University of Birmingham

School of Engineering
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Individual Project Report

FINAL REPORT

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Project Title	Design and Implementation of Carbon Fibre Suspension Linkages for a Formula Student Race Car.

Abstract

This thesis presents the development and validation of carbon fibre suspension links for the 2026 UBRacing Formula Student car. Strain gauge testing was used to validate theoretical suspension loads, while laminate analysis, bonded joint testing and full scale tensile testing were used to drive the final design. The selected carbon tube met the strength target set and the bonded joint achieved a design shear strength of 16.2 MPa at 40°C after surface treatment and temperature correction. Full link testing achieved a stiffness of 10,611 N/mm, exceeding the 7,140 N/mm target, and sustained 1.5 times the design load before yielding. The final carbon fibre suspension package offers a 1.5 kg mass saving over the steel counterpart which equates to 5.5 points gained in all dynamic events while meeting the required strength and stiffness targets for competition use.

Nomenclature

CFRP	Carbon fibre reinforced polymer
FSUK	Formula Student UK
CLT	Classical Laminate Theory
CoG	Centre of gravity
DAQ	Data acquisition system
DP490	3M Scotch-Weld DP490 structural epoxy adhesive
FS	Formula Student
FUWB	Front upper wishbone
FLWB	Front lower wishbone
IMU	Inertial measurement unit
IPA	Isopropyl alcohol
SG	Strain gauge
SFE	Surface free energy
UD	Uni-directional
UTS	Ultimate tensile strength
7075-T651	High-strength aluminium alloy temper designations
ABD	Extensional, coupling, and bending laminate stiffness matrix

Acknowledgments

I would like to acknowledge the contributions and support of the following individuals:

Dr. José Martin Herreros	For his support and guidance throughout the project, as well as for providing access to the Civil Engineering Laboratory MTS tensile testing machine.
Mr. Aleksander Matuszkiewicz	For his committed support during the strain gauge investigation, particularly with the electronic integration of the measurement devices.
Mr. Maninder Dayal	For his extensive support with carbon machining and for making the Matsuura FX-5 available for this work.
Mr. Emmanuel Asare	For sharing his composite expertise and providing valuable practical support throughout the project.
Mr. Samuel Wilson	For the generous allocation of team resources towards the project.
Mr. Christopher Finister, Mr. David Jackson & Mr. Sebastian van Os	For their generous mentorship and guidance during my time in the Systems department at Red Bull Technology, as well as for their continued support throughout this project..
Mr. Matthew Lloyd & UK Composites team	For their exceptional generosity in machining the wishbone tooling patterns, providing tooling carbon and supplying composite consumables.
Mr. Shavair Brown	For machining the R&D lugs used in the tensile testing.
Mr. Christopher Howey & Mr. Steve Laurie	For sharing extensive knowledge on plasma treatment and for supporting the project through sponsorship from Tantec Ltd.
Mr Jack Chester	For sharing extensive knowledge on precision measurements and for supporting the project through sponsorship from Procter & Chester Measurements Ltd.
Mr. Adrian Fitts	For providing Iscar tooling for the machining of carbon fiber components.
Mr. Sasi Karthikeyan & Mr. William Sandford	For giving their time to help organise and laminate the composite moulds for the wishbones.

Contents

1 Introduction

1.1 Motivation

Formula Student (FS) is an engineering competition in which multidisciplinary student teams compete annually with a self-developed race car. Since racing performance depends on continuous changes in velocity, suspension design is critical to maintaining tyre contact, stability, and driver control [1]. Competitor analysis conducted within UBRacing, the University of Birmingham's Formula Student team, revealed that the top five teams achieved an average 7% overall improvement across all dynamic events. In response, the team has set ambitious design targets for the 2026 competitor, including a total vehicle mass of under 180 kg.

The suspension assembly forms part of the vehicle's unsprung mass, which directly affects the tyre's ability to follow road surface variations and maintain consistent contact with the track. Race car performance depends not only on suspension geometry, but on how accurately that geometry is maintained under load [2]. Compliance in the suspension links can cause unintended changes in wheel alignment, particularly toe angle, during braking and cornering. This toe compliance can reduce predictability and alter the intended handling balance.

Carbon fibre suspension members therefore offer a strong design justification, as their high specific strength & stiffness provides the potential to reduce unsprung mass while limiting elastic deflection and preserving the designed suspension kinematics under load.

1.2 Aim of Work

The aim of this thesis is to implement a carbon fibre suspension link solution for the 2026 UBRacing car with a sub 2.5 kg total mass whilst meeting the axial deflection and strength targets set.

1.3 Objectives

- Conduct on-track strain gauge testing on the 2025 FSUK entrant to determine suspension link loads and correlate results with the theoretical model.
- Set appropriate strength and stiffness targets to which components should be designed to.
- Perform physical testing of bonded joints and carbon lug specimens to validate analytical calculations.
- Apply test driven design improvements and manufacture components for the FSUK 2026 competition car.

2. Design Loads

2.1 Strain Gauging

Representative suspension loads were required to size the carbon suspension members and metallic interfaces against tensile and compressive loading. The design process therefore relied on a theoretical suspension load model, which predicted the axial forces in each wishbone member under braking, cornering and combined loading cases. To provide confidence in these predictions, strain gauge (SG) testing was carried out on the previous year's vehicle and compared against the existing load model. This allowed the theoretical loads to be checked against physical vehicle data before being used for material selection, laminate sizing, metallic insert design and joint sizing [3].

2.1.1 Strain Gauge Selection

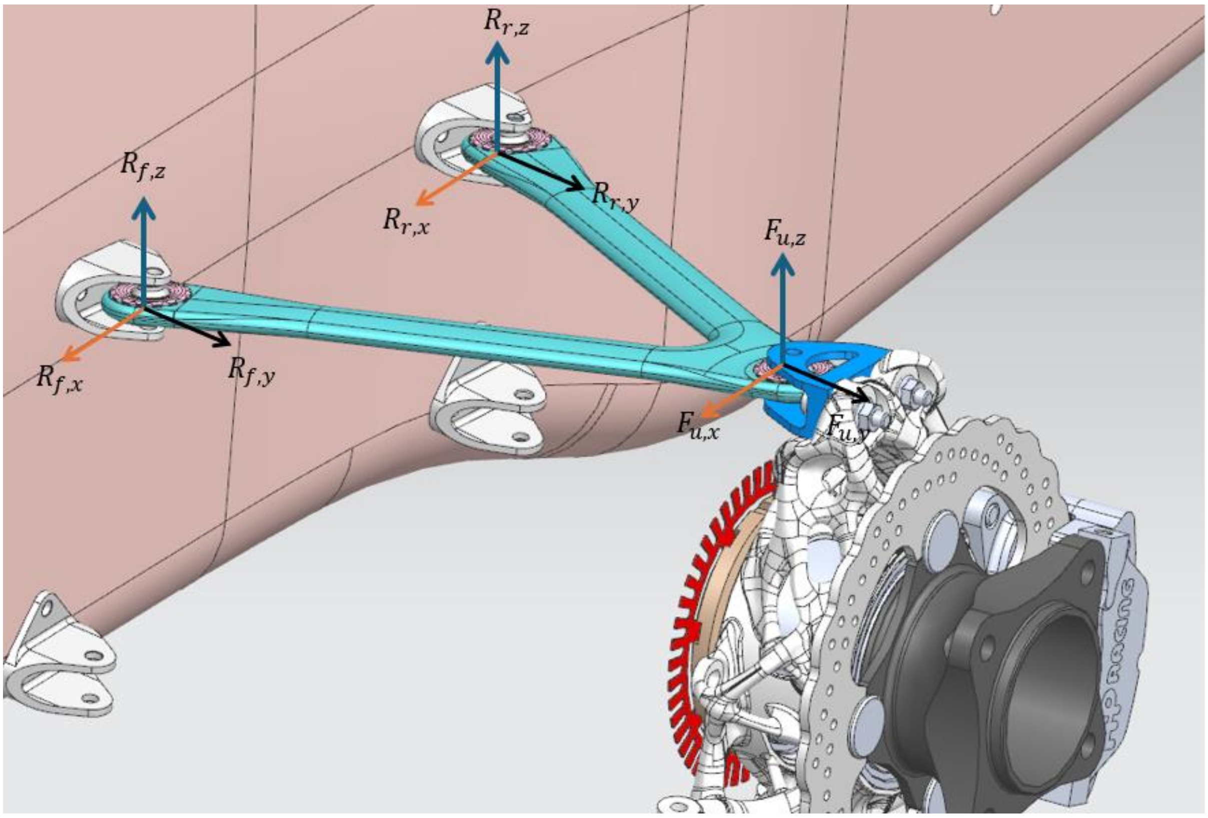


Figure 1a: Overall upper wishbone free-body diagram.

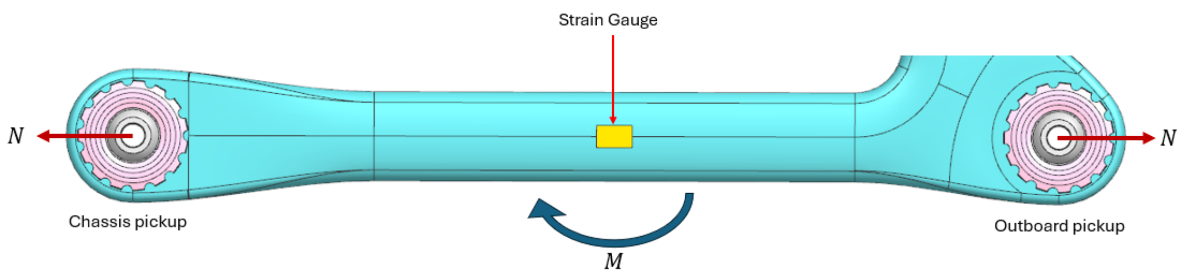


Figure 1b: Instrumented wishbone member (axial model).

The upper wishbone load path was idealised using the free-body diagrams shown in Figure 1a. This represents the overall wishbone assembly, where loads from the tyre and upright are applied at the outer joint and reacted at the front and rear chassis pickups. These forces are transferred through the wishbone legs, allowing the selected member to be considered for (SG) instrumentation.

Figure 1b isolates the instrumented wishbone leg. For the purpose of load validation, the member was treated primarily as an axial load-carrying component, with the dominant force acting along the member axis. The strain gauge was therefore aligned parallel to the leg to measure the axial strain associated with the member force, N. Although local bending and shear may be present due to joint offsets and assembly stiffness, the measurement was considered suitable for validating the predicted axial load from the suspension model.

A single linear strain gauge in a quarter-bridge configuration was selected as a practical compromise between measurement accuracy, installation complexity and available acquisition hardware. A full-bridge arrangement would provide improved bending compensation and thermal stability; however, wiring complexity and requirement for a robust trackside setup made a single-gauge solution more practical. As a result, the measured strain was treated as a representative local axial strain rather than a complete description of the member's strain field.

The SGD-5/350-LY11 SG was selected because the instrumented wishbone leg was treated primarily as an axial load-carrying member. The single linear grid was aligned parallel to the member axis so that the measured strain corresponded mainly to the axial force in the wishbone leg. The 5 mm gauge length provided a suitable compromise between local strain measurement and strain averaging. The 350 Ω resistance reduced self-heating and lead wire sensitivity compared with lower-resistance gauges, improving measurement stability during vehicle testing. The polyimide backing was suitable for general static and dynamic stress analysis and provided sufficient flexibility for installation on the wishbone surface [4]. Although the free-body diagram shows that shear and bending may also be present, the single-gauge arrangement was considered acceptable because the aim was to validate the predicted axial member force rather than determine the complete multi-axial stress state.

For an expected strain of 850 με, the resistance change can be estimated using:

$$\frac{\Delta R}{R} = k\varepsilon \qquad (1)\ [5]$$

Where:

ΔR is the change in SG resistance, Ω

R is the nominal SG resistance, Ω

k is the gauge factor of the SG

ε is the measured strain

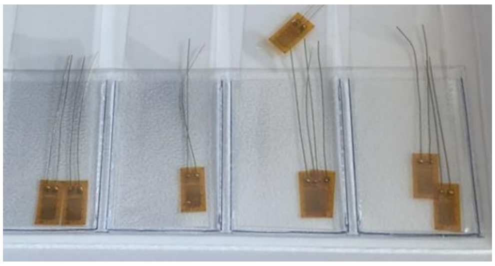


Figure 2: SGD-5/350-LY 11 SGs.

Using a k of 2.05 as stated by the manufacturer, this corresponds to a resistance change of around 0.60 Ω, making the signal suitable for acquisition using a Wheatstone bridge and SG amplifier.

2.1.2 Installation & Calibration

The nitrocarburised surface layer was locally removed at the gauge location to expose the base material and improve strain transfer between the wishbone substrate and the strain gauge. This was necessary because the surface layer may have different stiffness and strain behaviour from the underlying material, which could reduce the accuracy of the measured substrate strain. The gauge was positioned using low-residue tape. Care was taken to avoid contaminating the prepared surface, as adhesive residue could reduce bond quality and strain transfer. A cyanoacrylate-based adhesive was used because it is commonly used for room-temperature strain gauge installations, provides rapid bonding, and is compatible with polyimide-backed foil gauges. The adhesive was selected over slower-curing alternatives because of the lower overall cost.

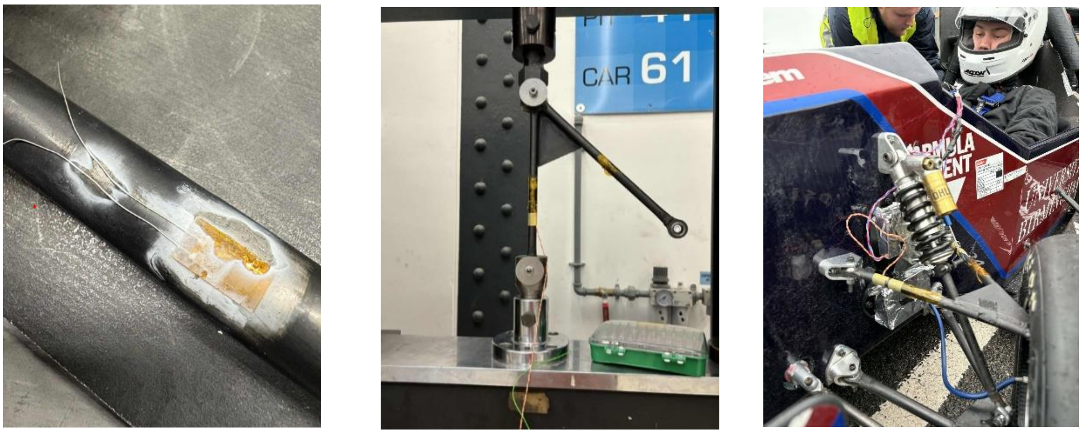


Figure 3: Strain gauge installation & calibration.

BS 8422 was used as a reference for strain gauge load-cell calibration practice; however, a full BS 8422 calibration curve was not produced. The standard is intended for the calibration of strain gauge load-cell systems and requires a controlled calibration procedure including multiple force increments, repeated loading series and assessment of non-linearity and reproducibility. In this project, the instrumented wishbone was not being certified as a standalone load cell, but was instead used to provide an approximate axial force measurement for comparison with the suspension load model.

A simplified first-order calibration was therefore applied. The wishbone was loaded in tension using an Instron machine, which provided the reference force measurement. The unloaded bridge output was recorded as the zero offset, and the change in Arduino output under known tensile load was used to define a voltage-to-force sensitivity. This produced the relationship:

$$val = 5.41 \times (frl - 547) \times 5 \div 1024 \qquad (2)$$

Where:

frl is the numerical output from the forward leg Wheatstone bridge

val is the load in kN

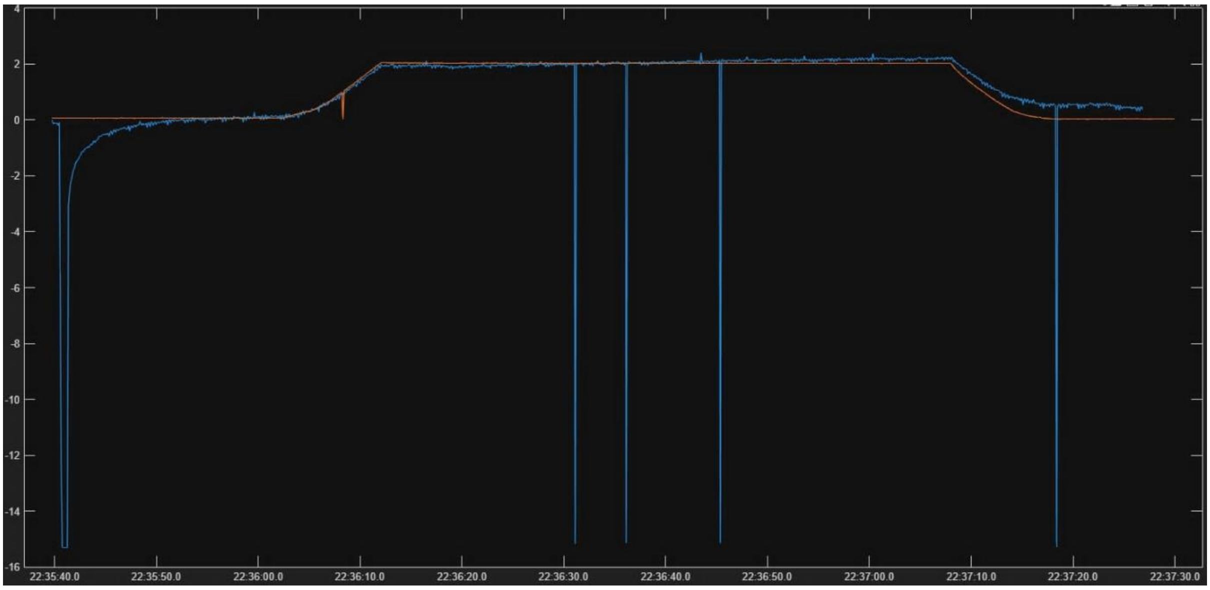


Figure 4: Calibration load curve showing Instron force output in orange and strain gauge amplifier output in blue.

2.1.3 Dynamic Vehicle Testing

To correlate the SG load output with the vehicle acceleration vector, an inertial measurement unit (IMU) was installed at the predetermined vehicle centre of gravity location, $CoG_{x,y,z}$. The Adafruit ICM-20948 9-DoF IMU was selected to record vehicle motion during on track testing. This sensor integrates a 3-axis accelerometer and 3-axis gyroscope, enabling acceleration, angular velocity and orientation related data to be captured.

The IMU provides digital output through SPI communication, making it compatible with the Arduino data acquisition system (DAQ) used in the test setup. A dedicated enclosure was designed for the board to ensure secure mounting and correct alignment with the vehicle coordinate system. This ensured that the measured acceleration components corresponded accurately to the longitudinal and lateral axes of the vehicle.

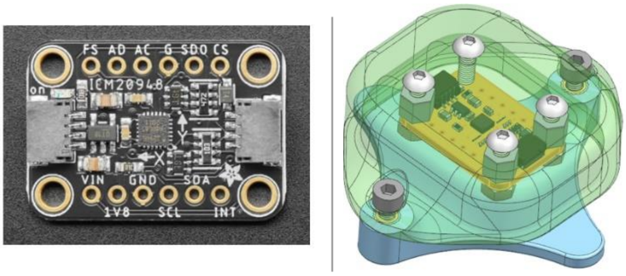


Figure 4: IMU hardware and mounting design: (a) Adafruit ICM-20948 9-DoF IMU breakout board; (b) CAD model of the designed enclosure used to mount and align the IMU on the vehicle..

All of the IMU data accumulated from the runs has been entered into a MATLAB script that creates the tractive circle diagrams (Figure 3) for the car from that specific run (Appendix A).

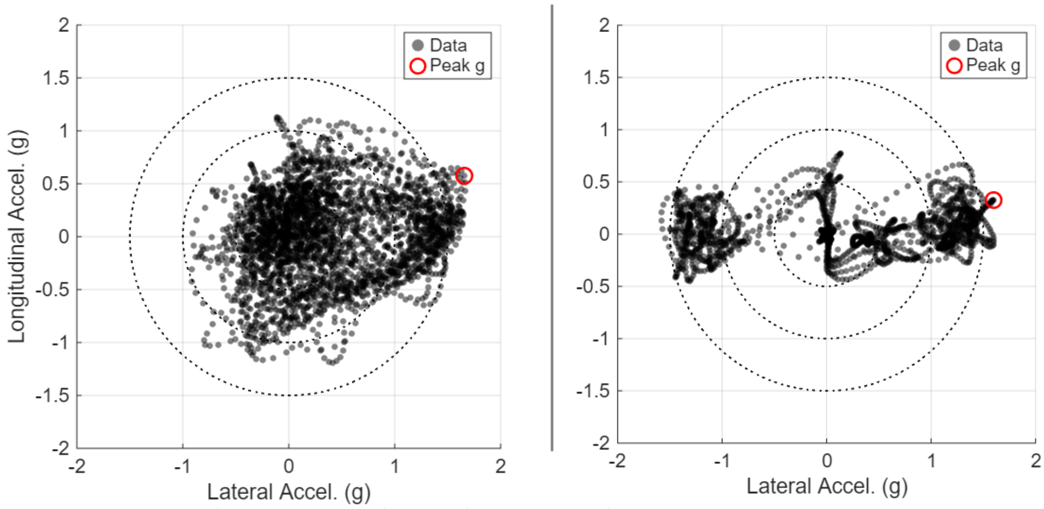


Figure 2: G-G plots for 8 minutes of clockwise running and the skid-pad test.

The raw acceleration data recorded by the IMU contained high frequency noise from sensor vibration and electrical noise within the DAQ. Before producing the G-G diagram, the longitudinal and lateral acceleration signals were therefore filtered to obtain a cleaner representation of the vehicle's dynamic behaviour.

A fourth-order Butterworth low-pass filter was applied to the acceleration data:

The sampling frequency, f_s, was 100 Hz. A cut-off frequency, f_c, of 5 Hz was selected to remove high frequency noise while retaining the lower frequency acceleration changes associated with braking, acceleration and cornering [7].

2.1.4 Data Processing

The SG amplifier output was converted into force using the calibration relationship obtained from the Instron testing $Eq. 2$.

To allow direct comparison, the SG force data and IMU acceleration data were trimmed to the same length. The resulting force and longitudinal acceleration signals were then plotted against time using a dual axis lot using the MATLAB script in Appendix A, as shown in Figure 6.

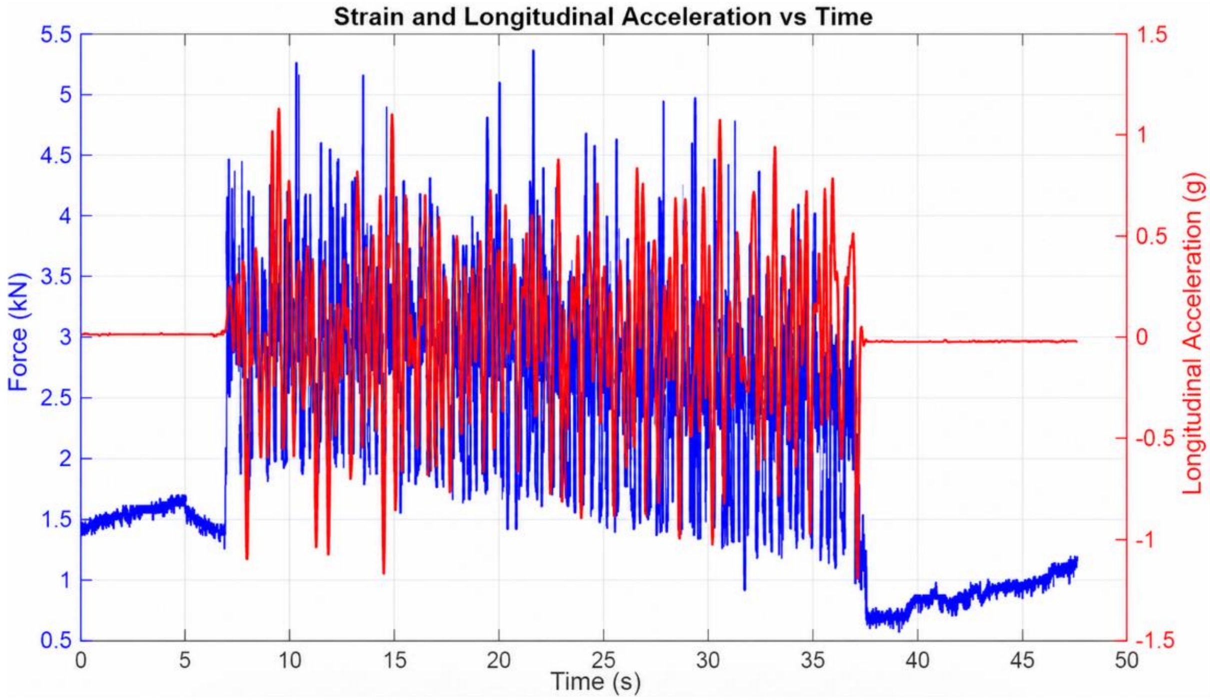


Figure 3: Force (kN) v Longitudinal acceleration (g).

Figure 6 shows that the measured wishbone force varies with the longitudinal acceleration of the vehicle during the dynamic section of the test, approximately between 7 s and 37 s. This correlation confirmed that the SG system was able to capture changes in suspension member loading during on-track running and provided a basis for comparing measured loads against the theoretical suspension load model.

2.1.5 Correlation with Theoretical Model

The theoretical load map contained predicted member loads for a range of longitudinal and lateral acceleration values. The measured IMU acceleration data was used as an input to the map, allowing a predicted load to be generated for each point in the test run.

Table 1: Extract from the theoretical load map showing four load cases across five suspension members.

G_Long	G_Lat	FL_LWB_FWD	FL_LWB_RWD	FL_UWB_FWD	FL_UWB_RWD	FL_TRD
-1.370	0.000	-1511.293	7504.652	1893.670	-3138.079	-2488.842
-1.354	0.340	-808.816	8170.459	1666.275	-3420.239	-2675.516
-1.338	0.479	-466.717	8383.191	1536.171	-3510.598	-2729.466
-1.323	0.585	-185.514	8518.769	1422.361	-3568.284	-2760.777

The strain gauged member, front left-upper wishbone-rearward leg (FL_UWB_RWD) , was selected from the theoretical load map for comparison with the SG data.

A 10-35 s event window was selected to isolate the main dynamic manoeuvres. Cross correlation was then used to correct any time lag between the measured and theoretical load signals. The comparison was first assessed using Figure 7a, which compares the lag corrected measured and theoretical load traces over time. This was then supported by Figure 7b, which shows the measured versus theoretical load agreement.

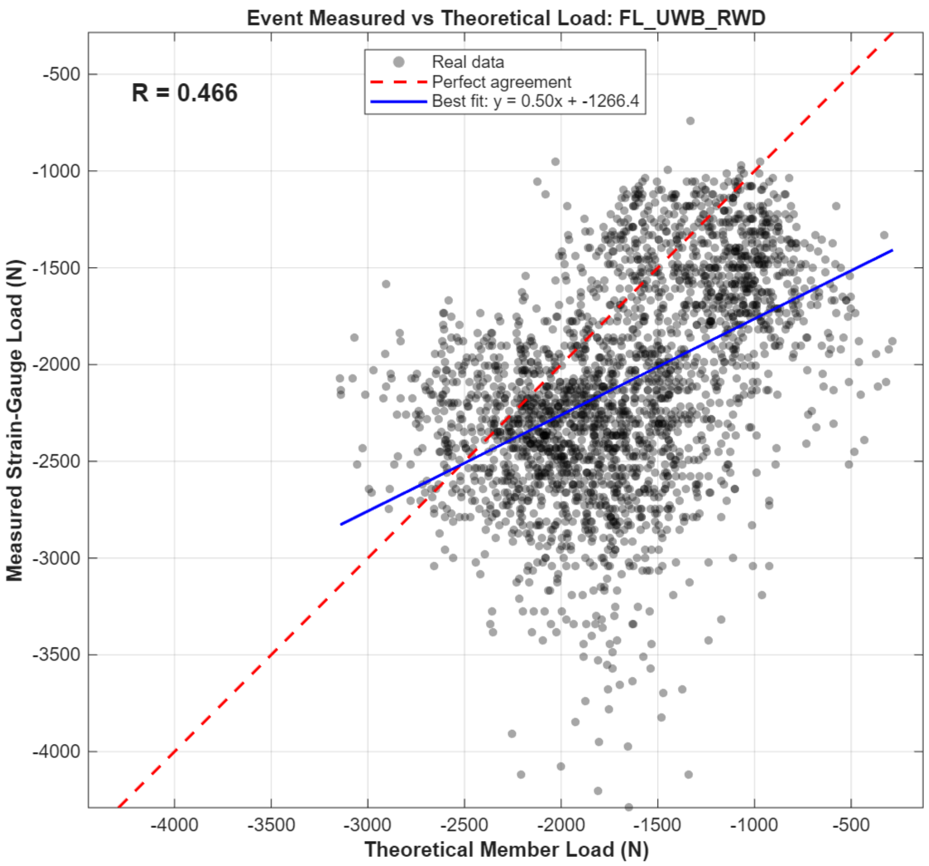


Figure 7a: Theoretical v SG data correlation plot.

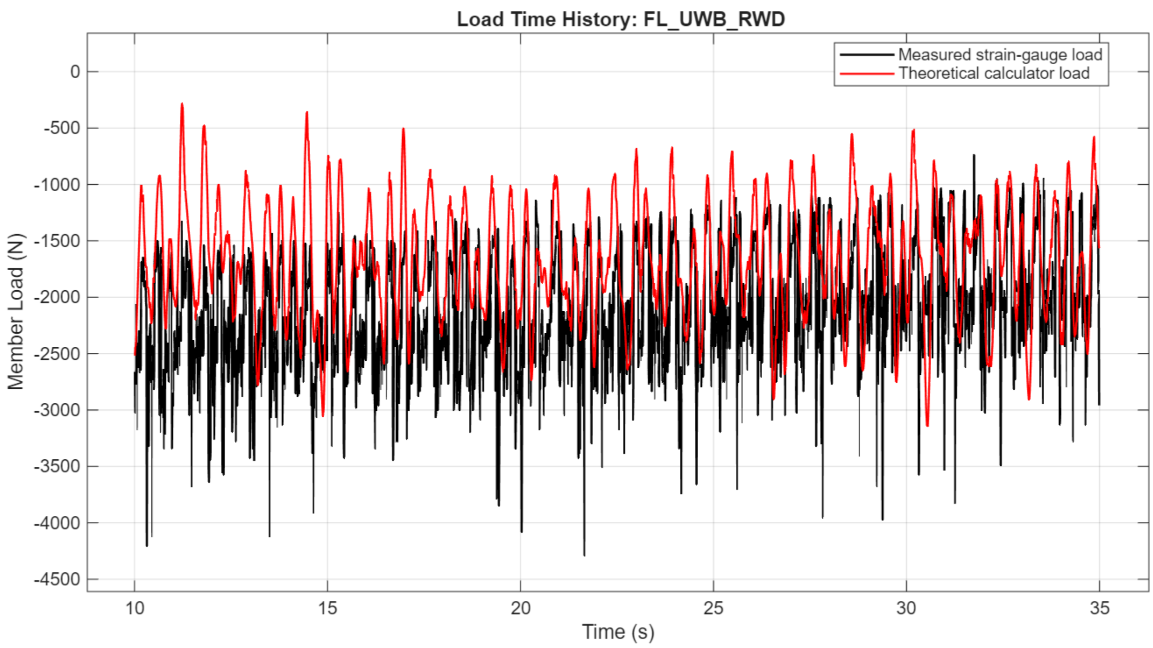


Figure 7b: Theoretical v measured force-time plot.

The final comparison produced a correlation coefficient of approximately (R = 0.466), indicating a moderate positive relationship between the theoretical member load and the strain-gauge-derived load. This suggests that the measured signal generally followed the predicted load trend during higher dynamic activity, although the agreement was not sufficient to validate the model as an absolute load prediction method.

The discrepancy between the two signals is likely to result from both measurement and modelling uncertainty. The strain gauge was installed in a quarter-bridge arrangement and therefore remained sensitive to temperature drift, local bending strain, gauge alignment error and electrical noise. In addition, the calibration was simplified rather than performed as a full load-cell calibration, meaning that non-linearity, hysteresis and repeatability were not fully quantified. The theoretical model also idealised the wishbone member as an axial load path and may not fully capture compliance, joint offsets or local bending effects.

Therefore, the result provides initial confidence that the theoretical model captures the main loading behaviour of the member, but further work would be required before using the strain gauge data as a precise absolute force reference. Improved calibration, temperature compensation, bridge completion and repeated test runs would be required to reduce uncertainty and improve correlation.

Table 2: UBR29 axial link loads.

Member	Max Tension (N)	Max Compression (N)
FLWB FWD Leg	7794.21	-2435.09
FLWB RWD Leg	8801.93	-2459.31
FUWB FWD Leg	1959.45	-3922.39
FUWB RWD Leg	1070.88	-3689.92
FTRD	1016.54	-2798.94
FPLRD	244.26	-2946.72
RLWB FWD Leg	5383.79	-1039.16
RLWB RWD Leg	7406.93	-4824.82
RUWB FWD Leg	1514.08	-4406.61
RUWB RWD Leg	1044.26	-2946.79
RTRD	5689.61	-3602.39
RPRD	0.00	-2869.22

2.2 Compliance Based Link Approach

2.2.1 Purpose

While the wishbone must satisfy strength requirements under the maximum design loads (Table 2), strength alone does not ensure acceptable suspension behaviour. The use of CF requires metallic end fittings or inserts to interface with spherical bearings and chassis/upright mounts. These metallic interfaces, bonded joints and bearings introduce compliance into the suspension system.

A stiffness target was therefore required to ensure that the wishbone links remained sufficiently stiff that compliance induced geometry changes were small relative to the designed kinematic toe and camber characteristics of the suspension. The analysis was attempted on the FLWB as they are subjected to the highest loading conditions.

2.2.2 Input Data

UBR29's suspension geometry was developed using OptimumK. The software was used to obtain the suspension kinematic characteristics required for the stiffness target calculation, including toe and camber angle gain, as shown in Figure 8.

The toe and camber compliance sensitivities were determined by virtually perturbing the wishbone link lengths incrementally in the Y-plane, then recording the resulting changes in toe and camber angle. A 2 mm displacement in the Y-direction resulted in a toe angle gain in roll of 0.121 deg/mm. The input parameters used for the stiffness target calculation are presented in Table 3.

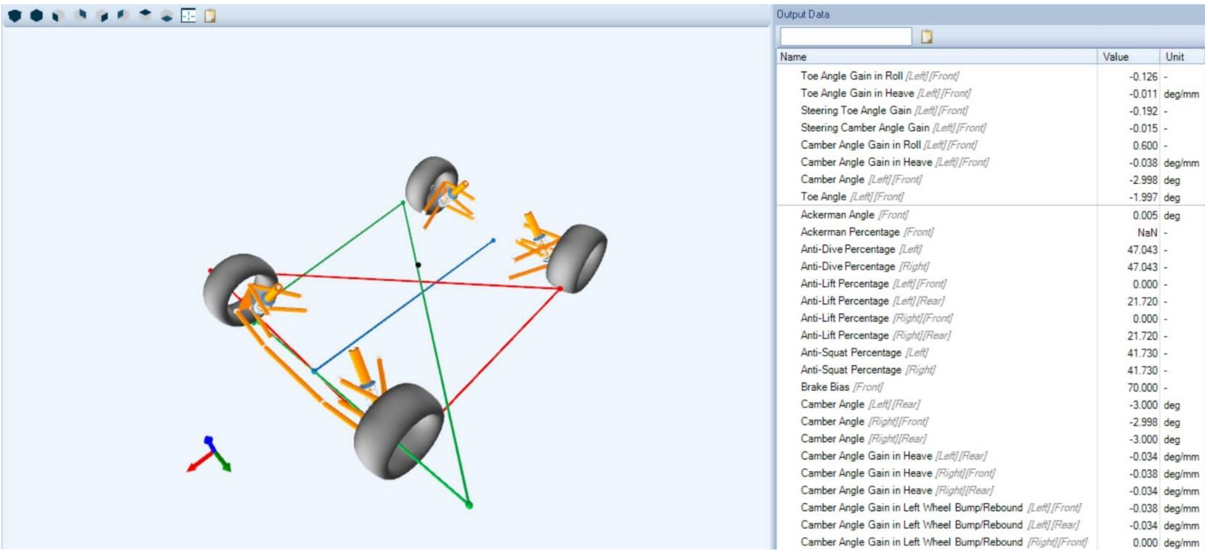


Figure 8: UBR29 suspension link setup.

