LAA/MOD 3
MODIFICATION APPLICATION
Issue 6

Mod No.
15610

This form is used to describe a modification in detail to constitute part of the aircraft build standard record. All pages must be included in any submission. A completed Modification Proposal form (LAA/MOD2) must have been submitted prior to submitting this form, see TL 3.01.
This form may be printed out, completed by hand and either posted to LAA Engineering or scanned and emailed to engineering@laa.uk.com, or it may be completed electronically, saved and emailed as an attachment to the same email address. If emailed without the owner's signature, it must be sent by the aircraft owner. Please retain a copy of the completed form for your records.

1. AIRCRAFT DETAILS

Registration	Type	Serial Number
G - *OUAV*	***TLAC Sherwood Scout***	***345-15480***

2. APPLICANT DETAILS (Note: Applicant must be a 'Full plus' member)

Applicant's Name	***Keith Towell***	Membership No.	***015778***

Name and address of person to be contacted regarding this modification:

Prof J Scanlan,
Faculty of Engineering and Physical Sciences,
University of Southampton,
University Road,
Southampton SO171BJ

Daytime Telephone Number:	***02380592369***	e-mail:	***J.P.Scanlan@soton.ac.uk***

3. MODIFICATION DETAILS

Title:	***Variable Stability Demonstrator***

Background: describe the purpose of the mod and what it consists of.

See Variable Stability Demonstrator Introduction

4. LIST OF ACCOMPANYING DOCUMENTS DESCRIBING MOD

Document No.	Title / Description	Issue
	See Attached Document List	

5. LIST OF ACCOMPANYING DOCUMENTS SUPPORTING AIRWORTHINESS OF MODIFICATION (e.g. test report, compliance checklist, etc)

Document Ref	Title / Description	Issue
	See attached Document List	***1***

6. PARTS LIST

List any new manufactured or procured parts. Where a new part is designed and used it should be drawn up with sufficient dimensions to define it and make it, including any protective treatments (e.g. paint). Where one exists, the manufacturer's part number should be given, otherwise it should be allocated a part number in the following convention: Part number = M (Mod number)-(sequence number), example : *M12345-01.* Include fasteners, clips, electrical components, etc.

Qty	Part No.	Description	Source
	See attached parts list		

Attach a continuation sheet as required.

7. IMPLEMENTATION

Describe:

- Health and safety provisions
- Any disassembly requirements
- Instructions for Installation of new parts.
- Re-assembly requirements to make aircraft flyable again.

See Document 4 - Installation and Maintenance Supplement

Is the proposed modification is currently fitted to the aircraft? (Note that once installed, the aircraft may not be flown until permission given)	YES ○	NO ◉
If yes, briefly describe any other work needed for the aircraft to be ready for flight (e.g. finish re-build)		
If no, when do you intend to fit the modification?	***Augest 2021***	

8. WEIGHT AND BALANCE EFFECT ON AIRCRAFT

Date of current W&B report:	***28/04/2021***	Weight (lb/kg)	CG (in/mm)	Moment
A/C pre-mod		***289.1kg***	***228mm***	***65914.8kgmm***
+/- weight change		***18.8kg***	(moment arm) ***1165.1mm***	***21903.8kgmm***
= A/C post-mod		***307.9kg***	***285.2***	***87818.6kgmm***

LAA Light Aircraft Association

LAA/MOD 3
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15610

9. INSPECTION CHECKS AND SPECIAL INSTRUCTIONS

All modifications will need to be inspected for quality and conformity. State any additional proposed requirements e.g. function check, full and free checks, friction, clearance from other structures and systems, etc.

Find attached Operational Supplement

10. FLIGHT TEST AND SPECIAL INSTRUCTIONS

Example statements may be:

- *25 hours of reliability testing.*
- *Full performance and handling check by a qualified test pilot.*
- *20 landings on various surfaces.*

Find Attached Flight Test Plan

11. OWNER'S DECLARATION

I declare that the foregoing information is correct and I agree to abide by any conditions pertaining to this modification.
I agree that this modification, if approved, can be used free of charge by others.

Name (owner): **(on behalf of all the owners)**	***Jim Scanlan***
Signature:	
Date:	***28/04/2021***

Note: a signature is not required if the owner is submitting this form by email; however, by submitting the application, you signify that you agree with the Owner's Declaration.

If this mod is successful, are you willing to allow potential applicants wishing to fit the same mod to their aircraft to contact you?◯YES / NO◯
If so, which means of contact is acceptable to be published on the LAA's web site?
home phone □, mobile phone □, email □, address □ [Tick whichever apply]

Data privacy: personal data submitted on this application form may be stored electronically but will only be used in relation to the application and to support the safety of any aircraft to which it relates. Statutory obligations excepting, personal data will not be passed on to third parties without your permission. The full LAA data protection policy can be found on our website at www.laa.uk.com

Document 1 – Document List

Aircraft Registration:	G-OUAV
Aircraft Type:	TLAC Sherwood Scout
Aircraft Serial Number:	345-15480
Modification Number:	15610
Date Created:	29/04/2021

Authors:

Jerin George, Callum Breslin, Daniel Newman-Sanders, Andrew Kernan and Declan Clifford

Document List

Document Number	Document	Issue
1	Document List	29/4/2021
2	Variable Stability Demonstrator Modification	27/4/2021
3	Operational Supplement	03/4/2021
4	Installation and Maintenance Supplement	03/4/2021
5	Failure Mode and Effects Analysis	03/4/2021
6	Pseudocode	29/4/2021
7	Electrical Load Analysis	29/4/2021
8	Structural Report	27/4/2021
9	Compliance Checklist	28/4/2021
10	Flight Test Plan	03/4/2021
11	Parts List	29/4/2021
12	Drawing	27/4/2021
13	Specification Datasheet	29/4/2021

Document 1 - Variable Stability Demonstrator Modification

Aircraft Registration:	G-OUAV
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Variable Stability Demonstrator

Contents

Variable Stability Demonstrator

Project Overview

This project aims to convert the Sherwood Scout (G-OUAV) light aircraft into a variable stability demonstrator in the pitch axis. This will be achieved by modifying the existing elevator control system at both the control stick and the idler to allow for an independent elevator response to the pilot input as shown in Figure 1. The pilot input will be modified by means of the control system outlined in Figure 2 to make the G-OUAV's elevator motion such that G-OAUV mimics the longitudinal stability characteristic of a target aircraft. The control system will also provide force feedback to the pilot via the control stick to allow them to feel the stability characteristics of the target aircraft.

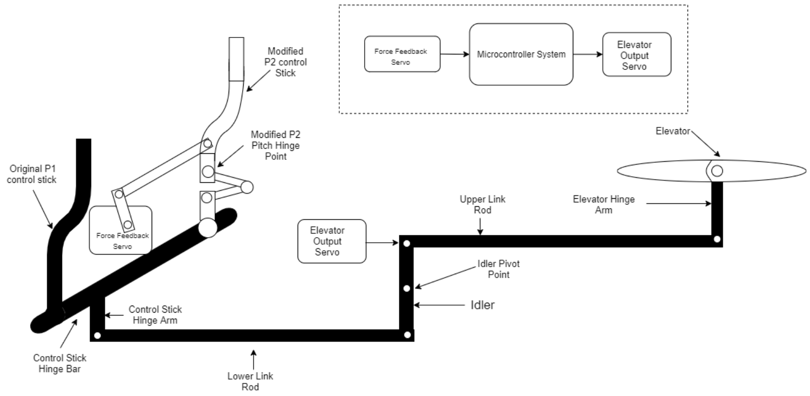

Figure 1: Full elevator control system diagram.

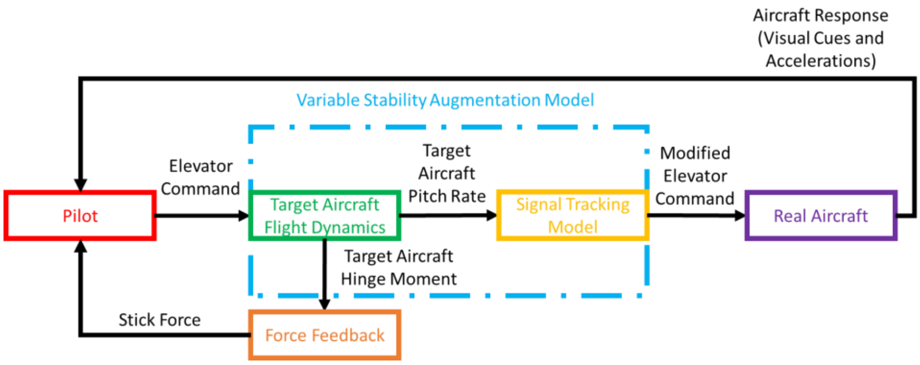

Figure 2: Control system block diagram.

To gather real time inputs needed for the control system we intend to use an Arduino based accelerometer and gyroscope module for orientation and a differential pressure senor with two pressure tappings for static and dynamic pressure via a pitot static tube attached onto the wing strut for airspeed.

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Commented [JG2R1]: There are two tappings

Force Feedback System

This modification will see us replace the existing control stick mechanism shown in Figure 3 with the modified system shown in Figure 4. This will ensure independent motion on the control stick in the longitudinal direction against the main elevator control system, while directly transmitting the lateral motion to and from the existing aileron control circuit.

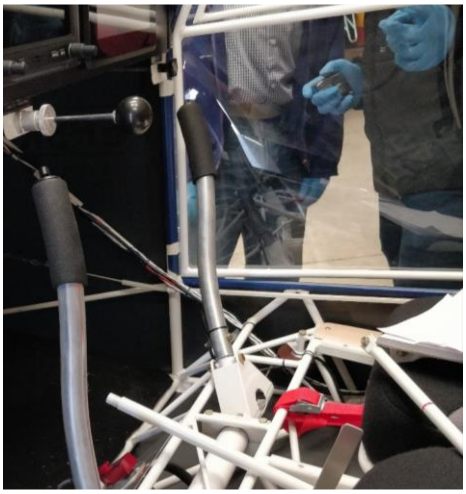

Figure 3: Existing control stick mechanism

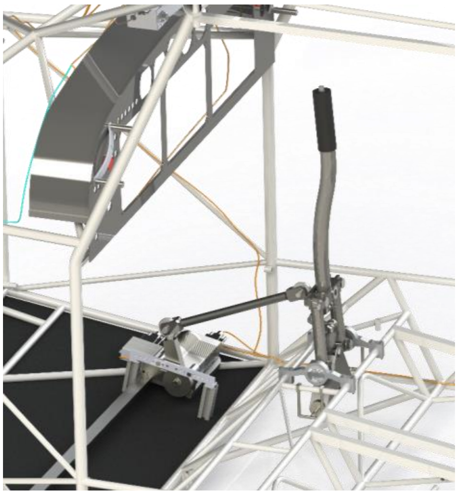

Figure 4: Render of the proposed control stick mechanism

To provide the force feedback a single servo fixed to the floor of the P2 pilot footwell and control stick, as per Figure 5, will be used to provide a variable resistance to a pilot input. This variable resistance will be altered to provide the pilot with the feel of the target aircraft stability characteristics. Further to this, a position sensor built into the servo will be used as the source for the pilot input into the control system.

The design shown in Figure 5 will be designed to ensure the pilots range of motion within the cockpit is not hindered.

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Figure 5: Render of proposed mechanism for attaching control stick to servo.

Elevator Output system

High loads are expected on the elevator due to us trying to mimic more dynamic aircraft, and due to this our design entails coupling two servos, both fitted with electromagnetic clutches, and attaching them onto the existing control system at the top of the idler as shown in Figure 6.

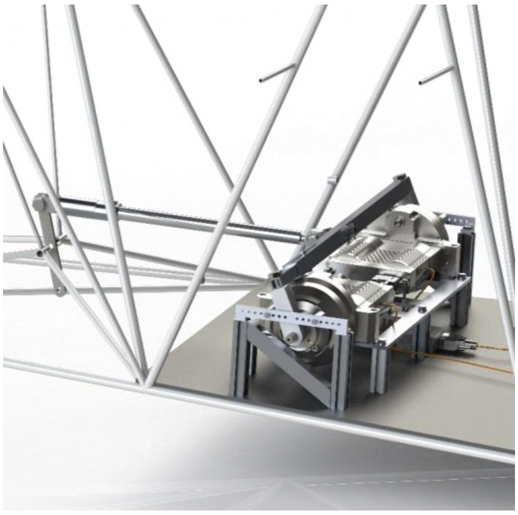

Figure 6: Render of idler servo attachment.

The servos will be fitted within the constraints of the baggage bay and connected via a link rod to the idler. This is to limit the effect on the centre of gravity position of the aircraft.

Control System

The control system will follow the basic block diagram shown in Figure 2 and will run on an Arduino Mega. The control system code itself will run with pre-determined flight parameters obtained through a linear aerodynamic and flight dynamic model developed as part of this project and will be precompiled to ensure robustness within the system.

Rack Mounted Electronics Tray

A 19-inch tray will be added to the existing rack fitted to the aircraft to hold the external battery, Arduino and all other electronic modules needed to control the dead man's switches, pilot indication display, flight data sensing equipment and the servos themselves as shown in Figure 7.

Figure 7: Render of rack with server tray installed.

Pitot Static Tube System

To avoid interaction with the aircraft's existing electrical system, we will use an external pitot static tube as shown in the maintenance and installation supplement. This will be done by linking the pitot static tube to a differential pressure sensor connected to PCB 2 on the Arduino, via a dynamic and static pressure tapping from the pitot static tube mounted on the wing strut.

Accelerometer and Gyroscope System

For the aircraft's angle of attack and pitch rate two Arduino accelerometer and gyroscope modules will be used. These modules will also be fixed onto the 19-inch rack via a PCB as shown in Figure 8.

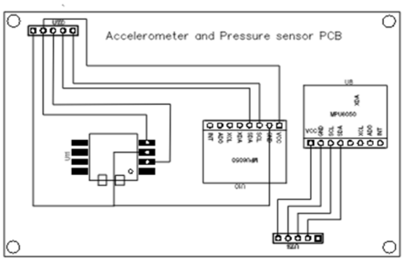

Figure 8: PCB 2 design used to mount accelerometer and pressure sensor.

Pilot Indication Display

To avoid any interaction with the existing aircraft displays, we intend to use a display module with a rotary switch and 5 LEDS to indicate to the pilot the status of the system. This module will be powered by the Arduino and will be fitted on top of the dashboard and attached to the top of the dashboard using M5 bolts as shown in Figure 9.

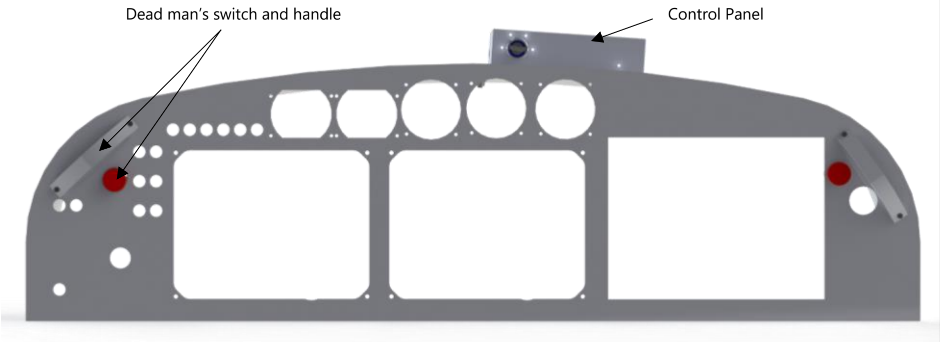

Figure 9: Dashboard placement diagram for dead man's switches, grip handle and control panel.

The control panel consists of a rotary switch and 5 LEDs. It will form the pilot interface of the control system. Both pilots will be able to use the rotary switch to turn the system on/off, or to change the mode in which the system is operating. Before each flight, 3 target aircraft configurations will be programmed onto the Arduino, and whilst in the air, the pilots will be able to switch between these.

Dead Man's Switches

Two dead man's switches will be fitted to the dashboard as per Figure 9. This will ensure both pilots can disengage the system and hand control back over to P1, as when either of the switches are opened it will disconnect the mechanical clutch. This will be achieved by wiring the switches in series from a 5 V supply from the Arduino to a relay. The relay will then be able to disconnect the power supply to the electromagnetic clutch, therefore disconnecting the system.

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To aid the pilots in maintaining contact with the dead man's switches at high load factors, 2 grab handles have been added.

Electrical Schematic

A schematic of our electrical system is given in Figure 10.

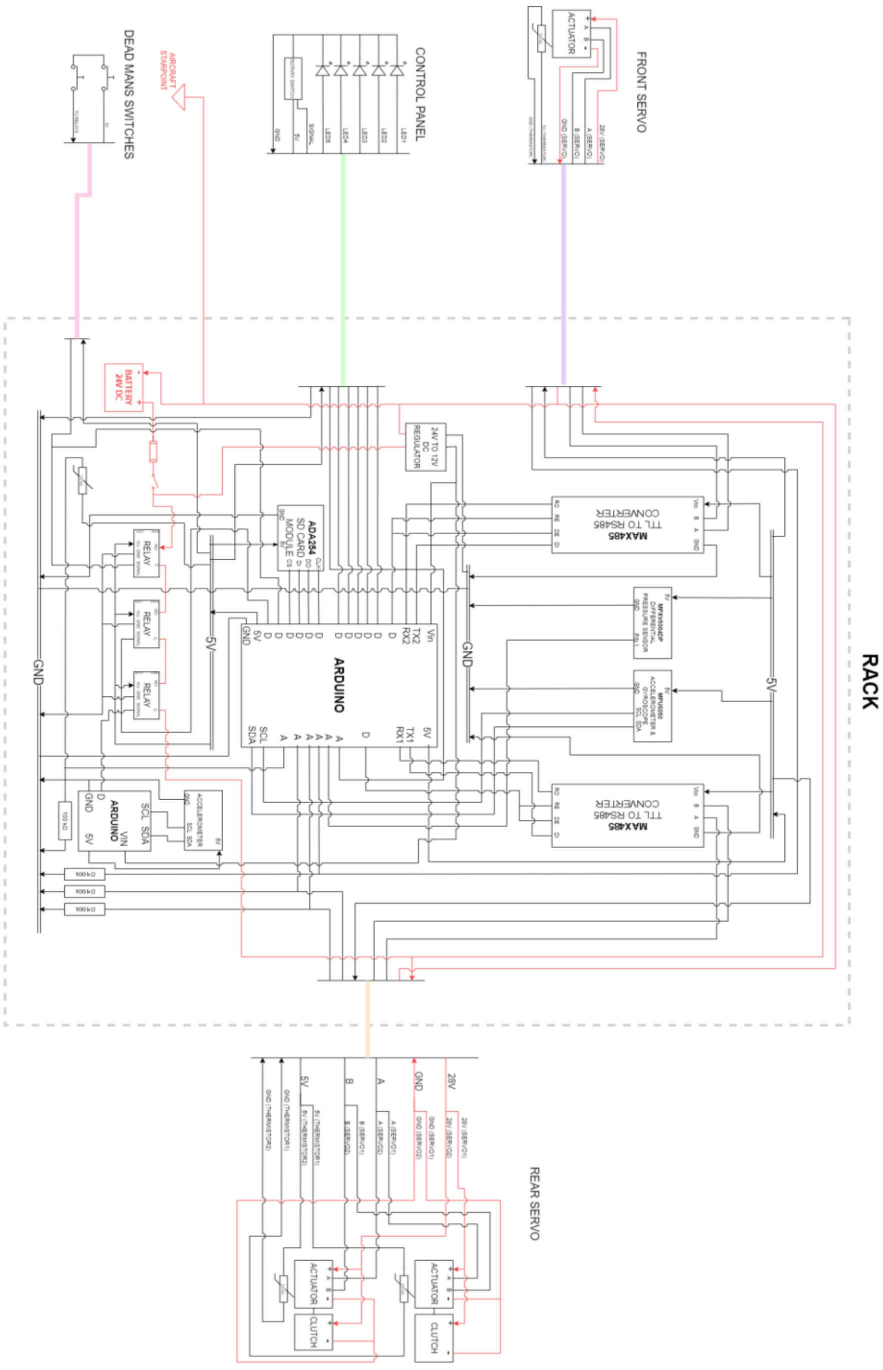

Figure 10: Wiring schematic of the electrical system.

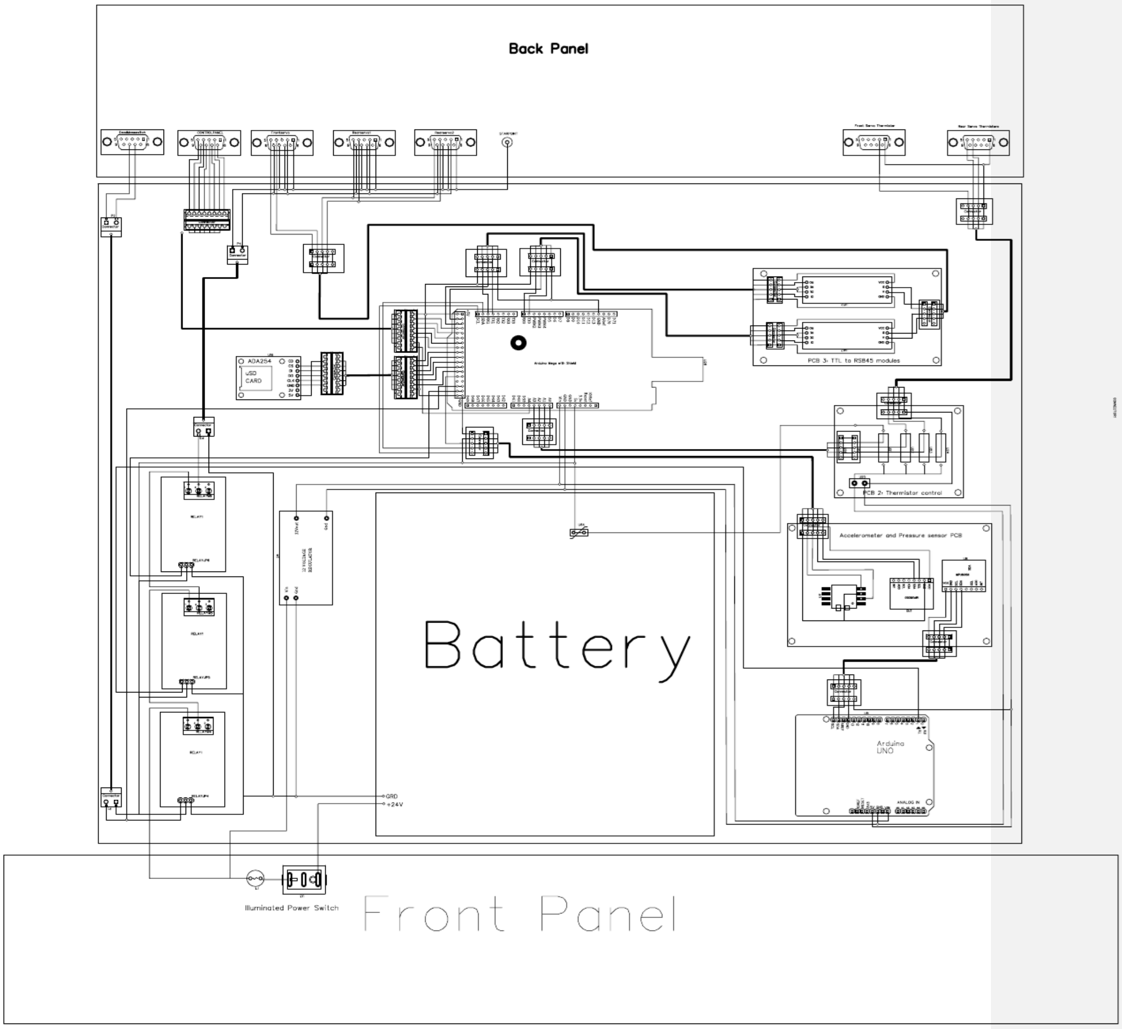

Figure 11: Wiring Diagram of Server Tray

As shown in Figure 10 and Figure 11 the modification will be powered by a 24 V battery and so will be independent of the aircraft power supply. The 24 V supply will then be regulated down to 3 voltage levels. These are 24 V for power to the servos/clutches, 12 V for the two Arduino microcontrollers and two 5 V rails, powered by the 5 V pins from the primary Arduino. Most of the system will be powered by the 5 V rails, including our sensors and flight data recording module. All these components will be grounded to the aircraft Starpoint as well, including the Arduino. To ensure the electrical demands of our system do not exceed the capability of our battery we have carried out an electrical load analysis.

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In Figure 11, all parts of the system internal to the server rack where most of the control system is located can be seen.

To verify that our system works, we will need flight data recording capability. The simplest way of doing this on an Arduino is via an SD card module. At a frequency suitable to the task, flight data, as calculated from the accelerometer, gyroscope and differential pressure sensor, will be written and saved to the SD card.

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Flight safety mitigation measures

Servos

- The two proposed servos at the idler will be fitted with electromagnetic clutches. When power to the clutch is disconnected by the Arduino itself or through one of the pilots releasing the dead man's switch, it will disconnect the servo from the existing elevator control circuit. This will allow P1 to take over flight control, hereby forming a redundancy measure where the original flight control system and handling qualities of G-OUAV will be restored (apart from the P2 control stick being disconnected from the system).
- The P2 control stick will be connected to the servo via a pin joint and so if the pilot determines the system is not safe, they can physically disconnect the control stick from the servo.
- The force feedback servo attached to P2 is only expected to provide a maximum aerodynamic load of 123 N and given the maximum permissible pilot effort force according to CS-VLA 391 on the control surface load is 740 N, the pilots should be able to overpower the servo if needed.

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Structural

- A structural load analysis has been carried out on all new parts added as part of the modification, using the ultimate structural loads expected at the relevant points in the elevator control circuit. (With a safety factor of 1.5). This will ensure the flight control system is structurally sound, as the minimum safety factor defined by the LAA is 1.5 according to CS-VLA 303.
- A structural load analysis will be carried out on the mounting of any parts aft of the pilots. This is to ensure any structures we fit can withstand a 18 g load in case of a head on impact as per the CS-VLA 561 General guidelines on aircraft crashworthiness.
- The servo mechanism at the idler will have a mechanical fuse, which will act as a further layer of safety, as if the specified shear load of 6916 N as this is double the expected maximum load respectively are exceeded, the system will be disconnected. (Details on the shear pin can be found in the structural report).
- The grab handle added as part of the dead man's switch will also be tested for a secondary load of 600 N as per AMC VLA 405, we will also use the 1.5 times safety factor outline in CS VLA 303 bringing the total to 900 N.

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Control system

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- A hierarchy-based coding structure will be used to ensure robustness. This means that all functions will be ranked in terms of importance for system safety to be maintained, and timed interrupts will be used on the most safety critical parts of the code. Therefore, if an input is not received in time, or at all, the code does not crash and is able to deal with the situation.
- Both Arduinos will have a dedicated digital output safety pin, which if not high will disconnect one of the clutches and deactivate the system. This allows all 3 of the clutches (and therefore servos) to be disconnected instantaneously by the Arduino. The Arduino will disconnect the clutches if:
  - A set of conditions checked within the code at each timestep exceed the aircraft's pre-defined flight envelope.
  - At any timestep any input is above a pre-determined limit or is not received in time.
- A saturation block will be added to the elevator output to ensure the output is within the capabilities of the elevator's range of motion. If the desired output is larger than the maximum elevator deflection, the output is capped at the maximum elevator deflection.
- When the control system disconnects the system, it will alert the pilots by flashing all the LEDs on the control panel for the system, which is located on top of the Scout's existing instrument dashboard.
- The control system code will be pre-compiled onto the Arduino and will be tested on the ground to ensure all safety measures are working before every flight.

Electronics and Wiring

- All electronic components, such as relays, will be mounted to the tray in the 19-inch rack.
- All electrical connections will be strain relieved and connected using aerospace grade connectors.
- All wiring will also be shielded using fire resistant insulating material and will be colour coded to identify live and signal wires.
- All wiring will also be bundled together and run through the aircraft in a manner to avoid any interference with the existing wiring and to avoid hindering the pilot's range of motion.
- The wiring will all be grounded to the aircraft ground at the aircraft starpoint.
- To avoid any interference with the aircraft electrical system the modification will be run from an additional battery fitted in the 19-inch rack.
- For extra redundancy, we will always monitor the battery temperature using a thermistor and include a fuse to protect the control system from any current surges.

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Other safety considerations

- The total weight of the modification added will not exceed 20 kg and so should not exceed the baggage allowance on the aircraft. This means the additional equipment

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on the aircraft should not have an adverse impact on the weight balance of the aircraft.

- Since this system will affect the flight control system, please find attached an Operational Supplement.
- As we intend to make this system removable, please find an Installation and Maintenance Supplement.

Document List

Operational Supplement
Installation and Maintenance Supplement
Failure Mode and Effects Analysis
Pseudocode
Electrical Load Analysis
Structural Report
Compliance Checklist
Weight and Balance
Flight Test Plan
Drawings

Document 3 - G-OUAV Operational Supplement

Variable Stability Demonstrator Modification

Aircraft Registration:	G-OUAV
Aircraft Type:	TLAC Sherwood Scout
Aircraft Serial Number:	345-15480
Modification Number:	15610
Date Created:	03/04/2021

Authors:

Jerin George, Callum Breslin, Daniel Newman-Sanders, Andrew Kernan and Declan Clifford

G-OUAV Operational Supplement

1 Contents

2 Pre-flight Checklist

1. Check the battery level.
    a. If below 80 %: Do not operate the system.
    b. If above 80 %: Safe to continue flight.
2. Check the electrical connections and ensure all the fittings and the wiring is secured correctly.
3. Ensure the desired three flight modes are programmed.
4. Check the control panel indication LEDs are functional.
5. Run safety checks (start the Arduino in GROUND TEST mode).
    a. Check the servos are free to move.
        i. Check the force feedback servo can move through the full range of motion required unhindered by moving the P2 stick. Check against the markings on the force feedback servo.
        ii. Check the elevator servos can move through the full range of motion required unhindered by moving the elevator. Check against the markings on the elevator servos.
    b. Check the mechanical stops for the force feedback servo and elevator servos are in place.
    c. Start the Arduino in GROUND TEST MODE
        i. Check the operation of the sensors.
            1. Check the gyro and accelerometer react to moving the aircraft.
            2. Check the readings from the pitot static tube.
        ii. Check the dead man's switch operation is satisfactory and P1 can regain control with the safety switch disengaged (MODE 1 on control panel).
        iii. Check the operation of the servos.
            1. Ensure there is someone sitting in the P2 seat with a firm grip on the stick.

    2. Select MODE 2 on the control panel. The force feedback servo will apply a sinusoidal force to the P2 stick.
    3. Select MODE 3 on the control panel. The rear servos will move the elevator through the full range of motion.
6. If the safety checks are complete, reset the Arduino to flight mode.

3 Operational Manual

3.1 Control Panel

The control panel is shown in Figure 1.

Figure 1: Control panel.

3.1.1 Location

The control panel is located on top of the instrument panel as per Figure 2.

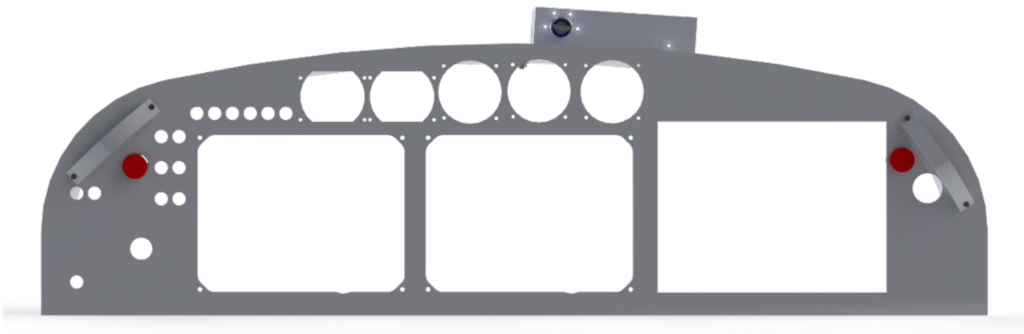

Figure 2: Location of the control panel on the Scout's instrument panel.

3.1.2 Usage

Changing settings of the control system in flight is done **only** through the control panel.

There are 4 settings available in flight. These settings are selected through a rotary switch (Figure 3).

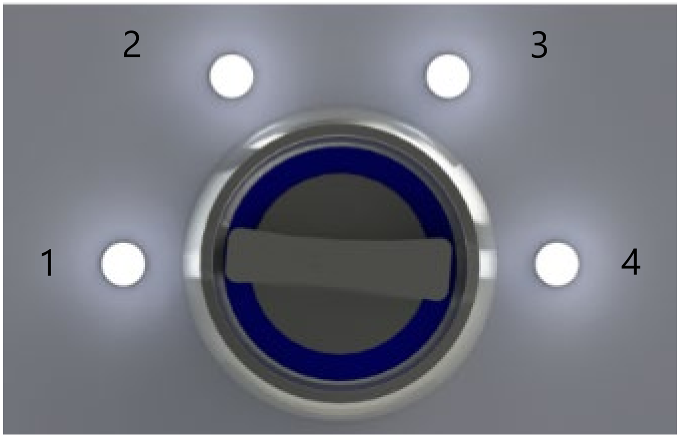

Figure 3: Control panel rotary switch.

The settings available and their positions are:

1. OFF
2. MODE 1
3. MODE 2
4. MODE 3

WARNING

Updating the configuration of a mode must be done on the ground only. The flight controller code must be ground tested before each flight; even if there have been no changes made to it from the previous flight.

3.1.3 Modes

3.1.3.1 OFF

The pilot stick force feedback servo and elevator servos are disconnected. The flight computer is powered and will log data from the sensors.

3.1.3.2 Active MODES

MODE 1, MODE 2 and MODE 3 are active modes.

The flight computer, pilot stick force feedback servo and elevator servos are powered when an active mode is selected, as long as the dead man’s switches are depressed.

NOTE

A mode is a target aircraft the control system uses to modify the pilot stick force feedback and elevator position to give the stick-fixed longitudinal characteristics of the target aircraft.

WARNING

P1 should not apply any force to the stick when an Active MODE is selected.

3.1.4 Indicator LEDs

The LEDs provide a secondary indication of the MODE that has been selected with the rotary switch.

LED 4 is ON when the dead man's switches are ENGAGED.

All LEDs will flash ON and OFF when the automated safety check has DISENGAGED the system.

3.1.5 Control System Server Tray

- 2U tray designed to fit into the existing 6U server rack installed in the aircraft's baggage bay.
- The rack contains the battery and all other electronic subsystems required for the control system.
- The Front Panel includes:
    - An illuminated switch to engage/disengage the battery.
    - A fuse holder for system overload protection (Requires a 16A fuse).
- The Back Panel includes:
    - D-Sub connectors for the dead man's switches, control panel, thermistors (x2 for the front servo and the two rear servo assembly).
    - Single pin connector to ground the system to the aircraft star point.
- This modification will weigh 5 kg.

4 Safety Notes

4.1 Elevator Limits

The range of motion of the elevator servos is limited to ± 27° by mechanical stops on the elevator servos when the flight augmentation system is ACTIVE OR DISENGAGED.

The range of motion of the elevator is limited to ± 25° in the control system software when the flight augmentation system is ACTIVE.

4.2 Disengaging the System

The flight augmentation system can be nominally disengaged by selecting the OFF position using the rotary switch on the control panel.

4.3 Manual Disengagement in an Emergency

There are two dead man's switches built into the control system. The location of these switches is shown in Figure 4.

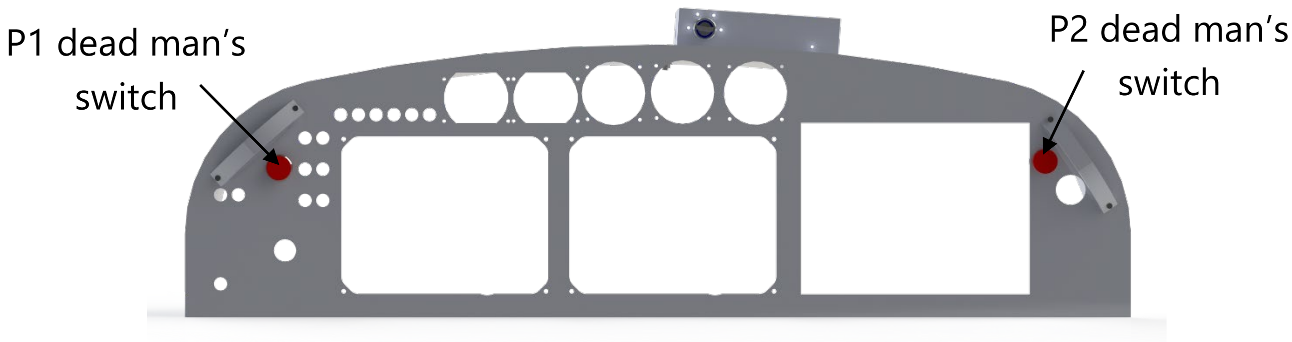

Figure 4: Location of the dead man's switches on the Scout's instrument panel.

If either P1 or P2 believes the flight augmentation system is causing an imminent risk to the aircraft or pilots the flight augmentation system can be immediately DISENGAGED by releasing one of the dead man's switches.

NOTE

There is a pin in the connection of the P2 stick. This pin can be removed which will disconnect the P2 stick from the force-feedback servo.

4.4 Automatic Disengagement in an Emergency

As part of the flight augmentation system the flight computer performs a safety check at each timestep in the control system software.

If the control system detects the aircraft is about to exceed the test envelope it will automatically depower the servos.

Automatic Disengagement Conditions

- Flight speed **exceeding 0.9 V_d**
- Flight speed decreasing **below 0.9 V_a**
- Aircraft angle of attack **exceeding + 10° or – 5°**
- Elevator deflection **exceeding ± 25°**
- Aircraft G-loading **exceeding + 1.5 g or + 0.5 g**
- Aircraft rate of change of G-loading exceeding **7.6 g/s**.

NOTE

There is a structural fuse between the elevator servos and the idler. This fuse will break if a force greater than 7 kN is applied. When the fuse is broken, the elevator servos are no longer connected to the elevator.

4.5 Requirements of Pilot Experience

- Given the modification is designed for training purposes P1 should be an experienced pilot.
- P2 should also be an experienced pilot till the system has matured and can be proven to be safe.

4.6 G Ratings

- Initially the system will be set to never exceed + 1.5 g or + 0.5 g but can be increased in incremental steps as the system matures to that of the aircraft design flight envelope (+ 3.8 g and - 1.8 g).

5 Extra Pilot Notes

- When the system is engaged the movement of the P1 and the P2 control columns will be different.
- When the dead man's switch is disengaged the return of control to P1 is sudden and so P1 should always be prepared to take over manual flight.
- Expect an additional but negligible increment in stick force when the system is engaged for P1 due to the added inertia from the rear servo mechanism.
- When the system is installed the full elevator deflection of the aircraft will not be available:
    - Limited to ± 27° by mechanical stops.
    - If the system is ACTIVE limited to ± 25° by the control system.

Document 4 - G-OUAV Maintenance and Installation Supplement

Variable Stability Demonstrator Modification

Aircraft Registration:	G-OUAV
Aircraft Type:	TLAC Sherwood Scout
Aircraft Serial Number:	345-15480
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Date Created:	03/04/2021

Authors: Jerin George, Callum Breslin, Dan Newman-Sanders, Andrew Kernan and Declan Clifford

G-OUAV Maintenance and Installation Supplement

Contents

Installation Guide

Front Servo Assembly

Figure 1 shows the full P2 control stick and force feedback assembly.

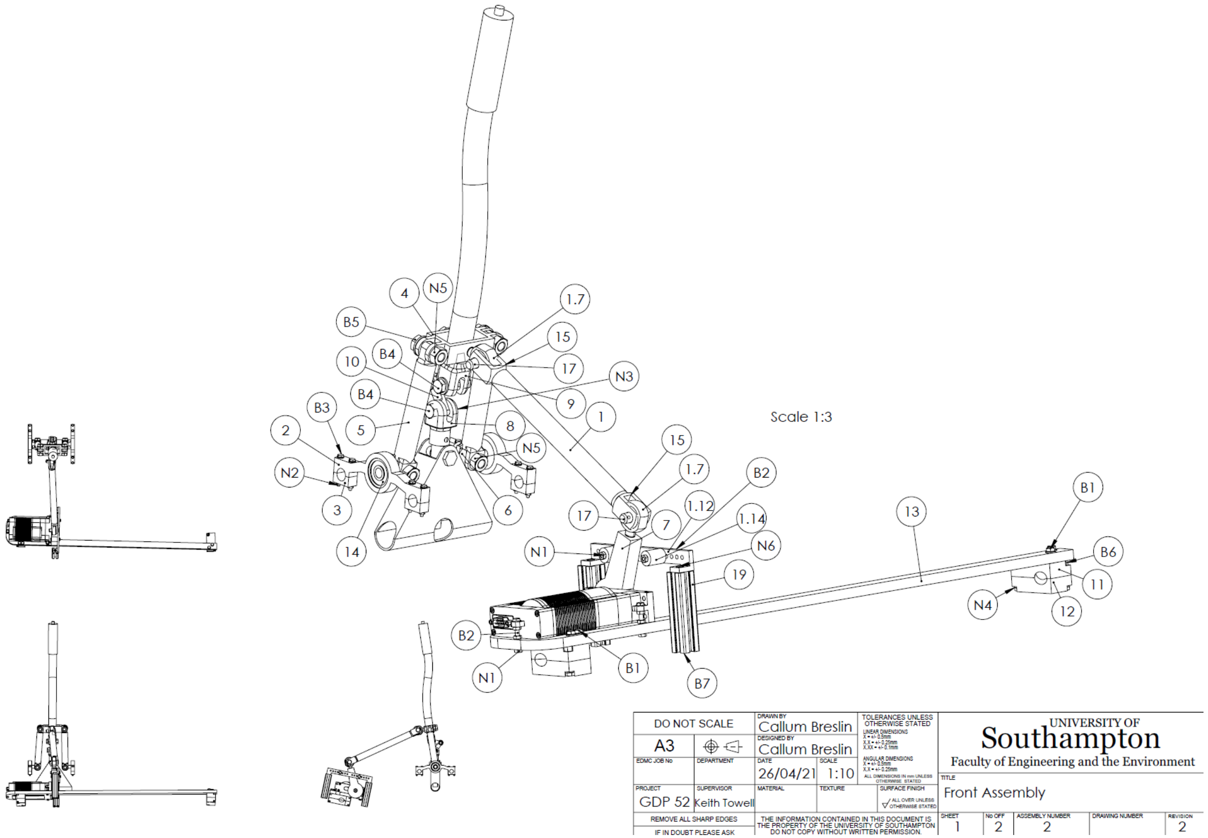

Figure 1: Front servo assembly drawing.

Step 1

Having removed the original control stick from the P2 side of the cockpit, affix the lower scissor attachment to the existing aileron connection rod. This is fixed in place by a screw through the longitudinal axis of the part when installed, through the pre-made hole in the part and existing hole in the aileron rod.

Next take the two scissor links and position them relative to each other as shown below. Use two M8 bolts, nuts and washers to attach these together and to the lower scissor attachment. These should be torqued to 28.4 Nm.

Finally connect the upper scissor attachment with the last set of M8 hardware to the top of the second scissor link. The result should be as shown on the right hand side of the Figure 2.

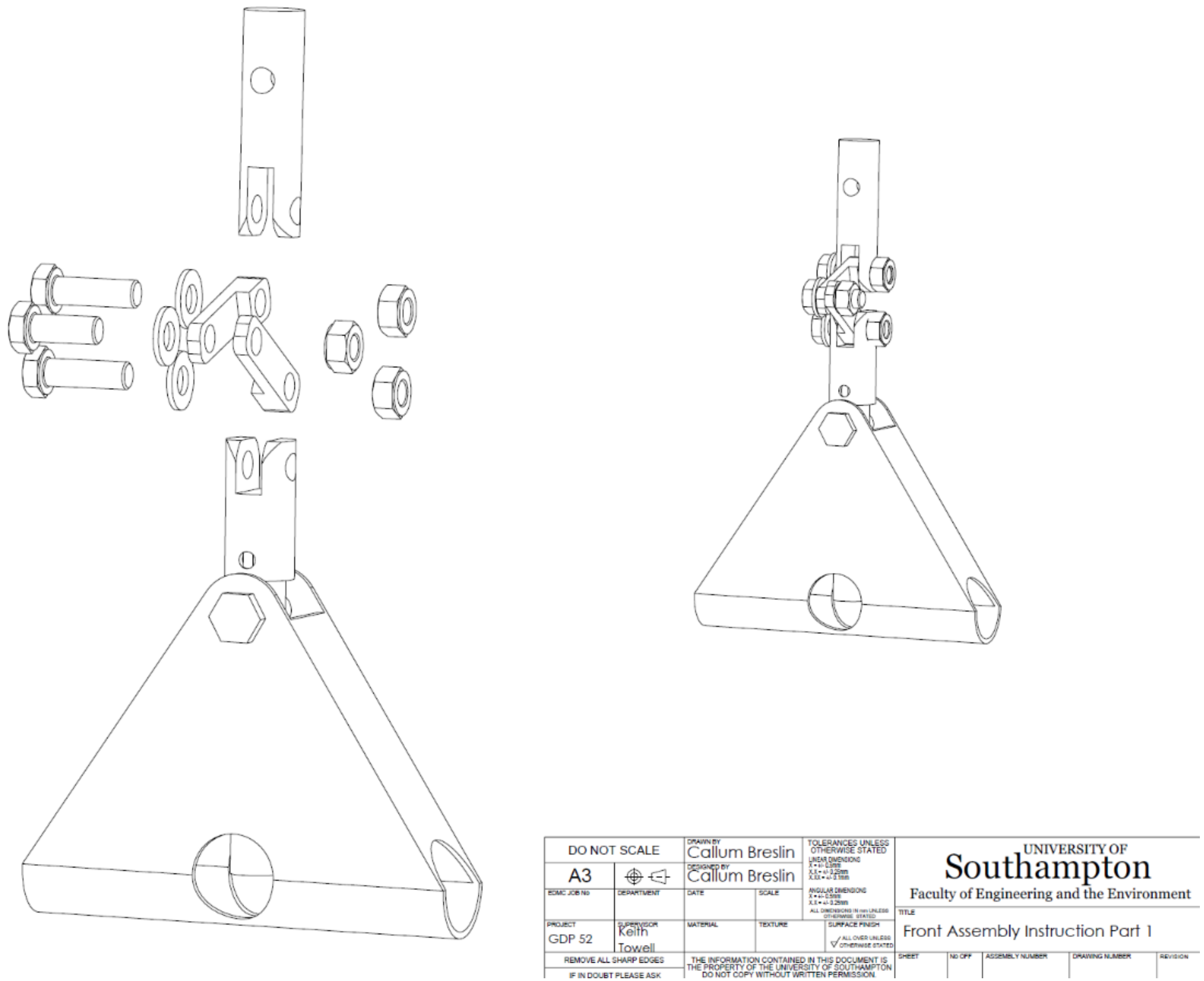

Figure 2: P2 stick scissor mechanism.

Step 2

Using two M10 bolts, washers and nuts, attach the stick-frame-bearing links to either side of the stick mounting frame as shown. The bolts should be torqued to 56.3 Nm.

Then using the same hardware, connect the afore mentioned stick-frame-bearing links at the bottom to the bearing longitudinal pivot pieces. Once this is done, the assembly should match that on the right hand side of the Figure 3.

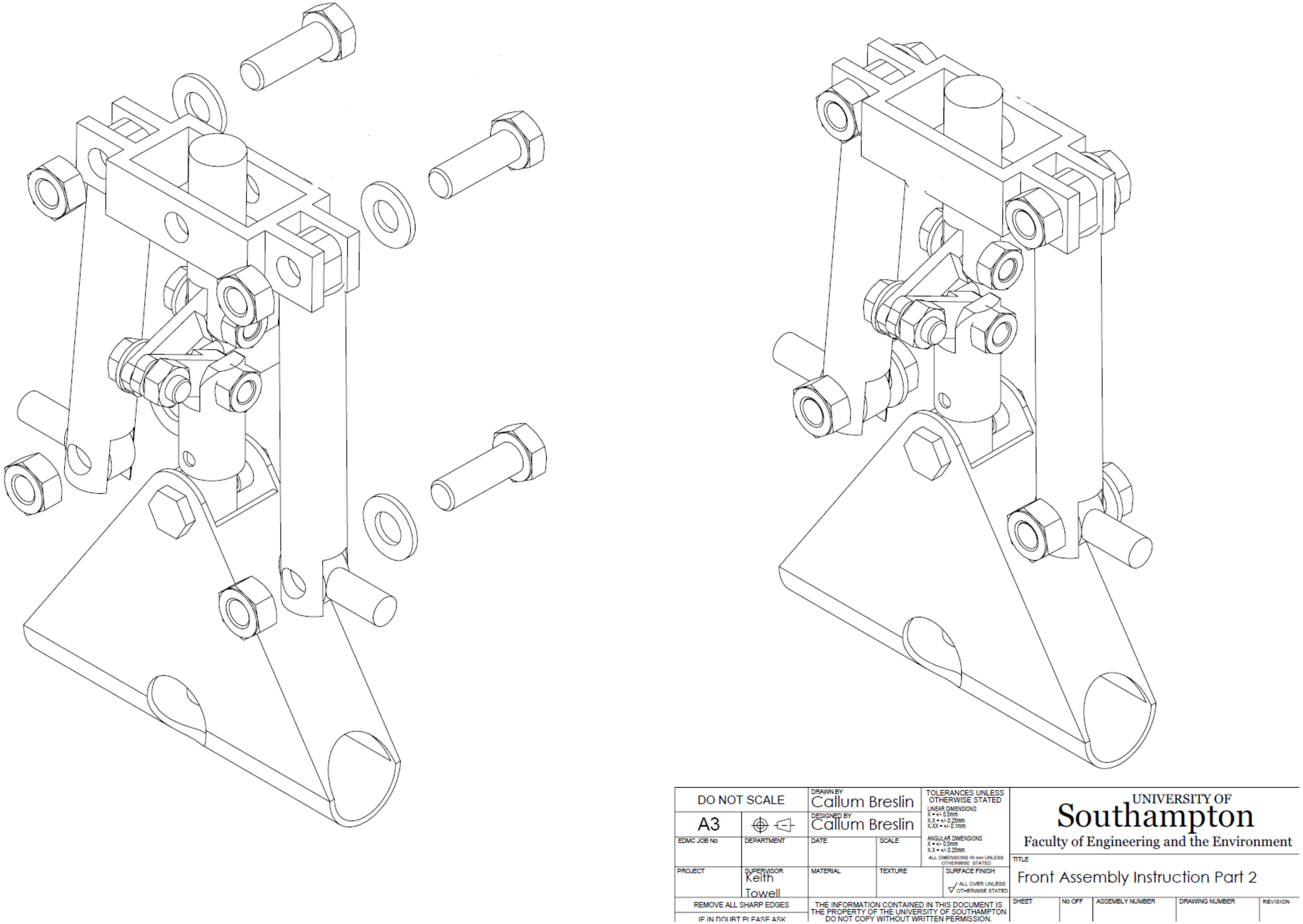

Figure 3: P2 stick frame assembly.

Step 3

Press the protruding "tails" of the bearing longitudinal pivot pieces into the central bore of the bearings which are pressed into the bearing mount tops. This should be done in a workshop with an adequate press.

One at a time, place the bearing mount top parts onto the existing fuselage tubes which run laterally across the cockpit fore and aft of the original control stick. Once this is seated such that the tubes pass through the notches cut into the part, attach the bearing mount bottom parts from underneath the tube using M3 bolts, washers and nuts. This will clamp the part to the fuselage. Attach these loosely at first to allow for the clamp to slide across the tubes for adjustment of the location. The bolts should be torqued to

Once the position is satisfactory, tighten the nuts and lock the mount into place. The mechanism should now resemble the right hand side of Figure 4.

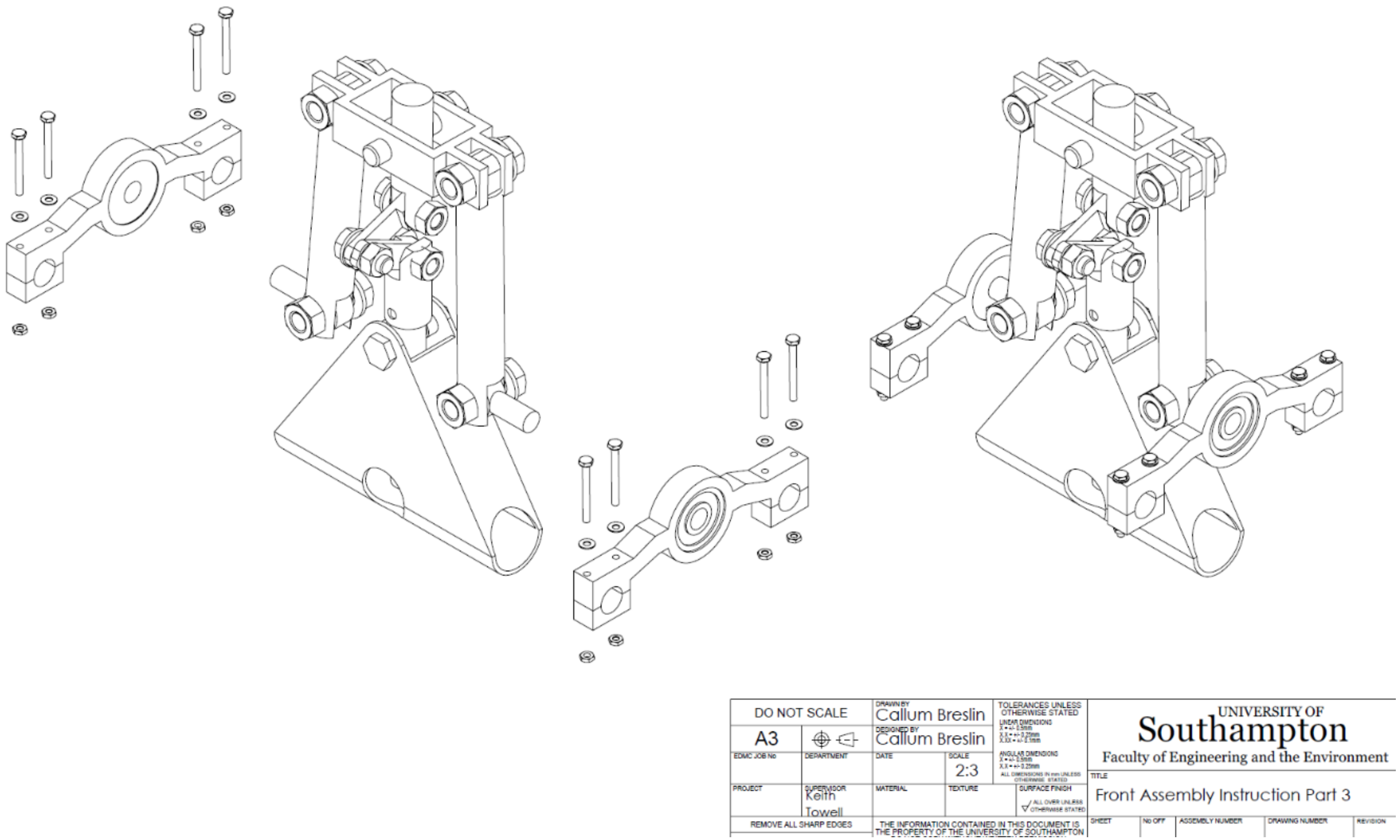
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Figure 4

Step 4

Allow the stick mechanism to rotate backwards towards the seat of the aircraft, this will allow you better access to the cockpit footwell. Take the front servo mounting plate and the footwell fuselage attachments. Pair the footwell fuselage attachments such that there is one of each type in each pair. Proceed to place one half beneath the diagonal strut in the footwell and the other above the strut. This should be done one both the P1 and P2 sides of the cockpit. Loosely clamp these onto the diagonal bars through the M5 bolts, washers and nuts, to allow for adjustment.

Take the front servo mounting plate and move the footwell fuselage attachments at either side such that they are the same distance apart as the associated holes for attaching them to the servo mounting plate. This is illustrated in figure 5. Once the position of the footwell fuselage attachments is such that the holes line up, tighten the bolts such that they are clamped in position and will not move. The bolts should be torqued to 6.9 Nm.

Next place the front servo mounting plate on top and use M5 bolts and washers to affix this to the footwell fuselage attachments via the threaded holes. This assembly should now match the one shown in Figure 5.

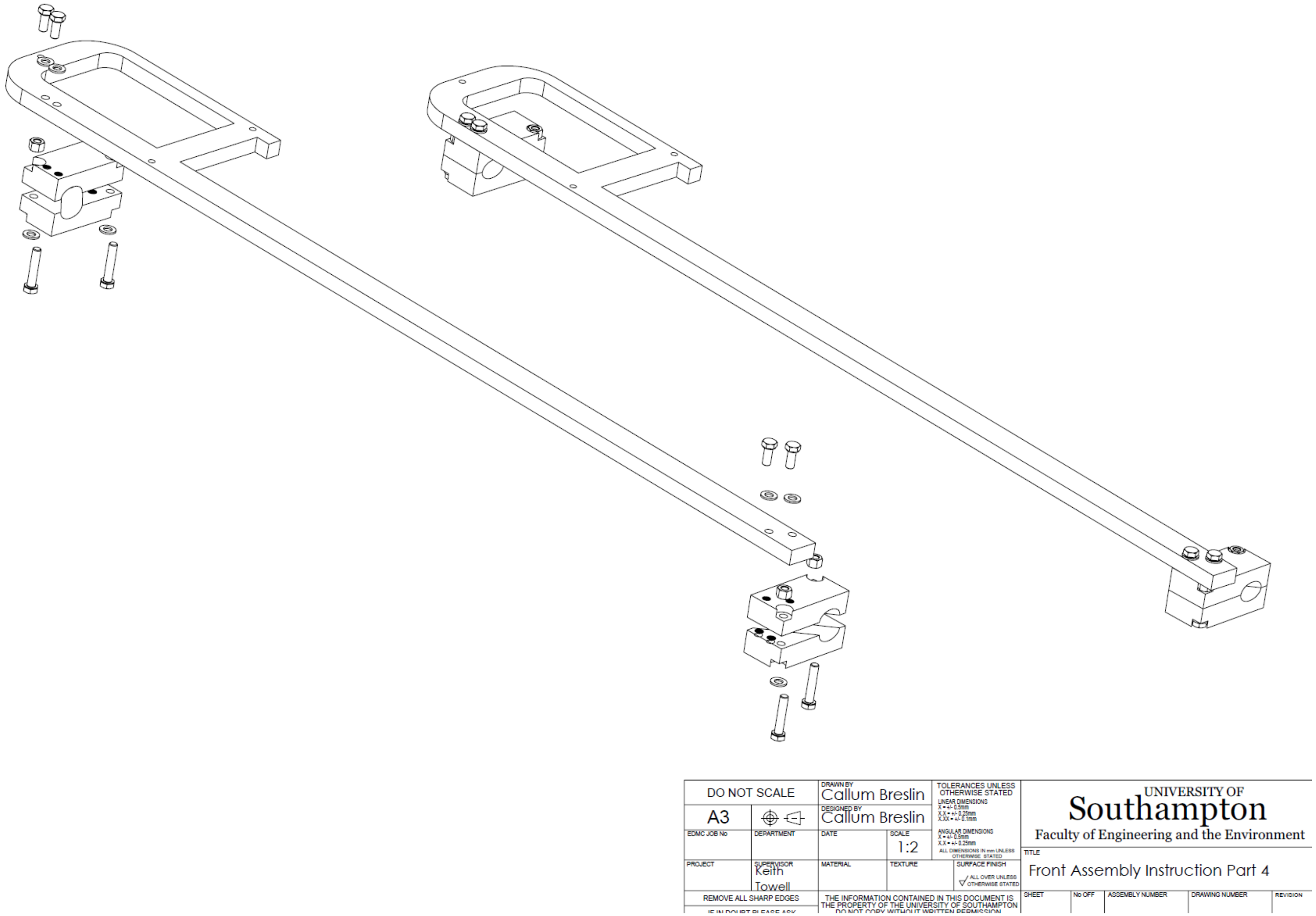
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Figure 5

Step 5

Take the front servo, the Volz DA-30-HT and feed through the long M4 bolts with a washer, place a nut immediately next to the hole on the servo through which the bolt passes on each bolt. Place a further nut onto each of these bolts before slotting the bolts through the associated holes in the front servo mounting plate. Finally place another bolt on the bolt on the other side of the front servo mounting plate. It is then possible to move the two latest nut on each bolt such that the servo sits level vertically and without interfering and coming into contact with the mounting plate. There should be an appropriate gap between the mounting plate and the servo.

After this step, the cockpit footwell assembly should look like the right hand side of Figure 6.

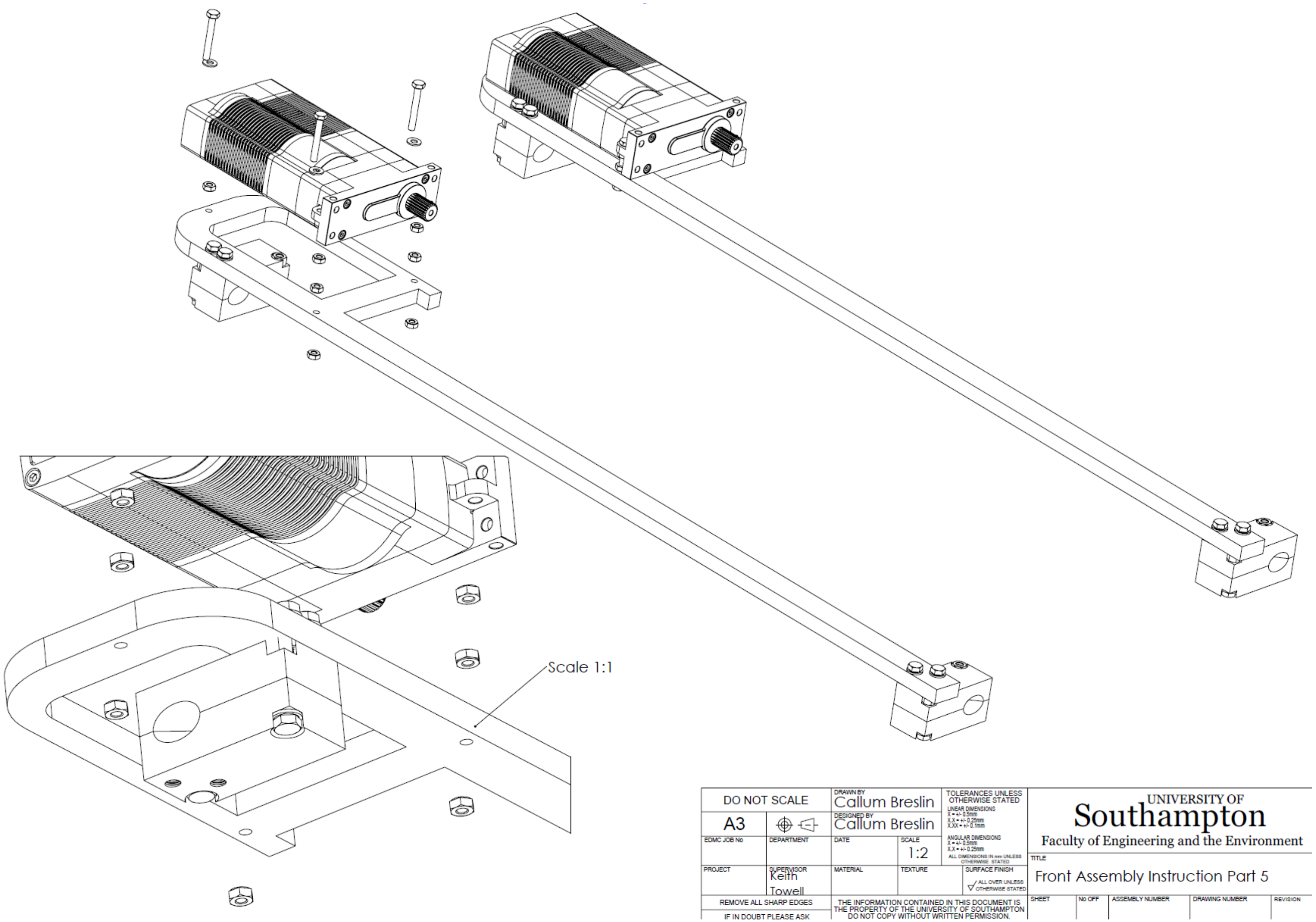
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Figure 6

Step 6

Push the front servo arm onto the shaft of the servo, taking care to align the splines. Once this is secured with a screw in the end of the shaft, begin by attaching the off-the-shelf clevis hardware. The spherical bearing part should be attached to the front servo arm such that the axis of the bore hole is perpendicular to the plane of motion of the servo (i.e., it is port to starboard). This should be attached by the thread into the tapped hole on the end of the servo arm. This is shown in Figure 7.

Place the clevis fork such that the hole in the spherical bearing aligns with the holes in the fork section of the part. Insert the clevis pin into the hole and attach the retaining clip.

The same methodology should be employed at the previously assembled stick assembly. With the spherical bearing being pushed through the hole in the stick mounting frame, passing through both the upper scissor attachment and the control stick through their appropriate holes. An M10 nut should then be used on the other side of the stick frame to secure this part in place. This is shown in Figure 8.

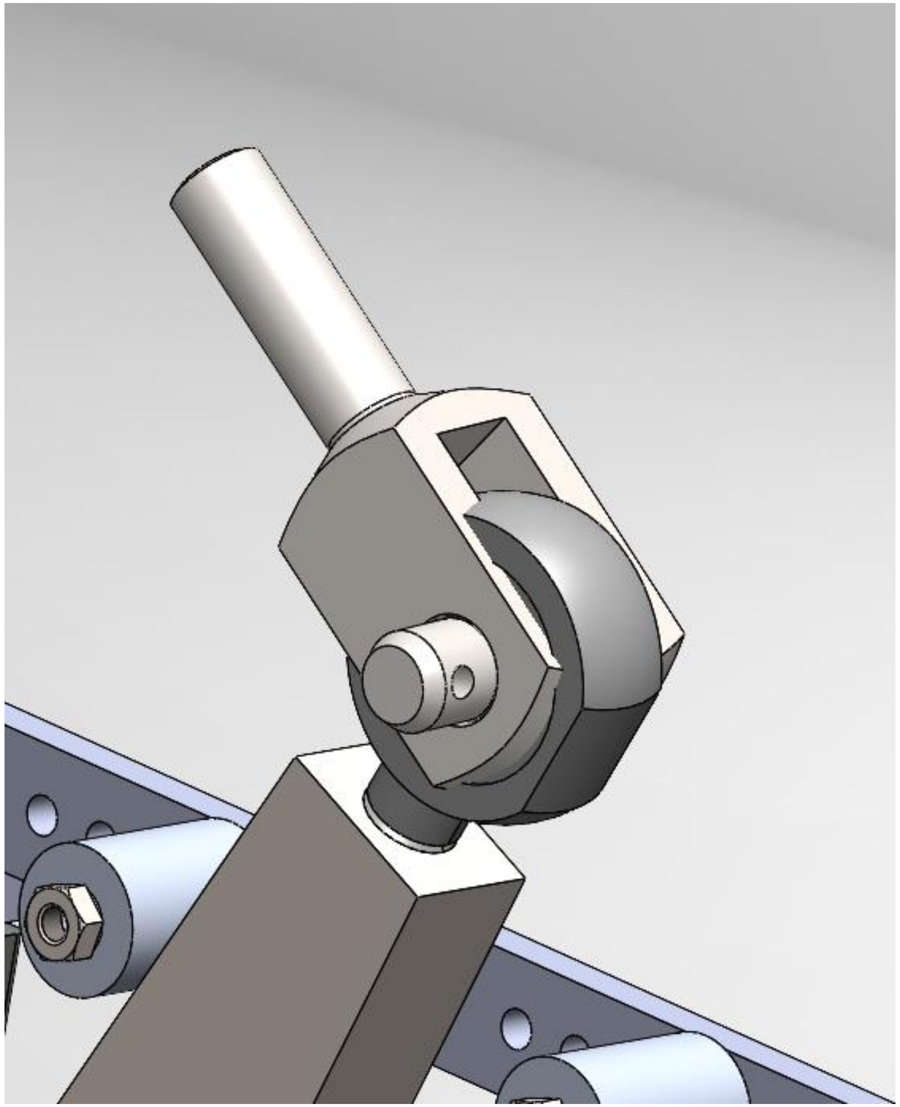

Figure 7

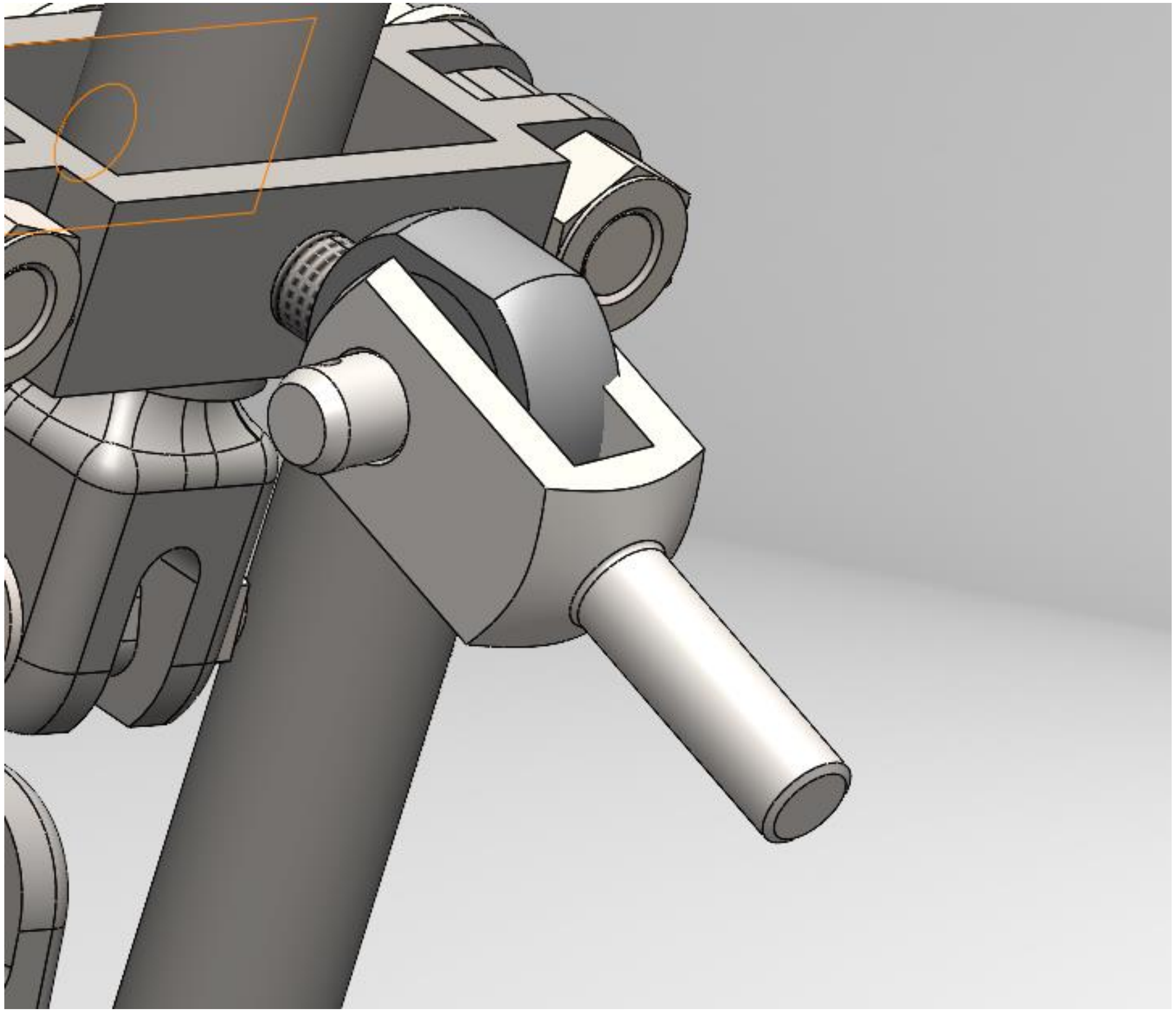

Figure 8

Step 6

The penultimate stage is to attach the two sub-assemblies together with the front push rod. Starting at the servo end, screw the push rod onto the male protrusion of the clevis fork joint, making use of the threaded hole in the push rod. Secondly attach the other end of the push rod, making note that the ends of the push rod are threaded with opposite directions, i.e., one end has a left hand thread, the other has a right hand thread. This allows both ends to be simultaneously tightened. As an alternative, it is possible to detach the clevis forks by removing the clevis pins, and affix these to each end of the push rod in isolation. This would allow the push rod to be installed by simply replacing the clevis forks to their previous positions and inserting the clevis pins and retaining pins. Figure 9 illustrates this process.

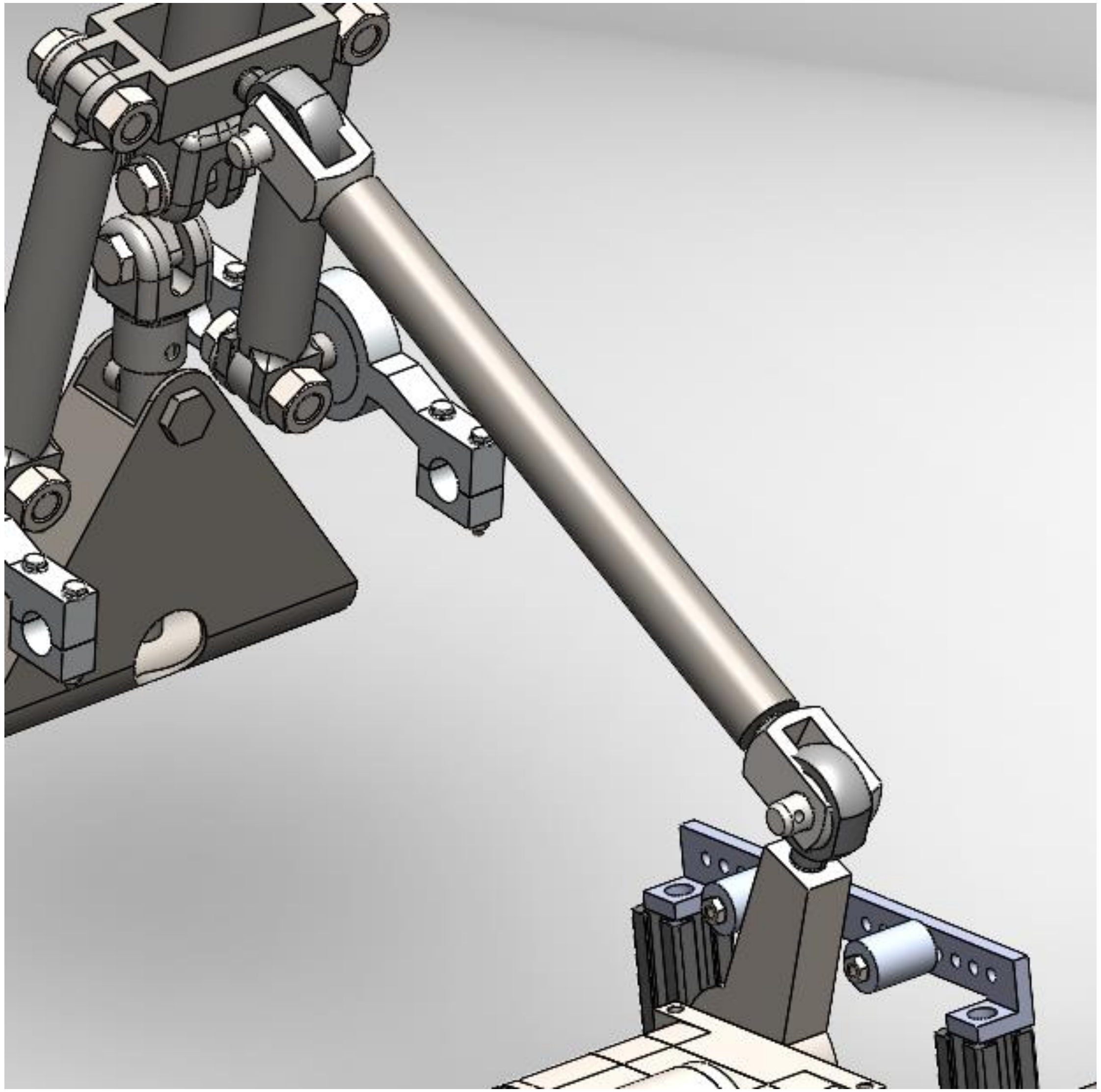

Figure 9

Step 7

Finally, it is time to attach the control stick, this is left to last to allow for better access without the stick being in the way. To install the stick, remove the longer bolt from the centre of the stick mounting frame, slide the stick over the upper scissor attachment and replace the bolt such that it links the two aforementioned components. This completes the front assembly as shown in Figure 10.

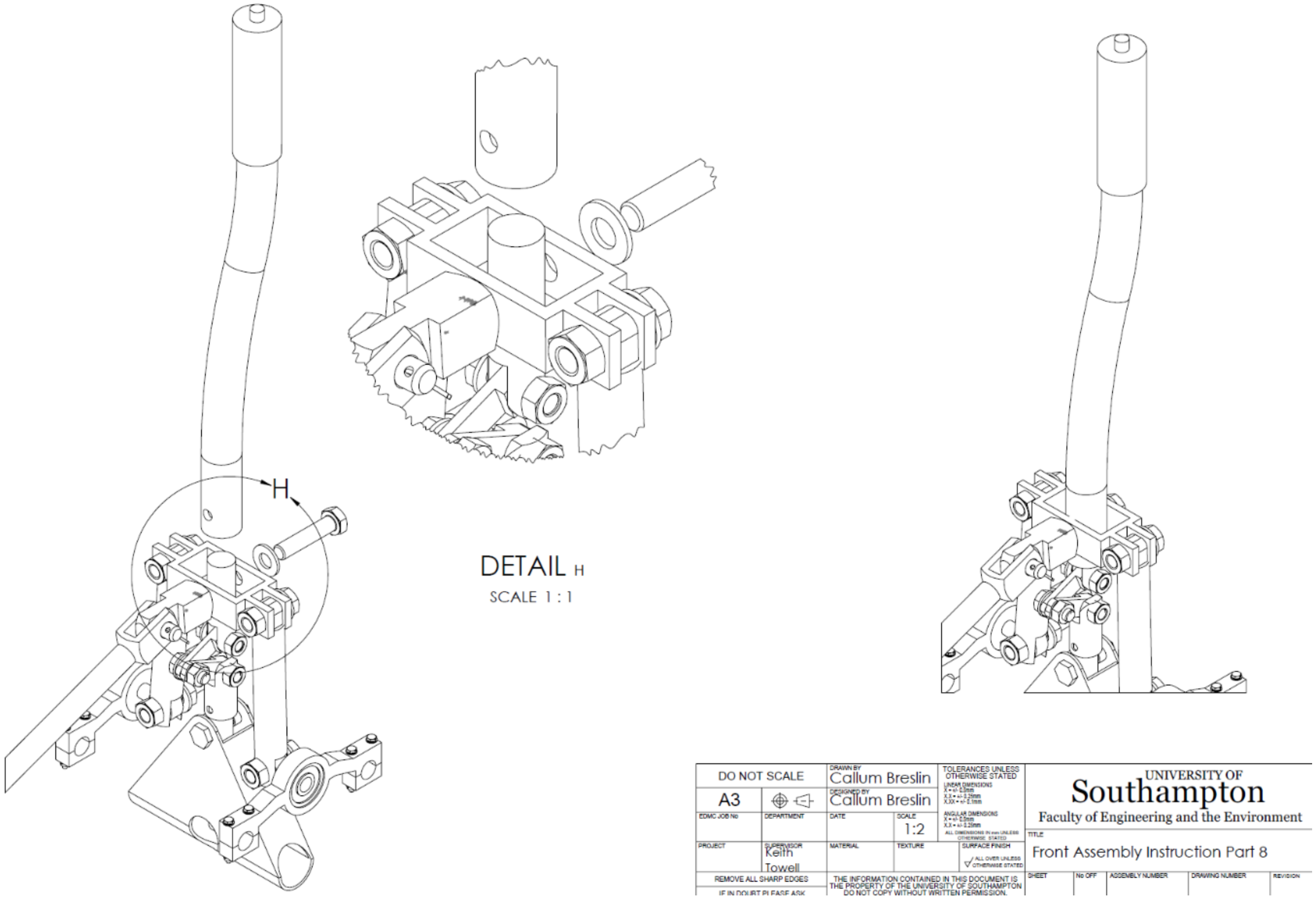
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Figure 10

Rear Servo Assembly

Step 1

Take the rear servo mounting plate and attach the 6 rear servo plate legs via M6 bolts and washers into the threaded holes in the top of the leg components. This will form the table-like structure for the servos to sit atop of. This process is illustrated in Figure 11.

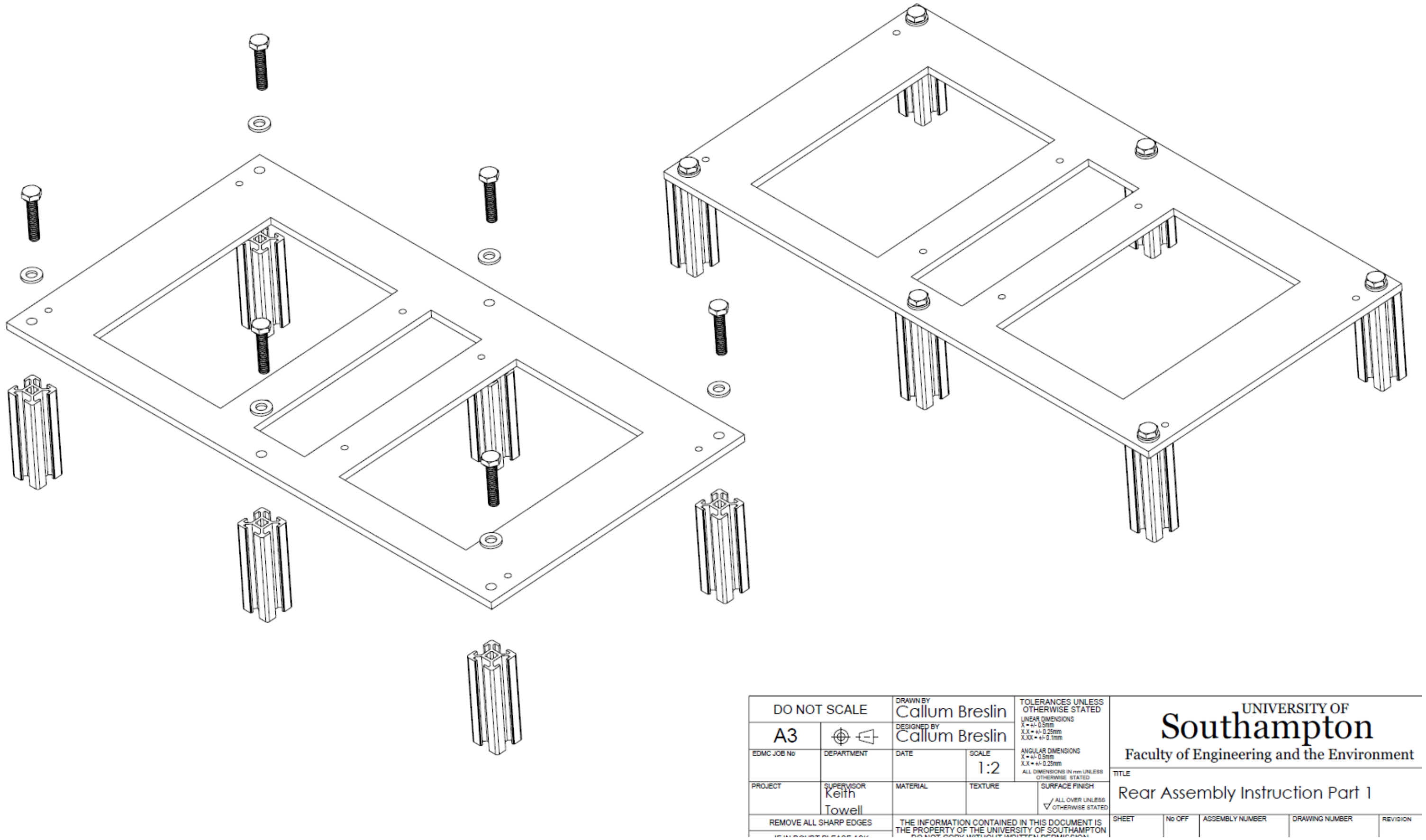
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Figure 11

Step 2

In a similar fashion to step 1 and as shown in Figure 12, attach the table structure to the floor of the baggage bay by M6 bolts and washers through the pre-drilled holes in the floor. This will secure the structure to the aircraft.

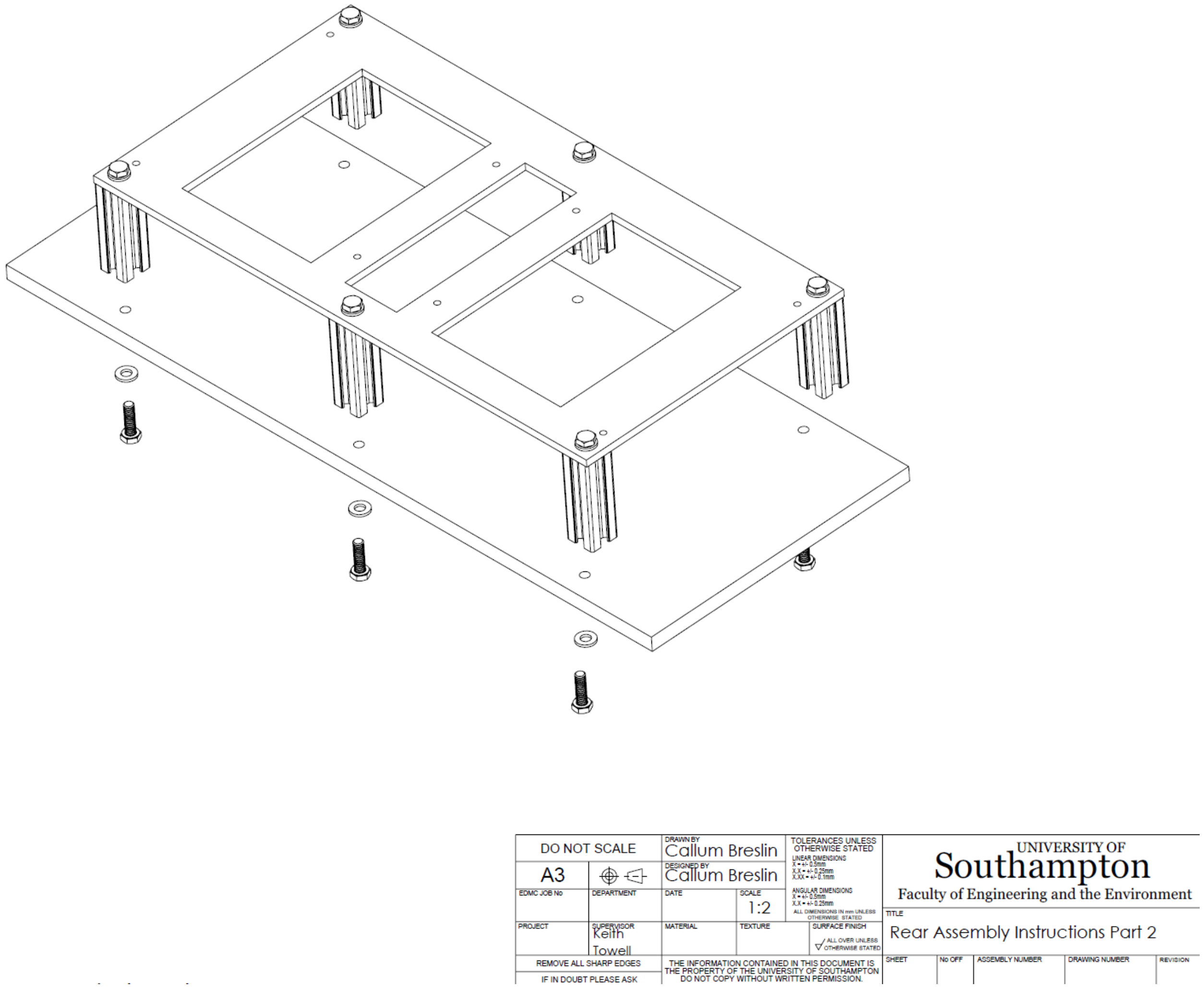
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Figure 12

Step 3

Insert M4 bolts with washers into the mounting holes on each servo, these are located on all 4 corners of the servo housing. Align these bolts with the mounting holes on the rear servo mounting plate. Use nuts in the same fashion as explained in step 5 of the front assembly instructions to ensure that the servos are not in contact with the plate itself.

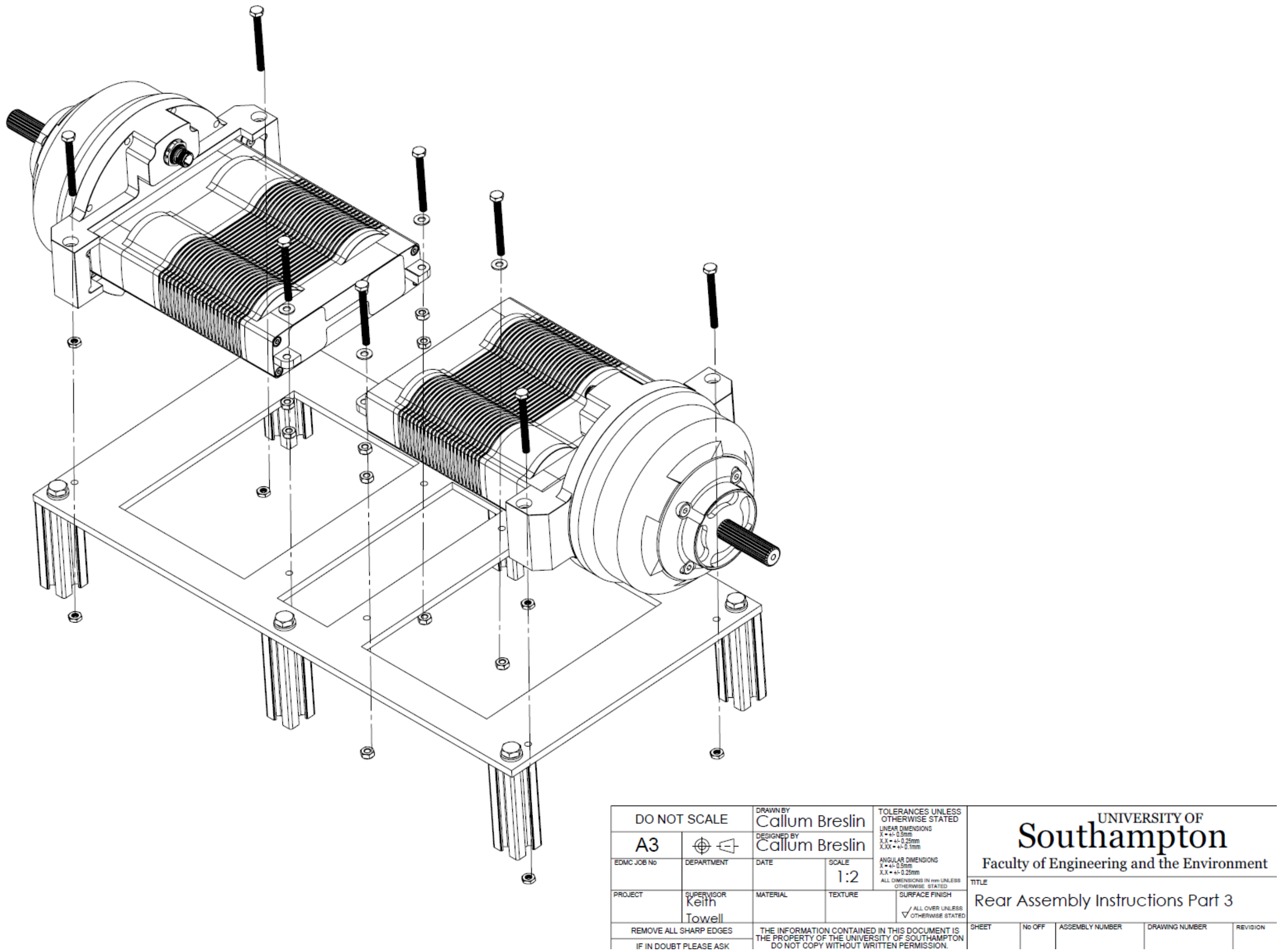
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Figure 13

Step 4

The rear servo arms should be pushed onto the servo shafts, taking care to align the splines on the shaft and corresponding pattern on the servo arms. Then take the combiner, ensure that the slot on the top and bottom of one side of the combiner is on the starboard side of the aircraft. Attach the combiner with an M10 bolt with washer to the servo arm, making use of the threaded hole with the bolt. Then take the combiner slider part and slide this inside the hollowed end of the combiner, making sure that the M10 hole is at the exposed end of the part when it is partially inserted. Now fix this to the servo arm through another M10 bolt and washer as previously done with the combiner and other servo arm.

The assembly thus far should look like the right hand imagine in Figure 14.

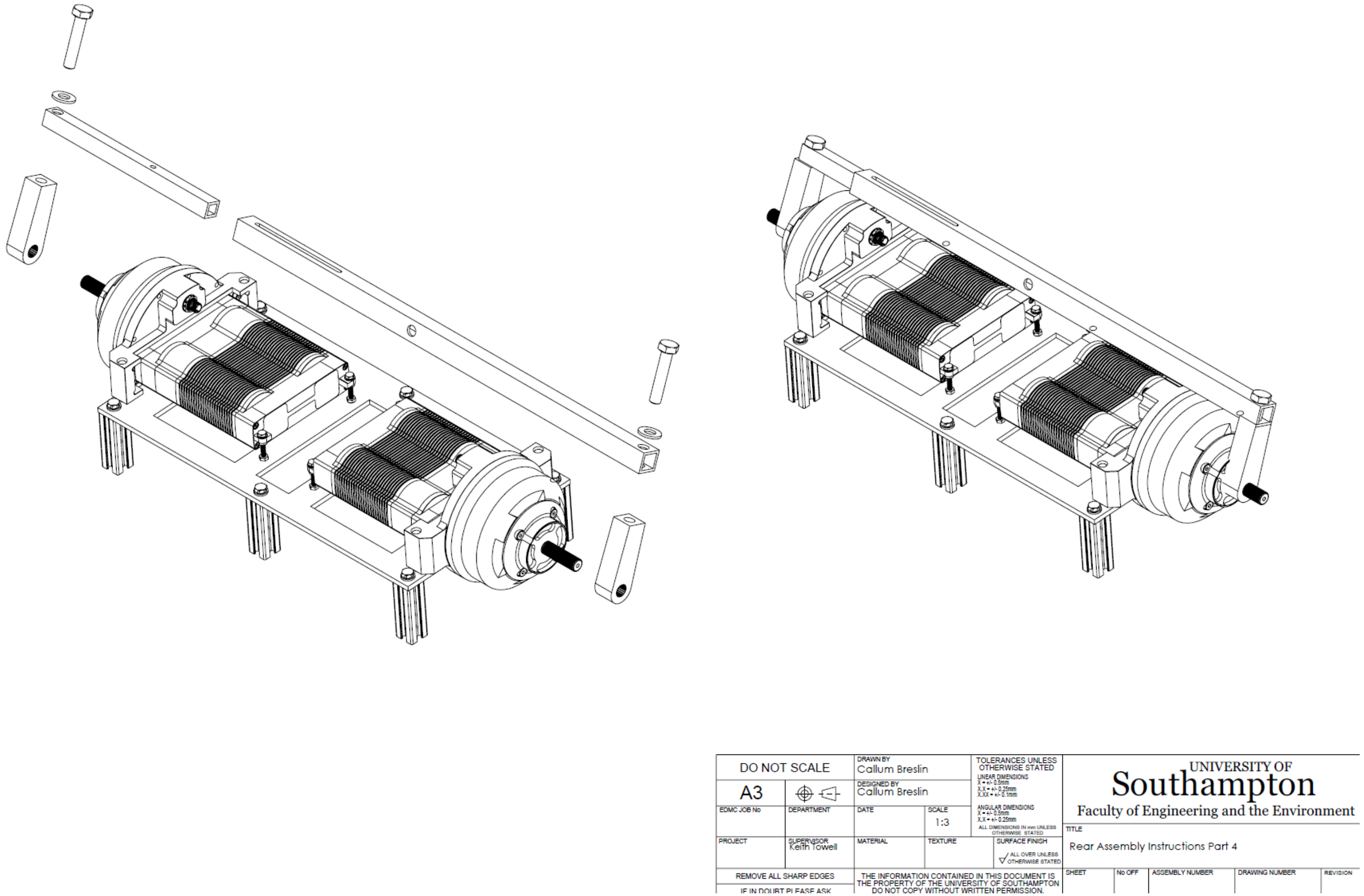
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Figure 14

Step 5

Pass the male protrusion of a clevis fork through the hole in the centre of the combiner such that the fork end is pointing towards the rear of the aircraft. This should then be secured from the other side using an M10 nut.

Next insert the retaining M5 bolt with washer through the slot in the combiner, in through the hole in the combiner slider and back out through the slot in the other side of the combiner. This should then be secured with the corresponding nut.

Take the final clevis fork and attach it by bolt over the top connection of the existing idler. This is where our system will provide an output. It should now resemble the right hand image in Figure 15.

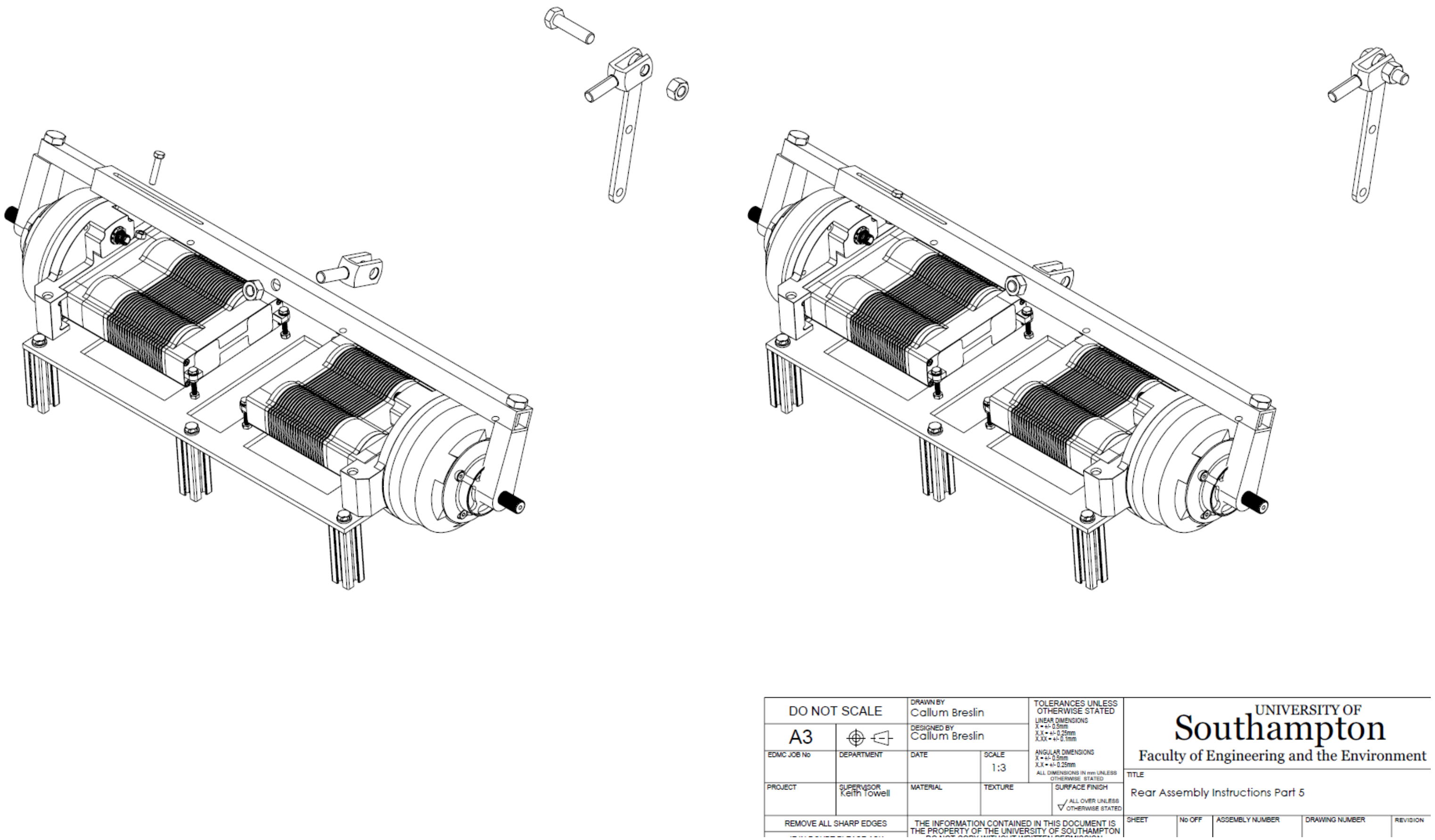
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Figure 15

Step 6

The spherical bearing should now be inserted into the combiner-side clevis fork slot and secured with an M10 bolt with a washer and corresponding nut. The structural fuse connector should then be screwed via the threaded hole on the rear of the part onto the idler-sider clevis fork. Care should be taken to ensure that the structural fuse connector is in the proper orientation with the elongated axis of the forward section being parallel with the ground and level. This is shown in Figure 16.

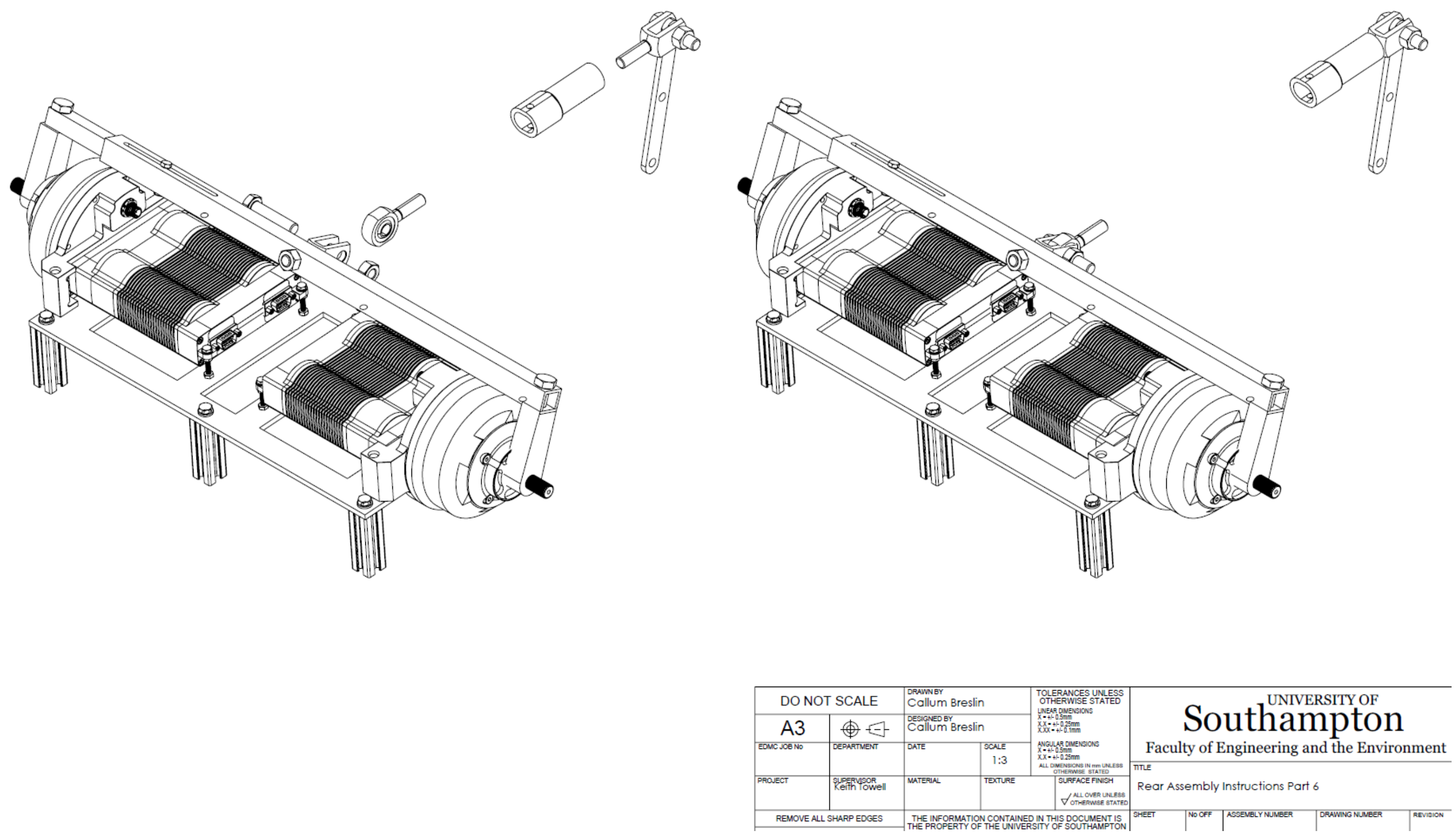
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Figure 16

Step 7

The rear push rod should now be screwed onto the spherical bearing male threaded protrusion, care should be taken such that the hole in one end of the push rod is perpendicular to the elongated axis of the structural fuse connector and that the hole aligns with the corresponding hole on the structural fuse connector itself. This should then be secured in place through the shear 6 mm diameter shear pin and secured from the underside with an M6 nut.

This is shown in Figure 17 and concludes the rear assembly installation. The complete rear assembly is shown in Figure 18

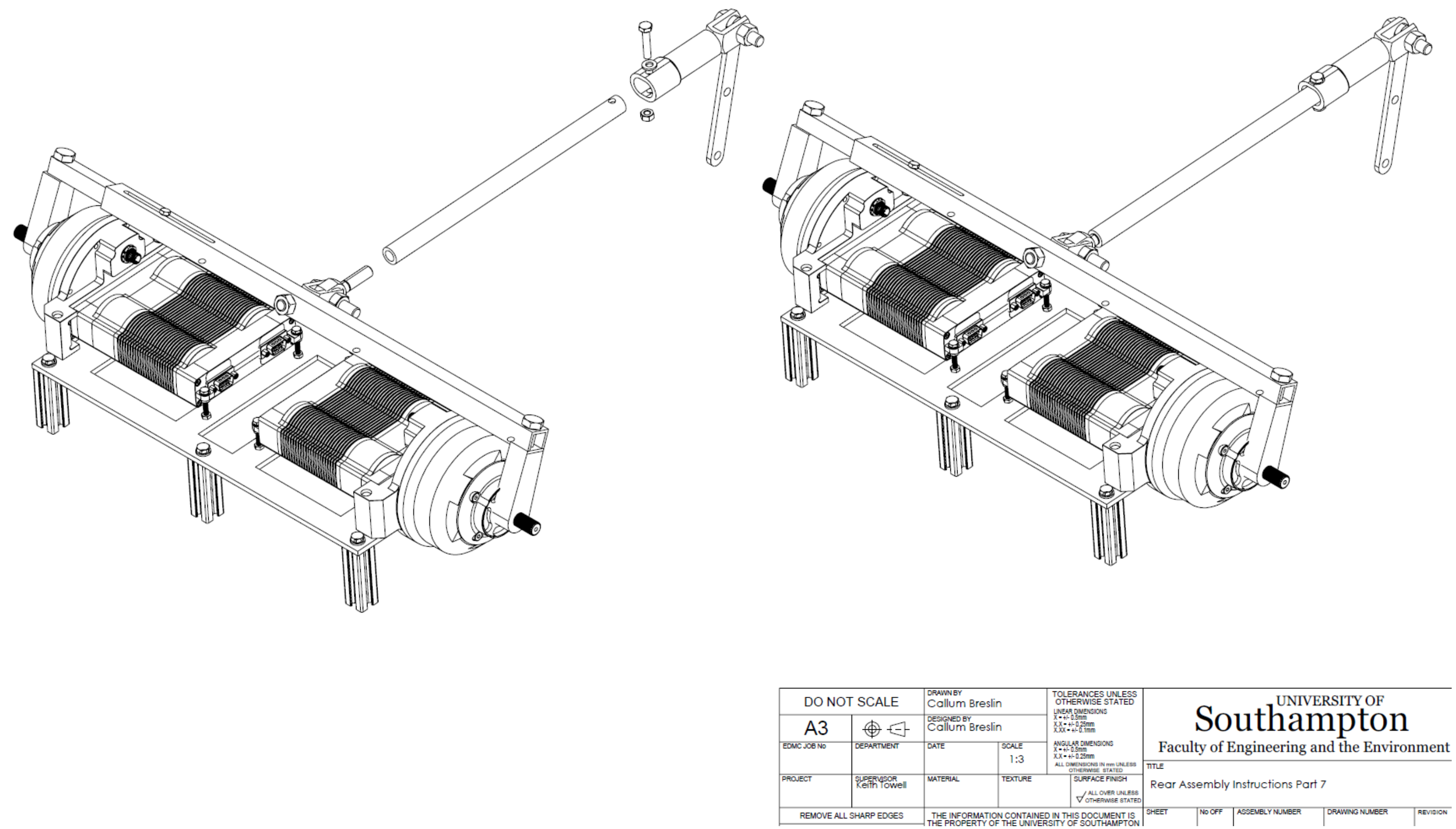
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Figure 17

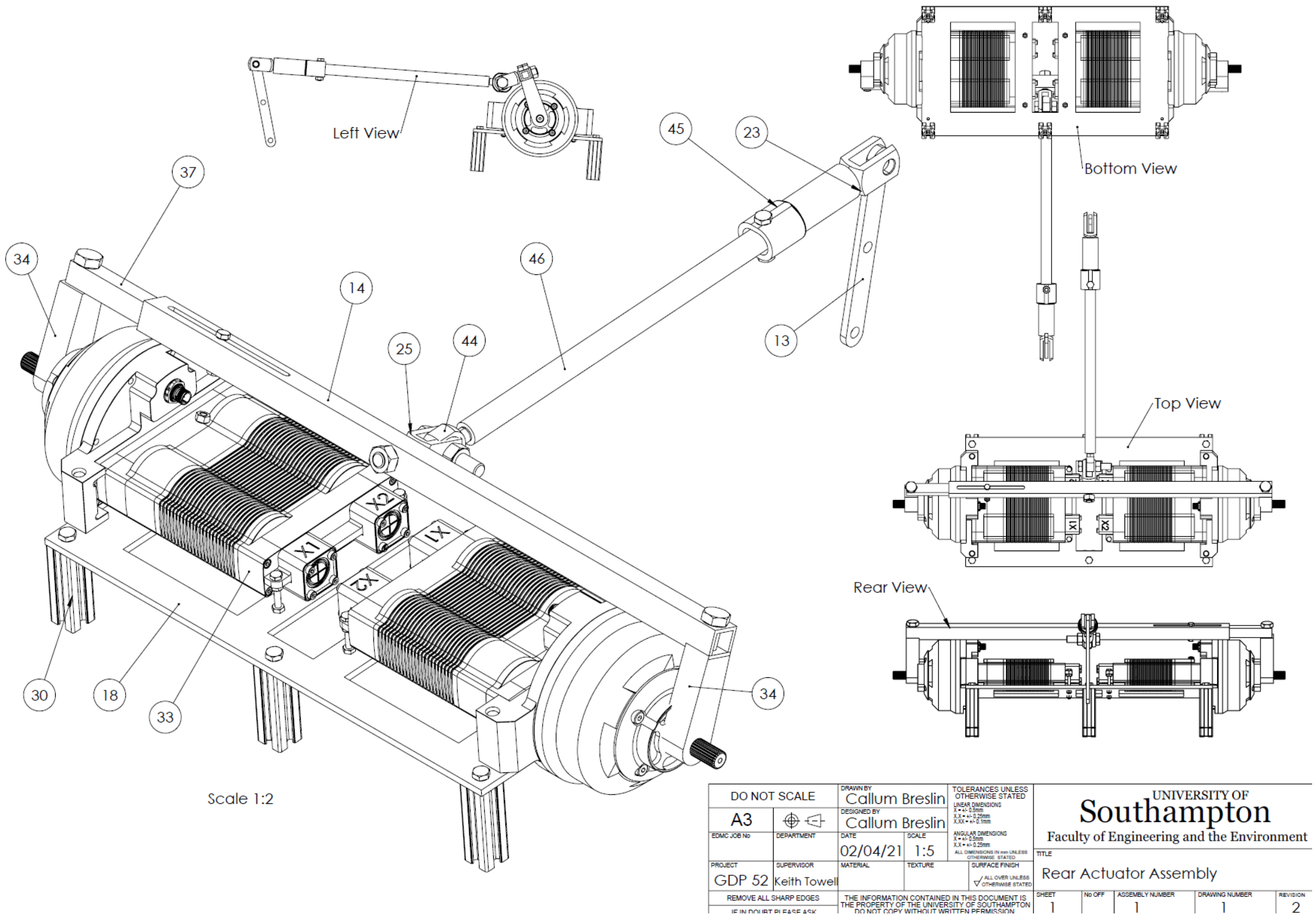
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Figure 18

End Stop Installation

Step 1

Firstly, take the two longest aluminium extrusion legs and the diagonal bracing component. Slot the head of the M6 bolt into the slot on each leg, thread a washer on to the bolt shaft such that it sits on the outside of the leg. Take the diagonal brace and fit the bolt shaft through the hole, before securing it in place with an M6 nut. Repeat this for the other end of the diagonal brace such that the structure forms an N-shape as shown in Figure 19.

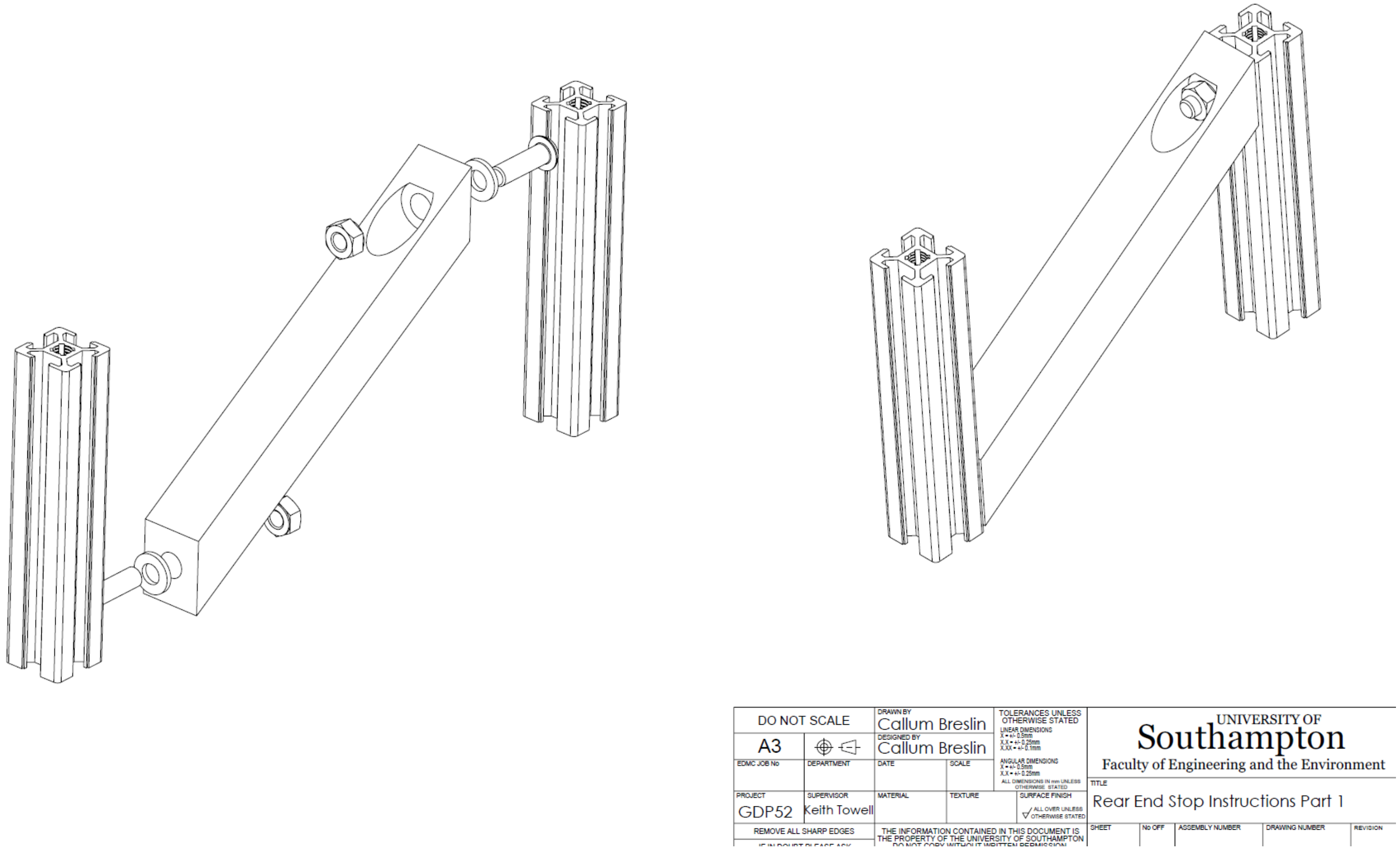
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Figure 19

Step 2

Attach the structure to the floor using M6 bolts and washers as shown in Figure 20 into the threaded holes in the base of the legs.

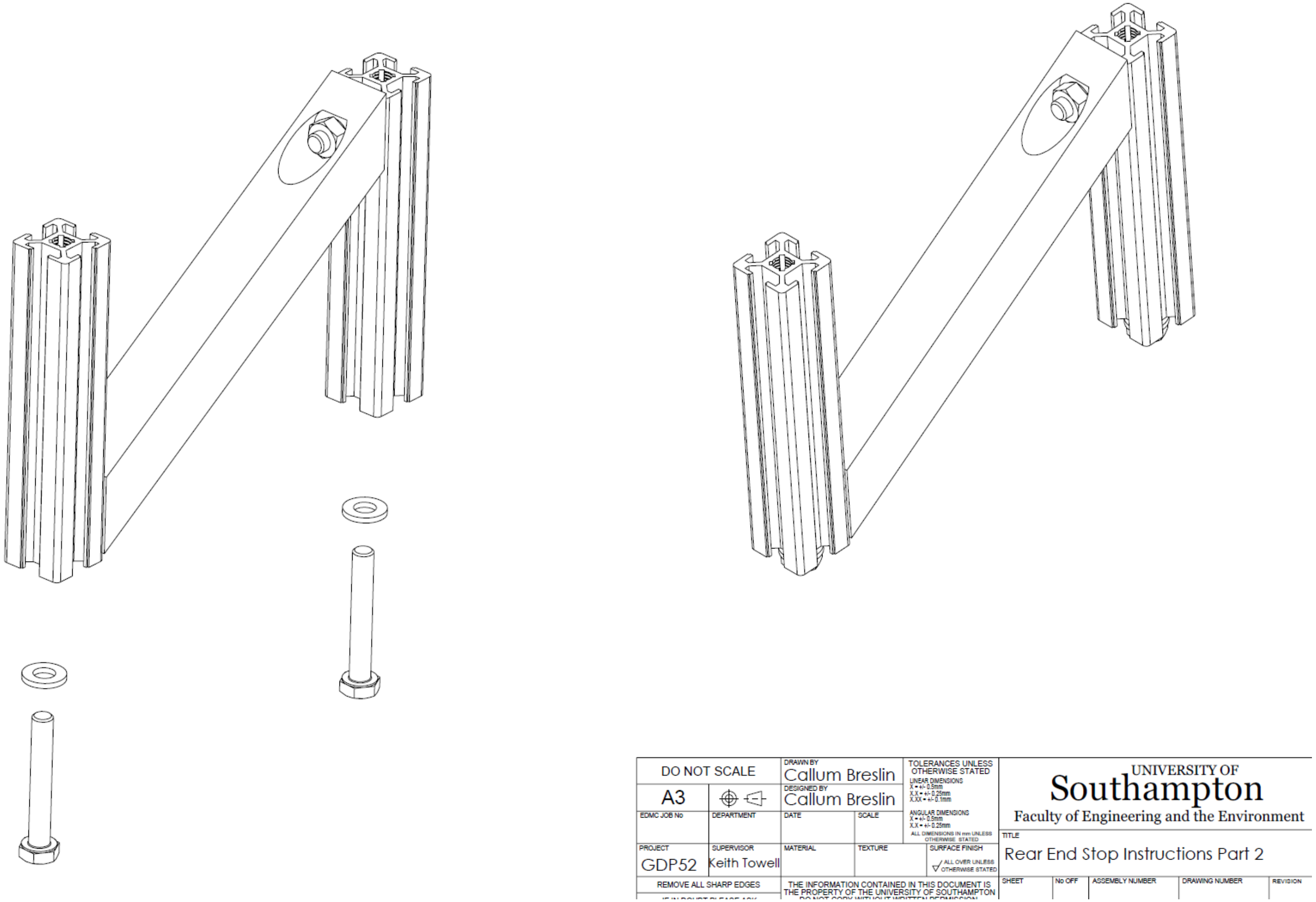
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Figure 20

Step 3

Place the end stop bracket atop the leg structure. Fix it in place using the M6 nuts and washers into the threaded holes in the aluminium extrusion legs. This process is shown in Figure 21.

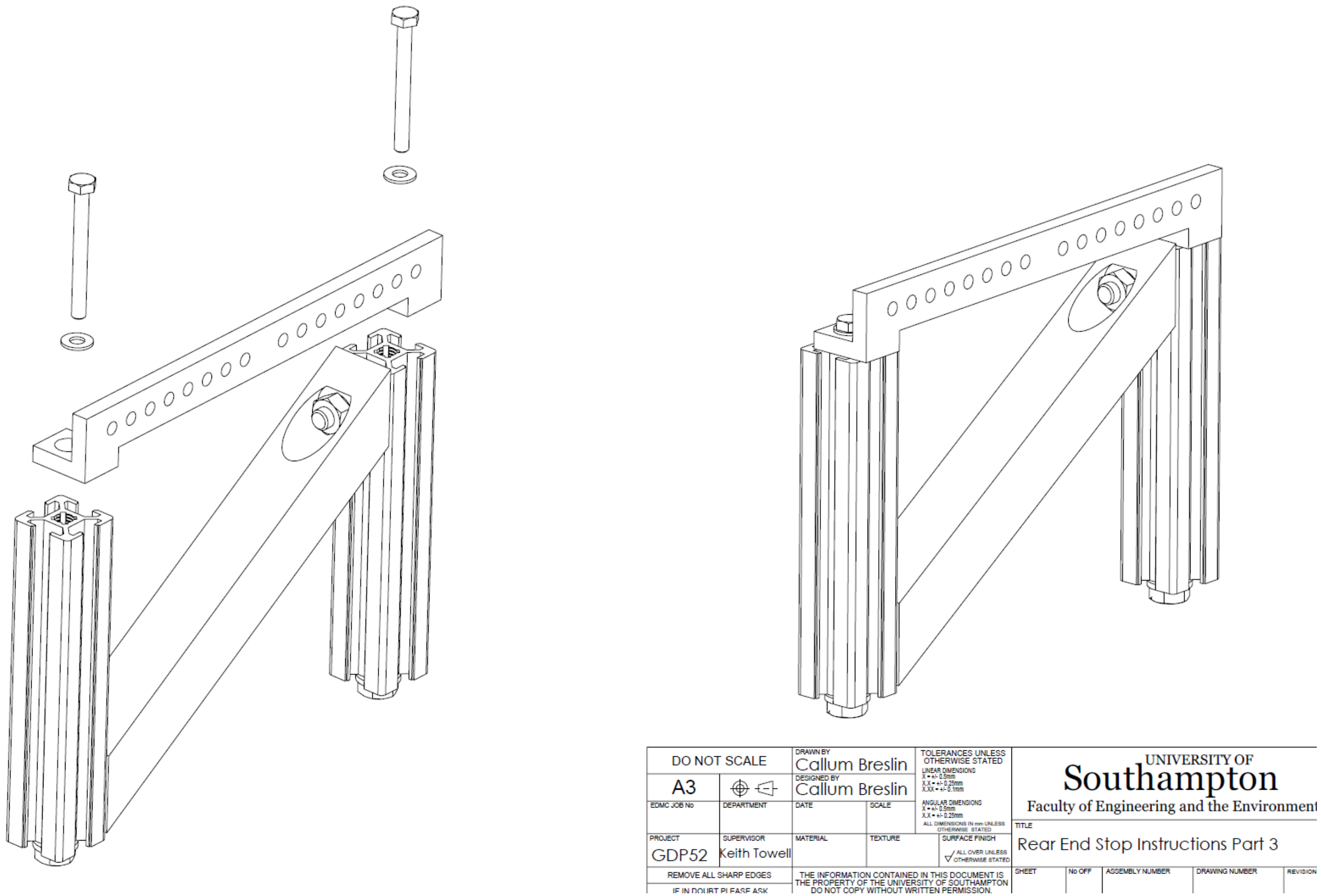
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Figure 21

Step 4

Finally, attach the end stop pieces into the desired setting by selecting a hole in the position where the range of motion of the servos is limited to the desired degree. Use M4 bolts, washers and nuts to secure these in place. This concludes the front assembly, as shown in Figure 22.

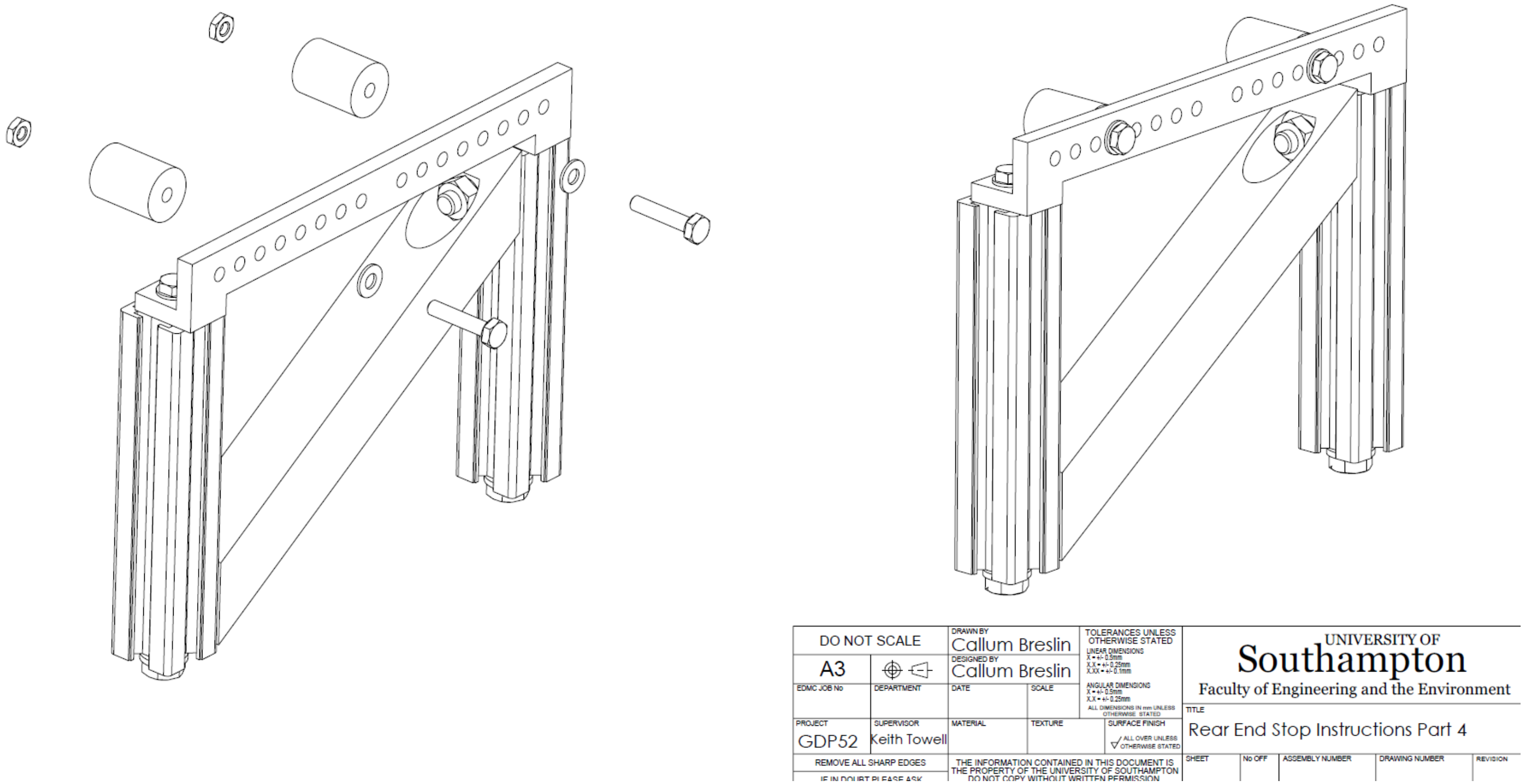
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Figure 22

Server Tray Installation Guide

- The control system for this modification is contained within a 19 inch 2U server tray.
- A 2U Server Tray will be attached onto a preinstalled 6U Rack.

Components Attached to the Server Tray

Battery Installation

- The battery used on this project will be a (Ultramax Slaumxli 10-24) and weighs 2.7 kg.
- Battery dimensions: L = 168 mm, W = 181 mm, H = 77 mm.
- The battery is secured against the front panel using a 2 mm thick aluminium bracket (Balloon 3 on Figure 23).
- It is further secured against the server tray itself using another aluminium bracket (Balloon 2 on Figure 23).
- The aluminium brackets are secured using a M10 bolt, washer and nut.

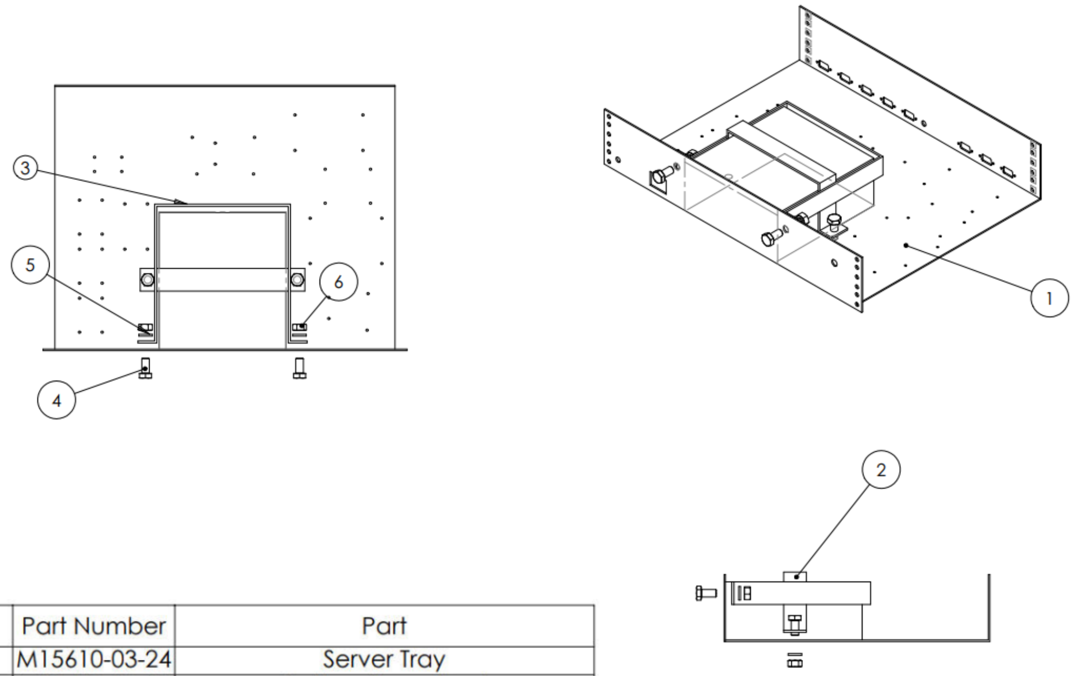
Battery Wiring

- The battery terminal connection should be made using 2 adjustable ring connectors (terminal size M5) and soldered onto AWG 10 gauge wires.
- The terminals must be isolated using terminal end caps.
- All soldering must be done to a high standard and inspected by a LAA inspector afterwards.
- All exposed wire must be insulated using heat shrink insulatation tubing.

Additional Information

- The Battery datasheet can be found in Appendix A.

Please find the battery installation assembly drawing in Figure 23.



Balloon	Part Number	Part
1	M15610-03-24	Server Tray
2	M15610-03-25	Battery Strap Short
3	M15610-03-26	Battery Strap Long
4	M15610-03-37	M10 L25mm Bolt ISO 4017 Grade 8.8
5	M15610-03-38	M10 Washer ISO 7089 Grade 8.8
6	M15610-03-39	M10 Nut ISO 4032 Grade 8.8

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Figure 23: Battery Installation Assembly.

All Other components

Server Tray

The following components will be fitted to the server tray as per the instructions shown in Figure 24 and Figure 25.

- Relay module (x3).
- 24 V to 12 V DC converter.
- Arduino SD card module.
- Arduino Mega with screw shield.
- PCB 3: TTL to RS485 converter module.
- PCB 2: Thermistor control module.
- PCB 1: Accelerometer and Pressure sensor module.
- Arduino Uno with screw shield.

All the above-mentioned components will be attached using M3 bolts, nuts and washers except the Arduino. The Arduino should be attached using 60 mm threaded M3 rods and secured on both sides using M3 nuts and washers as shown in Figure 25.

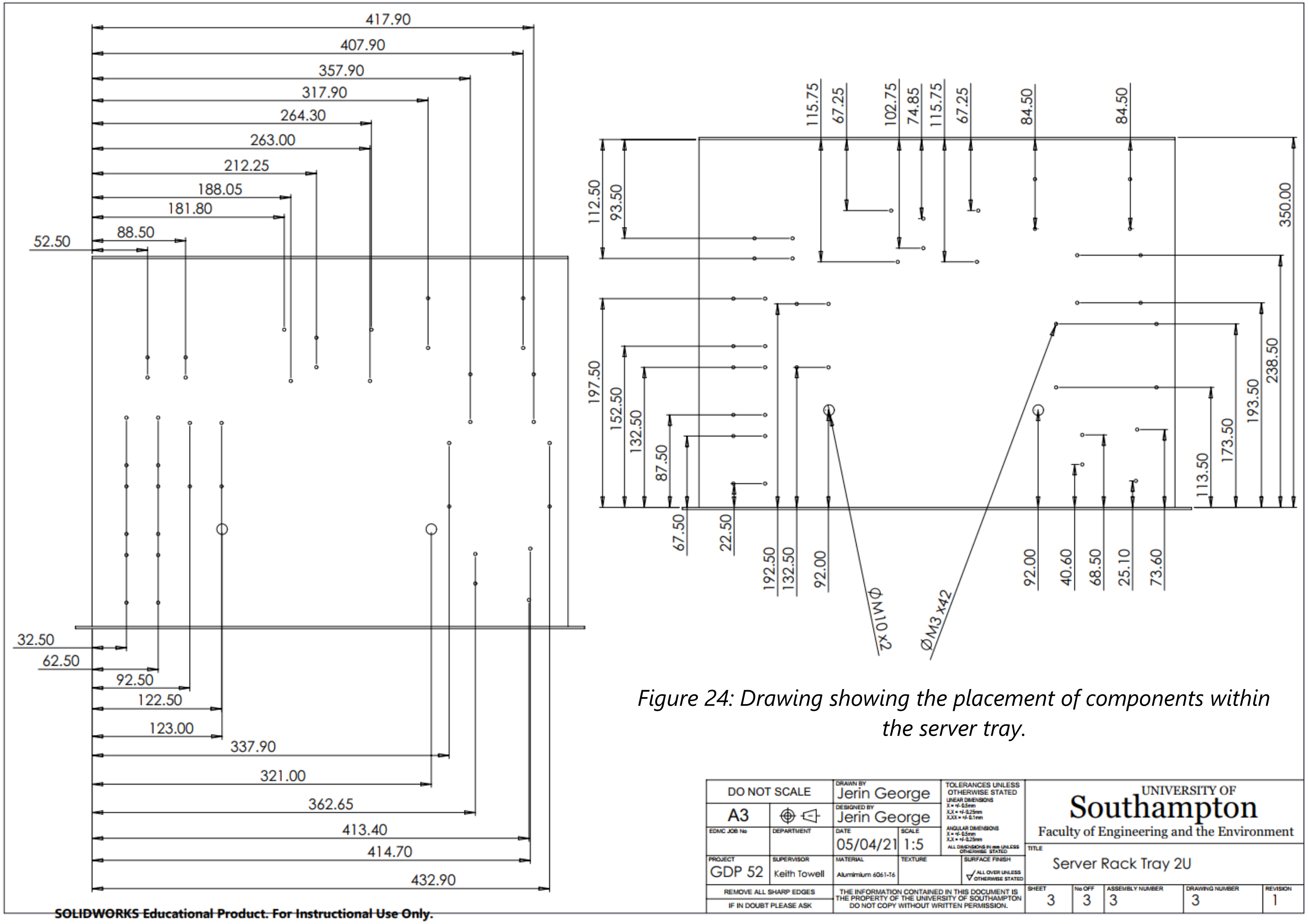


Figure 24: Drawing showing the placement of components within the server tray.

Front Panel

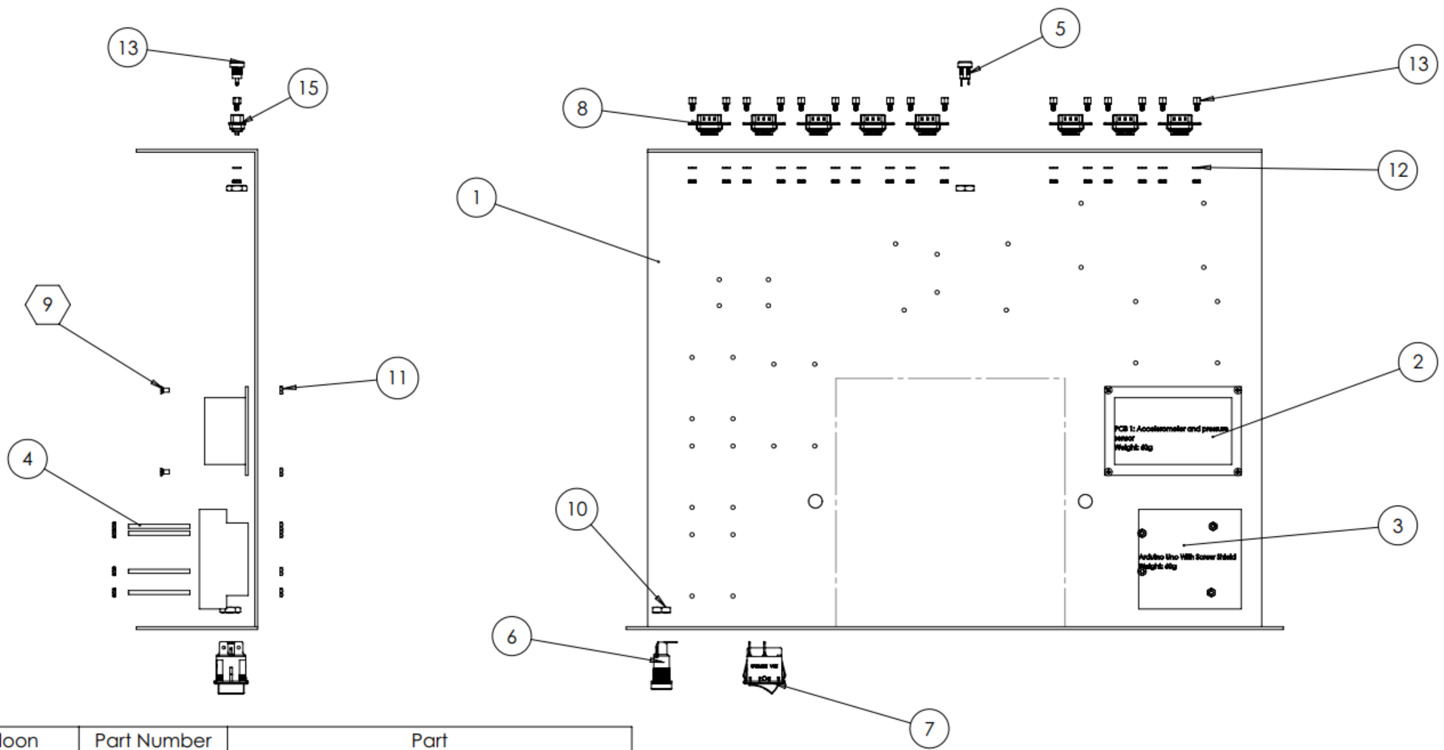
The front panel will be used to secure the tray to the server rack and to house the following components:

- Illuminated On/Off Switch (Attached using integrated attachment mechanism).
- Fuse Holder (Must include a 15A fuse within) (Circular design and should be secured using a M8 nut).
- 10mm hole for the tube running from the Pitot tube to the pressure sensor.

Rear Panel

The rear panel consists of the following connectors used to send power and commands to various parts of the system external to the server tray.

- 9 pin D-Sub Female connector (x8) (Note: an extra one is included for later integration with a further modification) (Secured using M3 bolts).
- DC Chassis Socket (secured using an M8 nut).



Balloon	Part Number	Part
1	M15610-03-24	Server Tray
2	M15610-03-12	PCB 1
3	M15610-03-8/9	Arduino UNO with Shield
4	M15610-03-40	M3 L60mm DIN975 Treaded ROD Pin x10
5	M15610-03-29	M8 DC Chassis Socket
6	M15610-03-3	M8 Fuse Holder
7	M15610-03-28	Illuminated Power Switch
8	M15610-03-27	9 Pin D-Sub Connector Female x8
9	M15610-03-42	M3 L8mm ISO4017 Grade 8.8 Bolt x32
10	M15610-03-41	M8 Nut x2 (ISO4032 Grade 8.8)
11	M15610-03-44	M3 Nut x68 (ISO4032 Grade 8.8)
12	M15610-03-45	M3 Washer x16 (ISO7089 Grade 8.8)
13	M15610-03-43	M3 D-Sub Screw

Figure 25: Server tray component attachment guide.

Note: Only attachment of PCB 1 and Arduino Uno showed
but all components attched the same way

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Server Tray Wiring

The wiring diagram and wiring schematic for the server tray is shown in Figure 26 and Figure 27 respectively. Please find below the instructions to compliment the figures below:

- The wires within the server tray are running at 24 V, 12 V and 5 V. The wire gauges to use are categorised by voltage and are shown below:
  - 24 V - AGW 10
  - 12 V - AGW 20
  - 5 V – AGW 20
- The colour of wires used should also be altered according to the following category:
  - Live – Red
  - Ground – Blue
  - Signal – Orange
- All internal connectors used within the server tray should be JST HL block connectors and shall be secured to the tray using adhesive. They should be stress relieved though the use of cable ties to secure the wire on both sides of the connector.
  - Except:
    - 24 V connector connecting the relay to the D-Sub connectors for the servo connection, these should be JST VL connector rated to 20 A. (Due to an expected maximum current of 15.7A for the three servos)

All the forementioned connectors are crimp style connectors and thus a crimping tool must be used.

- All wiring joints on Figure 26 should be joined using 3-way connectors and insulated using heat shrink insulation.
- All thick wires shown in Figure 26 represent wires bundled together and should be bundled together using cable ties and secured over long distances to the tray itself.
- The connections to the Arduino's are through screw shields and so the ends of the cable should be securely connected, and a strong connection ensured.
- All exposed wires should be insulated using heat shrink tubing.

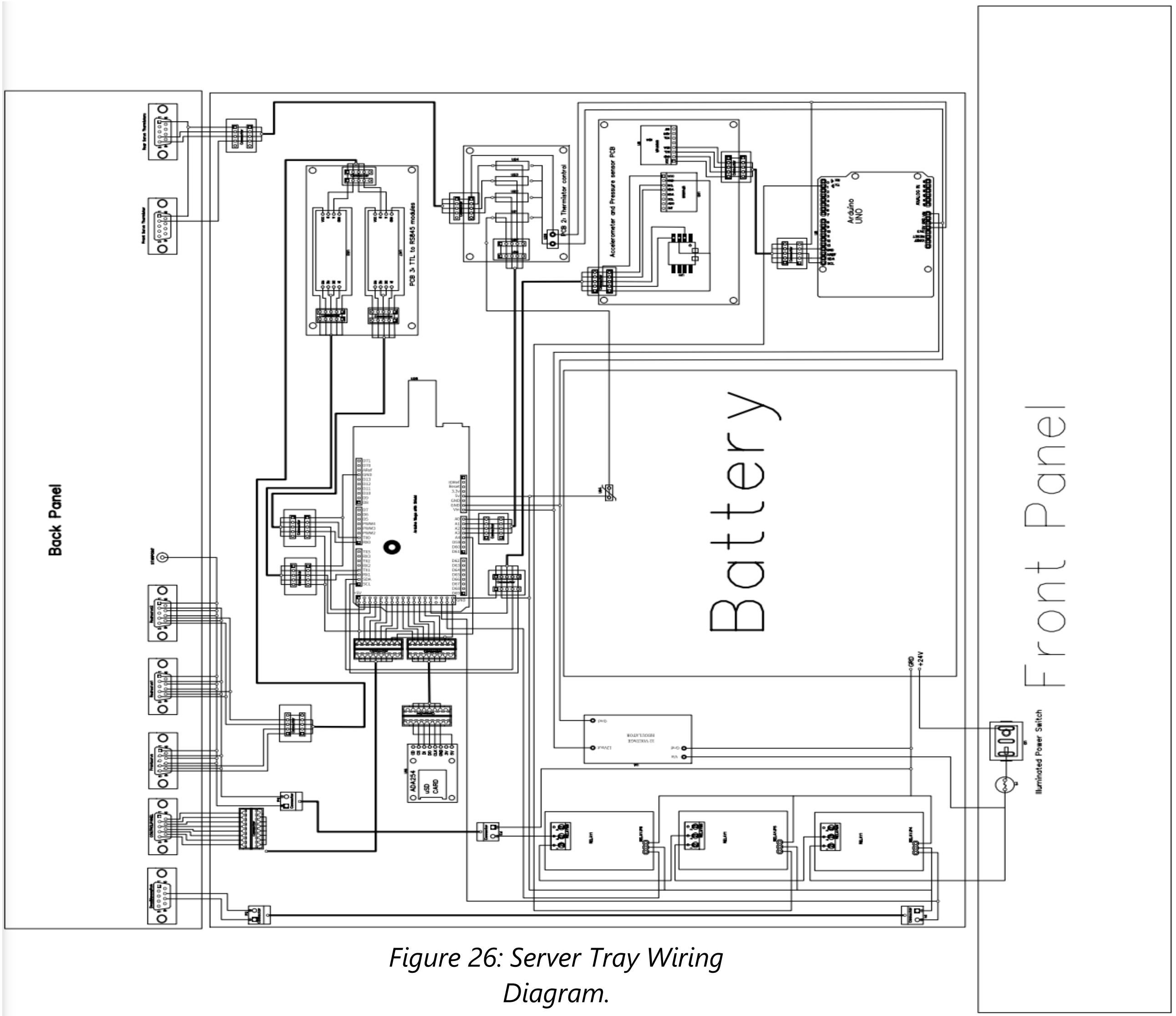


Figure 26: Server Tray Wiring Diagram.

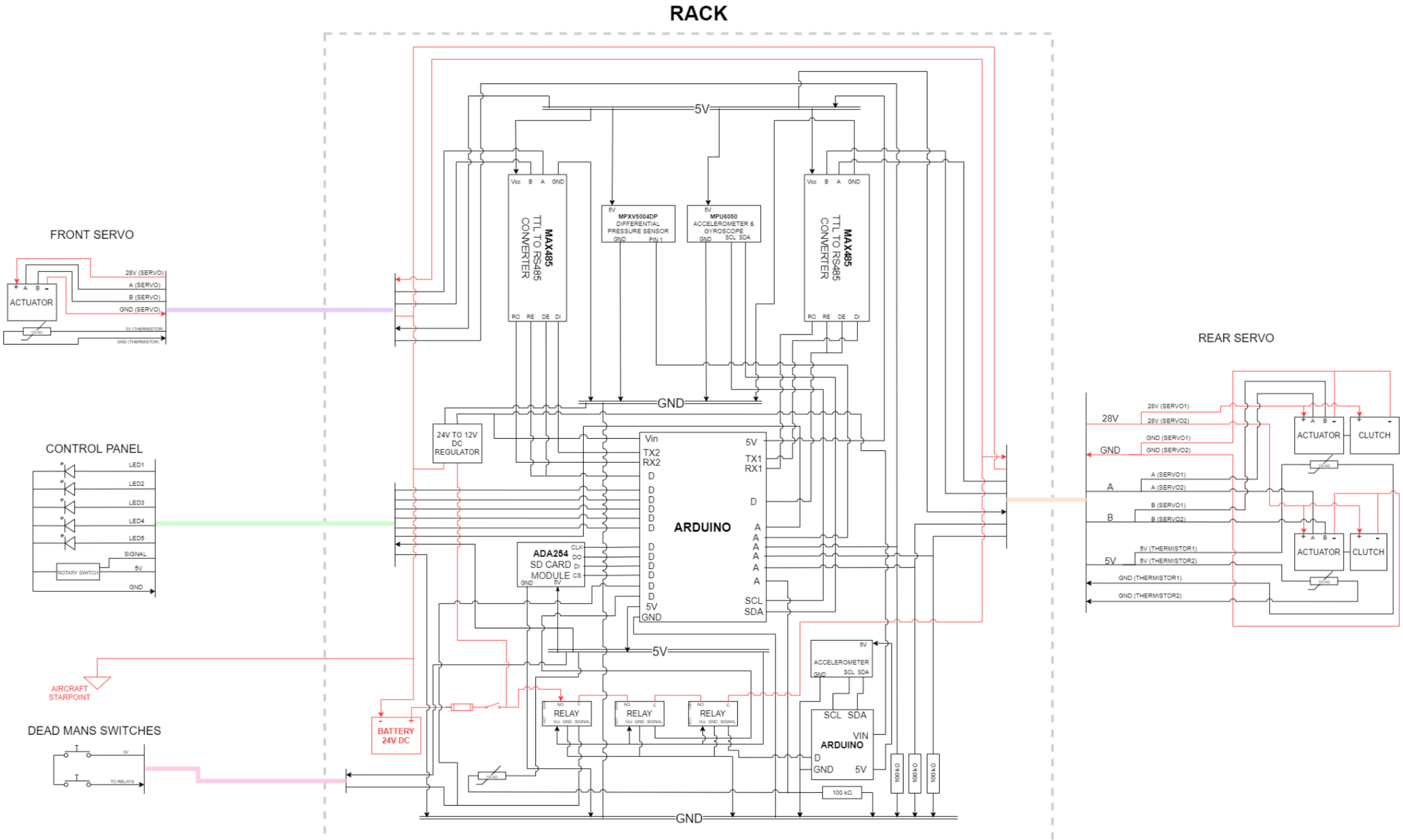


Figure 27: Server rack electrical schematic.

Designs Required For PCB Manufacturing.

Contents of PCBs

PCB 1:

- Accelerometer (MMA8451-2019)
- Accelerometer 2 (ADA163)
- Pressure Sensor (MPXV5004DP).
- 5 Pin JST PAF Connector (x2).

PCB 2:

- 100K Ohm Resister (x4).
- 5 Pin JST PAF Connector (x2).
- 2 pin JST PAF Connector.

PCB 3:

- TTL to RS 485 Convertor (x2).
- 5 Pin JST PAF Connector (x3).

