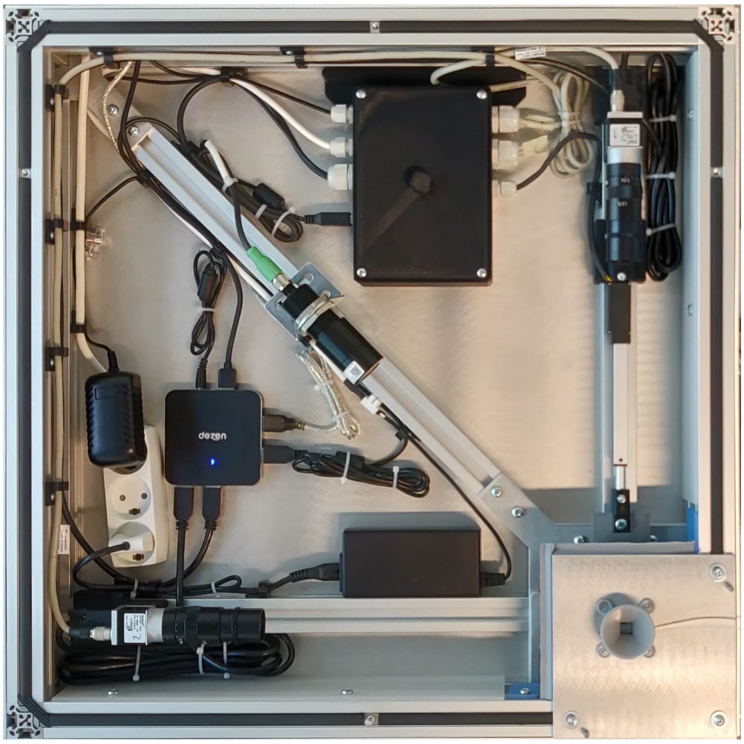

Figure 7: System overview, internal.

2 REQUIREMENTS

The system requirements are separated into four parts containing the main aspects of the system:

1. SRS Case
2. Flush Through System (FTS)

3. Refill System (RFS)
4. Software

Table 1: SRS Case - Functional requirement

	Importance	Functional requirements (SRS Case)
1.1	Must have	An automatic flush through system (FTS).
1.2		Sufficient ventilation for a working environment with ethanol fumes.
1.3		The possibility to open and inspect the system and components.
1.4		Sufficient light proofing to minimize light "bleeding" in and out of the system.
1.5		A frame that is easy to fixate.
1.6		Standard components when possible for reproducibility.
1.7		The test specimen fall through the cuvette filled with ethanol.
1.8		The image acquisition be of the test specimen falling through the cuvette filled with ethanol.
1.9		The test specimen fall at a fixed distance from cameras.
1.10		The test specimen fall at a fixed distance from the light source.
1.11		Minimal parts obstructing the camera view of the insects for optimal image acquisition.
1.12		Adjustable light distance.
1.13		Adjustable camera distance.
1.14		Cameras optical axis fixed perpendicular to the cuvette surface.
1.15	Should have	The possibility to retrofit an X-Y platform for future sorting of samples.
1.16		Adjustable light distance.
1.17		All components fixed to the SRS framework.

Table 2: Flush Through System (FTS) - Functional requirements

	Importance	Functional requirements (FTS)
2.1	Must have	Autonomous removal of test specimen (flush through) after image acquisition.
2.2		Sufficient ethanol resistant.
2.3		No splashing and or spilling of ethanol during flush through.
2.4		No blocking of the cuvette opening, allowing insertion of insects.
2.5		Compatibility with 10mm cuvette.
2.6		Minimal interference with the camera view (air, whirl, reflection, etc.).
2.7		The insect(s) deposited in a container after flush through.
2.8		No parts of the insect(s) present in cuvette after flush through.
2.9		No damage dealt to the insect(s).
2.10		No - to very rare, supervision needed through a full test sample (20 insects).
2.11		A return signal sent to the system when the process is finished.
2.12		No leak of liquid ethanol during standby.
2.13		No air bubbles from the bottom during standby (Air tight).

Continued on next page

Table 2: (continued) Flush Through System (FTS) - Functional requirements

	Importance	Functional requirement (FTS)
2.14		Autonomous refilling of cuvette after flush through.
2.15	Should have	Finished flush through and refilling before the next insect is ready to be inserted.
2.16		Fully autonomous operation from an input.
2.17		The insects not clumping together after flush through.
2.18		The ability to handle insects of different sizes (0.1 - 20 mm).
2.19		The ability to run fully unsupervised until the need for ethanol container refill.
2.20		Parts that are easy to clean.
2.21		Parts that can be replaced.
2.22		Fully autonomous operation without supervision.
2.23		The possibility to be compatible with an X-Y platform.
2.24	Could have	Compatibility with Tecan Cavro XE 1000 pump.
2.25		Sorting of the insects after flush through.

Table 3: Refill System (RFS) - Functional requirements

	Importance	Functional requirements (RFS)
3.1	Must have	Autonomous refill of cuvette after flush through process.
3.2		Be able to handle ethanol.
3.3		No splashing of ethanol during operation.
3.4		No blocking of the cuvette opening, allowing insertion of insects.
3.5		Precise amount of ethanol dispensed each time.
3.6		Communication to the connected system (PC).
3.7	Should have	Minimal number of moving parts.
3.8		Minimal number of moving parts.
3.9		Return signal to system when the process is finished.
3.10	Could have	A system to reuse ethanol, to limit waste.
3.11		A filtering system to clean used ethanol.

Table 4: Software - Functional requirements

	Importance	Functional requirements (Software)
4.1	Must have	A system saving sample information and all image settings, linking images to the given settings.
4.2		A graphical user interface that allows control of the system.
4.3		A system that detects insects falling through the cuvette.
4.4		A system that crops and saves images of the insects falling through the cuvette.
4.5		A folder structure for saving images, that allows separation of different samples and settings.

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Table 4: (continued) Software - Functional requirements

	Importance	Functional requirement (Software)
4.6	Should have	Adjustable camera exposure time through the user interface.
4.7		An initial cropping of the images, cropping to the sides of the cuvette.
4.7		A stable frame rate during operation.
4.7		A default crop size to make post processing of images easier during classification.
4.7		No part of the insects cut due to cropping of the images.
4.11	Could have	Adjustable camera aperture through the user interface.
4.12		Adjustable cropping to the sides of the cuvette through the user interface.

3 CONSTRUCTION

A case is constructed to enclose, mount, and protect the electrical and mechanical components of the SRS. A flushing mechanism is designed to allow for the emptying of the cuvette according to the requirement specification. This chapter will describe the construction, challenges, and choices made in the development process.

3.1 Overview

The case is constructed of Rose-Krieger(2) F-30x30 structural aluminum profiles. The case is illustrated in Figure 1 and the internal framework can be seen illustrated in Figure 8.

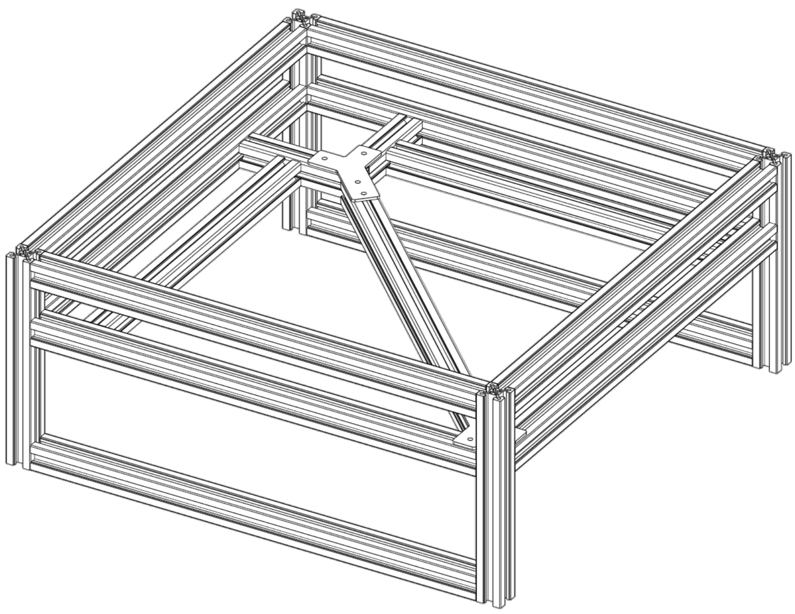


Figure 8: Framework, illustration

The flushing mechanism functions as a valve and implements the stationary stage (square glass cuvette) for image gathering, refilling, collection container and a moving flushing mechanism. All of these are implemented while ensuring a good seal for the liquid in the system. A overview of the constructed mechanism can be seen illustrated in Figure 9.

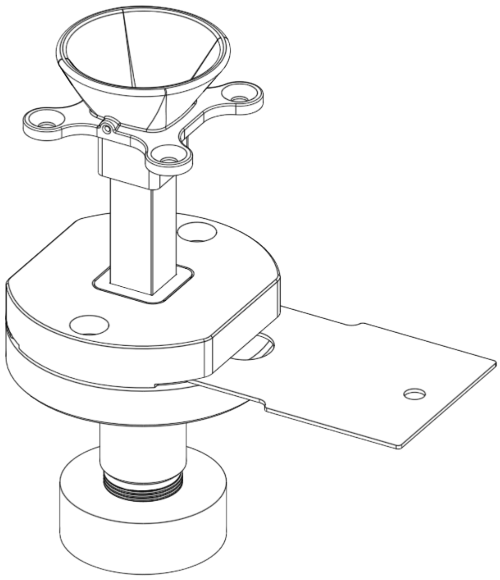


Figure 9: Flush Through System, illustration

3.2 Case

The profile system and design for the framework is chosen for the flexibility and simplicity, as this increased the adaptability during the development phase. The framework then enables easy mounting and assembly accordingly to the requirements.

The framework is encased in aluminum plates to protect the system from external influences such as light and foreign objects as well as to protect users from strobing light from inside the case. Aluminum is chosen for the entire construction of the case for its acceptable strength compared to the low density and easy work-ability. The plate thicknesses is chosen to 3mm in general and 5mm for the top plates. This is done to ensure the structural integrity of the plates for mounting and use based on the intended function of the part. All plates are laser cut and threaded afterwards. Furthermore the contact faces between the framework and encasing plates is light proofed with rubber sealing, shown in Figure 10.

Figure 10: Light proofing of SRS Case.

3.3 Flushing Mechanism

The flushing mechanism is custom design and manufactured by a combination of technologies such as; 3D printing, milling, turning, laser cutting, and molding.

A section view of the Flushing Mechanism with numbering can be see in Figure 11, and a corresponding description listed in Table 5. The considerations regarding the construction elements is reviewed in the next subsections.

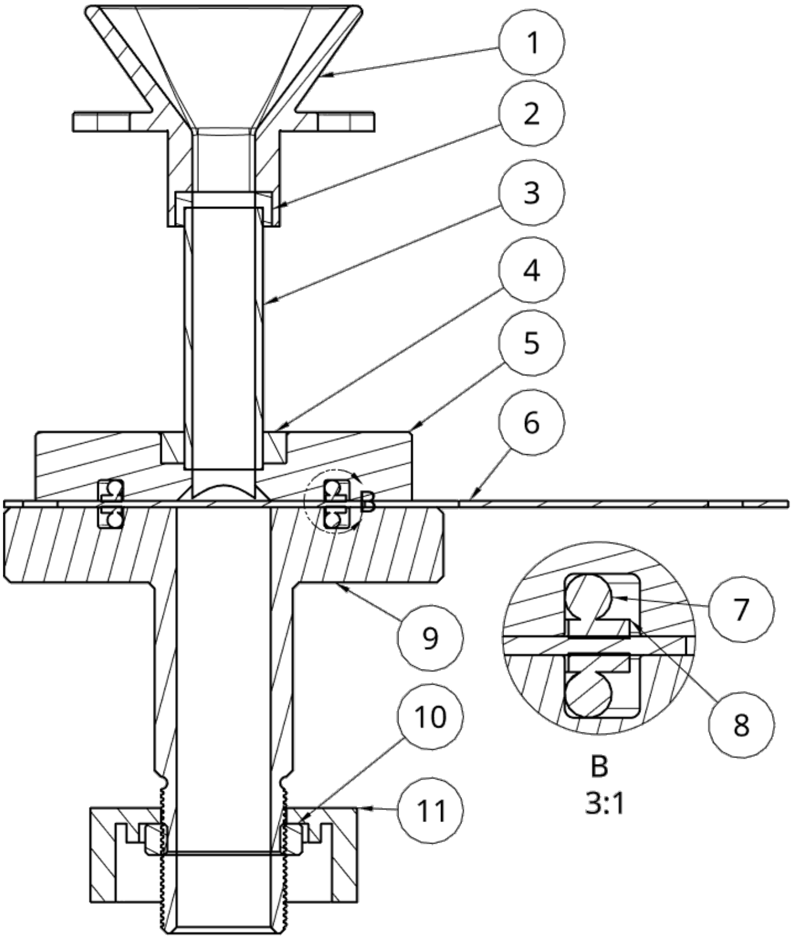


Figure 11: FTS, section view.

Table 5: FTS - Description

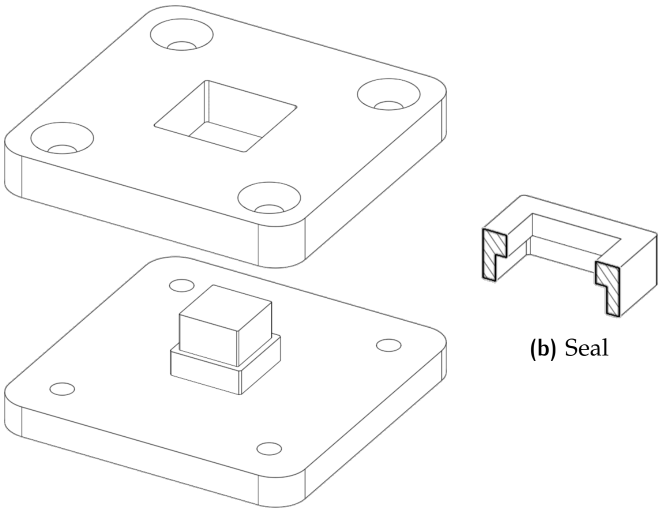
Balloon nr.	Name	Description
1	Funnel	Ensures deposit of test specimens, fixes the cuvette from above and dispenses ethanol into the cuvette.
2	Top Silicone Seal	Custom molded square silicone seal inserted into the Funnel.
3	10mm Cuvette Glass	Standard 10mm optical cuvette with removed bottom for emptying.
4	Bottom Silicone Seal	Custom molded square silicone seal inserted into Top Fixture.
5	Top Fixture	Fixes the bottom of the cuvette and seals the Sliding Plate over the entire linear motion.
6	Sliding Plate	Thin plate with a hole, functioning as a valve by linear motion.
7	Rubber O-ring	Gives flexibility to the sealing assembly ensuring a good seal.
8	Teflon Washer	Gives a low friction of the Sliding Plate ensuring a smooth and fast motion.
9	Bottom Fixture	Seals the Sliding Plate, directs test sample out of the case and is threaded allowing flexible end mounting.
10	Bottle Fixture Nut	Fixes the Bottle Mounting Cap against the bottom plate of the Case.
11	Bottle Mounting Cap	Mounting for collection container.

3.3.1 *Funnel*

The Funnel is designed for and produced by 3D printing, due to the complex geometry and no need for high structural integrity. A funnel design is chosen allowing an easy insertion of insect samples, for both small and large insects. A tunnel is added for feeding through the ethanol for refilling and this is inserted at an angle to allow a higher flow rate. The bottom part of the Funnel fixates the top of the Glass Cuvette with a seal applying a slight force, ensuring that the Cuvette stays fixed and the seal does not leak. The Funnel is illustrated in Figure 9 and 11.

3.3.2 *Silicone Seals*

Before deciding on using custom molded silicone seals a lot of different designs was explored and some tested, such as rubber face sealing cut to match the end face of the cuvette. However, any typical solution to sealing the glass square cuvette was inadequate duo to a typical round design or large forces required, hence a custom approach was chosen. Silicone was chosen due to its resistance to ethanol, lower Shore A hardness compared to rubber and easy moldability. A Shore A 22 2-component model silicone is chosen as the molding material. The molds are made of several 3D printed parts to easily obtain the special geometry with core pulls and without slip angles. An example of the molds designed is illustrated in Figure 12.



(a) Mold

(b) Seal

Figure 12: Custom Silicone Mold, Illustration

3.3.3 *10mm Cuvette Glass*

The square glass cuvette has been used in the previous system and found suitable although expensive. A custom approach was explored in collaboration with a glass-blower, but the production quality, consistency, and physical dimensions was found inadequate, so the standard cuvette was kept as the optical test chamber. However, with the added flushing through system the bottom of the cuvette is removed and corners polished to a chamfer to increase the edge strength. This is done due to no standard components available without a bottom part.

3.3.4 *Sliding Plate fixtures*

The two main components of the FTS is the machined Top Fixture and lathed Bottom Fixture which works as interface for the cuvette and end effector while combined supports the valve mechanism from the linear motion of the Sliding Plate. An illustration of these can be found in Figure 13. Both parts are designed for the production method and as a sandwich construction around the Sliding Plate. A groove is added in between the parts for adding a seal against the Sliding Plate. The inner dimensions for the flushing of test specimens are chosen such that it will not narrow down and result in them getting stuck. Therefor the machined part is kept with a square hole in extension on the square cuvette and the lathed part turned with a diameter in accordance with the diagonal. Finally a mechanical end stop for the sliding plate is implemented to ensure that the sliding plate centers in open position.