Table 3: Input Parameters.

Parameter	Symbol	Value
Reference wheel travel range	Δz	10 mm
Toe gain	G_τ	0.126 deg/mm
Camber gain in roll	G_{camber}	0.600 deg/mm
Total compliance allowance	C	5% of kinematic change
Wishbone compliance budget fraction	τ_{allow}	40% of total allowance
Forward lower link design load	F_f	7794 N
Rearward lower link design load	F_r	8801 N
Link length	L	350 mm
Toe sensitivity	S_τ	0.01 deg/mm

2.2.3 Stiffness Targets & Interpretation

Table 4: Resultant stiffness targets.

Lower wishbone leg	Load (N)	Allowable axial deflection (mm)	Required stiffness (kN/mm)	Required EA (MN)
Forward leg	7794	1.26	6.35	2.22
Rearward leg	8801	1.26	7.14	2.50

These values are not to govern the sizing of the carbon fibre tube itself, as the axial stiffness of a suitably selected carbon tube is expected to exceed the required minimum. However, the result remains significant because the effective stiffness of the complete wishbone member is not determined by the carbon tube alone. The metallic lugs and bonded inserts will introduce additional compliance into the load path.

Therefore, the stiffness target should be treated as a requirement for the complete wishbone assembly, rather than only the composite tube. While the carbon tube may provide sufficient axial stiffness, excessive deformation in the bonded joint or metallic end fittings could still produce unwanted toe compliance. As a result, the design of the lugs, bond length and insert geometry must also be considered when validating the final wishbone stiffness.

The detailed stiffness target calculations are provided in Appendix B.

2.2.4 Fatigue Analysis

Rainflow counting was used to convert the measured variable amplitude load into fatigue relevant stress cycles. Fatigue damage depends on repeated cycle amplitude and count and not the maximum stress reached. Rainflow counting is a method for storing service measurements in a form suitable for fatigue analysis and life prediction, by decomposing the load history into cycles defined by their mean value and amplitude [8].

The SG derived force ranged from approximately 0.5 to 4.0 kN, corresponding to raw stresses of 12 to 91 MPa for a cross-sectional area of 43.35 mm^2 . However, Figure 9 shows that full range cycles were not present. Instead, rainflow counting identified typical cycle amplitudes of only around 13 MPa.

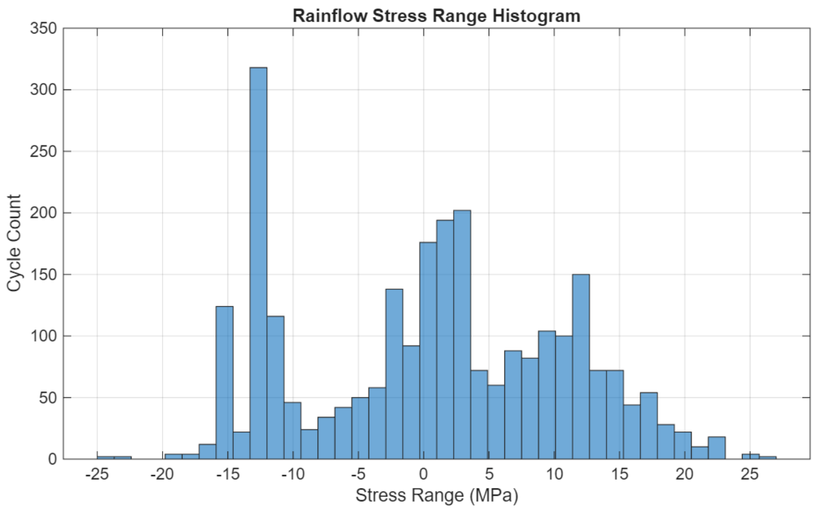


Figure 9: Rainflow stress histogram.

As meaningful fatigue damage in 7075-T6 aluminium generally requires much higher cyclic amplitudes, the predicted fatigue life is effectively infinite under the measured loading conditions. Therefore, the component experiences minimal fatigue demand, unless higher stress amplitudes, a smaller critical section, or significant bending stresses are introduced.

3 Component Sizing

3.1 Composite Laminate Sizing

3.1.1 Theory

Classical Laminate Theory (CLT) was used to predict the stresses developed in each ply of the composite tube under the applied loading. A composite laminate is made up of multiple plies stacked at different fibre orientations. By changing the ply angle, thickness and material type, the laminate stiffness and strength can be tailored to suit the expected load case [9].

Each ply has a local material coordinate system, where direction 1 is along the fibre and direction 2 is transverse to the fibre. The full laminate is analysed in the global tubular coordinate system. Since the plies may be orientated at different angles, the stiffness and stress state of each ply are transformed between the local and global coordinate systems.

The analysis uses the material elastic properties to calculate the ply stiffness, combines all ply stiffnesses into the laminate ABD matrix, solves for the laminate strains and curvatures and then calculates the local stresses in each ply. These local stresses are then used with the Tsai-Wu failure criterion to assess whether each ply is safe. A ply is predicted to fail when Tsai-Wu index > 1 [10].

3.1.2 Material Choice & Properties

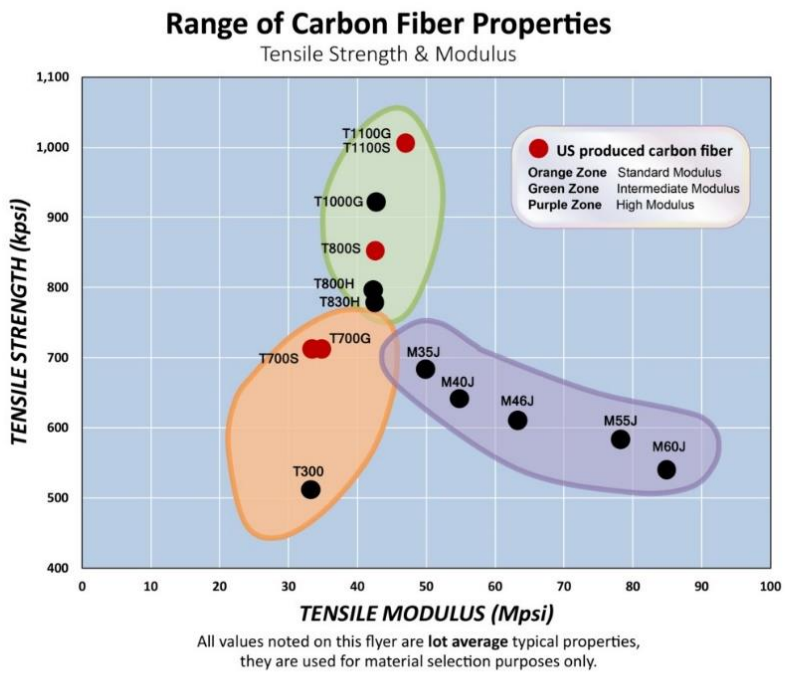


Figure 10: Toray fibres; tensile strength v modulus plot [11].

Toray is a leading manufacturer of carbon fibre materials and is widely used within aerospace and motorsport industries. Toray fibres are also commonly supplied as pre-impregnated materials by a range of composite manufacturers, making them relatively accessible for manufacturing.

For this application, fibres from Toray's M-series high modulus range were selected, as shown in Figure 10. These fibres provide a suitable balance between high tensile strength and increased stiffness, making them appropriate for lightweight structures. Higher stiffness fibres, such as M55J and M60J, were not selected because their very high modulus can make them more difficult to handle, process and manufacture reliably.

Table 5: Pre-impregnated fibre properties (Datasheets in Appendix D).

Property	Symbol	Unit	MTC400-1-C200T-M40J-42%RW-1250	MTC400-1-UD140-M46J-33%RW-300P
Longitudinal tensile modulus	E_1	GPa	67	226.6
Transverse tensile modulus	E_2	GPa	66.5	1
In-plane shear modulus	G_{12}	GPa	4	5
Major Poisson's ratio	ν_{12}	-	0.07	0.26
Longitudinal tensile strength	X_t	MPa	981	1994
Longitudinal compressive strength	X_c	MPa	737	1030
Transverse tensile strength	Y_t	MPa	893	1
Transverse compressive strength	Y_c	MPa	765	1
In-plane shear strength	S	MPa	95.9	77.2

3.1.3 Implementation

The laminate is defined in the MATLAB code using three main arrays:

```
plyAngles = [45 0 0 90 45 90 0 0 45];          % deg
plyT      = [0.20 0.133 0.133 0.20 0.20 0.20 0.133 0.133 0.2]' * 1e-3;  % m
plyMatID  = [1 2 2 1 1 1 2 2 1]';             % material per ply
```

Here, *plyAngles* defines the fibre angle of each ply, *plyT* defines the ply thickness, and *plyMatID* assigns the material type to each ply. This allows each ply to have its own orientation, thickness, and material.

The reduced stiffness terms are then calculated from the material properties:

$$Q_{11} = \frac{E_1}{1 - \nu_{21}\nu_{12}}$$

$$Q_{12} = \frac{\nu_{12}E_2}{1 - \nu_{21}\nu_{12}}$$

$$Q_{22} = \frac{E_2}{1 - \nu_{21}\nu_{12}}$$

$$Q_{66} = G_{12} \qquad \text{(3a-d) [9]}$$

These terms form the local ply stiffness matrix [Q]. The code then transforms this stiffness matrix according to the ply angle to generate the transformed stiffness matrix, allowing angled plies to be included in the global laminate model.

The transformed stiffness matrices are summed through the laminate thickness to form the ABD stiffness matrices:

[A] = in plane stiffness
[B] = extension bending coupling stiffness
[D] = bending stiffness

These are then assembled and solved which gives the laminate mid plane strains. The strain at each ply is calculated using its position through the thickness and the global ply strain is then transformed into the local ply coordinate system. The local ply stress is calculated producing the local stress components:

$\sigma_1 =$ stress along fibre
$\sigma_2 =$ stress transverse to the fibre
$\tau_{12} =$ in-plane shear stress

Finally, the Tsai-Wu failure criterion is applied to each ply using the local stresses and material strength values:

$$H_1\sigma_1 + H_2\sigma_2 + H_6\tau_{12} + H_{11}\sigma_1^2 + H_{22}\sigma_2^2 + H_{66}\tau_1^2 + 2H_{12}\sigma_1\sigma_2 \quad (4)\ [10]$$

Full script can be found in Appendix A.

3.1.4 Laminate Strength analysis

Table 6: CLT script output.

Ply	Material	Angle_deg	t_mm	sig1_MPa	sig2_MPa	tau12_MPa	Critical	TsaiWu
1	"MTC400-1-C200T-M40J-42%RW-1250"	45	0.2	38.672	39.035	-5.1923	"Shear"	-0.015283
2	"MTC400-1-UD140-M46J-33%RW-300P"	0	0.133	416.77	-0.27838	-0.020562	"Transverse"	0.047403
3	"MTC400-1-UD140-M46J-33%RW-300P"	0	0.133	416.77	-0.27838	-0.016663	"Transverse"	0.047403
4	"MTC400-1-C200T-M40J-42%RW-1250"	90	0.2	-42.334	119.39	0.0094259	"Transverse"	0.022453
5	"MTC400-1-C200T-M40J-42%RW-1250"	45	0.2	38.916	38.792	-5.1923	"Shear"	-0.015321
6	"MTC400-1-C200T-M40J-42%RW-1250"	90	0.2	-42.334	119.39	4.5866e-05	"Transverse"	0.022453
7	"MTC400-1-UD140-M46J-33%RW-300P"	0	0.133	416.77	-0.27838	0.0048232	"Transverse"	0.047406
8	"MTC400-1-UD140-M46J-33%RW-300P"	0	0.133	416.77	-0.27838	0.0087218	"Transverse"	0.047406
9	"MTC400-1-C200T-M40J-42%RW-1250"	-45	0.2	38.82	38.887	5.1923	"Shear"	-0.015306

A longitudinal tensile load of 16 kN was applied to the 9-ply laminate, with the resulting ply stresses and Tsai-Wu indices shown in Table 5. As expected, the 0° uni-directional (UD) plies carry the majority of the axial load, reaching a longitudinal stress of approximately 417 MPa. This is roughly 20% of the longitudinal tensile strength, indicating a strong margin under the applied tensile load.

The woven 45° plies experience much lower axial stress and mainly provide torsional support. Addition of these plys are necessary since loading is unlikely to be perfectly axial due to joint misalignment, bending and vibration. The woven 90° ply adds circumferential support, improving resistance to transverse deformation or splitting.

The maximum Tsai-Wu index is approximately 0.047, which is far below the failure limit of 1. This indicates that no ply is close to failure under the applied load.

The tubes are to be manufactured in accordance to the layup schedule discussed. The internal surface is to be controlled by laminating around a metallic mandrel whilst external surface is controlled by two semi-circular carbon composite moulds.

3.2 Metallic Insert Sizing

3.2.1 Approach

Figure 11: Inboard (left) and FLWB outboard (right) inserts.

The end fittings are treated as conventional single-eye lugs because the suspension load is transferred through a single pinned connection at the lug hole. The geometry is simple and the load path is direct, with the load passing from the composite tube into the metallic lug and then through the bolt at the eye.

For this type of component, the critical design region is the material surrounding the hole. The main expected failure modes are therefore bearing failure at the pin hole, shear tear-out from the hole to the free edge and tensile failure across the reduced section. These are the standard failure modes considered in lug sizing calculations.

A more complex analysis is not required as the load is primarily carried along the axis of the member and reacted through the lug eye. Therefore, the insert can be sized using the standard geometric parameters of hole diameter, lug thickness, lug width and edge distance.

3.2.2 Lug Calculation

The performance of the lugs was assessed using empirical design data. The McDonnell Douglas structural design manual provides lug strength methods based on experimental test results, with charts used to determine efficiency factors for the relevant failure modes. These charts allow the effects of lug geometry, such as edge distance, width, thickness and hole diameter to be included in the strength assessment. The lug sizing method and associated design charts were therefore taken from the McDonnell Douglas structural design manual [12].

The main failure modes considered were bearing failure, shear tear-out, net-section tension, lug yielding and bushing yielding. The lug geometry was defined using the hole diameter D, lug thickness t, lug width W, edge distance e and applied load P.

Bearing and shear tear-out were assessed using the empirical bearing equation:

$$P_{bru} = k_{br} F_{tux} A_{br} \tag{5)[12}$$

where the bearing area is

$$A_{br} = Dt \tag{6)[12}$$

The bearing efficiency factor, k_{br} was taken from the relevant bearing efficiency curve for 7075 aluminium (Appendix C). The graph relates k_{br} to the lug geometry ratios e/D and D/t.

The net-section tensile strength was checked using:

$$P_{tu} = k_t F_{tu}(W - D)t \tag{7)[12}$$

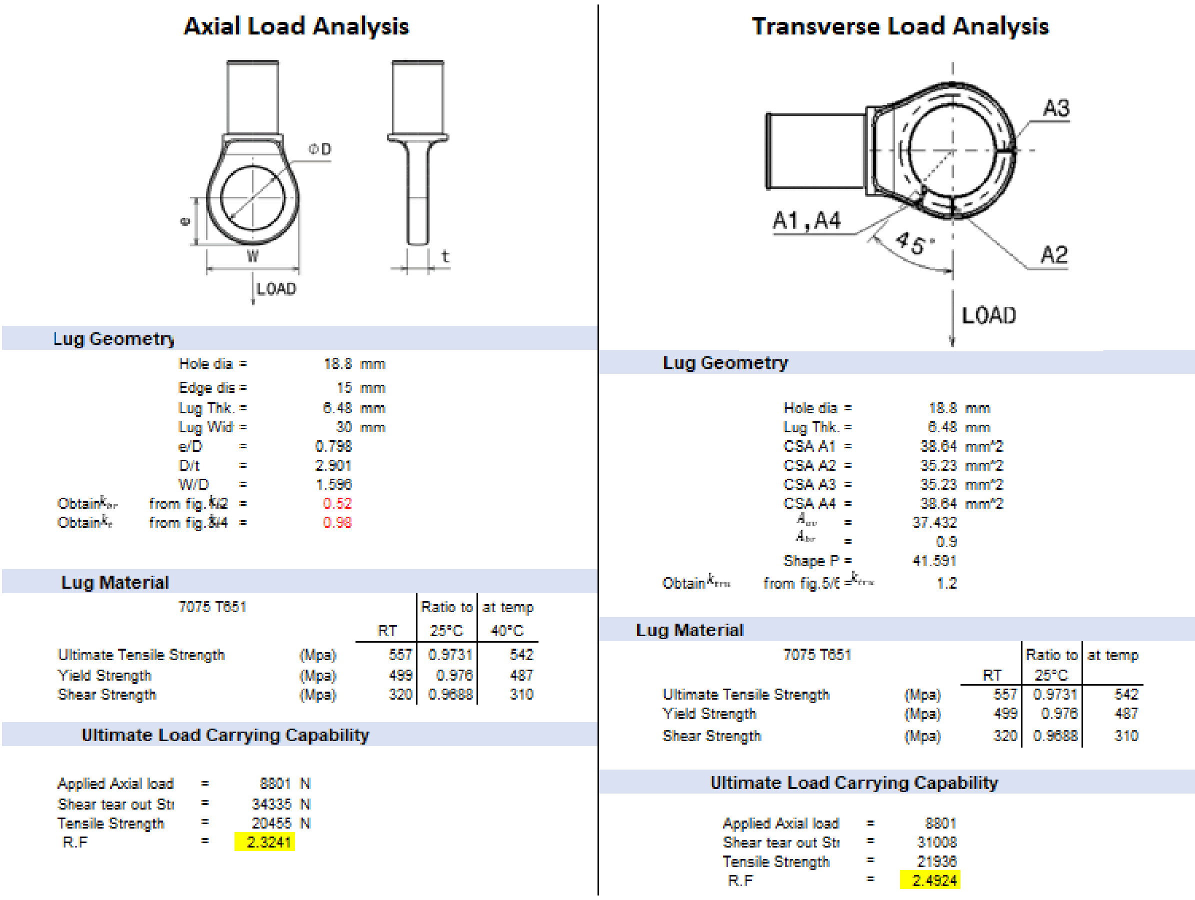
The tension efficiency factor, k_t was taken from figure C3.3.1-4a in Appendix C. These figures account for the reduction in tensile strength caused by the stress concentration at the bolt hole.

Yielding was checked using:

$$P_{bry} = k_{bry} F_{ty} A_{br} \tag{8)[12}$$

where k_{bry} was obtained from Figure C3.3.1-5 in Appendix C.

A spreadsheet was then created to be able to iterate different lug geometries quickly to come up with the most optimised shape. The lug geometry used is shown in Figure 9.



Axial Load Analysis

Lug Geometry

	Hole dia	=	18.8	mm
	Edge dis	=	15	mm
	Lug Thk.	=	6.48	mm
	Lug Wid	=	30	mm
	e/D	=	0.798	
	D/t	=	2.901	
	W/D	=	1.596	
Obtain k_{br}	from fig. 1/2	=	0.52	
Obtain k_t	from fig. 3/4	=	0.98	

Lug Material

7075 T651		RT	Ratio to 25°C	at temp 40°C
Ultimate Tensile Strength	(Mpa)	557	0.9731	542
Yield Strength	(Mpa)	499	0.976	487
Shear Strength	(Mpa)	320	0.9688	310

Ultimate Load Carrying Capability

Applied Axial load	=	8801	N
Shear tear out Str	=	34335	N
Tensile Strength	=	20455	N
R.F	=	2.3241	

Transverse Load Analysis

Lug Geometry

	Hole dia	=	18.8	mm
	Lug Thk.	=	6.48	mm
	CSA A1	=	38.64	mm^2
	CSA A2	=	35.23	mm^2
	CSA A3	=	35.23	mm^2
	CSA A4	=	38.64	mm^2
	A_{av}	=	37.432	
	A_{av}/A_{br}	=	0.9	
	Shape P	=	41.591	
Obtain k_{tru}	from fig.5/6	= k_{tru}	1.2	

Lug Material

7075 T651		RT	Ratio to 25°C	at temp
Ultimate Tensile Strength	(Mpa)	557	0.9731	542
Yield Strength	(Mpa)	499	0.976	487
Shear Strength	(Mpa)	320	0.9688	310

Ultimate Load Carrying Capability

Applied Axial load	=	8801
Shear tear out Str	=	31008
Tensile Strength	=	21936
R.F	=	2.4924

Figure 12: Lug Calculator.

3.3 Bonded Joint Sizing

3.3.1 Adhesive Selection

3M DP490 was selected instead of 3M 9323 mainly for manufacturing consistency. Although 9323 may be suitable for structural bonding, its viscosity is too high to reliably fill the adhesive gap between the insert and tube [13]. This and its difficulty to prepare makes it less practical for bonding.

DP490 was preferred because it is a two-part structural epoxy designed for high toughness and strength, with a 90-minute work life and 2:1 mix ratio, making it easier to apply accurately during assembly [14]. The datasheet also reports strong bonding performance on relevant substrates, including 30 MPa overlap shear strength on sandblasted aluminium and 36 MPa on CFRP, supporting its suitability for aluminium to carbon composite bonding.

The main remaining concern is adhesive failure at the carbon-aluminium interfaces, which will be addressed through careful surface preparation before bonding.

3.3.2 Surface Treatment Scope

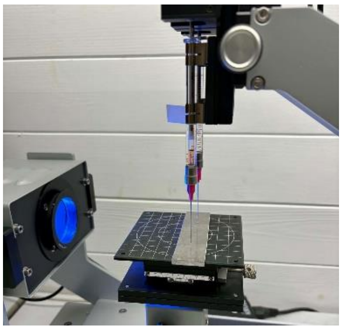
The shear strength values from the datasheet cannot be directly used to size the final joints. They are based on controlled laboratory coupon tests with specific substrates, surface preparation and cure conditions. It was important to carry out physical single lap shear testing to determine what real world shear strength values could be achieved using the actual materials, preparation method and bonding process.

Surface treatment was critical because adhesive joint strength depends heavily on the condition of the bonding surfaces [15]. The aluminium samples were sandblasted before bonding to roughen the surface and increase mechanical keying, allowing the adhesive to physically interlock with the substrate. This was followed by vacuum plasma treatment. Vacuum plasma is a surface treatment process where a material is placed in a vacuum chamber and drawn down to a low vacuum. High voltage electrodes inside the chamber are then activated which ionise the remaining air. The material is then exposed to this plasma for a fixed duration before the chamber repressurises and the part can be removed. In this way, the material is uniformly exposed to a low intensity and highly repeatable treatment.

3.3.3 Plasma Treatment Trials

The aim was to identify the specific surface free energies at various vacuum plasma settings, prior to bonding lap shears. Contact angle measurements were carried out on the samples in their as received condition. Contact angle describes the angle formed between a liquid droplet and the surface of a material [15]. A lower contact angle generally indicates a more hydrophilic surface, which can correspond to a higher surface free energy (SFE).

For the aluminium samples, only the water contact angle was measured, as additional test liquids may interact with the metal surface and produce unreliable results. For the carbon fibre samples, contact angle measurements were taken using both water and diiodomethane. A minimum of three measurements were taken for each sample, and the mean value was used to calculate the surface free energy.



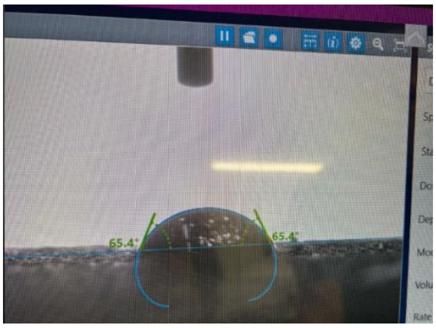


Figure 13a: Contact angle measurements using DSA - Contact Angle and SFE analyser

The following results were taken from sample 1:

Table 7a: Initial contact angle measurements.

	Measured Contact Angle (°)		Calculated SFE (mN/m)		
	Water	Diiodomethane	Polar	Disperse	Total
Aluminium	90-65*	-	-	-	-
Carbon Fiber	68.01	37.35	7.97	40.85	48.83

* the measured contact angle changed over 1-2 seconds, starting at ~90° and stabilising ~65°. This would indicate the water was reacting with a contaminant on the surface.

The same sample was then cleaned with IPA and retested:

Table 7b: Contact angle measurement post IPA cleaning.

	Measured Contact Angle (°)		Calculated SFE (mN/m)		
	Water	Diiodomethane	Polar	Disperse	Total
Aluminium	70	-	-	-	-
Carbon Fiber	84.36	38.67	2.10	40.21	42.31

The change observed between the initial and IPA cleaned sample would indicate the samples have some surface contamination that has been removed or reduced by the cleaning process. All further testing was completed on samples that are first cleaned with IPA. All samples were treated in vacuum plasma using a VacuTEC 2020 with metal electrodes. There are 3 main parameters that can be adjusted with vacuum plasma. Duration (s) - Typical exposure to plasma ranges between 20 seconds and 5 minutes depending on the material and required result.

Pressure (mb) - Typical pressures are 0.5 mb – 3 mb. At lower pressures, there are fewer interactions but the ions will likely be more energetic when they make contact with the surface. At higher pressures, there are more collisions but they will tend to be less energetic.

Power (W) - Power is relative to the chamber size. On the system used, up to 1kw can be generated but more general power settings are 300-500 W for this size.

For the tests, a setting of 0.7 mb and 500 W were used, with only the duration changing between tests.

Setting 1 - 45 seconds

Setting 2 - 90 seconds

Setting 3 - 2x 90 second cycles

Setting 4 - 180 seconds

Figure 13b: Sample Treatment chamber.

Table 7c: Contact angle measurement post treatment.

		Measured Contact Angle (°)		Calculated SFE (mN/m)		
		Water	Diiodomethane	Polar	Disperse	Total
Setting 1	Aluminium	23	-	-	-	-
	Carbon Fiber	26.04	31.45	28.72	43.55	72.27
Setting 2	Aluminium	33-19*	-	-	-	-
	Carbon Fiber	23.89	26.84	28.61	45.41	74.01
Setting 3	Aluminium	15	-	-	-	-
	Carbon Fiber	18.80	19.12	29.06	47.97	77.03
Setting 4	Aluminium	11	-	-	-	-
	Carbon Fiber	19.56	23.23	29.47	49.70	76.17

The following graph is then plotted from the acquired results:

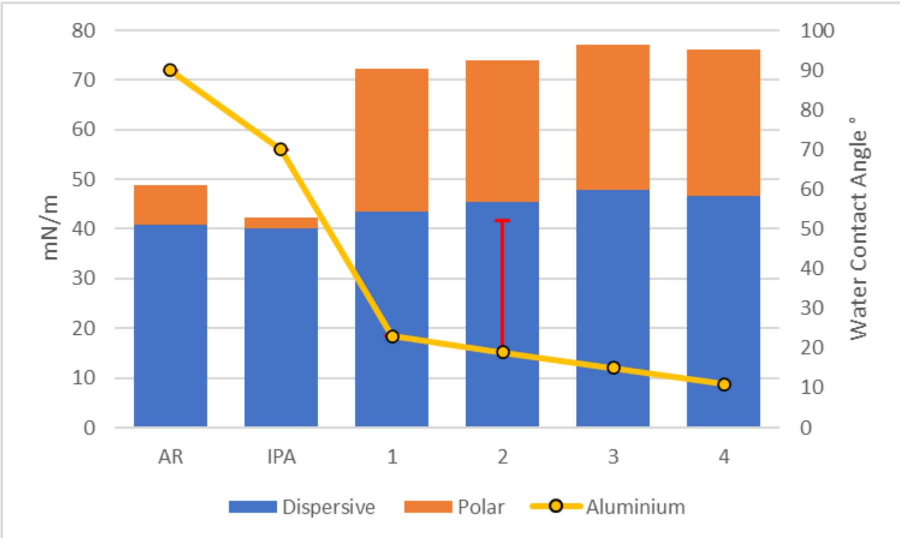


Figure 13c: Plot of CA for Aluminium, calculated SFE for CFRP samples.

The aluminium samples showed a clear trend, with increasing treatment time leading to a reduction in contact angle. Full wetting of the aluminium surface was not achieved. However, minor adjustments to the plasma power and pressure would likely allow this to be reached with minimal further development.

The carbon fibre samples showed a significant increase in polar SFE, even after short treatment durations. Longer treatment times produced further small increases in the polar component, although an increase in the dispersive component was also observed. As plasma treatment is expected to primarily affect the polar component of surface energy, an increase in the dispersive component may suggest that the surface was beginning to be over-treated. To confirm the optimum treatment condition, the surface free energy results should be compared against the corresponding lap shear strength results.

The samples were then placed in a bonding jig to control the 0.25 mm adhesive gap and left to cure at room temperature for 24h before oven curing for 1h at 80°C.

Figure 13d: Bonded samples.

3.3.4 Sample Testing

Single lap shear tests were conducted in accordance with ASTM D5868. Each specimen was pulled under displacement control at a constant crosshead speed of 13 mm/min until a brittle failure was detected by the machine [17].

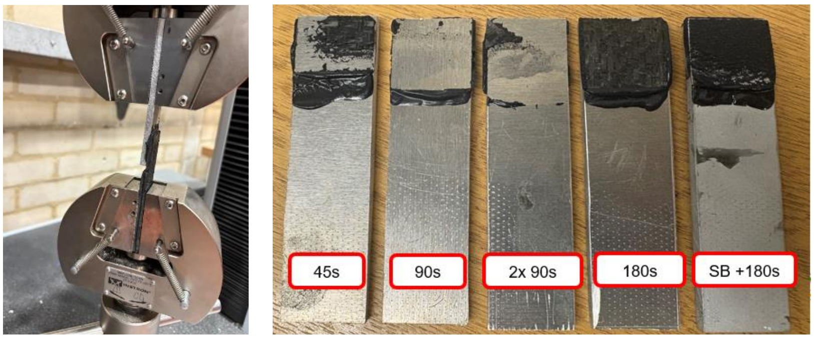


Figure 14a: Tested samples.

The maximum load at failure was recorded, and the corresponding shear strength was calculated based on the bonded area. Observations of the failure surfaces were made to assess the failure mode and verify consistency between samples.

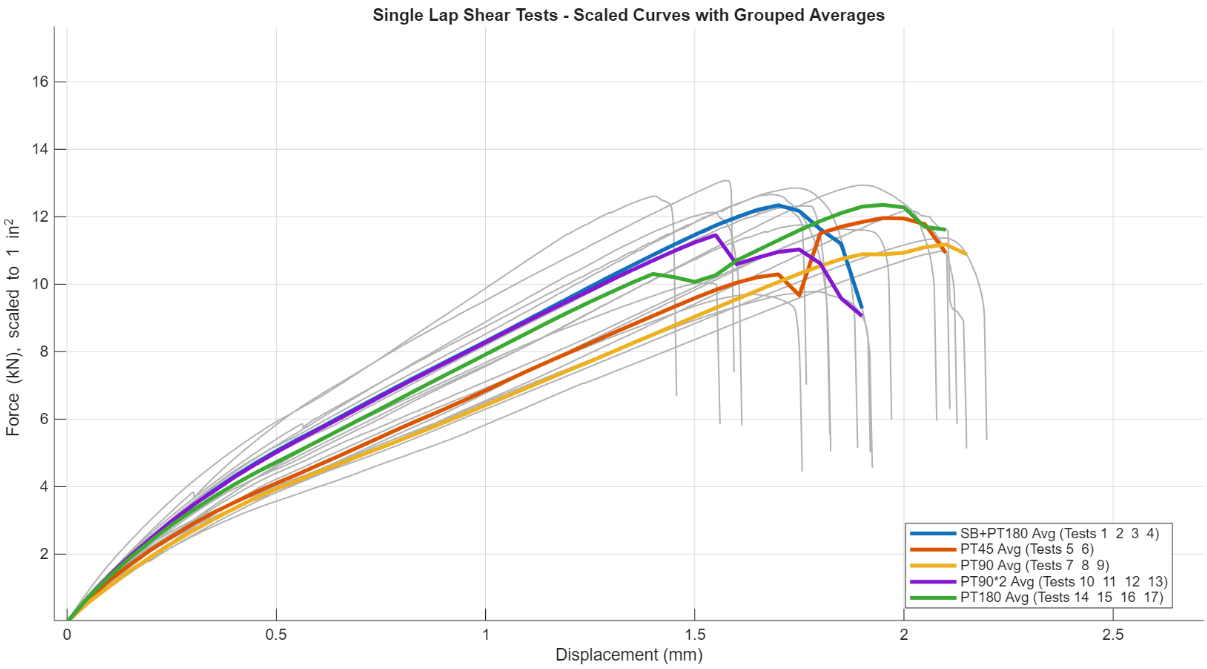


Figure 14b: Force V displacement curves for tested samples.

- The sandblasted trials with the 180 s plasma treatment showed a peak force only slightly higher than the 180 s plasma only samples.

- Although the maximum forces were not significantly improved, the sandblasted joints are noticeably stiffer and exhibit less compliance.

- The failure mechanisms for these joints are much more consistent and favourable, showing less adhesive failure and more cohesive failure.

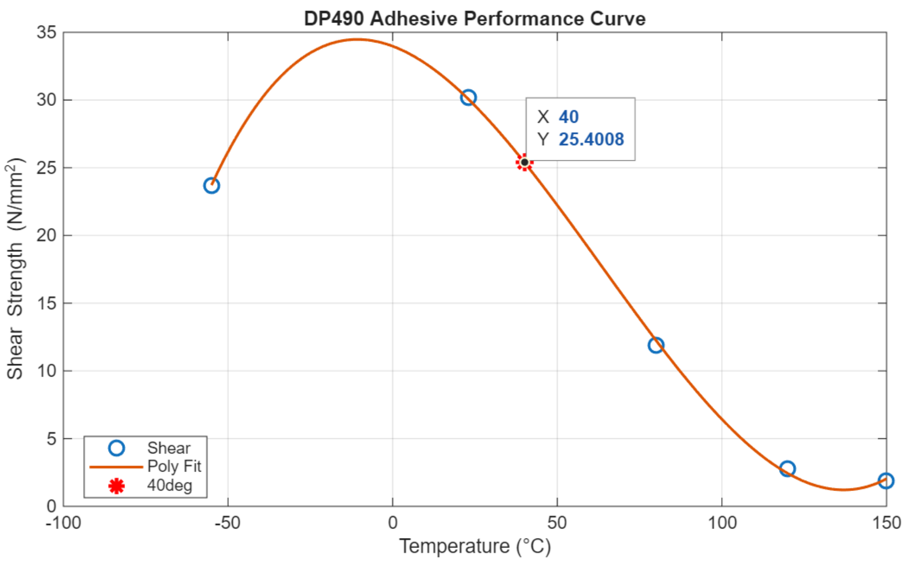


Figure 14c: DP490 extrapolated temperature dependant performance curve.

The highest shear strength achieved with the selected surface treatment was 19.3 MPa at room temperature. Figure 14c shows a polynomial fit of the manufacturer's adhesive performance data against temperature. As the joint is specified for 40°C with a safety factor of 3, the room-temperature strength was reduced to account for temperature effects.