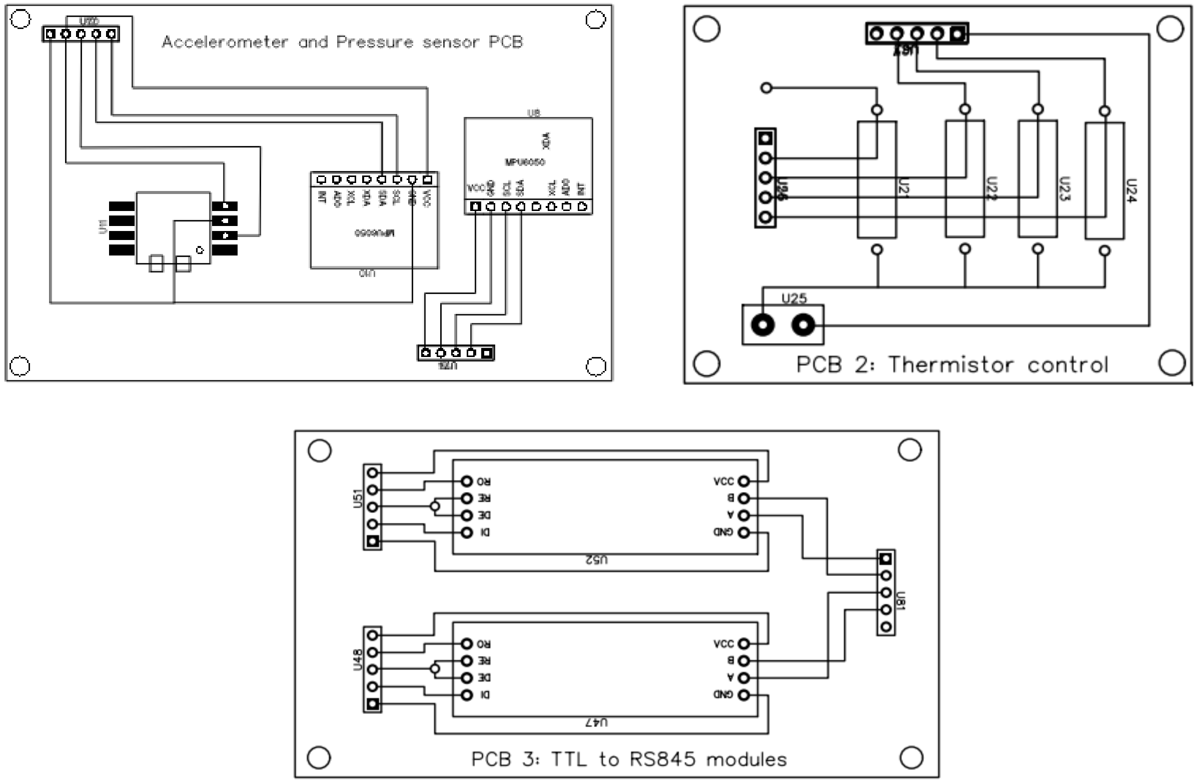


Figure 28: PCB

Tray Attachment to Rack

The tray has been designed to allow it to be slide in from the front face of the rack and can be secured to the rack on both sides. The tray should further be secured at the rear to the rack using the Server Tray Connector at both sides as shown in Figure 29.

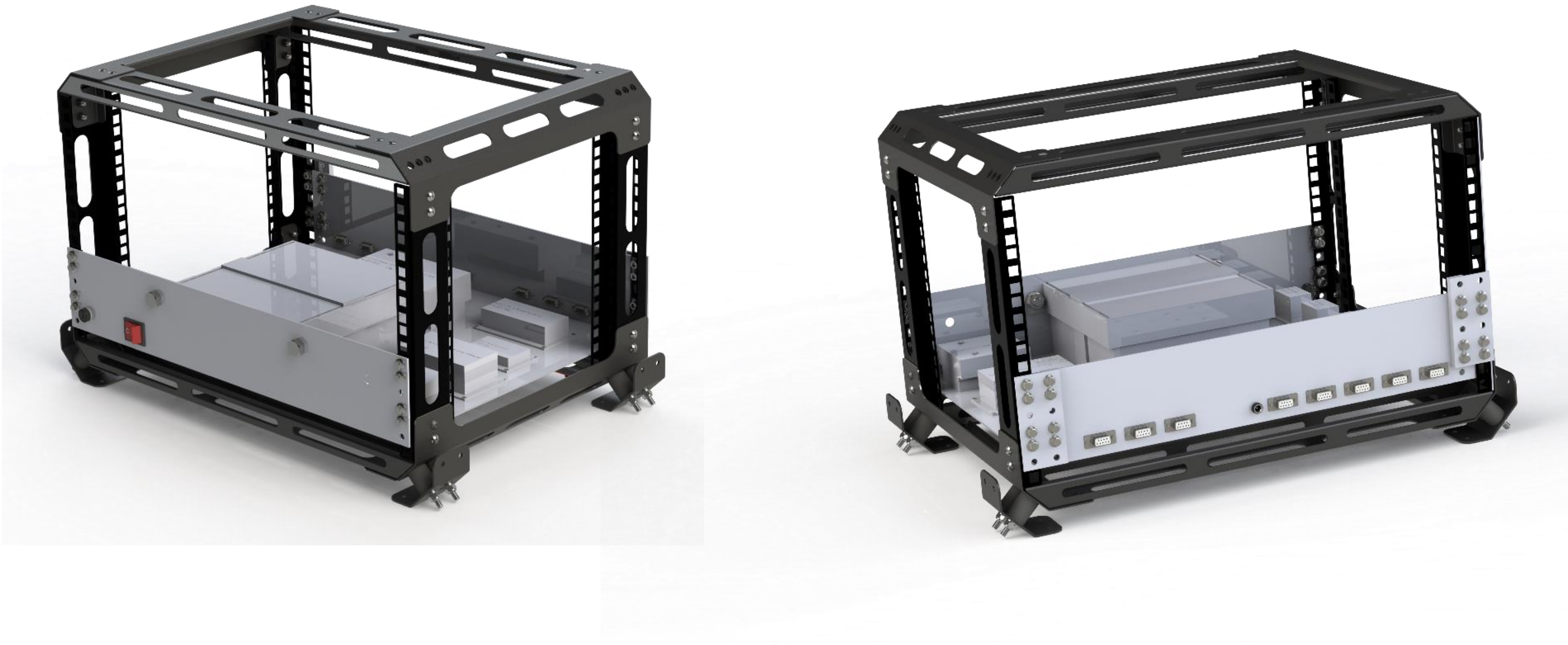
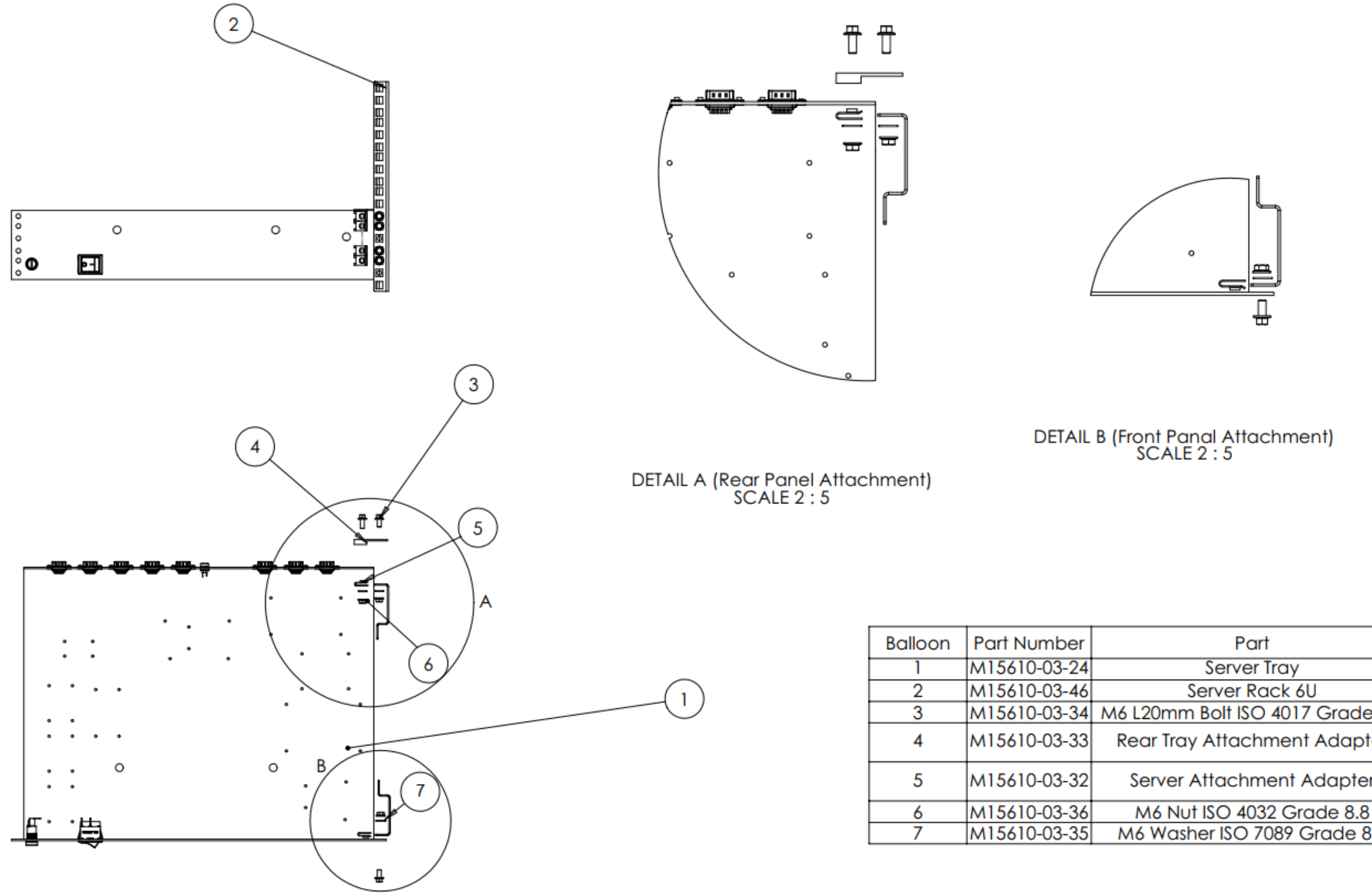


Figure 29: Render of Rack Assembly

Note: The rack tray connector is offset on one side as shown on the righthand side of Figure 29, this is to utilise the same part on both sides.



Balloon	Part Number	Part
1	M15610-03-24	Server Tray
2	M15610-03-46	Server Rack 6U
3	M15610-03-34	M6 L20mm Bolt ISO 4017 Grade 8.8
4	M15610-03-33	Rear Tray Attachment Adapter
5	M15610-03-32	Server Attachment Adapter
6	M15610-03-36	M6 Nut ISO 4032 Grade 8.8
7	M15610-03-35	M6 Washer ISO 7089 Grade 8.8

Figure 30: Rack Tray Assembly Installation Guide

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Control Panel and Dead Man's Switch Installation

Control Panel

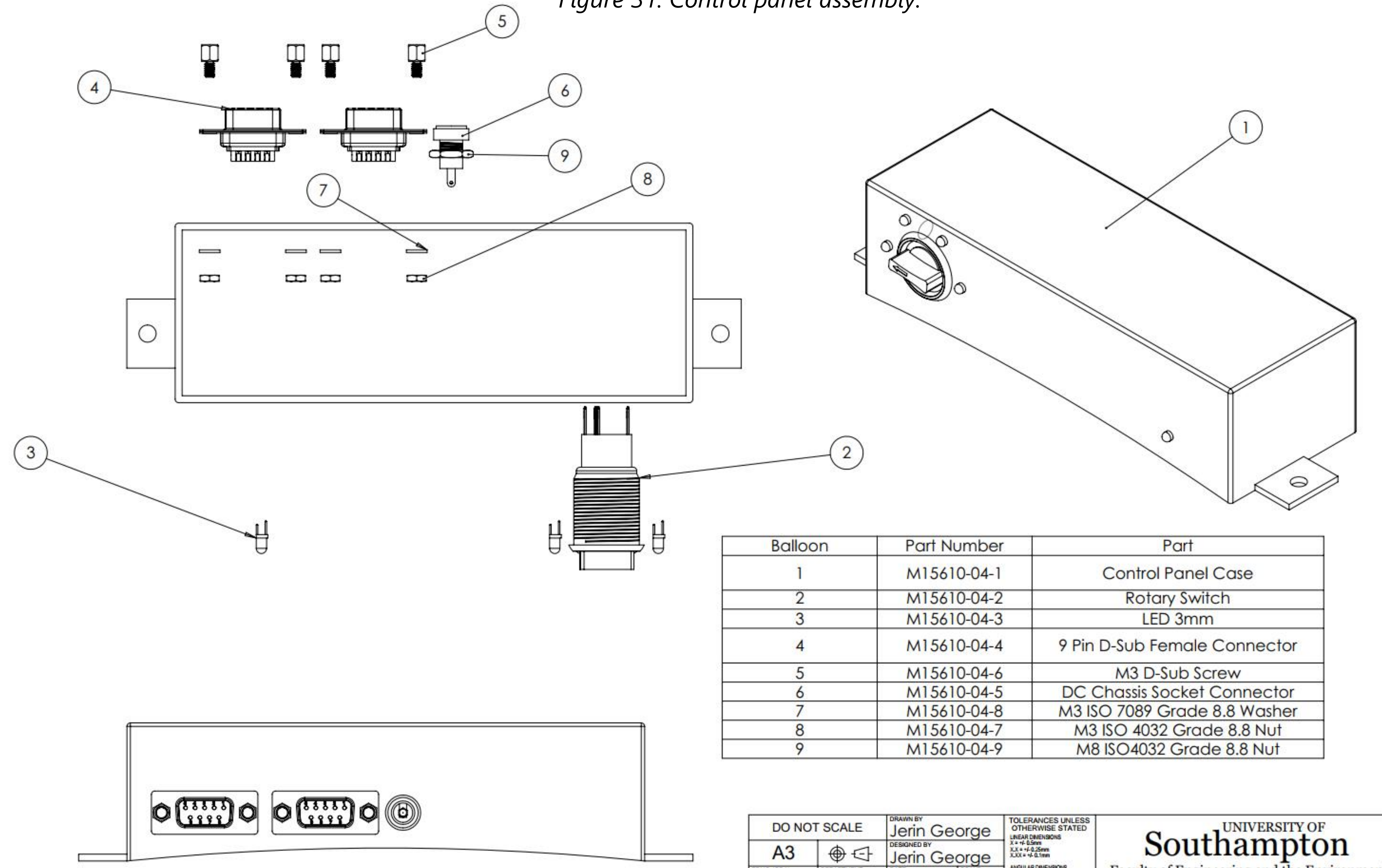
The control panel will be mounted onto the top of the dashboard using two M5 bolts, nuts and washers. It will contain with it the following items:

- Rotary switch.
- 3 mm LED for mode indication (x5).
- 9 pin D-Sub connector (x2) (for connection to rack for dead man's switch and control panel).
- DC Chassis Socket (secured using an M8 nut).
- 10 mm hole (to allow wires to be run from the control panel to the aircraft star point and dead man's switches).

Safety notes

- All wires except aircraft ground wire should be AWG 20.
- Wire connecting to aircraft star point should be AWG 10.
- All wires with in the control panel should be bundled together using cable ties and secured to the components via soldering.
- All soldering should be double checked by a second person to ensure quality.
- All exposed wiring should be insulated using heat shrink tubing.
- All wiring should also be checked to ensure it does not short with any components (ensure this by routing wire around components and secure them to the control panel casing).

Figure 31: Control panel assembly.



Balloon	Part Number	Part
1	M15610-04-1	Control Panel Case
2	M15610-04-2	Rotary Switch
3	M15610-04-3	LED 3mm
4	M15610-04-4	9 Pin D-Sub Female Connector
5	M15610-04-6	M3 D-Sub Screw
6	M15610-04-5	DC Chassis Socket Connector
7	M15610-04-8	M3 ISO 7089 Grade 8.8 Washer
8	M15610-04-7	M3 ISO 4032 Grade 8.8 Nut
9	M15610-04-9	M8 ISO4032 Grade 8.8 Nut

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Dead Man's Switch and Dashboard Assembly

The dead man's switch and handle associated with it to ensure a strong grip is available to the pilot at high G loads will be placed on the front face of the control panel as shown in Figure 32 and Figure 33.

Contents of dashboard assembly:

- 22mm round push switch (x2).
- Grip Handle (x2).
- Control Panel Assembly.

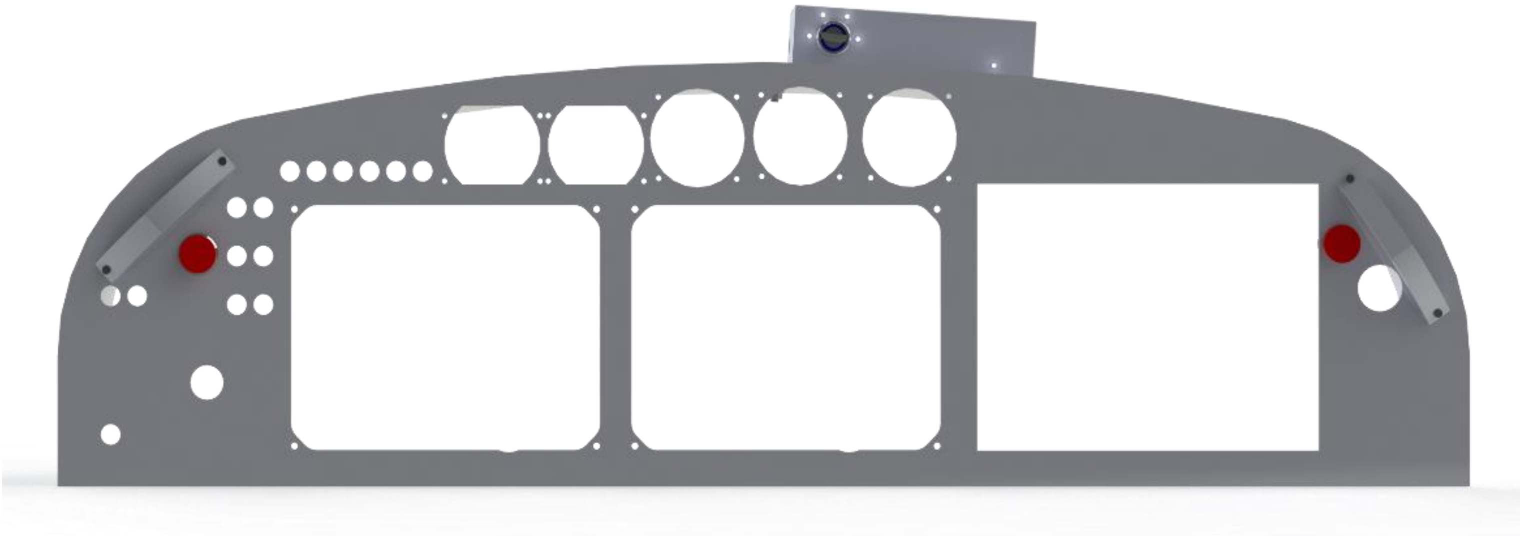
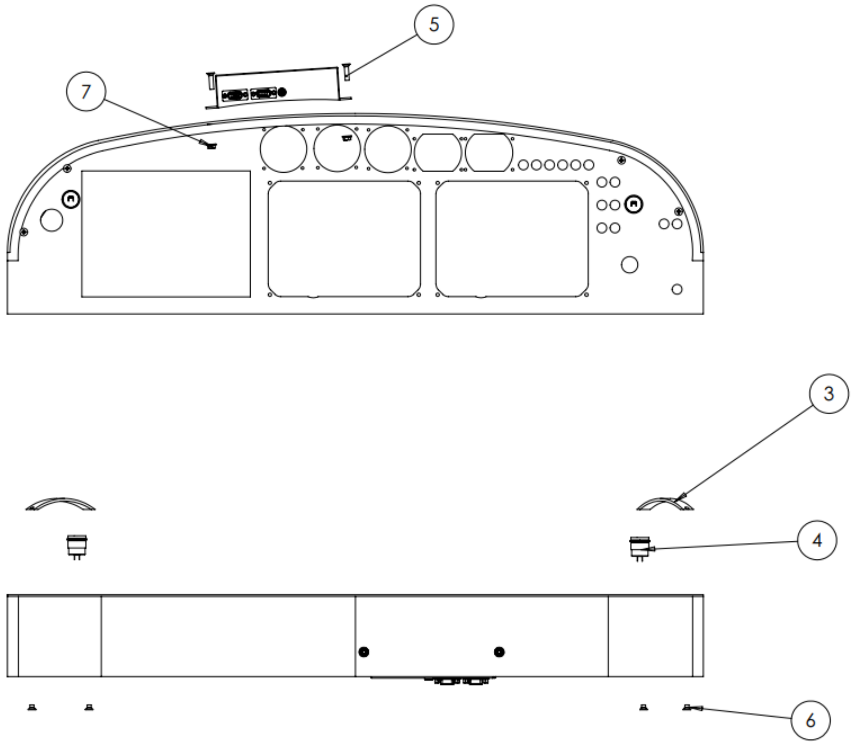
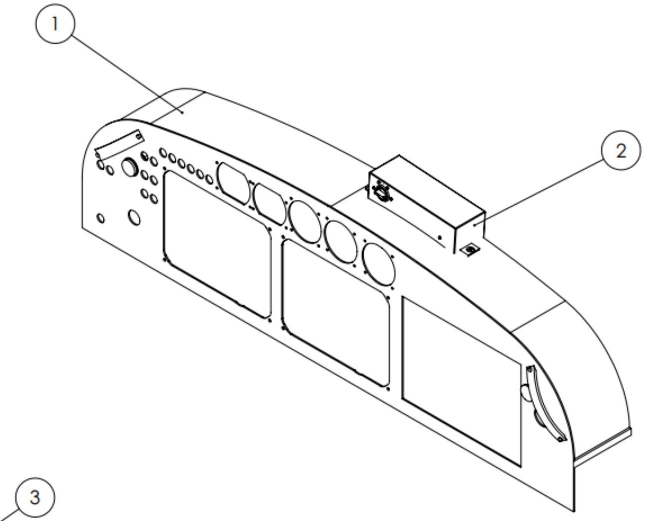


Figure 32: Dead man's switch and control panel positioning.





Balloon	Part Number	Part
1	M15610-05-1	Dashboard
2	M15610-05-2	Control Panel Assembly
3	M15610-05-3	Handle
4	M15610-05-4	Dead Man's Switch
5	M15610-05-6	M5 L20mm Bolt ISO 4017 Grade 8.8
6	M15610-05-5	M5 L15mm Screw ISO 7046 Grade 8.8
7	M15610-05-7	M5 Nut ISO 4032 Grade 8.8

Figure 33: Dashboard assembly installation guide

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Routing of wires through the aircraft

Figure 34, Figure 35, Figure 36, Figure 37, Figure 38 and Figure 39 show the planned routing of the wiring harness through the aircraft and should be read along with the wiring diagram in Figure 26.

Wiring procedure:

- All wiring should be securely connected at both ends using connectors.
- All wiring should be bundled into a harness and secured to aircraft tubing using cable ties.
- As shown in Figure 35, the wiring should be routed to avoid any interference with the flight control system.
- Should use orange coloured sleeves around all wiring except:
    - Wire to aircraft common ground at star point (Blue).

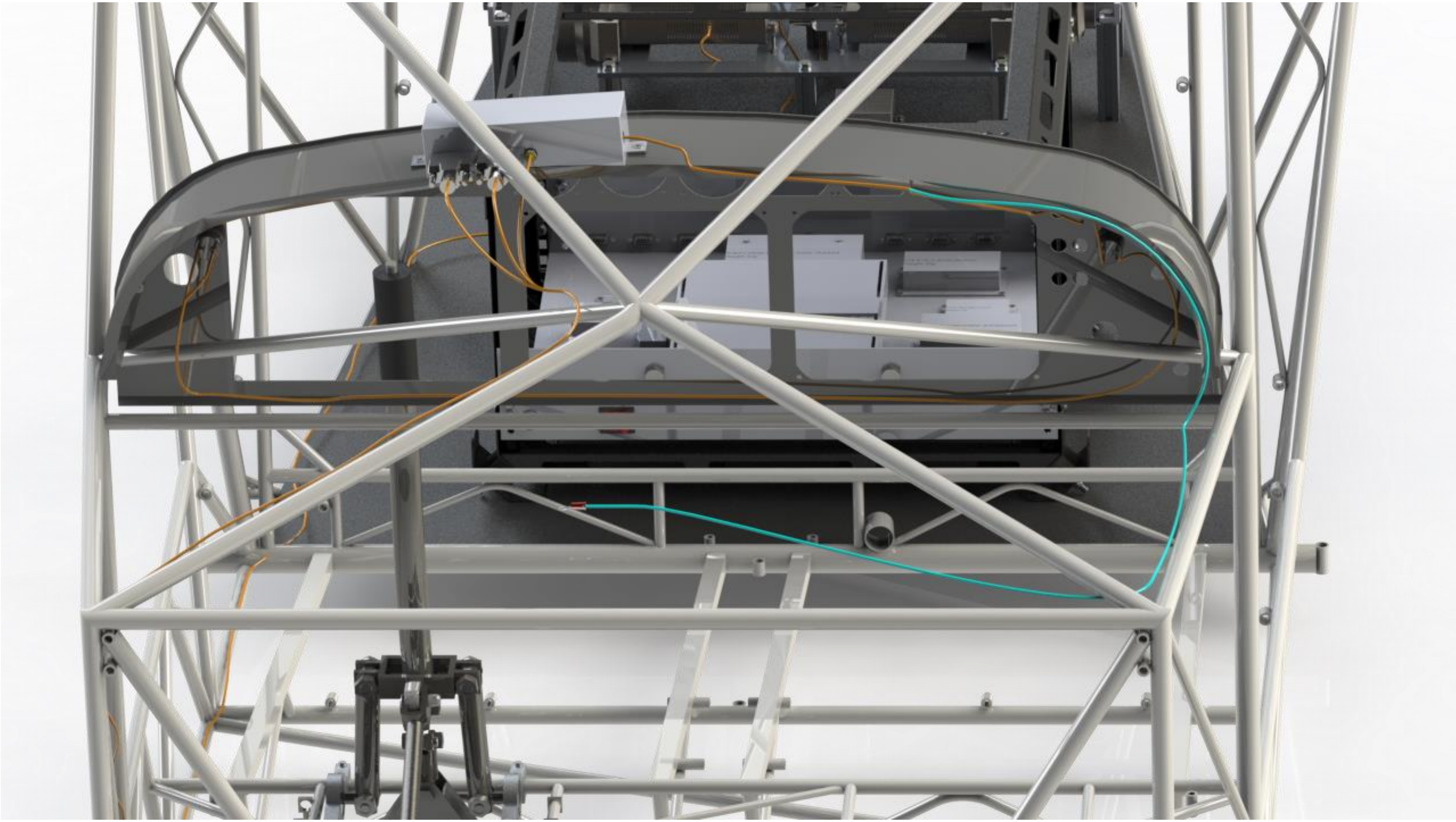


Figure 34: Routing diagram of the dead Man's switch wiring and aircraft ground

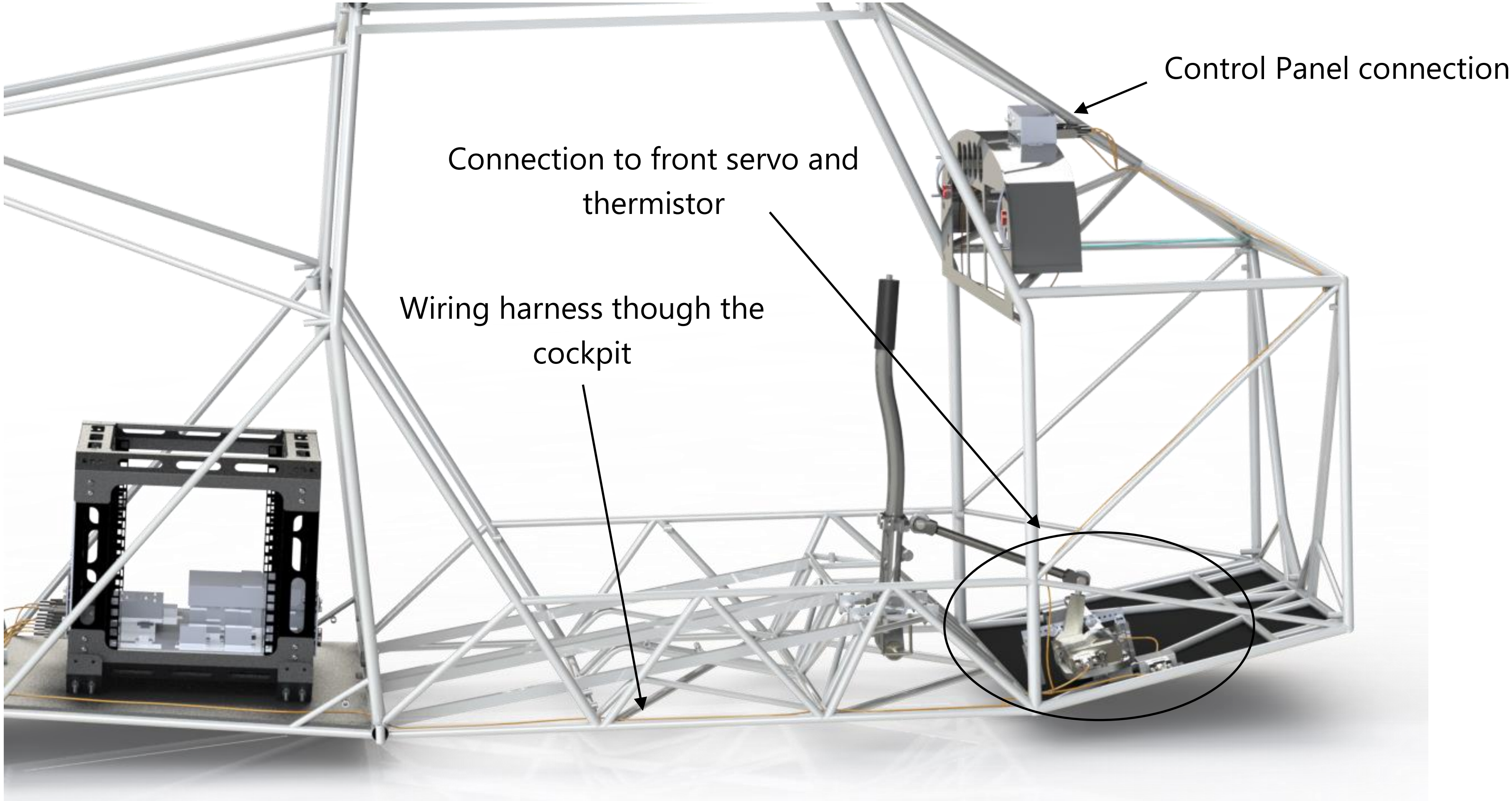


Figure 35: Routing diagram of routing though the cockpit to the front servo assembly and control panel

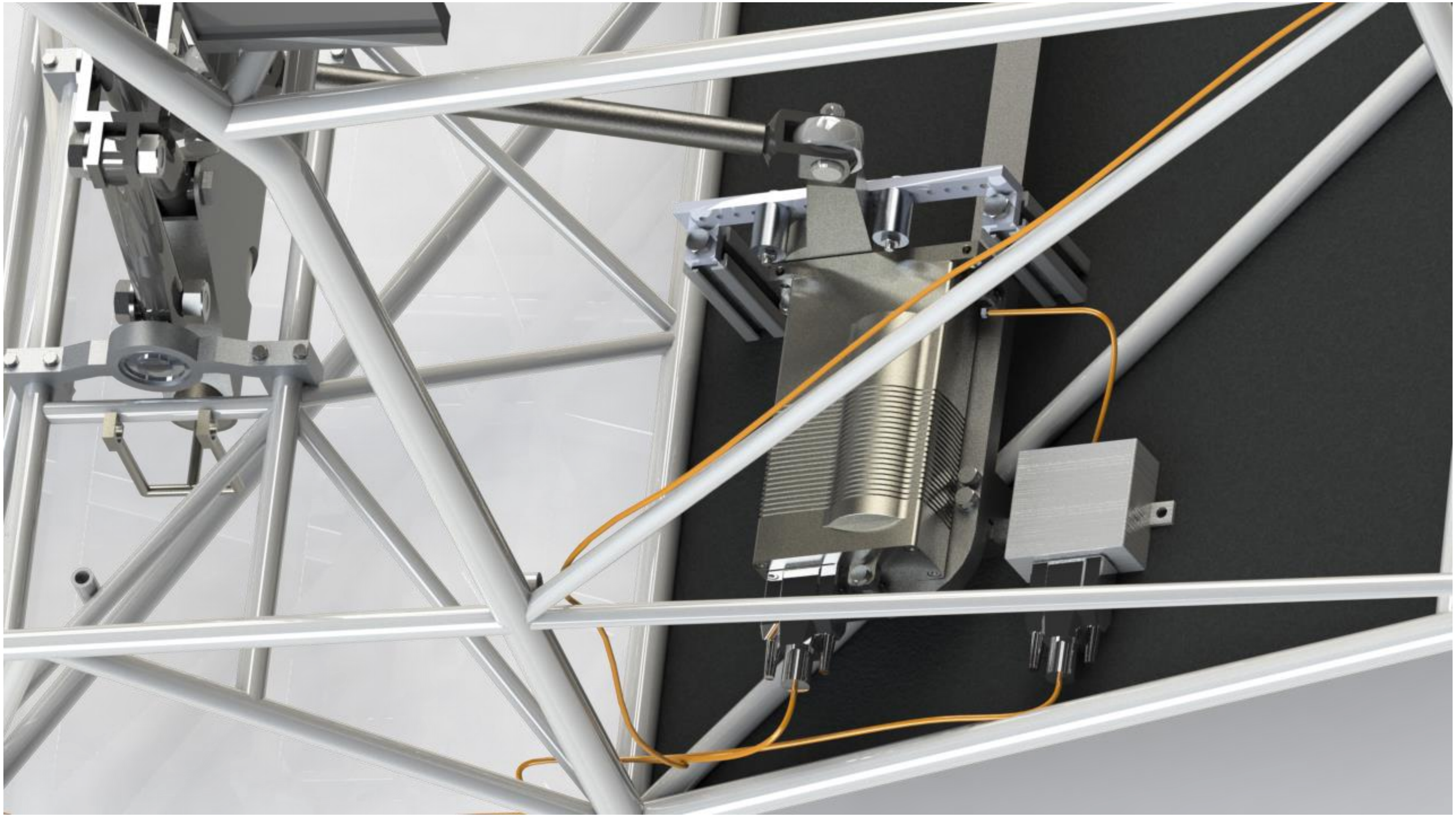


Figure 36: Routing diagram of the front servo and thermistor

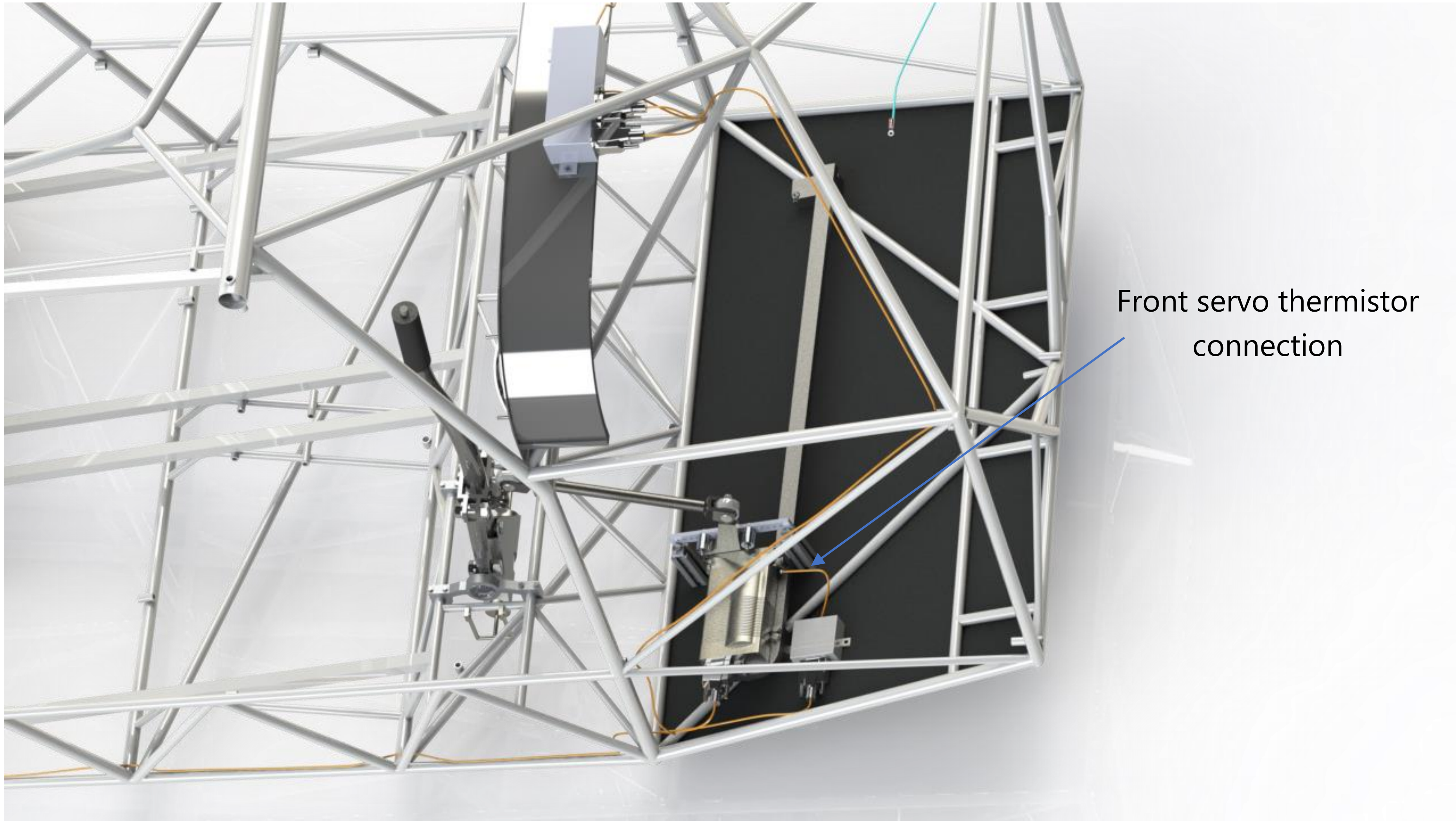


Figure 37: Routing diagram showing the front servo assembly and control panel connection.

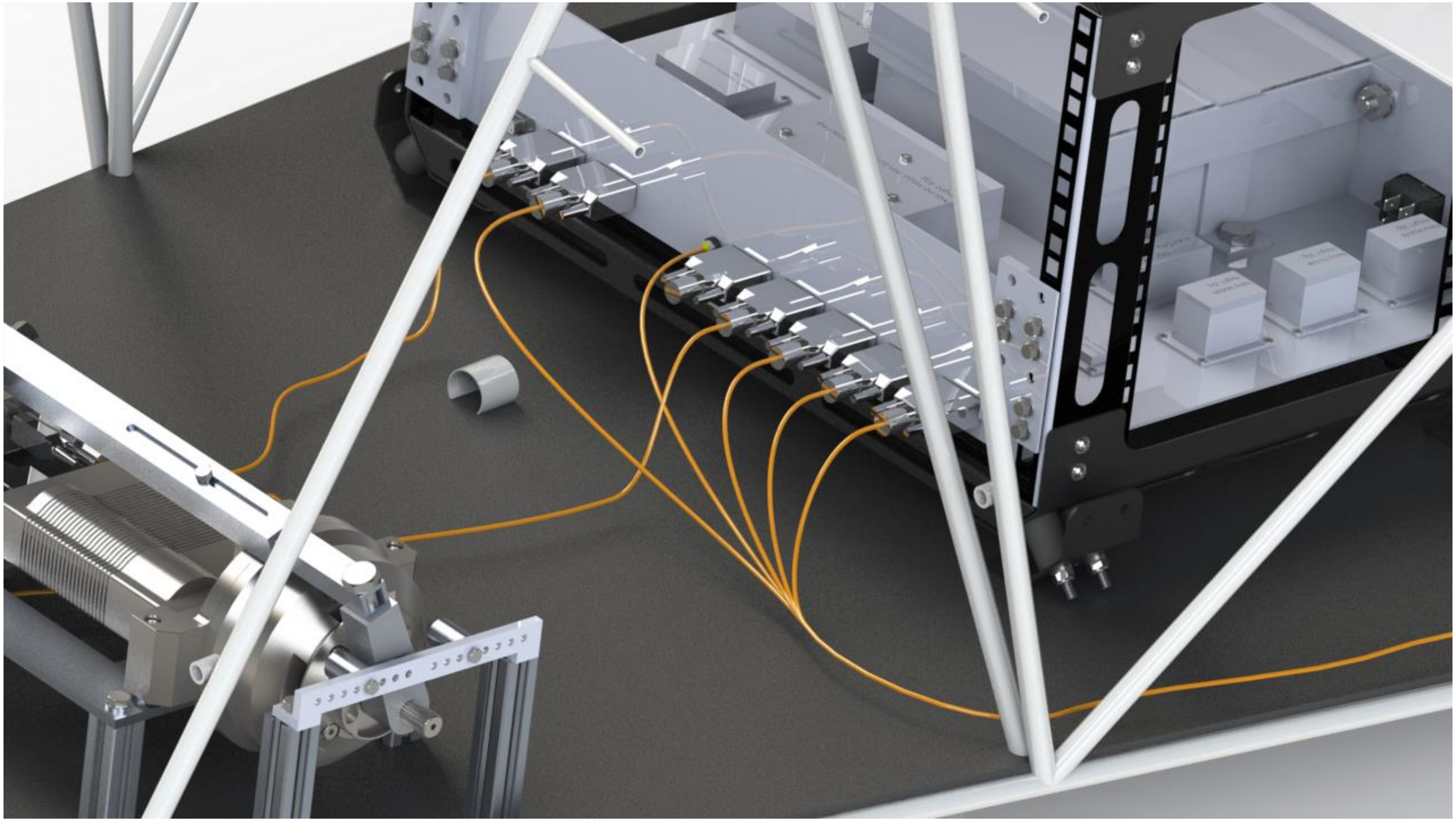


Figure 38: Routing diagram of connections out of the server rack.

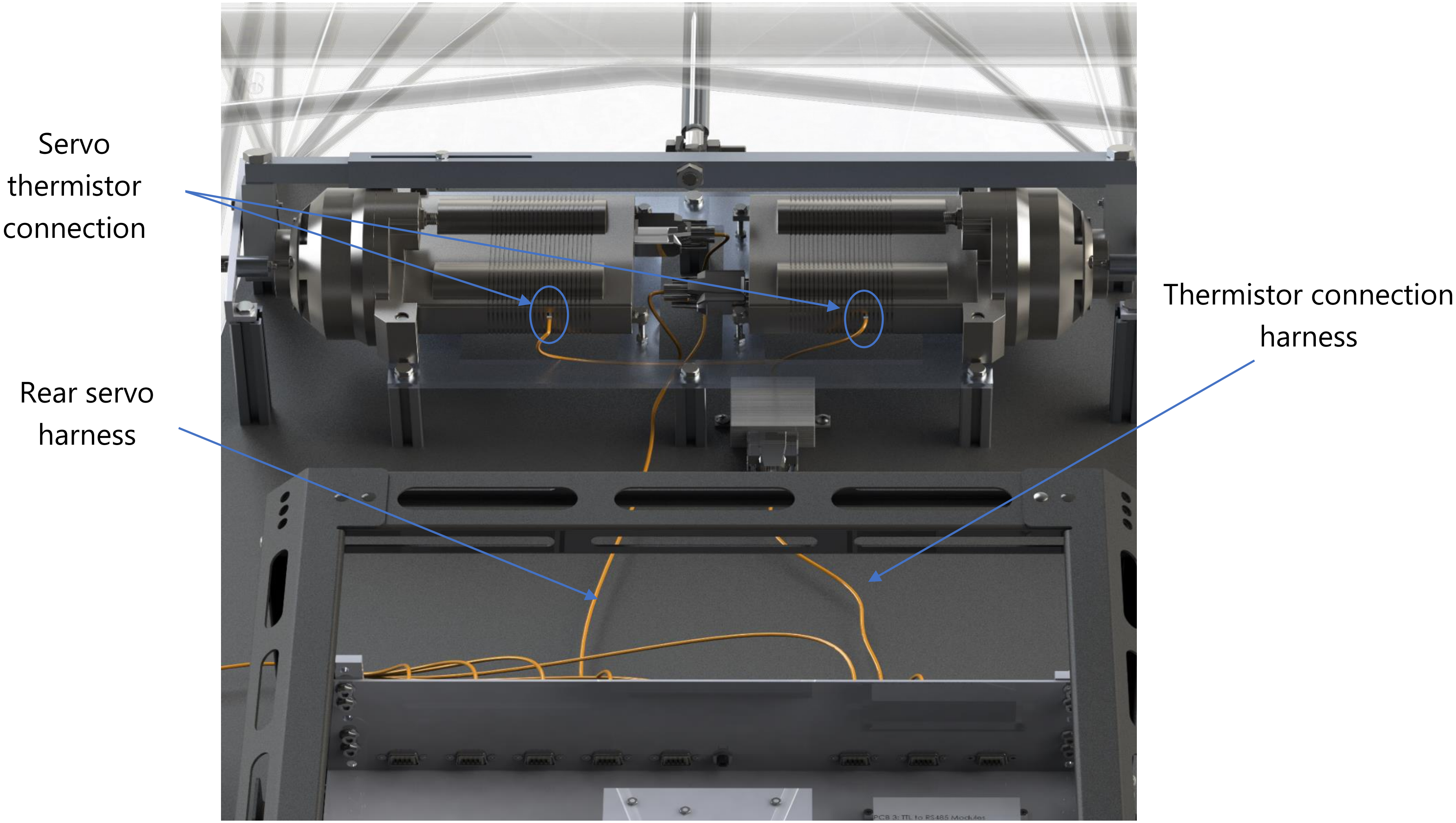


Figure 39: Routing diagram of the rear servos and thermistor from server rack.

Pitot Tube Installation

The pitot static tube should be mounted from port side wing struts, as shown in Figure 40. The pitot tube is mounted via a pitot tube strut, which ensures the pitot tube is sufficiently forward of the wing and wing struts to avoid the effects of wing downwash, whilst also being sufficiently far away from the fuselage to avoid the effects of the propeller wash. The details of the pitot tube mount assembly and installation can be found on the next page.

The pressure tube from the pitot static tube assembly is to be run down the port side rear wing strut and through the window down the side of the P1 pilot to the server tray. Then through the hole left for this purpose on the front face of the tray to the pressure sensor.

*Note: This tubing is to be flexible and secured to the wing strut and inside the aircraft to the aircraft tubing using cable ties.

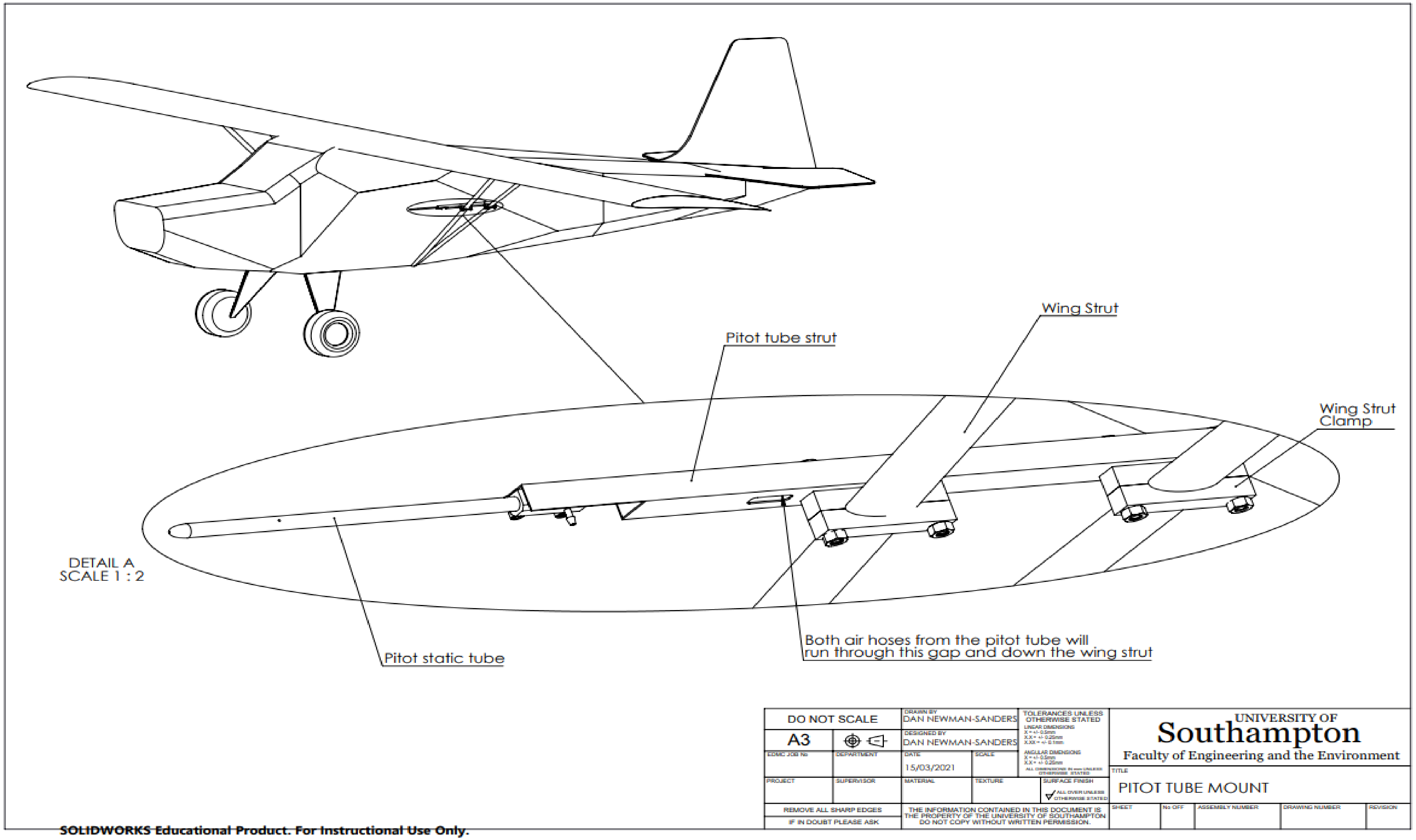
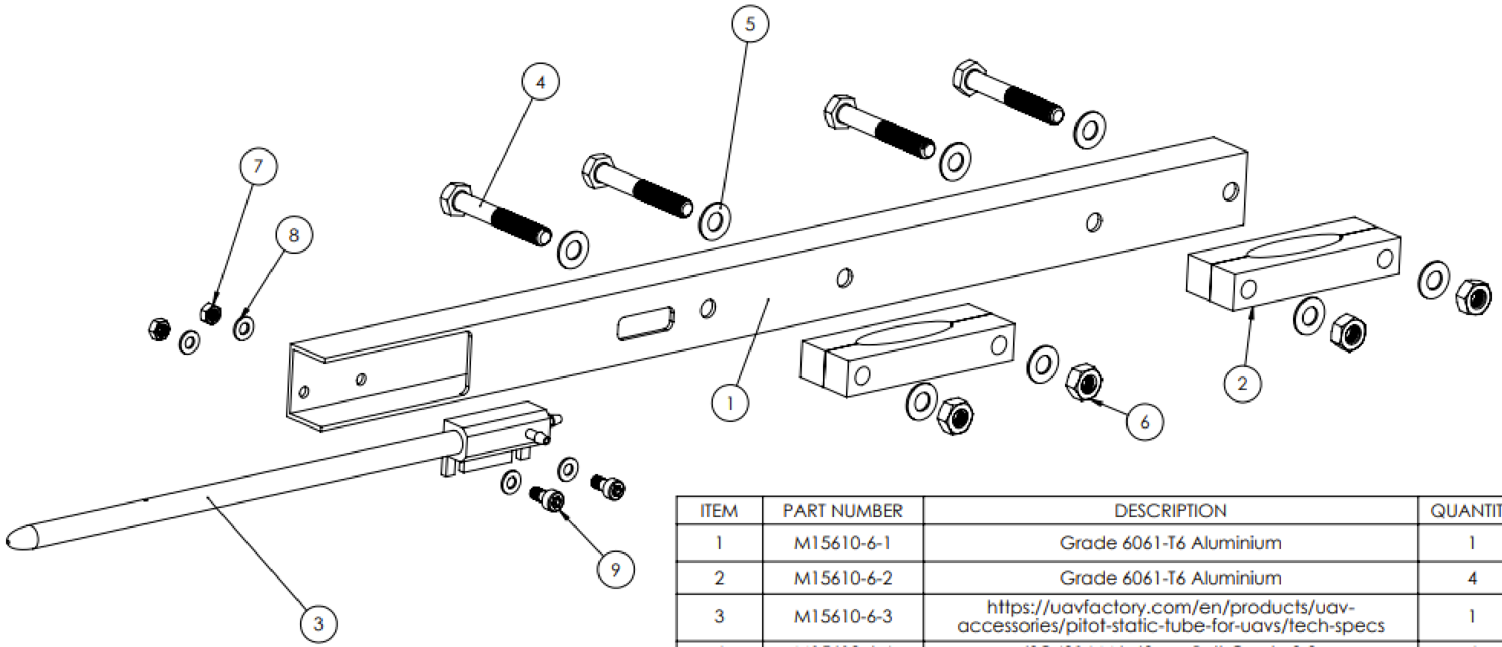


Figure 40: Pitot static tube assembly drawing 1.



ITEM	PART NUMBER	DESCRIPTION	QUANTITY
1	M15610-6-1	Grade 6061-T6 Aluminium	1
2	M15610-6-2	Grade 6061-T6 Aluminium	4
3	M15610-6-3	https://uavfactory.com/en/products/uav-accessories/pitot-static-tube-for-uavs/tech-specs	1
4	M15610-6-4	ISO4014 M6x60mm Bolt Grade 8.8	4
5	M15610-6-5	M6 Washer Grade 8.8	8
6	M15610-6-6	ISO4032 M6 Nut Grade 8.8	4
7	M15610-6-7	ISO4032 M5 Nut Grade 8.8	2
8	M15610-6-8	M5 Washer Grade 8.8	4
9	M15610-6-9	ISO4762 M5x10mm Bolt Grade 8.8	2
-	M15610-6-10	Tygon Tubing - 4mm (Inner Diameter) x 2m	2

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Figure 41: Pitot static tube assembly drawing 2.

Full Assembly Reference Drawing

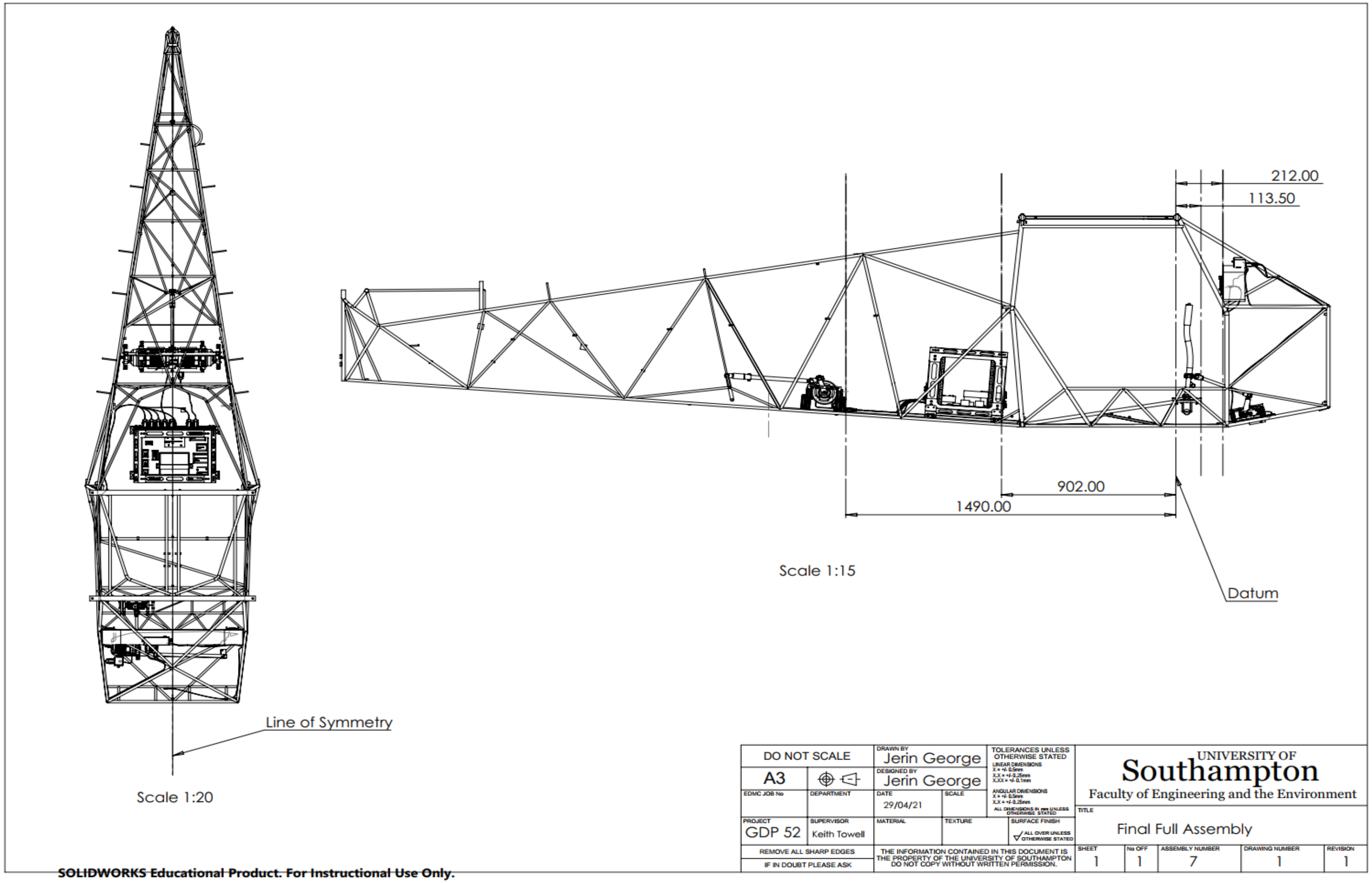

Figure 42: Full assembly drawing for reference.

Maintenance

Nuts and Bolts

All nuts and bolts should be checked before flight is conducted and tightened accordingly. If a thread on any component is found to be damaged in any way, the part should be immediately replaced.

Pins

Where pins are used, such as clevis pins in the front assembly, it should be checked that once the retaining pin is removed, the main pin is easily removable in case of an emergency. It is important that this is checked before each flight. The shear pin at the rear of the aircraft should be checked for damage and replaced if necessary before each flight as well.

Bearings

Bearings should be properly greased and regularly checked by movement of the mechanism to look for components which no longer function correctly through unwanted resistance to movement caused by bearing damage or other similar issues. Bearings should be easy to rotate and offer little resistance.

Slider

The combiner slider should also be tested by moving the mechanism with your hands, being careful to keep fingers away from the zone where the components meet which could cause harm by trapping skin. This should offer little resistance and can be loosed through the retaining bolt which passes through the combiner and combiner slider.

Servos

Before any form of use, the servos should be tested as recommended in the Operational Supplement. The servos fitted with clutches should offer little resistance when unpowered and should be movable by hand. When performing this check, the full range of motion of the servos should be used and attention paid to any inconsistencies or jerkiness in feel.

Sensors

Before first use all sensors must be calibrated and checked to ensure calibration is correct before each flight.

Sensors to check are:

- Servo position
- Pitot Tube
- Accelerometer
- Pressure sensor

Document 5 – Failure Modes and Effects Analysis

Variable Stability Demonstrator Modification

Aircraft Registration:	G-OUAV
Aircraft Type:	TLAC Sherwood Scout
Aircraft Serial Number:	345-15480
Modification Number:	15610
Date Created:	03/04/2021

Authors:

Jerin George, Callum Breslin, Daniel Newman-Sanders, Andrew Kernan and Declan Clifford

Failure Mode and Effects Analysis

Failure Mode Category	Potential Failure Mode	Potential Effect(s) of Failure	SEVi	Potential Cause(s) of Failure	OCCi	Current Process Controls (Prevention)	Current Process Controls (Detection)	DETi	RPNi	Recommend Action(s)	Responsibility & Planned Completion Date	SEVr	OCCr	DETr	RPNr
Installation															
Mechanical	Improper installation.	Mechanical parts will not act as expected, leading to safety hazards through impaired control system through jams of components.	9	Components jam due to incorrect alignment caused by parts not being in the correct position through human error, such that they interfere with each other and block the path of movement.	4	Provide detailed diagrams for installation and thoroughly check before flight.	Perform ground based testing to ensure the mechanisms move as intended.	2	72						
			7	Screws/nuts and bolts not being tightened sufficiently or overtightened such that they erroneously allow or disallow movement of parts relative to each other.	5	Provide detailed diagrams for installation and thoroughly check before flight by 3 independent people.	Perform ground based testing to ensure the mechanisms move as intended.	3	105	Use a torque wrench to ensure correct tightening of fixtures and thread locking compounds to prevent loosening	Installer - TBD	7	2	3	42
Electrical	Loose electrical connections.	Control system does not receive updated flight data values from sensor.	7	Communication with a sensor is lost due to a wire becoming unplugged.	3	All soldering will be thoroughly checked and all connectors will be secured.	All connections will be checked with a multimeter.	1	21						
		Actuator becomes jammed.	7	servo(s) lose power due to broken electrical connection.	3	All soldering will be thoroughly checked and all connectors will be secured.	All connections will be checked with a multimeter.	2	42						
		Actuator becomes jammed.	7	Communication between servo(s) and Arduino is lost due to broken electrical connection.	3	All soldering will be thoroughly checked and all connectors will be secured.	All connections will be checked with a multimeter.	2	42						
		Clutches open and actuators rotate independently of elevator motion.	5	Clutch(es) lose power due to broken electrical connection.	3	All soldering will be thoroughly checked and all connectors will be secured.	All connections will be checked with a multimeter.	2	30						
	Blockage of pitot tube.	Incorrect flight speeds are fed to the control model, resulting in possible dangerous elevator commands being outputted from the control model.	8	Build up of dust in pitot tube from aircraft hanger.	2	A cover will be placed on the pitot tube whilst the aircraft is in the hanger during the installation of the system.	We will visually inspect the pitot tube for blockages.	2	32						
Software	Failed installation of the Arduino code.	Incomplete functionality of the electronics.	9	Failure of code compilation or corruption of code during upload to the Arduino.	1	Ensure the Arduino is not unplugged during the upload process.	The Arduino code will be tested on the ground before flight to ensure full functionality.	1	9						
Calibration															
Electrical	Uncalibrated sensors.	Fire aboard the aircraft whilst in flight.	9	Improper calibration of thermistors could lead to overheating of battery/servos.	2	All sensors will be calibrated before flight on the ground. The connection to the battery is through a fuse which will break if the current draw exceeds 15 A.	Thermistor readings during calibration on the ground will be checked against expected values to ensure their correct operation.	2	36						
		Incorrect flight speeds are fed to the control model, resulting in possible dangerous elevator commands being outputted from the control model.	4	Improper calibration of differential pressure sensor.	2	All sensors will be calibrated before flight on the ground.	Differential pressure readings during calibration on the ground will be checked against expected values to ensure their correct operation.	5	40						
		Incorrect pitch values are fed to the control model, resulting in possible dangerous elevator commands being outputted from the control model.	4	Improper calibration of accelerometer.	2	All sensors will be calibrated before flight on the ground.	Accelerometer readings during calibration on the ground will be checked against expected values to ensure their correct operation.	5	40						

		Incorrect pitch rates are fed to the control model, resulting in possible dangerous elevator commands being outputted from the control model.	4	Improper calibration of gyroscope.	2	All sensors will be calibrated before flight on the ground.	Gyro readings during calibration on the ground will be checked against expected values to ensure their correct operation.	5	40						
Ground Test															
Mechanical	Incorrectly calibrated servos.	Incorrect elevator deflection and potential damage to aircraft.	7	Rear elevator output servos are misaligned or the servo deflection range is incorrectly defined in the code.	2	Mechanical stops will be installed to ensure the deflection never exceeds the design limits.	Maintenance and installation supplements will be provided to guide though the calibration process.	4	56						
	Improper Installation.	Mechanical parts will not act as expected, leading to safety hazards through impaired control system through jams of components.	9	Components jam due to incorrect alignment caused by parts not being in the correct position through human error, such that they interfere with each other and block the path of movement.	4	Provide detailed diagrams for installation and thoroughly check before flight. Perform ground based testing to ensure the mechanisms move as intended.		2	72						
			7	Screws/nuts and bolts not being tightened sufficiently or overtightened such that they erroneously allow or disallow movement of parts relative to each other.	5	Provide detailed diagrams for installation and thoroughly check before flight by 3 independent people. Perform ground based testing to ensure the mechanisms move as intended.		3	105	Use a torque wrench to ensure correct tightening of fixtures and thread locking compounds to prevent loosening.	Installer - TBD	7	2	3	42
	Insufficiently Charged Battery	System malfunction.	5	Drained Battery.	1	Ensure the battery is charged to at least 80 % before each flight.		1	5						
Software	Incorrect command sent to rear servos.	Elevator servos being driven beyond maximum range of the elevator motion.	6	Failure within the control code resulting in an invalid servo command.	1	Elevator saturation is built directly into the control code. The range of motion of the servos is limited by mechanical stops.	During a test of the control system the range of motion of the servos can be observed.	1	6						
	The elevator check in the control code fails.	Elevator servos being driven beyond maximum range of the elevator motion.	6	Failure of the elevator check in the control code.	1	Mechnical stops on the elevator servos will prevent the elevator from being pushed beyond the range of motion possible. The stops prevent the elevator from moving within 5 degrees of maximum deflection up or down.	During a test of the control system the range of motion of the servos can be observed.	1	6						
	Incorrect command sent to front servo.	Front servo being driven beyond maximum range of the elevator motion.	6	Failure within the control code resulting in an invalid servo command.	1	Position saturation is built directly into the control code. The range of motion of the servos is limited by mechanical stops.	During a test of the control system the range of motion of the front servo can be observed.	1	6						
	Position check of the front servo in the control code fails.	Front servo being driven beyond maximum range of the elevator motion.	6	Failure of the position check in the control code.	1	Mechnical stops on the front servo will prevent the stick from being pushed beyond the range of motion possible.	During a test of the control system the range of motion of the front servo can be observed.	1	6						
	Jamming of the dead man's switch(es)	Pilots will not have a means of quickly disengaging the system	7	Build up of dirt, dust and oil behind button can result in button becoming jammed.	2		The operation of the dead mans switches will be checked before each flight.	1	14						

Electrical	Blockage of pitot tube	Incorrect flight speeds are fed to the control model, resulting in possible dangerous elevator commands being outputed from the control model	8	Build up of dust and dirt in pitot tube from aircraft hanger	2	A cover will be placed on the pitot tube whilst it is stored in the hangar.	We will visually inspect the pitot tube for blockages. We will also test that the sensor reacts to someone blowing over it.	2	32						
	Failure of sensors	Incorrect sensor readings are fed into the control model, resulting in possible dangerous elevator commands being outputed from the control model	8	Long term storage of sensors may result in degredation of internal/external electrical connections.	3		We will check that the sensors respond as expected to ground tests.	2	48						
	Failure of thermistors	Fire aboard aircraft whilst in flight.	9	Long term storage of thermistors may result in them becoming faulty.	3	The connection to the battery is through a fuse which will break if the current draw exceeds 15 A.	We will check that the thermistors respond to temperature changes on the ground as expected.	2	54						
Flight															
Electrical	Failure of the primary accelerometer in flight	The Arduino would not be able to detect if the aircraft is exceeding the G-loading limits.	9	Vibrations caused by flight could cause accelerometer electrical connections to loosen.	4	All connections will be throughly checked and reinforced where necessary.	All connections will be checked with a multimeter (pre-flight).	3	108	We will therefore be implementing a secondary accelerometer (connected to a second Arduino) as a redundancy. The models of both the accelerometer and Arduino will be different, to increase the dissimilarity between the primary and secondary systems.		4	4	3	48
	Current surge from the battery	Excessive heating of wires could lead to the deteriation of insulation layers, resulting in contact between adjacent wires and catastrophic short circuits.	8	An actuator jam would lead to an increased current demand from the battery.	3	An 15 A fuse will be placed between the battery and the actuators/electrical system, meaning that our system is protected from excessive current surges.		2	48						
		Excessive heating of wires could lead to a fire onboard the aircraft.	9	An actuator jam would lead to an increased current demand from the battery.	2	An 15 A fuse will be placed between the battery and the actuators/electrical system, meaning that our system is protected from excessive current surges.		2	36						
	Relays being jammed open	Any rapid increase in G-loading would not result in the system being disengaged automatically by the Arduino.	5	If the primary Arduino were to fail and lock all pins 'HIGH' (which is a common failure mode of Arduinos), the primary Arduino would have no way of disengaging the actuators, and the pilots only mode of disengaging the system would be by releasing the dead man's switches.	3	This is why we have a secondary Arduino and accelerometer in the system, connected to a secondary relay. Even if the primary safety relay was jammed open, the secondary safety relay would be able to react to G-loading which exceeds our limits.		2	30						
	Incorrect command sent to rear servos.	Elevator servos being driven beyond maximum range of the elevator motion.	6	Failure within the control code resulting in an invalid servo command.	1	Elevator saturation is built directly into the control code. The range of motion of the servos is limited by mechanical stops.	During a test of the control system the range of motion of the servos can be observed.	1	6						

Software	The elevator check in the control code fails.	Elevator servos being driven beyond maximum range of the elevator motion.	6	Failure of the elevator check in the control code.	1	Mechnical stops on the elevator servos will prevent the elevator from being pushed beyond the range of motion possible. The stops prevent the elevator from moving within 5 degrees of maximum deflection up or down.	During a test of the control system the range of motion of the servos can be observed.	1	6						
	Incorrect command sent to front servo.	Front servo being driven beyond maximum range of the elevator motion.	6	Failure within the control code resulting in an invalid servo command.	1	Position saturation is built directly into the control code. The range of motion of the servos is limited by mechanical stops.	During a test of the control system the range of motion of the front servo can be observed.	1	6						
	Position check of the front servo in the control code fails.	Front servo being driven beyond maximum range of the elevator motion.	6	Failure of the position check in the control code.	1	Mechnical stops on the front servo will prevent the stick from being pushed beyond the range of motion possible.	During a test of the control system the range of motion of the front servo can be observed.	1	6						
Mechanical	Breakage of a structural component	Reduction or complete halt of system function	6	Structural failure due to high loading	1	All parts have been through analysis with a 1.5 times safety factor to ensure the sutiability of their dimensions and strength. The rear assembly has a shear pin which is designed to be the point of failure if the expected load is exceeded, this can then be easily replaced so the system is not ruined.	Observation of the system having no effect on the aircraft handling or visually seeing the front assembly break. The servo position sensor will show if the servo is not moving when it is supposed to.	2	12						
	Incorrect deflection limits	The elevator could move beyond the desired limits which could cause handling issues	3	Incorrect installation of the end stops for the servos or incorrect setting of the position within the adjustable bracket	2	Position will be checked and double checked prior to flight. Other software controls are in place to limit the deflection of the elevator and the mechanical stops will hopefully never be needed	The servos have position sensing which is monitored in software to ensure the limits are not passed	1	6						
	Difficulty moving mechanism	Stiffness or completed locking up of the mechanism could lead to the system being difficult or impossible to use to control the aircraft	8	Incorrect torquing of the fasteners, leading to too much friction between components Improper alignment of components leading to interference	1	The system will be constructed with the aid of a torque wrench to ensure everything is correctly tightened The system will be extensively tested on the ground before use in the air	Visual and tactile pre-flight inspection	1	8						
Post-Flight															
Electrical	Data corruption/loss	Loss of data from the SD card	1	Removal of SD card from SD card module occasionally causes data loss on the SD card	7	Instead of removing the SD card and plugging it into a laptop, we will write Arduino code which reads the data off the SD card, and transfers it to a laptop connected to the Arduino		2	14						
Mechanical	Incorrect Powering Down	Damage to components through unexpected action of the servo during the shutdown	2	The wrong commands being sent to the servo during shutdown	1	The software has been carefully written to avoid this happening	Visual/Audible drastic change in position of front or rear servos upon shutdown of the system	3	6						

Document 6 - Pseudocode

Variable Stability Demonstrator Modification

Aircraft Registration:	G-OUAV
Aircraft Type:	TLAC Sherwood Scout
Aircraft Serial Number:	345-15480
Modification Number:	15610
Date Created:	29/04/2021

Authors:

Jerin George, Callum Breslin, Daniel Newman-Sanders, Andrew Kernan and Declan Clifford

Document 6 - Pseudocode

```
INITIALISATION SEQUENCE


Initialise all Arduino modules
Run control loop initialization function

INTERRUPT SEQUENCE  (~1kHz)

        if STATE = OFF then
                Run flight data update function
        if STATE =! OFF then
                Run flight data update function
                Run safety check function
                if safety check function returns FALSE then
                        Set system to OFF state
                        Light all LED's to inform pilots that system has been disabled
                        Record to SD card that system was disabled
                else
                        Light dead mans switch LED to indicate depression of dead mans switches
                        Run stick force function
                        Run control loop
                        Send updated position requirement to actuators

LOOP SEQUENCE (~10Hz)

        Run status check function
        if status = OFF
                Light the 'OFF' LED
        if status = 1
                Light the '1' LED
        if status = 2
                Light the '2' LED
        if status = 3
                Light the '3' LED
        Write current flight and control data to SD card
        delay

FUNCTIONS

Func: Flight Data Update
        Func: Update airspeed:
                Read MPX5004DP sensor value using analogRead()
                Calibrate sensor reading, using pre-defined sensor offset value
                Convert result to voltage reading
                Using equations from datasheet, convert voltage into differential pressure reading
                Convert differential pressure reading into airspeed using rearranged Bernoulli equation
        Func: Update pitch and pitch angle:
                Read x, y and z accelerations from MPU6050 sensor
                Use trigonometry to calculate pitch angle
                Read pitch rate from MPU6050 sensor
```

```
Func: Status Check
    if position of rotary switch has changed
        Change system mode to new position of rotary switch

Func: Safety Check
        Check g loading not exceeded
        Check flight speed not exceeded
        Check aircraft angle of attack not exceeded
        Check elevator deflection not exceeded
        Check that dead mans switches are still depressed
        if all of the conditions are true
            return TRUE
        else
            return FALSE

Func: Control Loop Initialization
    timestep size
    timestep counter
    u vector
    old u value
    x vector for target aircraft
    x vector for modified Scout
    array for storing x vector at each timestep for target aircraft
    array for storing x vector at each timestep for modified Scout
    array for storing unmodified u vector at each timestep for target aircraft
    array for storing modified u vector at each timestep for modified Scout
    u vector for modified Scout
    integral term used in PD controller
    array for storing the state-space matrices for the Scout
    array for storing the state-space matrices for the target aircraft
    Func: Read in aircraft state-space matrices
        read in state-space matrices for the Scout
        read in state-space matrices for the target aircraft

Func: Control Loop
    Func: Store the current values of the x vectors and u vectors
        Write x vectors
        Write u vetors
    Update the timestep counter
    Func: Solve the target aircraft states
        Calculate inverse of (I-A) matrix
        Calculate product of B matrix and u vector
        Update x vector: product of inverse (I-A) matrix and B*u vector
    get the pitch rate output of the target aircraft
    Func: Solve the modified Scout states
        initialise the iteratation counter
        Func: Forward Euler method to guess the new states
        Do:
            Func: Get the input into the modifed Scout using the PD controller
            Func: Limit the control input to the permissable range of elevator inputs
            Solve the inverse of the Jacobian matrix
            Update the modified Scout states
```

```
            Increment the iteration counter
        While: max number of iterations has not been reached or the u vector into the modified Scout has not converged
    Output the required elevator command

Func: Stick Force
    Func: Calculate stick torque
        Calculate the total lift coefficient
        Calculate the fuselage datum angle of attack
        Calculate the wing angle of attack
        Calculate the tail effective angle of attack
        Calculate the tail hinge moment coefficient
        Calculate the hinge moment
        Calculate the stick torque
    Get force feedback servo torque
    Func: Calculate required torque command
        Subtract the servo torque from the stick torque
        Correct the error with a PID controller
        Saturate the torque command to +- 100 %
```

Document 7 – Electrical Load Analysis

Variable Stability Demonstrator Modification

Aircraft Registration:	G-OUAV
Aircraft Type:	TLAC Sherwood Scout
Aircraft Serial Number:	345-15480
Modification Number:	15610
Date Created:	29/04/2021

Authors:

Jerin George, Callum Breslin, Daniel Newman-Sanders, Andrew Kernan and Declan Clifford

Electrical Load Analysis

Arduino Load Analysis

In order to make sure that our Arduino can cope with the electrical demands that our system will put on it, we completed an electrical load analysis on all of the components that are connected to the Arduino 5V rail. The 5V pins on the Arduino are connected directly to the output of the LD1117 voltage regulator on the board. That chip has a maximum current rating of 800 mA, however there are thermal limits that need to be taken into consideration.

Using a built-in PCB analysis tool on the Arduino website, we measured that the surface area of copper (per side) of the LD1117 heatsink is approximately 0.25 inches squared. This means that when the top and bottom surface areas are combined, the total surface area of copper is approximately 0.5 inches squared.

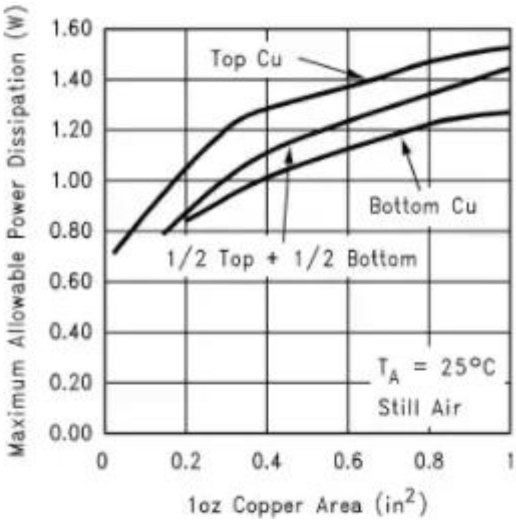

Figure 1 – Maximum Allowable Power Dissipation vs 1-oz Copper Area for SOT-223

Referring to Figure 1, which is taken from the datasheet for the LM1117 800-mA Low-Dropout Linear Regulator (which is Texas Instrument's own version of the LD1117), it can be seen that for a surface area of copper of 0.5 square inches, distributed evenly between the top and bottom surfaces, the maximum allowable power dissipation is 1.2 W. As the supply to the Arduino is 12V, the voltage drop across the LD1117 is 12-5=7V, meaning that the maximum current is given by:

$$I_{MAX} = \frac{P}{V} = \frac{1.2W}{7V} = 171\ mA$$

Therefore, we simply need to check that the sum of maximum current draws of all the components connected to our 5V rail does not exceed 171 mA. This calculation can be found in the table below.

Component	Maximum current draw per component (mA)	Voltage (V)	Quantity	Total maximum current draw (mA)	Power (W)
MPX5010DP Differential Pressure Sensor	10	5	1	10	0.05
MPU6050 Accelerometer and Gyroscope	3.9	5	1	3.9	0.0195
ADA254 SD Card Module	100	5	1	100	0.075
MAX485 TTL to RS485 converter	0.5	5	2	1	0.0025
Arduino Relay Module	5	5	2	10	0.05
				124.9	

As can be seen in the table, our maximum current draw of 129.4 mA is well within the thermal limit of 171 mA.

System Load Analysis

In order to size our battery and fuse, we needed to complete an electrical load analysis for our entire system. This load analysis can be found in the table below. The load analysis is assuming a system operating time of 60s per run.

	Component	Estimated Max Current Draw (A)	Voltage (V)	Quantity	Power (W)	Charge required @ 24V (Ah)	Total Current Draw @ 24V (A)	Total Power Usage (W)
Rear	Volz Servo	4.5	24	2	108	0.15	9	216
	Volz Clutch	1.1	24	2	26.4	0.037	2.2	52.8
Front	Volz Servo	4.5	24	1	108	0.075	4.5	108
	Arduino and Electronics	0.2	5	1	1	0.0008*	0.042	1
						0.262	15.742	377.8

*Assuming the 24V-12V step down regulator has an efficiency of 90%

Although the maximum expected current draw is 15.742A, the battery selected is only rated for 15A. Therefore, the current of each of the rear servos will be limited to 4A each electronically via current feedback signal from the servo. This decision is temporary and has been taken to limit the overall weight of the battery; a new battery will be fitted once the aircraft’s maximum take-off weight is increased though a further planned modification.

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Variable Stability Demonstrator Modification

Aircraft Registration:	G-OUAV
Aircraft Type:	TLAC Sherwood Scout
Aircraft Serial Number:	345-15480
Modification Number:	15610
Date Created:	27/04/2021

Authors:

Jerin George, Callum Breslin, Daniel Newman-Sanders, Andrew Kernan and Declan Clifford

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Force Value Origins

Rear

The forces I used for these analyses came from multiple sources. The maximum force on the rear assembly components is mainly derived from a maximum aerodynamic load on the elevator surface. This force is transmitted through the existing mechanical linkage to the idler. It is from here that the force acts upon the rear push rod and subsequently acts on the components attached to it. It is stronger than the combined maximum force from the actuator servos so it is the “worst case” loading.

The maximum aerodynamic force was calculated by the Aerodynamics and Flight Dynamics team in the first semester of the project. This value was 3456.5 N in the longitudinal direction of the aircraft, in accordance with CS-VLA-303, this and other loads will be subject to a 1.5 times safety factor.

The rear should hopefully experience very little lateral loading under normal conditions. The only introduction of lateral force into the rear actuation system would be if one servo were to fail and become locked in place. This would mean the combiner bar and slider would be held in place at the failed servo and pivot around that point, resulting in some lateral loading.

Front

The dominating force in the front assembly is sourced from the maximum force exerted by the pilot at the top of the stick, which is 740 N, both longitudinally and laterally. Due to the stick acting as a lever, the force at the front push rod attachment is amplified to 3007 N, which is stronger than the maximum force from the servo we are using. Therefore this is the force used for a lot of the front component calculations (or fractions of this force for parts which share the load). Again, this is combined with the 1.5 times safety factor.

Lateral loading will occur in the testing on the front assembly, as it will be needed to perform “wind up turns” using the roll control axis. Due to the nature of the 740 N maximum force at the top of the stick also being applied laterally, the same 3007 N force is used within the assembly components mounted lower down the stick (again due to the moments and the stick acting as a lever).

Materials

All manufactured parts are made from Aluminium 6061-T6, which has the following properties:

- Density 2700 kgm^{-3}
- Modulus of Elasticity 68 GPa
- Yield Strength 276 MPa
- Ultimate Tensile Strength 310 MPa
- Shear Modulus 26 GPa

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Rough Calculations

My rough calculations to give ballpark figures as sanity checks for the analysis were run using a MATLAB script I created. There are two scripts, one for circular and one for rectangular cross-sections. I have the definitions for the shape of the member at the top of the script and loading conditions follow this. It outputs stress, deflection and the safety factor applied loading which was used. Depending on the situation, there is a simply supported or cantilever loading option which is decided before running the analysis.

The code used for this is shown below. First is the rectangular cross-section members, below that is the circular cross section code.

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```
% Definitions
outer_width = 20 / 1000; % Outer width in metres
outer_depth = 20 / 1000; % Outer depth (thickness) diamter in metres
inner_width = 15 / 1000; % Inner width in metres
inner_depth = 15/ 1000; % Inner depth (thickness) diamter in metres
E = 68000000000; % Young's Modulus in Pa
L_Initial = 500 / 1000; % Initial length in metres
Moment_Arm = 0.06; % Length of servo arm in metres

% Conditions
F = 0; % Axial force in Newtons
P = 5184.8; % Transverse loading

% Elongation Calculation
A = (outer_width * outer_depth) - (inner_width * inner_depth); % Cross-sectional area in metres^2
sigma = P / A; % Stress in Pa
epsilon = sigma / E; % Strain
L_Delta = epsilon * L_Initial; % Change in length in metres

% Buckling Calculation
I = (outer_width * (outer_depth ^ 3) / 12) - (inner_width * (inner_depth ^ 3) / 12); % Second moment of area for circular section in metres^4
F_Crit = ((pi ^ 2) * E * I) / (L_Initial + L_Delta); % Critical buckling force

% Transverse
delta_max = 1000 * (P * ((L_Initial) ^ 3)/(48 * E * I)); % Maximum Deflection in simple supported beams
%delta_max = 1000 * (P * ((L_Initial + L_Delta) ^ 3)/(3 * E * I)); % Maximum Deflection in cantilever beams


% Reporting
disp(strcat('Max expected force: ',num2str(F),' N','  Safety Factor: ',num2str(F * 1.5),' N'));
disp(strcat('Critical buckling force: ',num2str(F_Crit),' N','  Stress: ',num2str(sigma / 1000000),' MPa','  Deflection: ',num2str(delta_max),' mm'));
```

Figure 1

G-OUAV Structural Report – Document 8

```matlab
% Definitions
d_outer = 18 / 1000; % Outer diameter in metres
d_inner = 10 / 1000; % Inner diamter in metres
E = 68000000000; % Young's Modulus in Pa
rho = 2700; % Density of Aluminium 6061-T6
L_Initial = 0.27; % Original length in metres

% Conditions
F = 3007.1; % Expected force in Newtons
P = 6014.2;

% Elongation Calculation
A = (pi * (d_outer ^ 2) / 4) - (pi * (d_inner ^ 2) / 4); % Cross-sectional area in metres^2
sigma = F / A; % Stress in Pa
epsilon = sigma / E; % Strain
L_Delta = epsilon * L_Initial; % Change in length in metres

% Buckling Calculation
I = ((pi * (d_outer ^ 4)) / 64) - ((pi * (d_inner ^ 4)) / 64); % Second moment of area for circular section in metres^4
F_Crit = ((pi ^ 2) * E * I) / (L_Initial + L_Delta); % Critical buckling force

% Transverse
delta_max = 1000 * (P * ((L_Initial + L_Delta) ^ 3)/(48 * E * I)); % Maximum Deflection in simple supported beams
%delta_max = 1000 * (P * ((L_Initial + L_Delta) ^ 3)/(3 * E * I)); % Maximum Deflection in cantilever beams