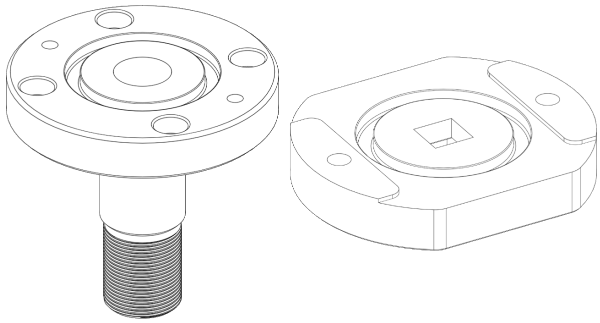


Figure 13: Sliding plate fixture, illustration.

3.3.5 *Sliding Plate*

The Sliding Plate functions as a regular valve disk, where the linear motion enables the regulation of the two states, open and closed. The plate is laser cut in 1mm thick stainless steel and polished for a reduced surface friction. The second half of the end stop is implemented to fit the fixture. The plate is designed to fit the seal dimensions, and the translational dimensions is chosen such that the opening hole sits outside the seal to ensure that the seal will hold when filled with ethanol. The Sliding Plate can be seen illustrated in Figure 14 and the valve mechanism is shown in Figure 15.

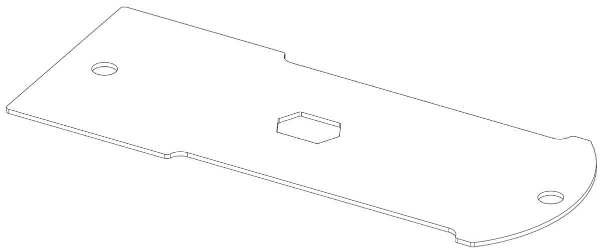
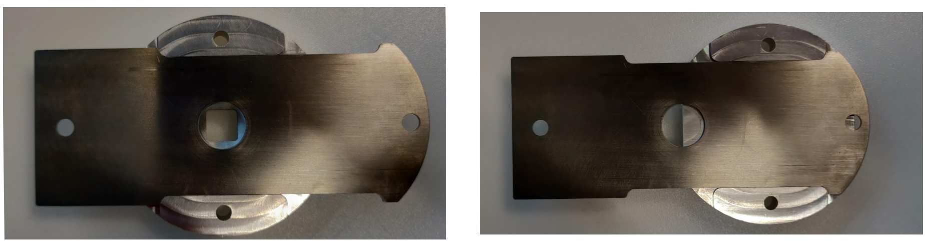


Figure 14: Sliding Plate, illustration.



(a) Sliding Plate open.

(b) Sliding Plate closed.

Figure 15: Sliding Plate functionality as valve.

3.3.6 *Sliding Plate sealing*

The biggest challenge regarding the chosen design with a sliding valve mechanism is the seal. Therefor this has undergone a comprehensive development with several prototyping. The specific areas that has been experimented with is the sealing material and amount of deformation of the seal with respect to friction force and sealing efficiency. Initial tests showed that using standard rubber O-rings with Shore 70A in DIN 3771-1 O-ring groove resulted in a high friction force on the sliding plate. Increasing the depth of the groove and thereby reducing the deformation of the O-ring greatly reduced the friction force and found an adequate sealing. However, further experimentation was done to reduce the friction force even more, as this will allow the system to open and close faster. The final seal developed uses the lower friction force of a PTFE as a washer sliding against the sliding plate, combined with a rubber O-ring to obtain the force required for a good seal. This seal can be seen illustrated in Figure 11.

3.3.7 *End effector*

The End effector is the connecting element between the flushing system and the test specimen collection container. The FTS end interface is M20x1 threads on the outside of the FTS exiting tube, this flexible design allows for changing the end effector setup based on the task at hand. In the initial design a collection container is wanted as a standard test specimen bottle Ø50mm (3), an end effector is designed for that. This is done by fitting the exiting tube with a bottle cap fitting the container and fixing it against the bottom of the case with a custom nut. The End effector assembly can be seen illustrated at the bottom of Figure 11.

4 ELECTRICAL

The following chapter will describe the electrical components used in the SRS with associated circuits and routing. Many of the components have been used in the previous system, however the circuitry is remodeled to fit the new software and the added components. The section is split into three main components for each major function of the electrical system and finally assembled in a routing diagram:

1. Flush Through System (FTS)
2. Refill System (RFS)
3. Image acquisition
4. Cable Routing and Component Placement

4.1 Flush Through System (FTS)

The electrical components of the FTS consists of the linear actuator and the underlying driving circuit based on an Arduino processor and an H-bridge. The circuit can be seen in Figure 17. The selection of a Linear Actuator is based on stroke length, speed, feedback, force and power input. The minimal required stroke is based on the construction at 30mm and the power input is chosen to 24V as this is the highest voltage available in the system resulting in the highest force/speed output. Although the system has a mechanical endstop a feedback is wanted to minimize mechanical wear. The speed and force is proportional, meaning a higher speed results in a lower force in accordance to the data sheets. A higher gear ratio would result in a lower speed but more power, and the lowest gearing is therefor wanted for speed in combination with a medium sized driving motor. L16 Micro Linear Actuator 35:1, 50mm, 12V with Potentiometer Feedback from Actuonix is chosen, however a bigger model w. 100mm stroke is in storage and implemented in the initial system shown in Figure 16.

Figure 16: Linear Actuator, L16 35:1 100 mm stroke (4)

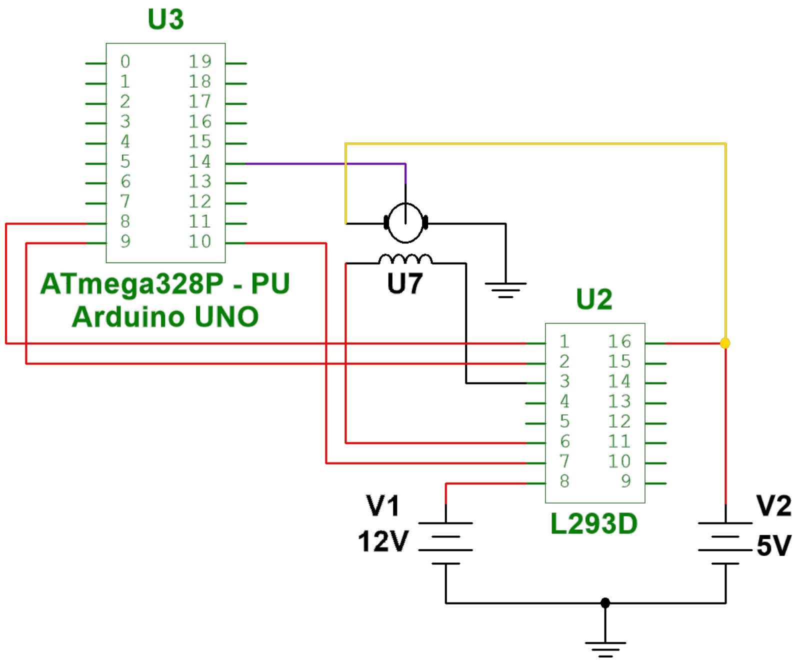


Figure 17: Linear Actuator, electrical diagram.

The driving circuit is designed around an Arduino UNO for convenient communication by USB and connection interface. The Linear Actuator's potentiometer is wired into the Arduino for position readings. An H-bridge is used to drive the motor inside the actuator, and a model in stock is chosen (L293D).

4.2 Refill System (RFS)

The RFS consists of a dispenser for refilling the system with ethanol, and electrically mainly deals with connections to this. The electrical diagram for connecting the dispenser (Cavro XE 1000 Pump, Figure 18) can be found in Figure 19. The dispenser interface is a DB-15 connector where serial RS-232 communication is used, according to the datasheet (5). Connections and addressing is setup for a single pump connection also according to the datasheet. The communication is converted from RS-232 to USB, using a RS-232 to USB Converter. Furthermore a capacitor is added over the power source as a security to minimize current spikes.

Figure 18: Tecan, Cavro XE 1000 Pump.

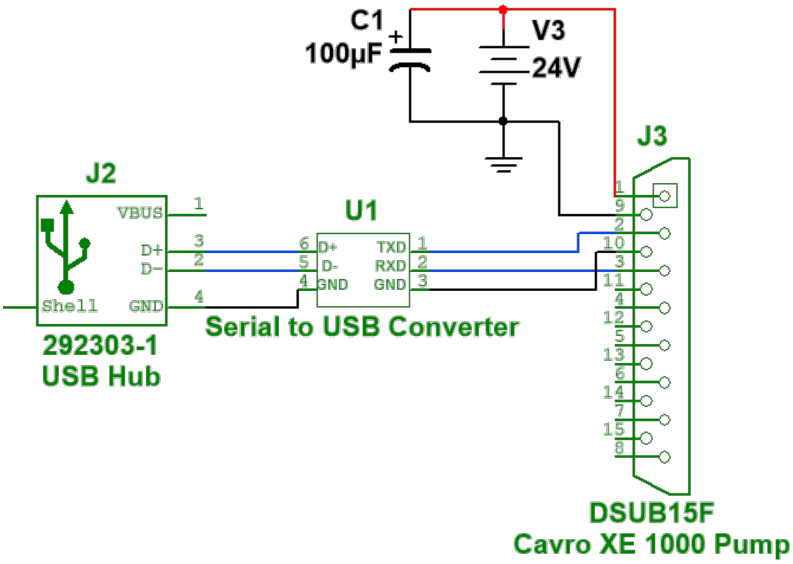


Figure 19: Dispenser, electrical diagram.

4.3 Image Acquisition

For syncing up the cameras and light source an electrical hardware trigger is created to ensure optimal synchronization of all components. The cameras used are the two existing Basler acA1920-155uc (6) (Figure 20)and a newly acquired ODSX30-WHI Prox Light (7) (Figure 21). The light source has a maximum pulse duty cycle of 10%, resulting in a maximum achievable frame rate calculated from the exposure time using equation 1. Meaning an exposure time of 1000 µs (1 ms) will result in a maximum frame rate of 100 frames per second.

$$\frac{1\,\mathrm{s}}{n \cdot 10} = \mathrm{FPS} \tag{1}$$

Where n is the exposure time in seconds.

The camera lens used is an LD75 lens (8) with x0.15 to x0.35 magnification and 5 aperture settings with a maximum aperture ratio of 1:3.8, allowing for different focal depths at the trade off of light, requiring a higher exposure time resulting in a lower frame rate. The combination of aperture and exposure time (with resulting frame rate) all lead to different results. To find the optimal combination of settings, 9 different combinations are undergoing tests, three aperture settings (3.8, 8, and 16) and three exposure times (1,000µs, 1,500µs, 2,000µs).

Figure 20: Basler, acA1920-155uc.

Figure 21: Stemmer, ODSX30-WHI Prox Light.

The hardware trigger is setup with Camera 2 sending a signal when it is taking a picture opening a Mosfet, triggering the light and Camera 1 to take a picture as well. The light is powered by 24V DC and a capacitor is added on the circuit as protection, as well as an over current fuse.

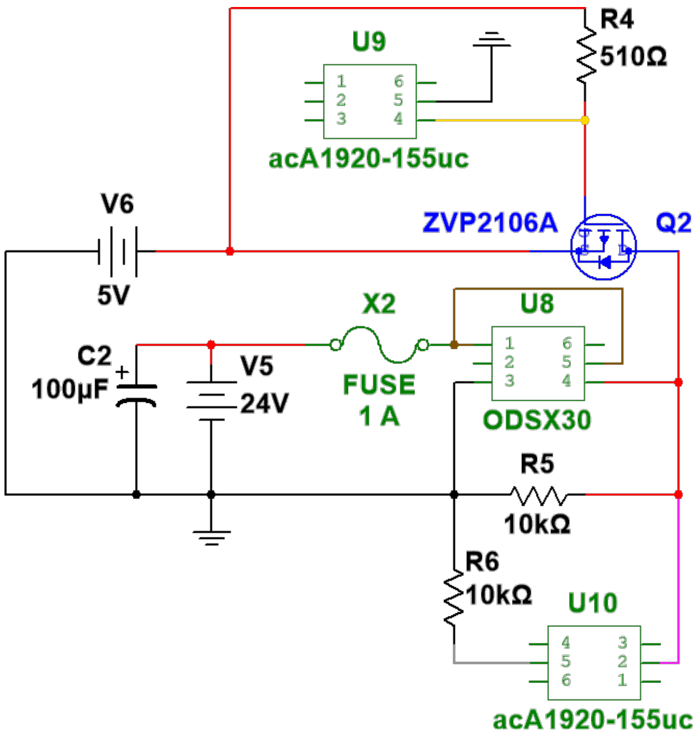


Figure 22: Camera trigger, circuit diagram.

4.4 Cable Routing and Component Placement

In Figure 23 a overview of the planned cable routing and component placement can be found with a corresponding reading guide in Table 6. The final product can be seen in Figure 24

Table 6: Wiring configuration

Function	Signal	Wire Color
Power In	+230VAC	**WHITE**
Power	+24VDC	**RED**
Power	+12VDC	**BROWN**
Signal	USB	**BLUE**
Cam HW Trigger	0-5VDC	**GREEN**
Light HW Trigger and Power	0-5VDC +24VDC	**YELLOW**
Linear Actuator Signal and Power	0-5VCD +12VDC	**ORANGE**

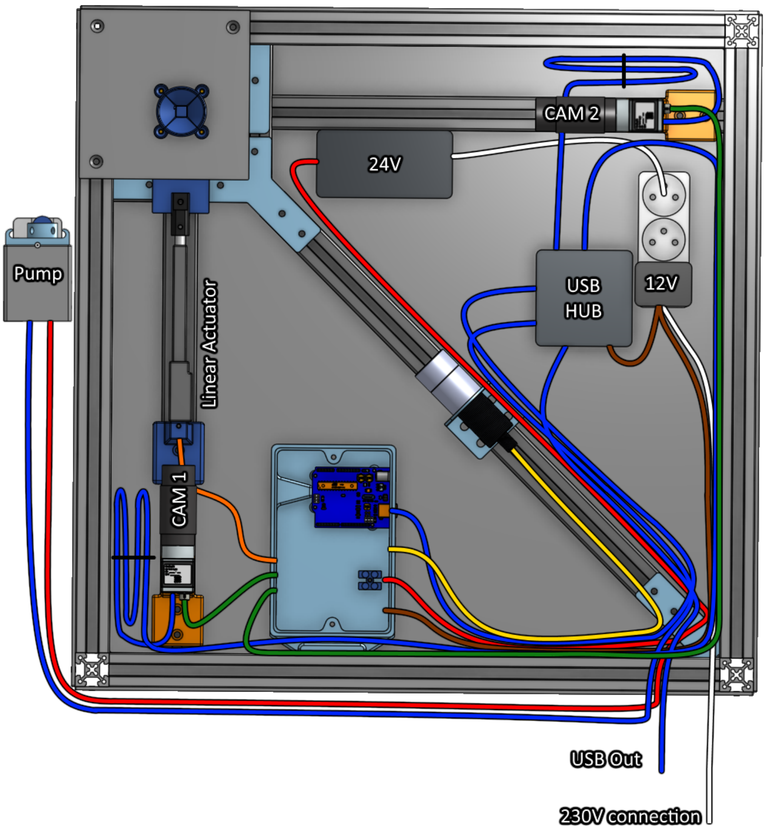


Figure 23: SRS Routing.

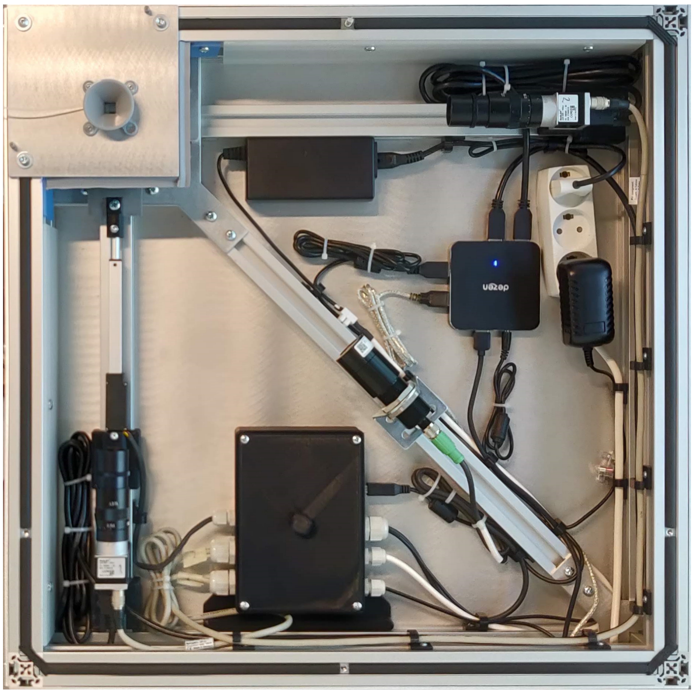


Figure 24: SRS Routing, final.

The setup follows the previous system design, with the cameras set perpendicular to the test chamber and the light source in between. The linear actuator is mounted underneath the camera Field of View and the electrical circuit box is placed nearby for easy routing. Excess cable length are stored conveniently in the corners fixed to the bottom plate, the USB hub and power components are fixed in the remaining compartment of the box. The external dispenser and the 230V power input is feed through the case with a cable gland in the corner. Cable routing is done with custom 3D-printed cable clips, see Figure 25.