The manufacturer's data indicates an approximate 16% loss in performance from room temperature to 40°C, reducing the design shear strength from 19.3 MPa to 16.2 MPa. This adjusted value can therefore be used to specify the bonded joint with confidence.

4 Physical Testing

4.1 Test Specimen Manufacture

Two aluminium lugs were machined to the specification given in Section 3.2.2, with the technical drawing provided in Appendix I, before being sandblasted. The carbon tube was laid up around a mandrel using the laminate specified in Section 3.1.4. To reduce manufacturing cost and complexity, an external mould was not used.

The components were then plasma treated for 180 s according to the parameters defined in Section 3.3.3. Bonding was carried out using a dedicated jig to ensure correct alignment. Pilot holes were drilled in the carbon tube to allow the adhesive to be injected into the bond region during assembly.

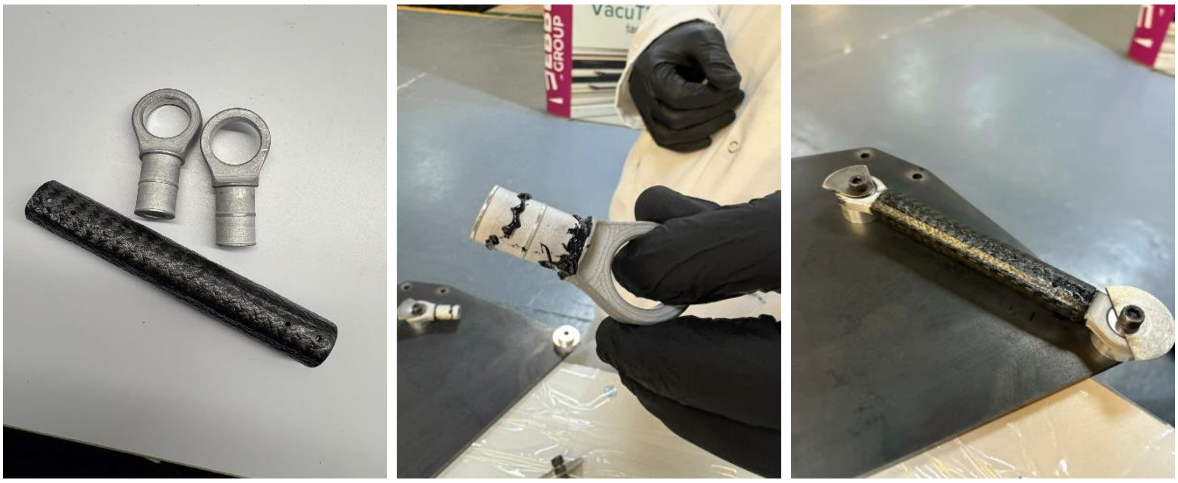


Figure 15: Test specimen manufacturing.

4.2 Bonded Link Validation Test

The specimen was mounted in the Instron and loaded in tension until failure. Failure was attributed to the aluminium lug, as shown in Figure 12. The lug performed worse than expected, reaching a UTS of 15 kN and beginning to yield at approximately 12.3 kN (Figure 16b).

It should be noted that the central bearing hole was not machined concentrically with the external lug profile, with an offset of approximately 0.5 mm measured. In addition, the stress/strain response shown in Figure 13c indicates that the material began yielding at around 275 MPa, which is significantly below the expected yield strength of 7075-T651 aluminium. This suggests that the supplied material may not have matched the stated specification. A lye test performed on the material confirmed this.

Despite this, yielding still occurred at approximately 1.5 times the design load, and a member stiffness of 10,611 N/mm was extrapolated from the test data. This exceeds the target stiffness of 7,140 N/mm defined in Section 2.2.3. Therefore, while the lug material and machining accuracy require further verification, the bonded tube assembly successfully met the stiffness requirement and demonstrated adequate load capacity relative to the design target.

Figure 16a: Tensile test setup and material failure.

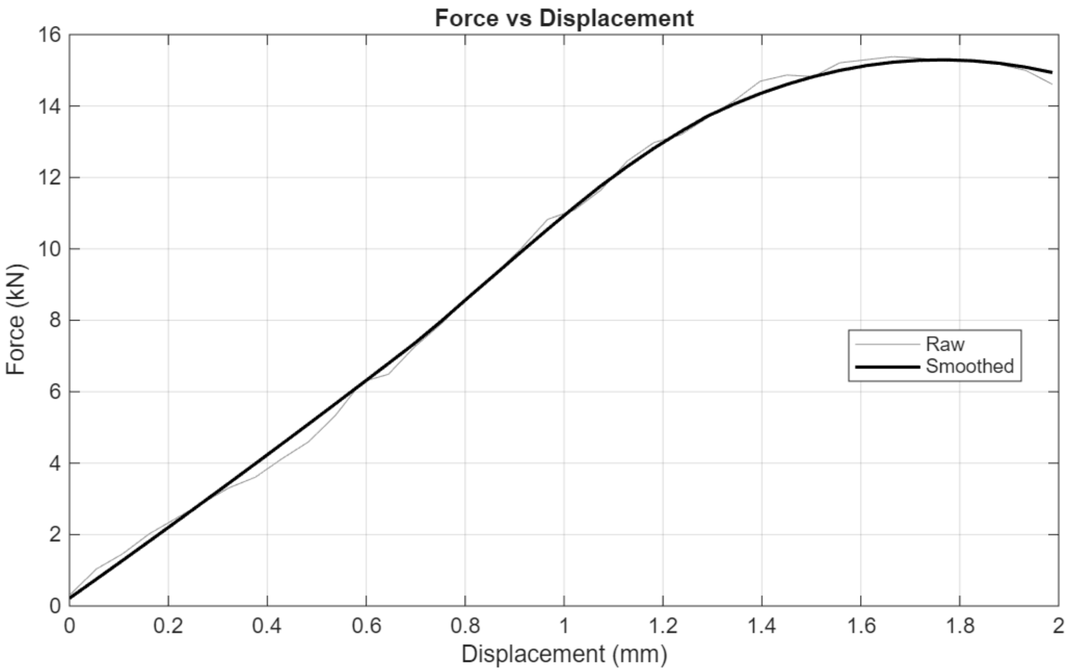


Figure 16b: Recorded and cleaned force vs displacement curve.

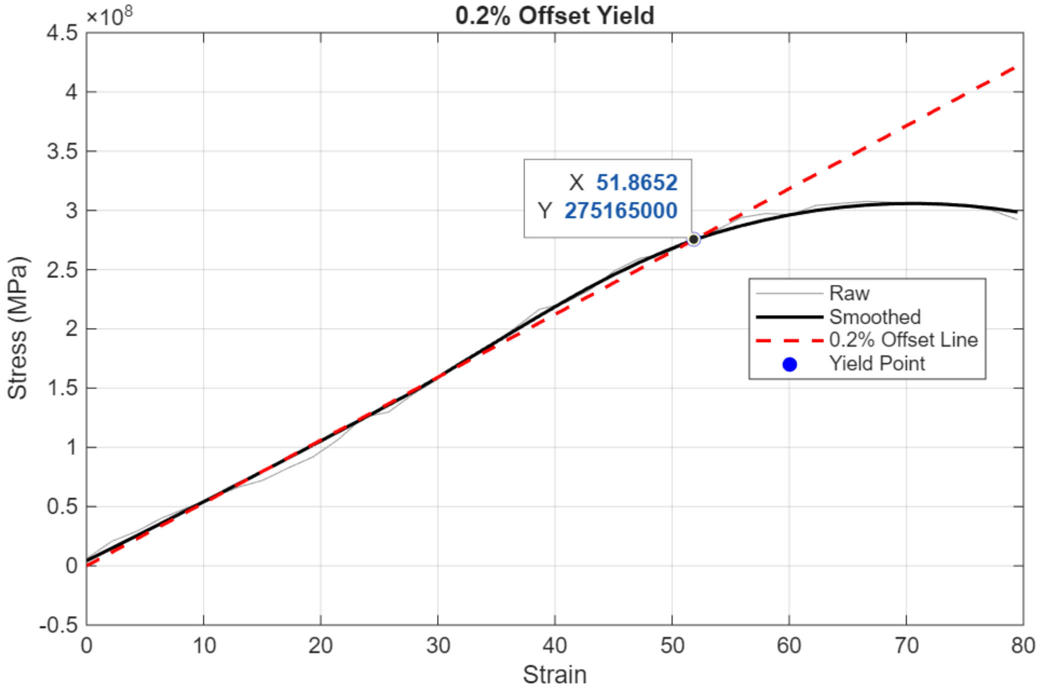


Figure 16c: Extrapolated stress vs strain curve.

5 Component Detailing

5.1 Front Suspension

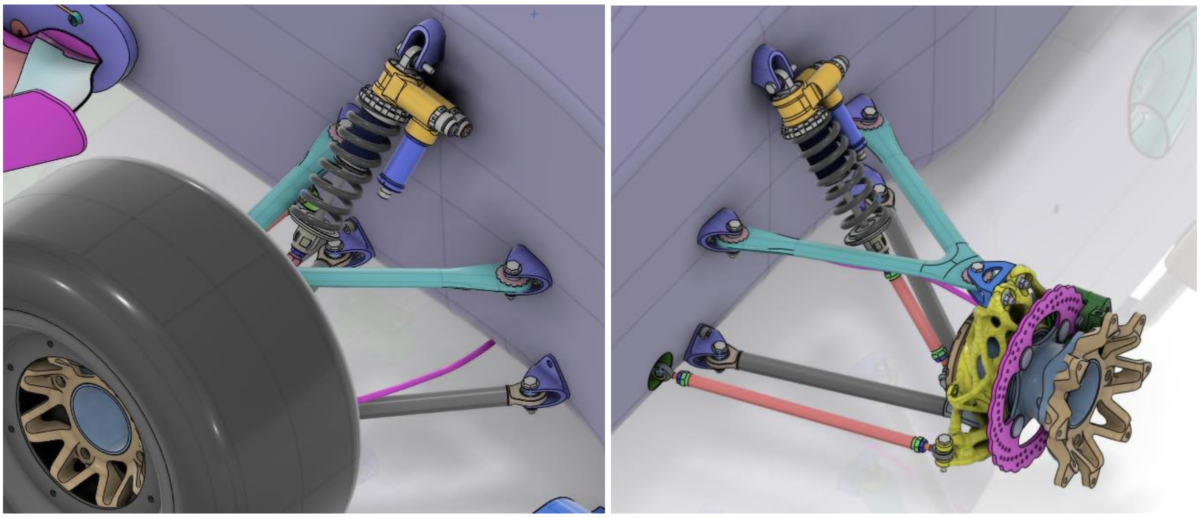


Figure 17a: Front suspension renders.

The UBR29 car uses a double unequal-length A-arm suspension configuration with a direct-acting spring and damper arrangement (Figure 17a). The pushrod pickup point is located on the lower wishbone; therefore, the outboard cowbell insert incorporates an integrated mounting boss to provide the required attachment point (Figure 17b).

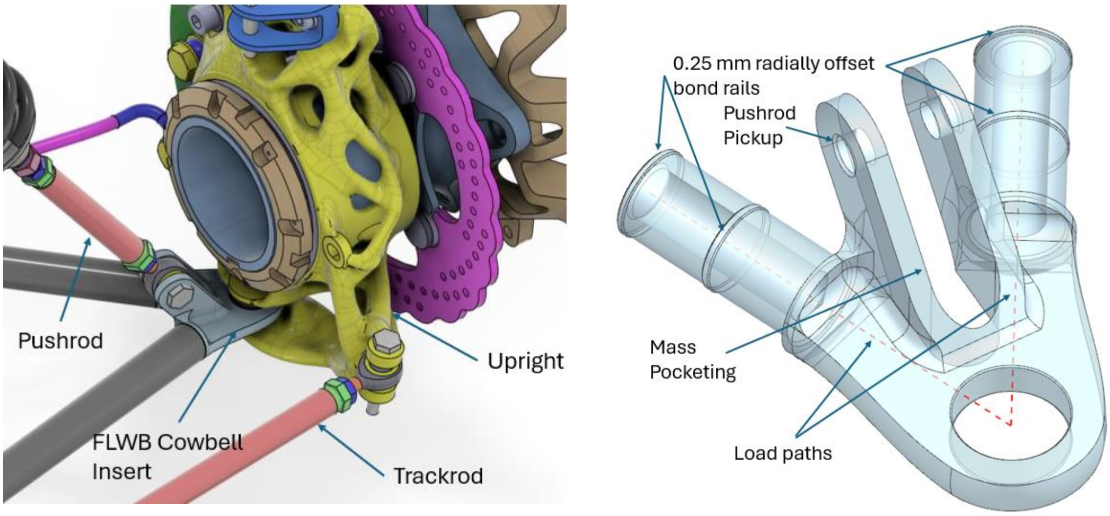


Figure 17b: FLWB / cowbell detail (Technical DWGs in Appendix I).

Table 8: Front suspension mass delta estimate per corner.

Member	Steel link mass (g)	CFRP link mass (g)	
FUWB	360	220	
FLWB	486	235	
Track rod	186	102	
	1032	557	Total

5.2 Moulded Front Upper Wishbone

An aerodynamic performance benefit was identified by reducing the cross-sectional area of the upper wishbone. This required the wishbone to be profiled rather than manufactured with a constant circular section.

The development of a fully moulded composite lug wishbone was carried out in parallel with the bonded tube to metallic lug design. This concept is manufactured in two composite halves, which are laid up separately, machined and then bonded together to form the final wishbone assembly. The laminate schedule is provided in Appendix F while the machining scheme is detailed in Appendix H.

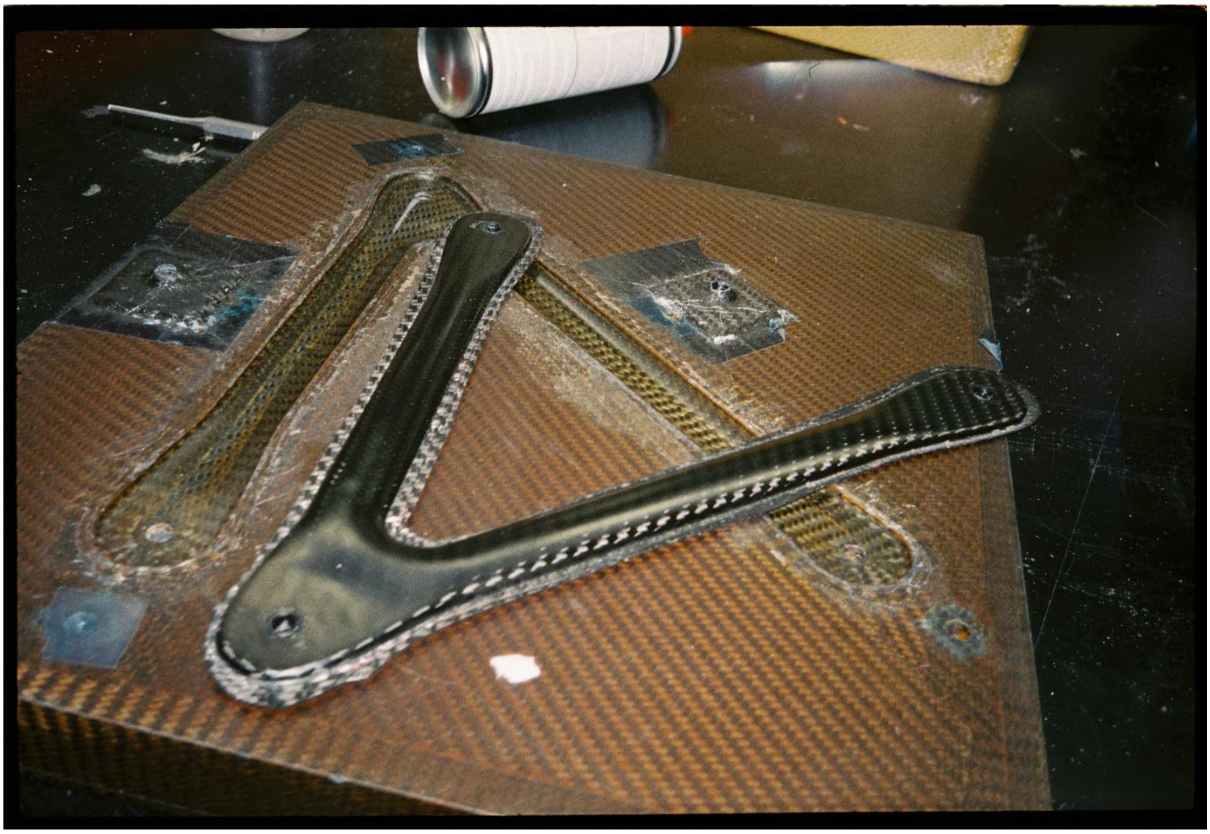


Figure 18: Moulded FUWB half pre-machining.

Instead of using aluminium inserts bonded at either end to retain the spherical bearings, threaded bearing housings with mating threads were used. The threaded interface provides the required preload to resist axial loads through the bearing housing and securely retain the spherical bearing within the wishbone.

In addition, the threaded housing provides a mechanical retention feature, helping to reduce peel loading at the bonded interface and improving the robustness of the wishbone assembly.

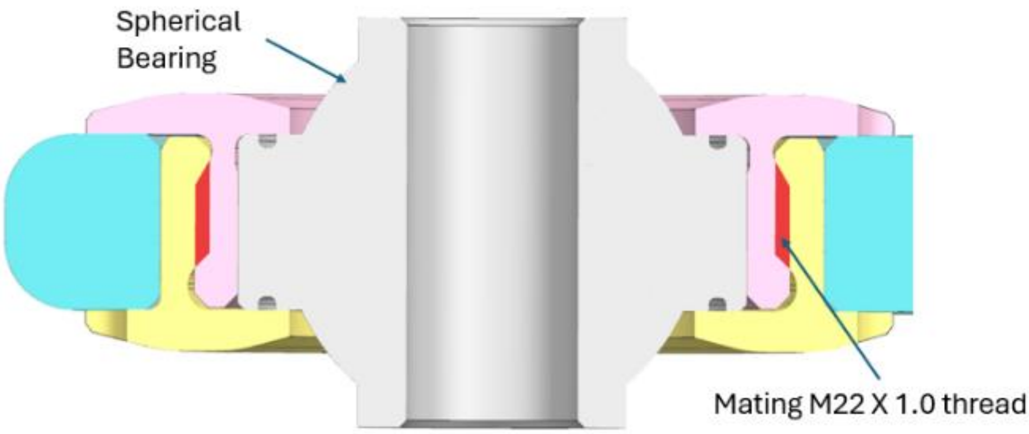


Figure 19a: Bearing housing cross-section

Figure 19b: Mating top-hats (Technical DWG In Appendix I)

Figure 19c: Assembled pair.

5.3 Rear Suspension

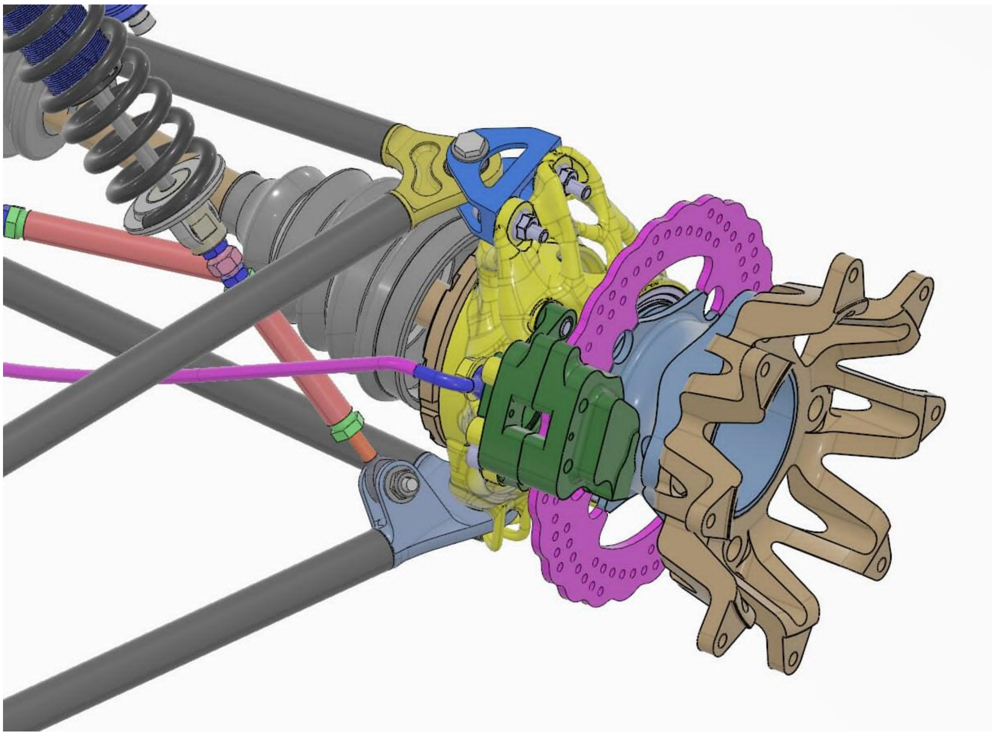


Figure 20: Rear suspension render

Table 9: Rear suspension mass delta estimate per corner

Member	Steel link mass (g)	CFRP link mass (g)	
RUWB	382	270	
RLWB	453	210	
Track rod	122	96	
	957	576	Total

6 Conclusion and Further Work

The SG testing gave a useful validation of the theoretical load model, with the measured wishbone loads following the same general trend as the predicted loads. Although the correlation was affected by noise and calibration uncertainty, it was sufficient to support the model as a design basis.

Physical testing confirmed the strength and stiffness requirement, with the bonded link achieving a stiffness of 10,611 N/mm, exceeding the target of 7,140 N/mm. The assembly also reached a UTS of 15 kN, with yielding beginning at approximately 1.5 times the design load. While the aluminium lug underperformed due to material and machining issues, the bonded carbon tube assembly itself performed successfully.

The bonded joint testing also provided confidence in the selected adhesive and surface preparation method, giving a design shear strength of 16.2 MPa at 40°C after temperature correction.

Overall, the carbon fibre suspension package provides a clear mass-saving benefit, reducing the estimated front corner mass by 475 g and the rear by 381 g. The work therefore meets the main objectives of reducing unsprung mass while satisfying the required strength and stiffness targets.

Further work should focus on:

- Improving the strain gauge measurement system to reduce noise and provide a more accurate conversion between vehicle acceleration and member force, allowing absolute load values to be used with greater confidence.
- Further investigating surface preparation methods, including the potential use of sol-gel treatments, to improve bond durability and reduce the risk of adhesive failure.
- Conducting tensile and compressive load testing on complete wishbone assemblies to validate their performance under representative suspension loading conditions.
- Research & development into machining of composite materials from tool selection, fixturings and optimised tool paths.

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Appendix A - Scripts

IMU data into readable plots script

```
filename = 'serial_20251025_152527';
raw = readlines(filename);

% Remove empty or malformed lines
raw = raw(strlength(raw) > 0);
raw = raw(contains(raw, ','));

data = split(raw, ',');

% Extract numeric columns
ax = str2double(strtrim(data(:, end-2)));
ay = str2double(strtrim(data(:, end-1)));
az = str2double(strtrim(data(:, end)));

% Create time vector
fs = 10;
t = (0:length(ax)-1)' / fs;

g0 = 9.81;


% Subtract gravity
az = az - g0;
```

Filter the acceleration

```
fs = 100;    % sampling freq Hz
fc = 5;    % cutoff freq Hz

[b, a] = butter(4,fc/(fs/2), 'low');    % 4th-order low-pass
axf = filtfilt(b, a, ax);
ayf = filtfilt(b, a, ay);
azf = filtfilt(b, a, az);
```

Convert to g

```
ax_g = axf / g0;

ay_g = ayf / g0;

az_g = azf / g0;
```

Plot G-G diagram

```
figure('Color', 'w');
scatter(az_g, ax_g, 10, 'k', 'filled', 'MarkerFaceAlpha', 0.5);
hold on;
```

```
% mark the max combined g
g_total = sqrt(ax_g.^2 + az_g.^2);
[max_g, idx] = max(g_total);
plot(az_g(idx), ax_g(idx), 'ro', 'MarkerSize', 8, 'LineWidth', 1.2);

% draw constant g circles
theta = linspace(0, 2*pi, 200);
for r = [0.5 1.0 1.5]
    plot(r*cos(theta), r*sin(theta), 'k:', 'LineWidth', 0.8);
end

xlabel('Lateral Accel. (g)');
ylabel('Longitudinal Accel. (g)');
title('G-G Diagram');
axis equal;
grid on;
xlim([-2 2]);
ylim([-2 2]);

legend('Data', 'Peak g', 'Location', 'best');
```

Rainflow Fatigue

Compute total acceleration magnitude

```
g_total = sqrt(ax_g.^2 + ay_g.^2);




% Perform rainflow counting on total g magnitude
RF = rainflow(g_total);

% Display rainflow matrix plot
figure('Color', 'w');
rainflow(g_total);
title('Rainflow Histogram - Combined G Magnitude');
xlabel('Δg Range');
ylabel('Cycle Count');

% Extract cycle ranges and counts
ranges = [RF.Range];
counts = [RF.Count];

% Display summary table
disp('=== Rainflow Cycle Summary (G Magnitude) ===');
disp(table(ranges', counts', 'VariableNames', {'Δg_Range', 'Cycle_Count'}));

% Compute a relative fatigue damage index
damage_index = sum(counts .* (ranges .^ 3));
fprintf('\nRelative fatigue damage index: %.3f\n', damage_index);

% Histogram of Δg ranges
figure('Color', 'w');
histogram(ranges, 30);
xlabel('Δg Range');
ylabel('Cycle Count');
title('Distribution of Acceleration Cycle Amplitudes');
grid on;
```

Strain into Force and Rainflow Histogram script

Load accelerometer data

```
filename = 'serial_20251025_152527';
raw = readlines(filename);

% Remove empty or malformed lines
raw = raw(strlength(raw) > 0);    % remove blank lines
raw = raw(contains(raw, ','));    % keep only lines with commas

% Split by commas
data = split(raw, ',');

% Extract numeric columns
ax = str2double(strtrim(data(:, end-2)));
ay = str2double(strtrim(data(:, end-1)));
az = str2double(strtrim(data(:, end)));
```

Time vector

```
fs = 100;                              % sampling frequency (Hz)
t = (0:length(ax)-1)' / fs;            % time in seconds
```

Filter the lateral acceleration

```
fc = 4.5;                              % cutoff frequency (Hz)
[b, a] = butter(4, fc/(fs/2), 'low'); % 4th order low-pass
axf = filtfilt(b, a, ax);

g0 = 9.81;
ax_g = axf / g0;
```

Load SG data

```
% Convert SG amplifier output to force
val_raw = 5.41 .* ((frl - 547) .* 5 ./ 1024);    % kN


baseline_time = 5;                               % first 5 seconds assumed
stationary
baseline_samples = baseline_time * fs;

F0 = mean(val_raw(1:baseline_samples));          % installed static preload
val = val_raw - F0;                              % change in axial force, kN
```

Match vector lengths

```
minLen = min(length(t), length(val));

t   = t(1:minLen);

val = val(1:minLen);

ax_g = ax_g(1:minLen);
```

Plot strain and lateral acceleration

```
figure('Color','w');
yyaxis left
plot(t, val, 'b', 'LineWidth', 1.2);
ylabel('Force (kN)');

yyaxis right
plot(t, ax_g, 'r', 'LineWidth', 1.2);
ylabel('Longitudinal Acceleration (g)');

xlabel('Time (s)');
title('Strain and Longitudinal Acceleration vs Time');
legend({'Strain','Longitudinal (g)'}, 'Location','best');
grid on;
```

force to stress

```
A = 43.35;    % mm^2

sigma = (val * 1000) / A;      % MPa

sigma = sigma - mean(sigma);
```

Rainflow on stress

```
RF = rainflow(sigma);



if istable(RF)
    ranges = RF.Range;
    counts = RF.Count;
elseif isstruct(RF)
    ranges = [RF.Range]';
    counts = [RF.Count]';
else
    ranges = RF(:,3);
    counts = ones(size(ranges));
end

ranges = ranges(:);
counts = counts(:);

sigma_a = ranges / 2;
```

S–N curve: approximate 7075

```
m  = 6.64;

C  = 2.87e21;



sigma_a_eff = max(sigma_a, 1e-3);

Nf = C ./ (sigma_a_eff.^m);
```

Miner damage

```
D_i = counts ./ Nf;

D   = sum(D_i);



fprintf('\n FATIGUE RESULTS (7075-T6 ) \n');
fprintf('Miner damage for this run: %.3e\n', D);
fprintf('Estimated number of repeats to failure: %.3e\n', 1/D);

blockMinutes = t(end)/60;
lifeHours = (1/D) * blockMinutes/60;
fprintf('Estimated fatigue life: %.3e hours\n', lifeHours);
fprintf('Force (kN): min=%.3f, max=%.3f\n', min(val), max(val));
fprintf('sigma_a: min = %.3f, max = %.3f MPa\n', min(sigma_a), max(sigma_a));
fprintf('\nRAW STRESS (with mean):\n');
sigma_raw = (val * 1000) / A;
fprintf('sigma_raw: min = %.3f, max = %.3f MPa\n', min(sigma_raw), max(sigma_raw));

sigma = sigma_raw - mean(sigma_raw);
fprintf('sigma (mean removed): min = %.3f, max = %.3f MPa\n', min(sigma),
max(sigma));

fprintf('sigma_a from rainflow: min = %.3f, max = %.3f MPa\n', min(sigma_a),
max(sigma_a));
```

```
 FATIGUE RESULTS (7075-T6 )

Miner damage for this run: 1.296e-13

Estimated number of repeats to failure: 7.716e+12

Estimated fatigue life: 1.020e+11 hours

Force (kN): min=-1.778, max=1.682

sigma_a: min = -12.405, max = 13.340 MPa



RAW STRESS (with mean):

sigma_raw: min = -41.016, max = 38.811 MPa

sigma (mean removed): min = -39.436, max = 40.391 MPa

sigma_a from rainflow: min = -12.405, max = 13.340 MPa
```

Histogram of stress range

```
figure('Color','w');

supportsWeights =
~isempty(findprop(matlab.graphics.chart.primitive.Histogram,'Weights'));

if supportsWeights

    histogram(ranges, 40, 'Weights', counts);
```

```
else

    % Expand counts manually:
    expandedRanges = arrayfun(@(r,c) repmat(r, round(c*2), 1), ranges, counts,
'UniformOutput', false);
    expandedRanges = vertcat(expandedRanges{:});

    histogram(expandedRanges, 40);
end

xlabel('Stress Range (MPa)');
ylabel('Cycle Count');
title('Rainflow Stress Range Histogram');
grid on;
```

CLT script

Geometry

```
r = 8.516e-3;    % mean radius (m)
```

Materials

mat = [E1 E2 G12 v12 Xt Xc Yt Yc S]

```
%E1 = longitudinal tensile modulus
%E2 = transverse tensile modulus
%G12 = shear modulus
%v12 = Poisson's ratio
%Xt = longitudinal tensile strength
%Xc = longitudinal compressive strength
%Yt = transverse tensile strength
%Yc = transverse compressive strength
%S  = in-plane shear strength
mat(1).name = "MTC400-1-C200T-M40J-42%RW-1250";
mat(1).prop = [67e9 66.5e9 4e9 0.07 981e6 737e6 893e6 765e6 95.9e6];

mat(2).name = "MTC400-1-UD140-M46J-33%RW-300P";
mat(2).prop = [226.6e9 1e9 5e9 0.26 1994e6 1030e6 1e6 1e6 77.2e6];
```

Layup

```
plyAngles = [45 0 0 90 45 90 0 0 45];          % deg
plyT      = [0.20 0.133 0.133 0.20 0.20 0.20 0.133 0.133 0.2]' * 1e-3;  % m
plyMatID  = [1 2 2 1 1 1 2 2 1]';             % material per ply
```

Loads

```
F_axial  = 16e3;    % N
T_torque = 0;       % N.m
p_int    = 0;       % Pa
M_global = 0;       % N.m

N = [
    F_axial/(2*pi*r)
    p_int*r
    T_torque/(2*pi*r)
```

```
];

M = [
    M_global/(2*pi*r)
    0
    0
];
```

Setup

```
n = numel(plyAngles);

plyAngles = plyAngles(:);



if numel(plyT) ~= n || numel(plyMatID) ~= n
    error('plyAngles, plyT, and plyMatID must have the same length.');
end

h = sum(plyT);
z = [-h/2; -h/2 + cumsum(plyT)];

A = zeros(3); B = zeros(3); D = zeros(3);
Qloc = cell(n,1);
```

ABD matrix

```
for k = 1:n
    p = mat(plyMatID(k)).prop;

    E1=p(1); E2=p(2); G12=p(3); v12=p(4);
    v21 = v12*E2/E1;

    Q11 = E1/(1-v12*v21);
    Q22 = E2/(1-v12*v21);
    Q12 = v12*E2/(1-v12*v21);
    Q66 = G12;

    Q = [Q11 Q12 0; Q12 Q22 0; 0 0 Q66];
    Qloc{k} = Q;

    th = deg2rad(plyAngles(k));
    c = cos(th); s = sin(th);

    Qb = qbar(Q11,Q22,Q12,Q66,c,s);

    z0 = z(k);
    z1 = z(k+1);

    A = A + Qb*(z1-z0);
    B = B + 0.5*Qb*(z1^2-z0^2);
    D = D + (1/3)*Qb*(z1^3-z0^3);
end
```

Solve laminate strains

```
ABD = [A B; B D];

ek = ABD \ [N; M];
```

```
eps0  = ek(1:3);

kappa = ek(4:6);



fprintf('\nMid-plane strains:\n');
fprintf('eps_x = %.3e, eps_y = %.3e, gamma_xy = %.3e\n', eps0);
fprintf('kappa_x = %.3e, kappa_y = %.3e, kappa_xy = %.3e\n', kappa);
```

```
Mid-plane strains:

eps_x = 1.840e-03, eps_y = -7.566e-04, gamma_xy = -3.552e-06

kappa_x = 3.699e-16, kappa_y = -4.545e-16, kappa_xy = 1.085e-19
```

Ply stresses and failure

```
for k = 1:n
    p = mat(plyMatID(k)).prop;

    Xt=p(5); Xc=p(6); Yt=p(7); Yc=p(8); S=p(9);

    zmid = 0.5*(z(k)+z(k+1));
    epsG = eps0 + zmid*kappa;

    th = deg2rad(plyAngles(k));
    c = cos(th); s = sin(th);

    Te = [
        c^2 s^2 2*c*s
        s^2 c^2 -2*c*s
       -c*s c*s c^2-s^2
    ];

    epsL = Te*epsG;
    sigL = Qloc{k}*epsL;

    s1 = sigL(1);
    s2 = sigL(2);
    t12 = sigL(3);

    FI_fiber = max(s1/Xt, -s1/Xc);
    FI_trans = max(s2/Yt, -s2/Yc);
    FI_shear = abs(t12)/S;

    [FImax, idx] = max([FI_fiber FI_trans FI_shear]);
    modes = ["Fiber","Transverse","Shear"];

    F1=1/Xt-1/Xc; F2=1/Yt-1/Yc;
    F11=1/(Xt*Xc); F22=1/(Yt*Yc); F66=1/S^2;
    F12=-0.5*sqrt(F11*F22);

    TW = F1*s1 + F2*s2 + F11*s1^2 + F22*s2^2 + ...
         F66*t12^2 + 2*F12*s1*s2;

    out(k,:) = table( ...
        k, mat(plyMatID(k)).name, plyAngles(k), plyT(k)*1e3, ...
        s1/1e6, s2/1e6, t12/1e6, ...
           modes(idx), TW, ...
        FImax >= 1, TW >= 1, ...
        'VariableNames', {'Ply','Material','Angle_deg','t_mm', ...
        'sig1_MPa','sig2_MPa','tau12_MPa', ...
        'Critical','TsaiWu', ...
```

```
        'Fail_MaxStress','Fail_TsaiWu'});
end

disp(out);


fprintf('Max Tsai-Wu = %.3f\n', max(out.TsaiWu));
```