% Reporting
disp(strcat('Max expected force: ',num2str(F),' N',' Safety Factor: ',num2str(F * 1.5),' N'));
disp(strcat('Critical buckling force: ',num2str(F_Crit),' N',' Stress: ',num2str(sigma / 1000000),' MPa',' Deflection: ',num2str(delta_max),' mm'));
```

Figure 2

G-OUAV Structural Report – Document 8

Rear Assembly

Rear Push Rod

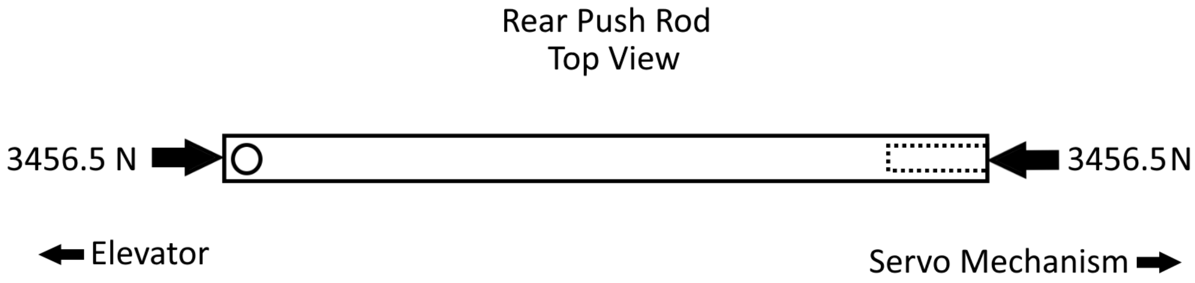

Figure 3

The rear push rod is loaded simply under normal conditions with purely axial loading. MATLAB gives a stress of 17.09 MPa, 7.79 mm deflection and a critical buckling force of 11,586 N. FEA concurs with these results as shown below. This force direction dominates as in normal operation, the push rod should experience no lateral forces. In the event of a servo failure, the push rod is able to twist slightly to allow one servo to continue operating. In these conditions however, the forces will be a fraction of the forces exerted longitudinally so as the tube is at only 20% of the yield stress under normal conditions, it can be assumed that the slight additional lateral loading will not impact the safety of this part.

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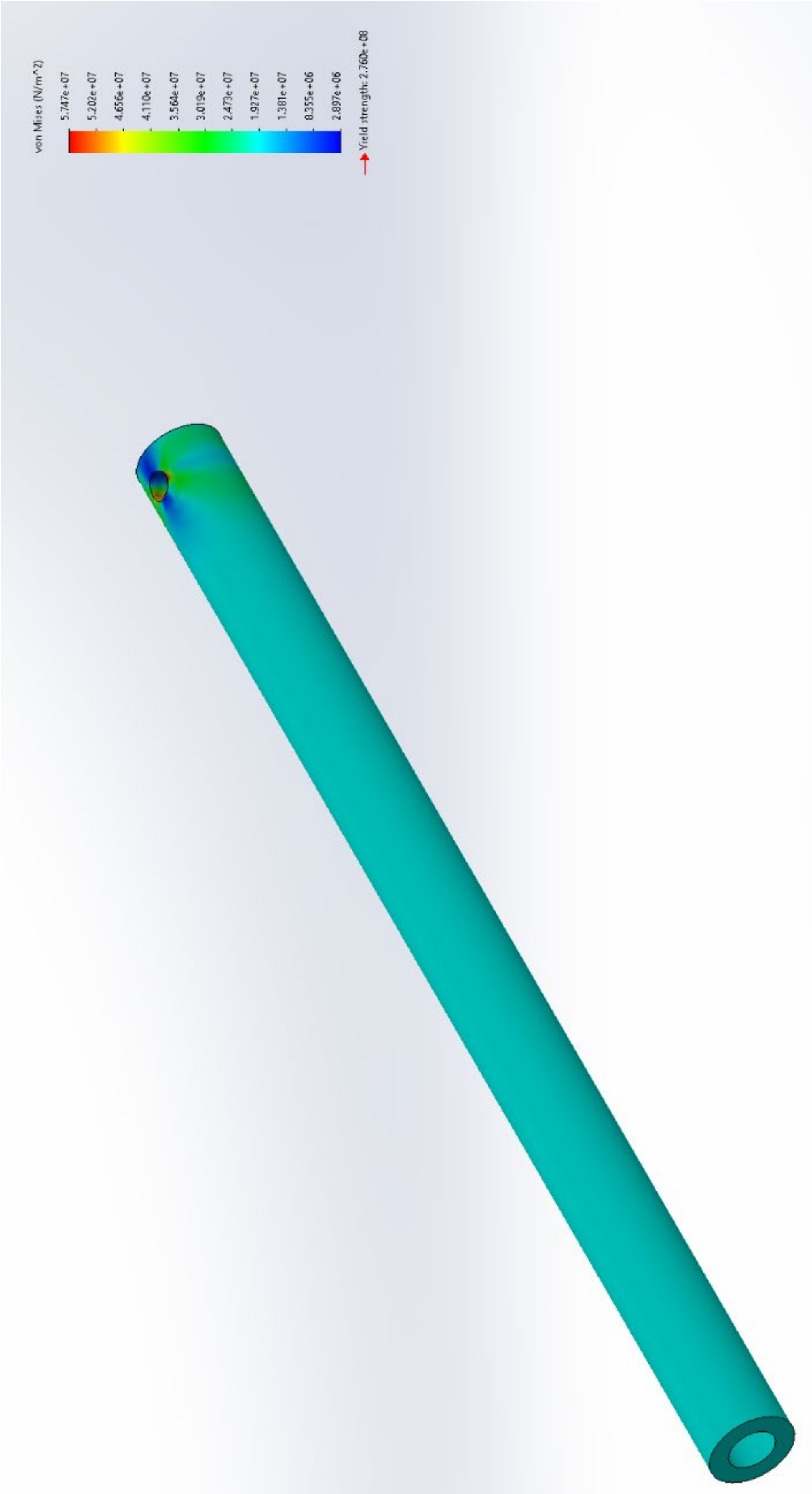

Figure 4

G-OUAV Structural Report – Document 8

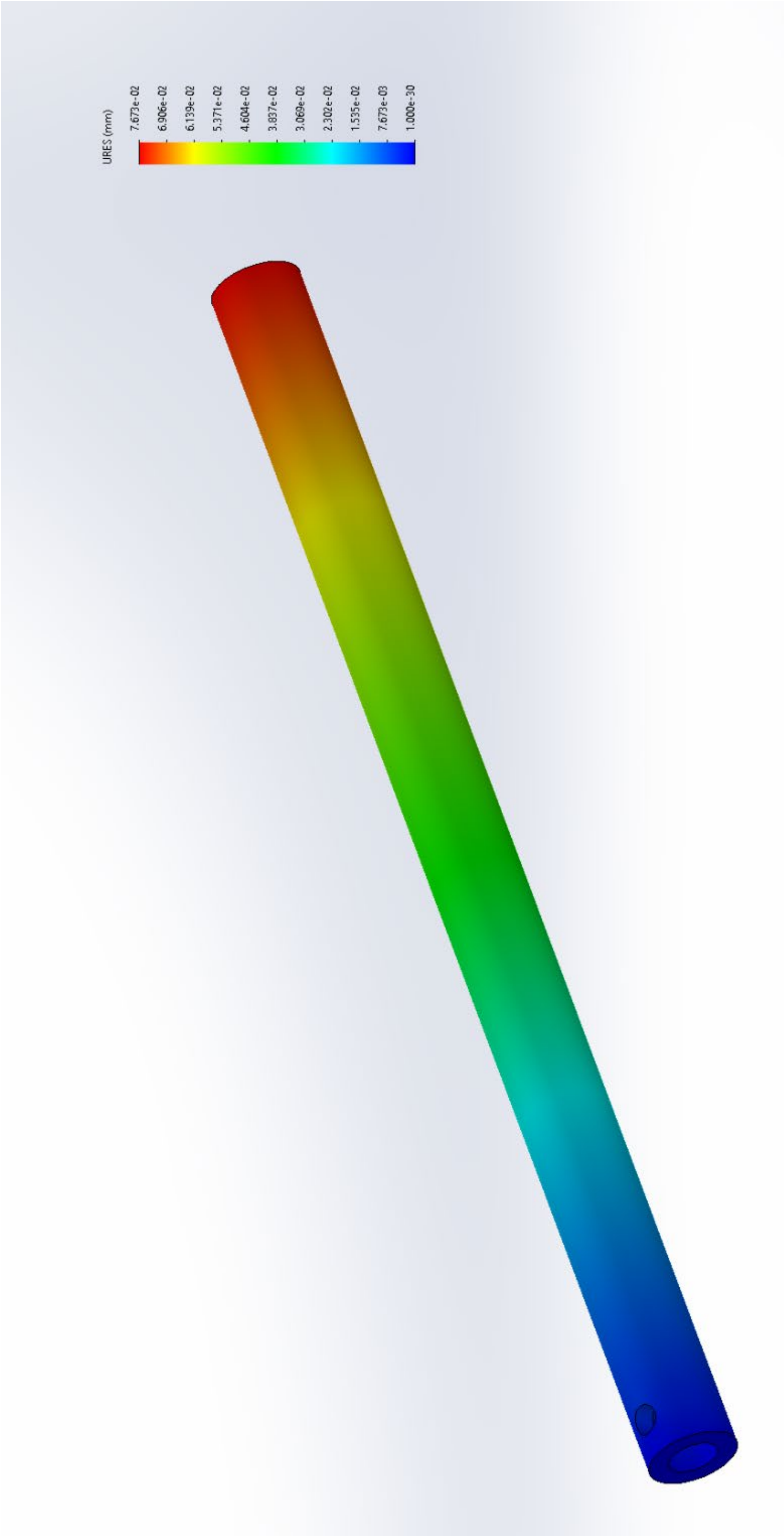

Figure 5

G-OUAV Structural Report – Document 8

<u>Combiner</u>

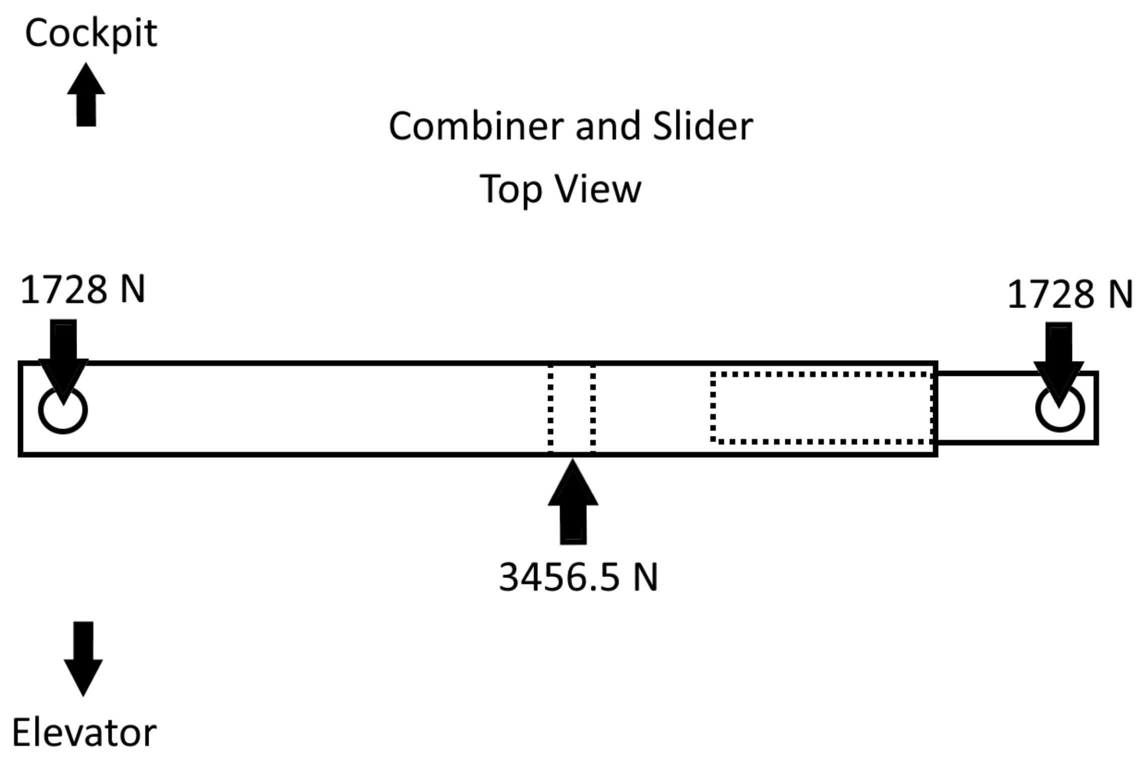

Figure 6

The combiner mechanism receives the full load from the rear push rod at its centre, with the reaction force therefore being equally split between the attachments to the rear servo arms at either end. Half the elevator force acts at each end, giving 1728 N. The loading is complicated by the slider mechanism. I have elected to fix the slider in place along with the bolt location at the opposite end, with these providing the reaction forces to my input elevator force.

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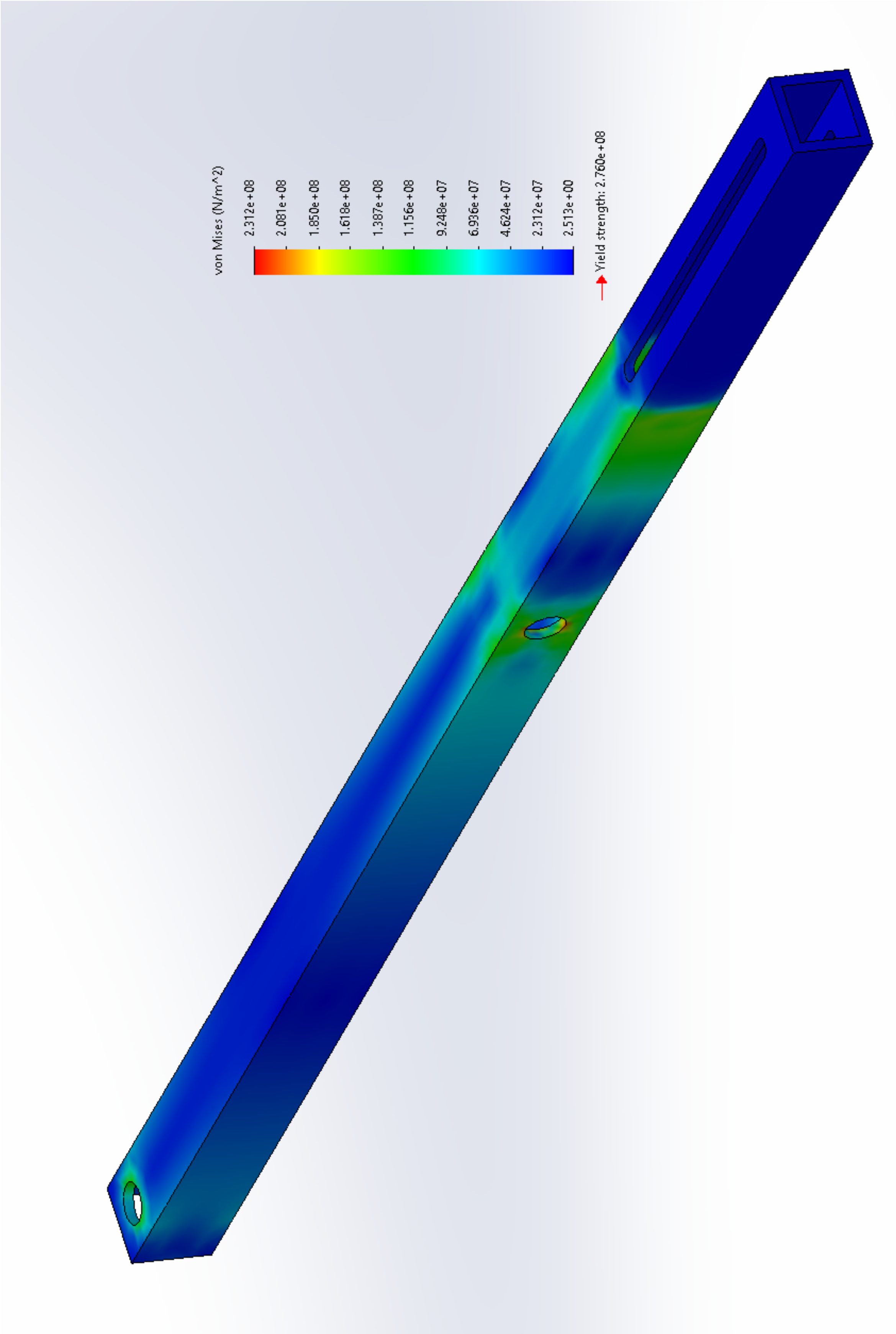

Figure 7

G-OUAV Structural Report – Document 8

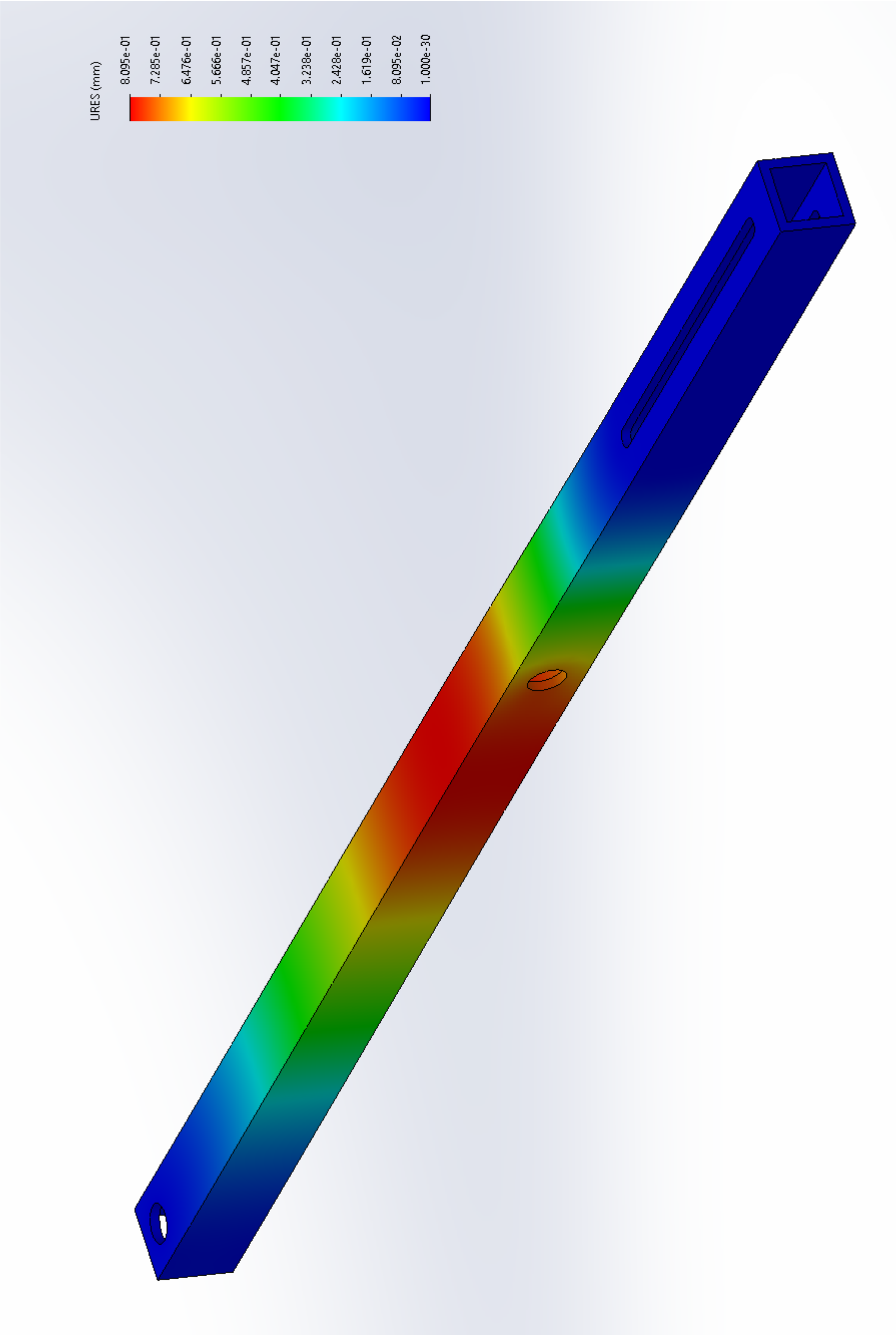

Figure 8

G-OUAV Structural Report – Document 8

<u>Combiner Slider</u>

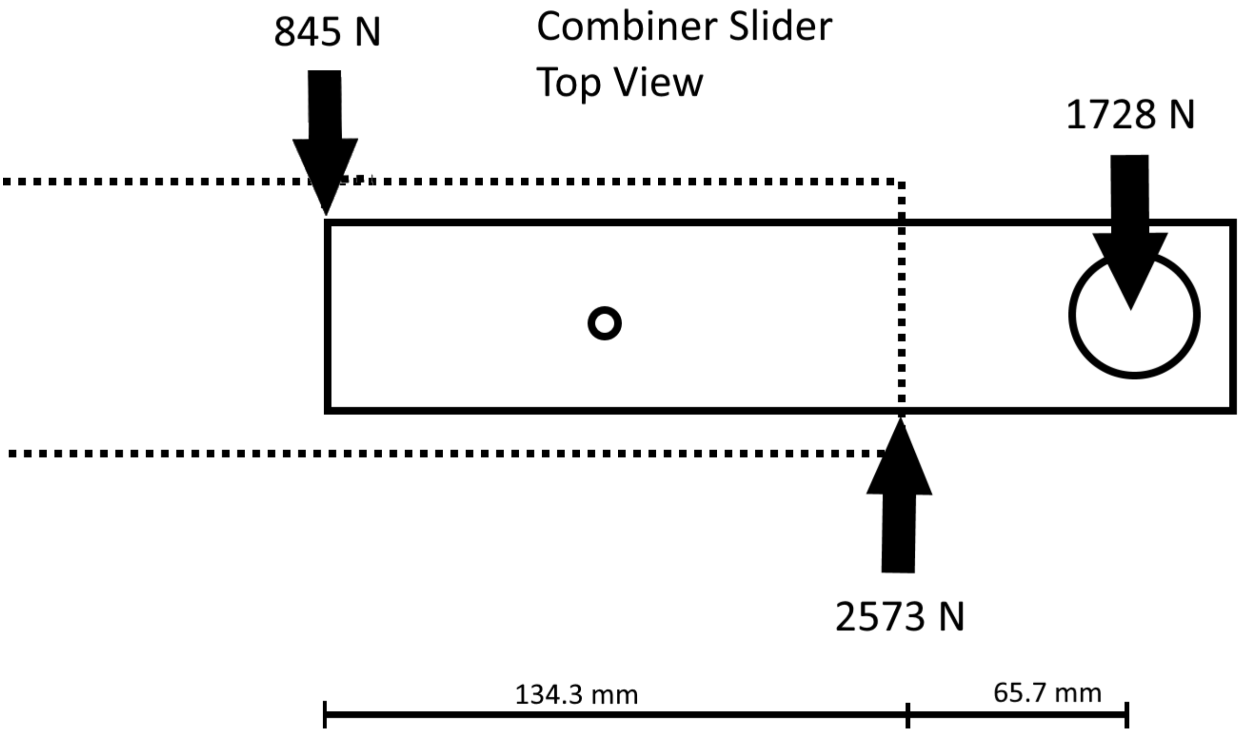

Figure 9

The 1728 N is derived from half the force acting on the combiner, this is a reaction force from the rear servo arm. In order to account for moment forces, three-point contact forces are required to balance the part. I took moments around the point at which the combiner ends (where the 2573 N force acts) to calculate the reactions.

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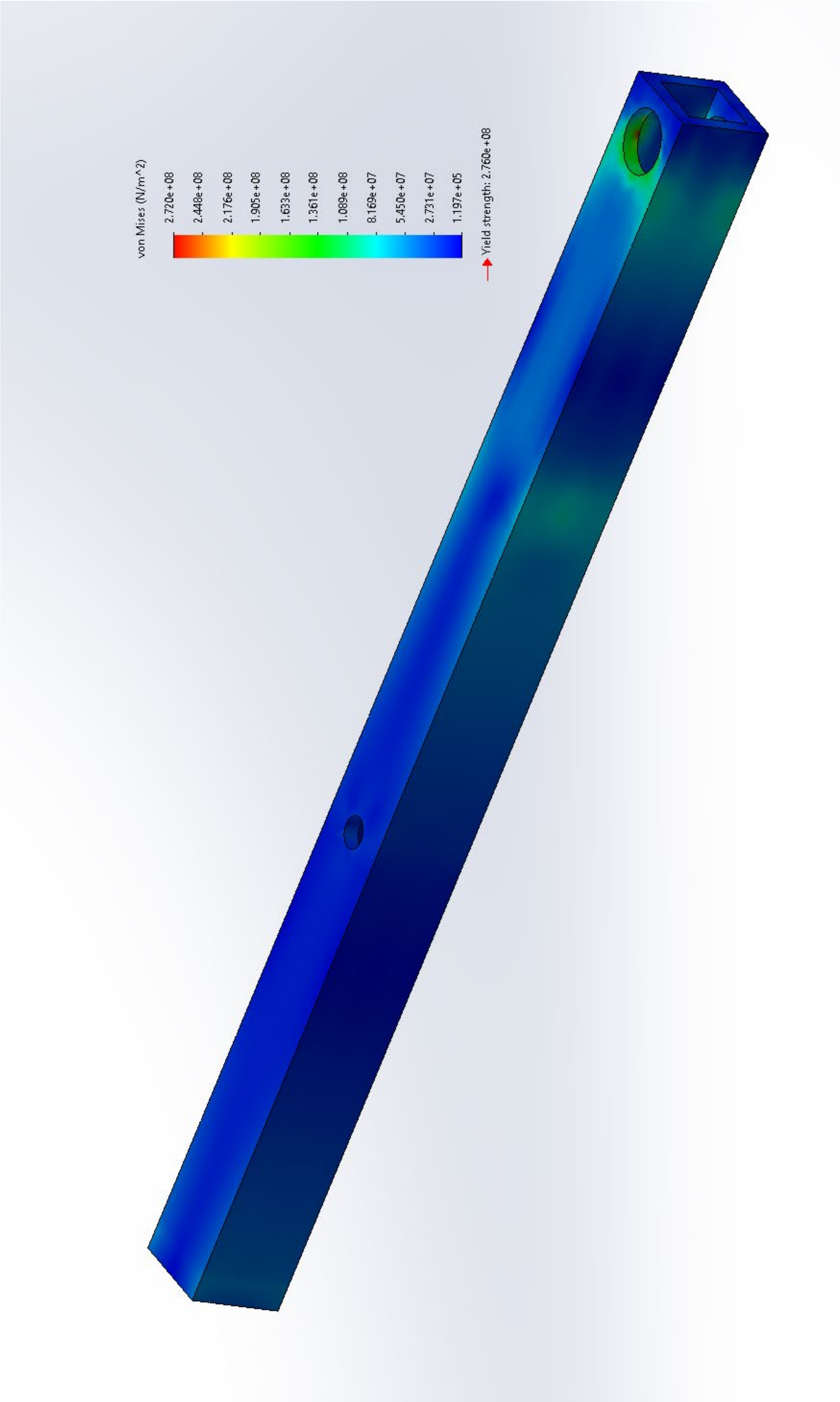

Figure 10

G-OUAV Structural Report – Document 8

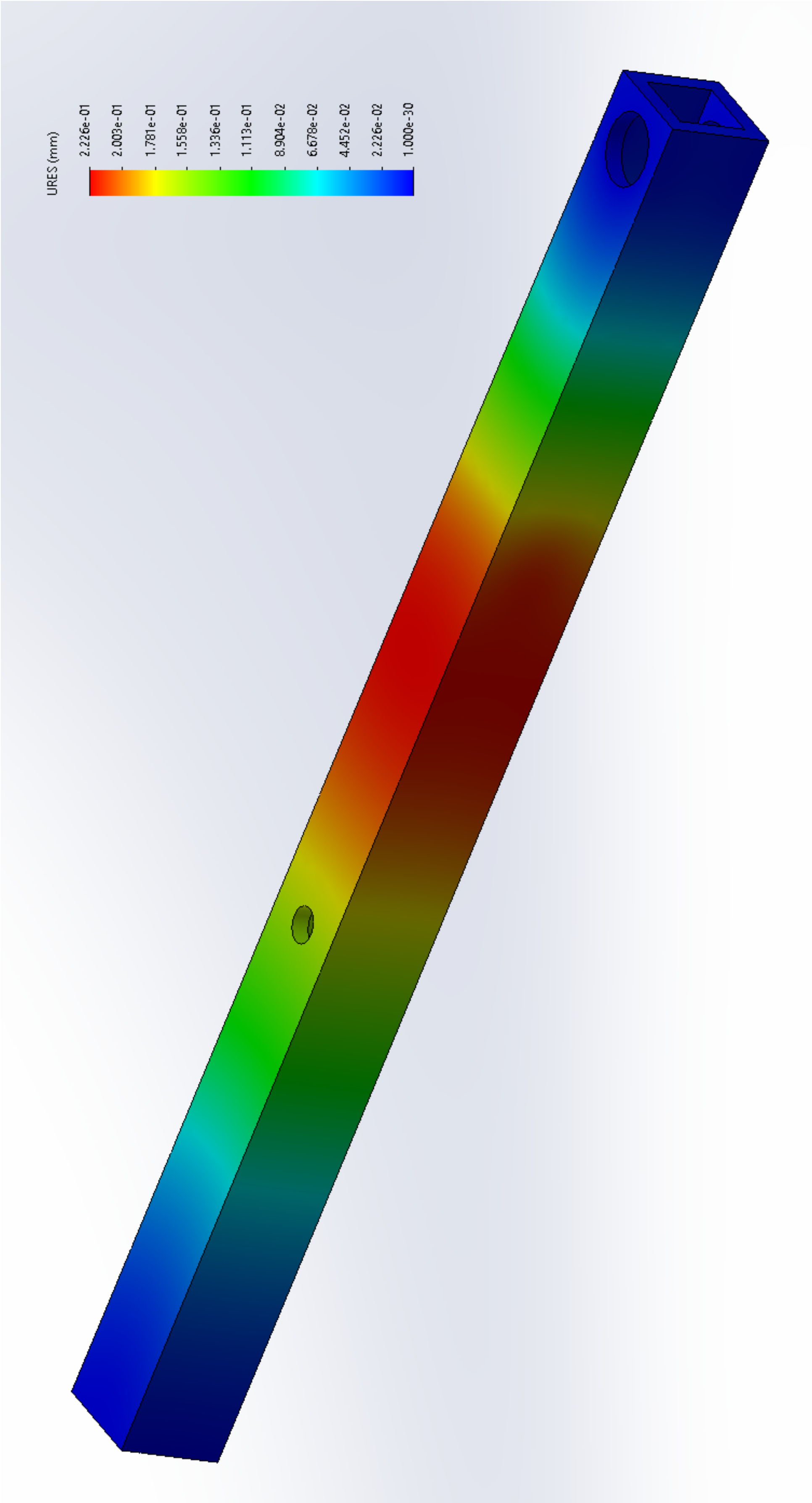

Figure 11

G-OUAV Structural Report – Document 8

<u>Rear Servo Arm</u>

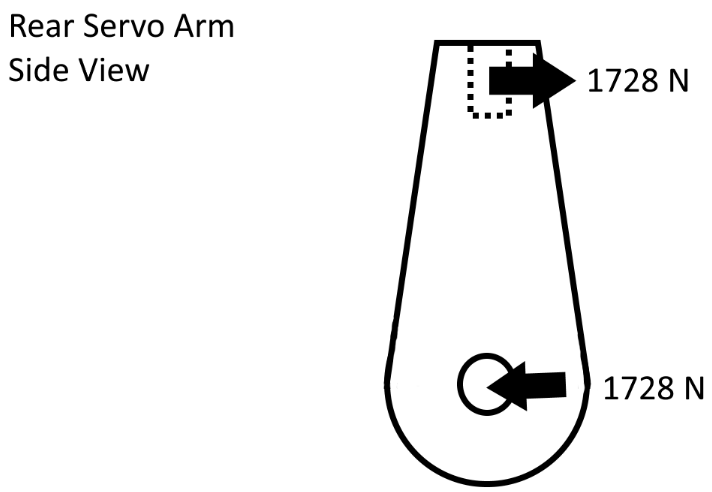

Figure 12

As in the slider part, the force felt by the rear servo arms is 1728 N on the top of each arm respectively. With our safety factor, this amounts to 2592 N, which is easily withstood by the design as shown below. As expected, the highest stress is around the splines which attach the part to the servo axle, however due to the distribution, the stresses are still low.

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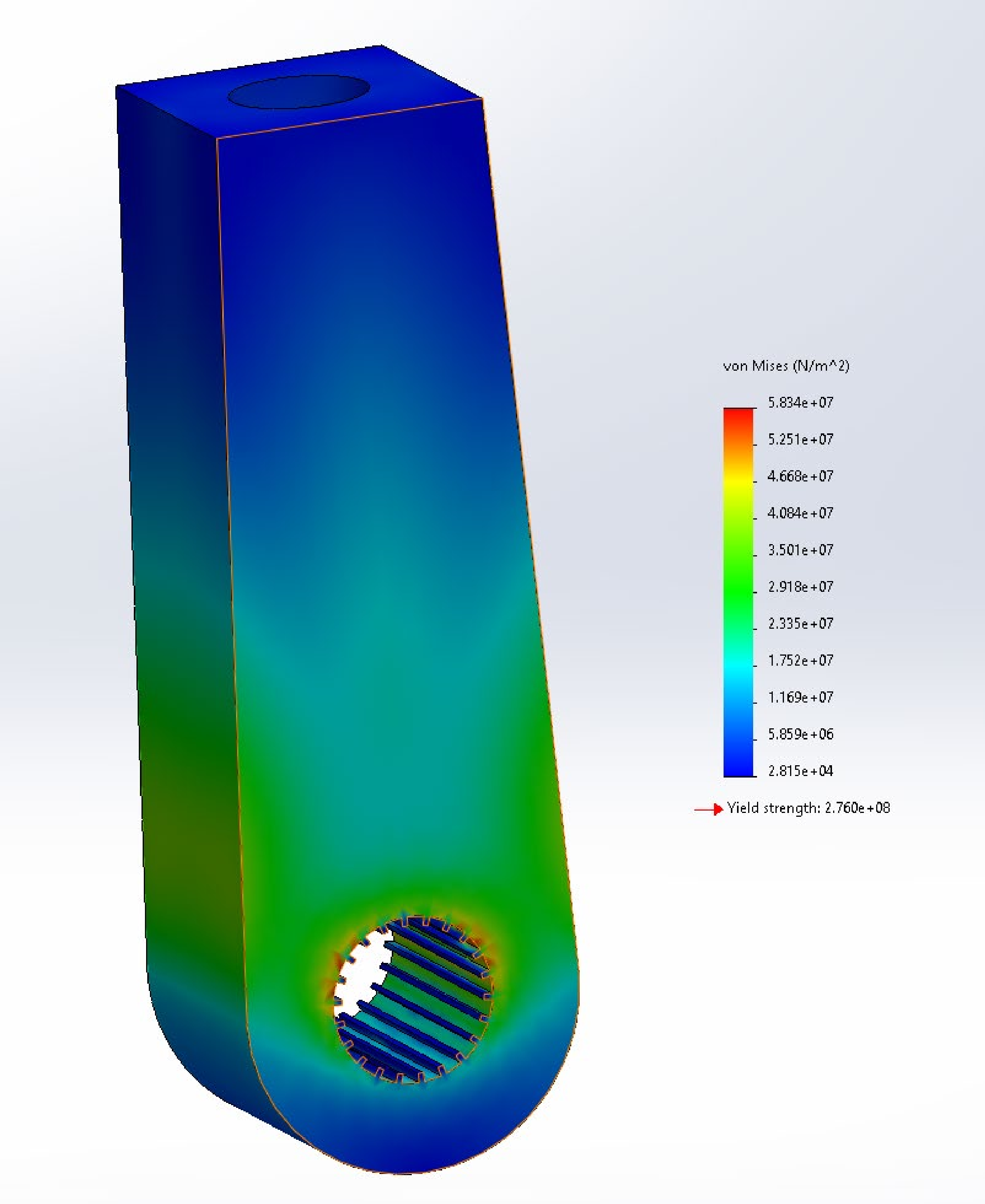

Figure 13

G-OUAV Structural Report – Document 8

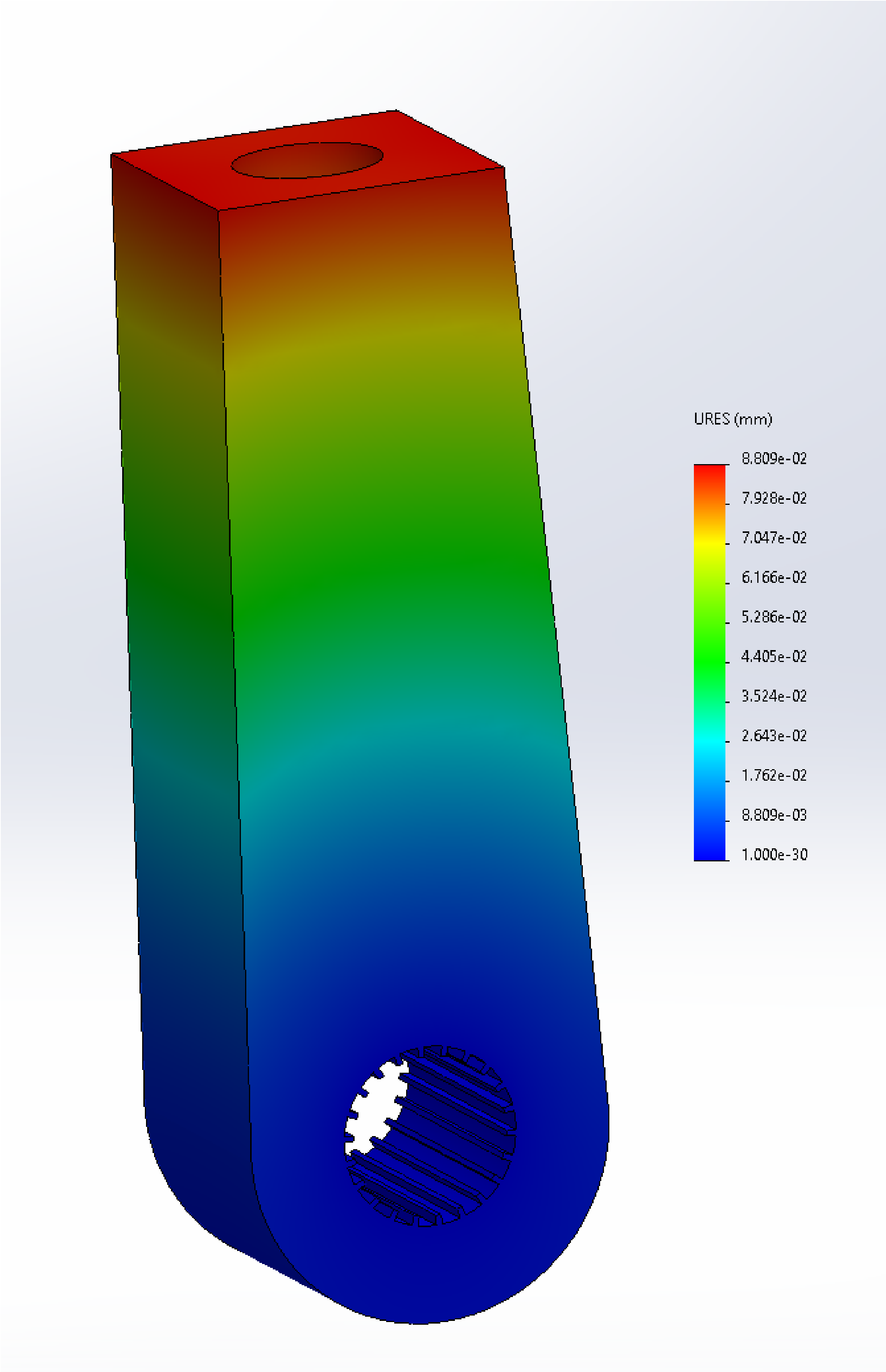

Figure 14

G-OUAV Structural Report – Document 8

Rear Servo Mounting Plate

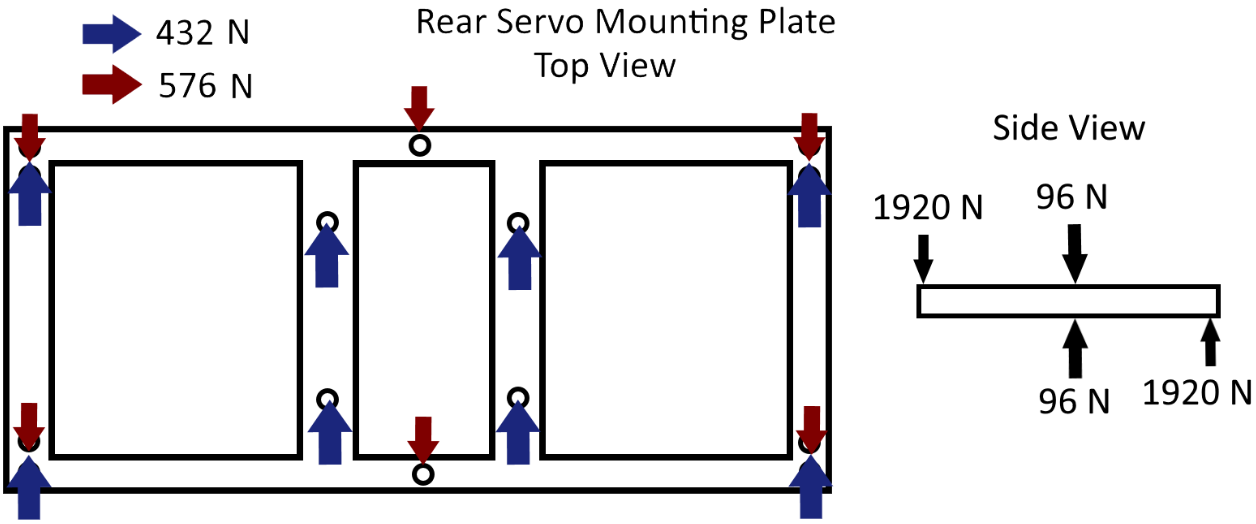

Figure 15

The loading of this plate is more complex, with forces being distributed across the plate. These forces arise from the 3456.5 N exerted by the elevator aerodynamic forces. The blue arrows show the distribution via the servo mounting bolts, the red arrows show the reaction forces which come from the six legs holding the plate off the floor of the aircraft. On the side view, a reactive moment, counteracting the torque of the servo can be seen. This is 32 Nm, which will be opposed by a couple type force acting at the attachment of the mounting plate to the legs which support it. The weight of the components mounted on top of the plate is also taken into account with the 96 N force.

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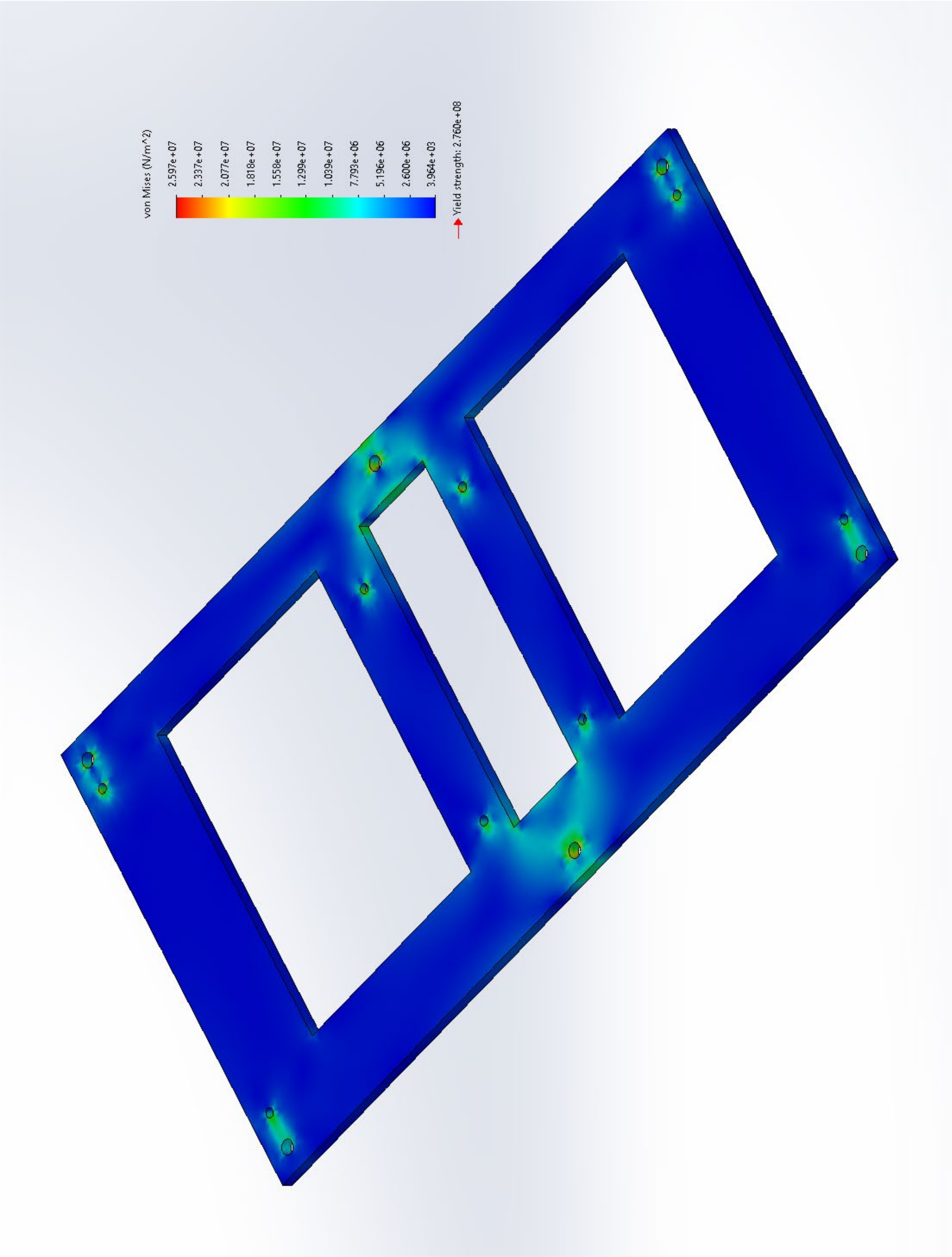


Figure 16

G-OUAV Structural Report – Document 8

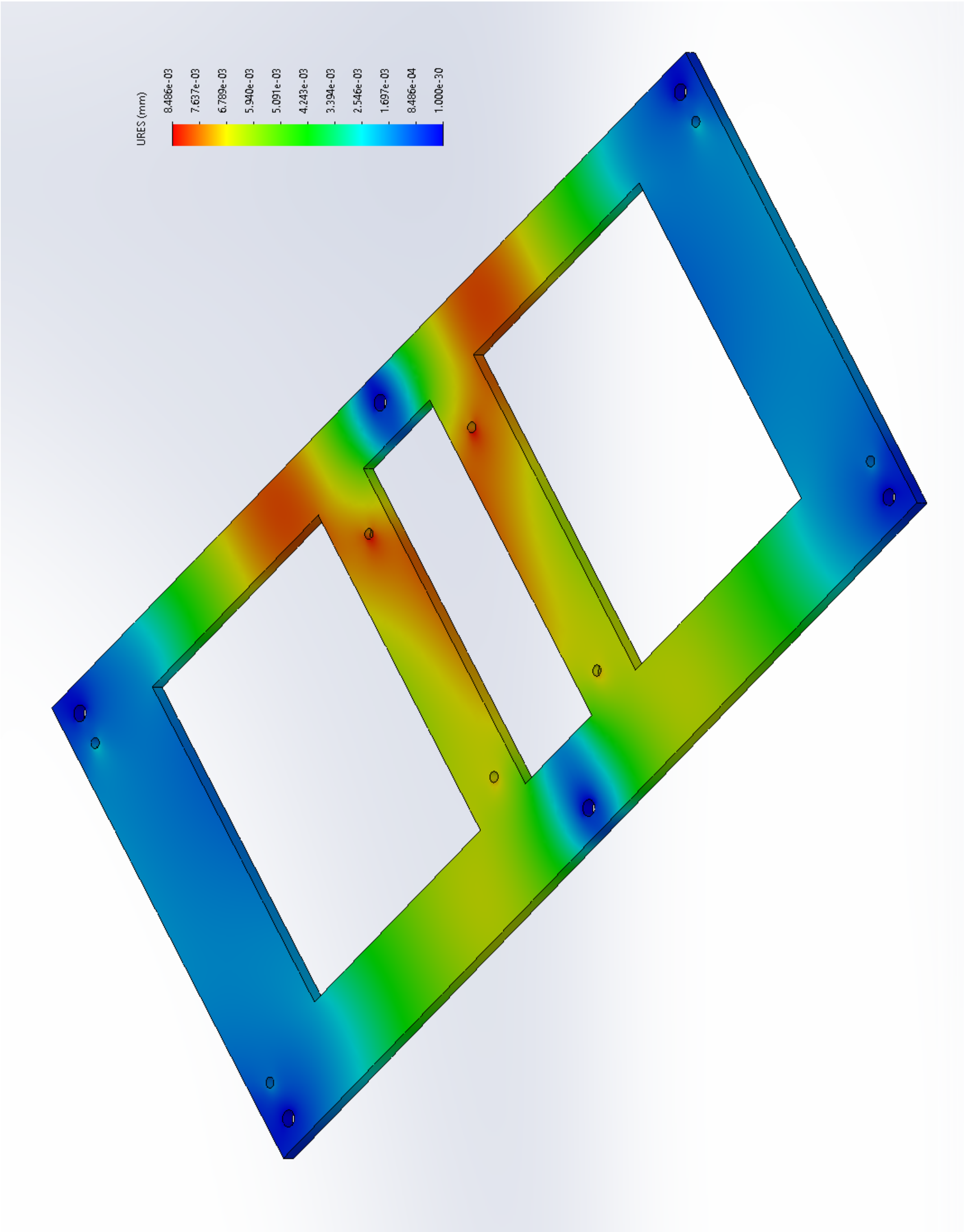


Figure 17

G-OUAV Structural Report – Document 8

Rear Servo Plate Leg

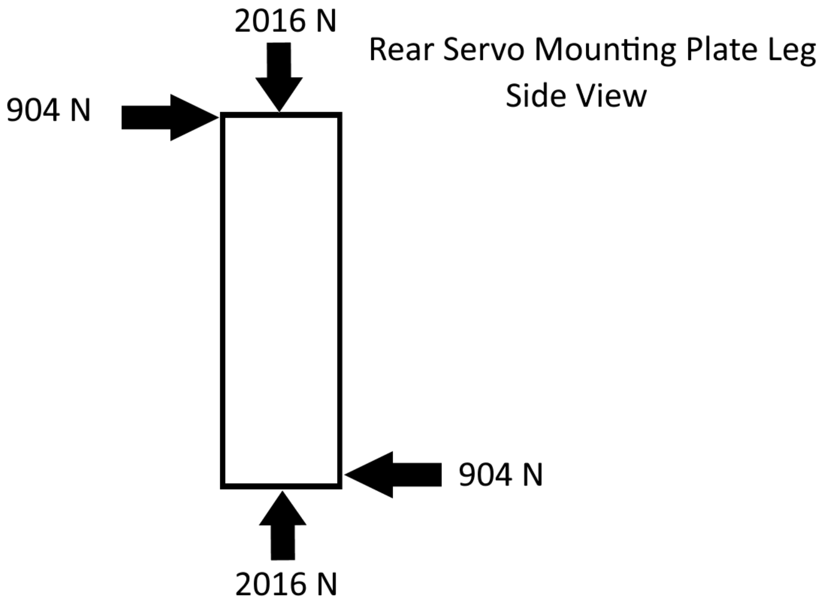


Figure 18

This component feels the 904 N force from the servo mounting plate above, weight of the components on top of the part is also taken into account as it is now non-negligible with the 4.26 kg servos being supported, along with the other manufactured components. The legs also feel the force from the servo moment counteraction forces. Again the analysis shows that the maximum stress is well below the yield stress of the material.

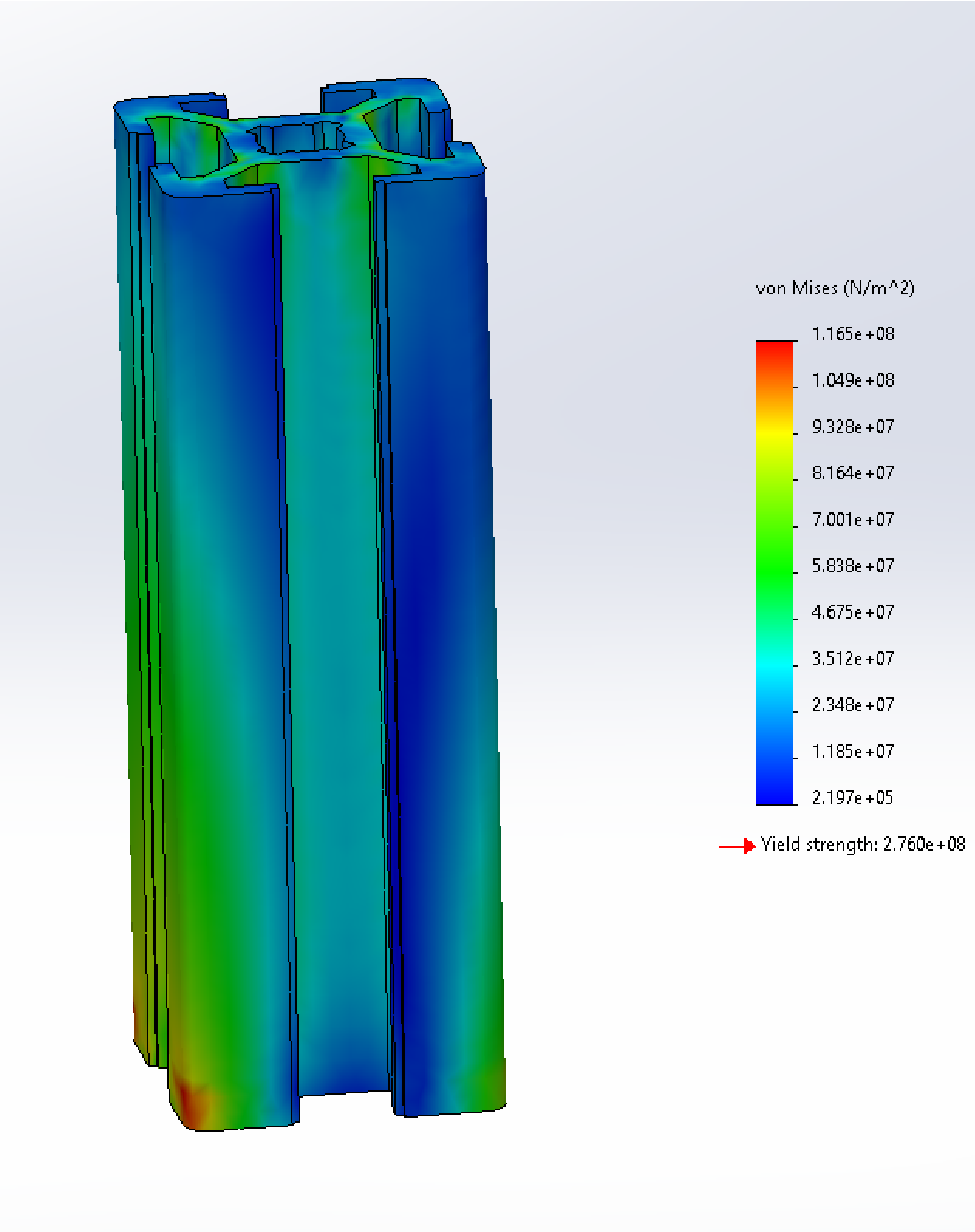


Figure 19

G-OUAV Structural Report – Document 8

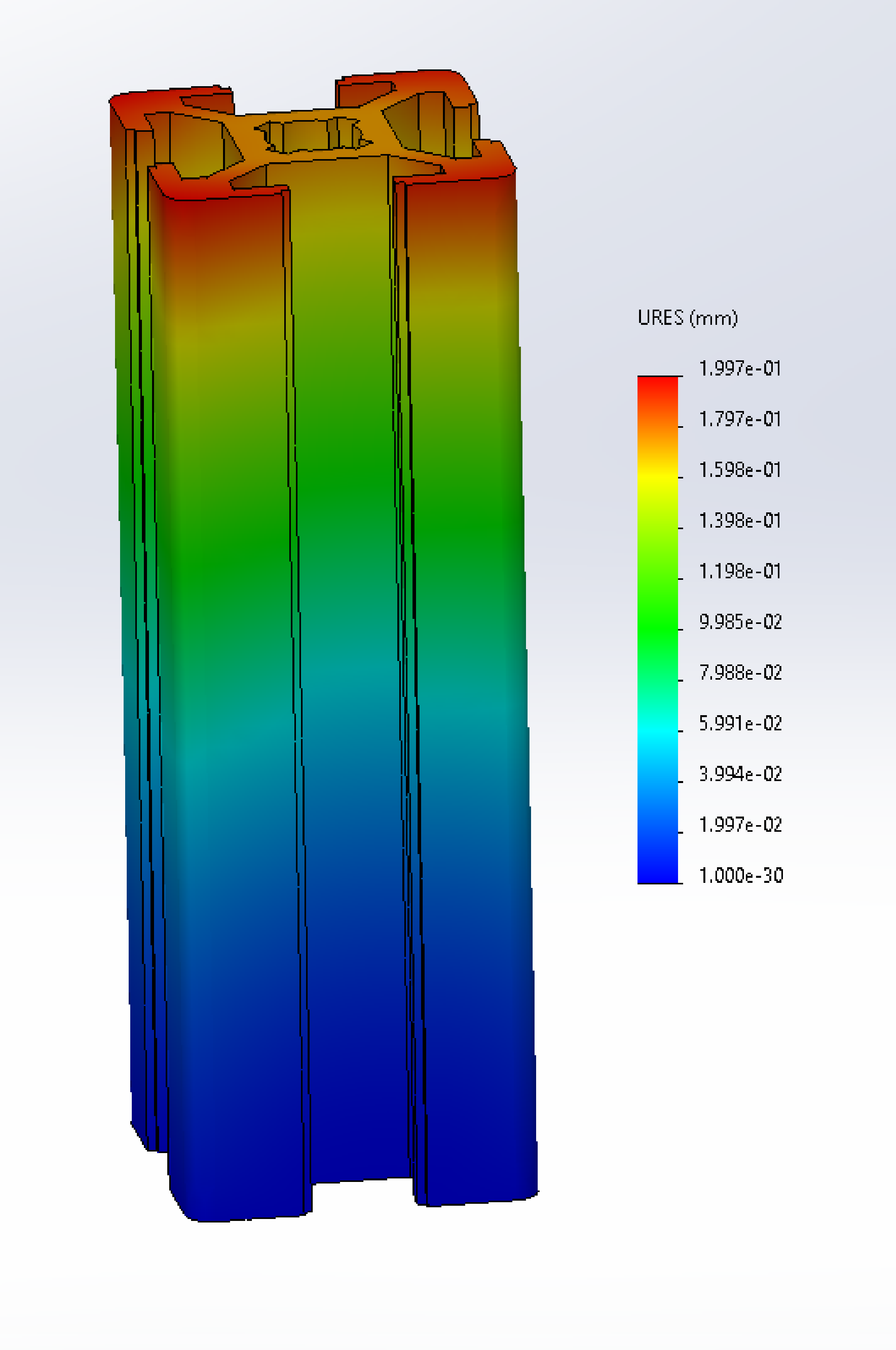


Figure 20

G-OUAV Structural Report – Document 8

<u>Shear Pin Connector</u>

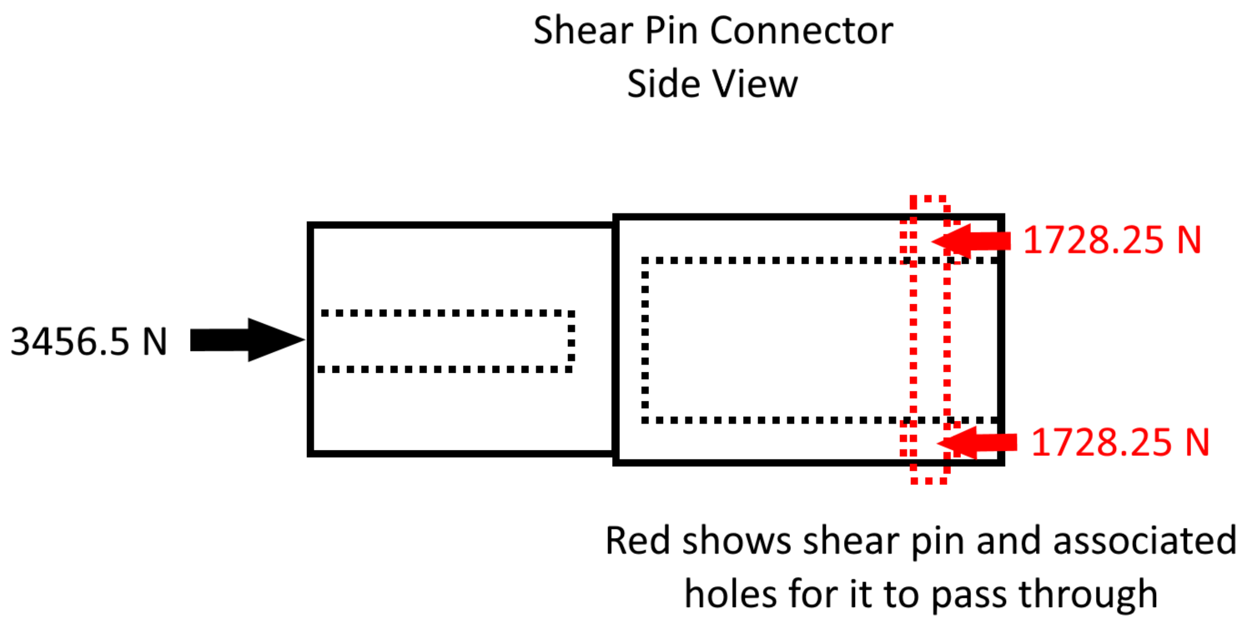
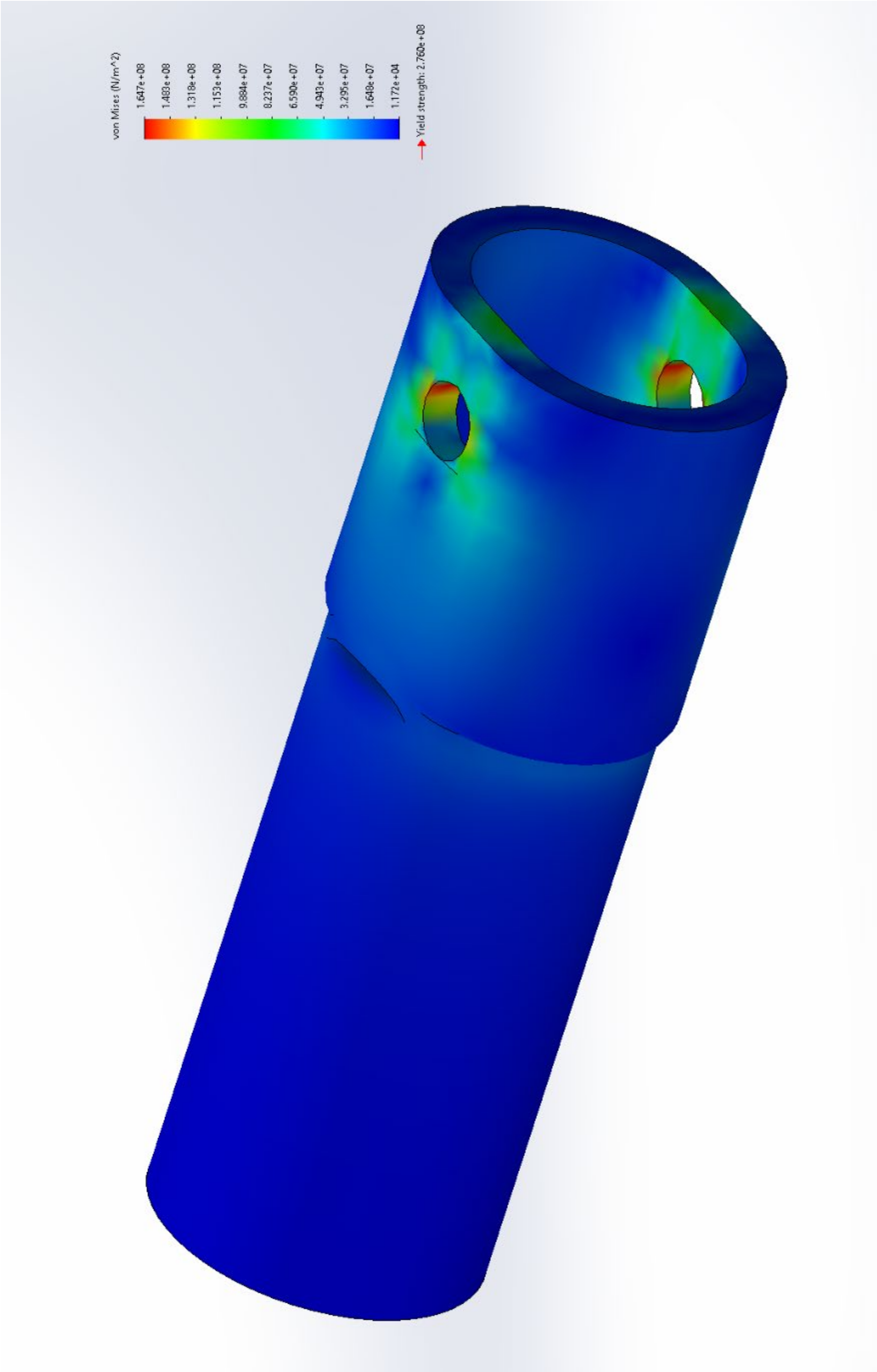


Figure 21

This part sits between the idler and the rear push rod, therefore it experiences the same 3456.5 N force from the elevator. This is balanced by an equal and opposite reaction force on the shear pin which is inserted to connect the rear push rod. The 3456.5 N is split between the two contact surfaces with the part and the shear pin. Stress is concentrated as expected around the holes.



von Mises (N/m^2)
1.647e+08
1.483e+08
1.318e+08
1.153e+08
9.884e+07
8.237e+07
6.590e+07
4.943e+07
3.295e+07
1.648e+07
1.172e+04
Yield strength: 2.760e+08

Figure 22

G-OUAV Structural Report – Document 8

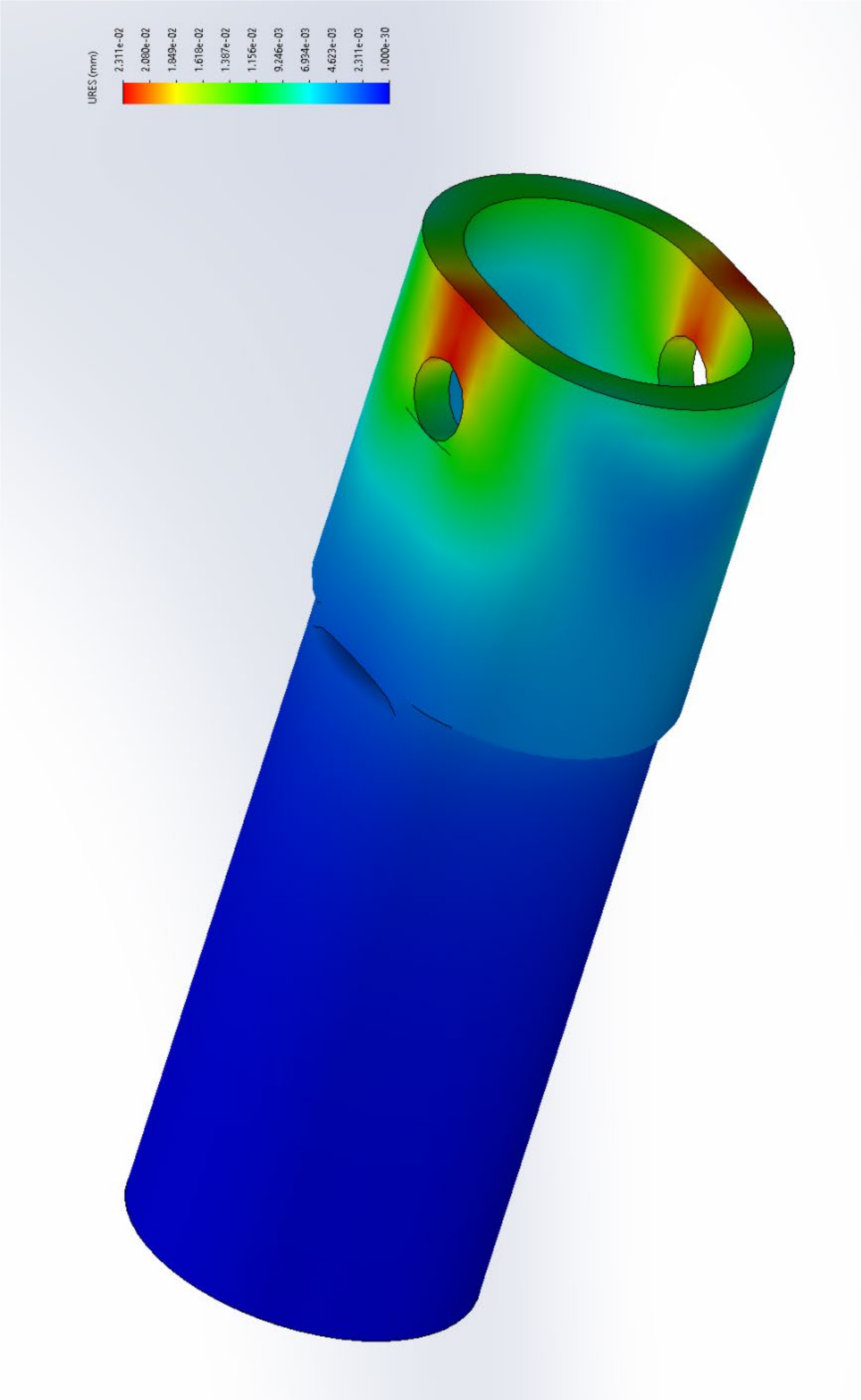


Figure 23

G-OUAV Structural Report – Document 8

<u>End Stop Bracket</u>

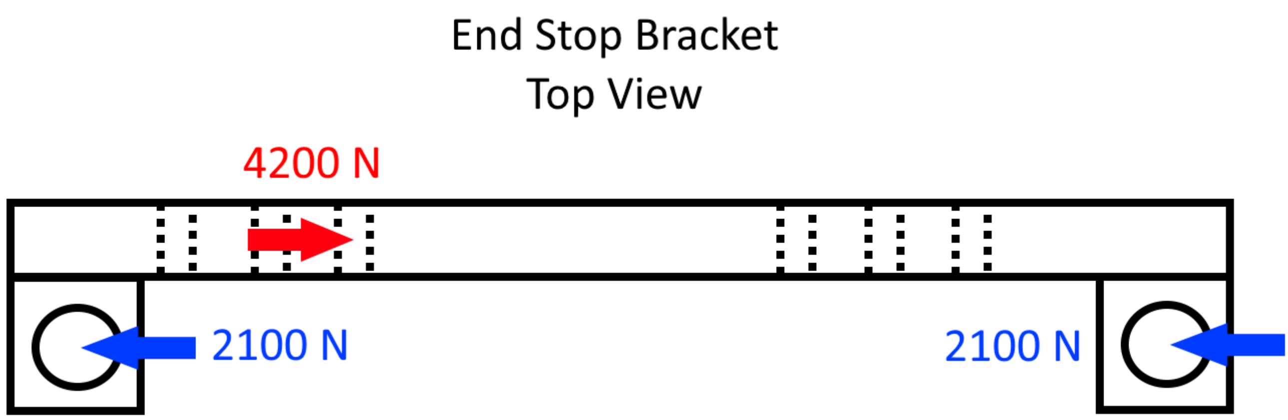


Figure 24

The worst case loading on this part comes from the maximum load through the rear push rod combined with the full force of the servo operating in the wrong direction (which could happen due to an error in the program). The reaction force is provided by the bolts which attach the bracket to the aluminium legs.

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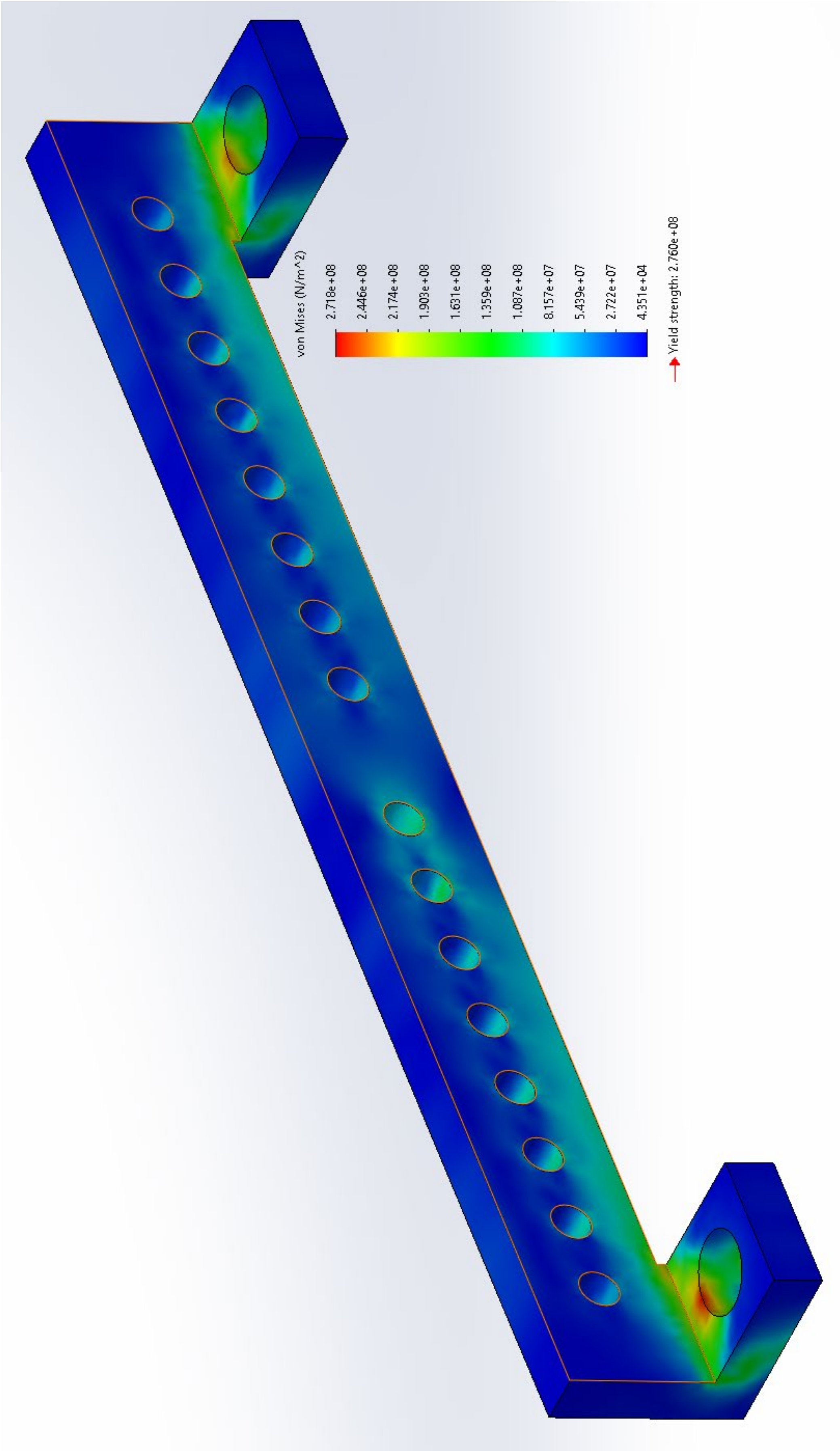

Figure 25

G-OUAV Structural Report – Document 8

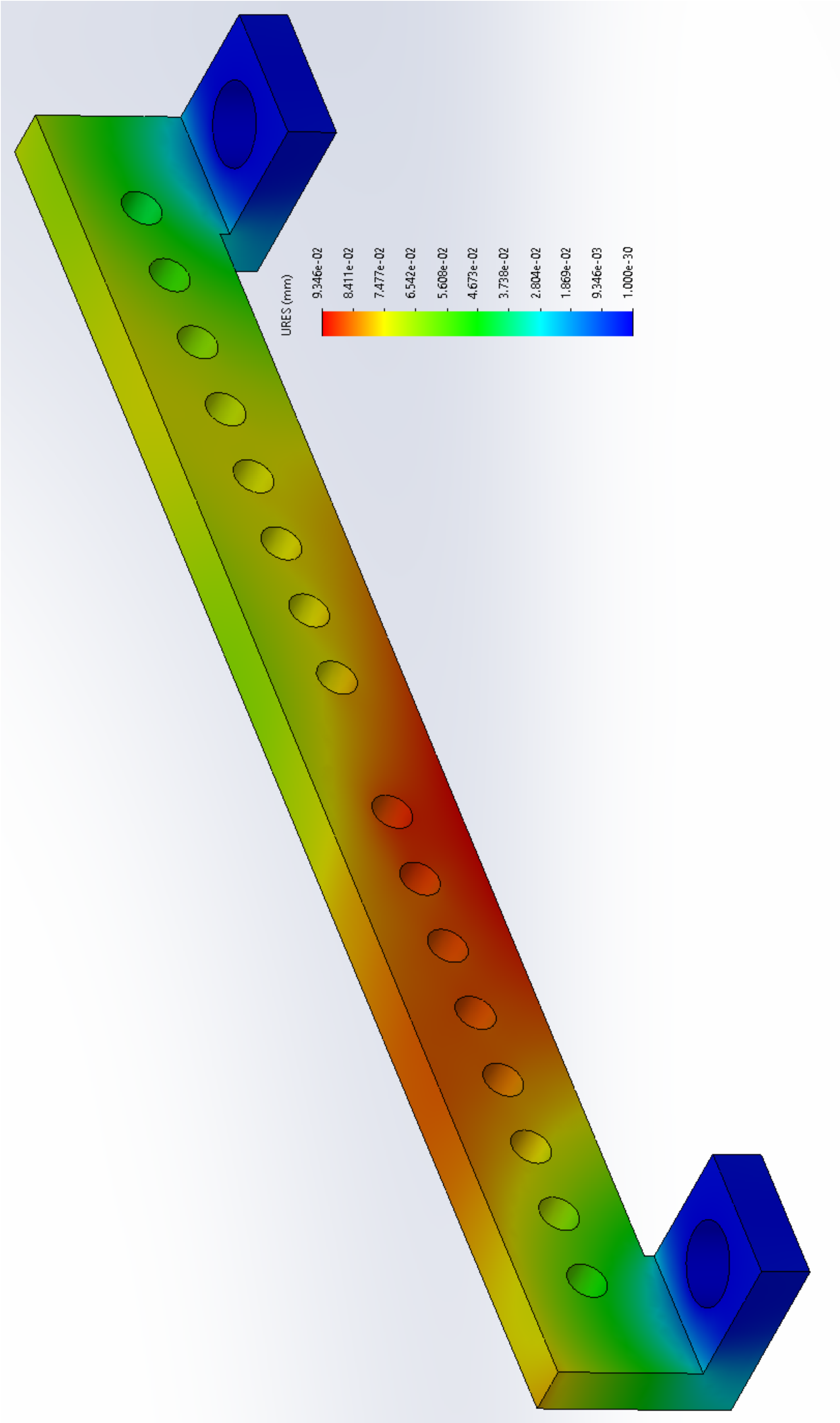

Figure 26

<u>Front End Stop Legs</u>

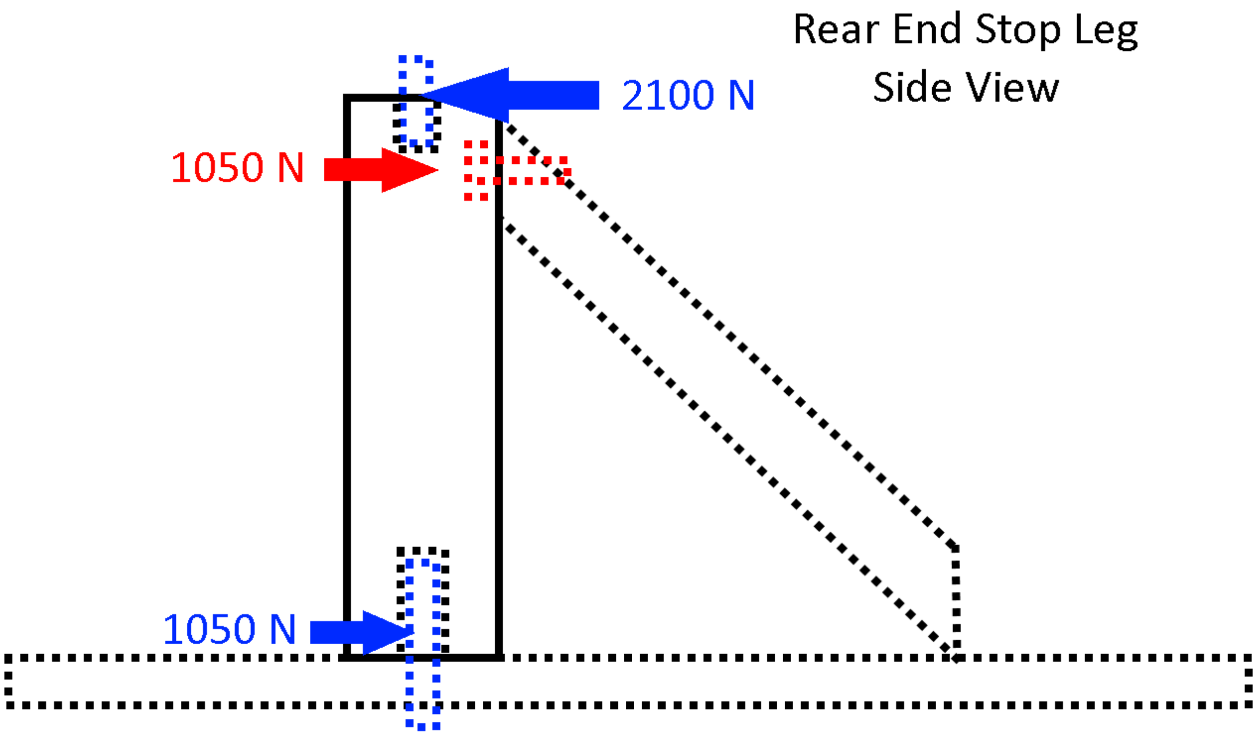

Figure 27

The rear end stop legs are stabilised and reinforced by a diagonal brace. I have assumed that half the force is supported by this brace for the analysis. 2100N at the top of the leg comes from half of the force from the end stop as shown above.

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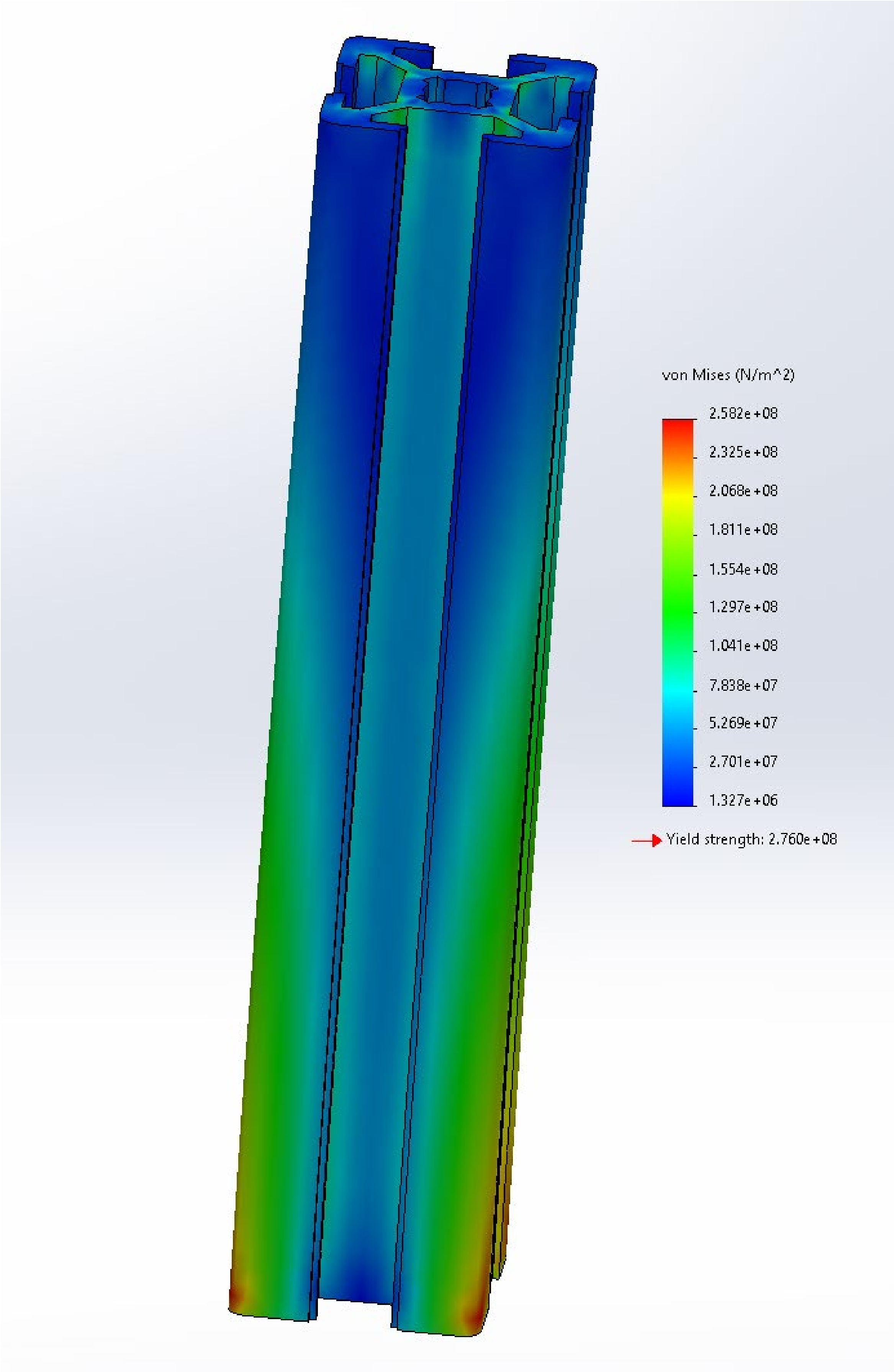

Figure 28

G-OUAV Structural Report – Document 8

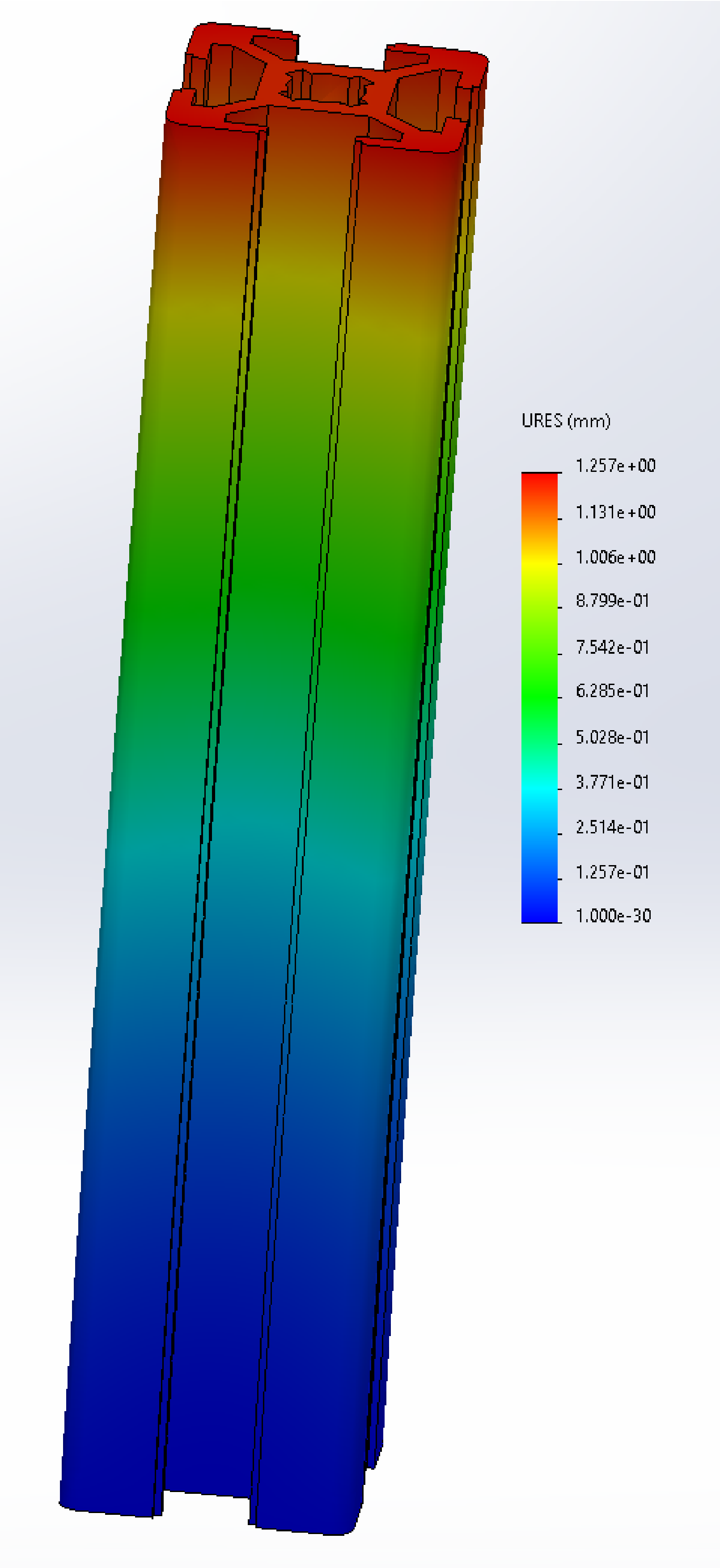

Figure 29

G-OUAV Structural Report – Document 8

Diagonal Brace

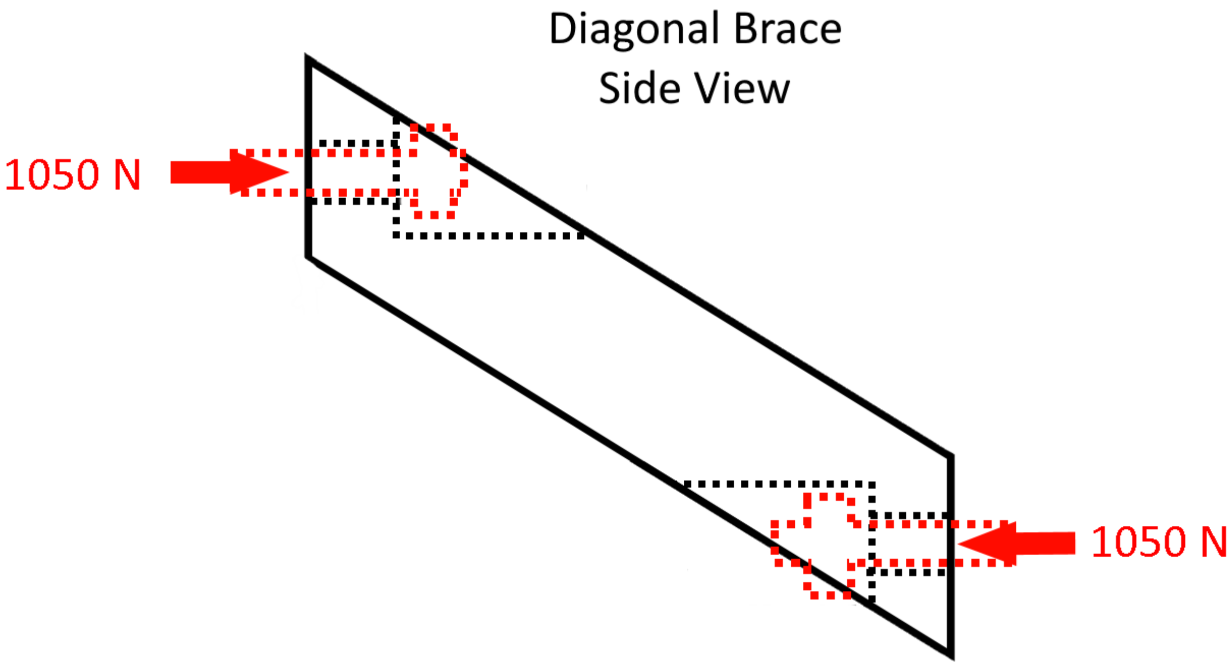

Figure 30

This part fits between the two rear end stop legs and provides additional strength to stop the translational motion of the end stop bracket at the top. The forces come from the assumption in the part above but there is plenty of headroom for the brace to take much more force comfortably.

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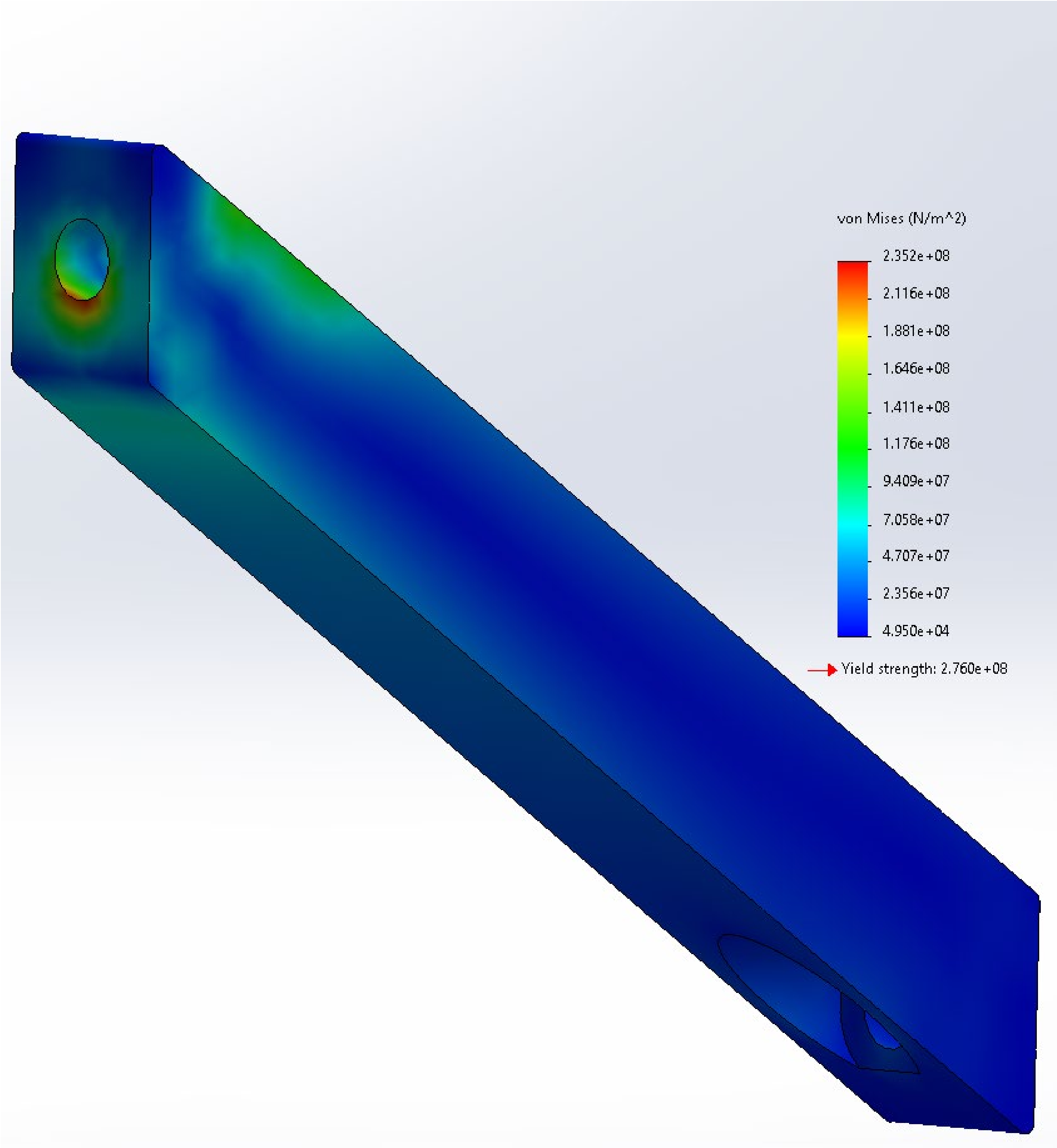

Figure 31

G-OUAV Structural Report – Document 8

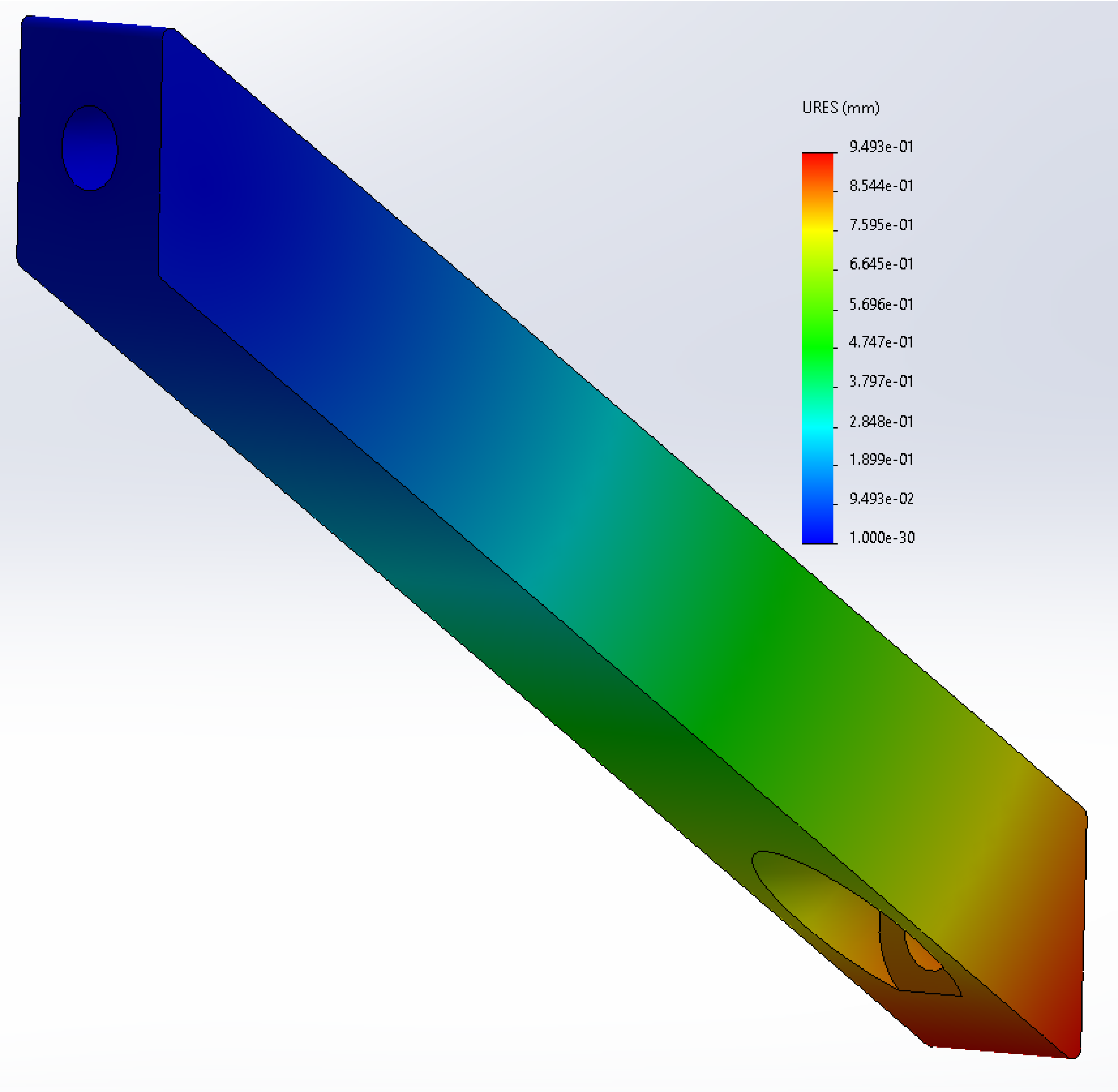

Figure 32

G-OUAV Structural Report – Document 8

<u>Front Assembly</u>

<u>Front Push Rod</u>

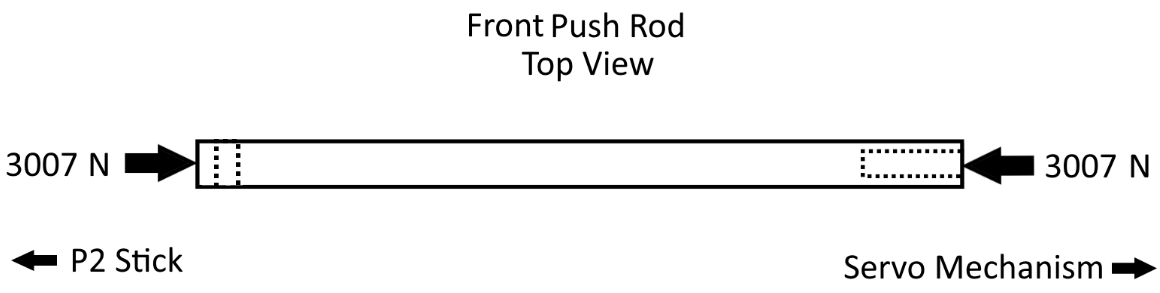

Figure 33

Similarly to the rear servo push rod, this part is loaded axially for the most part. It is will also experience some

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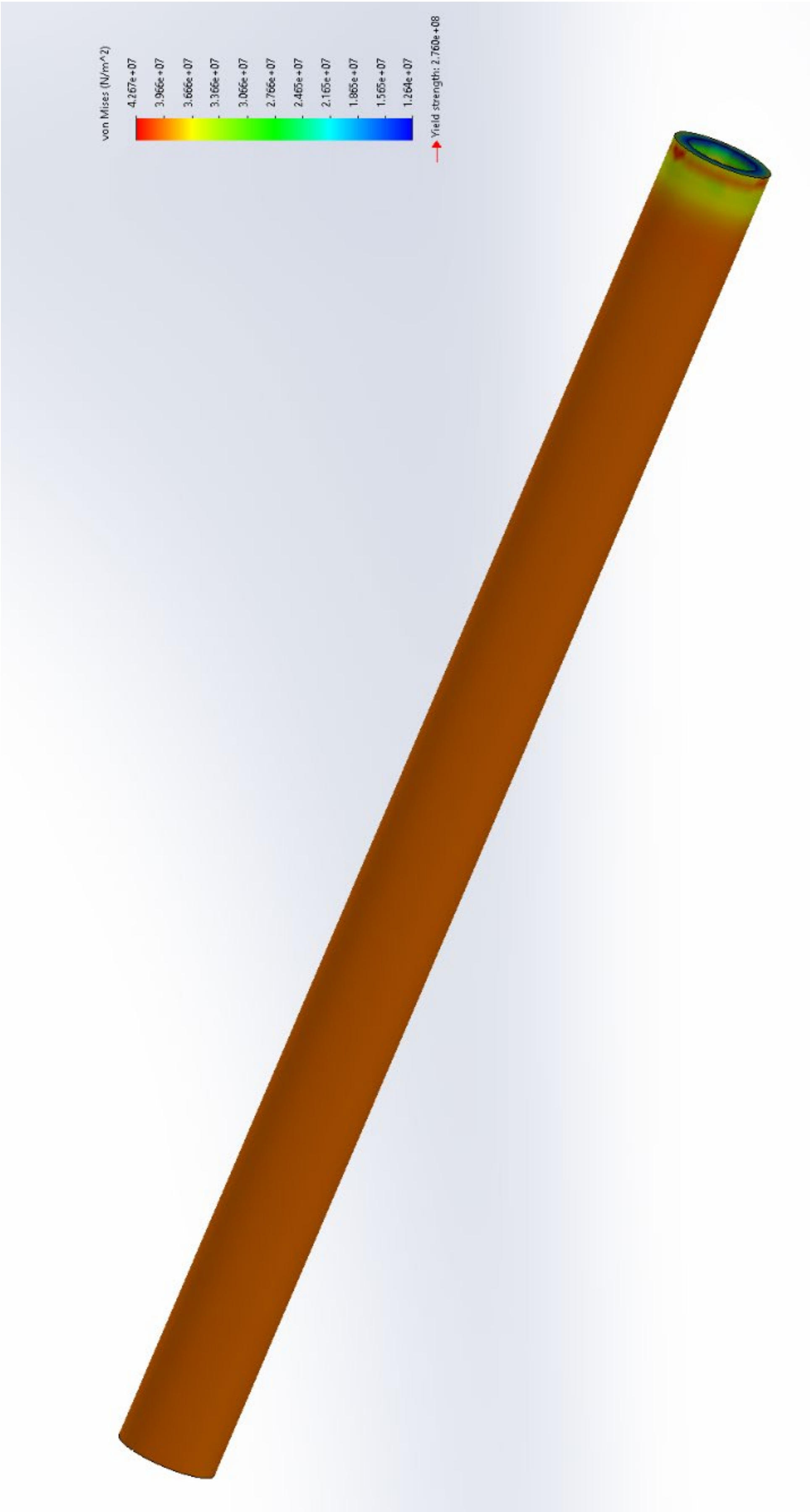

Figure 34

G-OUAV Structural Report – Document 8

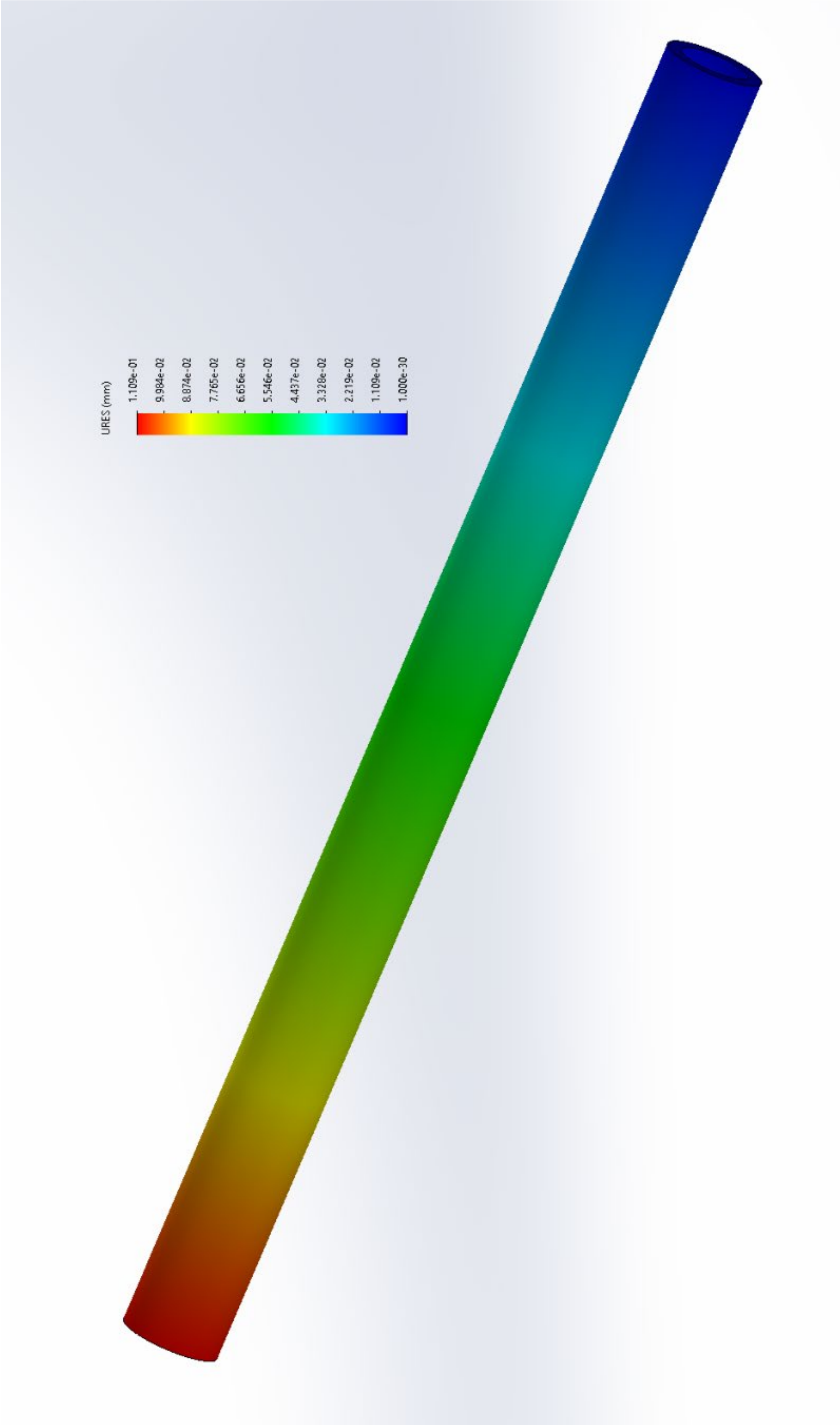

Figure 35

G-OUAV Structural Report – Document 8

Bearing Mount Top

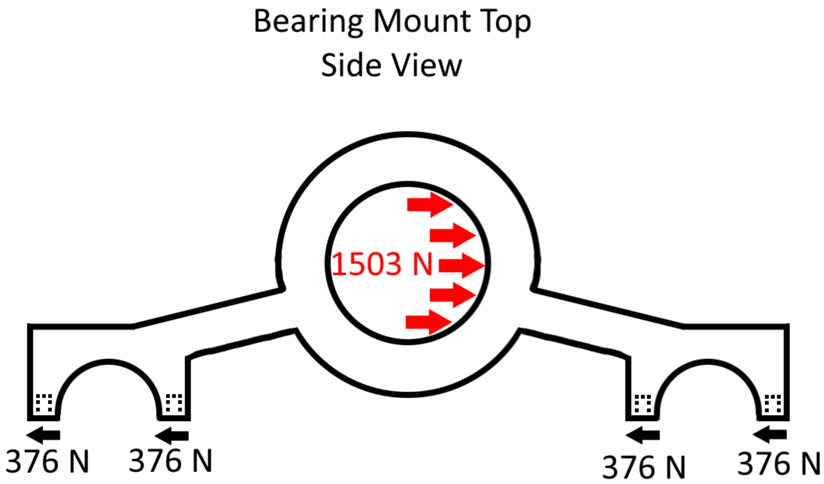

Figure 36

The loading on this part comes from the pilot's maximum force input on the stick. This force is split between the two instances of this part (one on either side of the stick), this is a generous estimate. The load is distributed over the inner surface where the bearing is mounted, with opposing reaction forces acting at the bolts which attach the lower section of the mount which mates with this piece. I have assumed that the 1503 N is equally split between the four bolts.

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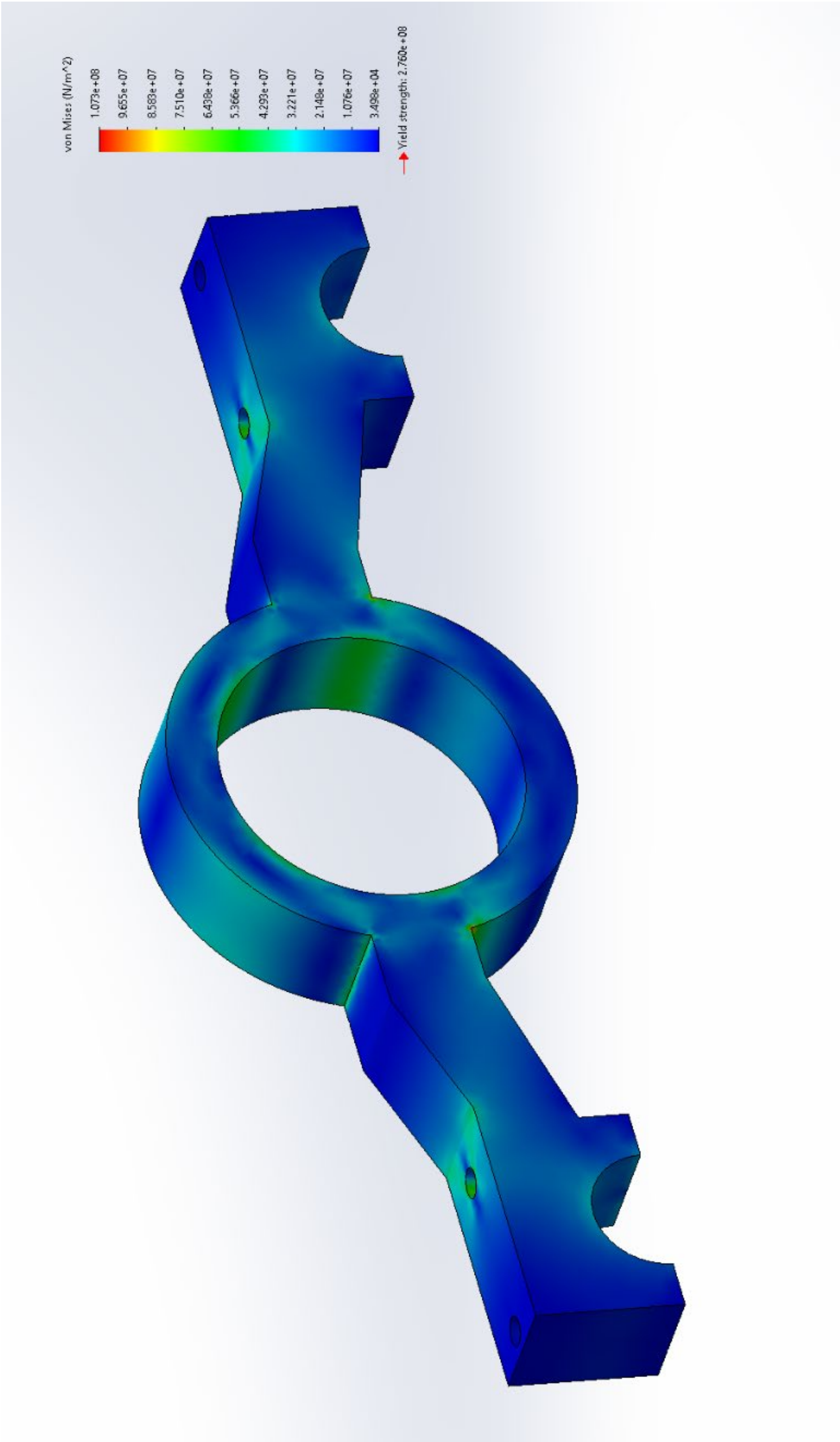

Figure 37

G-OUAV Structural Report – Document 8

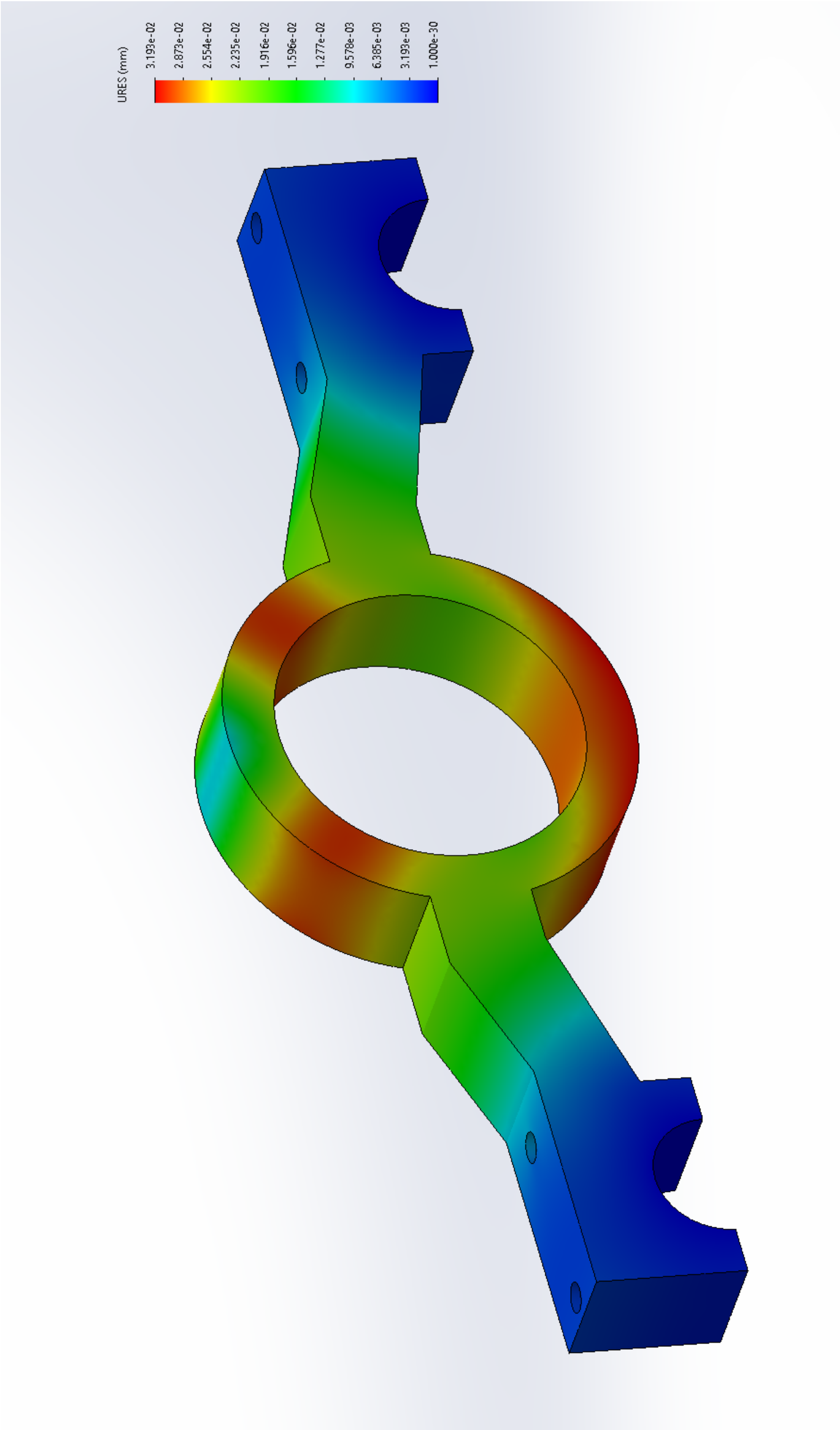

Figure 38

G-OUAV Structural Report – Document 8

<u>Bearing Mount Bottom</u>

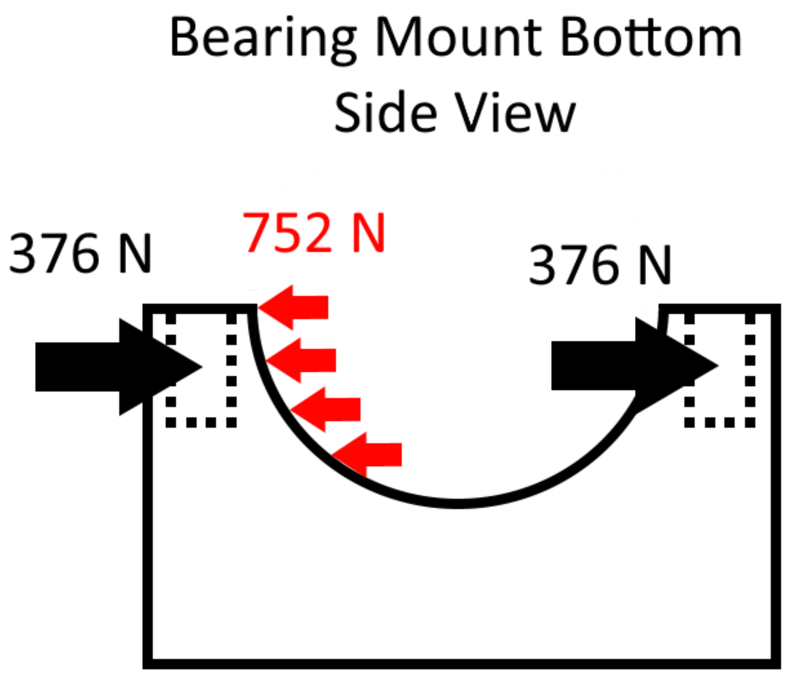

Figure 39

This component mates with the previous part, and thus the loading is transferred from the bolts which connect the parts. The opposing force comes from the contact with the fuselage member to which it clamps.

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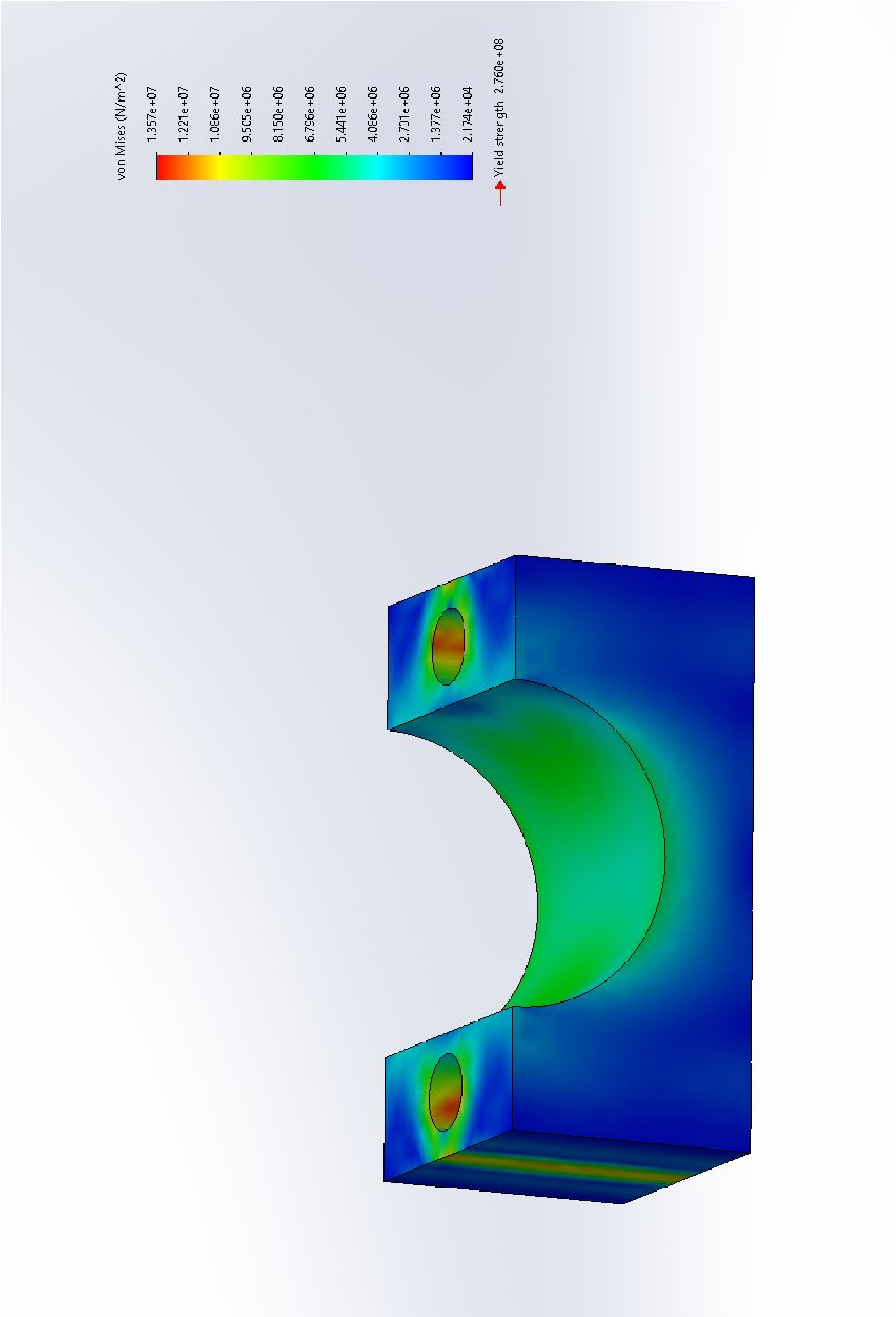

Figure 40

G-OUAV Structural Report – Document 8

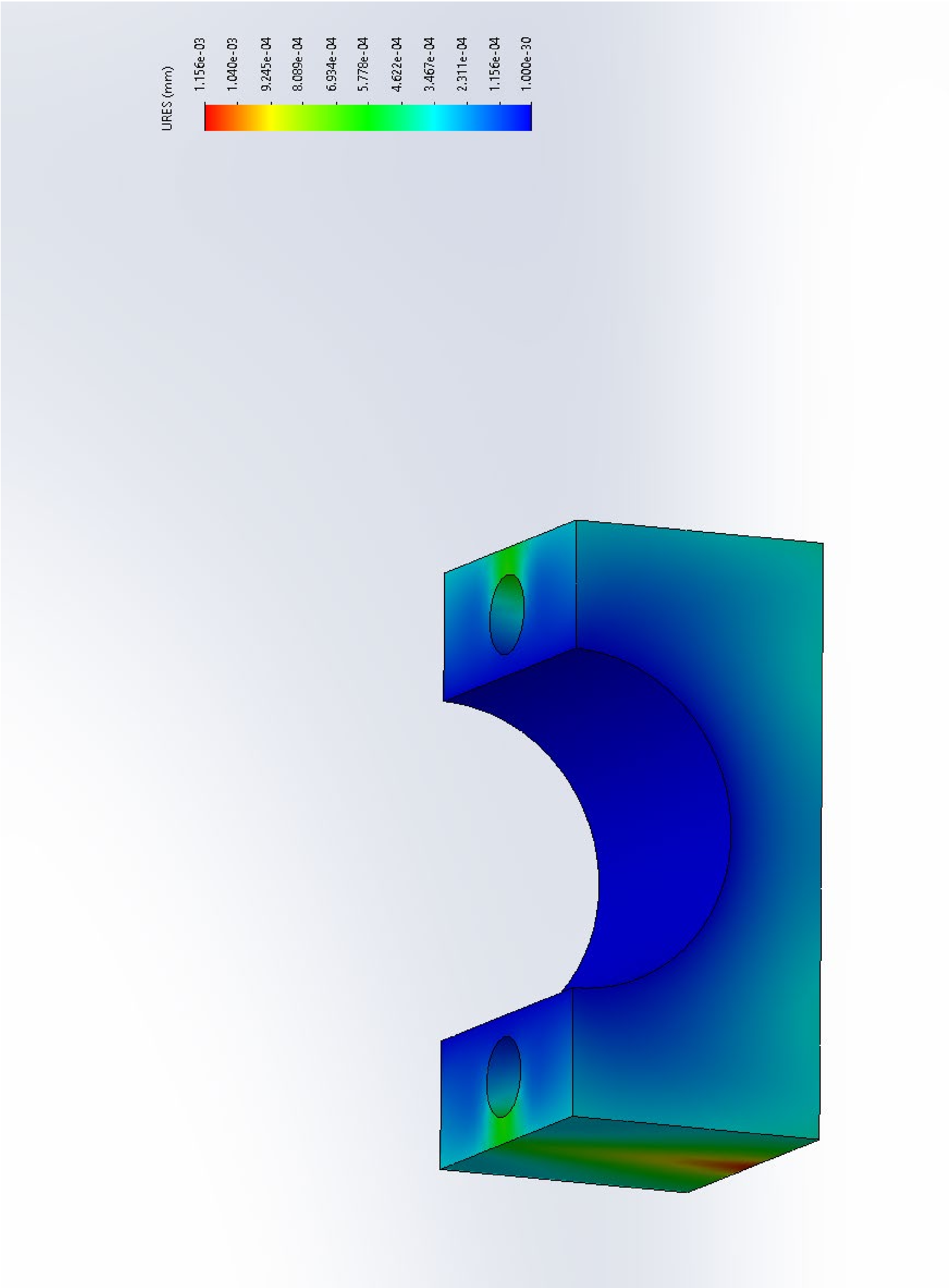

Figure 41

G-OUAV Structural Report – Document 8

Stick Mounting Frame

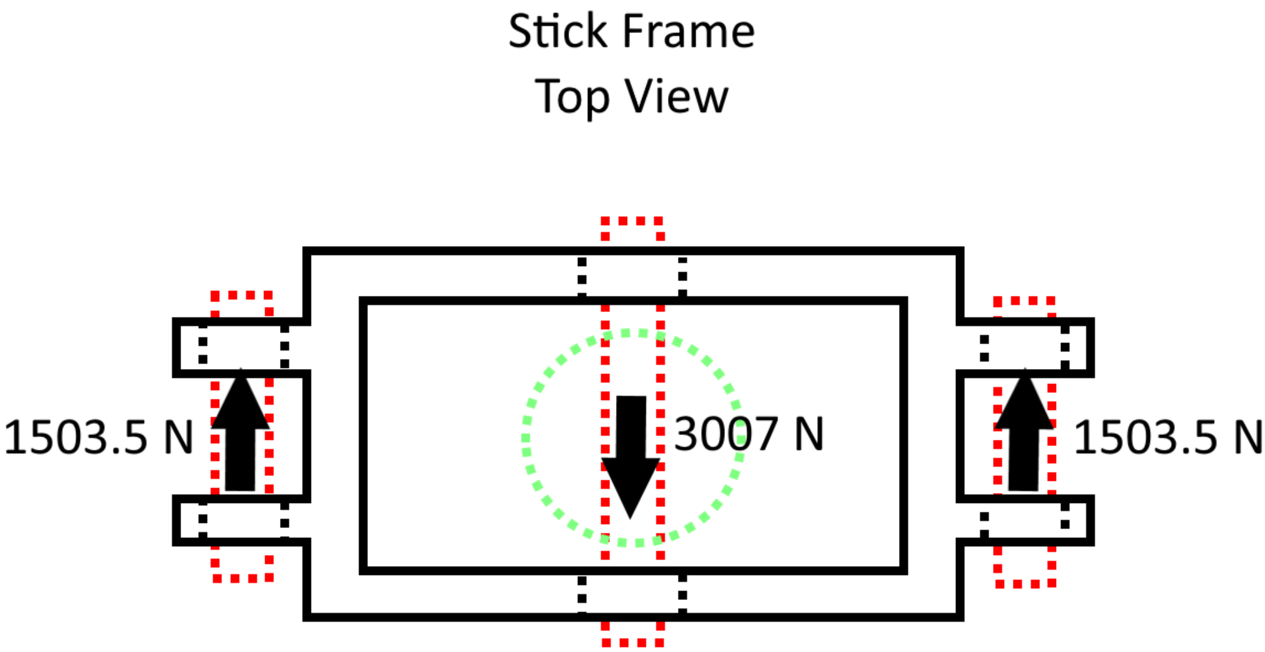

Figure 42

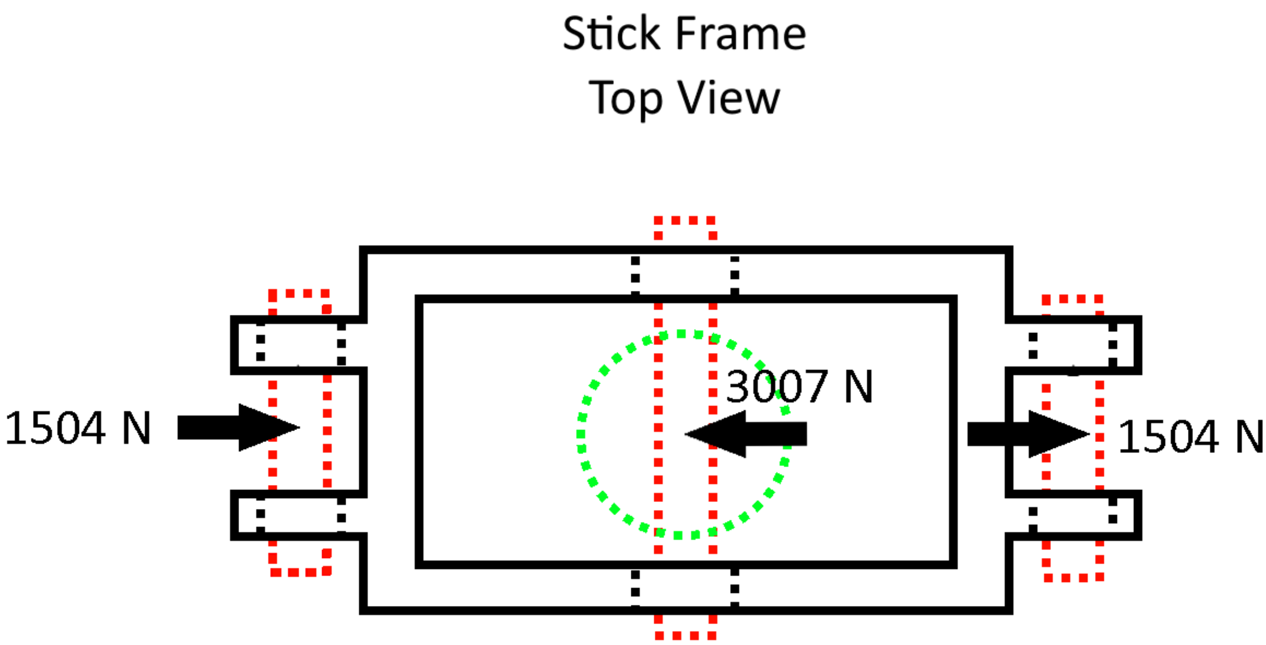

Figure 43

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For this part, there is both longitudinal and lateral cases. The force is derived from the 740 N of pilot force at the top of the stick. Both cases show results well below the yield stress of the material. The first set shows longitudinal values with the second pair of results being for lateral conditions.

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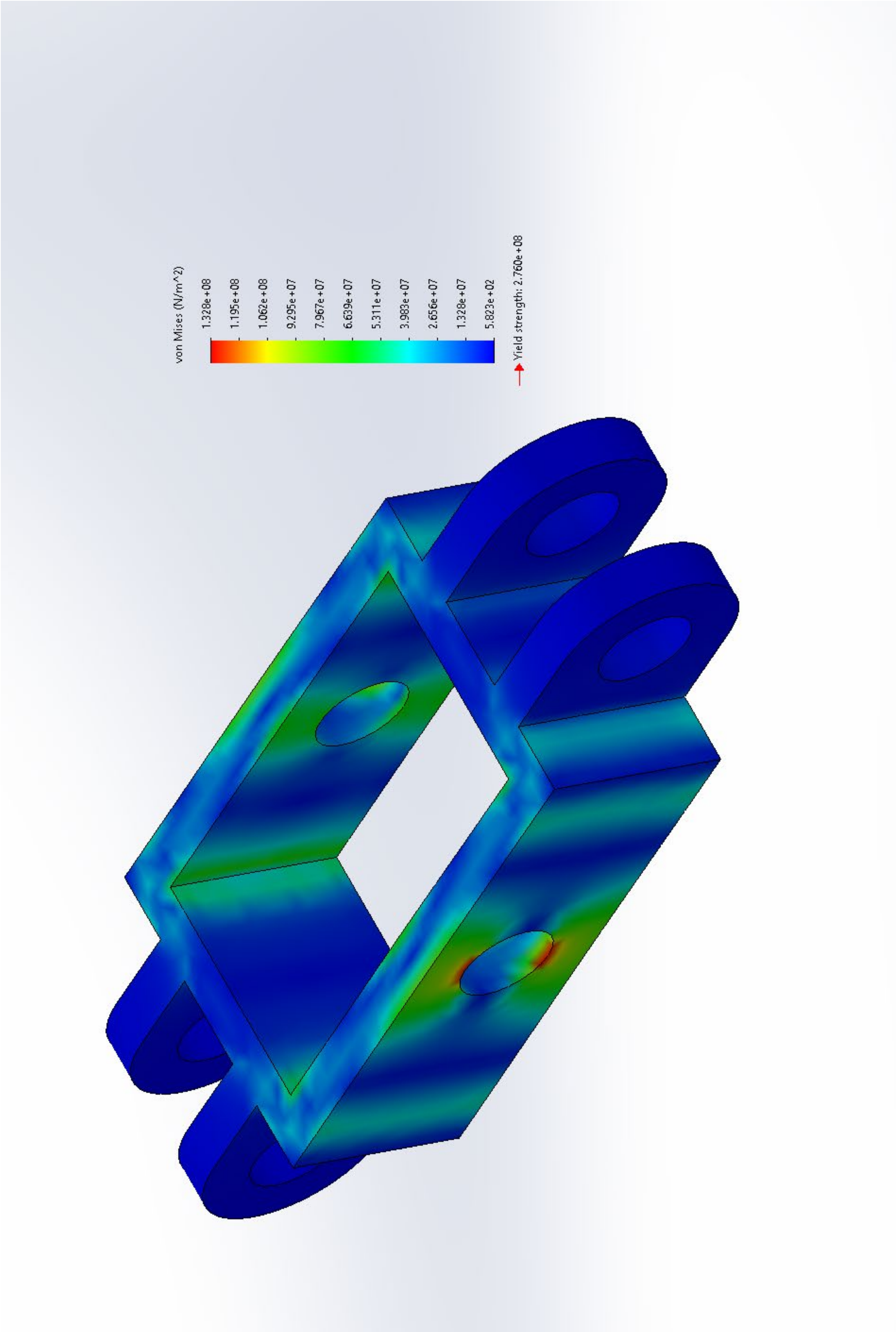


Figure 44

G-OUAV Structural Report – Document 8

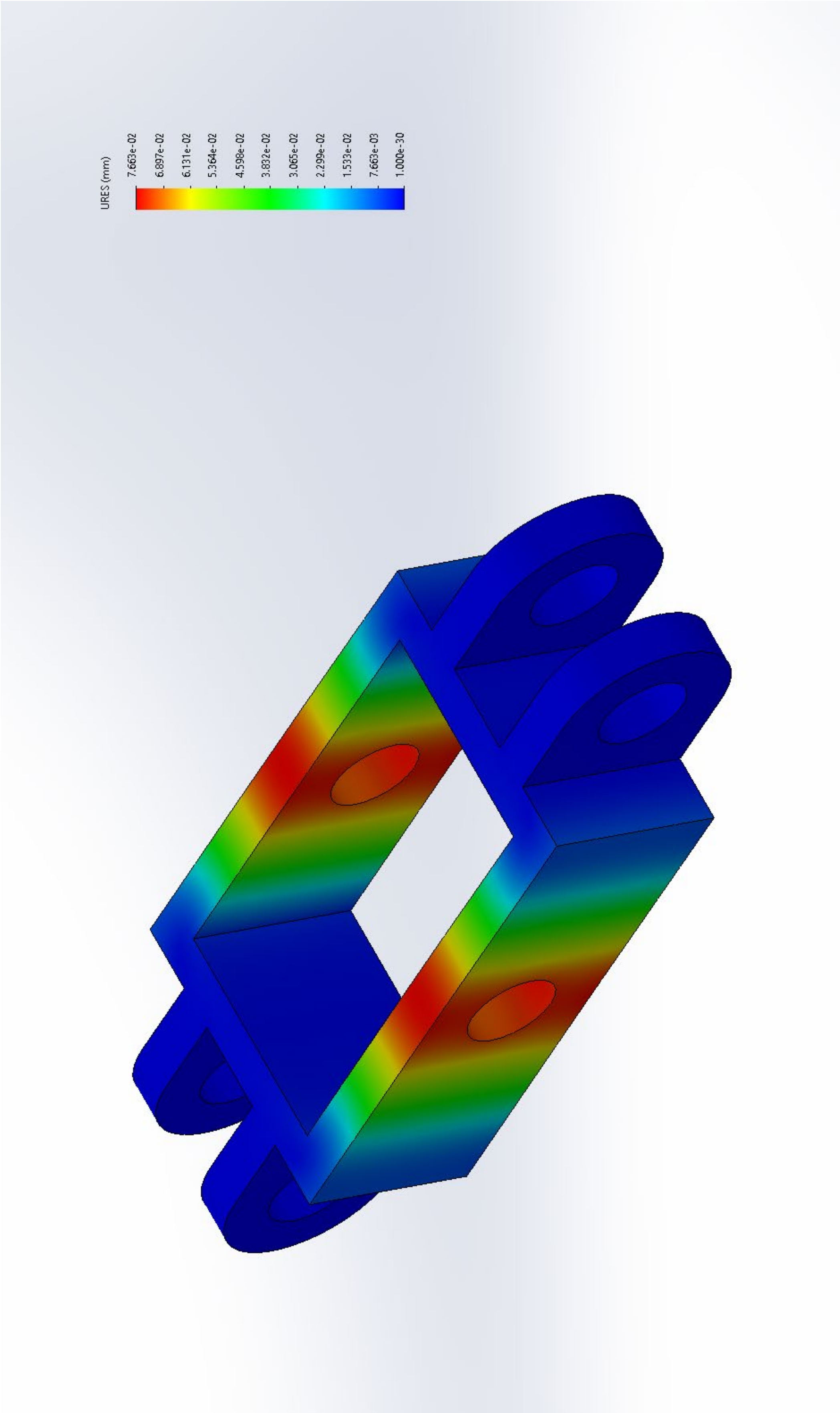


Figure 45

G-OUAV Structural Report – Document 8

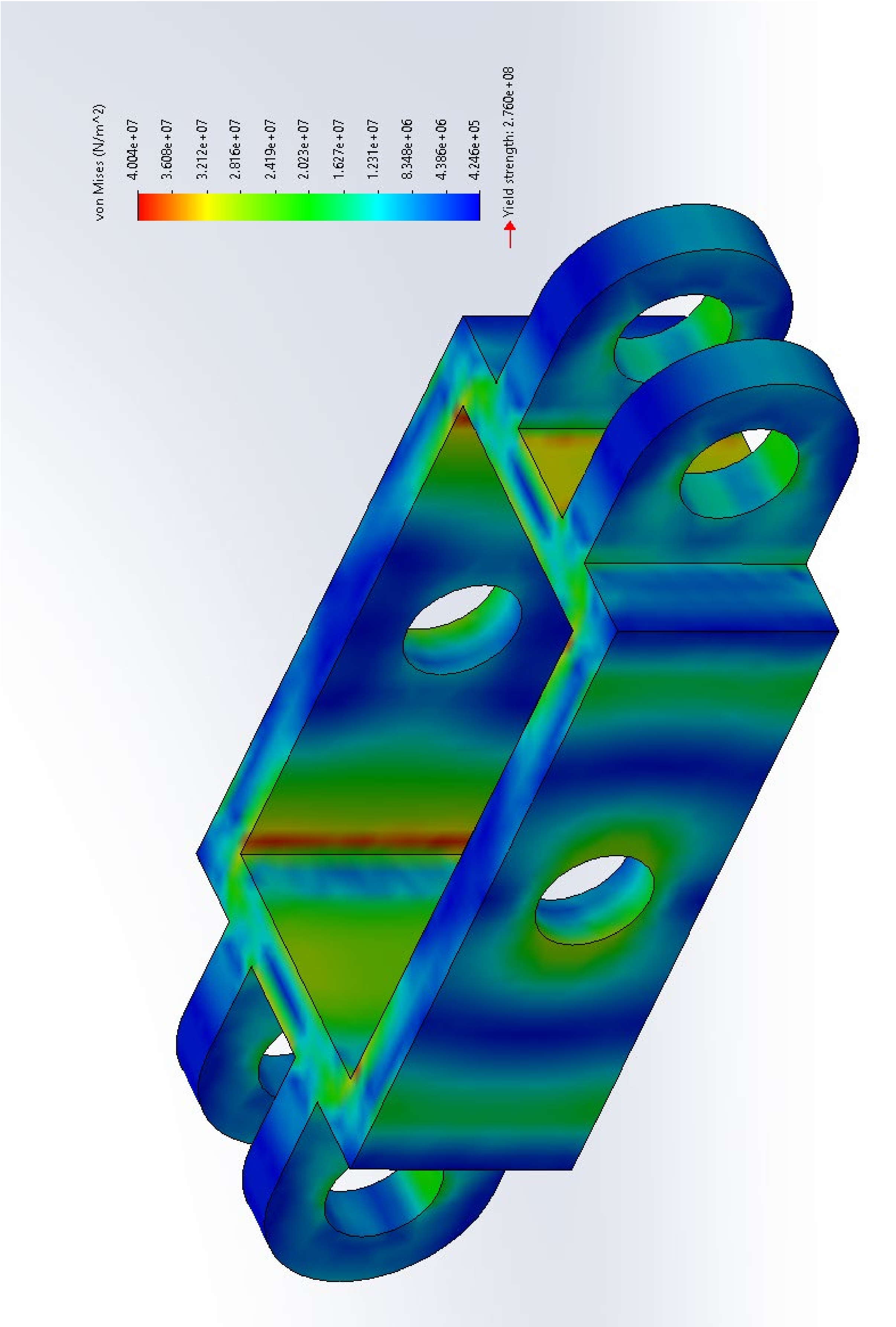


Figure 46

G-OUAV Structural Report – Document 8

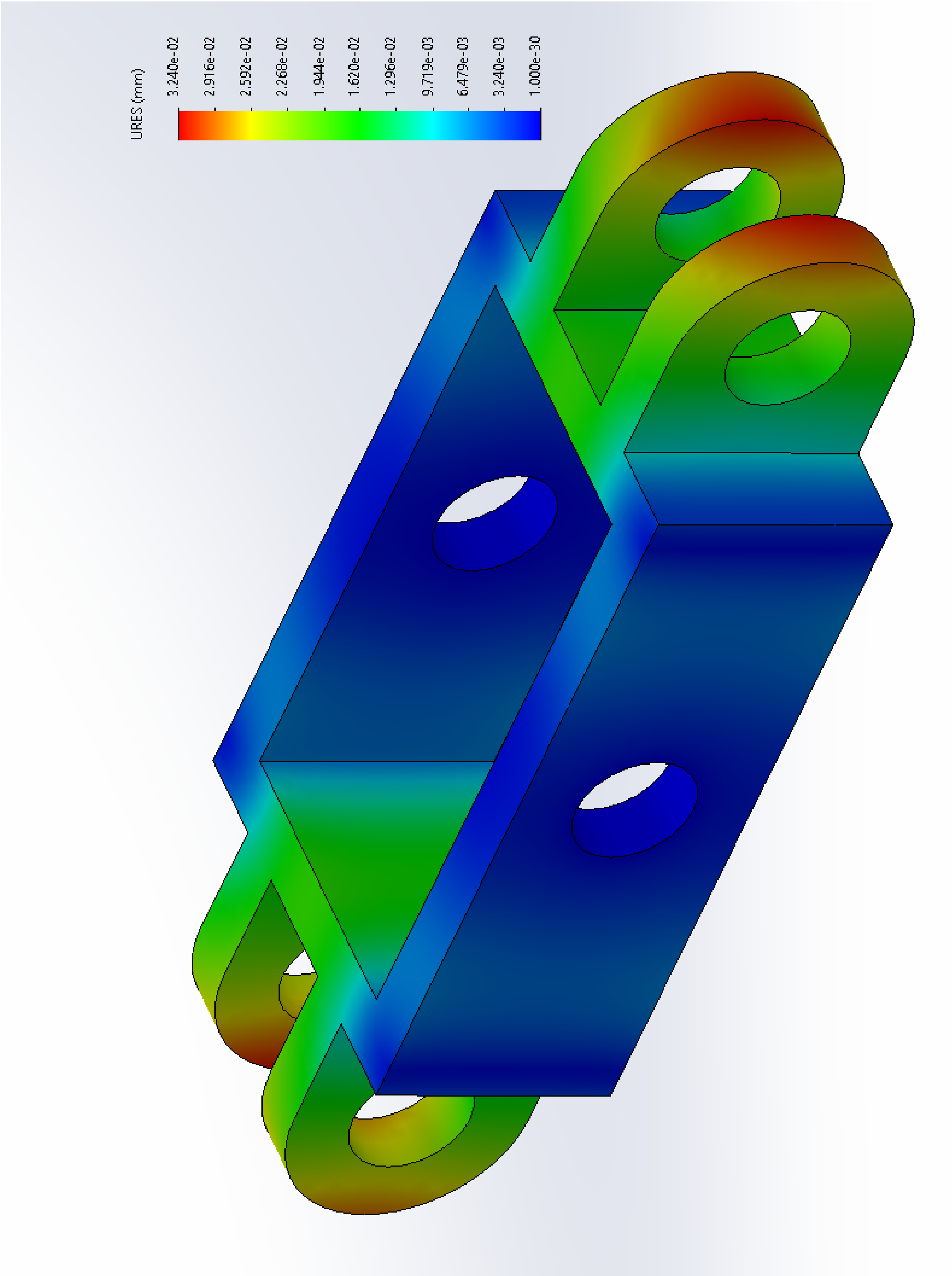
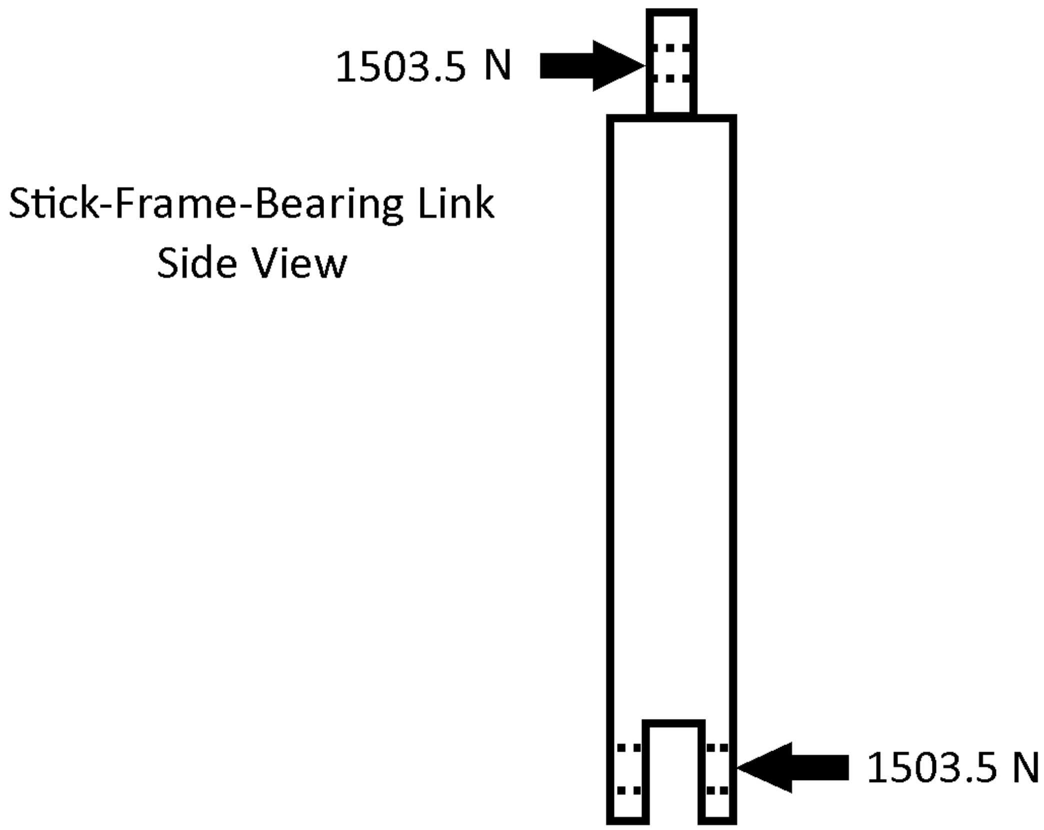


Figure 47

G-OUAV Structural Report – Document 8

Stick-Frame-Bearing Link

Equation 1



This piece connects the stick frame to the bearing pivots and therefore transmits the force felt between them. The reaction forces on the previous component come from this one, therefore the 3007 N total reaction is split on each side and therefore this component feels a 1503.5 N force.

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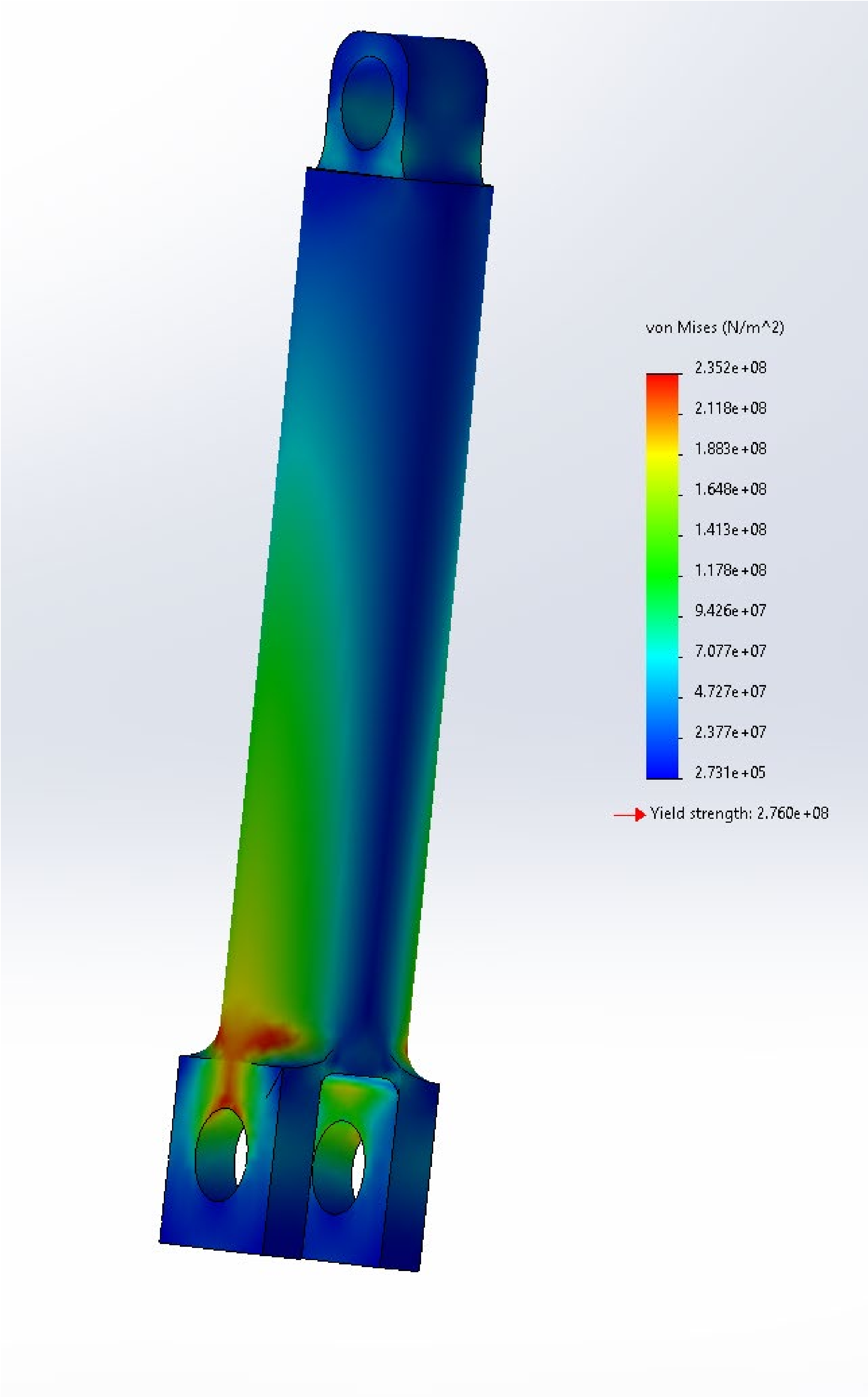

Figure 48

G-OUAV Structural Report – Document 8

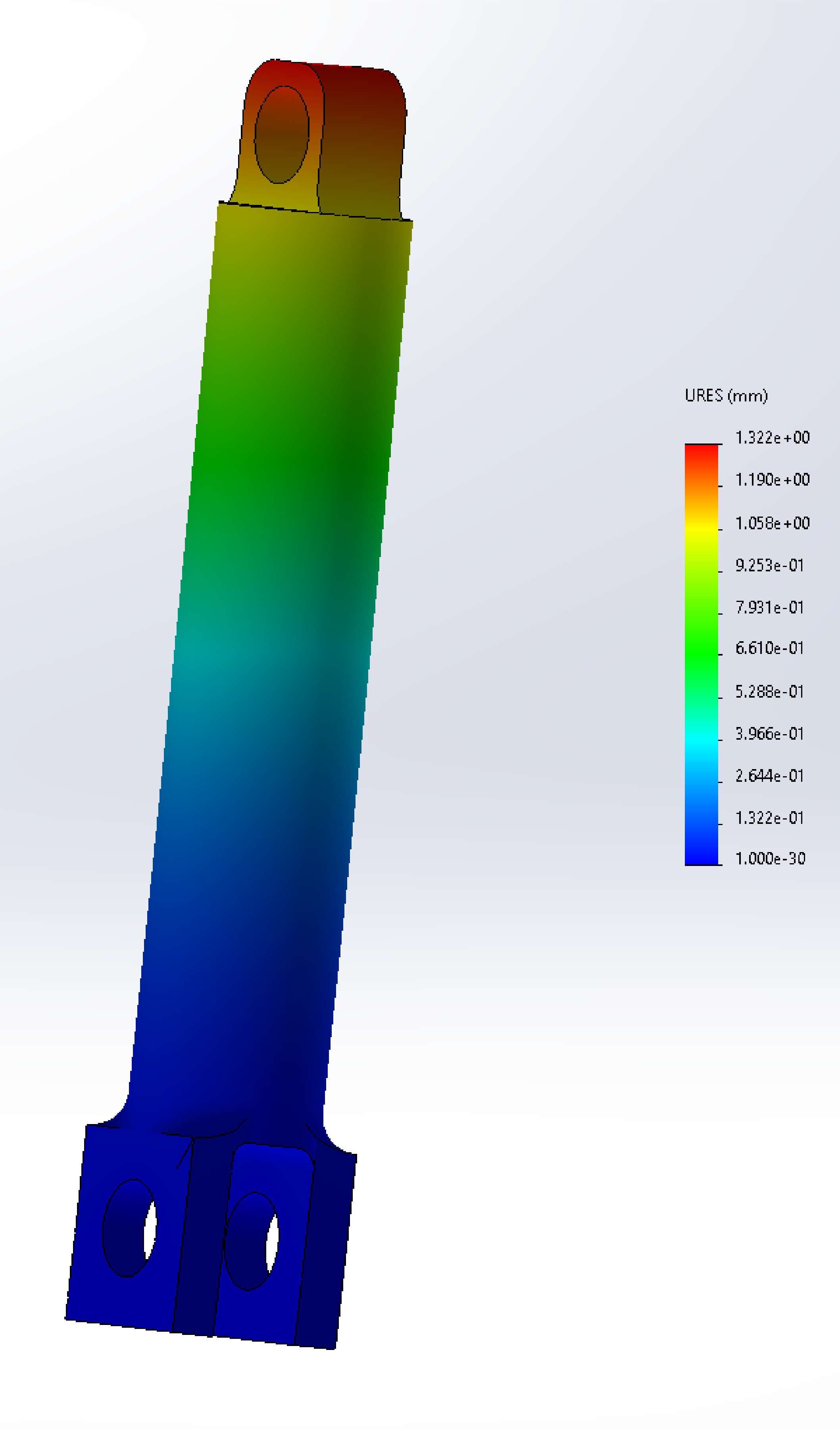

Figure 49

Bearing Longitudinal Pivot

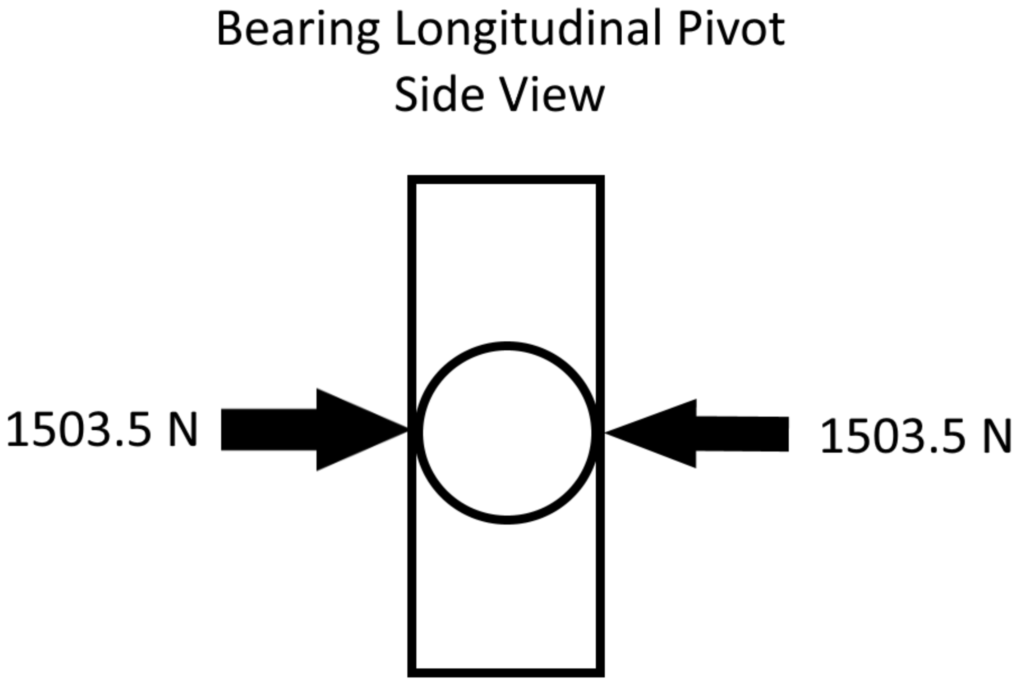

Figure 50

This component is again subject to the forces from the previous component acting on it, this results in a 1503.5 N force and corresponding reaction force.

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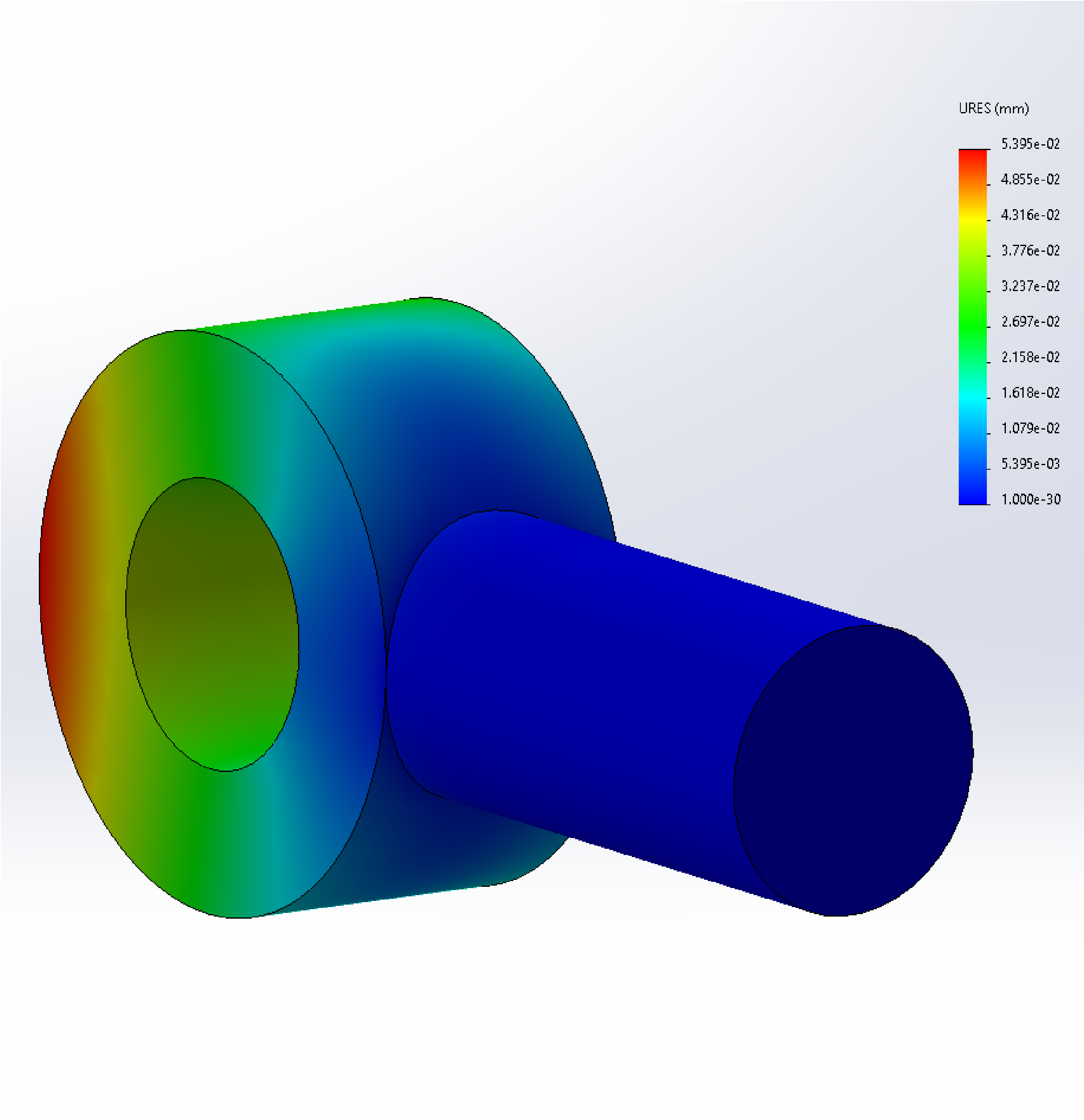

Figure 51

Front Servo Arm

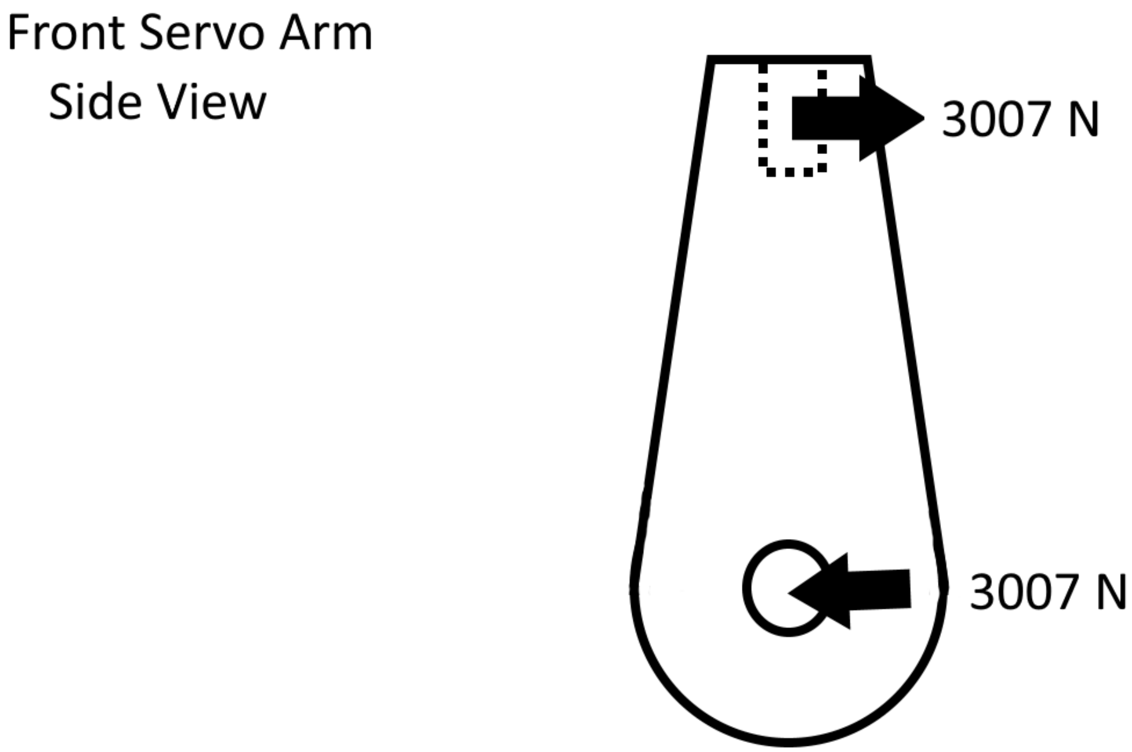

Figure 52

As the 3007 N force from the pilot via the stick acting as a lever is greater than the maximum force from the servo, it is the force I will use in the analysis. Similarly to the rear servo arm, the maximum stress is around the splines in the centre. The maximum stress is still less than half of the yield stress.

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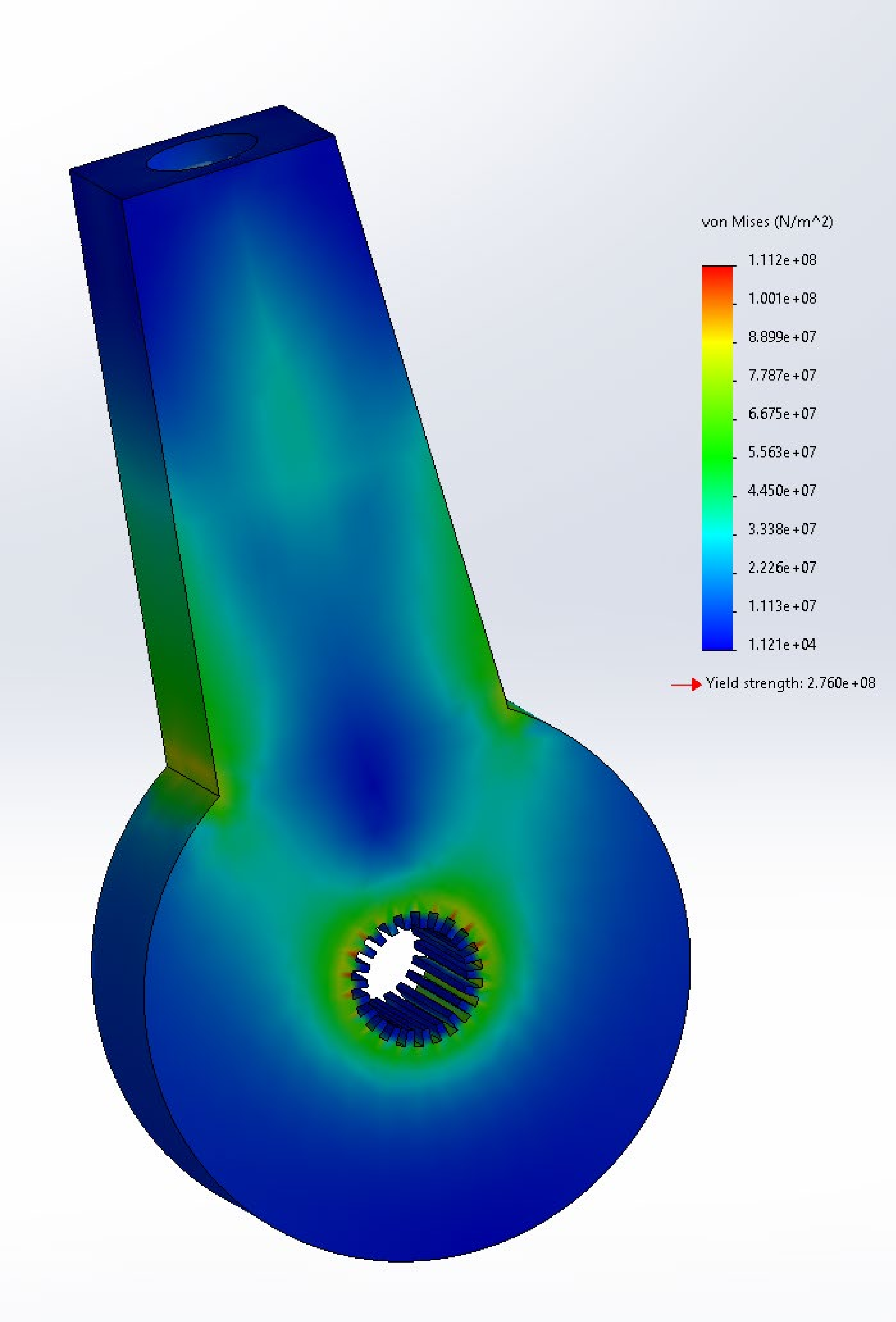

Figure 53

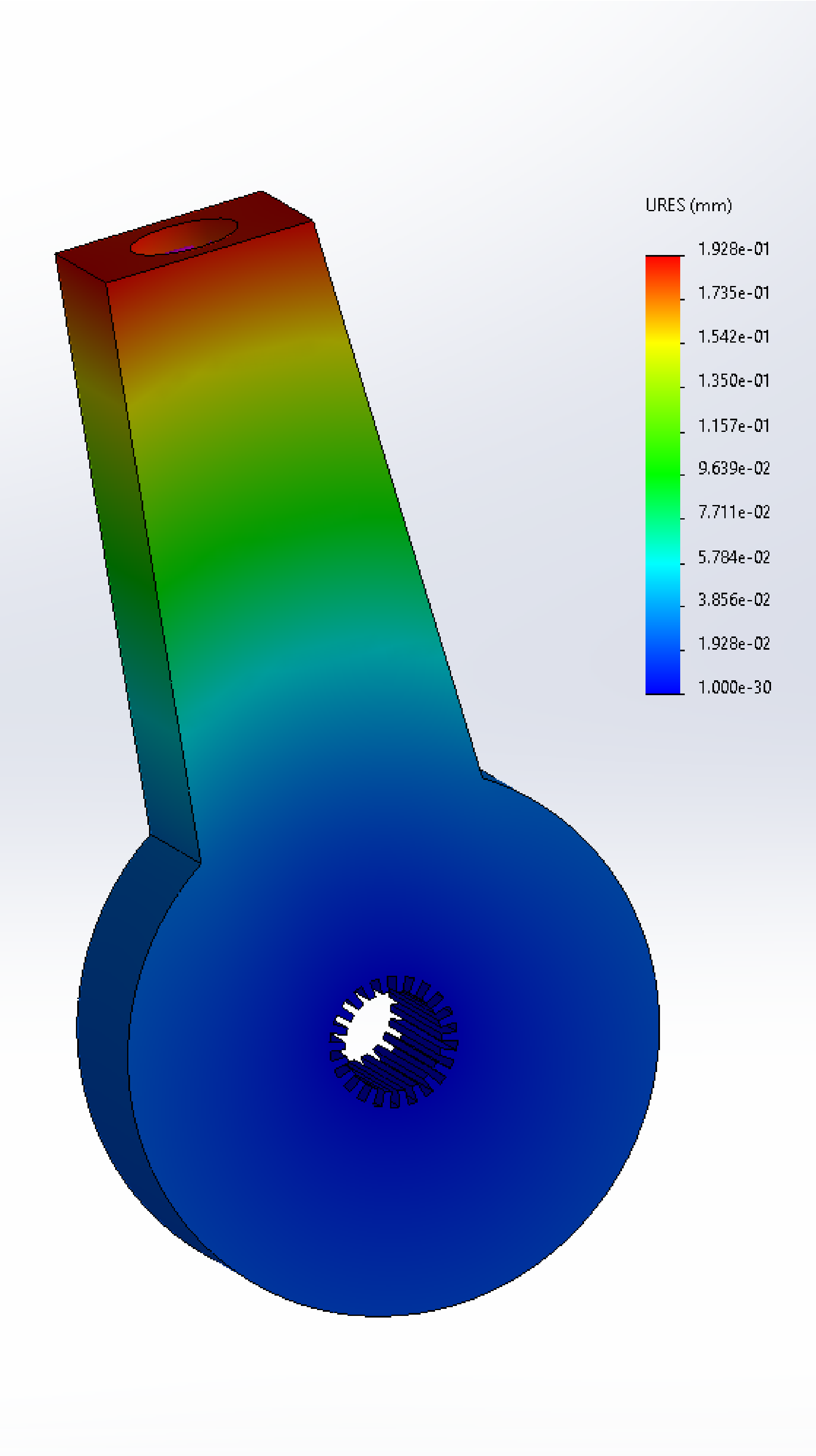
URES (mm)
1.928e-01
1.735e-01
1.542e-01
1.350e-01
1.157e-01
9.639e-02
7.711e-02
5.784e-02
3.856e-02
1.928e-02
1.000e-30

Figure 54

G-OUAV Structural Report – Document 8

<u>Lower Scissor Attachment</u>

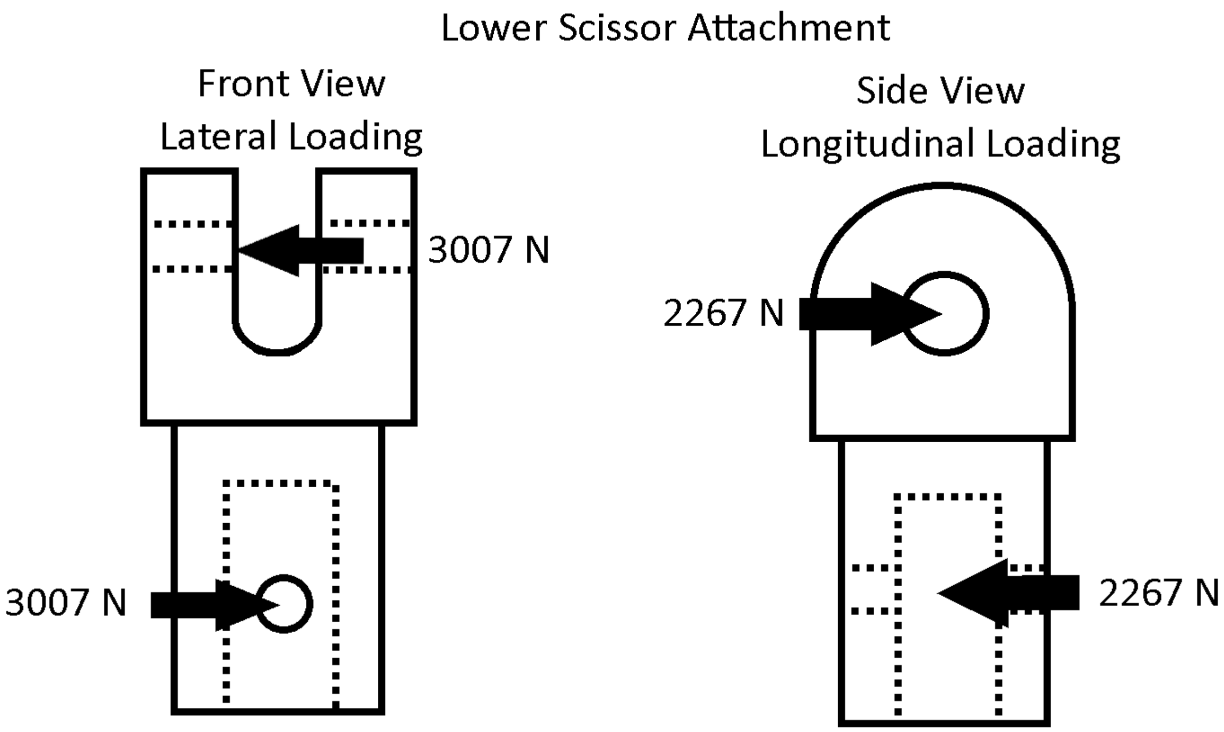

Figure 55

This is another part with both longitudinal and lateral loading as can be seen above. With both types of loading, the maximum stress is still below the yield strength even with a safety factor. The stress is a resultant stress with both longitudinal and lateral loading, with the displacements being longitudinal and lateral respectively.

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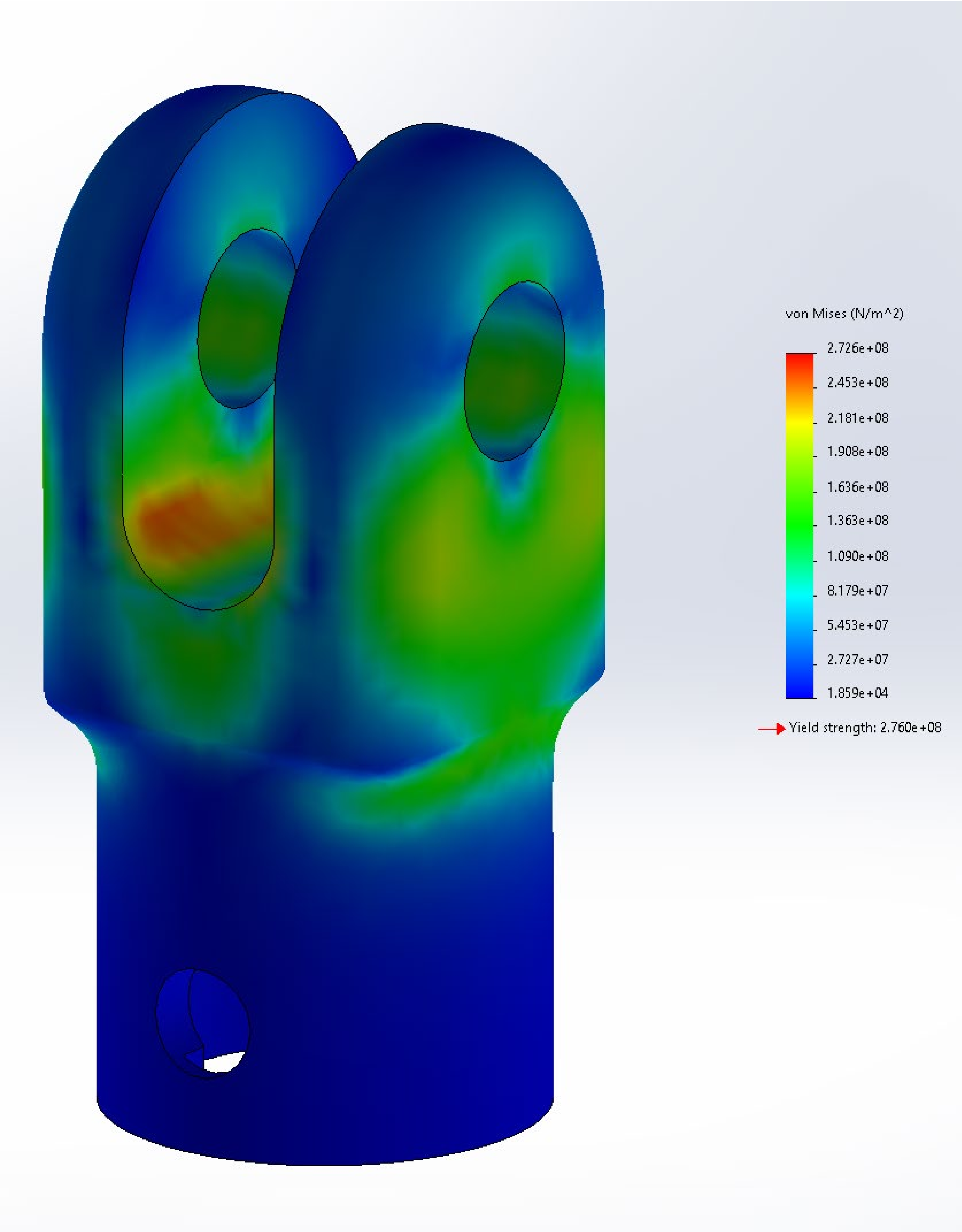


Figure 56

G-OUAV Structural Report – Document 8

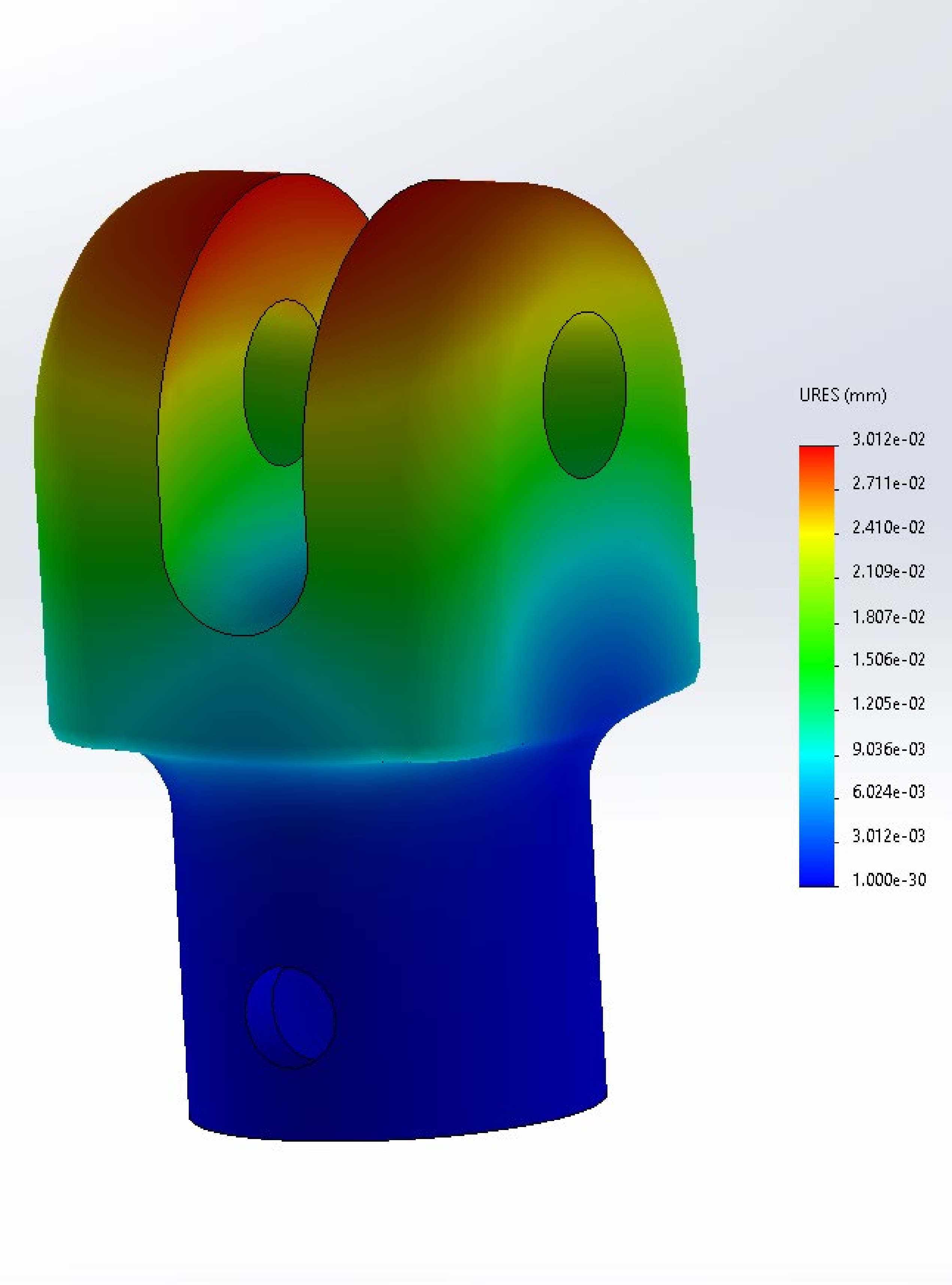


Figure 57

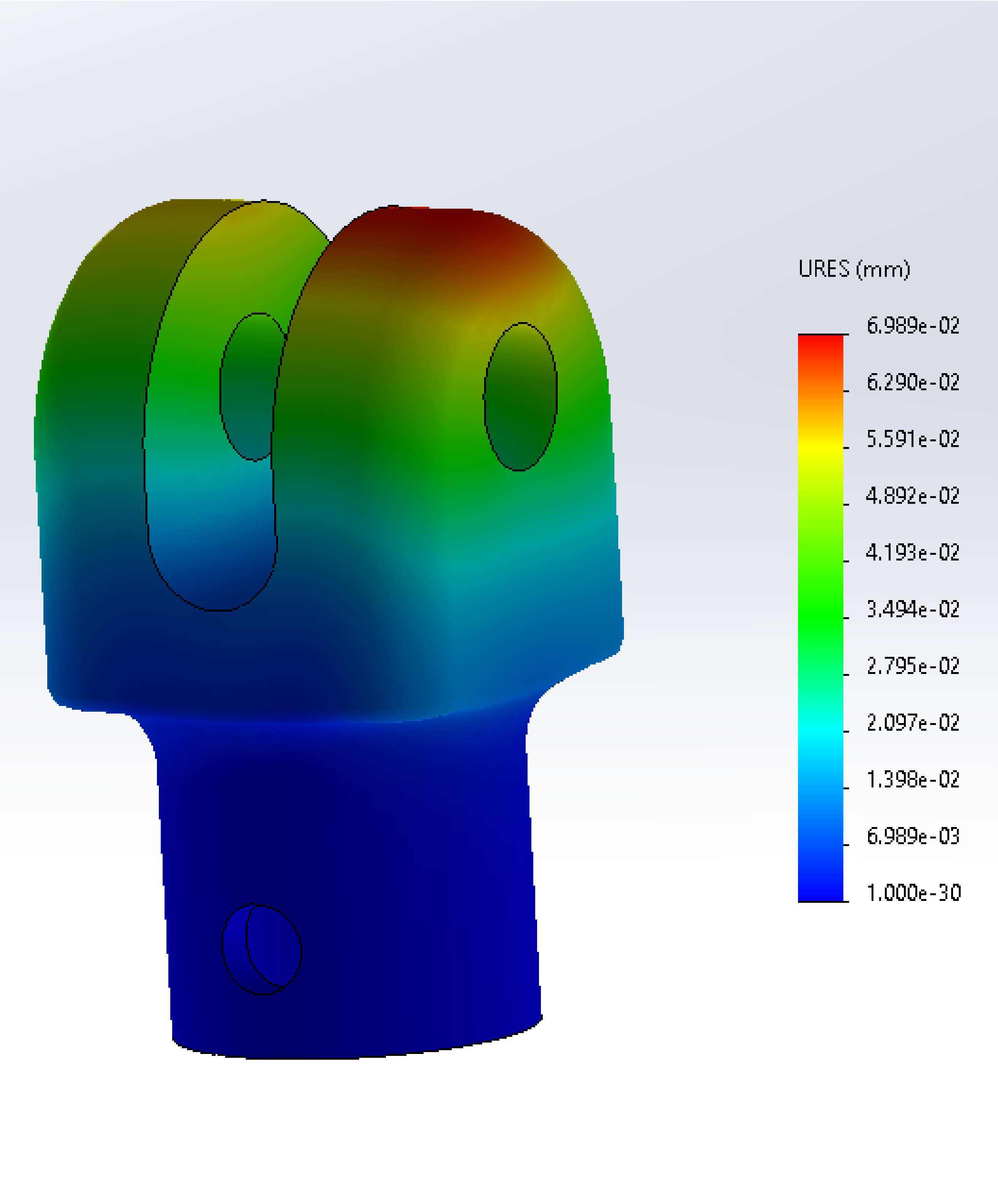

URES (mm)
6.989e-02
6.290e-02
5.591e-02
4.892e-02
4.193e-02
3.494e-02
2.795e-02
2.097e-02
1.398e-02
6.989e-03
1.000e-30

Figure 58

G-OUAV Structural Report – Document 8

Upper Scissor Attachment

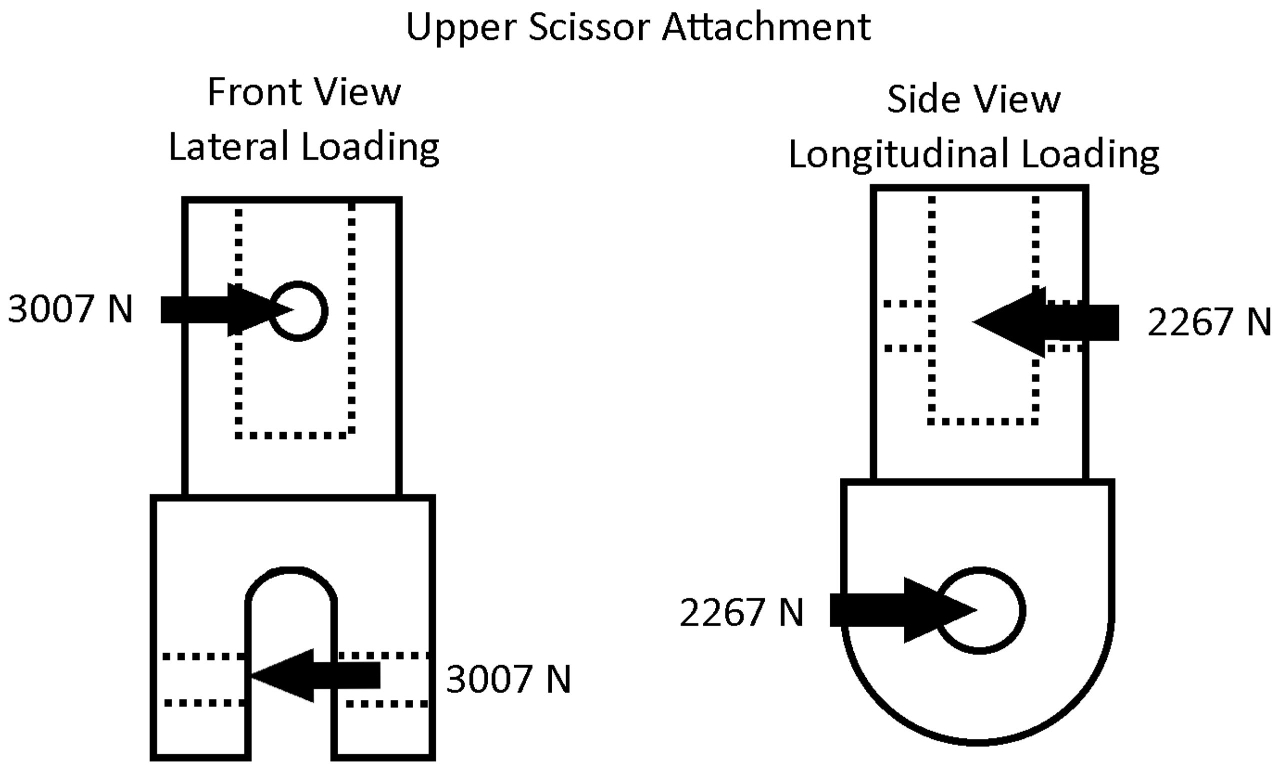


Figure 59

This part is very similar to the previous part in both loading conditions and the result of the analysis.

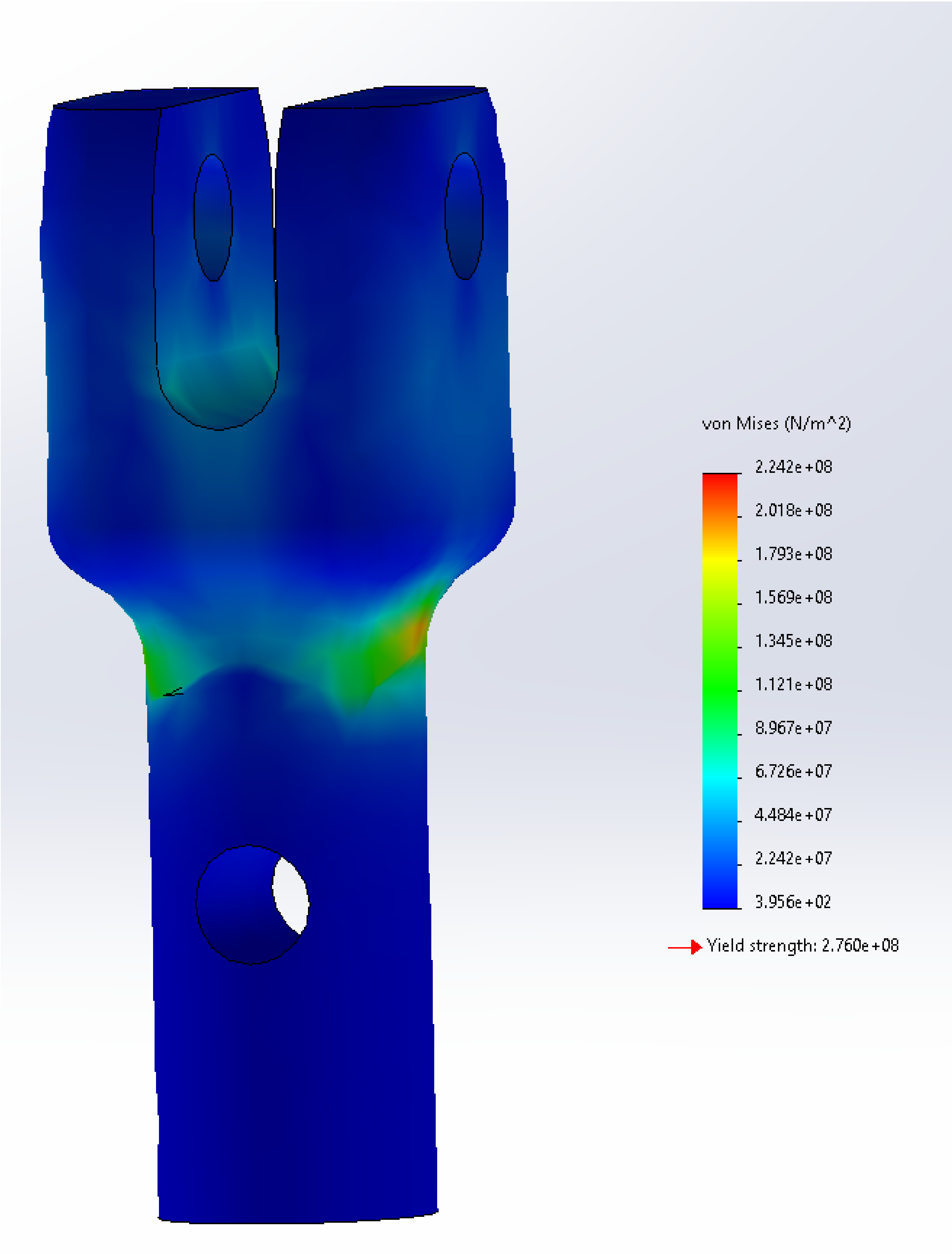

von Mises (N/m^2)
2.242e+08
2.018e+08
1.793e+08
1.569e+08
1.345e+08
1.121e+08
8.967e+07
6.726e+07
4.484e+07
2.242e+07
3.956e+02
Yield strength: 2.760e+08

Figure 60

G-OUAV Structural Report – Document 8

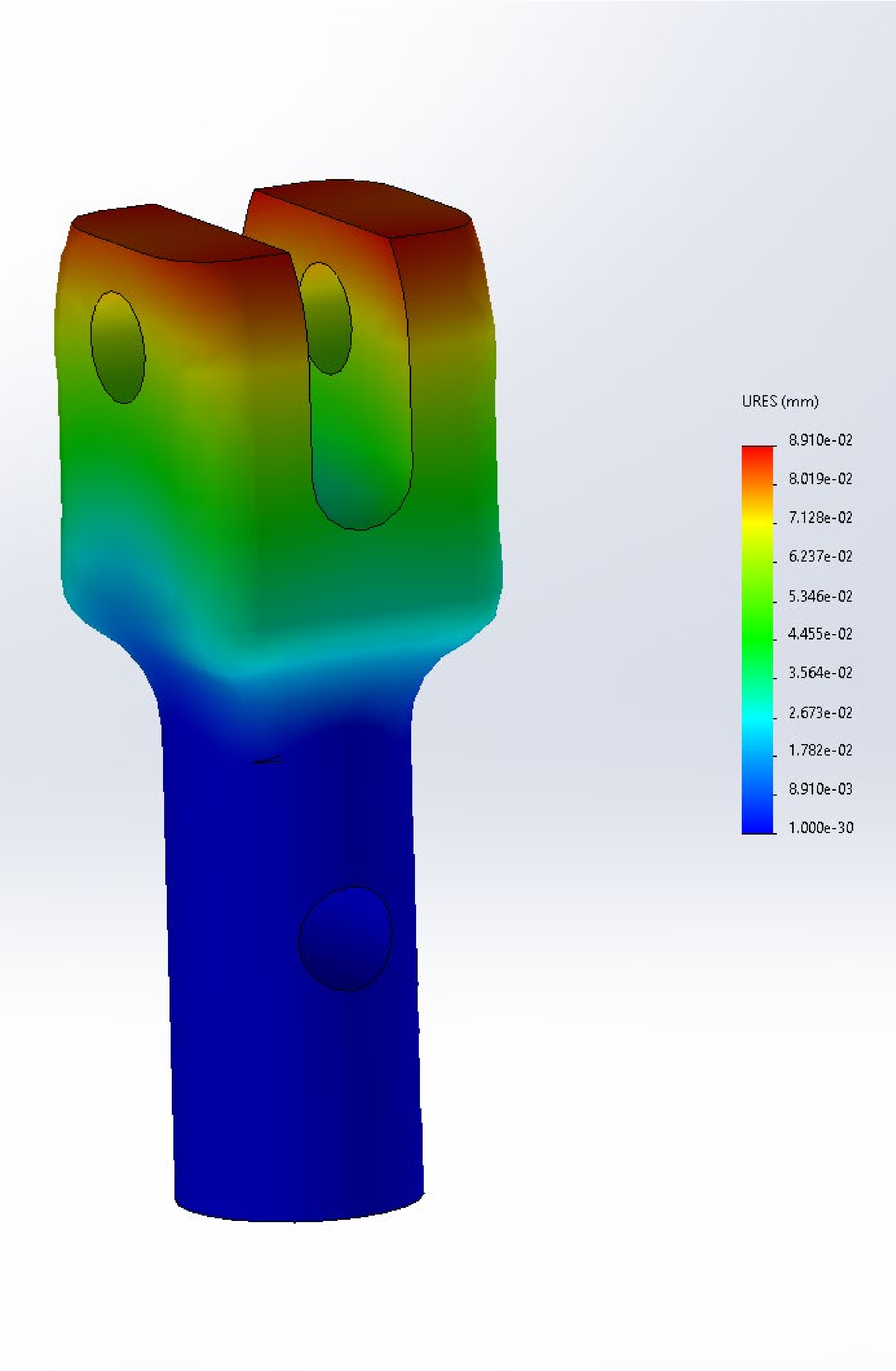
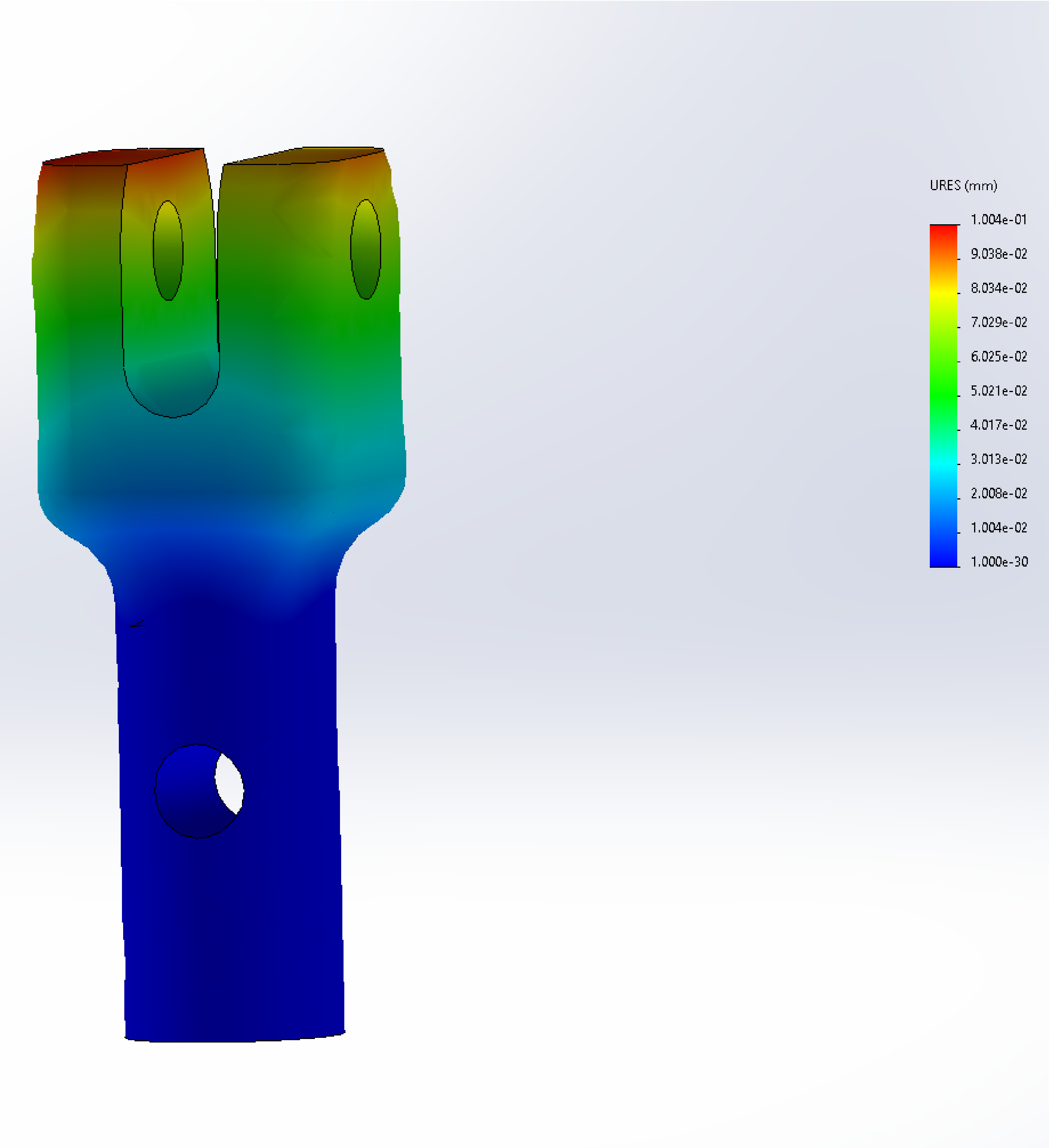


Figure 61


URES (mm)
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8.034e-02
7.029e-02
6.025e-02
5.021e-02
4.017e-02
3.013e-02
2.008e-02
1.004e-02
1.000e-30

Figure 62

G-OUAV Structural Report – Document 8

Scissor Link

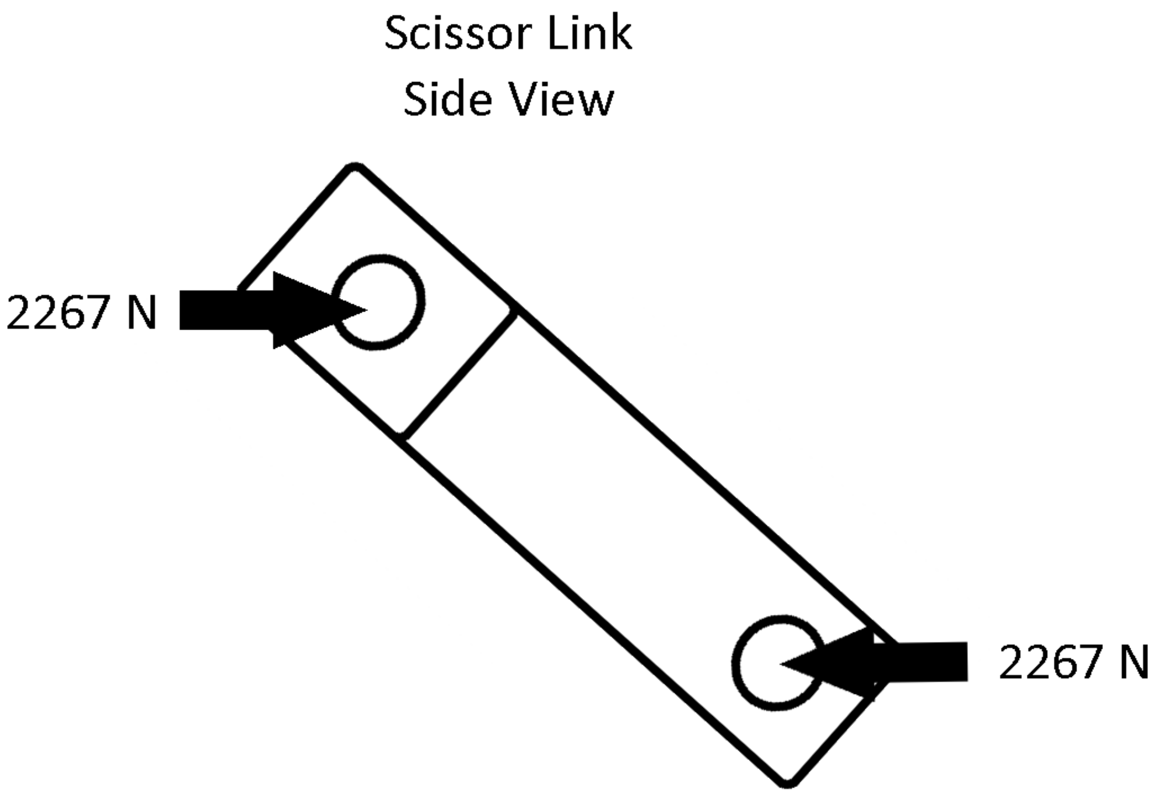

Figure 63

This part sits between the two previous components and links them, hence the force is transmitted through it. The maximum stress is close to but still below the yield stress of the 6061-T6 material.

G-OUAV Structural Report – Document 8

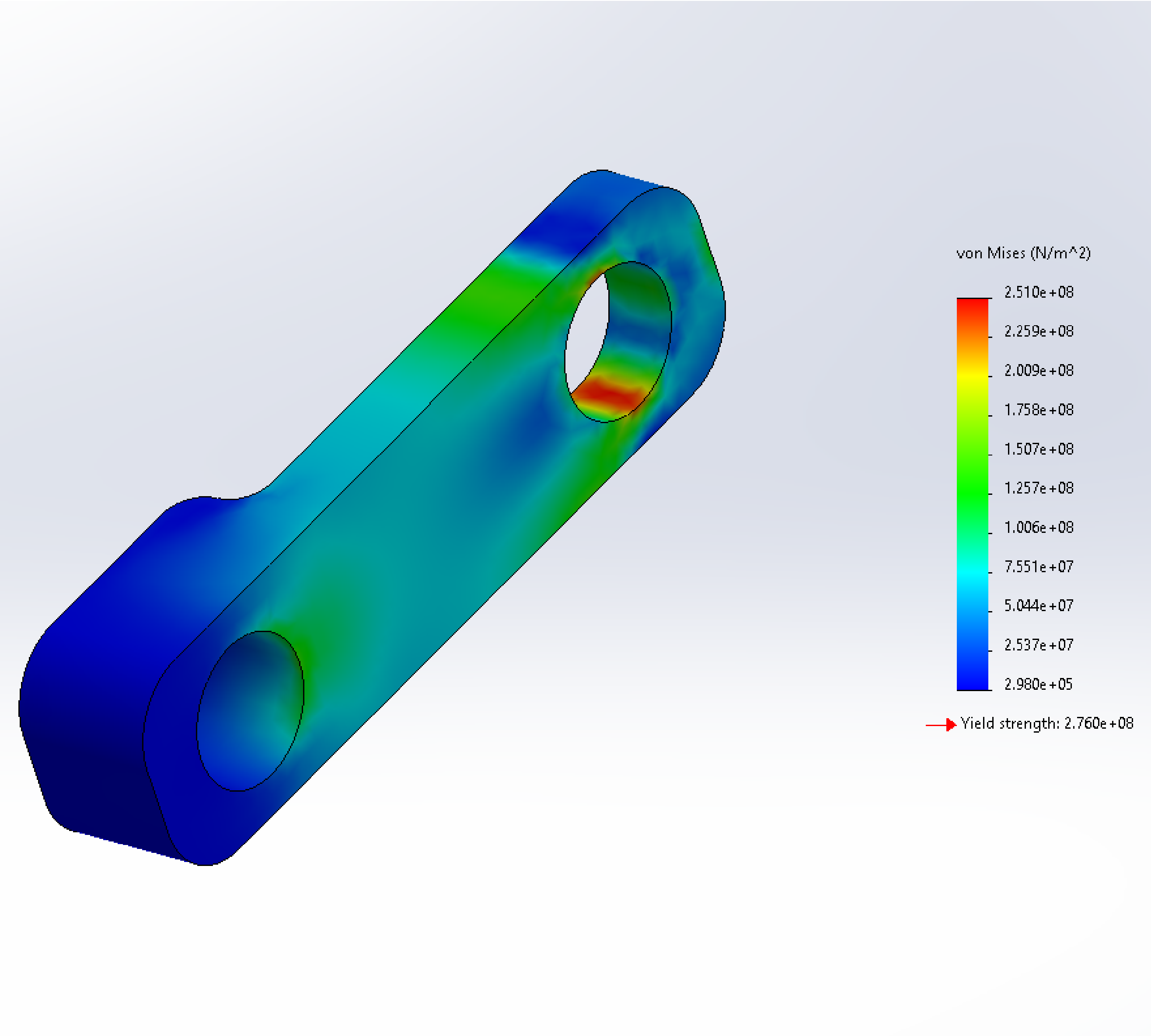

Figure 64

G-OUAV Structural Report – Document 8

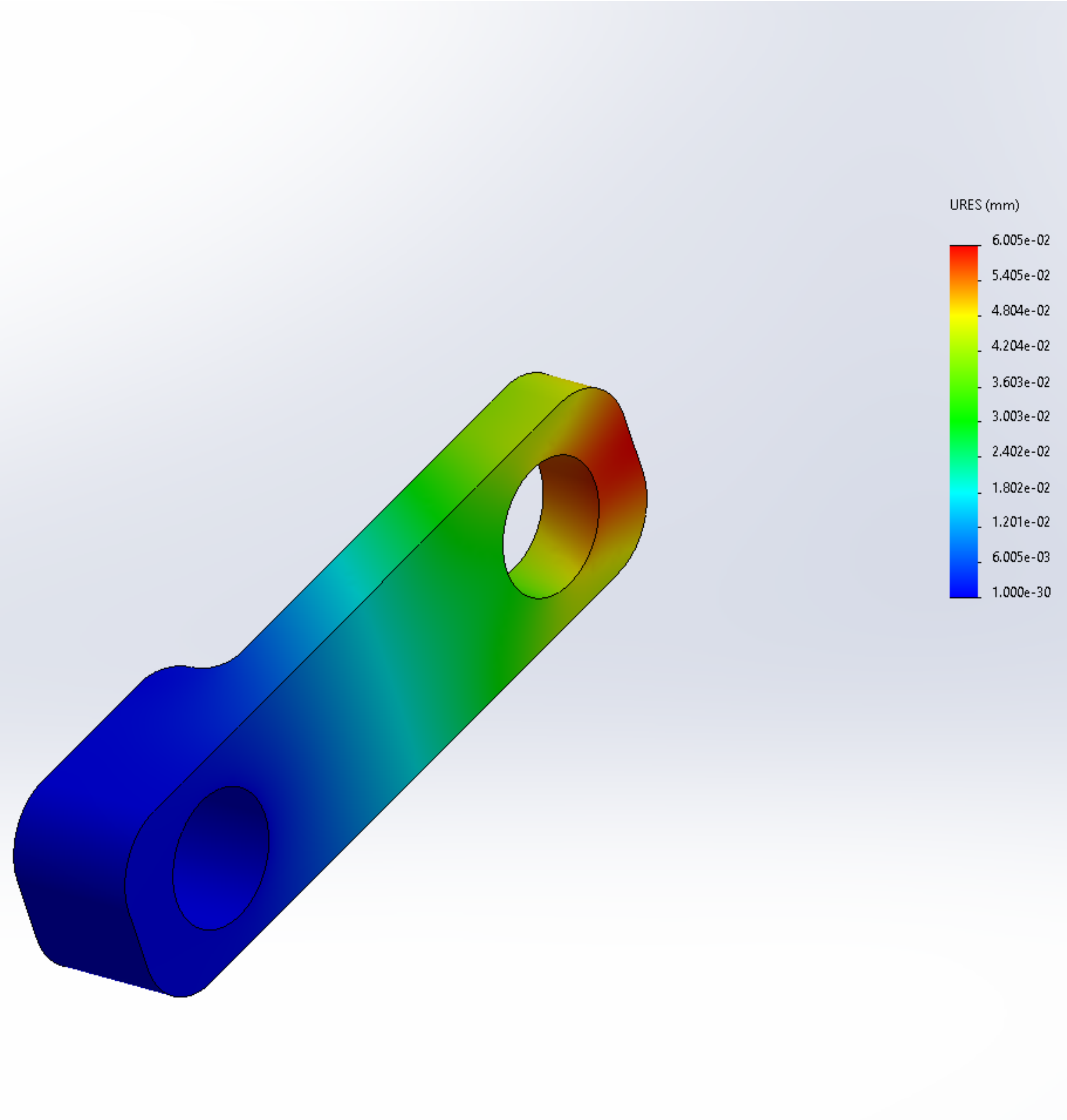

Figure 65

<u>Footwell Fuselage Attachment A</u>

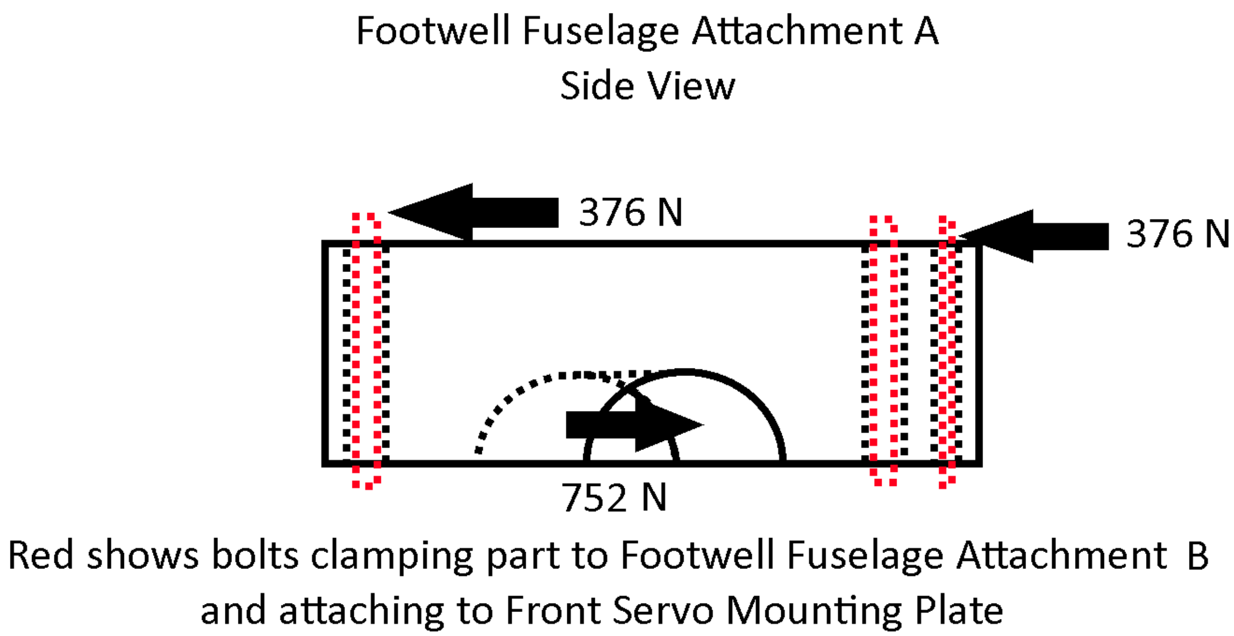

Figure 66

The footwell attachment parts have the force transmitted via the bolts which attach them together and to the front servo mounting plate. The reaction forces are provided by the fuselage tube which they clamp around. Parts A and B are mated together to created a sub-assembly which surrounds the fuselage tube.

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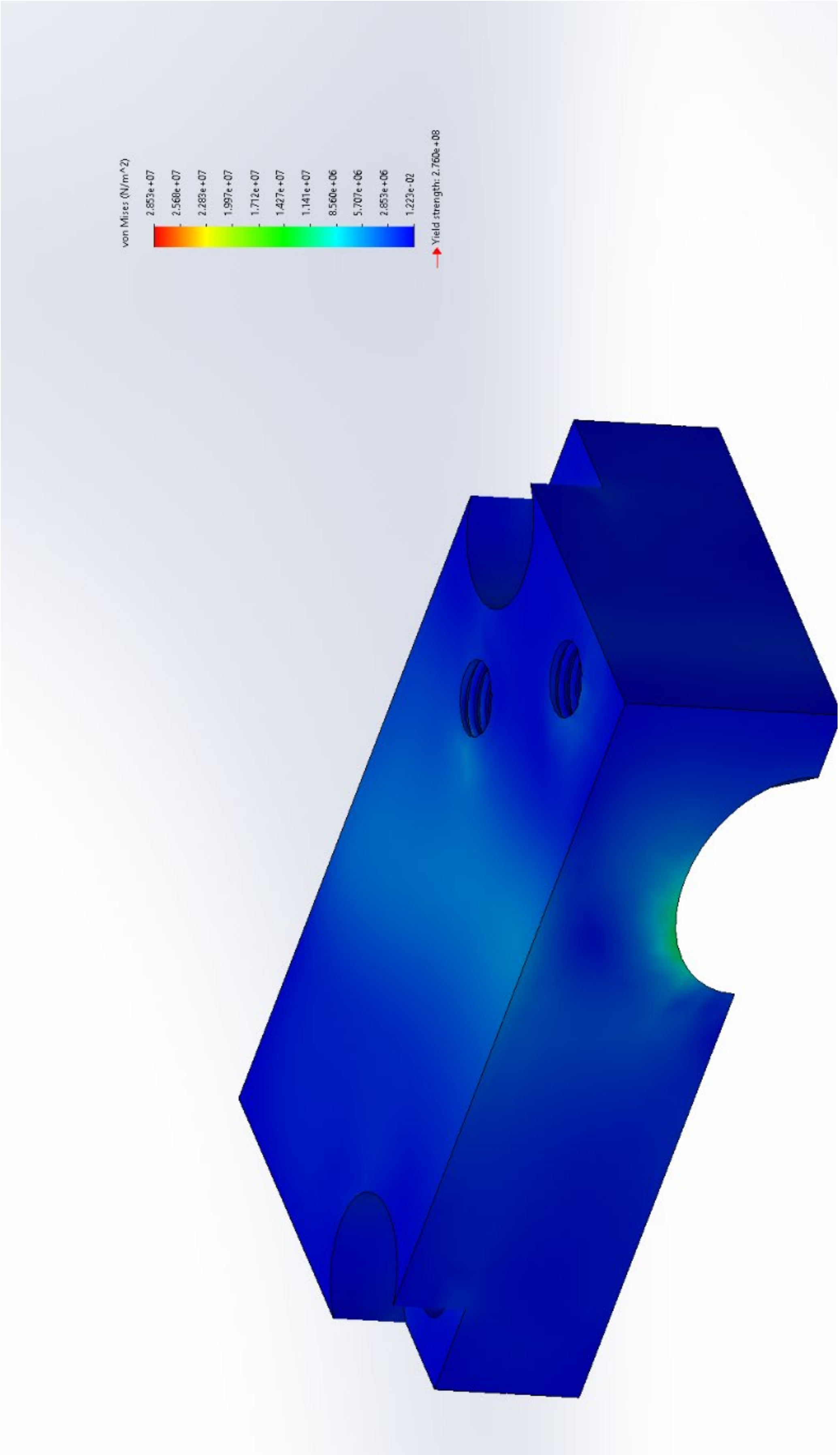

Figure 67

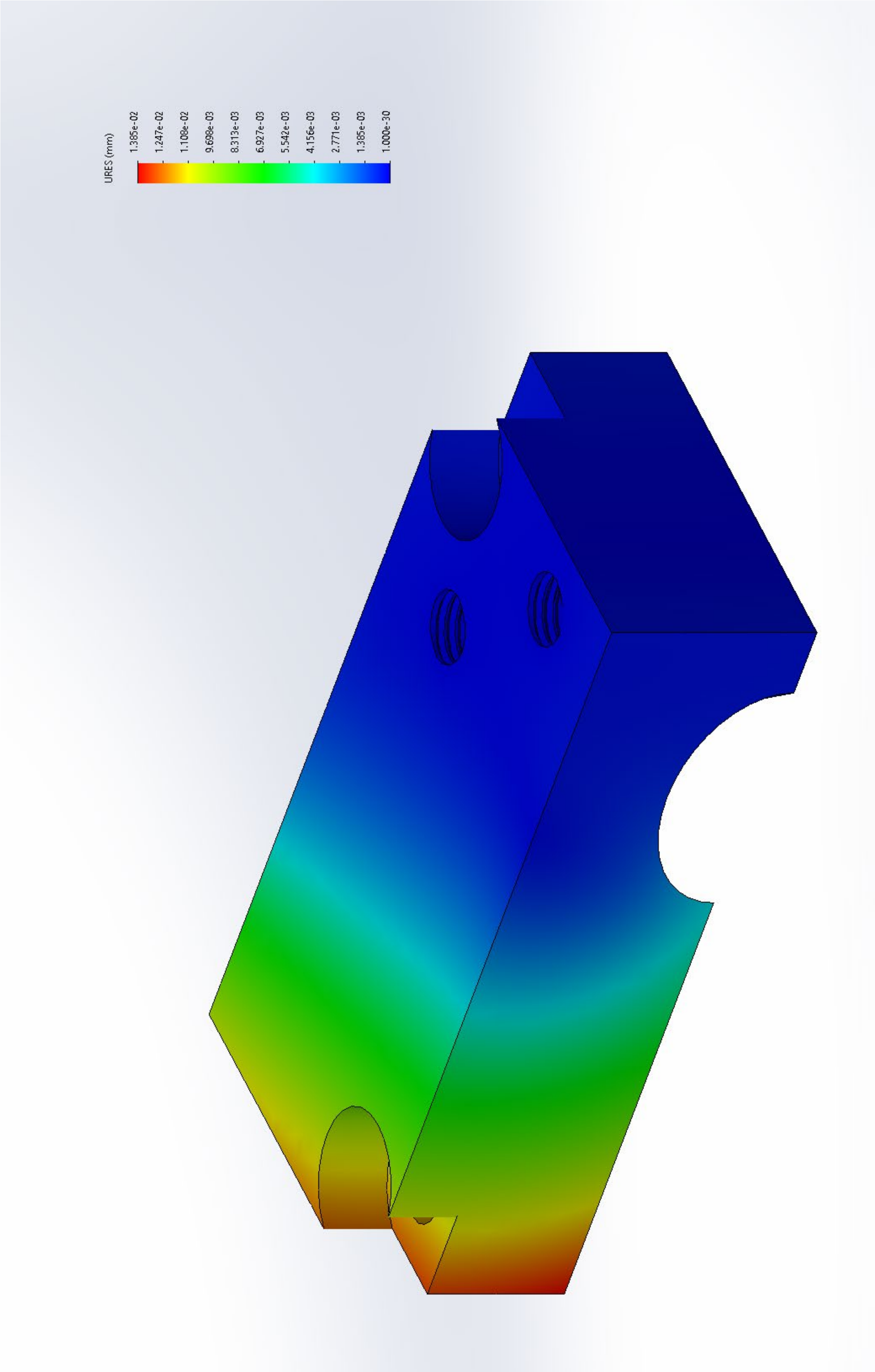
URES (mm)
1.385e-02
1.247e-02
1.108e-02
9.698e-03
8.313e-03
6.927e-03
5.542e-03
4.156e-03
2.771e-03
1.385e-03
1.000e-30

Figure 68

G-OUAV Structural Report – Document 8

Footwell Fuselage Attachment B

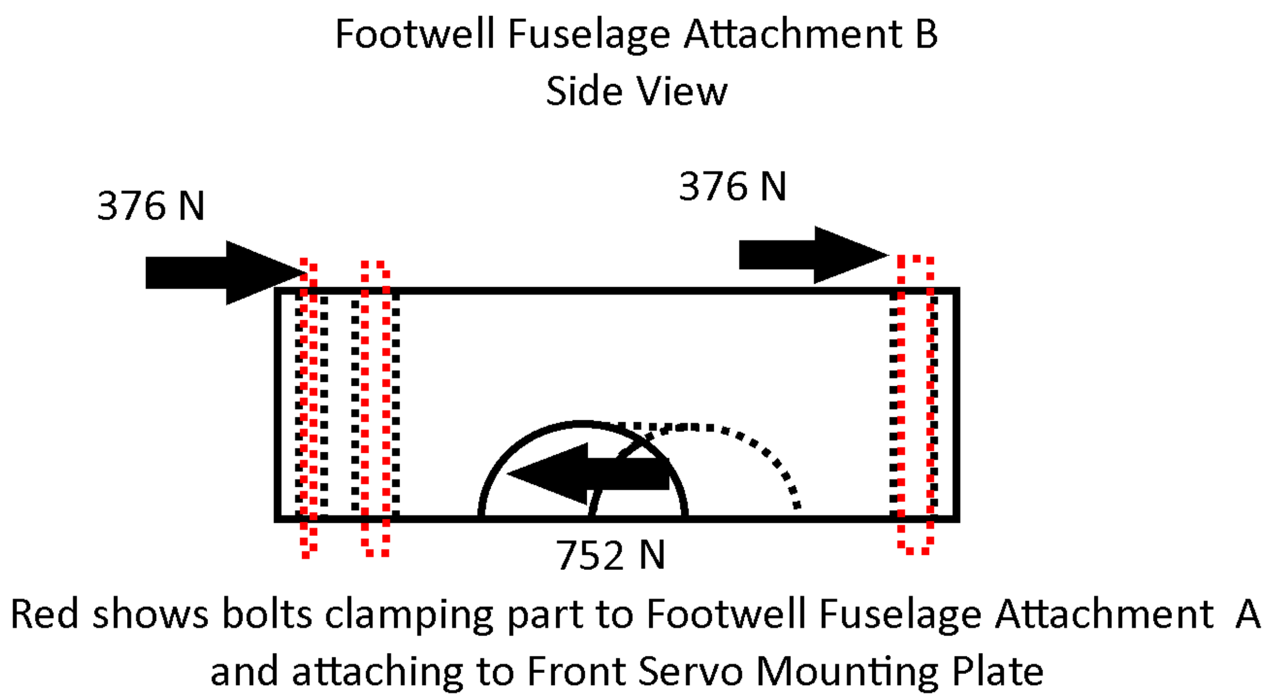

Figure 69

This is the other variant of the footwell attachment.

G-OUAV Structural Report – Document 8

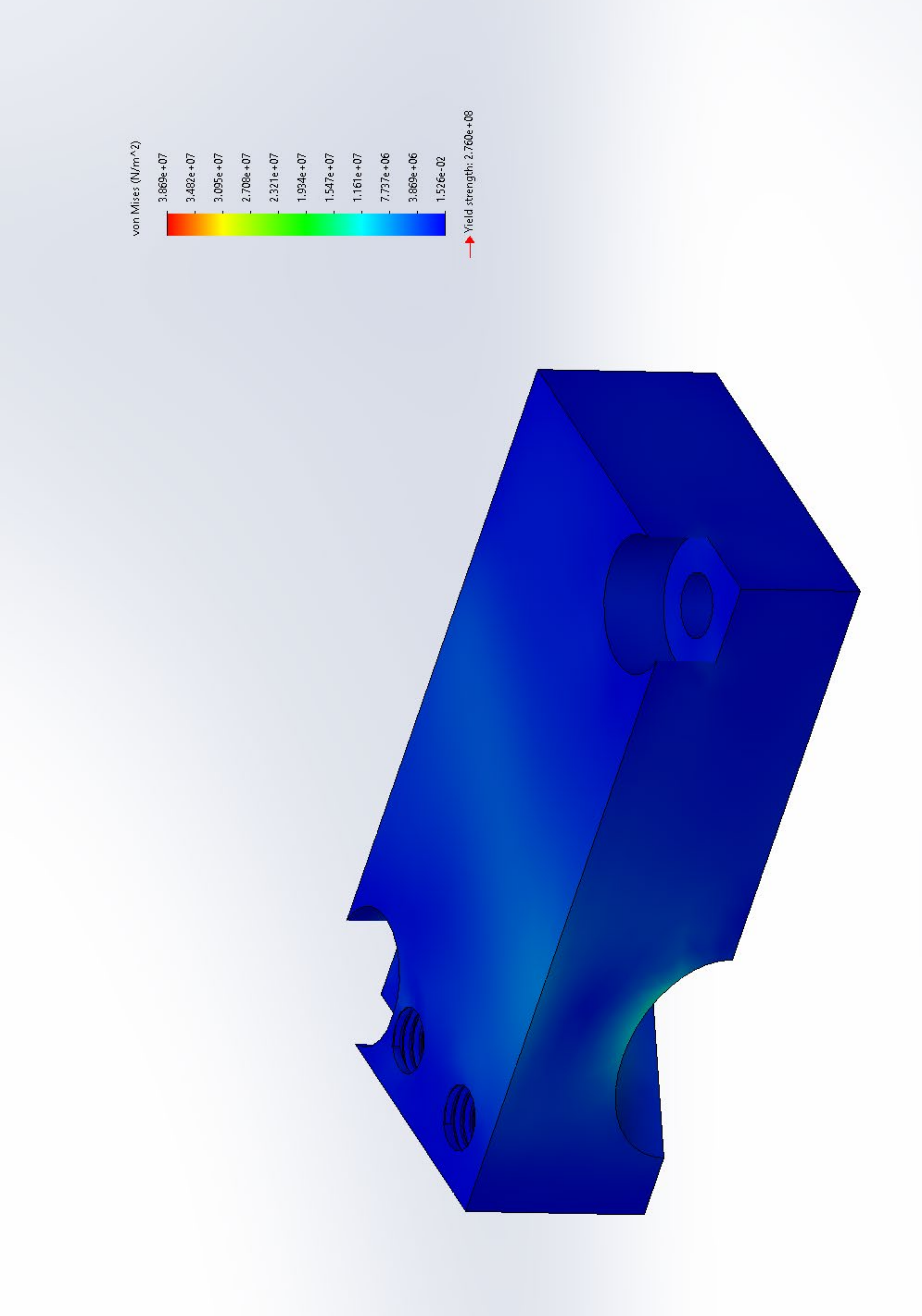

Figure 70

G-OUAV Structural Report – Document 8

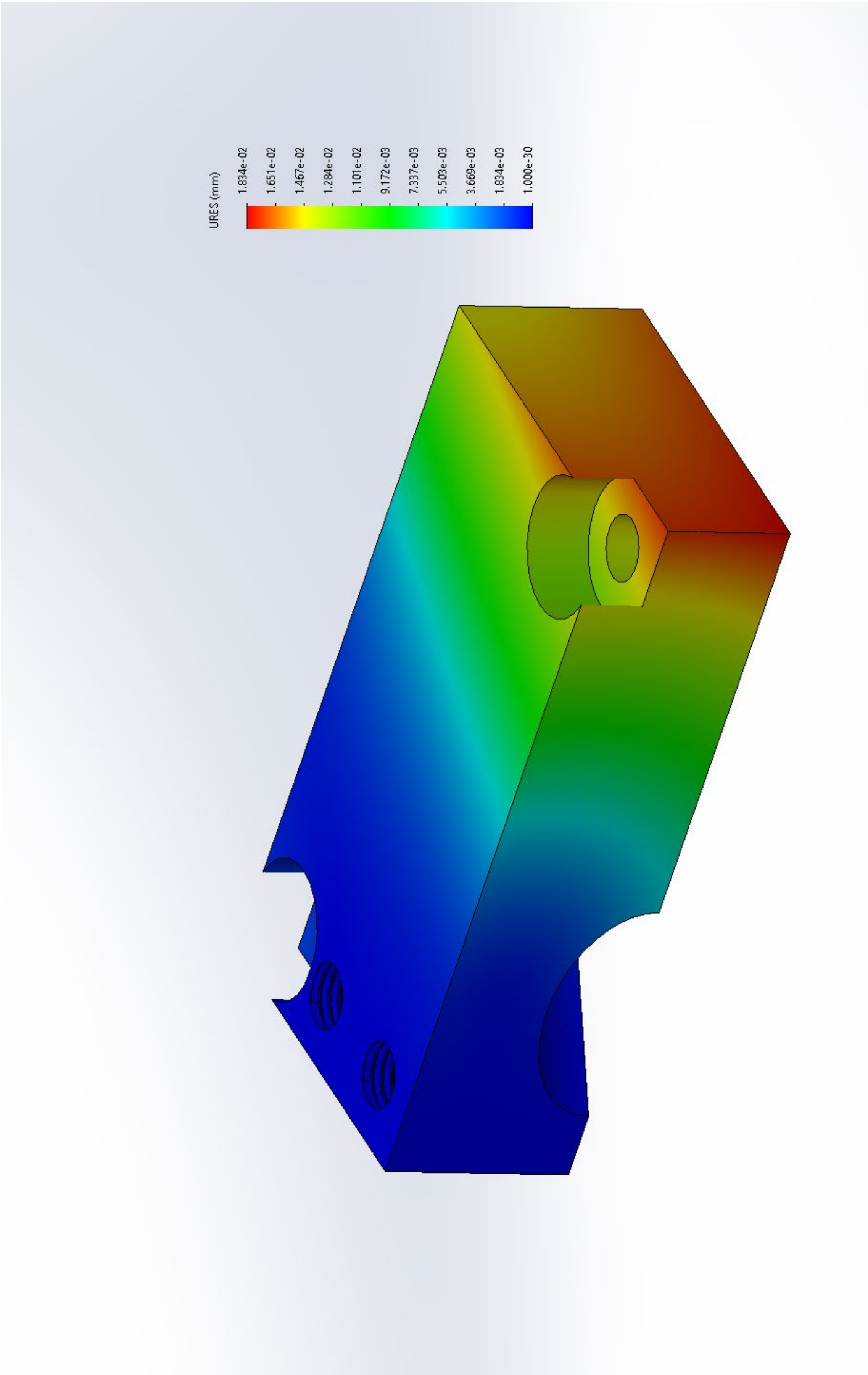

Figure 71

<u>Front Servo Mounting Plate</u>

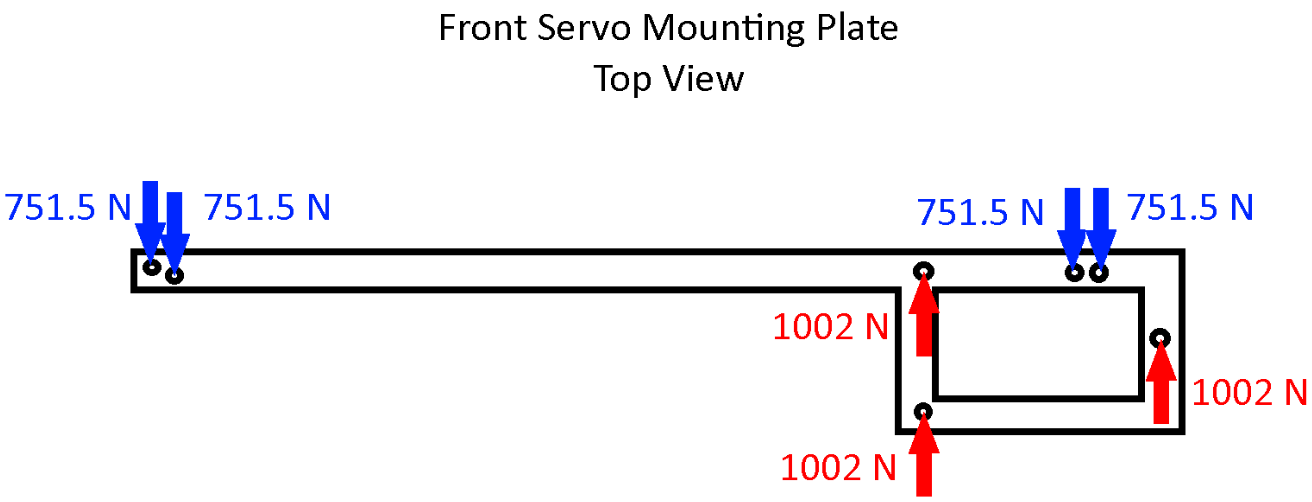

Figure 72

This plate is used to mount the servo. The force from the stick assembly is transmitted via the push rod into the servo. The force is then counteracted by a reaction force from the servo mounting bolts, these transmits the force into the mounting plate. The force then passes through the bolts into the footwell attachment pieces. For the analysis, the force is acting through the bolt holes and the other holes are set as fixed geometry such that they provide a reaction force to oppose the push rod force.

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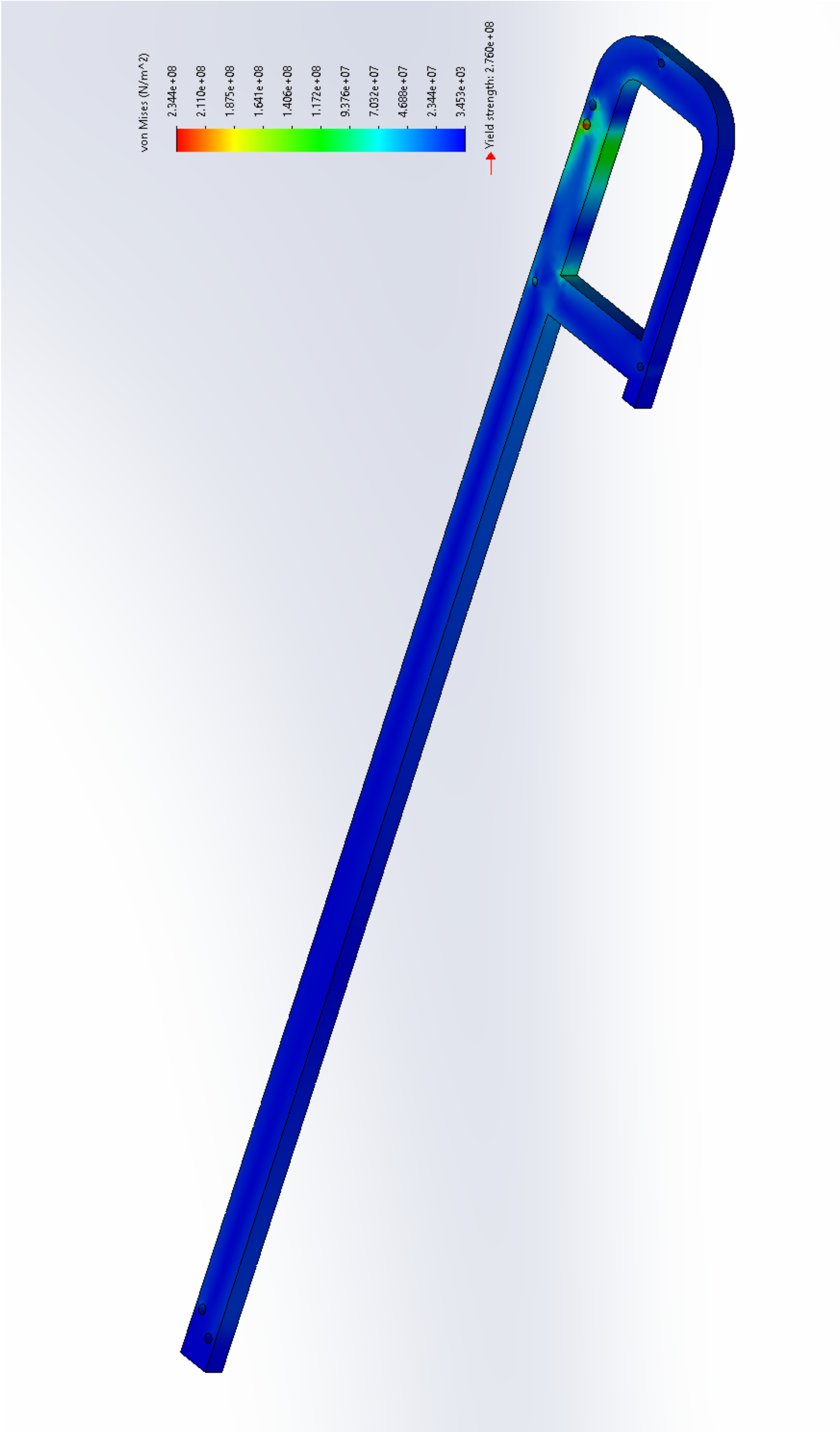

Figure 73

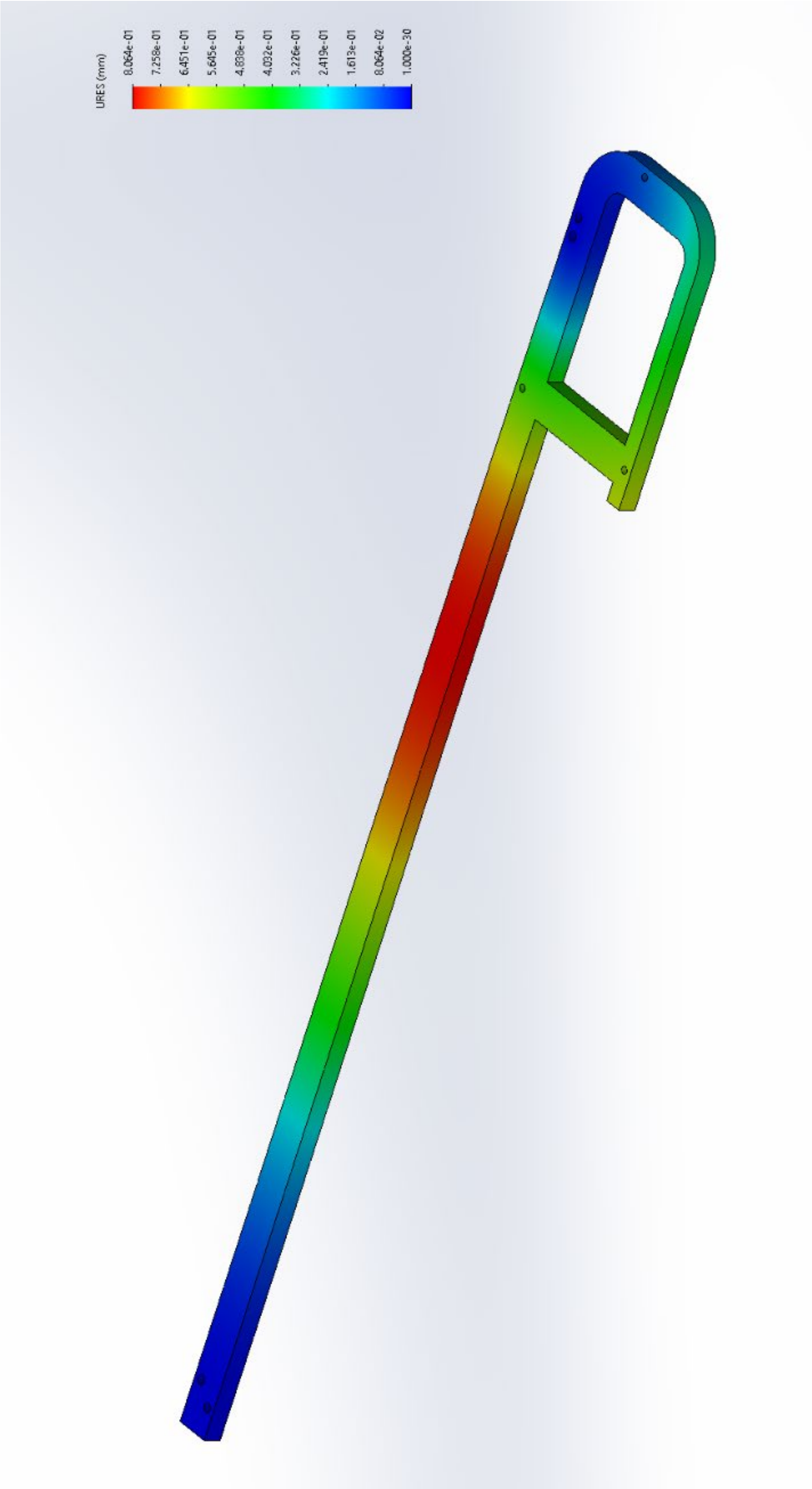
URES (mm)
8.064e-01
7.258e-01
6.451e-01
5.645e-01
4.838e-01
4.032e-01
3.226e-01
2.419e-01
1.613e-01
8.064e-02
1.000e-30

Figure 74

G-OUAV Structural Report – Document 8

18g Loading

Assembly Parts

Crash worthiness is assessed by performing an analysis on components mounted aft of the pilot using the formula:

$$F = n \times m \times g$$

Where n is the load factor, CS-VLA-561 calls for 9g loading, however in a meeting with the LAA, it was decided that we should use a minimum of 18g for testing. Mass of the component/assembly is denoted by m in this equation and g is taken to be $9.81ms^{-1}$. This formula gives a static force which acts longitudinally in the event of a head on collision.

Due to the lightweight Aluminium-6061-T6 being used for all manufactured components, component mass and therefore 18g forces are very low. This can be seen in the table below.

Table 1

Part	Mass (kg)	18g Force (N)
Rear Assembly		
Rear Push Rod	0.128	22.53587
Combiner	0.221	39.05236
Combiner Slider	0.054	9.579621
Rear Servo Arm	0.074	13.06687
Rear Servo Mounting Plate	0.515	90.8608
Rear Servo Plate Leg	0.027	4.73586
Shear Pin Connector	0.082	14.41549
Front Assembly		
Front Push Rod	0.040	7.009724
Bearing Mount Top	0.047	8.244548
Bearing Mount Bottom	0.005	0.810826
Stick Mounting Frame	0.038	6.773195
Stick-Frame-Bearing Link	0.058	10.16227
Bearing Longitudinal Pivot	0.005	0.823642
Front Servo Arm	0.118	20.87088
Lower Scissor Attachment	0.016	2.773791
Upper Scissor attachment	0.031	5.559606
Scissor Link	0.006	1.04622
Footwell Fuselage Attachment A	0.053	9.295316
Footwell Fuselage Attachment B	0.053	9.295306
Front Servo Mounting Plate	0.476	84.00807

As this analysis only affects the parts aft of the cockpit, only the rear assembly is necessary to analyse. The forced summed across all the components of the rear assembly is ~1707 N. Most of the components are already tested to forces above this during normal operation, only the rear servo plate legs are tested to forces below this. There are 6 legs, so the load would be spread between these, making the actual force less than 300 N. However I still performed this analysis at the full 1707 N as a worst case scenario.

Rear Servo Plate Leg

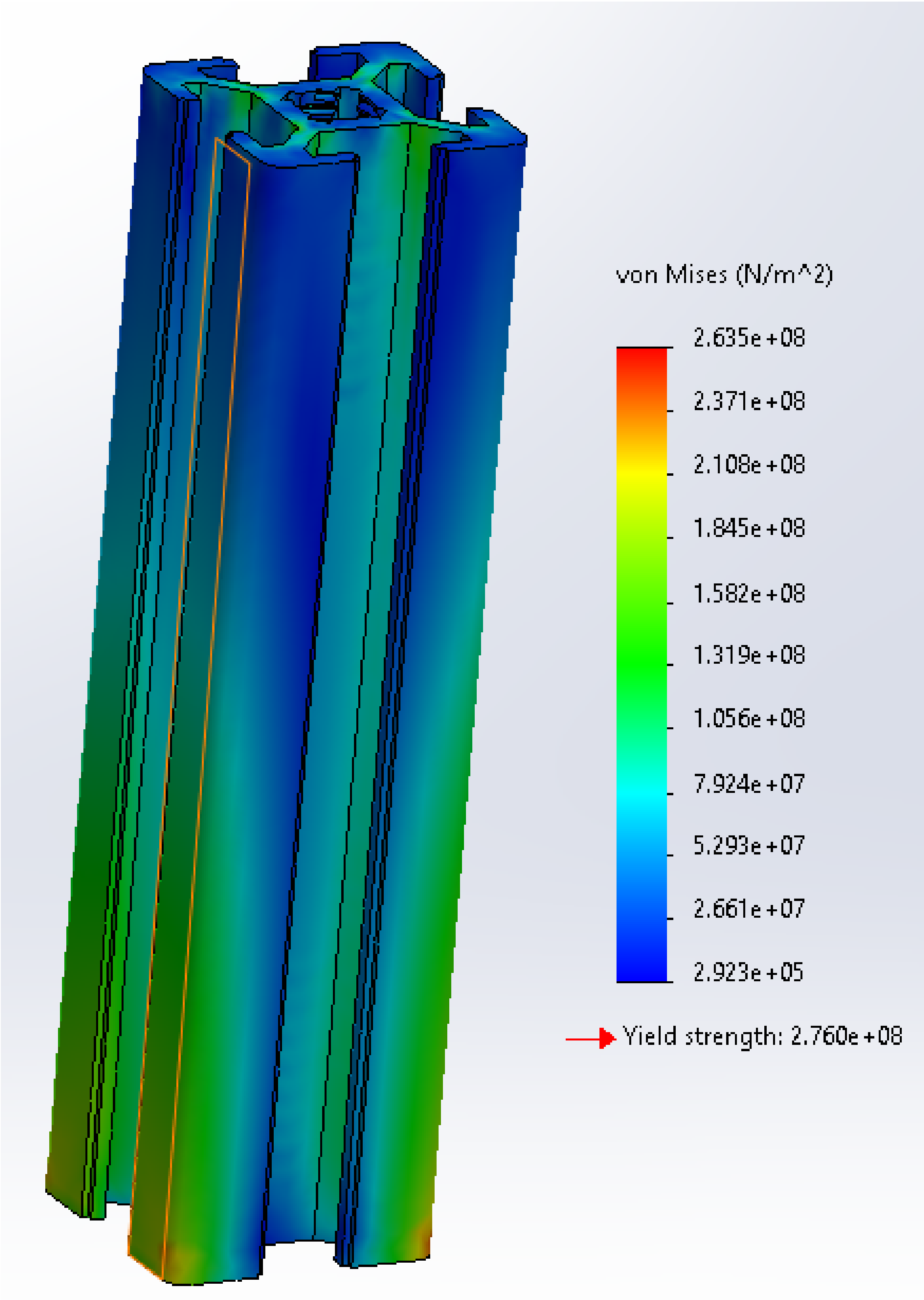
von Mises (N/m^2)
2.635e+08
2.371e+08
2.108e+08
1.845e+08
1.582e+08
1.319e+08
1.056e+08
7.924e+07
5.293e+07
2.661e+07
2.923e+05
Yield strength: 2.760e+08

Figure 75

G-OUAV Structural Report – Document 8

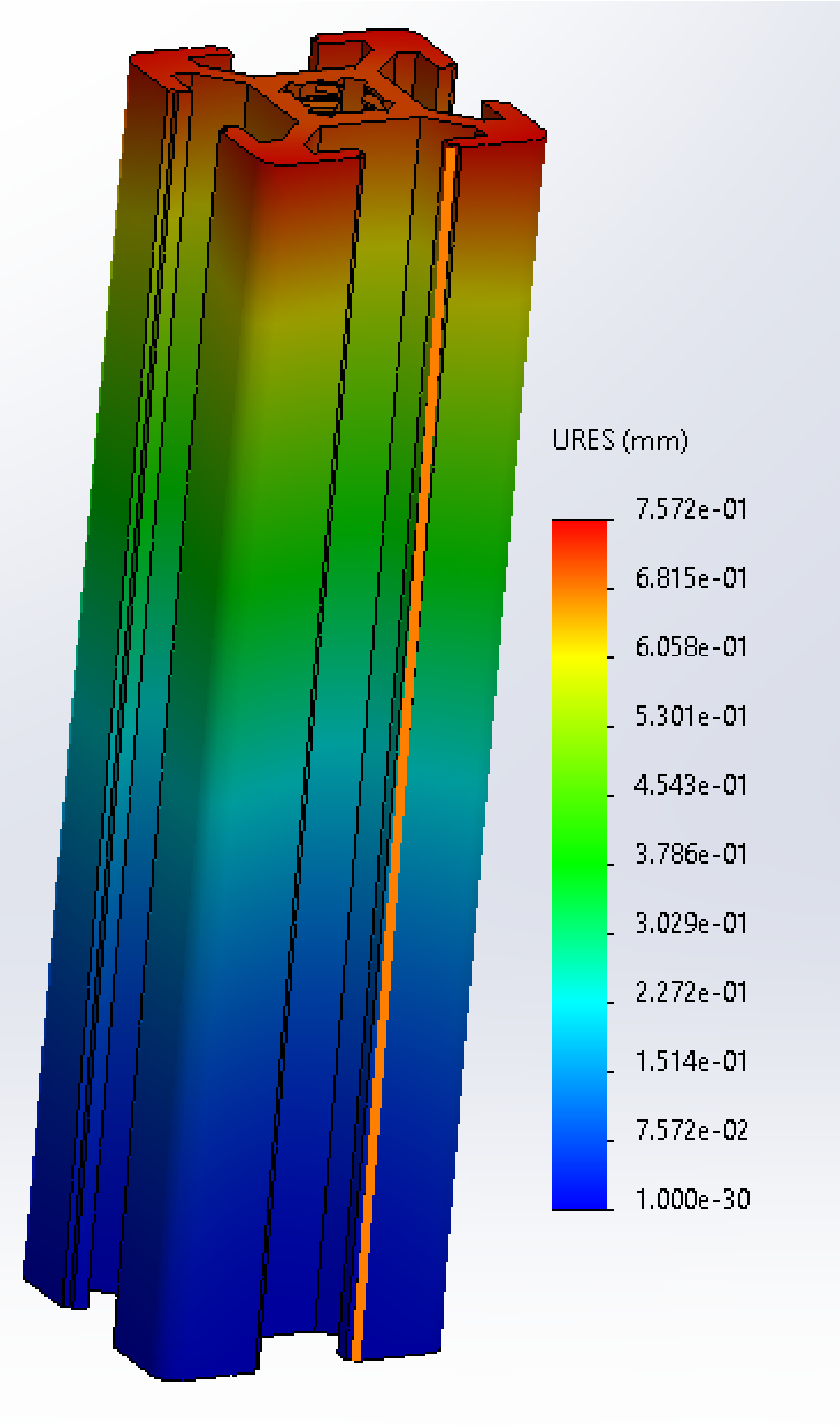

Figure 76

G-OUAV Structural Report – Document 8

Even with this exaggerated force, the stresses within the component are still below the yield stress and therefore I am confident that in the event of a crash, with 18g loading, the rear assembly will stay in one piece.

Fasteners

This system uses grade 8.8 fasteners to secure components together, properties of these components in their different dimensions are listed in the table below. I will use proof loads for my discussion.

Table 2

Part	Property Class	Proof Load		Ultimate Load	
		Tensile (N)	Shear (N)	Tensile (N)	Shear (N)
M3	8.8	2920	1947	4020	2680
M4	8.8	5100	3400	7020	4680
M5	8.8	8230	5487	11350	7567
M6	8.8	11600	7720	16100	10733
M8	8.8	21100	14100	29200	19467
M10	8.8	33400	22300	46400	30933

This shows that the M6 fasters which attach the legs to the floor, and the mounting plate to the legs are capable of 7720 N which is far more than the maximum 1707 N force expected in a crash. This 1707 N load would be spread over 6 legs so the actual force would be even less.

The servos are mounted to the plate with four M4 bolts, which can take 3400 N each, giving a total of 13600 N of shear resistance. This is far more than can reasonably be expected to be exerted.

The combiner and combiner slider are attached to the servo arms by M10 bolts which are more than capable of withstanding the loads required of them in shear.

The rear push rod is attached by M10 thread on the spherical bearing and a nut. This is capable of withstanding 10 kN of force which is more than could be required. This is the rated load from the data sheet.

The shear pin connector piece is attached to the idler by M10 bolt which, again, is more than adequate in shear to withstand the forces it will experience.

The shear pin itself is capable of more than the 1707 N of load expected in this crash, however if it were to break, then it would be performing its job.

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Server Rack

As the rack has no moving parts, during steady flight, there will be no forces acting on the components contained other than weight forces. Therefore it is only really necessary to analyse these parts of the system for the 18g crash case.

Mounting Tray

The mounting tray is secured by 16 M6 grade 8.8 bolts to the rack, with 4 bolts in each corner of the part. With all 8 of the bolts at the rear of the assembly, up to 100 kN can be withstood in tension, i.e longitudinally. This is far more than could ever be expected in the lifetime of the assembly.

In shear, the bolts can withstand 123.5 kN of force, i.e in the vertical direction which would correspond to the weight of the components. The weight of the entire tray assembly will be a maximum of 5 kg which is around 50 N. This means that by inspection it is possible to pass the tray mounting.

The tray itself is analysed later with respect to how the battery inertial forces.

Battery Straps

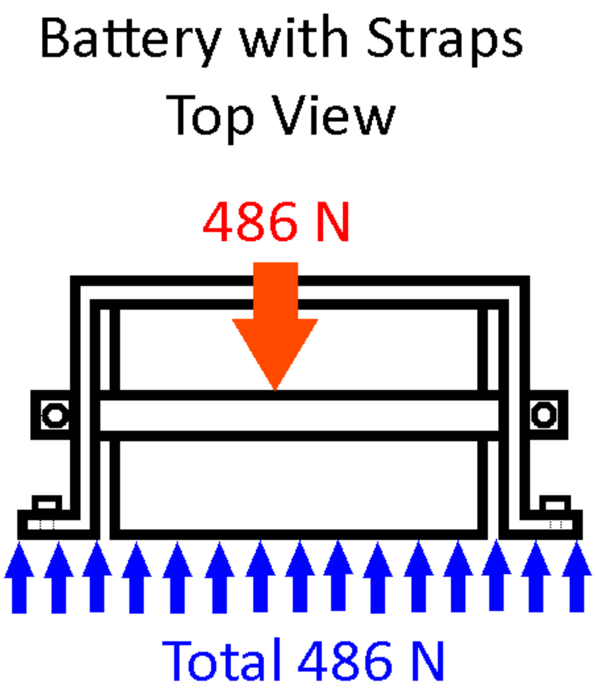

Figure 77

G-OUAV Structural Report – Document 8

In this situation, the battery will be subject to an inertial force of 18 *2.75 * 9.81 which gives 486 N due to the 2.75 kg mass. This force will act on the straps holding down the battery, which I will analyse first, then I will look at the bolts which secure these to the tray. By letting all the reaction force act through the contact with the front wall of the tray which the battery rests against, the 486 N can be modelled as a distributed force across the contact face of the two components.

As can be seen from the analysis, the front plate of the mounting tray is very capable of taking the full force of this 18g load from the battery. The plate experiences a deflection of around 7.5 mm which would mean the part would probably need to be replaced, however in the conditions where this force would be felt, the plane would likely not fly again anyway.

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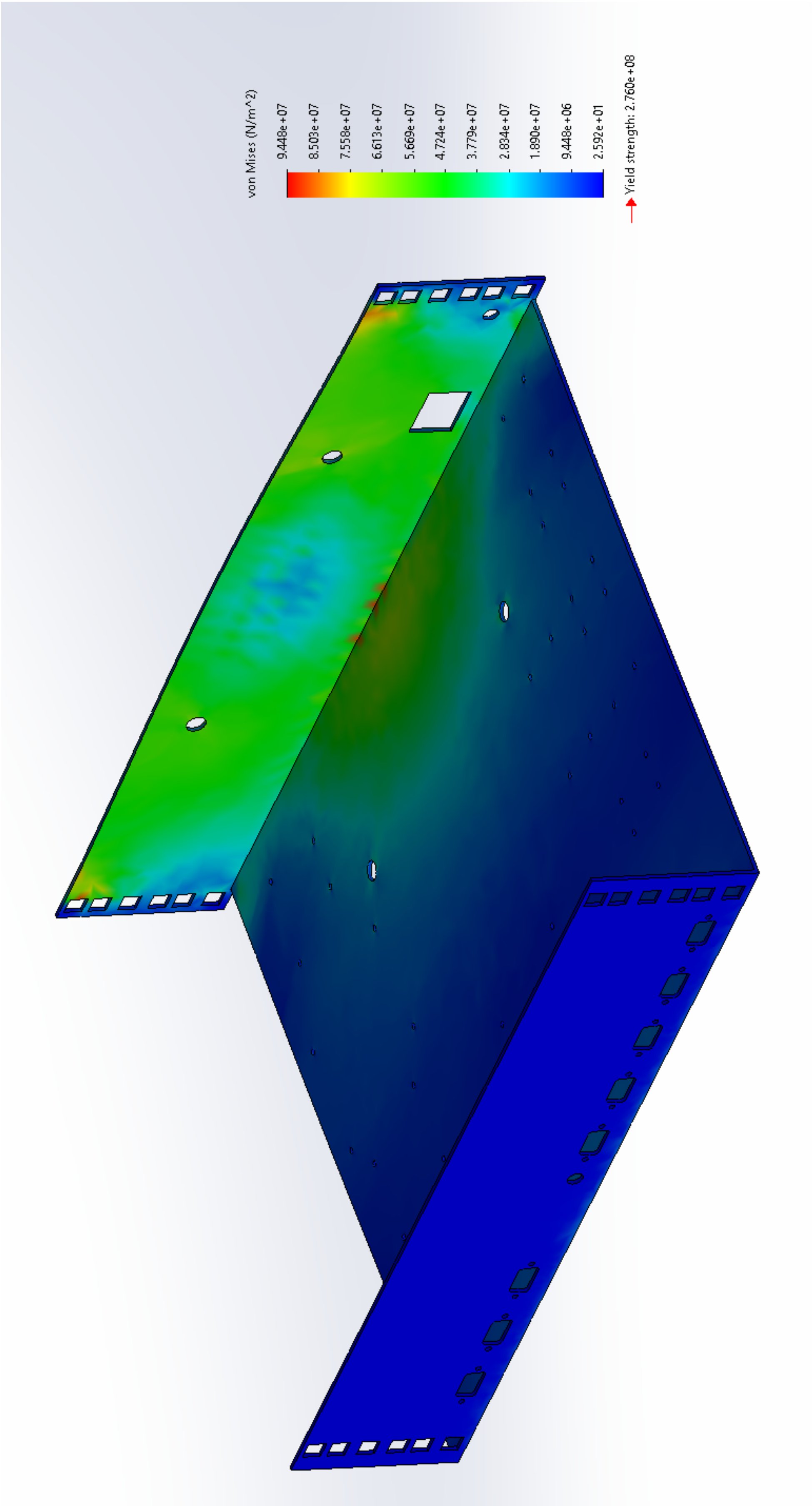

G-OUAV Structural Report – Document 8

Figure 78

G-OUAV Structural Report – Document 8

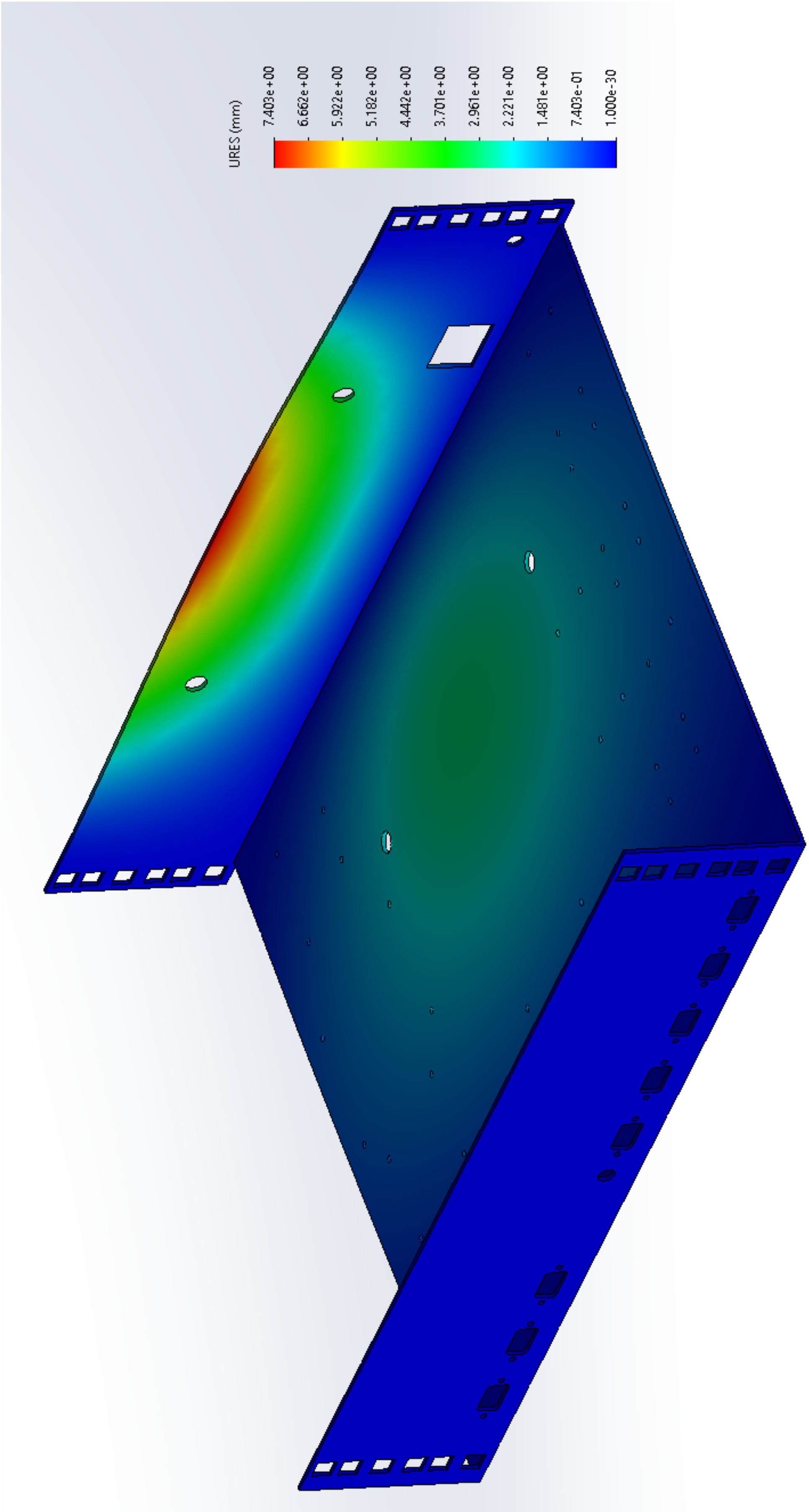

Figure 79

It is also possible to model the reaction force being purely transmitted through the strap which passes around the back of the battery. This would mean that the full 486 N would be acting on the strap and the bolts which hold it in place. The bolts are M10 grade 8.8 which as shown in the previous table, can withstand 33.4 kN of tensile force, so these are not an issue.

As is shown in the analysis, the maximum stress is less than half of the yield strength of the material so this would work fine, it has a small deflection of 3.5 mm at this force level which should not be a problem. The part is also easy to replace should this happen.

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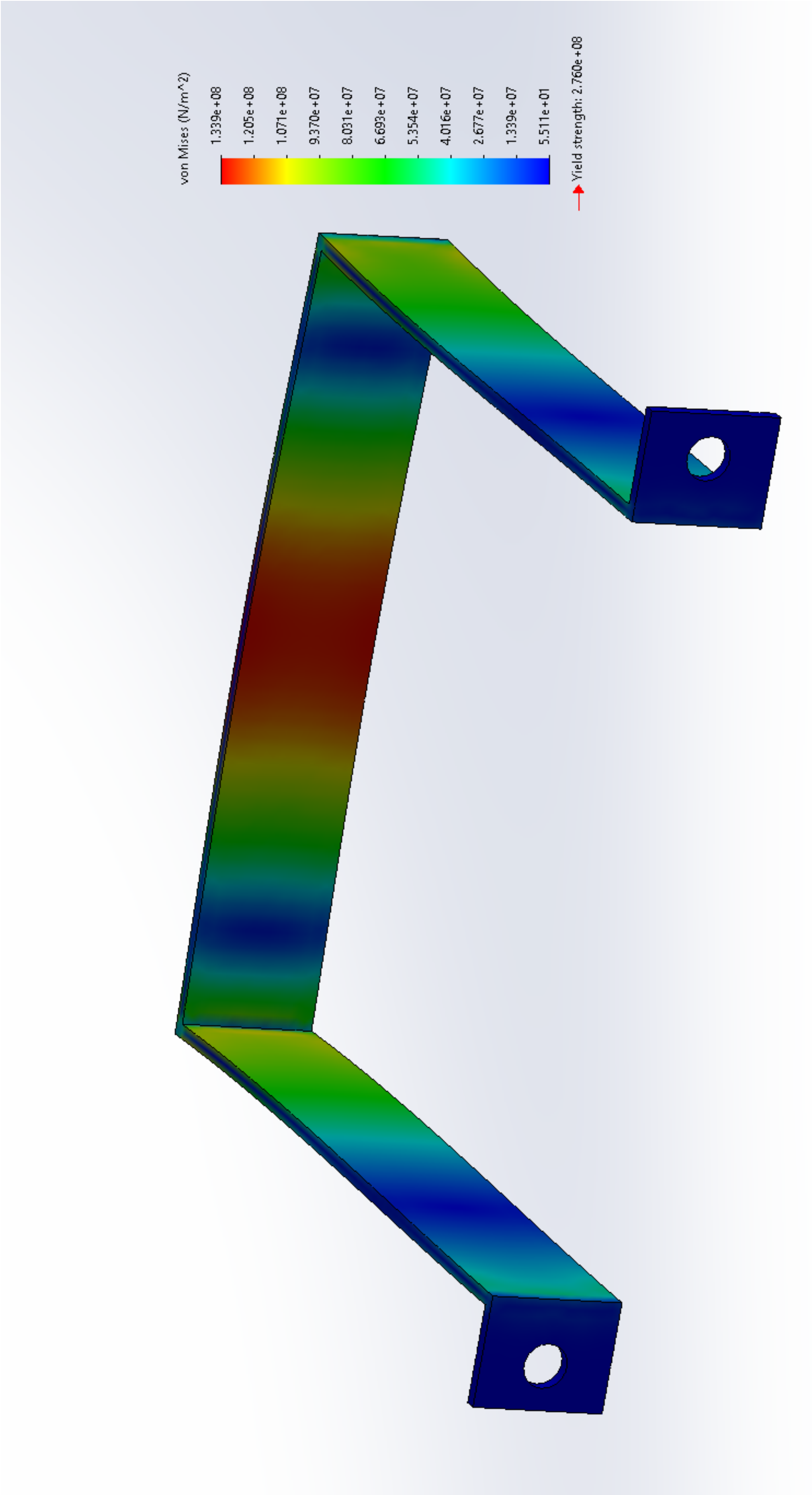

Figure 80

G-OUAV Structural Report – Document 8

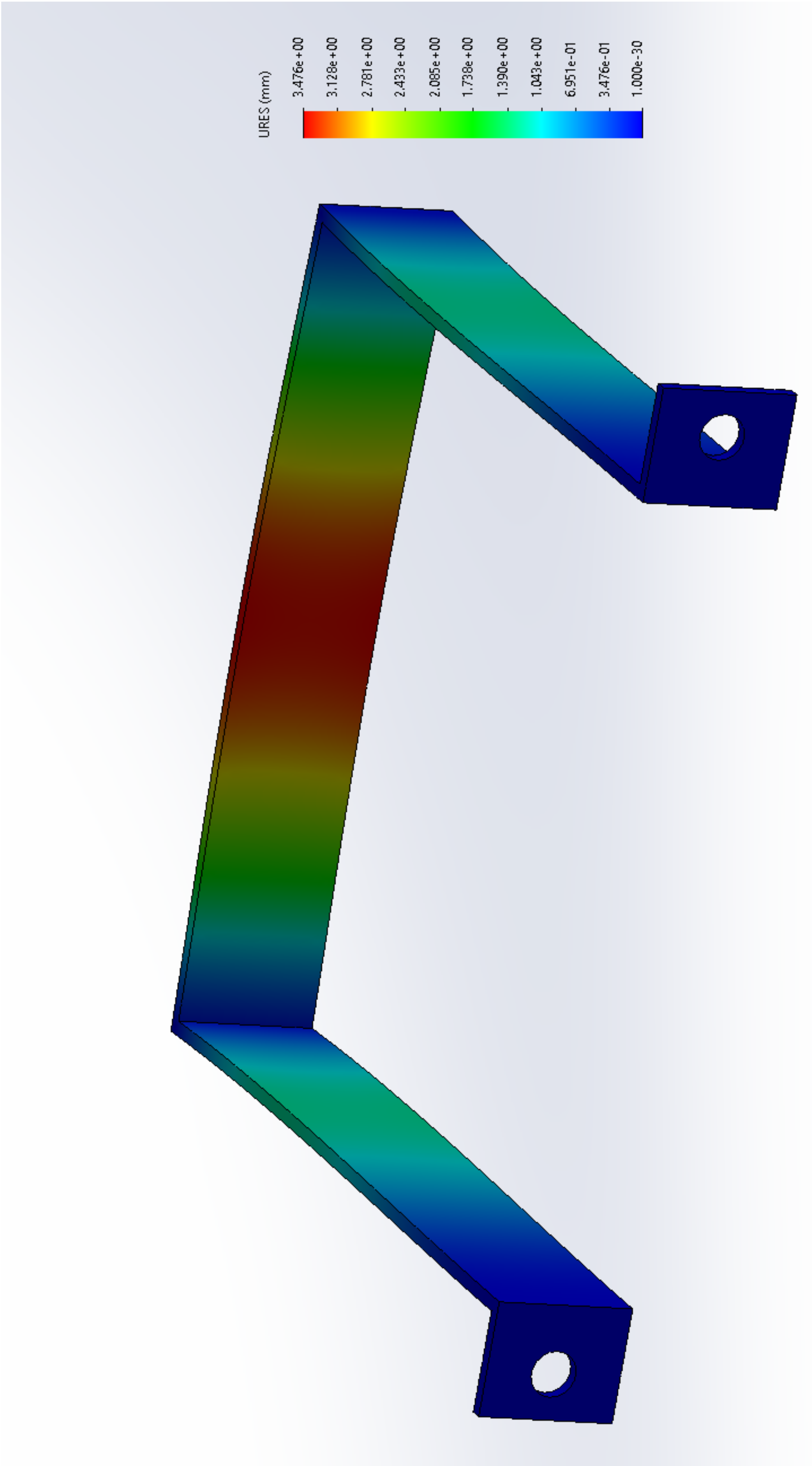

Figure 81

G-OUAV Structural Report – Document 8

Tray Mounted Components

The heaviest tray mounted component is the Arduino mega with shield installed. These together add up to a mass of 82 grams. This would result in a force of 14.5 N in the 18g case. As the component is mounted with M3 hardware, which has a shear resistance of 2 kN, the mounting of all small electronic components can be passed by inspection.

Pilot Grab Handle

The handle is an off-the-shelf component, mounted to the dashboard using M5 hardware. The maximum force as outlined in AMC VLA 403 is 600 N, and with a 1.5 times safety factor this is 900 N. In tension, M5 bolts and nuts at grade 8.8 are rated to take a load of 8230 N. This means that the bolt will not break under 600 N loading conditions.

G-OUAV Structural Report – Document 8

Shear Pin Calculations

Definition of shear strength

$$\tau = \frac{F}{A}$$

Substituting in formula for the resisting area (cross section of the pin with diameter d)

$$\tau = \frac{F}{\frac{\pi d^2}{4}}$$

Substituting in the worst case scenario for forces from both servos acting with full torque (984.6 N from each servo) opposing the force from the elevator, which is also experiencing the highest expected force (3456.5 N). Also substituting in ultimate shear strength of 207 MPa for Aluminium 6061-T6 gives:

$$207\ 000\ 000 = \frac{\left((3456.5 \times 2)\right)}{\frac{\pi d^2}{4}}$$

$$207\ 000\ 000 = \frac{6913}{\frac{\pi d^2}{4}}$$

$$162\ 577\ 419 = \frac{6913}{d^2}$$

$$d^2 = \frac{6193}{162\ 577\ 419}$$

$$d^2 = 4.252 \ldots \times 10^{-5}$$

$$d = 6.52 \times 10^{-5} \ldots\ m$$

$$d \approx 6.52\ mm$$

Therefore, use a 6.5 mm diameter rod of aluminium 6061-T6.

Document 9 - G-OUAV Compliance Checklist

Variable Stability Demonstrator Modification

Aircraft Registration:	G-OUAV
Aircraft Type:	TLAC Sherwood Scout
Aircraft Serial Number:	345-15480
Modification Number:	15610
Date Created:	27/04/2021

Authors:

Jerin George, Callum Breslin, Daniel Newman-Sanders, Andrew Kernan and Declan Clifford

G-OUAV Compliance Checklist

Compliance Check List

The Flying Control System

Modification has been done to the P2 control Column and the Elevator control system.

Measures taken to ensure safety:

CS-VLA regulations:

- CS - VLA - 561
- CS - VLA - 303

Additional Equipment Added

Measures taken to ensure safety:

CS-VLA regulations:

- CS - VLA - 561
- CS - VLA - 303

Reply to LAA Meeting Suggestions

- **We note that the aircraft weight will be quite high with the system installed, resulting in only a small fuel load possible with 2x 86 kg occupants. Note that 86 kg is not a terribly heavy person, so the fuel load will be further reduced with occupants of a more typical weight.**

  Flight time is limited to 45 minutes. This may increase in the future with upgrades to the aircraft.

- **The P2 control column and associated mounting will need to be able to withstand appropriate pilot input forces in both pitch and roll axes. We note that FEA is being done to check this, but there will need to be some substantiation of the results from this, either manual calcs showing good reserve factors or physical load tests of representative structure.**

G-OUAV Compliance Checklist

While FEA has been used to generate diagrams and results for stress and deflection, these results are backed up by the results of my MATLAB code as a check to validate the results.

- **We noted that the P2 control column arrangement, along with the servo link arm, may present a greater crashworthiness hazard that the normal arrangement, and consideration should be given to mitigate this.**

  Adding to the control stick mechanism will always add bulk and therefore present a hazard. Care has been taken to compact the design as much as reasonably possible and the system has been compacted to be as small an obstruction as possible while still performing the task required of it.

- **The rear servos are currently designed to drive the elevator to deflection limits that are reached before the normal physical stops: this is fine although the operating notes should advise the pilot that the normal full elevator range won't be available, with the consequence that the nose-up authority in the landing flare may be restricted, particularly at forward cg positions.**

  This has been noted in the appropriate supplemental documentation.

- **The rear servo connection mixer (where they connect mechanically to the elevator system) needs to be designed to be able to accommodate one servo jamming while the other doesn't, i.e. the cross-beam must be able to angle to accommodate the asymmetry.**

- *This has been addressed by allowing a degree of freedom at the idler to push rod connector which will allow the push rod to pivot slightly to allow for the combiner member to rotate. This is also enabled by the sliding mechanism which lets the combiner assembly change length with this rotation. Combined, these mechanisms allow for one of the servos to lock in place but still allow the other to operate at a reduced capacity, but still offering control of the aircraft.*

- **Physical stops should be incorporated in all the servos to prevent any possibilities of geometric over-centre locking of the system – these should be (just) beyond the existing control surface/system stops.**

- *All servos now have end stop assemblies which are adjustable so the limits of deflection can be set before flight. These parts are tested to the maximum expected force which could be experience in flight.*

- **Consideration should be given to installing shear pins/mechanical fuses to allow the system to be overcome and normal elevator**

control to be achieved via the P1 stick should any part of the modified system become jammed.

- *A shear pin has been used to limit the maximum forces which the system will withstand, and the servos are able to be overcome by a pilot pushing on them.*

- **The risk/hazard analysis for the system needs to assume that the software will command the worst possible deflection at the maximum rate and at the worst time/speed. Operational requirements might help mitigate this: e.g. system must not be active above Va.**

  The safety cut-offs have been decided and are detailed in the operational supplement.

- **Consideration should be given as to how the system releases: sudden disengagement of the servos could result in a rapid increase in force in the P1 control stick.**

  After consideration and discussion with the manufacturer of the servo, we have been informed that the clutches should not be slowly de-powered to prevent damage, so this is something which would be impossible to achieve.

- **Could the system cause the P1 stick to move with sufficient speed/force to injure the pilot?**

  It is advised that P1 keeps their hand on the control stick when disengaging the system so as to avoid the stick moving dangerously.

- **We have a concern that the high servo 'rate' (full deflection in 0.1 second?) could overload the mechanical control system and hinges, and be inappropriate for control surfaces of this size.**

  Maximum forces are limited for this reason so there should be no overloading of the mechanical system.

- **We note that the system is designed to be modular and readily removeable. In due course, consideration needs to be given as to how the configuration of the aircraft will be managed: who will be in charge of deciding the configuration, ensuring correct weight and balance, operating requirements are met, what LAA inspector input is required, etc.**

  This will be the responsibility of the aircraft's registered owner.

- **Operating notes should include the level of experience/briefing required of the pilot, the requirement for a qualified pilot to be in**

the P1 position for all flights with the system installed, no flying training to take place of occupants of the P2 seat, etc.

This is noted in the operational supplement.

- **We suggested that the software should restrict the flight envelope to something like 0.5g to 2g initially, with expansion of the envelope increasing if required once experience has been gained with the system.**

  This is now recommended in the flight test plan.

- **Could the system be proven with cheaper servos with it being adapted to the more capable servos once the principle of the system has been proven?**

  No, we do not see much merit in this approach as it will waste both time and money in acquiring and adapting the system to use these servos.

- **It would be a sensible precaution to have a completely separate processor monitor the vertical acceleration (and possibly other parameters) to cause the system to disengage once limits are exceeded.**

  We have implemented this and details can be found in the documentation.

- **It was noted that buttons on panels (e.g. the "deadman's handles") can be very difficult to locate and/or maintain contact with in extreme g conditions. Thought should be given to whether the buttons might be better positioned on or near the throttle control or another position easier to reach.**

  Handles are now positioned next to the buttons which will allow the pilots to hold on to these such that their hands will not be moved in the event of turbulence or extreme manoeuvres

- **We suggested that the flight test arrangements should include provision for in-flight variation of key system parameters so that the proper working of the system can be evaluated by altering the parameters and feeling the results on the control response and stick force immediately, rather than trying to remember the 'feel' of a previous flight.**

  This will not be possible as it required the code to be recompiled mid-flight which could lead to major errors and will slow the response of the system drastically.

Document 10 - Flight Test Plan

Variable Stability Demonstrator Modification

Aircraft Registration:	G-OUAV
Aircraft Type:	TLAC Sherwood Scout
Aircraft Serial Number:	345-15480
Modification Number:	15610
Date Created:	03/04/2021

Authors:

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Flight Test Plan

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Ground Test Plan

1. Check the battery level.
    a. If below 80 %: Do not operate the system.
    b. If above 80 %: Safe to continue flight.
2. Check the electrical connections and ensure all the fittings and the wiring is secured correctly.
3. Ensure the desired three flight modes are programmed.
4. Check the control panel indication LEDs are functional.
5. Run safety checks (start the Arduino in GROUND TEST mode).
    a. Check the servos are free to move.
        i. Check the force feedback servo can move through the full range of motion required unhindered by moving the P2 stick. Check against the markings on the force feedback servo.
        ii. Check the elevator servos can move through the full range of motion required unhindered by moving the elevator. Check against the markings on the elevator servos.
    b. Check the mechanical stops for the force feedback servo and elevator servos are in place.

c. Start the Arduino in GROUND TEST MODE
    i. Check the operation of the sensors.
        1. Check the gyro and accelerometer react to moving the aircraft.
        2. Check the readings from the pitot static tube.
    ii. Check the dead man's switch operation is satisfactory and P1 can regain control with the safety switch disengaged (MODE 1 on control panel).
    iii. Check the operation of the servos.
        1. Ensure there is someone sitting in the P2 seat with a firm grip on the stick.
        2. Select MODE 2 on the control panel. The force feedback servo will apply a sinusoidal force to the P2 stick.