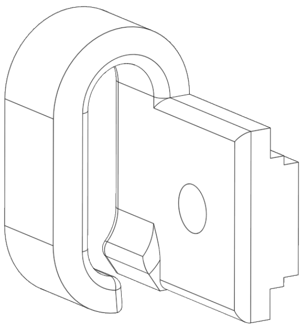


Figure 25: Custom Cable Clip.

5 SOFTWARE

The SRS Software controls the entire system and runs on NI LabVIEW Runtime 2019, as well as using several National Instrument Vision- and Serial communication modules. Through a Graphical User Interface an operator can control the software and with it the system and its three main functionalities, which are:

1. Capturing and saving images of insects
2. Flush Through System (FTS)
3. Refill System (RFS)

The software is compiled into an executable file (as well as having an installer) making it possible to install and run on any device supported by NI LabVIEW. The rest of this chapter is separated into six parts going more in depth with the functionalities and the code behind:

1. Overview of Main Application
2. Graphical User Interface
3. Image Acquisition
4. Image Processing
5. Image Saving
6. FTS
7. RFS

All source files and software is available online (1).

5.1 Overview of Main Application

The SRS software consists of four main loops, shown in Figure 26, and are explained in greater details in the following sections.

1. *Main VI State Machine*, is the main loop that handles user inputs, connections, and general setup. The GUI and its functionalities are primarily handled in this loop.
2. *Camera handler*, handles image acquisition and stores the images in a buffer that is accessed by *Image Processing*.
3. *Image Processing*, detects the insects in the images, using calibration images, crops the images to a set size around the insect, and sends the cropped image to *Image Save*.
4. *Image Save*, saves the cropped images and appends the sample and setup information to the given insect into a data file containing all samples and their information.

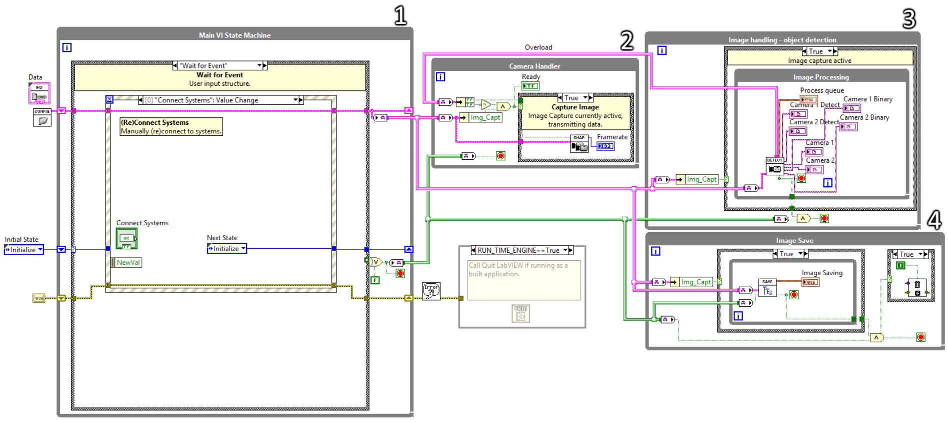


Figure 26: Block Diagram of main application, with four main loops:
1. *Main VI State Machine*, handles user input and controls system.
2. *Camera handler*, capture and send images to *Image Processing*.
3. *Image Processing*, detect objects, crop and send images to *Image Save*.
4. *Image Save*, saves cropped images and appends setup info to data file.

5.2 Graphical User Interface

The Graphical User Interface (GUI) allows an operator to control the system through the software and is primarily handled by *Main VI State Machine*, introduced in Section 5.1 Overview of Main Application. The GUI has several input fields for sample information, as well as inputs for selecting different camera exposure time and lens aperture. Once ready the operator can starts image capture and the system is running. In Figure 27 the GUI is shown in its idle mode.

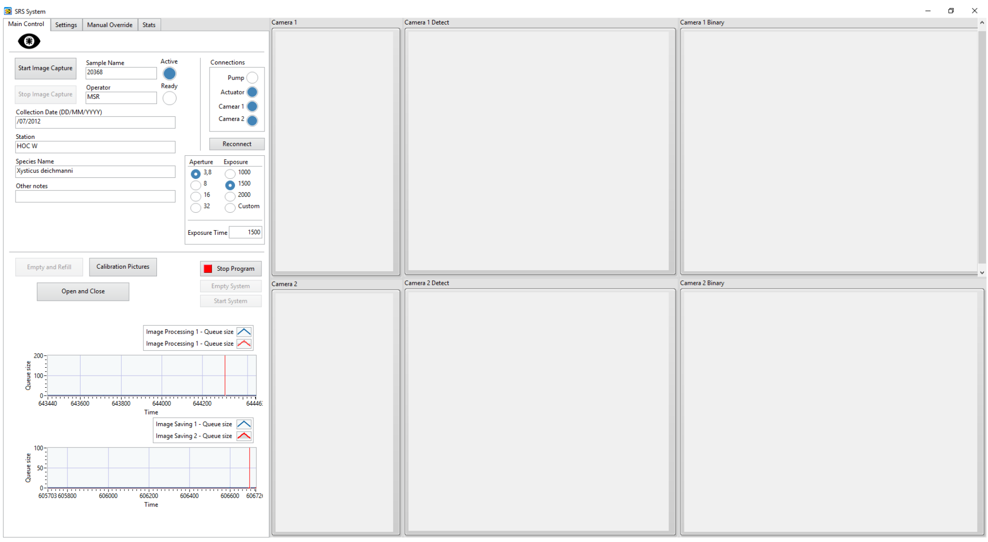


Figure 27: Graphical User Interface, main screen shown in idle mode

The top left of the GUI, shown in Figure 28, has the main input fields for sample information, as well as the primary buttons for functionalities such as: starting and stopping image capture, reconnecting systems, changing camera settings and more. All settings and fields are saved upon exiting the program, and loaded when the program is launched. If there are no settings saved, or a corrupt settings file, default values are loaded. The software automatically detects and connects to the system and its devices, and the current connection statuses are displayed in the top right.

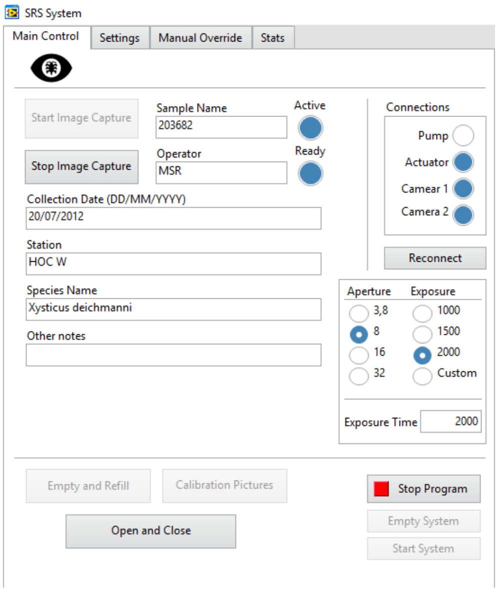


Figure 28: Graphical User Interface, main inputs

The object detection functions using calibration images for a selected combination of settings. The calibration images can be taken using the *Calibration Pictures* button, if no calibration images are found for the selected combination of camera settings the operator will be prompted with a message, shown in Figure 29.

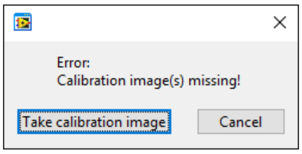


Figure 29: Graphical User Interface, main inputs

The bottom left of the GUI, shown in Figure 30, shows the system's buffer sizes, that essentially are the system's data left to be processed. There are buffers for image processing and image saving operations, for both camera 1 and camera 2. The buffers allow for image capture to be at the desired frame rate, that can be higher than the image processing can achieve. The image processing and saving operations handle the images in the correct order using a first in first out (FIFO) register and at the speed at which they are capable. When no object is detected, and the buffer is above a set *Overload threshold* the image capture halts until the remaining images are handled.

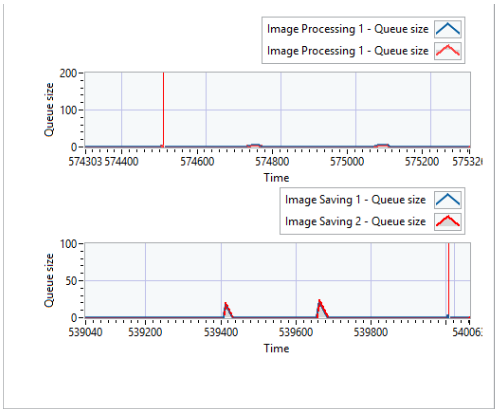


Figure 30: Missing calibration images, error

The right side of the GUI shows all camera feeds (top row is camera 1 and the bottom row is camera 2). The blocks are from left to right: raw camera feed, cropped image, and binary image. The binary image is calculated using a calibration image and is essentially what the system sees. In Figure 31 the GUI is shown during a sample operation, where a spider can be seen falling through the system.

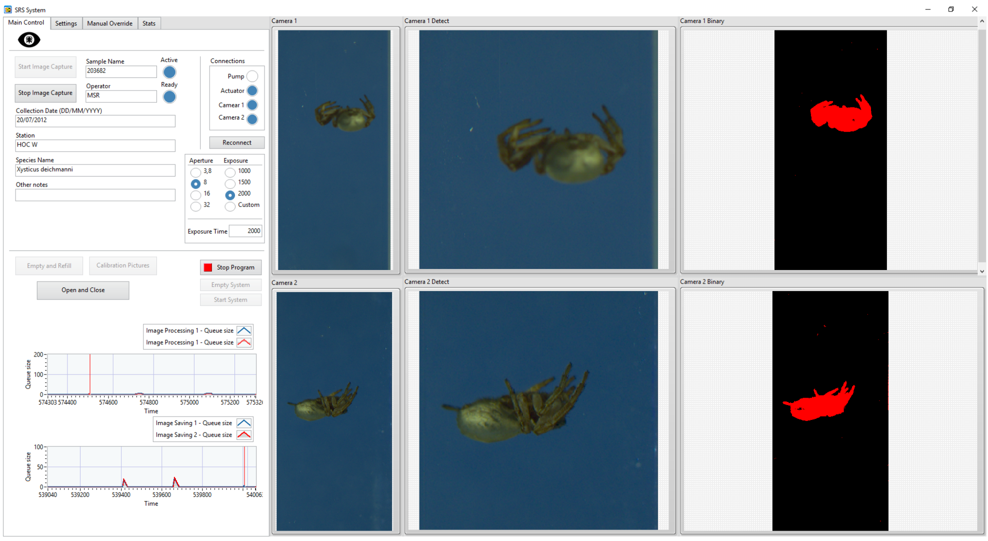


Figure 31: Graphical User Interface - Main screen, insect sample falling

Several system settings are accessible through the *Settings* tab on the main screen, shown in Figure 32. Here buffer sizes and overload thresholds can be changed, as well as limiting the maximum frame rate and several detection settings that are described in section 5.4 Image Processing.

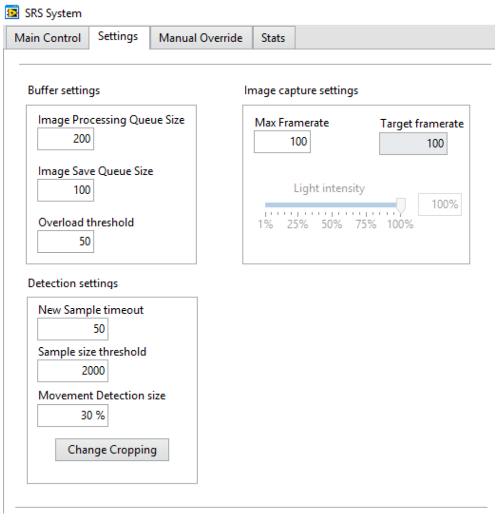


Figure 32: Graphical User Interface - Buffer, Image Capture, and Detection Settings

The last functionalities are in the *Manual Override* tab, where manual control of the hatch and pump are accessed, shown in Figure 33. The operator can use these controls to manually send pump commands, as well as open and close the hatch for inspection or maintenance.

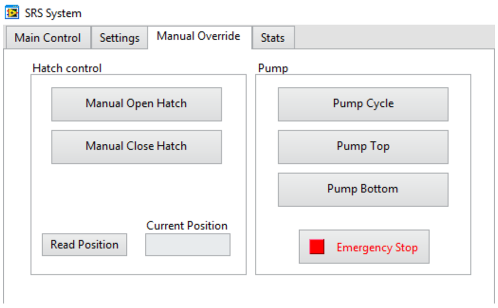


Figure 33: Graphical User Interface - Manual Override, hatch and pump control

5.3 Image Acquisition

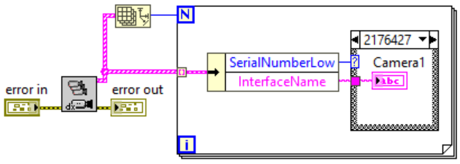
The SRS system image acquisition consists of two basler acA1920-155uc cameras (Figure 34) and a ODSX30-WHI Prox Light (Figure 35). Data communication and image transfer is done via USB 3.0, allowing for high speed data transfer.

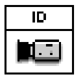
Figure 34: Basler acA1920-155uc USB 3.0 camera (6)

Figure 35: Stemmer Imaging, ODSX30-WHI Prox Light (7)

The essential part of the image acquisition is synchronizing the cameras and the lights together, to ensure a consistent light level as exposure times are as low as 1000 µs (1 ms). The synchronization of cameras and lights is achieved using hardware triggers for one camera and the light. Camera 1 and the light is set up to trigger on a signal from camera 2, this ensures a consistent synchronization, even in the presence of inconsistent processing speeds. The electrical aspects of the hardware triggers are explained in Section 4.3 Image Acquisition.

Initiating connection to the cameras happen automatically when the software is started. The software searches available cameras and scans for the two serial numbers of the installed cameras as shown in Figure 36, the case structure contains the two serial numbers for Camera 1 and 2.



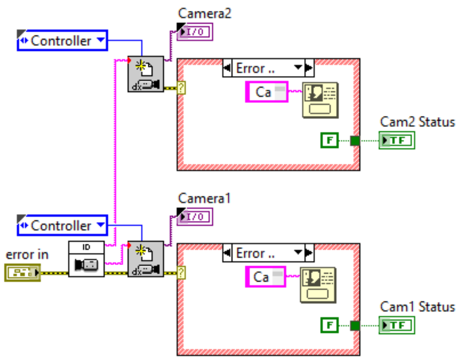


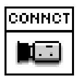
(b) Icon

(a) Block diagram

Figure 36: Camera ID scanning all available cameras for two known camera serial numbers

After the cameras have been found, the software opens the connection to the two cameras. If an error occurs, for example, if cameras are unable to be found or connected to, a custom error message displays which camera(s) are unable to be connected to. The block diagram of the code can be seen in Figure 37.





(b) Icon

(a) Block diagram

Figure 37: Initialize camera connections, send status and display error if needed

When cameras are connected next step is to configure the two devices, setting up hardware triggers, frame rates, Region Of Interest (ROI, cropping) and exposure times. The image is initially cropped to the internal sides of the cuvette, this way processing time is reduced and unnecessary data is removed, shown as ROI 1 in Figure 38. To further reduce processing time a Movement Detection Region (MDR) is used to only process a % of the top of the cuvette until an object is detected, shown as ROI 2 in Figure 38. The size of the MDR measured as a % of the entire image is set in the GUI and is measured from the top of the image. Once an object is detected in the MDR the cropping is changed to ROI 1 and further image processing can be done.

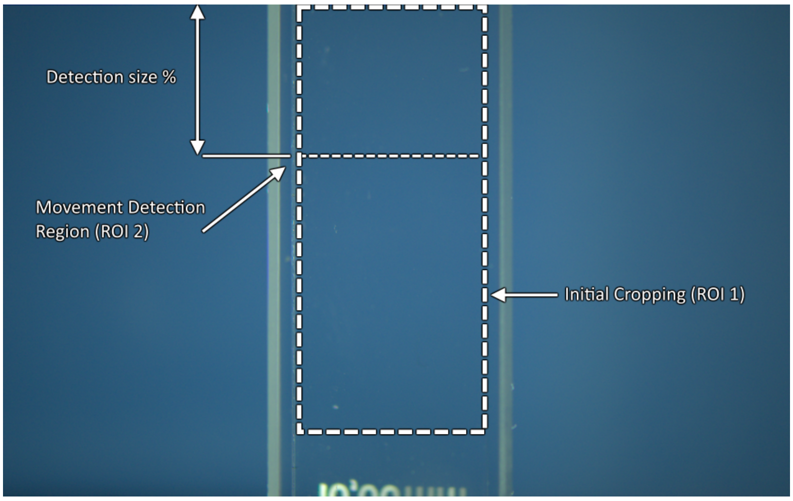


Figure 38: Region Of Interests for camera views.

The configuration of the cameras are set in the camera attributes, and can only be set/changed when the cameras have no current image acquisition in progress. The two ROI are also set in the camera attributes and swapped when an object is detected, to change the ROI the cameras has to be stopped, reconfigured and started again. This method is overall significantly faster than cropping the images in the software or constantly using the full cuvette images.