Ply	Material	Angle_deg	t_mm	sig1_MPa	sig2_MPa	tau12_MPa	Critical	TsaiWu	Fail_MaxStress	Fail_TsaiWu
1	"MTC400-1-C200T-M40J-42%RW-1250"	45	0.2	38.768	38.939	-5.1923	"Shear"	-0.015298	false	false
2	"MTC400-1-UD140-M46J-33%RW-300P"	0	0.133	416.77	-0.27838	-0.017759	"Transverse"	0.047404	false	false
3	"MTC400-1-UD140-M46J-33%RW-300P"	0	0.133	416.77	-0.27838	-0.017759	"Transverse"	0.047404	false	false
4	"MTC400-1-C200T-M40J-42%RW-1250"	90	0.2	-42.334	119.39	0.014208	"Transverse"	0.022453	false	false
5	"MTC400-1-C200T-M40J-42%RW-1250"	45	0.2	38.768	38.939	-5.1923	"Shear"	-0.015298	false	false
6	"MTC400-1-C200T-M40J-42%RW-1250"	90	0.2	-42.334	119.39	0.014208	"Transverse"	0.022453	false	false
7	"MTC400-1-UD140-M46J-33%RW-300P"	0	0.133	416.77	-0.27838	-0.017759	"Transverse"	0.047404	false	false
8	"MTC400-1-UD140-M46J-33%RW-300P"	0	0.133	416.77	-0.27838	-0.017759	"Transverse"	0.047404	false	false
9	"MTC400-1-C200T-M40J-42%RW-1250"	45	0.2	38.768	38.939	-5.1923	"Shear"	-0.015298	false	false

```
Max Tsai-Wu = 0.047
```

Local function

```
function Qb = qbar(Q11,Q22,Q12,Q66,c,s)

c2 = c^2; s2 = s^2;

Qb = zeros(3);

Qb(1,1) = Q11*c2^2 + Q22*s2^2 + 2*(Q12+2*Q66)*c2*s2;
Qb(1,2) = (Q11+Q22-4*Q66)*c2*s2 + Q12*(c2^2+s2^2);
Qb(2,2) = Q11*s2^2 + Q22*c2^2 + 2*(Q12+2*Q66)*c2*s2;

Qb(1,3) = (Q11-Q12-2*Q66)*c^3*s - (Q22-Q12-2*Q66)*c*s^3;
```

```
Qb(2,3) = (Q11-Q12-2*Q66)*c*s^3 - (Q22-Q12-2*Q66)*c^3*s;

Qb(3,3) = (Q11+Q22-2*Q12-2*Q66)*c2*s2 + Q66*(c^4+s^4);

Qb(2,1) = Qb(1,2);
Qb(3,1) = Qb(1,3);
Qb(3,2) = Qb(2,3);

end
```

Single Lap Shear Force Equaliser Script

Input

```
A_target = 645.16;  % Target bond area (mm^2)

% Actual areas for each test
bondAreas = [624.75,666.35,634.95,641.3,575.04,640.6,640,609.84,563.2,524.475,...
             539.116,486.92,603.6,517.2,647.806,655.69,487.97];

folder = 'C:\Users\anton\Documents\UBR29\Testing\28.10.25\Tensile tests
28.10.25.is_qtest_Exports';
files = dir(fullfile(folder, '*.csv'));
nFiles = numel(files);

if nFiles == 0
    error('No CSV files found in folder: %s', folder);
end


if numel(bondAreas) < nFiles
    warning('bondAreas has fewer entries (%d) than files (%d).', ...
        numel(bondAreas), nFiles);
    bondAreas = [bondAreas, nan(1, nFiles - numel(bondAreas))];
elseif numel(bondAreas) > nFiles
    bondAreas = bondAreas(1:nFiles);
end


forceCol = 'Force';
dispCol  = 'Displacement';
```

Groups definition

```
groups = { [1 2 3 4], [5 6], [7 8 9], [10 11 12 13], [14 15 16 17] };
```

Compute common displacement grid

```
commonStep = 0.05; % mm
maxDisp = 0;
for iFile = 1:nFiles
    tbl = readtable(fullfile(folder, files(iFile).name));
    if ~ismember(dispCol, tbl.Properties.VariableNames) || ~ismember(forceCol,
tbl.Properties.VariableNames)
        error('File %s does not contain required columns "%s" and "%s".',
files(iFile).name, dispCol, forceCol);
    end
    displacement = tbl.(dispCol);
    maxDisp = max(maxDisp, max(displacement));
end
```

```
commonDisp = 0:commonStep:maxDisp;
```

Allocate Storage

```
allForces = nan(length(commonDisp), nFiles);

maxForces = nan(nFiles,1);

maxDisps  = nan(nFiles,1);
```

Plotting: individual scaled curves

```
figPlot = figure('Name','Scaled Curves with Grouped Averages','Position',[100 100
1000 700]);
hold on;
% colors for groups
groupColors = lines(numel(groups));

for iFile = 1:nFiles
    fname = files(iFile).name;
    tbl = readtable(fullfile(folder, fname));
    displacement = tbl.(dispCol);          % renamed variable
    force_raw    = tbl.(forceCol);

    A_actual = bondAreas(iFile);
    if isnan(A_actual)

        warning('bondAreas(%d) is NaN — using scale=1 for file %s', iFile, fname);
        scale = 1;
    else
        scale = A_target / A_actual;
    end

    force = force_raw * scale;


    interpForce = interp1(displacement, force, commonDisp, 'linear', NaN);
    allForces(:, iFile) = interpForce;

    % compute max force and displacement at max
    [Fmax, idxMax] = max(force);
    Dmax = displacement(idxMax);
    maxForces(iFile) = Fmax;
    maxDisps(iFile)  = Dmax;

    % Plot original curve as light gray
    plot(displacement, force, 'Color', [0.7 0.7 0.7], 'LineWidth', 1.0,
'HandleVisibility','off');
end
```

Grouped Averages

```
for g = 1:numel(groups)
    idx = groups{g};

    idx = idx(idx >= 1 & idx <= nFiles);
    if isempty(idx)
        continue;
    end
```

```
    groupForce = allForces(:, idx);
    avgForce = mean(groupForce, 2, 'omitnan');
    stdForce = std(groupForce, 0, 2, 'omitnan');

    % plot average line
    plot(commonDisp, avgForce, 'Color', groupColors(g,:), 'LineWidth', 2.5, ...
         'DisplayName', sprintf('Group %d Avg (Tests %s)', g, num2str(idx)));
end

xlabel('Displacement (mm)');
ylabel('Force (kN), scaled to 1 in^2 target');
title('Single Lap Shear Tests - Scaled Curves with Grouped Averages');
legend('Location','eastoutside');
grid on;
hold off;
```

TABLE: create summary table of max forces

```
groupIDs = nan(nFiles,1);

for g = 1:numel(groups)
    idx = groups{g};
    idx = idx(idx >= 1 & idx <= nFiles);
    groupIDs(idx) = g;
end

T = table((1:nFiles)', groupIDs, bondAreas(1:nFiles)', maxForces, maxDisps, ...
    'VariableNames', {'Test','Group','BondArea (mm2)','MaxForce (kN)','Disp_at_max
(mm)'});

% Print in command window
fprintf('\n=== Summary of Maximum Forces ===\n');
display(T);
```

```
=== Summary of Maximum Forces ===

T =

  17×5 table
```

Test	Group	BondArea (mm2)	MaxForce (kN)	Disp_at_max (mm)
1	1	624.75	12.67	1.6823
2	1	666.35	12.302	1.7107
3	1	634.95	12.856	1.7391

4	1	641.3	11.759	1.7565
5	2	575.04	11.987	1.9707
6	2	640.6	9.6976	1.6382
7	3	640	10.992	2.0973
8	3	609.84	11.376	2.0955
9	3	563.2	11.642	1.8573
10	4	524.48	12.324	1.7674
11	4	539.12	12.127	1.5415
12	4	486.92	13.074	1.574
13	4	603.6	9.7836	1.7874
14	5	517.2	12.94	1.9039
15	5	647.81	12.216	2.009
16	5	655.69	10.037	1.5108
17	5	487.97	12.61	1.4066

```
try
    figTable = figure('Name','Max Force Summary','Position',[200 150 800 350]);
    % create uitable using the figure as parent so it shows
    uit = uitable(figTable, ...
        'Data', table2cell(T), ...
        'ColumnName', T.Properties.VariableNames, ...
        'Units', 'normalized', ...
        'Position', [0 0 1 1]);

    try
        ncol = width(T);
        % set pixel widths proportionally
        colWidth = repmat({floor(800/ncol)}, 1, ncol);
        uit.ColumnWidth = colWidth;
    catch

    end
    movegui(figTable, 'center'); % bring it into view
catch ME
    warning('Could not create uitable figure: %s\nTable is still available in
workspace and saved as CSV if possible.', ME.message);
end
```

Stress-Strain plot Script

```
filename = 'cleaned';
```

```
raw = readlines(filename);
raw = raw(strlength(raw) > 0);

data = split(raw);

F_kN = str2double(data(:, end-1));   % Force in kN
d_mm = str2double(data(:, end));     % Displacement in mm

valid = ~isnan(F_kN) & ~isnan(d_mm);
F_kN = F_kN(valid);
d_mm = 0.5*d_mm(valid);

A0 = 5e-8;      % m^2
L0 = 0.05;      % m
```

Sort force-displacement data by displacement

```
[d_mm, orderFD] = sort(d_mm);

F_kN = F_kN(orderFD);



[d_mm, iaFD] = unique(d_mm, 'stable');
F_kN = F_kN(iaFD);
```

Smooth force-displacement data

```
wFD = max(11, 2*floor(0.04*numel(F_kN))+1);

F_kN_s = movmean(movmedian(F_kN, wFD), wFD);



if numel(F_kN) >= 27
    F_kN_s = smoothdata(F_kN, "sgolay", 27);
end
```

Calculate stiffness from force-displacement curve

```

maxElasticDisplacement = 0.25;

iK = find(d_mm <= maxElasticDisplacement & d_mm >= 0);

if numel(iK) < 10
    iK = 1:min(round(0.5*numel(d_mm)), numel(d_mm));
end

pK = polyfit(d_mm(iK), F_kN_s(iK), 1);

stiffness_kN_per_mm = pK(1);
stiffness_N_per_mm = stiffness_kN_per_mm * 1000;
```

Plot force-displacement graph

```
figure('Color','w');
plot(d_mm, F_kN, 'Color', [0.6 0.6 0.6]); hold on;
plot(d_mm, F_kN_s, 'k', 'LineWidth', 1.5);
```

```
grid on;
xlabel('Displacement (mm)');
ylabel('Force (kN)');
title('Force vs Displacement');
legend('Raw','Smoothed','Linear stiffness fit','Location','best');
```

```
Warning: Ignoring extra legend entries.
```

Convert units for stress-strain

```
F_N = F_kN * 1000;        % kN to N
d_m = d_mm / 1000;        % mm to m
```

Stress-strain

```
stress = F_N / A0;        % Pa
strain = d_m / L0;

[strain, order] = sort(strain);
stress = stress(order);

[strain, ia] = unique(strain, 'stable');
stress = stress(ia);

w = max(11, 2*floor(0.04*numel(stress))+1);
stress_s = movmean(movmedian(stress, w), w);

if numel(stress) >= 27
    stress_s = smoothdata(stress, "sgolay", 27);
end
```

Estimate Young's modulus

```
maxElasticStrain = 0.005;   % adjust if needed

iE = find(strain <= maxElasticStrain & strain >= 0);

if numel(iE) < 10
    iE = 1:min(round(0.5*numel(strain)), numel(strain));
end

p = polyfit(strain(iE), stress_s(iE), 1);
E = p(1);
```

0.2% offset line

```
offset = 0.002;

offset_line = E * (strain - offset);
```

Find yield point

```
diff = stress_s - offset_line;
```

```
crossIdx = find(diff(1:end-1) .* diff(2:end) <= 0);



if isempty(crossIdx)
    warning('No intersections found. Try smoothing more or adjust elastic-fit
region.');
    yield_strain = NaN;
    yield_stress = NaN;
else
    yi = nan(size(crossIdx));
    xi = nan(size(crossIdx));

    for kk = 1:numel(crossIdx)
        i = crossIdx(kk);

        x1 = strain(i);
        x2 = strain(i+1);
        y1 = diff(i);
        y2 = diff(i+1);

        if y2 ~= y1
            x0 = x1 - y1*(x2 - x1)/(y2 - y1);
        else
            x0 = x1;
        end

        s0 = interp1(strain([i i+1]), stress_s([i i+1]), x0, 'linear', 'extrap');

        xi(kk) = x0;
        yi(kk) = s0;
    end

    [yield_stress, kbest] = max(yi);
    yield_strain = xi(kbest);
end
```

Plot stress-strain graph

```
figure('Color','w');
plot(strain, stress, 'Color', [0.6 0.6 0.6]); hold on;
plot(strain, stress_s, 'k', 'LineWidth', 1.5);
plot(strain, offset_line, '--r', 'LineWidth', 1.5);

if ~isnan(yield_stress)
    plot(yield_strain, yield_stress, 'bo', 'MarkerFaceColor','b');
end

grid on;
xlabel('Strain');
ylabel('Stress (Pa)');
title('0.2% Offset Yield');
legend('Raw','Smoothed','0.2% Offset Line','Yield Point','Location','best');
```

Print results

```
fprintf('Stiffness       = %.3f N/mm\n', stiffness_N_per_mm);
fprintf('E (fit)         = %.3f GPa\n', E/1e9);
fprintf('Yield Stress    = %.2f MPa\n', yield_stress/1e6);
fprintf('Yield Strain    = %.6f\n', yield_strain);
```

```
Stiffness       = 10611.160 N/mm
```

```
E (fit)          = 10611.160 GPa

Yield Stress     = 287942.97 MPa
```

DP490 shear strength v temp plot Script

```
% Adhesive Performance - Smoothed Curve
clc;
clear;
close all;

% Data
temperature = [-55 23 80 120 150];
shear_strength = [23.7 30.2 11.9 2.8 1.9];

% Polynomial fit (degree 3)
p = polyfit(temperature, shear_strength, 3);

% Generate smooth curve points
x_smooth = linspace(min(temperature), max(temperature), 200);
y_smooth = polyval(p, x_smooth);

% Plot
figure;
plot(temperature, shear_strength, 'o', 'MarkerSize', 8, 'LineWidth', 1.5);
hold on;
plot(x_smooth, y_smooth, 'LineWidth', 1.5);

xlabel('Temperature (°C)');
ylabel('Shear Strength (N/mm^2)');
title('Smoothed Adhesive Performance Curve');
grid on;
legend('Experimental Data', 'Polynomial Fit', 'Location', 'best');
```

Appendix B – Axial Stiffness Calculations

Axial Stiffness Calculation

Parameter	Symbol	Value
Reference wheel travel range	Δz	10 mm
Toe gain	G_τ	0.126 deg/mm
Camber gain in roll	G_{camber}	0.600 deg/mm
Total compliance allowance	C	5% of kinematic change
Wishbone compliance budget fraction	τ_{allow}	40% of total allowance
Forward lower link design load	F_f	7794 N
Rearward lower link design load	F_r	8801 N
Link length	L	350 mm
Toe sensitivity	S_τ	0.01 deg/mm

$$\Delta\tau = G_\tau \Delta z$$

$$\Delta\tau = 0.126 * 10 = 1.26\ deg$$

$$\tau_{allowTotal} = C\Delta\tau$$

$$\tau_{allowTotal} = 0.05 * 1.26 = 0.063\ deg$$

$$\tau_{allow}LWB = \eta\tau_{allowTotal}$$

$$\tau_{allow}LWB = 0.40 * 0.063 = 0.0252\ deg$$

$$\tau_{allow}leg = \tau_{allow}LWB/2$$

$$\tau_{allow}leg = \frac{0.0252}{2} = 0.0126\ deg$$

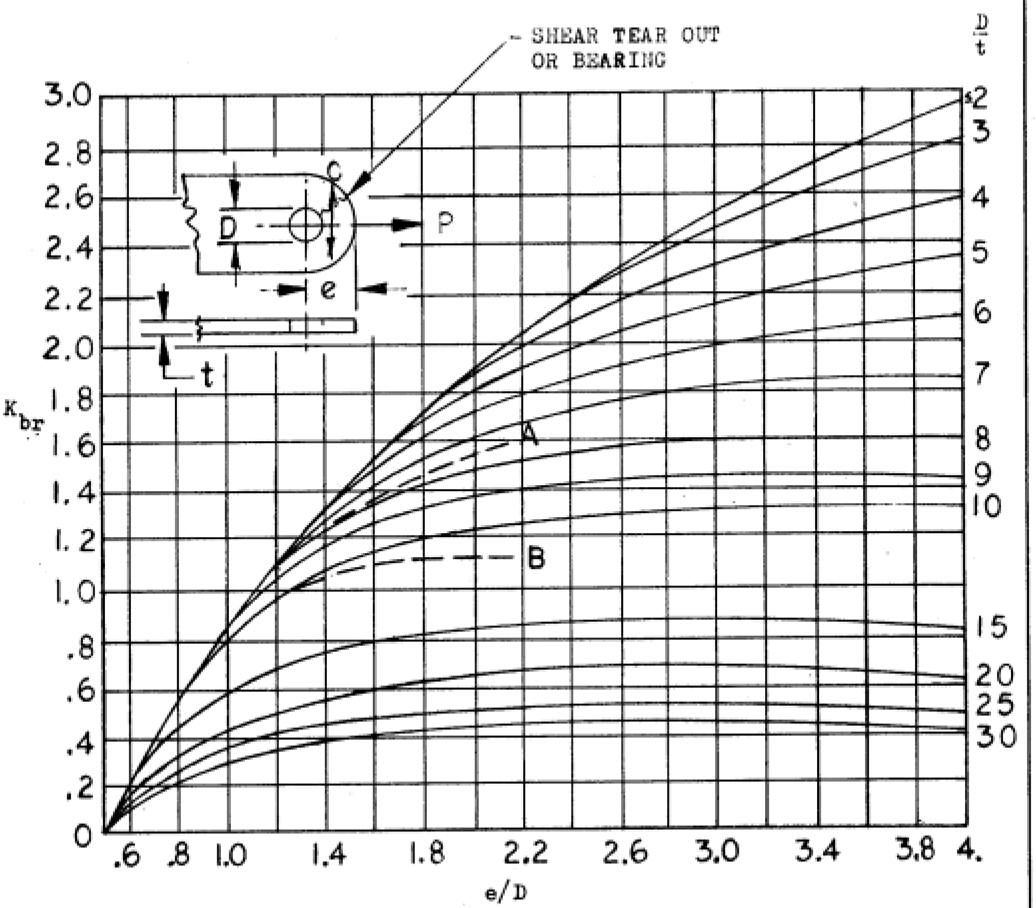
$$\delta_{allow\ toe} = \tau_{allow}leg/S_\tau$$

$$\delta_{allow\ toe} = \frac{0.0126}{0.01} = 1.26\ mm$$

$$k = F/\delta_{allow\ toe}$$

$$k = \frac{8801}{1.26} = 7104\ N$$

Appendix C – Lug Performance Curves



Note: For lugs of aluminum alloy plate, bar, or hand forged billets one half inch thick or thicker, the value of K_{br} is restricted to 2.0.

Curve A is a cutoff to be used for all aluminum alloy hand forged billet when the long transverse grain direction has the general direction C in the sketch.

Curve B is a cutoff to be used for all aluminum alloy plate, bar, and hand forged billet when the short transverse grain direction has the general direction C in the sketch, and for die forging when the lug contains the parting plane in a directional approximately normal to the direction C.

Figure C3.3.1-1 Bearing Efficiency Factors For Aluminum Lugs

Material	Curve No.
2014-T6 & 7075-T6 Plate ≤ .5" (L, T)	1
7075-T6 Bar & Extrusion (L)	1
2014-T6 Hand Forged Billet ≤144 Sq. In. (L)	1
2014-T6 & 7075-T6 Die Forgings (L)	1
2014-T6 & 7075-T6 Plate >.5", ≤1" (L,T)	2
7075-T6 Extrusion (T, ST)	2
7075-T6 Hand Forged Billet ≤30 Sq. In. (L)	2
2014-T6 Hand Forged Billet >144 Sq. In. (L)	2
2014-T6 Hand Forged Billet ≤36 Sq. In. (T)	2
2014-T6 & 7075-T6 Die Forgings (T)	2
2024-T6 Plate (L, T)	3
2024-T4 & 2024-T42 Extrusion (L, T, ST)	3
2024-T4 Plate (L, T)	4
2024-T3 Plate (L, T)	4
2014-T6 & 7075-T6 Plate >1" (L, T)	4

Material	Curve No.
2024-T4 Bar (L, T)	4
7075-T6 Hand Forged Billet >36 Sq. In. (L)	4
7075-T6 Hand Forged Billet ≤16 Sq. In. (T)	4
195-T6, 220-T4, & 356-T6 Aluminum Alloy Cast	5
7075-T6 Hand Forged Billet >16 Sq. In. (T)	5
2014-T6 Hand Forged Billet >36 Sq. In. (T)	5
Aluminum Alloy Plate Bar, Hand Forged Billet, and Die Forgings (ST). NOTE: For Die forgings, ST direction exists only at parting Plane.)	6
7075-T6 Bar (T)	6
7075-T76 H.S. Clad Plate (T)	7
7075-T73 Die Forging (L) ≤3.0 In.	8
7075-T73 Die Forging (ST) ≤3.0 In.	9

L, T, and ST indicate grain in direction "F" in sketch:
L = Longitudinal, T = Long Transverse, ST = Short Transverse.
(Curves for plate apply to both clad and bare material.)

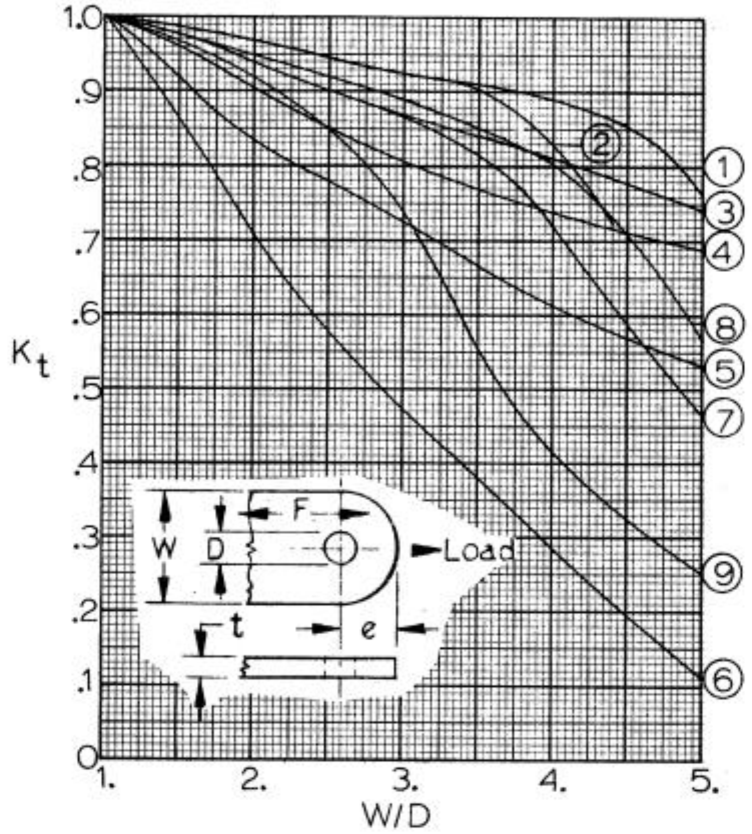


Figure C3.3.1-4a Tension Efficiency Factors for Lugs

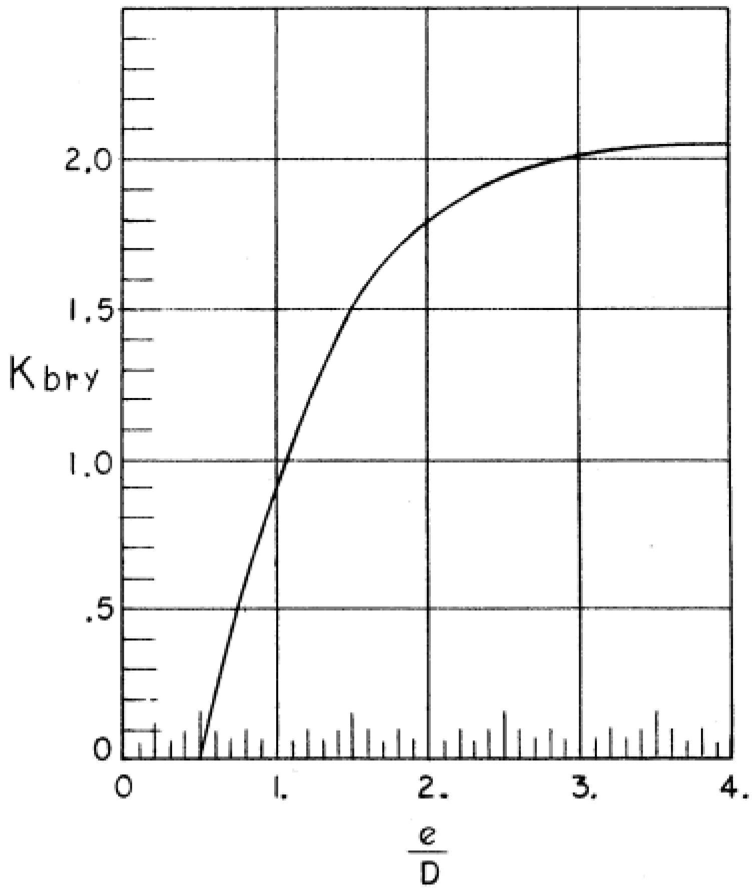


Figure C3.3.1-5 Bearing Yield Efficiency Factors for Lugs

Appendix D – Datasheets

3M DP490

3M

Scotch-Weld™

EPX™ Adhesive DP490

Product Data Sheet

Updated : March 1996
Supersedes : November 1993

Product Description

DP490 is a black, thixotropic, gap filling two component epoxy adhesive with particularly good application characteristics.

It is designed for use where toughness and high strength are required and shows special benefits in the construction of composite assemblies.

The product has excellent heat and environmental resistance.

Physical Properties
Not for specification purposes

	BASE	ACCELERATOR
Specific Gravity	1.00	1.00
Consistency	Non-sag paste	Non-sag paste
Mix Ratio By Weight By Volume	100 100	50 50
Colour	Black	Off-White
Work Life	1.5 hours minimum at 23°C	
Time to Handling Strength	4 to 6 hours at 23°C	
Time to Full Strength	7 days (test to full performance at one week)	
Shelf Life	15 months from date of despatch by 3M when stored in the original carton at 21°C (70°F) & 50 % Relative Humidity	

Performance Characteristics
Not for specification purposes

Performance Characteristics of the Cured Adhesive.

Two cure cycles were evaluated as follows:

Cure Cycle 1	7 days at 23°C
Cure Cycle 2	24 hours at 23°C, 1 hour at 80°C

Performance Characteristics (Cont...)
Not for specification purposes

Temperature Performance in Shear and Peel.

(Etched Aluminium) Shear Strength to BS 5350 C5, Peel Strength was floating roller peel to BS5350 C9.

Tests were performed at 23°C unless otherwise stated.

Temperature (°C)	Shear Strength (1) (N/mm²)	Shear Strength (2) (N/mm²)	Peel Strength DaN/cm
-55	23.7	31.6	N/A
23	30.2	28.7	9.24
80	11.9	12.7	7.32
120	2.8	3.2	N/A
150	1.9	1.7	N/A

Adhesion to Etched Aluminium after Environmental Ageing

Ageing Condition	Shear Strength (N/mm²)
RT Control	26.2
Water at 23°C, 750 hours	25.6
50°C, 96% RH, 750 hours	22.0
120°C, 750 hours	25.3
175°C, dry heat, 120 hours	29.6
Skydroll 500B at 23°C, 750 hours	27.6
JP4 at 23°C, 750 hours	28.7
Hydraulic Oil at 23°C, 750 hours	29.5

DP490 shows good adhesion to many plastic surfaces even by simply solvent wiping.

This can be improved still further by the use of 3M Scotchbrite abrasion and/or use of the primer Scotch-Weld 3901.

Plastics	Shear Strength (N/mm²)
Carbon Fibre Reinforced Epoxy	36.1 (cohesive)
Polyester Sheet Moulding Compound	4.3 (substrate)
Glass Fibre Reinforced Phenolic	30.3 (cohesive)
ABS (filled)	3.2 (substrate)
PVC (filled)	2.9 (substrate)
Azloy (glass filled polycarbonate)	3.0 (adhesion)
Valox (glass filled PET)	1.4 (substrate)
PMMA	3.7 (adhesion)
Noryl (tm XTRA) (glass filled PPO)	4.9 (adhesion)

Storage Conditions

Store product at 15°C to 25°C for maximum storage life.

Directions for Use /Clean Up

Place the cartridge into the 3M EPX Applicator and clip into position.

Remove the resealable cap.

Expel a small quantity of adhesive and ensure both components flow freely.

Attach correct mixer nozzle (this should have 20 or more elements).

Dispense the adhesive as required.

When finished either leave the nozzle in place and store, or remove the nozzle, wipe clean the tip, and replace cap.

To re-start after storage remove the old nozzle with cured adhesive and re-fit a new nozzle, or remove the cap and fit a new nozzle.

Surface Preparation:
The degree of surface preparation depends on the bond strength required and the environment likely to be encountered by the bonded structure. For most plastics solvent wiping with 3M VHB surface cleaner, followed by abrasion with 3M Scotchbrite 7447, followed by a further solvent wipe until clean, will give good performance (except for acetal, polyethylene and polypropylene and some other low surface energy materials). This also applies to powder coat paints and other stoved paint systems.

The same surface preparation will also give good adhesion to metal surfaces. The objective is to remove loosely attached surface films such as oils, waxes, dusts, mill-scale, loose paints and all other surface contaminants in addition to enhancing mechanical adhesion. Grit-blasting using a clean, fine grit also offers excellent adhesion on many metallic substrates.

Where humid environments are likely to be encountered by metallic substrates we recommend additional priming with 3M Scotch-Weld 3901. Alternatively, chemical conversion coating techniques combined with priming can offer the best durability.

Clean-Up:
Excess uncured adhesive can be removed with the following solvents:

3M VHB Surface Cleaner (mild alcohol based cleaner)
3M Scotch-Grip Solvent No2. (Ketone blend)
3M Industrial Cleaner (Aerosol).

Additional Product Information

Please contact your 3M Sa lesperson for additional information on the prepar

Health & Safety Information

Precautions:
Causes severe eye irritation, may cause permanent eye damage. Irritating to skin. May cause sensitisation by skin contact. Avoid contact with the skin and eyes. Wear suitable gloves and eye/face protection.

Launder contaminated clothing before re-use. Avoid prolonged breathing of vapours. Avoid inhalation of dust when grinding or cutting cured material.

First Aid:

Eye Contact: Immediately flush eyes with copious amounts of water for at least 15 minutes, holding eyes open. Call a physician.

Skin Contact: Wash immediately with plenty of soap and water.

For further information please contact the Toxicology Department at the Bracknell Head Office on (0344) 858000.

Specialty Tapes & Adhesives

3M United Kingdom PLC
3M House,
28 Great Jackson Street,
Manchester,
M15 4PA

Customer Service :

Tel 0161 236 8500
Fax 0161 237 1105

3M Ireland
3M House, Adelphi Centre,
Upper Georges Street,
Dun Laoghaire,Co. Dublin,
Ireland

Customer Service :

Tel (01) 280 3555
Fax (01) 280 3509

PRECISION STRAIN GAGE

OMEGA®

PRECISION LINEAR PATTERN FOR STATIC AND DYNAMIC APPLICATIONS

SGD Series

- **Very Flexible, Mechanically Strong**
- **Small Bending Radius**
- **Broad Temperature Range**
- **Ribbon Leads or Solder Pads**
- **Clear Alignment Marks**
- **Affix with Cold or Hot Curing Adhesives**

OMEGA® strain gages are available in a variety of models to cover most strain measurement applications. Their rugged construction and flexibility make them suitable for highly accurate static and dynamic measurement. The measuring grid is formed by etching constantan foil, which is then completely sealed in a carrier medium composed of polyimide film. The linear pattern strain gages are used to measure strain in a single direction. They are often used for experimental stress analysis applications. The strain gage pattern is shown on the left side of the table. Notice the "arrow" which indicates the principal stress direction.

The linear pattern strain gages are available in a variety or styles and sizes. OMEGA is offering miniature linear patterns for strain measurement of a stress concentration or high gradient areas. We also have wide or narrow grid patterns, and small, medium or large patterns. To determine if the strain gages have temperature characteristics matched to steel or aluminum, see the column labeled "COMP" short for compensation, "ST" indicates steel, "AL" indicates aluminum, "UNC" indicates uncompensated. See the column labeled "BTP" for accessory bondable terminal pad model numbers.

Dimensions are listed for pattern gage grid length (A) and width (B), and the matrix or carrier length (C) and width (D). The patterns include alignment triangles. The carrier or matrix material on the patterns may be trimmed in the field on all sides to within 0.25 mm of the foil grid with no effect on strain gage performance.

To Order

Visit us online

GAGE PATTERN Leads not shown	MODEL NO. Pkg of 10	NOM. RESISTANCE (Ω)	DIMENSIONS mm (inch)† GRID A	GRID B	CARRIER C	CARRIER D	MAX V* (Vrms)	TERMINATION	TEMP COMP	TERM PAD
Shown actual size 4.70 mm	SGD-1.5/120-LY11	120	1.50 (0.059)	1.20 (0.047)	4.70 (0.185)	3.40 (0.134)	2.5	Ribbon Leads	ST	BTP-1
	SGD-1.5/120-LY13	120	Miniature linear pattern Measurement of stress concentration 120 Ω				3.5	Ribbon Leads	AL	
	SGD-1.5/120-LY41	120					2.5	Solder Pads	ST	
	SGD-1.5/120-LY43	120					3.5	Solder Pads	AL	
Shown actual size 7.60 mm	SGD-2/350-LY11	350	2.00 (0.079)	2.50 (0.098)	7.60 (0.299)	5.80 (0.228)	7.5	Ribbon Leads	ST	BTP-1
	SGD-2/350-LY13	350	Miniature linear pattern Measurement of stress concentration, higher resistance reduced heat generation 350 Ω				10	Ribbon Leads	AL	
	SGD-2/350-LY41	350					7.5	Solder Pads	ST	
	SGD-2/350-LY43	350					10	Solder Pads	AL	
Shown actual size 7.10 mm	SGD-2D/350-LY11	350	1.90 (0.075)	4.80 (0.189)	7.10 (0.280)	6.60 (0.260)	10	Ribbon Leads	ST	BTP-2
	SGD-2D/350-LY13	350	Miniature linear pattern grid width, wide 350 Ω				14	Ribbon Leads	AL	
	SGD-2D/350-LY41	350					10	Solder Pads	ST	
	SGD-2D/350-LY43	350					14	Solder Pads	AL	
Shown actual size 7.00 mm	SGD-3/350-LY11	350	3.20 (0.126)	2.50 (0.098)	7.00 (0.276)	4.00 (0.157)	9.5	Ribbon Leads	ST	BTP-3
	SGD-3/350-LY13	350	linear pattern leads/ pads at on end of grid 350 Ω				13	Ribbon Leads	AL	
	SGD-3/350-LY41	350					9.5	Solder Pads	ST	
	SGD-3/350-LY43	350					13	Solder Pads	AL	

DISCOUNT SCHEDULE

1 to 10 pkgs.	Net
11 to 24 pkgs.	5%
25 to 49 pkgs.	10%
50 and up and OEM	Consult Factory

† For dimensions key, visit us online.
** Maximum permitted bridge energizing voltage (Vrms).*
***Note:** For strain gage accessories visit us online.*
***Ordering Example: SGD-3/350-LY11,** 3.2 mm grid, 350 Ω nominal-resistance strain gage.*

Custom-Designed Strain Gages Available! No Minimum Quantities. Consult Engineering.