        3. Select MODE 3 on the control panel. The rear servos will move the elevator through the full range of motion.

6. If the safety checks are complete, reset the Arduino to flight mode.

Flight Test Plan

Test 1

Objective

- To confirm that our system has no effect on the roll control of the aircraft (i.e. To confirm the inertial effects of our system are not large enough to impede the pilot's ability to control the bank of the aircraft).

Restrictions

- As the system is disengaged, disconnected and depowered, our system is not restricting the operation of the aircraft in any way.

Instructions to Pilots

- As the system is disconnected, P1 should fly the aircraft.
- Attain steady level flight at the specified altitude. Slowly bank the aircraft to an angle of approximately + 30°. Slowly roll the aircraft to - 30°. Return to level flight.
- Give feedback on the roll control of the aircraft, especially comparing it to the roll control of a Scout without the variable stability system installed.
- NOTE: When P2 has hands off the stick, the P2 control stick will move freely, independently and possibly erratically.

Flight Test Plan

Test Plan 1	
Test Altitudes:	5000 ft
Indicated Flight Speed	84 knots (43 m/s)
Duration	30 seconds
Repeats:	1
Control Panel Mode	N/A
Data to be measured:	N/A
Pilot notes comparing the roll control feel of the Scout with variable stability system to a Scout without variable stability system.	

Flight Test Plan

Test 2

Objective

- To test the operation of the dead man's switches, sensors and the calibration of the control system.
- To simulate the original Scout with the modified Scout using the aerodynamic model of the original aircraft to understand any unseen errors in the control system.

Restrictions

- Limit the vertical acceleration envelope protection on the aircraft to + 1.5 g and + 0.5 g.
- Limit the electronic elevator deflection protection to ± 10°.

Instructions to Pilots

- Engage the system at the specified altitude and airspeed and at a steady level condition.
- Keep the maximum elevator deflection to ± 5° when the system is engaged and keep any elevator input steady and slow.
- After a flight time of around 30 seconds, disengage the system by releasing one of the dead mans switches. Give feedback on the response of the aircraft to the release of the dead mans switches.
- Abort the test if either of the pilots feel the system is not behaving as expected by releasing one of the dead man's switches. (Note when the system is engaged the P1 stick will move independently of the P2 stick).
- Unless the system is engaged P1 should fly the aircraft.
- Be advised the electronic system disengagement parameters are set lower for this flight to test the system.
- Give feedback on the handling quality of the aircraft and force feedback through the P2 control stick compared with the original unmodified aircraft.

Flight Test Plan

Test Plan 1	
Test Altitudes:	5000 ft
Indicated Flight Speed	84 knots (43 m/s)
Duration	30 seconds
Repeats:	At least 2
Control Panel Mode	1 (Set to original aircraft)
Data to be measured:	Evaluate the data quality from sensors and calibration of servos though post flight analysis of recorded data on the SD Card
Pilot notes comparing the handling qualities of the Scout with and without the modification.	
Please select from 1-10 for the stick positioning of modified Scout against unmodified Scout.	1 2 3 4 5 6 7 8 9 10 (1=much smaller movements required, 5=identical to unmodified Scout, 10=much larger movements required)
Please select from 1-10 for the stick force of modified Scout against unmodified Scout.	1 2 3 4 5 6 7 8 9 10 (1=much lighter feel, 5=identical feel to unmodified Scout, 10=much heavier feel)
Please select from 1-10 for the response rate of modified Scout against unmodified Scout.	1 2 3 4 5 6 7 8 9 10 (1=much more responsive, 5=identical to unmodified Scout, 10=much less responsive)
Pilot notes describing the response of the aircraft to the release of the DMS	

Test 3

Objective:

- To test the operation of the automatic cut-off functionality of the system, which is triggered by an airspeed, angle of attack, G loading, rate of change of G or elevator deflection reading which exceeds the pre-determined envelope.

Restrictions:

- Limit the vertical acceleration envelope protection on the aircraft to + 1.5 g and + 0.5 g.
- Limit the electronic elevator deflection protection to ± 25°
- Limit the airspeed as per the operational supplement
- Limit the angle of attack to + 10° and - 5°.
- Limit the rate of change of G-loading as per the operational supplement.

Instructions to Pilots:

- In this test, 3 runs will be made.
- For the 1st run, the pilot should enter a windup turn, with a slowly increasing bank angle. The pilot should increase the bank angle until the system automatically disconnects due to the detected G loading. This cut-off should happen at a bank angle of approximately 40-50 degrees. Following the cut-off, the pilot should return to steady level flight.
- On the 2nd run, the pilot should engage the system and proceed to reduce the throttle, thus checking that the automatic cut-off is triggered by the reducing airspeed.
- On the 3rd run, the pilots should engage the system and then increase the throttle, thus checking that the automatic cut-off is triggered by the increasing airspeed.
- Only engage the system at the specified altitude and airspeed from a steady level condition.
- Abort the test if either of the pilots feel the system is not behaving as expected by releasing one of the dead man's switches (Note

when system is engaged the P1 stick will move independently of the P2 stick).

- Unless system is engaged P1 should fly the aircraft.
- Give feedback on the handling quality of the aircraft and force feedback through the P2 control stick compared with the original unmodified aircraft.

Test Plan 1	
Test Altitudes:	5000 ft
Indicated Flight Speed	84 knots (43 m/s)
Duration	30 seconds
Repeats:	3
Control Panel Mode	1 (Set to original aircraft)
Data to be measured:	Evaluate the data from sensors and the points at which the automatic cut-off was triggered
Pilot notes comparing the handling qualities of the Scout with and without the modification.	
Please select from 1-10 for the stick positioning of modified Scout against original aircraft.	1 2 3 4 5 6 7 8 9 10 (1=much smaller movements required, 5=identical to unmodified Scout, 10=much larger movements required)
Please select from 1-10 for the stick force of modified Scout against original aircraft.	1 2 3 4 5 6 7 8 9 10 (1=much lighter feel, 5=identical feel to unmodified Scout, 10=much heavier feel)
Please select from 1-10 for the response rate of modified	1 2 3 4 5 6 7 8 9 10

Scout against original aircraft.	(1=much more responsive, 5=identical to unmodified Scout, 10=much less responsive)
Bank angle and airspeed at which system disengaged (1st run)	
Airspeed at which system disengaged (2nd run)	
Airspeed at which system disengaged (3rd run)	

Test 4

Objective

- To test the performance of the system at the operational CG limits of the Sherwood Scout.

Restrictions

- Limit the vertical acceleration envelope protection on the aircraft to + 1.5 g and + 0.5 g.
- Limit the electronic elevator deflection protection to ± 25°.
- Limit the airspeed as per the operational supplement.
- Limit the angle of attack to + 10° and - 5°.
- Limit the rate of change of G-loading as per the operational supplement.

Instructions to Pilots

- In this test, 3 sets of 3 runs will be made (total of 9 runs). For each set, the system will be simulating the Sherwood Scout at a different CG location. Within each set, 3 runs will be made, with the pilots first making a slow initial movement on the control stick, followed by a medium initial movement on the control stick, and finally a fast initial movement on the control stick.
- Only engage the system at the specified altitude and airspeed from a steady level condition.
- Abort the test if either of the pilots feel the system is not behaving as expected by releasing one of the dead man's switches. (Note when system is engaged the P1 stick will move independently of the P2 stick).
- Unless system is engaged P1 should fly the aircraft.
- Give feedback on the handling quality of the aircraft and force feedback through the P2 control stick compared with the original unmodified aircraft.

Flight Test Plan

Test Plan 1	
Test Altitudes:	5000 ft
Indicated Flight Speed	84 knots (43 m/s)
Duration	30 seconds
Repeats:	3
Control Panel Mode	1 (Set to Sherwood Scout with a neutral CG position)
Data to be measured:	Evaluate the data from sensors and the points at which the automatic cut-off was triggered
Pilot notes comparing the handling qualities of the Scout with and without the modification.	
Please select from 1-10 for the stick positioning of modified Scout against unmodified Scout.	1 2 3 4 5 6 7 8 9 10 (1=much smaller movements required, 5=identical to unmodified Scout, 10=much larger movements required)
Please select from 1-10 for the stick force of modified Scout against unmodified Scout.	1 2 3 4 5 6 7 8 9 10 (1=much lighter feel, 5=identical feel to unmodified Scout, 10=much heavier feel)
Please select from 1-10 for the response rate of modified Scout against unmodified Scout.	1 2 3 4 5 6 7 8 9 10 (1=much more responsive, 5=identical to unmodified Scout, 10=much less responsive)

Flight Test Plan

Test Plan 2	
Test Altitudes:	5000 ft
Indicated Flight Speed	84 knots (43 m/s)
Duration	30 seconds
Repeats:	3
Control Panel Mode	2 (Set to Sherwood Scout with a forward CG position of 0.223c)
Data to be measured:	Evaluate the data from sensors and the points at which the automatic cut-off was triggered
Pilot notes comparing the handling qualities of the Scout with and without the modification.	
Please select from 1-10 for the stick positioning of modified Scout against unmodified Scout.	1 2 3 4 5 6 7 8 9 10 (1=much smaller movements required, 5=identical to unmodified Scout, 10=much larger movements required)
Please select from 1-10 for the stick force of modified Scout against unmodified Scout.	1 2 3 4 5 6 7 8 9 10 (1=much lighter feel, 5=identical feel to unmodified Scout, 10=much heavier feel)
Please select from 1-10 for the response rate of modified Scout against unmodified Scout.	1 2 3 4 5 6 7 8 9 10 (1=much more responsive, 5=identical to unmodified Scout, 10=much less responsive)

Flight Test Plan

Test Plan 3	
Test Altitudes:	5000 ft
Indicated Flight Speed	84 knots (43 m/s)
Duration	30 seconds
Repeats:	3
Control Panel Mode	3 (Set to Sherwood Scout with an aft CG position of 0.364c)
Data to be measured:	Evaluate the data from sensors and the points at which the automatic cut-off was triggered
Pilot notes comparing the handling qualities of the Scout with and without the modification.	
Please select from 1-10 for the stick positioning of modified Scout against unmodified Scout.	1 2 3 4 5 6 7 8 9 10 (1=much smaller movements required, 5=identical to unmodified Scout, 10=much larger movements required)
Please select from 1-10 for the stick force of modified Scout against unmodified Scout.	1 2 3 4 5 6 7 8 9 10 (1=much lighter feel, 5=identical feel to unmodified Scout, 10=much heavier feel)
Please select from 1-10 for the response rate of modified Scout against unmodified Scout.	1 2 3 4 5 6 7 8 9 10 (1=much more responsive, 5=identical to unmodified Scout, 10=much less responsive)

Test 5

Objective

- To test the performance of the system at the extreme CG limits of the Sherwood Scout (with restricted flight limits).

Restrictions

- Limit the vertical acceleration envelope protection on the aircraft to + 1.5 g and + 0.5 g.
- Limit the electronic elevator deflection protection to ± 25°.
- Limit the airspeed as per the operational supplement.
- Limit the angle of attack to 10° and -5°.
- Limit the rate of change of G-loading as per the operational supplement.

Instructions to Pilots

- In this test 2 sets of 3 runs will be made. (A total of 6 runs). For each set, the system will be simulating the Sherwood Scout at a different CG location. Within each set, 3 runs will be made, with the pilots first making a slow initial movement on the control stick, followed by a medium initial movement on the control stick, and finally a fast initial movement on the control stick.
- Only engage the system at the specified altitude and airspeed from a steady level condition.
- Abort the test if either of the pilots feel the system is not behaving as expected by releasing one of the dead man's switches (Note when the system is engaged the P1 stick will move independently of the P2 stick).
- Unless the system is engaged P1 should fly the aircraft.
- Give feedback on the handling quality of the aircraft and force feedback through the P2 control stick compared with the original unmodified aircraft.

Flight Test Plan

Test Plan 1	
Test Altitudes:	5000 ft
Indicated Flight Speed	84 knots (43 m/s)
Duration	30 seconds
Repeats:	3
Control Panel Mode	1 (Set to Sherwood Scout with a forward CG position of 0.1c)
Data to be measured:	Evaluate the data from sensors and the points at which the automatic cut-off was triggered
Pilot notes comparing the handling qualities of the Scout with and without the modification.	
Please select from 1-10 for the stick positioning of modified Scout against unmodified Scout.	1 2 3 4 5 6 7 8 9 10 (1=much smaller movements required, 5=identical to unmodified Scout, 10=much larger movements required)
Please select from 1-10 for the stick force of modified Scout against unmodified Scout.	1 2 3 4 5 6 7 8 9 10 (1=much lighter feel, 5=identical feel to unmodified Scout, 10=much heavier feel)
Please select from 1-10 for the response rate of modified Scout against unmodified Scout.	1 2 3 4 5 6 7 8 9 10 (1=much more responsive, 5=identical to unmodified Scout, 10=much less responsive)

Flight Test Plan

Test Plan 2	
Test Altitudes:	5000 ft
Indicated Flight Speed	84 knots (43 m/s)
Duration	30 seconds
Repeats:	3
Control Panel Mode	2 (Set to Sherwood Scout with an aft CG position of 0.5c)
Data to be measured:	Evaluate the data from sensors and the points at which the automatic cut-off was triggered
Pilot notes comparing the handling qualities of the Scout with and without the modification.	
Please select from 1-10 for the stick positioning of modified Scout against unmodified Scout.	1 2 3 4 5 6 7 8 9 10 (1=much smaller movements required, 5=identical to unmodified Scout, 10=much larger movements required)
Please select from 1-10 for the stick force of modified Scout against unmodified Scout.	1 2 3 4 5 6 7 8 9 10 (1=much lighter feel, 5=identical feel to unmodified Scout, 10=much heavier feel)
Please select from 1-10 for the response rate of modified Scout against unmodified Scout.	1 2 3 4 5 6 7 8 9 10 (1=much more responsive, 5=identical to unmodified Scout, 10=much less responsive)

Test 6

Objective

- To test the performance of the system at the extreme CG limits of the Sherwood Scout (with extended flight limits).

Restrictions

- Limit the vertical acceleration envelope protection on the aircraft to + 2.5 g and - 0.5 g.
- Limit the electronic elevator deflection protection to ± 25°.
- Limit the airspeed as per the operational supplement.
- Limit the angle of attack to 10° and -5°.
- Limit the rate of change of G-loading as per the operational supplement.

Instructions to Pilots

- In this test, 2 sets of 3 runs will be made. (A total of 6 runs). For each set, the system will be simulating the Sherwood Scout at a different CG location. Within each set, 3 runs will be made, with the pilots first making a slow initial movement on the control stick, followed by a medium initial movement on the control stick, and finally a fast initial movement on the control stick.
- Only engage the system at the specified altitude and airspeed from a steady level condition.
- Abort the test if either of the pilots feel the system is not behaving as expected by releasing one of the dead man's switches. (Note when the system is engaged the P1 stick will move independently of the P2 stick).
- Unless system is engaged P1 should fly the aircraft.
- Give feedback on the handling quality of the aircraft and force feedback through the P2 control stick compared with the original unmodified aircraft.

Flight Test Plan

Test Plan 1	
Test Altitudes:	5000 ft
Indicated Flight Speed	84 knots (43 m/s)
Duration	30 seconds
Repeats:	3
Control Panel Mode	1 (Set to Sherwood Scout with a forward CG position of 0.1c)
Data to be measured:	Evaluate the data from sensors and, if it is triggered, the points at which the automatic cut-off was triggered
Pilot notes comparing the handling qualities of the Scout with and without the modification.	
Please select from 1-10 for the stick positioning of modified Scout against unmodified Scout.	1 2 3 4 5 6 7 8 9 10 (1=much smaller movements required, 5=identical to unmodified Scout, 10=much larger movements required)
Please select from 1-10 for the stick force of modified Scout against unmodified Scout.	1 2 3 4 5 6 7 8 9 10 (1=much lighter feel, 5=identical feel to unmodified Scout, 10=much heavier feel)
Please select from 1-10 for the response rate of modified Scout against unmodified Scout.	1 2 3 4 5 6 7 8 9 10 (1=much more responsive, 5=identical to unmodified Scout, 10=much less responsive)

Flight Test Plan

Test Plan 2	
Test Altitudes:	5000 ft
Indicated Flight Speed	84 knots (43 m/s)
Duration	30 seconds
Repeats:	3
Control Panel Mode	2 (Set to Sherwood Scout with an aft CG position of 0.5c)
Data to be measured:	Evaluate the data from sensors and, if it is triggered, the points at which the automatic cut-off was triggered
Pilot notes comparing the handling qualities of the Scout with and without the modification.	
Please select from 1-10 for the stick positioning of modified Scout against unmodified Scout.	1 2 3 4 5 6 7 8 9 10 (1=much smaller movements required, 5=identical to unmodified Scout, 10=much larger movements required)
Please select from 1-10 for the stick force of modified Scout against unmodified Scout.	1 2 3 4 5 6 7 8 9 10 (1=much lighter feel, 5=identical feel to unmodified Scout, 10=much heavier feel)
Please select from 1-10 for the response rate of modified Scout against unmodified Scout.	1 2 3 4 5 6 7 8 9 10 (1=much more responsive, 5=identical to unmodified Scout, 10=much less responsive)

Test 7

Objective

- To test the performance of the system when it is simulating a Cessna 172 at a forward and aft CG location.

Restrictions:

- Limit the vertical acceleration envelope protection on the aircraft to + 2.5 g and - 0.5 g.
- Limit the electronic elevator deflection protection to ± 25°.
- Limit the airspeed as per the operational supplement.
- Limit the angle of attack to 10° and -5°.
- Limit the rate of change of G-loading as per the operational supplement..

Instructions to Pilots

- In this test, 2 sets of 3 runs will be made. (A total of 6 runs). For each set, the system will be simulating the Cessna 172 at a different CG location. Within each set, 3 runs will be made, with the pilots first making a slow initial movement on the control stick, followed by a medium initial movement on the control stick, and finally a fast initial movement on the control stick.
- Only engage the system at the specified altitude and airspeed from a steady level condition.
- Abort the test if either of the pilots feel the system is not behaving as expected by releasing one of the dead man’s switches. (Note when the system is engaged the P1 stick will move independently of the P2 stick).
- Unless system is engaged P1 should fly the aircraft.
- Give feedback on the handling quality of the aircraft and force feedback through the P2 control stick compared with the original unmodified aircraft.

Flight Test Plan

Test Plan 1	
Test Altitudes:	5000 ft
Indicated Flight Speed	84 knots (43 m/s)
Duration	30 seconds
Repeats:	3
Control Panel Mode	1 (Set to Cessna 172 with a forward CG position of 0.1c)
Data to be measured:	Evaluate the data from sensors and, if it is triggered, the points at which the automatic cut-off was triggered
Pilot notes comparing the handling qualities of the Scout with and without the modification.	
Please select from 1-10 for the stick positioning of modified Scout against unmodified Scout.	1 2 3 4 5 6 7 8 9 10 (1=much smaller movements required, 5=identical to unmodified Scout, 10=much larger movements required)
Please select from 1-10 for the stick force of modified Scout against unmodified Scout.	1 2 3 4 5 6 7 8 9 10 (1=much lighter feel, 5=identical feel to unmodified Scout, 10=much heavier feel)
Please select from 1-10 for the response rate of modified Scout against unmodified Scout.	1 2 3 4 5 6 7 8 9 10 (1=much more responsive, 5=identical to unmodified Scout, 10=much less responsive)

Test Plan 2	
Test Altitudes:	5000 ft
Indicated Flight Speed	84 knots (43 m/s)
Duration	30 seconds
Repeats:	3
Control Panel Mode	2 (Set to Cessna 172 with an aft CG position of 0.5c)
Data to be measured:	Evaluate the data from sensors and, if it is triggered, the points at which the automatic cut-off was triggered
Pilot notes comparing the handling qualities of the Scout with and without the modification.	
Please select from 1-10 for the stick positioning of modified Scout against Cessna 172.	1 2 3 4 5 6 7 8 9 10 (1=much smaller movements required, 5=identical to unmodified Scout, 10=much larger movements required)
Please select from 1-10 for the stick force of modified Scout against Cessna 172.	1 2 3 4 5 6 7 8 9 10 (1=much lighter feel, 5=identical feel to unmodified Scout, 10=much heavier feel)
Please select from 1-10 for the response rate of modified Scout against Cessna 172.	1 2 3 4 5 6 7 8 9 10 (1=much more responsive, 5=identical to unmodified Scout, 10=much less responsive)

Test 8

Objective

- To test the performance of the system when it is simulating a Boeing 747-100.

Restrictions

- Limit the vertical acceleration envelope protection on the aircraft to + 2.5 g and - 0.5 g.
- Limit the electronic elevator deflection protection to ± 25°.
- Limit the airspeed as per the operational supplement.
- Limit the angle of attack to 10° and -5°.
- Limit the rate of change of G-loading as per the operational supplement..

Instructions to Pilots

- In this test, 3 runs will be made. The pilots will first make a slow initial movement on the control stick, followed by a medium initial movement on the control stick, and finally a fast initial movement on the control stick.
- Only engage the system at the specified altitude and airspeed from a steady level condition.
- Abort the test if either of the pilots feel the system is not behaving as expected by releasing one of the dead man's switches. (Note when the system is engaged the P1 stick will move independently of the P2 stick).
- Unless system is engaged P1 should fly the aircraft.
- Give feedback on the handling quality of the aircraft and force feedback through the P2 control stick compared with the original unmodified aircraft.

Flight Test Plan

Test Plan 1	
Test Altitudes:	5000 ft
Indicated Flight Speed	84 knots (43 m/s)
Duration	30 seconds
Repeats:	3
Control Panel Mode	1 (Set to Boeing 747-100)
Data to be measured:	Evaluate the data from sensors and, if it is triggered, the points at which the automatic cut-off was triggered
Pilot notes comparing the handling qualities of the Scout with and without the modification.	
Please select from 1-10 for the stick positioning of modified Scout against a large transport aircraft.	1 2 3 4 5 6 7 8 9 10 (1=much smaller movements required, 5=identical to unmodified Scout, 10=much larger movements required)
Please select from 1-10 for the stick force of modified Scout against a large transport aircraft.	1 2 3 4 5 6 7 8 9 10 (1=much lighter feel, 5=identical feel to unmodified Scout, 10=much heavier feel)
Please select from 1-10 for the response rate of modified Scout against a large transport aircraft.	1 2 3 4 5 6 7 8 9 10 (1=much more responsive, 5=identical to unmodified Scout, 10=much less responsive)

Document 11 – Parts List

Variable Stability Demonstrator Modification

Aircraft Registration:	G-OUAV
Aircraft Type:	TLAC Sherwood Scout
Aircraft Serial Number:	345-15480
Modification Number:	15610
Date Created:	29/04/2021

Authors:

Jerin George, Callum Breslin, Daniel Newman-Sanders, Andrew Kernan and Declan Clifford

Variable Stability Demonstrator Parts List									
Sub Assembly	**Part**	**Purchased/Manufactured**	**Part Number**	**External Part Number**	**Quantity**	**Extra Detail**	**Drawing**	**Source**	**Complicance Checked**
Rear Servo Assembly	Rear Push Rod	Manufactured	M15610-01-1		1	Aluminium 6061-T6	Assembly 1, Drawing 1	University of Southampton	CS-VLA-303, CS-VLA-561
	Combiner	Manufactured	M15610-01-2		1	Aluminium 6061-T6	Assembly 1, Drawing 2	University of Southampton	CS-VLA-303, CS-VLA-561
	Combiner Slider	Manufactured	M15610-01-3		1	Aluminium 6061-T6	Assembly 1, Drawing 3	University of Southampton	CS-VLA-303, CS-VLA-561
	Rear Servo Arm	Manufactured	M15610-01-4		2	Aluminium 6061-T6	Assembly 1, Drawing 4	University of Southampton	CS-VLA-303, CS-VLA-561
	Rear Servo Mounting Plate	Manufactured	M15610-01-5		1	Aluminium 6061-T6	Assembly 1, Drawing 5	University of Southampton	CS-VLA-303, CS-VLA-561
	Rear Servo Plate Leg	Manufactured	M15610-01-6		6	Modified 20x20 Aluminium Extrusion	Assembly 1, Drawing 6	University of Southampton	CS-VLA-303, CS-VLA-561
	SKF Rod End Spherical Bearing	Purchased	M15610-01-7	SALKAC 10M	1			RS-Online	
	Male Theaded Clevis Joint	Purchased	M15610-01-8	WDS 851-110	2	DIN 71752		WDS Components	
	Clevis Pin	Purchased	M15610-01-9	WDS 851-510	1	DIN 71752		WDS Components	
	Clevis E-Clip	Purchased	M15610-01-10	WDS 851-610	1			WDS Components	
	Rear End Stop Leg	Manufactured	M15610-01-11		4	Modified 20x20 Aluminium Extrusion	Assembly 1, Drawing 11	University of Southampton	CS-VLA-303, CS-VLA-561
	End Stop Bracket	Manufactured	M15610-01-12		2	Aluminium 6061-T6	Assembly 1, Drawing 12	University of Southampton	CS-VLA-303, CS-VLA-561
	Rear End Stop Diagonal Brace	Manufactured	M15610-01-13		2	Aluminium 6061-T6	Assembly 1, Drawing 13	University of Southampton	CS-VLA-303, CS-VLA-561
	End Stop	Manufactured	M15610-01-14		4	Aluminium 6061-T6	Assembly 1, Drawing 14	University of Southampton	CS-VLA-303, CS-VLA-561
	Shear Pin Connector	Manufactured	M15610-01-15		1	Aluminium 6061-T6	Assembly 1, Drawing 15	University of Southampton	CS-VLA-303, CS-VLA-561
	Shear Pin	Manufactured	M15610-01-16		1	Aluminium 6061-T7	Assembly 1, Drawing 16	University of Southampton	CS-VLA-303, CS-VLA-561
Front Servo Assembly	Front Push Rod	Manufactured	M15610-02-1		1	Aluminium 6061-T6	Assembly 2, Drawing 1	University of Southampton	CS-VLA-303, CS-VLA-561
	Bearing Mount Top	Manufactured	M15610-02-2		2	Aluminium 6061-T6	Assembly 2, Drawing 2	University of Southampton	CS-VLA-303, CS-VLA-561
	Bearing Mount Bottom	Manufactured	M15610-02-3		4	Aluminium 6061-T6	Assembly 2, Drawing 3	University of Southampton	CS-VLA-303, CS-VLA-561
	Stick Mounting Frame	Manufactured	M15610-02-4		1	Aluminium 6061-T6	Assembly 2, Drawing 4	University of Southampton	CS-VLA-303, CS-VLA-561
	Stick-Frame-Bearing Link	Manufactured	M15610-02-5		2	Aluminium 6061-T6	Assembly 2, Drawing 5	University of Southampton	CS-VLA-303, CS-VLA-561
	Bearing Longitudinal Pivot	Manufactured	M15610-02-6		2	Aluminium 6061-T6	Assembly 2, Drawing 6	University of Southampton	CS-VLA-303, CS-VLA-561
	Front Servo Arm	Manufactured	M15610-02-7		1	Aluminium 6061-T6	Assembly 2, Drawing 7	University of Southampton	CS-VLA-303, CS-VLA-561
	Lower Scissor Attachment	Manufactured	M15610-02-8		1	Aluminium 6061-T6	Assembly 2, Drawing 8	University of Southampton	CS-VLA-303, CS-VLA-561
	Upper Scissor attachment	Manufactured	M15610-02-9		1	Aluminium 6061-T6	Assembly 2, Drawing 9	University of Southampton	CS-VLA-303, CS-VLA-561
	Scissor Link	Manufactured	M15610-02-10		2	Aluminium 6061-T6	Assembly 2, Drawing 10	University of Southampton	CS-VLA-303, CS-VLA-561
	Footwell Fuselage Attachment A	Manufactured	M15610-02-11		2	Aluminium 6061-T6	Assembly 2, Drawing 11	University of Southampton	CS-VLA-303, CS-VLA-561
	Footwell Fuselage Attachment B	Manufactured	M15610-02-12		2	Aluminium 6061-T6	Assembly 2, Drawing 12	University of Southampton	CS-VLA-303, CS-VLA-561
	Front Servo Mounting Plate	Manufactured	M15610-02-13		1	Aluminium 6061-T6	Assembly 2, Drawing 13	University of Southampton	CS-VLA-303, CS-VLA-561
	SKF Rod End Spherical Bearing	Purchased	M15610-01-7	SALKAC 10M	2			RS-Online	
	RS PRO 10mm I.D. 30mm O.D. Bearing	Purchased	M15610-02-14	6200-2RS/C3	2	Aluminium 6061-T6		RS-Online	
	Male Theaded Clevis Joint	Purchased	M15610-02-15	WDS 851-110	2	DIN 71752		WDS Components	
	Clevis Pin	Purchased	M15610-02-17	WDS 851-510	2	DIN 71752		WDS Components	
	Clevis E-Clip	Purchased	M15610-02-18	WDS 851-610	2			WDS Components	
	End Stop	Manufactured	M15610-01-14		2	Aluminium 6061-T6	Assembly 1, Drawing 14	University of Southampton	CS-VLA-303, CS-VLA-561
	Front End Stop Leg	Manufactured	M15610-02-19		2	Modified 20x20 Aluminium Extrusion	Assembly 2, Drawing 19	University of Southampton	CS-VLA-303, CS-VLA-561
	End Stop Bracket	Manufactured	M15610-01-12		1	Aluminium 6061-T6	Assembly 1, Drawing 12	University of Southampton	CS-VLA-303, CS-VLA-561
Servo Rack Assembly	Battery	Purchased	M15610-03-1	SLAUMXLI10-25	1	15A rated		The Battery Masters	
	Battery Connector	Purchased	M15610-03-2	BLSE16/1	2			Electrical Car Services	
	Fuse Holder	Purchased	M15610-03-3	3101.012	1	Panel mounted		schurter (Farnell)	
	15A Fuse	Purchased	M15610-03-4	0217015.MXP	1	15A rated		University of Southampton	
	Relay Module	Purchased	M15610-03-5	A71000104UK	3	30A rated		Amazon	
	24V to 12V DC voltage converter	Purchased	M15610-03-6	LM2596	1	3A rated output		Ebay	
	Arduino Uno Prototyping Shield	Purchased	M15610-03-7		1			Ebay	
	Arduino Uno Rev3	Purchased	M15610-03-8	A000066	1			University of Southampton	
	Wingoneer Arduino Mega Prototyping Shield	Purchased	M15610-03-9	JT0589	1			Amazon	
	Arduino Mega 2560 Rev3	Purchased	M15610-03-10	A000067	1			Amazon	
	SD Card Module	Purchased	M15610-03-11	ADA254	1			ThePiHuT	
	PCB 1: Sensors	Manufactured	M15610-03-12		1	Single sided PCB board		University of Southampton	
	Accelerometer Module 1	Purchased	M15610-03-13	MMA8451 2019	1			RS Components	
	Accelerometer Module 2	Purchased	M15610-03-14	ADA163	1			ThePiHut	
	Pressure Sensor	Purchased	M15610-03-15	MPXV5004DP	1	Differential Pressure Sensor, Max Range +/- 4 kPa		Farnell	
	5 Pin JST PAF Connector	Purchased	M15610-03-16	PAF-05V-S	1			JST Connectors	
	PCB 2: Thermistor Control	Manufactured	M15610-03-17			Single sided PCB board		University of Southampton	
	100K Ohm Resistors	Purchased	M15610-03-18	1772593	4			Farnell	
	JST PAF Connector (5 Pin)	Purchased	M15610-03-19	PAF-05V-S	2			JST Connectors	
	JST PAF Connector (2 Pin)	Purchased	M15610-03-20	PAF-02V-S				JST Connectors	
	PCB 3: TTL to RS485 Module	Manufactured	M15610-03-21			Single sided PCB board		University of Southampton	
	TTL TO RS485 convertor module	Purchased	M15610-03-22	B06Y2XHSMW	2			HALJIA (through Amazon)	
	JST PAF Connector (5 Pin)	Purchased	M15610-03-23	PAF-05V-S	3			JST Connectors	
	Server Tray	Manufactured	M15610-03-24		1	Grade 6061-T6 Aluminium	Assembly 3 Drawing 3	University of Southampton	CS-VLA-561

	Battery Strap Short	Manufactured	M15610-03-25		1	Grade 6061-T6 Aluminium	Assembly 3 Drawing 4	University of Southampton	CS-VLA-561
	Battery Strap Long	Manufactured	M15610-03-26		1	Grade 6061-T6 Aluminium	Assembly 3 Drawing 4	University of Southampton	CS-VLA-561
	9 Pin D-Sub Connector Female	Purchased	M15610-03-27	9672094704	8	5A rated		RS Components	
	Illuminated Power Switch	Purchased	M15610-03-28	RS-B-BLK-YEL-A-F-1	1			E-Switch (though Farnell)	
	M8 DC Chassis Socket	Purchased	M15610-03-29	1614 09	1			LUMBERG (through Farnell)	
	JST VL connector	Purchased	M15610-03-30	VLP-92V-1		20A rated, 2 pin		JST Connectors	
	JST HL block connector	Purchased	M15610-03-31	HRL-08V		8 Pin connector		JST Connectors	
	Server Attachment Adapter	Purchased	M15610-03-32	PM6CNK	16	M6 Rail Clip Nuts		Penn Elcom	
	Rear Tray attachment adapter	Manufactured	M15610-03-33		2	Grade 6061-T6 Aluminium	Assembly 3 Drawing 4		
Control Panel Assembly	Control Panel Case	Manufactured	M15610-04-1		1	Aluminium 6061-T6		University Of Southampton	
	Rotary Switch	Purchased	M15610-04-2	HW1S-5T	1			Farnell	
	LED 3mm	Purchased	M15610-04-3	NSPW315DS	5			University of Southampton	
	9 Pin D-SUB Female Connector	Purchased	M15610-04-4	9672094704	2	5A rated		RS Components	
	M8 DC Chassis Socket Connector	Purchased	M15610-04-5	1614 09	1			LUMBERG (Through Farnell)	
Dashboard Assembly	Dashboard	Pre-Installed	M15610-05-1		1			University of Southampton	
	Control Panel Assembly	Manufactured	M15610-05-2		1			University of Southampton	
	Handle	Purchased	M15610-05-3	456-551	2			RS Components	AMC-VLA-403, CS-VLA-303
	Dead Man's Switch	Purchased	M15610-05-4	ZB5AA4	2			RS Components	
Pitot Tube Assembly	Pitot Tube Strut	Manufactured	M15610-06-1		1	Grade 6061-T6 aluminium	Assembly 6 Drawing 3	University of Southampton	
	Wing Strut Clamp	Manufactured	M15610-06-2		4	Grade 6061-T6 aluminium		University of Southampton	
	Pitot Static Tube	Purchased	M15610-06-3		1	https://uavfactory. com/en/products/ uav accessories/pitot static-tube-for uavs/tech-specs		UAV Factory	
	Tygon Tubing - 4mm (Inner Diameter) x 2m	Purchased	M15610-06-10	15119194	2	https://www.fishersci.co.uk/shop/products/tygon-lab-tubing- 4/15119194		Fisher Scientific	
Additional Parts	Thermistor	Purchased	M15610-07-1	B59173C1130A151	3			Fernell	
	D-Sub connector Box	Manufactured	M15610-07-2		2	Grade 6061-T6 aluminum	Assembly 7, Drawing 2	University of Southampton	
	9 Pin D-SUB Female Connector	Purchased	M15610-07-3	9672094704	2	5A rated		RS Components	
					Fasteners				
Pitot Tube Assembly	M6x60mm Bolt	Purchased	M15610-06-4		4	M6x60mm ISO4017 Grade 8.8		University of Southampton	
	M6 Washer	Purchased	M15610-06-5		8	M6 ISO7089 Grade 8.8		University of Southampton	
	M6 Nut	Purchased	M15610-06-6		4	M6 ISO4032 Grade 8.8		University of Southampton	
	M5x10mm Bolt	Purchased	M15610-06-9		2	M5x10mm ISO4762 Grade 8.8		University of Southampton	
	M5 Washer	Purchased	M15610-06-8		4	M5 ISO7089 Grade 8.8		University of Southampton	
	M5 Nut	Purchased	M15610-06-7		2	M5 ISO4032 Grade 8.8		University of Southampton	
Servo Rack Assembly	M6 Bolts	Purchased	M15610-03-34		16	M6x20mm ISO4017 Grade 8.8		University of Southampton	
	M6 Washer	Purchased	M15610-03-35		16	M6 ISO7089 Grade 8.8		University of Southampton	
	M6 Nut	Purchased	M15610-03-36		16	M6 ISO4032 Grade 8.8		University of Southampton	
	M10 Bolt	Purchased	M15610-03-37		4	M10x25mm ISO4017 Grade 8.8		University of Southampton	
	M10 Washer	Purchased	M15610-03-38		4	M10 ISO7089 Grade 8.8		University of Southampton	
	M10 Nut	Purchased	M15610-03-39		4	M10 ISO4032 Grade 8.8		University of Southampton	