Stopping, reconfiguring and starting the cameras will result in a small time delay, measured to approximately 70 ms. This process however, results in a much higher maximum achievable frame rate, and the reconfiguration time is done while the insect is still falling into frame, so the amount of lost data is very minimal. Cropping of images in the software is a significant demanding process which will result in a lower maximum achievable frame rate. Constantly using the full cuvette images at high frame rates will likewise result in a much maximum achievable frame rate as the.

The ROI attributes for the Basler acA1920-155uc consists of 4 variables, each with different allowed increments and summed values ($\mathtt{OffsetX} + \mathtt{Width}$, $\mathtt{OffsetY} + \mathtt{Height}$), as shown in Table 7.

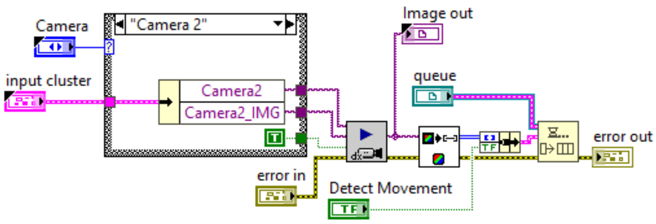
Table 7: Basler acA1920-155uc - ROI allowed values

Variable	Minimum Value	Minimum Increment	Maximum sum
Width	4	4	1936
OffsetX	0	4	
Height	2	2	1216
OffsetY	0	2	

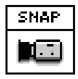
When changing the cameras' ROI attributes, the order at which an attribute is set has a high significance as each variable is set one by one. Taking Width and Offset X as an example:

When changing from 1920 `Width`, and 0 `OffsetX`, to 500 `Width` and 500 `OffsetX` (both of which are divisible by 4, and sums up to less than 1936). The `Width` then has to be changed to 500 before changing the `OffsetX`. If the `OffsetX` is set to 500 first it will result in the sum being 2420, which is above the allowed value. When changing back from the 500 `Width` and 500 `OffsetX` to 1920 `Width` and 0 `OffsetX`, the order has to be reversed, so the `OffsetX` is changed before the `Width`, for the same reason as before.

As explained earlier Camera 2 is configured to trigger the light and Camera 1 using hardware triggers, so the order at which the image acquisition has to follow this. Between each captured frame the system waits for Camera 2 to capture the next frame, once an image is acquired the image is compressed to an array and stored in the Camera 2 Image Processing buffer. After Camera 2 the latest image in Camera 1's buffer is acquired, compressed and stored in the Camera 1 Image Processing buffer. The loop then returns and waits for Camera 2 again.



(a) Block diagram



(b) Icon

Figure 39: Image Acquisition, shown for Camera 2.

5.4 Image Processing

Image processing runs of the 3rd loop shown in Section 5.1 Overview of Main Application. The processing of the images start by having an image array is dequeued from the front of the Image Processing Buffer. The image is run through the detection algorithm, determining if an object is present, and if the object is within certain criteria, if both are true an image is cropped to the object. The cropped image is then compressed into an image array and sent to the Image Save Buffer, along with a time stamp and a sample number. The overview of the image handling is shown in Figure 40.

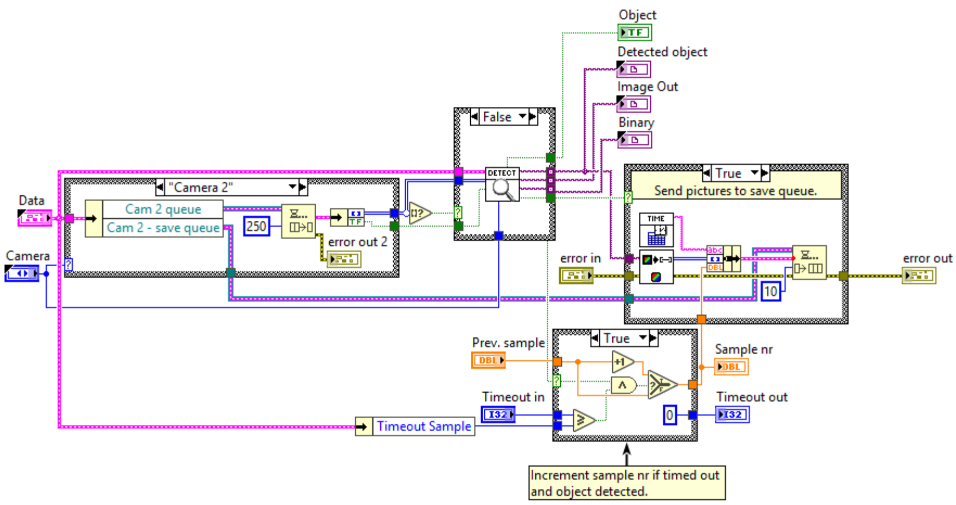
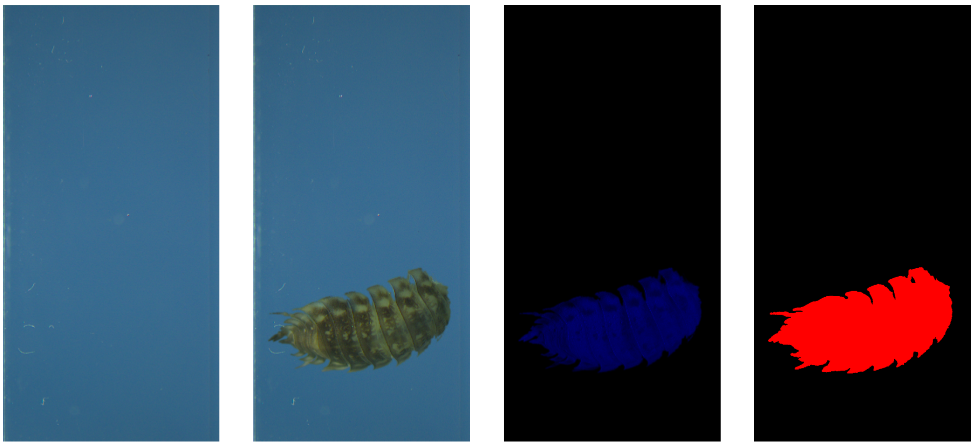


Figure 40: Image handling - dequeues, processes, and sends images

The detection algorithm works (illustrated in Figure 41) by taking a new image (b) and subtracting it from a calibration image (a), resulting in an image with clear view of the object (c). The image is then passed through a filter resulting in a binary image (d) that has the object as a particle. A blue background is used to improve this algorithm, as it only uses the blue plane of the new image, calibration and the resulting subtracted image, essentially reducing the data by 1/3. The Original RGB image is used as live feed to the GUI, and saved as the cropped versions.



(a) Calibration **(b)** New Image **(c)** Subtract **(d)** Binary

Figure 41: Detection Algorithm - subtracts new image from calibration image and through a filter.

The binary image is passed through a particle analysis returning all particles' centers, areas and boundaries. The largest particle is then tested for several criteria, and if all are passed the original RGB image is copied, cropped, compressed and sent to the Image Saving Buffer. The different criteria ensures that small objects are not falsely approved, and that the entire insect is within frame. An overview of the different terms can be seen in Figure 42.

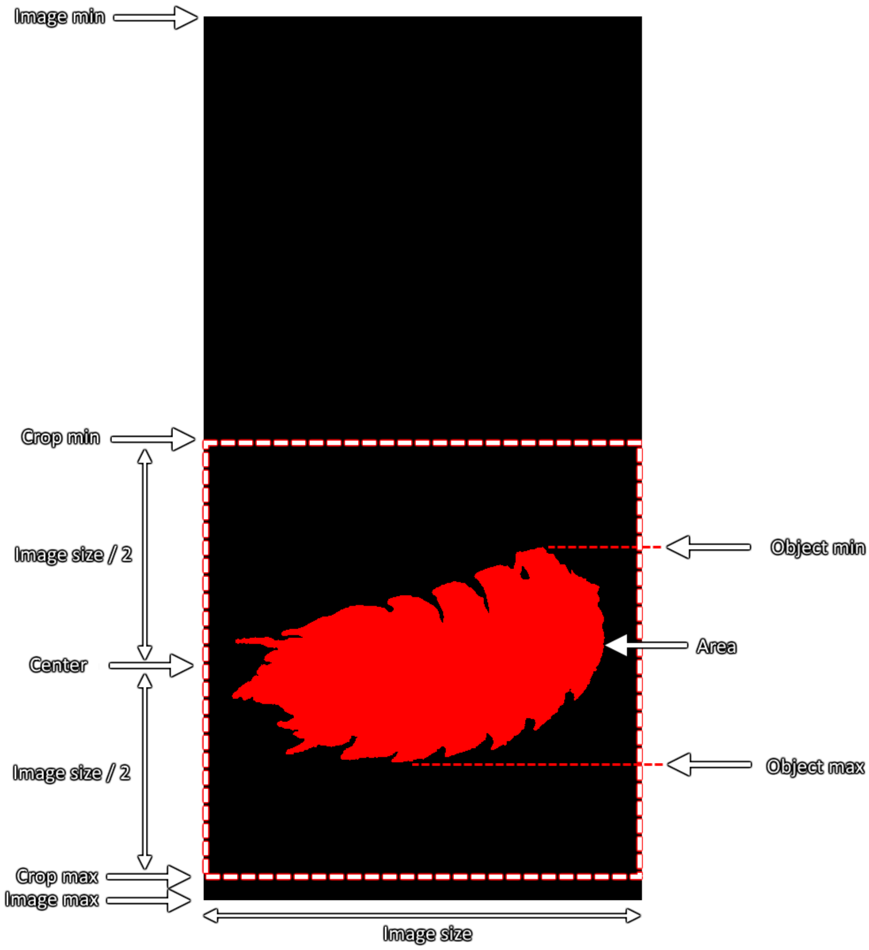


Figure 42: Image criteria overview

The criteria for an object to be accepted, cropped and saved are as follows:

1. Area > Threshold
2. Crop min > Image min
3. Crop max < Image max

where:

- Image size = Width of image
- Crop min = min(Center − Image size/2, Object min)
- Crop max = max(Center + Image size/2, Object max)

The outputs of the criteria algorithm are the boundaries (top left, and bottom right) coordinates and two booleans. The boundaries will result in a crop that is a square around the center of the object, with the height and width equal to the cuvette width, unless the object is longer than the default length. If the object would not fit inside the default square around the center, the image will be lengthened to a rectangle that has a sufficient height. This is done to ensure a default image size, for easier implementation in the developed machine learning software, but still ensuring no loss of data for larger insects.

The first boolean output checks all criteria and determines if the image will be cropped and sent into the buffer to be saved. The second boolean only checks the area threshold, while this criteria is not fulfilled the system is set to MDR (Movement Detection Region). As soon as an object fulfills the area threshold, the boolean goes high and the cameras crop to the full cuvette size. This also means, that while the system is set to MDR a different cropped calibration image is used.

The resulting image after going through the full Detection Algorithm and criteria is as illustrated in Figure 43. The image is compressed into an image array and enqueued in the Image Saving Buffer, along with a time stamp and sample index.

Figure 43: Final cropped image

5.5 Image Saving

When an object has passed the set criteria, the image cropped and sent to the Image Saving Buffer, the last control loop (number four as shown in Section 5.1), handles the last process of an image. Here an image array is dequeued from the buffer, uncompressed from an image array back into an image and saved in the application folder according to the following:

.../images/Expo_Ap/Species_Name/Sample_Name/Sample_Name_increment

Where Expo being the exposure time and Ap being the aperture, used to separate the images taken with different settings.

Along with the images, the used settings and entered sample information are saved in one Setup Data file in .csv format, containing all samples. The file allows for ease of access to all samples' information and settings, as well as statistical analysis. Each row in the setup file contains one insect, while the columns contain the sample information, as illustrated in Table 8.

Table 8: Sample Data structure, illustrated

Sample Name	**Exposure Time** [μs]	**Frame Rate** [FPS]	...
17131_1	1000	100	...
17131_2	1000	100	...
17145_1	1500	67	...
17145_2	1500	67	...
17158_1	2000	50	...
⋮	⋮	⋮	⋱

Note that a sample, can contain several individual insects, each insect gets an incremental sample name. As an example; sample name 17131 containing two insects: 17131_1, 17131_2. The entire list of the saved sample information is:

- Sample Name
- Exposure time [µs]
- Frame Rate [FPS]
- Light Intensity [%]
- Aperture
- Species Name
- Sample Collection Date
- Sample Station
- Other Notes
- Image Path
- System Operator Name
- Date

5.6 FT

The Flush Through (FT) is done using of a linear actuator moving a sliding plate and that way functioning as a valve, as explained in Section 3.3. The FT empties the cuvette dispensing the insect and ethanol into a container connected below the cuvette. The linear actuator is controlled using an Arduino Uno and an H-bridge as explained in Section 4.1. Using the potentiometer feedback from the actuator two positions are set (fully open and closed). Communication with the Arduino is done by sending commands over a USB connection. The communication is done by the operator using buttons on the GUI, and the communication is handled by the *Main VI State Machine* loop. The following commands are currently supported:

Table 9: Arduino Control Commands

Command	Description
101	Manually close the valve.
102	Manually open the valve.
103	Run a full cycle (open valve, wait 1 sec, close).
104	Send current position data.

When a '103' command is sent to the Arduino, the valve is opened, held open for 1 second and then closed, once closed a '1' is sent back signifying a finished cycle. The Arduino measures the Potentiometer and uses the position to determine when to stop, when opening or closing the valve. Due to a slight inaccuracy in measurements when in motion, the linear actuator is halted for a short duration when an end point is reached, position is then remeasured and a decision is made to stop or continue moving again. A safety duration is also set to stop the linear actuator after the set duration, used in case something prevents the valve from opening or closing.

The operator has two ways to operate the valve's main cycles: 'Empty Cuvette' and 'Empty and Refill'. The 'Empty Cuvette', runs an FT operation sending a '103' command to the linear actuator opening and closing the valve as explained earlier as well as halting image capture if currently active. The program then await the return signal '1', signifying the cycle as complete, then returns back to normal operation. If no return signal is received within a timeout period (default to 10 sec) a valve timeout error will appear.

The 'Empty and Refill' operation functions the same as 'Empty Cuvette' does, except after a successful cycle (indicated by the returned '1' signal from the valve cycle) the system then initiates the Refill operation (RF) filling the cuvette, explained in the following section.

5.7 RF

The Refill (RF) is done using a Cavro XE 1000 Pump with a 5 mL dispenser explained in Section 4.2. The communication is over USB converted to RS-232 serial connection, a full list of all available commands are found in the datasheet (5). Before operating the pump an initialization is made, selecting the input and output valve. Once the pump is initialized, the remaining commands are available, an overview of the used commands can be seen in Table 10.

Table 10: Cavro XE 1000 Pump - Control Commands

Command	Value	Description
Y<n>	<n>= 2-20 = seconds	Initializes the pump and sets the valve input at right port and out at left port. 'n' indicates initialization speed.
S<n>	<n>= 20..600	Sets speed, 2 - 60 seconds per stroke (S20 = 2 seconds/stroke)
A<n>	<n>= 0.. 1000 steps	Absolute Position
I		Moves valve to input position
O		Moves valve to output position
R		Execute command or command string
T		Terminate commands

An example command string, used for refilling the cuvette (Pump cycle):

```
/1IS20A800S60OA0R
```

A breakdown of the command string is as follows:

- '/' is the ASCII start command, followed by a '1' selects the pump address.
- 'I' turns valve to input port.
- 'S20' sets the speed to 20 (2 sec per stroke, fast filling of dispenser).
- 'A800' moves plunger to position 800, filling the dispenser with 4 mL ethanol.
- 'S60' sets the speed to 60 (6 sec per stroke, ensuring no splash during dispense).
- 'O' turns valve to output port.
- 'A0' moves plunger to top position, emptying it.
- 'R' executes the command string.

The refilling of the system is handled automatically when the operator presses the 'Empty and Refill' button. First, the FT initiates, emptying the cuvette, once completed and the return signal indicating a successful cycle. the RF starts, following the command string as explained above filling the cuvette to an exact level.

Two more buttons are available to the operator: 'Start System' and 'Empty System'. The 'Start System' button will initialize the pump, run one pump cycle (as explained above) and then initiate the Empty and Refill procedure (FT + RF). The 'Start System' operation fills the tubes between the pump and the ethanol container, and between the pump and the cuvette, as well as filling the cuvette making the system ready for operation. The 'Empty System' runs an FT emptying the cuvette and then the pump runs a reversed dispense (draining from the output valve and dispensing into the input valve, back into the ethanol container) four times to empty the connected tubes.

6 DISCUSSION

This section will review the problems experienced in the development of the SRS and discuss what could have been done differently in retrospect for a better result.

6.1 FTS

Some of the more crucial challenges experiences with the system is the centering of the cuvette for optimal cropping of pictures and small insects not flushing but sticking to the sides of the system. Initially it was assumed that fixing the bottom part of the FTS to the case frame and the top plate to the frame would ensure a good alignment, but this was disproved by initial testing, where tiny visual misalignments showed up as a substantial problem. In retrospect the frame mounting with T-nuts and countersunk holes is not precise enough for the alignment of the cuvette and some sort of pin connection should have been implemented. The challenge of smaller insects, especially ones with wings, sticking to the internal walls of the system was unexpected. As it was expected that flushing with ethanol would drag the test specimens along. This is likely due to the change of dimensions of the system from the squared cuvette to the round exit shaft and the valve opening method of the FTS. It is expected that a ethanol hydrophobic surface coating would solve these problems.