NOTE: ST = Steel, AL = Aluminum

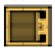
STRAIN GAGES E

E-16

PRECISION STRAIN GAGE

PRECISION LINEAR PATTERN FOR STATIC AND DYNAMIC APPLICATIONS

To Order

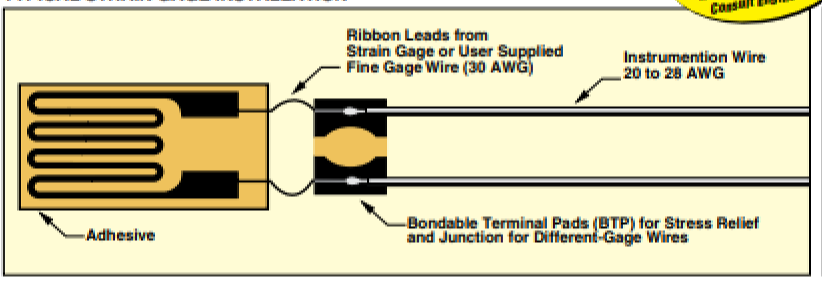
GAGE PATTERN Leads not shown	MODEL NO. Pkg of 10	NOM. RESISTANCE (Ω)	DIMENSIONS mm (inch)† GRID A		CARRIER C		MAX V* (Vrms)	TERMINATION	TEMP COMP	TERM PAD
			A	B	C	D				
Shown actual size 7.80 mm 	SGD-3/120-LY11	120	3.00 (0.118)	1.50 (0.059)	7.80 (0.307)	3.80 (0.150)	4	Ribbon Leads	ST	BTP-3
	SGD-3/120-LY13	120	Linear pattern, grid width narrow 120 Ω				5.5	Ribbon Leads	AL	
	SGD-3/120-LY41	120					4	Solder Pads	ST	
	SGD-1.5/120-LY43	120					5.5	Solder Pads	AL	
Shown actual size 6.60 mm 	SGD-3S/120-LY11	120	3.00 (0.118)	1.70 (0.067)	6.60 (0.260)	3.30 (0.130)	4.5	Ribbon Leads	ST	BTP-3
	SGD-3S/120-LY13	120	Linear pattern, small size 120 Ω				6	Ribbon Leads	AL	
	SGD-3S/120-LY41	120					4.5	Solder Pads	ST	
	SGD-3S/120-LY43	120					6	Solder Pads	AL	
Shown actual size 7.90 mm 	SGD-4/120-LY11	120	3.80 (0.150)	5.70 (0.224)	7.90 (0.311)	7.10 (0.280)	9	Ribbon Leads	ST	BTP-3
	SGD-4/120-LY13	120	Linear pattern, grid width wide 120 Ω				12	Ribbon Leads	AL	
	SGD-4/120-LY41	120					9	Solder Pads	ST	
	SGD-4/120-LY43	120					12	Solder Pads	AL	
Shown actual size 9.80 mm 	SGD-5/350-LY11	350	4.50 (0.177)	3.20 (0.126)	9.80 (0.386)	5.20 (0.205)	12	Ribbon Leads	ST	BTP-4
	SGD-5/350-LY13	350	Linear pattern, medium size 350 Ω				17	Ribbon Leads	AL	
	SGD-5/350-LY41	350					12	Solder Pads	ST	
	SGD-5/350-LY43	350					17	Solder Pads	AL	

DISCOUNT SCHEDULE	
1 to 10 pkgs.	Net
11 to 24 pkgs.	5%
25 to 49 pkgs.	10%
50 and up and OEM	Consult Factory

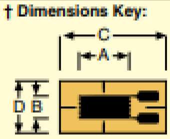
** Maximum permitted bridge energizing voltage (Vrms).*
Note: *For strain gage accessories visit us online.*
Ordering Example: SGD-4/120-LY13, *3.8 mm grid, 120 Ω nominal-resistance strain gage.*

NOTE: ST = Steel
AL = Aluminum

TYPICAL STRAIN GAGE INSTALLATION



† Dimensions Key:

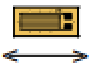
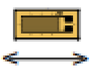
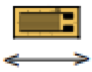
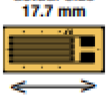


GRID
A: Active gage length
B: Active gage width
CARRIER
C: Matrix length
D: Matrix width

PRECISION STRAIN GAGE
PRECISION LINEAR PATTERN FOR STATIC AND DYNAMIC APPLICATIONS

To Order

Visit us online

GAGE PATTERN Leads not shown	MODEL NO. Pkg of 10	NOM. RESIS-TANCE (Ω)	DIMENSIONS mm (inch)† GRID A	GRID B	CARRIER C	CARRIER D	MAX V* (Vrms)	TERMINATION	TEMP COMP	TERM PAD
Shown actual size 11.4 mm 	SGD-6/120-LY11	120	6.50 (0.256)	3.10 (0.122)	11.40 (0.449)	5.10 (0.201)	9	Ribbon Leads	ST	BTP-4
	SGD-6/120-LY13	120	Linear pattern, medium size 120 Ω				12	Ribbon Leads	AL	
	SGD-6/120-LY41	120					9	Solder Pads	ST	
	SGD-6/120-LY43	120					12	Solder Pads	AL	
Shown actual size 11.4 mm 	SGD-7/350-LY11	350	6.50 (0.256)	3.10 (0.122)	11.40 (0.449)	5.10 (0.201)	15	Ribbon Leads	ST	BTP-5
	SGD-7/350-LY13	350	Linear pattern, medium size 350 Ω				20	Ribbon Leads	AL	
	SGD-7/350-LY41	350					15	Solder Pads	ST	
	SGD-7/350-LY43	350					20	Solder Pads	AL	
Shown actual size 11.8 mm 	SGD-7/1000-LY11	1000	7.00 (0.276)	3.60 (0.142)	11.80 (0.465)	5.60 (0.220)	27	Ribbon Leads	ST	BTP-5
	SGD-7/1000-LY13	1000	Medium size, higher resistance, reduced heat genaration 1000 Ω				37	Ribbon Leads	AL	
	SGD-7/1000-LY41	1000					27	Solder Pads	ST	
	SGD-7/1000-LY43	1000					37	Solder Pads	AL	
Shown actual size 17.7 mm 	SGD-10/120-LY11	120	10.00 (0.394)	4.90 (0.193)	17.70 (0.697)	8.00 (0.315)	14	Ribbon Leads	ST	BTP-5
	SGD-10/120-LY13	120	Linear pattern, Large size 120 Ω				19	Ribbon Leads	AL	
	SGD-10/120-LY41	120					14	Solder Pads	ST	
	SGD-10/120-LY43	120					19	Solder Pads	AL	

DISCOUNT SCHEDULE	
1 to 10 pkgs.	Net
11 to 24 pkgs.	5%
25 to 49 pkgs.	10%
50 and up and OEM	Consult Factory

** Maximum permitted bridge energizing voltage (Vrms).*
***Note:** For strain gage accessories visit us online.*
***Ordering Example: SGD-6/120-LY13,** 6.5 mm grid, 120 Ω nominal-resistance strain gage.*

Custom-Designed Strain Gages Available! No Minimum Quantities. Consult Engineering.

NOTE: ST = Steel, AL = Aluminum

BONDABLE TERMINAL PADS

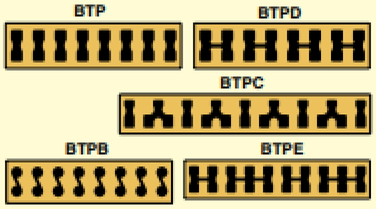
When installing strain gages with ribbon leads or solder pads, use Bondable Terminal Pads (BTP) between the strain gage and the wires to your instrumentation.

The Bondable Terminal Pads provide a large easy to use soldering area and provide strain relief between the strain gage and the heavy instrument wires.

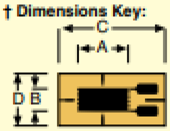
Using Bondable Terminal Pads is simple. Use the same adhesive and bonding procedure on the Bondable Terminal Pads as you use on the strain gage.

OMEGA offers BTPs in several sizes and wiring configurations to fit most all strain gage applications.

Terminal pad patterns.



† Dimensions Key:



GRID
A: Active gage length
B: Active gage width
CARRIER
C: Matrix length
D: Matrix width

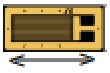
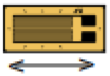
STRAIN GAGES E

PRECISION STRAIN GAGE

PRECISION LINEAR PATTERN AND EXTRA LONG PATTERN

To Order

Visit us online

GAGE PATTERN Leads not shown	MODEL NO. Pkg of 10	NOM. RESIS-TANCE (Ω)	DIMENSIONS mm (inch)† GRID A	GRID B	CARRIER C	CARRIER D	MAX V* (Vrms)	TERMINATION	TEMP COMP	TERM PAD
Shown actual size 17.7 mm 	SGD-10/350-LY11	350	10.00 (0.394)	4.90 (0.193)	17.70 (0.697)	8.00 (0.315)	22	Ribbon Leads	ST	BTP-5
	SGD-10/350-LY13	350	Linear pattern, large size 350 Ω				32	Ribbon Leads	AL	
	SGD-10/350-LY41	350					22	Solder Pads	ST	
	SGD-10/350-LY43	350					32	Solder Pads	AL	
Shown actual size 17.7 mm 	SGD-10/1000-LY11	1000	10.00 (0.394)	4.90 (0.193)	17.70 (0.697)	8.00 (0.315)	40	Ribbon Leads	ST	BTP-5
	SGD-10/1000-LY13	1000	Linear pattern, large size, higher resistance, reduced heat generation 1000 Ω				55	Ribbon Leads	AL	
	SGD-10/1000-LY41	1000					40	Solder Pads	ST	
	SGD-10/1000-LY43	1000					55	Solder Pads	AL	
Shown actual size 22.7 mm 	SGD-13/350-LY11	350	13.00 (0.511)	7.20 (0.283)	22.70 (0.893)	10.00 (0.393)	30	Ribbon Leads	ST	BTP-6
	SGD-13/350-LY13	350	Linear pattern, grid length long 350 Ω				40	Ribbon Leads	AL	
	SGD-13/350-LY41	350					30	Solder Pads	ST	
	SGD-13/350-LY43	350					40	Solder Pads	AL	
Shown actual size 22.7 mm 	SGD-13/1000-LY11	1000	13.00 (0.511)	7.20 (0.283)	22.70 (0.893)	10.00 (0.393)	55	Ribbon Leads	ST	BTP-6
	SGD-13/1000-LY13	1000	Linear pattern, grid length long, higher resistance, reduced heat generation 1000 Ω				75	Ribbon Leads	AL	
	SGD-13/1000-LY41	1000					55	Solder Pads	ST	
	SGD-13/1000-LY43	1000					75	Solder Pads	AL	

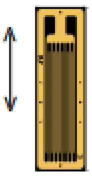
DISCOUNT SCHEDULE	
1 to 10 pkgs.	Net
11 to 24 pkgs.	5%
25 to 49 pkgs.	10%
50 and up and OEM	Consult Factory

† For dimensions key, visit us online.
** Maximum permitted bridge energizing voltage (Vrms).*
***Note:** For strain gage accessories, visit us online.*
***Ordering Example: SGD-13/350-LY13**, 13 mm grid, 350 Ω nominal-resistance strain gage.*

NOTE
ST = Steel
AL = Aluminum

Extra-Long For Inhomogeneous Material

To Order

GAGE PATTERN Leads not shown	MODEL NO. Pkg of 5	NOM. RESIS-TANCE (Ω)	DIMENSIONS mm (inch)† GRID A	GRID B	CARRIER C	CARRIER D	MAX V* (Vrms)	TERMINATION	TEMP COMP	TERM PAD
Shown smaller than actual size 50 mm 	SGD-30/120-LY40	120	25.00 (0.984)	8.00 (0.315)	40.00 (1.575)	12.00 (0.472)	12	Solder Pads	UNC	BTP-6
	SGD-30N/120-LY40	120	30.00 (1.181)	3.00 (0.118)	36.00 (1.417)	5.00 (0.197)	10	Solder Pads	UNC	
	SGD-30/350-LY40	350	30.00 (1.181)	3.00 (0.118)	36.00 (1.417)	5.00 (0.197)	14	Solder Pads	UNC	
	SGD-50/120-LY40	120	50.00 (1.969)	4.30 (0.169)	60.00 (2.362)	9.00 (0.354)	12	Solder Pads	UNC	
	SGD-150/240-LY40	240	150.00 (5.906)	5.00 (0.197)	165.00 (6.496)	9.00 (0.354)	35	Solder Pads	UNC	

† For dimensions key,visit us online.
** Maximum permitted bridge energizing voltage (Vrms).*
***Note:** For strain gage accessories, visit us online.*
***Ordering Example: SGD-30/120-LY40**, 120 Ω nominal-resistance strain gage.*

NOTE
UNC = Uncompensated

E-19

SHD COMPOSITE MATERIALS INC
203 McKenzie Road
Mooresville
NC 28117

www.shdcomposites.com

Tel: +1 (704) 6266876
us-sales@shdcomposites.com

MTC400-1

Epoxy Component Prepreg

Introduction

MTC400-1 is an epoxy resin system designed to cure between 175°F and 275°F allowing flexibility in component manufacture. It is a toughened epoxy resin system designed for component manufacturing that can be supplied on a variety of fabrics and in UD format to meet your cost and manufacturing requirements.

Typical applications: *Motorsport / Aerospace*

Key Features & Benefits

- Cure temperature from **175°F** to **275°F**
- Service temperature up to **390°F** after post cure
- Low CTE and shrinkage
- Work life at 70°F: **30 days**
- Storage life at 0°F: **12 months**
- Very low VOC content – no added solvents during manufacture
- **Improved toughness** over MTC400

Storage & Out Life

This material should be kept frozen at 0°F. It must be kept sealed in a polythene bag which must not be opened until fully thawed to room temperature. If the material is not fully used, then the material must be resealed in the polythene bag to prevent moisture absorption.

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us-sales@shdcomposites.com

Cure Cycles & performances

CURE CYCLE OPTIONS:

Temperature		Duration		Tg
175°F	(minimum)	16	hours	195°F
195°F		8	hours	210°F
210°F		4	hours	230°F
230°F		2	hours	250°F
275°F	(maximum)	1	hour	295°F
355°F	Post Cure	2	hours	400°F

- Curing Schedule is meant to be a guide only and is subject to local conditions.
- To avoid exotherm particular care must be taken with thick laminates.
  Ramp rates must not exceed **5°F** per minute during **initial cure**.
  Ramp rates must not exceed **1°F** per minute during **post cure** (free standing).

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us-sales@shdcomposites.com

Cured Material Properties

PLY: ***200gsm 2x2 twill 6k, 42% resin weight***

Material description: *MTC400-1-C200T-T800-42%RW-1250 (SHD0447-1250)*

Test	Results			Standard
Vf	Fibre volume fraction	**48.79**	**%**	*BS EN ISO 14127 Method B*
CPT	Cured ply thickness	**0.225**	**mm**	*BS EN ISO 14127 Method B*
Tensile 0°	Tensile strength	**981**	**MPa**	*BS EN ISO 527-4*
	Tensile modulus	**67.0**	**GPa**	
	Poisson's ratio	**0.07**		
Tensile 90°	Tensile strength	**893**	**MPa**	
	Tensile modulus	**66.5**	**GPa**	
	Poisson's ratio	**0.07**		
Compressive 0°	Compressive strength	**737**	**MPa**	*prEN 2850 Type B*
	Compressive modulus	**61.0**	**GPa**	
Compressive 90°	Compressive strength	**765**	**MPa**	
	Compressive modulus	**61.7**	**GPa**	
Flexural 0°	Flexural strength	**1032**	**MPa**	*BS EN ISO 14125*
	Flexural modulus	**64.5**	**GPa**	
Flexural 90°	Flexural strength	**1056**	**MPa**	
	Flexural modulus	**64.9**	**GPa**	
In-Plane Shear ±45°	In-Plane shear strength (5% strain)	**95.9**	**MPa**	*BS EN ISO 14129*
	In-Plane shear strength (ultimate)	**118.6**	**MPa**	
	In-Plane shear modulus	**4.00**	**GPa**	
Interlaminar Shear 0°	Interlaminar shear strength	**97.4**	**MPa**	*BS EN ISO 14130*
Interlaminar Shear 90°	Interlaminar shear strength	**91.8**	**MPa**	
Fracture Toughness (G1c)	G_{1c}	**390**	**J/m²**	*prEN 6033*
DMA – Dry Tg	Tg E' Onset	**309**	**°F**	*Modified ASTM D7028*
	Tg Peak Tan δ	**432**	**°F**	*(Single Cantilever)*

Cure schedule: 15 mins @ 185°F then 90 mins @ 275°F, 4°F/min ramp rate (solid release, autoclave cured, 6 bar). All figures in this table are actual test results and have not been normalised. Complete test reports can be supplied independently upon request.

SHDUS/MISC/945 Issue: 1 21st June 2022

Revised: 21st February 2023 Uncontrolled copy when printed

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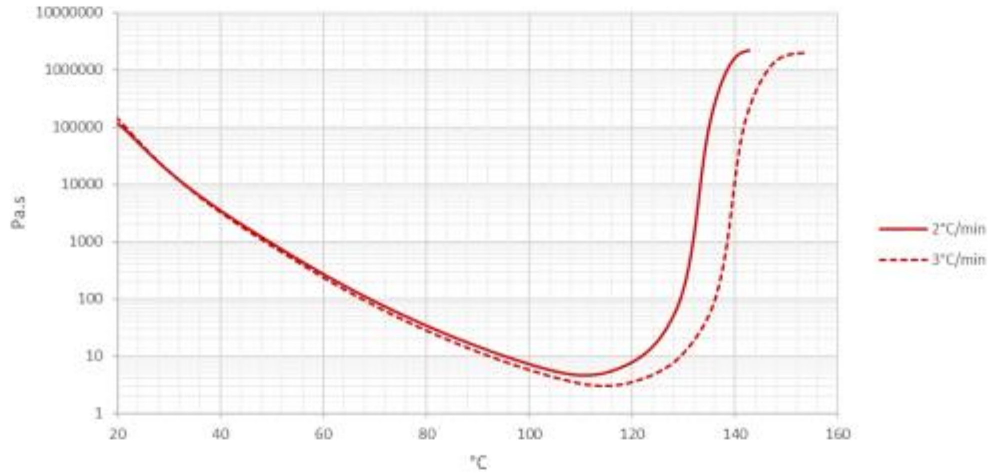
Viscosity Profile

Measured using a rotational rheometer



Health and Safety

This material contains epoxy resin which can cause allergic reactions with skin contact and must avoid repeated and prolonged skin contact.

Please refer to the product Safety Data Sheet before using this material. The following precautions must be taken when using epoxy resin prepregs:

- Overalls must be worn.
- Impervious gloves must be worn.
- Curing schedule is meant to be as a guide only and is subject to local conditions.
- To avoid exotherm, particular care must be taken with thick laminates.
- Ramp rates must not exceed 5°F/min during initial cure and 1°F/min during post cure.

EN24

Technical Datasheet

Engineering Steel Service. Quality. Value.

Applications

- High strength shafts
- Punches & dies
- Drill bushings
- Retaining rings
- Gears

Key features:

- Very high strength steel alloy
- Easy to heat treat and temper
- Supplied hardened & tempered
- Good combination of strength, ductility and wear resistance

Product Description

EN24 is a very high strength steel alloy which is supplied hardened and tempered. The grade is a nickel chromium molybdenum combination - this offers high tensile steel strength, with good ductility and wear resistance characteristics. With relatively good impact properties at low temperatures, EN24 is also suitable for a variety of elevated temperature applications.

Machinability

Readily machinable

Related material specifications

BS 970:1955	EN24T
BS 970:1991	817M40T
German / DIN	34CrNiMo6
French AFNOR	35NCD6
American AISI / SAE	4340
German Werkstoff No.	1.6582
European Standard	EN10277-5

Hardening

Supplied hardened and tempered.

Availability

Round bar, flat bar, square bar and plate

Chemical Composition (weight %)

	C	Si	Mn	P	S	Mo	Cr	Ni
min.	0.36	0.10	0.45			0.20	1.00	1.30
max.	0.44	0.35	0.70	0.035	0.04	0.35	1.40	1.70

Mechanical Properties (subject to ruling section)

Condition	Tensile N/mm²	Yield N/mm²	Elongation %	Izod KCV J	Hardness Brinell
T	850-1000	650	13	35	248-302
U	925-1000	755	12	42	269-331
V	1000-1150	850	12	42	293-352
W	1075-1225	940	11	35	311-375
X	1150-1300	1020	10	28	341-401
Y	1225-1375	1095	10	21	363-429
Z	1550	1235	5	9	444

Technical Assistance

Our knowledgeable staff backed up by our resident team of qualified metallurgists and engineers, will be pleased to assist further on any technical topic.

UK Service Centres:

Smiths Belfast	02895 908 897	Smiths Leeds	0113 307 5167
Smiths Biggleswade	01767 604 704	Smiths Manchester	0161 794 8650
Smiths Birmingham	0121 728 4940	Smiths Norwich	01603 789 878
Smiths Bristol	0117 971 2800	Smiths Nottingham	0115 925 4801
Smiths Chelmsford	01245 466 664	Smiths Redruth	01209 315 512
Smiths Gateshead	0191 469 5428	Smiths Verwood	01202 824 347
Smiths Horsham	01403 261 981	Main Office	0845 527 3331

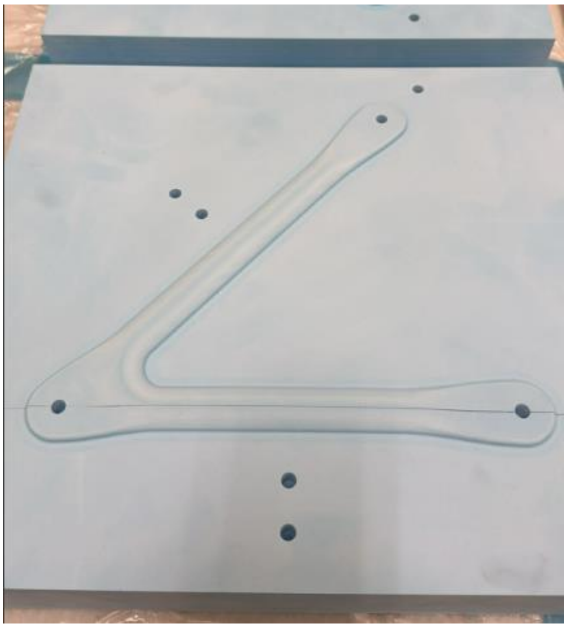
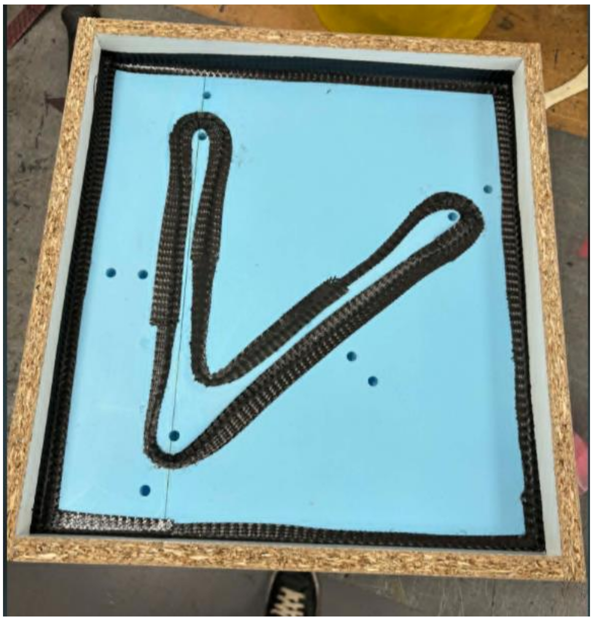
Quality & Testing:

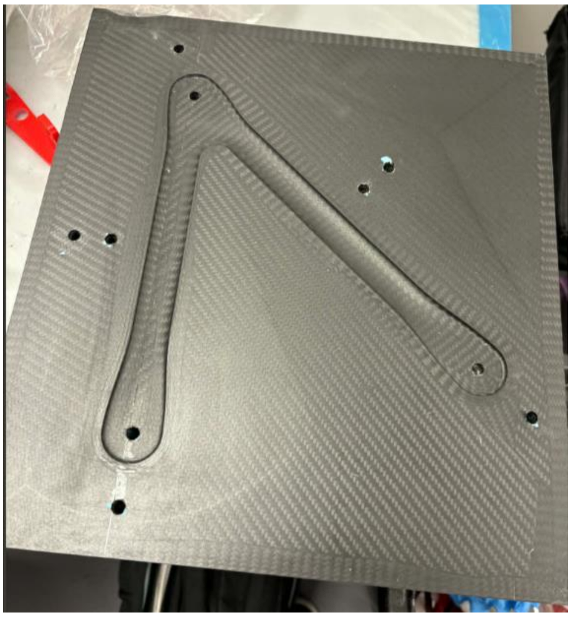
bsi ISO 9001 Quality Management Systems CERTIFIED

UKAS TESTING 1930

www.smithmetal.com info@smithmetal.com

Appendix E – FUWB Manufacturing

	
1. BE978 epoxy tooling board used as a male pattern for creating the female carbon moulds.	2. Once machined the pattern was sealed and released. Chipboard shuttering was screwed into the block to create the mould returns to add stiffness. A 1-8-1 layup was used bringing the total laminate thickness to ~ 5.5 mm

	
3. Carbon moulds prior to the addition of laminating bushes.	4. Once fully laminated the moulds were bagged and cured in an autoclave at 60deg for 12h at 90psi pressure.
	
5. Wishbone mould cured and taken off the pattern. A post cure of the mould followed to increase its glass transition temperature	6. The mould was sealed and release. Lamination as per laminate book in appendix E began.

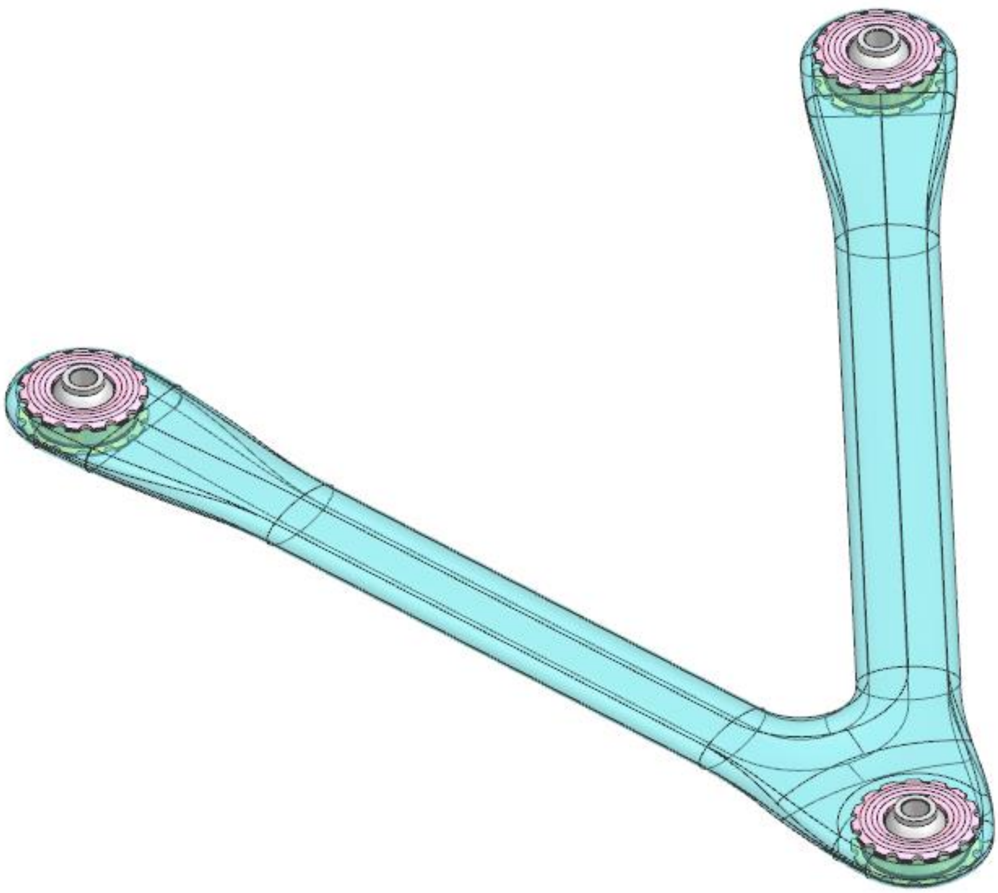

7.Cured wishbone half. The machining of the wishbone is then carried out according to the processes outlines in Appendix F.