	M3 Arduino Attachment Threaded Pin	Purchased	M15610-03-40		10	M3x60mm DIN 975 Grade 8.8		University of Southampton	
	M8 Nut	Purchased	M15610-03-41		2	M8 ISO4032 Grade 8.8		University of Southampton	
	M3 Bolt	Purchased	M15610-03-42		32	M3x8mm ISO4017 Grade 8.8		University of Southampton	
	M3 D-Sub Screw	Purchased	M15610-03-43	94518233	16	M3 D-SUB Connector Screw		Farnell	
	M3 Nut	Purchased	M15610-03-44		68	M3 ISO4032 Grade 8.8		University of Southampton	
	M3 Washer	Purchased	M15610-03-45		16	M3 ISO7089 Grade 8.8		University of Southampton	
Dashboard Assembly	M5 Screw	Purchased	M15610-05-05		2	M5 L15mm Screw ISO 7046 Grade 8.8		University of Southampton	
	M5 Bolt	Purchased	M15610-05-06		2	M5 L20mm Bolt ISO4017 Grade 8.8		University of Southampton	
	M5 Nut	Purchased	M15610-05-07		2	M5 Nut ISO4032 Grade 8.8		University of Southampton	
Control Panel Assembly	M3 D-Sub Screw	Purchased	M15610-04-6	94518233	4	M3 D-SUB Connector Screw		Farnell	
	M3 Nut	Purchased	M15610-04-7		4	M3 ISO4032 Grade 8.8		University of Southampton	
	M3 Washer	Purchased	M15610-04-8		4	M3 ISO7089 Grade 8.8		University of Southampton	
	M8 Nut	Purchased	M15610-04-9		1	M8 ISO4032 Grade 8.8		University of Southampton	
	M10 Bolt	Purchased	M15610-02-B5		4	M10x30mm ISO4017 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M8 Bolt	Purchased	M15610-02-B4		3	M8x35mm ISO4017 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M6 Bolt	Purchased	M15610-02-B7		4	M6x25mm ISO4017 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561

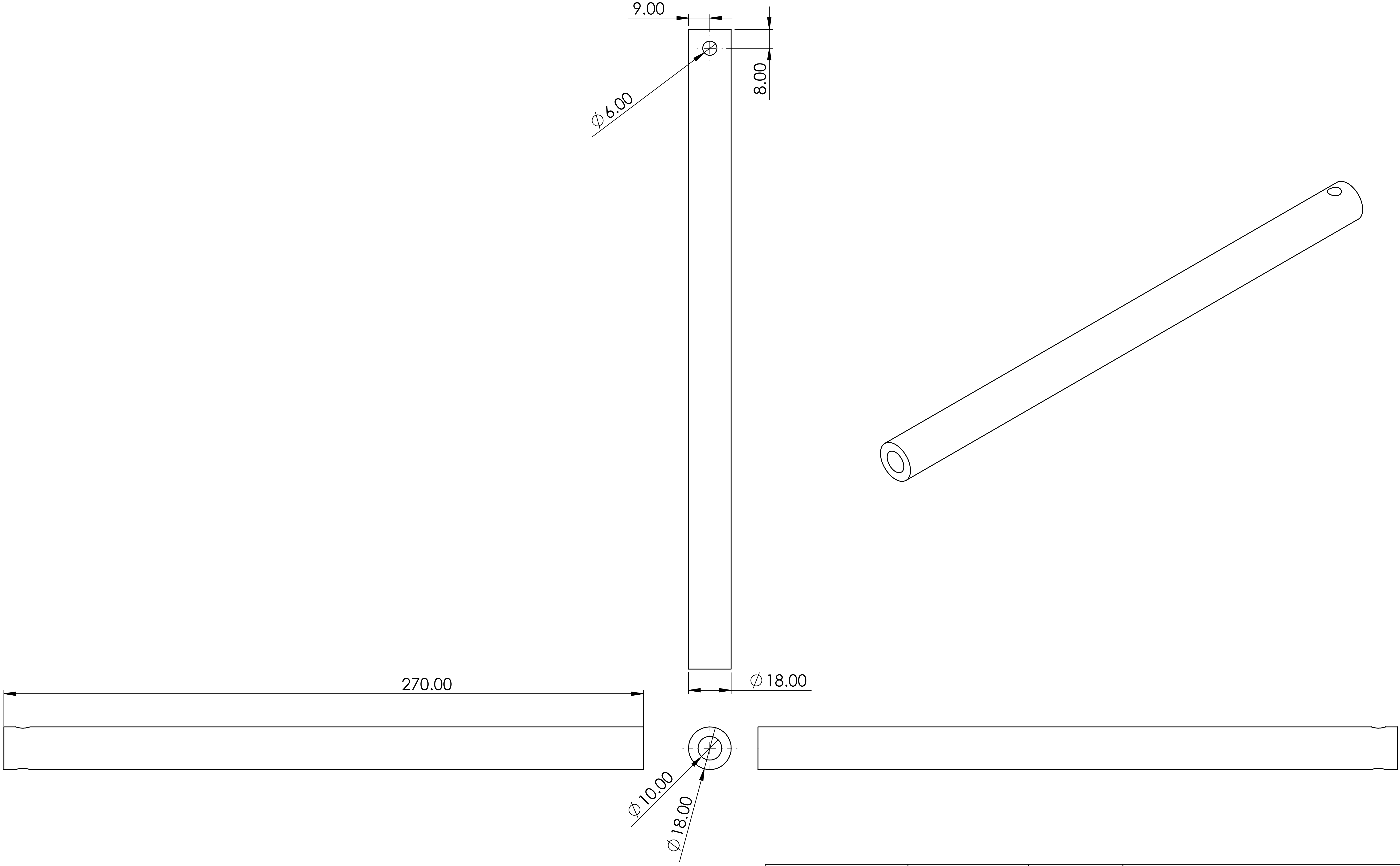
	M5 Bolt	Purchased	M15610-02-B1		4	M5x25mm ISO4017 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M5 Bolt	Purchased	M15610-02-B6		4	M5x30mm ISO4017 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M4 Bolt	Purchased	M15610-02-B2		5	M4x30mm ISO4017 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M3 Bolt	Purchased	M15610-02-B3		8	M3x35mm ISO4017 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M10 Nut	Purchased	M15610-02-N5		4	M10 ISO4032 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M8 Nut	Purchased	M15610-02-N3		3	M8 ISO4032 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
Front Assembly	M6 Nut	Purchased	M15610-02-N6		4	M6 ISO4032 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M5 Nut	Purchased	M15610-02-N4		4	M5 ISO4032 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M4 Nut	Purchased	M15610-02-N1		11	M4 ISO4032 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M3 Nut	Purchased	M15610-02-N2		8	M3 ISO4032 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M10 Washer	Purchased	M15610-02-W1		4	M10 ISO7089 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M8 Washer	Purchased	M15610-02-W2		3	M8 ISO7089 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M6 Washer	Purchased	M15610-02-W3		4	M6 ISO7089 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M5 Washer	Purchased	M15610-02-W4		8	M5 ISO7089 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M4 Washer	Purchased	M15610-02-W5		5	M4 ISO7089 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M3 Washer	Purchased	M15610-02-W6		8	M3 ISO7089 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M10 Bolt	Purchased	M15610-01-B2		2	M10x40mm ISO4017 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M10 Bolt	Purchased	M15610-01-B3		1	M10x45mm ISO4017 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M6 Bolt	Purchased	M15610-01-B1		24	M6x20mm ISO4017 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M5 Bolt	Purchased	M15610-01-B5		1	M5x30mm ISO4017 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M4 Bolt	Purchased	M15610-01-B4		4	M4x30mm ISO4017 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M4 Bolt	Purchased	M15610-01-B6		8	M4x40mm ISO4017 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
Rear Assembly	M10 Nut	Purchased	M15610-01-N2		2	M10 ISO4032 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M6 Nut	Purchased	M15610-01-N4		5	M6 ISO4032 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M5 Nut	Purchased	M15610-01-N2		1	M5 ISO4032 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M4 Nut	Purchased	M15610-01-N1		20	M4 ISO4032 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M10 Washer	Purchased	M15610-01-W1		3	M10 ISO7089 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M6 Washer	Purchased	M15610-01-W2		24	M6 ISO7089 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M5 Washer	Purchased	M15610-01-W3		1	M5 ISO7089 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M4 Washer	Purchased	M15610-01-W4		12	M4 ISO7089 Grade 8.8		University of Southampton	CS-VLA-303, CS-VLA-561
	M5 Bolt	Purchased	M15610-07-4		2	M5 L15mm Bolt ISO4017 Grade 8.8		University of Southampton	
	M5 Nut	Purchased	M15610-07-5		2	M5 Nut ISO4032 Grade 8.8		University of Southampton	
Additional Parts	M3 D-Sub Screw	Purchased	M15610-07-6	94518233	4	M3 D-SUB Connector Screw		Farnell	
	M3 Nut	Purchased	M15610-07-7		4	M3 ISO4032 Grade 8.8		University of Southampton	
	M3 Washer	Purchased	M15610-04-8		4	M3 ISO7089 Grade 8.8		University of Southampton	
	M5 Washer	Purchased	M15610-04-9		5	M5 ISO7089 Grade 8.9		University of Southampton	

Document 12 - Part and Assembly Drawings

Aircraft Registration: G-OUAV
Aircraft Type: TLAC Sherwood Scout
Aircraft Serial Number: 345-15480
Modification Number: 15610
Date Created: 27/04/2021

Authors:
Jerin George, Callum Breslin, Daniel Newman-Sanders, Andrew Kernan and Declan Clifford

Sub Assembly 1: Rear Assembly



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A3		DESIGNED BY Callum Breslin			
EDMC JOB No	DEPARTMENT	DATE 02/04/21	SCALE 2:3		TITLE
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	Rear Push Rod
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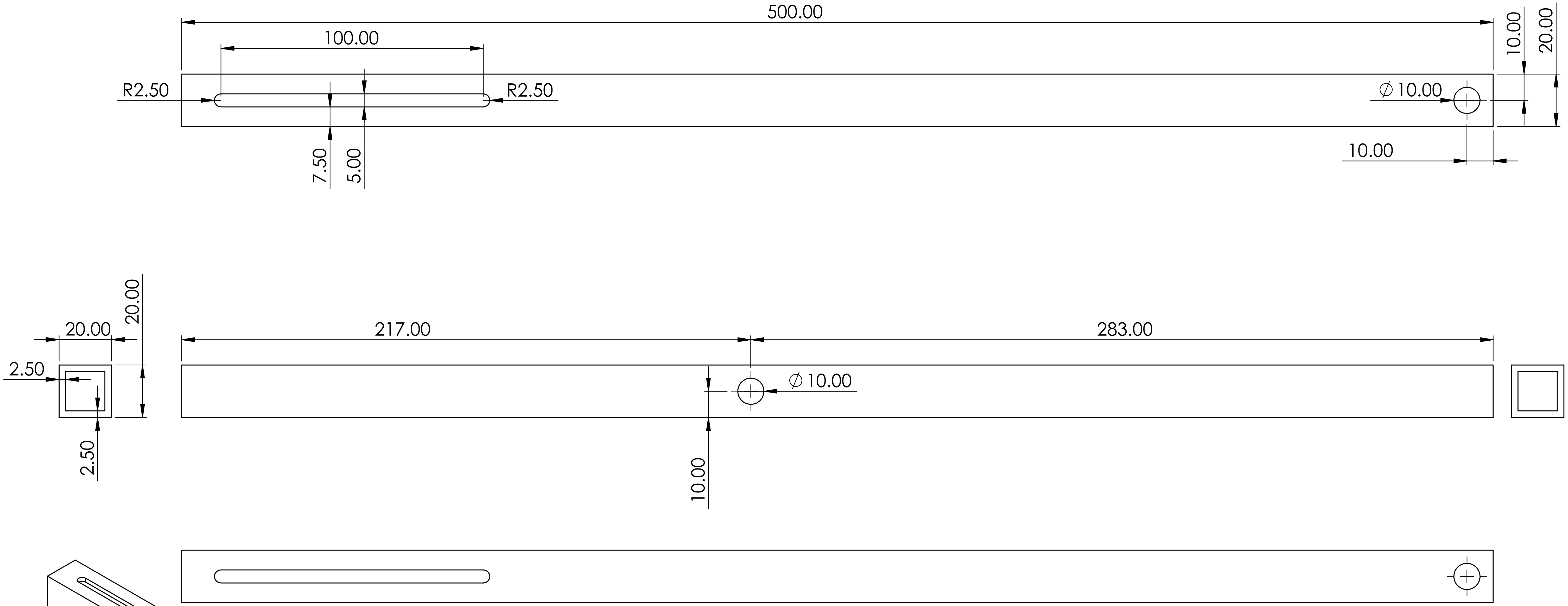

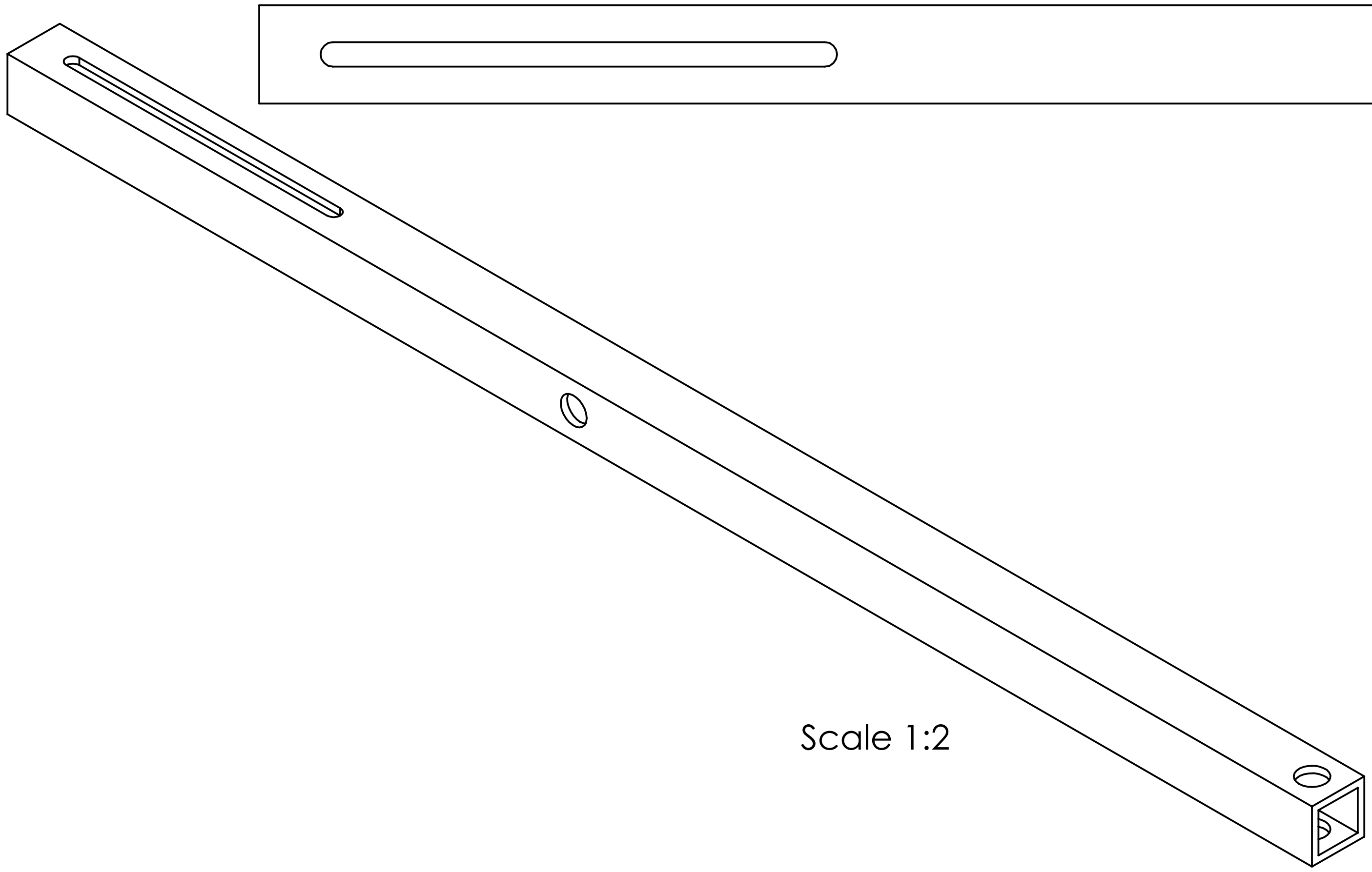

Scale 1:2

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EDMC JOB No	DEPARTMENT	DATE 02/04/21	SCALE 2:3		TITLE
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	Combiner
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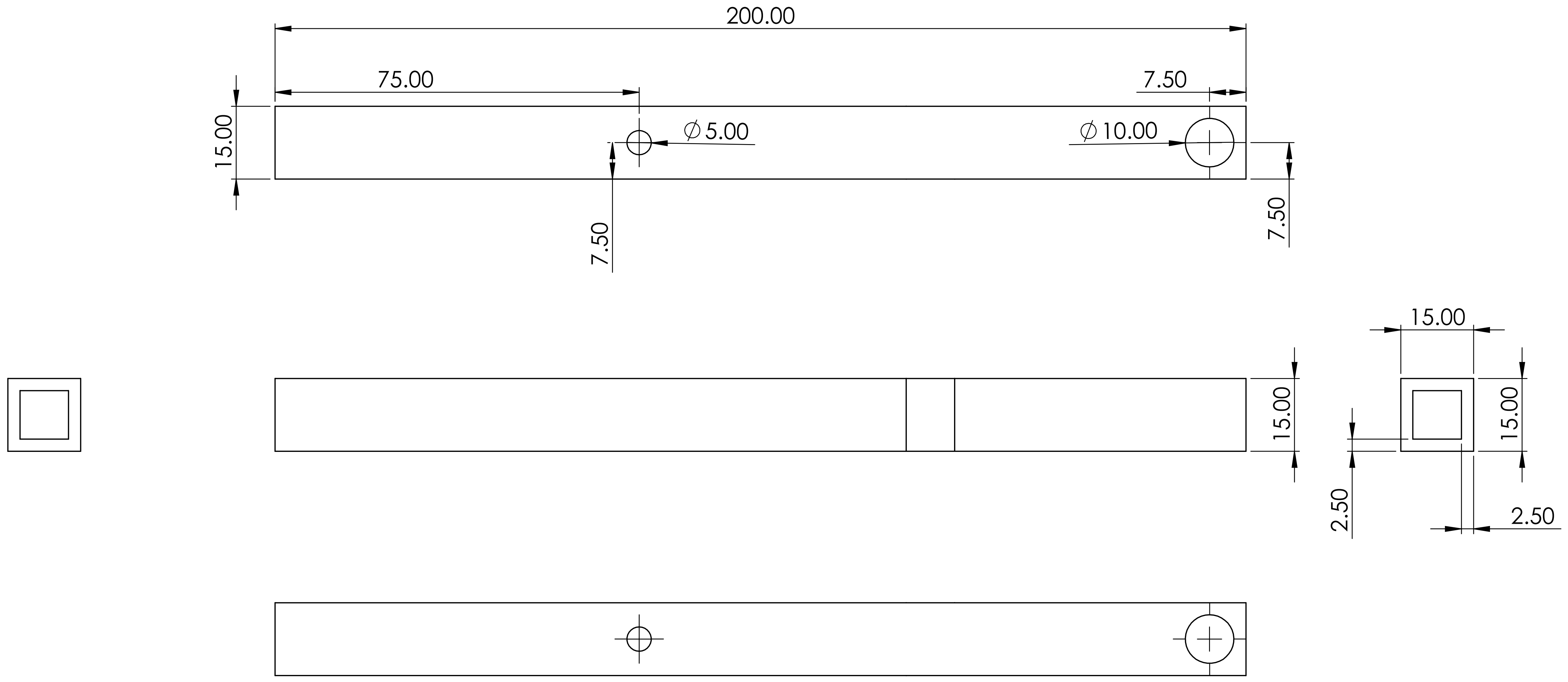

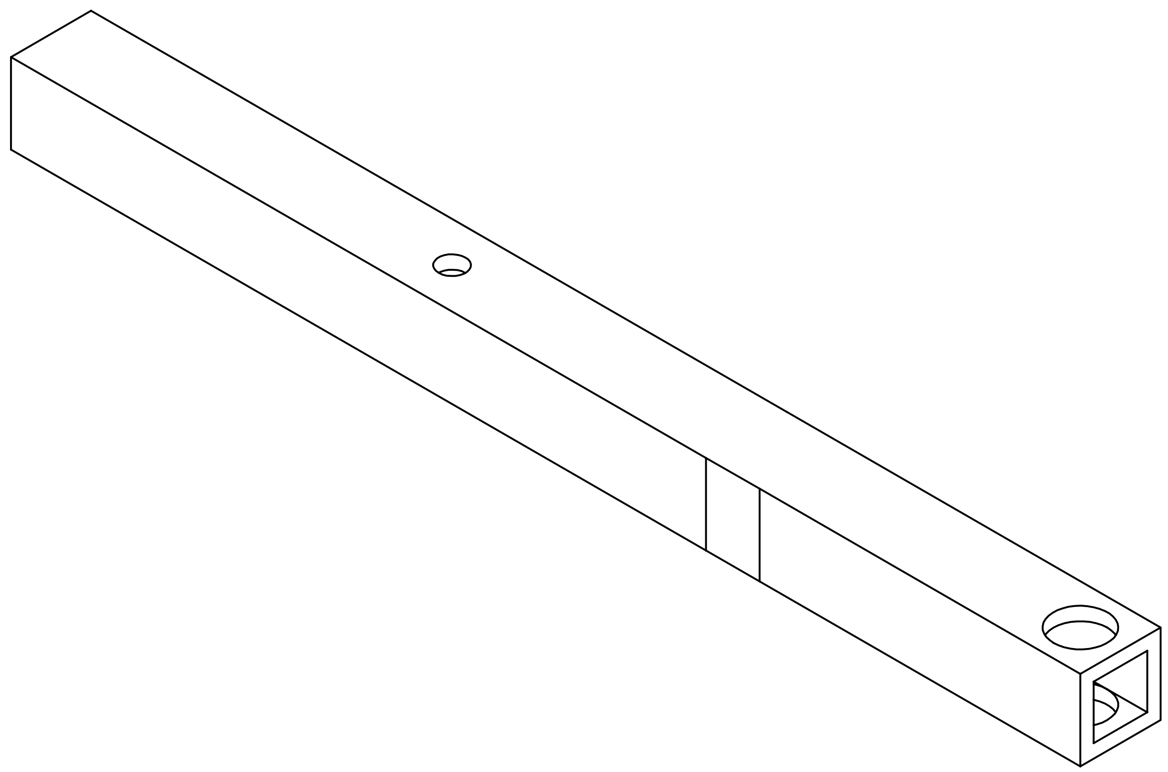

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A3		DESIGNED BY Callum Breslin			
EDMC JOB No	DEPARTMENT	DATE 02/04/21	SCALE 1:1		TITLE
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	Combiner Slider
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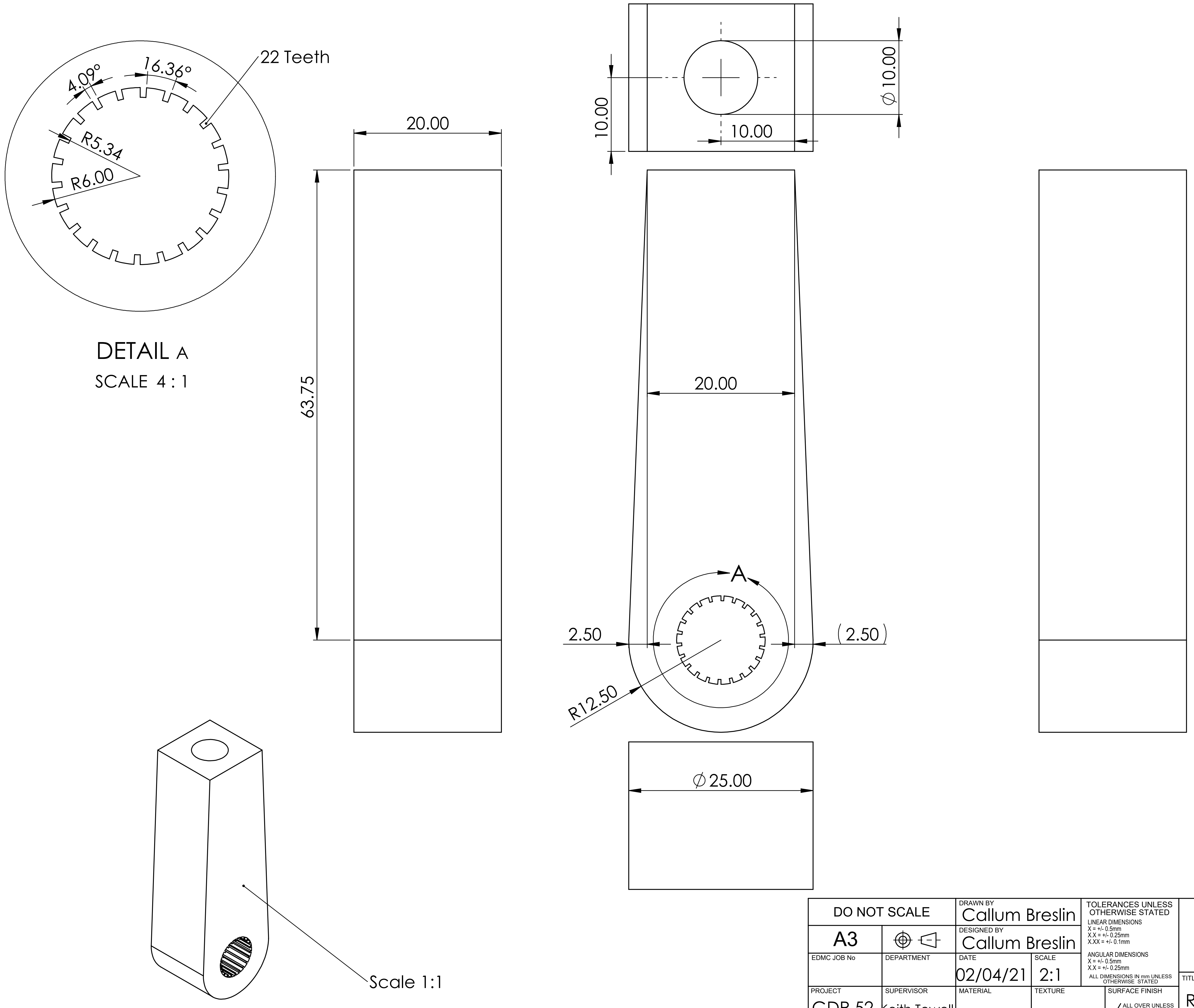

DO NOT SCALE		DRAWN BY Callum Breslin		TOLERANCES UNLESS OTHERWISE STATED LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED	UNIVERSITY OF Southampton Faculty of Engineering and the Environment	
A3		DESIGNED BY Callum Breslin				
EDMC JOB No	DEPARTMENT	DATE 02/04/21	SCALE 2:1		TITLE Rear Servo Arm	
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED		
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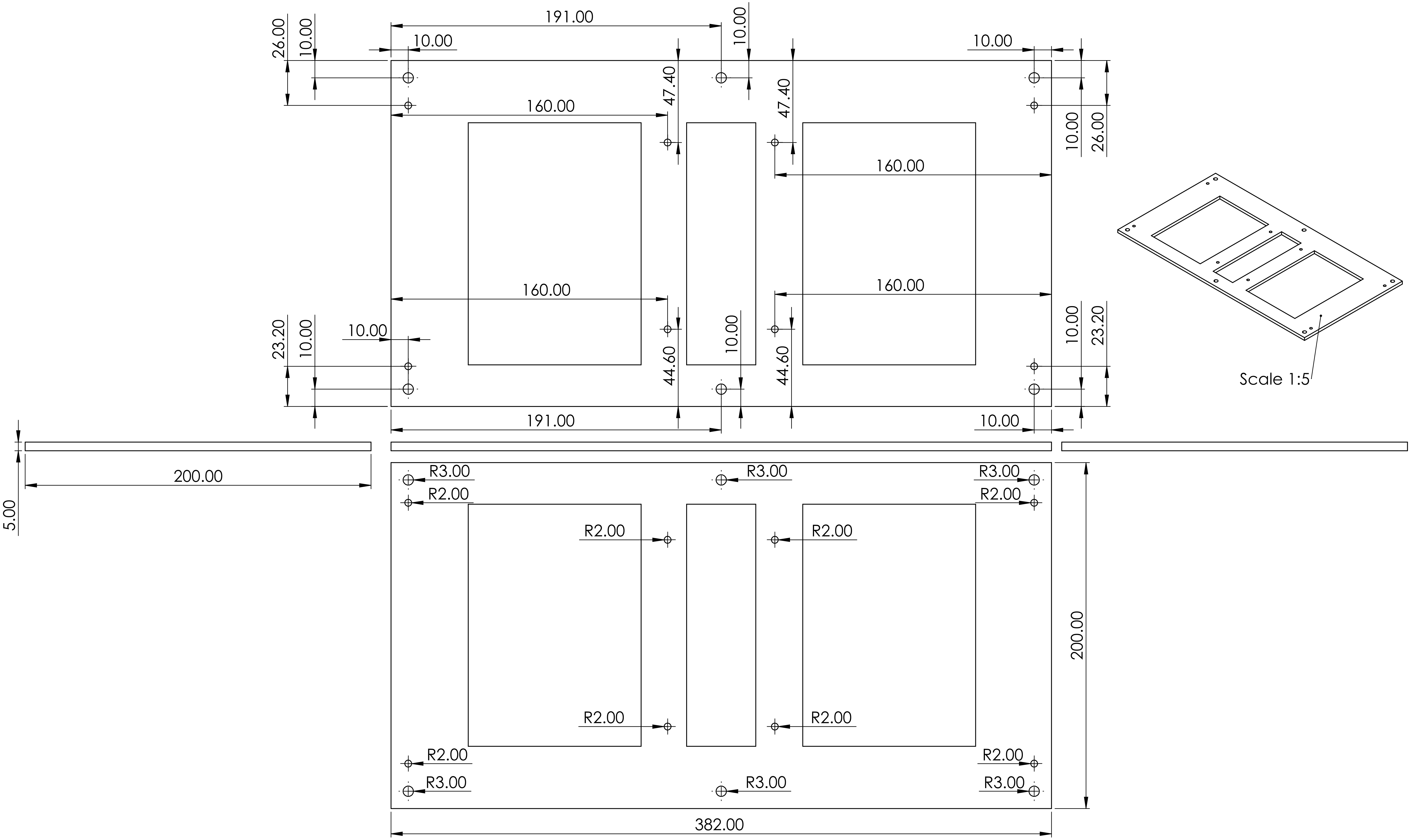

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A3		DESIGNED BY Callum Breslin			
EDMC JOB No	DEPARTMENT	DATE 02/04/21	SCALE 1:2		TITLE
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	Rear Servo Mounting Plate
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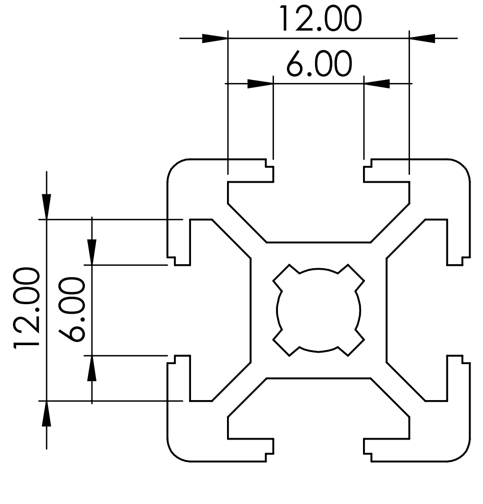
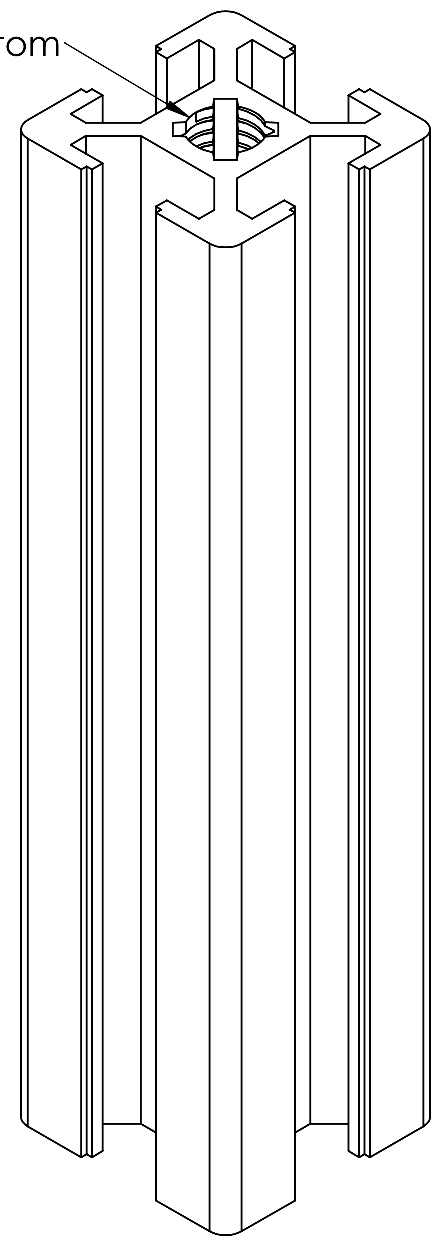
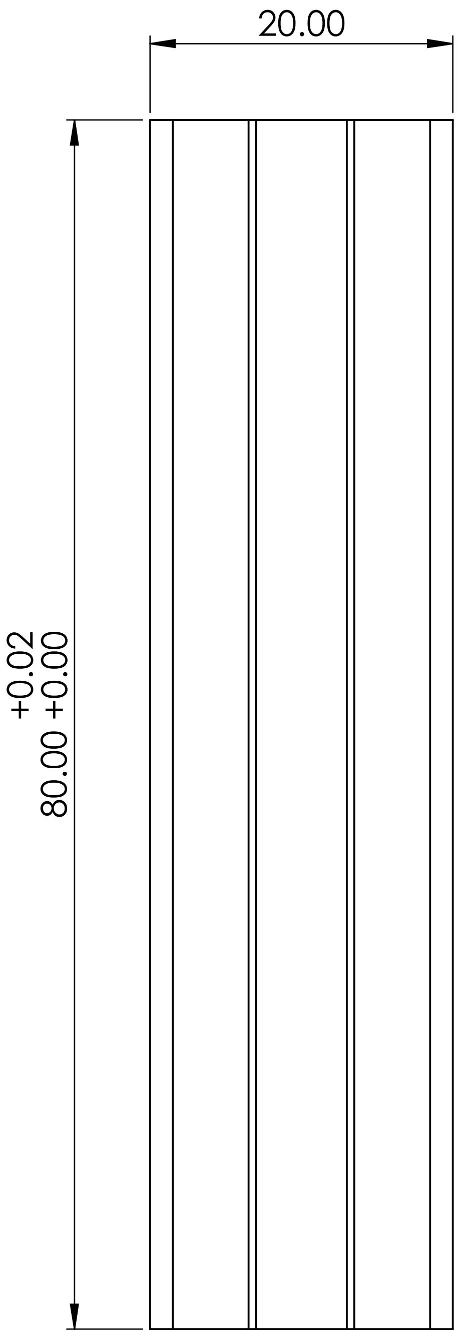
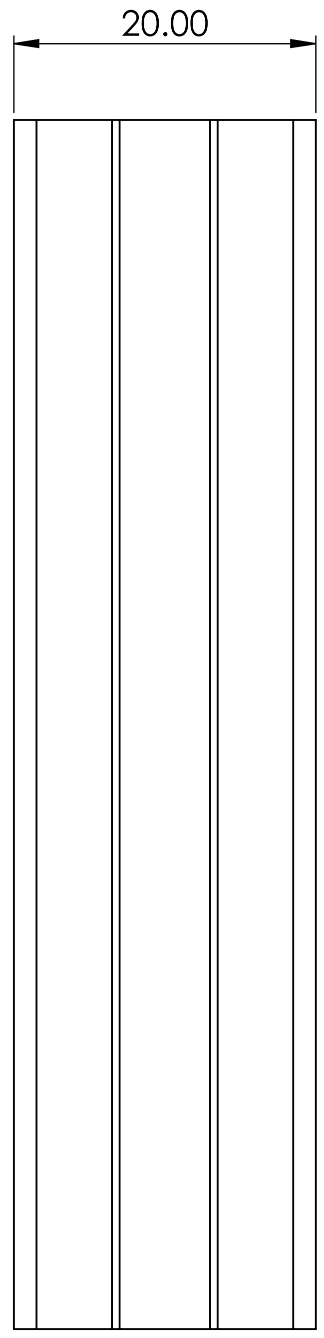


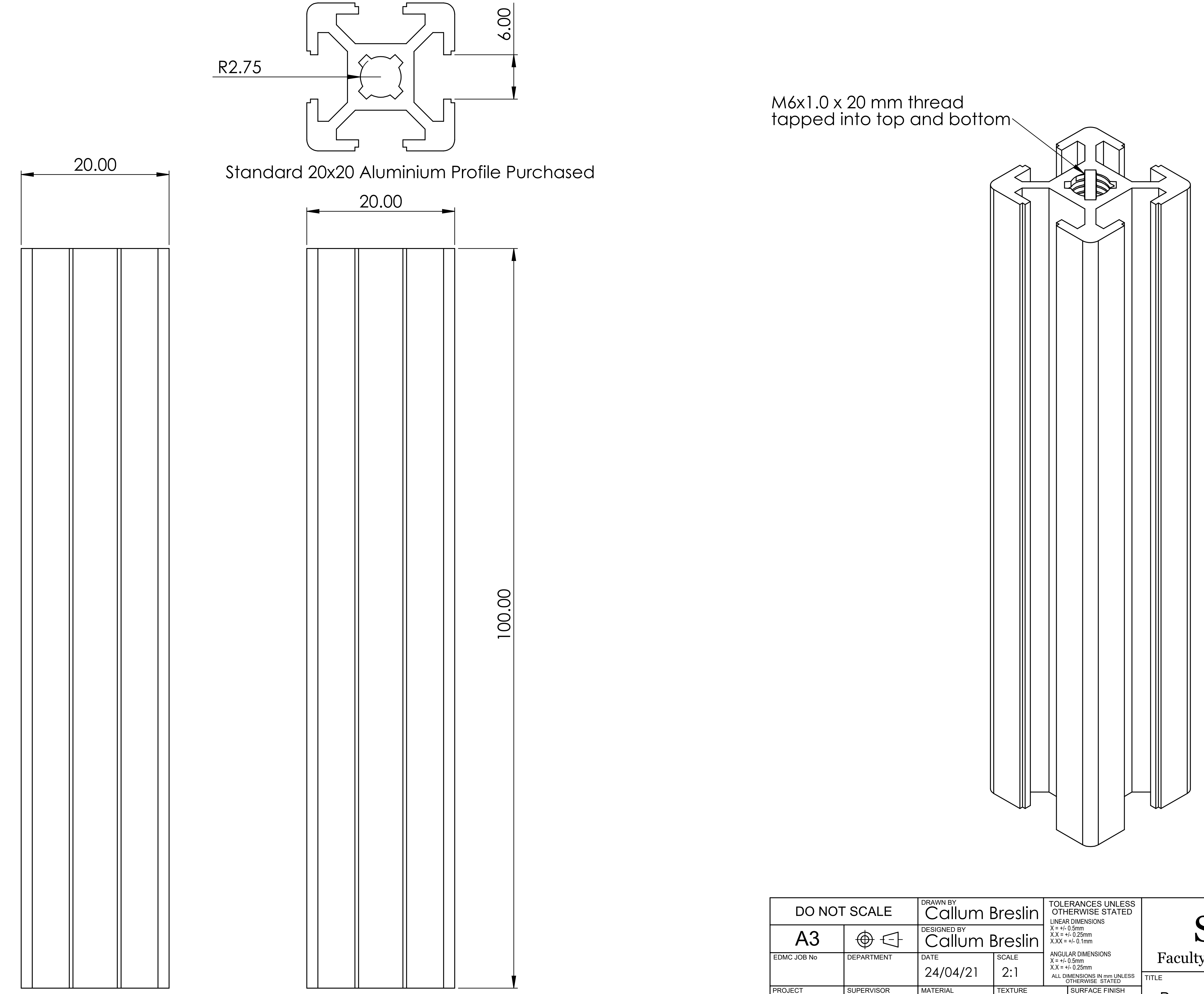
Standard 20x20 Aluminium Profile Purchased



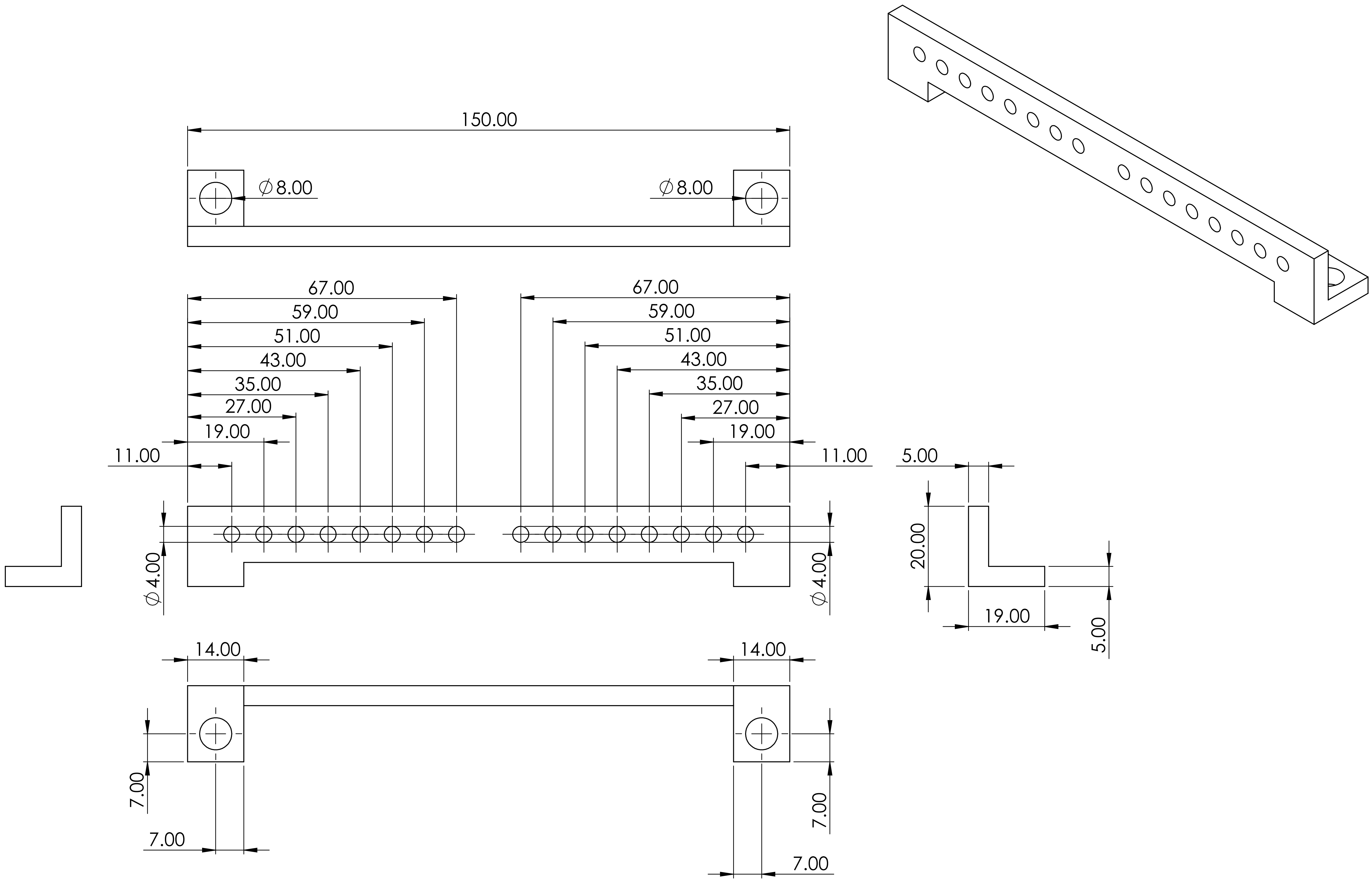




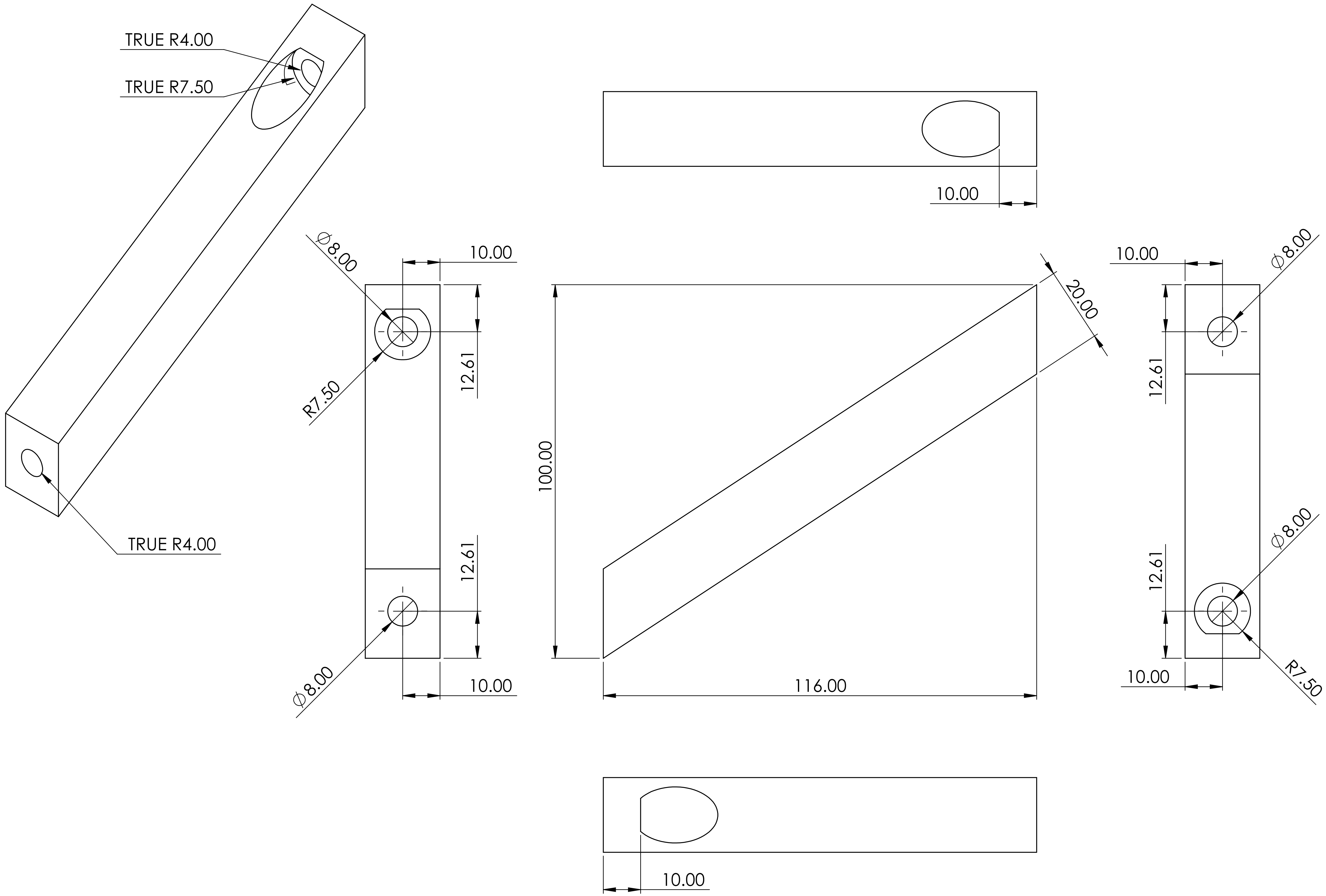
DO NOT SCALE		DRAWN BY Callum Breslin		TOLERANCES UNLESS OTHERWISE STATED LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED	UNIVERSITY OF Southampton Faculty of Engineering and the Environment
A3		DESIGNED BY Callum Breslin			
EDMC JOB No	DEPARTMENT	DATE 24/04/21	SCALE 1:1		TITLE Rear End Stop Leg
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	
REMOVE ALL SHARP EDGES		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.			SHEET 1 / No OFF / ASSEMBLY NUMBER 1 / DRAWING NUMBER 6 / REVISION 1
IF IN DOUBT PLEASE ASK					



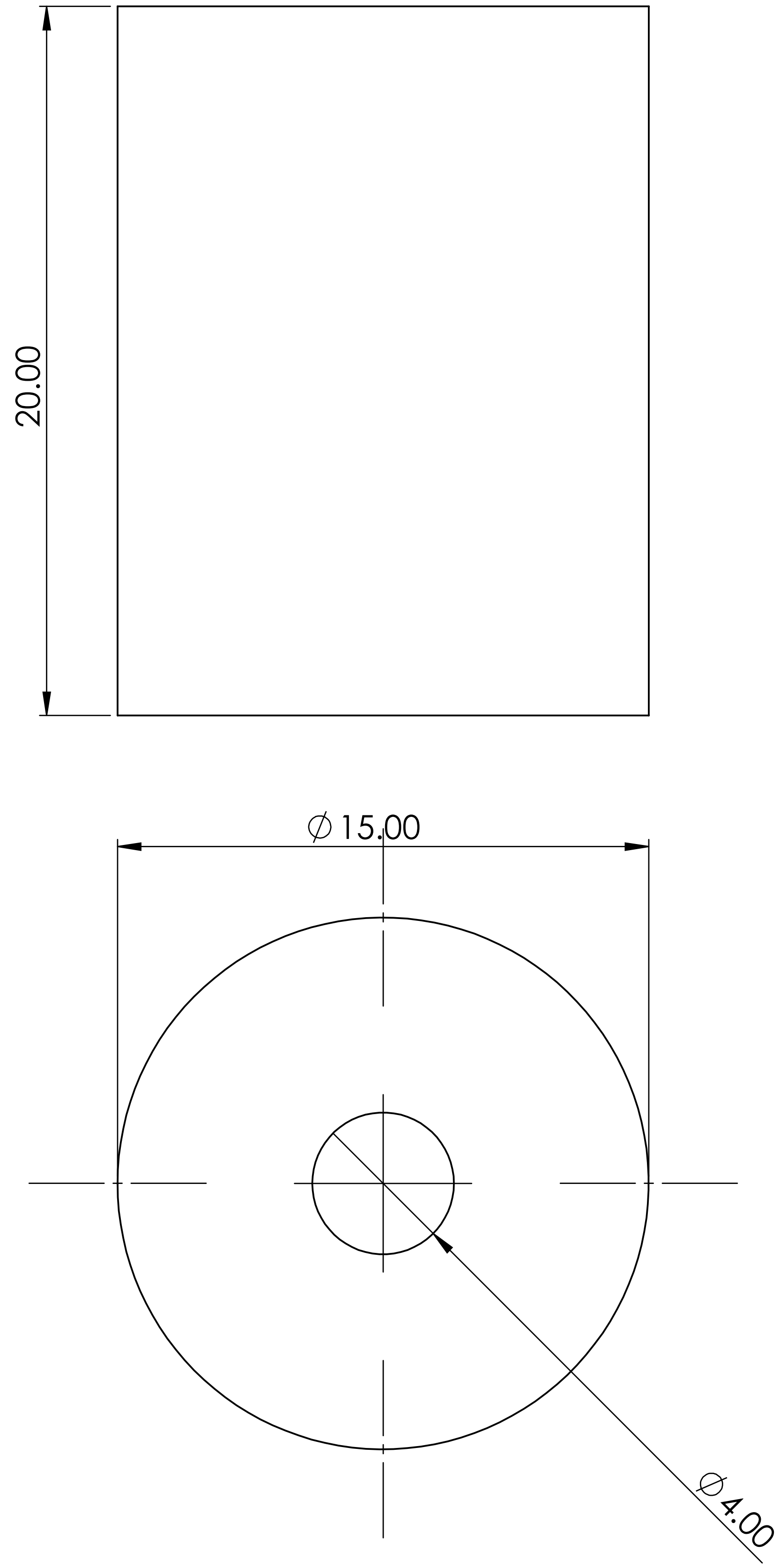
DO NOT SCALE		DRAWN BY Callum Breslin		TOLERANCES UNLESS OTHERWISE STATED LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED	UNIVERSITY OF Southampton Faculty of Engineering and the Environment
A3		DESIGNED BY Callum Breslin			
EDMC JOB No	DEPARTMENT	DATE 24/04/21	SCALE 2:1		TITLE Rear End Stop Leg
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	
REMOVE ALL SHARP EDGES IF IN DOUBT PLEASE ASK		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.			SHEET 1 / No OFF / ASSEMBLY NUMBER 1 / DRAWING NUMBER 11 / REVISION 1

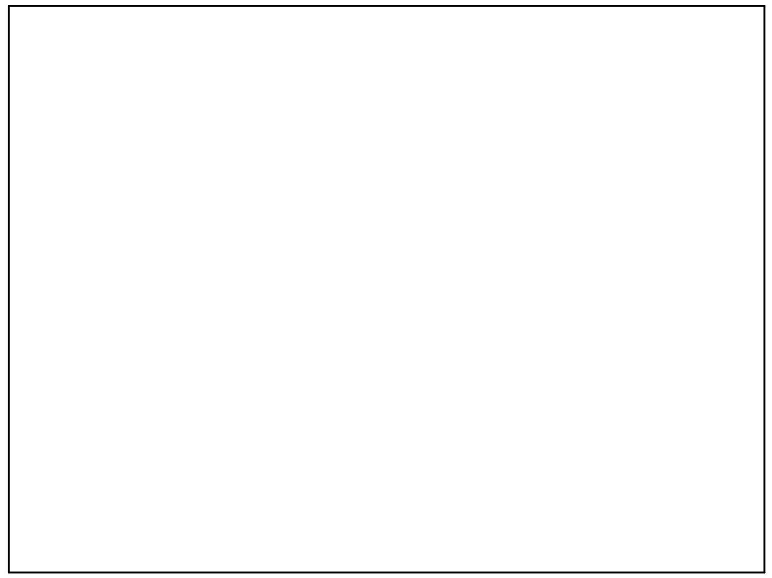


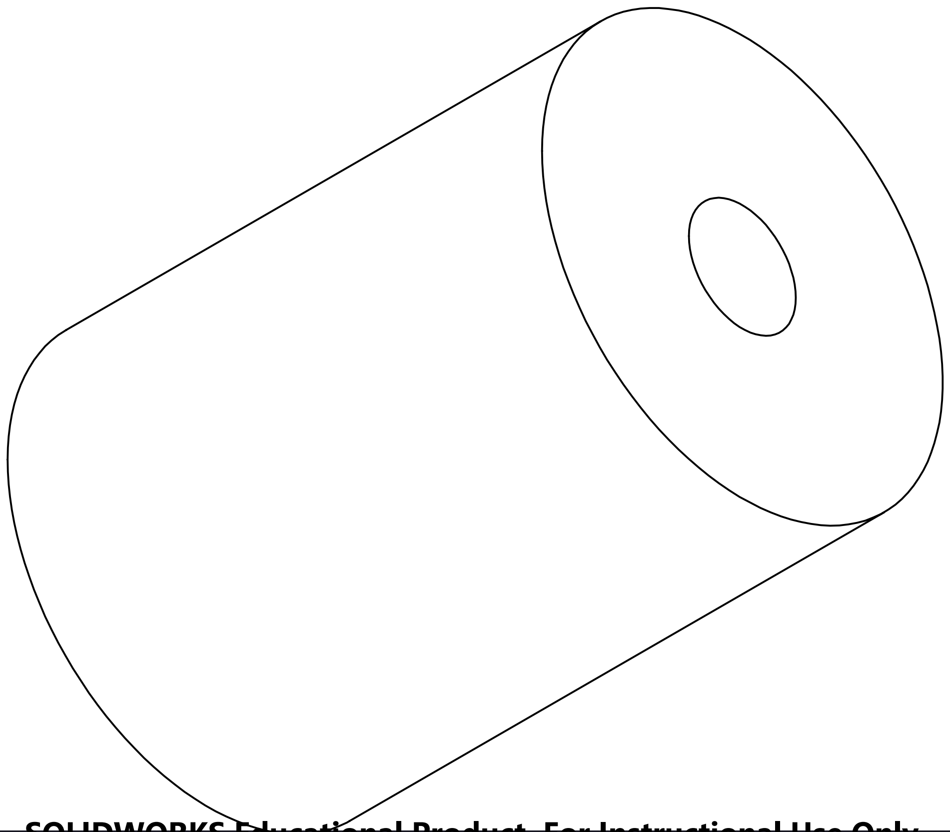
DO NOT SCALE		DRAWN BY Callum Breslin		TOLERANCES UNLESS OTHERWISE STATED LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED	UNIVERSITY OF Southampton Faculty of Engineering and the Environment		
A3		DESIGNED BY Callum Breslin					
EDMC JOB No	DEPARTMENT	DATE 24/04/21	SCALE 1:1		TITLE		
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	End Stop Bracket		
REMOVE ALL SHARP EDGES		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.			SHEET 1	No OFF	ASSEMBLY NUMBER 1
IF IN DOUBT PLEASE ASK					DRAWING NUMBER 1	REVISION 1	



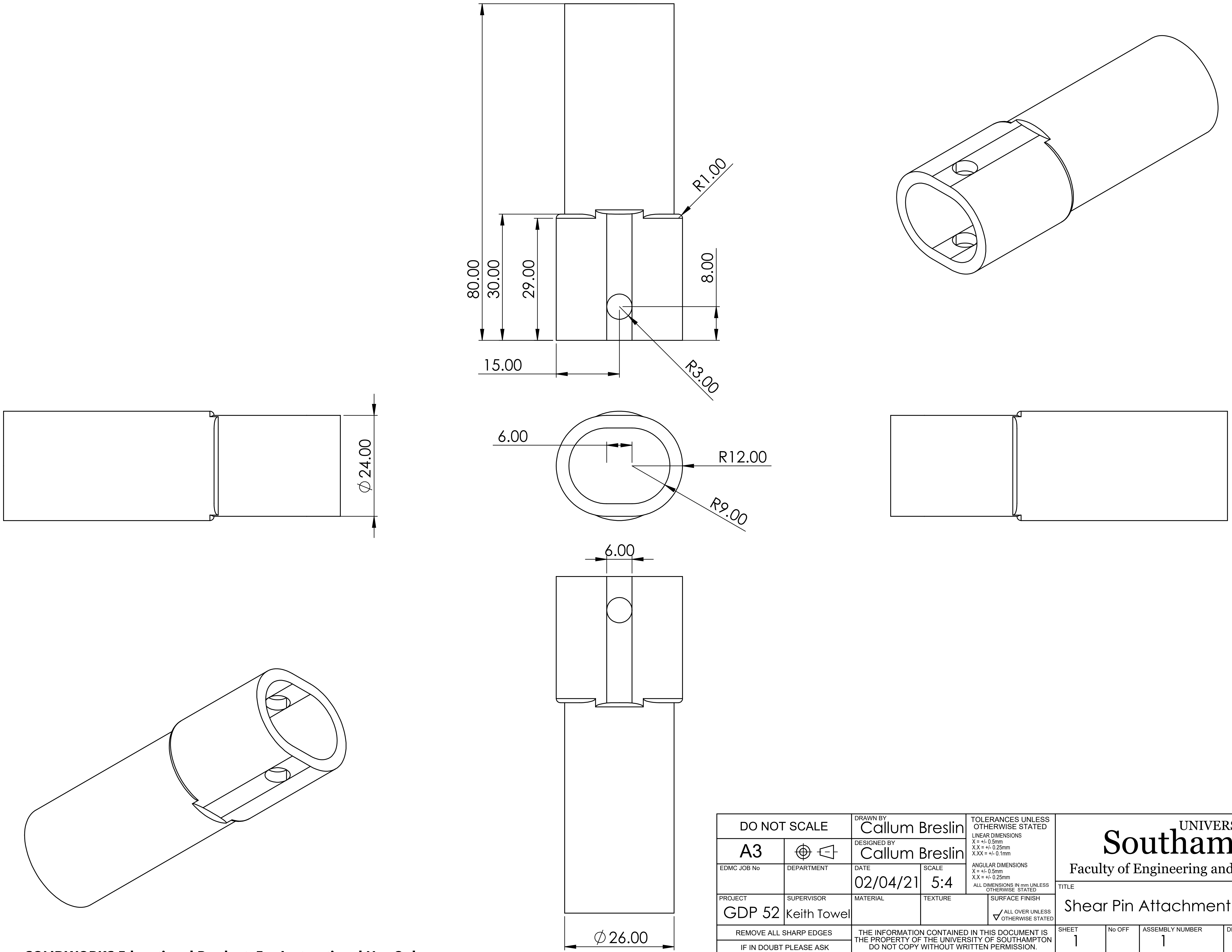
DO NOT SCALE		DRAWN BY Callum Breslin		TOLERANCES UNLESS OTHERWISE STATED LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED	UNIVERSITY OF Southampton Faculty of Engineering and the Environment
A3		DESIGNED BY Callum Breslin			
EDMC JOB No	DEPARTMENT	DATE 25/04/21	SCALE 1:1		TITLE Rear End Stop Diagonal Brace
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	
REMOVE ALL SHARP EDGES		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.			SHEET 1 | No OFF | ASSEMBLY NUMBER 1 | DRAWING NUMBER 13 | REVISION 1
IF IN DOUBT PLEASE ASK					



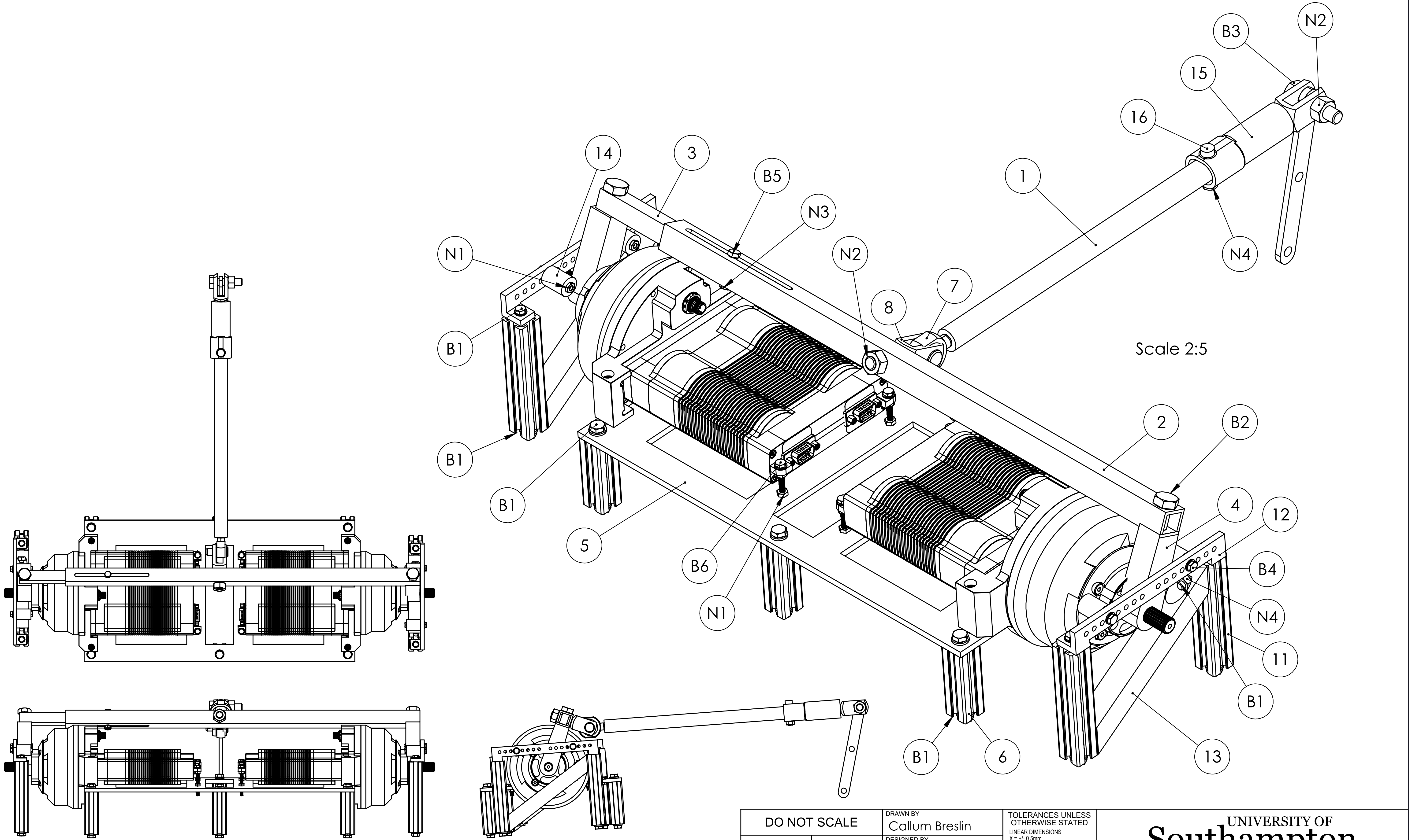




DO NOT SCALE		DRAWN BY Callum Breslin		TOLERANCES UNLESS OTHERWISE STATED LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED	UNIVERSITY OF Southampton Faculty of Engineering and the Environment
A3		DESIGNED BY Callum Breslin			
EDMC JOB No	DEPARTMENT	DATE 25/04/21	SCALE 5:1		TITLE End Stop
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	
REMOVE ALL SHARP EDGES IF IN DOUBT PLEASE ASK		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.			SHEET 1 | No OFF | ASSEMBLY NUMBER 1 & 2 | DRAWING NUMBER 14 | REVISION 1



DO NOT SCALE		DRAWN BY Callum Breslin		TOLERANCES UNLESS OTHERWISE STATED LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED	UNIVERSITY OF Southampton Faculty of Engineering and the Environment
A3		DESIGNED BY Callum Breslin			
EDMC JOB No	DEPARTMENT	DATE 02/04/21	SCALE 5:4		TITLE Shear Pin Attachment
PROJECT GDP 52	SUPERVISOR Keith Towel	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	
REMOVE ALL SHARP EDGES		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.			SHEET 1 | No OFF | ASSEMBLY NUMBER 1 | DRAWING NUMBER 15 | REVISION 1
IF IN DOUBT PLEASE ASK					



DO NOT SCALE		DRAWN BY Callum Breslin		TOLERANCES UNLESS OTHERWISE STATED LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED
A3		DESIGNED BY Callum Breslin		
EDMC JOB No	DEPARTMENT	DATE 24/04/21	SCALE 1:5	
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED
REMOVE ALL SHARP EDGES		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.		
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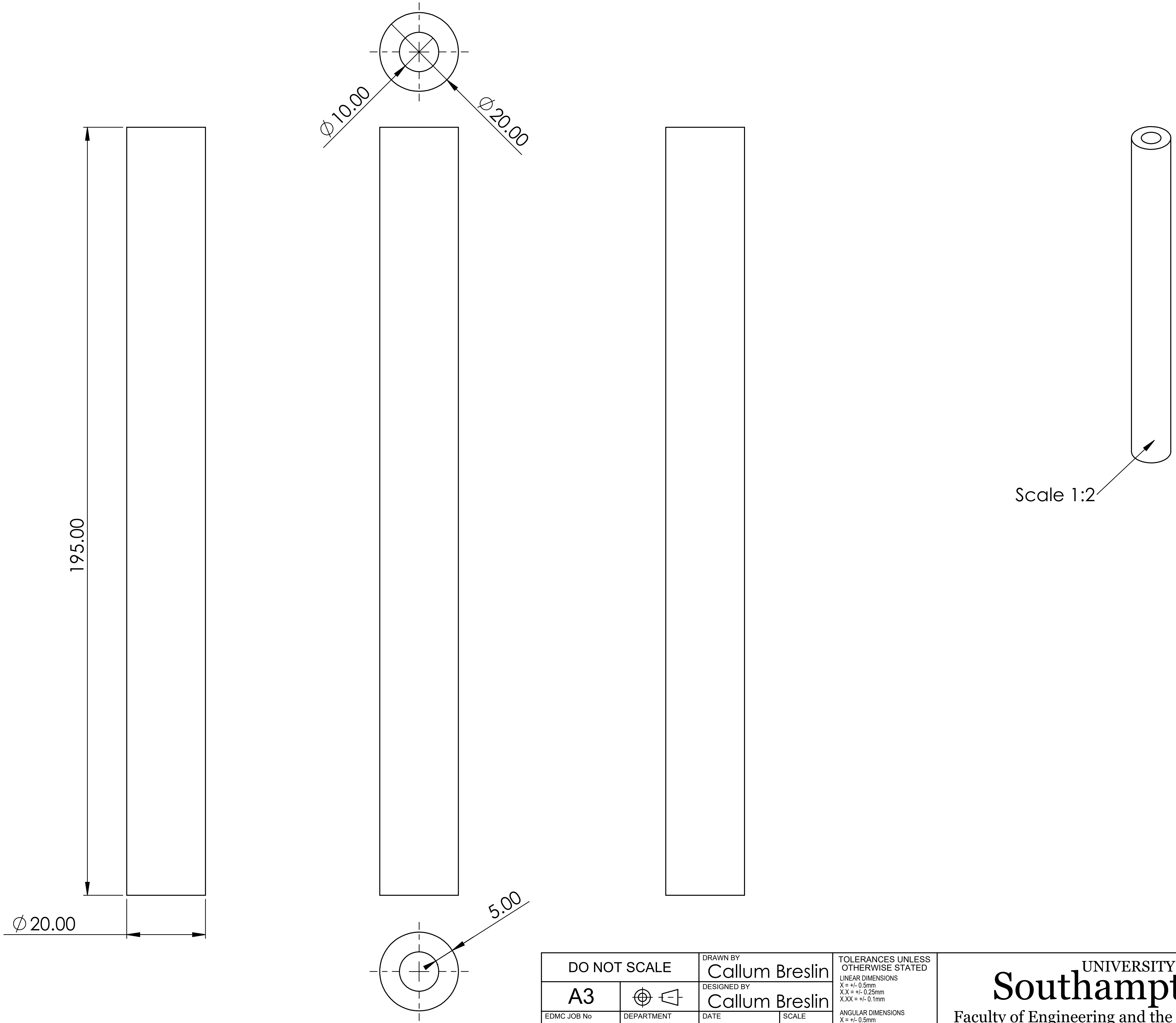
TITLE				
Rear Servo Assembly				
SHEET	No OFF	ASSEMBLY NUMBER	DRAWING NUMBER	REVISION
1	2	1	1	3

Number	Part Number	Part Name	Quantity
1	M15610-01-1	Rear Push Rod	1
2	M15610-01-2	Combiner	1
3	M15610-01-3	Combiner Slider	1
4	M15610-01-4	Rear Servo Arm	2
5	M15610-01-5	Rear Servo Mounting Plate	1
6	M15610-01-6	Rear Servo Plate Leg	6
7	M15610-01-7	SKF Rod End Spherical Bearing	1
8	M15610-01-8	Male Threaded Clevis Joint	2
9	M15610-01-9	Clevis Pin	1
10	M15610-01-10	Clevis E-Clip	1
11	M15610-01-11	Rear End Stop Leg	4
12	M15610-01-12	End Stop Bracket	2
13	M15610-01-13	Diagonal Brace	2
14	M15610-01-14	End Stop	4
15	M15610-01-15	Shear Pin Connector	1
16	M15610-01-16	Shear Pin	1

Number	Part Number	Part Name	Quantity
B1	M15610-01-B1	M6x20mm Grade 8.8 Bolt	24
B2	M15610-01-B2	M10x40mm Grade 8.8 Bolt	2
B3	M15610-01-B3	M10x45mm Grade 8.8 Bolt	1
B4	M15610-01-B4	M4x30mm Grade 8.8 Bolt	4
B5	M15610-01-B5	M5x30mm Grade 8.8 Bolt	1
B6	M15610-01-B6	M4x40mm Grade 8.8 Bolt	8
N1	M15610-01-N1	M4 Grade 8.8 Nut	20
N2	M15610-01-N2	M10 Grade 8.8 Nut	2
N3	M15610-01-N3	M5 Grade 8.8 Nut	1
N4	M15610-01-N4	M6 Grade 8.8 Nut	5
W1	M15610-01-W1	M10 Grade 8.8 Washer	3
W2	M15610-01-W2	M6 Grade 8.8 Washer	24
W3	M15610-01-W3	M5 Grade 8.8 Washer	1
W4	M15610-01-W4	M4 Grade 8.8 Washer	12

DO NOT SCALE		DRAWN BY Callum Breslin		TOLERANCES UNLESS OTHERWISE STATED LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED	UNIVERSITY OF Southampton Faculty of Engineering and the Environment
A3		DESIGNED BY Callum Breslin			
EDMC JOB No	DEPARTMENT	DATE 24/04/21	SCALE		TITLE
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	Rear Servo Assembly
REMOVE ALL SHARP EDGES IF IN DOUBT PLEASE ASK		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.			SHEET 2 / No OFF 2 / ASSEMBLY NUMBER 1 / DRAWING NUMBER 1 / REVISION 3

Sub Assembly 2: Front Assembly



DO NOT SCALE		DRAWN BY: Callum Breslin	
A3	(third-angle projection symbol)	DESIGNED BY: Callum Breslin	
EDMC JOB No	DEPARTMENT	DATE: 03/04/21	SCALE: 1:1
PROJECT: GDP 52	SUPERVISOR: Keith Towell	MATERIAL	TEXTURE
REMOVE ALL SHARP EDGES		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.	
IF IN DOUBT PLEASE ASK			

TOLERANCES UNLESS OTHERWISE STATED
LINEAR DIMENSIONS
X = +/- 0.5mm
X.X = +/- 0.25mm
X.XX = +/- 0.1mm

ANGULAR DIMENSIONS
X = +/- 0.5mm
X.X = +/- 0.25mm

ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED

SURFACE FINISH
ALL OVER UNLESS OTHERWISE STATED

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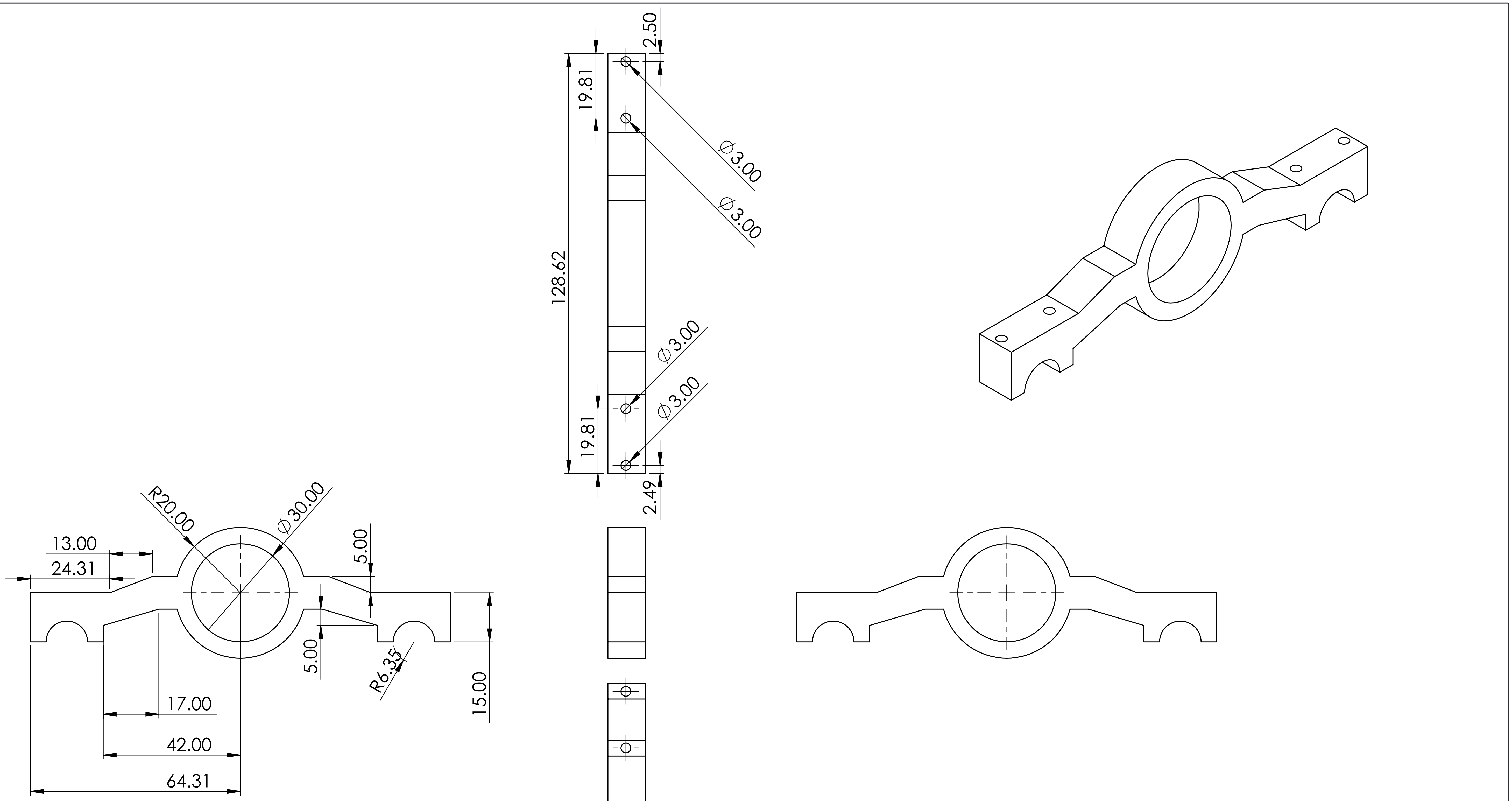
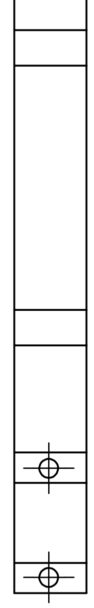
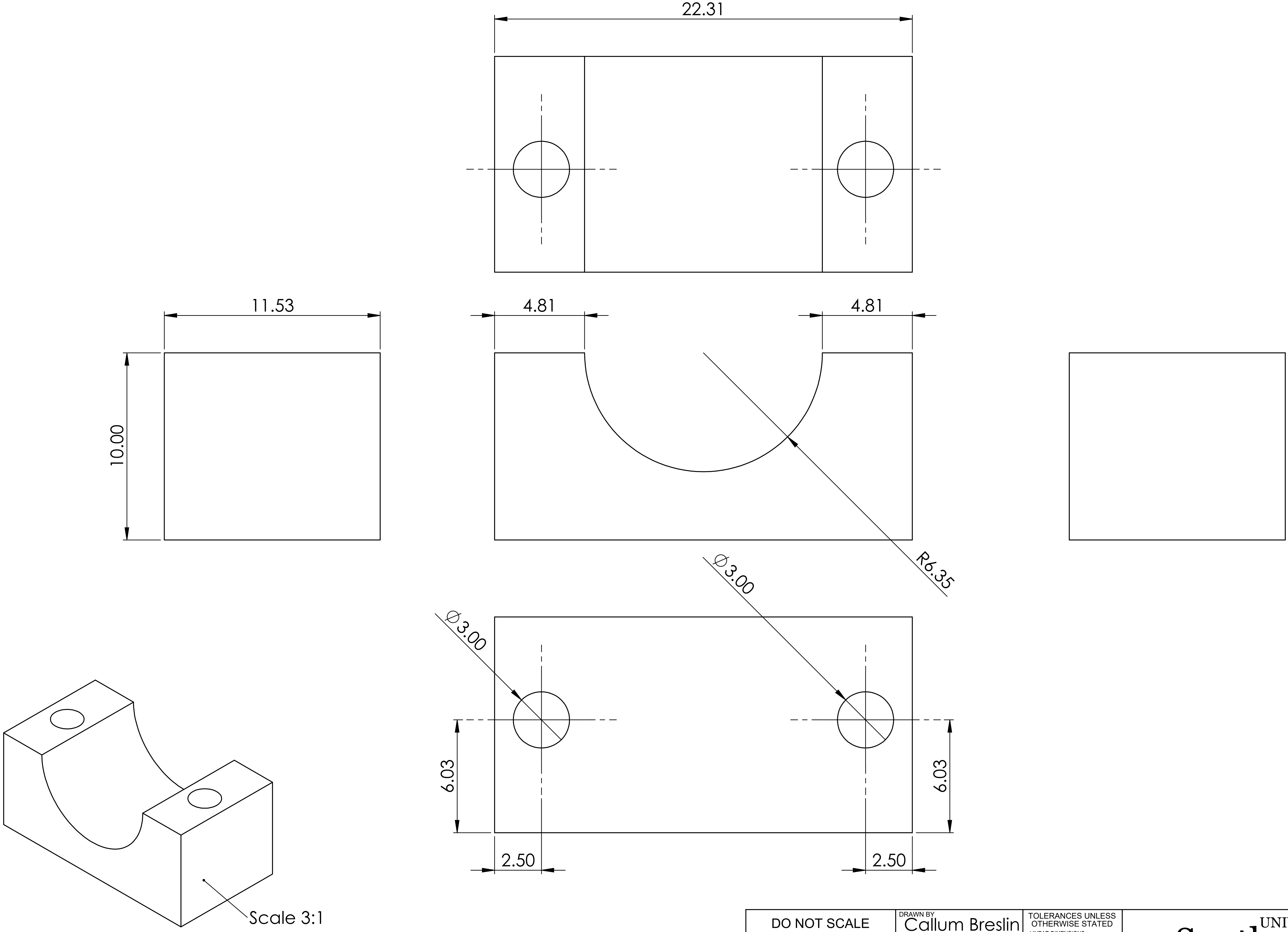
TITLE
Front Push Rod

SHEET	No OFF	ASSEMBLY NUMBER	DRAWING NUMBER	REVISION
1		2	1	2





DO NOT SCALE		DRAWN BY Callum Breslin		TOLERANCES UNLESS OTHERWISE STATED LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED	UNIVERSITY OF Southampton Faculty of Engineering and the Environment
A3		DESIGNED BY Callum Breslin			
EDMC JOB No	DEPARTMENT	DATE 03/04/21	SCALE 5:6		TITLE
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	Bearing Mount Top
REMOVE ALL SHARP EDGES		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.			SHEET 1 | No OFF | ASSEMBLY NUMBER 2 | DRAWING NUMBER 2 | REVISION 2
IF IN DOUBT PLEASE ASK					



DO NOT SCALE		DRAWN BY Callum Breslin		TOLERANCES UNLESS OTHERWISE STATED LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED
A3		DESIGNED BY Callum Breslin		
EDMC JOB No	DEPARTMENT	DATE 03/04/21	SCALE 5:1	
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED
REMOVE ALL SHARP EDGES IF IN DOUBT PLEASE ASK		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.		

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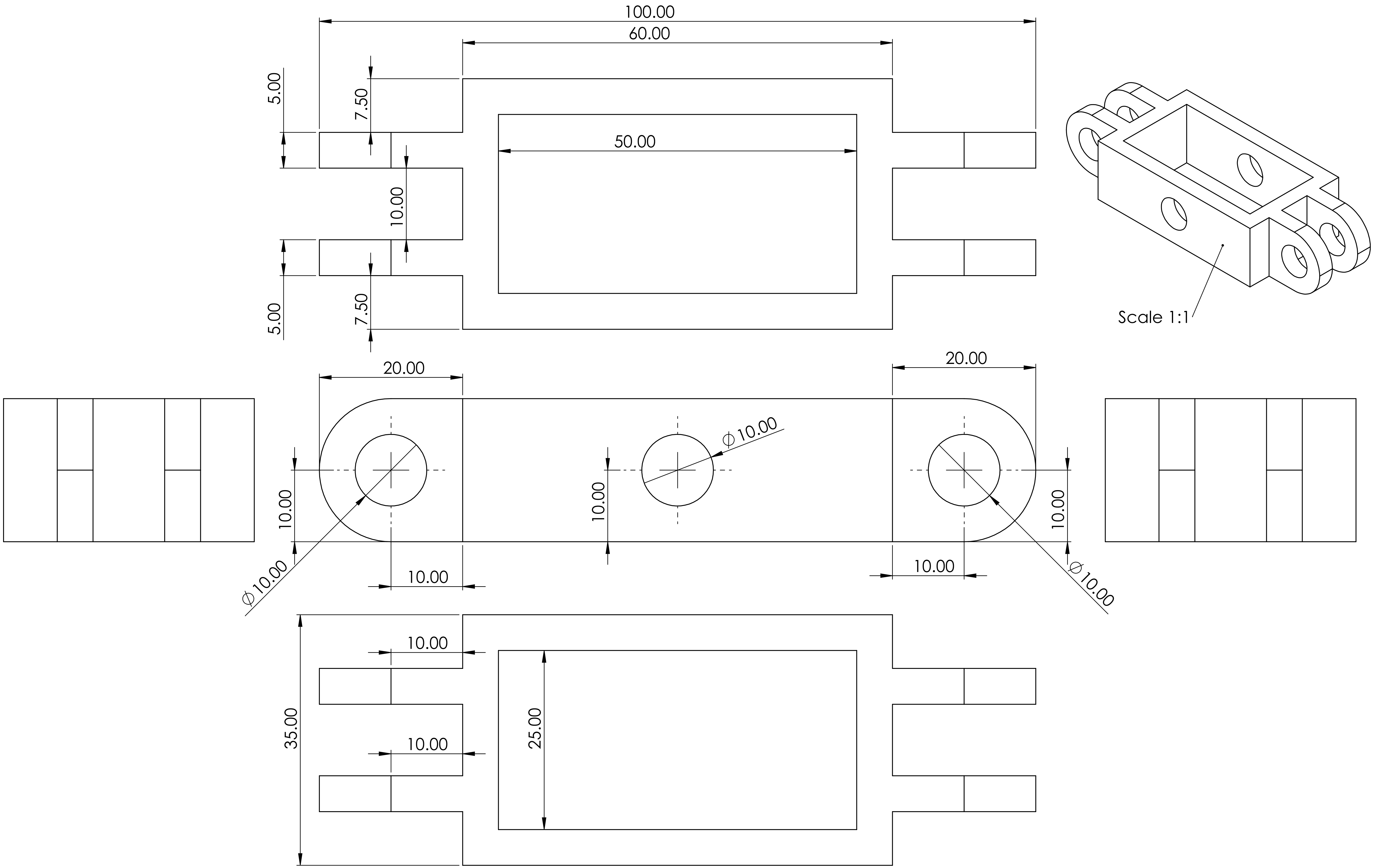
TITLE				
Bearing Mount Bottom				
SHEET	No OFF	ASSEMBLY NUMBER	DRAWING NUMBER	REVISION
1		2	3	2



DO NOT SCALE

A3

EDMC JOB No

DEPARTMENT

DRAWN BY Callum Breslin

DESIGNED BY Callum Breslin

DATE 03/04/21

SCALE 2:1

TOLERANCES UNLESS OTHERWISE STATED
LINEAR DIMENSIONS
X = +/- 0.5mm
X.X = +/- 0.25mm
X.XX = +/- 0.1mm
ANGULAR DIMENSIONS
X = +/- 0.5mm
X.X = +/- 0.25mm
ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED

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PROJECT GDP 52

SUPERVISOR Keith Towel

MATERIAL

TEXTURE

SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED

TITLE Stick Frame

REMOVE ALL SHARP EDGES

IF IN DOUBT PLEASE ASK

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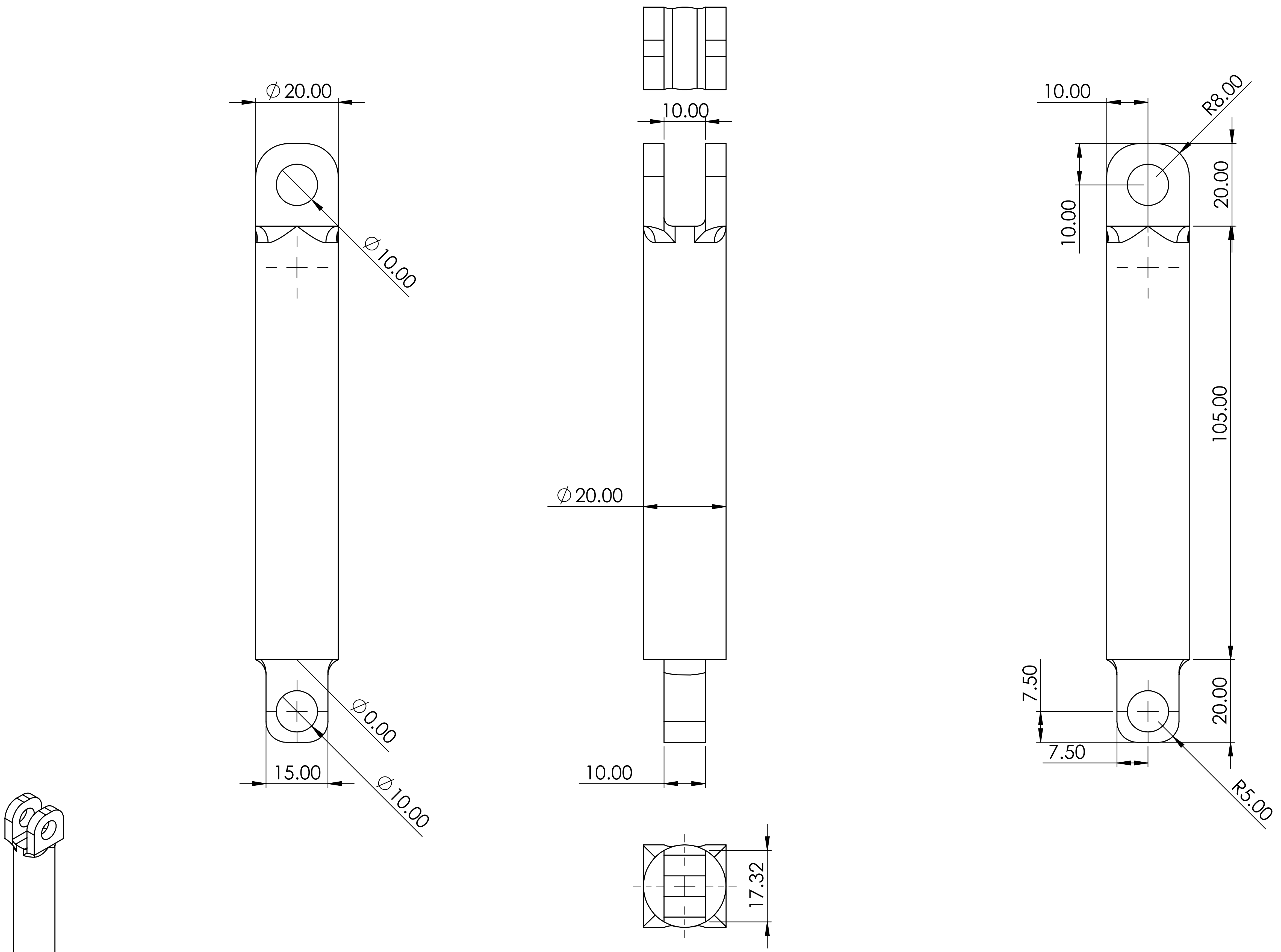
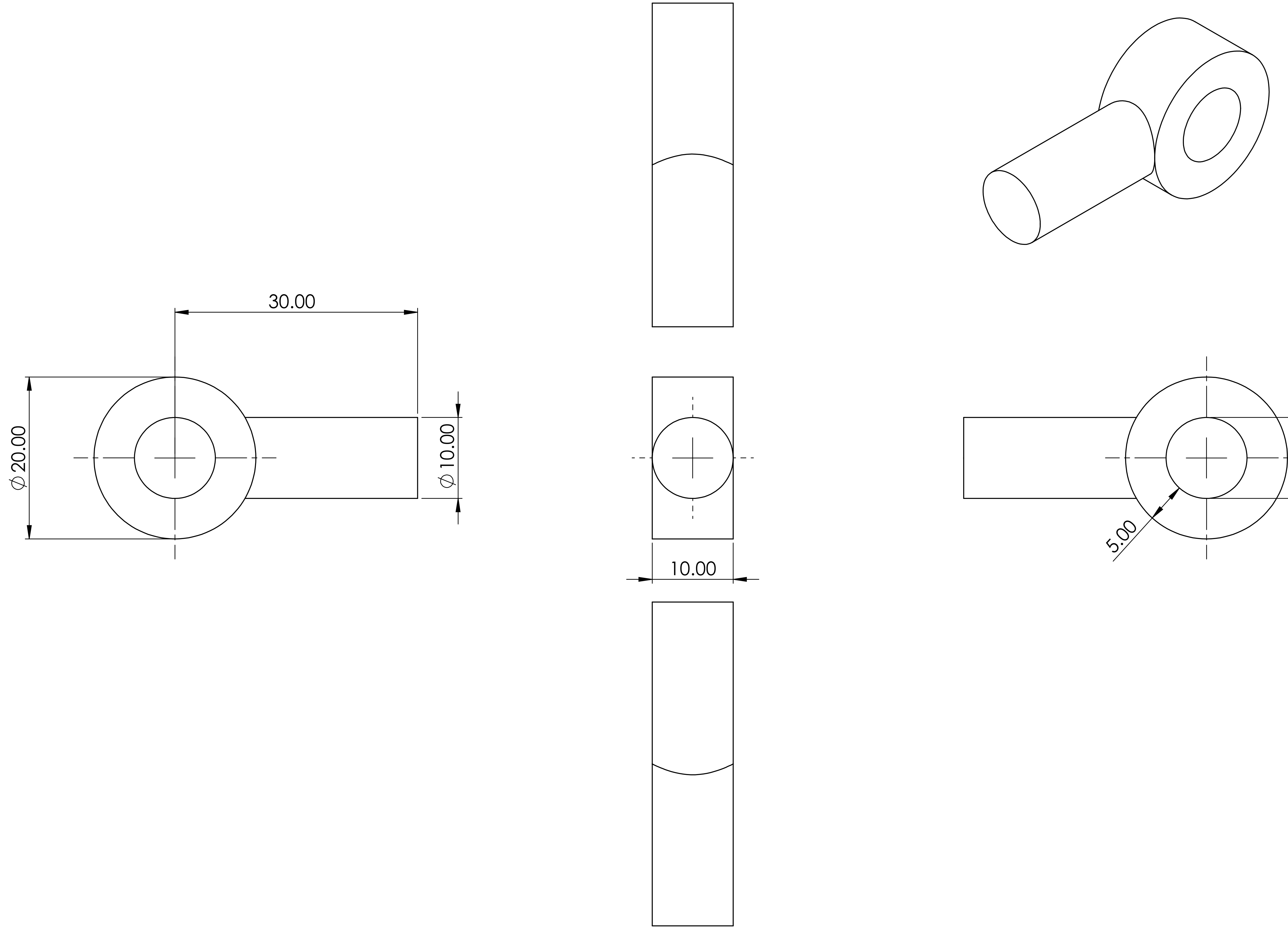
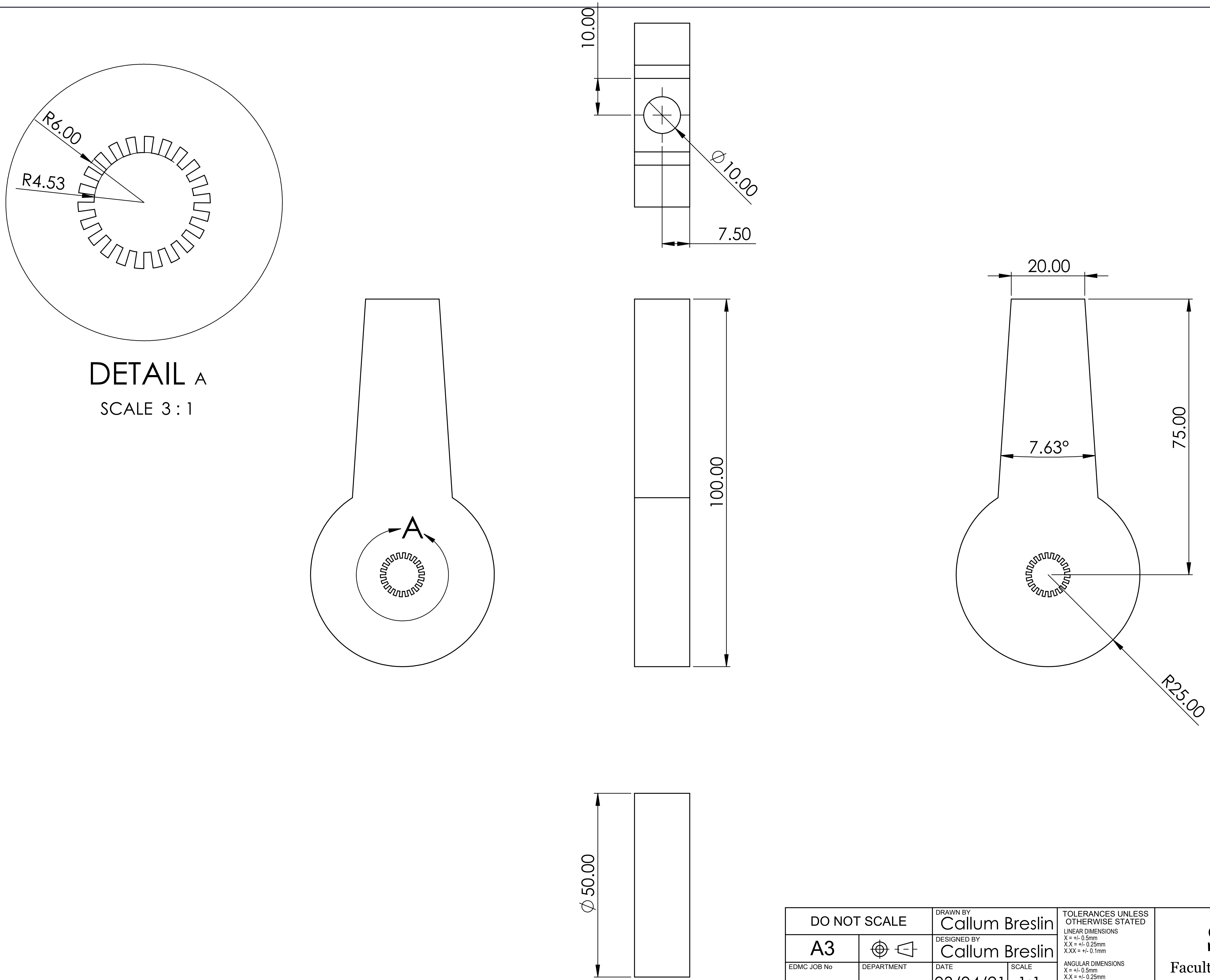
SHEET	No OFF	ASSEMBLY NUMBER	DRAWING NUMBER	REVISION
1		2	4	2



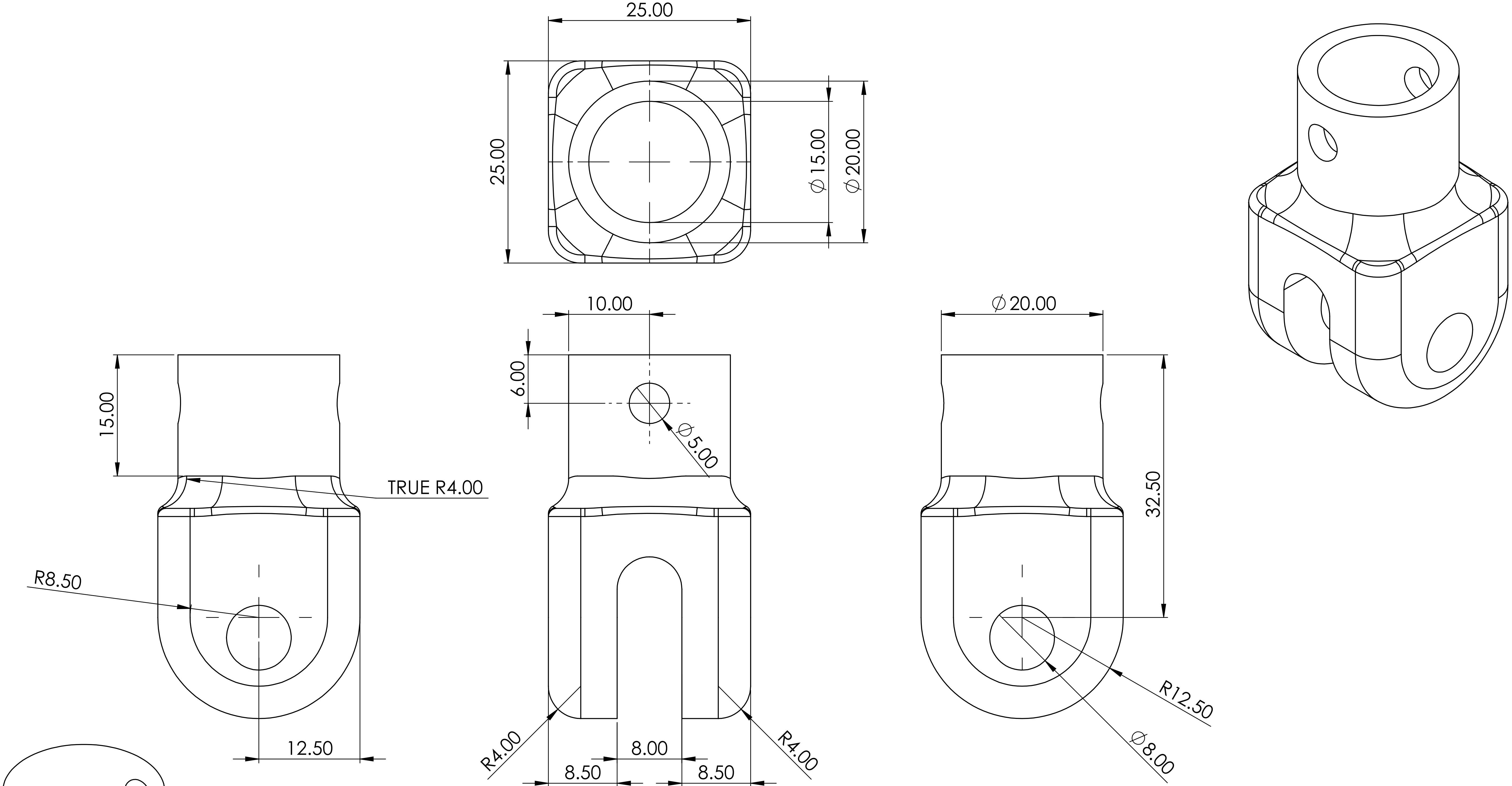
DO NOT SCALE		DRAWN BY Callum Breslin		TOLERANCES UNLESS OTHERWISE STATED LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED	UNIVERSITY OF Southampton Faculty of Engineering and the Environment
A3		DESIGNED BY Callum Breslin			
EDMC JOB No	DEPARTMENT	DATE 03/04/21	SCALE 1:1		TITLE
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	Stick Frame Bearing Link
REMOVE ALL SHARP EDGES / IF IN DOUBT PLEASE ASK		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.			SHEET 1 / No OFF / ASSEMBLY NUMBER 2 / DRAWING NUMBER 5 / REVISION 2

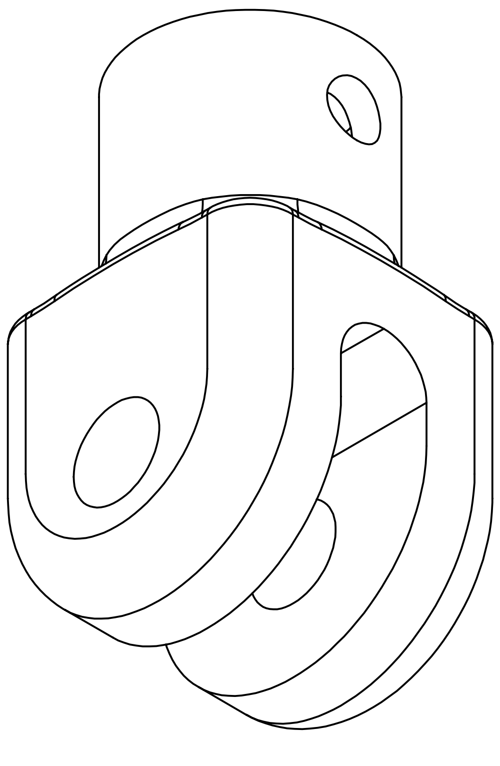


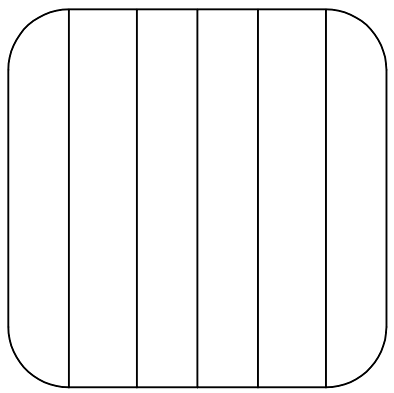
DO NOT SCALE		DRAWN BY Callum Breslin		TOLERANCES UNLESS OTHERWISE STATED		UNIVERSITY OF Southampton Faculty of Engineering and the Environment			
A3		DESIGNED BY Callum Breslin		LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm					
EDMC JOB No	DEPARTMENT	DATE 03/04/21	SCALE 2:1	ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED		TITLE			
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED		Bearing Longitudinal Pivot			
REMOVE ALL SHARP EDGES		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.				SHEET 6	No OFF	ASSEMBLY NUMBER 2	DRAWING NUMBER 6 / REVISION 2
IF IN DOUBT PLEASE ASK									



DO NOT SCALE		DRAWN BY Callum Breslin		TOLERANCES UNLESS OTHERWISE STATED LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED	UNIVERSITY OF Southampton Faculty of Engineering and the Environment
A3		DESIGNED BY Callum Breslin			
EDMC JOB No	DEPARTMENT	DATE 03/04/21	SCALE 1:1		TITLE
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	Front Servo Arm
REMOVE ALL SHARP EDGES IF IN DOUBT PLEASE ASK		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.			SHEET 1 | No OFF | ASSEMBLY NUMBER 2 | DRAWING NUMBER 7 | REVISION 1







DO NOT SCALE		DRAWN BY Callum Breslin		TOLERANCES UNLESS OTHERWISE STATED	UNIVERSITY OF Southampton Faculty of Engineering and the Environment
A3		DESIGNED BY Callum Breslin		LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED	
EDMC JOB No	DEPARTMENT	DATE 03/04/21	SCALE 2:1		TITLE
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	Lower Scissor Attachment
REMOVE ALL SHARP EDGES		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.			SHEET 1 · No OFF · ASSEMBLY NUMBER 2 · DRAWING NUMBER 8 · REVISION 1
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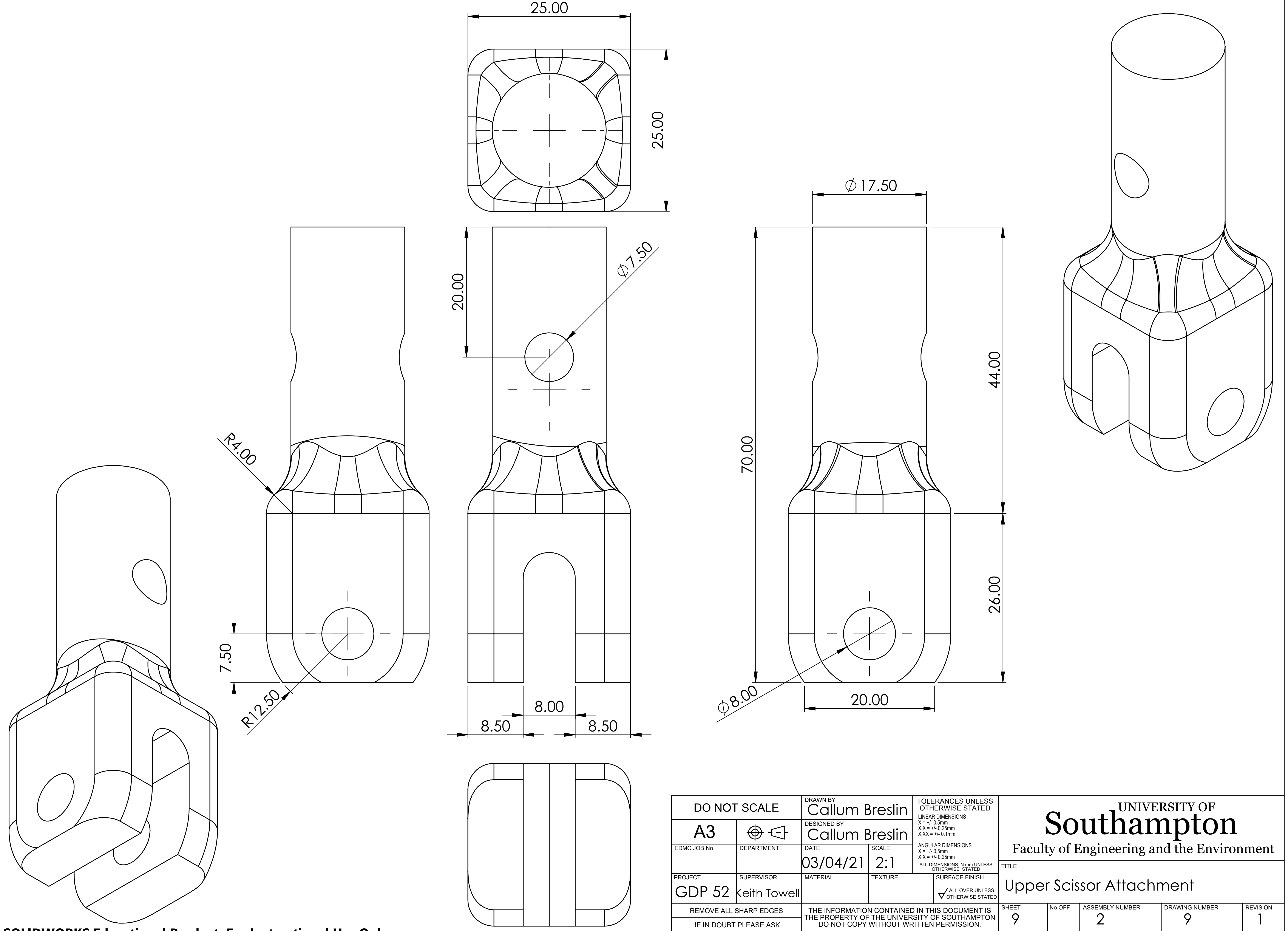
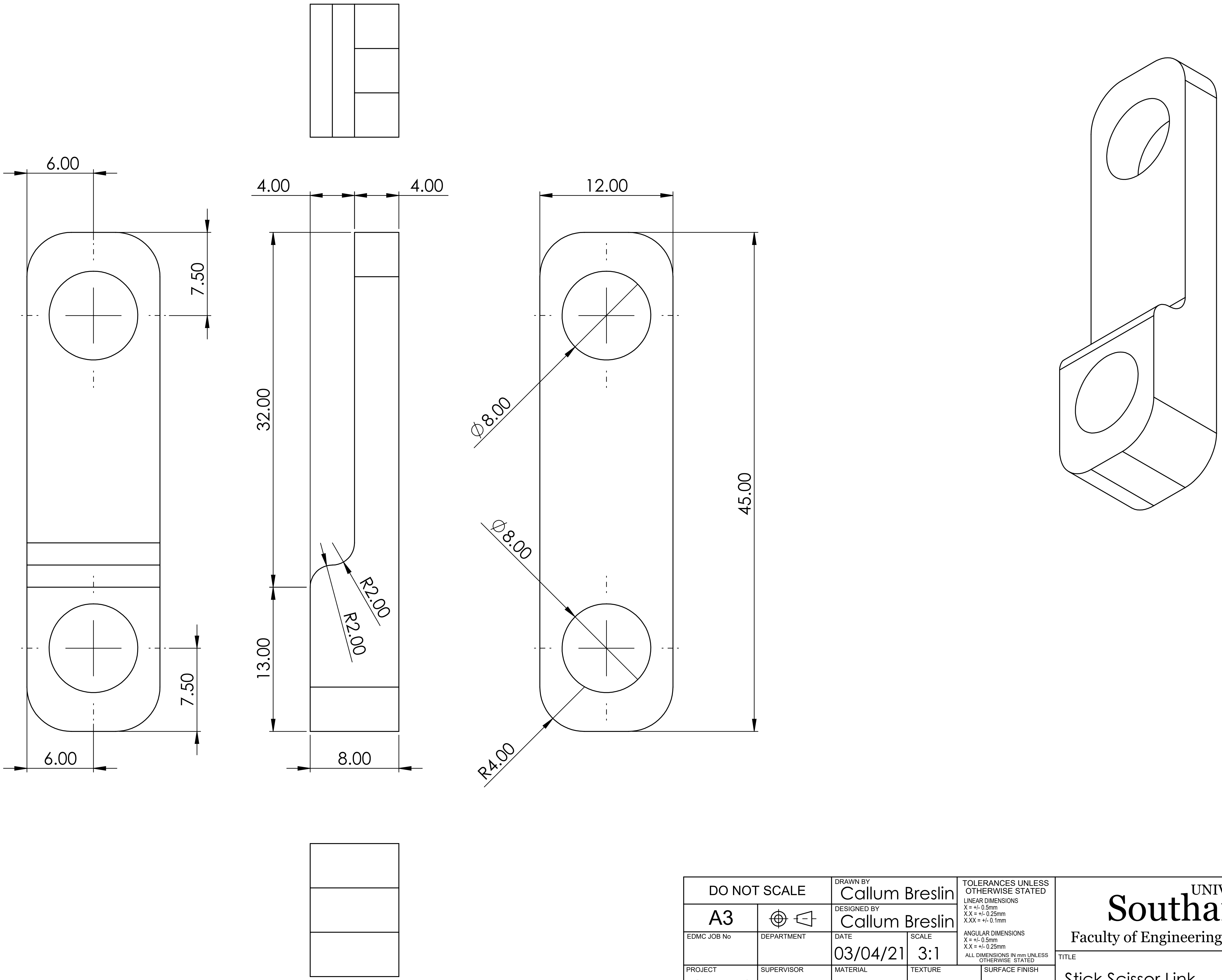
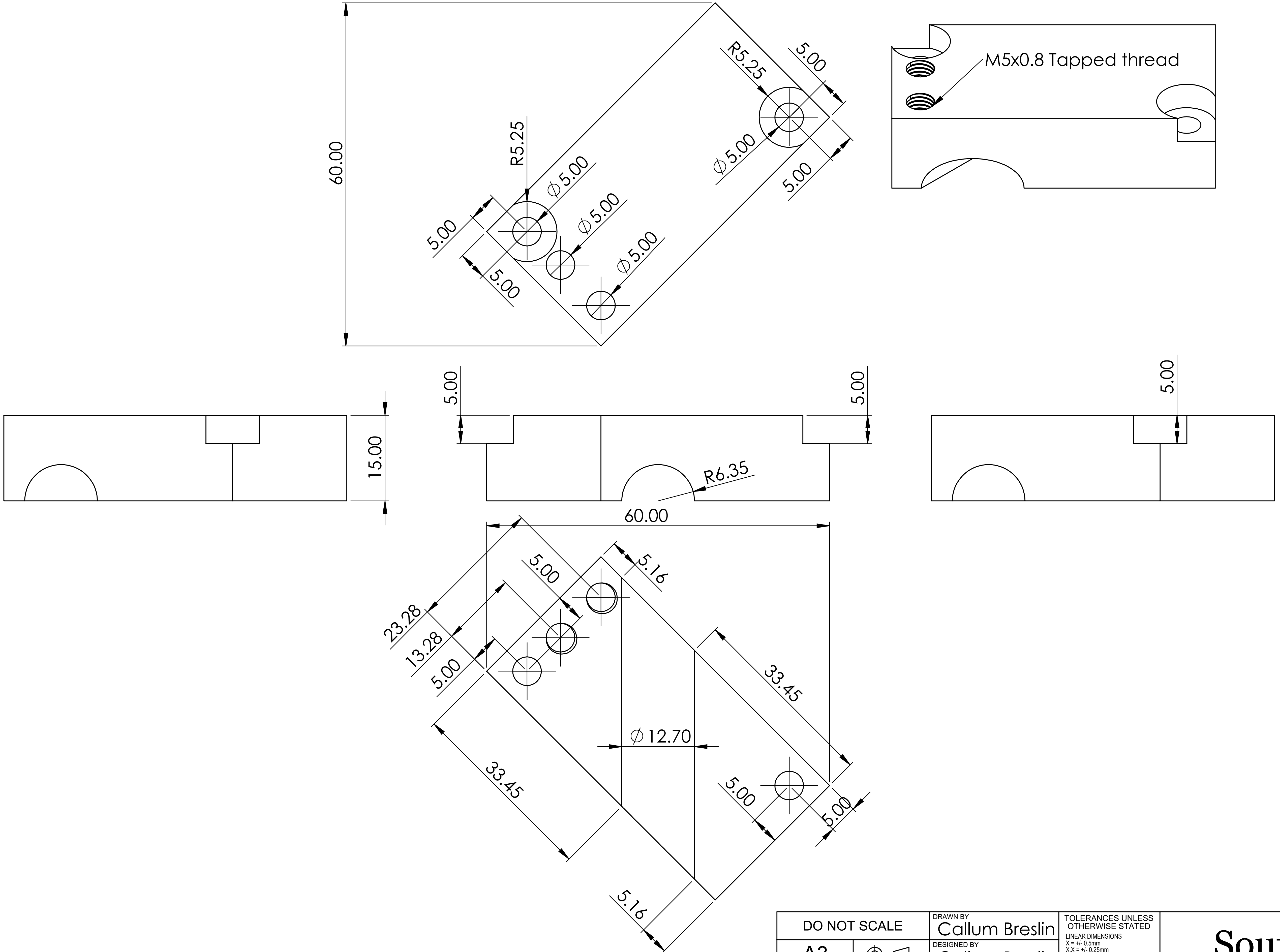


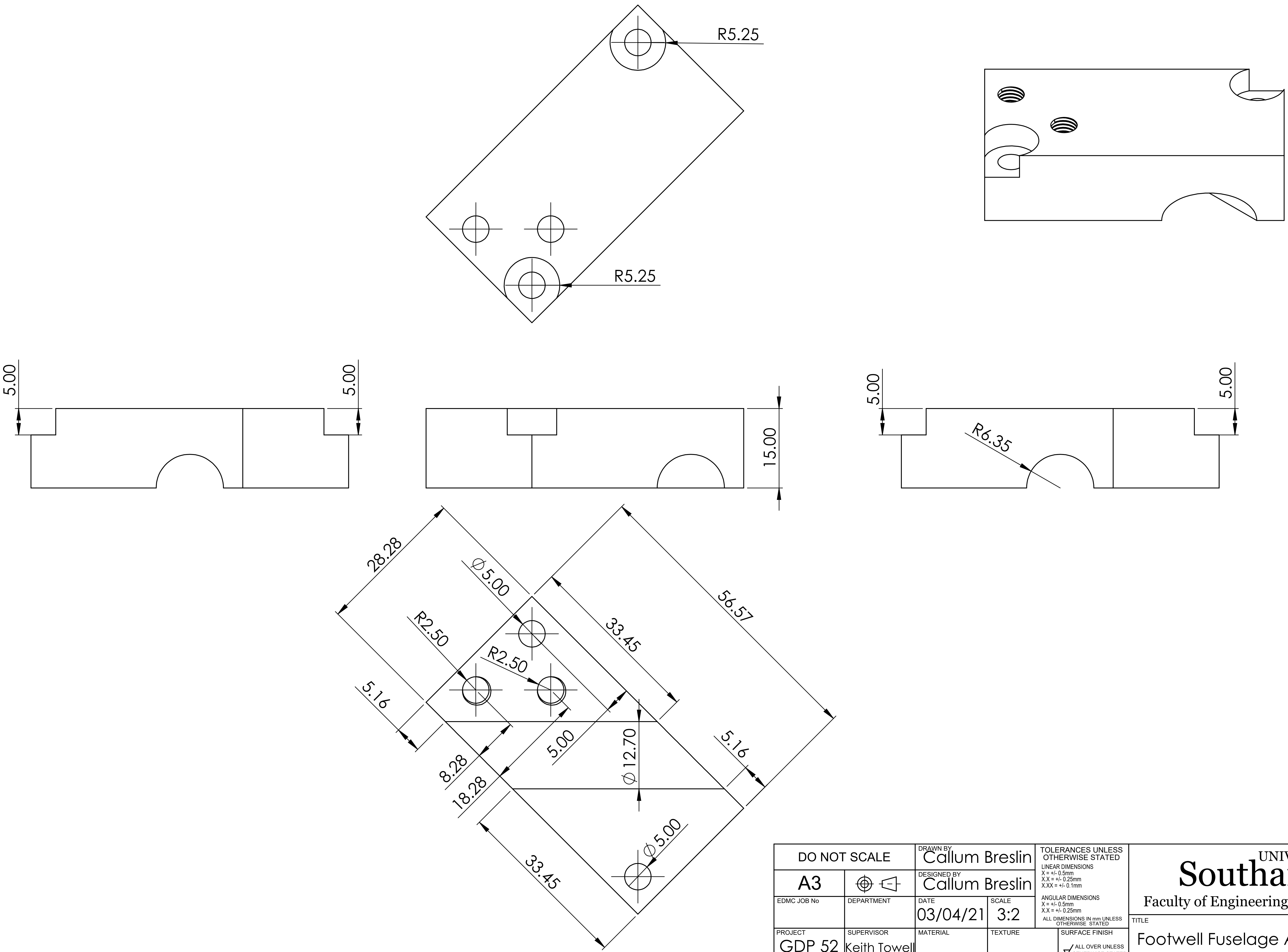
DO NOT SCALE		DRAWN BY Callum Breslin		TOLERANCES UNLESS OTHERWISE STATED LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED	UNIVERSITY OF Southampton Faculty of Engineering and the Environment
A3		DESIGNED BY Callum Breslin			
EDMC JOB No	DEPARTMENT	DATE 03/04/21	SCALE 2:1		TITLE
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	Upper Scissor Attachment
REMOVE ALL SHARP EDGES IF IN DOUBT PLEASE ASK		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.			SHEET 9 | No OFF | ASSEMBLY NUMBER 2 | DRAWING NUMBER 9 | REVISION 1



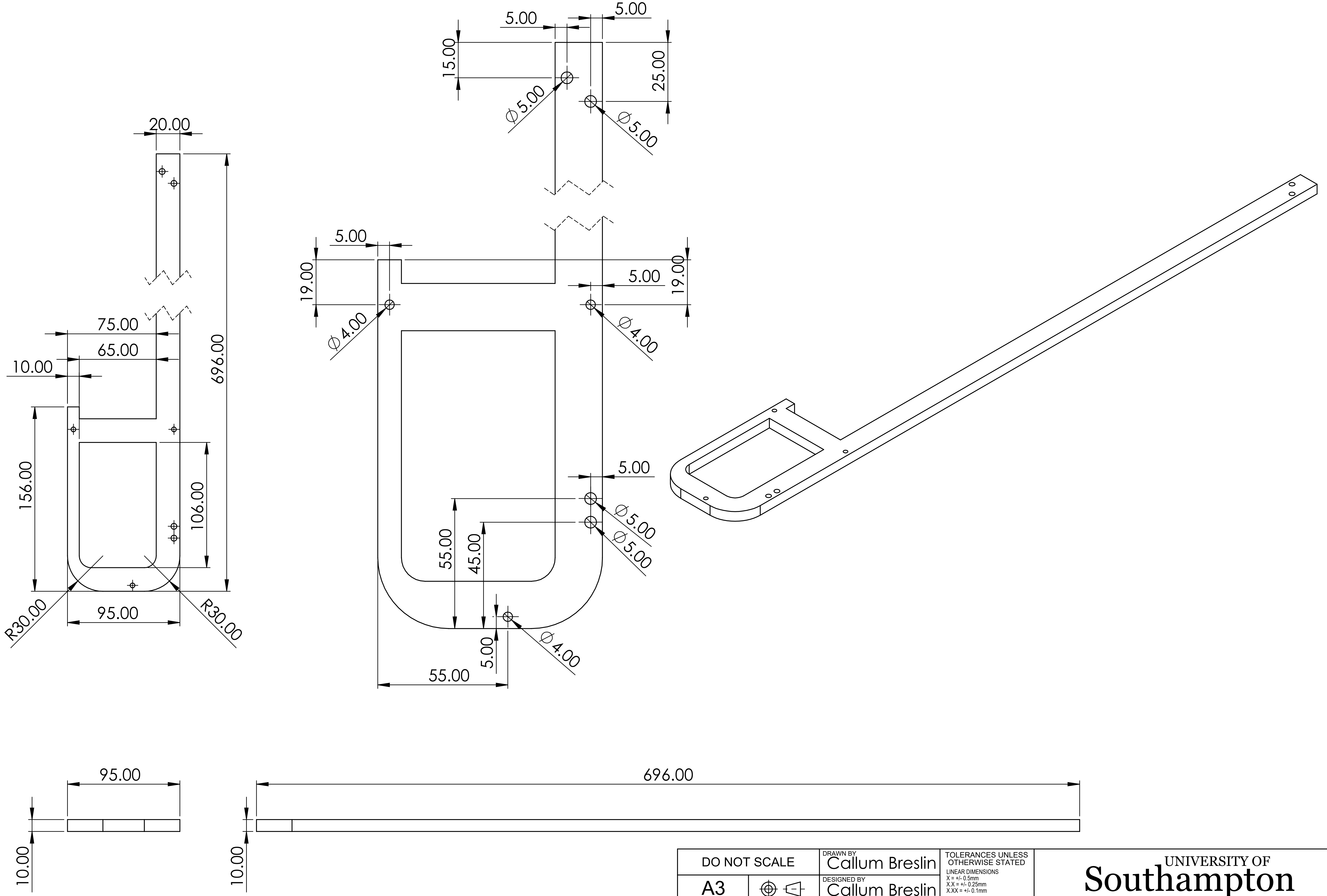
DO NOT SCALE		DRAWN BY Callum Breslin		TOLERANCES UNLESS OTHERWISE STATED LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED	UNIVERSITY OF Southampton Faculty of Engineering and the Environment
A3		DESIGNED BY Callum Breslin			
EDMC JOB No	DEPARTMENT	DATE 03/04/21	SCALE 3:1		TITLE Stick Scissor Link
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	
REMOVE ALL SHARP EDGES IF IN DOUBT PLEASE ASK		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.			SHEET 1 / No OFF / ASSEMBLY NUMBER 2 / DRAWING NUMBER 10 / REVISION 2



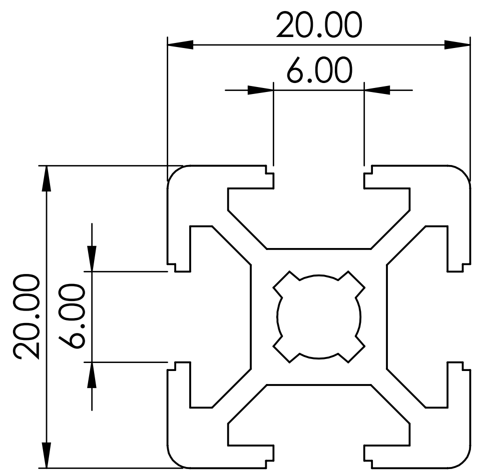
DO NOT SCALE		DRAWN BY Callum Breslin		TOLERANCES UNLESS OTHERWISE STATED LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED	UNIVERSITY OF Southampton Faculty of Engineering and the Environment			
A3		DESIGNED BY Callum Breslin						
EDMC JOB No	DEPARTMENT	DATE 03/04/21	SCALE 3:2		TITLE			
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	Footwell Fuselage Attachment A			
REMOVE ALL SHARP EDGES		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.			SHEET 1	No OFF	ASSEMBLY NUMBER 2	DRAWING NUMBER 11
IF IN DOUBT PLEASE ASK								REVISION 1



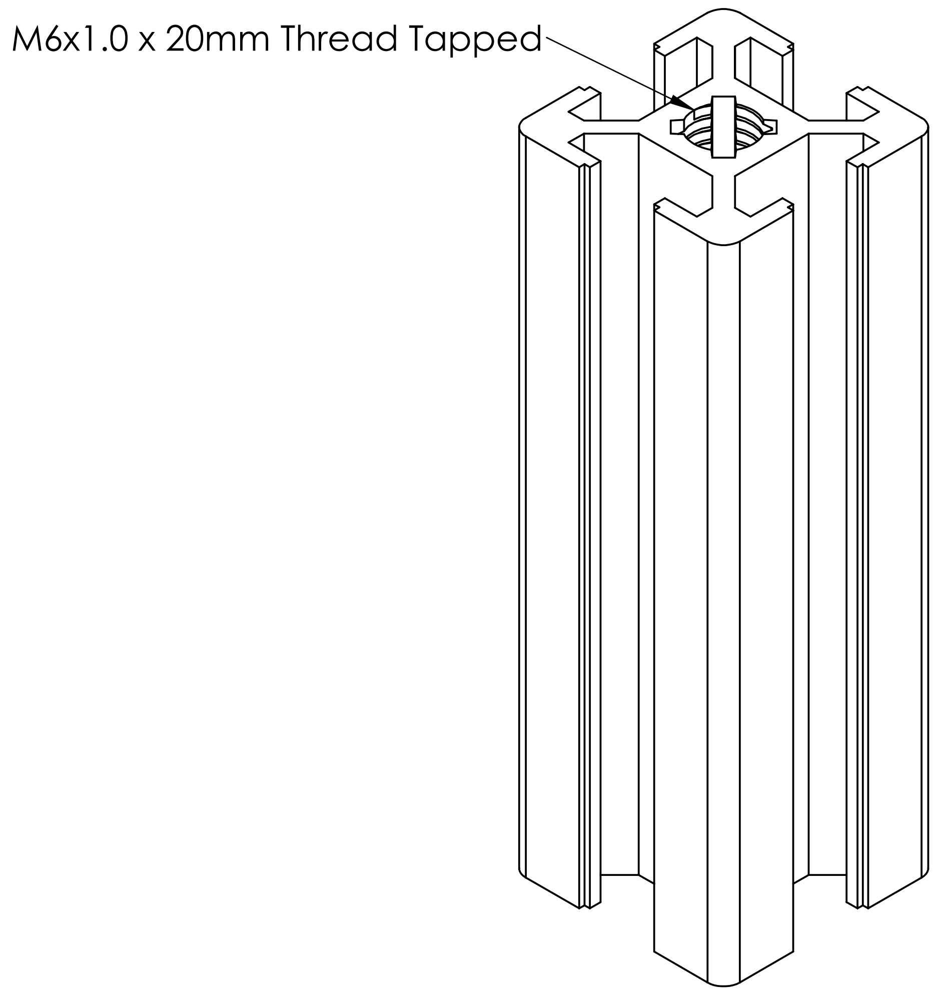
DO NOT SCALE		DRAWN BY Callum Breslin		TOLERANCES UNLESS OTHERWISE STATED LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED	UNIVERSITY OF Southampton Faculty of Engineering and the Environment
A3		DESIGNED BY Callum Breslin			
EDMC JOB No	DEPARTMENT	DATE 03/04/21	SCALE 3:2		TITLE
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	Footwell Fuselage Attachment B
REMOVE ALL SHARP EDGES		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.			SHEET 1 / No OFF / ASSEMBLY NUMBER 2 / DRAWING NUMBER 12 / REVISION 1
IF IN DOUBT PLEASE ASK					

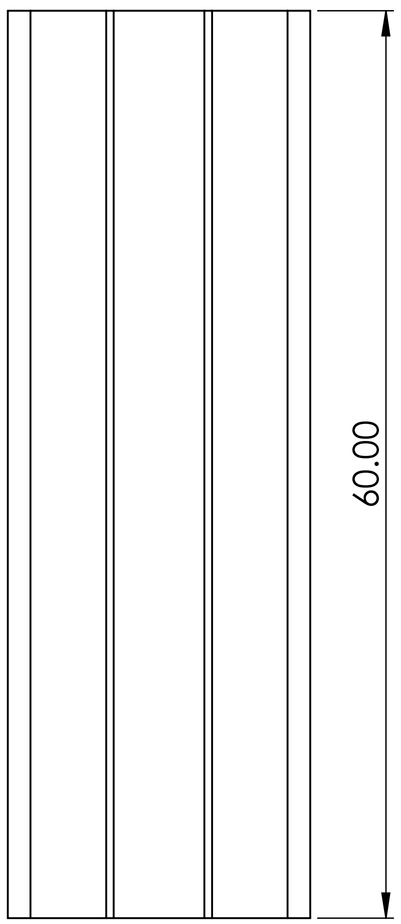


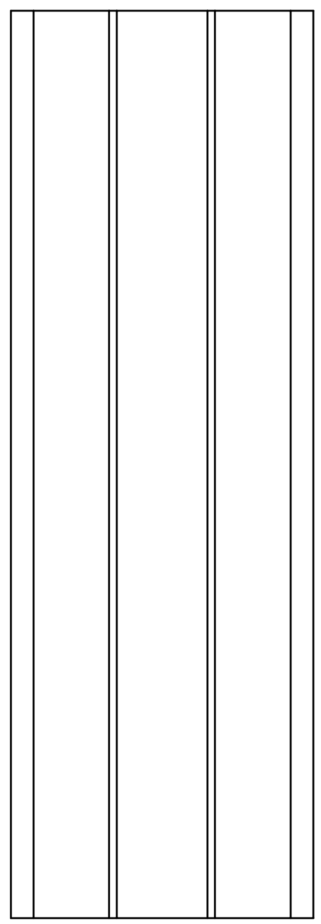
DO NOT SCALE		DRAWN BY Callum Breslin		TOLERANCES UNLESS OTHERWISE STATED LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED	UNIVERSITY OF Southampton Faculty of Engineering and the Environment	
A3		DESIGNED BY Callum Breslin				
EDMC JOB No	DEPARTMENT	DATE 25/04/21	SCALE 2:3		TITLE	
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	Front Servo Mounting Plate	
REMOVE ALL SHARP EDGES		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.			SHEET 1 / No OFF / ASSEMBLY NUMBER 2	DRAWING NUMBER 13 / REVISION 1
IF IN DOUBT PLEASE ASK						



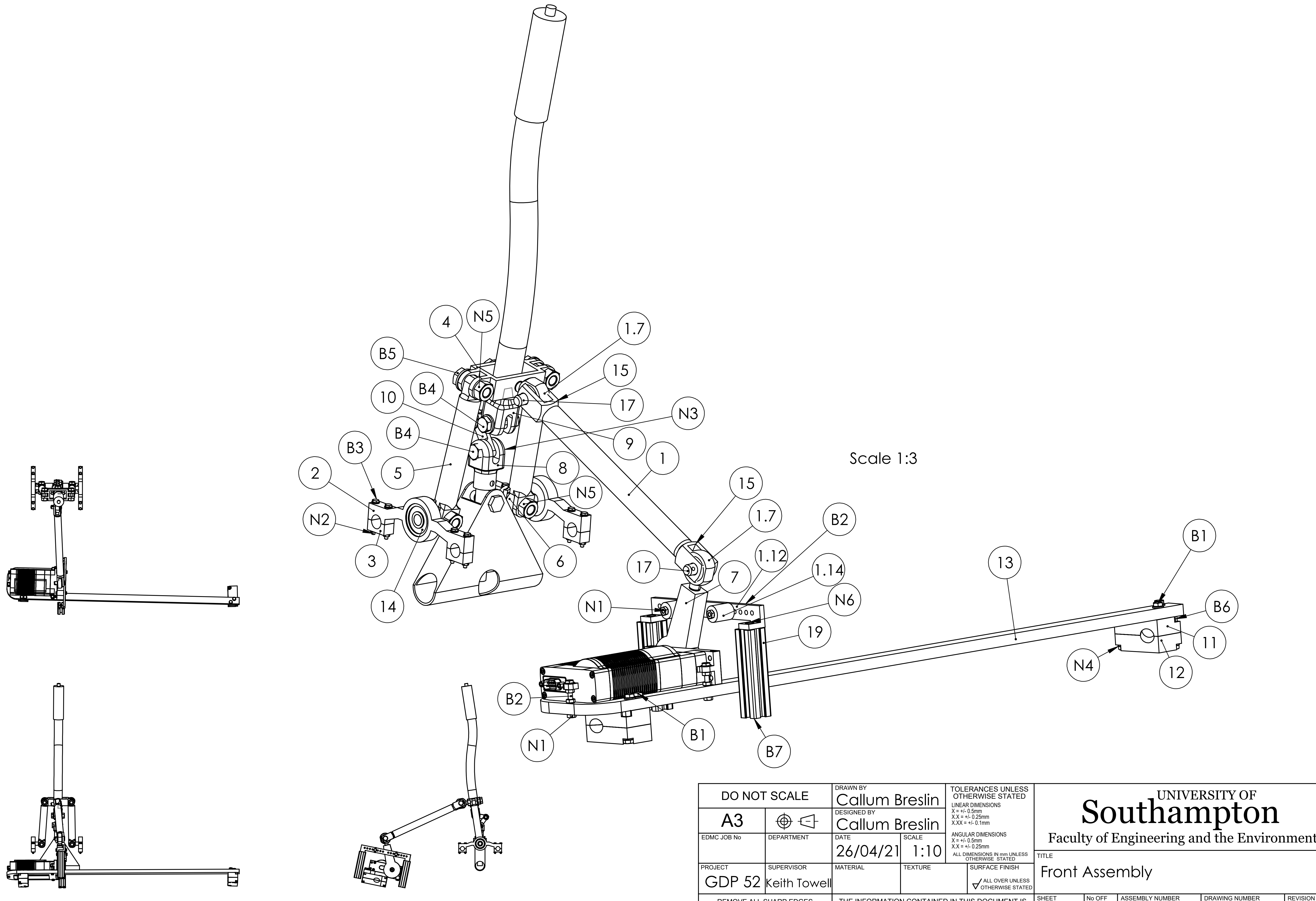
Standard 20x20 Aluminium Extrusion Purchased







DO NOT SCALE		DRAWN BY Callum Breslin		TOLERANCES UNLESS OTHERWISE STATED LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED	UNIVERSITY OF Southampton Faculty of Engineering and the Environment
A3		DESIGNED BY Callum Breslin			
EDMC JOB No	DEPARTMENT	DATE 25/04/21	SCALE 2:3		TITLE
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	Front End Stop Leg
REMOVE ALL SHARP EDGES		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.			SHEET 1 / No OFF / ASSEMBLY NUMBER 2 / DRAWING NUMBER 19 / REVISION 1
IF IN DOUBT PLEASE ASK					



DO NOT SCALE		DRAWN BY Callum Breslin		TOLERANCES UNLESS OTHERWISE STATED LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED	UNIVERSITY OF Southampton Faculty of Engineering and the Environment
A3		DESIGNED BY Callum Breslin			
EDMC JOB No	DEPARTMENT	DATE 26/04/21	SCALE 1:10		TITLE Front Assembly
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	
REMOVE ALL SHARP EDGES		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.			SHEET 1 · No OFF 2 · ASSEMBLY NUMBER 2 · DRAWING NUMBER · REVISION 2
IF IN DOUBT PLEASE ASK					

Number	Part Number	Part Name	Quantity
1	M15610-02-01	Front Push Rod	1
2	M15610-02-02	Bearing Mount Top	2
3	M15610-02-03	Bearing Mount Bottom	4
4	M15610-02-04	Stick Mounting Frame	1
5	M15610-02-05	Stick-Frame-Bearing Link	2
6	M15610-02-06	Bearing Longitudinal Pivot	2
7	M15610-02-07	Front Servo Arm	1
8	M15610-02-08	Lower Scissor Attachment	1
9	M15610-02-09	Upper Scissor Attachment	1
10	M15610-02-10	Scissor Link	2
11	M15610-02-11	Footwell Fuselage Attachment A	2
12	M15610-02-12	Footwell Fuselage Attachment B	2
13	M15610-02-13	Front Servo Mounting Plate	1
14	M15610-02-14	RS PRO 10mm I.D. 30mm O.D. Bearing	2
15	M15610-02-15	Male Threaded Clevis Joint	2
17	M15610-02-17	Clevis Pin	2
18	M15610-02-18	Clevis E-Clip	2
19	M15610-02-19	Front End Stop Leg	2
1.7	M15610-01-07	SKF Rod End Spherical Bearing	2
1.12	M15610-01-12	End Stop Bracket	1
1.14	M15610-01-14	End Stop	2

Number	Part Number	Part Name	Quantity
B1	M15610-02-B1	M5x25mm Grade 8.8 Bolt	4
B2	M15610-02-B2	M4x30mm Grade 8.8 Bolt	5
B3	M15610-02-B3	M3x30mm Grade 8.8 Bolt	8
B4	M15610-02-B4	M8x35mm Grade 8.8 Bolt	3
B5	M15610-02-B5	M10x30mm Grade 8.8 Bolt	4
B6	M15610-02-B6	M5x30mm Grade 8.8 Bolt	4
B7	M15610-02-B7	M6x25mm Grade 8.8 Bolt	4
N1	M15610-02-N1	M4 Grade 8.8 Nut	11
N2	M15610-02-N2	M3 Grade 8.8 Nut	8
N3	M15610-02-N3	M8 Grade 8.8 Nut	3
N4	M15610-02-N4	M5 Grade 8.8 Nut	4
N5	M15610-02-N5	M10 Grade 8.8 Nut	4
N6	M15610-02-N6	M6 Grade 8.8 Nut	4
W1	M15610-02-W1	M10 Grade 8.8 Washer	4
W2	M15610-02-W2	M8 Grade 8.8 Washer	3
W3	M15610-02-W3	M6 Grade 8.8 Washer	4
W4	M15610-02-W4	M5 Grade 8.8 Washer	8
W5	M15610-02-W5	M4 Grade 8.8 Washer	5
W6	M15610-02-W6	M3 Grade 8.8 Washer	8

DO NOT SCALE

A3

EDMC JOB No | DEPARTMENT

DRAWN BY Callum Breslin

DESIGNED BY Callum Breslin

DATE 26/04/21 | SCALE 1:10

TOLERANCES UNLESS OTHERWISE STATED
LINEAR DIMENSIONS
X = +/- 0.5mm
X.X = +/- 0.25mm
X.XX = +/- 0.1mm
ANGULAR DIMENSIONS
X = +/- 0.5mm
X.X = +/- 0.25mm
ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED

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Faculty of Engineering and the Environment

PROJECT GDP 52 | SUPERVISOR Keith Towell | MATERIAL | TEXTURE | SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED

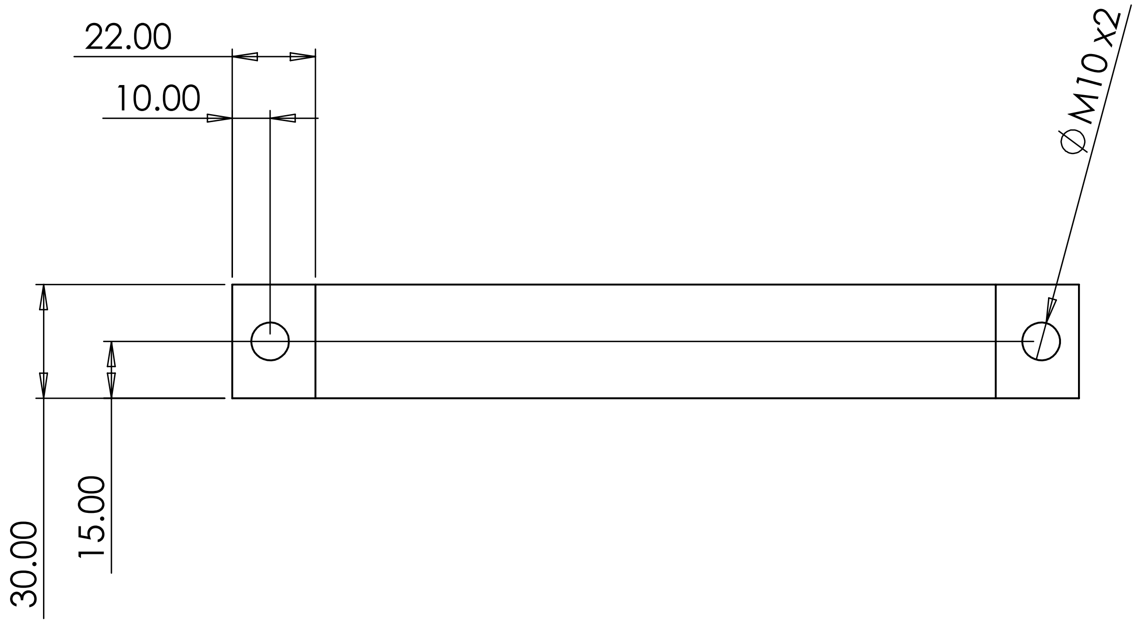
TITLE Front Assembly

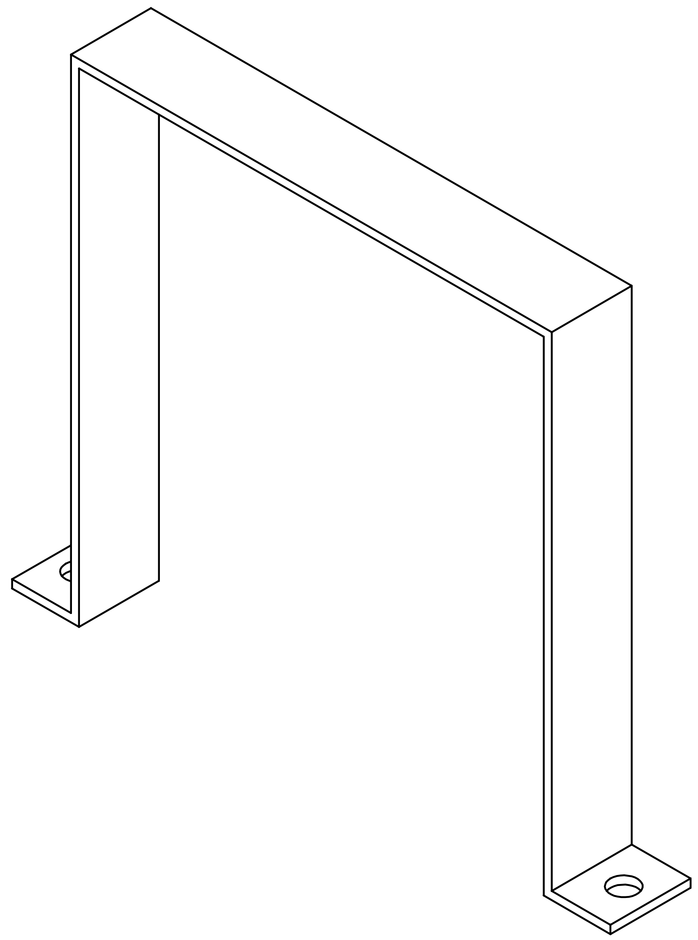
REMOVE ALL SHARP EDGES

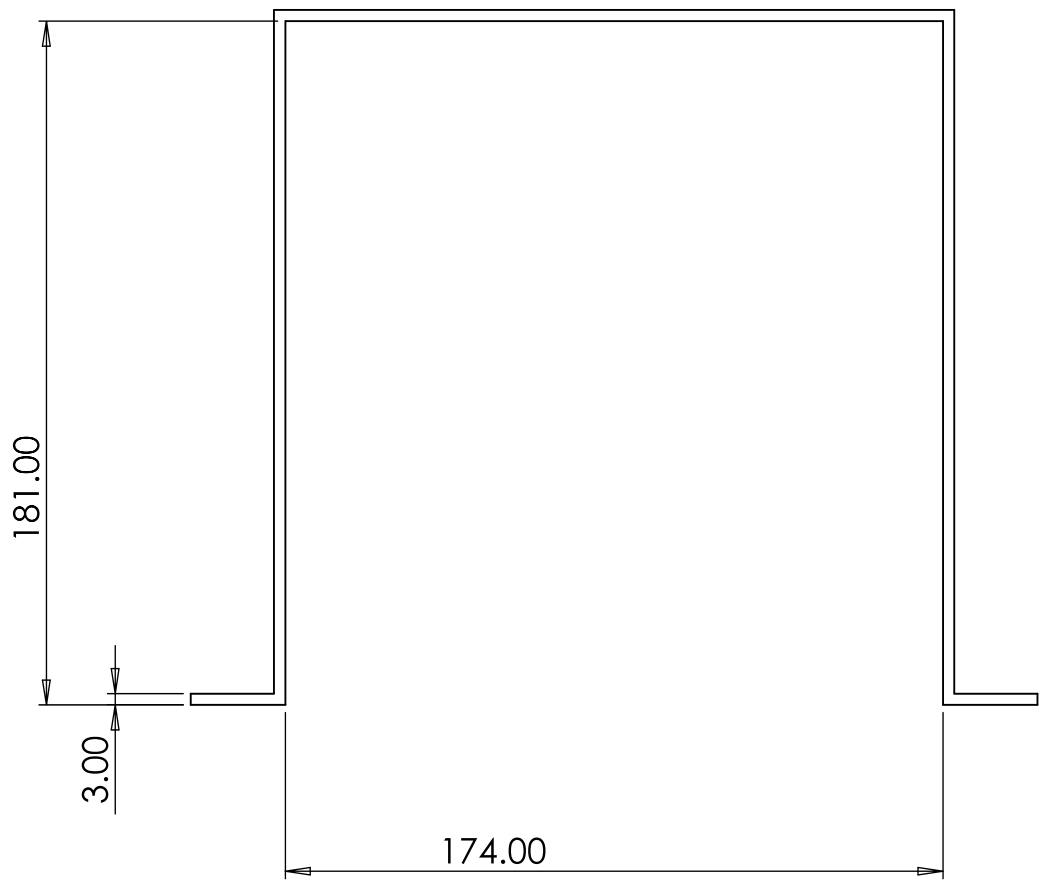
IF IN DOUBT PLEASE ASK

SHEET 2 | No OFF 2 | ASSEMBLY NUMBER 2 | DRAWING NUMBER | REVISION 2

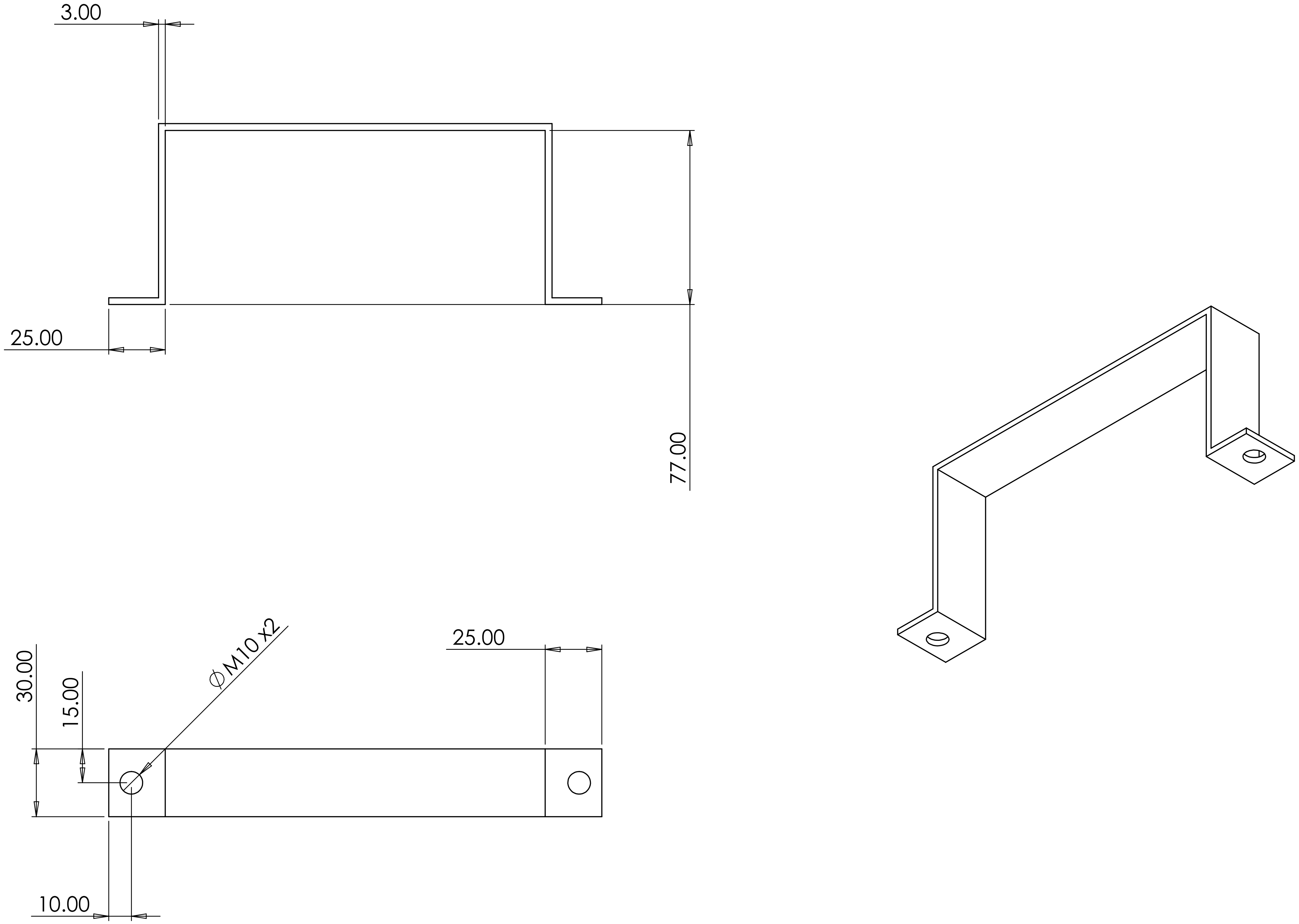
Sub Assembly 3: Server Rack Assembly



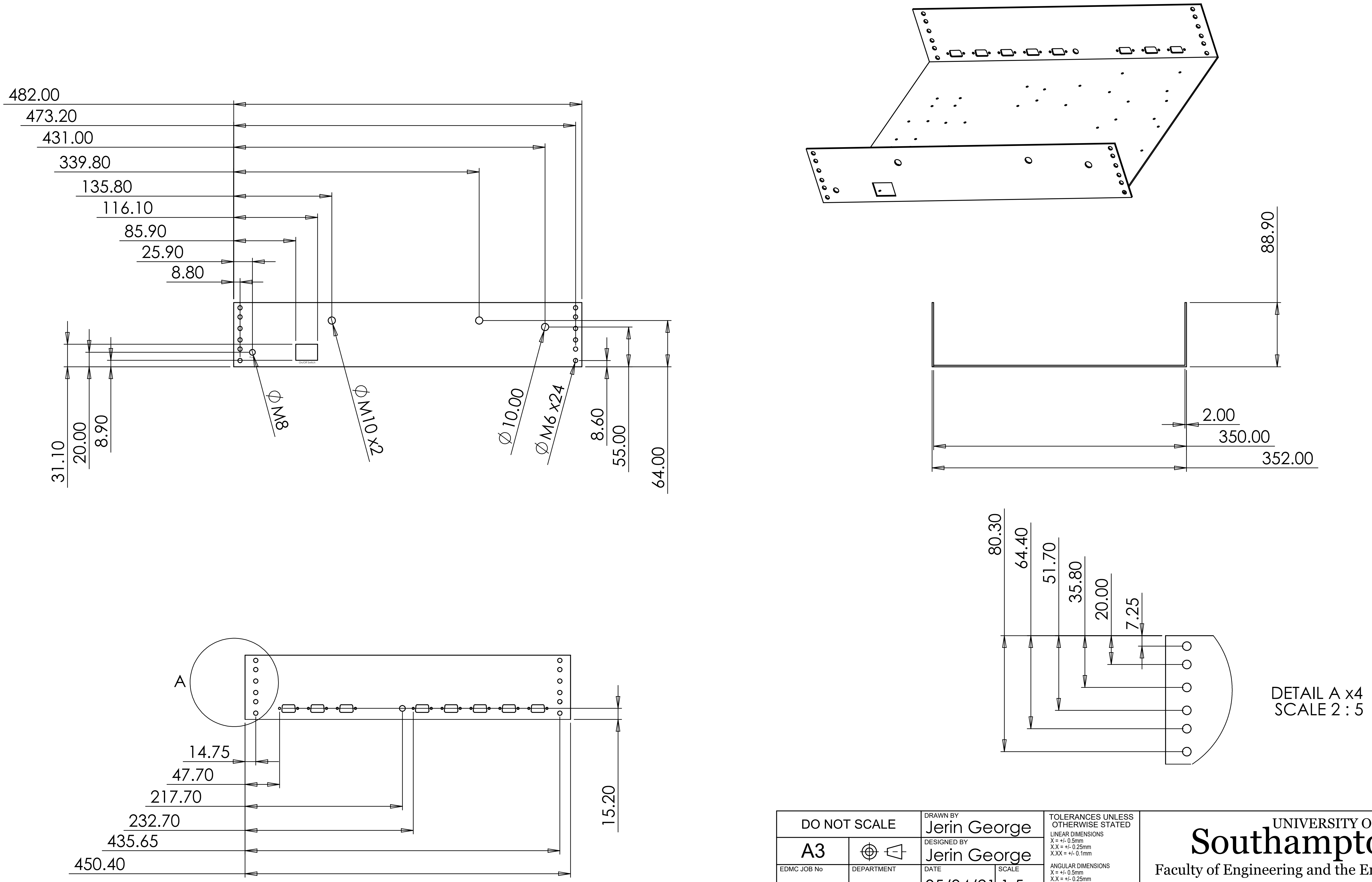




DO NOT SCALE		DRAWN BY Jerin George		TOLERANCES UNLESS OTHERWISE STATED LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED	UNIVERSITY OF Southampton Faculty of Engineering and the Environment
A3		DESIGNED BY Jerin George			
EDMC JOB No	DEPARTMENT	DATE 05/04/21	SCALE 1:2		TITLE Battery Bracket Long
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL Alumimium 6061-T6	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	
REMOVE ALL SHARP EDGES IF IN DOUBT PLEASE ASK		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.			SHEET 1 | No OFF 1 | ASSEMBLY NUMBER 3 | DRAWING NUMBER 1 | REVISION 1



DO NOT SCALE		DRAWN BY Jerin George		TOLERANCES UNLESS OTHERWISE STATED LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED	UNIVERSITY OF Southampton Faculty of Engineering and the Environment	
A3		DESIGNED BY Jerin George				
EDMC JOB No	DEPARTMENT	DATE 05/04/21	SCALE 1:2		TITLE Battery Bracket Short	
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL Alumimium 6061-T6	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED		
REMOVE ALL SHARP EDGES IF IN DOUBT PLEASE ASK		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.			SHEET 1 | No OFF 1 | ASSEMBLY NUMBER 3 | DRAWING NUMBER 2	REVISION 1



DO NOT SCALE		DRAWN BY Jerin George		TOLERANCES UNLESS OTHERWISE STATED LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED
A3		DESIGNED BY Jerin George		
EDMC JOB No	DEPARTMENT	DATE 05/04/21	SCALE 1:5	
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL Alumimium 6061-T6	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED
REMOVE ALL SHARP EDGES		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.		
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Faculty of Engineering and the Environment

TITLE
Server Rack Tray 2U

SHEET	No OFF	ASSEMBLY NUMBER	DRAWING NUMBER	REVISION
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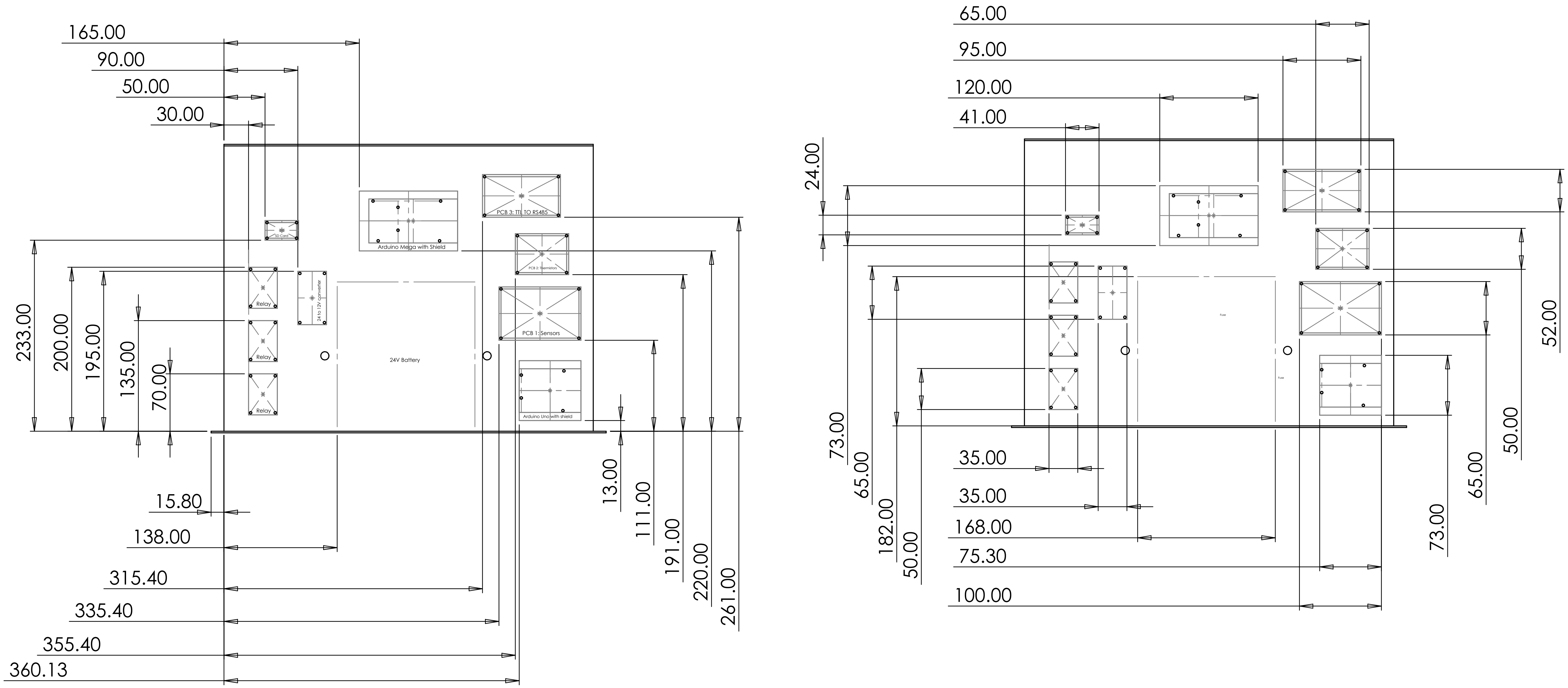

DO NOT SCALE

A3

EDMC JOB No | DEPARTMENT

PROJECT: GDP 52

SUPERVISOR: Keith Towell

REMOVE ALL SHARP EDGES

IF IN DOUBT PLEASE ASK

DRAWN BY: Jerin George

DESIGNED BY: Jerin George

DATE: 05/04/21

SCALE: 1:5

MATERIAL: Alumimium 6061-T6

TEXTURE

TOLERANCES UNLESS OTHERWISE STATED
LINEAR DIMENSIONS
X = +/- 0.5mm
X.X = +/- 0.25mm
X.XX = +/- 0.1mm
ANGULAR DIMENSIONS
X = +/- 0.5mm
X.X = +/- 0.25mm
ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED

SURFACE FINISH: ALL OVER UNLESS OTHERWISE STATED

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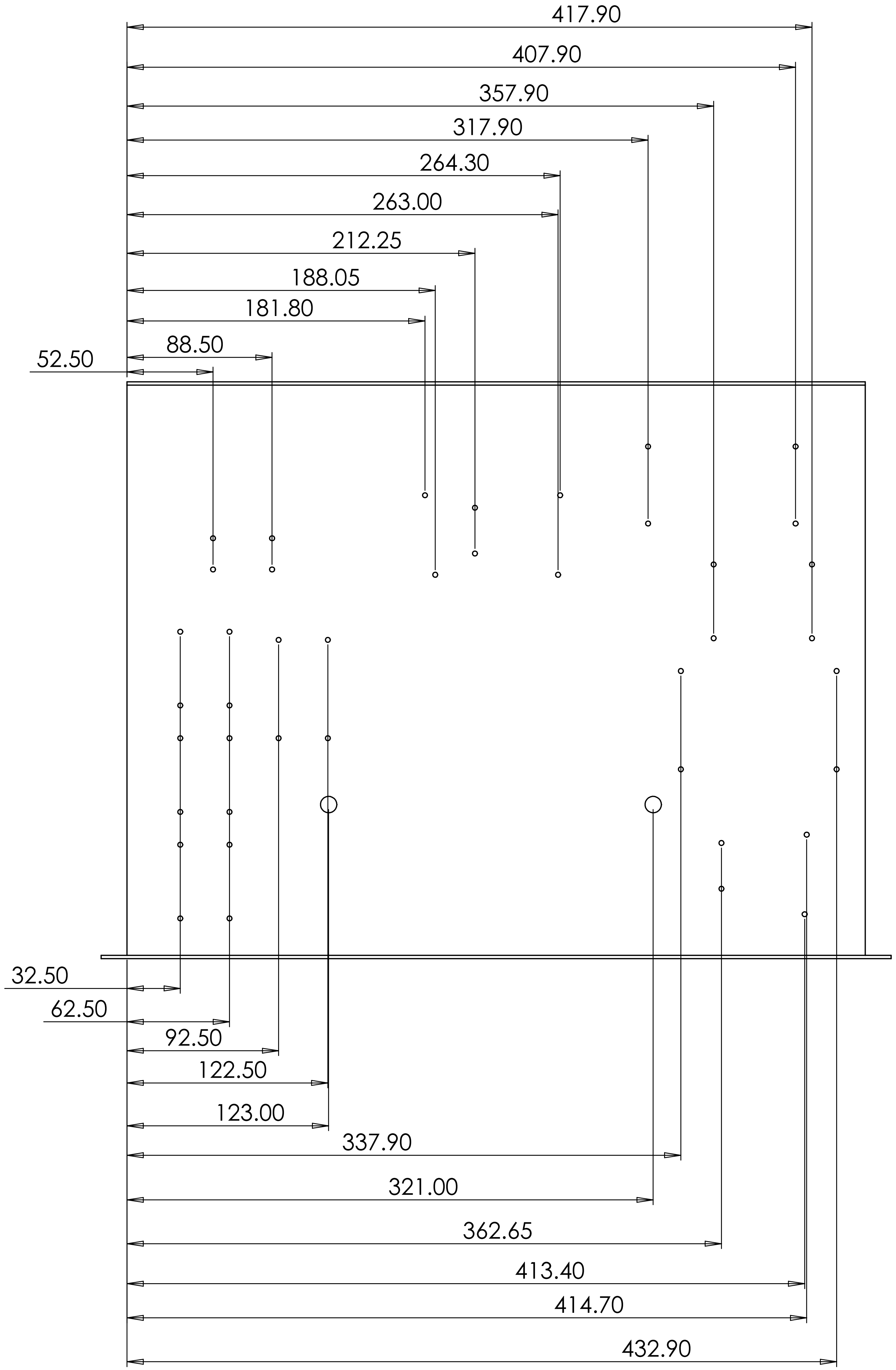
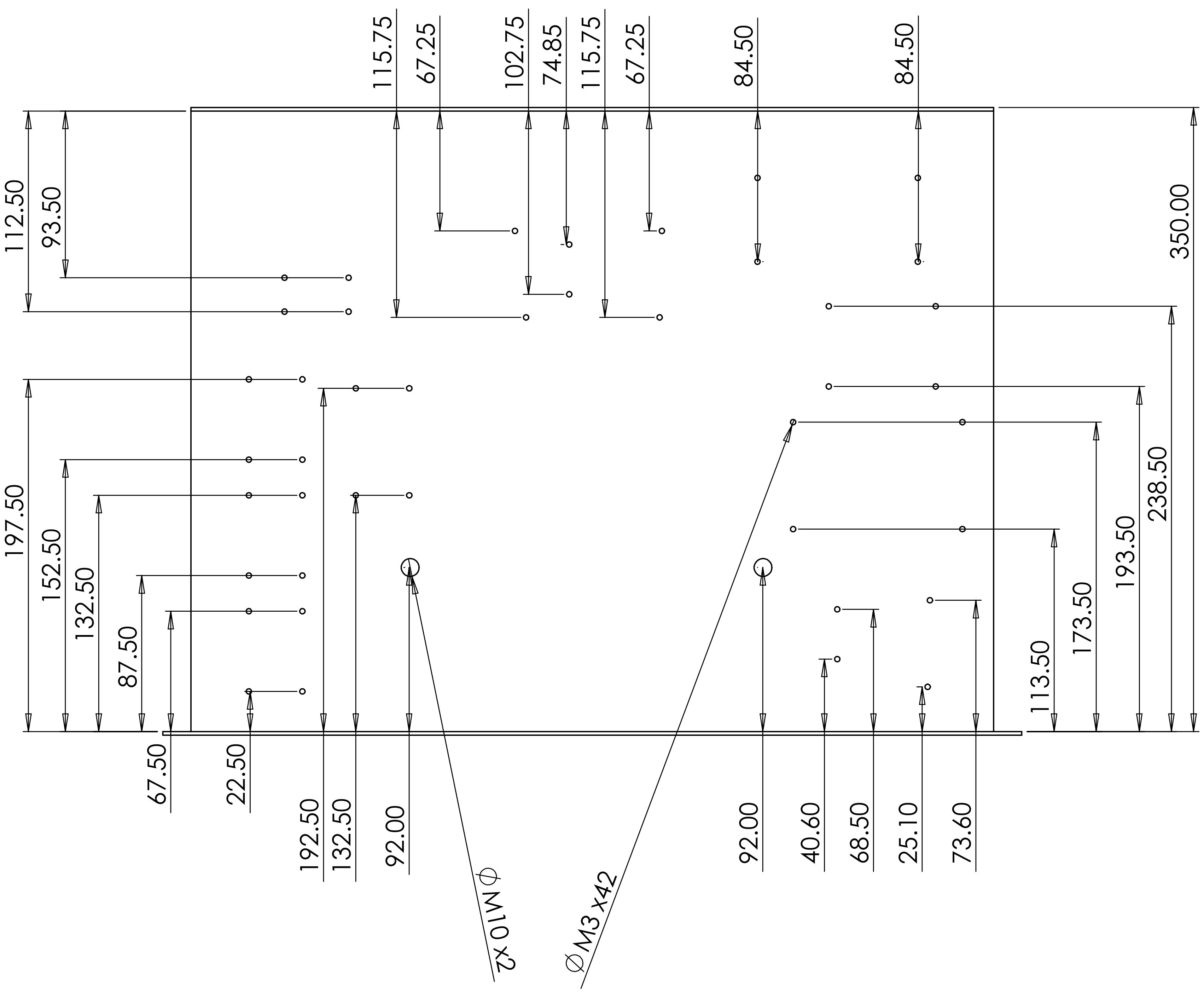
Faculty of Engineering and the Environment

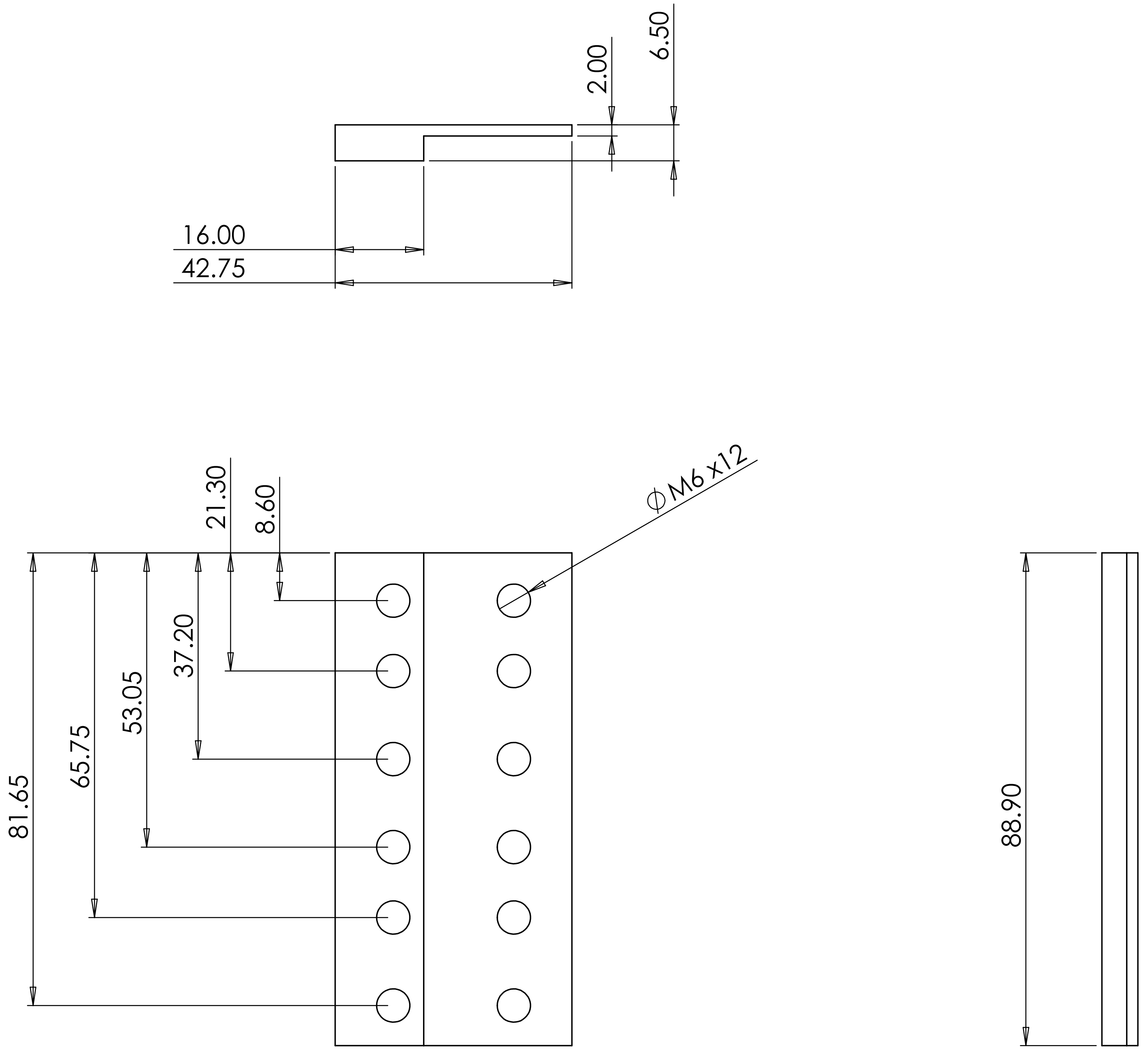
TITLE: Server Rack Tray 2U

SHEET	No OFF	ASSEMBLY NUMBER	DRAWING NUMBER	REVISION
2	3	3	3	1

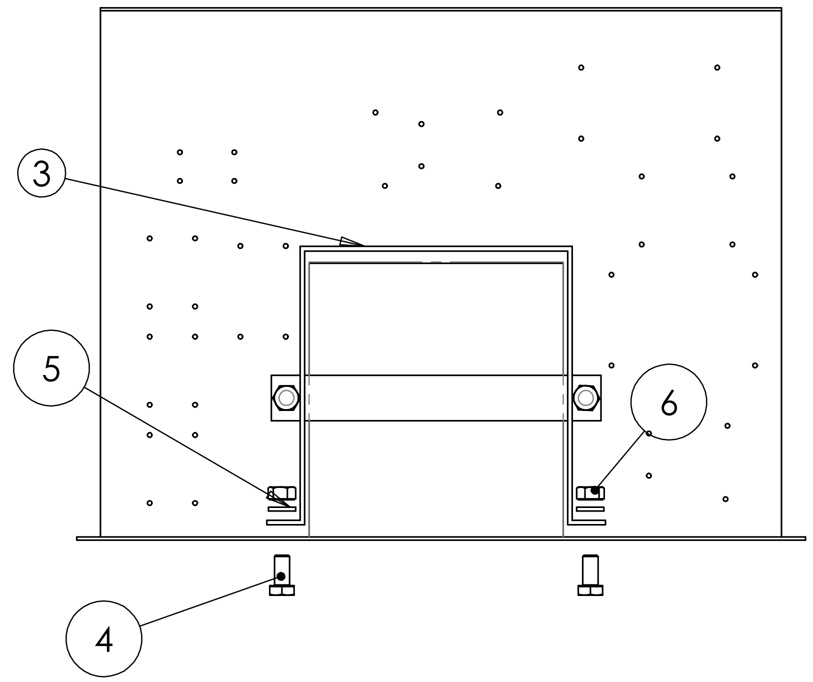


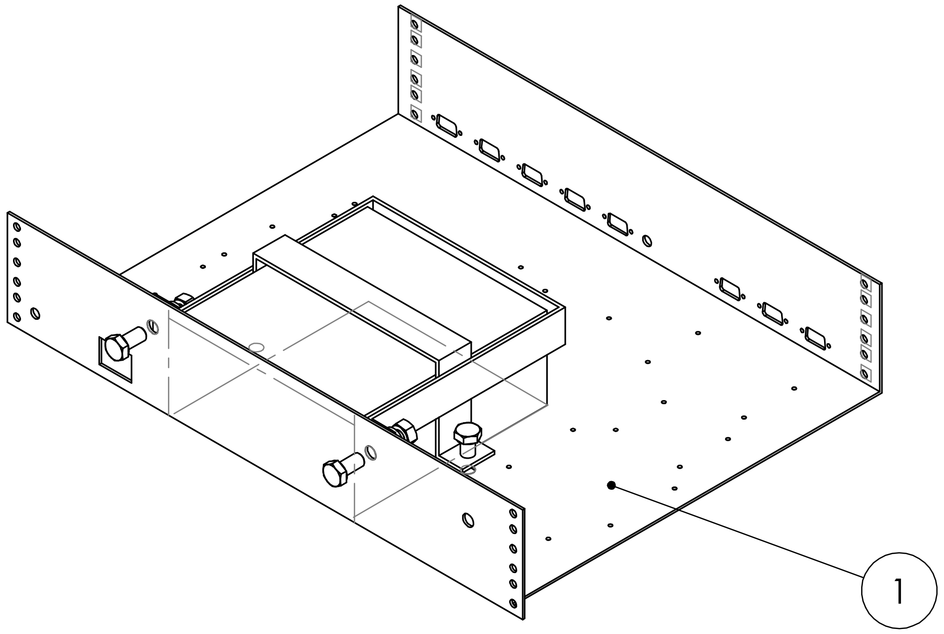


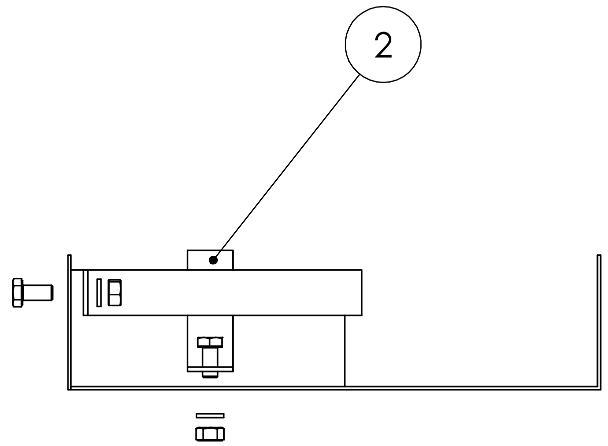
DO NOT SCALE		DRAWN BY Jerin George		TOLERANCES UNLESS OTHERWISE STATED LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED	UNIVERSITY OF Southampton Faculty of Engineering and the Environment
A3		DESIGNED BY Jerin George			
EDMC JOB No	DEPARTMENT	DATE 05/04/21	SCALE 1:5		TITLE Server Rack Tray 2U
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL Alumimium 6061-T6	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	
REMOVE ALL SHARP EDGES IF IN DOUBT PLEASE ASK		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.			SHEET 3 | No OFF 3 | ASSEMBLY NUMBER 3 | DRAWING NUMBER 3 | REVISION 1



DO NOT SCALE		DRAWN BY Jerin George		TOLERANCES UNLESS OTHERWISE STATED LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED	UNIVERSITY OF Southampton Faculty of Engineering and the Environment
A3		DESIGNED BY Jerin George			
EDMC JOB No	DEPARTMENT	DATE 05/04/21	SCALE 1:1		TITLE Rack Tray Attachment Adapter
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL Alumimium 6061-T6	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	
REMOVE ALL SHARP EDGES IF IN DOUBT PLEASE ASK		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.			SHEET 1 | No OFF 1 | ASSEMBLY NUMBER 3 | DRAWING NUMBER 4 | REVISION 1







Balloon	Part Number	Part
1	M15610-03-24	Server Tray
2	M15610-03-25	Battery Strap Short
3	M15610-03-26	Battery Strap Long
4	M15610-03-37	M10 L25mm Bolt ISO 4017 Grade 8.8
5	M15610-03-38	M10 Washer ISO 7089 Grade 8.8
6	M15610-03-39	M10 Nut ISO 4032 Grade 8.8

DO NOT SCALE

A3

EDMC JOB No

DEPARTMENT

DRAWN BY Jerin George

DESIGNED BY Jerin George

DATE 06/04/21

SCALE 1:5

TOLERANCES UNLESS OTHERWISE STATED

LINEAR DIMENSIONS
X = +/- 0.5mm
X.X = +/- 0.25mm
X.XX = +/- 0.1mm

ANGULAR DIMENSIONS
X = +/- 0.5mm
X.X = +/- 0.25mm

ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED

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PROJECT GDP 52

SUPERVISOR Keith Towell

MATERIAL

TEXTURE

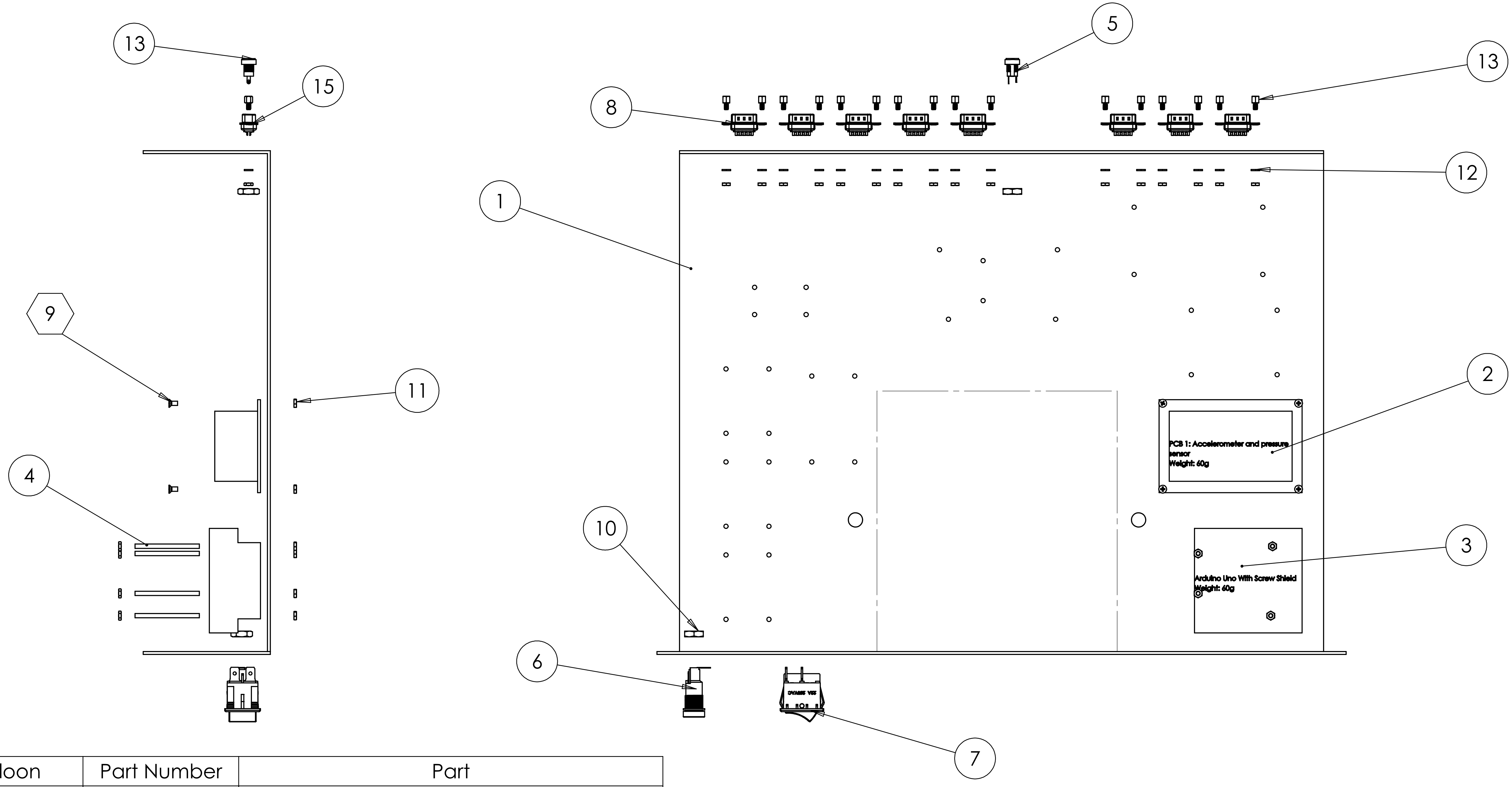
SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED

TITLE Battery Installation Assembly

REMOVE ALL SHARP EDGES

IF IN DOUBT PLEASE ASK

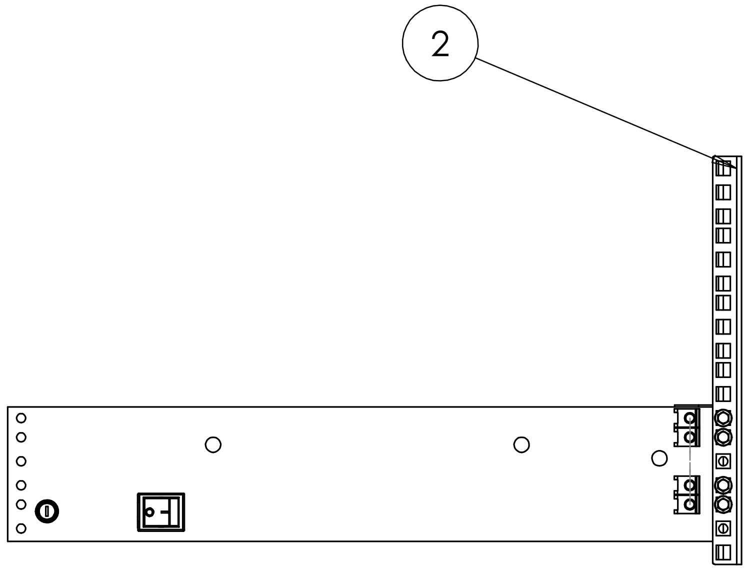
SHEET	No OFF	ASSEMBLY NUMBER	DRAWING NUMBER	REVISION
1	1	3	5	1

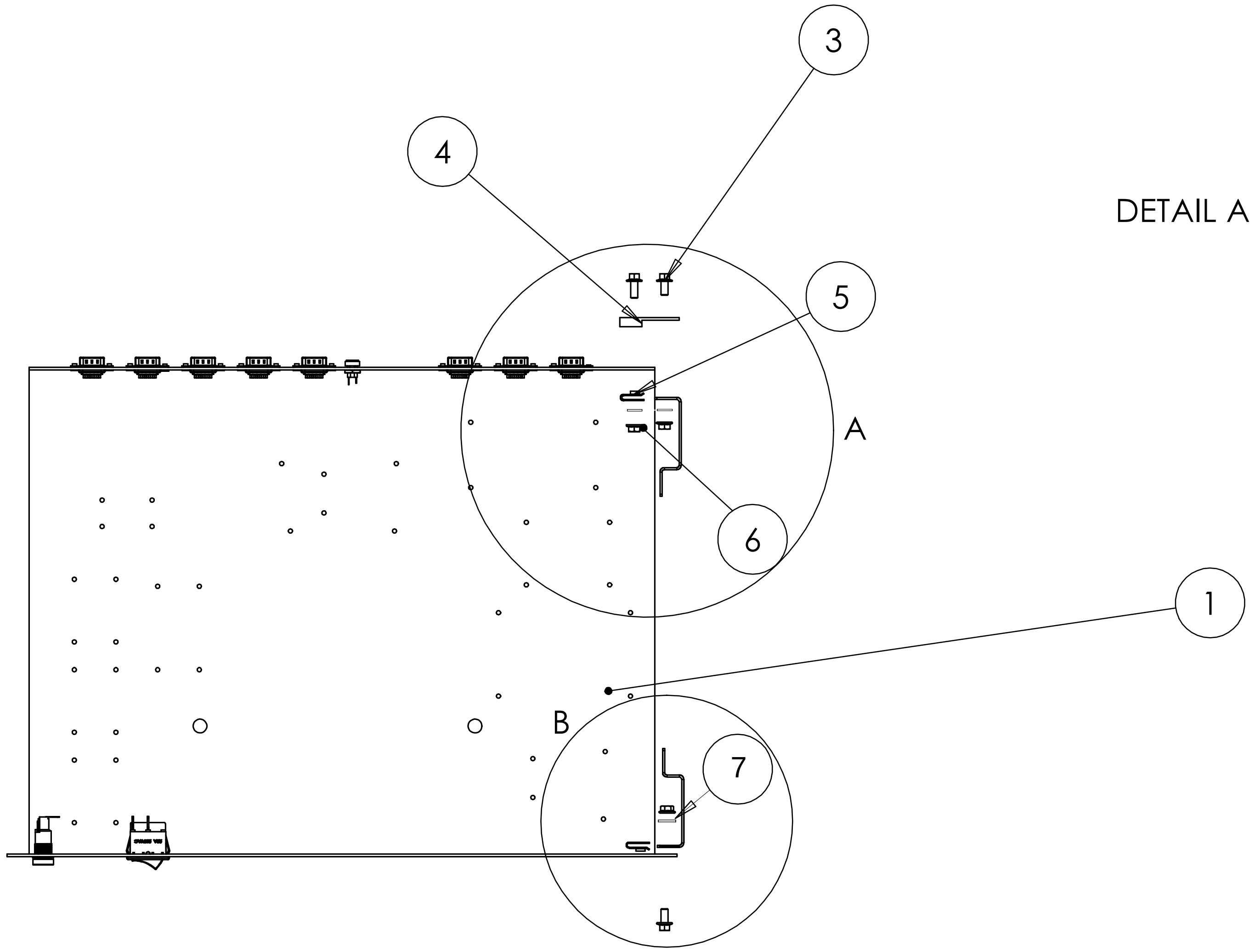


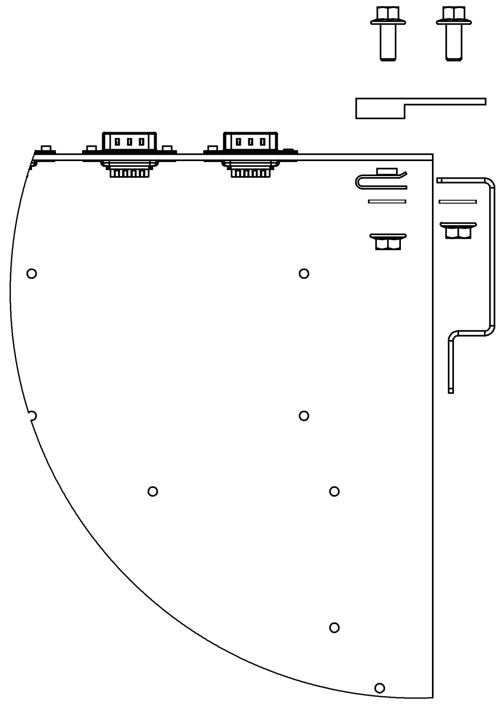
Balloon	Part Number	Part
1	M15610-03-24	Server Tray
2	M15610-03-12	PCB 1
3	M15610-03-8/9	Arduino UNO with Shield
4	M15610-03-40	M3 L60mm DIN975 Treaded ROD Pin x10
5	M15610-03-29	M8 DC Chassis Socket
6	M15610-03-3	M8 Fuse Holder
7	M15610-03-28	Illuminated Power Switch
8	M15610-03-27	9 Pin D-Sub Connector Female x8
9	M15610-03-42	M3 L8mm ISO4017 Grade 8.8 Bolt x32
10	M15610-03-41	M8 Nut x2 (ISO4032 Grade 8.8)
11	M15610-03-44	M3 Nut x68 (ISO4032 Grade 8.8)
12	M15610-03-45	M3 Washer x16 (ISO7089 Grade 8.8)
13	M15610-03-43	M3 D-Sub Screw

Note: Only attachment of PCB 1 and Arduino Uno showed
but all components attched the same way

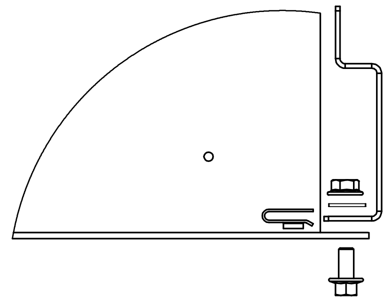
DO NOT SCALE	DRAWN BY Jerin George		TOLERANCES UNLESS OTHERWISE STATED LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED	UNIVERSITY OF Southampton Faculty of Engineering and the Environment
A3	DESIGNED BY Jerin George			
EDMC JOB No / DEPARTMENT	DATE 26/04/21	SCALE 1:3		TITLE Component Attachment Guide
PROJECT GDP 52 / SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	
REMOVE ALL SHARP EDGES / IF IN DOUBT PLEASE ASK	THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.			SHEET 1 / No OFF 1 / ASSEMBLY NUMBER 3 / DRAWING NUMBER 6 / REVISION 2







DETAIL A (Rear Panel Attachment)
SCALE 2 : 5



DETAIL B (Front Panal Attachment)
SCALE 2 : 5

Balloon	Part Number	Part
1	M15610-03-24	Server Tray
2	M15610-03-46	Server Rack 6U
3	M15610-03-34	M6 L20mm Bolt ISO 4017 Grade 8.8
4	M15610-03-33	Rear Tray Attachment Adapter
5	M15610-03-32	Server Attachment Adapter
6	M15610-03-36	M6 Nut ISO 4032 Grade 8.8
7	M15610-03-35	M6 Washer ISO 7089 Grade 8.8

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A3		DESIGNED BY Jerin George			
EDMC JOB No	DEPARTMENT	DATE 05/04/21	SCALE 1:5		TITLE Tray Attachment Guide
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL Alumimium	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	
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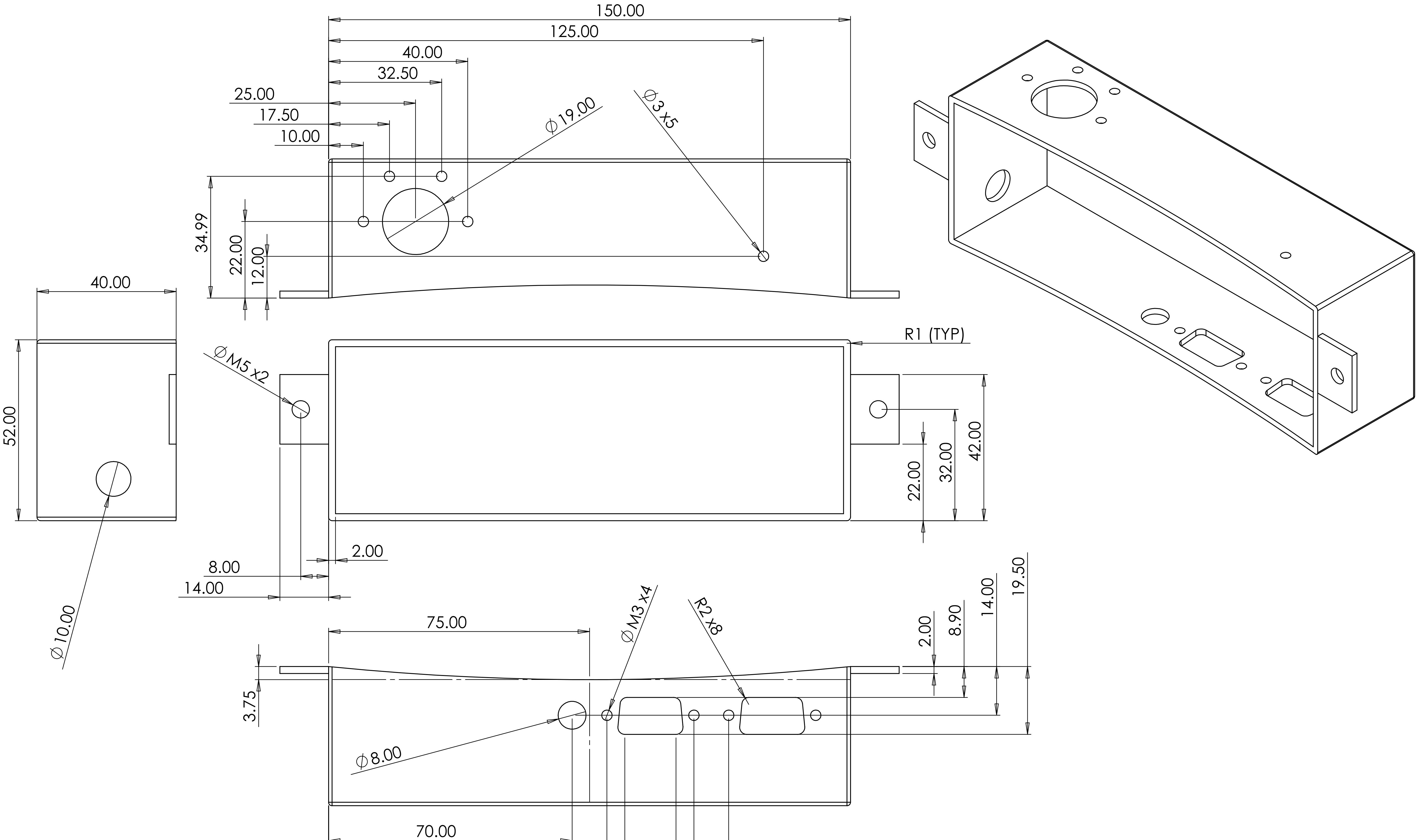
Sub Assembly 4: Control Panel Assembly



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A3		DESIGNED BY Jerin George	LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm	Faculty of Engineering and the Environment	
EDMC JOB No	DEPARTMENT	DATE 05/04/21	SCALE 1:1	ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED	TITLE Control Panel Case
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL ALUMINIUM 6061-T6	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	
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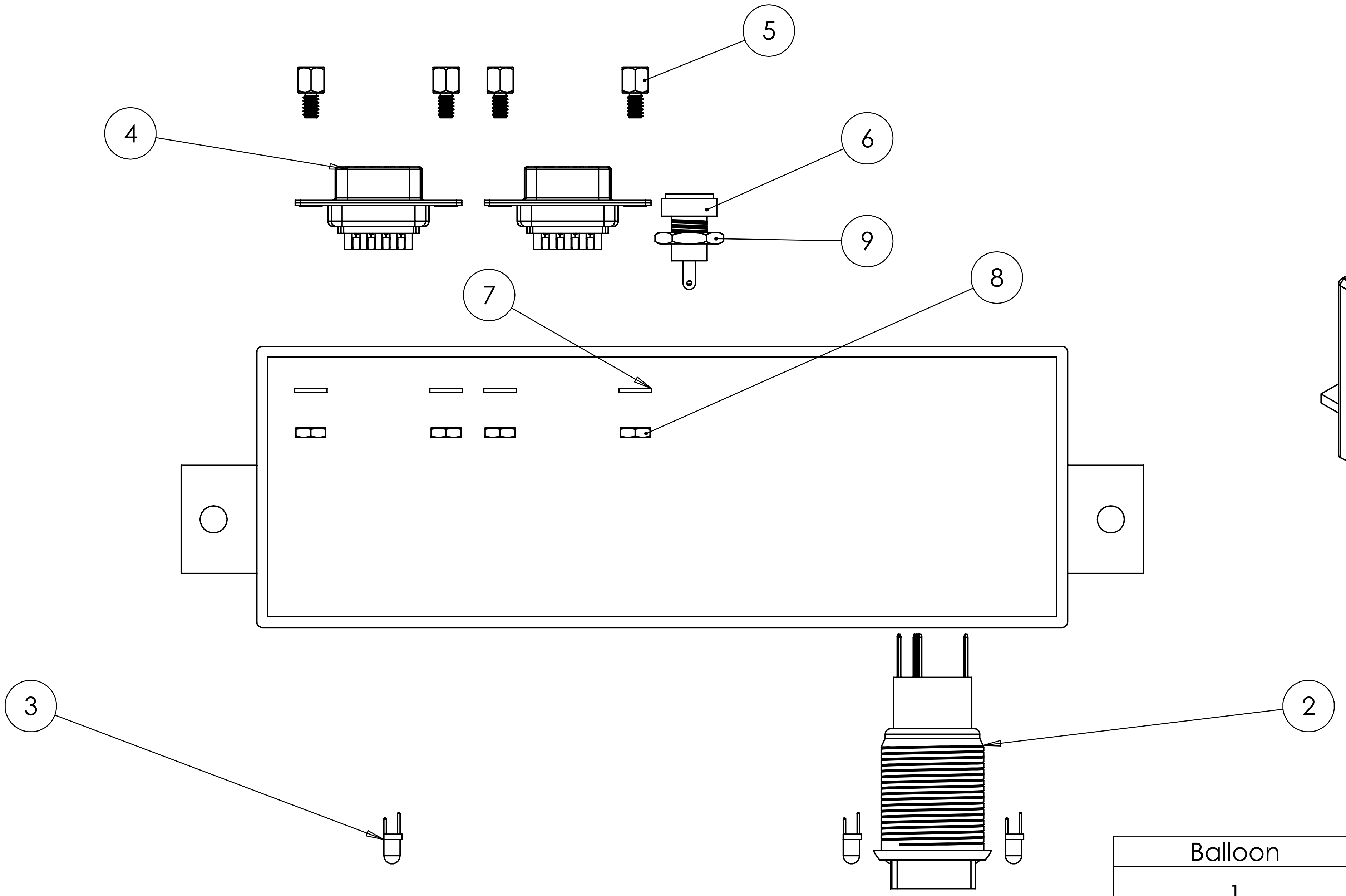
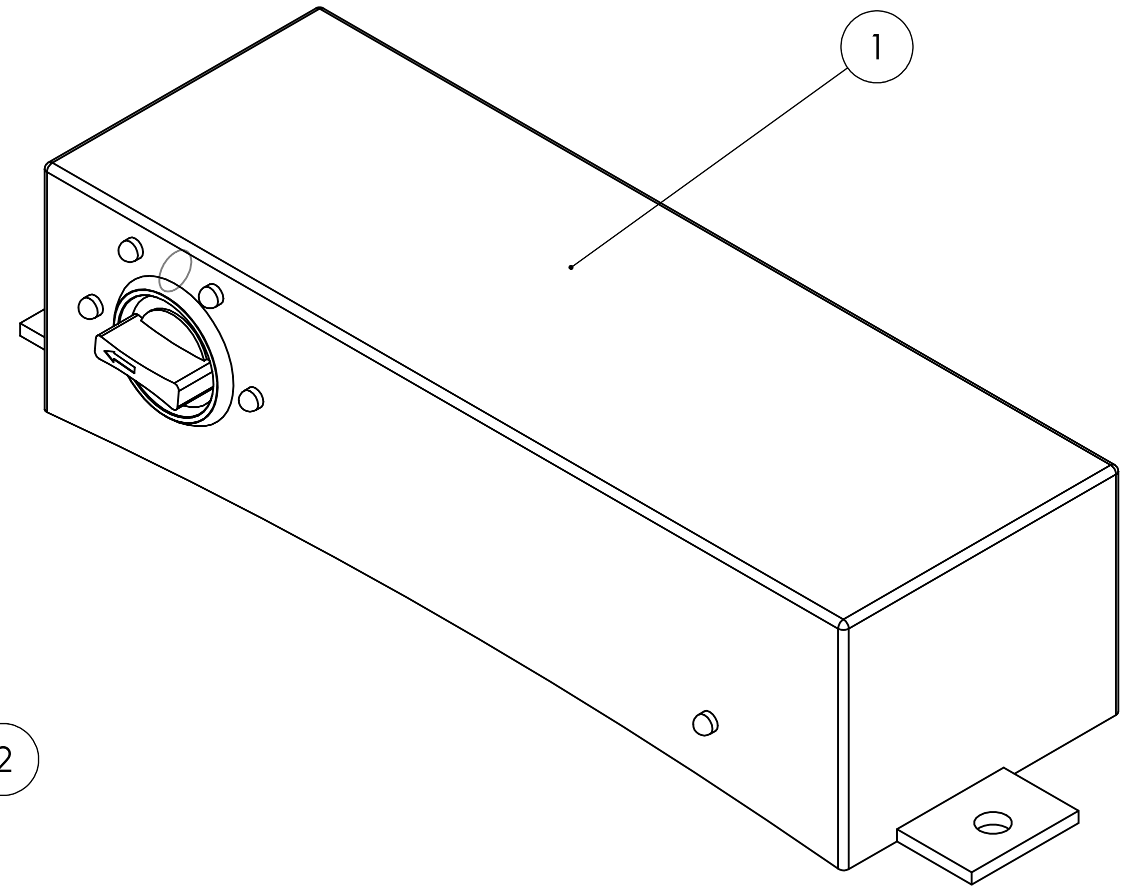
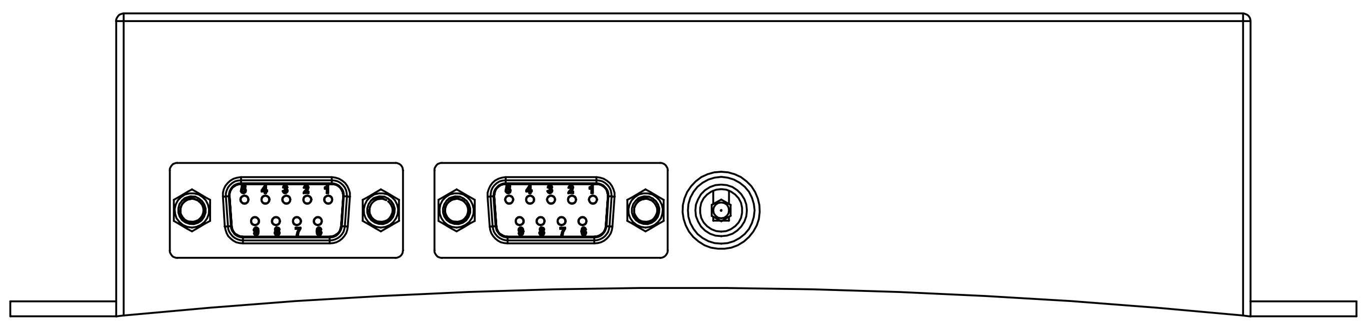




Balloon	Part Number	Part
1	M15610-04-1	Control Panel Case
2	M15610-04-2	Rotary Switch
3	M15610-04-3	LED 3mm
4	M15610-04-4	9 Pin D-Sub Female Connector
5	M15610-04-6	M3 D-Sub Screw
6	M15610-04-5	DC Chassis Socket Connector
7	M15610-04-8	M3 ISO 7089 Grade 8.8 Washer
8	M15610-04-7	M3 ISO 4032 Grade 8.8 Nut
9	M15610-04-9	M8 ISO4032 Grade 8.8 Nut



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DATE 05/04/21 | SCALE 1:1

TOLERANCES UNLESS OTHERWISE STATED
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X.X = +/- 0.25mm
X.XX = +/- 0.1mm
ANGULAR DIMENSIONS
X = +/- 0.5mm
X.X = +/- 0.25mm
ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED

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PROJECT GDP 52 | SUPERVISOR Keith Towell | MATERIAL | TEXTURE | SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED

TITLE Control Panel Assembly Guide

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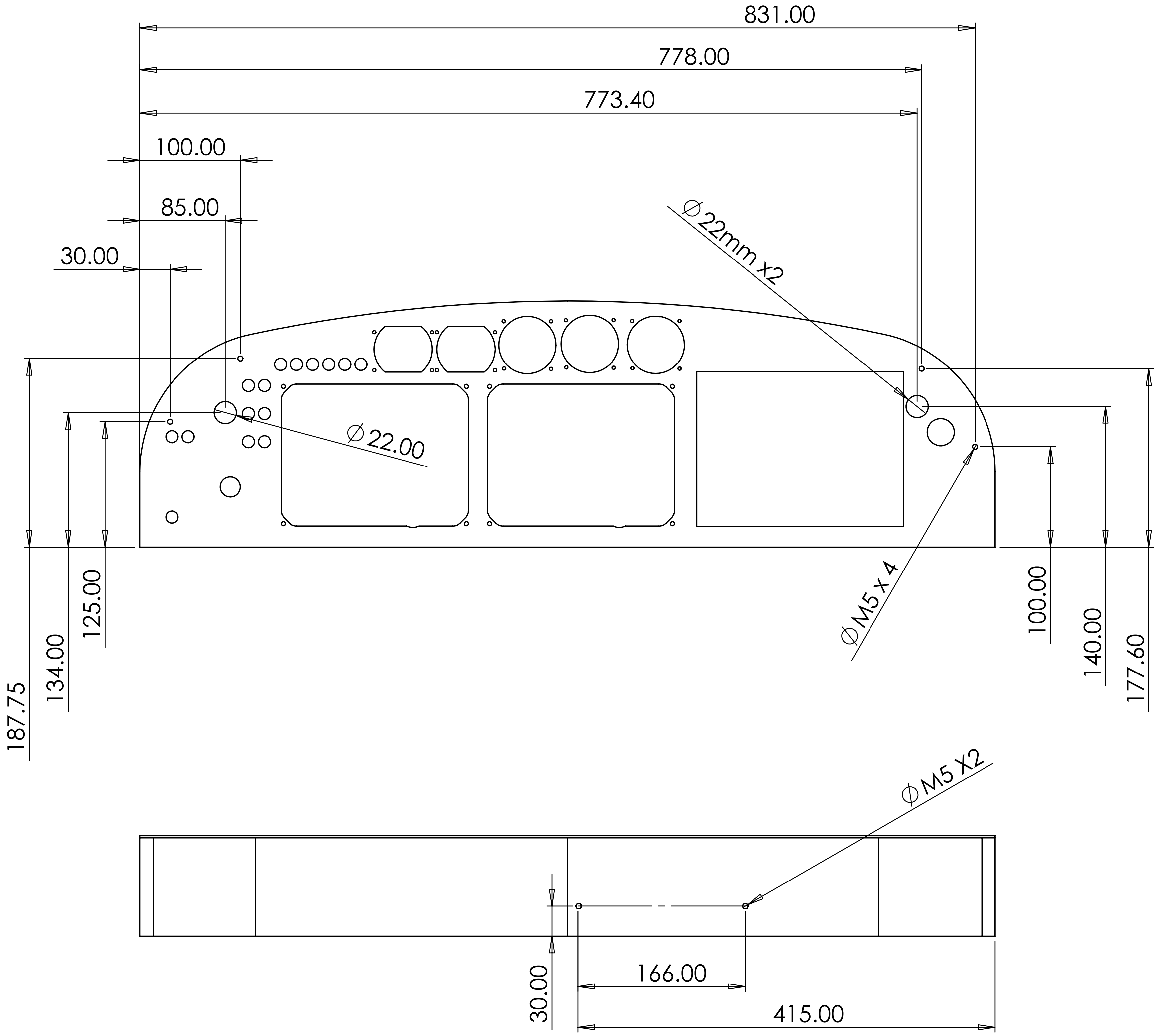
Sub Assembly 5: Dead Man's Switches and Control Panel Installation



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A3	DESIGNED BY Jerin George			
EDMC JOB No / DEPARTMENT	DATE 05/04/21 / SCALE 1:5		TITLE	
PROJECT GDP 52 / SUPERVISOR Keith Towell	MATERIAL / TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	Dead Man's Switch and Control Panel Mounts on Dashboard	
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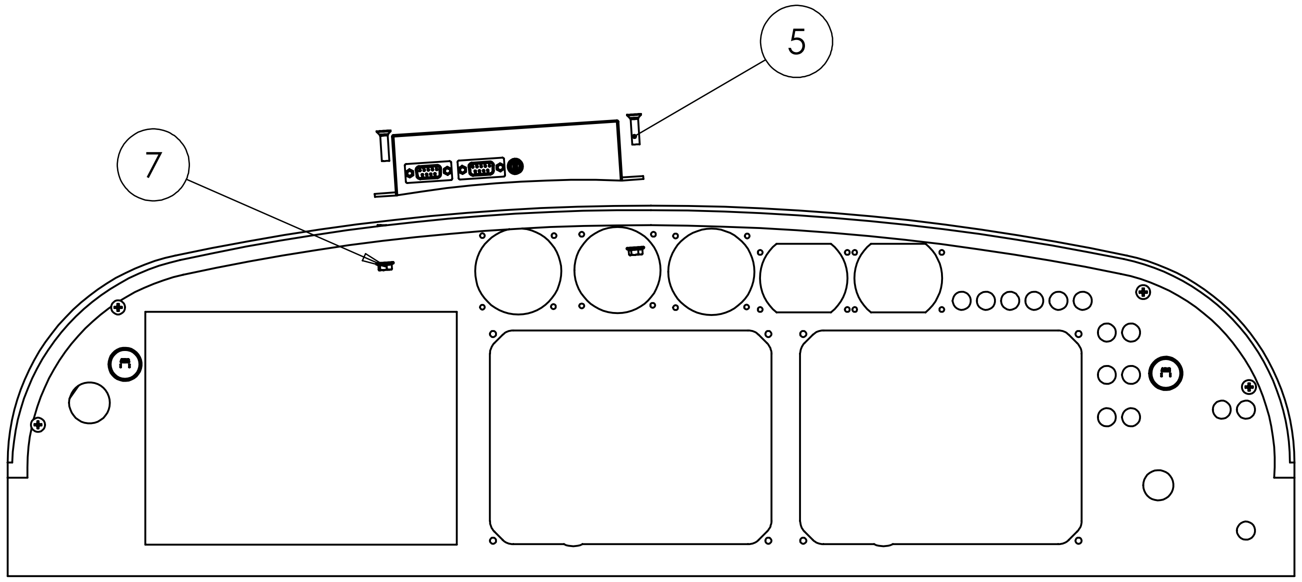

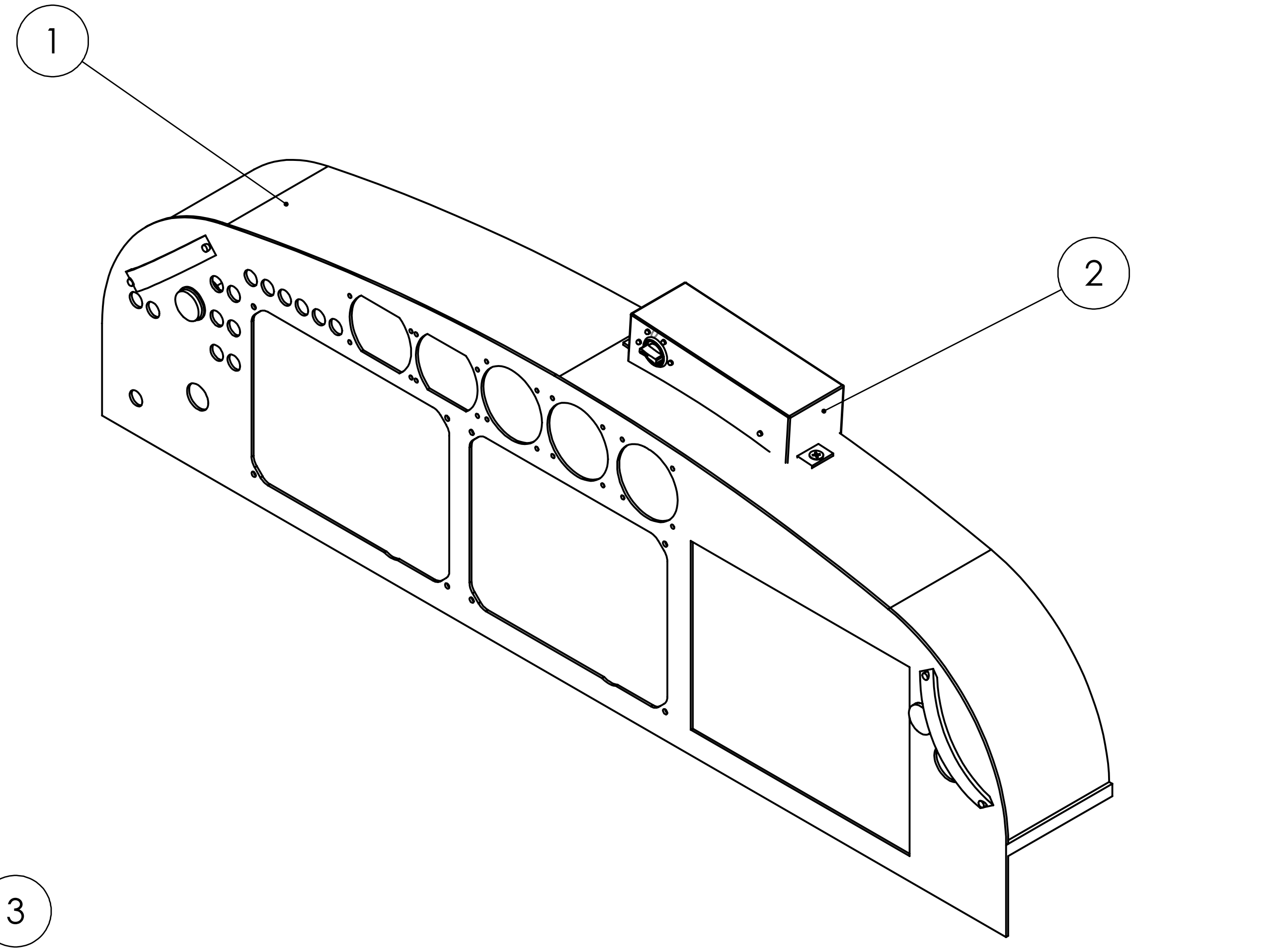

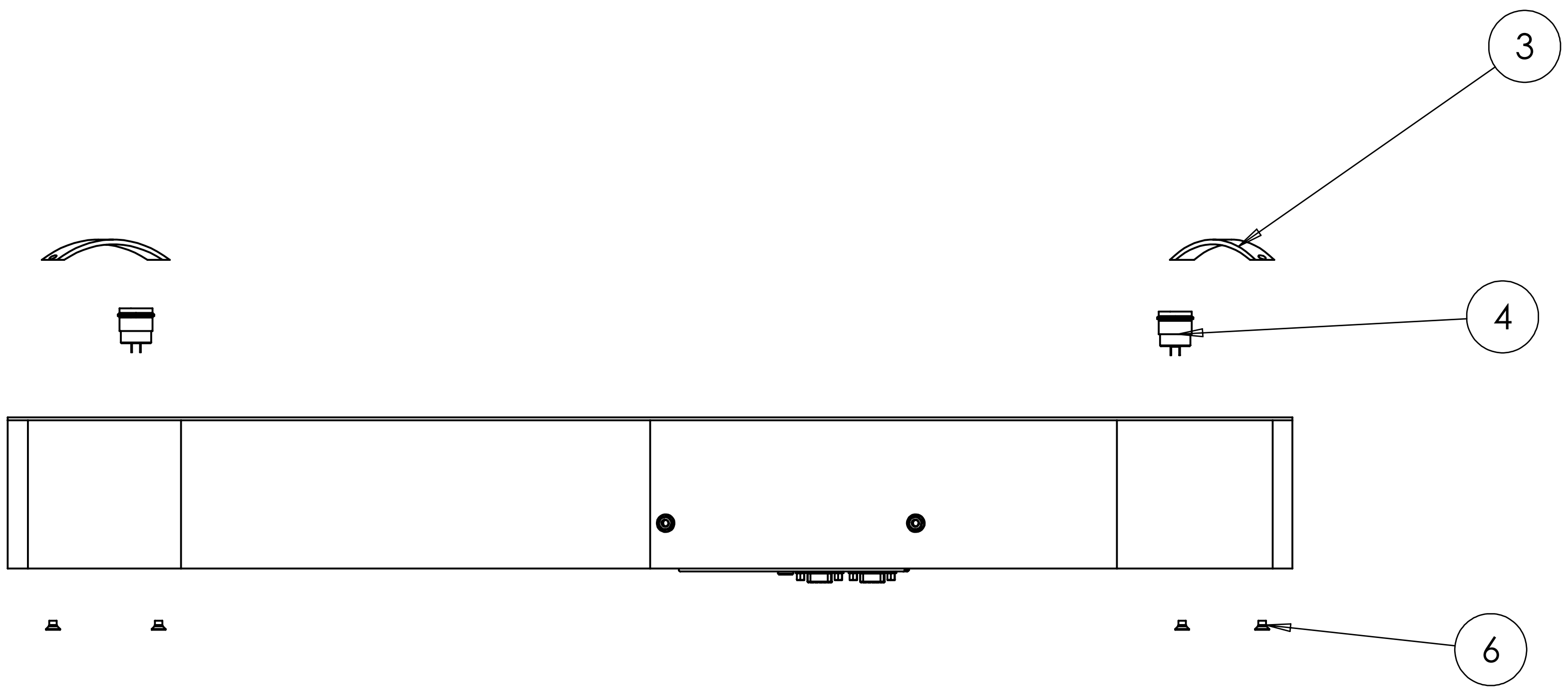

Balloon	Part Number	Part
1	M15610-05-1	Dashboard
2	M15610-05-2	Control Panel Assembly
3	M15610-05-3	Handle
4	M15610-05-4	Dead Man's Switch
5	M15610-05-6	M5 L20mm Bolt ISO 4017 Grade 8.8
6	M15610-05-5	M5 L15mm Screw ISO 7046 Grade 8.8
7	M15610-05-7	M5 Nut ISO 4032 Grade 8.8