Furthermore, a dispenser was previously purchased for the project and this was implemented in the system for easy accessibility. This choice allows for easy adaptation with the rest of the system, but seems unnecessary advanced and precise for the application. Furthermore, the dispenser is too big, which does not allow for implementation inside the SRS and therefore requires the system to have undesirable external components and connections. A design change could have been made to implement the dispenser into the case or a smaller dispenser could have been used.

The custom molded silicone seals has been a great concern regarding the sealing of the cuvette when filled with ethanol, as showed by initial testing of the system. The first stress test of the system showed good results regarding the sealing with a run-in system such that the liquid height is above the visible area but under the sealing edge. However, further testing showed that if the cuvette is filled above the top of the seal that is, the bottom rim of the 3D printed mount, a steady leaking would occur. This problem was not discovered during the initial testing, as the liquid height would be constant. It is expected that the rough surface of the 3D print does not grant sufficient sealing against constant liquid pressure, but is sufficient for liquid flowing over the seal. As the system is designed to work with a pump that dispenses a fixed amount every time the problem is not deemed low priority. By gluing the seal into the 3D printed part a better seal could possibly be obtained.

The size of the system is ideal for medium sized insects (beetles, spiders, etc.), although larger insects has shown to be too large for chamber to handle and will not flush or even sink properly. Smaller insects has shown difficulties in flushing as well, sometimes sticking to the sliding plate or the bottom pipe. Tests with different coatings and redesigns has been made, but non has shown promising results yet.

6.2 Processing

The processing speed of the system has been a main factor in software optimization. With up to 200 frames per second (100 per camera) a high processing speed is required to detect, crop, and save images as the insects fall. Having the software optimized for parallel execution as well as some implemented functionalities allows for a high frame rate. With different processing power from PC to PC different settings has to be used to allow for a high frame rate. Settings such as a higher buffer sizes and smaller movement detection region will allow for a higher stable frame rate. To increase the processing speed a minimal amount of image processes has been used, a possibility to increase the potential, would be to off load some of the image processes from the CPU to the GPU. By far the most demanding process is in saving the images to a drive, therefore a high speed drive, such as a Solid State Drive (SSD) is preferable for the PC running the system.

6.3 Case

In the initial construction of the case, the cable routing was not implemented. This resulted in a few modifications and challenges such as cable gland feed through of the case and mounting of cables inside the case along the framework for routing. The side plates of the case is modified for mounting of cable glands for easy replaceability, this however showed to cause challenges regarding mounting up against surfaces as the cable gland would be in the way. The cable gland mounting placement is also in the way for flight case installation for secure transportation, as the protruding cable gland would result in a far larger than necessary flight case. A obvious solution would be to move the cable feed through to the bottom of the case out of the way. A cable clip was quickly designed and 3D printed for cable routing inside the SRS, which worked sufficiently to some degree. However, a standard component would be desired to reduce price and increase the standardization of the final product.

7 RECOMMENDATIONS

The following sections describe the recommendations for the project going forward within: construction, electrical, software, general system and improvements.

7.1 Scalability

A big part in the design process was having scalability in mind for the upcoming steps. A previous bachelor project involved the design and programming of a robotic setup using a Universal Robot 5 (UR5) for automatic insertion of insects into the old SRS case. The next steps in the project involve the implementation and expansion of this design and setup. The system being scalable also means that two cases could be made to work simultaneous.

7.2 Large insects

Large insects has shown to not fit inside the glass cuvette, as well as being unable to flush reliably. A different version of the case and design in a larger size (both cuvette and accommodating flush through system) is a possibility to allow for the system to handle more sizes of insects. Although the larger cuvette will result in a larger amount of ethanol flushed with each sample. A redesign of the system should be made to either reuse, filter or in some way handle the increased amount of ethanol.

7.3 Small insects

Smaller insects and some medium sized insects has shown to not flush, or in rare occasions get cut, during flush, this is due to insects sticking to parts of the construction. The parts the insects stick to is primarily the metal parts of the Flush Through System. An ethanol resilient coating or design, allowing for an easier flush of smaller insects, should be found and tested reducing the probability of insects getting stuck during flush through. This will allow for the system to reliably handle smaller insects.

7.4 Camera and lens settings

As discussed in previous chapters the camera and lens have several adjustable settings, primarily aperture and exposure time. The immediate task regarding these is to find the optimal combination of settings, which requires a large data set of the same samples using different settings. A large data set has been collected using 9 different combinations of aperture and exposure times. Using this data set to compare the results between the different settings should show one optimal combination of settings, which should be using going forward.

7.5 Processing

The processing speed of the software has been a primary concern throughout development, with a feed of up to 200 images per second a high processing speed is required. A place where optimizing is possible is within the image processing, offloading some of the processes to the GPU might prove beneficial.

7.6 Construction

Several parts of the construction has been improved from the first design. These improvements have not all been retrofitted into the construction, but should be implemented for future SRS cases being made. Other improvements, such as surface mounted connections will also give the case a more finished look.

A feature highly requested is the implementation of an X-Y platform below the SRS case, allowing for a sorting of the insects once classified. This requires a slight remodel of the case as well as the FTS. The insects should be separated into their species, and insects of the same species should be sorted together, allowing for fewer individual samples as well as a more compact storage.

7.7 Control board (PCB)

The SRS case has a few connections, for valve control, image acquisition hardware trigger and more, these are currently connected on a prototype PCB board. Ideally a custom PCB should be made to make reproducibility easier, as well as ensuring stable connections.

REFERENCES

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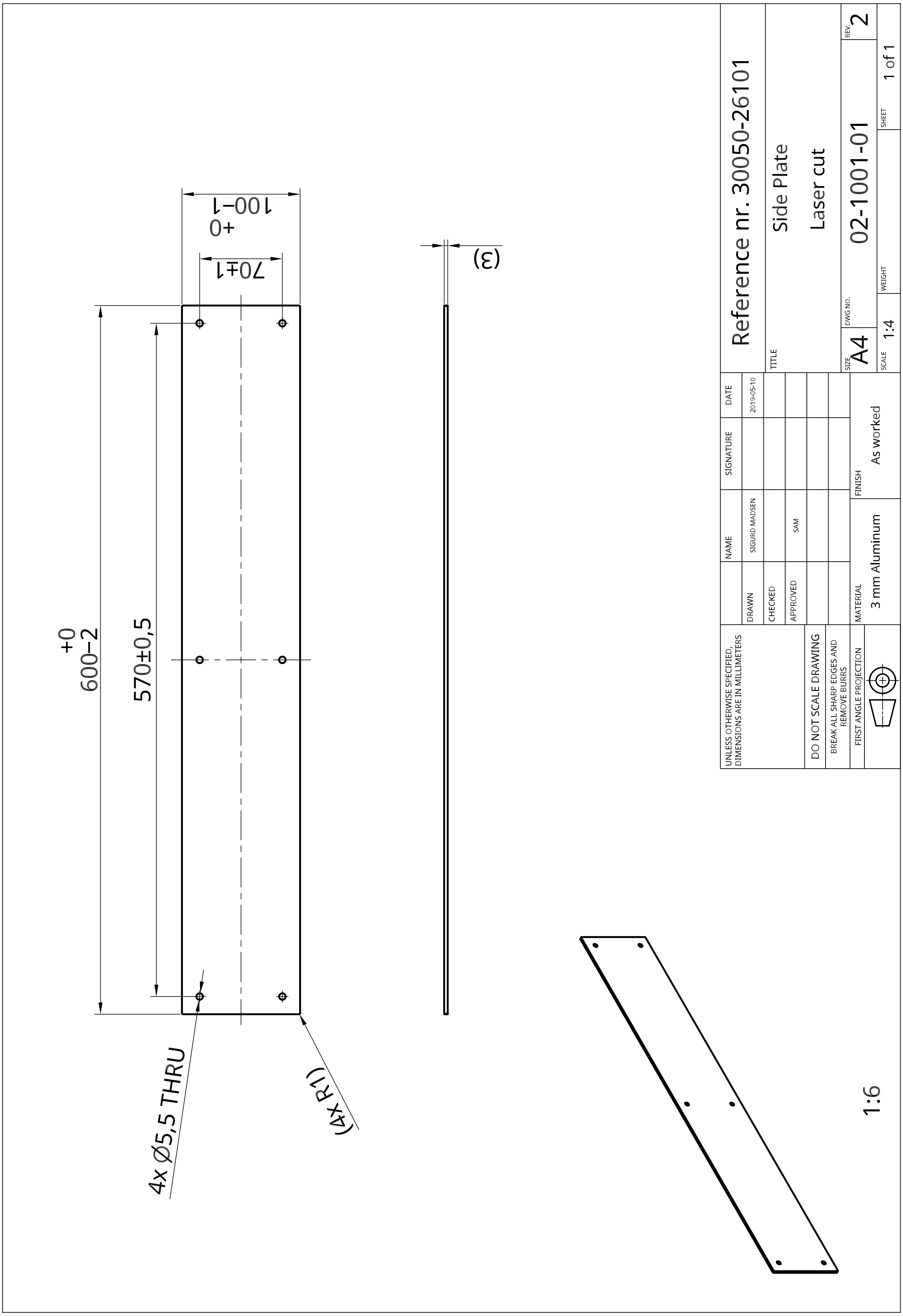
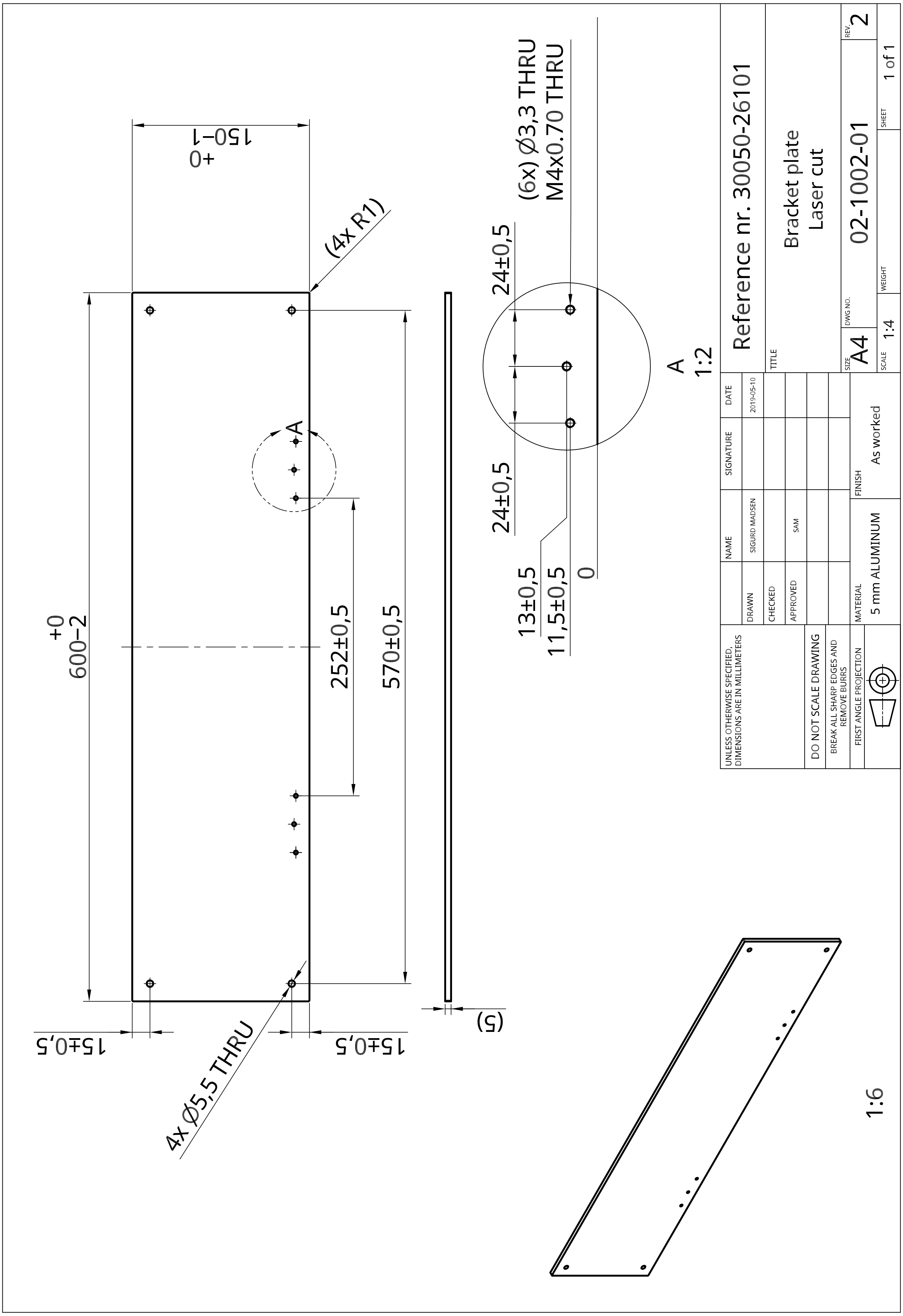
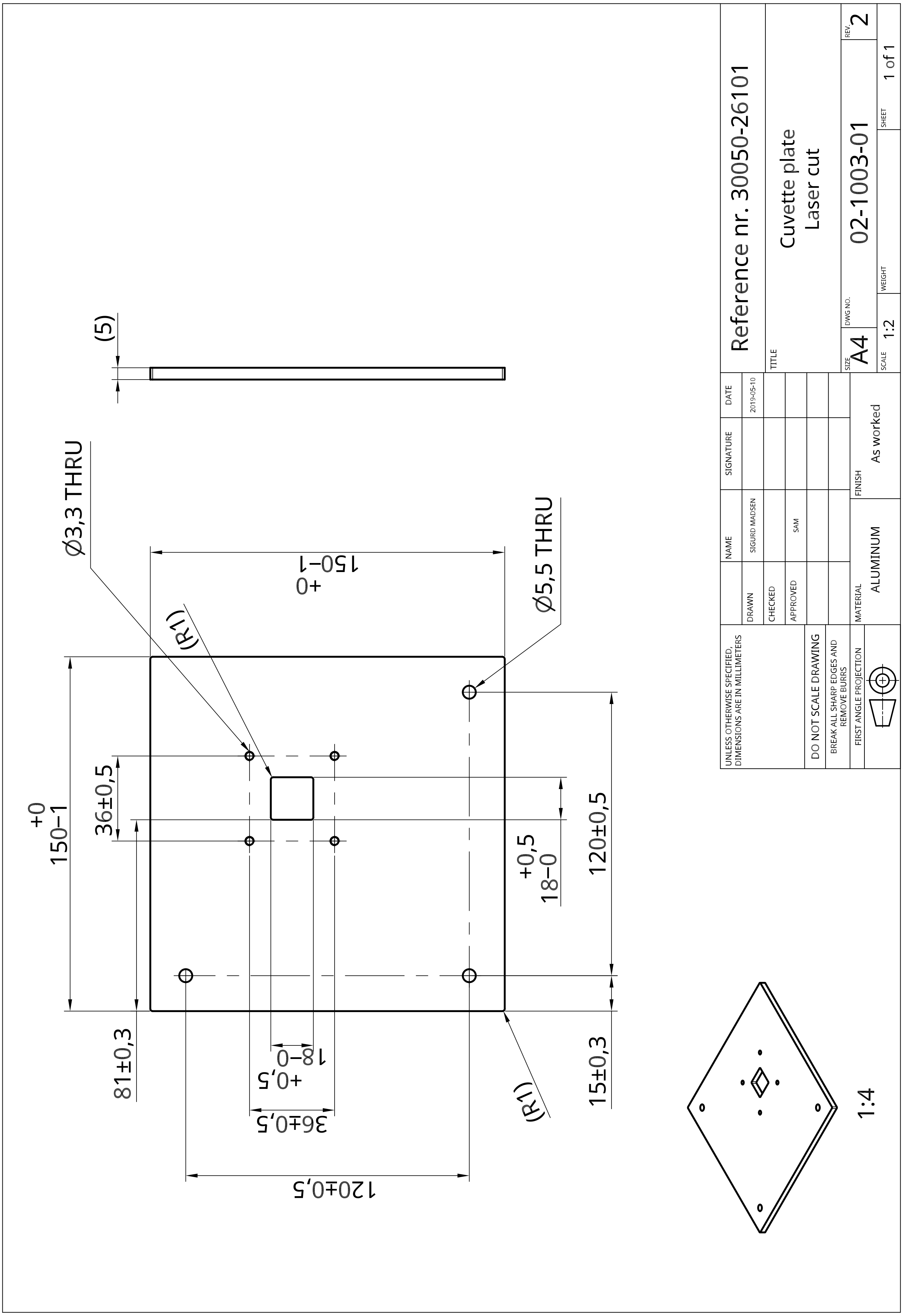
Appendices