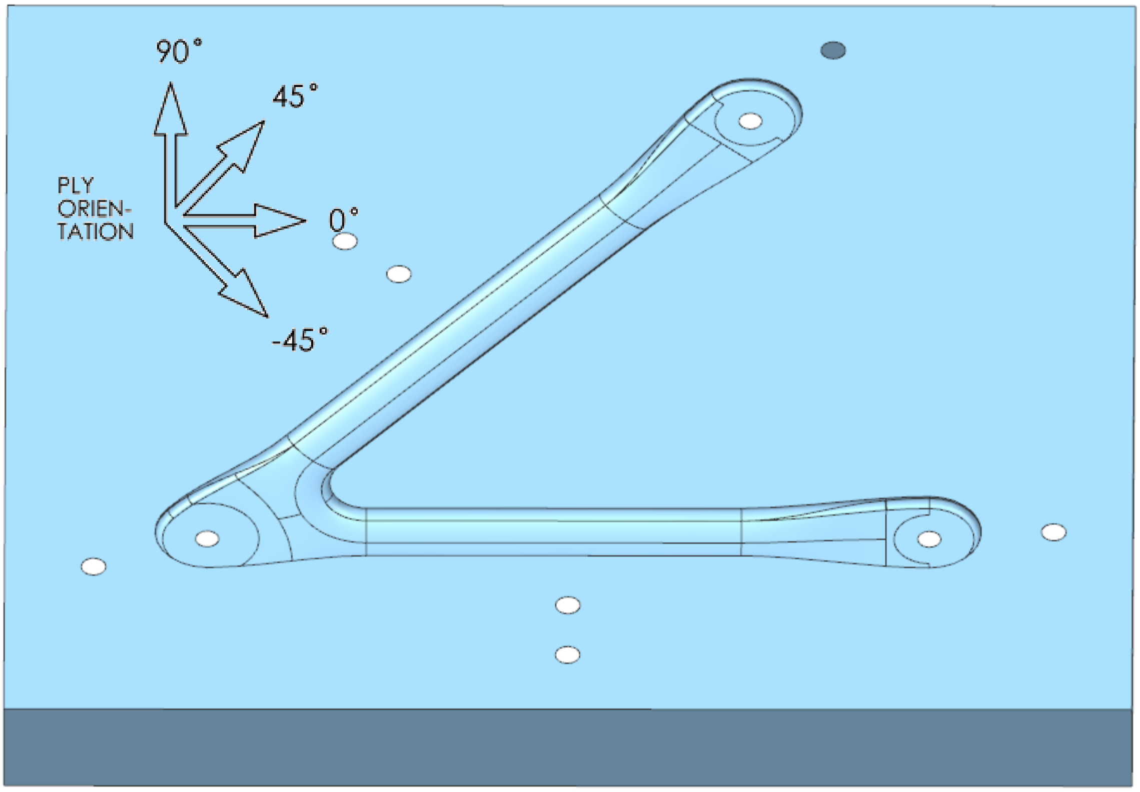
Appendix F – Laminate Schedule- FUWB

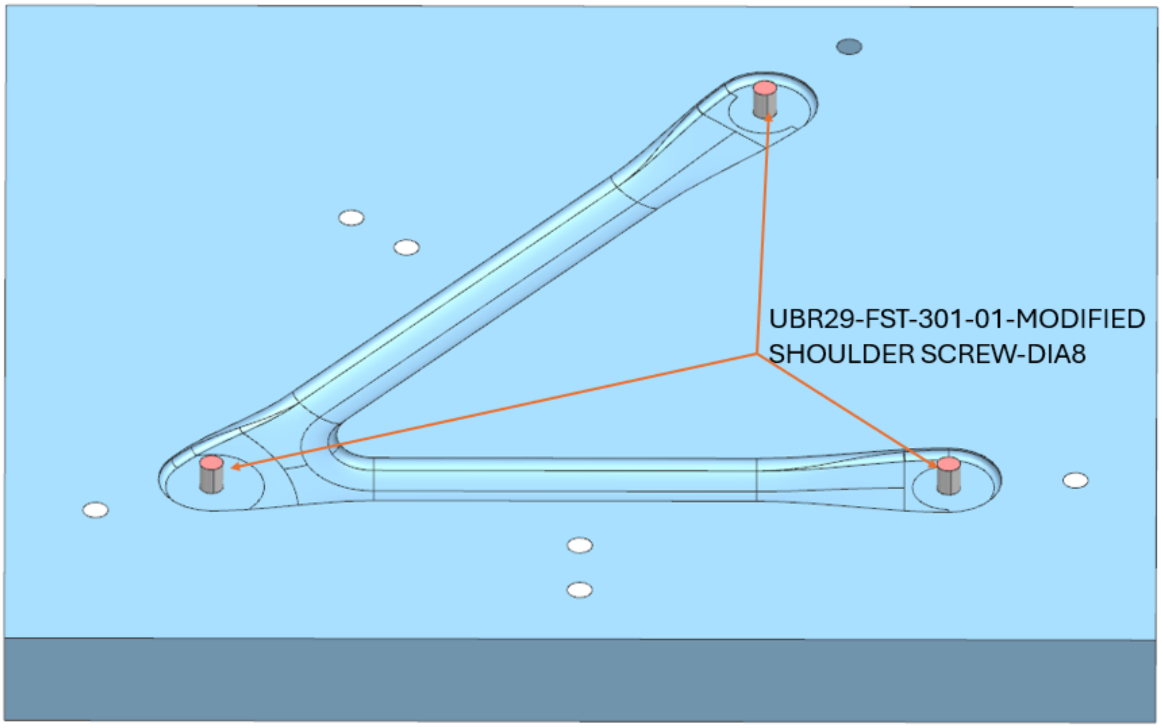
Laminate Schedule

UBR29-FS-003-01-MLDG-FUWB

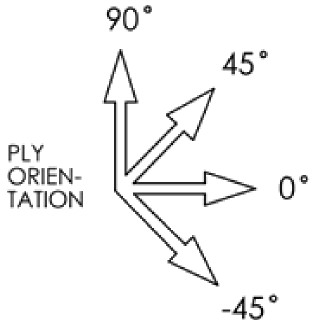
From: AS	Release Date: 01.04.26

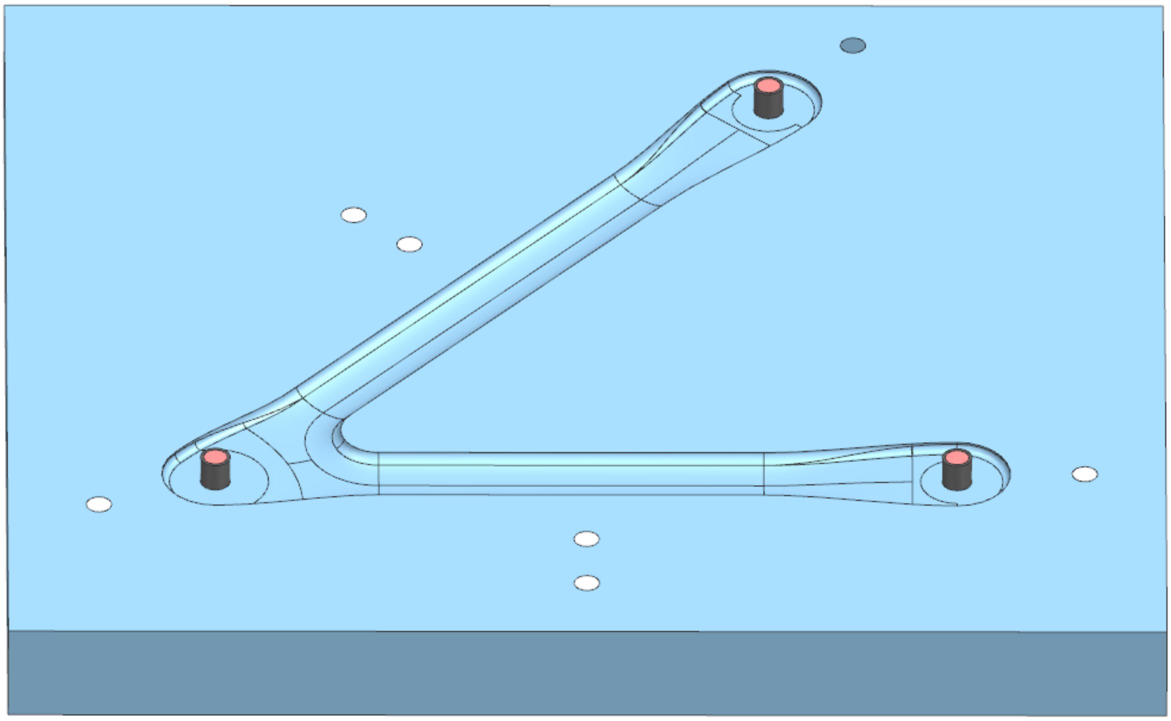




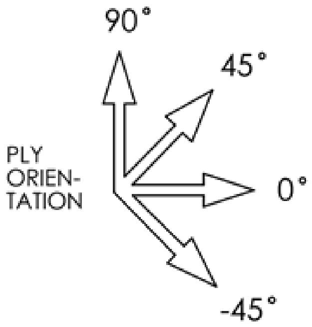


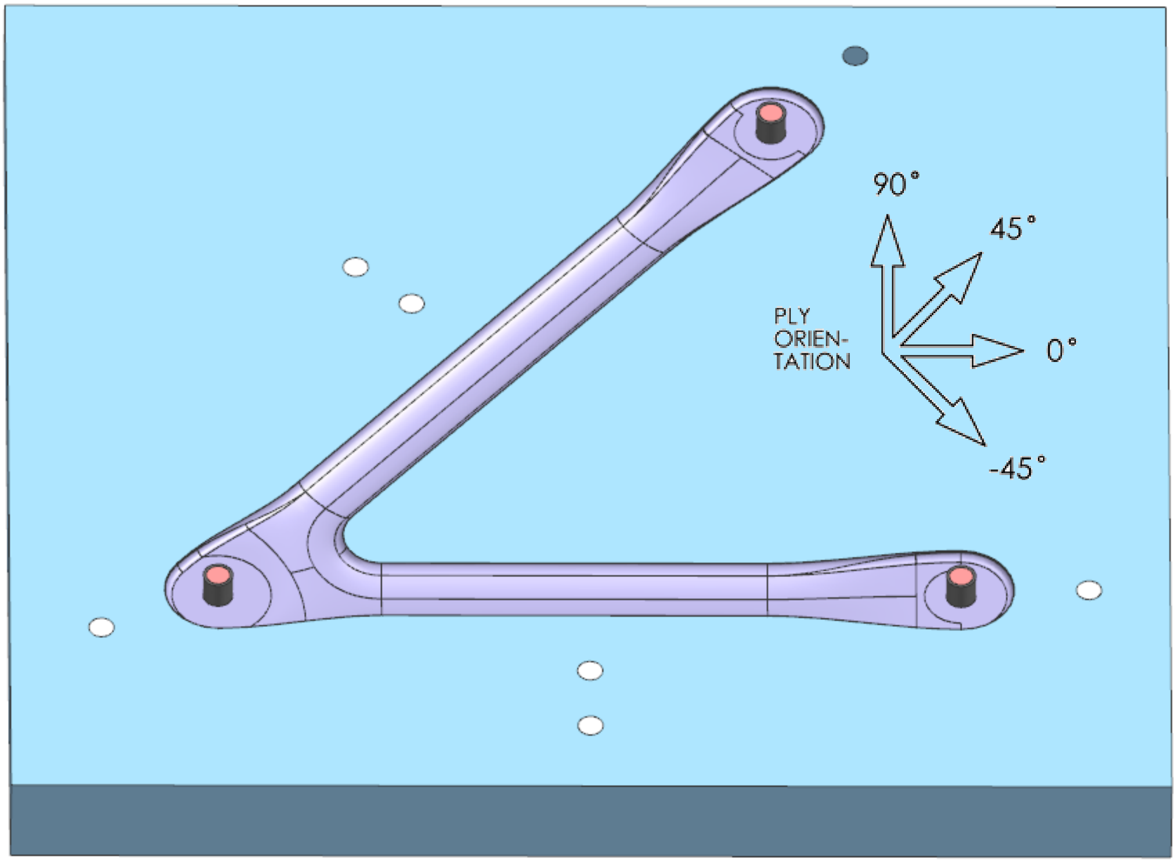
OP No.	Material Spec.	Orientation	Comments	Laminator
01		-	Orientate mould as shown and note rosette.	



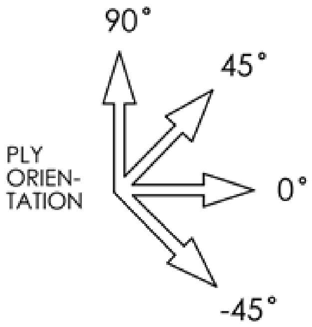


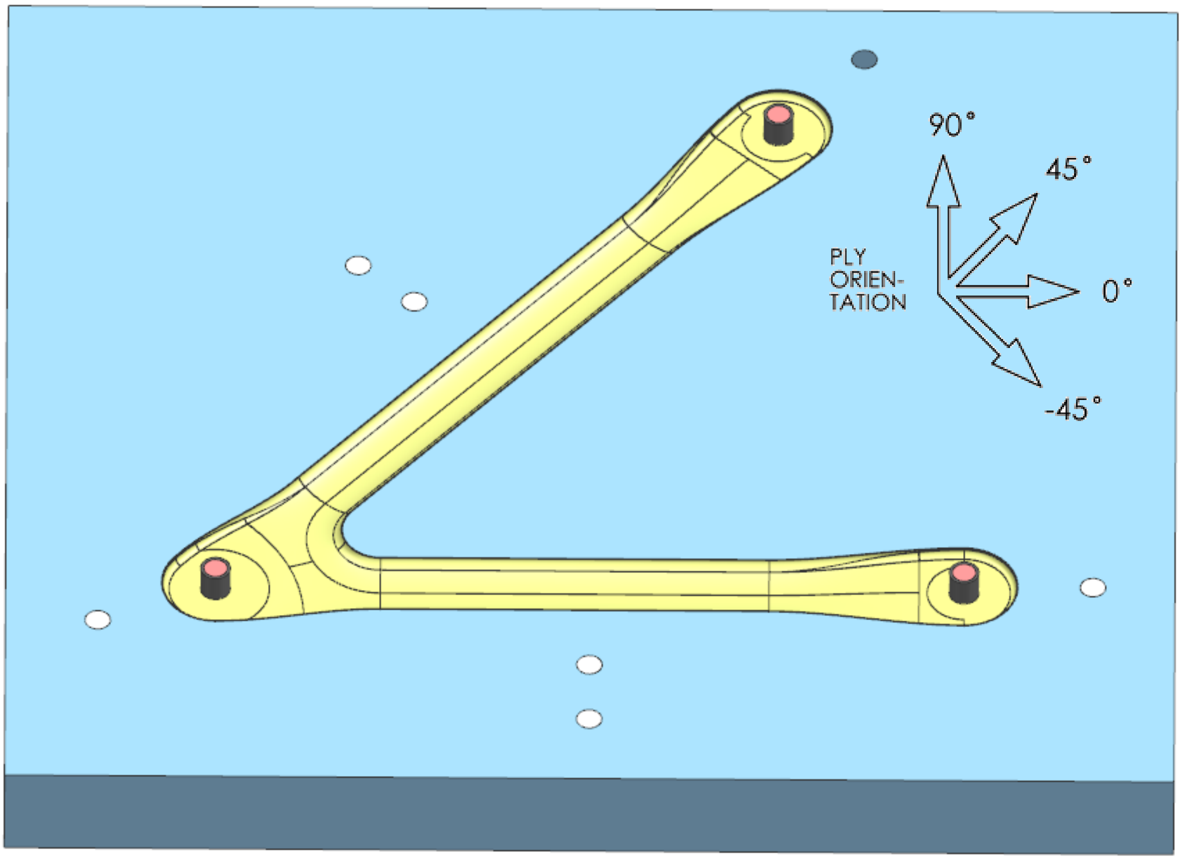
OP No.	Material Spec.	Orientation	Comments	Laminator
02	MTC400-1-C200T-M40J-42%RW-1250	-	Install pre-released dowels and wrap 4x around diameter.	



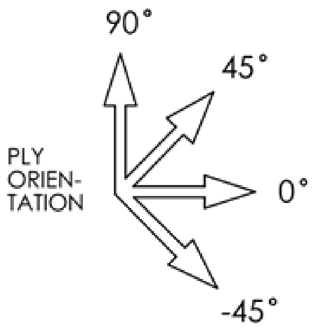


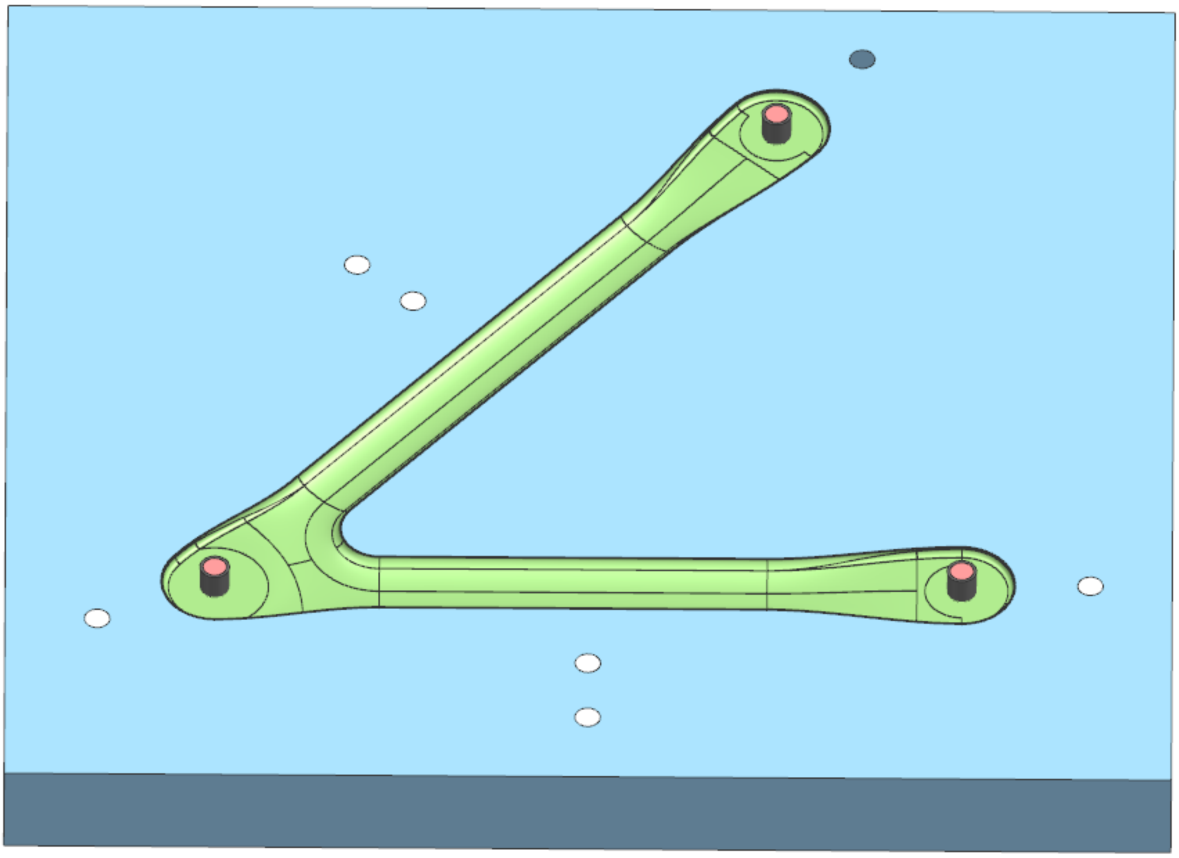
OP No.	Material Spec.	Orientation	Comments	Laminator
03	MTC400-1-C200T-M40J-42%RW-1250	+-45	Star ply around dowels and lay over dowel	
04	Room Temperature Debulk – 15 min			



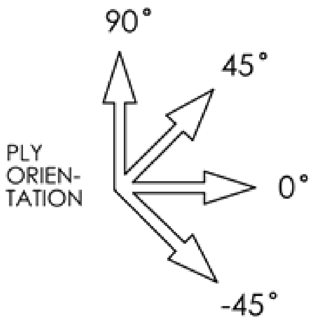


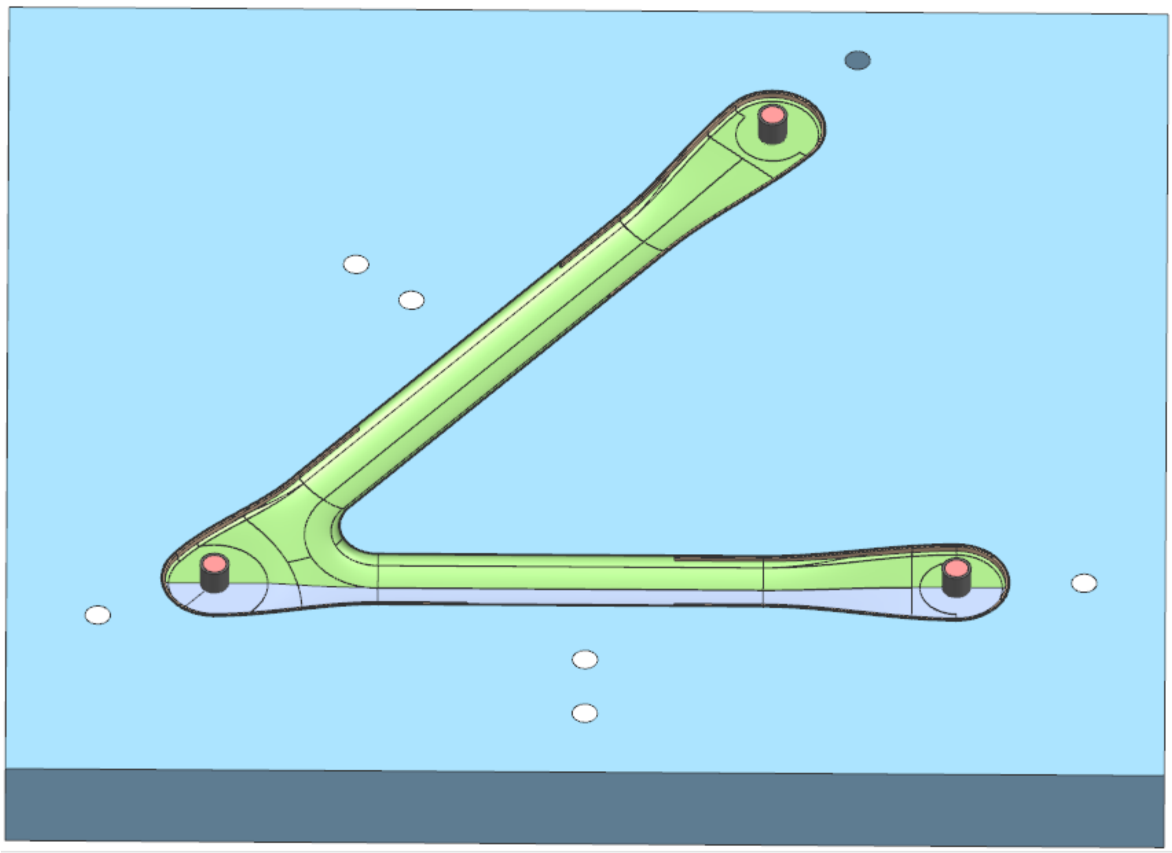
OP No.	Material Spec.	Orientation	Comments	Laminator
05	MTC400-1-C200T-M40J-42%RW-1250	0/90	Star ply around dowels and lay over dowel	



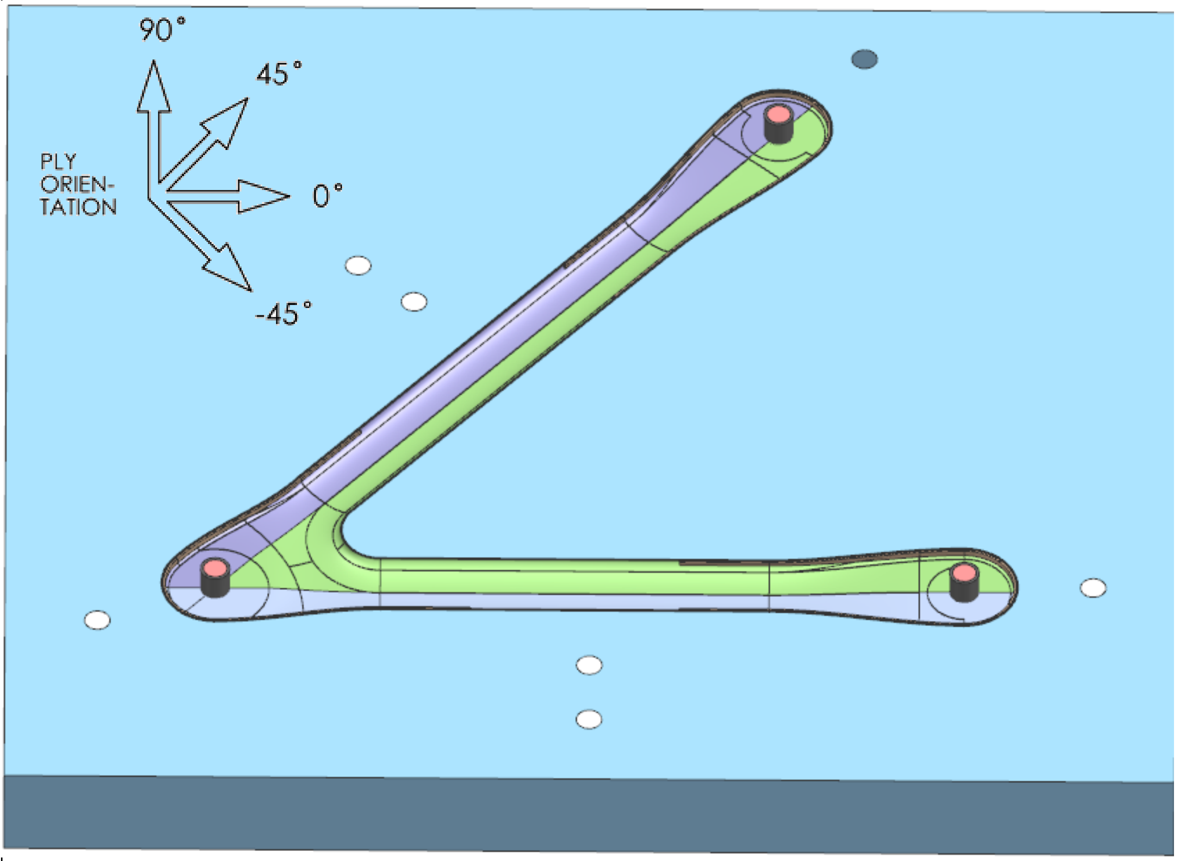


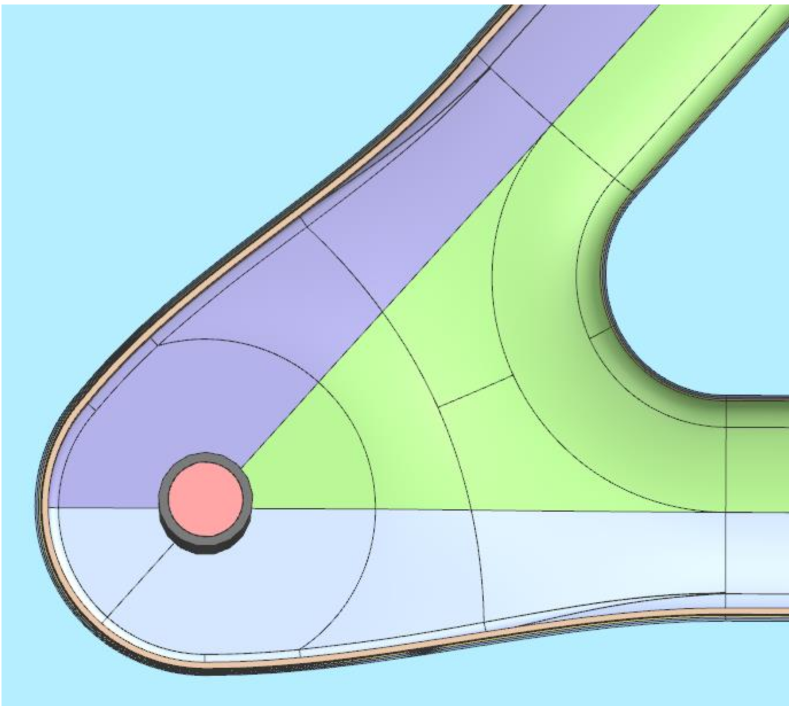
OP No.	Material Spec.	Orientation	Comments	Laminator
06	MTC400-1-C200T-M40J-42%RW-1250	+-45	Star ply around dowel and lay over dowel	



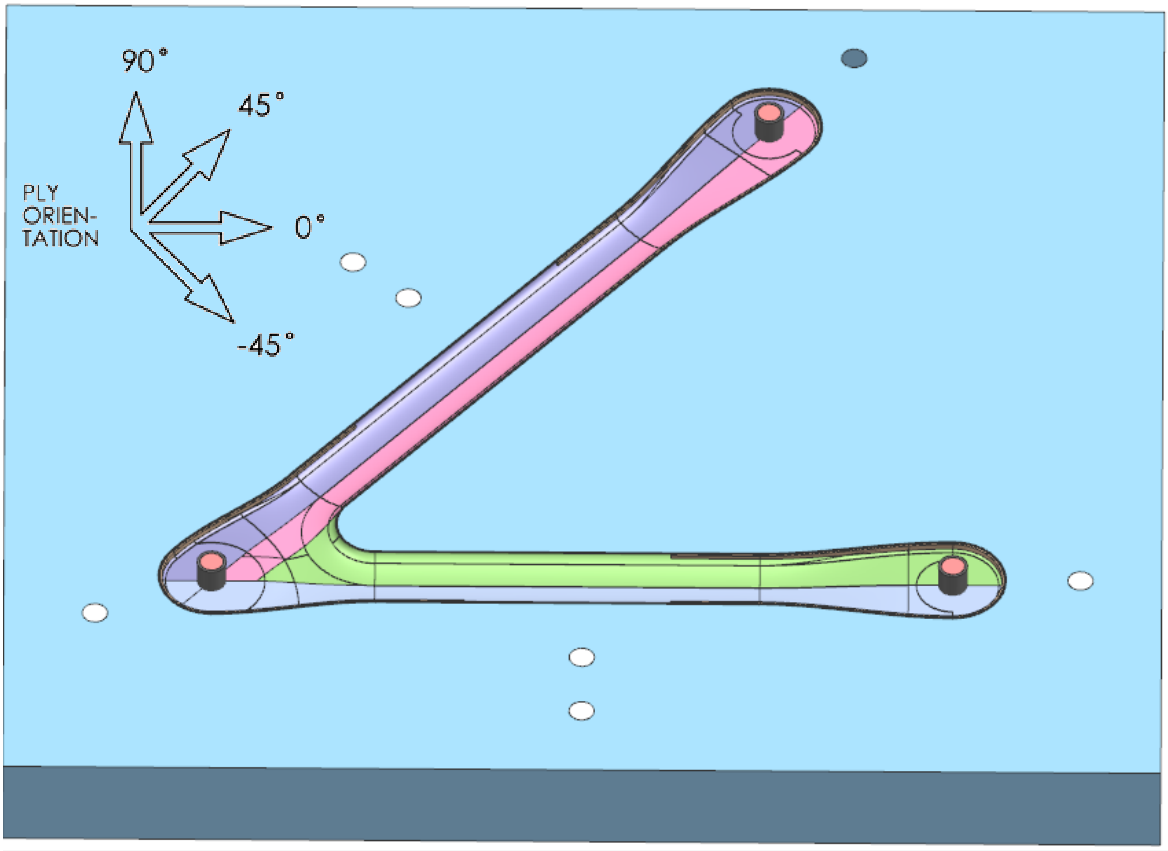


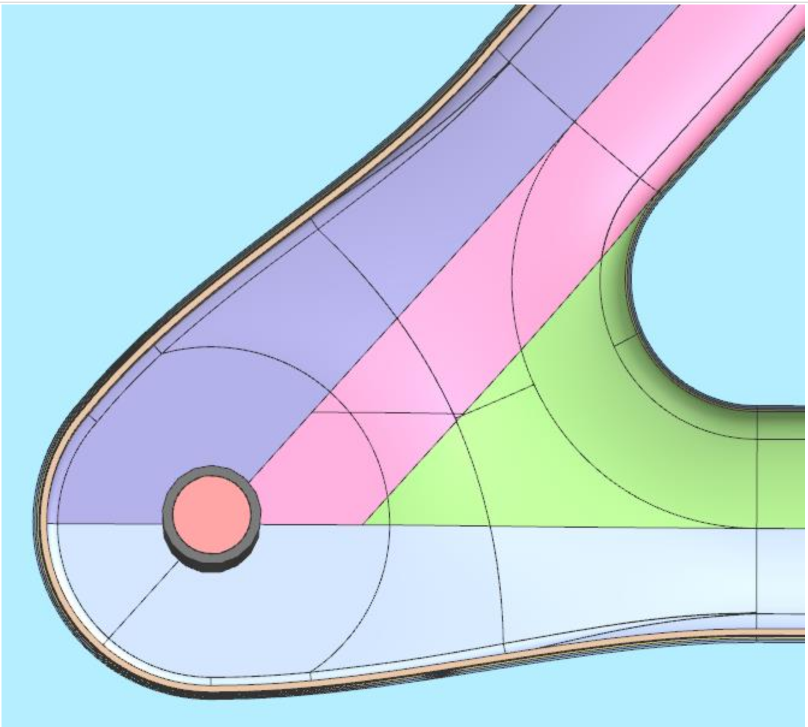
OP No.	Material Spec.	Orientation	Comments	Laminator
07	MTC400-1-UD140-M46J-33%RW-300P	0	Do not overlap ply onto dowels.	



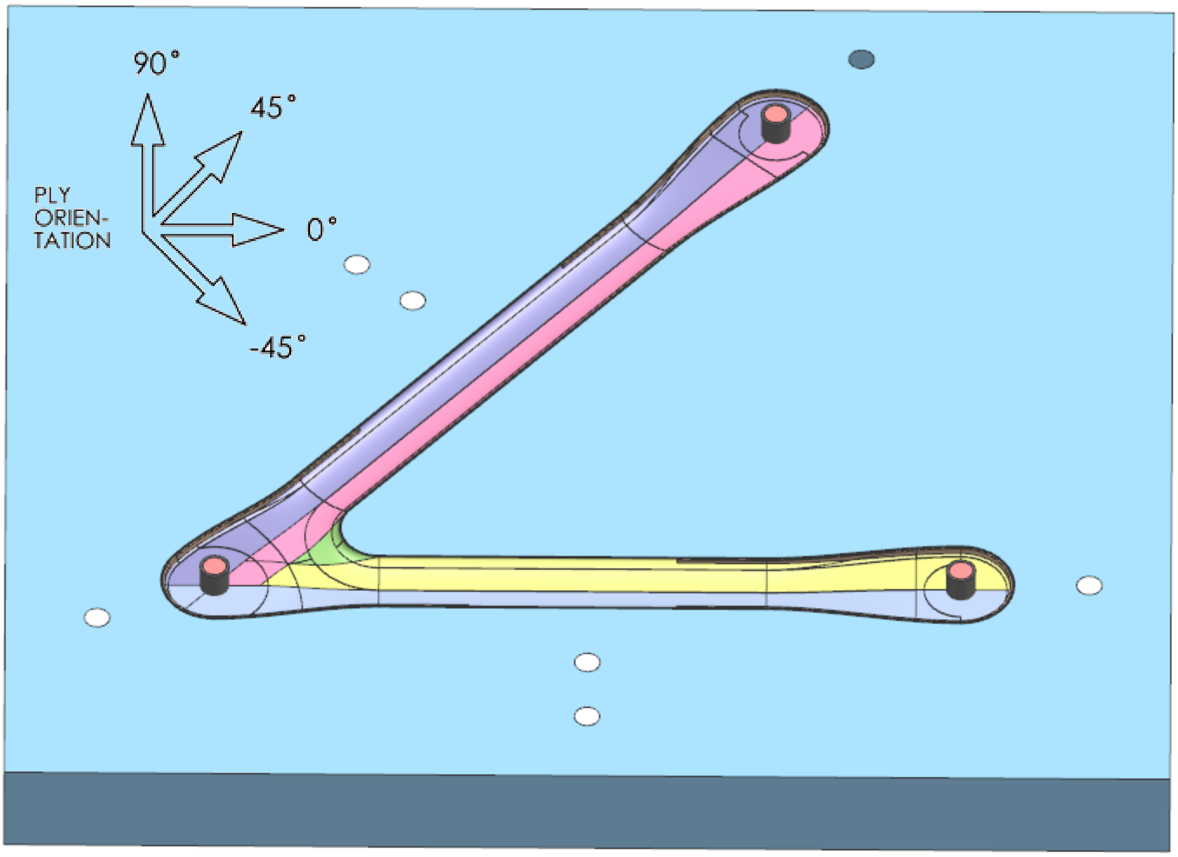


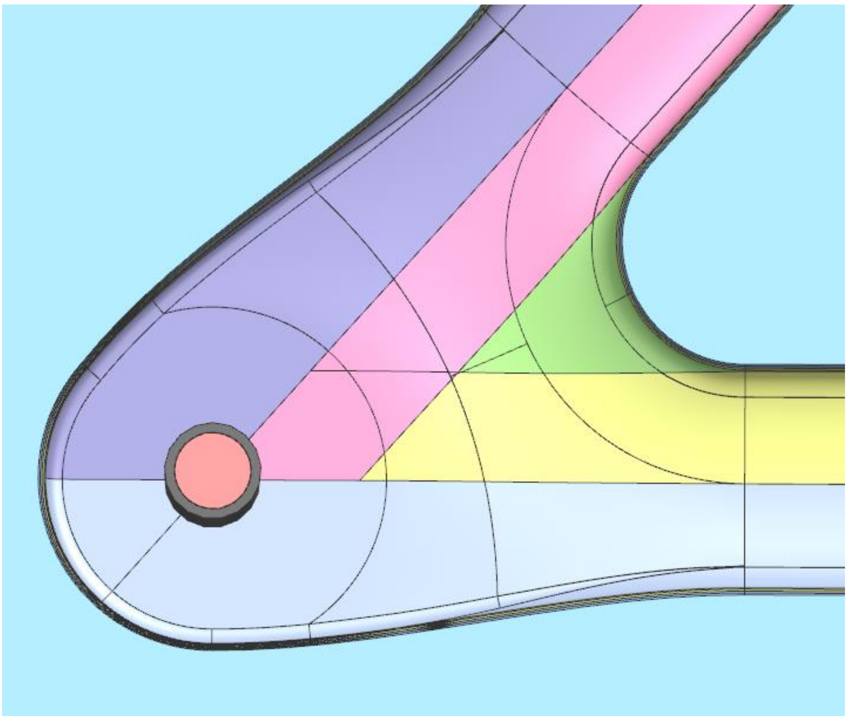
OP No.	Material Spec.	Orientation	Comments	Laminator
08	MTC400-1-UD140-M46J-33%RW-300P	0	Do not overlap ply onto dowels. Butt plys as shown.	