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DESIGNED BY: Jerin George

DATE: 05/04/21 | SCALE: 1:5

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X.X = +/- 0.25mm
X.XX = +/- 0.1mm
ANGULAR DIMENSIONS
X = +/- 0.5mm
X.X = +/- 0.25mm
ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED

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PROJECT: GDP 52 | SUPERVISOR: Keith Towell | MATERIAL | TEXTURE | SURFACE FINISH: ALL OVER UNLESS OTHERWISE STATED

TITLE: Dead Man's Switch and Control Panel Installation Guide

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SHEET	No OFF	ASSEMBLY NUMBER	DRAWING NUMBER	REVISION
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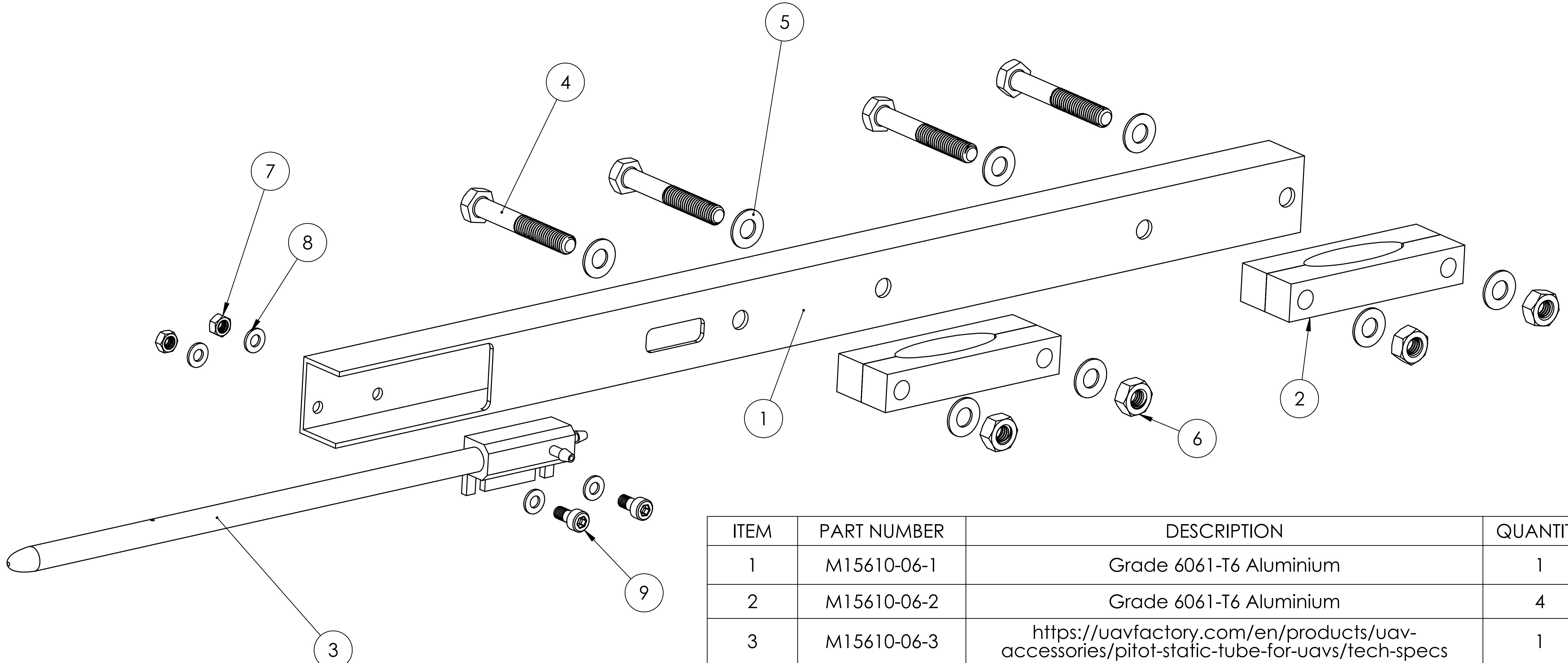
Sub Assembly 6: Pitot Static Tube Assembly



ITEM	PART NUMBER	DESCRIPTION	QUANTITY
1	M15610-06-1	Grade 6061-T6 Aluminium	1
2	M15610-06-2	Grade 6061-T6 Aluminium	4
3	M15610-06-3	https://uavfactory.com/en/products/uav-accessories/pitot-static-tube-for-uavs/tech-specs	1
4	M15610-06-4	ISO4014 M6x60mm Bolt Grade 8.8	4
5	M15610-06-5	M6 Washer Grade 8.8	8
6	M15610-06-6	ISO4032 M6 Nut Grade 8.8	4
7	M15610-06-7	ISO4032 M5 Nut Grade 8.8	2
8	M15610-06-8	M5 Washer Grade 8.8	4
9	M15610-06-9	ISO4762 M5x10mm Bolt Grade 8.8	2
-	M15610-06-10	Tygon Tubing - 4mm (Inner Diameter) x 2m	2

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EDMC JOB No	DEPARTMENT	DATE 23/03/2021	SCALE	
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED
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TITLE
PITOT TUBE MOUNT ASSEMBLY

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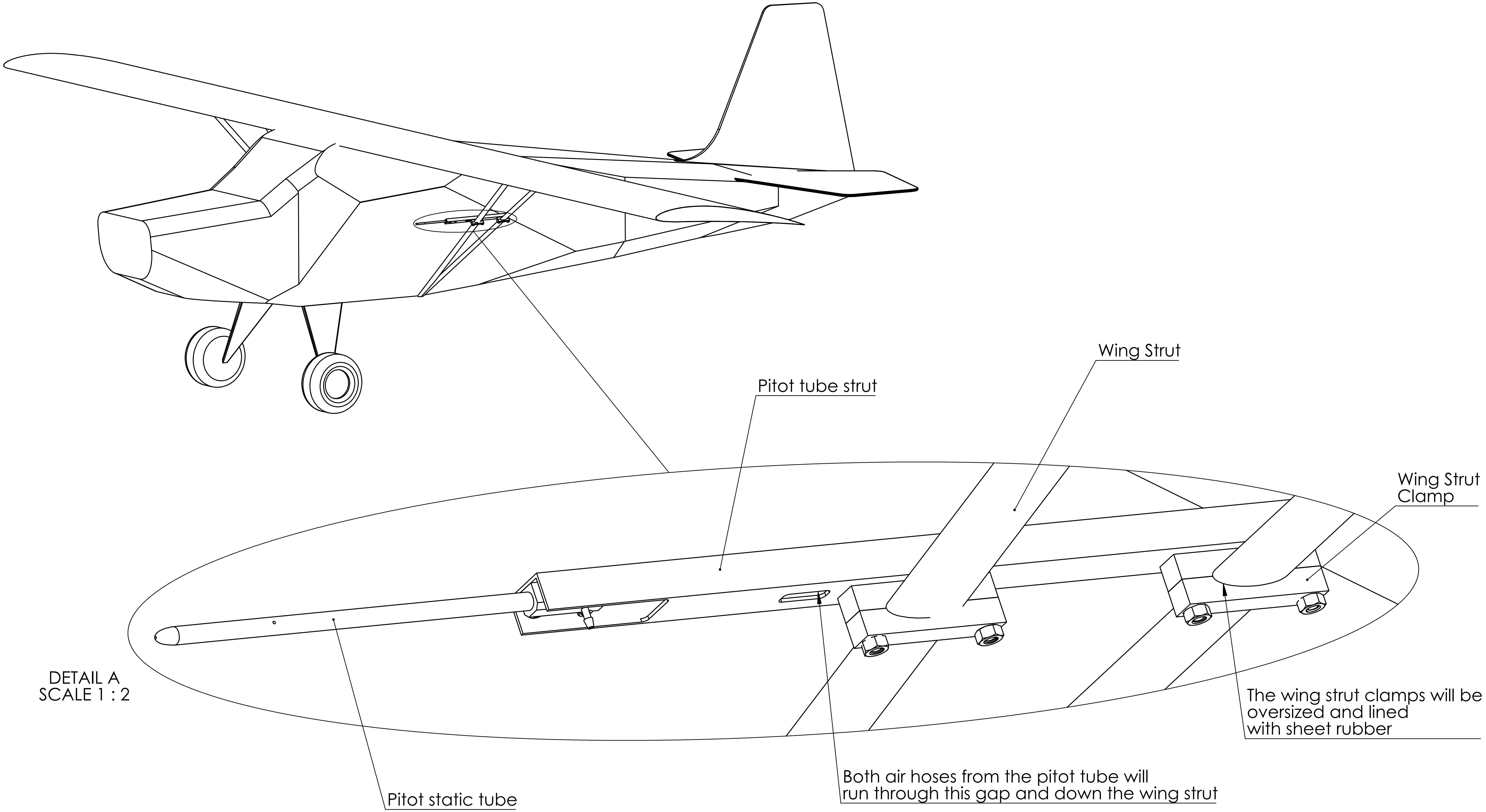

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A3		DESIGNED BY DAN NEWMAN-SANDERS			
EDMC JOB No	DEPARTMENT	DATE 15/03/2021	SCALE		TITLE
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	PITOT TUBE MOUNT SCHEMATIC
REMOVE ALL SHARP EDGES		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.			SHEET 1 / No OFF 1 / ASSEMBLY NUMBER 6 / DRAWING NUMBER 2 / REVISION 1
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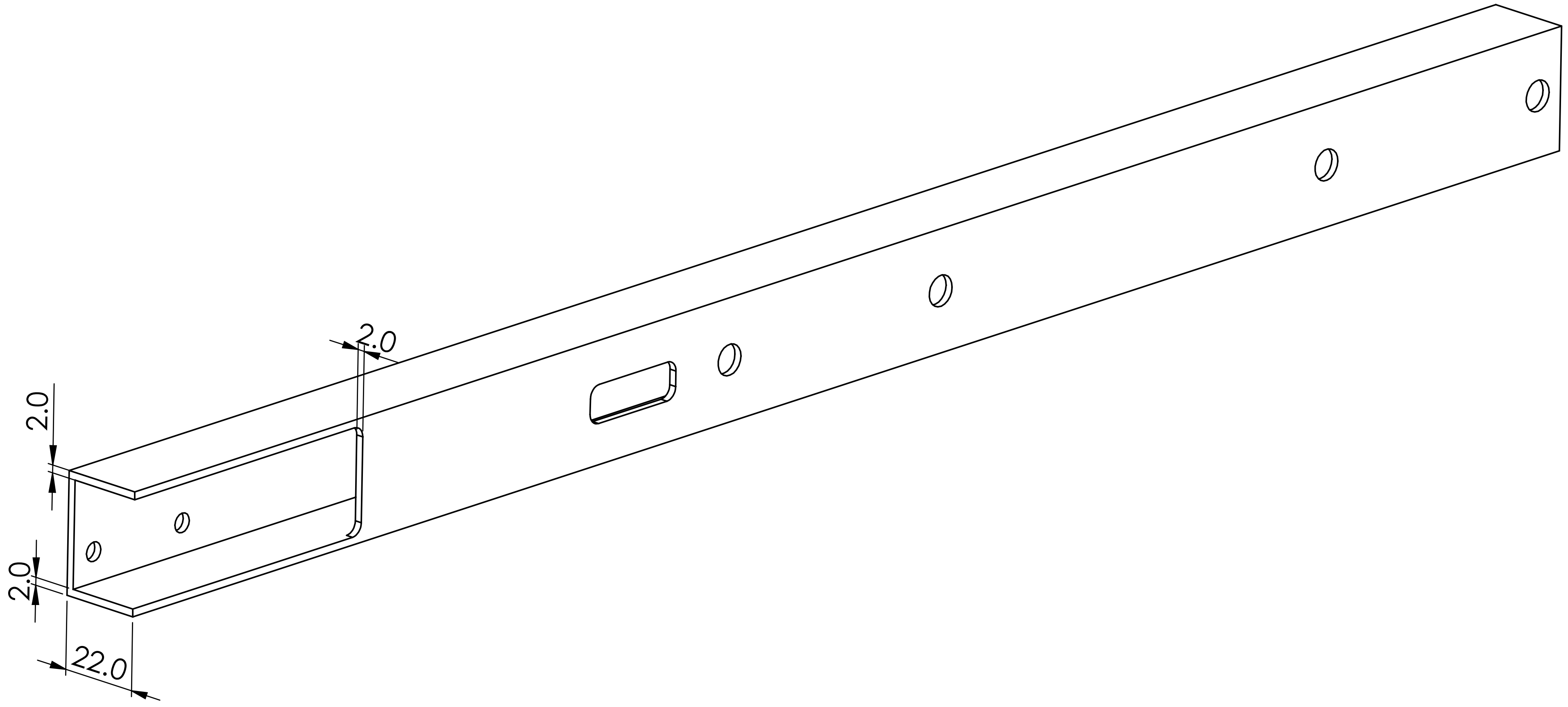

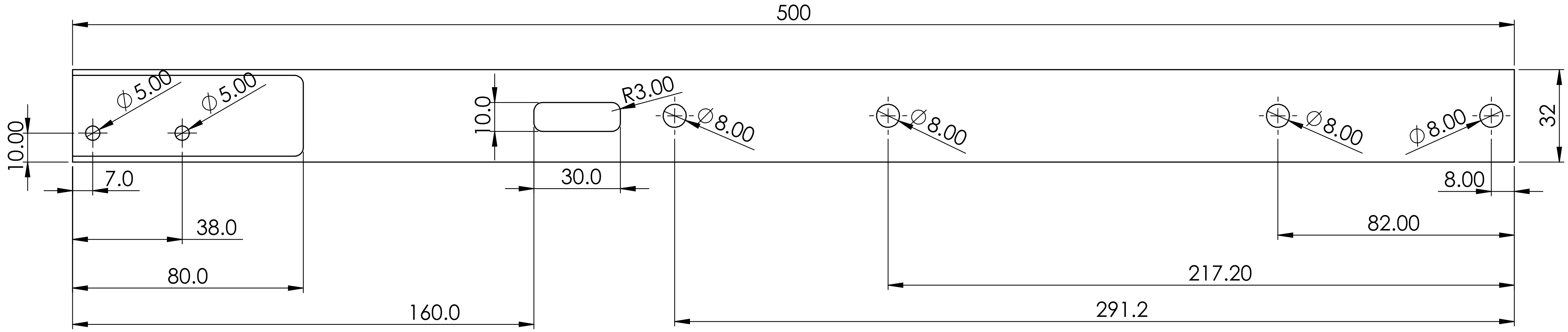

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EDMC JOB No	DEPARTMENT	DATE 11/4/21	SCALE 1:1.5	
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED
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TITLE				
PITOT TUBE STRUT (M15610-06-1)				
SHEET	No OFF	ASSEMBLY NUMBER	DRAWING NUMBER	REVISION
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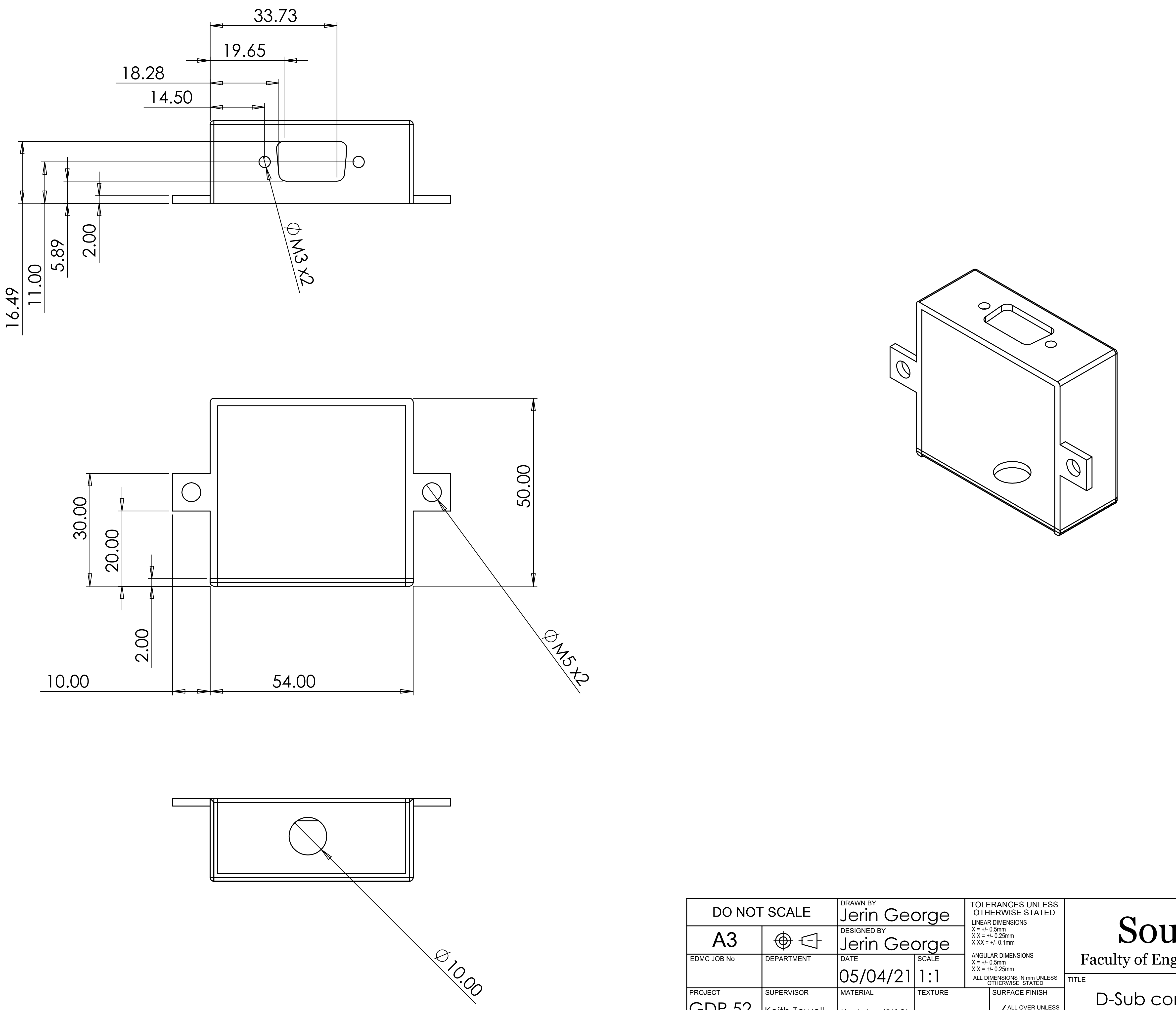
Sub Assembly 7: Connector Boxes Assembly



DO NOT SCALE		DRAWN BY Jerin George		TOLERANCES UNLESS OTHERWISE STATED LINEAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm X.XX = +/- 0.1mm ANGULAR DIMENSIONS X = +/- 0.5mm X.X = +/- 0.25mm ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED	UNIVERSITY OF Southampton Faculty of Engineering and the Environment
A3		DESIGNED BY Jerin George			
EDMC JOB No	DEPARTMENT	DATE 05/04/21	SCALE 1:1		TITLE D-Sub connector box
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL Alumimium 6061-T6	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	
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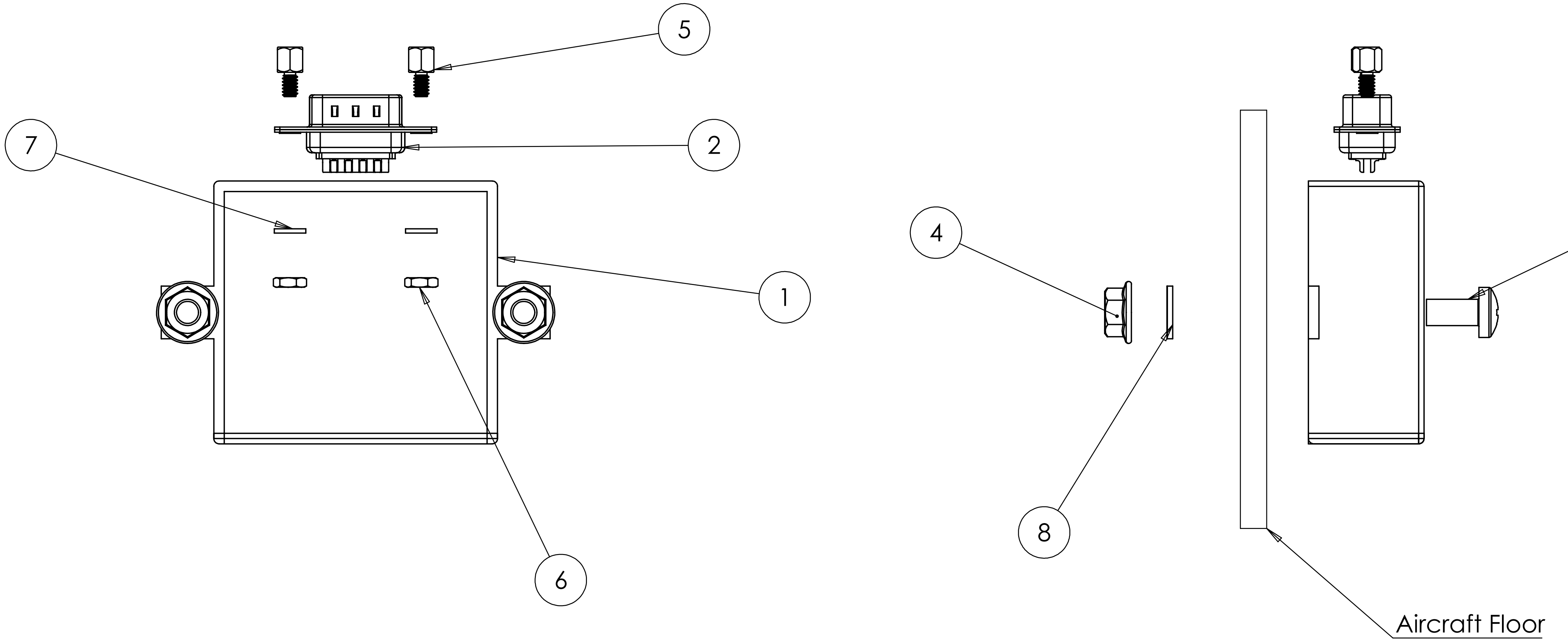

Balloon	Part Number	Part
1	M15610-07-2	D-Sub Connector Box
2	M15610-07-3	9 pIn D-Sub Female Connector
3	M15610-07-4	M5 L15mm Bolt ISO4017 Grade 8.8
4	M15610-07-05	M5 Nut ISO4032 Grade 8.8
5	M15610-07-06	M3 D-Sub Connector Screw
6	M15610-07-07	M3 NUT ISO4032 Grade 8.8
7	M15610-07-08	M3 Washer ISO7089 Grade 8.8
8	M15610-07-09	M5 Washer ISO7089 Grade 8.8

DO NOT SCALE

A3

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DESIGNED BY Jerin George

EDMC JOB No

DEPARTMENT

DATE 29/04/21

SCALE 1:1

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LINEAR DIMENSIONS
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X.X = +/- 0.25mm
X.XX = +/- 0.1mm
ANGULAR DIMENSIONS
X = +/- 0.5mm
X.X = +/- 0.25mm
ALL DIMENSIONS IN mm UNLESS OTHERWISE STATED

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Faculty of Engineering and the Environment

PROJECT GDP 52

SUPERVISOR Keith Towell

MATERIAL

TEXTURE

SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED

TITLE D-Sub Connector Assembly

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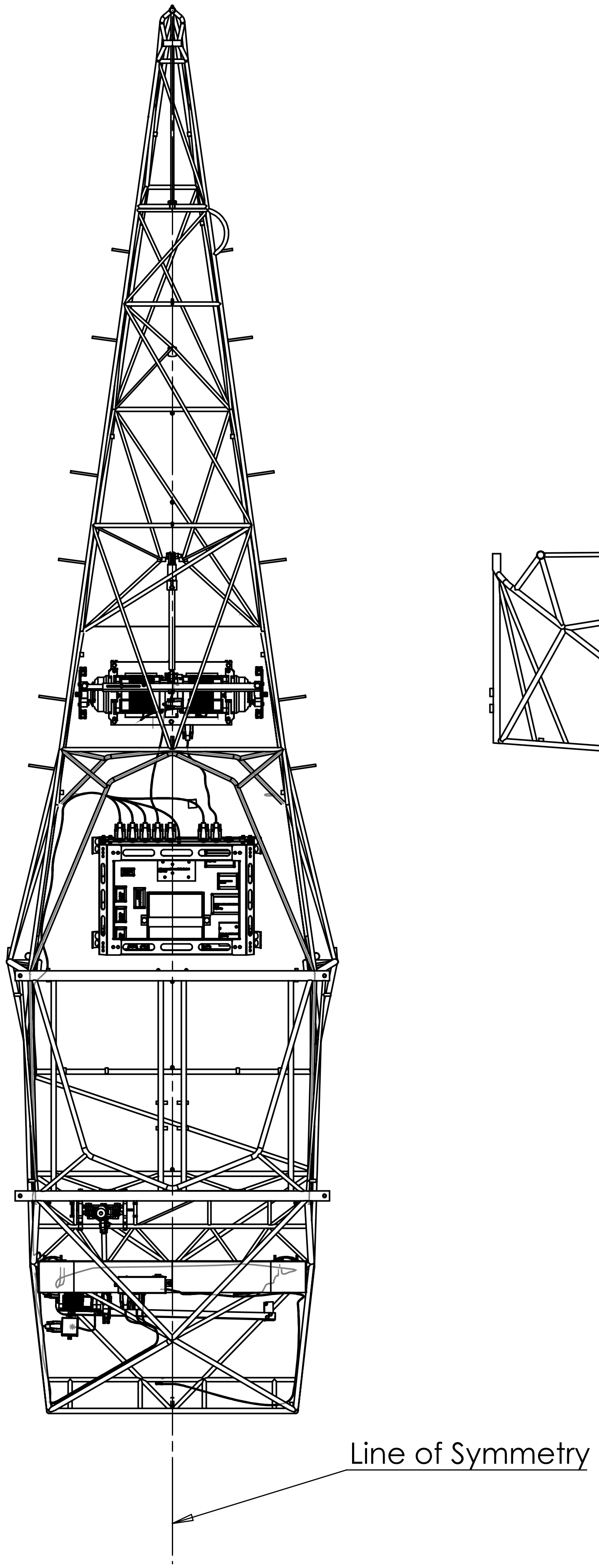
Modification Assembly



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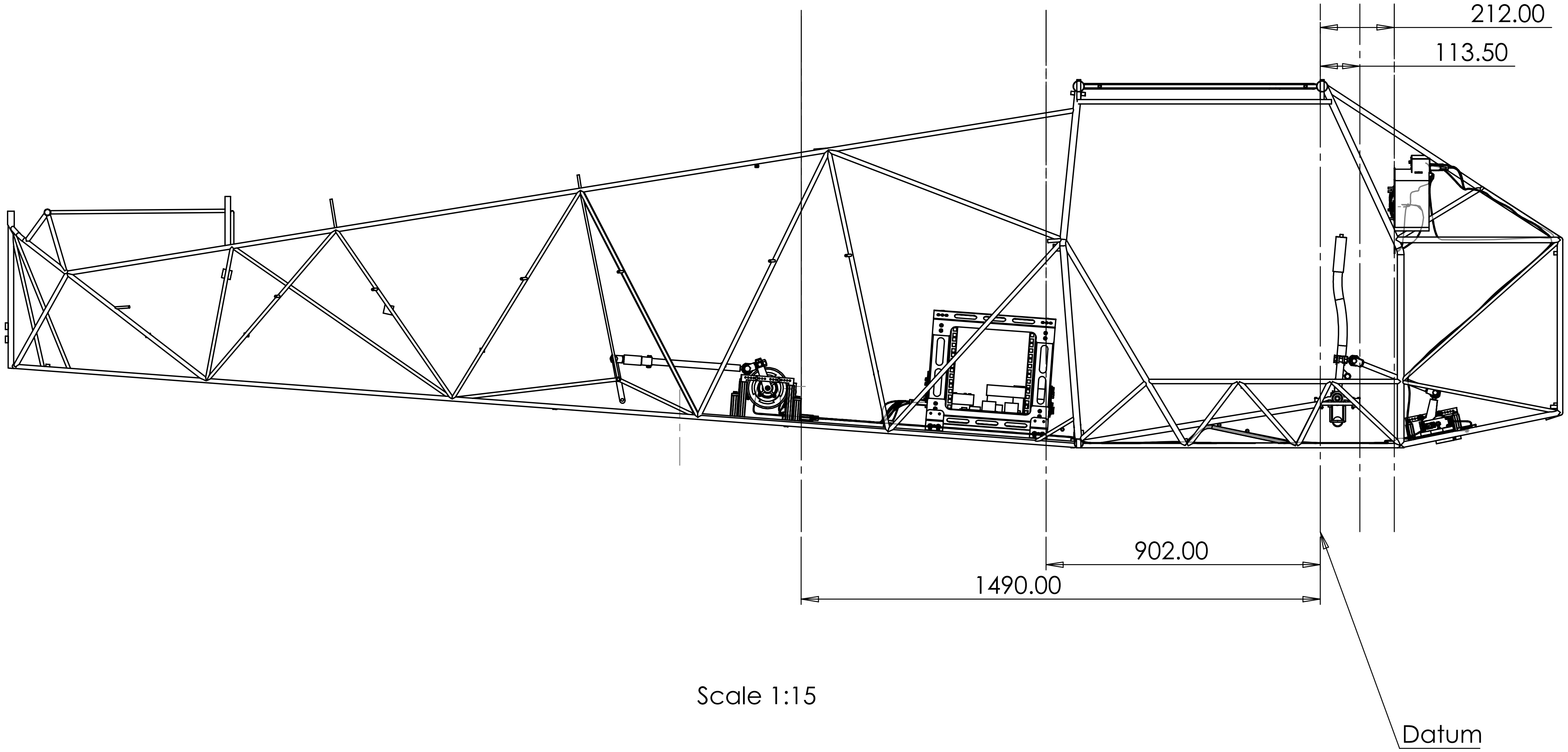

Scale 1:15

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A3		DESIGNED BY Jerin George			
EDMC JOB No	DEPARTMENT	DATE 29/04/21	SCALE		TITLE Final Full Assembly
PROJECT GDP 52	SUPERVISOR Keith Towell	MATERIAL	TEXTURE	SURFACE FINISH ALL OVER UNLESS OTHERWISE STATED	
REMOVE ALL SHARP EDGES IF IN DOUBT PLEASE ASK		THE INFORMATION CONTAINED IN THIS DOCUMENT IS THE PROPERTY OF THE UNIVERSITY OF SOUTHAMPTON DO NOT COPY WITHOUT WRITTEN PERMISSION.			SHEET 1 | No OFF 1 | ASSEMBLY NUMBER 7 | DRAWING NUMBER 1 | REVISION 1

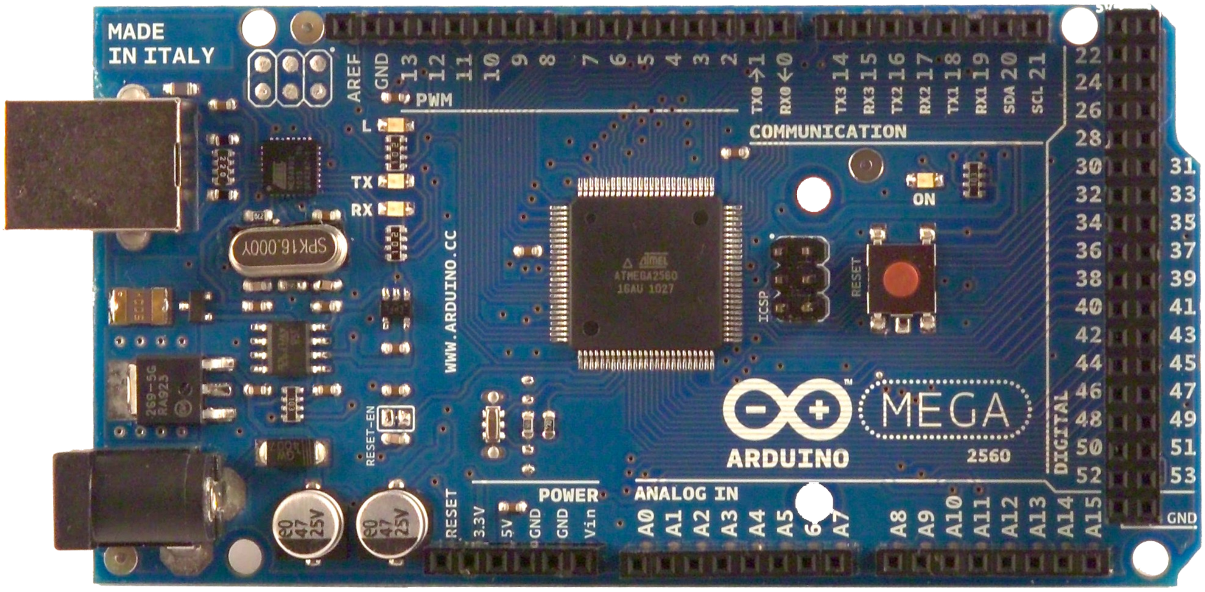
Document 12 – Specification Datasheets

Aircraft Registration:	G-OUAV
Aircraft Type:	TLAC Sherwood Scout
Aircraft Serial Number:	345-15480
Modification Number:	15610
Date Created:	29/04/2021

Authors:

Jerin George, Callum Breslin, Daniel Newman-Sanders, Andrew Kernan and Declan Clifford

Arduino MEGA 2560



Product Overview

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560 (datasheet). It has 54 digital input/output pins (of which 14 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Mega is compatible with most shields designed for the Arduino Duemilanove or Diecimila.

Index

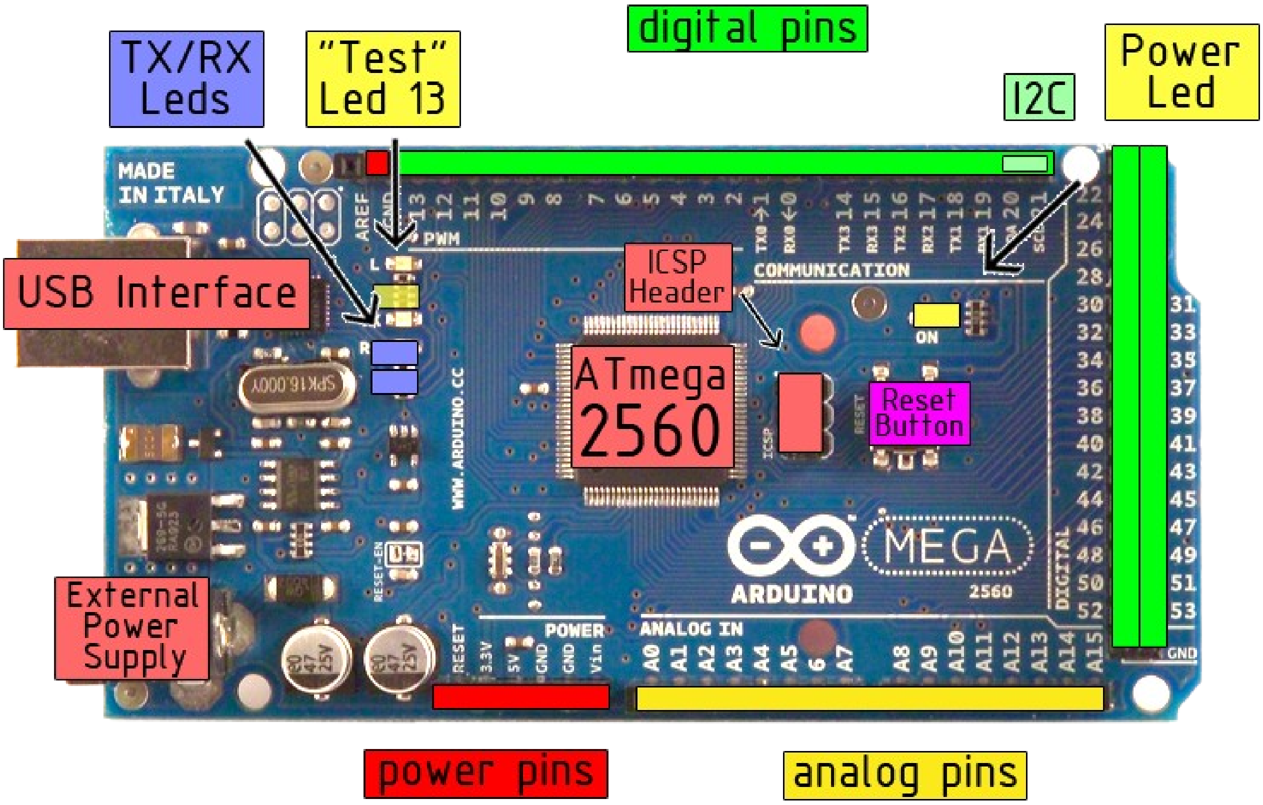
Technical Specification

EAGLE files: arduino-mega2560-reference-design.zip Schematic: arduino-mega2560-schematic.pdf

Summary

Microcontroller	ATmega2560
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	54 (of which 14 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 KB of which 8 KB used by bootloader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz

the board



Power

The Arduino Mega2560 can be powered via the USB connection or with an external power supply. The power source is selected automatically. External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and Vin pin headers of the POWER connector.

The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

The Mega2560 differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega8U2 programmed as a USB-to-serial converter.

The power pins are as follows:

- **VIN.** The input voltage to the Arduino board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). You can supply voltage through this pin, or, if supplying voltage via the power jack, access it through this pin.
- **5V.** The regulated power supply used to power the microcontroller and other components on the board. This can come either from VIN via an on-board regulator, or be supplied by USB or another regulated 5V supply.
- **3V3.** A 3.3 volt supply generated by the on-board regulator. Maximum current draw is 50 mA.
- **GND.** Ground pins.

Memory

The ATmega2560 has 256 KB of flash memory for storing code (of which 8 KB is used for the bootloader), 8 KB of SRAM and 4 KB of EEPROM (which can be read and written with the EEPROM library).

Input and Output

Each of the 54 digital pins on the Mega can be used as an input or output, using pinMode(), digitalWrite(), and digitalRead() functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms. In addition, some pins have specialized functions:

- **Serial: 0 (RX) and 1 (TX); Serial 1: 19 (RX) and 18 (TX); Serial 2: 17 (RX) and 16 (TX); Serial 3: 15 (RX) and 14 (TX).** Used to receive (RX) and transmit (TX) TTL serial data. Pins 0 and 1 are also connected to the corresponding pins of the ATmega8U2 USB-to-TTL Serial chip .
- **External Interrupts: 2 (interrupt 0), 3 (interrupt 1), 18 (interrupt 5), 19 (interrupt 4), 20 (interrupt 3), and 21 (interrupt 2).** These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the attachInterrupt() function for details.
- **PWM: 0 to 13.** Provide 8-bit PWM output with the analogWrite() function.
- **SPI: 50 (MISO), 51 (MOSI), 52 (SCK), 53 (SS).** These pins support SPI communication, which, although provided by the underlying hardware, is not currently included in the Arduino language. The SPI pins are also broken out on the ICSP header, which is physically compatible with the Duemilanove and Diecimila.
- **LED: 13.** There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.
- **I^2C: 20 (SDA) and 21 (SCL).** Support I^2C (TWI) communication using the Wire library (documentation on the Wiring website). Note that these pins are not in the same location as the I^2C pins on the Duemilanove.

The Mega2560 has 16 analog inputs, each of which provide 10 bits of resolution (i.e. 1024 different values). By default they measure from ground to 5 volts, though is it possible to change the upper end of their range using the AREF pin and analogReference() function.

There are a couple of other pins on the board:

- **AREF.** Reference voltage for the analog inputs. Used with analogReference().
- **Reset.** Bring this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block the one on the board.

Communication

The Arduino Mega2560 has a number of facilities for communicating with a computer, another Arduino, or other microcontrollers. The ATmega2560 provides four hardware UARTs for TTL (5V) serial communication. An ATmega8U2 on the board channels one of these over USB and provides a virtual com port to software on the computer (Windows machines will need a .inf file, but OSX and Linux machines will recognize the board as a COM port automatically. The Arduino software includes a serial monitor which allows simple textual data to be sent to and from the board. The RX and TX LEDs on the board will flash when data is being transmitted via the ATmega8U2 chip and USB connection to the computer (but not for serial communication on pins 0 and 1).

A SoftwareSerial library allows for serial communication on any of the Mega's digital pins.

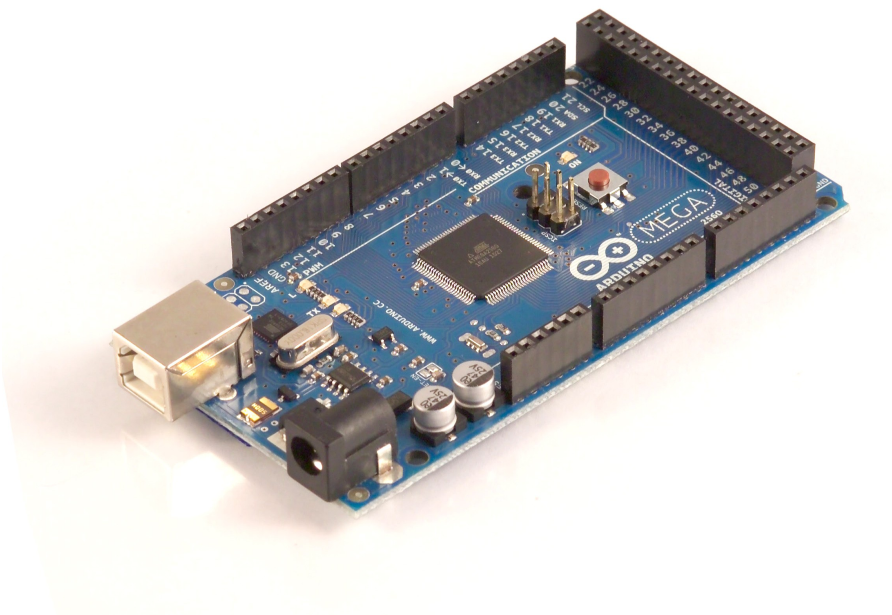
The ATmega2560 also supports I2C (TWI) and SPI communication. The Arduino software includes a Wire library to simplify use of the I2C bus; see the documentation on the Wiring website for details. To use the SPI communication, please see the ATmega2560 datasheet.

Programming

The Arduino Mega2560 can be programmed with the Arduino software (download). For details, see the reference and tutorials.

The Atmega2560 on the Arduino Mega comes preburned with a bootloader that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol (reference, C header files).

You can also bypass the bootloader and program the microcontroller through the ICSP (In-Circuit Serial Programming) header; see these instructions for details.



Automatic (Software) Reset

Rather then requiring a physical press of the reset button before an upload, the Arduino Mega2560 is designed in a way that allows it to be reset by software running on a connected computer. One of the hardware flow control lines (DTR) of the ATmega8U2 is connected to the reset line of the ATmega2560 via a 100 nanofarad capacitor. When this line is asserted (taken low), the reset line drops long enough to reset the chip. The Arduino software uses this capability to allow you to upload code by simply pressing the upload button in the Arduino environment. This means that the bootloader can have a shorter timeout, as the lowering of DTR can be well-coordinated with the start of the upload.

This setup has other implications. When the Mega2560 is connected to either a computer running Mac OS X or Linux, it resets each time a connection is made to it from software (via USB). For the following half-second or so, the bootloader is running on the Mega2560. While it is programmed to ignore malformed data (i.e. anything besides an upload of new code), it will intercept the first few bytes of data sent to the board after a connection is opened. If a sketch running on the board receives one-time configuration or other data when it first starts, make sure that the software with which it communicates waits a second after opening the connection and before sending this data.

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USB Overcurrent Protection

The Arduino Mega has a resettable polyfuse that protects your computer's USB ports from shorts and overcurrent. Although most computers provide their own internal protection, the fuse provides an extra layer of protection. If more than 500 mA is applied to the USB port, the fuse will automatically break the connection until the short or overload is removed.

Physical Characteristics and Shield Compatibility

The maximum length and width of the Mega PCB are 4 and 2.1 inches respectively, with the USB connector and power jack extending beyond the former dimension. Three screw holes allow the board to be attached to a surface or case. Note that the distance between digital pins 7 and 8 is 160 mil (0.16"), not an even multiple of the 100 mil spacing of the other pins.

The Mega is designed to be compatible with most shields designed for the Diecimila or Duemilanove. Digital pins 0 to 13 (and the adjacent AREF and GND pins), analog inputs 0 to 5, the power header, and ICSP header are all in equivalent locations. Further the main UART (serial port) is located on the same pins (0 and 1), as are external interrupts 0 and 1 (pins 2 and 3 respectively). SPI is available through the ICSP header on both the Mega and Duemilanove / Diecimila. **Please note that I^{2}C is not located on the same pins on the Mega (20 and 21) as the Duemilanove / Diecimila (analog inputs 4 and 5).**

How to use Arduino

Arduino can sense the environment by receiving input from a variety of sensors and can affect its surroundings by controlling lights, motors, and other actuators. The microcontroller on the board is programmed using the Arduino programming language (based on Wiring) and the Arduino development environment (based on Processing). Arduino projects can be stand-alone or they can communicate with software on running on a computer (e.g. Flash, Processing, MaxMSP).

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Linux Install

Windows Install

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Once you have downloaded/unzipped the arduino IDE, you can Plug the Arduino to your PC via USB cable.

Blink led

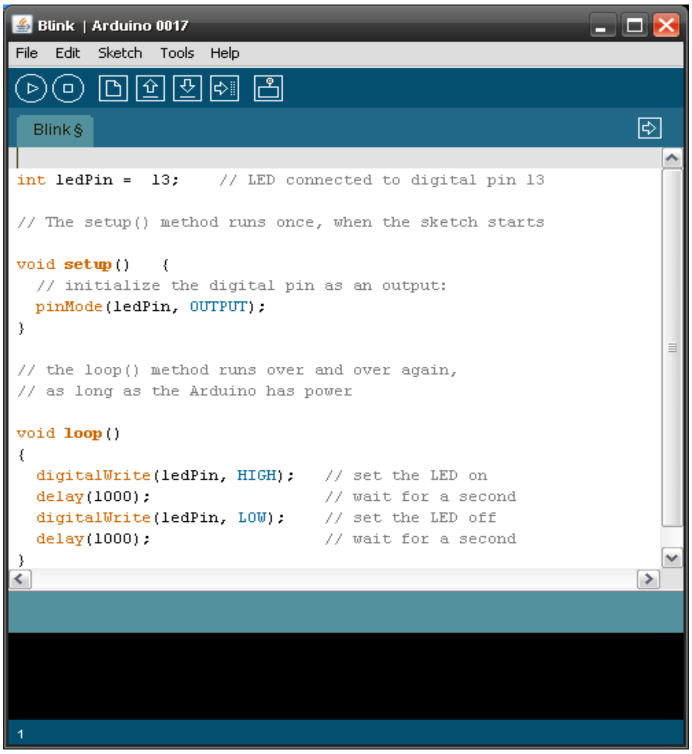
Now you're actually ready to "burn" your first program on the arduino board. To select "blink led", the physical translation of the well known programming "hello world", select

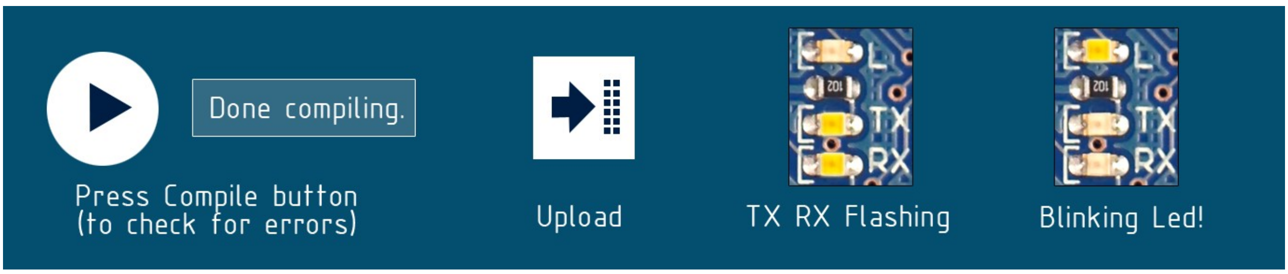
File>Sketchbook>
Arduino-0017>Examples>
Digital>Blink

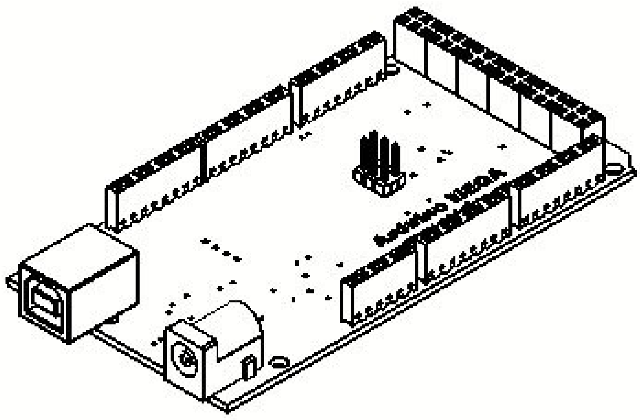
Once you have your skecth you'll see something very close to the screenshot on the right.

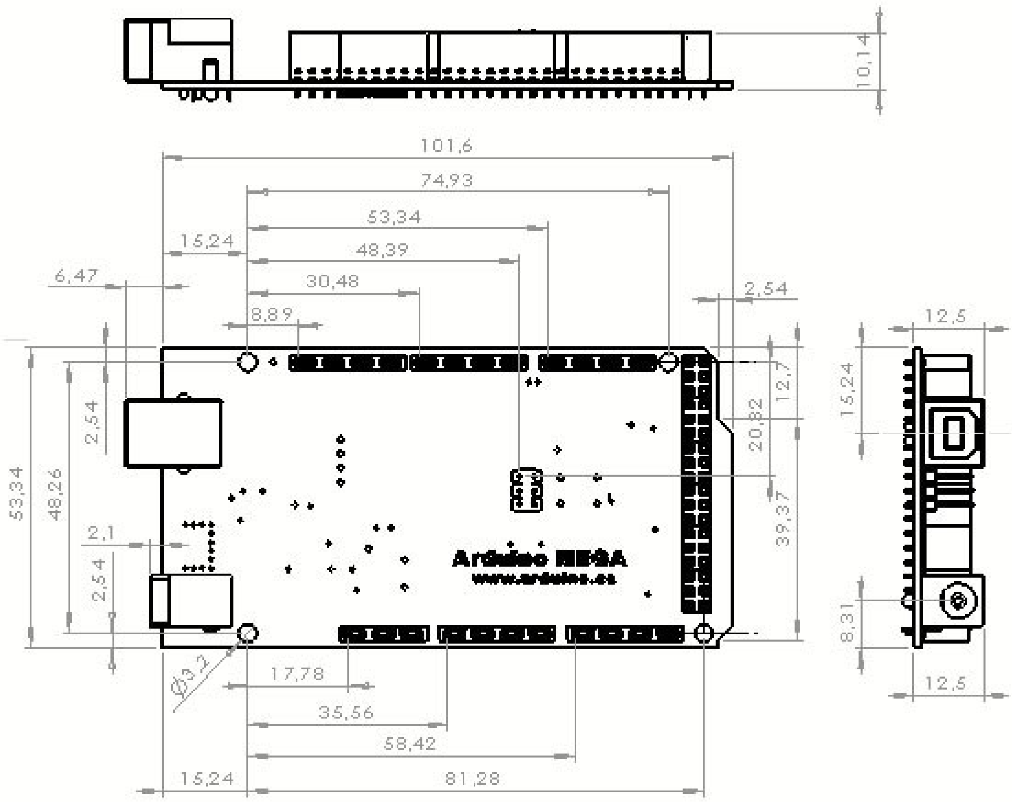
In **Tools>Board** select MEGA

Now you have to go to
Tools>SerialPort
and select the right serial port, the one arduino is attached to.





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Arduino MEGA
www.arduino.cc

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1.2 If any products fail to conform to the warranty set forth above, the producer's sole liability shall be to replace such products. The producer's liability shall be limited to products that are determined by the producer not to conform to such warranty. If the producer elects to replace such products, the producer shall have a reasonable time to replacements. Replaced products shall be warranted for a new full warranty period.

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1.4 Customer agrees that prior to using any systems that include the producer products, Customer will test such systems and the functionality of the products as used in such systems. The producer may provide technical, applications or design advice, quality characterization, reliability data or other services. Customer acknowledges and agrees that providing these services shall not expand or otherwise alter the producer's warranties, as set forth above, and no additional obligations or liabilities shall arise from the producer providing such services.

1.5 The Arduino™ products are not authorized for use in safety-critical applications where a failure of the product would reasonably be expected to cause severe personal injury or death. Safety-Critical Applications include, without limitation, life support devices and systems, equipment or systems for the operation of nuclear facilities and weapons systems. Arduino™ products are neither designed nor intended for use in military or aerospace applications or environments and for automotive applications or environment. Customer acknowledges and agrees that any such use of Arduino™ products which is solely at the Customer's risk, and that Customer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

1.6 Customer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products and any use of Arduino™ products in Customer's applications, notwithstanding any applications-related information or support that may be provided by the producer.

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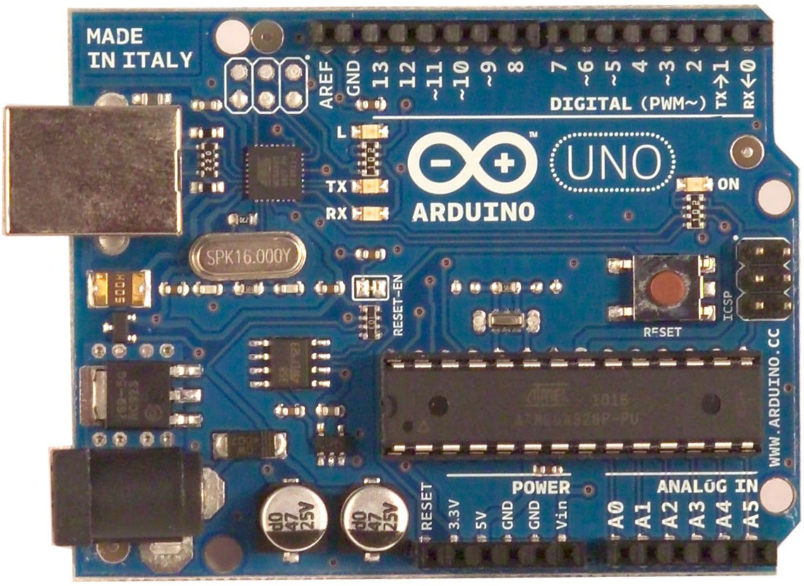
Arduino UNO



Product Overview

The Arduino Uno is a microcontroller board based on the ATmega328 (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega8U2 programmed as a USB-to-serial converter.

"Uno" means one in Italian and is named to mark the upcoming release of Arduino 1.0. The Uno and version 1.0 will be the reference versions of Arduno, moving forward. The Uno is the latest in a series of USB Arduino boards, and the reference model for the Arduino platform; for a comparison with previous versions, see the index of Arduino boards.

Index

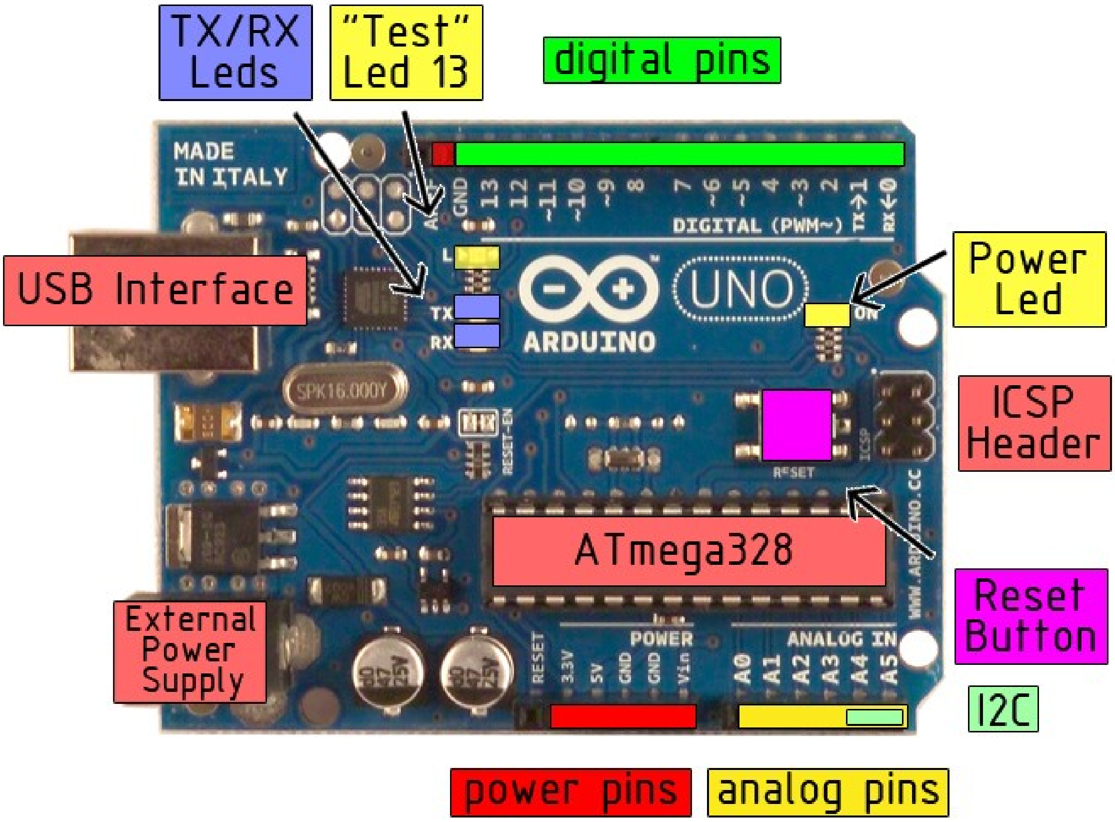
Technical Specification

EAGLE files: arduino-duemilanove-uno-design.zip Schematic: arduino-uno-schematic.pdf

Summary

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB of which 0.5 KB used by bootloader
SRAM	2 KB
EEPROM	1 KB
Clock Speed	16 MHz

the board



Power

The Arduino Uno can be powered via the USB connection or with an external power supply. The power source is selected automatically.

External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and Vin pin headers of the POWER connector.

The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

The power pins are as follows:

- **VIN.** The input voltage to the Arduino board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). You can supply voltage through this pin, or, if supplying voltage via the power jack, access it through this pin.
- **5V.** The regulated power supply used to power the microcontroller and other components on the board. This can come either from VIN via an on-board regulator, or be supplied by USB or another regulated 5V supply.
- **3V3.** A 3.3 volt supply generated by the on-board regulator. Maximum current draw is 50 mA.
- **GND.** Ground pins.

Memory

The Atmega328 has 32 KB of flash memory for storing code (of which 0,5 KB is used for the bootloader); It has also 2 KB of SRAM and 1 KB of EEPROM (which can be read and written with the EEPROM library).

Input and Output

Each of the 14 digital pins on the Uno can be used as an input or output, using pinMode(), digitalWrite(), and digitalRead() functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms. In addition, some pins have specialized functions:

- **Serial: 0 (RX) and 1 (TX).** Used to receive (RX) and transmit (TX) TTL serial data. TThese pins are connected to the corresponding pins of the ATmega8U2 USB-to-TTL Serial chip .
- **External Interrupts: 2 and 3.** These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the attachInterrupt() function for details.
- **PWM: 3, 5, 6, 9, 10, and 11.** Provide 8-bit PWM output with the analogWrite() function.
- **SPI: 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK).** These pins support SPI communication, which, although provided by the underlying hardware, is not currently included in the Arduino language.

- **LED: 13.** There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.

The Uno has 6 analog inputs, each of which provide 10 bits of resolution (i.e. 1024 different values). By default they measure from ground to 5 volts, though is it possible to change the upper end of their range using the AREF pin and the analogReference() function. Additionally, some pins have specialized functionality:

- **I²C: 4 (SDA) and 5 (SCL).** Support I²C (TWI) communication using the Wire library.

There are a couple of other pins on the board:

- **AREF.** Reference voltage for the analog inputs. Used with analogReference().
- **Reset.** Bring this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block the one on the board.

See also the mapping between Arduino pins and Atmega328 ports.

Communication

The Arduino Uno has a number of facilities for communicating with a computer, another Arduino, or other microcontrollers. The ATmega328 provides UART TTL (5V) serial communication, which is available on digital pins 0 (RX) and 1 (TX). An ATmega8U2 on the board channels this serial communication over USB and appears as a virtual com port to software on the computer. The '8U2 firmware uses the standard USB COM drivers, and no external driver is needed. However, on Windows, an *.inf file is required..

The Arduino software includes a serial monitor which allows simple textual data to be sent to and from the Arduino board. The RX and TX LEDs on the board will flash when data is being transmitted via the USB-to-serial chip and USB connection to the computer (but not for serial communication on pins 0 and 1).

A SoftwareSerial library allows for serial communication on any of the Uno's digital pins.

The ATmega328 also support I2C (TWI) and SPI communication. The Arduino software includes a Wire library to simplify use of the I2C bus; see the documentation for details. To use the SPI communication, please see the ATmega328 datasheet.

Programming

The Arduino Uno can be programmed with the Arduino software (download). Select "Arduino Uno w/ ATmega328" from the **Tools > Board** menu (according to the microcontroller on your board). For details, see the reference and tutorials.

The ATmega328 on the Arduino Uno comes preburned with a bootloader that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol (reference, C header files).

You can also bypass the bootloader and program the microcontroller through the ICSP (In-Circuit Serial Programming) header; see these instructions for details.

The ATmega8U2 firmware source code is available . The ATmega8U2 is loaded with a DFU bootloader, which can be activated by connecting the solder jumper on the back of the board (near the map of Italy) and then resetting the 8U2. You can then use Atmel's FLIP software (Windows) or the DFU programmer (Mac OS X and Linux) to load a new firmware. Or you can use the ISP header with an external programmer (overwriting the DFU bootloader).

Automatic (Software) Reset

Rather than requiring a physical press of the reset button before an upload, the Arduino Uno is designed in a way that allows it to be reset by software running on a connected computer. One of the hardware flow control lines (DTR) of the ATmega8U2 is connected to the reset line of the ATmega328 via a 100 nanofarad capacitor. When this line is asserted (taken low), the reset line drops long enough to reset the chip. The Arduino software uses this capability to allow you to upload code by simply pressing the upload button in the Arduino environment. This means that the bootloader can have a shorter timeout, as the lowering of DTR can be well-coordinated with the start of the upload.

This setup has other implications. When the Uno is connected to either a computer running Mac OS X or Linux, it resets each time a connection is made to it from software (via USB). For the following half-second or so, the bootloader is running on the Uno. While it is programmed to ignore malformed data (i.e. anything besides an upload of new code), it will intercept the first few bytes of data sent to the board after a connection is opened. If a sketch running on the board receives one-time configuration or other data when it first starts, make sure that the software with which it communicates waits a second after opening the connection and before sending this data.

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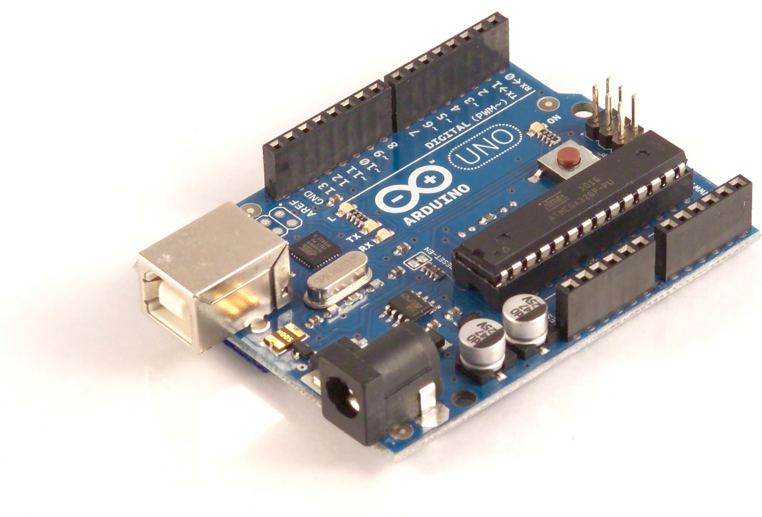
USB Overcurrent Protection

The Arduino Uno has a resettable polyfuse that protects your computer's USB ports from shorts and overcurrent. Although most computers provide their own internal protection, the fuse provides an extra layer of protection. If more than 500 mA is applied to the USB port, the fuse will automatically break the connection until the short or overload is removed.

Physical Characteristics

The maximum length and width of the Uno PCB are 2.7 and 2.1 inches respectively, with the USB connector and power jack extending beyond the former dimension. Three screw holes allow the board to be attached to a surface or case. Note that the distance between digital pins 7 and 8 is 160 mil (0.16"), not an even multiple of the 100 mil spacing of the other pins.



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Blink led

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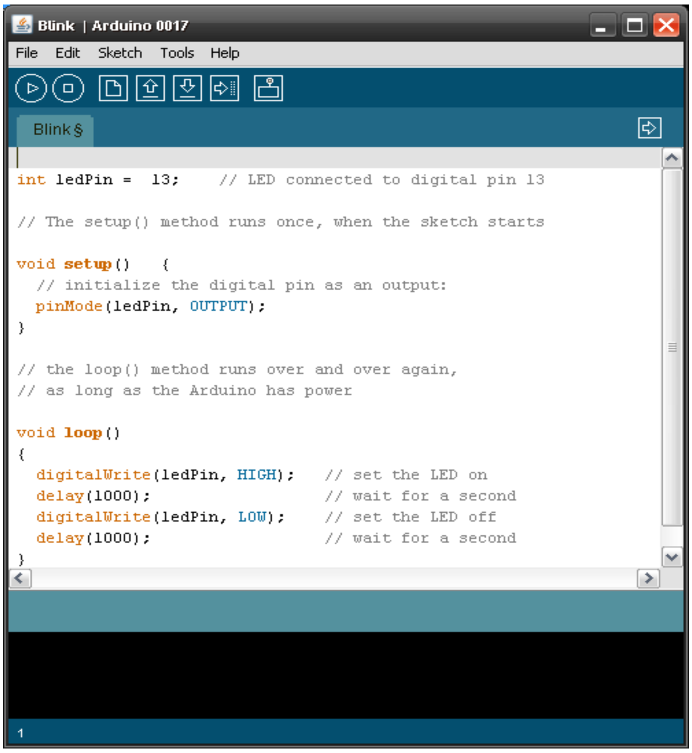

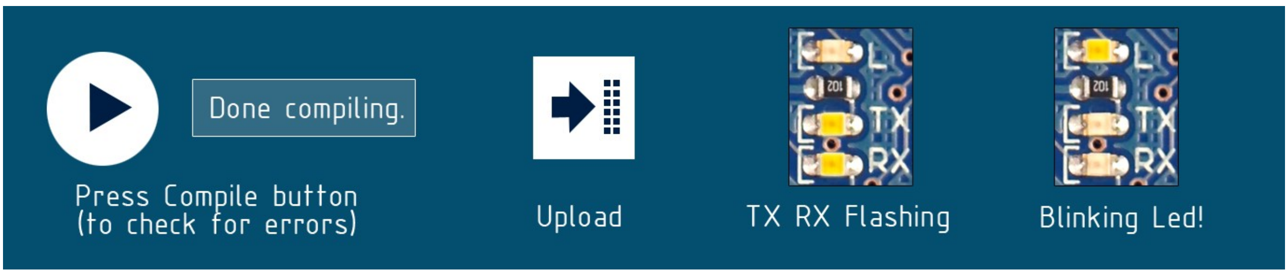

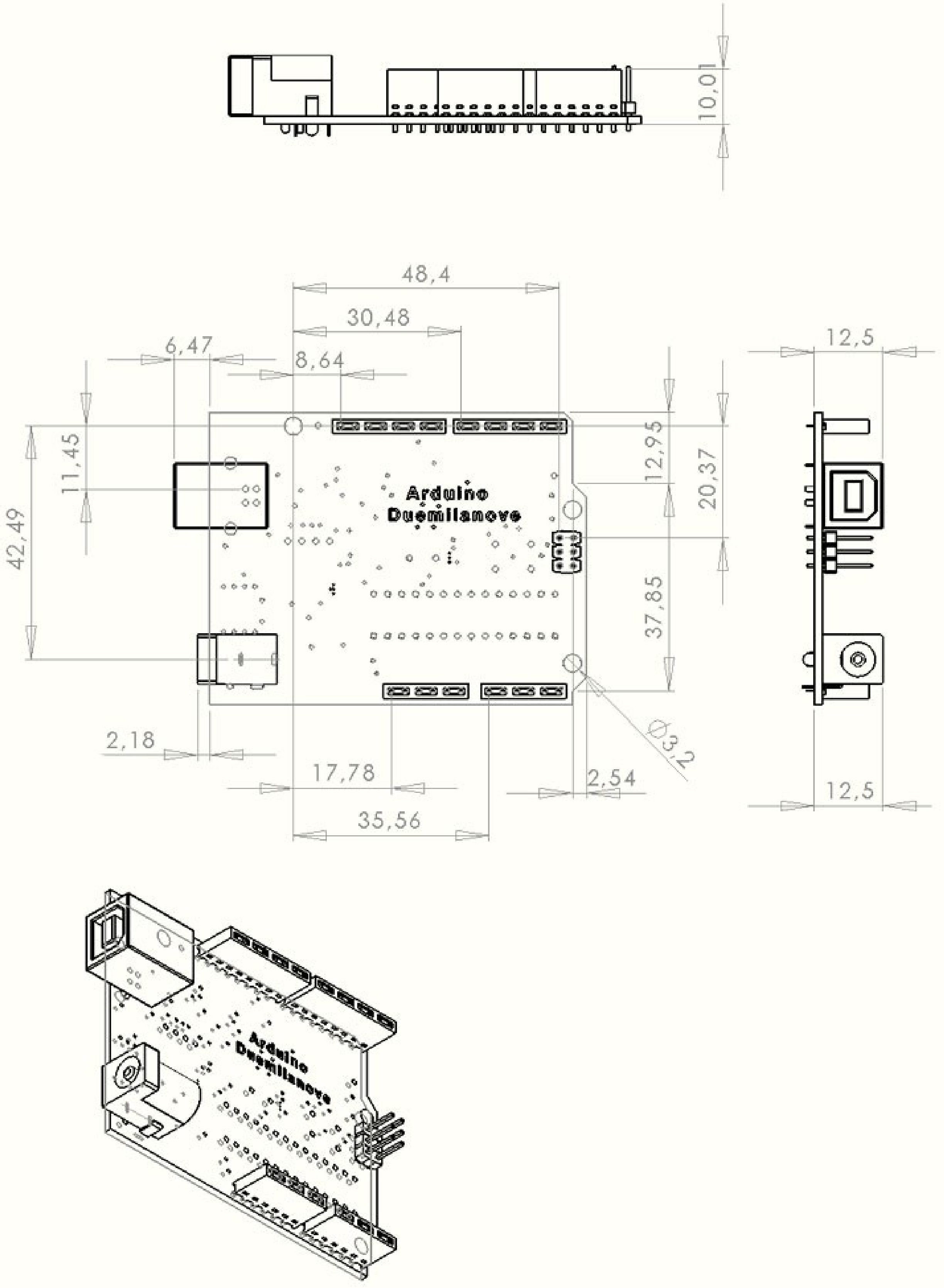

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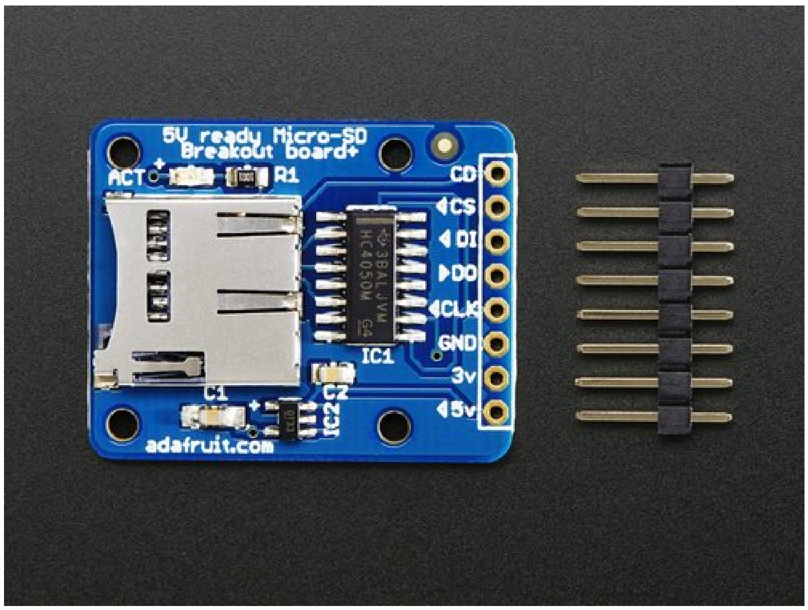
Micro SD Card Breakout Board Tutorial

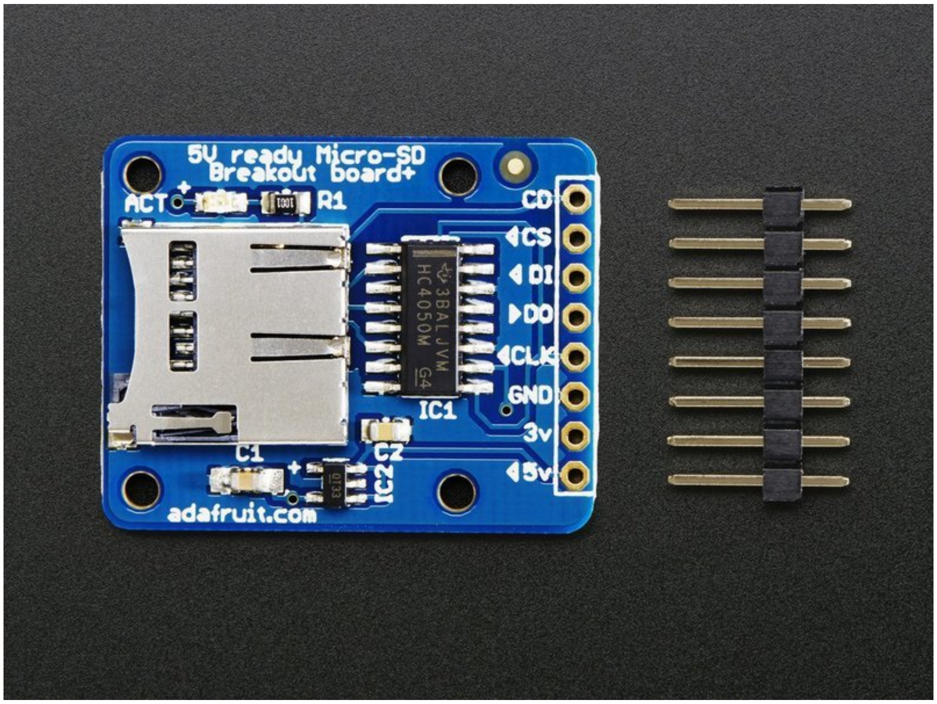
Created by lady ada



Last updated on 2018-09-17 04:33:40 AM UTC

Guide Contents

Introduction



If you have a project with any audio, video, graphics, data logging, etc in it, you'll find that having a removable storage option is essential. Most microcontrollers have extremely limited built-in storage. For example, even the Arduino Mega chip (the Atmega2560) has a mere 4Kbytes of EEPROM storage. There's more flash (256K) but you can't write to it as easily and you have to be careful if you want to store information in flash that you don't overwrite the program itself!

If you're doing any sort of data logging, graphics or audio, you'll need at least a megabyte of storage, and 64 M is probably the minimum. To get that kind of storage we're going to use the same type that's in every digital camera and mp3 player: flash cards! Often called SD or microSD cards, they can pack **gigabytes** into a space smaller than a coin. They're also available in every electronics shop so you can easily get more and best of all, many computers have SD or microSD card readers built in so you can move data back and forth between say your Arduino GPS data logger and your computer graphing software:

Look out!

What to watch for!

There are a few things to watch for when interacting with SD cards:

One is that they are strictly 3.3V devices and the power draw when writing to the card can be fairly high, up to 100mA (or more)! That means that you **must** have a fairly good 3.3V power supply for the card. Secondly you must also have 3.3V logic to interface to the pins. We've found that SD cards are fairly sensitive about the interface pins - the newest cards are edge triggered and require very 'square' transitions - things like resistor dividers and long wires will have a deleterious effect on the transition speed, so **keep wires short, and avoid using resistor dividers for the 3.3V logic lines**. We suggest instead using level shifters, such as **HEF4050**, **74LVX245** or **74AHC125** chips.

For the level shifter we use the CD74HC4050 (https://adafru.it/Boj) which has a typical propagation delay of ~10ns

Secondly, there are two ways to interface with SD cards - **SPI mode** and **SDIO mode**. SDIO mode is faster, but is more complex and as far as we can tell, requires signing non-disclosure documents. For that reason, you will likely never encounter SDIO mode interface code. Instead, every SD card has a 'lower speed' SPI mode that is easy for any microcontroller to use. SPI mode requires four pins (we'll discuss them in detail later) so it's not pin-heavy like some parallel-interface components

SD cards come in two popular flavors - **microSD** and **SD**. The interface, code, structure, etc is all the same. The only differences is the size. MicroSD are much much smaller in physical size.

Third, SD cards are 'raw' storage. They're just sectors in a flash chip, there's no structure that you *have* to use. That means you could format an SD card to be a Linux filesystem, a FAT (DOS) filesystem or a Mac filesystem. You could also not have any filesystem at all! However, 99% of computers, cameras, MP3 players, GPS loggers, etc require **FAT16** or **FAT32** for the filesystem. The tradeoff here is that for smaller microcontrollers (like the Arduino) the addition of the complex file format handling can take a lot of flash storage and RAM.

Formatting notes

Even though you can/could use your SD card 'raw' - it's most convenient to format the card to a filesystem. For the Arduino library we'll be discussing, and nearly every other SD library, the card must be formatted FAT16 or FAT32. Some only allow one or the other. The Arduino SD library can use either.

If you bought an SD card, chances are it's already pre-formatted with a FAT filesystem. However you may have problems with how the factory formats the card, or if it's an old card it needs to be reformatted. The Arduino SD library we use supports both **FAT16** and **FAT32** filesystems. If you have a very small SD card, say 8-32 Megabytes you might find it is formatted **FAT12** which isn't supported. You'll have to reformat these card. Either way, it's **always** good idea to format the card before using, even if it's new! Note that formatting will erase the card so save anything you want first.

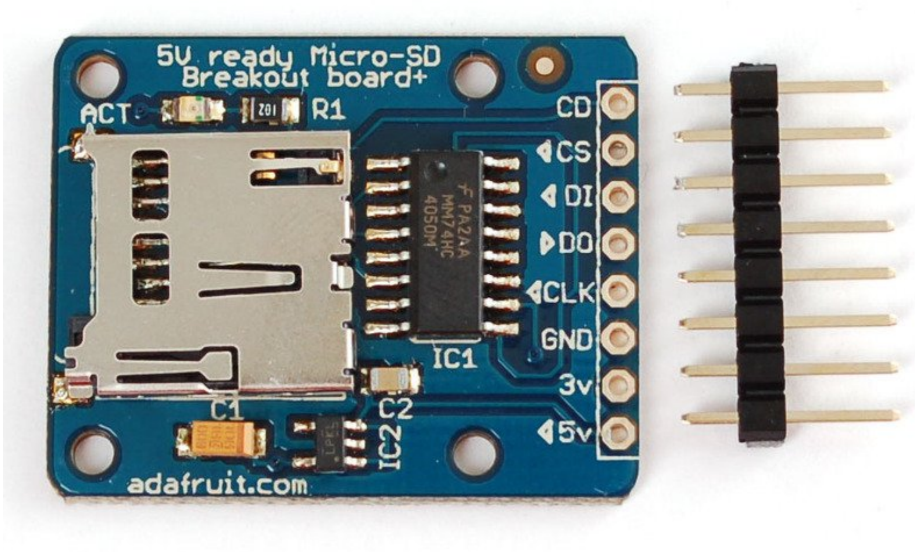
> We strongly recommend you use the official SD card formatter utility - written by the SD association it solves many problems that come with bad formatting!

Download the formatter from https://www.sdcard.org/downloads/formatter_3/ (https://adafru.it/c73)

Download it and run it on your computer, there's also a manual linked from that page for use.

Arduino Wiring

Now that your card is ready to use, we can wire up the microSD breakout board! The breakout board we designed takes care of a lot for you. There's an onboard ultra-low dropout regulator that will convert voltages from 3.3V-6v down to ~3.3V (**IC2**). There's also a level shifter that will convert the interface logic from 3.3V-5V to 3.3V. That means you can use this board to interact with a 3.3V or 5V microcontrollers.

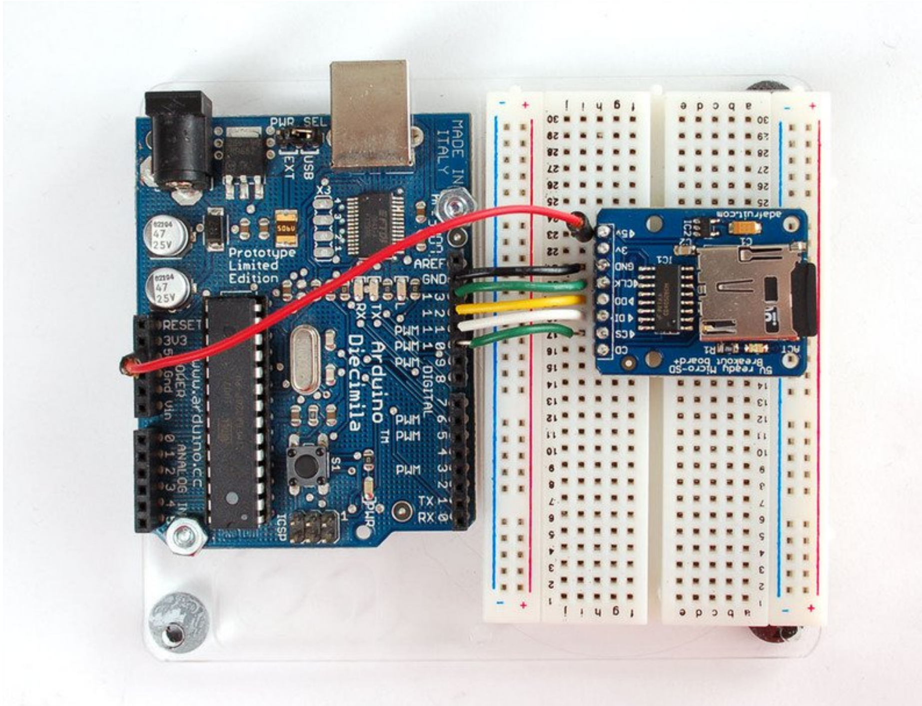


In this tutorial we will be using an Arduino to demonstrate the wiring and interfacing. If you have another microcontroller, you'll need to adapt the wiring and code to match!

Because SD cards require a lot of data transfer, they will give the best performance when connected up to the **hardware** SPI pins on a microcontroller. The hardware SPI pins are much faster than 'bit-banging' the interface code using another set of pins. For 'classic' Arduinos such as the Duemilanove/Diecimila/Uno those pins are **digital 13 (SCK), 12 (MISO)** and **11 (MOSI)**. You will also need a fourth pin for the 'chip/slave select' (**SS**) line. Traditionally this is pin **10** but you can actually use any pin you like. If you have a Mega, the pins are different! You'll want to use digital **50 (MISO), 51 (MOSI), 52 (SCK),** and for the CS line, the most common pin is **53 (SS).** Again, you can change the SS (pin **10** or **53**) later but for now, stick with those pins.

- Connect the **5V** pin to the **5V** pin on the Arduino
- Connect the **GND** pin to the **GND** pin on the Arduino
- Connect **CLK** to pin **13** or **52**
- Connect **DO** to pin **12** or **50**
- Connect **DI** to pin **11** or **51**
- Connect **CS** to pin **10** or **53**

There's one more pin **CD** - this is the Card Detect pin. It shorts to ground when a card is *not* inserted. (Note that some card holders are the other way around). You should connect a pull up resistor (10K or so) and wire this to another pin if you want to detect when a card is inserted. We won't be using it for now.



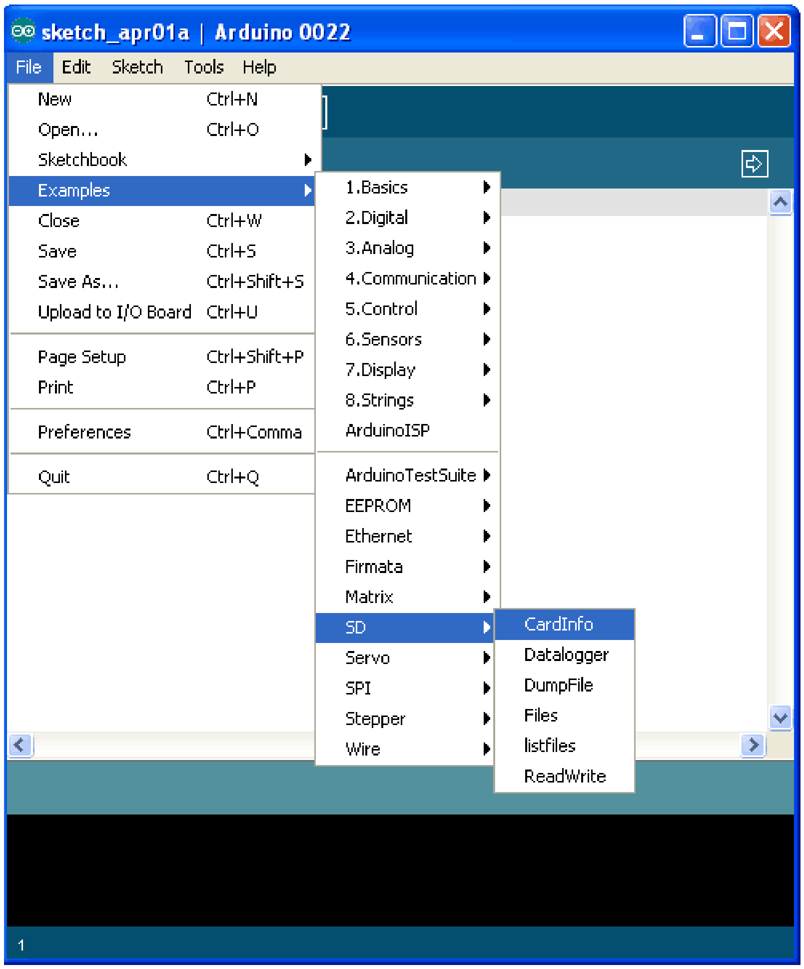
That's it! Now you're ready to rock!

Arduino Library

Arduino Library & First Test

Interfacing with an SD card is a bunch of work, but luckily for us, Adafruit customer fat16lib (William G) has written a very nice Arduino library just for this purpose and it's now part of the Arduino IDE known as **SD** (pretty good name, right?) You can see it in the Examples submenu

Next, select the **CardInfo** example sketch.

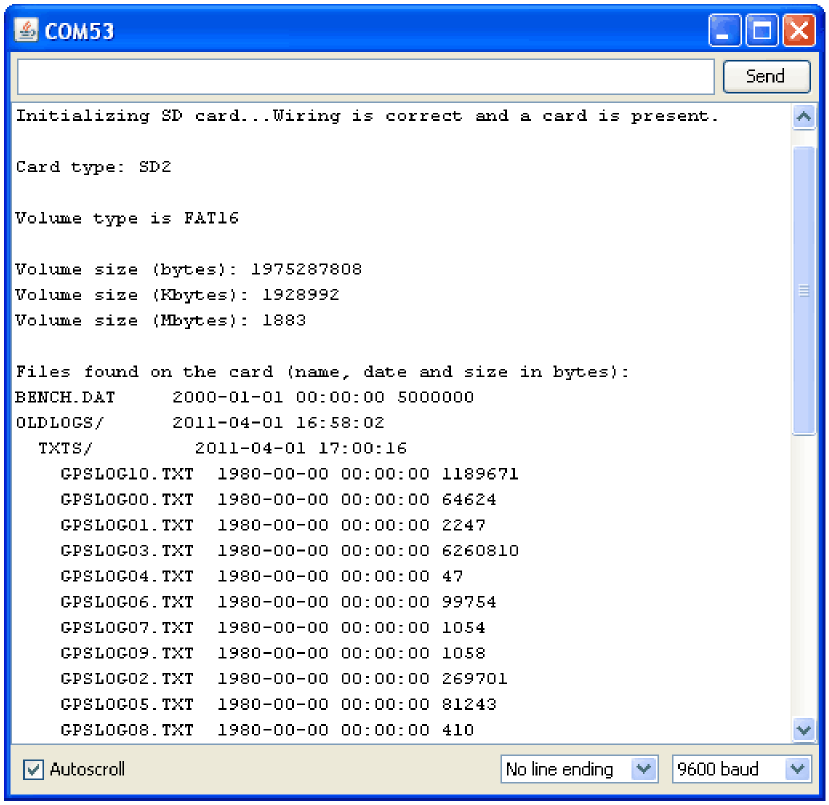


This sketch will not write any data to the card, just tell you if it managed to recognize it, and some information about it. This can be **very** useful when trying to figure out whether an SD card is supported. Before trying out a new card, please try out this sketch!

Go to the beginning of the sketch and make sure that the **chipSelect** line is correct, for this wiring we're using digital pin 10 so change it to 10!

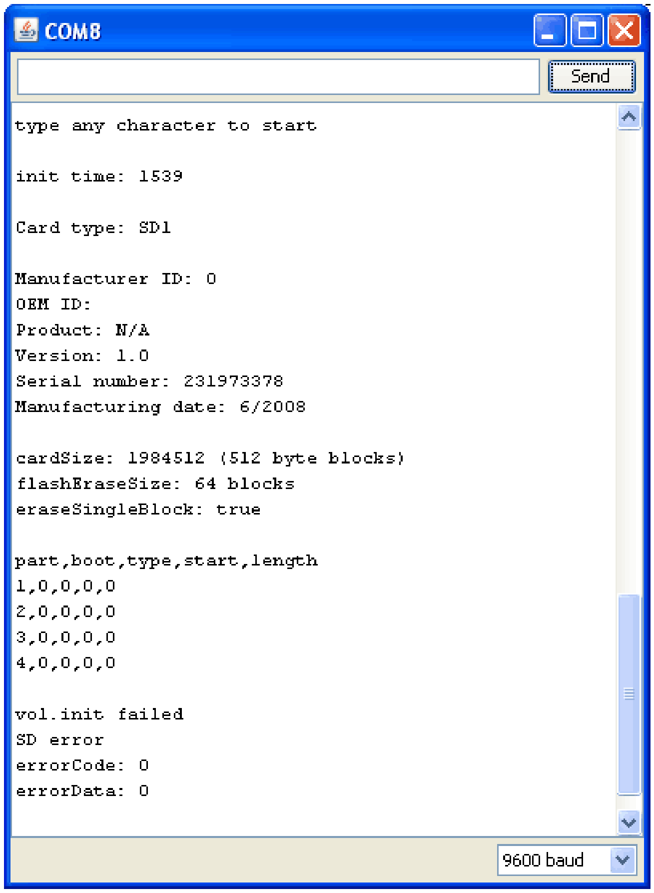
OK, now insert the SD card into the breakout board and upload the sketch.

Open up the Serial Monitor and type in a character into the text box (& hit send) when prompted. You'll probably get something like the following:



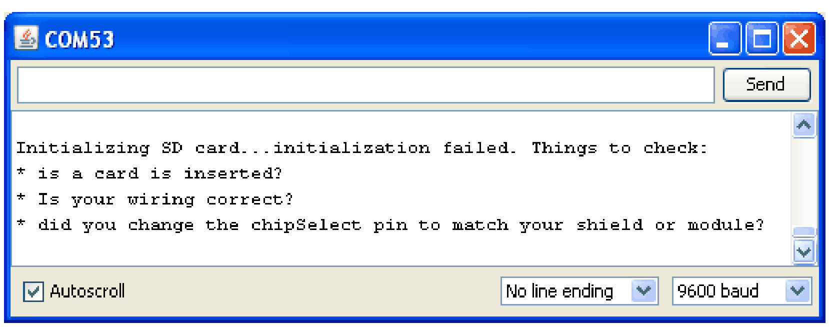
It's mostly gibberish, but it's useful to see the **Volume type is FAT16** part as well as the size of the card (about 2 GB which is what it should be) etc.

If you have a bad card, which seems to happen more with ripoff version of good brands, you might see:



The card mostly responded, but the data is all bad. Note that the **Product ID** is **"N/A"** and there is no **Manufacturer ID** or **OEM ID**. This card returned some SD errors. It's basically a bad scene, I only keep this card around to use as an example of a bad card! If you get something like this (where there is a response but it's corrupted) you can try to reformat it or if it still flakes out, should toss the card.

Finally, try taking out the SD card and running the sketch again, you'll get the following,



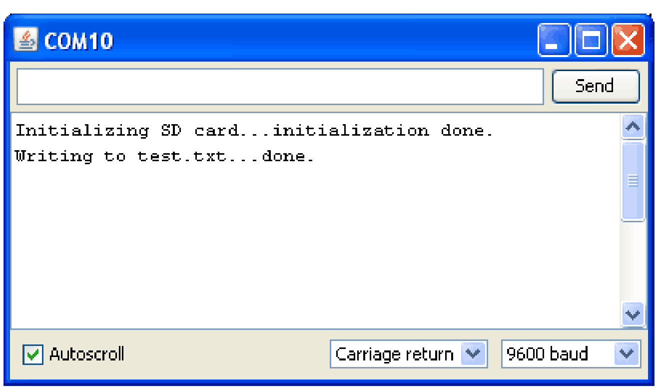
It couldn't even initialize the SD card. This can also happen if there's a soldering or wiring error or if the card is *really* damaged.

Writing files

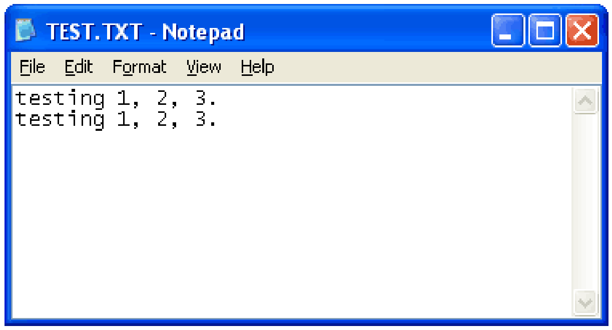
The following sketch will do a basic demonstration of writing to a file. This is a common desire for datalogging and such.