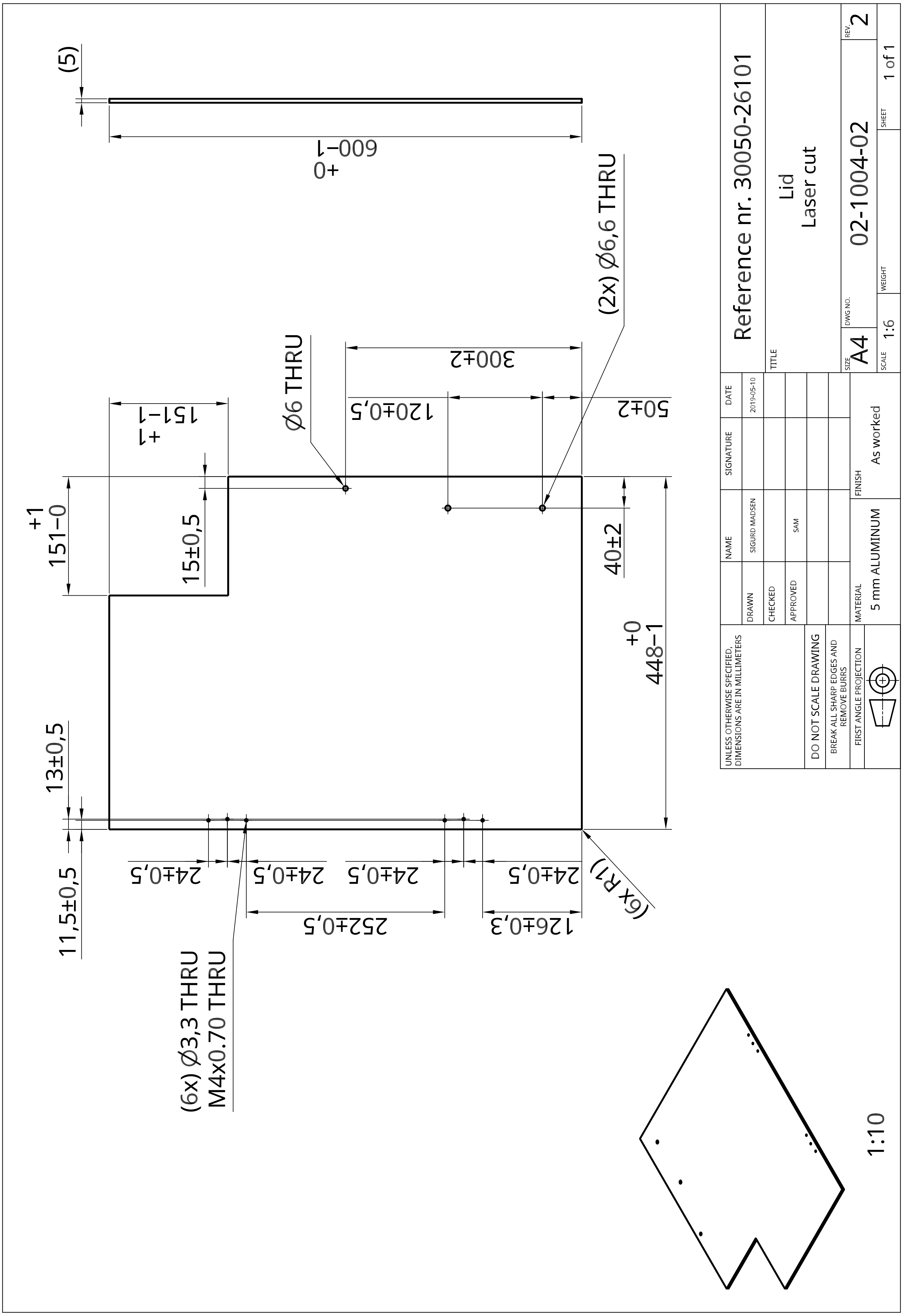
A TECHNICAL DRAWINGS

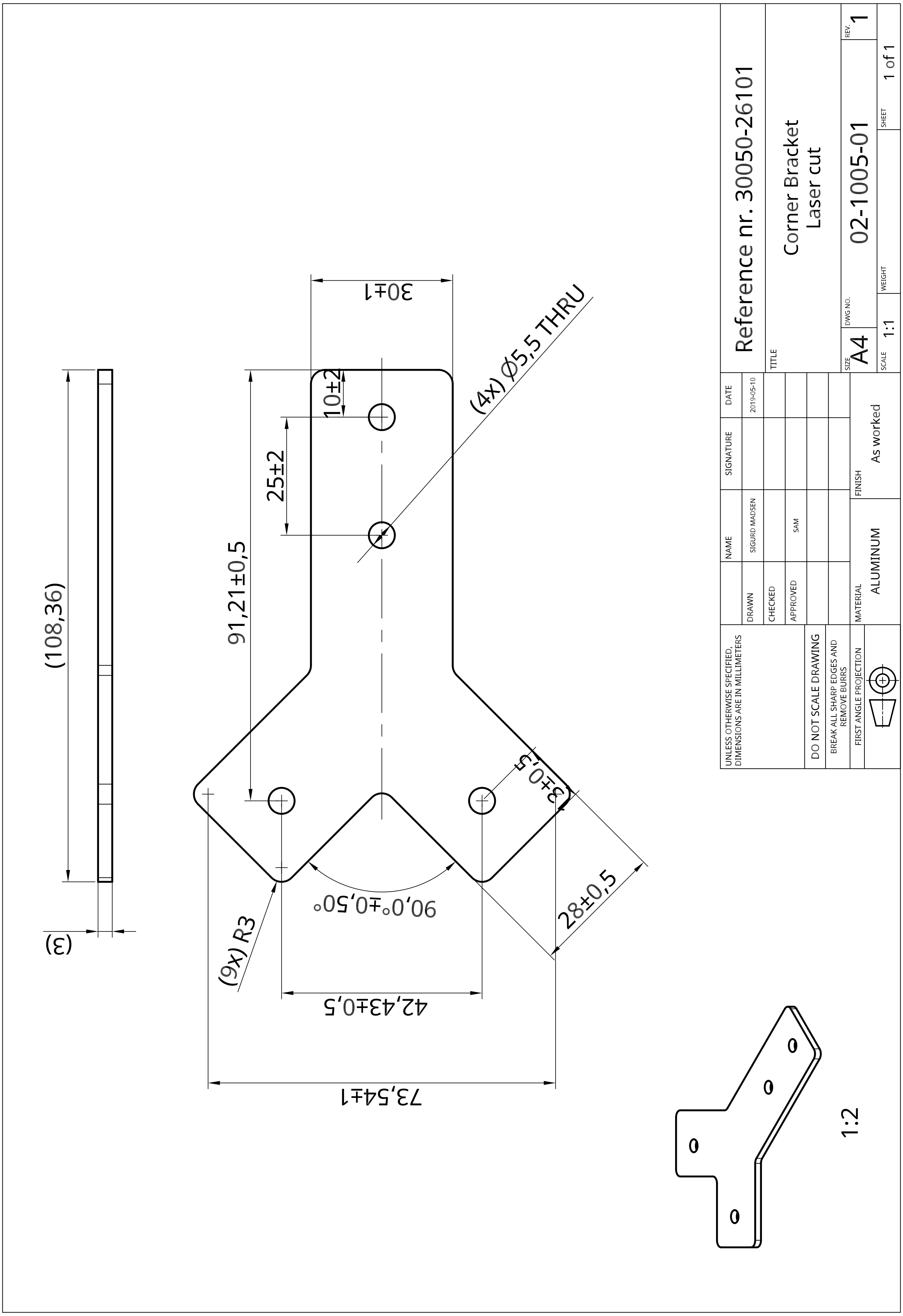

600−2
+0
570±0,5
4x ⌀5,5 THRU
(4x R1)
70±1
100−1
+0
(3)
1:6
UNLESS OTHERWISE SPECIFIED,
DIMENSIONS ARE IN MILLIMETERS
NAME
SIGNATURE
DATE
DRAWN
SIGURD MADSEN
2019-05-10
CHECKED
APPROVED
SAM
DO NOT SCALE DRAWING
BREAK ALL SHARP EDGES AND REMOVE BURRS
FIRST ANGLE PROJECTION
MATERIAL
3 mm Aluminum
FINISH
As worked
Reference nr. 30050-26101
TITLE
Side Plate
Laser cut
SIZE
A4
DWG NO.
02-1001-01
REV.
2
SCALE
1:4
WEIGHT
SHEET
1 of 1

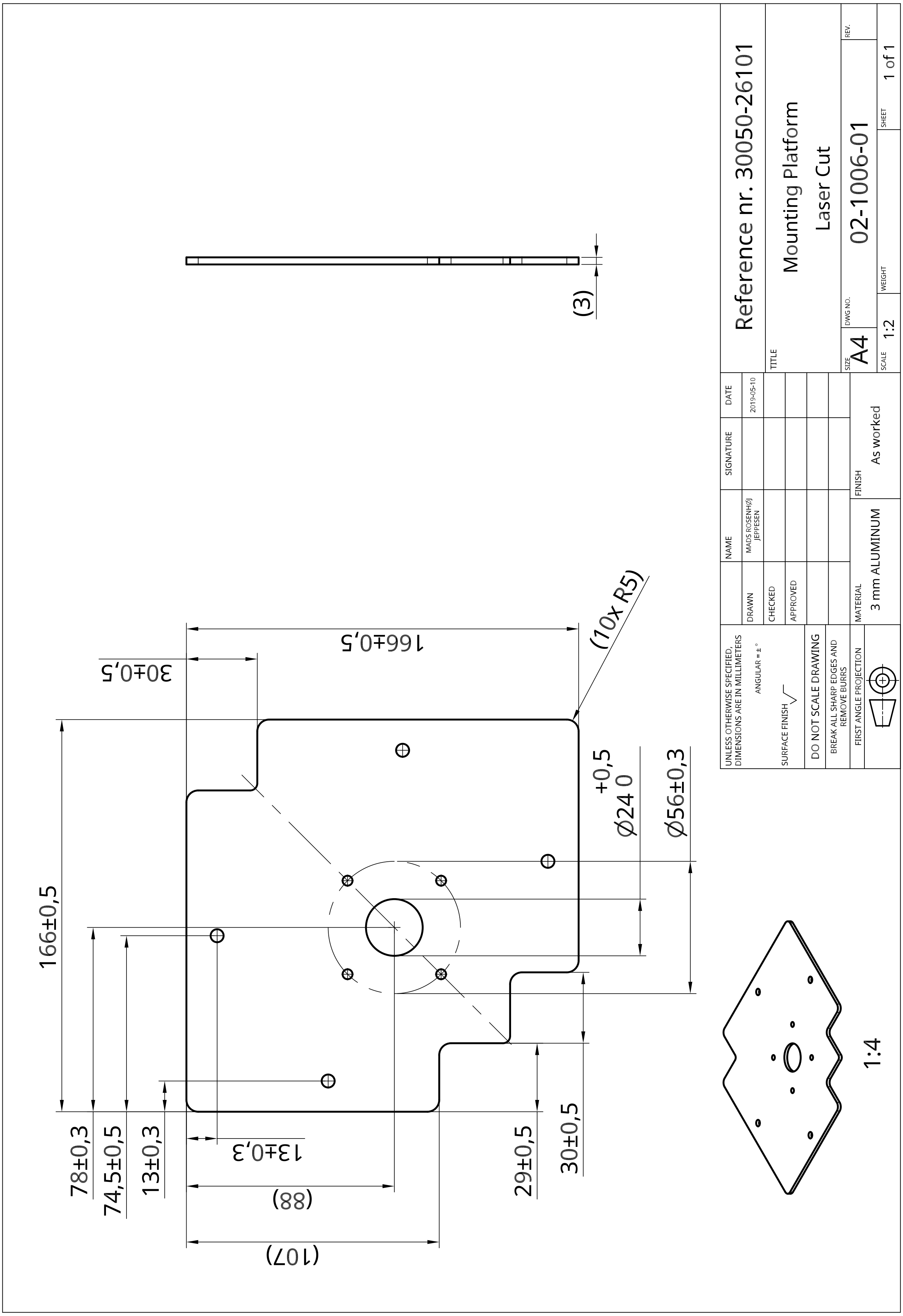

600−2 +0
150−1 +0
(4x R1)
A
252±0,5
570±0,5
15±0,5
15±0,5
4x Ø5,5 THRU
(5)
24±0,5
24±0,5
(6x) Ø3,3 THRU
M4x0.70 THRU
13±0,5
11,5±0,5
0
A
1:2
1:6
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS
DO NOT SCALE DRAWING
BREAK ALL SHARP EDGES AND REMOVE BURRS
FIRST ANGLE PROJECTION
NAME
SIGNATURE
DATE
DRAWN
SIGURD MADSEN
2019-05-10
CHECKED
APPROVED
SAM
MATERIAL
5 mm ALUMINUM
FINISH
As worked
Reference nr. 30050-26101
TITLE
Bracket plate
Laser cut
SIZE
A4
DWG NO.
02-1002-01
REV.
2
SCALE
1:4
WEIGHT
SHEET
1 of 1