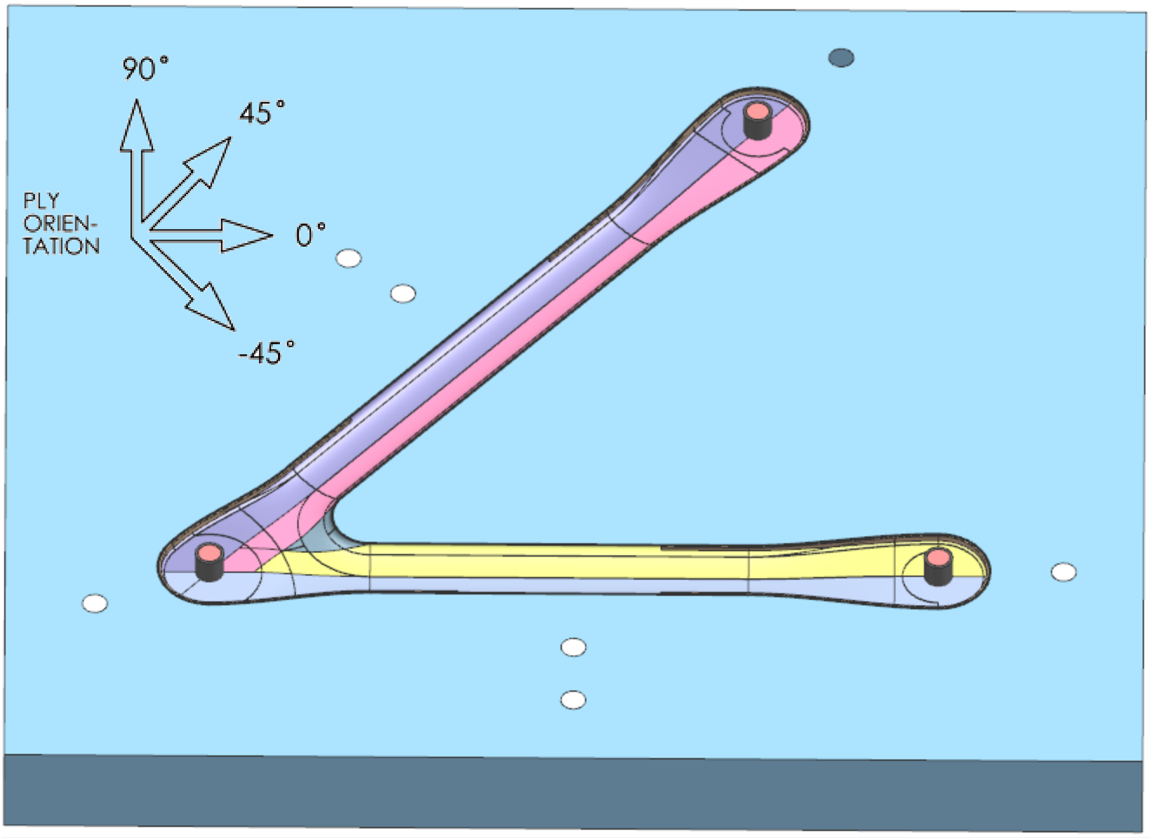


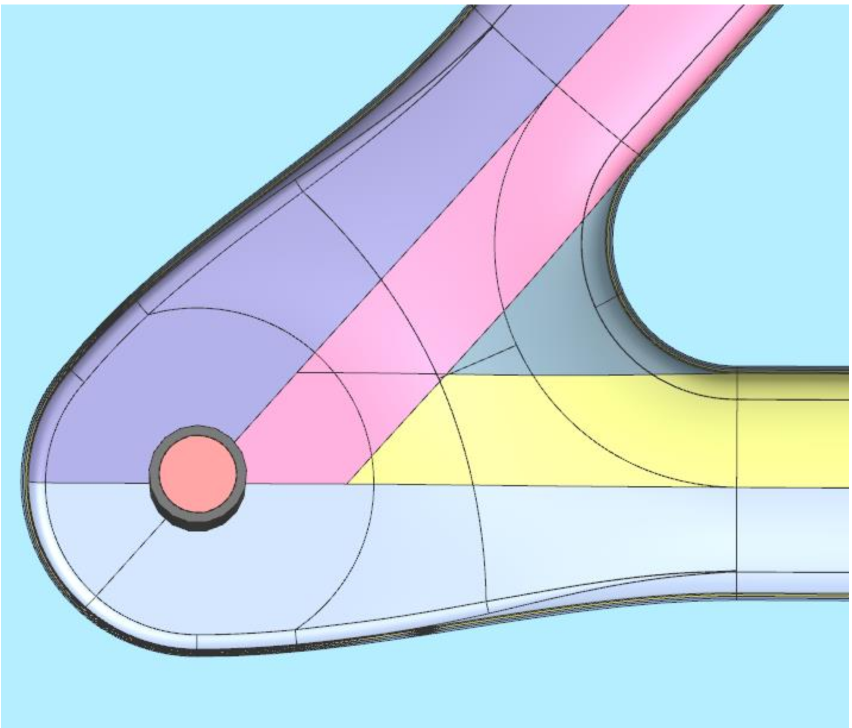
OP No.	Material Spec.	Orientation	Comments	Laminator
9	MTC400-1-UD140-M46J-33%RW-300P	0	Do not overlap ply onto dowels. Butt plys as shown	



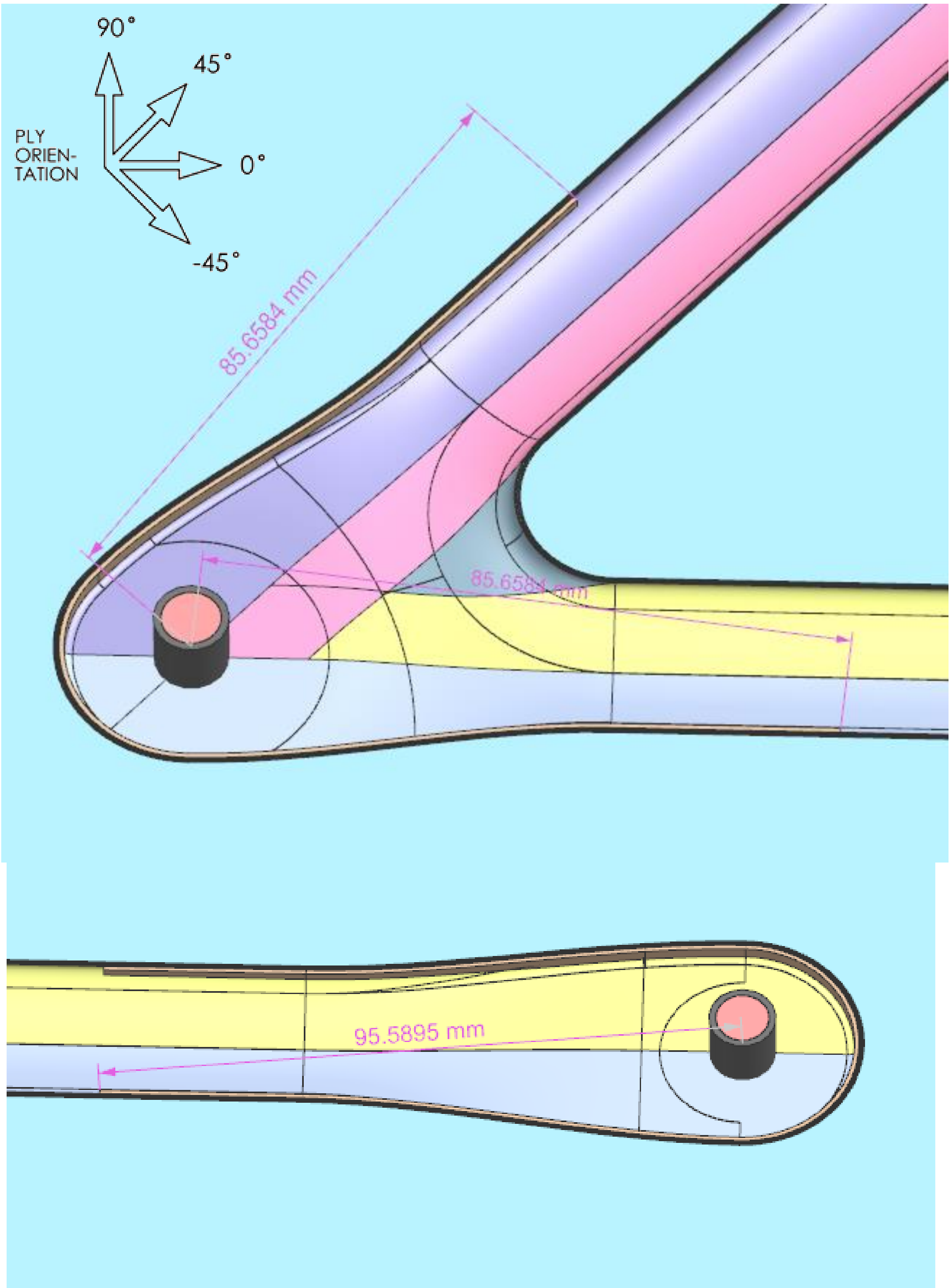


OP No.	Material Spec.	Orientation	Comments	Laminator
10	MTC400-1-UD140-M46J-33%RW-300P	0	Butt plys as shown	

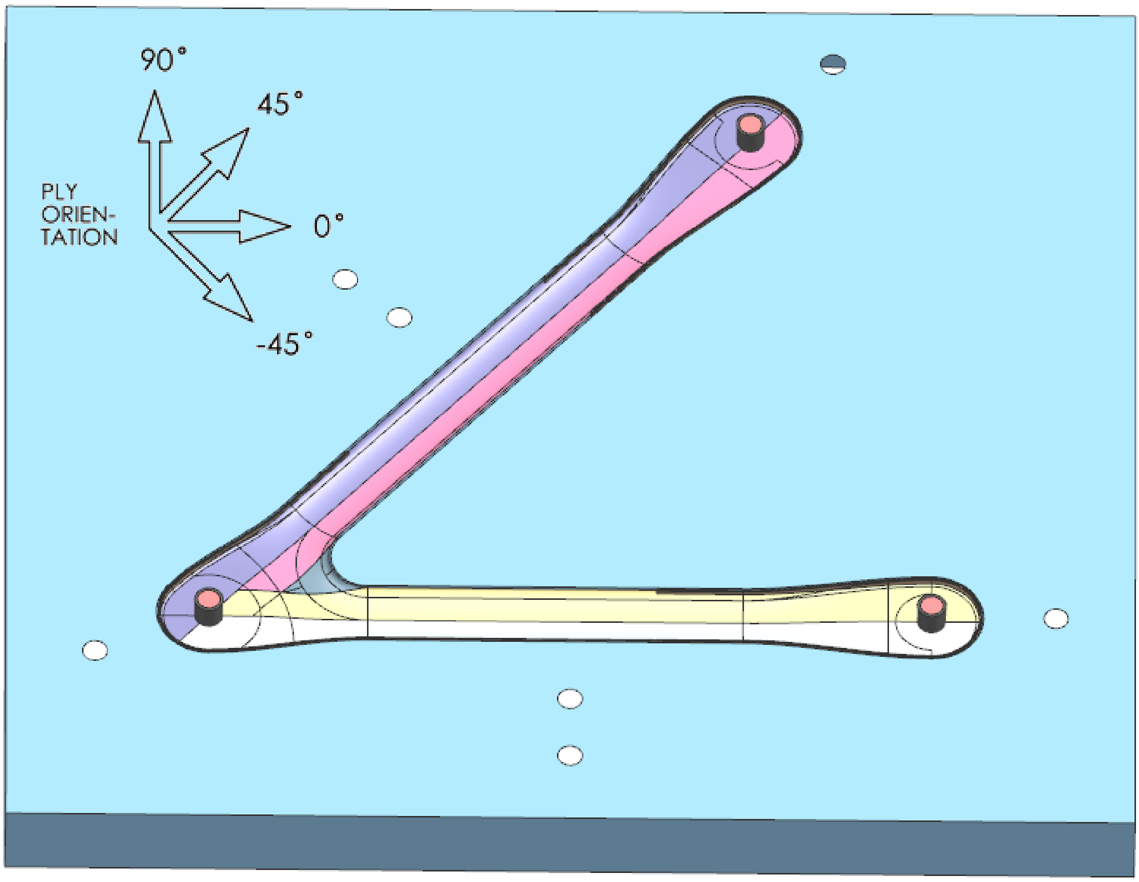


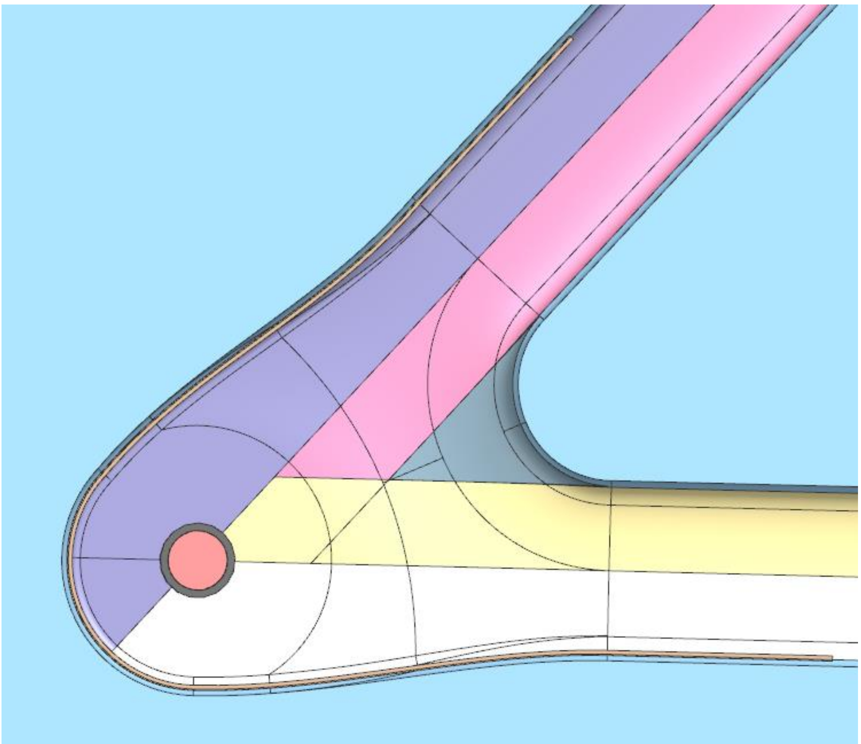


OP No.	Material Spec.	Orientation	Comments	Laminator
11	MTC400-1-UD140-M46J-33%RW-300P	0	Fill remaining area as shown. Do not overlap plys	

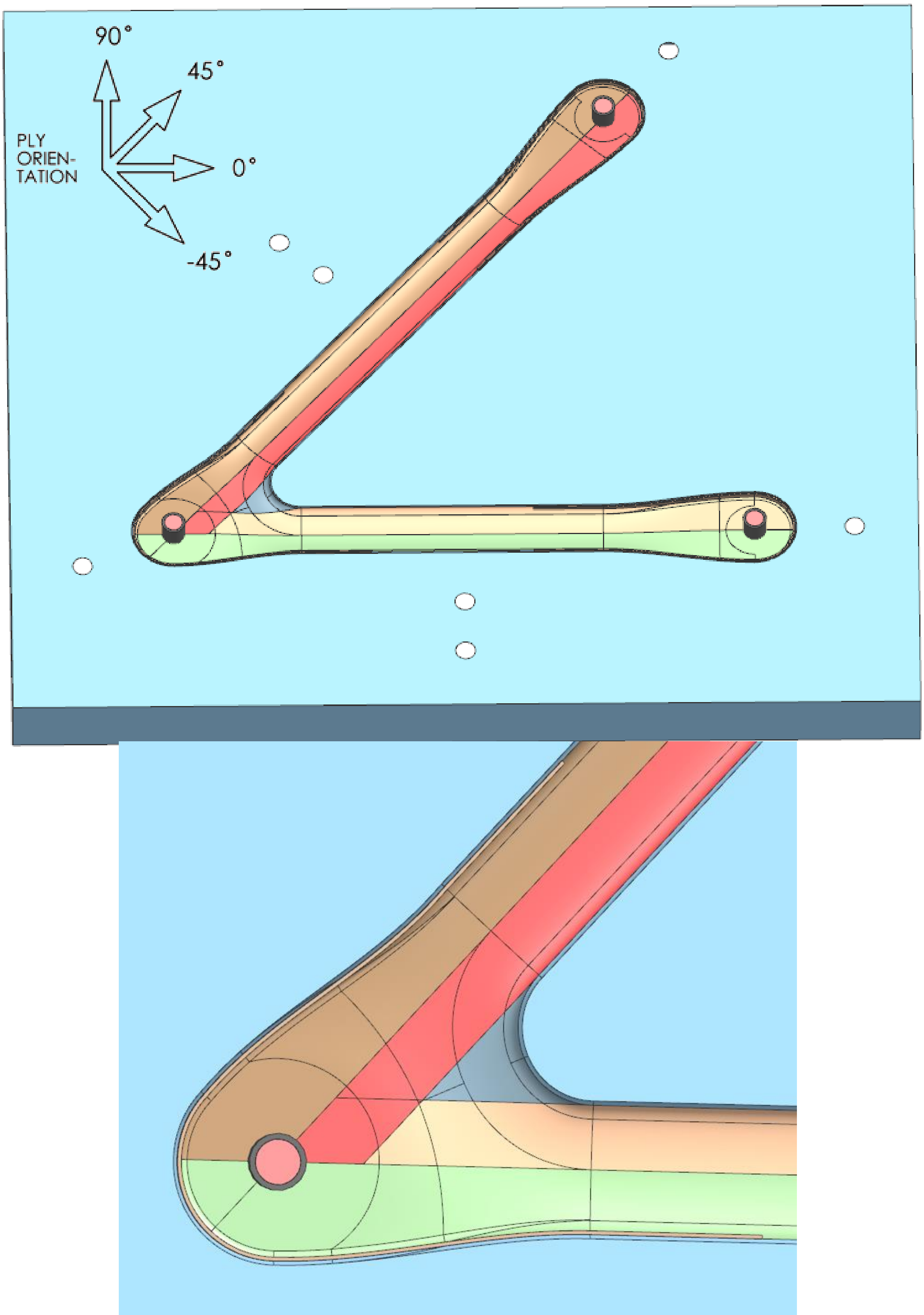


OP No.	Material Spec.	Orientation	Comments	Laminator
12	MTC400-1-UD140-M46J-33%RW-300P	0/90	Transfer preforms onto job. NB: Dimensions +- 2mm	
13	Room Temperature Debulk - 15 min			

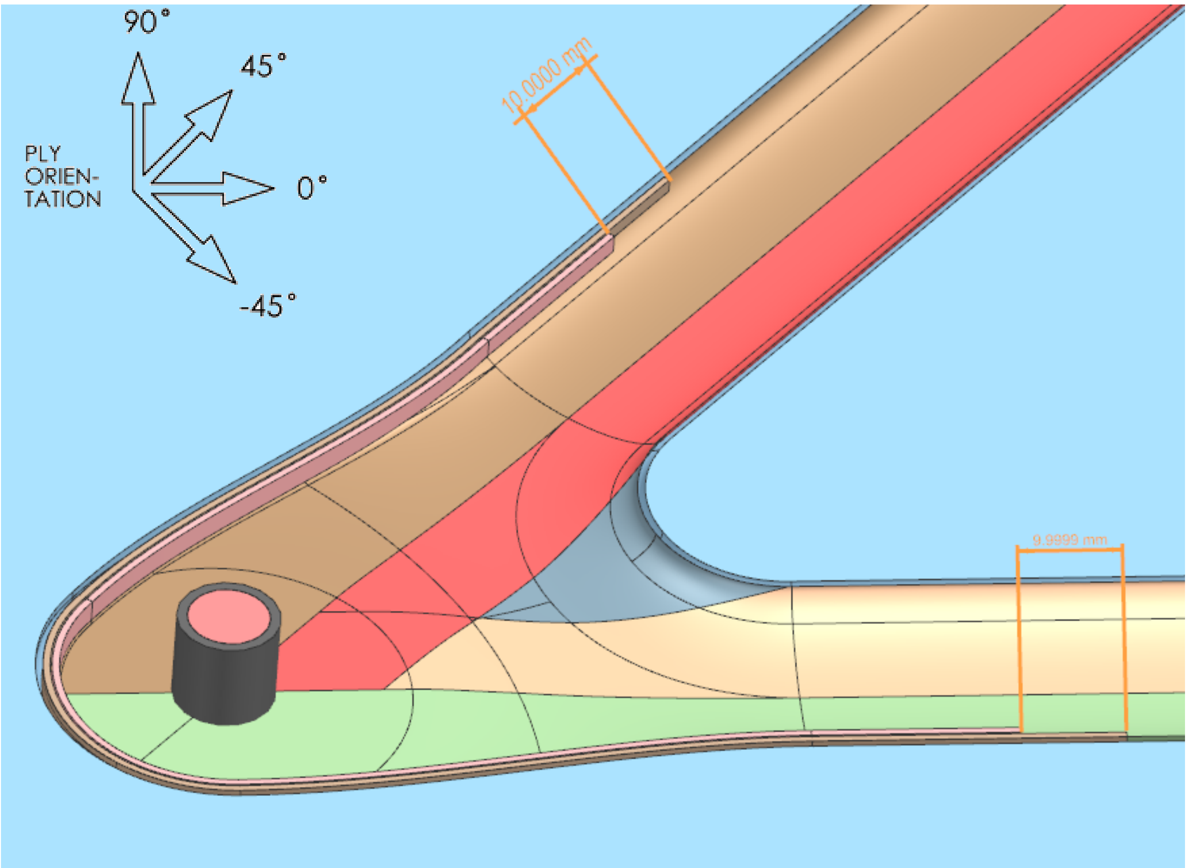


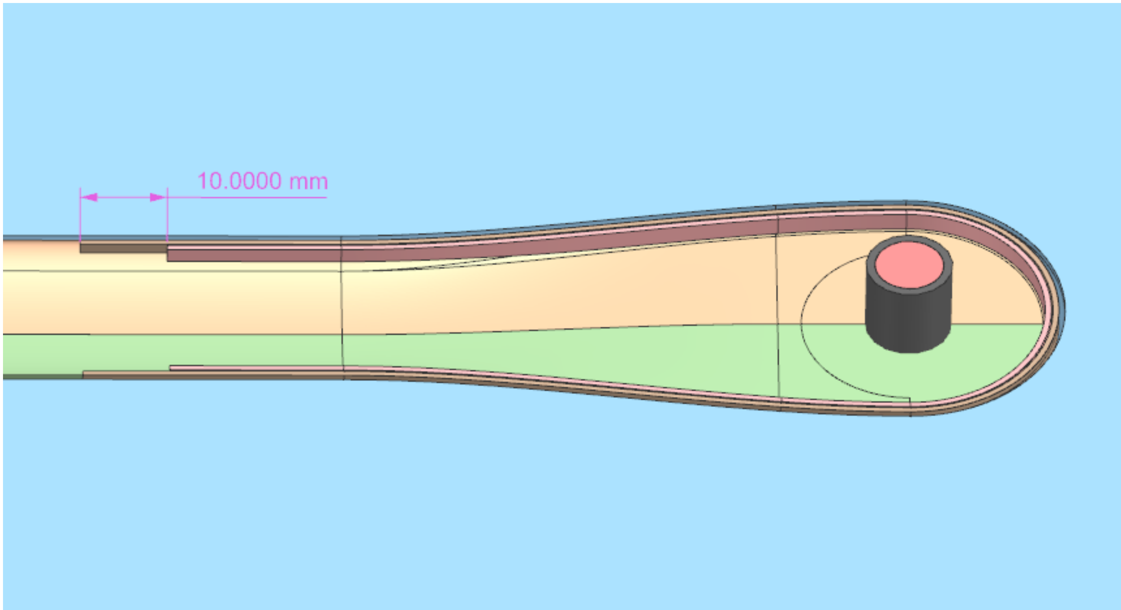


OP No.	Material Spec.	Orientation	Comments	Laminator
14	MTC400-1-UD140-M46J-33%RW-300P	0	Butt plys as shown. Op 7-10 as reference	

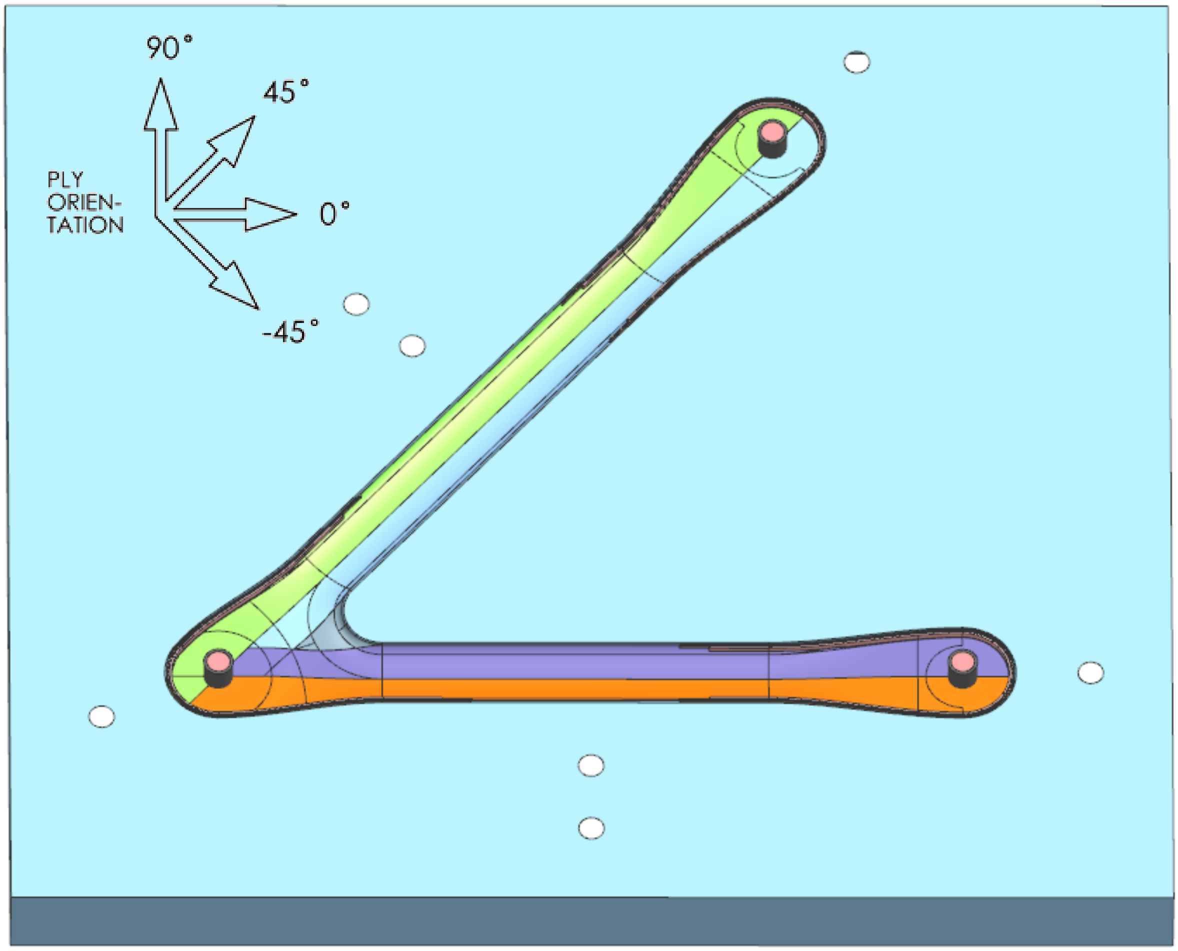


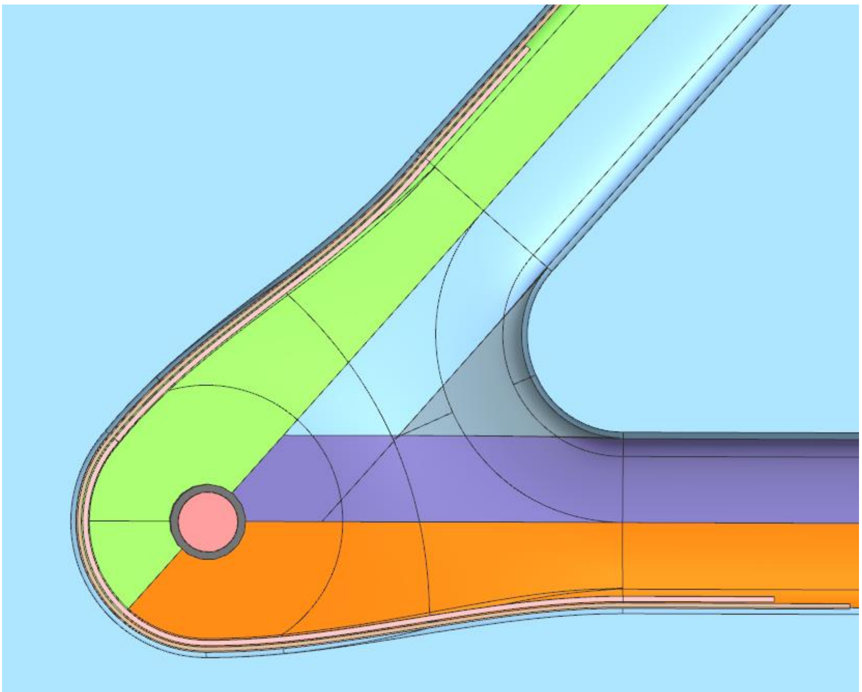
OP No.	Material Spec.	Orientation	Comments	Laminator
15	MTC400-1-UD140-M46J-33%RW-300P	0	Butt plys as shown. Op 7-10 as reference	



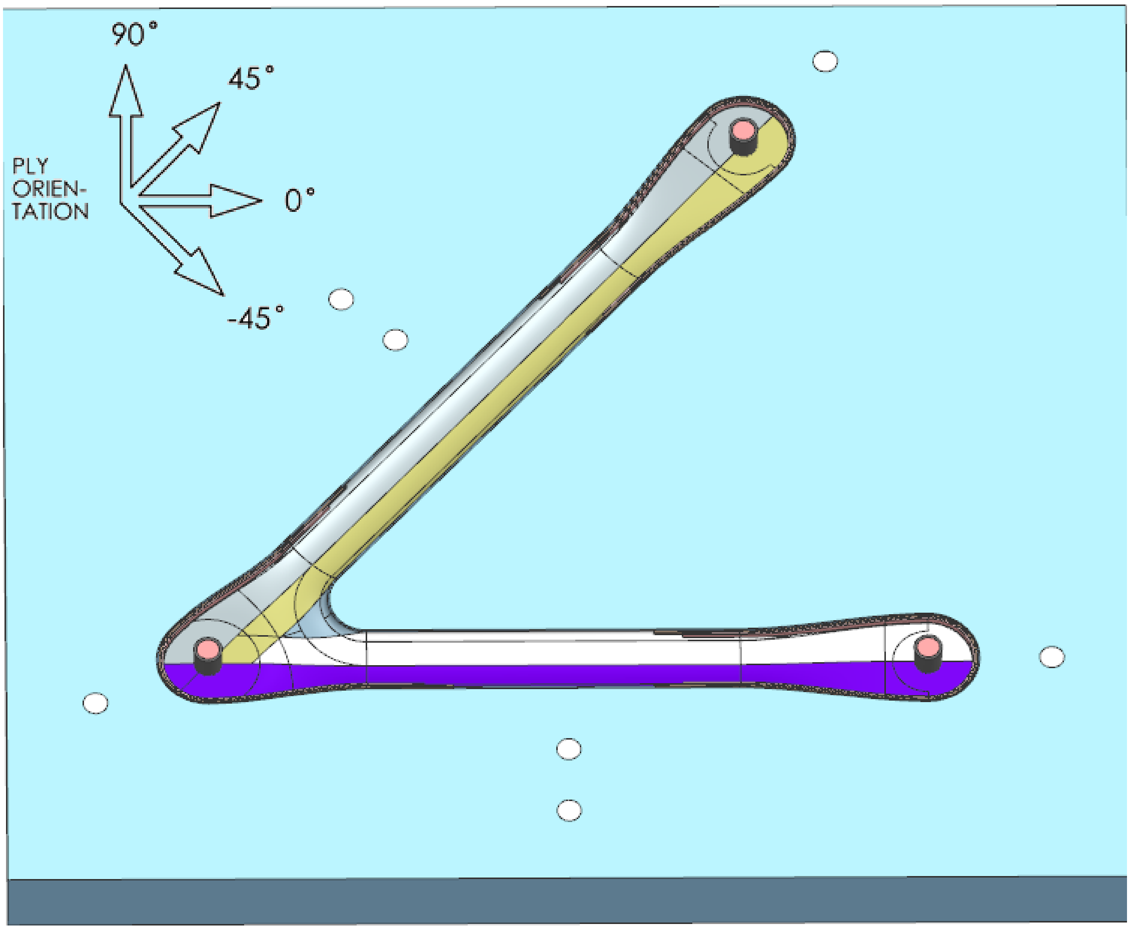


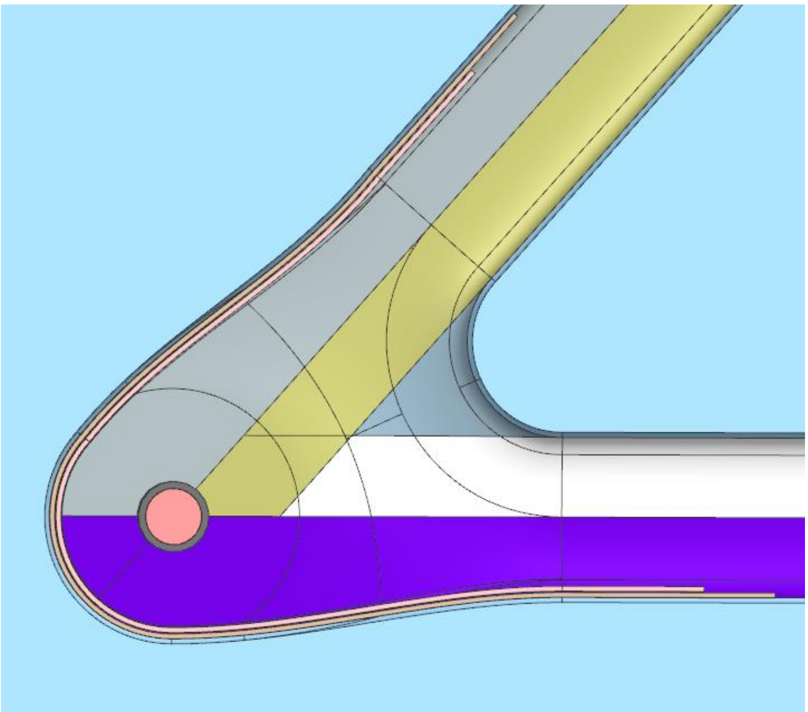
OP No.	Material Spec.	Orientation	Comments	Laminator
16	MTC400-1-UD140-M46J-33%RW-300P	0/90	Transfer preforms onto job. NB: Dimensions +- 2mm	
17	Room Temperature Debulk - 15 min			



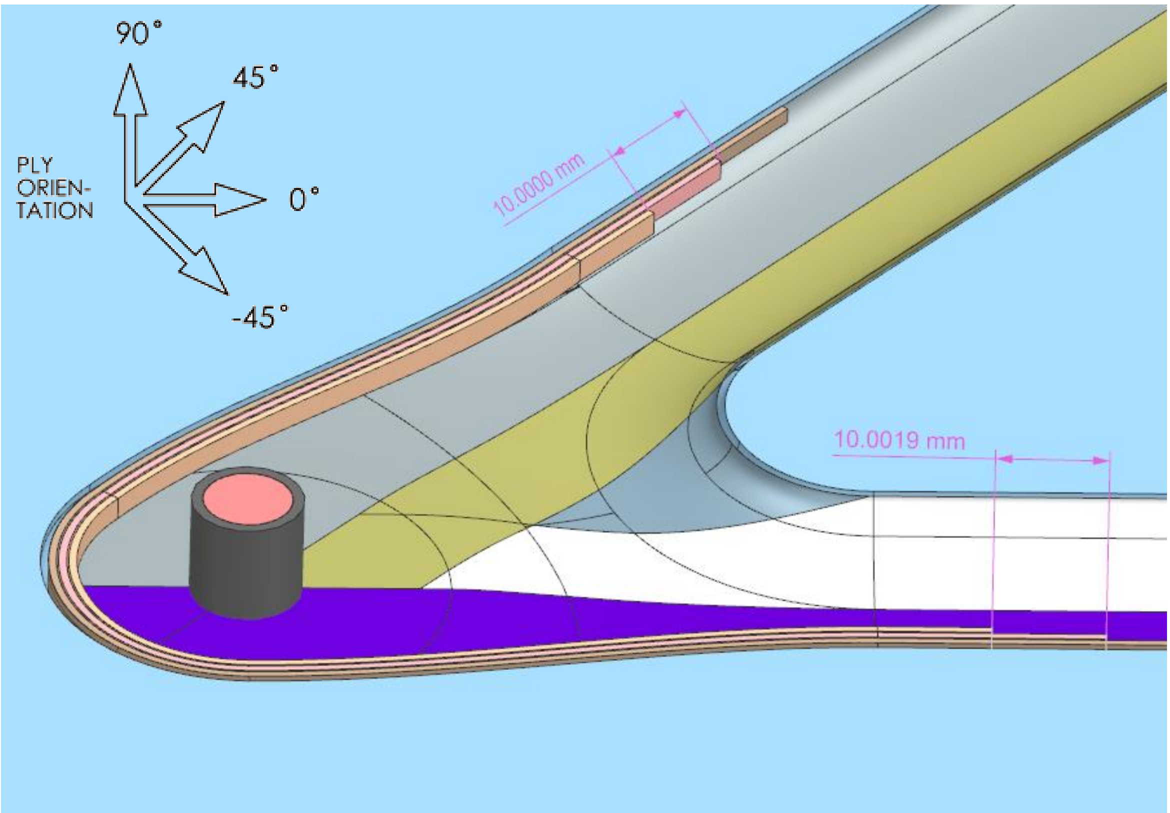


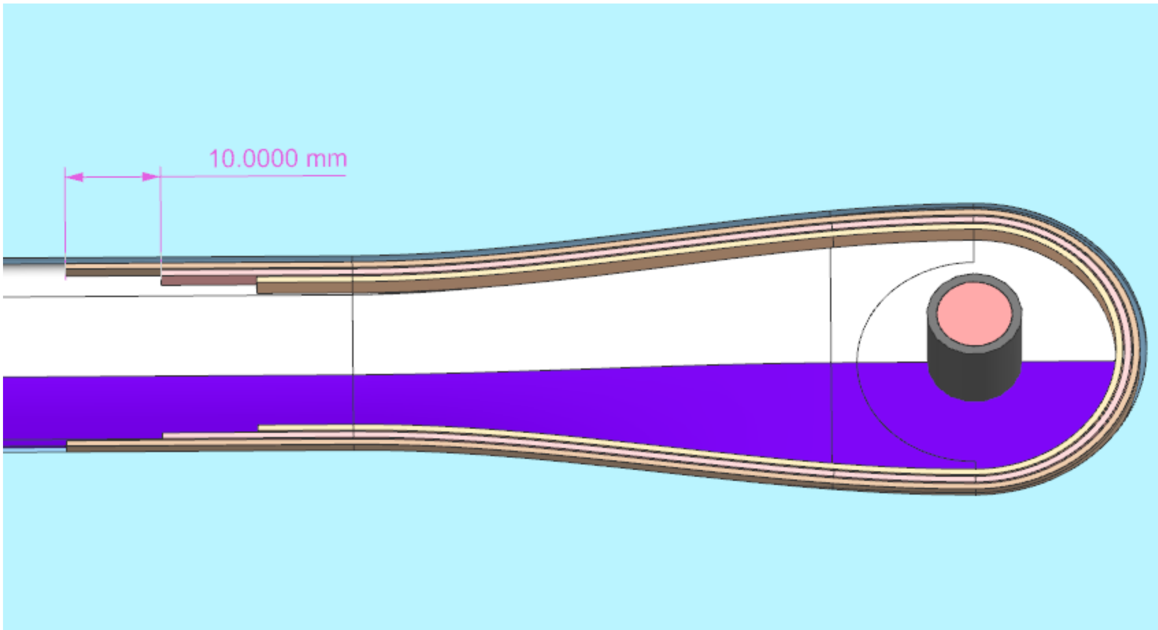
OP No.	Material Spec.	Orientation	Comments	Laminator
18	MTC400-1-UD140-M46J-33%RW-300P	0	Butt plys as shown. Op 7-10 as reference	