```
#include <SD.h>

File myFile;

void setup()
{
  Serial.begin(9600);
  Serial.print("Initializing SD card...");
  // On the Ethernet Shield, CS is pin 4. It's set as an output by default.
  // Note that even if it's not used as the CS pin, the hardware SS pin
  // (10 on most Arduino boards, 53 on the Mega) must be left as an output
  // or the SD library functions will not work.
   pinMode(10, OUTPUT);

  if (!SD.begin(10)) {
    Serial.println("initialization failed!");
    return;
  }
  Serial.println("initialization done.");

  // open the file. note that only one file can be open at a time,
  // so you have to close this one before opening another.
  myFile = SD.open("test.txt", FILE_WRITE);

  // if the file opened okay, write to it:
  if (myFile) {
    Serial.print("Writing to test.txt...");
    myFile.println("testing 1, 2, 3.");
 // close the file:
    myFile.close();
    Serial.println("done.");
  } else {
    // if the file didn't open, print an error:
    Serial.println("error opening test.txt");
  }
}

void loop()
{
 // nothing happens after setup
}
```

When you run it you should see the following:



You can then open up the file in your operating system by inserting the card. You'll see one line for each time the sketch ran. That is to say, it **appends** to the file, not overwriting it.



Some things to note:

- You can have multiple files open at a time, and write to each one as you wish.
- You can use **print** and **println()** just like Serial objects, to write strings, variables, etc
- You must **close()** the file(s) when you're done to make sure all the data is written permanently!
- You can open files in a directory. For example, if you want to open a file in the directory such as **/MyFiles/example.txt** you can call **SD.open("/myfiles/example.txt")** and it will do the right thing.

The SD card library does not support 'long filenames' such as we are used to. Instead, it uses the 8.3 format for file names, so keep file names short! For example IMAGE.JPG is fine, and datalog.txt is fine but "My GPS log file.text" is not! Also keep in mind that short file names do not have 'case' sensitivity, so datalog.txt is the same file as DataLog.Txt is the same file as DATALOG.TXT

Reading from files

Next up we will show how to read from a file, it's very similar to writing in that we **SD.open()** the file but this time we don't pass in the argument **FILE_WRITE** this will keep you from accidentally writing to it. You can then call **available()** (which will let you know if there is data left to be read) and **read()** from the file, which will return the next byte.

```
#include <SD.h>

File myFile;

void setup()
{
  Serial.begin(9600);
  Serial.print("Initializing SD card...");
  // On the Ethernet Shield, CS is pin 4. It's set as an output by default.
  // Note that even if it's not used as the CS pin, the hardware SS pin
  // (10 on most Arduino boards, 53 on the Mega) must be left as an output
  // or the SD library functions will not work.
   pinMode(10, OUTPUT);

  if (!SD.begin(10)) {
    Serial.println("initialization failed!");
    return;
  }
  Serial.println("initialization done.");

  // open the file for reading:
  myFile = SD.open("test.txt");
  if (myFile) {
    Serial.println("test.txt:");

    // read from the file until there's nothing else in it:
    while (myFile.available()) {
     Serial.write(myFile.read());
    }
    // close the file:
    myFile.close();
  } else {
   // if the file didn't open, print an error:
    Serial.println("error opening test.txt");
  }
}

void loop()
{
 // nothing happens after setup
}
```

Some things to note:

- You can have multiple files open at a time, and read from each one as you wish.
- **Read()** only returns a byte at a time. It does not read a full line or a number!
- You should **close()** the file(s) when you're done to reduce the amount of RAM used.

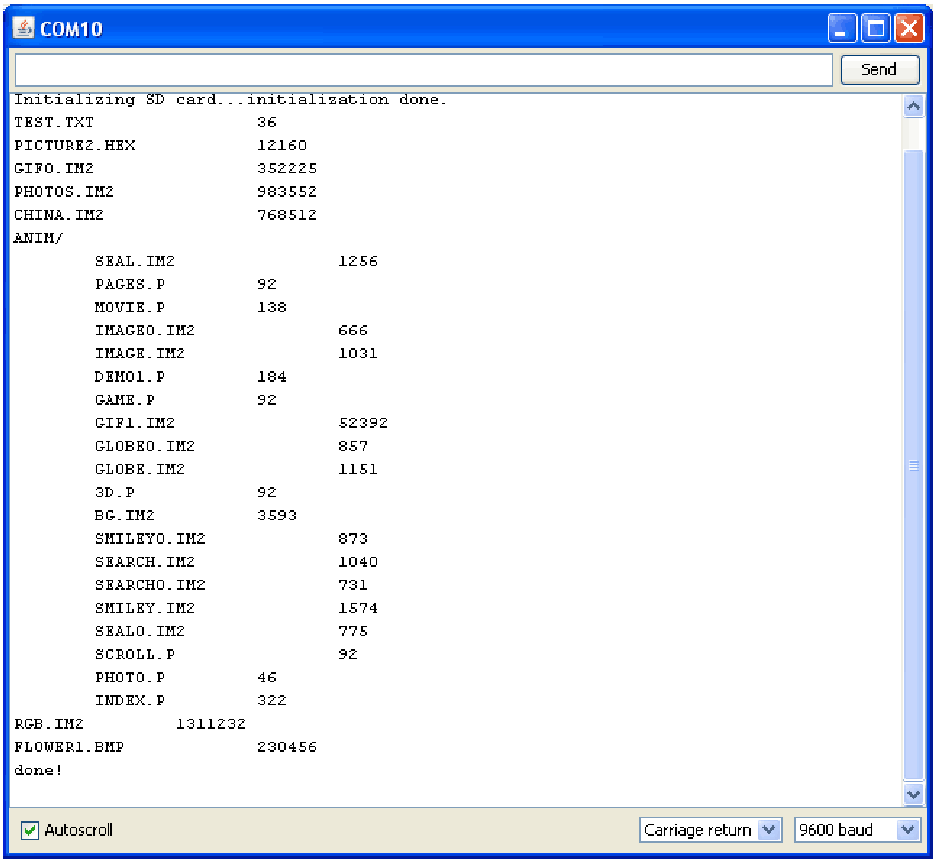
The SD card library does not support 'long filenames' such as we are used to. Instead, it uses the 8.3 format for file names, so keep file names short! For example IMAGE.JPG is fine, and datalog.txt is fine by "My GPS log file.text" is not! Also keep in mind that short file names do not have 'case' sensitivity, so datalog.txt is the same file as DataLog.Txt is the same file as DATALOG.TXT

Recursively listing/reading files

The last example we have shows more advanced use. A common request is for example wanting to list every file on the SD card, or play ever music file or similar. In the latest version of the SD library, you can *recurse* through a directory and call **openNextFile**() to get the next available file. These aren't in alphabetical order, they're in order of creation so just watch out for that!

To see it, run the **SD→listfiles** example sketch

Here you can see that we have a subdirectory **ANIM** (we have animation files in it). The numbers after each file name are the size in bytes of the file. This sketch is handy if you want to check what files are called on your card. The sketch also demonstrates how to do directory handling.



Arduino Library Docs

Other useful functions

There's a few useful things you can do with **SD** objects we'll list a few here:

- If you just want to check if a file exists, use **SD.exists("filename.txt")** which will return true or false.
- You can delete a file by calling **SD.remove("unwanted.txt")** - be careful! This will really delete it, and there's no 'trash can' to pull it out of.
- You can create a subdirectory by calling **SD.mkdir("/mynewdir")** handy when you want to stuff files in a location. Nothing happens if it already exists but you can always call **SD.exists()** above first.

Also, there's a few useful things you can do with **File** objects:

- You can **seek()** on a file. This will move the reading/writing pointer to a new location. For example **seek(0)** will take you to the beginning of the file, which can be very handy!
- Likewise you can call **position()** which will tell you where you are in the file.
- If you want to know the size of a file, call **size()** to get the number of bytes in the file.
- Directories/folders are special files, you can determine if a file is a directory by calling **isDirectory()**
- Once you have a directory, you can start going through all the files in the directory by calling **openNextFile()**
- You may end up with needing to know the name of a file, say if you called **openNextFile()** on a directory. In this case, call **name()** which will return a pointer to the 8.3-formatted character array you can directly **Serial.print()** if you want.

Examples

More examples!

If you want to use an SD card for datalogging, we suggest checking out our Datalogging shield (https://adafru.it/dpH) and GPS logging shield (https://adafru.it/dpI) - there's example code specifically for those purposes.

If you want to use the SD card for loading images (such as for a color display) look at our 2.8" TFT shield (https://adafru.it/dpJ) and 1.8" TFT breakout tutorials (https://adafru.it/ckK). Those have examples of how we read BMP files off disk and parse them.

CircuitPython

Adafruit CircuitPython Module Install

To use a microSD card with your Adafruit CircuitPython board you'll need to install the Adafruit_CircuitPython_SD (https://adafru.it/zwC) module on your board.

First make sure you are running the latest version of Adafruit CircuitPython (https://adafru.it/Amd) for your board.

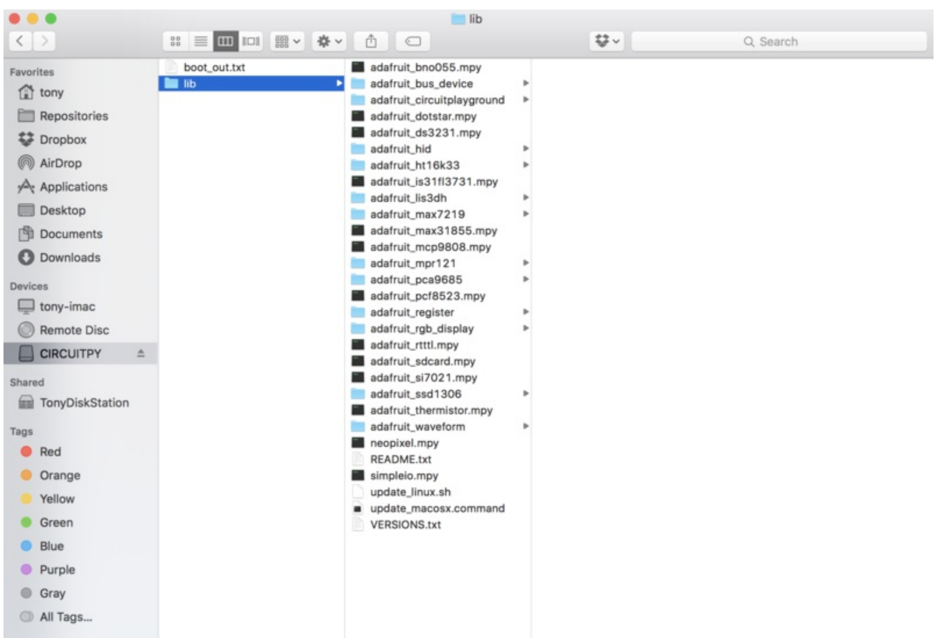
Next you'll need to install the necessary libraries to use the hardware--carefully follow the steps to find and install these libraries from Adafruit's CircuitPython library bundle (https://adafru.it/zdx). Our introduction guide has a great page on how to install the library bundle (https://adafru.it/ABU) for both express and non-express boards. **Be sure to use the latest CircuitPython Bundle** as it includes an updated version of the SD card module with a few necessary fixes!

Remember for non-express boards like the, you'll need to manually install the necessary libraries from the bundle:

- **adafruit_sdcard.mpy**
- **adafruit_bus_device**

If your board doesn't support USB mass storage, like the ESP8266, then use a tool like ampy to copy the file to the board (https://adafru.it/s1f). You can use the latest version of ampy and its new directory copy command (https://adafru.it/q2A) to easily move module directories to the board.

Before continuing make sure your board's lib folder or root filesystem has the **adafruit_sdcard.mpy** and **adafruit_bus_device** modules copied over.



Usage

The following section will show how to initialize the SD card and read & write data to it from the board's Python prompt / REPL.

Next connect to the board's serial REPL (https://adafru.it/Awz)so you are at the CircuitPython >>> prompt.

Initialize & Mount SD Card Filesystem

Before you can use the microSD card you need to initialize its SPI connection and mount its filesystem. First import the necessary modules to initialize the SPI and CS line physical connections:

```
import board
import busio
import digitalio
```

Next create the SPI bus and a digital output for the microSD card's chip select line (be sure to select the right pin name or number for your wiring):

```
spi = busio.SPI(board.SCK, MOSI=board.MOSI, MISO=board.MISO)
# Use board.SD_CS for Feather M0 Adalogger
cs = digitalio.DigitalInOut(board.SD_CS)
# Or use a GPIO pin like 15 for ESP8266 wiring:
#cs = digitalio.DigitalInOut(board.GPIO15)
```

Now import modules to access the SD card and filesystem:

```
import adafruit_sdcard
import storage
```

At this point you're ready to create the microSD card object and the filesystem object:

```
sdcard = adafruit_sdcard.SDCard(spi, cs)
vfs = storage.VfsFat(sdcard)
```

Notice the **adafruit_sdcard** module has a **SDCard** class which contains all the logic for talking to the microSD card at a low level. This class needs to be told the SPI bus and chip select digital IO pin in its initializer.

After a **SDCard** class is created it can be passed to the **storage** module's **VfsFat** class. This class has all the logic for translating CircuitPython filesystem calls into low level microSD card access. Both the **SDCard** and **VfsFat** class instances are required to mount the card as a new filesystem.

Finally you can mount the microSD card's filesystem into the CircuitPython filesystem. For example to make the path **/sd** on the CircuitPython filesystem read and write from the card run this command:

```
storage.mount(vfs, "/sd")
```

The first parameter to the storage.mount command is the **VfsFat** class instance that was created above, and the second parameter is the location within the CircuitPython filesystem that you'd like to 'place' the microSD card. Remember the mount location as you'll need it to read and write files on the card!

Reading & Writing Data

Once the microSD card is mounted inside CircuitPython's filesystem you're ready to read and write data from it. Reading and writing data is simple using Python's file operations like open (https://adafru.it/reL), close (https://adafru.it/ryE), read (https://adafru.it/ryE), and write (https://adafru.it/ryE). The beauty of CircuitPython and MicroPython is that they try to be as similar to desktop Python as possible, including access to files.

For example to create a file and write a line of text to it you can run:

```
with open("/sd/test.txt", "w") as f:
    f.write("Hello world!\r\n")
```

Notice the with statement is used to create a context manager that opens and automatically closes the file. This is handy because with file access you Python you **must** close the file when you're done or else all the data you thought was written might be lost!

The **open** function is used to open the file by telling it the path to it, and the mode (w for writing). Notice the path is under **/sd**, **/sd/test.txt**. This means the file will be created on the microSD card that was mounted as that path.

Inside the context manager you can access the f variable to operate on the file while it's open. The **write** function is called to write a line of text to the file. Notice that unlike a print statement you need to end the string passed to write with explicit carriage returns and new lines.

You can also open a file and read a line from it with similar code:

```
with open("/sd/test.txt", "r") as f:
    print("Read line from file:")
    print(f.readline())
```

If you wanted to read and print all of the lines from a file you could call **readline** in a loop. Once **readline** reaches the end of the file it will return an empty string so you know when to stop:

```
with open("/sd/test.txt", "r") as f:
    print("Printing lines in file:")
    line = f.readline()
    while line != '':
        print(line)
        line = f.readline()
```

There's even a **readlines** function that will read all of the lines in the file and return them in an array of lines. Be careful though as this means the entire file must be loaded into memory, so if the file is very large you might run out of memory. If you know your file is very small you can use it though:

```
with open("/sd/test.txt", "r") as f:
    lines = f.readlines()
    print("Printing lines in file:")
    for line in lines:
        print(line)
```

Finally one other very common file scenario is opening a file to add new data at the end, or append data. This works exactly the same as in Python and the **open** function can be told you'd like to append instead of erase and write new data (what normally happens with the **w** option for **open**). For example to add a line to the file:

```
with open("/sd/test.txt", "a") as f:
    f.write("This is another line!\r\n")
```

Notice the **a** option in the open function--this tells Python to add data at the end of the file instead of erasing it and starting over at the top. Try reading the file with the code above to see the new line that was added!

That's all there is to manipulating files on microSD cards with CircuitPython!

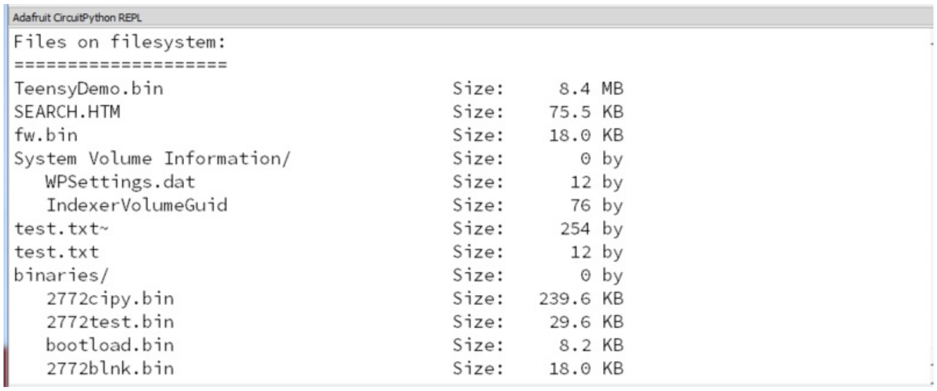
Here are a few more complete examples of using a SD card from the Trinket M0 CircuitPython guides (https://adafru.it/Bvi). These are great as a reference for more SD card usage.

List Files

Load this into **main.py:**

```
import os

import adafruit_sdcard
import board
import busio
import digitalio
import storage

# Use any pin that is not taken by SPI
SD_CS = board.D0

# Connect to the card and mount the filesystem.
spi = busio.SPI(board.SCK, board.MOSI, board.MISO)
cs = digitalio.DigitalInOut(SD_CS)
sdcard = adafruit_sdcard.SDCard(spi, cs)
vfs = storage.VfsFat(sdcard)
storage.mount(vfs, "/sd")


# Use the filesystem as normal! Our files are under /sd

# This helper function will print the contents of the SD


def print_directory(path, tabs=0):
    for file in os.listdir(path):
        stats = os.stat(path + "/" + file)
        filesize = stats[6]
        isdir = stats[0] & 0x4000

        if filesize < 1000:
            sizestr = str(filesize) + " by"
        elif filesize < 1000000:
            sizestr = "%0.1f KB" % (filesize / 1000)
        else:
            sizestr = "%0.1f MB" % (filesize / 1000000)

        prettyprintname = ""
        for _ in range(tabs):
            prettyprintname += "   "
        prettyprintname += file
        if isdir:
            prettyprintname += "/"
        print('{0:<40} Size: {1:>10}'.format(prettyprintname, sizestr))

        # recursively print directory contents
        if isdir:
            print_directory(path + "/" + file, tabs + 1)


print("Files on filesystem:")
print("====================")
print_directory("/sd")
```

Once it's loaded up, open up the REPL (and restart it with ^D if necessary) to get a printout of all the files included. We recursively print out all files and also the filesize. This is a good demo to start with because you can at least tell if your files exist!



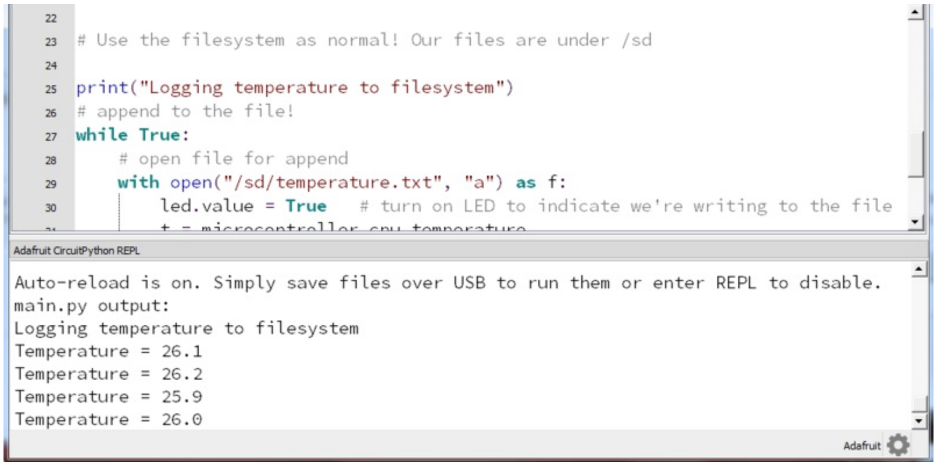

```
Files on filesystem:
====================
TeensyDemo.bin                          Size:     8.4 MB
SEARCH.HTM                              Size:    75.5 KB
fw.bin                                  Size:    18.0 KB
System Volume Information/              Size:       0 by
   WPSettings.dat                       Size:      12 by
   IndexerVolumeGuid                    Size:      76 by
test.txt~                               Size:     254 by
test.txt                                Size:      12 by
binaries/                               Size:       0 by
   2772cipy.bin                         Size:   239.6 KB
   2772test.bin                         Size:    29.6 KB
   bootload.bin                         Size:     8.2 KB
   2772blnk.bin                         Size:    18.0 KB
```

But you probably want to do a little more, lets log the temperature from the chip to a file.

Here's the new script

```
import time

import adafruit_sdcard
import board
import busio
import digitalio
import microcontroller
import storage

# Use any pin that is not taken by SPI
SD_CS = board.D0

led = digitalio.DigitalInOut(board.D13)
led.direction = digitalio.Direction.OUTPUT

# Connect to the card and mount the filesystem.
spi = busio.SPI(board.SCK, board.MOSI, board.MISO)
cs = digitalio.DigitalInOut(SD_CS)
sdcard = adafruit_sdcard.SDCard(spi, cs)
vfs = storage.VfsFat(sdcard)
storage.mount(vfs, "/sd")

# Use the filesystem as normal! Our files are under /sd

print("Logging temperature to filesystem")
# append to the file!
while True:
    # open file for append
    with open("/sd/temperature.txt", "a") as f:
        led.value = True  # turn on LED to indicate we're writing to the file
        t = microcontroller.cpu.temperature
        print("Temperature = %0.1f" % t)
        f.write("%0.1f\n" % t)
        led.value = False  # turn off LED to indicate we're done
    # file is saved
    time.sleep(1)
```

When saved, the Trinket will start saving the temperature once per second to the SD card under the file **temperature.txt**



The key part of this demo is in these lines:

```
print("Logging temperature to filesystem")
# append to the file!
while True:
    # open file for append
    with open("/sd/temperature.txt", "a") as f:
        led.value = True   # turn on LED to indicate we're writing to the file
        t = microcontroller.cpu.temperature
        print("Temperature = %0.1f" % t)
        f.write("%0.1f\n" % t)
        led.value = False   # turn off LED to indicate we're done
    # file is saved
    time.sleep(1)
```

This is a slightly complex demo but it's for a good reason. We use **with** (a 'context') to open the file for **a**ppending, that way the file is only opened for the very short time its written to. This is safer because then if the SD card is removed or the board turned off, all the data will be safe(r).

We use the LED to let the person using this know that the temperature is being written, it turns on just before the write and then off right after.

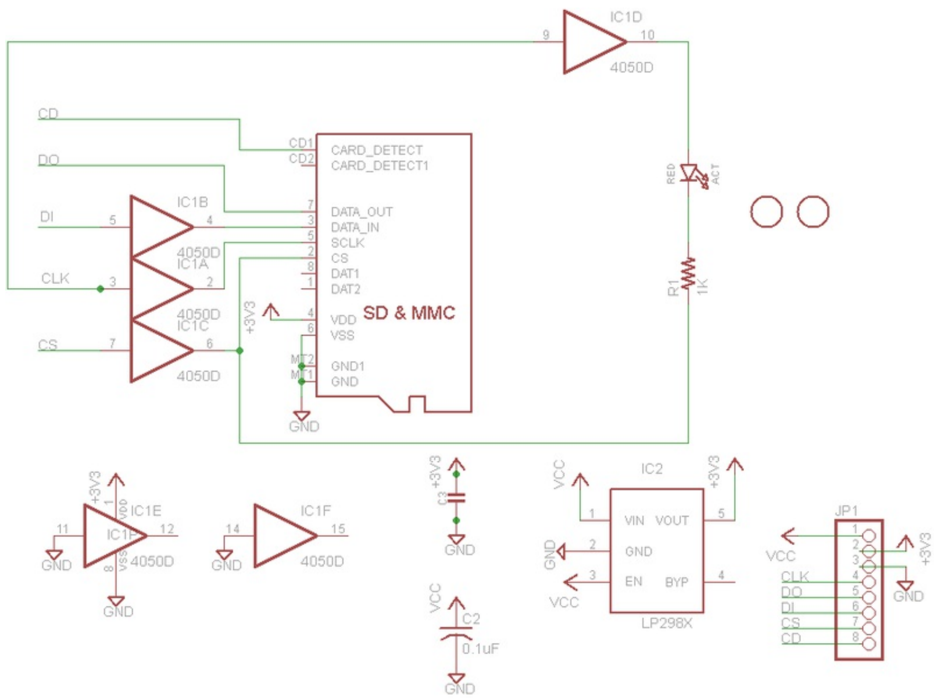
After the LED is turned off the **with** ends and the context closes, the file is safely stored.

Download

- Transcend microSD card datasheet (https://adafru.it/cma)
- EagleCAD PCB files on GitHub (https://adafru.it/rfT)
- Fritzing object in the Adafruit Fritzing library (https://adafru.it/aP3)

Schematic

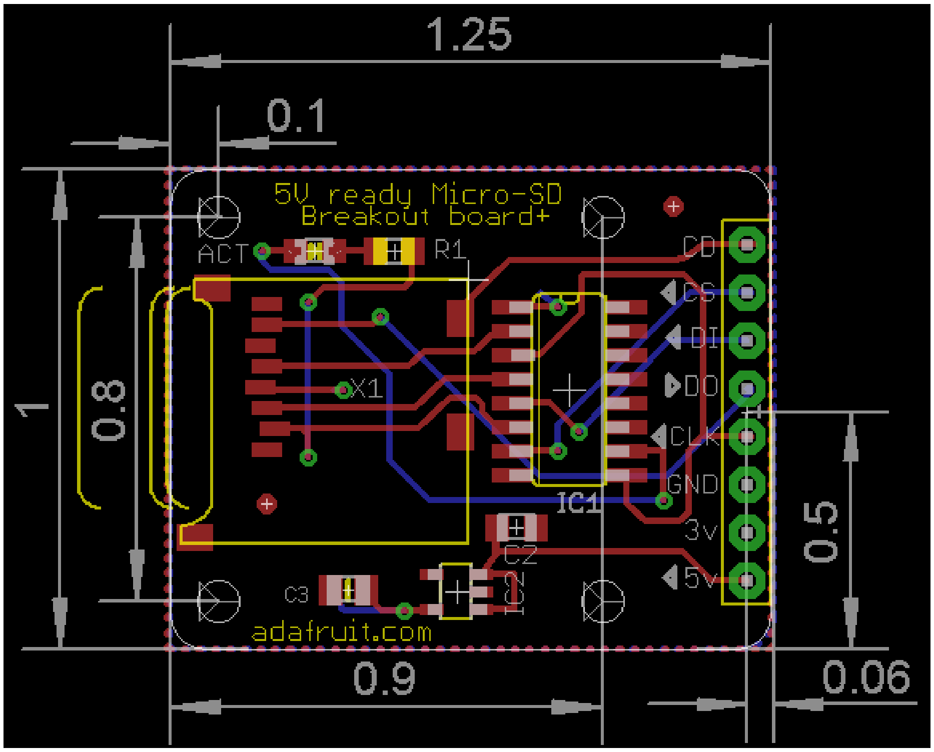
Click to embiggen



For the level shifter we use the CD74HC4050 (https://adafru.it/Boj) which has a typical propagation delay of ~10ns

Fabrication Print

Dims in inches


1.25
0.1
5V ready Micro-SD
Breakout board+
ACT
R1
CD
CS
DI
DO
CLK
GND
3v
5v
X1
IC1
C2
C3
IC2
adafruit.com
1
0.8
0.5
0.9
0.06

MPU-6000 and MPU-6050 Product Specification Revision 3.4

CONTENTS

1 Revision History

Revision Date	Revision	Description
11/24/2010	1.0	Initial Release
05/19/2011	2.0	For Rev C parts. Clarified wording in sections (3.2, 5.1, 5.2, 6.1-6.4, 6.6, 6.9, 7, 7.1-7.6, 7.11, 7.12, 7.14, 8, 8.2-8.4, 10.3, 10.4, 11, 12.2)
07/28/2011	2.1	Edited supply current numbers for different modes (section 6.4)
08/05/2011	2.2	Unit of measure for accelerometer sensitivity changed from LSB/m*g* to LSB/*g*
10/12/2011	2.3	Updated accelerometer self test specifications in Table 6.2. Updated package dimensions (section 11.2). Updated PCB design guidelines (section 11.3)
10/18/2011	3.0	For Rev D parts. Updated accelerometer specifications in Table 6.2. Updated accelerometer specification note (sections 8.2, 8.3, & 8.4). Updated qualification test plan (section 12.2).
10/24/2011	3.1	Edits for clarity Changed operating voltage range to 2.375V-3.46V Added accelerometer Intelligence Function increment value of 1m*g*/LSB (Section 6.2) Updated absolute maximum rating for acceleration (any axis, unpowered) from 0.3ms to 0.2ms (Section 6.9) Modified absolute maximum rating for Latch-up to Level A and ±100mA (Section 6.9, 12.2)
11/16/2011	3.2	**Updated self-test response specifications for Revision D parts dated with date code 1147 (YYWW) or later.** Edits for clarity Added Gyro self-test (sections 5.1, 6.1, 7.6, 7.12) Added Min/Max limits to Accel self-test response (section 6.2) Updated Accelerometer low power mode operating currents (Section 6.3) Added gyro self test to block diagram (section 7.5) Updated packaging labels and descriptions (sections 11.8 & 11.9)
5/16/2012	3.3	Updated Gyro and Accelerometer self test information (sections 6.1, 6.2, 7.12) Updated latch-up information (Section 6.9) Updated programmable interrupts information (Section 8) Changed shipment information from maximum of 3 reels (15K units) per shipper box to 5 reels (25K units) per shipper box (Section 11.7) Updated packing shipping and label information (Sections 11.8, 11.9) Updated reliability references (Section 12.2)
8/19/2013	3.4	Updates section 4

2 Purpose and Scope

This product specification provides advanced information regarding the electrical specification and design related information for the MPU-6000™ and MPU-6050™ MotionTracking™ devices, collectively called the MPU-60X0™ or MPU™.

Electrical characteristics are based upon design analysis and simulation results only. Specifications are subject to change without notice. Final specifications will be updated based upon characterization of production silicon. For references to register map and descriptions of individual registers, please refer to the MPU-6000/MPU-6050 Register Map and Register Descriptions document.

The self-test response specifications provided in this document pertain to Revision D parts with date codes of 1147 (YYWW) or later. Please see Section 11.6 for package marking description details.

3 Product Overview

3.1 MPU-60X0 Overview

MotionInterface™ is becoming a "must-have" function being adopted by smartphone and tablet manufacturers due to the enormous value it adds to the end user experience. In smartphones, it finds use in applications such as gesture commands for applications and phone control, enhanced gaming, augmented reality, panoramic photo capture and viewing, and pedestrian and vehicle navigation. With its ability to precisely and accurately track user motions, MotionTracking technology can convert handsets and tablets into powerful 3D intelligent devices that can be used in applications ranging from health and fitness monitoring to location-based services. Key requirements for MotionInterface enabled devices are small package size, low power consumption, high accuracy and repeatability, high shock tolerance, and application specific performance programmability – all at a low consumer price point.

The MPU-60X0 is the world's first integrated 6-axis MotionTracking device that combines a 3-axis gyroscope, 3-axis accelerometer, and a Digital Motion Processor™ (DMP) all in a small 4x4x0.9mm package. With its dedicated I^2C sensor bus, it directly accepts inputs from an external 3-axis compass to provide a complete 9-axis MotionFusion™ output. The MPU-60X0 MotionTracking device, with its 6-axis integration, on-board MotionFusion™, and run-time calibration firmware, enables manufacturers to eliminate the costly and complex selection, qualification, and system level integration of discrete devices, guaranteeing optimal motion performance for consumers. The MPU-60X0 is also designed to interface with multiple non-inertial digital sensors, such as pressure sensors, on its auxiliary I^2C port. The MPU-60X0 is footprint compatible with the MPU-30X0 family.

The MPU-60X0 features three 16-bit analog-to-digital converters (ADCs) for digitizing the gyroscope outputs and three 16-bit ADCs for digitizing the accelerometer outputs. For precision tracking of both fast and slow motions, the parts feature a user-programmable gyroscope full-scale range of ±250, ±500, ±1000, and ±2000°/sec (dps) and a user-programmable accelerometer full-scale range of ±2*g*, ±4*g*, ±8*g*, and ±16*g*.

An on-chip 1024 Byte FIFO buffer helps lower system power consumption by allowing the system processor to read the sensor data in bursts and then enter a low-power mode as the MPU collects more data. With all the necessary on-chip processing and sensor components required to support many motion-based use cases, the MPU-60X0 uniquely enables low-power MotionInterface applications in portable applications with reduced processing requirements for the system processor. By providing an integrated MotionFusion output, the DMP in the MPU-60X0 offloads the intensive MotionProcessing computation requirements from the system processor, minimizing the need for frequent polling of the motion sensor output.

Communication with all registers of the device is performed using either I^2C at 400kHz or SPI at 1MHz (MPU-6000 only). For applications requiring faster communications, the sensor and interrupt registers may be read using SPI at 20MHz (MPU-6000 only). Additional features include an embedded temperature sensor and an on-chip oscillator with ±1% variation over the operating temperature range.

By leveraging its patented and volume-proven Nasiri-Fabrication platform, which integrates MEMS wafers with companion CMOS electronics through wafer-level bonding, InvenSense has driven the MPU-60X0 package size down to a revolutionary footprint of 4x4x0.9mm (QFN), while providing the highest performance, lowest noise, and the lowest cost semiconductor packaging required for handheld consumer electronic devices. The part features a robust 10,000*g* shock tolerance, and has programmable low-pass filters for the gyroscopes, accelerometers, and the on-chip temperature sensor.

For power supply flexibility, the MPU-60X0 operates from VDD power supply voltage range of 2.375V-3.46V. Additionally, the MPU-6050 provides a VLOGIC reference pin (in addition to its analog supply pin: VDD), which sets the logic levels of its I^2C interface. The VLOGIC voltage may be 1.8V±5% or VDD.

The MPU-6000 and MPU-6050 are identical, except that the MPU-6050 supports the I^2C serial interface only, and has a separate VLOGIC reference pin. The MPU-6000 supports both I^2C and SPI interfaces and has a single supply pin, VDD, which is both the device's logic reference supply and the analog supply for the part. The table below outlines these differences:

Primary Differences between MPU-6000 and MPU-6050

Part / Item	MPU-6000	MPU-6050
VDD	2.375V-3.46V	2.375V-3.46V
VLOGIC	n/a	1.71V to VDD
Serial Interfaces Supported	I^2C, SPI	I^2C
Pin 8	/CS	VLOGIC
Pin 9	AD0/SDO	AD0
Pin 23	SCL/SCLK	SCL
Pin 24	SDA/SDI	SDA

4 Applications

- *BlurFree*™ technology (for Video/Still Image Stabilization)
- *AirSign*™ technology (for Security/Authentication)
- *TouchAnywhere*™ technology (for "no touch" UI Application Control/Navigation)
- *MotionCommand*™ technology (for Gesture Short-cuts)
- Motion-enabled game and application framework
- InstantGesture™ iG™ gesture recognition
- Location based services, points of interest, and dead reckoning
- Handset and portable gaming
- Motion-based game controllers
- 3D remote controls for Internet connected DTVs and set top boxes, 3D mice
- Wearable sensors for health, fitness and sports
- Toys

5 Features

5.1 Gyroscope Features

The triple-axis MEMS gyroscope in the MPU-60X0 includes a wide range of features:

- Digital-output X-, Y-, and Z-Axis angular rate sensors (gyroscopes) with a user-programmable full-scale range of ±250, ±500, ±1000, and ±2000°/sec
- External sync signal connected to the FSYNC pin supports image, video and GPS synchronization
- Integrated 16-bit ADCs enable simultaneous sampling of gyros
- Enhanced bias and sensitivity temperature stability reduces the need for user calibration
- Improved low-frequency noise performance
- Digitally-programmable low-pass filter
- Gyroscope operating current: 3.6mA
- Standby current: 5µA
- Factory calibrated sensitivity scale factor
- User self-test

5.2 Accelerometer Features

The triple-axis MEMS accelerometer in MPU-60X0 includes a wide range of features:

- Digital-output triple-axis accelerometer with a programmable full scale range of ±2*g*, ±4*g*, ±8*g* and ±16*g*
- Integrated 16-bit ADCs enable simultaneous sampling of accelerometers while requiring no external multiplexer
- Accelerometer normal operating current: 500µA
- Low power accelerometer mode current: 10µA at 1.25Hz, 20µA at 5Hz, 60µA at 20Hz, 110µA at 40Hz
- Orientation detection and signaling
- Tap detection
- User-programmable interrupts
- High-G interrupt
- User self-test

5.3 Additional Features

The MPU-60X0 includes the following additional features:

- 9-Axis MotionFusion by the on-chip Digital Motion Processor (DMP)
- Auxiliary master I^2C bus for reading data from external sensors (e.g., magnetometer)
- 3.9mA operating current when all 6 motion sensing axes and the DMP are enabled
- VDD supply voltage range of 2.375V-3.46V
- Flexible VLOGIC reference voltage supports multiple I^2C interface voltages (MPU-6050 only)
- Smallest and thinnest QFN package for portable devices: 4x4x0.9mm
- Minimal cross-axis sensitivity between the accelerometer and gyroscope axes
- 1024 byte FIFO buffer reduces power consumption by allowing host processor to read the data in bursts and then go into a low-power mode as the MPU collects more data
- Digital-output temperature sensor
- User-programmable digital filters for gyroscope, accelerometer, and temp sensor
- 10,000 *g* shock tolerant
- 400kHz Fast Mode I^2C for communicating with all registers
- 1MHz SPI serial interface for communicating with all registers (MPU-6000 only)
- 20MHz SPI serial interface for reading sensor and interrupt registers (MPU-6000 only)

- MEMS structure hermetically sealed and bonded at wafer level
- RoHS and Green compliant

5.4 MotionProcessing

- Internal Digital Motion Processing™ (DMP™) engine supports 3D MotionProcessing and gesture recognition algorithms
- The MPU-60X0 collects gyroscope and accelerometer data while synchronizing data sampling at a user defined rate. The total dataset obtained by the MPU-60X0 includes 3-Axis gyroscope data, 3-Axis accelerometer data, and temperature data. The MPU's calculated output to the system processor can also include heading data from a digital 3-axis third party magnetometer.
- The FIFO buffers the complete data set, reducing timing requirements on the system processor by allowing the processor burst read the FIFO data. After burst reading the FIFO data, the system processor can save power by entering a low-power sleep mode while the MPU collects more data.
- Programmable interrupt supports features such as gesture recognition, panning, zooming, scrolling, tap detection, and shake detection
- Digitally-programmable low-pass filters
- Low-power pedometer functionality allows the host processor to sleep while the DMP maintains the step count.

5.5 Clocking

- On-chip timing generator ±1% frequency variation over full temperature range
- Optional external clock inputs of 32.768kHz or 19.2MHz

6 Electrical Characteristics

6.1 Gyroscope Specifications

VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS	NOTES
GYROSCOPE SENSITIVITY						
Full-Scale Range	FS_SEL=0		±250		º/s	
	FS_SEL=1		±500		º/s	
	FS_SEL=2		±1000		º/s	
	FS_SEL=3		±2000		º/s	
Gyroscope ADC Word Length			16		bits	
Sensitivity Scale Factor	FS_SEL=0		131		LSB/(º/s)	
	FS_SEL=1		65.5		LSB/(º/s)	
	FS_SEL=2		32.8		LSB/(º/s)	
	FS_SEL=3		16.4		LSB/(º/s)	
Sensitivity Scale Factor Tolerance	25°C	-3		+3	%	
Sensitivity Scale Factor Variation Over Temperature			±2		%	
Nonlinearity	Best fit straight line; 25°C		0.2		%	
Cross-Axis Sensitivity			±2		%	
GYROSCOPE ZERO-RATE OUTPUT (ZRO)						
Initial ZRO Tolerance	25°C		±20		º/s	
ZRO Variation Over Temperature	-40°C to +85°C		±20		º/s	
Power-Supply Sensitivity (1-10Hz)	Sine wave, 100mVpp; VDD=2.5V		0.2		º/s	
Power-Supply Sensitivity (10 - 250Hz)	Sine wave, 100mVpp; VDD=2.5V		0.2		º/s	
Power-Supply Sensitivity (250Hz - 100kHz)	Sine wave, 100mVpp; VDD=2.5V		4		º/s	
Linear Acceleration Sensitivity	Static		0.1		º/s/*g*	
SELF-TEST RESPONSE						
Relative	Change from factory trim	-14		14	%	1
GYROSCOPE NOISE PERFORMANCE	**FS_SEL=0**					
Total RMS Noise	DLPFCFG=2 (100Hz)		0.05		º/s-rms	
Low-frequency RMS noise	Bandwidth 1Hz to10Hz		0.033		º/s-rms	
Rate Noise Spectral Density	At 10Hz		0.005		º/s/ √ Hz	
GYROSCOPE MECHANICAL FREQUENCIES						
X-Axis		30	33	36	kHz	
Y-Axis		27	30	33	kHz	
Z-Axis		24	27	30	kHz	
LOW PASS FILTER RESPONSE						
	Programmable Range	5		256	Hz	
OUTPUT DATA RATE						
	Programmable	4		8,000	Hz	
GYROSCOPE START-UP TIME	**DLPFCFG=0**					
ZRO Settling (from power-on)	to ±1º/s of Final		30		ms	

1. Please refer to the following document for further information on Self-Test: *MPU-6000/MPU-6050 Register Map and Descriptions*

6.2 Accelerometer Specifications

VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS	NOTES
ACCELEROMETER SENSITIVITY						
Full-Scale Range	AFS_SEL=0		±2		*g*	
	AFS_SEL=1		±4		*g*	
	AFS_SEL=2		±8		*g*	
	AFS_SEL=3		±16		*g*	
ADC Word Length	Output in two's complement format		16		bits	
Sensitivity Scale Factor	AFS_SEL=0		16,384		LSB/*g*	
	AFS_SEL=1		8,192		LSB/*g*	
	AFS_SEL=2		4,096		LSB/*g*	
	AFS_SEL=3		2,048		LSB/*g*	
Initial Calibration Tolerance			±3		%	
Sensitivity Change vs. Temperature	AFS_SEL=0, -40°C to +85°C		±0.02		%/°C	
Nonlinearity	Best Fit Straight Line		0.5		%	
Cross-Axis Sensitivity			±2		%	
ZERO-G OUTPUT						
Initial Calibration Tolerance	X and Y axes		±50		m*g*	1
	Z axis		±80		m*g*	
Zero-G Level Change vs. Temperature	X and Y axes, 0°C to +70°C		±35			
	Z axis, 0°C to +70°C		±60		m*g*	
SELF TEST RESPONSE						
Relative	Change from factory trim	-14		14	%	2
NOISE PERFORMANCE						
Power Spectral Density	@10Hz, AFS_SEL=0 & ODR=1kHz		400		$\mu g/\sqrt{Hz}$	
LOW PASS FILTER RESPONSE						
	Programmable Range	5		260	Hz	
OUTPUT DATA RATE						
	Programmable Range	4		1,000	Hz	
INTELLIGENCE FUNCTION INCREMENT			32		m*g*/LSB	

1. Typical zero-g initial calibration tolerance value after MSL3 preconditioning
2. Please refer to the following document for further information on Self-Test: *MPU-6000/MPU-6050 Register Map and Descriptions*

6.3 Electrical and Other Common Specifications

VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C

PARAMETER	CONDITIONS	MIN	TYP	MAX	Units	Notes
TEMPERATURE SENSOR						
Range			-40 to +85		°C	
Sensitivity	Untrimmed		340		LSB/ºC	
Temperature Offset	35°C		-521		LSB	
Linearity	Best fit straight line (-40°C to +85°C)		±1		°C	
VDD POWER SUPPLY						
Operating Voltages		2.375		3.46	V	
Normal Operating Current	Gyroscope + Accelerometer + DMP		3.9		mA	
	Gyroscope + Accelerometer (DMP disabled)		3.8		mA	
	Gyroscope + DMP (Accelerometer disabled)		3.7		mA	
	Gyroscope only (DMP & Accelerometer disabled)		3.6		mA	
	Accelerometer only (DMP & Gyroscope disabled)		500		µA	
Accelerometer Low Power Mode Current	1.25 Hz update rate		10		µA	
	5 Hz update rate		20		µA	
	20 Hz update rate		70		µA	
	40 Hz update rate		140		µA	
Full-Chip Idle Mode Supply Current			5		µA	
Power Supply Ramp Rate	Monotonic ramp. Ramp rate is 10% to 90% of the final value			100	ms	
VLOGIC REFERENCE VOLTAGE	MPU-6050 only					
Voltage Range	VLOGIC must be ≤VDD at all times	1.71		VDD	V	
Power Supply Ramp Rate	Monotonic ramp. Ramp rate is 10% to 90% of the final value			3	ms	
Normal Operating Current			100		µA	
TEMPERATURE RANGE						
Specified Temperature Range	Performance parameters are not applicable beyond Specified Temperature Range	-40		+85	°C	

6.4 Electrical Specifications, Continued

VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C

PARAMETER	CONDITIONS	MIN	TYP	MAX	Units	Notes
SERIAL INTERFACE						
SPI Operating Frequency, All Registers Read/Write	MPU-6000 only, Low Speed Characterization		100 ±10%		kHz	
	MPU-6000 only, High Speed Characterization		1 ±10%		MHz	
SPI Operating Frequency, Sensor and Interrupt Registers Read Only	MPU-6000 only		20 ±10%		MHz	
I^2C Operating Frequency	All registers, Fast-mode			400	kHz	
	All registers, Standard-mode			100	kHz	
I^2C ADDRESS	AD0 = 0		1101000			
	AD0 = 1		1101001			
DIGITAL INPUTS (SDI/SDA, AD0, SCLK/SCL, FSYNC, /CS, CLKIN)						
V_{IH}, High Level Input Voltage	MPU-6000	0.7*VDD			V	
	MPU-6050	0.7*VLOGIC			V	
V_{IL}, Low Level Input Voltage	MPU-6000			0.3*VDD	V	
	MPU-6050			0.3*VLOGIC	V	
C_I, Input Capacitance			< 5		pF	
DIGITAL OUTPUT (SDO, INT)						
V_{OH}, High Level Output Voltage	R_{LOAD}=1MΩ; MPU-6000	0.9*VDD			V	
	R_{LOAD}=1MΩ; MPU-6050	0.9*VLOGIC			V	
V_{OL1}, LOW-Level Output Voltage	R_{LOAD}=1MΩ; MPU-6000			0.1*VDD	V	
	R_{LOAD}=1MΩ; MPU-6050			0.1*VLOGIC	V	
$V_{OL.INT1}$, INT Low-Level Output Voltage	OPEN=1, 0.3mA sink Current			0.1	V	
Output Leakage Current	OPEN=1		100		nA	
t_{INT}, INT Pulse Width	LATCH_INT_EN=0		50		µs	

6.5 Electrical Specifications, Continued

Typical Operating Circuit of Section 7.2, VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C

Parameters	Conditions	Typical	Units	Notes
Primary I²C I/O (SCL, SDA)				
V_{IL}, LOW-Level Input Voltage	MPU-6000	-0.5 to 0.3*VDD	V	
V_{IH}, HIGH-Level Input Voltage	MPU-6000	0.7*VDD to VDD + 0.5V	V	
V_{hys}, Hysteresis	MPU-6000	0.1*VDD	V	
VIL, LOW Level Input Voltage	MPU-6050	-0.5V to 0.3*VLOGIC	V	
VIH, HIGH-Level Input Voltage	MPU-6050	0.7*VLOGIC to VLOGIC + 0.5V	V	
Vhys, Hysteresis	MPU-6050	0.1*VLOGIC	V	
V_{OL1}, LOW-Level Output Voltage	3mA sink current	0 to 0.4	V	
I_{OL}, LOW-Level Output Current	V_{OL} = 0.4V	3	mA	
	V_{OL} = 0.6V	5	mA	
Output Leakage Current		100	nA	
t_{of}, Output Fall Time from V_{IHmax} to V_{ILmax}	C_b bus capacitance in pF	20+0.1C_b to 250	ns	
C_I, Capacitance for Each I/O pin		< 10	pF	
Auxiliary I²C I/O (AUX_CL, AUX_DA)	**MPU-6050: *AUX_VDDIO*=0**			
V_{IL}, LOW-Level Input Voltage		-0.5V to 0.3*VLOGIC	V	
V_{IH}, HIGH-Level Input Voltage		0.7*VLOGIC to VLOGIC + 0.5V	V	
V_{hys}, Hysteresis		0.1*VLOGIC	V	
V_{OL1}, LOW-Level Output Voltage	VLOGIC > 2V; 1mA sink current	0 to 0.4	V	
V_{OL3}, LOW-Level Output Voltage	VLOGIC < 2V; 1mA sink current	0 to 0.2*VLOGIC	V	
I_{OL}, LOW-Level Output Current	V_{OL} = 0.4V	1	mA	
	V_{OL} = 0.6V	1	mA	
Output Leakage Current		100	nA	
t_{of}, Output Fall Time from V_{IHmax} to V_{ILmax}	C_b bus capacitance in pF	20+0.1C_b to 250	ns	
C_I, Capacitance for Each I/O pin		< 10	pF	

6.6 Electrical Specifications, Continued

Typical Operating Circuit of Section 7.2, VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C

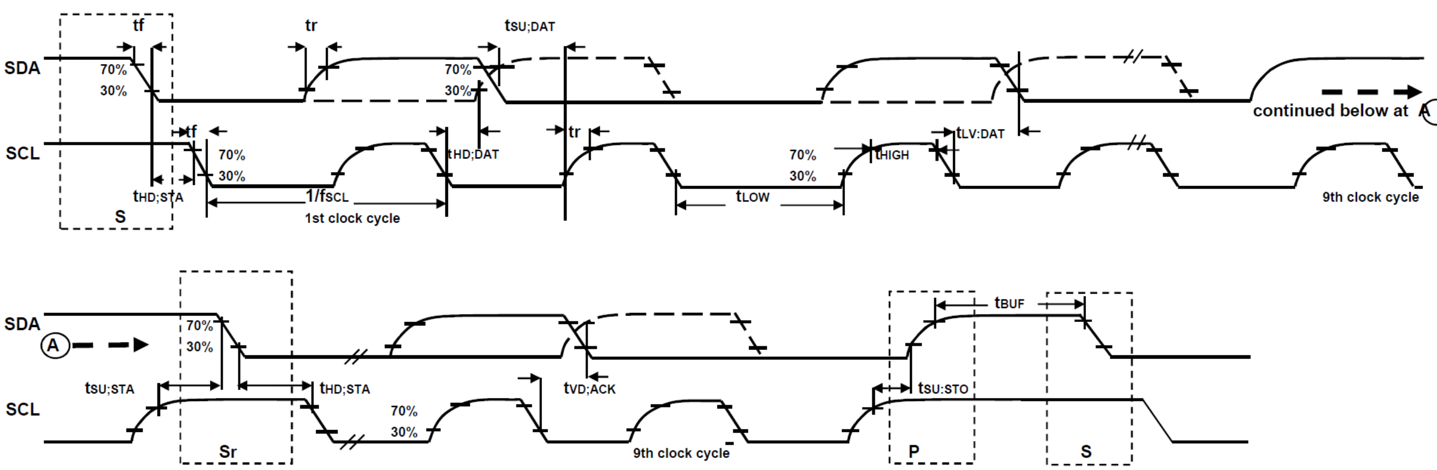
Parameters	Conditions	Min	Typical	Max	Units	Notes
INTERNAL CLOCK SOURCE	**CLK_SEL=0,1,2,3**					
Gyroscope Sample Rate, Fast	DLPFCFG=0 SAMPLERATEDIV = 0		8		kHz	
Gyroscope Sample Rate, Slow	DLPFCFG=1,2,3,4,5, or 6 SAMPLERATEDIV = 0		1		kHz	
Accelerometer Sample Rate			1		kHz	
Clock Frequency Initial Tolerance	CLK_SEL=0, 25°C	-5		+5	%	
	CLK_SEL=1,2,3; 25°C	-1		+1	%	
Frequency Variation over Temperature	CLK_SEL=0		-15 to +10		%	
	CLK_SEL=1,2,3		±1		%	
PLL Settling Time	CLK_SEL=1,2,3		1	10	ms	
EXTERNAL 32.768kHz CLOCK	**CLK_SEL=4**					
External Clock Frequency			32.768		kHz	
External Clock Allowable Jitter	Cycle-to-cycle rms		1 to 2		µs	
Gyroscope Sample Rate, Fast	DLPFCFG=0 SAMPLERATEDIV = 0		8.192		kHz	
Gyroscope Sample Rate, Slow	DLPFCFG=1,2,3,4,5, or 6 SAMPLERATEDIV = 0		1.024		kHz	
Accelerometer Sample Rate			1.024		kHz	
PLL Settling Time			1	10	ms	
EXTERNAL 19.2MHz CLOCK	**CLK_SEL=5**					
External Clock Frequency			19.2		MHz	
Gyroscope Sample Rate	Full programmable range	3.9		8000	Hz	
Gyroscope Sample Rate, Fast Mode	DLPFCFG=0 SAMPLERATEDIV = 0		8		kHz	
Gyroscope Sample Rate, Slow Mode	DLPFCFG=1,2,3,4,5, or 6 SAMPLERATEDIV = 0		1		kHz	
Accelerometer Sample Rate			1		kHz	
PLL Settling Time			1	10	ms	

6.7 I²C Timing Characterization

Typical Operating Circuit of Section 7.2, VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C

Parameters	Conditions	Min	Typical	Max	Units	Notes
I²C TIMING	**I²C FAST-MODE**					
f_{SCL}, SCL Clock Frequency				400	kHz	
$t_{HD.STA}$, (Repeated) START Condition Hold Time		0.6			µs	
t_{LOW}, SCL Low Period		1.3			µs	
t_{HIGH}, SCL High Period		0.6			µs	
$t_{SU.STA}$, Repeated START Condition Setup Time		0.6			µs	
$t_{HD.DAT}$, SDA Data Hold Time		0			µs	
$t_{SU.DAT}$, SDA Data Setup Time		100			ns	
t_r, SDA and SCL Rise Time	C_b bus cap. from 10 to 400pF	20+0.1C_b		300	ns	
t_f, SDA and SCL Fall Time	C_b bus cap. from 10 to 400pF	20+0.1C_b		300	ns	
$t_{SU.STO}$, STOP Condition Setup Time		0.6			µs	
t_{BUF}, Bus Free Time Between STOP and START Condition		1.3			µs	
C_b, Capacitive Load for each Bus Line			< 400		pF	
$t_{VD.DAT}$, Data Valid Time				0.9	µs	
$t_{VD.ACK}$, Data Valid Acknowledge Time				0.9	µs	

Note: Timing Characteristics apply to both Primary and Auxiliary I²C Bus

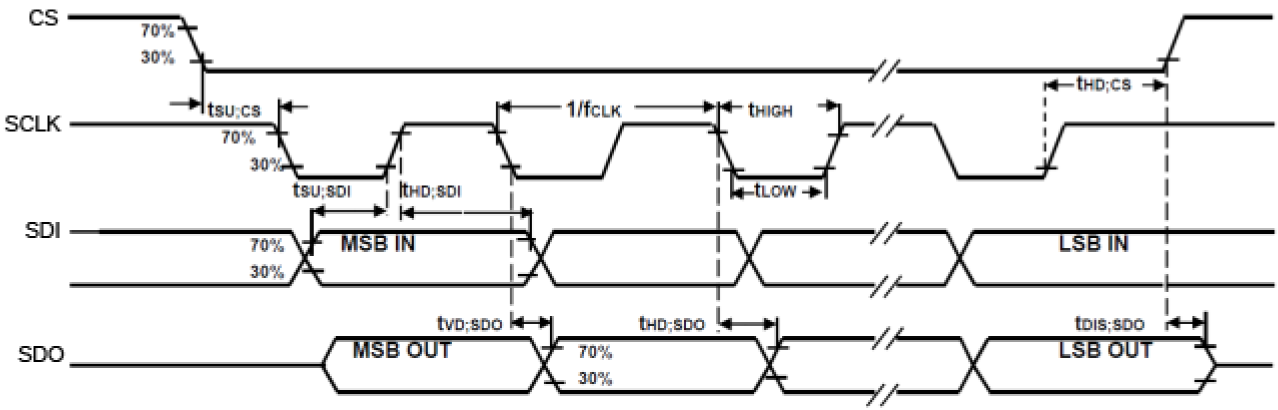


I²C Bus Timing Diagram

6.8 SPI Timing Characterization (MPU-6000 only)

Typical Operating Circuit of Section 7.2, VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C, unless otherwise noted.

Parameters	Conditions	Min	Typical	Max	Units	Notes
SPI TIMING						
f_{SCLK}, SCLK Clock Frequency				1	MHz	
t_{LOW}, SCLK Low Period		400			ns	
t_{HIGH}, SCLK High Period		400			ns	
$t_{SU.CS}$, CS Setup Time		8			ns	
$t_{HD.CS}$, CS Hold Time		500			ns	
$t_{SU.SDI}$, SDI Setup Time		11			ns	
$t_{HD.SDI}$, SDI Hold Time		7			ns	
$t_{VD.SDO}$, SDO Valid Time	C_{load} = 20pF			100	ns	
$t_{HD.SDO}$, SDO Hold Time	C_{load} = 20pF	4			ns	
$t_{DIS.SDO}$, SDO Output Disable Time				10	ns	



SPI Bus Timing Diagram

6.9 Absolute Maximum Ratings

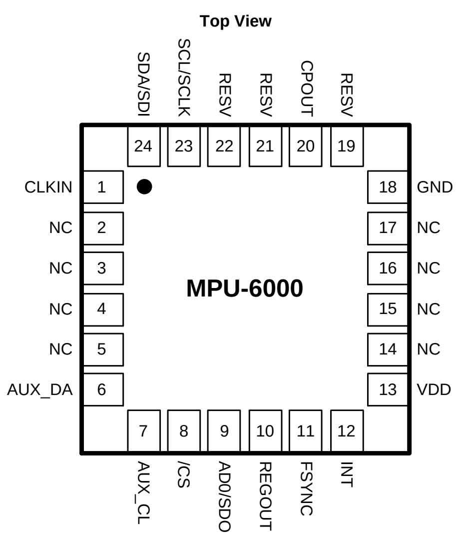
Stress above those listed as “Absolute Maximum Ratings” may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these conditions is not implied. Exposure to the absolute maximum ratings conditions for extended periods may affect device reliability.

Parameter	Rating
Supply Voltage, VDD	-0.5V to +6V
VLOGIC Input Voltage Level (MPU-6050)	-0.5V to VDD + 0.5V
REGOUT	-0.5V to 2V
Input Voltage Level (CLKIN, AUX_DA, AD0, FSYNC, INT, SCL, SDA)	-0.5V to VDD + 0.5V
CPOUT (2.5V ≤ VDD ≤ 3.6V)	-0.5V to 30V
Acceleration (Any Axis, unpowered)	10,000g for 0.2ms
Operating Temperature Range	-40°C to +105°C
Storage Temperature Range	-40°C to +125°C
Electrostatic Discharge (ESD) Protection	2kV (HBM); 250V (MM)
Latch-up	JEDEC Class II (2),125°C ±100mA

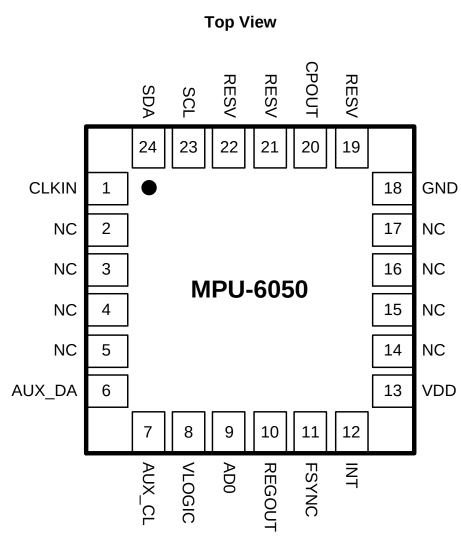
7 Applications Information

7.1 Pin Out and Signal Description

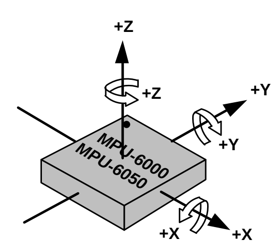
Pin Number	MPU-6000	MPU-6050	Pin Name	Pin Description
1	Y	Y	CLKIN	Optional external reference clock input. Connect to GND if unused.
6	Y	Y	AUX_DA	I^2C master serial data, for connecting to external sensors
7	Y	Y	AUX_CL	I^2C Master serial clock, for connecting to external sensors
8	Y		/CS	SPI chip select (0=SPI mode)
8		Y	VLOGIC	Digital I/O supply voltage
9	Y		AD0 / SDO	I^2C Slave Address LSB (AD0); SPI serial data output (SDO)
9		Y	AD0	I^2C Slave Address LSB (AD0)
10	Y	Y	REGOUT	Regulator filter capacitor connection
11	Y	Y	FSYNC	Frame synchronization digital input. Connect to GND if unused.
12	Y	Y	INT	Interrupt digital output (totem pole or open-drain)
13	Y	Y	VDD	Power supply voltage and Digital I/O supply voltage
18	Y	Y	GND	Power supply ground
19, 21	Y	Y	RESV	Reserved. Do not connect.
20	Y	Y	CPOUT	Charge pump capacitor connection
22	Y	Y	RESV	Reserved. Do not connect.
23	Y		SCL / SCLK	I^2C serial clock (SCL); SPI serial clock (SCLK)
23		Y	SCL	I^2C serial clock (SCL)
24	Y		SDA / SDI	I^2C serial data (SDA); SPI serial data input (SDI)
24		Y	SDA	I^2C serial data (SDA)
2, 3, 4, 5, 14, 15, 16, 17	Y	Y	NC	Not internally connected. May be used for PCB trace routing.



QFN Package
24-pin, 4mm x 4mm x 0.9mm

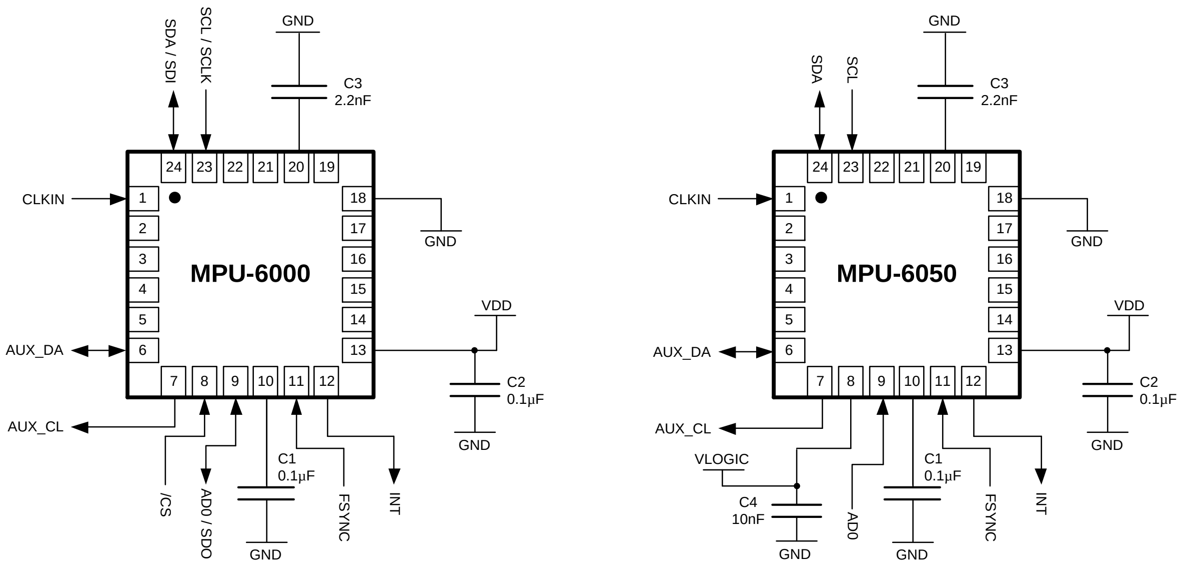


QFN Package
24-pin, 4mm x 4mm x 0.9mm



Orientation of Axes of Sensitivity and Polarity of Rotation

7.2 Typical Operating Circuit



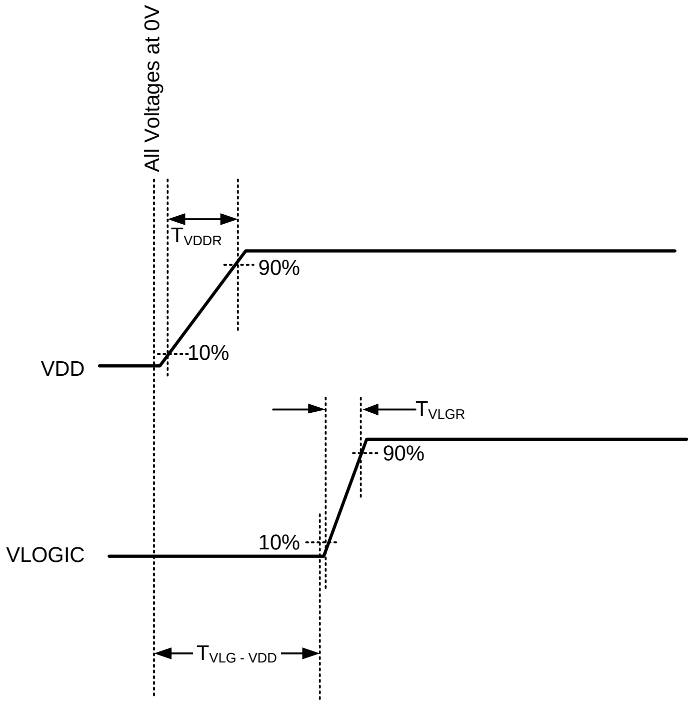
Typical Operating Circuits

7.3 Bill of Materials for External Components

Component	Label	Specification	Quantity
Regulator Filter Capacitor (Pin 10)	C1	Ceramic, X7R, 0.1µF ±10%, 2V	1
VDD Bypass Capacitor (Pin 13)	C2	Ceramic, X7R, 0.1µF ±10%, 4V	1
Charge Pump Capacitor (Pin 20)	C3	Ceramic, X7R, 2.2nF ±10%, 50V	1
VLOGIC Bypass Capacitor (Pin 8)	C4*	Ceramic, X7R, 10nF ±10%, 4V	1

* MPU-6050 Only.

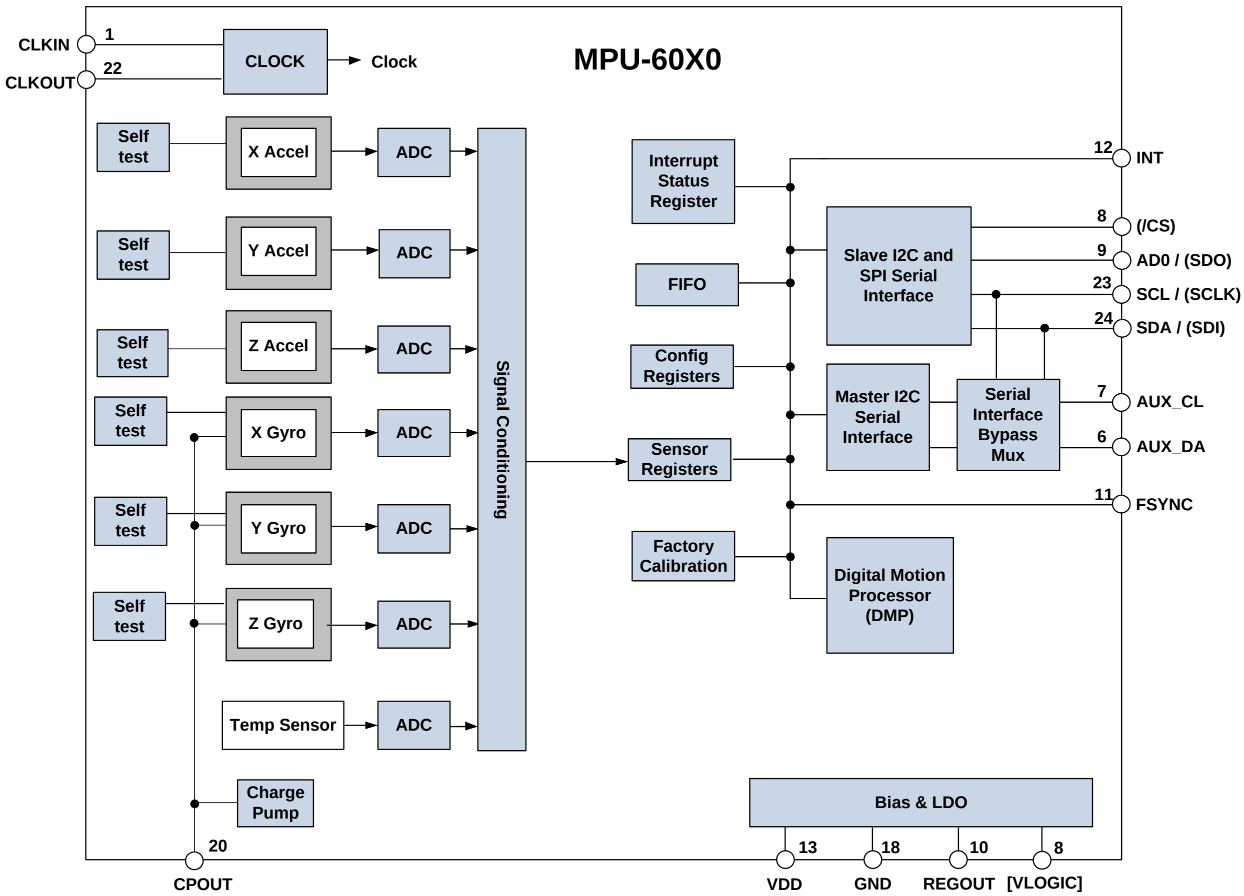
7.4 Recommended Power-on Procedure



Power-Up Sequencing

1. VLOGIC amplitude must always be ≤VDD amplitude
2. T_{VDDR} is VDD rise time: Time for VDD to rise from 10% to 90% of its final value
3. T_{VDDR} is ≤100ms
4. T_{VLGR} is VLOGIC rise time: Time for VLOGIC to rise from 10% to 90% of its final value
5. T_{VLGR} is ≤3ms
6. $T_{VLG-VDD}$ is the delay from the start of VDD ramp to the start of VLOGIC rise
7. $T_{VLG-VDD}$ is ≥0
8. VDD and VLOGIC must be monotonic ramps

7.5 Block Diagram



Note: Pin names in round brackets ( ) apply only to MPU-6000
Pin names in square brackets [ ] apply only to MPU-6050

7.6 Overview

The MPU-60X0 is comprised of the following key blocks and functions:

- Three-axis MEMS rate gyroscope sensor with 16-bit ADCs and signal conditioning
- Three-axis MEMS accelerometer sensor with 16-bit ADCs and signal conditioning
- Digital Motion Processor (DMP) engine
- Primary I^{2}C and SPI (MPU-6000 only) serial communications interfaces
- Auxiliary I^{2}C serial interface for 3rd party magnetometer & other sensors
- Clocking
- Sensor Data Registers
- FIFO
- Interrupts
- Digital-Output Temperature Sensor
- Gyroscope & Accelerometer Self-test
- Bias and LDO
- Charge Pump

7.7 Three-Axis MEMS Gyroscope with 16-bit ADCs and Signal Conditioning

The MPU-60X0 consists of three independent vibratory MEMS rate gyroscopes, which detect rotation about the X-, Y-, and Z- Axes. When the gyros are rotated about any of the sense axes, the Coriolis Effect causes a vibration that is detected by a capacitive pickoff. The resulting signal is amplified, demodulated, and filtered to produce a voltage that is proportional to the angular rate. This voltage is digitized using individual on-chip 16-bit Analog-to-Digital Converters (ADCs) to sample each axis. The full-scale range of the gyro sensors may be digitally programmed to ±250, ±500, ±1000, or ±2000 degrees per second (dps). The ADC sample rate is programmable from 8,000 samples per second, down to 3.9 samples per second, and user-selectable low-pass filters enable a wide range of cut-off frequencies.

7.8 Three-Axis MEMS Accelerometer with 16-bit ADCs and Signal Conditioning

The MPU-60X0's 3-Axis accelerometer uses separate proof masses for each axis. Acceleration along a particular axis induces displacement on the corresponding proof mass, and capacitive sensors detect the displacement differentially. The MPU-60X0's architecture reduces the accelerometers' susceptibility to fabrication variations as well as to thermal drift. When the device is placed on a flat surface, it will measure 0*g* on the X- and Y-axes and +1*g* on the Z-axis. The accelerometers' scale factor is calibrated at the factory and is nominally independent of supply voltage. Each sensor has a dedicated sigma-delta ADC for providing digital outputs. The full scale range of the digital output can be adjusted to ±2*g*, ±4*g*, ±8*g*, or ±16*g*.

7.9 Digital Motion Processor

The embedded Digital Motion Processor (DMP) is located within the MPU-60X0 and offloads computation of motion processing algorithms from the host processor. The DMP acquires data from accelerometers, gyroscopes, and additional 3rd party sensors such as magnetometers, and processes the data. The resulting data can be read from the DMP's registers, or can be buffered in a FIFO. The DMP has access to one of the MPU's external pins, which can be used for generating interrupts.

The purpose of the DMP is to offload both timing requirements and processing power from the host processor. Typically, motion processing algorithms should be run at a high rate, often around 200Hz, in order to provide accurate results with low latency. This is required even if the application updates at a much lower rate; for example, a low power user interface may update as slowly as 5Hz, but the motion processing should still run at 200Hz. The DMP can be used as a tool in order to minimize power, simplify timing, simplify the software architecture, and save valuable MIPS on the host processor for use in the application.

7.10 Primary I²C and SPI Serial Communications Interfaces

The MPU-60X0 communicates to a system processor using either a SPI (MPU-6000 only) or an I²C serial interface. The MPU-60X0 always acts as a slave when communicating to the system processor. The LSB of the of the I²C slave address is set by pin 9 (AD0).

The logic levels for communications between the MPU-60X0 and its master are as follows:

- MPU-6000: The logic level for communications with the master is set by the voltage on VDD
- MPU-6050: The logic level for communications with the master is set by the voltage on VLOGIC

For further information regarding the logic levels of the MPU-6050, please refer to Section 10.

7.11 Auxiliary I²C Serial Interface

The MPU-60X0 has an auxiliary I²C bus for communicating to an off-chip 3-Axis digital output magnetometer or other sensors. This bus has two operating modes:

- I²C Master Mode: The MPU-60X0 acts as a master to any external sensors connected to the auxiliary I²C bus
- Pass-Through Mode: The MPU-60X0 directly connects the primary and auxiliary I²C buses together, allowing the system processor to directly communicate with any external sensors.

Auxiliary I²C Bus Modes of Operation:

- I²C Master Mode: Allows the MPU-60X0 to directly access the data registers of external digital sensors, such as a magnetometer. In this mode, the MPU-60X0 directly obtains data from auxiliary sensors, allowing the on-chip DMP to generate sensor fusion data without intervention from the system applications processor.

  For example, In I²C Master mode, the MPU-60X0 can be configured to perform burst reads, returning the following data from a magnetometer:

  - X magnetometer data (2 bytes)
  - Y magnetometer data (2 bytes)
  - Z magnetometer data (2 bytes)

  The I²C Master can be configured to read up to 24 bytes from up to 4 auxiliary sensors. A fifth sensor can be configured to work single byte read/write mode.

- Pass-Through Mode: Allows an external system processor to act as master and directly communicate to the external sensors connected to the auxiliary I²C bus pins (AUX_DA and AUX_CL). In this mode, the auxiliary I²C bus control logic (3rd party sensor interface block) of the MPU-60X0 is disabled, and the auxiliary I²C pins AUX_DA and AUX_CL (Pins 6 and 7) are connected to the main I²C bus (Pins 23 and 24) through analog switches.

  Pass-Through Mode is useful for configuring the external sensors, or for keeping the MPU-60X0 in a low-power mode when only the external sensors are used.

  In Pass-Through Mode the system processor can still access MPU-60X0 data through the I²C interface.

Auxiliary I²C Bus IO Logic Levels

- MPU-6000: The logic level of the auxiliary I²C bus is VDD
- MPU-6050: The logic level of the auxiliary I²C bus can be programmed to be either VDD or VLOGIC

For further information regarding the MPU-6050's logic levels, please refer to Section 10.2.

7.12 Self-Test

Please refer to the MPU-6000/MPU-6050 Register Map and Register Descriptions document for more details on self test.

Self-test allows for the testing of the mechanical and electrical portions of the sensors. The self-test for each measurement axis can be activated by means of the gyroscope and accelerometer self-test registers (registers 13 to 16).

When self-test is activated, the electronics cause the sensors to be actuated and produce an output signal. The output signal is used to observe the self-test response.

The self-test response is defined as follows:

Self-test response = Sensor output with self-test enabled – Sensor output without self-test enabled

The self-test response for each accelerometer axis is defined in the accelerometer specification table (Section 6.2), while that for each gyroscope axis is defined in the gyroscope specification table (Section 6.1).

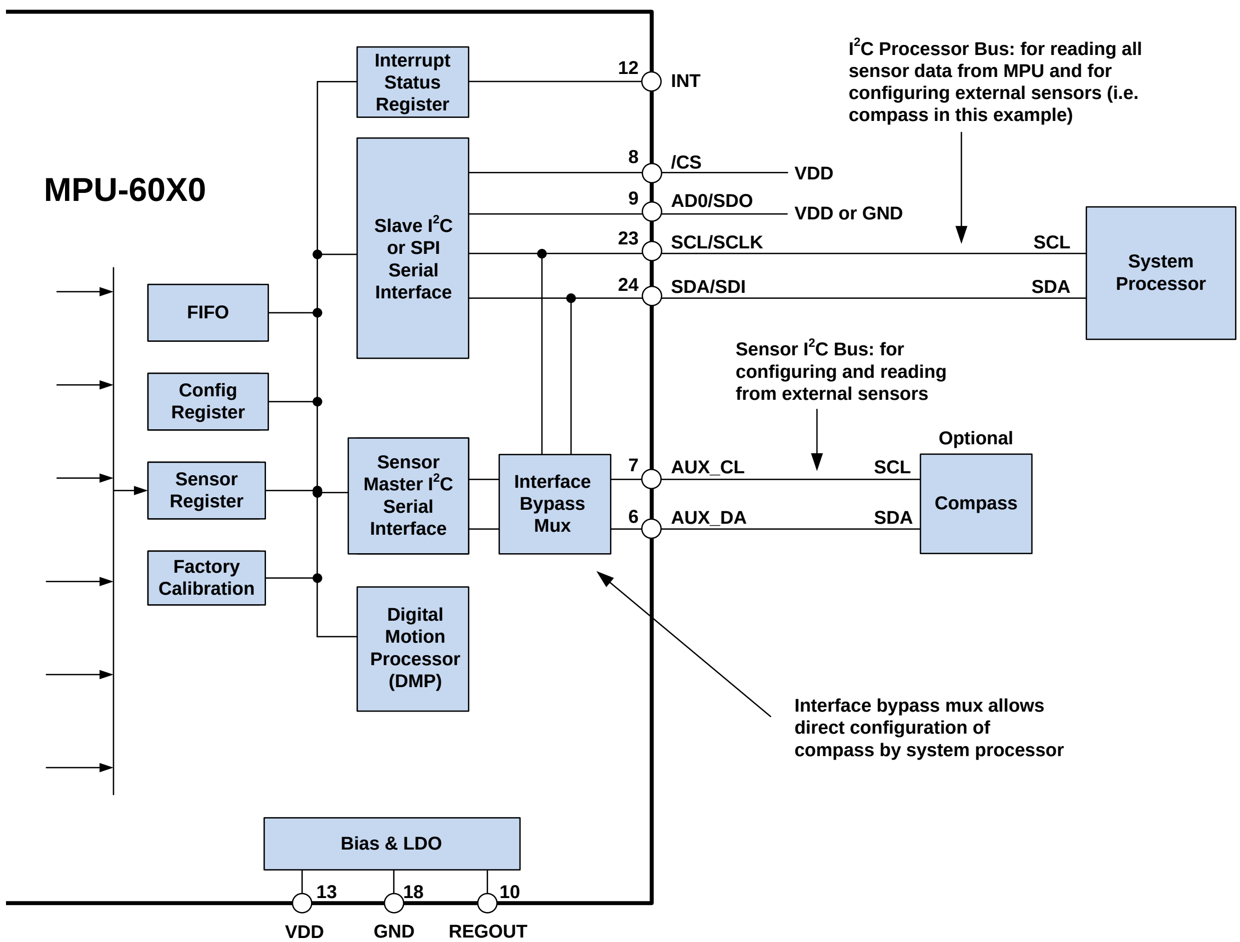
When the value of the self-test response is within the min/max limits of the product specification, the part has passed self test. When the self-test response exceeds the min/max values, the part is deemed to have failed self-test. Code for operating self test code is included within the MotionApps software provided by InvenSense.

7.13 MPU-60X0 Solution for 9-axis Sensor Fusion Using I²C Interface

In the figure below, the system processor is an I²C master to the MPU-60X0. In addition, the MPU-60X0 is an I²C master to the optional external compass sensor. The MPU-60X0 has limited capabilities as an I²C Master, and depends on the system processor to manage the initial configuration of any auxiliary sensors. The MPU-60X0 has an interface bypass multiplexer, which connects the system processor I²C bus pins 23 and 24 (SDA and SCL) directly to the auxiliary sensor I²C bus pins 6 and 7 (AUX_DA and AUX_CL).

Once the auxiliary sensors have been configured by the system processor, the interface bypass multiplexer should be disabled so that the MPU-60X0 auxiliary I²C master can take control of the sensor I²C bus and gather data from the auxiliary sensors.

For further information regarding I²C master control, please refer to Section 10.



7.14 MPU-6000 Using SPI Interface

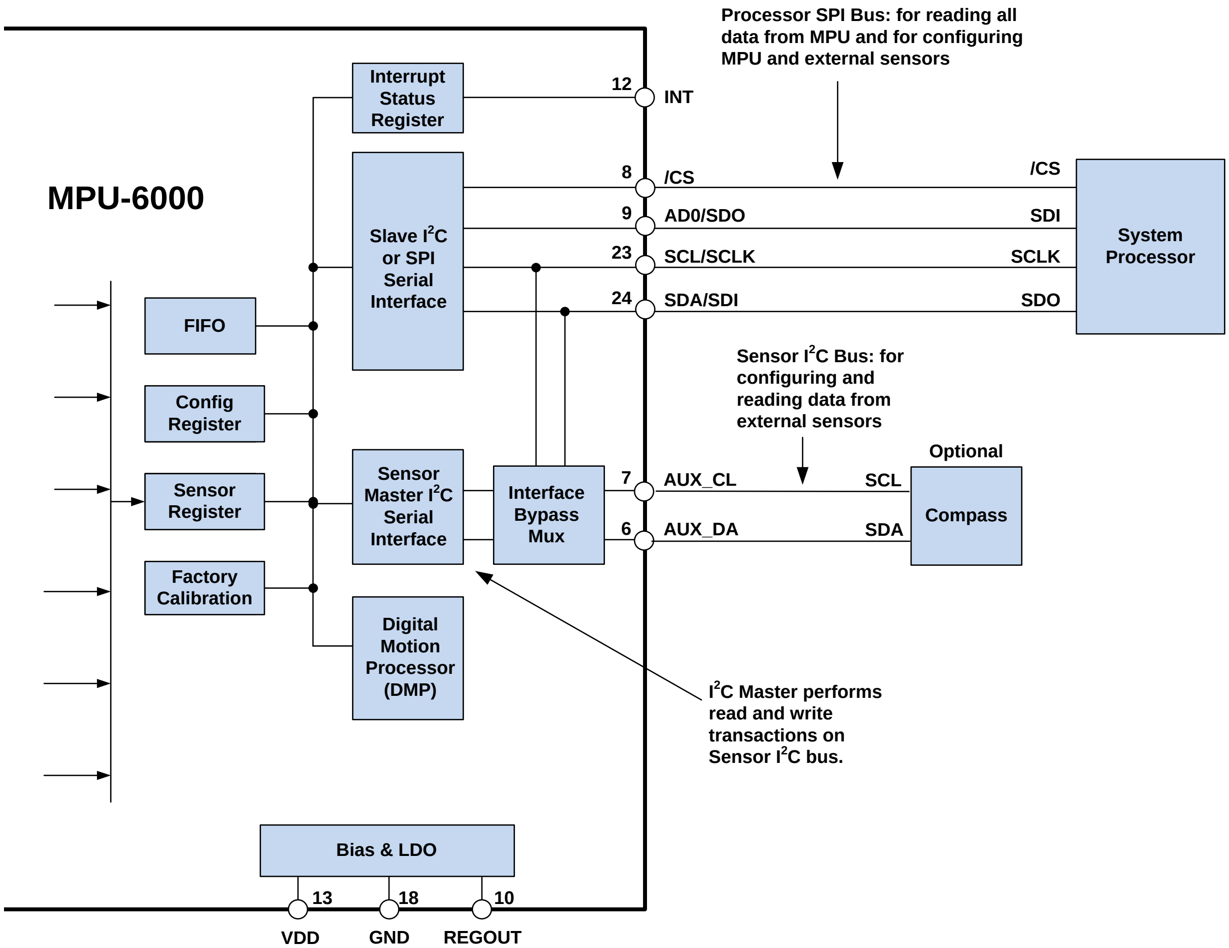
In the figure below, the system processor is an SPI master to the MPU-6000. Pins 8, 9, 23, and 24 are used to support the /CS, SDO, SCLK, and SDI signals for SPI communications. Because these SPI pins are shared with the I^{2}C slave pins (9, 23 and 24), the system processor cannot access the auxiliary I^{2}C bus through the interface bypass multiplexer, which connects the processor I^{2}C interface pins to the sensor I^{2}C interface pins.

Since the MPU-6000 has limited capabilities as an I^{2}C Master, and depends on the system processor to manage the initial configuration of any auxiliary sensors, another method must be used for programming the sensors on the auxiliary sensor I^{2}C bus pins 6 and 7 (AUX_DA and AUX_CL).

When using SPI communications between the MPU-6000 and the system processor, configuration of devices on the auxiliary I^{2}C sensor bus can be achieved by using I^{2}C Slaves 0-4 to perform read and write transactions on any device and register on the auxiliary I^{2}C bus. The I^{2}C Slave 4 interface can be used to perform only single byte read and write transactions.

Once the external sensors have been configured, the MPU-6000 can perform single or multi-byte reads using the sensor I^{2}C bus. The read results from the Slave 0-3 controllers can be written to the FIFO buffer as well as to the external sensor registers.

For further information regarding the control of the MPU-60X0's auxiliary I^{2}C interface, please refer to the MPU-6000/MPU-6050 Register Map and Register Descriptions document.



7.15 Internal Clock Generation

The MPU-60X0 has a flexible clocking scheme, allowing a variety of internal or external clock sources to be used for the internal synchronous circuitry. This synchronous circuitry includes the signal conditioning and ADCs, the DMP, and various control circuits and registers. An on-chip PLL provides flexibility in the allowable inputs for generating this clock.

Allowable internal sources for generating the internal clock are:

- An internal relaxation oscillator
- Any of the X, Y, or Z gyros (MEMS oscillators with a variation of ±1% over temperature)

Allowable external clocking sources are:

- 32.768kHz square wave
- 19.2MHz square wave

Selection of the source for generating the internal synchronous clock depends on the availability of external sources and the requirements for power consumption and clock accuracy. These requirements will most likely vary by mode of operation. For example, in one mode, where the biggest concern is power consumption, the user may wish to operate the Digital Motion Processor of the MPU-60X0 to process accelerometer data, while keeping the gyros off. In this case, the internal relaxation oscillator is a good clock choice. However, in another mode, where the gyros are active, selecting the gyros as the clock source provides for a more accurate clock source.

Clock accuracy is important, since timing errors directly affect the distance and angle calculations performed by the Digital Motion Processor (and by extension, by any processor).

There are also start-up conditions to consider. When the MPU-60X0 first starts up, the device uses its internal clock until programmed to operate from another source. This allows the user, for example, to wait for the MEMS oscillators to stabilize before they are selected as the clock source.

7.16 Sensor Data Registers

The sensor data registers contain the latest gyro, accelerometer, auxiliary sensor, and temperature measurement data. They are read-only registers, and are accessed via the serial interface. Data from these registers may be read anytime. However, the interrupt function may be used to determine when new data is available.

For a table of interrupt sources please refer to Section 8.

7.17 FIFO

The MPU-60X0 contains a 1024-byte FIFO register that is accessible via the Serial Interface. The FIFO configuration register determines which data is written into the FIFO. Possible choices include gyro data, accelerometer data, temperature readings, auxiliary sensor readings, and FSYNC input. A FIFO counter keeps track of how many bytes of valid data are contained in the FIFO. The FIFO register supports burst reads. The interrupt function may be used to determine when new data is available.

For further information regarding the FIFO, please refer to the MPU-6000/MPU-6050 Register Map and Register Descriptions document.

7.18 Interrupts

Interrupt functionality is configured via the Interrupt Configuration register. Items that are configurable include the INT pin configuration, the interrupt latching and clearing method, and triggers for the interrupt. Items that can trigger an interrupt are (1) Clock generator locked to new reference oscillator (used when switching clock sources); (2) new data is available to be read (from the FIFO and Data registers); (3) accelerometer event interrupts; and (4) the MPU-60X0 did not receive an acknowledge from an auxiliary sensor on the secondary I^2C bus. The interrupt status can be read from the Interrupt Status register.

For further information regarding interrupts, please refer to the MPU-60X0 Register Map and Register Descriptions document.

For information regarding the MPU-60X0's accelerometer event interrupts, please refer to Section 8.

7.19 Digital-Output Temperature Sensor

An on-chip temperature sensor and ADC are used to measure the MPU-60X0 die temperature. The readings from the ADC can be read from the FIFO or the Sensor Data registers.

7.20 Bias and LDO

The bias and LDO section generates the internal supply and the reference voltages and currents required by the MPU-60X0. Its two inputs are an unregulated VDD of 2.375 to 3.46V and a VLOGIC logic reference supply voltage of 1.71V to VDD (MPU-6050 only). The LDO output is bypassed by a capacitor at REGOUT. For further details on the capacitor, please refer to the Bill of Materials for External Components (Section 7.3).

7.21 Charge Pump

An on-board charge pump generates the high voltage required for the MEMS oscillators. Its output is bypassed by a capacitor at CPOUT. For further details on the capacitor, please refer to the Bill of Materials for External Components (Section 7.3).

8 Programmable Interrupts

The MPU-60X0 has a programmable interrupt system which can generate an interrupt signal on the INT pin. Status flags indicate the source of an interrupt. Interrupt sources may be enabled and disabled individually.

Table of Interrupt Sources

Interrupt Name	Module
FIFO Overflow	FIFO
Data Ready	Sensor Registers
I^2C Master errors: Lost Arbitration, NACKs	I^2C Master
I^2C Slave 4	I^2C Master

For information regarding the interrupt enable/disable registers and flag registers, please refer to the MPU-6000/MPU-6050 Register Map and Register Descriptions document. Some interrupt sources are explained below.

9 Digital Interface

9.1 I²C and SPI (MPU-6000 only) Serial Interfaces

The internal registers and memory of the MPU-6000/MPU-6050 can be accessed using either I²C at 400 kHz or SPI at 1MHz (MPU-6000 only). SPI operates in four-wire mode.

Serial Interface

Pin Number	MPU-6000	MPU-6050	Pin Name	Pin Description
8	Y		/CS	SPI chip select (0=SPI enable)
8		Y	VLOGIC	Digital I/O supply voltage. VLOGIC must be ≤ VDD at all times.
9	Y		AD0 / SDO	I²C Slave Address LSB (AD0); SPI serial data output (SDO)
9		Y	AD0	I²C Slave Address LSB
23	Y		SCL / SCLK	I²C serial clock (SCL); SPI serial clock (SCLK)
23		Y	SCL	I²C serial clock
24	Y		SDA / SDI	I²C serial data (SDA); SPI serial data input (SDI)
24		Y	SDA	I²C serial data

Note:

To prevent switching into I²C mode when using SPI (MPU-6000), the I²C interface should be disabled by setting the *I2C_IF_DIS* configuration bit. Setting this bit should be performed immediately after waiting for the time specified by the "Start-Up Time for Register Read/Write" in Section 6.3.

For further information regarding the *I2C_IF_DIS* bit, please refer to the MPU-6000/MPU-6050 Register Map and Register Descriptions document.

9.2 I²C Interface

I²C is a two-wire interface comprised of the signals serial data (SDA) and serial clock (SCL). In general, the lines are open-drain and bi-directional. In a generalized I²C interface implementation, attached devices can be a master or a slave. The master device puts the slave address on the bus, and the slave device with the matching address acknowledges the master.

The MPU-60X0 always operates as a slave device when communicating to the system processor, which thus acts as the master. SDA and SCL lines typically need pull-up resistors to VDD. The maximum bus speed is 400 kHz.

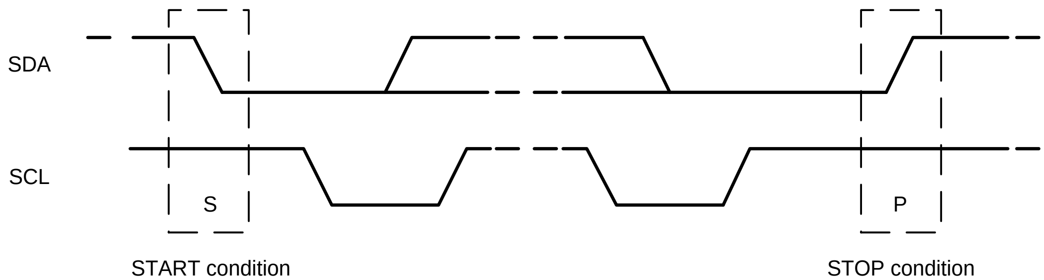
The slave address of the MPU-60X0 is b110100X which is 7 bits long. The LSB bit of the 7 bit address is determined by the logic level on pin AD0. This allows two MPU-60X0s to be connected to the same I²C bus. When used in this configuration, the address of the one of the devices should be b1101000 (pin AD0 is logic low) and the address of the other should be b1101001 (pin AD0 is logic high).

9.3 I²C Communications Protocol

START (S) and STOP (P) Conditions

Communication on the I²C bus starts when the master puts the START condition (S) on the bus, which is defined as a HIGH-to-LOW transition of the SDA line while SCL line is HIGH (see figure below). The bus is considered to be busy until the master puts a STOP condition (P) on the bus, which is defined as a LOW to HIGH transition on the SDA line while SCL is HIGH (see figure below).

Additionally, the bus remains busy if a repeated START (Sr) is generated instead of a STOP condition.

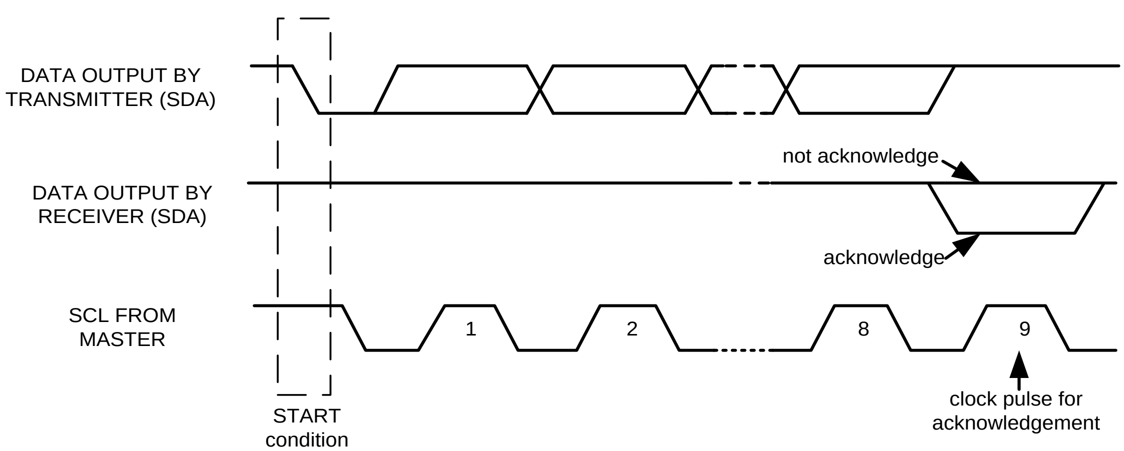


START and STOP Conditions

Data Format / Acknowledge

I^{2}C data bytes are defined to be 8-bits long. There is no restriction to the number of bytes transmitted per data transfer. Each byte transferred must be followed by an acknowledge (ACK) signal. The clock for the acknowledge signal is generated by the master, while the receiver generates the actual acknowledge signal by pulling down SDA and holding it low during the HIGH portion of the acknowledge clock pulse.

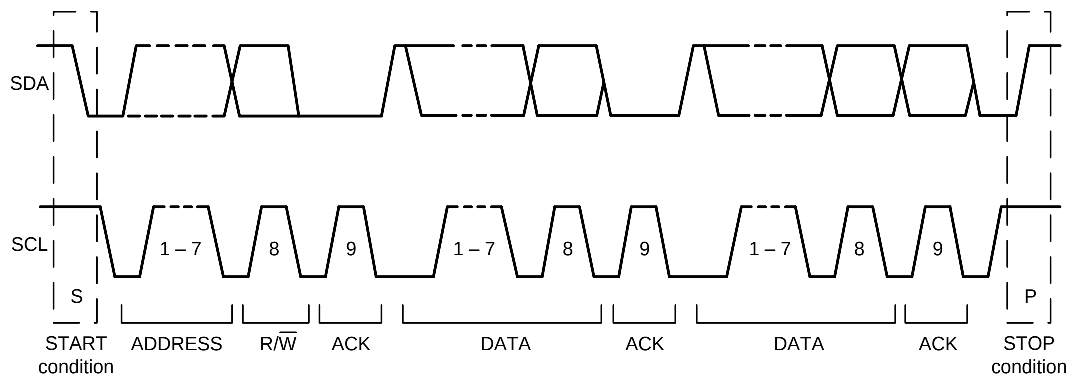
If a slave is busy and cannot transmit or receive another byte of data until some other task has been performed, it can hold SCL LOW, thus forcing the master into a wait state. Normal data transfer resumes when the slave is ready, and releases the clock line (refer to the following figure).



Acknowledge on the I^{2}C Bus

Communications

After beginning communications with the START condition (S), the master sends a 7-bit slave address followed by an 8th bit, the read/write bit. The read/write bit indicates whether the master is receiving data from or is writing to the slave device. Then, the master releases the SDA line and waits for the acknowledge signal (ACK) from the slave device. Each byte transferred must be followed by an acknowledge bit. To acknowledge, the slave device pulls the SDA line LOW and keeps it LOW for the high period of the SCL line. Data transmission is always terminated by the master with a STOP condition (P), thus freeing the communications line. However, the master can generate a repeated START condition (Sr), and address another slave without first generating a STOP condition (P). A LOW to HIGH transition on the SDA line while SCL is HIGH defines the stop condition. All SDA changes should take place when SCL is low, with the exception of start and stop conditions.



Complete I²C Data Transfer

To write the internal MPU-60X0 registers, the master transmits the start condition (S), followed by the I²C address and the write bit (0). At the 9th clock cycle (when the clock is high), the MPU-60X0 acknowledges the transfer. Then the master puts the register address (RA) on the bus. After the MPU-60X0 acknowledges the reception of the register address, the master puts the register data onto the bus. This is followed by the ACK signal, and data transfer may be concluded by the stop condition (P). To write multiple bytes after the last ACK signal, the master can continue outputting data rather than transmitting a stop signal. In this case, the MPU-60X0 automatically increments the register address and loads the data to the appropriate register. The following figures show single and two-byte write sequences.

Single-Byte Write Sequence

Master	S	AD+W		RA		DATA		P
Slave			ACK		ACK		ACK	

Burst Write Sequence

Master	S	AD+W		RA		DATA		DATA		P
Slave			ACK		ACK		ACK		ACK	

To read the internal MPU-60X0 registers, the master sends a start condition, followed by the I^{2}C address and a write bit, and then the register address that is going to be read. Upon receiving the ACK signal from the MPU-60X0, the master transmits a start signal followed by the slave address and read bit. As a result, the MPU-60X0 sends an ACK signal and the data. The communication ends with a not acknowledge (NACK) signal and a stop bit from master. The NACK condition is defined such that the SDA line remains high at the 9th clock cycle. The following figures show single and two-byte read sequences.

Single-Byte Read Sequence

Master	S	AD+W		RA		S	AD+R			NACK	P
Slave			ACK		ACK			ACK	DATA		

Burst Read Sequence

Master	S	AD+W		RA		S	AD+R			ACK		NACK	P
Slave			ACK		ACK			ACK	DATA		DATA		

9.4 I^{2}C Terms

Signal	Description
S	Start Condition: SDA goes from high to low while SCL is high
AD	Slave I^{2}C address
W	Write bit (0)
R	Read bit (1)
ACK	Acknowledge: SDA line is low while the SCL line is high at the 9th clock cycle
NACK	Not-Acknowledge: SDA line stays high at the 9th clock cycle
RA	MPU-60X0 internal register address
DATA	Transmit or received data
P	Stop condition: SDA going from low to high while SCL is high

9.5 SPI Interface (MPU-6000 only)

SPI is a 4-wire synchronous serial interface that uses two control lines and two data lines. The MPU-6000 always operates as a Slave device during standard Master-Slave SPI operation.

With respect to the Master, the Serial Clock output (SCLK), the Serial Data Output (SDO) and the Serial Data Input (SDI) are shared among the Slave devices. Each SPI slave device requires its own Chip Select (/CS) line from the master.

/CS goes low (active) at the start of transmission and goes back high (inactive) at the end. Only one /CS line is active at a time, ensuring that only one slave is selected at any given time. The /CS lines of the non-selected slave devices are held high, causing their SDO lines to remain in a high-impedance (high-z) state so that they do not interfere with any active devices.

SPI Operational Features

1. Data is delivered MSB first and LSB last
2. Data is latched on the rising edge of SCLK
3. Data should be transitioned on the falling edge of SCLK
4. The maximum frequency of SCLK is 1MHz
5. SPI read and write operations are completed in 16 or more clock cycles (two or more bytes). The first byte contains the SPI Address, and the following byte(s) contain(s) the SPI data. The first bit of the first byte contains the Read/Write bit and indicates the Read (1) or Write (0) operation. The following 7 bits contain the Register Address. In cases of multiple-byte Read/Writes, data is two or more bytes:

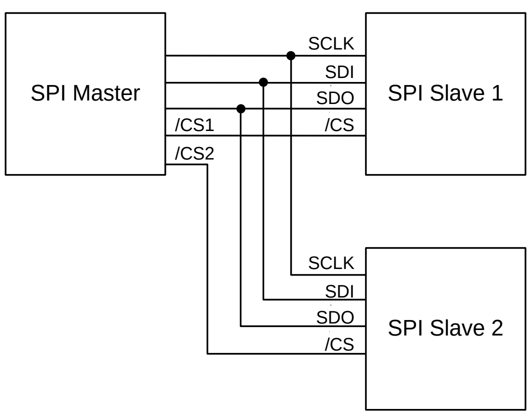
SPI Address format

MSB							**LSB**
R/W	A6	A5	A4	A3	A2	A1	A0

SPI Data format

MSB							**LSB**
D7	D6	D5	D4	D3	D2	D1	D0

6. Supports Single or Burst Read/Writes.



Typical SPI Master / Slave Configuration

10 Serial Interface Considerations (MPU-6050)

10.1 MPU-6050 Supported Interfaces

The MPU-6050 supports I^2C communications on both its primary (microprocessor) serial interface and its auxiliary interface.

10.2 Logic Levels

The MPU-6050's I/O logic levels are set to be VLOGIC, as shown in the table below. AUX_VDDIO must be set to 0.

I/O Logic Levels vs. *AUX_VDDIO*

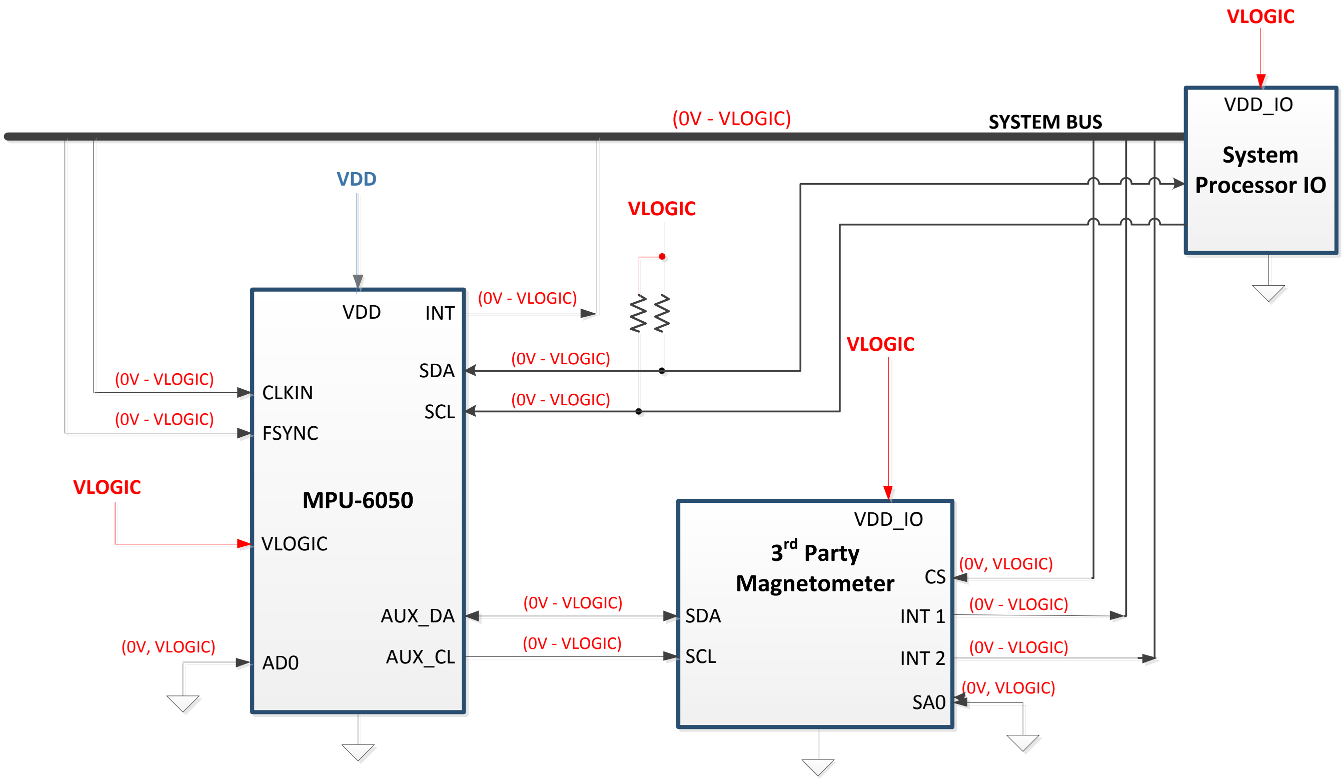
AUX_VDDIO	**MICROPROCESSOR LOGIC LEVELS** (Pins: SDA, SCL, AD0, CLKIN, INT)	**AUXILLARY LOGIC LEVELS** (Pins: AUX_DA, AUX_CL)
0	VLOGIC	VLOGIC

Note: The power-on-reset value for *AUX_VDDIO* is 0.

When *AUX_VDDIO* is set to 0 (its power-on-reset value), VLOGIC is the power supply voltage for both the microprocessor system bus and the auxiliary I^2C bus, as shown in the figure of Section 10.3.

10.3 Logic Levels Diagram for AUX_*VDDIO* = 0

The figure below depicts a sample circuit with a third party magnetometer attached to the auxiliary I^2C bus. It shows logic levels and voltage connections for *AUX_VDDIO* = 0. Note: Actual configuration will depend on the auxiliary sensors used.



I/O Levels and Connections for *AUX_VDDIO* = 0

Notes:

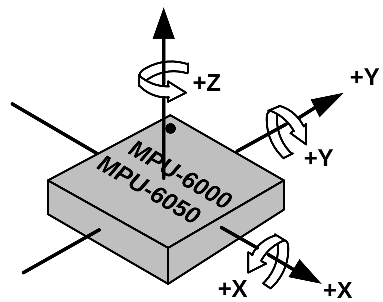
1. AUX_VDDIO determines the IO voltage levels of AUX_DA and AUX_CL
   (0 = set output levels relative to VLOGIC)
2. All other MPU-6050 logic IOs are referenced to VLOGIC.

11 Assembly

This section provides general guidelines for assembling InvenSense Micro Electro-Mechanical Systems (MEMS) gyros packaged in Quad Flat No leads package (QFN) surface mount integrated circuits.

11.1 Orientation of Axes

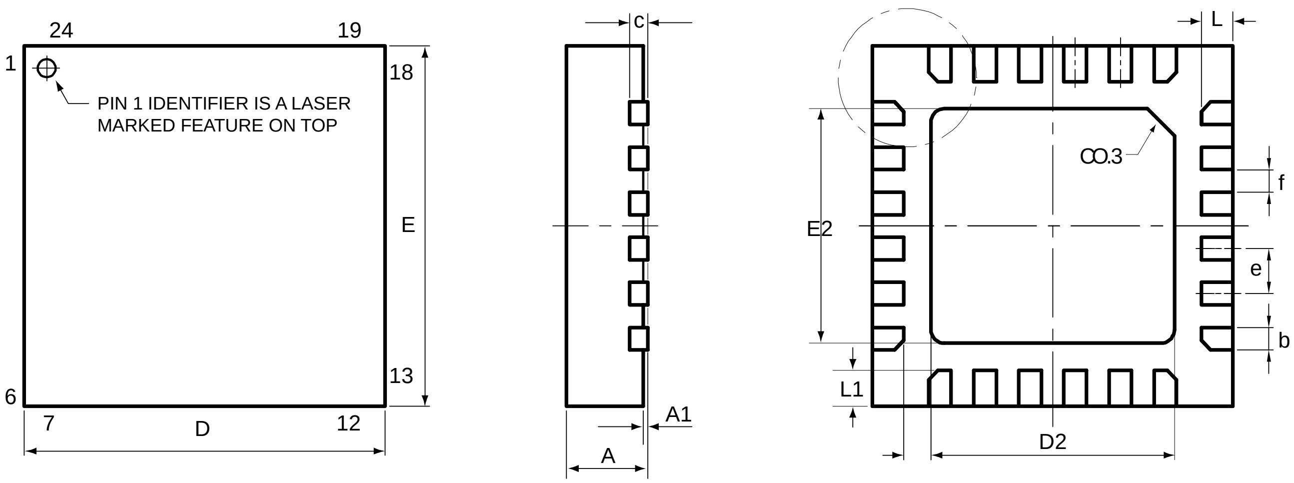
The diagram below shows the orientation of the axes of sensitivity and the polarity of rotation. Note the pin 1 identifier (•) in the figure.

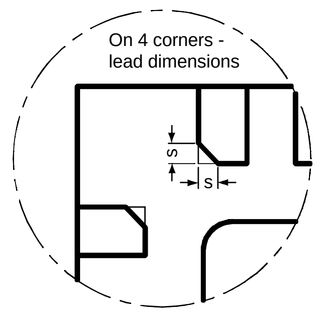


Orientation of Axes of Sensitivity and Polarity of Rotation

11.2 Package Dimensions

24 Lead QFN (4x4x0.9) mm NiPdAu Lead-frame finish

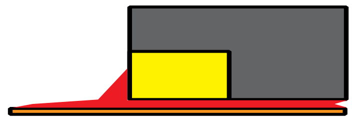




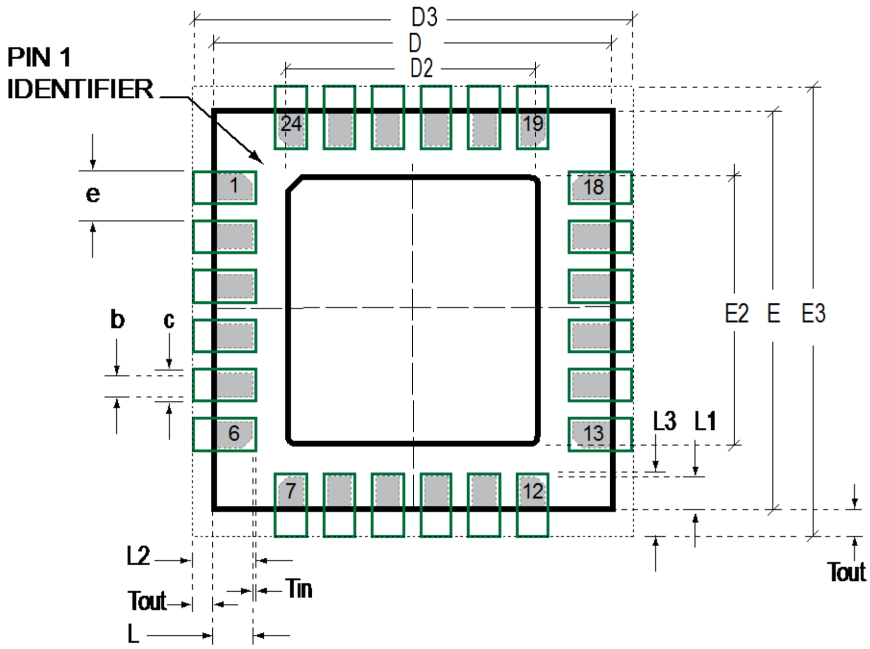
SYMBOLS	DIMENSIONS IN MILLIMETERS		
	MIN	NOM	MAX
A	0.85	0.90	0.95
A1	0.00	0.02	0.05
b	0.18	0.25	0.30
c	---	0.20 REF	---
D	3.90	4.00	4.10
D2	2.65	2.70	2.75
E	3.90	4.00	4.10
E2	2.55	2.60	2.65
e	---	0.50	---
f (e-b)	---	0.25	---
K	0.25	0.30	0.35
L	0.30	0.35	0.40
L1	0.35	0.40	0.45
s	0.05	---	0.15

11.3 PCB Design Guidelines

The Pad Diagram using a JEDEC type extension with solder rising on the outer edge is shown below. The Pad Dimensions Table shows pad sizing (mean dimensions) recommended for the MPU-60X0 product.



JEDEC type extension with solder rising on outer edge



PCB Layout Diagram

SYMBOLS	DIMENSIONS IN MILLIMETERS	NOM
	Nominal Package I/O Pad Dimensions	
e	Pad Pitch	0.50
b	Pad Width	0.25
L	Pad Length	0.35
L1	Pad Length	0.40
D	Package Width	4.00
E	Package Length	4.00
D2	Exposed Pad Width	2.70
E2	Exposed Pad Length	2.60
	I/O Land Design Dimensions (Guidelines)	
D3	I/O Pad Extent Width	4.80
E3	I/O Pad Extent Length	4.80
c	Land Width	0.35
Tout	Outward Extension	0.40
Tin	Inward Extension	0.05
L2	Land Length	0.80
L3	Land Length	0.85

PCB Dimensions Table (for PCB Lay-out Diagram)

11.4 Assembly Precautions

11.4.1 Gyroscope Surface Mount Guidelines

InvenSense MEMS Gyros sense rate of rotation. In addition, gyroscopes sense mechanical stress coming from the printed circuit board (PCB). This PCB stress can be minimized by adhering to certain design rules:

When using MEMS gyroscope components in plastic packages, PCB mounting and assembly can cause package stress. This package stress in turn can affect the output offset and its value over a wide range of temperatures. This stress is caused by the mismatch between the Coefficient of Linear Thermal Expansion (CTE) of the package material and the PCB. Care must be taken to avoid package stress due to mounting.

Traces connected to pads should be as symmetric as possible. Maximizing symmetry and balance for pad connection will help component self alignment and will lead to better control of solder paste reduction after reflow.

Any material used in the surface mount assembly process of the MEMS gyroscope should be free of restricted RoHS elements or compounds. Pb-free solders should be used for assembly.

11.4.2 Exposed Die Pad Precautions

The MPU-60X0 has very low active and standby current consumption. The exposed die pad is not required for heat sinking, and should not be soldered to the PCB. Failure to adhere to this rule can induce performance changes due to package thermo-mechanical stress. There is no electrical connection between the pad and the CMOS.

11.4.3 Trace Routing

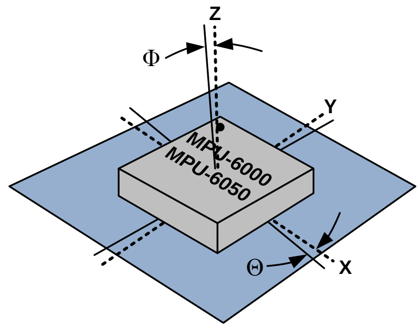
Routing traces or vias under the gyro package such that they run under the exposed die pad is prohibited. Routed active signals may harmonically couple with the gyro MEMS devices, compromising gyro response. These devices are designed with the drive frequencies as follows: X = 33±3Khz, Y = 30±3Khz, and Z=27±3Khz. To avoid harmonic coupling don't route active signals in non-shielded signal planes directly below, or above the gyro package. Note: For best performance, design a ground plane under the e-pad to reduce PCB signal noise from the board on which the gyro device is mounted. If the gyro device is stacked under an adjacent PCB board, design a ground plane directly above the gyro device to shield active signals from the adjacent PCB board.

11.4.4 Component Placement

Do not place large insertion components such as keyboard or similar buttons, connectors, or shielding boxes at a distance of less than 6 mm from the MEMS gyro. Maintain generally accepted industry design practices for component placement near the MPU-60X0 to prevent noise coupling and thermo-mechanical stress.

11.4.5 PCB Mounting and Cross-Axis Sensitivity

Orientation errors of the gyroscope and accelerometer mounted to the printed circuit board can cause cross-axis sensitivity in which one gyro or accel responds to rotation or acceleration about another axis, respectively. For example, the X-axis gyroscope may respond to rotation about the Y or Z axes. The orientation mounting errors are illustrated in the figure below.



Package Gyro & Accel Axes (– – –) Relative to PCB Axes (——) with Orientation Errors (Θ and Φ)

The table below shows the cross-axis sensitivity as a percentage of the gyroscope or accelerometer's sensitivity for a given orientation error, respectively.

Cross-Axis Sensitivity vs. Orientation Error

Orientation Error (θ or Φ)	Cross-Axis Sensitivity (sinθ or sinΦ)
0º	0%
0.5º	0.87%
1º	1.75%

The specifications for cross-axis sensitivity in Section 6.1 and Section 6.2 include the effect of the die orientation error with respect to the package.

11.4.6 MEMS Handling Instructions

MEMS (Micro Electro-Mechanical Systems) are a time-proven, robust technology used in hundreds of millions of consumer, automotive and industrial products. MEMS devices consist of microscopic moving mechanical structures. They differ from conventional IC products, even though they can be found in similar packages. Therefore, MEMS devices require different handling precautions than conventional ICs prior to mounting onto printed circuit boards (PCBs).

The MPU-60X0 has been qualified to a shock tolerance of 10,000*g*. InvenSense packages its gyroscopes as it deems proper for protection against normal handling and shipping. It recommends the following handling precautions to prevent potential damage.

- Do not drop individually packaged gyroscopes, or trays of gyroscopes onto hard surfaces. Components placed in trays could be subject to *g*-forces in excess of 10,000*g* if dropped.
- Printed circuit boards that incorporate mounted gyroscopes should not be separated by manually snapping apart. This could also create *g*-forces in excess of 10,000*g.*
- Do not clean MEMS gyroscopes in ultrasonic baths. Ultrasonic baths can induce MEMS damage if the bath energy causes excessive drive motion through resonant frequency coupling.

11.4.7 ESD Considerations

Establish and use ESD-safe handling precautions when unpacking and handling ESD-sensitive devices.

- Store ESD sensitive devices in ESD safe containers until ready for use. The Tape-and-Reel moisture-sealed bag is an ESD approved barrier. The best practice is to keep the units in the original moisture sealed bags until ready for assembly.

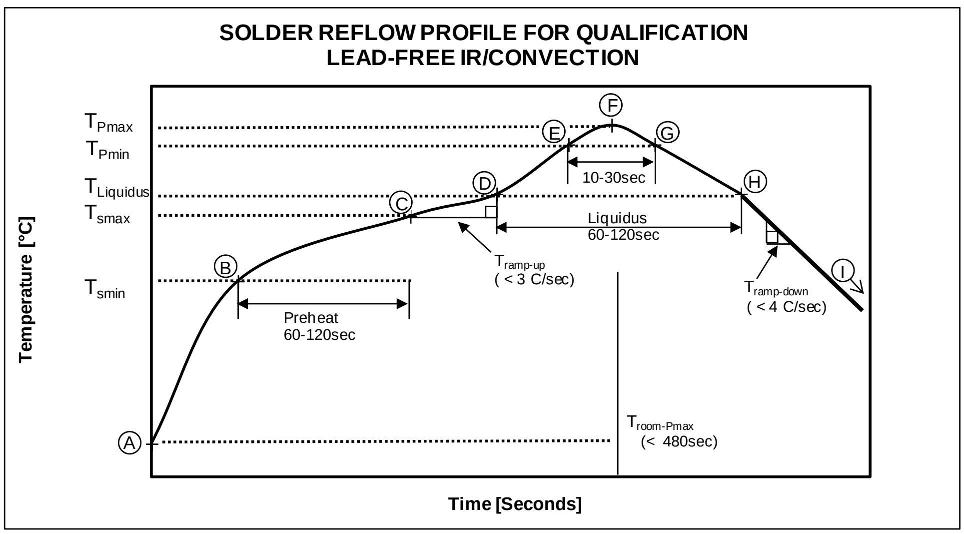
Restrict all device handling to ESD protected work areas that measure less than 200V static charge. Ensure that all workstations and personnel are properly grounded to prevent ESD.

11.4.8 Reflow Specification

Qualification Reflow: The MPU-60X0 was qualified in accordance with IPC/JEDEC J-STD-020D.1. This standard classifies proper packaging, storage and handling in order to avoid subsequent thermal and mechanical damage during the solder reflow attachment phase of PCB assembly.

The qualification preconditioning process specifies a sequence consisting of a bake cycle, a moisture soak cycle (in a temperature humidity oven), and three consecutive solder reflow cycles, followed by functional device testing.

The peak solder reflow classification temperature requirement for package qualification is (260 +5/-0°C) for lead-free soldering of components measuring less than 1.6 mm in thickness. The qualification profile and a table explaining the set-points are shown below:



Temperature Set Points Corresponding to Reflow Profile Above

Step	Setting	CONSTRAINTS		
		Temp (°C)	Time (sec)	Max. Rate (°C/sec)
A	T_{room}	25		
B	T_{Smin}	150		
C	T_{Smax}	200	$60 < t_{BC} < 120$	
D	$T_{Liquidus}$	217		$r_{(TLiquidus-TPmax)} < 3$
E	T_{Pmin} [255°C, 260°C]	255		$r_{(TLiquidus-TPmax)} < 3$
F	T_{Pmax} [260°C, 265°C]	260	$t_{AF} < 480$	$r_{(TLiquidus-TPmax)} < 3$
G	T_{Pmin} [255°C, 260°C]	255	$10 < t_{EG} < 30$	$r_{(TPmax-TLiquidus)} < 4$
H	$T_{Liquidus}$	217	$60 < t_{DH} < 120$	
I	T_{room}	25		

Notes: Customers must never exceed the Classification temperature (T_{Pmax} = 260°C).
All temperatures refer to the topside of the QFN package, as measured on the package body surface.

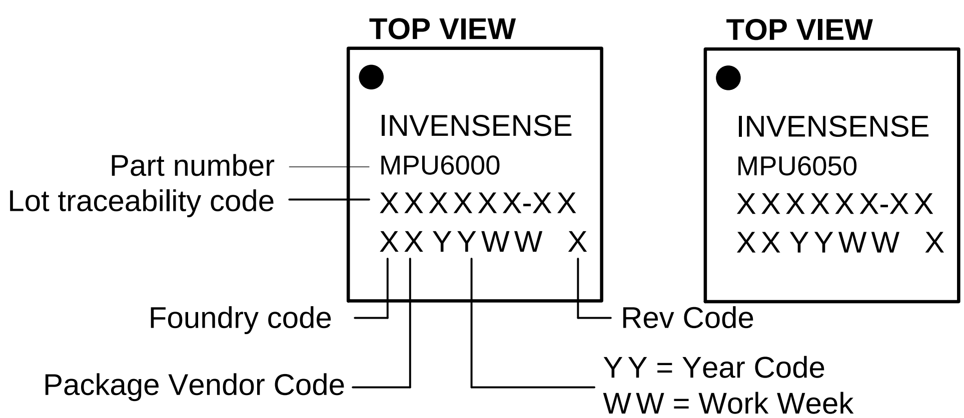
Production Reflow: Check the recommendations of your solder manufacturer. For optimum results, use lead-free solders that have lower specified temperature profiles (Tp_{max} ~ 235°C). Also use lower ramp-up and ramp-down rates than those used in the qualification profile. Never exceed the maximum conditions that we used for qualification, as these represent the maximum tolerable ratings for the device.

11.5 Storage Specifications

The storage specification of the MPU-60X0 conforms to IPC/JEDEC J-STD-020D.1 Moisture Sensitivity Level (MSL) 3.

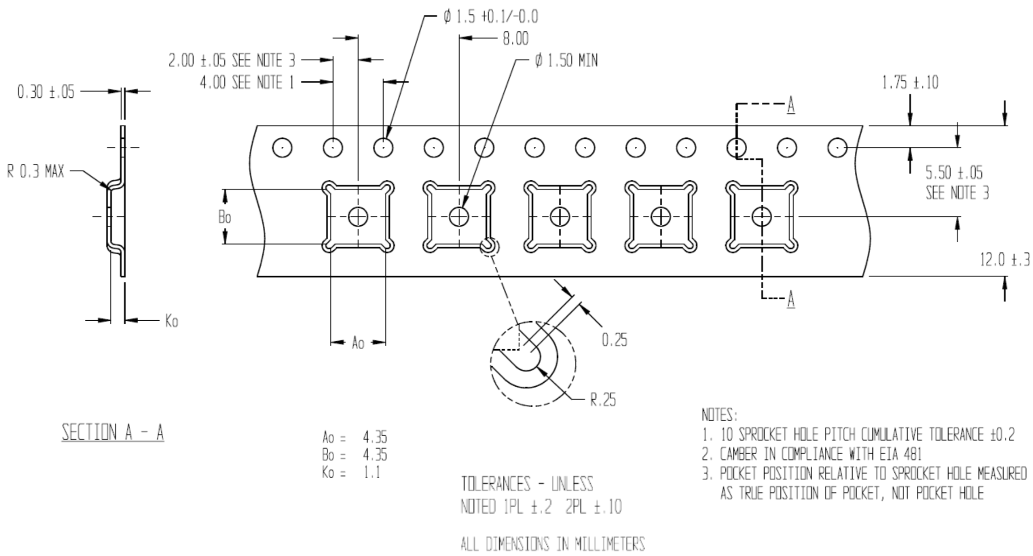
Calculated shelf-life in moisture-sealed bag	12 months -- Storage conditions: <40°C and <90% RH
After opening moisture-sealed bag	168 hours -- Storage conditions: ambient ≤30°C at 60%RH

11.6 Package Marking Specification

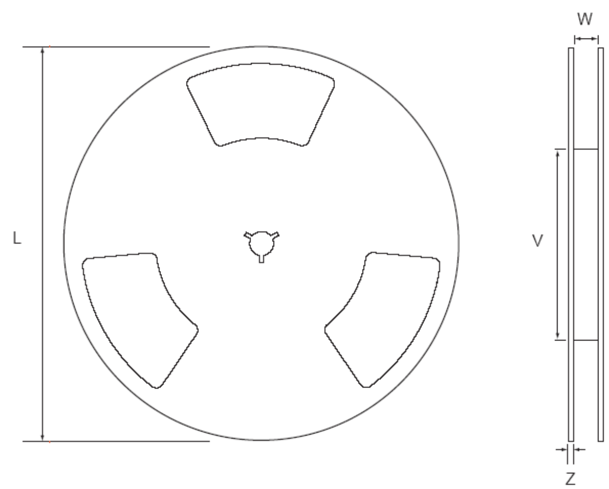


Package Marking Specification

11.7 Tape & Reel Specification



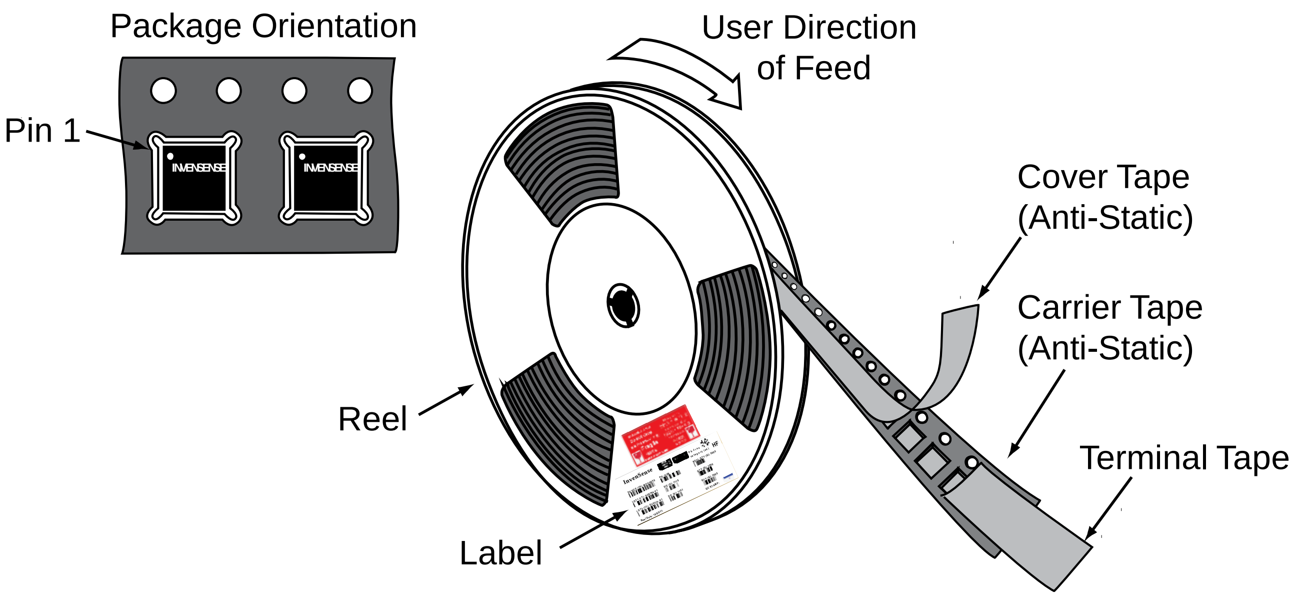
Tape Dimensions



Reel Outline Drawing

Reel Dimensions and Package Size

PACKAGE SIZE	REEL (mm)			
	L	V	W	Z
4x4	330	102	12.8	2.3



Tape and Reel Specification

Reel Specifications

Quantity Per Reel	**5,000**
Reels per Box	**1**
Boxes Per Carton (max)	**5**
Pcs/Carton (max)	**25,000**

11.8 Label

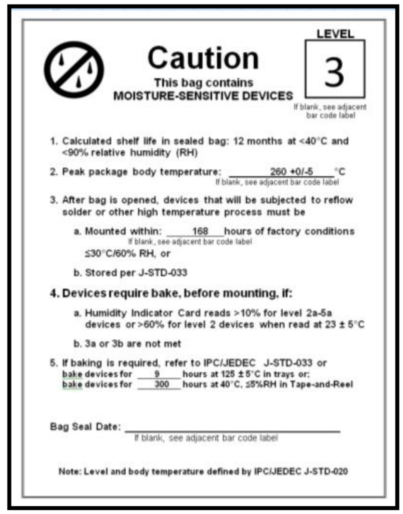
Barcode Label

Location of Label on Reel

11.9 Packaging

REEL – with Barcode & Caution labels

Vacuum-Sealed Moisture Barrier Bag with ESD, MSL3, Caution, and Barcode Labels



MSL3 Label

Caution Label

ESD Label

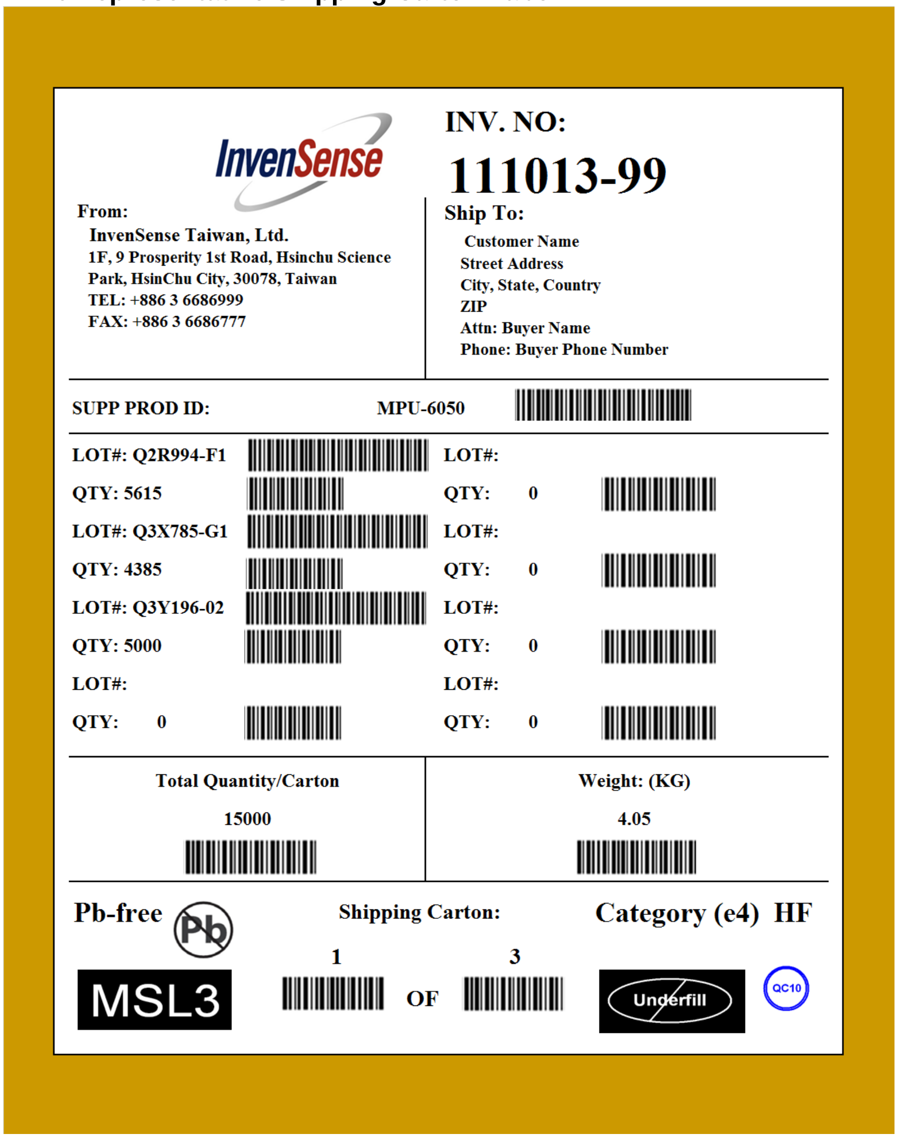
Inner Bubble Wrap

Pizza Box

Pizza Boxes Placed in Foam-Lined Shipper Box

Outer Shipper Label

11.10 Representative Shipping Carton Label



12 Reliability

12.1 Qualification Test Policy

InvenSense's products complete a Qualification Test Plan before being released to production. The Qualification Test Plan for the MPU-60X0 followed the JESD47I Standards, "Stress-Test-Driven Qualification of Integrated Circuits," with the individual tests described below.

12.2 Qualification Test Plan

Accelerated Life Tests

TEST	Method/Condition	Lot Quantity	Sample / Lot	Acc / Reject Criteria
(HTOL/LFR) High Temperature Operating Life	JEDEC JESD22-A108D, Dynamic, 3.63V biased, Tj>125°C [read-points 168, 500, 1000 hours]	3	77	(0/1)
(HAST) Highly Accelerated Stress Test (1)	JEDEC JESD22-A118A Condition A, 130°C, 85%RH, 33.3 psia. unbiased, [read-point 96 hours]	3	77	(0/1)
(HTS) High Temperature Storage Life	JEDEC JESD22-A103D, Cond. A, 125°C Non-Bias Bake [read-points 168, 500, 1000 hours]	3	77	(0/1)

Device Component Level Tests

TEST	Method/Condition	Lot Quantity	Sample / Lot	Acc / Reject Criteria
(ESD-HBM) ESD-Human Body Model	JEDEC JS-001-2012, (2KV)	1	3	(0/1)
(ESD-MM) ESD-Machine Model	JEDEC JESD22-A115C, (250V)	1	3	(0/1)
(LU) Latch Up	JEDEC JESD-78D Class II (2), 125°C; ±100mA	1	6	(0/1)
(MS) Mechanical Shock	JEDEC JESD22-B104C, Mil-Std-883, Method 2002.5, Cond. E, 10,000*g's*, 0.2ms, ±X, Y, Z – 6 directions, 5 times/direction	3	5	(0/1)
(VIB) Vibration	JEDEC JESD22-B103B, Variable Frequency (random), Cond. B, 5-500Hz, X, Y, Z – 4 times/direction	3	5	(0/1)
(TC) Temperature Cycling (1)	JEDEC JESD22-A104D Condition G [-40°C to +125°C], Soak Mode 2 [5'], 1000 cycles	3	77	(0/1)

Board Level Tests

TEST	Method/Condition	Lot Quantity	Sample / Lot	Acc / Reject Criteria
(BMS) Board Mechanical Shock	JEDEC JESD22-B104C,Mil-Std-883, Method 2002.5, Cond. E, 10000*g's*, 0.2ms, +-X, Y, Z – 6 directions, 5 times/direction	1	5	(0/1)
(BTC) Board Temperature Cycling (1)	JEDEC JESD22-A104D Condition G [-40°C to +125°C], Soak mode 2 [5'], 1000 cycles	1	40	(0/1)

(1) Tests are preceded by MSL3 Preconditioning in accordance with JEDEC JESD22-A113F

13 Environmental Compliance

The MPU-6000/MPU-6050 is RoHS and Green compliant.

The MPU-6000/MPU-6050 is in full environmental compliance as evidenced in report HS-MPU-6000, Materials Declaration Data Sheet.

Environmental Declaration Disclaimer:

InvenSense believes this environmental information to be correct but cannot guarantee accuracy or completeness. Conformity documents for the above component constitutes are on file. InvenSense subcontracts manufacturing and the information contained herein is based on data received from vendors and suppliers, which has not been validated by InvenSense.

Freescale Semiconductor
Data Sheet: Technical Data

MPX5010
Rev 13, 10/2012

Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPX5010 MPXV5010 MPVZ5010 Series

0 to 10 kPa (0 to 1.45 psi)
(0 to 1019.78 mm H_2O)
0.2 to 4.7 V Output

The MPxx5010 series piezoresistive transducers are state-of-the-art monolithic silicon pressure sensors designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure. The axial port has been modified to accommodate industrial grade tubing.

Features

- 5.0% Maximum Error over 0° to 85°C
- Ideally Suited for Microprocessor or Microcontroller-Based Systems
- Durable Epoxy Unibody and Thermoplastic (PPS) Surface Mount Package
- Temperature Compensated over -40° to +125°C
- Patented Silicon Shear Stress Strain Gauge
- Available in Differential and Gauge Configurations
- Available in Surface Mount (SMT) or Through-hole (DIP) Configurations

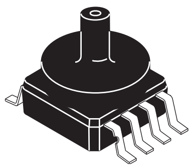
Application Examples

- Hospital Beds
- HVAC
- Respiratory Systems
- Process Control
- Washing Machine Water Level Measurement (Reference AN1950)
- Ideally Suited for Microprocessor or Microcontroller-Based Systems
- Appliance Liquid Level and Pressure Measurement

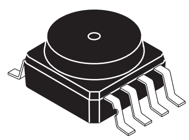
ORDERING INFORMATION

Device Name	Case No.	# of Ports			Pressure Type			Device Marking
		None	Single	Dual	Gauge	Differential	Absolute	
Unibody Package (MPX5010 Series)								
MPX5010DP	867C			•		•		MPX5010DP
MPX5010GP	867B		•		•			MPX5010GP
MPX5010GS	867E		•		•			MPX5010D
MPX5010GSX	867F		•		•			MPX5010D
Small Outline Package (MPXV5010 Series)								
MPXV5010DP	1351			•		•		MPXV5010DP
MPXV5010G6U	482	•			•			MPXV5010G
MPXV5010GC6T1	482A		•		•			MPXV5010G
MPXV5010GC6U	482A		•		•			MPXV5010G
MPXV5010GC7U	482C		•		•			MPXV5010G
MPXV5010GP	1369		•		•			MPXV5010GP
Small Outline Package (Media Resistant Gel) (MPVZ5010 Series)								
MPVZ5010G6U	482	•			•			MPVZ5010G
MPVZ5010G7U	482B	•			•			MPVZ5010G
MPVZ5010GW6U	1735		•		•			MZ5010GW
MPVZ5010GW7U	1560		•		•			MZ5010GW

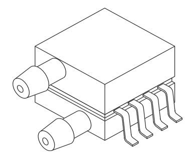
SMALL OUTLINE PACKAGES SURFACE MOUNT



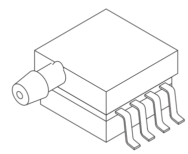
MPXV5010GC6U/C6T1
CASE 482A-01



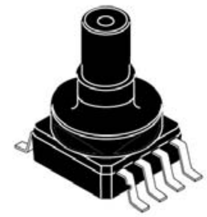
MPXV5010G6U,
MPVZ5010G6U
CASE 482-01



MPXV5010DP
CASE 1351-01

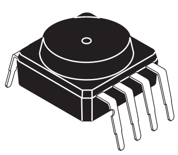


MPXV5010GP
CASE 1369-01

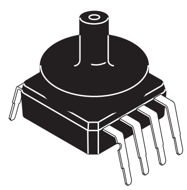


MPVZ5010GW6U
CASE 1735-01

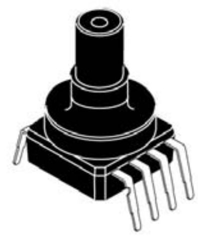
SMALL OUTLINE PACKAGES THROUGH-HOLE



MPVZ5010G7U
CASE 482B-03

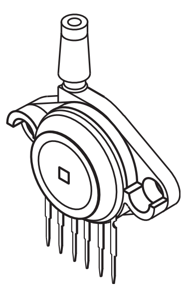


MPXV5010GC7U
CASE 482C-03

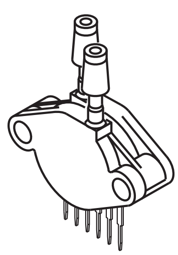


MPVZ5010GW7U
CASE 1560-02

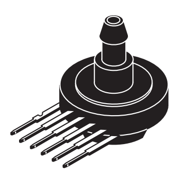
UNIBODY PACKAGES



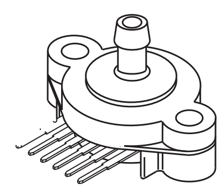
MPX5010GP
CASE 867B-04



MPX5010DP
CASE 867C-05



MPX5010GS
CASE 867E-03



MPX5010GSX
CASE 867F-03

Operating Characteristics

Table 1. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 3 required to meet specification.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range		P_{OP}	0	—	10 1019.78	kPa mm H_2O
Supply Voltage(1)		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_o	—	5.0	10	mAdc
Minimum Pressure Offset(2) @ V_S = 5.0 Volts	(0 to 85°C)	V_{off}	0	0.2	0.425	Vdc
Full Scale Output(3) @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSO}	4.475	4.7	4.925	Vdc
Full Scale Span(4) @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSS}	4.275	4.5	4.725	Vdc
Accuracy(5)	(0 to 85°C)	—	—	—	±5.0	$\%V_{FSS}$
Sensitivity		V/P	—	450 4.413	—	mV/mm mV/mm H_2O
Response Time(6)		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_{O+}	—	0.1	—	mAdc
Warm-Up Time(7)		—	—	20	—	ms
Offset Stability(8)		—	—	±0.5	—	$\%V_{FSS}$

1. Device is ratiometric within this specified excitation range.
2. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
3. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
4. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   Temperature Hysteresis:Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   Pressure Hysteresis:Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   TcOffset:Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   Variation from Nominal:The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
8. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

Maximum Ratings

Table 2. Maximum Ratings[1]

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{max}	40	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

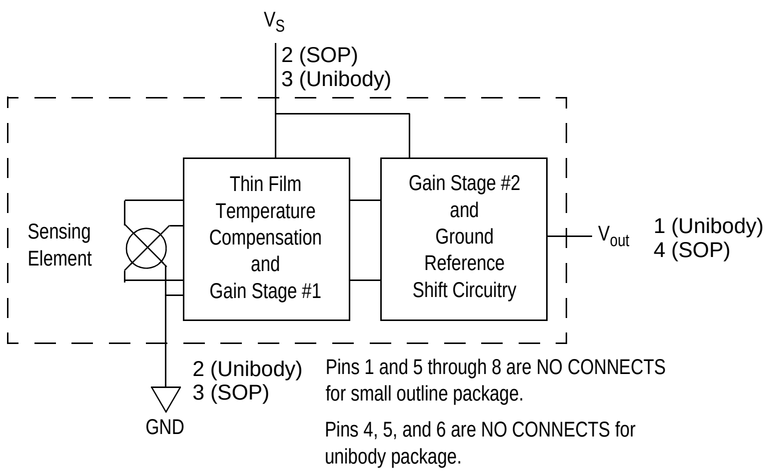


Figure 1. Fully Integrated Pressure Sensor Schematic

ON-CHIP TEMPERATURE COMPENSATION AND CALIBRATION

The performance over temperature is achieved by integrating the shear-stress strain gauge, temperature compensation, calibration and signal conditioning circuitry onto a single monolithic chip.

Figure 3 illustrates the Differential or Gauge configuration in the basic chip carrier (Case 482). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm.

The MPxx5010G series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 4 shows the recommended decoupling circuit for interfacing the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

Figure 5 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit shown in Figure 4. The output will saturate outside of the specified pressure range.

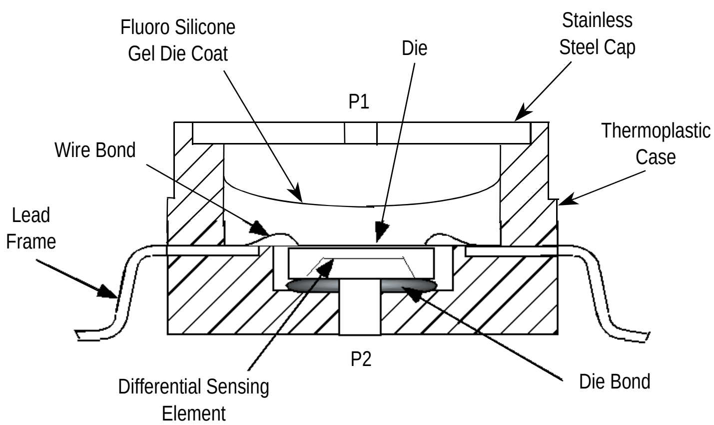


Figure 2. Cross-Sectional Diagram SOP (not to scale)

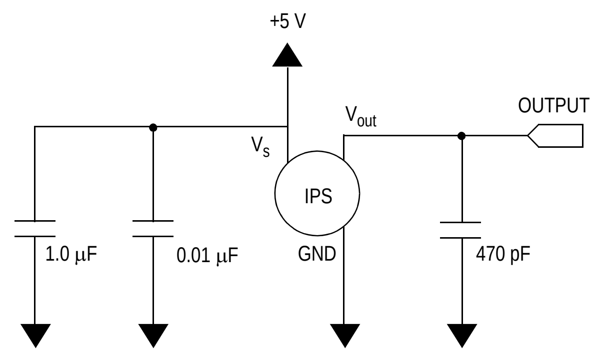


Figure 3. Recommended Power Supply Decoupling and Output Filtering

(For additional output filtering, please refer to Application Note AN1646.)

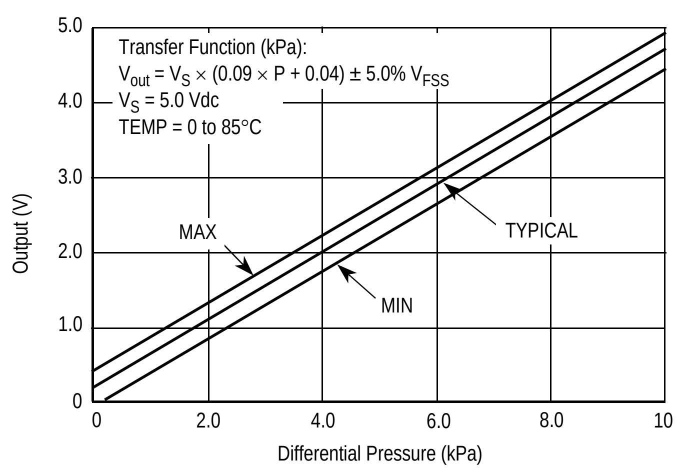
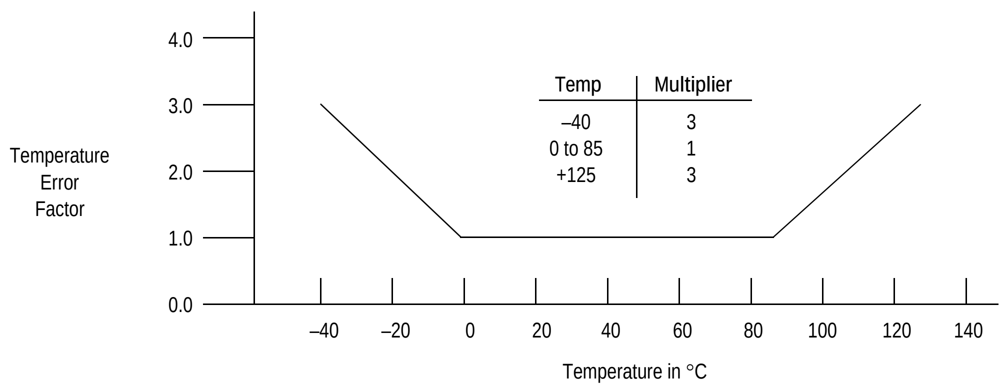


Figure 4. Output vs. Pressure Differential

Transfer Function

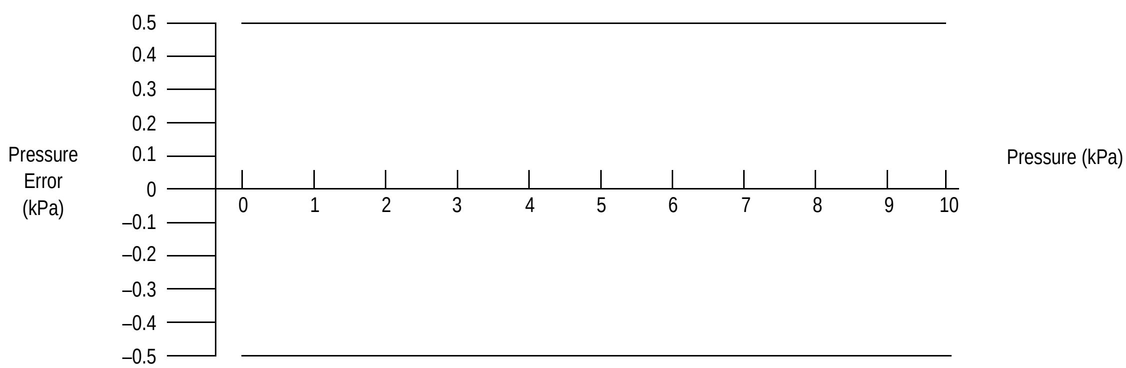
Nominal Transfer Value: $V_{out} = V_S \times (0.09 \times P + 0.04)$
$\pm$ (Pressure Error x Temp. Factor x 0.09 x V_S)
V_S = 5.0 V $\pm$ 0.25 Vdc

Temperature Error Band



NOTE: The Temperature Multiplier is a linear response from 0° to –40°C and from 85° to 125°C.

Pressure Error Band



Pressure	Error (Max)
0 to 10 (kPa)	±0.5 (kPa)

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluorosilicone gel which protects the die from harsh media. The MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX5010DP	867C	Side with Part Marking
MPX5010GP	867B	Side with Port Attached
MPX5010GS	867E	Side with Port Attached
MPX5010GSX	867F	Side with Port Attached
MPXV5010G6U	482	Stainless Steel Cap
MPXV5010GC6U/6T1	482A	Side with Port Attached
MPXV5010GC7U	482C	Side with Port Attached
MPXV5010GP	1369	Side with Port Attached
MPXV5010DP	1351	Side with Part Marking
MPVZ5010G6U	482	Stainless Steel Cap
MPVZ5010G7U	482B	Stainless Steel Cap
MPVZ5010GW6U	1735	Vertical Port Attached
MPVZ5010GW7U	1560	Vertical Port Attached

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

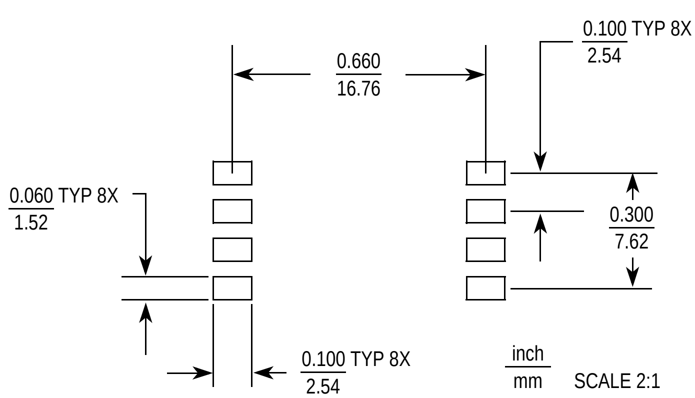
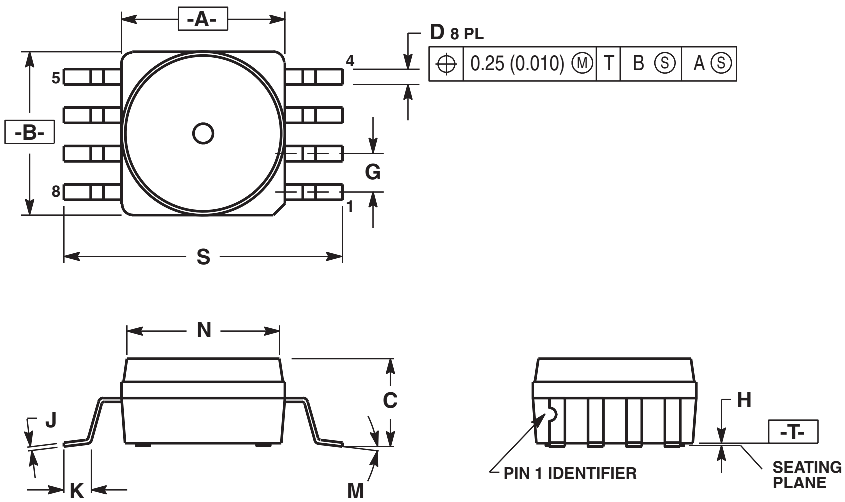


Figure 5. SOP Footprint (Case 482)

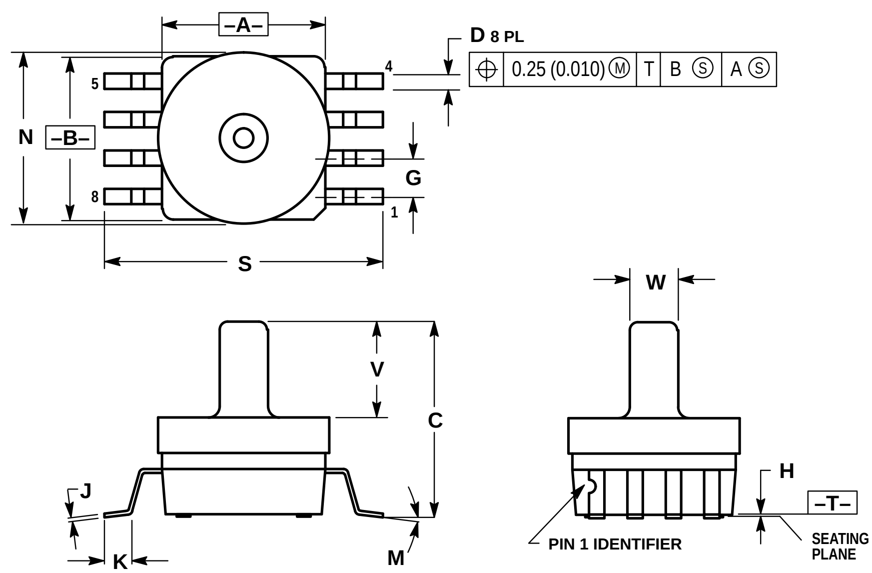
PACKAGE DIMENSIONS



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006).
5. ALL VERTICAL SURFACES 5˚ TYPICAL DRAFT.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.415	0.425	10.54	10.79
B	0.415	0.425	10.54	10.79
C	0.212	0.230	5.38	5.84
D	0.038	0.042	0.96	1.07
G	0.100 BSC		2.54 BSC	
H	0.002	0.010	0.05	0.25
J	0.009	0.011	0.23	0.28
K	0.061	0.071	1.55	1.80
M	0˚	7˚	0˚	7˚
N	0.405	0.415	10.29	10.54
S	0.709	0.725	18.01	18.41

CASE 482-01
ISSUE O
SMALL OUTLINE PACKAGE

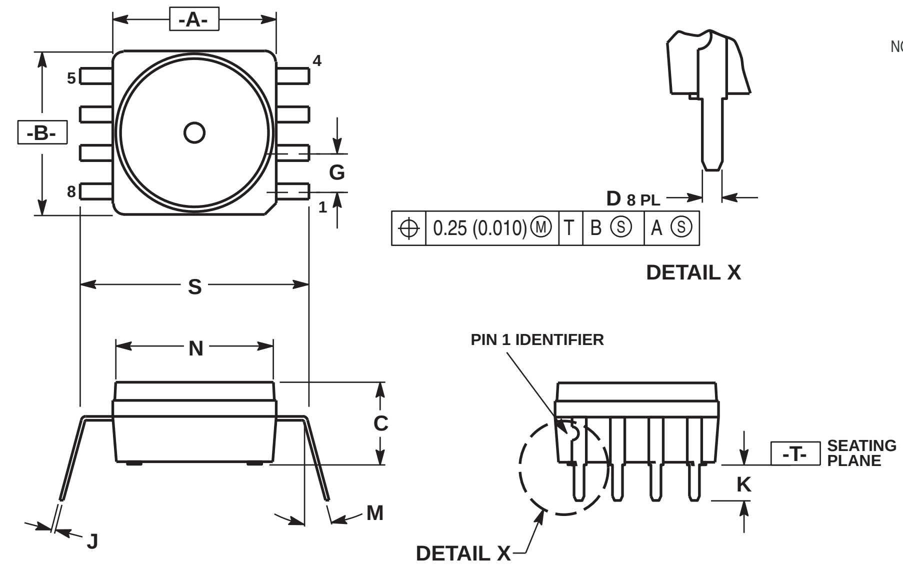


NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006).
5. ALL VERTICAL SURFACES 5° TYPICAL DRAFT.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.415	0.425	10.54	10.79
B	0.415	0.425	10.54	10.79
C	0.500	0.520	12.70	13.21
D	0.038	0.042	0.96	1.07
G	0.100 BSC		2.54 BSC	
H	0.002	0.010	0.05	0.25
J	0.009	0.011	0.23	0.28
K	0.061	0.071	1.55	1.80
M	0 °	7 °	0 °	7 °
N	0.444	0.448	11.28	11.38
S	0.709	0.725	18.01	18.41
V	0.245	0.255	6.22	6.48
W	0.115	0.125	2.92	3.17

CASE 482A-0
ISSUE A
SMALL OUTLINE PACKAGE

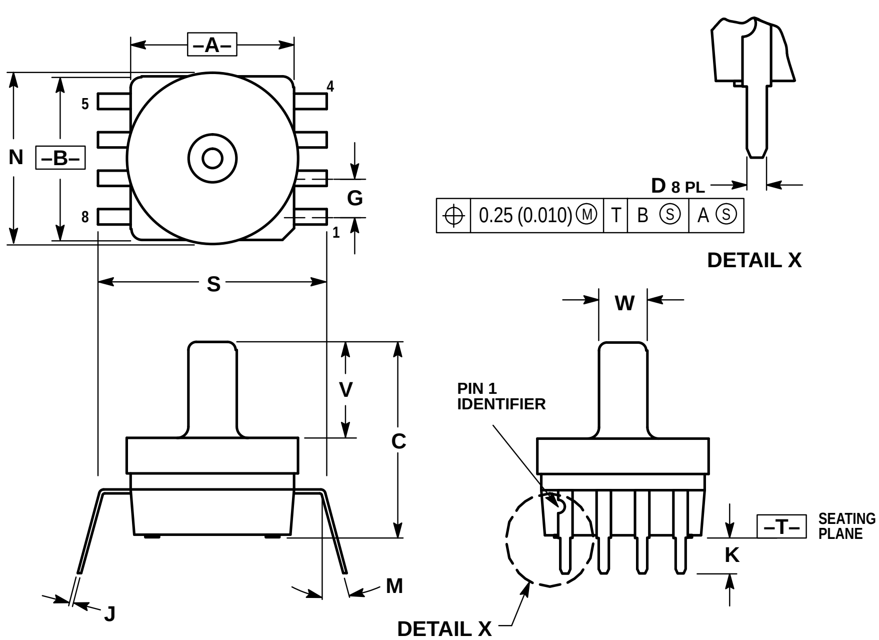
PACKAGE DIMENSIONS



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006).
5. ALL VERTICAL SURFACES 5˚ TYPICAL DRAFT.
6. DIMENSION S TO CENTER OF LEAD WHEN FORMED PARALLEL.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.415	0.425	10.54	10.79
B	0.415	0.425	10.54	10.79
C	0.210	0.220	5.33	5.59
D	0.026	0.034	0.66	0.864
G	0.100 BSC		2.54 BSC	
J	0.009	0.011	0.23	0.28
K	0.100	0.120	2.54	3.05
M	0˚	15˚	0˚	15˚
N	0.405	0.415	10.29	10.54
S	0.540	0.560	13.72	14.22

CASE 482B-03
ISSUE B
SMALL OUTLINE PACKAGE

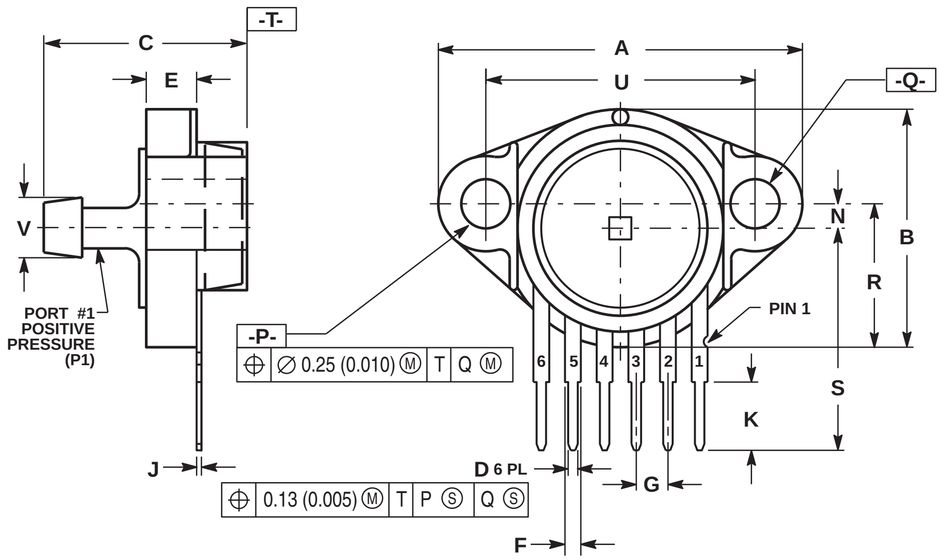


NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006).
5. ALL VERTICAL SURFACES 5° TYPICAL DRAFT.
6. DIMENSION S TO CENTER OF LEAD WHEN FORMED PARALLEL.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.415	0.425	10.54	10.79
B	0.415	0.425	10.54	10.79
C	0.500	0.520	12.70	13.21
D	0.026	0.034	0.66	0.864
G	0.100 BSC		2.54 BSC	
J	0.009	0.011	0.23	0.28
K	0.100	0.120	2.54	3.05
M	0 °	15 °	0 °	15 °
N	0.444	0.448	11.28	11.38
S	0.540	0.560	13.72	14.22
V	0.245	0.255	6.22	6.48
W	0.115	0.125	2.92	3.17

CASE 482C-03
ISSUE B
SMALL OUTLINE PACKAGE

PACKAGE DIMENSIONS



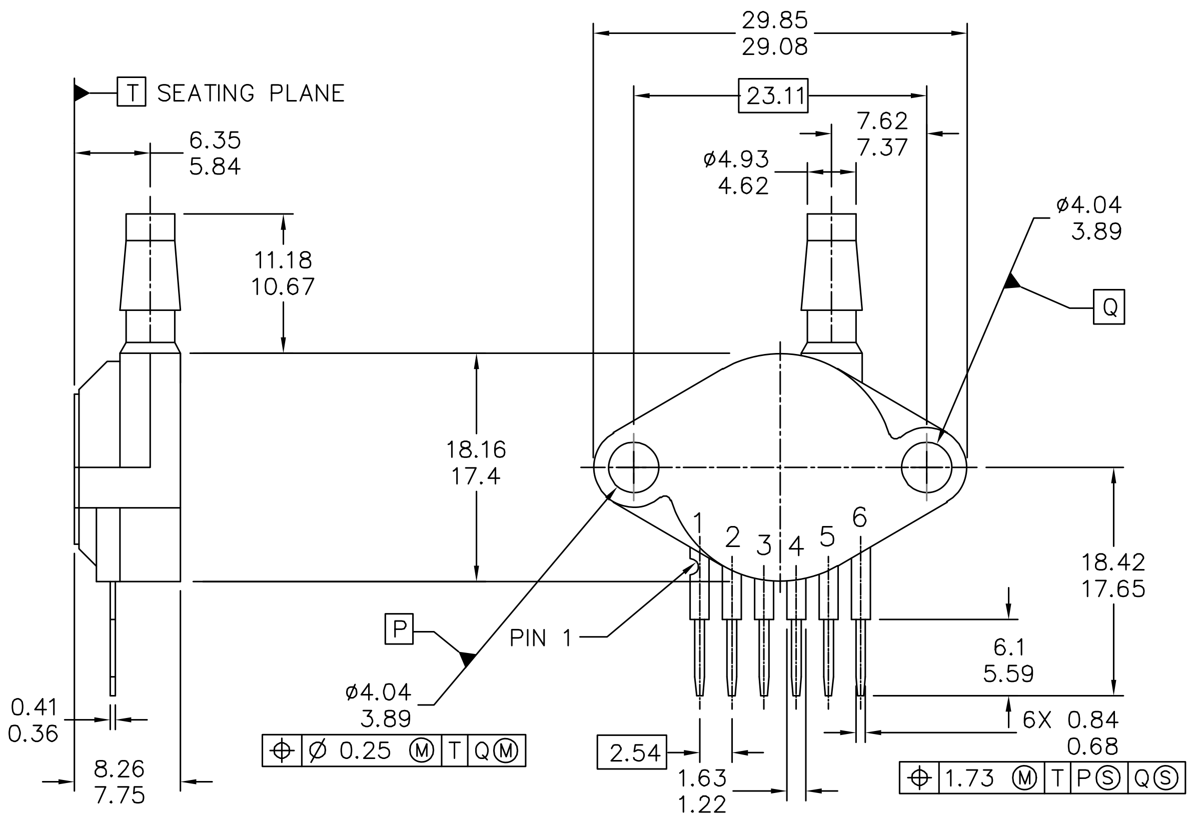
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX
A	1.080	1.120	27.43	28.45
B	0.740	0.760	18.80	19.30
C	0.630	0.650	16.00	16.51
D	0.027	0.033	0.68	0.84
E	0.160	0.180	4.06	4.57
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.41
K	0.220	0.240	5.59	6.10
N	0.070	0.080	1.78	2.03
P	0.150	0.160	3.81	4.06
Q	0.150	0.160	3.81	4.06
R	0.440	0.460	11.18	11.68
S	0.695	0.725	17.65	18.42
U	0.840	0.860	21.34	21.84
V	0.182	0.194	4.62	4.93

STYLE 1:
PIN 1. V_{OUT}
2. GROUND
3. V_{CC}
4. V1
5. V2
6. V_{EX}

CASE 867F-03
ISSUE D
UNIBODY PACKAGE

PACKAGE DIMENSIONS



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TITLE: SENSOR, 6 LEAD UNIBODY CELL, AP & GP 01ASB09087B		DOCUMENT NO: 98ASB42796B	REV: G
		CASE NUMBER: 867B-04	28 JUL 2005
		STANDARD: NON-JEDEC	

PAGE 1 OF 2

CASE 867B-04
ISSUE G
UNIBODY PACKAGE

PACKAGE DIMENSIONS

NOTES:

1. DIMENSIONS ARE IN MILLIMETERS.
2. DIMENSIONS AND TOLERANCES PER ASME Y14.5M–1994.
3. 867B–01 THRU –3 OBSOLETE, NEW STANDARD 867B–04.

STYLE 1:

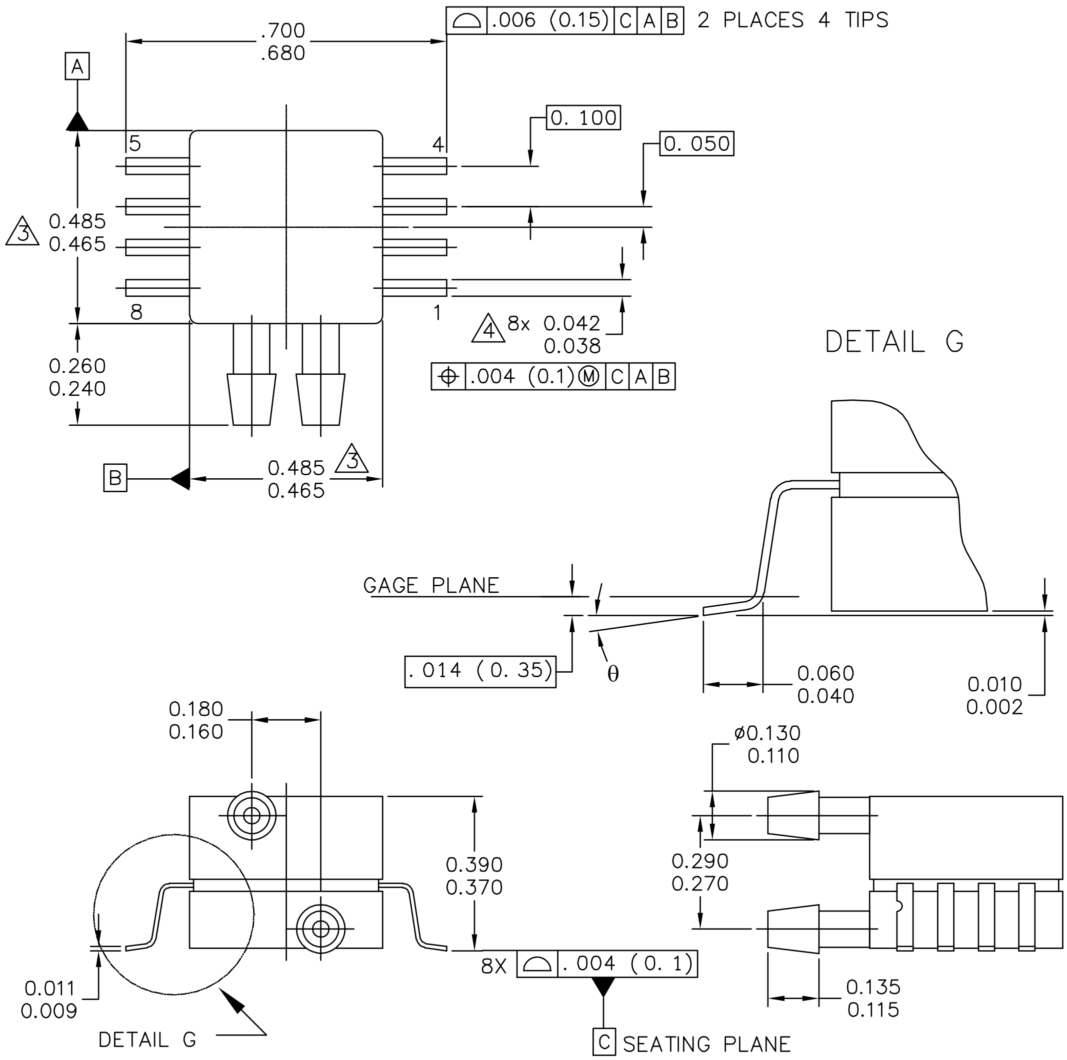
PIN 1: V OUT
2: GROUND
3: VCC
4: V1
5: V2
6: V EX

MECHANICAL OUTLINE		PRINT VERSION NOT TO SCALE	
TITLE: SENSOR, 6 LEAD UNIBODY CELL, AP & GP 01ASB09087B	DOCUMENT NO: 98ASB42796B		REV: G
	CASE NUMBER: 867B–04		28 JUL 2005
	STANDARD: NON–JEDEC		

PAGE 2 OF 2

CASE 867B-04
ISSUE G
UNIBODY PACKAGE

PACKAGE DIMENSIONS



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	CASE NUMBER: 1351-01	27 JUL 2005
	STANDARD: NON-JEDEC	

PAGE 1 OF 2

CASE 1351-01
ISSUE A
SMALL OUTLINE PACKAGE

PACKAGE DIMENSIONS

NOTES:

1. CONTROLLING DIMENSION: INCH
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M–1994.
3. DIMENSIONS DO NOT INCLUDE MOLD FLASH OR PPROTRUSIONS. MOLD FLASH AND PROTRUSIONS SHALL NOT EXCEED .006 PER SIDE.
4. DIMENSION DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE .008 MAXIMUM.

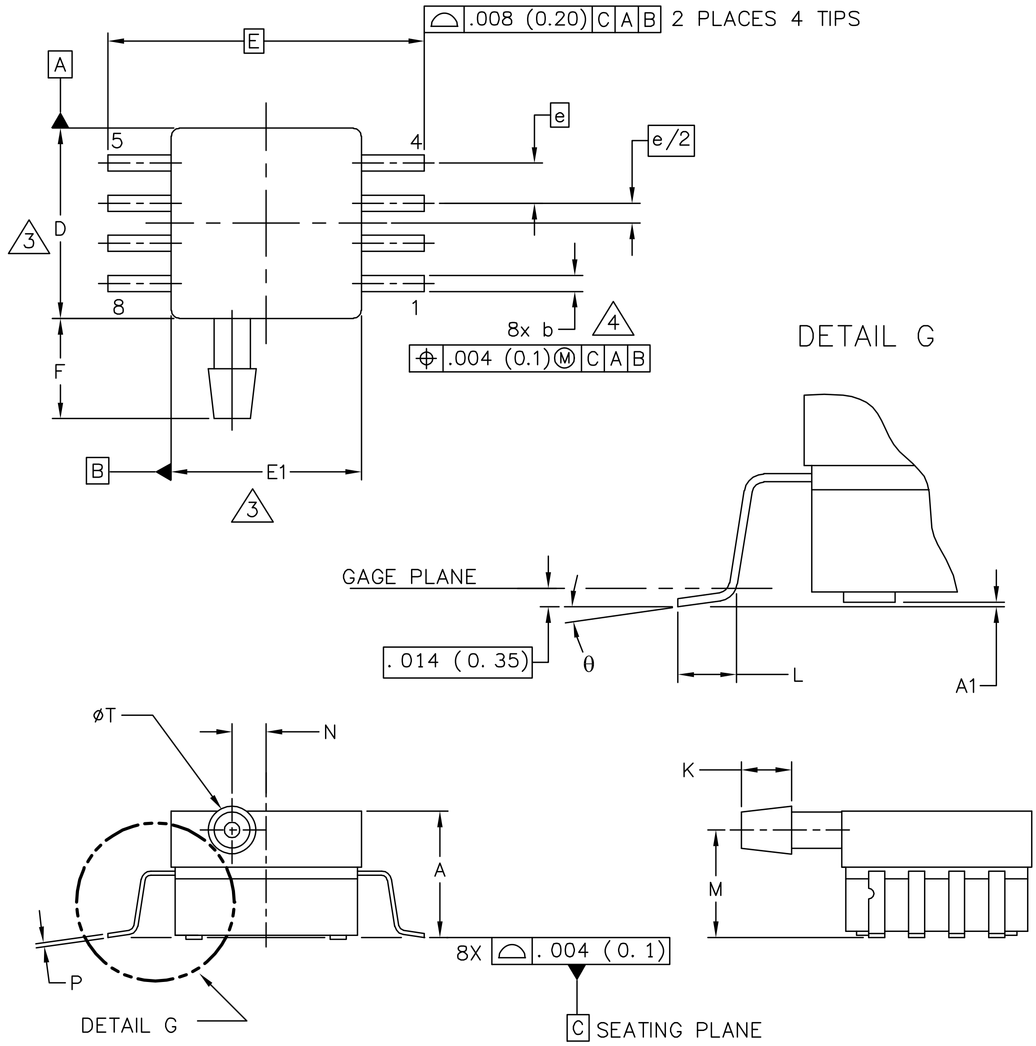
STYLE 1:		STYLE 2:	
PIN 1:	GND	PIN 1:	N/C
PIN 2:	+Vout	PIN 2:	Vs
PIN 3:	Vs	PIN 3:	GND
PIN 4:	–Vout	PIN 4:	Vout
PIN 5:	N/C	PIN 5:	N/C
PIN 6:	N/C	PIN 6:	N/C
PIN 7:	N/C	PIN 7:	N/C
PIN 8:	N/C	PIN 8:	N/C

	MECHANICAL OUTLINE	PRINT VERSION NOT TO SCALE
TITLE: 8 LD SNSR, DUAL PORT	DOCUMENT NO: 98ASA99255D	REV: A
	CASE NUMBER: 1351–01	27 JUL 2005
	STANDARD: NON–JEDEC	

PAGE 2 OF 2

CASE 1351-01
ISSUE A
SMALL OUTLINE PACKAGE

PACKAGE DIMENSIONS



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TITLE: 8 LD SOP, SIDE PORT	DOCUMENT NO: 98ASA99303D	REV: B
	CASE NUMBER: 1369-01	24 MAY 2005
	STANDARD: NON-JEDEC	

PAGE 1 OF 2

CASE 1369-01
ISSUE B
SMALL OUTLINE PACKAGE

PACKAGE DIMENSIONS

NOTES:
1. CONTROLLING DIMENSION: INCH
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M–1994.
3. DIMENSIONS DO NOT INCLUDE MOLD FLASH OR PPROTRUSIONS. MOLD FLASH AND PROTRUSIONS SHALL NOT EXCEED .006 (0.152) PER SIDE.
4. DIMENSION DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE .008 (0.203) MAXIMUM.

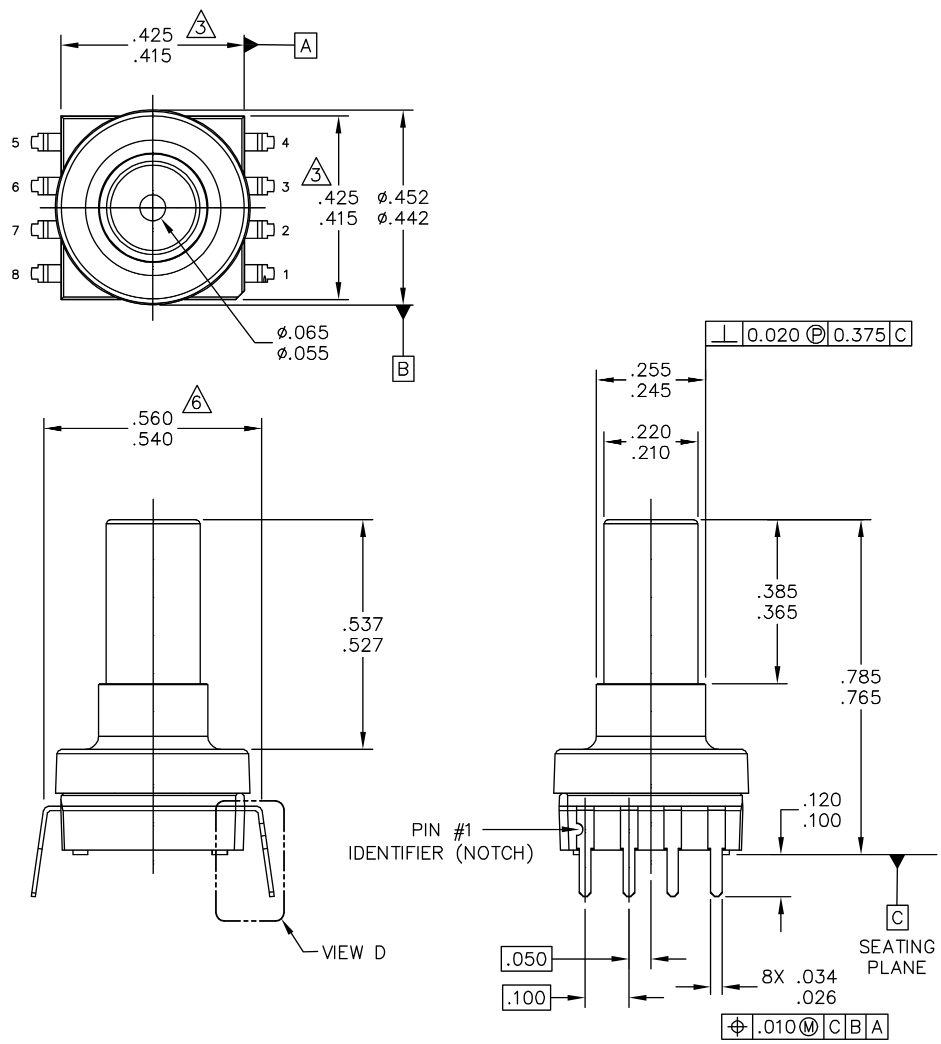
DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX	DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX
A	.300	.330	7.11	7.62	θ	0°	7°	0°	7°
A1	.002	.010	0.05	0.25	–	---	---	---	---
b	.038	.042	0.96	1.07	–	---	---	---	---
D	.465	.485	11.81	12.32	–	---	---	---	---
E	.717 BSC		18.21 BSC		–	---	---	---	---
E1	.465	.485	11.81	12.32	–	---	---	---	---
e	.100 BSC		2.54 BSC		–	---	---	---	---
F	.245	.255	6.22	6.47	–	---	---	---	---
K	.120	.130	3.05	3.30	–	---	---	---	---
L	.061	.071	1.55	1.80	–	---	---	---	---
M	.270	.290	6.86	7.36	–	---	---	---	---
N	.080	.090	2.03	2.28	–	---	---	---	---
P	.009	.011	0.23	0.28	–	---	---	---	---
T	.115	.125	2.92	3.17	–	---	---	---	---

	MECHANICAL OUTLINE	PRINT VERSION NOT TO SCALE
TITLE: 8 LD SOP, SIDE PORT	DOCUMENT NO: 98ASA99303D	REV: B
	CASE NUMBER: 1369–01	24 MAY 2005
	STANDARD: NON–JEDEC	

PAGE 2 OF 2

CASE 1369-01
ISSUE B
SMALL OUTLINE PACKAGE

PACKAGE DIMENSIONS



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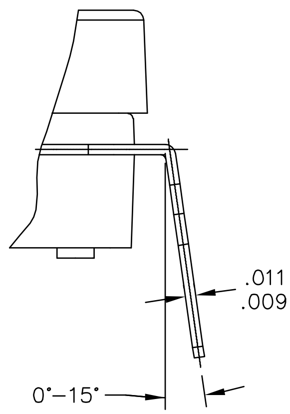
TITLE: SO, 8 I/O, .420 X .420 PKG, .100 IN PITCH	DOCUMENT NO: 98ASA10611D	REV: D
	CASE NUMBER: 1560–03	25 FEB 2009
	STANDARD: NON–JEDEC	

PAGE 1 OF 3

1560-03
ISSUE C
SMALL OUTLINE PACKAGE

PACKAGE DIMENSIONS



VIEW D

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TITLE: SO, 8 I/O, .420 X .420 PKG, .100 IN PITCH	DOCUMENT NO: 98ASA10611D	REV: D
	CASE NUMBER: 1560–03	25 FEB 2009
	STANDARD: NON–JEDEC	

PAGE 2 OF 3

CASE 1560-03
ISSUE D
SMALL OUTLINE PACKAGE

PACKAGE DIMENSIONS

NOTES:

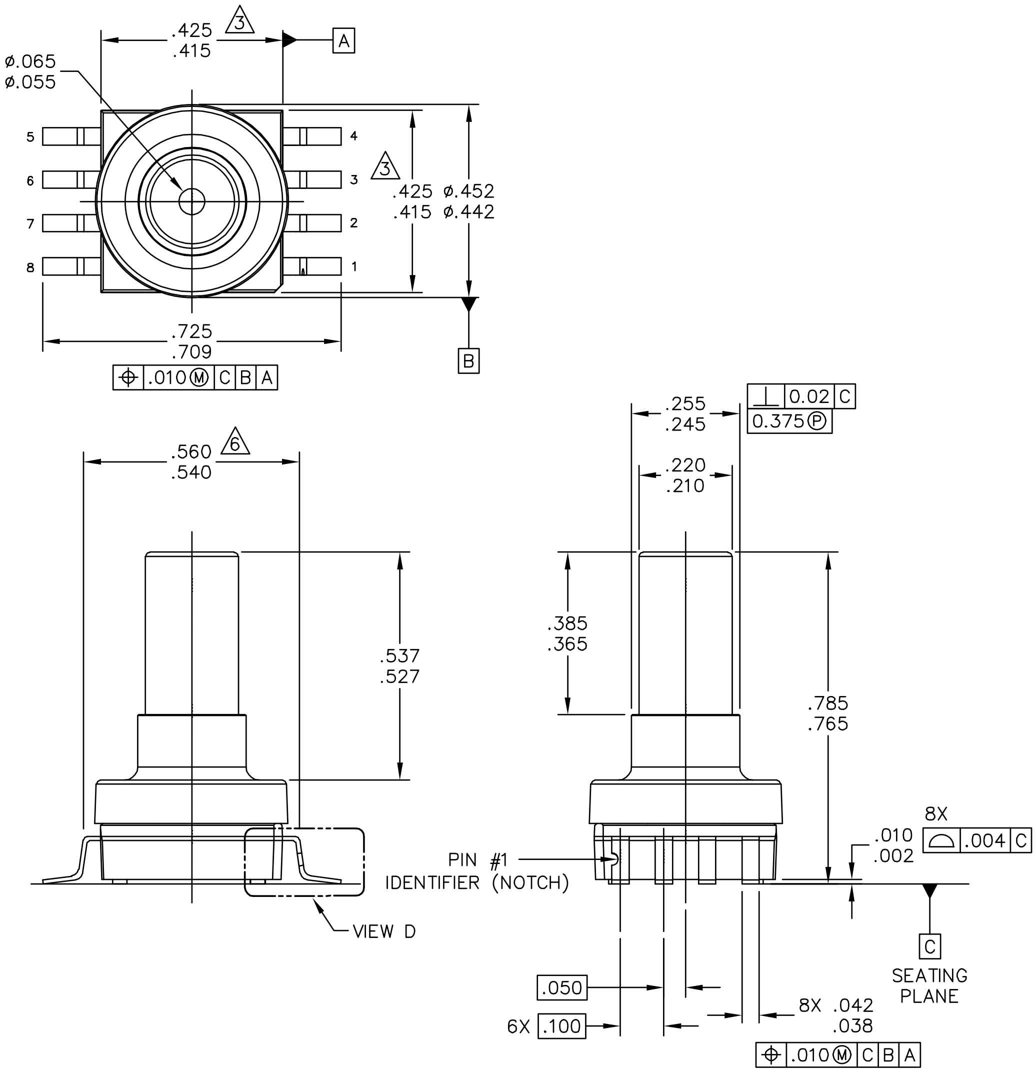
1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M – 1994.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSIONS DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION IS .006.
5. ALL VERTICAL SURFACES 5° TYPICAL DRAFT.
6. DIMENSION TO CENTER OF LEAD WHEN FORMED PARALLEL.

	MECHANICAL OUTLINE	PRINT VERSION NOT TO SCALE	
TITLE: SO, 8 I/O, .420 X .420 PKG, .100 IN PITCH	DOCUMENT NO: 98ASA10611D		REV: D
	CASE NUMBER: 1560–03		25 FEB 2009
	STANDARD: NON–JEDEC		

PAGE 3 OF 3

CASE 1560-03
ISSUE D
SMALL OUTLINE PACKAGE

PACKAGE DIMENSIONS



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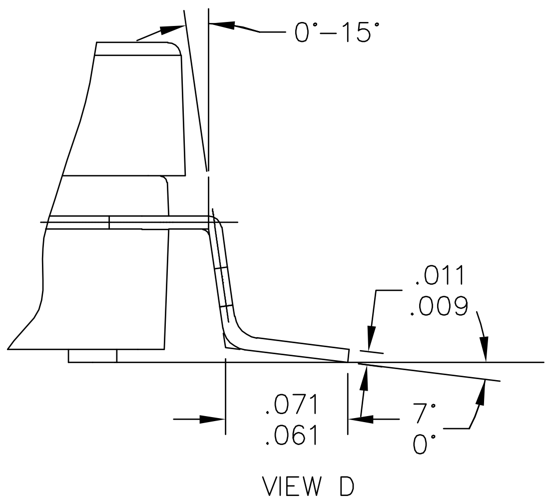
TITLE: SO, 8 I/O, .420 X .420 PKG, .100 IN PITCH	DOCUMENT NO: 98ASA10686D	REV: B
	CASE NUMBER: 1735–02	19 FEB 2009
	STANDARD: NON–JEDEC	

PAGE 1 OF 3

CASE 1735-02
ISSUE B
SMALL OUTLINE PACKAGE

PACKAGE DIMENSIONS



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TITLE: SO, 8 I/O, .420 X .420 PKG, .100 IN PITCH	DOCUMENT NO: 98ASA10686D		REV: B
	CASE NUMBER: 1735–02		19 FEB 2009
	STANDARD: NON–JEDEC		

PAGE 2 OF 3

CASE 1735-02
ISSUE B
SMALL OUTLINE PACKAGE

PACKAGE DIMENSIONS

NOTES:

1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M — 1994.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSIONS DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION IS .006.
5. ALL VERTICAL SURFACES 5° TYPICAL DRAFT.
6. DIMENSION TO CENTER OF LEAD WHEN FORMED PARALLEL.

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TITLE: SO, 8 I/O, .420 X .420 PKG, .100 IN PITCH	DOCUMENT NO: 98ASA10686D		REV: B
	CASE NUMBER: 1735–02		19 FEB 2009
	STANDARD: NON–JEDEC		

PAGE 3 OF 3

CASE 1735-02
ISSUE B
SMALL OUTLINE PACKAGE

Table 3. Revision History

Revision number	Revision date	Description of changes
13	10/2012	• Deleted references to device number MPVZ5010G6T1, MPVZ5010G6U/T1 and MPVZ5010G6U/6T1 throughout the document

How to Reach Us:

Home Page:
freescale.com

Web Support:
freescale.com/support

5V 1 Channel H/L Level Trigger Optocoupler Relay Module For Arduino Description:

The module uses genuine quality relay, normally open interfaces
Using SMD optocoupler isolation, driving ability, stable performance
The module can be high or low by a jumper setting trigger
Fault-tolerant design, even if the control line is broken, the relay will not operate
The power indicator (green), the relay status indicator (red)
The interface design of human nature, all interfaces are available through a direct connection terminal leads, very convenient

Specification:

Maximum load: AC 250V/10A, DC 30V/10A
Trigger current: 5mA
Working voltage: 5V
Module size: 50 x 26 x 18.5mm (L x W x H)
Four mounting bolts holes, diameter 3.1mm

Module interface:

DC+: positive power supply (VCC)
DC-: negative power supply (GND)
IN: can be high or low level control relay

Relay outputs:

NO: normally open relay interface
COM: Common Interface Relays
NC: normally closed relay interface

High and low level trigger options:

It is low level trigger when jumper connect to LOW pin
It is high level trigger when jumper connect to HIGH pin

Package included:

1 x 1 Channel H/L level trigger optocoupler relay module

MAX481/MAX483/MAX485/ MAX487–MAX491/MAX1487

Low-Power, Slew-Rate-Limited RS-485/RS-422 Transceivers

General Description

The MAX481, MAX483, MAX485, MAX487–MAX491, and MAX1487 are low-power transceivers for RS-485 and RS-422 communication. Each part contains one driver and one receiver. The MAX483, MAX487, MAX488, and MAX489 feature reduced slew-rate drivers that minimize EMI and reduce reflections caused by improperly terminated cables, thus allowing error-free data transmission up to 250kbps. The driver slew rates of the MAX481, MAX485, MAX490, MAX491, and MAX1487 are not limited, allowing them to transmit up to 2.5Mbps.

These transceivers draw between 120µA and 500µA of supply current when unloaded or fully loaded with disabled drivers. Additionally, the MAX481, MAX483, and MAX487 have a low-current shutdown mode in which they consume only 0.1µA. All parts operate from a single 5V supply.

Drivers are short-circuit current limited and are protected against excessive power dissipation by thermal shutdown circuitry that places the driver outputs into a high-impedance state. The receiver input has a fail-safe feature that guarantees a logic-high output if the input is open circuit.

The MAX487 and MAX1487 feature quarter-unit-load receiver input impedance, allowing up to 128 MAX487/MAX1487 transceivers on the bus. Full-duplex communications are obtained using the MAX488–MAX491, while the MAX481, MAX483, MAX485, MAX487, and MAX1487 are designed for half-duplex applications.

Applications

Low-Power RS-485 Transceivers

Low-Power RS-422 Transceivers

Level Translators

Transceivers for EMI-Sensitive Applications

Industrial-Control Local Area Networks

Next Generation Device Features

- **For Fault-Tolerant Applications**
  MAX3430: ±80V Fault-Protected, Fail-Safe, 1/4 Unit Load, +3.3V, RS-485 Transceiver
  MAX3440E–MAX3444E: ±15kV ESD-Protected, ±60V Fault-Protected, 10Mbps, Fail-Safe, RS-485/J1708 Transceivers
- **For Space-Constrained Applications**
  MAX3460–MAX3464: +5V, Fail-Safe, 20Mbps, Profibus RS-485/RS-422 Transceivers
  MAX3362: +3.3V, High-Speed, RS-485/RS-422 Transceiver in a SOT23 Package
  MAX3280E–MAX3284E: ±15kV ESD-Protected, 52Mbps, +3V to +5.5V, SOT23, RS-485/RS-422, True Fail-Safe Receivers
  MAX3293/MAX3294/MAX3295: 20Mbps, +3.3V, SOT23, RS-485/RS-422 Transmitters
- **For Multiple Transceiver Applications**
  MAX3030E–MAX3033E: ±15kV ESD-Protected, +3.3V, Quad RS-422 Transmitters
- **For Fail-Safe Applications**
  MAX3080–MAX3089: Fail-Safe, High-Speed (10Mbps), Slew-Rate-Limited RS-485/RS-422 Transceivers
- **For Low-Voltage Applications**
  MAX3483E/MAX3485E/MAX3486E/MAX3488E/MAX3490E/MAX3491E: +3.3V Powered, ±15kV ESD-Protected, 12Mbps, Slew-Rate-Limited, True RS-485/RS-422 Transceivers

Ordering Information appears at end of data sheet.

Selection Table

PART NUMBER	HALF/FULL DUPLEX	DATA RATE (Mbps)	SLEW-RATE LIMITED	LOW-POWER SHUTDOWN	RECEIVER/ DRIVER ENABLE	QUIESCENT CURRENT (µA)	NUMBER OF RECEIVERS ON BUS	PIN COUNT
MAX481	Half	2.5	No	Yes	Yes	300	32	8
MAX483	Half	0.25	Yes	Yes	Yes	120	32	8
MAX485	Half	2.5	No	No	Yes	300	32	8
MAX487	Half	0.25	Yes	Yes	Yes	120	128	8
MAX488	Full	0.25	Yes	No	No	120	32	8
MAX489	Full	0.25	Yes	No	Yes	120	32	14
MAX490	Full	2.5	No	No	No	300	32	8
MAX491	Full	2.5	No	No	Yes	300	32	14
MAX1487	Half	2.5	No	No	Yes	230	128	8

ABSOLUTE MAXIMUM RATINGS

Supply Voltage (V_{CC})..12V
Control Input Voltage ($\overline{RE}$, DE)...................-0.5V to (V_{CC} + 0.5V)
Driver Input Voltage (DI).............................-0.5V to (V_{CC} + 0.5V)
Driver Output Voltage (A, B)..................................-8V to +12.5V
Receiver Input Voltage (A, B)................................-8V to +12.5V
Receiver Output Voltage (RO)....................-0.5V to (V_{CC} + 0.5V)
Continuous Power Dissipation (T_A = +70°C)
8-Pin Plastic DIP (derate 9.09mW/°C above +70°C) 727mW
14-Pin Plastic DIP (derate 10.00mW/°C above +70°C) ..800mW
8-Pin SO (derate 5.88mW/°C above +70°C)................471mW
14-Pin SO (derate 8.33mW/°C above +70°C)...............667mW
8-Pin µMAX (derate 4.1mW/°C above +70°C)..............830mW
8-Pin CERDIP (derate 8.00mW/°C above +70°C).........640mW
14-Pin CERDIP (derate 9.09mW/°C above +70°C).......727mW
Operating Temperature Ranges
MAX4_ _C_ _/MAX1487C_ A ....0°C to +70°C
MAX4_ _E_ _/MAX1487E_ A............................-40°C to +85°C
MAX4_ _M_/MAX1487MJA ....-55°C to +125°C
Storage Temperature Range ....-65°C to +160°C
Lead Temperature (soldering, 10sec) ....+300°C

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

DC ELECTRICAL CHARACTERISTICS

(V_{CC} = 5V ±5%, T_A = T_{MIN} to T_{MAX}, unless otherwise noted.) (Notes 1, 2)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Differential Driver Output (no load)	V_{OD1}					5	V
Differential Driver Output (with load)	V_{OD2}	R = 50Ω (RS-422)		2			V
		R = 27Ω (RS-485), Figure 4		1.5		5	
Change in Magnitude of Driver Differential Output Voltage for Complementary Output States	ΔV_{OD}	R = 27Ω or 50Ω, Figure 4				0.2	V
Driver Common-Mode Output Voltage	V_{OC}	R = 27Ω or 50Ω, Figure 4				3	V
Change in Magnitude of Driver Common-Mode Output Voltage for Complementary Output States	ΔV_{OD}	R = 27Ω or 50Ω, Figure 4				0.2	V
Input High Voltage	V_{IH}	DE, DI, $\overline{RE}$		2.0			V
Input Low Voltage	V_{IL}	DE, DI, $\overline{RE}$				0.8	V
Input Current	I_{IN1}	DE, DI, $\overline{RE}$				±2	µA
Input Current (A, B)	I_{IN2}	DE = 0V; V_{CC} = 0V or 5.25V, all devices except MAX487/MAX1487	V_{IN} = 12V			1.0	mA
			V_{IN} = -7V			-0.8	
		MAX487/MAX1487, DE = 0V, V_{CC} = 0V or 5.25V	V_{IN} = 12V			0.25	mA
			V_{IN} = -7V			-0.2	
Receiver Differential Threshold Voltage	V_{TH}	-7V ≤ V_{CM} ≤ 12V		-0.2		0.2	V
Receiver Input Hysteresis	ΔV_{TH}	V_{CM} = 0V			70		mV
Receiver Output High Voltage	V_{OH}	I_O = -4mA, V_{ID} = 200mV		3.5			V
Receiver Output Low Voltage	V_{OL}	I_O = 4mA, V_{ID} = -200mV				0.4	V
Three-State (high impedance) Output Current at Receiver	I_{OZR}	0.4V ≤ V_O ≤ 2.4V				±1	µA
Receiver Input Resistance	R_{IN}	-7V ≤ V_{CM} ≤ 12V, all devices except MAX487/MAX1487		12			kΩ
		-7V ≤ V_{CM} ≤ 12V, MAX487/MAX1487		48			kΩ

DC ELECTRICAL CHARACTERISTICS (continued)

(V_{CC} = 5V ±5%, T_A = T_{MIN} to T_{MAX}, unless otherwise noted.) (Notes 1, 2)

PARAMETER	SYMBOL	CONDITIONS			MIN	TYP	MAX	UNITS
No-Load Supply Current (Note 3)	I_{CC}	MAX488/MAX489, DE, DI, $\overline{RE}$ = 0V or V_{CC}				120	250	µA
		MAX490/MAX491, DE, DI, $\overline{RE}$ = 0V or V_{CC}				300	500	
		MAX481/MAX485, $\overline{RE}$ = 0V or V_{CC}	DE = V_{CC}			500	900	
			DE = 0V			300	500	
		MAX1487, $\overline{RE}$ = 0V or V_{CC}	DE = V_{CC}			300	500	
			DE = 0V			230	400	
		MAX483/MAX487, $\overline{RE}$ = 0V or V_{CC}	DE = 5V	MAX483		350	650	
				MAX487		250	400	
			DE = 0V			120	250	
Supply Current in Shutdown	I_{SHDN}	MAX481/483/487, DE = 0V, $\overline{RE}$ = V_{CC}				0.1	10	µA
Driver Short-Circuit Current, V_O = High	I_{OSD1}	-7V ≤ V_O ≤12V (Note 4)			35		250	mA
Driver Short-Circuit Current, V_O = Low	I_{OSD2}	-7V ≤ V_O ≤12V (Note 4)			35		250	mA
Receiver Short-Circuit Current	I_{OSR}	0V ≤ V_O ≤ V_{CC}			7		95	mA

SWITCHING CHARACTERISTICS—MAX481/MAX485, MAX490/MAX491, MAX1487

(V_{CC} = 5V ±5%, T_A = T_{MIN} to T_{MAX}, unless otherwise noted.) (Notes 1, 2)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Driver Input to Output	t_{PLH}	Figures 6 and 8, R_{DIFF} = 54Ω, C_{L1} = C_{L2} = 100pF		10	30	60	ns
	t_{PHL}			10	30	60	
Driver Output Skew to Output	t_{SKEW}	Figures 6 and 8, R_{DIFF} = 54Ω, C_{L1} = C_{L2} = 100pF			5	10	ns
Driver Rise or Fall Time	t_R, t_F	Figures 6 and 8, R_{DIFF} = 54Ω, C_{L1} = C_{L2} = 100pF	MAX481, MAX485, MAX1487	3	15	40	ns
			MAX490C/E, MAX491C/E	5	15	25	
			MAX490M, MAX491M	3	15	40	
Driver Enable to Output High	t_{ZH}	Figures 7 and 9, C_L = 100pF, S2 closed			40	70	ns
Driver Enable to Output Low	t_{ZL}	Figures 7 and 9, C_L = 100pF, S1 closed			40	70	ns
Driver Disable Time from Low	t_{LZ}	Figures 7 and 9, C_L = 15pF, S1 closed			40	70	ns
Driver Disable Time from High	t_{HZ}	Figures 7 and 9, C_L = 15pF, S2 closed			40	70	ns
Receiver Input to Output	t_{PLH}, t_{PHL}	Figures 6 and 10, R_{DIFF} = 54Ω, C_{L1} = C_{L2} = 100pF	MAX481, MAX485, MAX1487	20	90	200	ns
			MAX490C/E, MAX491C/E	20	90	150	
			MAX490M, MAX491M	20	90	200	
$\lvert t_{PLH} - t_{PHL} \rvert$ Differential Receiver Skew	t_{SKD}	Figures 6 and 10, R_{DIFF} = 54Ω, C_{L1} = C_{L2} = 100pF			13		ns
Receiver Enable to Output Low	t_{ZL}	Figures 5 and 11, C_{RL} = 15pF, S1 closed			20	50	ns
Receiver Enable to Output High	t_{ZH}	Figures 5 and 11, C_{RL} = 15pF, S2 closed			20	50	ns
Receiver Disable Time from Low	t_{LZ}	Figures 5 and 11, C_{RL} = 15pF, S1 closed			20	50	ns
Receiver Disable Time from High	t_{HZ}	Figures 5 and 11, C_{RL} = 15pF, S2 closed			20	50	ns
Maximum Data Rate	f_{MAX}			2.5			Mbps
Time to Shutdown	t_{SHDN}	MAX481 (Note 5)		50	200	600	ns

SWITCHING CHARACTERISTICS—MAX481/MAX485, MAX490/MAX491, MAX1487 (continued)

(V_{CC} = 5V ±5%, T_A = T_{MIN} to T_{MAX}, unless otherwise noted.) (Notes 1, 2)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Driver Enable from Shutdown to Output High (MAX481)	$t_{ZH(SHDN)}$	Figures 7 and 9, C_L = 100pF, S2 closed		40	100	ns
Driver Enable from Shutdown to Output Low (MAX481)	$t_{ZL(SHDN)}$	Figures 7 and 9, C_L = 100pF, S1 closed		40	100	ns
Receiver Enable from Shutdown to Output High (MAX481)	$t_{ZH(SHDN)}$	Figures 5 and 11, C_L = 15pF, S2 closed, A - B = 2V		300	1000	ns
Receiver Enable from Shutdown to Output Low (MAX481)	$t_{ZL(SHDN)}$	Figures 5 and 11, C_L = 15pF, S1 closed, B - A = 2V		300	1000	ns

SWITCHING CHARACTERISTICS—MAX483, MAX487/MAX488/MAX489

(V_{CC} = 5V ±5%, T_A = T_{MIN} to T_{MAX}, unless otherwise noted.) (Notes 1, 2)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Driver Input to Output	t_{PLH}	Figures 6 and 8, R_{DIFF} = 54Ω, C_{L1} = C_{L2} = 100pF	250	800	2000	ns
	t_{PHL}		250	800	2000	
Driver Output Skew to Output	t_{SKEW}	Figures 6 and 8, R_{DIFF} = 54Ω, C_{L1} = C_{L2} = 100pF		100	800	ns
Driver Rise or Fall Time	t_R, t_F	Figures 6 and 8, R_{DIFF} = 54Ω, C_{L1} = C_{L2} = 100pF	250		2000	ns
Driver Enable to Output High	t_{ZH}	Figures 7 and 9, C_L = 100pF, S2 closed	250		2000	ns
Driver Enable to Output Low	t_{ZL}	Figures 7 and 9, C_L = 100pF, S1 closed	250		2000	ns
Driver Disable Time from Low	t_{LZ}	Figures 7 and 9, C_L = 15pF, S1 closed	300		3000	ns
Driver Disable Time from High	t_{HZ}	Figures 7 and 9, C_L = 15pF, S2 closed	300		3000	ns
Receiver Input to Output	t_{PLH}	Figures 6 and 10, R_{DIFF} = 54Ω, C_{L1} = C_{L2} = 100pF	250		2000	ns
	t_{PHL}		250		2000	
$\lvert t_{PLH} - t_{PHL} \rvert$ Differential Receiver Skew	t_{SKD}	Figures 6 and 10, R_{DIFF} = 54Ω, C_{L1} = C_{L2} = 100pF		100		ns
Receiver Enable to Output Low	t_{ZL}	Figures 5 and 11, C_{RL} = 15pF, S1 closed		20	50	ns
Receiver Enable to Output High	t_{ZH}	Figures 5 and 11, C_{RL} = 15pF, S2 closed		20	50	ns
Receiver Disable Time from Low	t_{LZ}	Figures 5 and 11, C_{RL} = 15pF, S1 closed		20	50	ns
Receiver Disable Time from High	t_{HZ}	Figures 5 and 11, C_{RL} = 15pF, S2 closed		20	50	ns
Maximum Data Rate	f_{MAX}	t_{PLH}, t_{PHL} < 50% of data period	250			kbps
Time to Shutdown	t_{SHDN}	MAX483/MAX487 (Note 5)	50	200	600	ns
Driver Enable from Shutdown to Output High	$t_{ZH(SHDN)}$	MAX483/MAX487, Figures 7 and 9, C_L = 100pF, S2 closed			2000	ns
Driver Enable from Shutdown to Output Low	$t_{ZL(SHDN)}$	MAX483/MAX487, Figures 7 and 9, C_L = 100pF, S1 closed			2000	ns
Receiver Enable from Shutdown to Output High	$t_{ZH(SHDN)}$	MAX483/MAX487, Figures 5 and 11, C_L = 15pF, S2 closed			2500	ns
Receiver Enable from Shutdown to Output Low	$t_{ZL(SHDN)}$	MAX483/MAX487, Figures 5 and 11, C_L = 15pF, S1 closed			2500	ns

NOTES FOR ELECTRICAL/SWITCHING CHARACTERISTICS

Note 1: All currents into device pins are positive; all currents out of device pins are negative. All voltages are referenced to device ground unless otherwise specified.

Note 2: All typical specifications are given for V_{CC} = 5V and T_A = +25°C.

Note 3: Supply current specification is valid for loaded transmitters when DE = 0V.

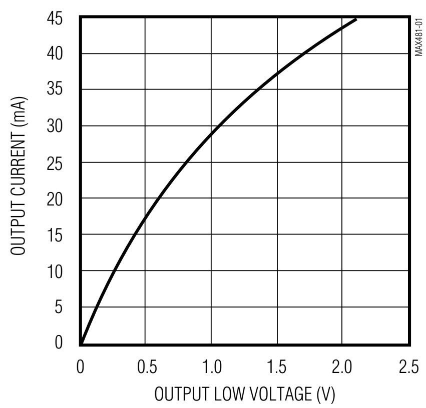
Note 4: Applies to peak current. See *Typical Operating Characteristics*.

Note 5: The MAX481/MAX483/MAX487 are put into shutdown by bringing $\overline{RE}$ high and DE low. If the inputs are in this state for less than 50ns, the parts are guaranteed not to enter shutdown. If the inputs are in this state for at least 600ns, the parts are guaranteed to have entered shutdown. See *Low-Power Shutdown Mode (MAX481/MAX483/MAX487)* section.

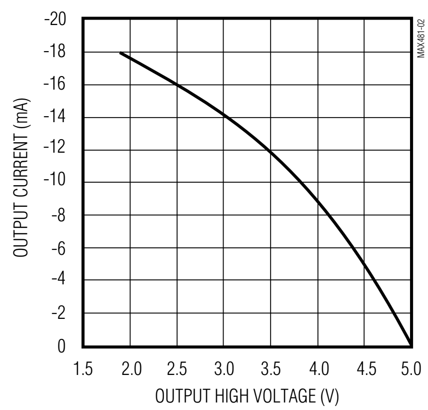
Typical Operating Characteristics

(V_{CC} = 5V, T_A = +25°C, unless otherwise noted.)

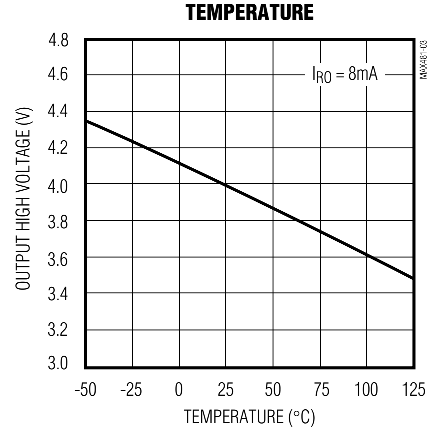
OUTPUT CURRENT vs. RECEIVER OUTPUT LOW VOLTAGE



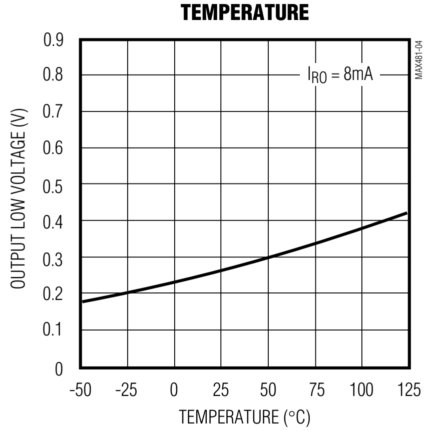
OUTPUT CURRENT vs. RECEIVER OUTPUT HIGH VOLTAGE



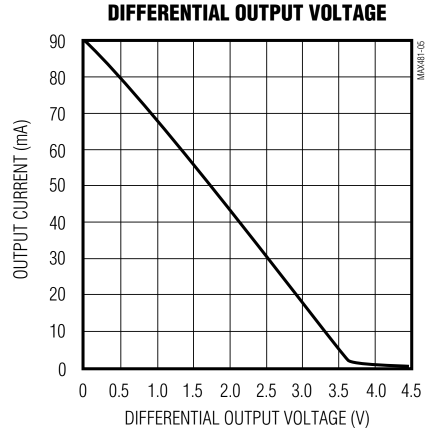
RECEIVER OUTPUT HIGH VOLTAGE vs. TEMPERATURE



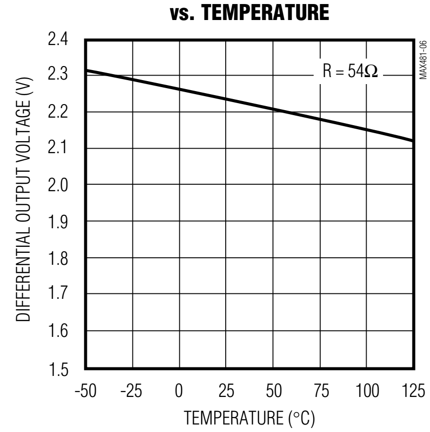
RECEIVER OUTPUT LOW VOLTAGE vs. TEMPERATURE



DRIVER OUTPUT CURRENT vs. DIFFERENTIAL OUTPUT VOLTAGE

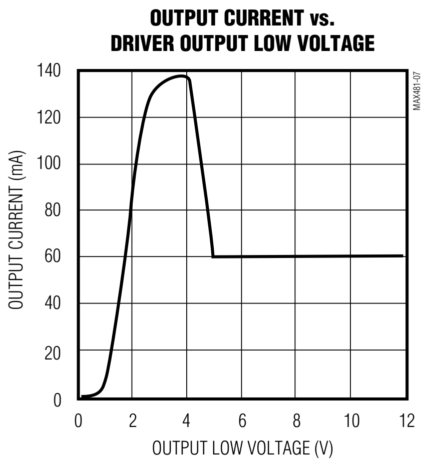


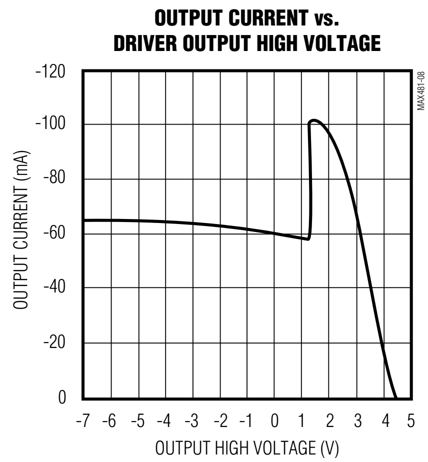
DRIVER DIFFERENTIAL OUTPUT VOLTAGE vs. TEMPERATURE

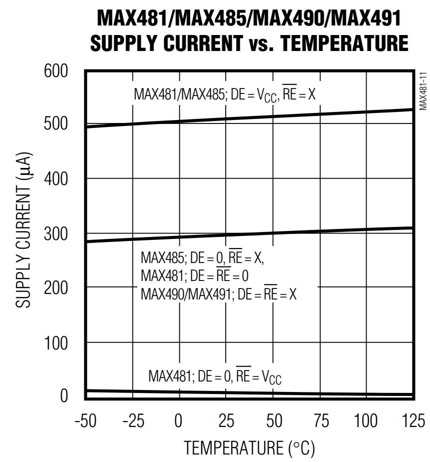


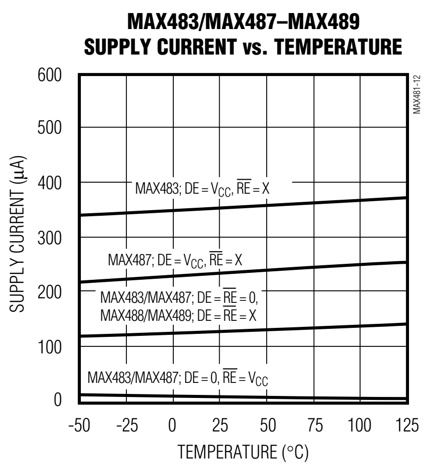
Typical Operating Characteristics (continued)

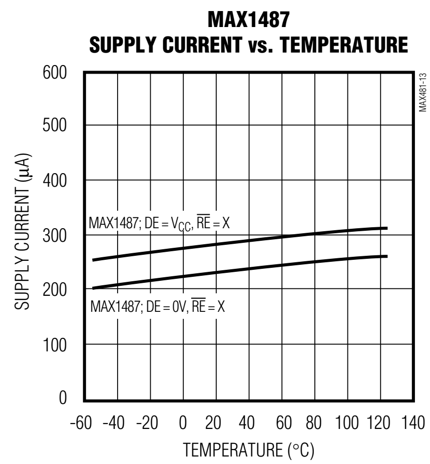
(V_{CC} = 5V, T_A = +25°C, unless otherwise noted.)











Pin Description

PIN					NAME	FUNCTION
MAX481/MAX483/ MAX485/MAX487/ MAX1487		MAX488/ MAX490		MAX489/ MAX491		
DIP/SO	μMAX	DIP/SO	μMAX	DIP/SO		
1	3	2	4	2	RO	Receiver Output: If A > B by 200mV, RO will be high; If A < B by 200mV, RO will be low.
2	4	—	—	3	$\overline{RE}$	Receiver Output Enable. RO is enabled when $\overline{RE}$ is low; RO is high impedance when $\overline{RE}$ is high.
3	5	—	—	4	DE	Driver Output Enable. The driver outputs, Y and Z, are enabled by bringing DE high. They are high impedance when DE is low. If the driver outputs are enabled, the parts function as line drivers. While they are high impedance, they function as line receivers if $\overline{RE}$ is low.
4	6	3	5	5	DI	Driver Input. A low on DI forces output Y low and output Z high. Similarly, a high on DI forces output Y high and output Z low.
5	7	4	6	6, 7	GND	Ground
—	—	5	7	9	Y	Noninverting Driver Output
—	—	6	8	10	Z	Inverting Driver Output
6	8	—	—	—	A	Noninverting Receiver Input and Noninverting Driver Output
—	—	8	2	12	A	Noninverting Receiver Input
7	1	—	—	—	B	Inverting Receiver Input and Inverting Driver Output
—	—	7	1	11	B	Inverting Receiver Input
8	2	1	3	14	V_{CC}	Positive Supply: $4.75V \le V_{CC} \le 5.25V$
—	—	—	—	1, 8, 13	N.C.	No Connect—not internally connected

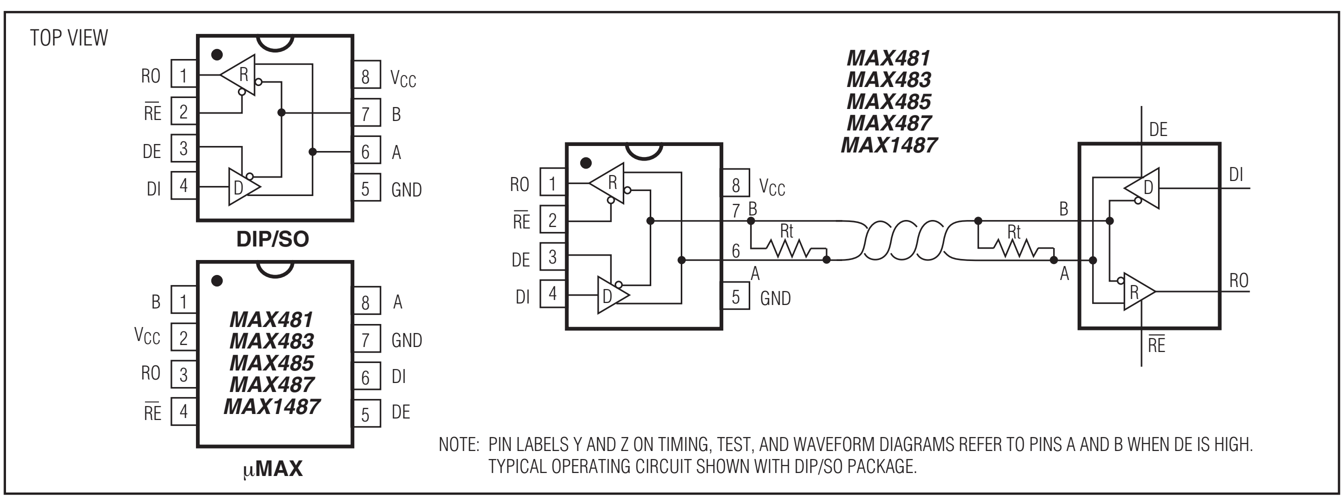


Figure 1. MAX481/MAX483/MAX485/MAX487/MAX1487 Pin Configuration and Typical Operating Circuit

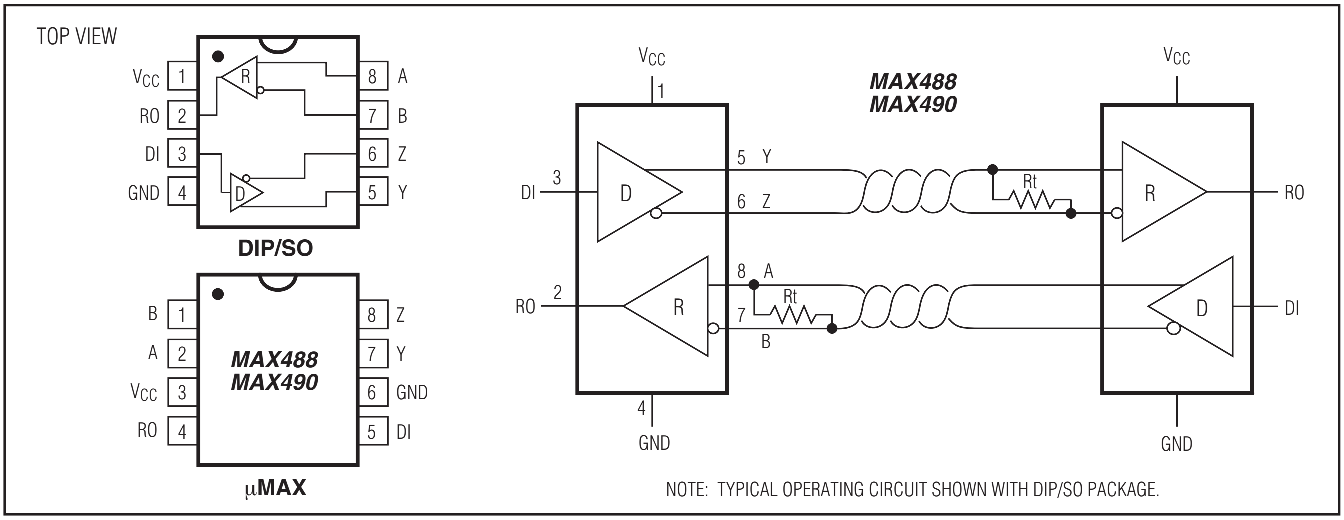


Figure 2. MAX488/MAX490 Pin Configuration and Typical Operating Circuit

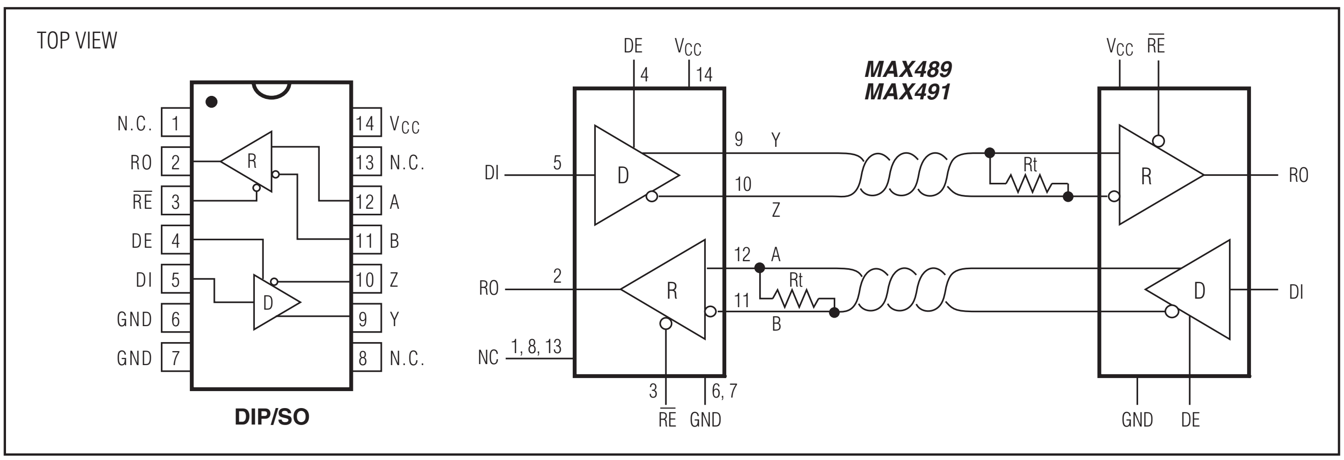


Figure 3. MAX489/MAX491 Pin Configuration and Typical Operating Circuit

Applications Information

The MAX481/MAX483/MAX485/MAX487–MAX491 and MAX1487 are low-power transceivers for RS-485 and RS-422 communications. The MAX481, MAX485, MAX490, MAX491, and MAX1487 can transmit and receive at data rates up to 2.5Mbps, while the MAX483, MAX487, MAX488, and MAX489 are specified for data rates up to 250kbps. The MAX488–MAX491 are full-duplex transceivers while the MAX481, MAX483, MAX485, MAX487, and MAX1487 are half-duplex. In addition, Driver Enable (DE) and Receiver Enable ($\overline{RE}$) pins are included on the MAX481, MAX483, MAX485, MAX487, MAX489, MAX491, and MAX1487. When disabled, the driver and receiver outputs are high impedance.

MAX487/MAX1487: 128 Transceivers on the Bus

The 48kΩ, 1/4-unit-load receiver input impedance of the MAX487 and MAX1487 allows up to 128 transceivers on a bus, compared to the 1-unit load (12kΩ input impedance) of standard RS-485 drivers (32 transceivers maximum). Any combination of MAX487/MAX1487 and other RS-485 transceivers with a total of 32 unit loads or less can be put on the bus. The MAX481/MAX483/MAX485 and MAX488–MAX491 have standard 12kΩ Receiver Input impedance.

Test Circuits

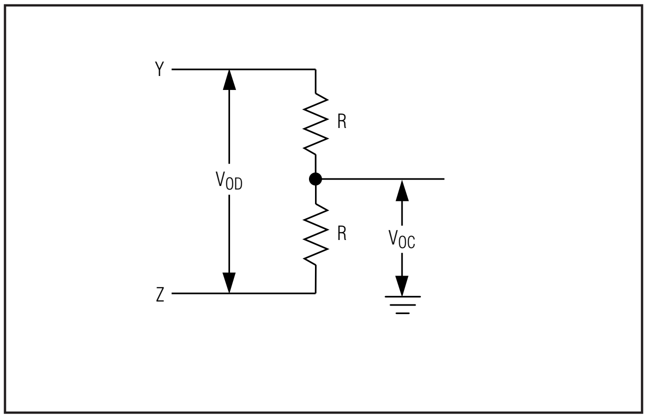


Figure 4. Driver DC Test Load

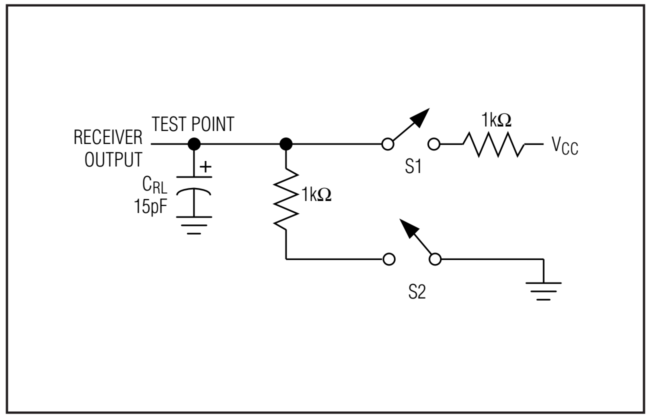


Figure 5. Receiver Timing Test Load

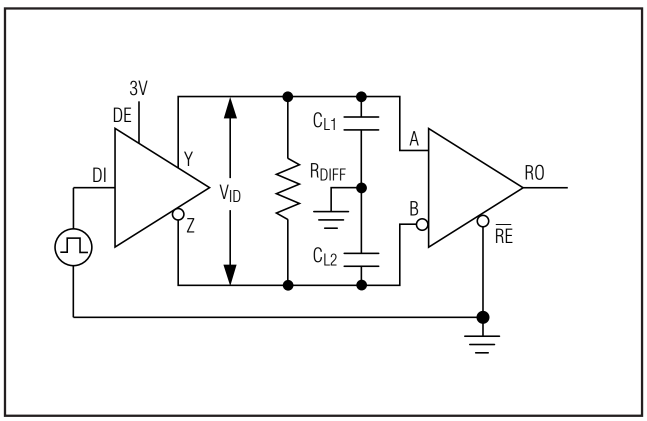


Figure 6. Driver/Receiver Timing Test Circuit

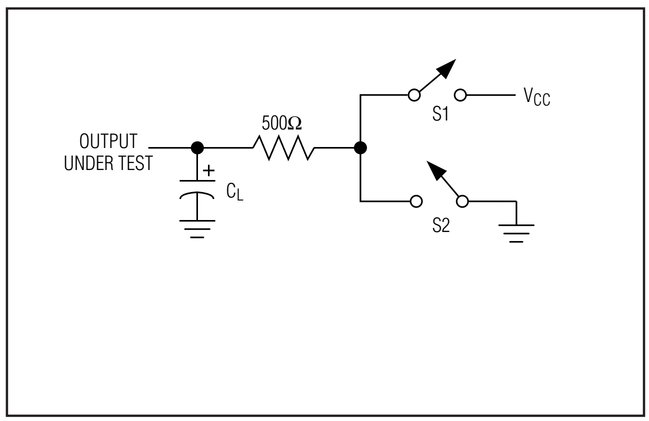


Figure 7. Driver Timing Test Load

MAX483/MAX487/MAX488/MAX489: Reduced EMI and Reflections

The MAX483 and MAX487–MAX489 are slew-rate limited, minimizing EMI and reducing reflections caused by improperly terminated cables. Figure 12 shows the driver output waveform and its Fourier analysis of a 150kHz signal transmitted by a MAX481, MAX485, MAX490, MAX491, or MAX1487. High-frequency harmonics with large amplitudes are evident. Figure 13 shows the same information displayed for a MAX483, MAX487, MAX488, or MAX489 transmitting under the same conditions. Figure 13's high-frequency harmonics have much lower amplitudes, and the potential for EMI is significantly reduced.

Low-Power, Slew-Rate-Limited RS-485/RS-422 Transceivers

Switching Waveforms

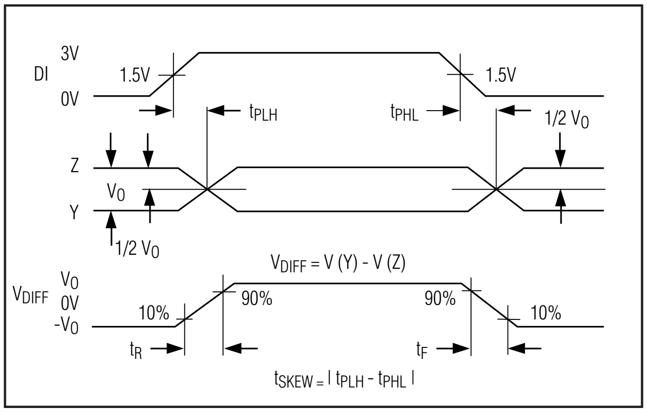


Figure 8. Driver Propagation Delays

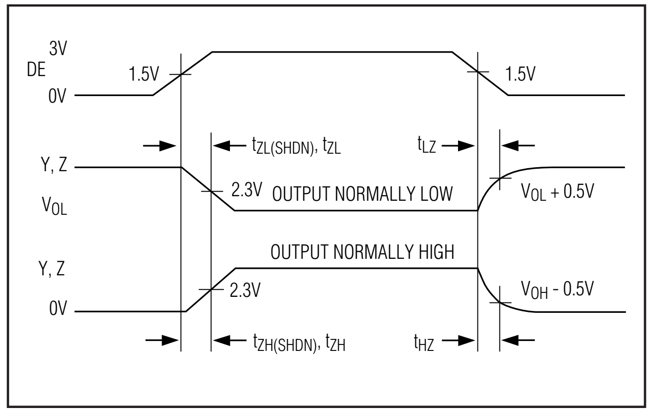


Figure 9. Driver Enable and Disable Times (except MAX488 and MAX490)

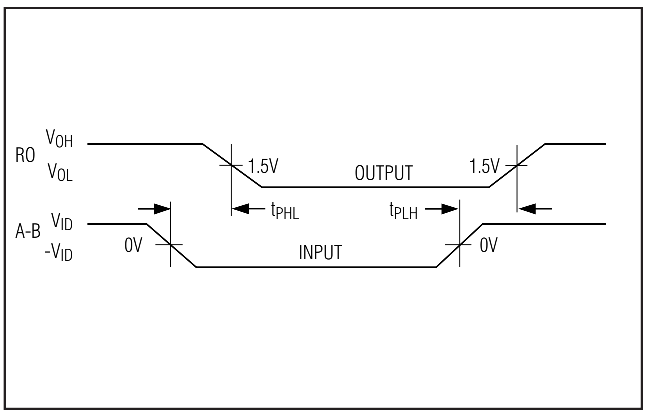


Figure 10. Receiver Propagation Delays

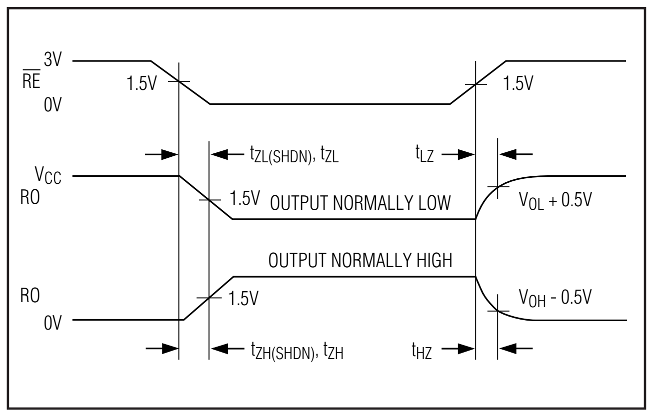


Figure 11. Receiver Enable and Disable Times (except MAX488 and MAX490)

Function Tables (MAX481/MAX483/MAX485/MAX487/MAX1487)

Table 1. Transmitting

INPUTS			OUTPUTS	
$\overline{RE}$	DE	DI	Z	Y
X	1	1	0	1
X	1	0	1	0
0	0	X	High-Z	High-Z
1	0	X	High-Z*	High-Z*

X = Don't care
High-Z = High impedance
**Shutdown mode for MAX481/MAX483/MAX487*

Table 2. Receiving

INPUTS			OUTPUT
$\overline{RE}$	DE	A-B	RO
0	0	≥ +0.2V	1
0	0	≤ -0.2V	0
0	0	Inputs open	1
1	0	X	High-Z*

X = Don't care
High-Z = High impedance
**Shutdown mode for MAX481/MAX483/MAX487*

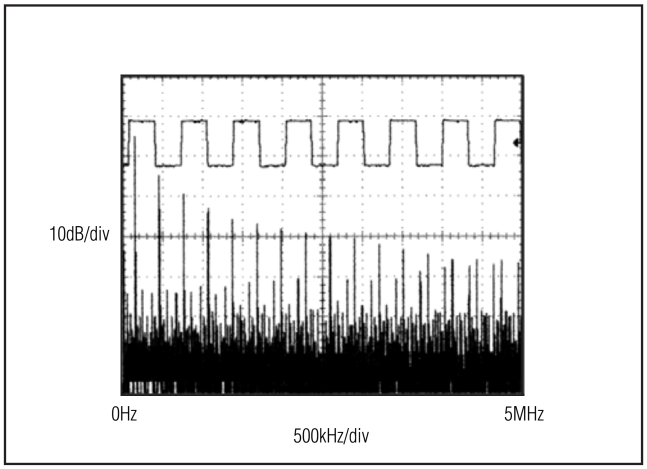


Figure 12. Driver Output Waveform and FFT Plot of MAX481/MAX485/MAX490/MAX491/MAX1487 Transmitting a 150kHz Signal

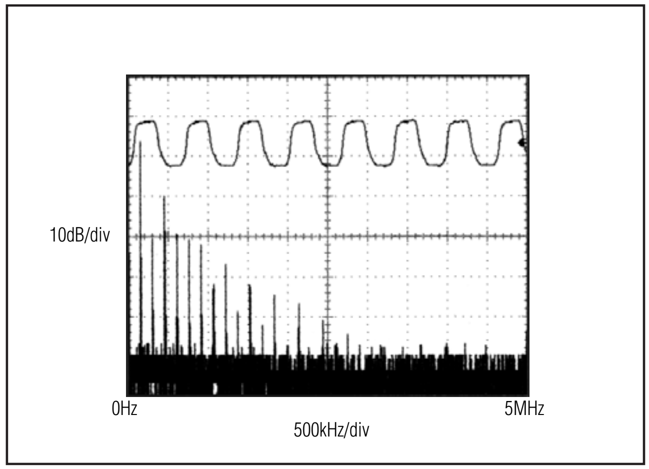


Figure 13. Driver Output Waveform and FFT Plot of MAX483/MAX487–MAX489 Transmitting a 150kHz Signal

Low-Power Shutdown Mode (MAX481/MAX483/MAX487)

A low-power shutdown mode is initiated by bringing both $\overline{RE}$ high and DE low. The devices will not shut down unless both the driver and receiver are disabled. In shutdown, the devices typically draw only 0.1µA of supply current.

$\overline{RE}$ and DE may be driven simultaneously; the parts are guaranteed not to enter shutdown if $\overline{RE}$ is high and DE is low for less than 50ns. If the inputs are in this state for at least 600ns, the parts are guaranteed to enter shutdown.

For the MAX481, MAX483, and MAX487, the t_{ZH} and t_{ZL} enable times assume the part was not in the low-power shutdown state (the MAX485/MAX488–MAX491 and MAX1487 can not be shut down). The $t_{ZH(SHDN)}$ and $t_{ZL(SHDN)}$ enable times assume the parts were shut down (see *Electrical Characteristics*).

It takes the drivers and receivers longer to become enabled from the low-power shutdown state ($t_{ZH(SHDN)}$, $t_{ZL(SHDN)}$) than from the operating mode (t_{ZH}, t_{ZL}). (The parts are in operating mode if the $\overline{RE}$, DE inputs equal a logical 0,1 or 1,1 or 0, 0.)

Driver Output Protection

Excessive output current and power dissipation caused by faults or by bus contention are prevented by two mechanisms. A foldback current limit on the output stage provides immediate protection against short circuits over the whole common-mode voltage range (see *Typical Operating Characteristics*). In addition, a thermal shutdown circuit forces the driver outputs into a high-impedance state if the die temperature rises excessively.

Propagation Delay

Many digital encoding schemes depend on the difference between the driver and receiver propagation delay times. Typical propagation delays are shown in Figures 15–18 using Figure 14's test circuit.

The difference in receiver delay times, $| t_{PLH} - t_{PHL} |$, is typically under 13ns for the MAX481, MAX485, MAX490, MAX491, and MAX1487 and is typically less than 100ns for the MAX483 and MAX487–MAX489.

The driver skew times are typically 5ns (10ns max) for the MAX481, MAX485, MAX490, MAX491, and MAX1487, and are typically 100ns (800ns max) for the MAX483 and MAX487–MAX489.

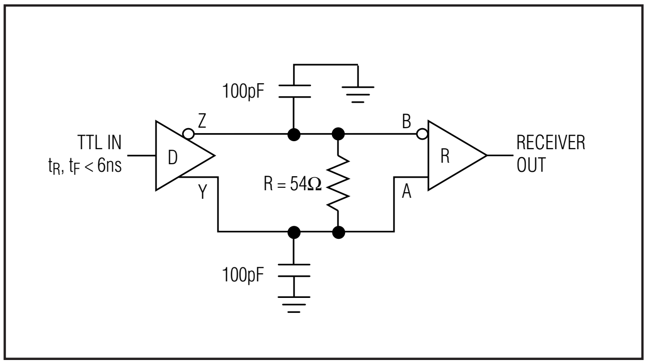


Figure 14. Receiver Propagation Delay Test Circuit

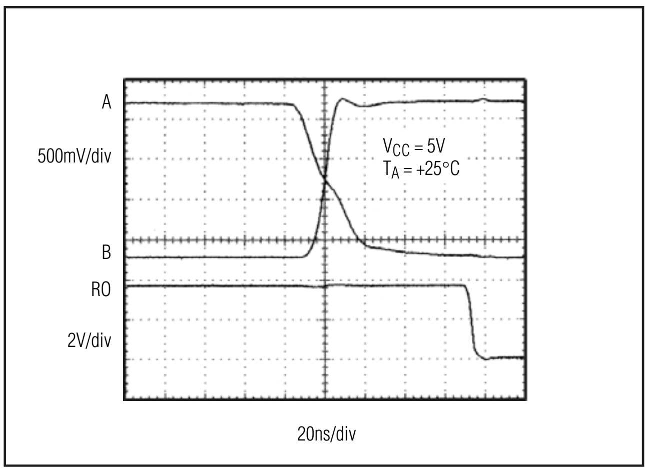


Figure 15. MAX481/MAX485/MAX490/MAX491/MAX1487 Receiver t_{PHL}

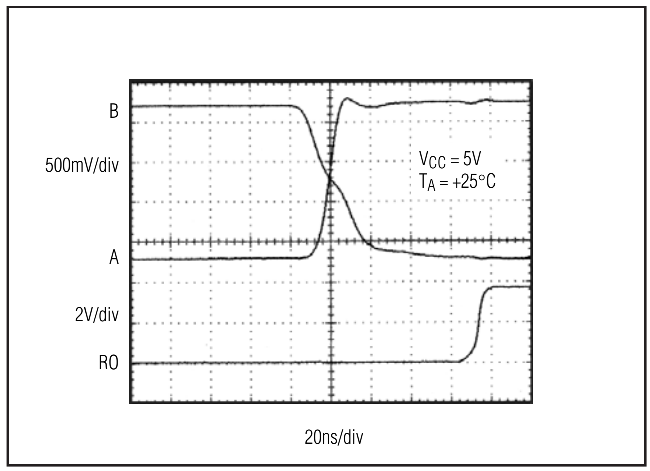


Figure 16. MAX481/MAX485/MAX490/MAX491/MAX1487 Receiver t_{PLH}

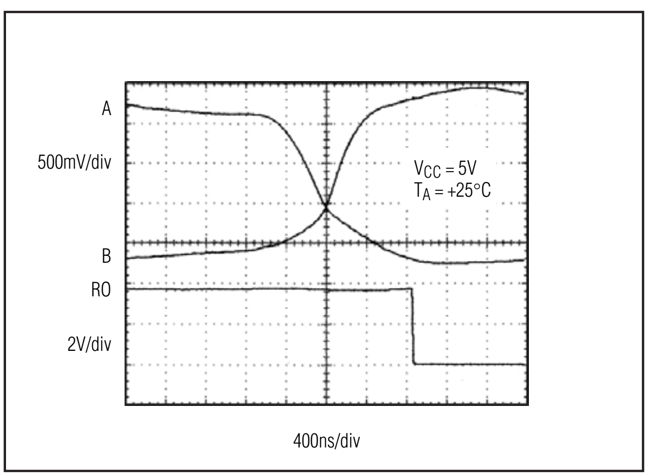


Figure 17. MAX483, MAX487–MAX489 Receiver t_{PHL}

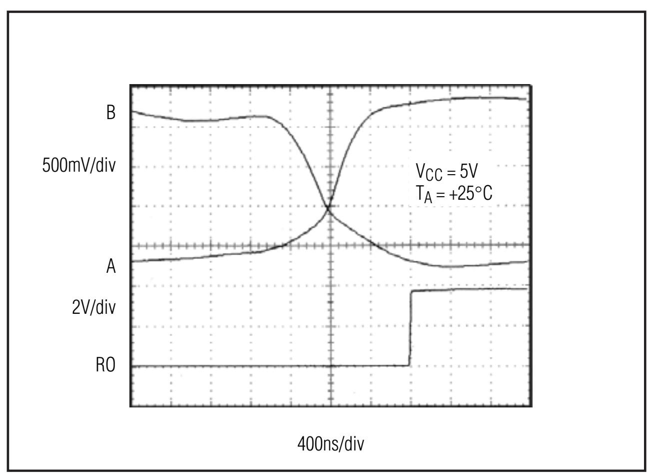


Figure 18. MAX483, MAX487–MAX489 Receiver t_{PLH}

Line Length vs. Data Rate

The RS-485/RS-422 standard covers line lengths up to 4000 feet. For line lengths greater than 4000 feet, see Figure 23.

Figures 19 and 20 show the system differential voltage for the parts driving 4000 feet of 26AWG twisted-pair wire at 110kHz into 120Ω loads.

Typical Applications

The MAX481, MAX483, MAX485, MAX487–MAX491, and MAX1487 transceivers are designed for bidirectional data communications on multipoint bus transmission lines. Figures 21 and 22 show typical network applications circuits. These parts can also be used as line repeaters, with cable lengths longer than 4000 feet, as shown in Figure 23.

To minimize reflections, the line should be terminated at both ends in its characteristic impedance, and stub lengths off the main line should be kept as short as possible. The slew-rate-limited MAX483 and MAX487–MAX489 are more tolerant of imperfect termination.

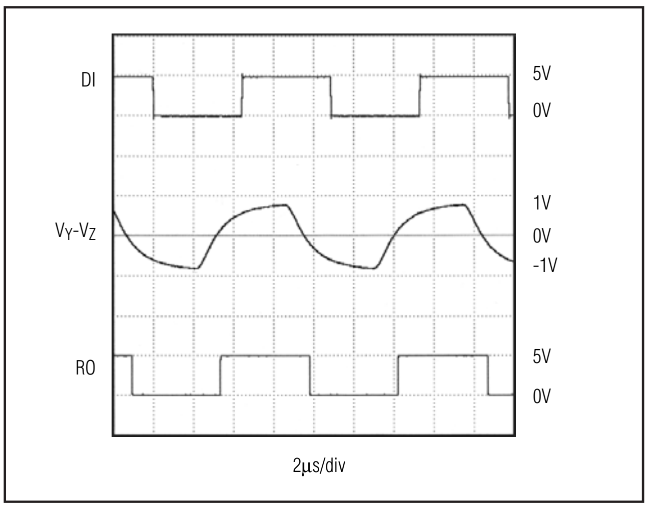


Figure 19. MAX481/MAX485/MAX490/MAX491/MAX1487 System Differential Voltage at 110kHz Driving 4000ft of Cable

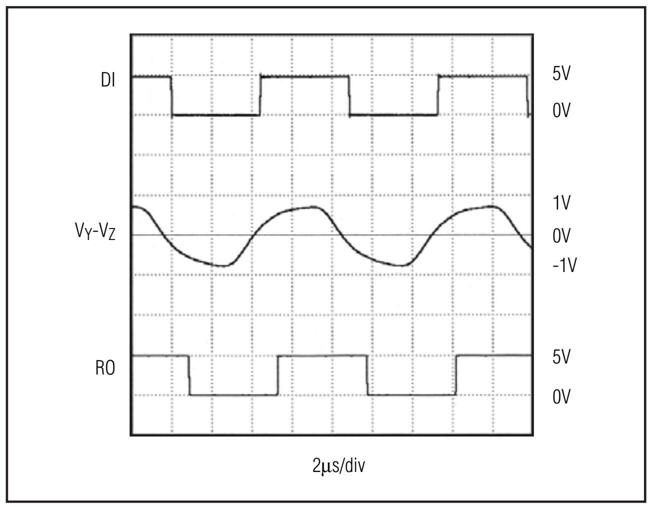


Figure 20. MAX483, MAX487–MAX489 System Differential Voltage at 110kHz Driving 4000ft of Cable

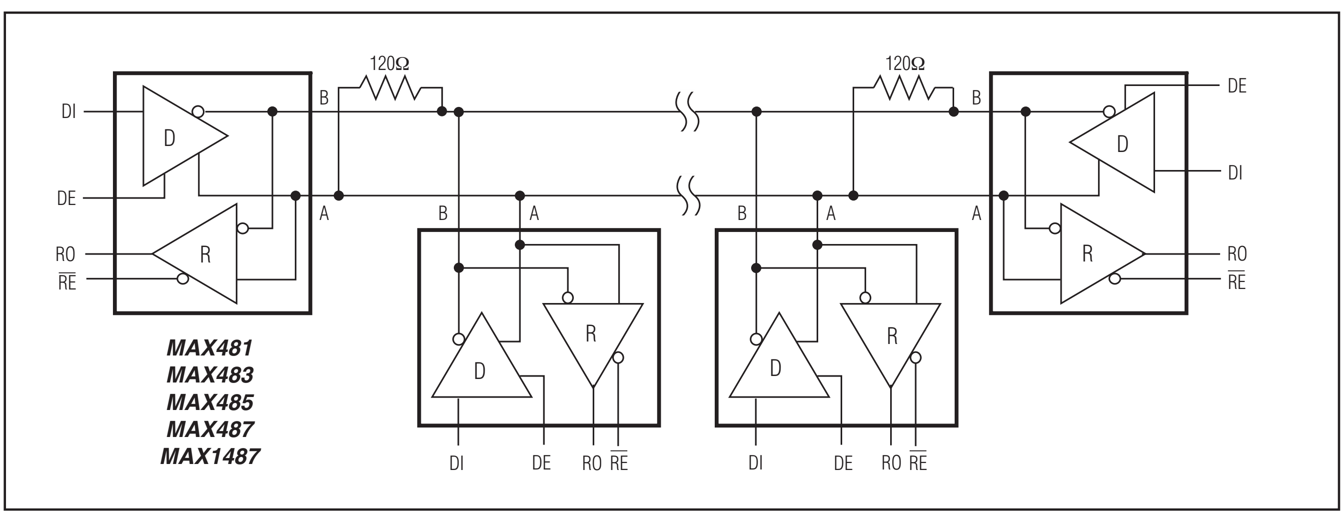


Figure 21. MAX481/MAX483/MAX485/MAX487/MAX1487 Typical Half-Duplex RS-485 Network

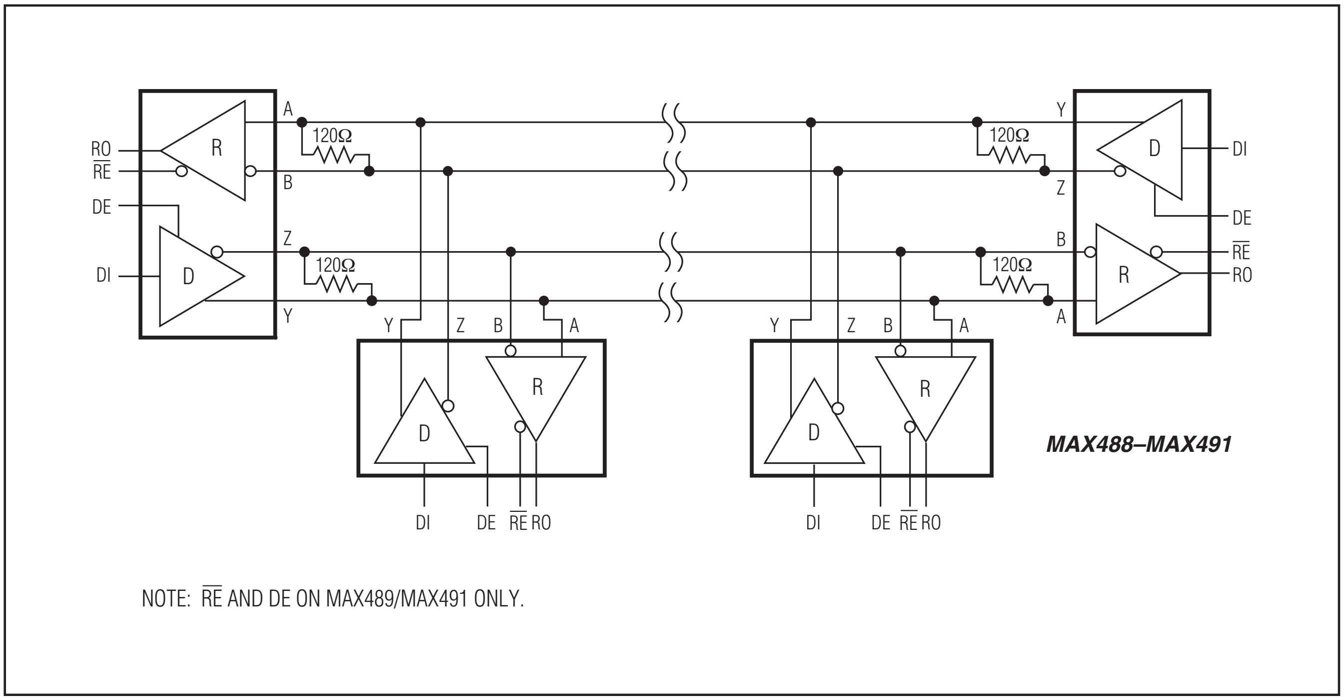


Figure 22. MAX488–MAX491 Full-Duplex RS-485 Network

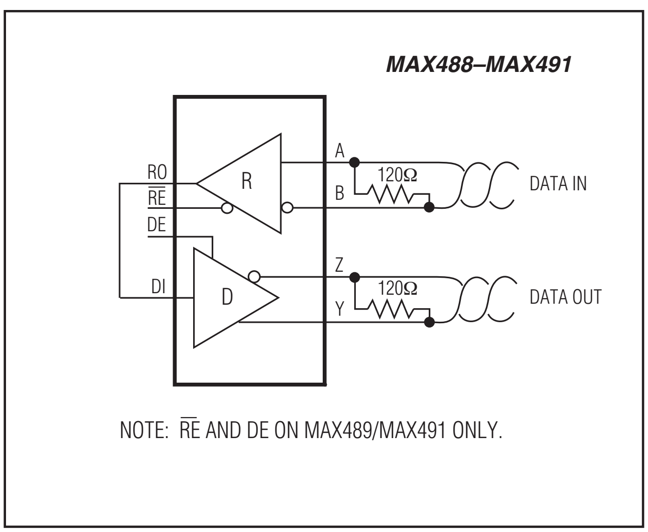


Figure 23. Line Repeater for MAX488–MAX491

Isolated RS-485

For isolated RS-485 applications, see the MAX253 and MAX1480 data sheets.

Ordering Information

PART	TEMP RANGE	PIN-PACKAGE
MAX481CPA	0°C to +70°C	8 Plastic DIP
MAX481CSA	0°C to +70°C	8 SO
MAX481CUA	0°C to +70°C	8 µMAX
MAX481C/D	0°C to +70°C	Dice*
MAX481EPA	-40°C to +85°C	8 Plastic DIP
MAX481ESA	-40°C to +85°C	8 SO
MAX481MJA	-55°C to +125°C	8 CERDIP
MAX483CPA	0°C to +70°C	8 Plastic DIP
MAX483CSA	0°C to +70°C	8 SO
MAX483CUA	0°C to +70°C	8 µMAX
MAX483C/D	0°C to +70°C	Dice*
MAX483EPA	-40°C to +85°C	8 Plastic DIP
MAX483ESA	-40°C to +85°C	8 SO
MAX483MJA	-55°C to +125°C	8 CERDIP
MAX485CPA	0°C to +70°C	8 Plastic DIP
MAX485CSA	0°C to +70°C	8 SO
MAX485CUA	0°C to +70°C	8 µMAX
MAX485C/D	0°C to +70°C	Dice*
MAX485EPA	-40°C to +85°C	8 Plastic DIP
MAX485ESA	-40°C to +85°C	8 SO
MAX485MJA	-55°C to +125°C	8 CERDIP
MAX487CPA	0°C to +70°C	8 Plastic DIP
MAX487CSA	0°C to +70°C	8 SO
MAX487CUA	0°C to +70°C	8 µMAX
MAX487C/D	0°C to +70°C	Dice*
MAX487EPA	-40°C to +85°C	8 Plastic DIP
MAX487ESA	-40°C to +85°C	8 SO
MAX487MJA	-55°C to +125°C	8 CERDIP
MAX488CPA	0°C to +70°C	8 Plastic DIP
MAX488CSA	0°C to +70°C	8 SO
MAX488CUA	0°C to +70°C	8 µMAX
MAX488C/D	0°C to +70°C	Dice*
MAX488EPA	-40°C to +85°C	8 Plastic DIP
MAX488ESA	-40°C to +85°C	8 SO
MAX488MJA	-55°C to +125°C	8 CERDIP
MAX489CPD	0°C to +70°C	14 Plastic DIP
MAX489CSD	0°C to +70°C	14 SO
MAX489C/D	0°C to +70°C	Dice*
MAX489EPD	-40°C to +85°C	14 Plastic DIP
MAX489ESD	-40°C to +85°C	14 SO
MAX489MJD	-55°C to +125°C	14 CERDIP

Ordering Information (continued)

PART	TEMP RANGE	PIN-PACKAGE
MAX490CPA	0°C to +70°C	8 Plastic DIP
MAX490CSA	0°C to +70°C	8 SO
MAX490CUA	0°C to +70°C	8 µMAX
MAX490C/D	0°C to +70°C	Dice*
MAX490EPA	-40°C to +85°C	8 Plastic DIP
MAX490ESA	-40°C to +85°C	8 SO
MAX490MJA	-55°C to +125°C	8 CERDIP
MAX491CPD	0°C to +70°C	14 Plastic DIP
MAX491CSD	0°C to +70°C	14 SO
MAX491C/D	0°C to +70°C	Dice*
MAX491EPD	-40°C to +85°C	14 Plastic DIP
MAX491ESD	-40°C to +85°C	14 SO
MAX491MJD	-55°C to +125°C	14 CERDIP
MAX491MSD/PR	-55°C to +125°C	14 CERDIP
MAX491MSD/PR-T	-55°C to +125°C	14 CERDIP
MAX1487CPA	0°C to +70°C	8 Plastic DIP
MAX1487CSA	0°C to +70°C	8 SO
MAX1487CUA	0°C to +70°C	8 µMAX
MAX1487C/D	0°C to +70°C	Dice*
MAX1487EPA	-40°C to +85°C	8 Plastic DIP
MAX1487ESA	-40°C to +85°C	8 SO
MAX1487MJA	-55°C to +125°C	8 CERDIP

**Contact factory for dice specifications.*

Low-Power, Slew-Rate-Limited RS-485/RS-422 Transceivers

Package Information

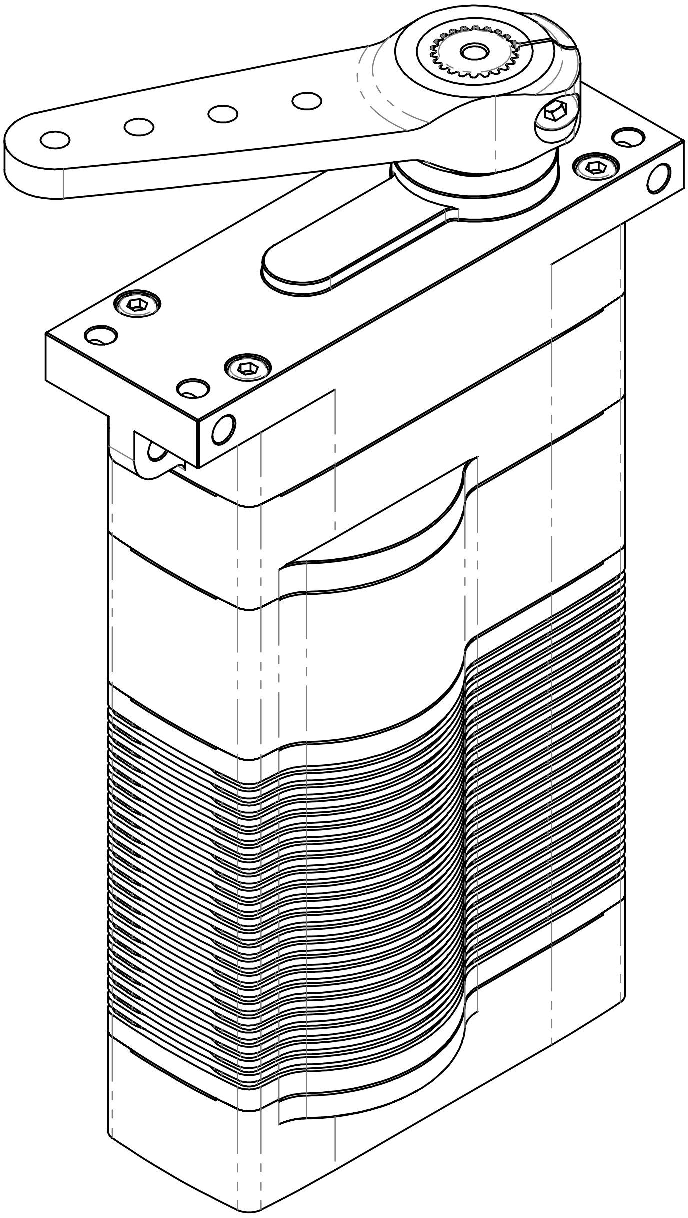
For the latest package outline information and land patterns, go to **www.maximintegrated.com/packages**. Note that a "+", "#", or "-" in the package code indicates RoHS status only. Package drawings may show a different suffix character, but the drawing pertains to the package regardless of RoHS status.

PACKAGE TYPE	PACKAGE CODE	OUTLINE NO.	LAND PATTERN NO.
8 PDIP	P8-1	21-0043	—
8 SO	S8-2	21-0041	90-0096
8 μMAX	U8-1	21-0036	90-0092
8 CERDIP	J8-2	21-0045	—
14 PDIP	P14-3	21-0043	—
14 SO	S14-1	21-0041	90-0112
14 CERDIP	J14-3	21-0045	—

Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	1/93	Initial release.	—
9	9/09	Changed column name in *Selection Table* to “Number of Receivers on Bus.”	1
10	9/14	Added MAX491MSD/PR and MAX491MSD/PR-T to data sheet. Updated *Absolute Maximum Ratings*.	2, 15

DA 30 High Torque
Technical Specification



DA 30-HT-30-5848

Content

1. General Description

To guarantee maximum safety and reliability, our DA 30 High Torque features a brushless motor and a contactless wear free position sensor. Its oversized motor makes it possible to provide very high continuous torque outputs. This means maximum service life with the greatest-possible power delivery and its design prevents electromagnetic emissions (EMI) caused by brush sparking. The housing made of saltwater-resistant aluminum is HART-coat treated, meets the IP-67 standard for water and dust sealing and provides an integrated Sub-D connector (MIL spec. circular connector or cable gland on request). Brackets integrated in the housing for horizontal and vertical assembly. 8-fold, ball-bearing supported, steel gear train, drive shaft with ANSI multi-tooth.

The DA 30 series can be equipped with a standard PWM input (Pulse Width Modulation) that has two different interfaces: a differential, galvanic isolated interface (Opto-Coupler) and a single-ended interface with CMOS levels that is also used to program the servo parameters. It includes analog position feedback to detect the drive shaft position. A differential RS-422 PWM interface can be chosen instead of the opto-coupled interface.

The DA 30 with digital serial command interface (RS-485) receives its commands via a CRC secured protocol. It can return not only the shaft position in digital format, but also several diagnostic data such as the level of the supply voltage, current consumption and the temperature of the motor and electronics in digital form (optionally also the humidity within the actuator case). These kind of diagnostic capabilities help to determine the health state of the actuators before, during and after deployment.

Interface Options:

PWM-OPTO
PWM-Level Compatible, OPTO-coupler PWM Interface

PWM-TTL
PWM-Level Compatible, TTL PWM Interface

RS 422/TTL
RS 422-Level Compatible, Differential PWM Interface

RS 485 (2-wire)
RS-485 Compatible, Asynchronous Serial Command Interface

RS 485 Redundant
RS 485 Redundant Communication Interface and Redundant Power Supply

RS 485 (4-wire)
RS 485 Separated Receiver and Transmitter Lines for Interface A and B

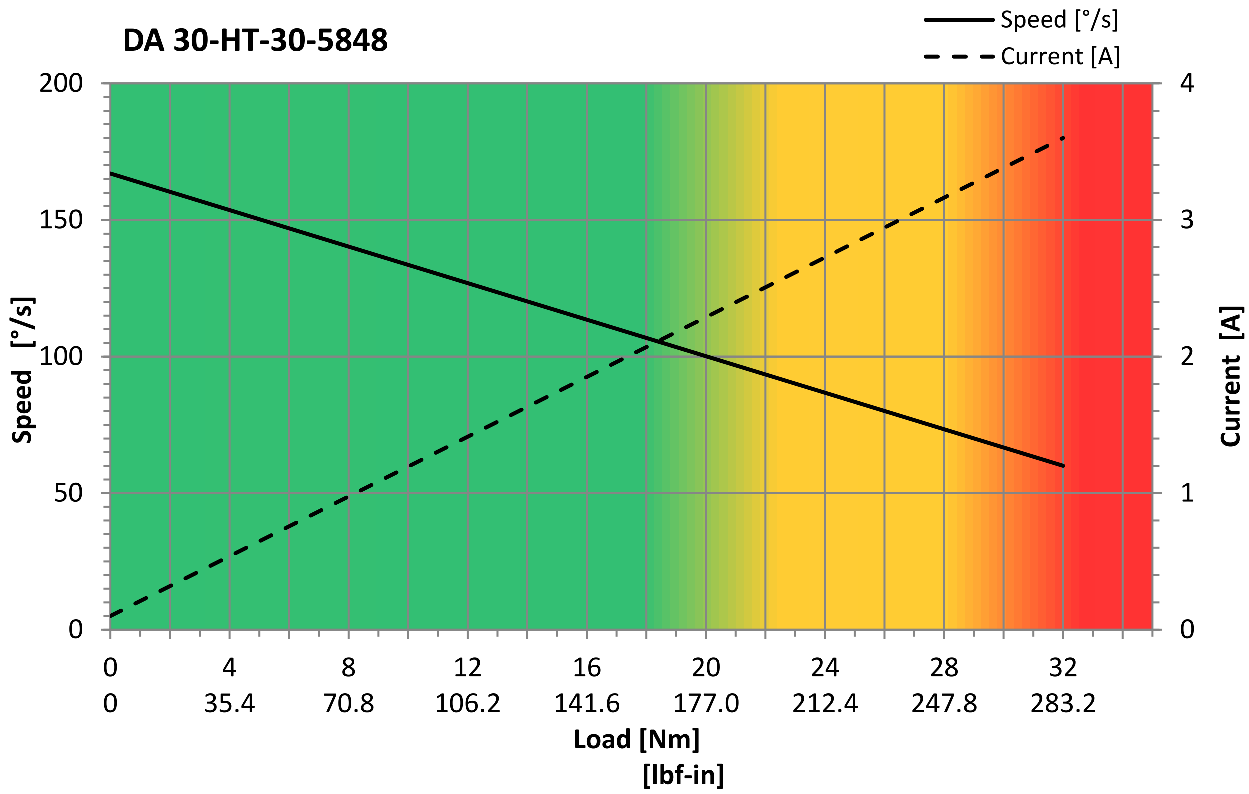
For RS 485-Versions Only:
Customized commands can be implemented on request. Humidity sensor available.

2. Operating Data

		DA 30-HT-30-5848…
Supply Voltage (rated)		28 V DC
Supply Voltage Range		24 … 32 V DC
Standby Current [1]	at rated voltage	< 0.05 A
Rated Current [1]	at rated voltage	2.0 A
Peak Current [1]	at rated voltage	3.6 A
Rated Torque [1]	at rated speed	18.0 Nm (159 lbf-in)
Peak Torque [1]	at rated voltage	32.0 Nm (283 lbf-in)
No Load Speed [1]	at rated voltage	165 °/s
Rated Speed [1]	at rated torque	100 °/s
Default Travel Angle		±45° = 90° total travel
Max. Travel Angle [2]		±85° = 170° total travel
Backlash (mechanical)		≤ 0.5°
Position Error under Temperature [3]		≤ ±1.0°
Operating Temperature Range [4]		-30°C … +70°C (-22°F … +158°F)
Storage Temperature Range		-55°C … +85°C (-67°F … +185°F)

1) Tolerance ±10%
2) Programming Tool # 985.4 for PWM-Versions required
3) -20°C … +50°C , Δt = 70°C (-4°F … +122°F , Δt = 126°F)
4) Low Temperature Modification (-70°C /-94°F) on request

3. Performance



Operation Mode:

Continuous	Short Time <10s , 60s cool down	Overload <1s , 60s cool down

4. Materials and Protective Features

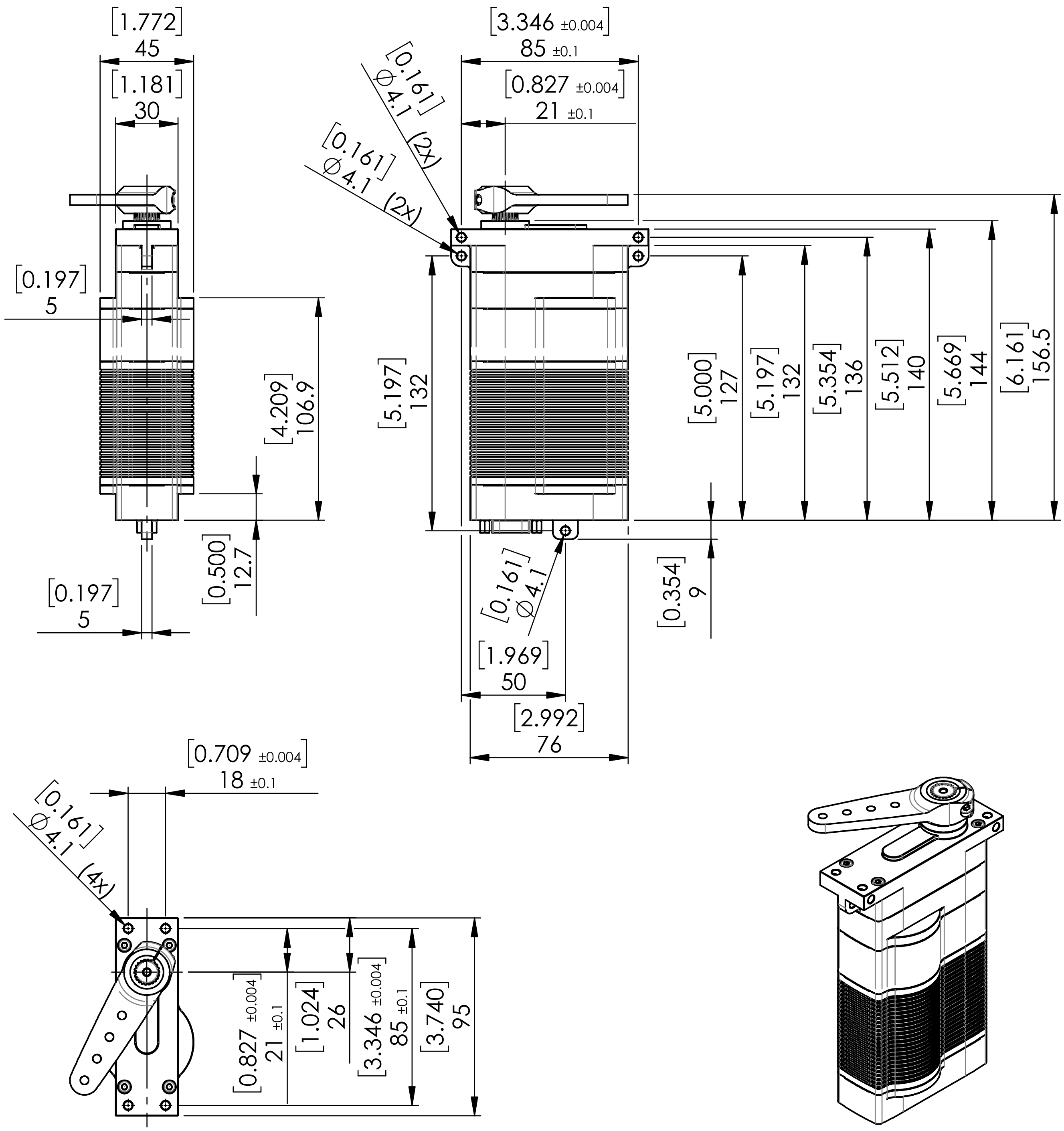
Case Material	Saltwater resistant Aluminum Alloy
Splash Water Resistance	IP 67
Case Surface Treatment	HART®-Coat
Salt Water Resistance	>100 hrs.
EMI / RFI Shielding	Case Shielding
Motor Type	Brushless DC Motor
Gear Set Material	Hardened Steel
Position Sensor	Contactless
Position Feedback	Standard
RS 485 Communication Interface	Optional
Humidity Sensor	Optional
Temperature Sensor	Standard, Motor and PCB

5. Dimensions

Case Dimensions	140 mm x 76 mm x 30.0 (45.0) mm 5.512 in x 2.992 in x 1.181 (1.772) in
Standard Tolerances	Unless otherwise specified according to DIN ISO 2768 - m
Weight	1100 g (38.8 oz) ±10%

5.1. Installation Dimensions

Valid for all Versions
DA 30-HT-30-5848...

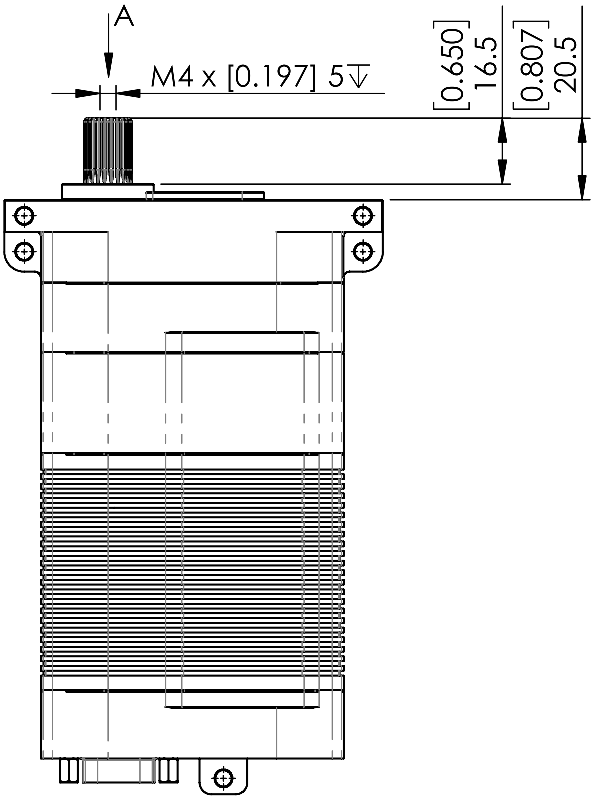


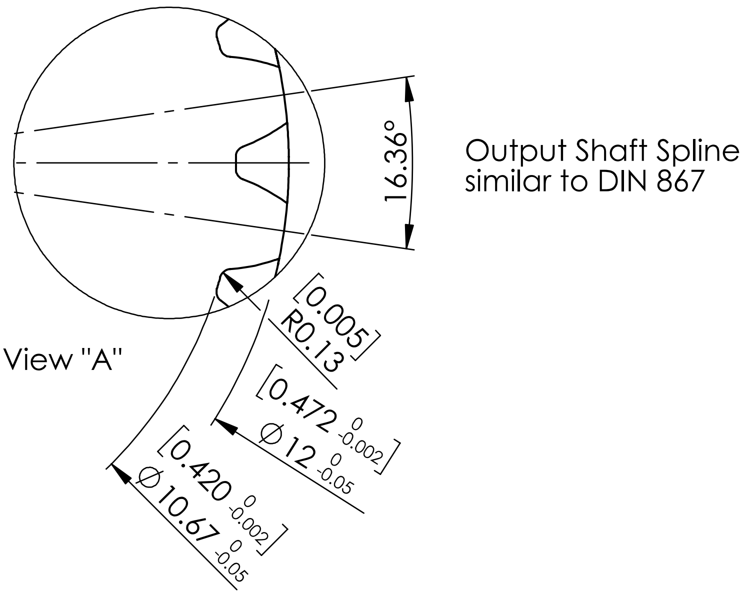
Not to scale

Dimensions: [in], mm

5.2. Output Shaft Spline

Valid for all Versions
DA 30-HT-30-5848...





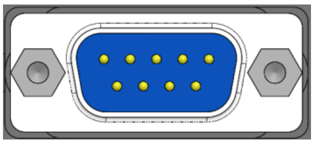
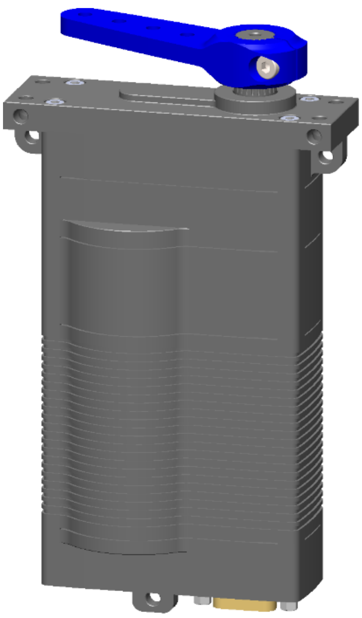
Not to scale

Dimensions: [in], mm

6. Electrical Connection Options

PWM-OPTO Interface

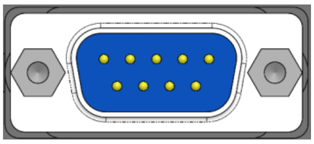
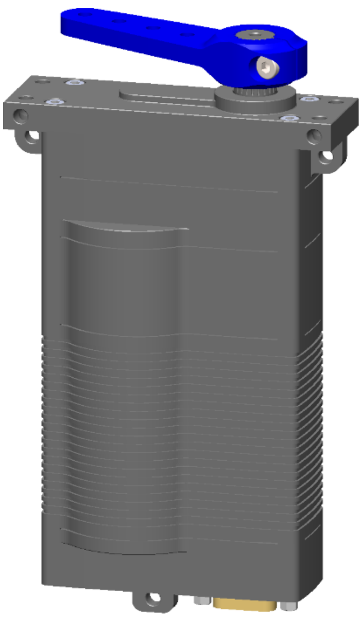
Integrated Connector **Item # DA 30-HT.30.5848.1._**

<table>
<tr><td rowspan="4">1 2 3 4 5

6 7 8 9</td><th colspan="3">Standard Connector</th></tr>
<tr><td colspan="2">Manufacturer</td><td>ITT Cannon</td></tr>
<tr><td colspan="2">Type</td><td>DEMM-9PE</td></tr>
<tr><td colspan="2">Mating</td><td>D-SUB DE-9f</td></tr>
<tr><td rowspan="10"></td><th colspan="3">PWM-OPTO Pin Assignment</th></tr>
<tr><td>1</td><td>PWM (AO)</td><td>Command Signal, Anode Optocoupler</td></tr>
<tr><td>2</td><td>PWM (CO)</td><td>Command Signal, Cathode Optocoupler</td></tr>
<tr><td>3</td><td>Diff FB A</td><td>Differential Position Feedback Signal, Output A</td></tr>
<tr><td>4</td><td>to Pin 7</td><td>Connect to Pin 7 (Supply Ground)</td></tr>
<tr><td>5</td><td>Case GND</td><td>Case Ground</td></tr>
<tr><td>6</td><td>+V DC</td><td>Supply Voltage</td></tr>
<tr><td>7</td><td>GND</td><td>Supply Ground, Signal Ground</td></tr>
<tr><td>8</td><td>Pos FB</td><td>Single Ended Position Feedback Signal</td></tr>
<tr><td>9</td><td>Diff FB B</td><td>Differential Position Feedback Signal, Output B</td></tr>
</table>

NOTE:
Access to the actuator parameters is possible via the TTL-PWM-Interface only.
Programming Tool # 985.4 required.

PWM-TTL Interface

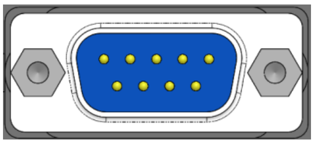
Integrated Connector **Item # DA 30-HT.30.5848.1._**

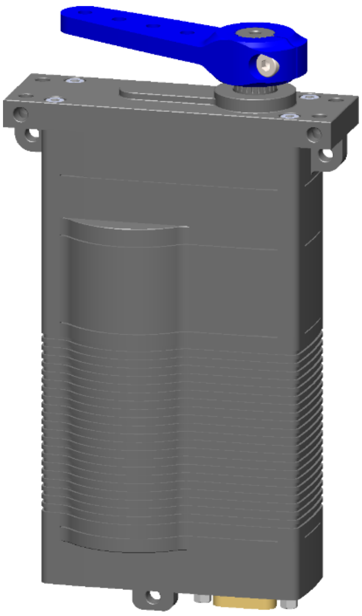
<table>
<tr><td rowspan="4">1 2 3 4 5

6 7 8 9</td><th colspan="3">Standard Connector</th></tr>
<tr><td colspan="2">Manufacturer</td><td>ITT Cannon</td></tr>
<tr><td colspan="2">Type</td><td>DEMM-9PE</td></tr>
<tr><td colspan="2">Mating</td><td>D-SUB DE-9f</td></tr>
<tr><td rowspan="10"></td><th colspan="3">PWM-TTL Pin Assignment</th></tr>
<tr><td>1</td><td>NC</td><td>Do not connect</td></tr>
<tr><td>2</td><td>NC</td><td>Do not connect</td></tr>
<tr><td>3</td><td>Diff FB A</td><td>Differential Position Feedback Signal, Output A</td></tr>
<tr><td>4</td><td>PWM</td><td>Command Signal</td></tr>
<tr><td>5</td><td>Case GND</td><td>Case Ground</td></tr>
<tr><td>6</td><td>+V DC</td><td>Supply Voltage</td></tr>
<tr><td>7</td><td>GND</td><td>Supply Ground, Signal Ground</td></tr>
<tr><td>8</td><td>Pos FB</td><td>Single Ended Position Feedback Signal</td></tr>
<tr><td>9</td><td>Diff FB B</td><td>Differential Position Feedback Signal, Output B</td></tr>
</table>

NOTE:
Access to the actuator parameters is possible via the TTL-PWM-Interface only.
Programming Tool # 985.4 required.

PWM-RS 422/TTL Interface

Integrated Connector **Item # DA 30-HT.30.5848.2._**





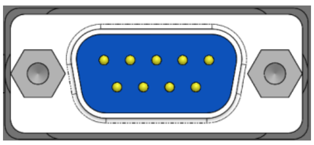
Standard Connector	
Manufacturer	ITT Cannon
Type	DEMM-9PE
Mating	D-SUB DE-9f

PWM-RS 422/TTL Pin Assignment		
1	RS 422 / PWM	Non-Inverted RS 422-Input
2	RS 422 / PWM	Inverted RS 422-Input
3	Diff FB A	Position Feedback Signal, Output A
4	TTL / PWM	Command and Parameter Input
5	Case GND	Case Ground
6	+V DC	Supply Voltage
7	GND	Supply Ground, Signal Ground
8	Pos FB	Single Ended Position Feedback Signal
9	Diff FB B	Differential Position Feedback Signal, Output B

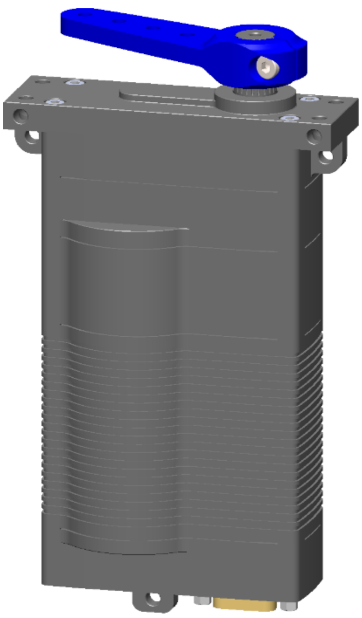
NOTE:
Access to the actuator parameters is possible via the TTL-PWM-Interface only.
Programming Tool # 985.4 required.

RS 485 Interface (2-wire)

Integrated Connector **Item # DA 30-HT.30.5848.3._**



Standard Connector	
Manufacturer	ITT Cannon
Type	DEMM-9PE
Mating	D-SUB DE-9f

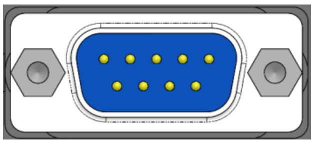


RS 485 (2-wire) Pin Assignment		
1	RS 485 A	Non-Inverted Input/Output
2	RS 485 B	Inverted Input/Output
3	-	Do not connect
4	+V DC (2)	Supply Voltage, Secondary
5	Case GND	Case Ground
6	+V DC (1)	Supply Voltage, Primary
7	GND (1)	Supply Ground, Signal Ground, Primary
8	GND (2)	Supply Ground, Signal Ground, Secondary
9	-	Do not connect

RS 485 Redundant Interface

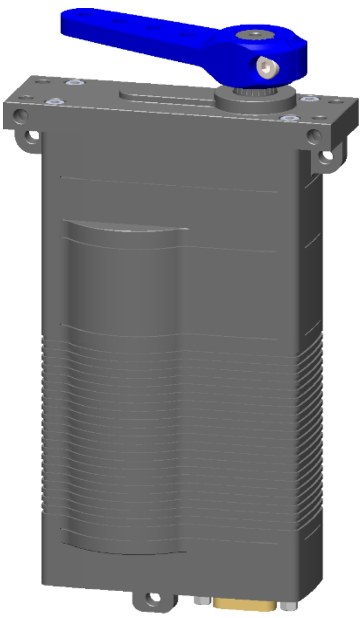
Integrated Connector **Item # DA 30-HT.30.5848.4._**

1 2 3 4 5



6 7 8 9

Standard Connector	
Manufacturer	ITT Cannon
Type	DEMM-9PE
Mating	D-SUB DE-9f

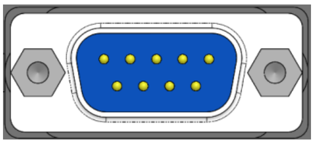


RS 485 Redundant Pin Assignment		
1	RS 485 A (1)	Interface 1, Non-Inverted Input/Output
2	RS 485 B (1)	Interface 1, Inverted Input/Output
3	RS 485 A (2)	Interface 2, Non-Inverted Input/Output
4	+V DC (2)	Supply Voltage, Secondary
5	Case GND	Case Ground
6	+V DC (1)	Supply Voltage, Primary
7	GND (1)	Supply Ground, Signal Ground, Primary
8	GND (2)	Supply Ground, Signal Ground, Secondary
9	RS 485 B (2)	Interface 2, Inverted Input/Output

RS 485 Interface (4-wire)

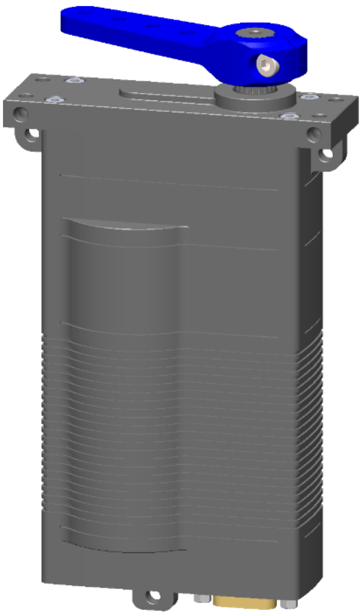
Integrated Connector **Item # DA 30-HT.30.5848.5._**

1 2 3 4 5



6 7 8 9

Standard Connector	
Manufacturer	ITT Cannon
Type	DEMM-9PE
Mating	D-SUB DE-9f



RS 485 (4-wire) Pin Assignment		
1	RS 485 A (Rx)	Receiver, Non-Inverted, Input
2	RS 485 B (Rx)	Receiver, Inverted, Input
3	RS 485 A (Tx)	Transmitter, Non-Inverted, Output
4	+V DC (2)	Supply Voltage, Secondary
5	Case GND	Case Ground
6	+V DC (1)	Supply Voltage, Primary
7	GND (1)	Supply Ground, Signal Ground,Primary
8	GND (2)	Supply Ground, Signal Ground, Secondary
9	RS 485 B (Tx)	Transmitter, Inverted, Output

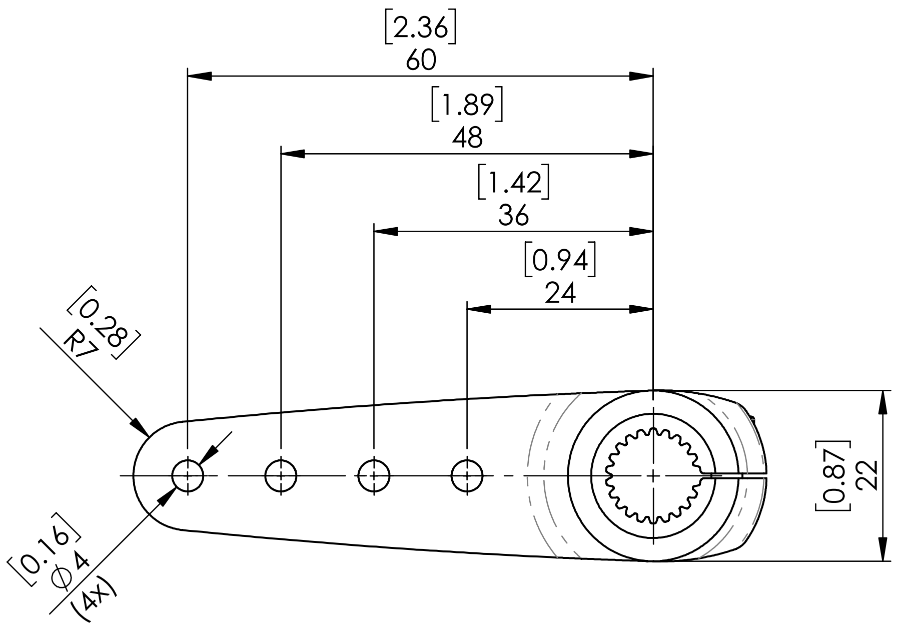
7. Accessories

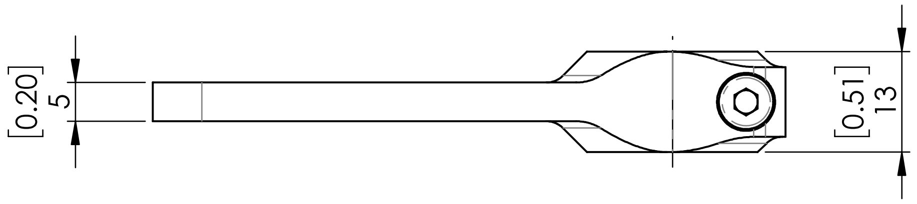
Item	Item-No.
Aluminum Servo Arm	1941.21
Programming Tool PWM	985.4
Programming Tool RS-485	985.5

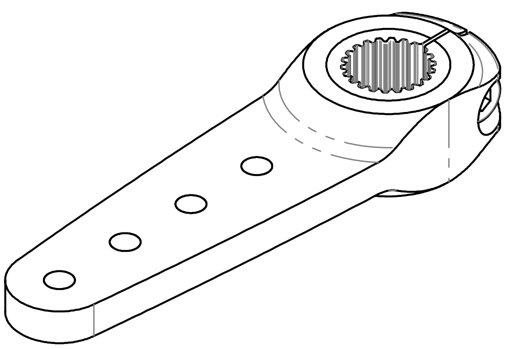
All accessories to be purchased separately.

7.1. Servo Arm

Item # 1941.21







Not to scale

Dimensions: [in], mm

8. Item Number System

DA 30-HT . 30 . 58 48 . 1 . H

Servo Class
30mm High Torque Class

Supply Voltage
30V DC **30**

Servo Type
5848

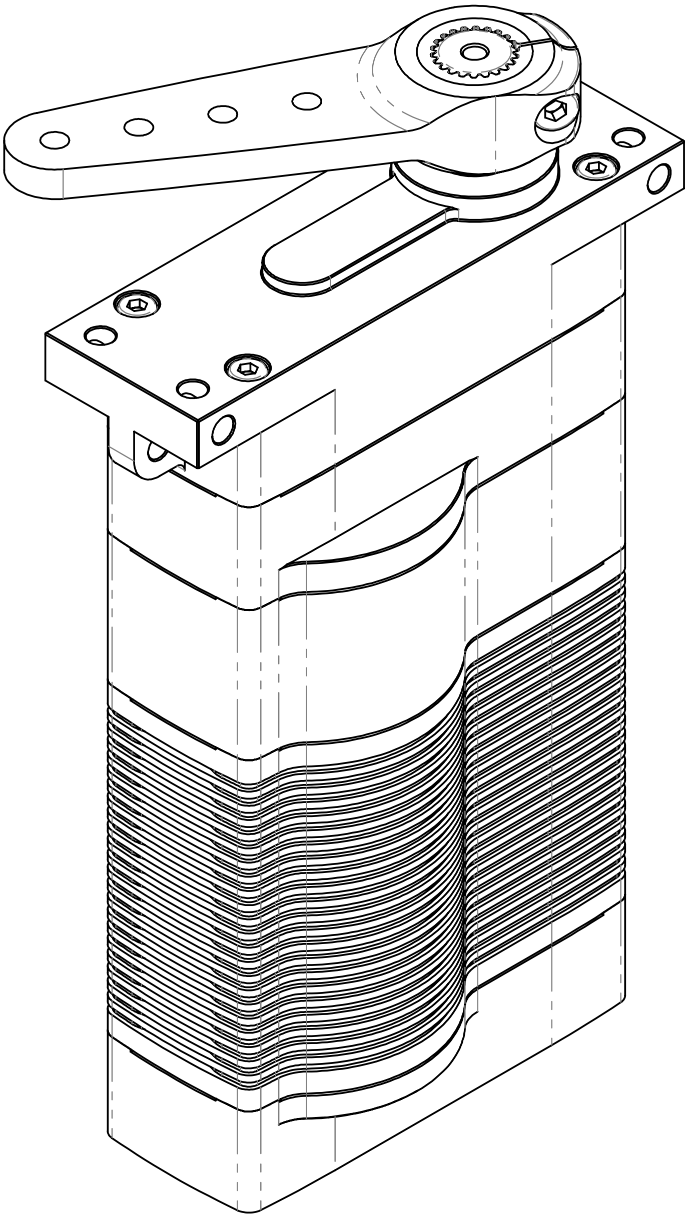
Interface
1 PWM-OPTO / TTL
2 PWM-RS 422 / TTL
3 RS 485 (2-wire)
4 RS 485 Redundant
5 RS 485 (4-wire)

Sensor
H Humidity
X without

Volz Servos GmbH & Co. KG
Heinrich-Krumm-Straße 5
63073 Offenbach
Germany
Tel. +49-69-985580-0
Fax +49-69-985580-40

e-Mail **mail@volz-servos.com**
Website **www.volz-servos.com**

DA 30 High Torque
Technical Specification



DA 30-HT-30-5848

Content

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The DA 30 with digital serial command interface (RS-485) receives its commands via a CRC secured protocol. It can return not only the shaft position in digital format, but also several diagnostic data such as the level of the supply voltage, current consumption and the temperature of the motor and electronics in digital form (optionally also the humidity within the actuator case). These kind of diagnostic capabilities help to determine the health state of the actuators before, during and after deployment.

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PWM-Level Compatible, OPTO-coupler PWM Interface

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PWM-Level Compatible, TTL PWM Interface

RS 422/TTL
RS 422-Level Compatible, Differential PWM Interface

RS 485 (2-wire)
RS-485 Compatible, Asynchronous Serial Command Interface

RS 485 Redundant
RS 485 Redundant Communication Interface and Redundant Power Supply

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RS 485 Separated Receiver and Transmitter Lines for Interface A and B

For RS 485-Versions Only:
Customized commands can be implemented on request. Humidity sensor available.

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Rated Speed [1]	at rated torque	100 °/s
Default Travel Angle		±45° = 90° total travel
Max. Travel Angle [2]		±85° = 170° total travel
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Position Error under Temperature [3]		≤ ±1.0°
Operating Temperature Range [4]		-30°C … +70°C (-22°F … +158°F)
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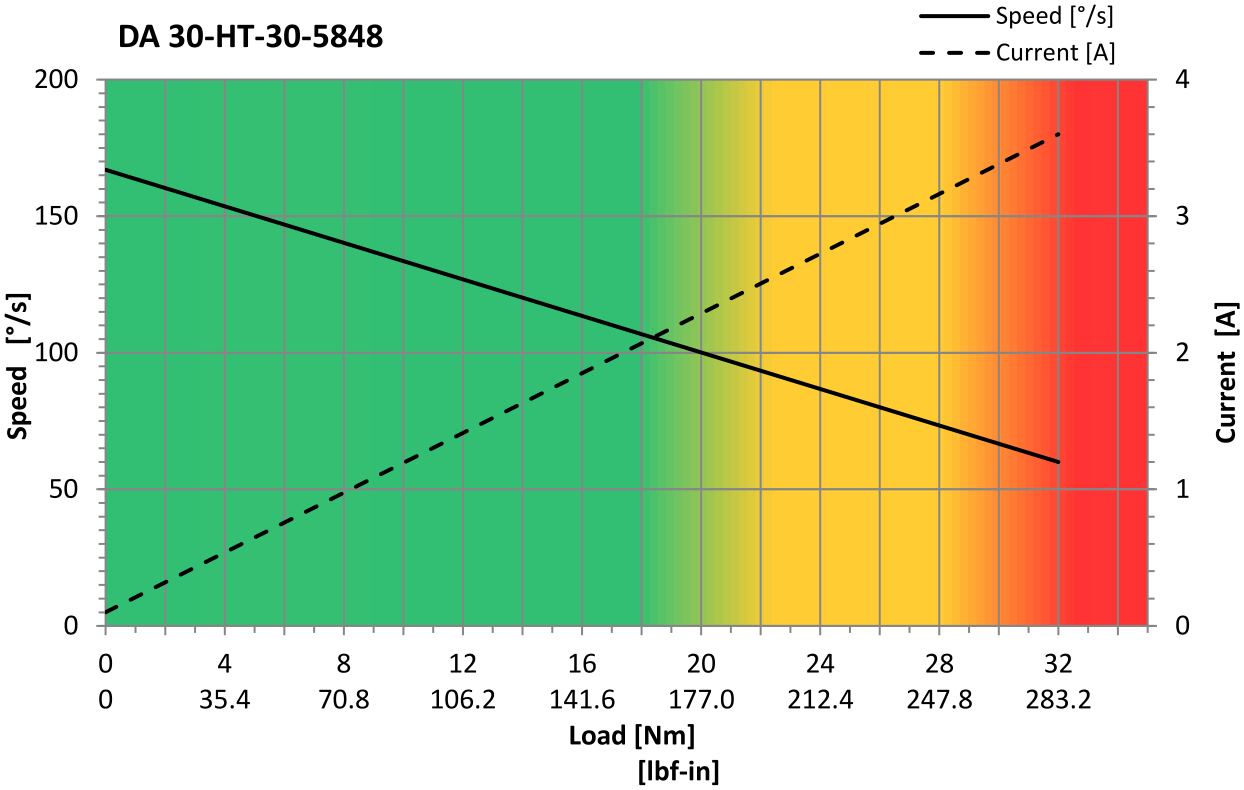
1) Tolerance ±10%
2) Programming Tool # 985.4 for PWM-Versions required
3) -20°C … +50°C , Δt = 70°C (-4°F … +122°F , Δt = 126°F)
4) Low Temperature Modification (-70°C /-94°F) on request

3. Performance



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4. Materials and Protective Features

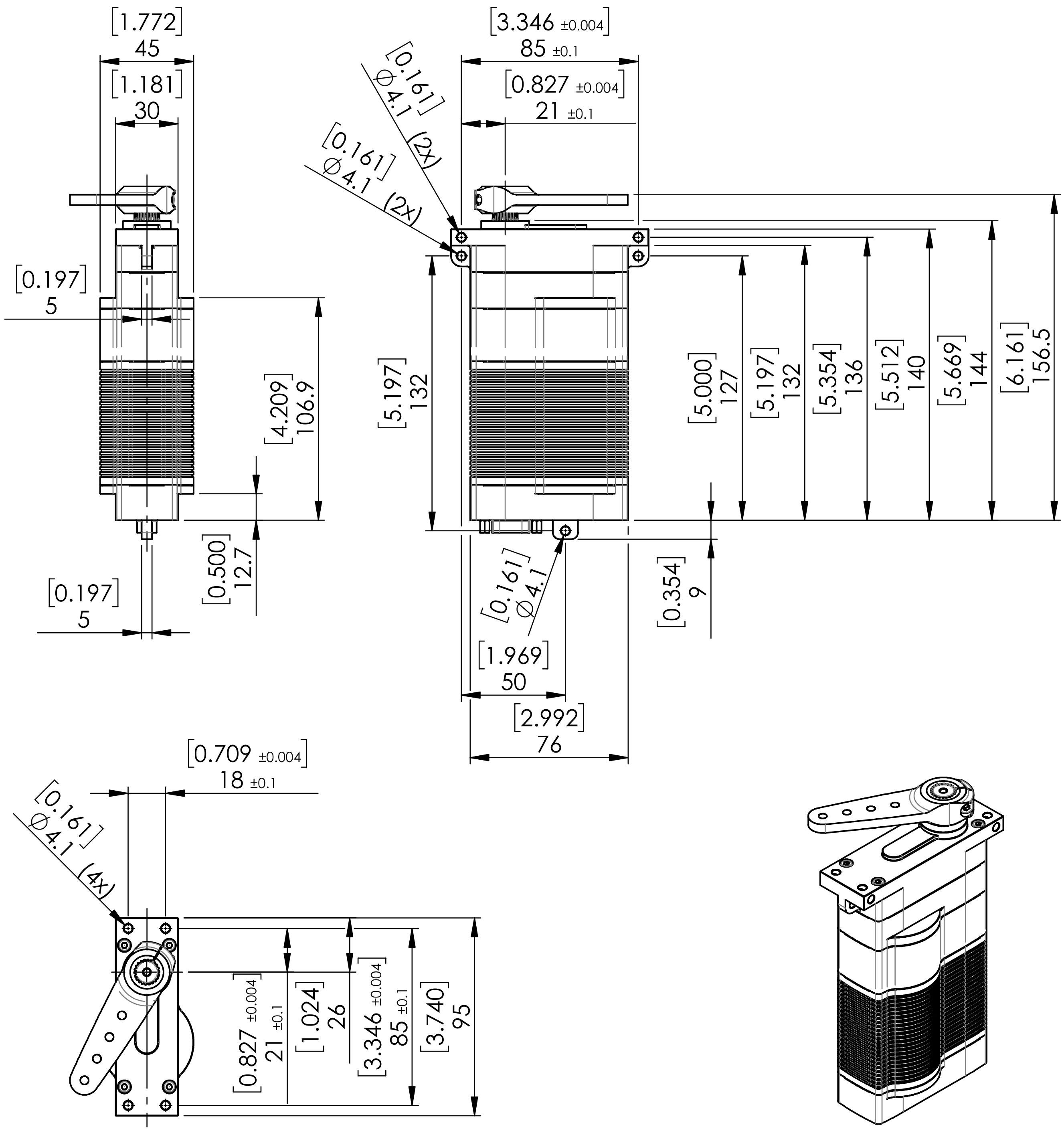
Case Material	Saltwater resistant Aluminum Alloy
Splash Water Resistance	IP 67
Case Surface Treatment	HART®-Coat
Salt Water Resistance	>100 hrs.
EMI / RFI Shielding	Case Shielding
Motor Type	Brushless DC Motor
Gear Set Material	Hardened Steel
Position Sensor	Contactless
Position Feedback	Standard
RS 485 Communication Interface	Optional
Humidity Sensor	Optional
Temperature Sensor	Standard, Motor and PCB

5. Dimensions

Case Dimensions	140 mm x 76 mm x 30.0 (45.0) mm 5.512 in x 2.992 in x 1.181 (1.772) in
Standard Tolerances	Unless otherwise specified according to DIN ISO 2768 - m
Weight	1100 g (38.8 oz) ±10%

5.1. Installation Dimensions

Valid for all Versions
DA 30-HT-30-5848...

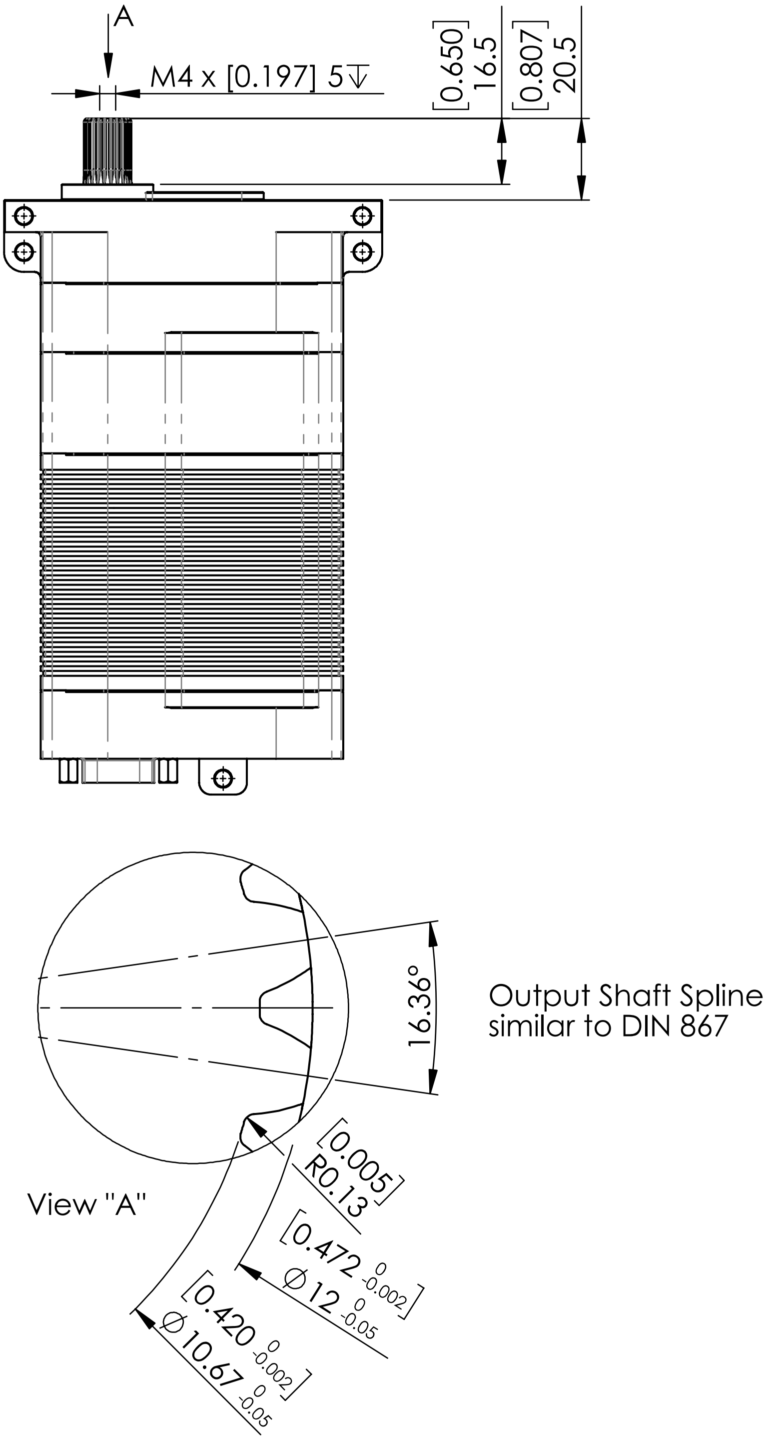


Not to scale

Dimensions: [in], mm

5.2. Output Shaft Spline

Valid for all Versions
DA 30-HT-30-5848...



Not to scale

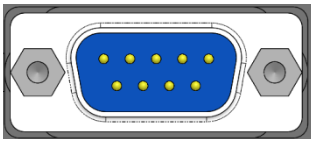
Dimensions: [in], mm

6. Electrical Connection Options

PWM-OPTO Interface

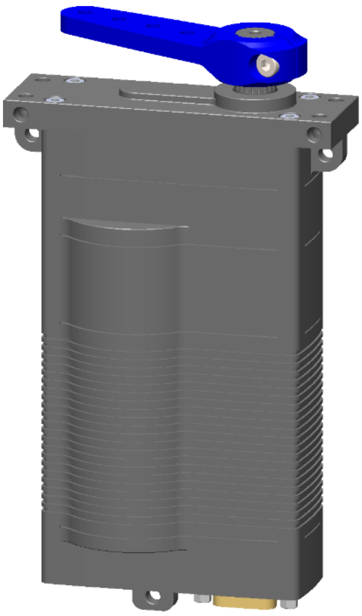
Integrated Connector **Item # DA 30-HT.30.5848.1._**

1 2 3 4 5



6 7 8 9

Standard Connector	
Manufacturer	ITT Cannon
Type	DEMM-9PE
Mating	D-SUB DE-9f



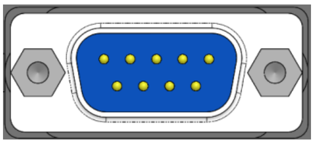
PWM-OPTO Pin Assignment		
1	PWM (AO)	Command Signal, Anode Optocoupler
2	PWM (CO)	Command Signal, Cathode Optocoupler
3	Diff FB A	Differential Position Feedback Signal, Output A
4	to Pin 7	Connect to Pin 7 (Supply Ground)
5	Case GND	Case Ground
6	+V DC	Supply Voltage
7	GND	Supply Ground, Signal Ground
8	Pos FB	Single Ended Position Feedback Signal
9	Diff FB B	Differential Position Feedback Signal, Output B

NOTE:
Access to the actuator parameters is possible via the TTL-PWM-Interface only.
Programming Tool # 985.4 required.

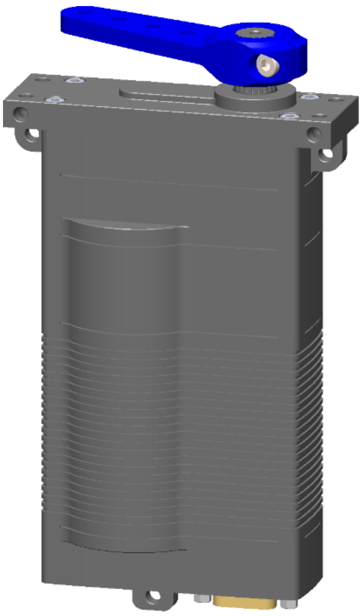
PWM-TTL Interface

Integrated Connector **Item # DA 30-HT.30.5848.1._**

1 2 3 4 5



6 7 8 9



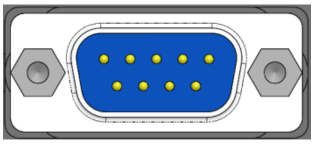
Standard Connector	
Manufacturer	ITT Cannon
Type	DEMM-9PE
Mating	D-SUB DE-9f

PWM-TTL Pin Assignment		
1	NC	Do not connect
2	NC	Do not connect
3	Diff FB A	Differential Position Feedback Signal, Output A
4	PWM	Command Signal
5	Case GND	Case Ground
6	+V DC	Supply Voltage
7	GND	Supply Ground, Signal Ground
8	Pos FB	Single Ended Position Feedback Signal
9	Diff FB B	Differential Position Feedback Signal, Output B

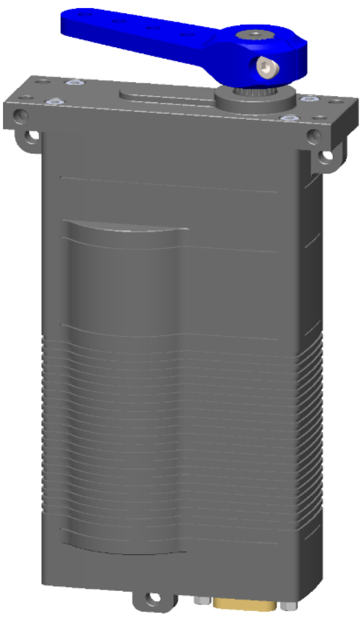
NOTE:
Access to the actuator parameters is possible via the TTL-PWM-Interface only.
Programming Tool # 985.4 required.

PWM-RS 422/TTL Interface

Integrated Connector **Item # DA 30-HT.30.5848.2._**



Standard Connector	
Manufacturer	ITT Cannon
Type	DEMM-9PE
Mating	D-SUB DE-9f



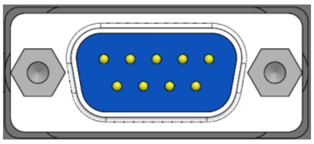
PWM-RS 422/TTL Pin Assignment		
1	RS 422 / PWM	Non-Inverted RS 422-Input
2	RS 422 / PWM	Inverted RS 422-Input
3	Diff FB A	Position Feedback Signal, Output A
4	TTL / PWM	Command and Parameter Input
5	Case GND	Case Ground
6	+V DC	Supply Voltage
7	GND	Supply Ground, Signal Ground
8	Pos FB	Single Ended Position Feedback Signal
9	Diff FB B	Differential Position Feedback Signal, Output B

NOTE:
Access to the actuator parameters is possible via the TTL-PWM-Interface only.
Programming Tool # 985.4 required.

RS 485 Interface (2-wire)

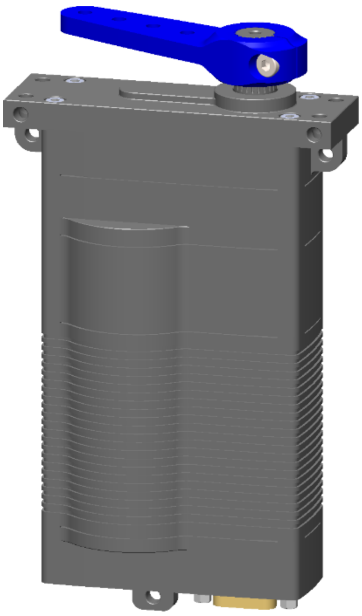
Integrated Connector **Item # DA 30-HT.30.5848.3._**

1 2 3 4 5



6 7 8 9

Standard Connector	
Manufacturer	ITT Cannon
Type	DEMM-9PE
Mating	D-SUB DE-9f

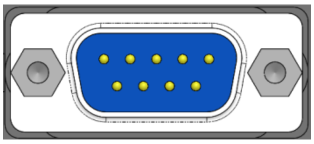


RS 485 (2-wire) Pin Assignment		
1	RS 485 A	Non-Inverted Input/Output
2	RS 485 B	Inverted Input/Output
3	-	Do not connect
4	+V DC (2)	Supply Voltage, Secondary
5	Case GND	Case Ground
6	+V DC (1)	Supply Voltage, Primary
7	GND (1)	Supply Ground, Signal Ground, Primary
8	GND (2)	Supply Ground, Signal Ground, Secondary
9	-	Do not connect

RS 485 Redundant Interface

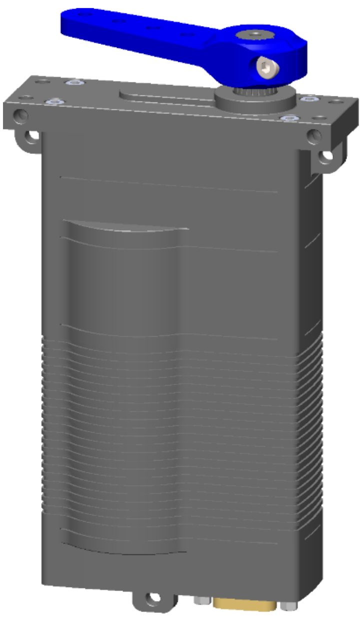
Integrated Connector **Item # DA 30-HT.30.5848.4._**

1 2 3 4 5



6 7 8 9

Standard Connector	
Manufacturer	ITT Cannon
Type	DEMM-9PE
Mating	D-SUB DE-9f

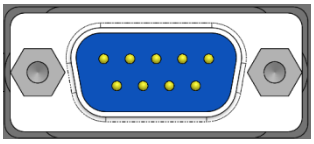


RS 485 Redundant Pin Assignment		
1	RS 485 A (1)	Interface 1, Non-Inverted Input/Output
2	RS 485 B (1)	Interface 1, Inverted Input/Output
3	RS 485 A (2)	Interface 2, Non-Inverted Input/Output
4	+V DC (2)	Supply Voltage, Secondary
5	Case GND	Case Ground
6	+V DC (1)	Supply Voltage, Primary
7	GND (1)	Supply Ground, Signal Ground, Primary
8	GND (2)	Supply Ground, Signal Ground, Secondary
9	RS 485 B (2)	Interface 2, Inverted Input/Output

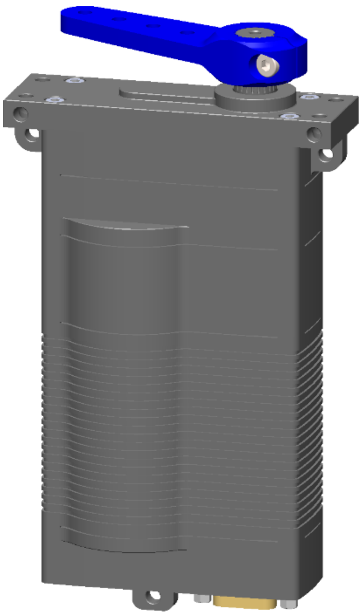
RS 485 Interface (4-wire)

Integrated Connector **Item # DA 30-HT.30.5848.5._**

1 2 3 4 5



6 7 8 9



Standard Connector		
Manufacturer		ITT Cannon
Type		DEMM-9PE
Mating		D-SUB DE-9f
RS 485 (4-wire) Pin Assignment		
1	RS 485 A (Rx)	Receiver, Non-Inverted, Input
2	RS 485 B (Rx)	Receiver, Inverted, Input
3	RS 485 A (Tx)	Transmitter, Non-Inverted, Output
4	+V DC (2)	Supply Voltage, Secondary
5	Case GND	Case Ground
6	+V DC (1)	Supply Voltage, Primary
7	GND (1)	Supply Ground, Signal Ground,Primary
8	GND (2)	Supply Ground, Signal Ground, Secondary
9	RS 485 B (Tx)	Transmitter, Inverted, Output

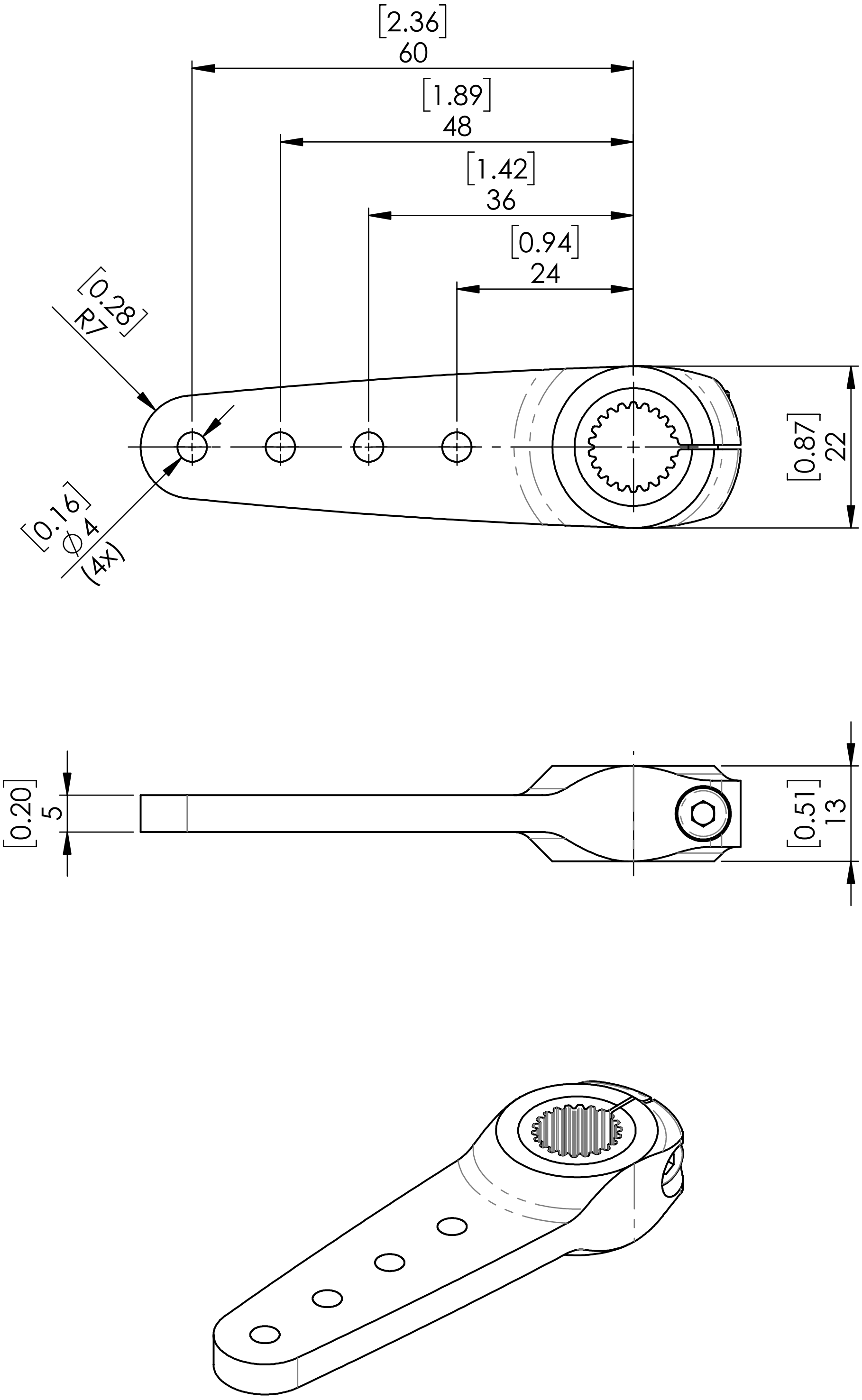
7. Accessories

Item	Item-No.
Aluminum Servo Arm	1941.21
Programming Tool PWM	985.4
Programming Tool RS-485	985.5

All accessories to be purchased separately.

7.1. Servo Arm

Item # 1941.21



Not to scale

Dimensions: [in], mm

8. Item Number System

DA 30-HT . 30 . 58 48 . 1 . H

Servo Class
30mm High Torque Class

Supply Voltage
30V DC **30**

Servo Type
5848

Interface
1 PWM-OPTO / TTL
2 PWM-RS 422 / TTL
3 RS 485 (2-wire)
4 RS 485 Redundant
5 RS 485 (4-wire)

Sensor
H Humidity
X without

Volz Servos GmbH & Co. KG
Heinrich-Krumm-Straße 5
63073 Offenbach
Germany
Tel. +49-69-985580-0
Fax +49-69-985580-40

e-Mail **mail@volz-servos.com**
Website **www.volz-servos.com**

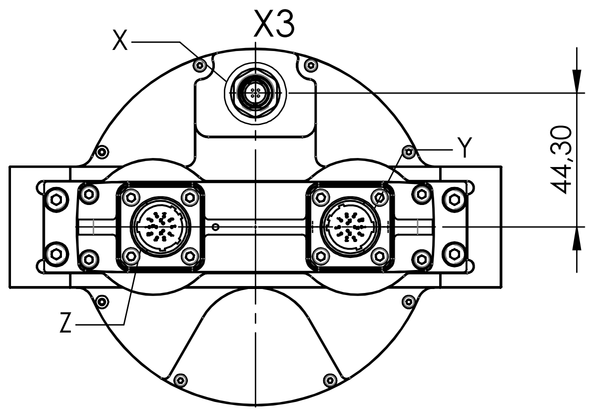
Parameter		Standard Mode	Degraded Mode
Operating Data Clutch			
Supply Voltage (rated)		28 V	
Supply Voltage Range		24 ... 30 V DC	
Rated Current 1	at rated voltage	1,1 A	
Rated transmittable Torque 2 at rated voltage (without slippage)		30 Nm	
Operating Temperature		-30 ... +40 °C	
Operating Data Servo (please see datasheet of DA 30-HT-D for more details)			
Supply Voltage (rated)		28 V DC	
Supply Voltage Range		12 ... 32 V DC	
Standby Current 1	at rated voltage	0,1 A	0,1 A
Rated Current 1	at rated voltage	4,5 A	2 A
Peak Current 1	at rated voltage	7,8 A	N.A.
Rated Torque 1	at rated speed	36,0 Nm	14,0 Nm
Peak Torque 1	at rated voltage	64,0 Nm	26,0 Nm
No Load Speed 1	at rated voltage	165 °/s	100 °/s
Rated Speed 1	at rated torque	115 °/s	75 °/s
Max. Travel Angle 3		±160° = 320° total travel	
Backlash (mechanical)		≤ 0,6°	
Position Error under Temperature 4		≤±1°	
Operating Temperature Range		-30 ... +70 °C	
Storage Temperature Range		-55 ... +85 °C	
Weight 1		4260 g	

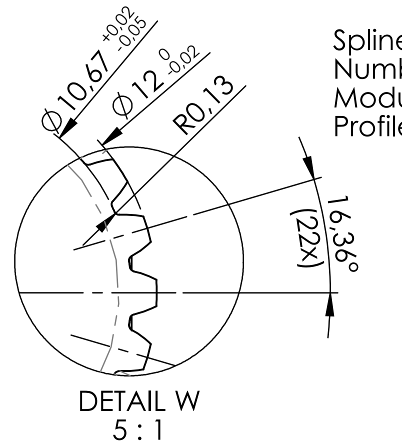
1) Tolerance ±10%
2) Tolerance ±20%
3) without clutch
4) -20...+50°C , Δt=70°C

Item No.:

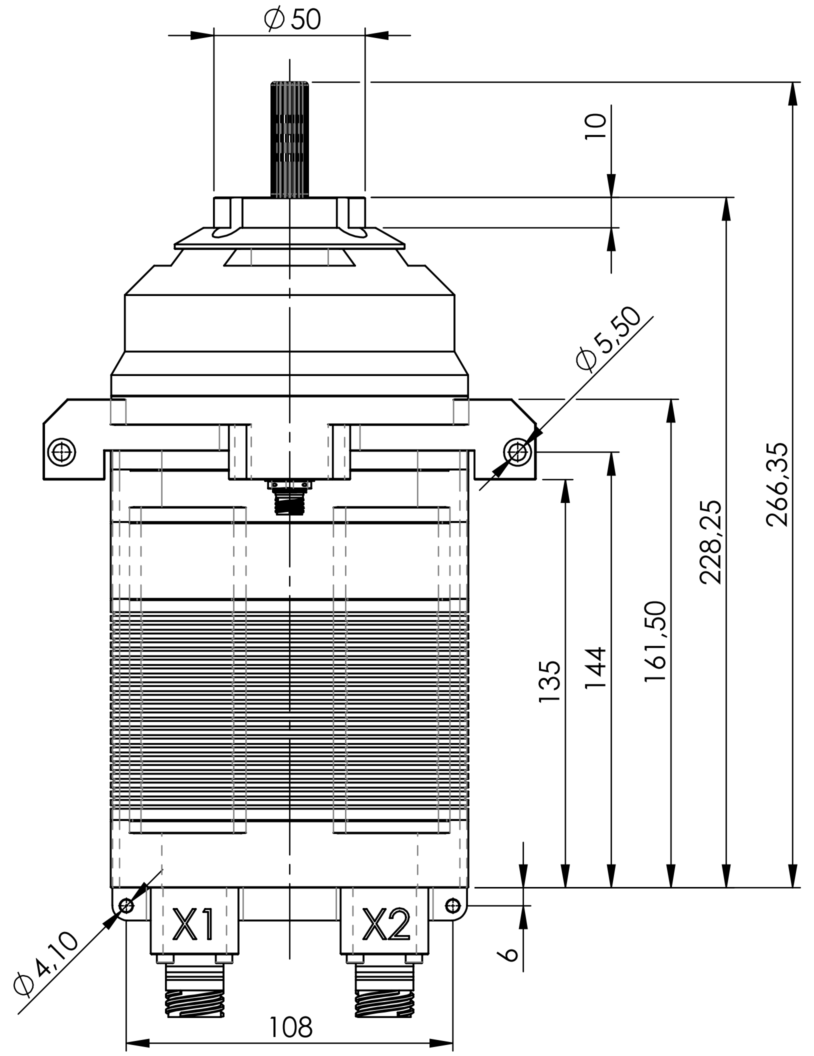
DA 30.HT.D.30.5848-3-MCCS

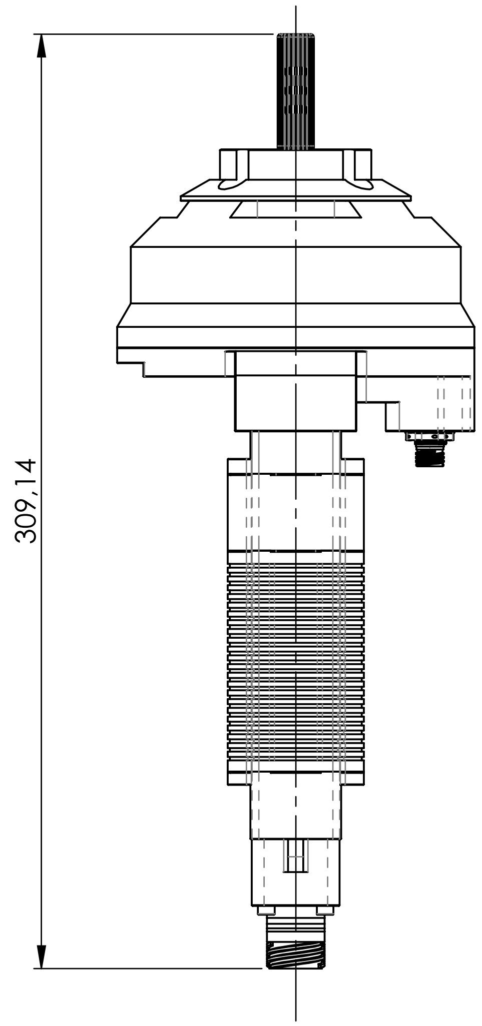
DA	Digital Actuator
30	30mm Class
HT	High Torque Version
D	Duplex (redundant) Version
30	28-32V DC Power Supply
5848	Internal Number
3	RS 485 Command Interface
MCCS	Magnetic Clutch, Coaxial Shaft with internal Sensor



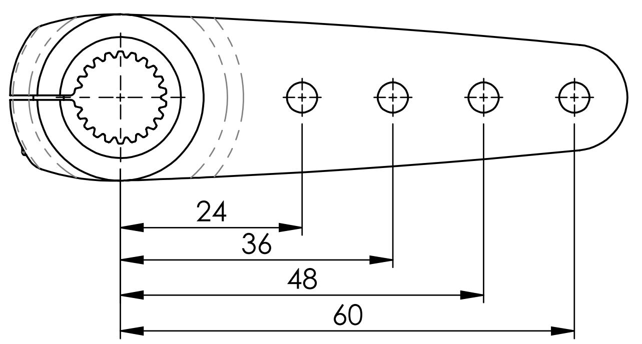


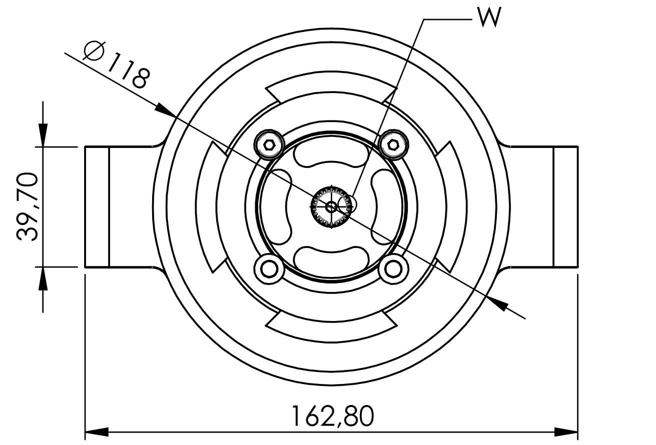
Spline similar to DIN 867
Number of teeth: z = 22
Module: m = 0,5mm
Profile shift coefficient: x = +1,0





Standard Servo Arm





Servo Case Surface Treatment: HART®-Coat

Drawing not to scale / Zeichnung nicht maßstäblich

VOLZ Servos GmbH & Co. KG
Heinrich-Krumm-Straße 5
63073 Offenbach
Germany
www.volz-servos.com

Title / Benennung:
DA 30-HT-D-MCCS
Configuration Control

Dwg. No. / Zch.-Nr.: 519-6000-06
Rev.: A
Scale / Maßstab: 1:2.5
Sheet / Blatt: 1/2
A3

Content is subject to change without notice

RS 485 Communication Parameters	
Baudrate 1)	115200
No. of Data Bits	8
No. of Stop Bits	2
Parity	None
Data Frame	6 bytes
Max. Frame Rate	100 Frames per second
Signal Polarity	One = High , Zero = Low
Address Range	0x01 ... 0x1E

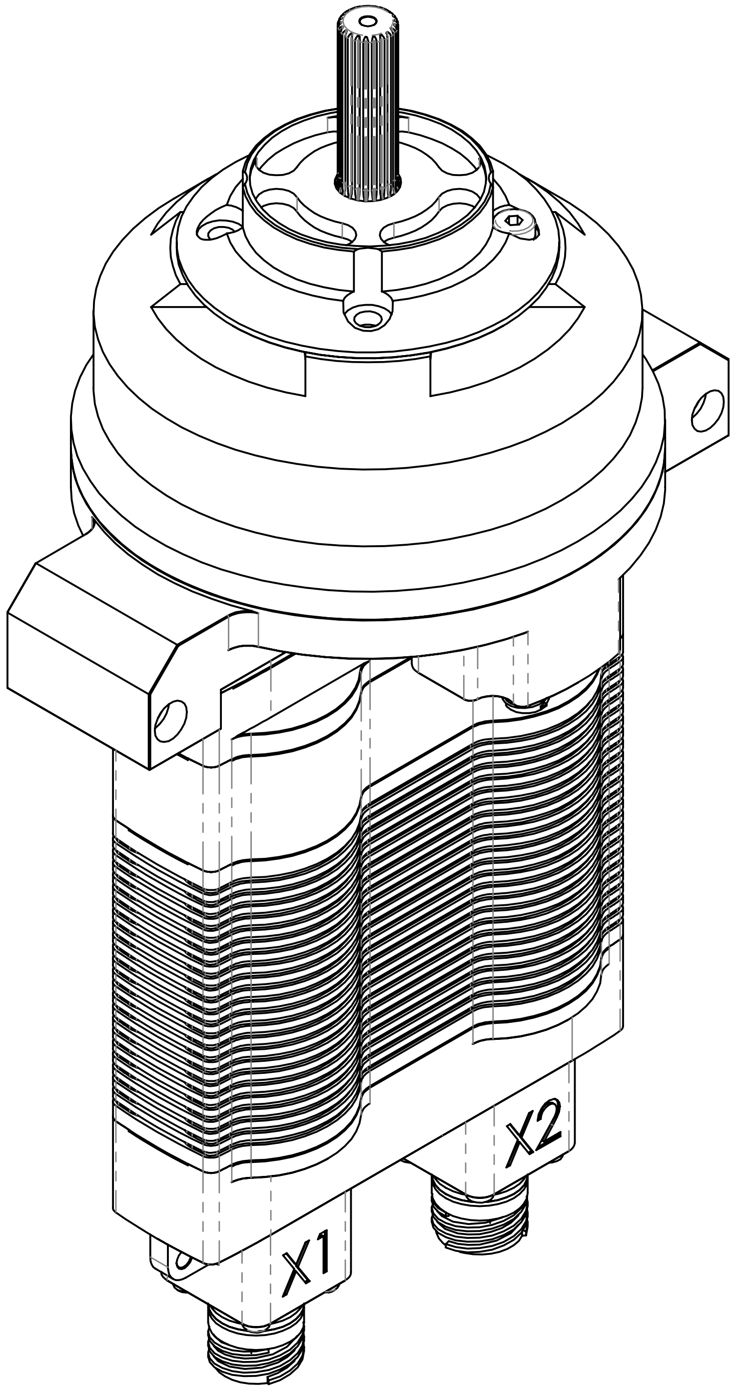
1) Other baudrate on request

RS 485 Command / Response Frame

Byte #	Description
1	Command / Response-Code
2	Actuator ID
3	Argument 1
4	Argument 2
5	CRC High Byte
6	CRC Low Byte

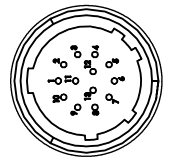
Harness Configuration

connect		to
X3 - Pin 2	→	X1 - Pin 10
X3 - Pin 4	→	X1 - Pin 13



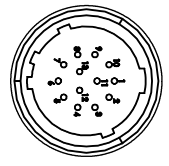
1 : 1.5

Amphenol
38999-20WB35PN
X1



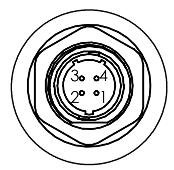
DETAIL Z
1 : 1

Amphenol
38999-20WB35PA
X2



DETAIL Y
1 : 1

Glenair MM
801-009-07M6-4PA
X3



DETAIL X
1 : 1

Pin Assignment

38999-20WB35PN (Detail Z) - X1

1	NC	Do not connect
2	PWR_1.1	Power Supply Input 1.1
3	NC	Do not connect
4	COM1_1.1	COM1 A (RS 485)
5	COM1_1.2	COM1 B (RS 485)
6	CASE_GND_1	Case Ground
7	COMi_1.1	COMi A (RS 485) / Do not connect
8	COMi_1.2	COMi B (RS 485) / Do not connect
9	NC	Do not connect
10	PWR_1.2	Power Supply Input 1.2 + Clutch Sense
11	NC	Do not connect
12	GND_1.1	Return, Signal Ground 1.1
13	GND_1.2	Return, Signal Ground 1.2

38999-20WB35PA (Detail Y) - X2

1	NC	Do not connect
2	PWR_2.1	Power Supply Input 2.1
3	NC	Do not connect
4	COM1_2.1	COM1 A (RS 485)
5	COM1_2.2	COM1 B (RS 485)
6	CASE_GND_2	Case Ground
7	COMi_2.1	COMi A (RS 485) / Do not connect
8	COMi_2.2	COMi B (RS 485) / Do not connect
9	NC	Do not connect
10	PWR_2.2	Power Supply Input 2.2 + Clutch Sense
11	NC	Do not connect
12	GND_2.1	Return, Signal Ground 2.1
13	GND_2.2	Return, Signal Ground 2.2

801-009-07M6-4PA (Detail X) - X3

1	PWR_3	Clutch Engage Power
2	CS	Clutch Sense
3	GND_3	Clutch Engage Return
4	CS_GND	Clutch Sense Ground

Drawing not to scale / Zeichnung nicht maßstäblich

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63073 Offenbach
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www.volz-servos.com

Title / Benennung:
DA 30-HT-D-MCCS
Configuration Control

Dwg. No. / Zch.-Nr.: 519-6000-06
Rev.: A

Scale / Maßstab: 1:2.5 | Sheet / Blatt: 2/2 | A3

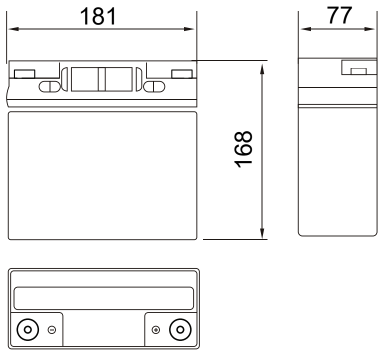
Content is subject to change without notice

ULTRA MAX®

Lithium Iron Phosphate (LiFePO4) Battery Specification

SLAUMXLI10-24(25.6V10AH)

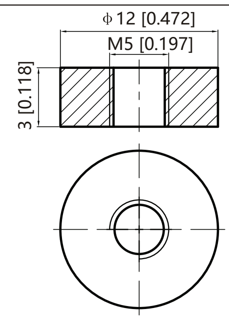
● Outer dimensions (mm)



● Specifications

Nominal Voltage		25.8V
Rated capacity (20 hour rate)		10Ah
Dimensions	Total Height	168 mm(6.62inches)
	Height	168 mm(6.62inches)
	Length	181 mm (7.13inches)
	Width	77 mm (3.03inches)
Weight Approx		2.7Kg (5.95 lbs)
Terminal		M5

● Terminal Type (mm)



● Characteristics

Capacity Retention		>80% at 28 days
Cycle Life		>80% at 1800 Cylces
1.5 hour discharge to 10.5V		4.0 A
Internal Resistance		<50 mΩ
Charge Charecteristics	Charge Voltage	28.8±0.1V
	Charger Current	<5A
Discharge Charecteristics	Continuous Current	15A
	Maximum Pulse Current	70A(<1s)
	Discharge Cut-off Voltage	20V
Tempreture	Charge Tempreture	0°C-45°C(32°F-113°F)
	Discharge Tempreture	-20°C-60°C(-4°F-140°F)
	Storage Tempreture	0°C-40°C(32°F-104°F)

● Discharge Curves 25℃(77℉)