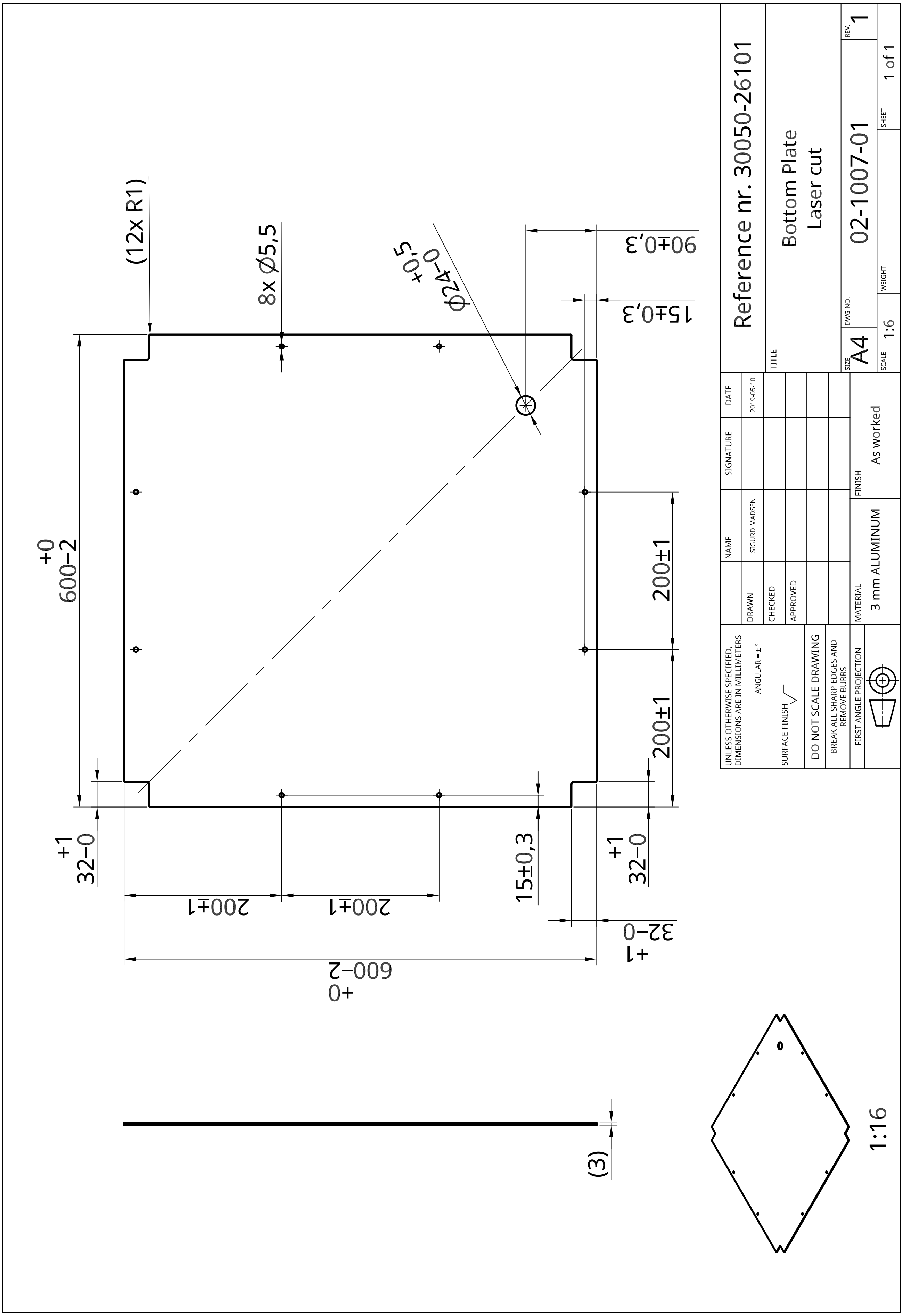


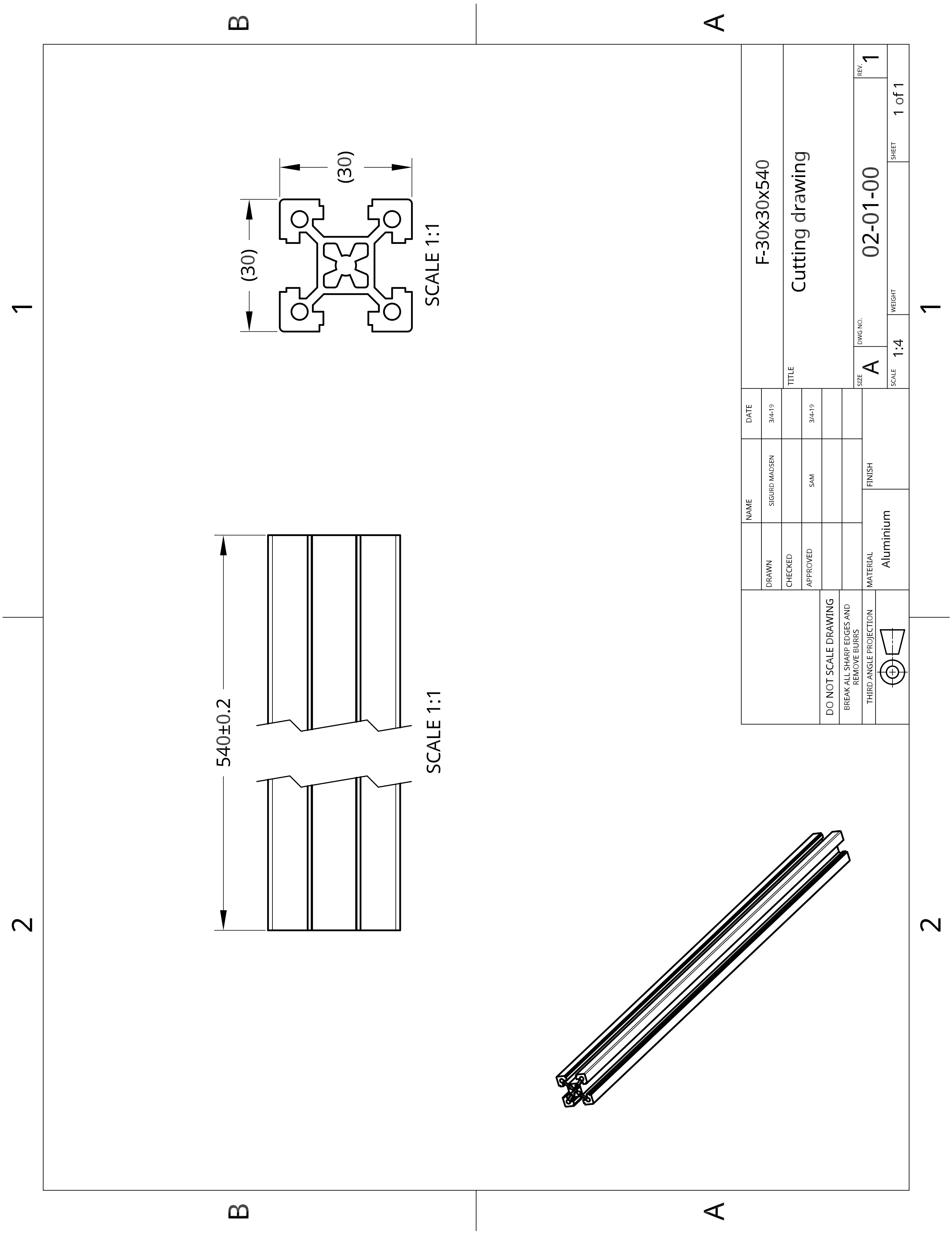
Reference nr. 30050-26101
TITLE
Cuvette plate
Laser cut
SIZE A4
DWG NO. 02-1003-01
REV. 2
SCALE 1:2
WEIGHT
SHEET 1 of 1
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS
DO NOT SCALE DRAWING
BREAK ALL SHARP EDGES AND REMOVE BURRS
FIRST ANGLE PROJECTION
NAME
SIGNATURE
DATE
DRAWN
SIGURD MADSEN
2019-05-10
CHECKED
APPROVED
SAM
MATERIAL
ALUMINUM
FINISH
As worked
Ø3,3 THRU
Ø5,5 THRU
(5)
150−1 +0
(R1)
36±0,5
120±0,5
18−0 +0,5
81±0,3
15±0,3
1:4


(5)
600−1 +0
(2x) Ø6,6 THRU
Ø6 THRU
300±2
151−1 +1
120±0,5
50±2
151−0 +1
15±0,5
40±2
448−1 +0
13±0,5
11,5±0,5
24±0,5
24±0,5
24±0,5
24±0,5
252±0,5
126±0,3
(6x R1)
(6x) Ø3,3 THRU
M4x0.70 THRU
1:10
UNLESS OTHERWISE SPECIFIED,
DIMENSIONS ARE IN MILLIMETERS
DO NOT SCALE DRAWING
BREAK ALL SHARP EDGES AND REMOVE BURRS
FIRST ANGLE PROJECTION
NAME
SIGNATURE
DATE
DRAWN
SIGURD MADSEN
2019-05-10
CHECKED
APPROVED
SAM
MATERIAL
5 mm ALUMINUM
FINISH
As worked
Reference nr. 30050-26101
TITLE
Lid
Laser cut
SIZE
A4
DWG NO.
02-1004-02
REV.
2
SCALE
1:6
WEIGHT
SHEET
1 of 1

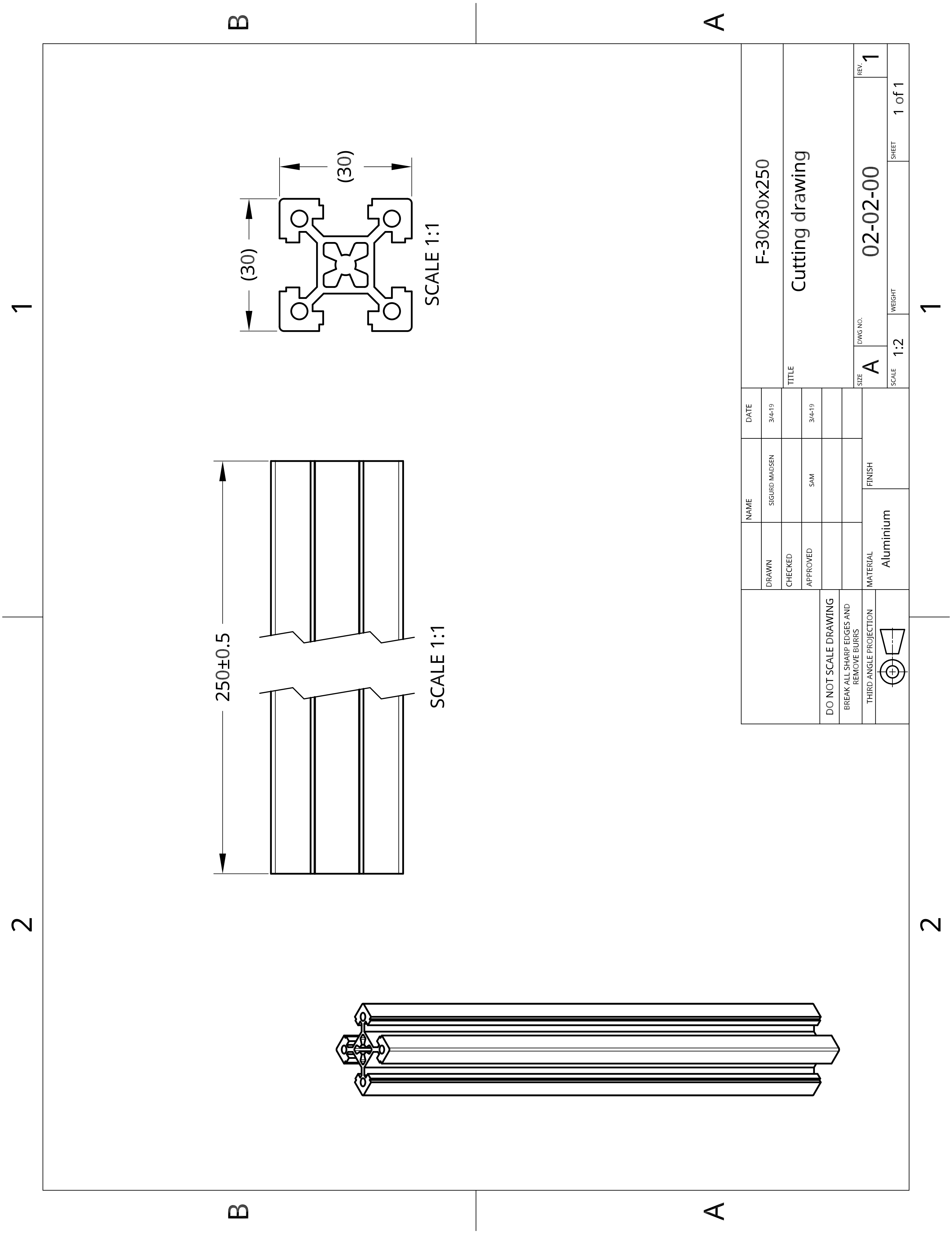

30±1
(4x) Ø5,5 THRU
10±2
25±2
91,21±0,5
(108,36)
(3)
3±0,5
28±0,5
90,0°±0,50°
(9x) R3
42,43±0,5
73,54±1
1:2
Reference nr. 30050-26101
TITLE
Corner Bracket
Laser cut
SIZE
A4
DWG NO.
02-1005-01
REV.
1
SCALE
1:1
WEIGHT
SHEET
1 of 1
NAME
SIGNATURE
DATE
DRAWN
SIGURD MADSEN
2019-05-10
CHECKED
APPROVED
SAM
UNLESS OTHERWISE SPECIFIED,
DIMENSIONS ARE IN MILLIMETERS
DO NOT SCALE DRAWING
BREAK ALL SHARP EDGES AND
REMOVE BURRS
FIRST ANGLE PROJECTION
MATERIAL
ALUMINUM
FINISH
As worked

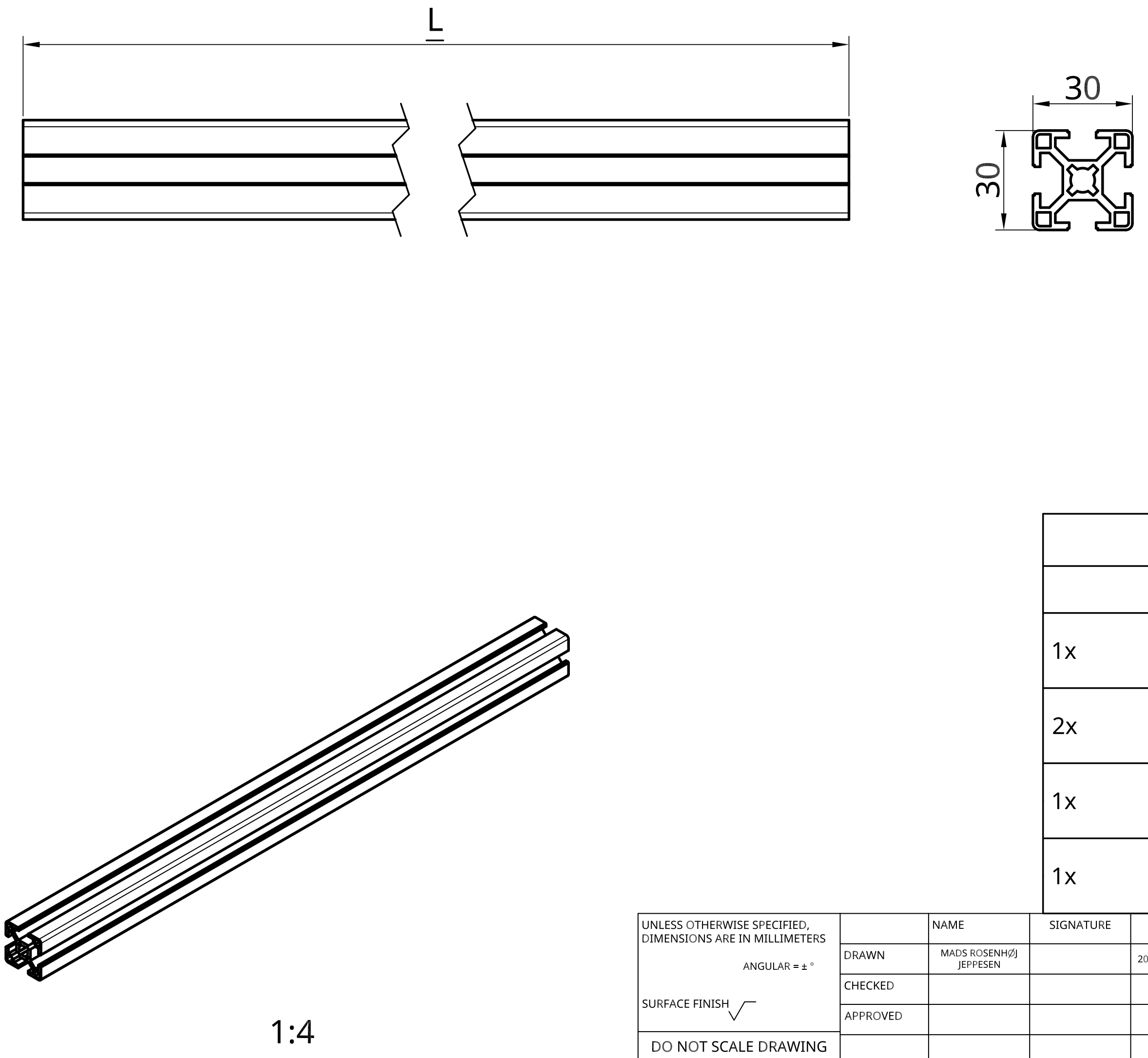

(3)
166±0,5
30±0,5
(10x R5)
+0,5
Ø24 0
Ø56±0,3
166±0,5
78±0,3
74,5±0,5
13±0,3
13±0,3
(88)
(107)
29±0,5
30±0,5
1:4
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS
ANGULAR = ± °
SURFACE FINISH
DO NOT SCALE DRAWING
BREAK ALL SHARP EDGES AND REMOVE BURRS
FIRST ANGLE PROJECTION
NAME
SIGNATURE
DATE
DRAWN
MADS ROSENHØJ JEPPESEN
2019-05-10
CHECKED
APPROVED
MATERIAL
3 mm ALUMINUM
FINISH
As worked
Reference nr. 30050-26101
TITLE
Mounting Platform
Laser Cut
SIZE
A4
DWG NO.
02-1006-01
REV.
SCALE
1:2
WEIGHT
SHEET
1 of 1


(12x R1)
8x Ø5,5
Ø24 +0,5 −0
90±0,3
15±0,3
600 +0 −2
200±1
200±1
32 +1 −0
15±0,3
200±1
200±1
32 +1 −0
600 +0 −2
(3)
1:16
Reference nr. 30050-26101
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS
ANGULAR = ± °
SURFACE FINISH
DO NOT SCALE DRAWING
BREAK ALL SHARP EDGES AND REMOVE BURRS
FIRST ANGLE PROJECTION
NAME
SIGNATURE
DATE
DRAWN
SIGURD MADSEN
2019-05-10
CHECKED
APPROVED
MATERIAL
3 mm ALUMINIUM
FINISH
As worked
TITLE
Bottom Plate
Laser cut
SIZE
A4
DWG NO.
02-1007-01
REV.
1
SCALE
1:6
WEIGHT
SHEET
1 of 1



(30)
(30)
SCALE 1:1
540±0.2
SCALE 1:1
F-30x30x540
Cutting drawing
TITLE
NAME
DATE
DRAWN
SIGURD MADSEN
3/4-19
CHECKED
APPROVED
SAM
3/4-19
DO NOT SCALE DRAWING
BREAK ALL SHARP EDGES AND REMOVE BURRS
THIRD ANGLE PROJECTION
MATERIAL
Aluminium
FINISH
SIZE
A
DWG NO.
02-01-00
REV.
1
SCALE
1:4
WEIGHT
SHEET
1 of 1


(30)
(30)
SCALE 1:1
250±0.5
SCALE 1:1
F-30x30x250
TITLE
Cutting drawing
SIZE
A
DWG NO.
02-02-00
REV.
1
SCALE 1:2
WEIGHT
SHEET 1 of 1
NAME
DATE
DRAWN
SIGURD MADSEN
3/4-19
CHECKED
APPROVED
SAM
3/4-19
MATERIAL
Aluminium
FINISH
DO NOT SCALE DRAWING
BREAK ALL SHARP EDGES AND REMOVE BURRS
THIRD ANGLE PROJECTION



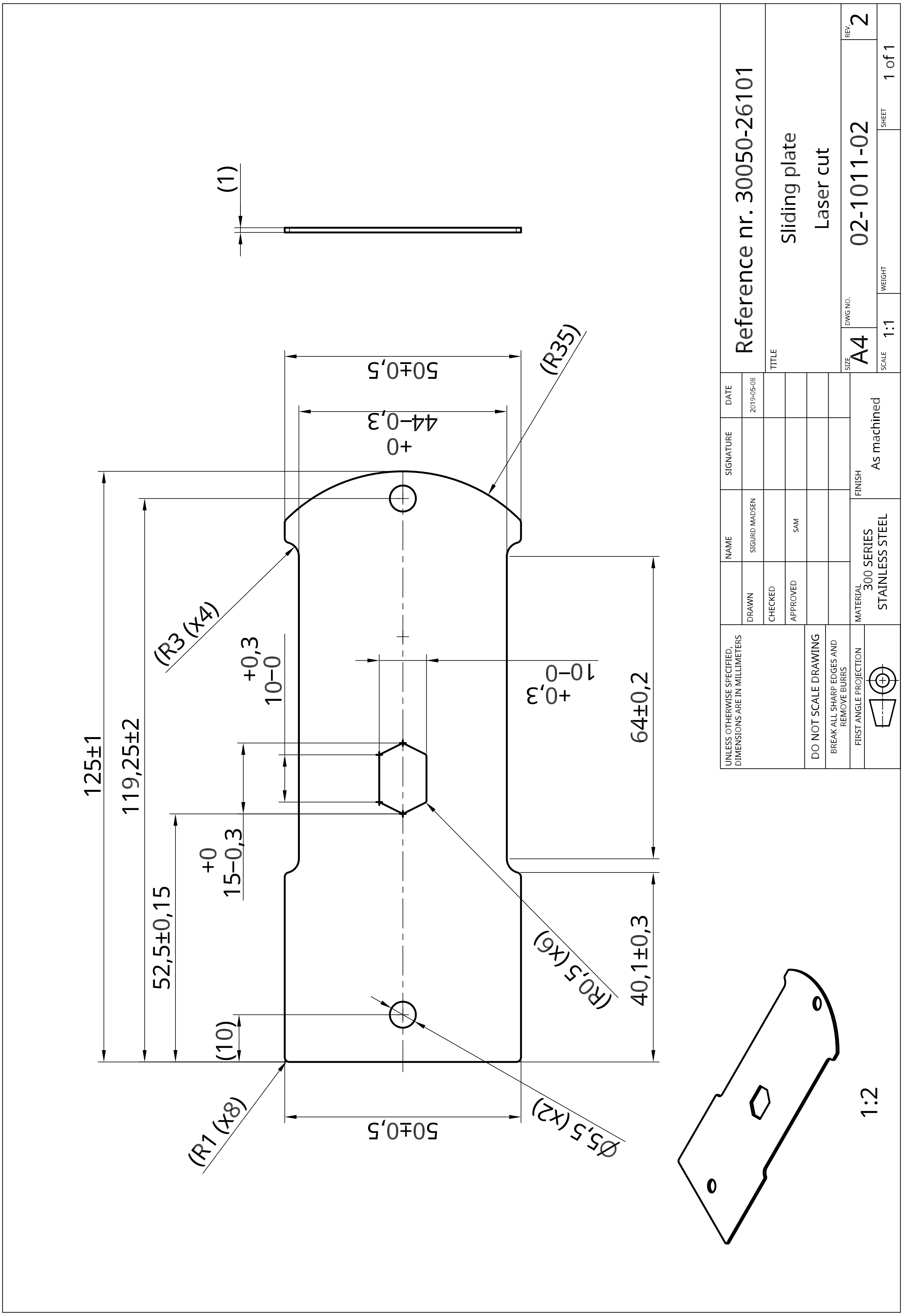
Lengths			
amount	length (L)	tolerance	
1x	540	+0	-2.5
2x	400	-0.5	-1
1x	140	+0	-0.5
1x	110	-0.5	-1

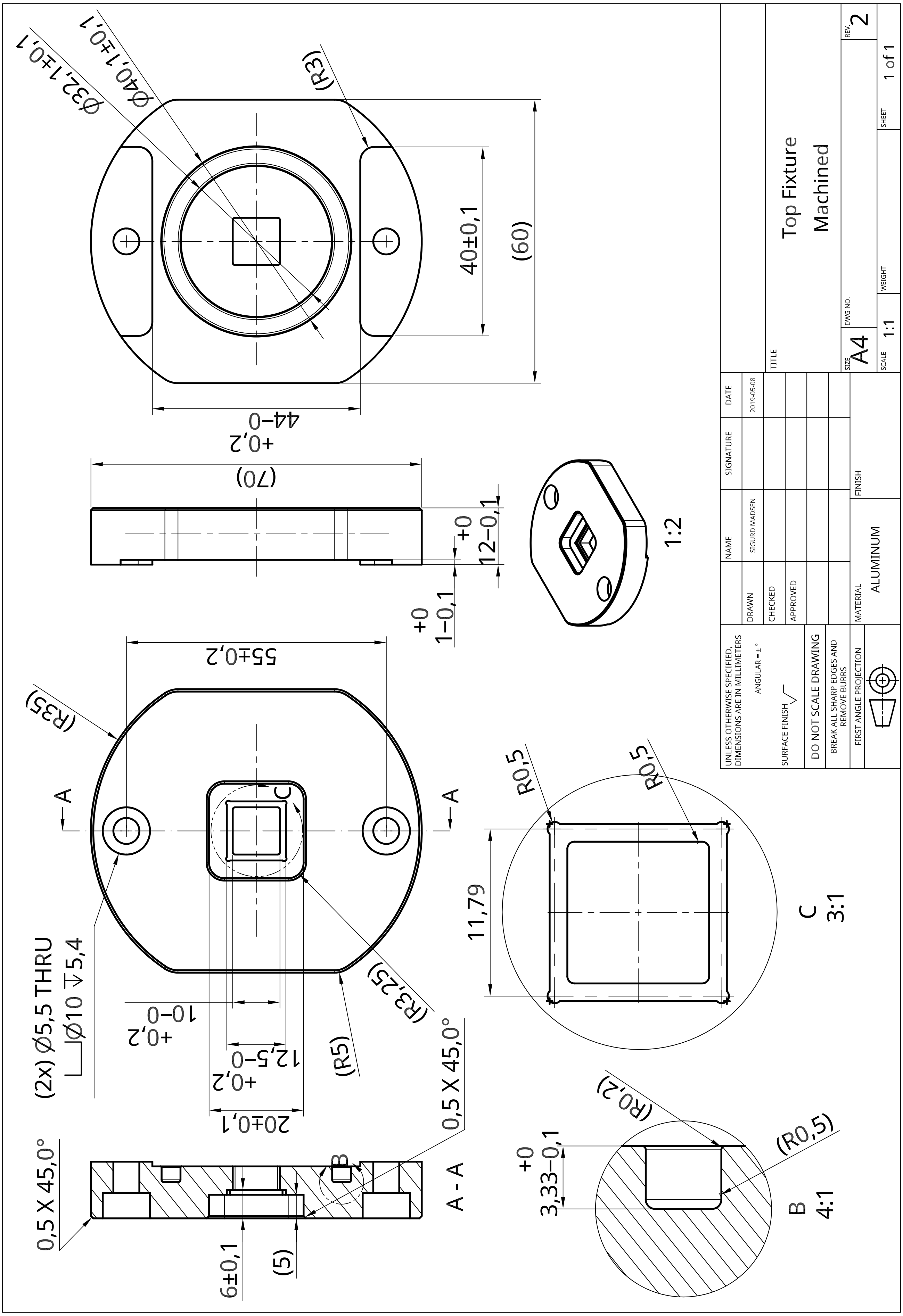
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS ANGULAR = ± ° SURFACE FINISH		NAME	SIGNATURE	DATE
	DRAWN	MADS ROSENHØJ JEPPESEN		2019-05-08
	CHECKED			
	APPROVED			
DO NOT SCALE DRAWING				
BREAK ALL SHARP EDGES AND REMOVE BURRS				
FIRST ANGLE PROJECTION	MATERIAL: Aluminum		FINISH	

TITLE: RK 30x30 profiles
Cut

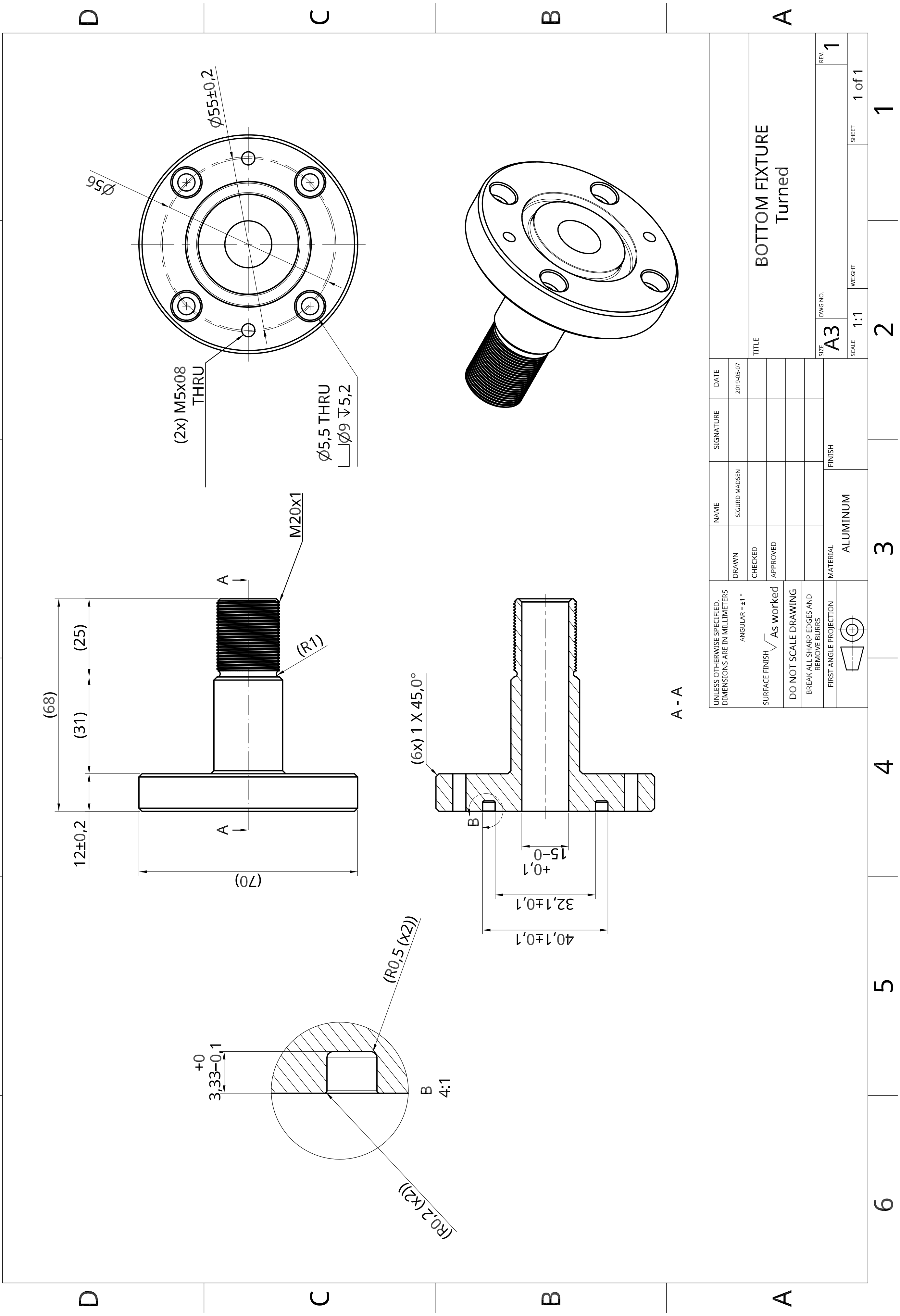
SIZE: A4 | DWG NO.: | REV.: 1

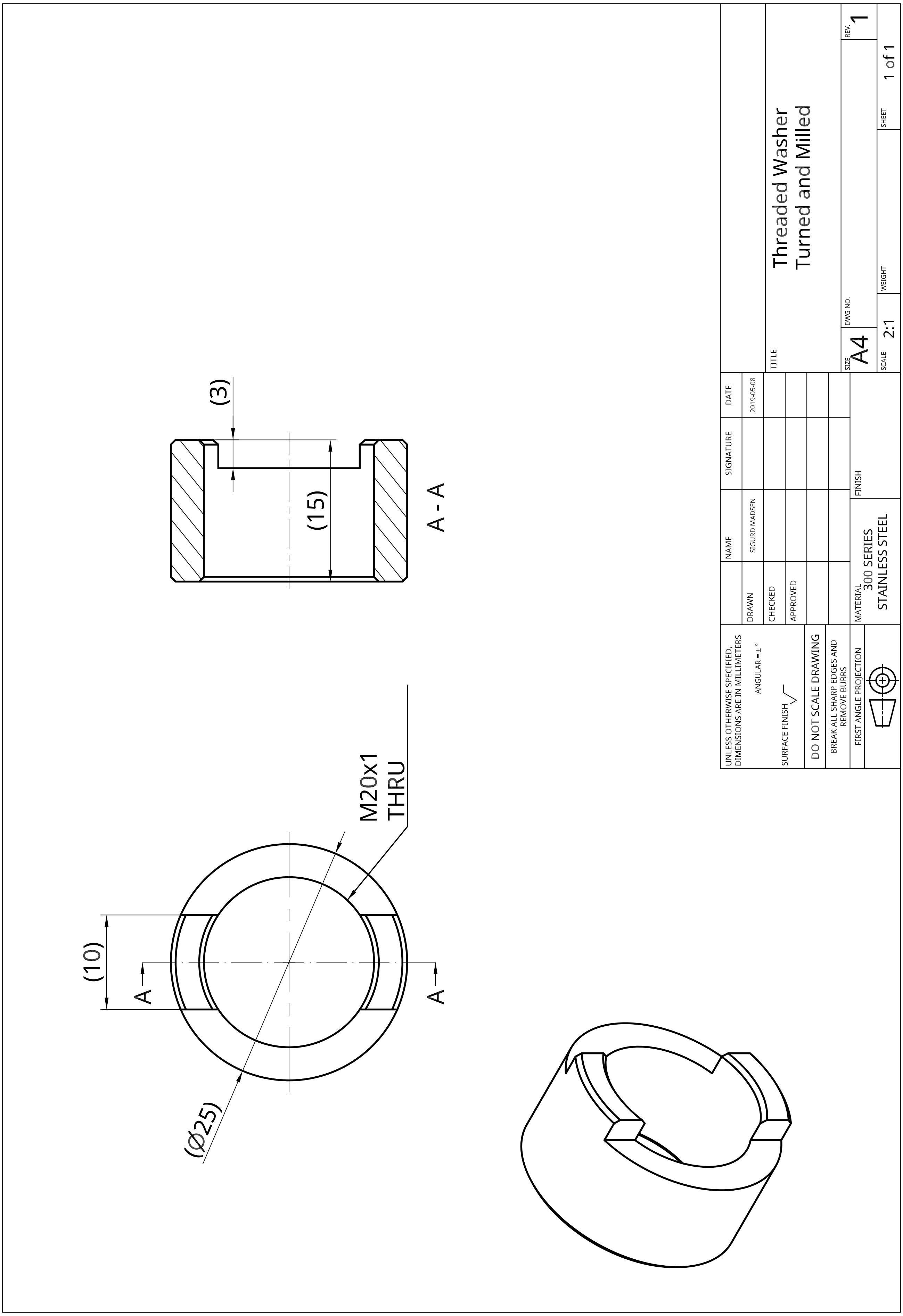
SCALE: 1:2 | WEIGHT: | SHEET: 1 of 1


(1)
50±0,5
44−0,3 +0
(R35)
125±1
119,25±2
(R3 (x4))
10−0 +0,3
+0,3 10−0
64±0,2
52,5±0,15
+0 15−0,3
(R0,5 (x6))
40,1±0,3
(10)
(R1 (x8))
50±0,5
Ø5,5 (x2)
1:2
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS
DO NOT SCALE DRAWING
BREAK ALL SHARP EDGES AND REMOVE BURRS
FIRST ANGLE PROJECTION
NAME
SIGNATURE
DATE
DRAWN
SIGURD MADSEN
2019-05-08
CHECKED
APPROVED
SAM
MATERIAL
300 SERIES STAINLESS STEEL
FINISH
As machined
Reference nr. 30050-26101
TITLE
Sliding plate
Laser cut
SIZE
A4
DWG NO.
02-1011-02
REV.
2
SCALE
1:1
WEIGHT
SHEET
1 of 1



Top Fixture
Machined
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS
ANGULAR = ± °
SURFACE FINISH
DO NOT SCALE DRAWING
BREAK ALL SHARP EDGES AND REMOVE BURRS
FIRST ANGLE PROJECTION
NAME
SIGNATURE
DATE
DRAWN
SIGURD MADSEN
2019-05-08
CHECKED
APPROVED
MATERIAL
ALUMINUM
FINISH
TITLE
SIZE
A4
DWG NO.
REV.
2
SCALE
1:1
WEIGHT
SHEET
1 of 1
A - A
B
4:1
C
3:1
1:2
(2x) Ø5,5 THRU
Ø10 ↧5,4
55±0,2
40±0,1
(60)
(70)
Ø32,1±0,1
Ø40,1±0,1
(R3)
(R35)
(R3,25)
(R5)
(R0,2)
(R0,5)
R0,5
11,79
20±0,1
6±0,1
(5)
0,5 X 45,0°


⌀55±0,2
⌀56
(2x) M5x08 THRU
⌀5,5 THRU
⌴⌀9 ↧5,2
M20x1
(R1)
(68)
(25)
(31)
12±0,2
(70)
A
A
(6x) 1 X 45,0°
A - A
B
15 +0,1 −0
32,1±0,1
40,1±0,1
(R0,5 (x2))
3,33 +0 −0,1
B
4:1
(R0,2 (x2))
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS
ANGULAR = ±1°
SURFACE FINISH √ As worked
DO NOT SCALE DRAWING
BREAK ALL SHARP EDGES AND REMOVE BURRS
FIRST ANGLE PROJECTION
NAME
SIGNATURE
DATE
DRAWN
SIGURD MADSEN
2019-05-07
CHECKED
APPROVED
MATERIAL
ALUMINUM
FINISH
TITLE
BOTTOM FIXTURE
Turned
SIZE
A3
DWG NO.
REV.
1
SCALE
1:1
WEIGHT
SHEET
1 of 1


(3)
(15)
A - A
(10)
A
A
M20x1
THRU
(Ø25)
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS
ANGULAR = ± °
SURFACE FINISH
DO NOT SCALE DRAWING
BREAK ALL SHARP EDGES AND REMOVE BURRS
FIRST ANGLE PROJECTION
NAME
SIGNATURE
DATE
DRAWN
SIGURD MADSEN
2019-05-08
CHECKED
APPROVED
MATERIAL
300 SERIES
STAINLESS STEEL
FINISH
TITLE
Threaded Washer
Turned and Milled
SIZE
A4
DWG NO.
REV.
1
SCALE
2:1
WEIGHT
SHEET
1 of 1