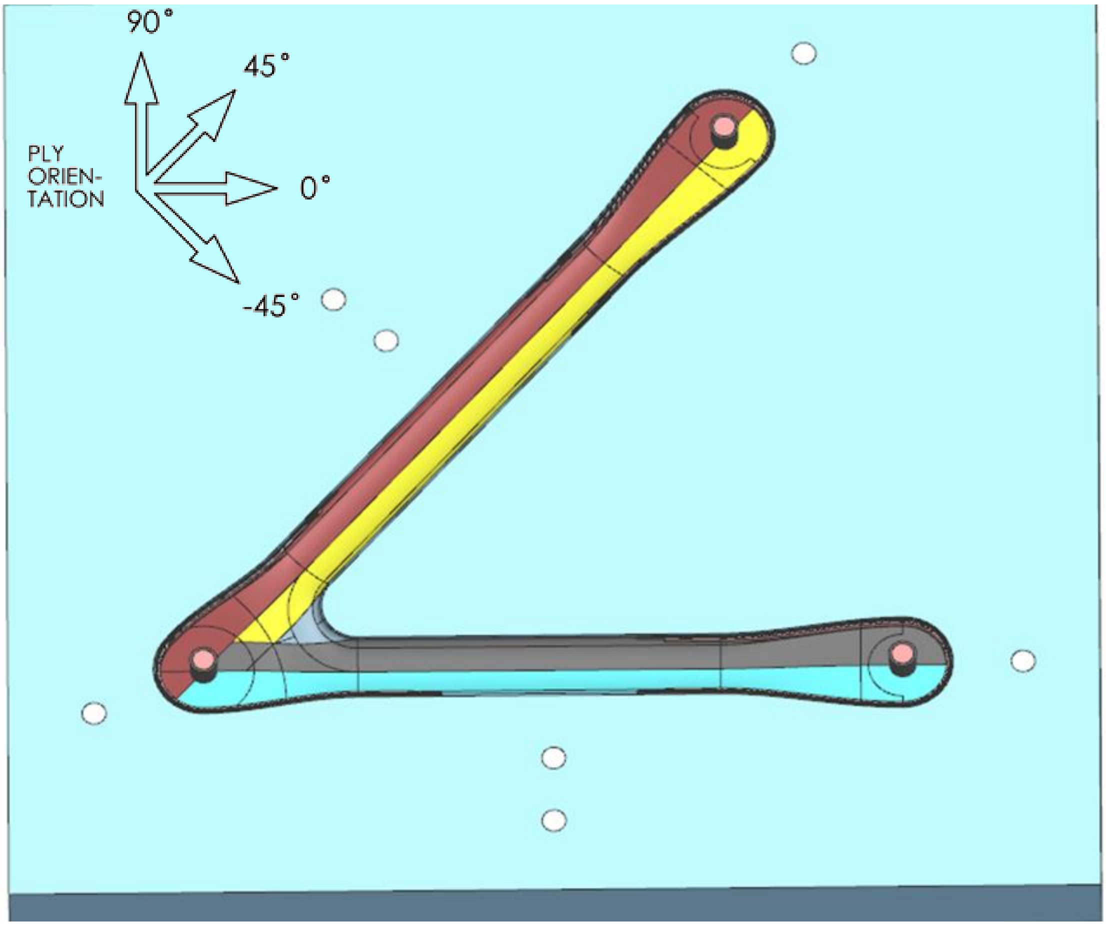


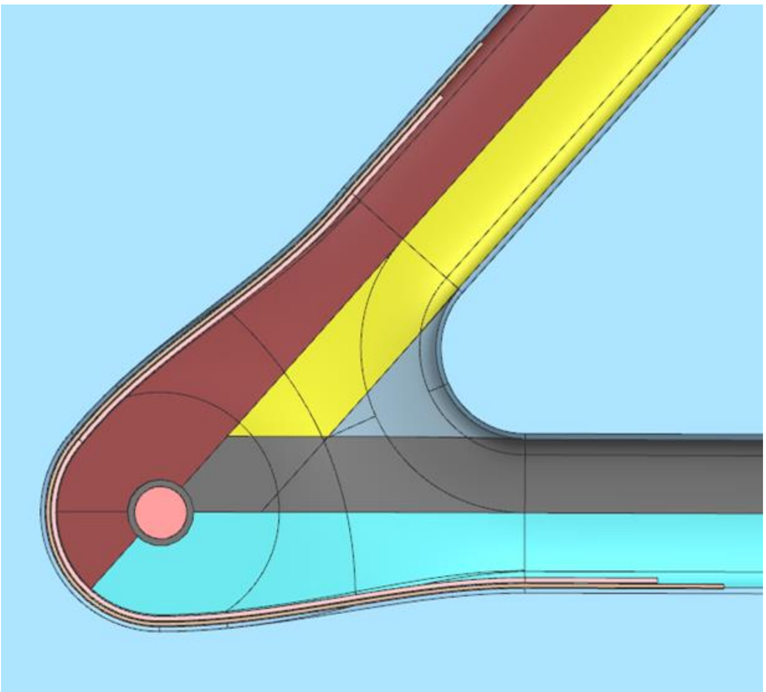
OP No.	Material Spec.	Orientation	Comments	Laminator
19	MTC400-1-UD140-M46J-33%RW-300P	0	Butt plys as shown. Op 7-10 as reference	



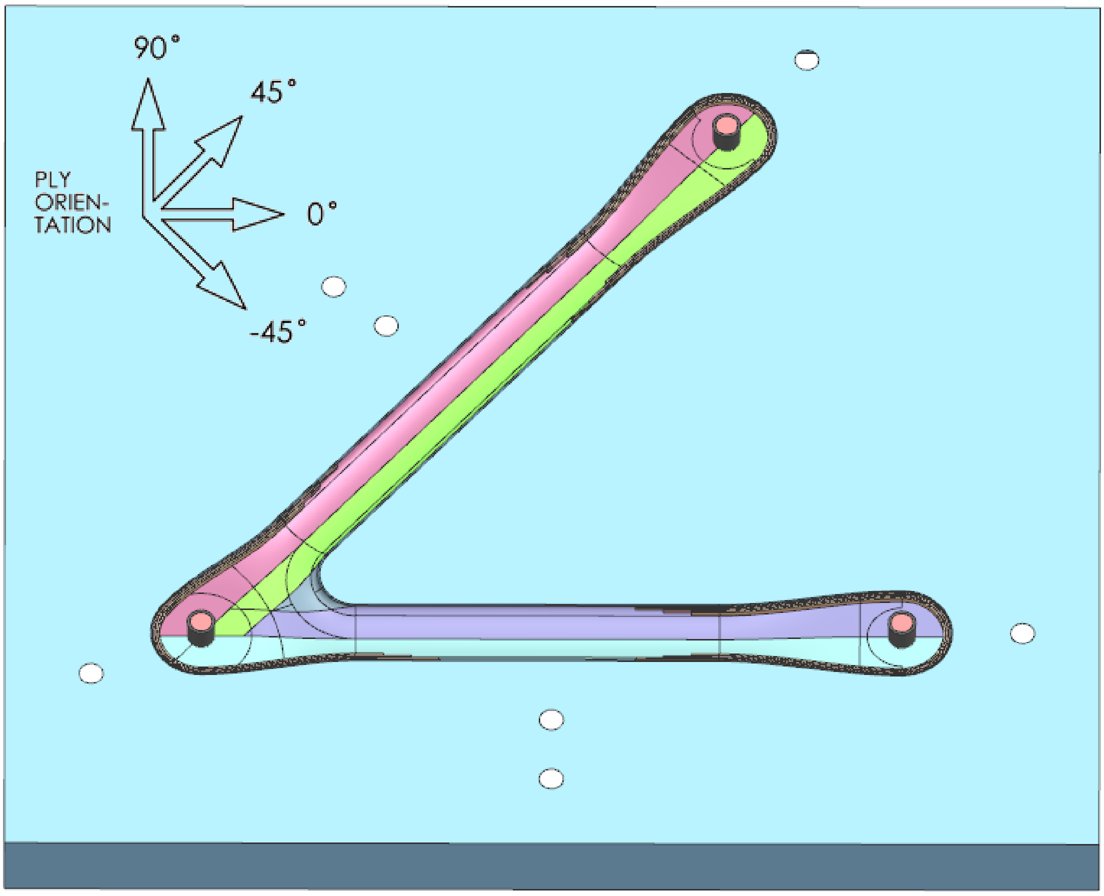


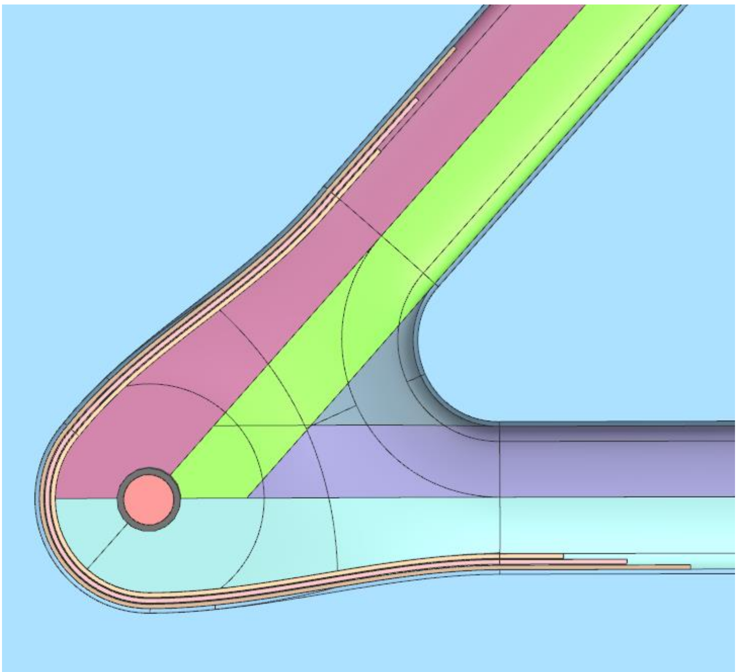
OP No.	Material Spec.	Orientation	Comments	Laminator
20	MTC400-1-UD140-M46J-33%RW-300P	0/90	Transfer preforms onto job. NB: Dimensions +- 2mm	
21	Room Temperature Debulk - 15 min			



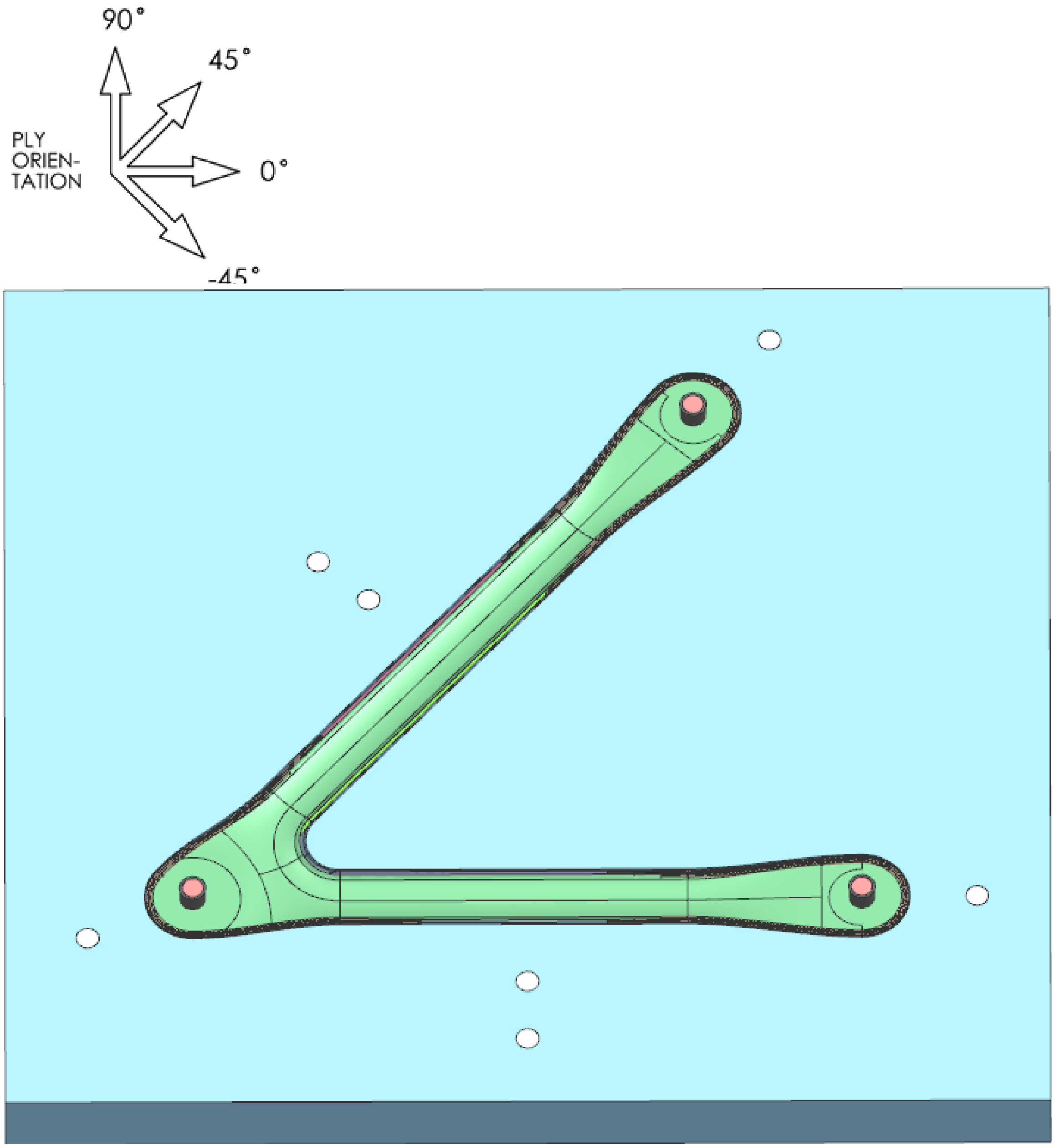


OP No.	Material Spec.	Orientation	Comments	Laminator
22	MTC400-1-UD140-M46J-33%RW-300P	0	Butt plys as shown. Op 7-10 as reference	

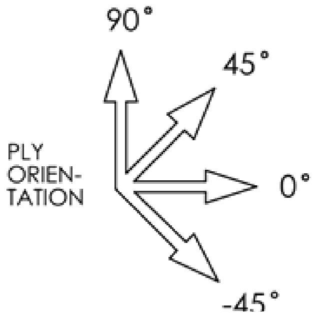


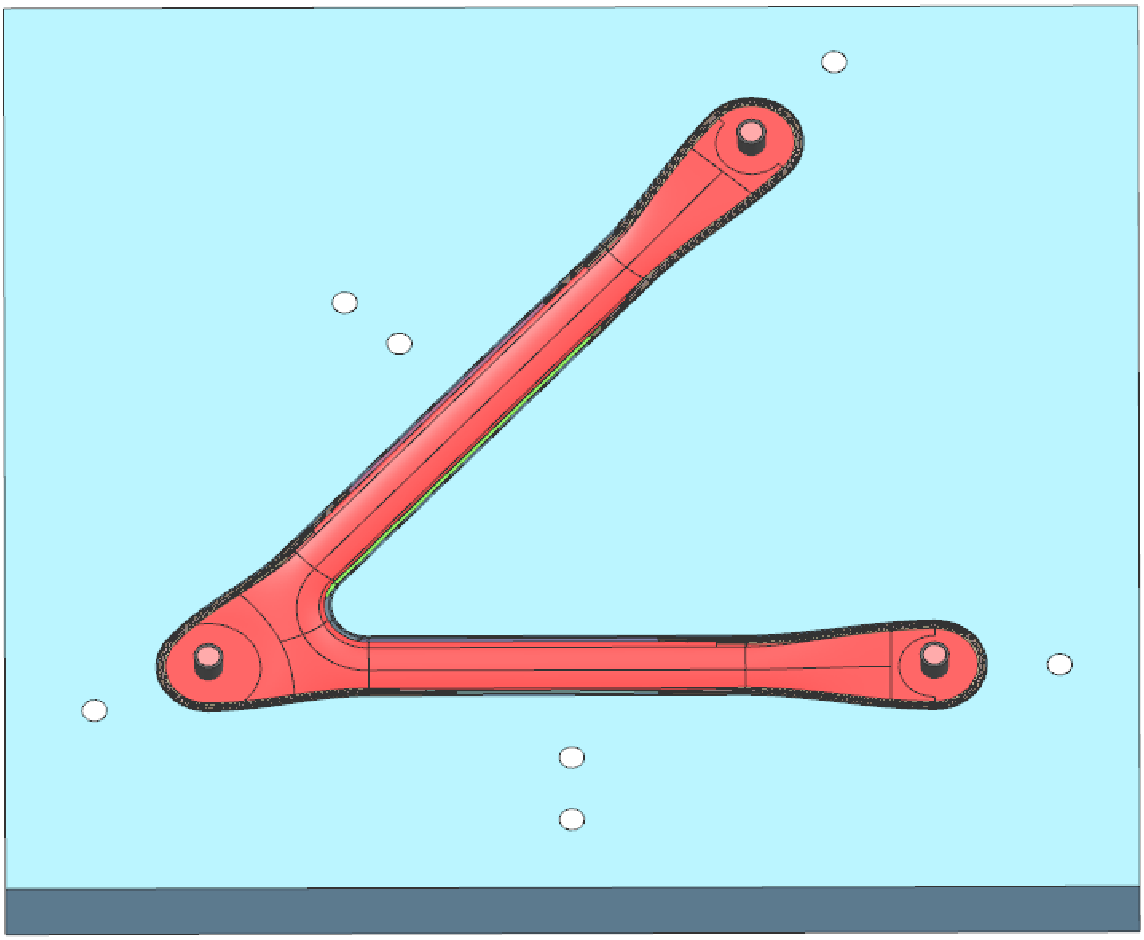


OP No.	Material Spec.	Orientation	Comments	Laminator
23	MTC400-1-UD140-M46J-33%RW-300P	0	Butt plys as shown. Op 7-10 as reference	

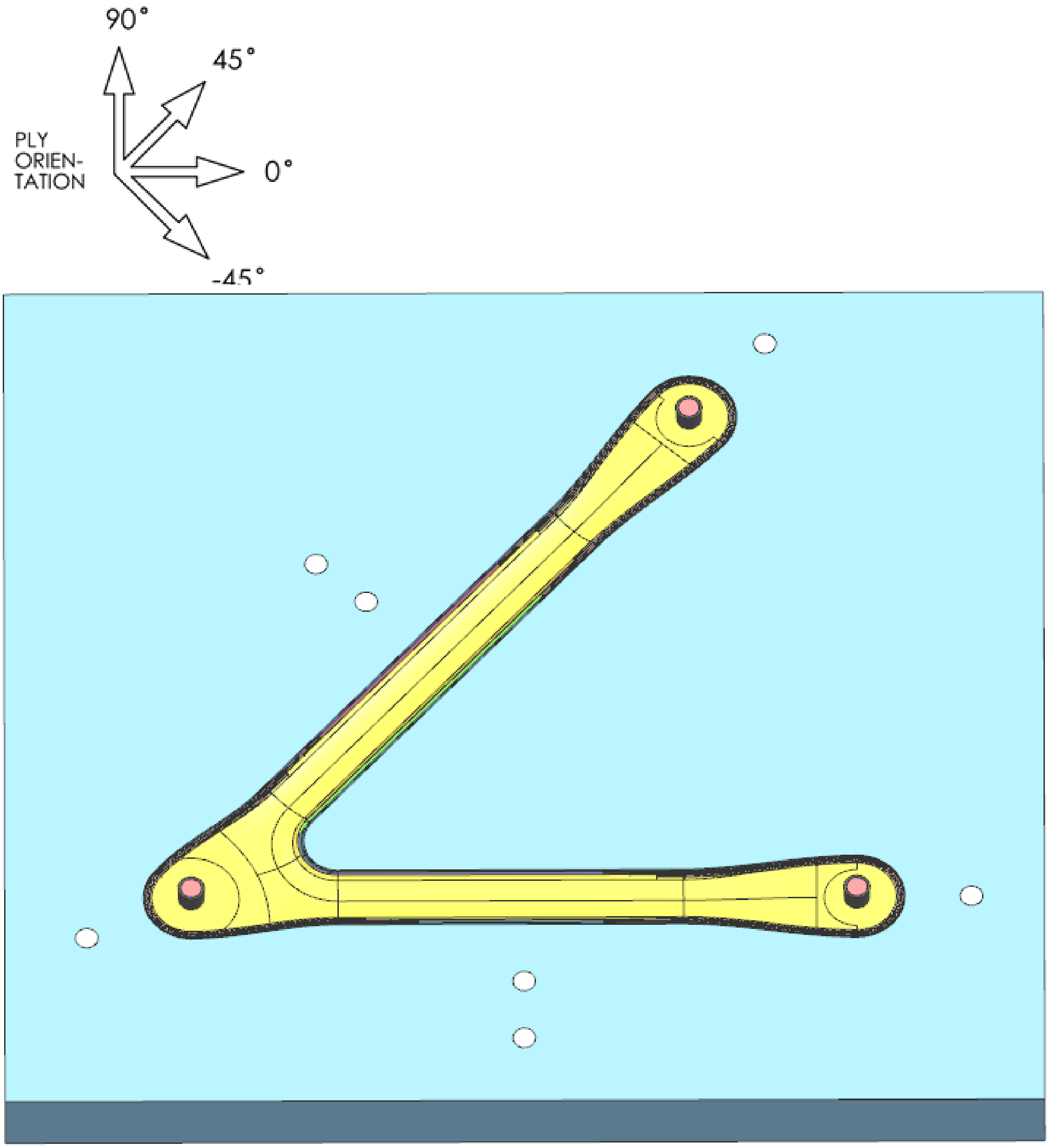


OP No.	Material Spec.	Orientation	Comments	Laminator
24	MTC400-1-C200T-M40J-42%RW-1250	0/90	Lay as shown. Trim excess material post debulk	
25	Room Temperature Debulk – 15 min			

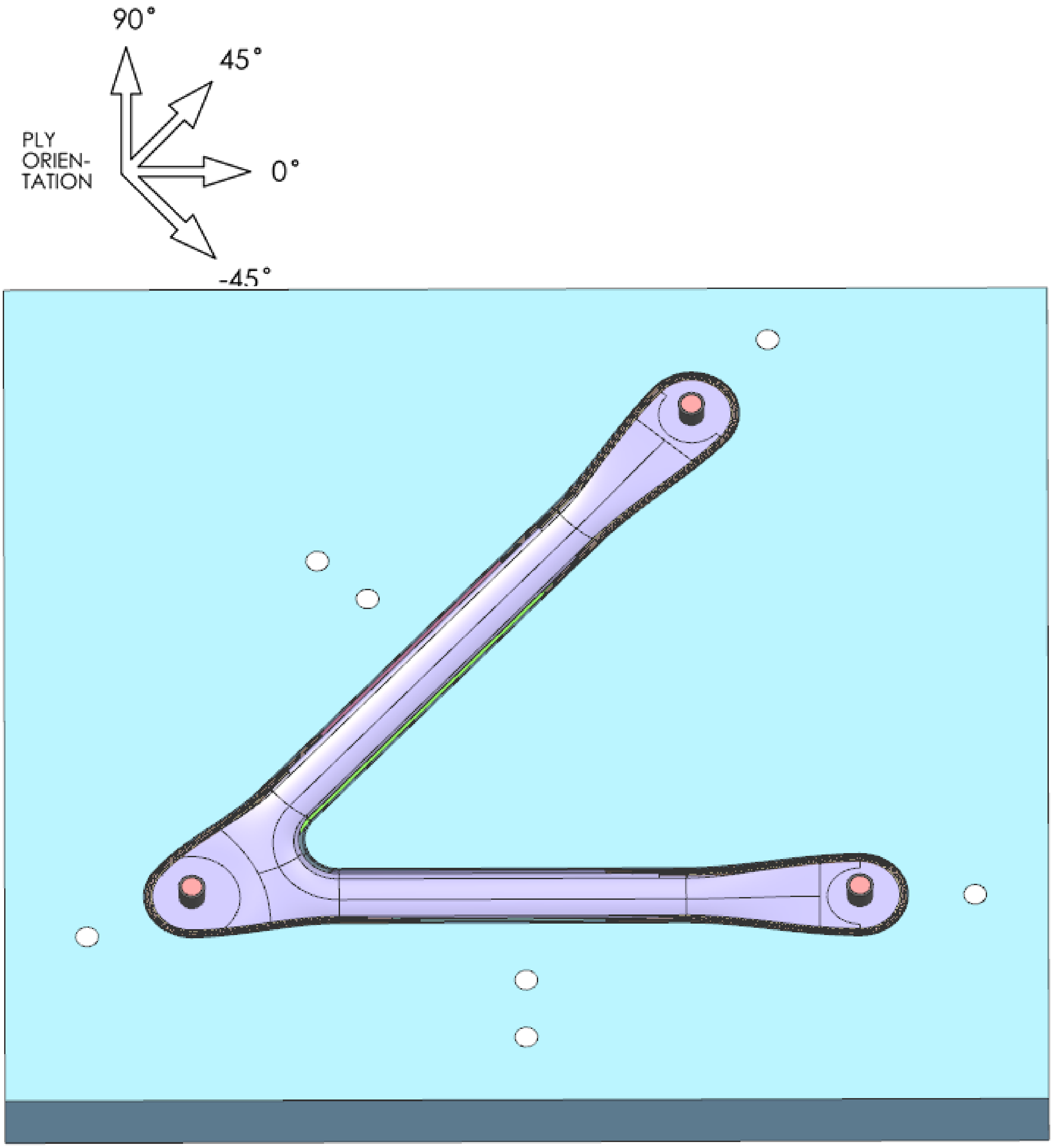




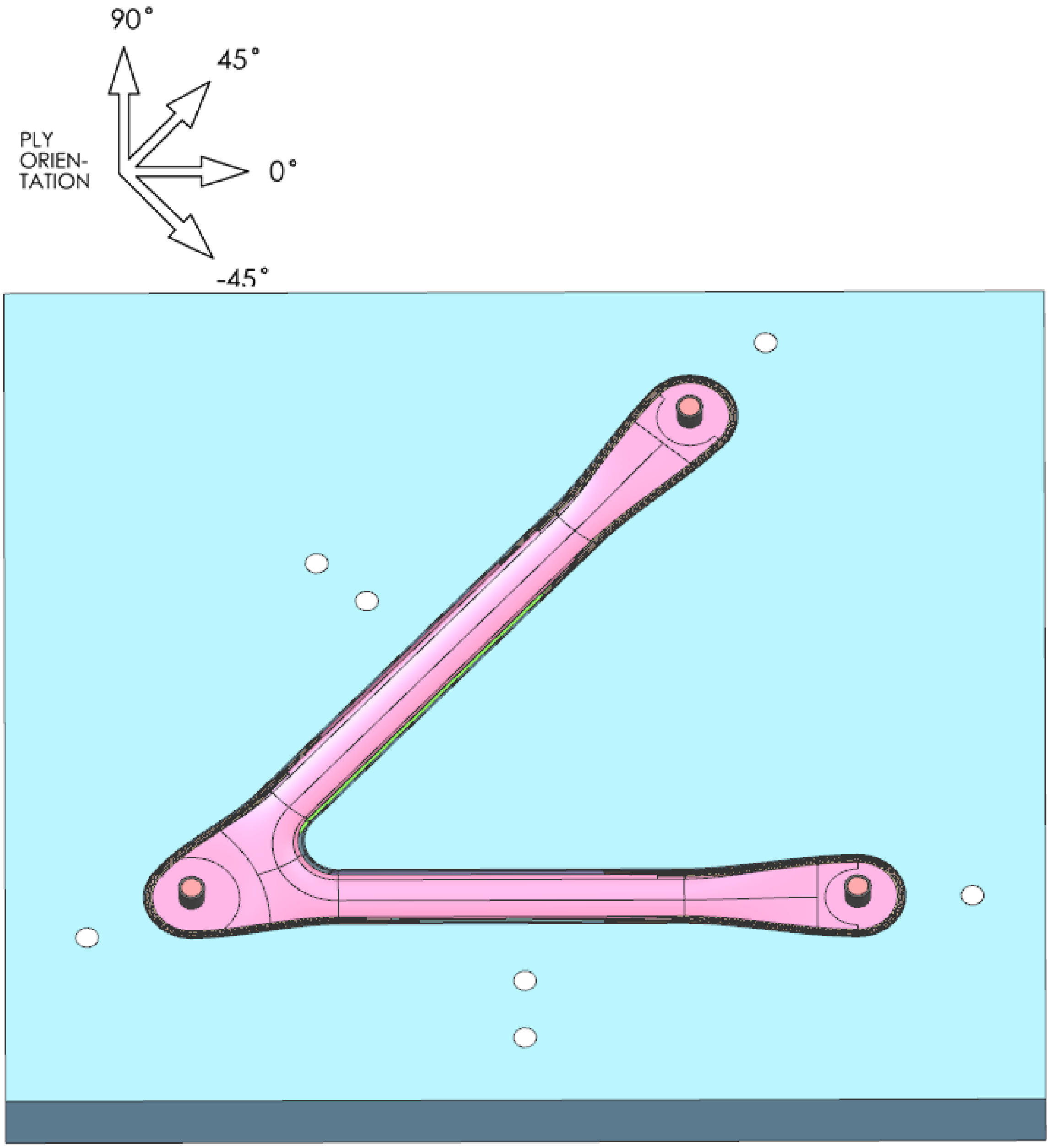
OP No.	Material Spec.	Orientation	Comments	Laminator
26	MTC400-1-C200T-M40J-42%RW-1250	0/90	Lay as shown.	



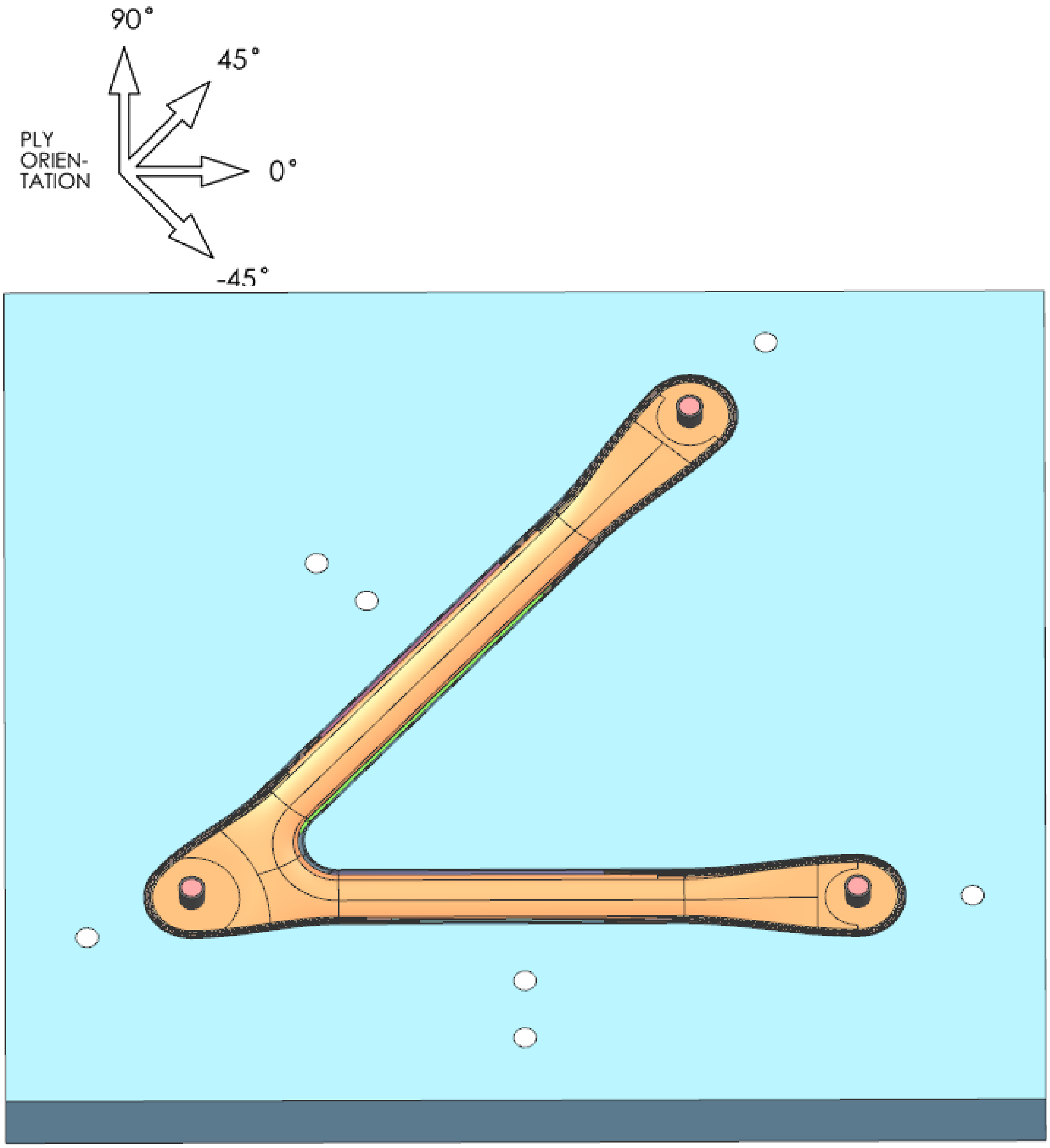
OP No.	Material Spec.	Orientation	Comments	Laminator
27	MTC400-1-C200T-M40J-42%RW-1250	45	Lay as shown. Trim excess material post debulk	
28	Room Temperature Debulk – 15 min			



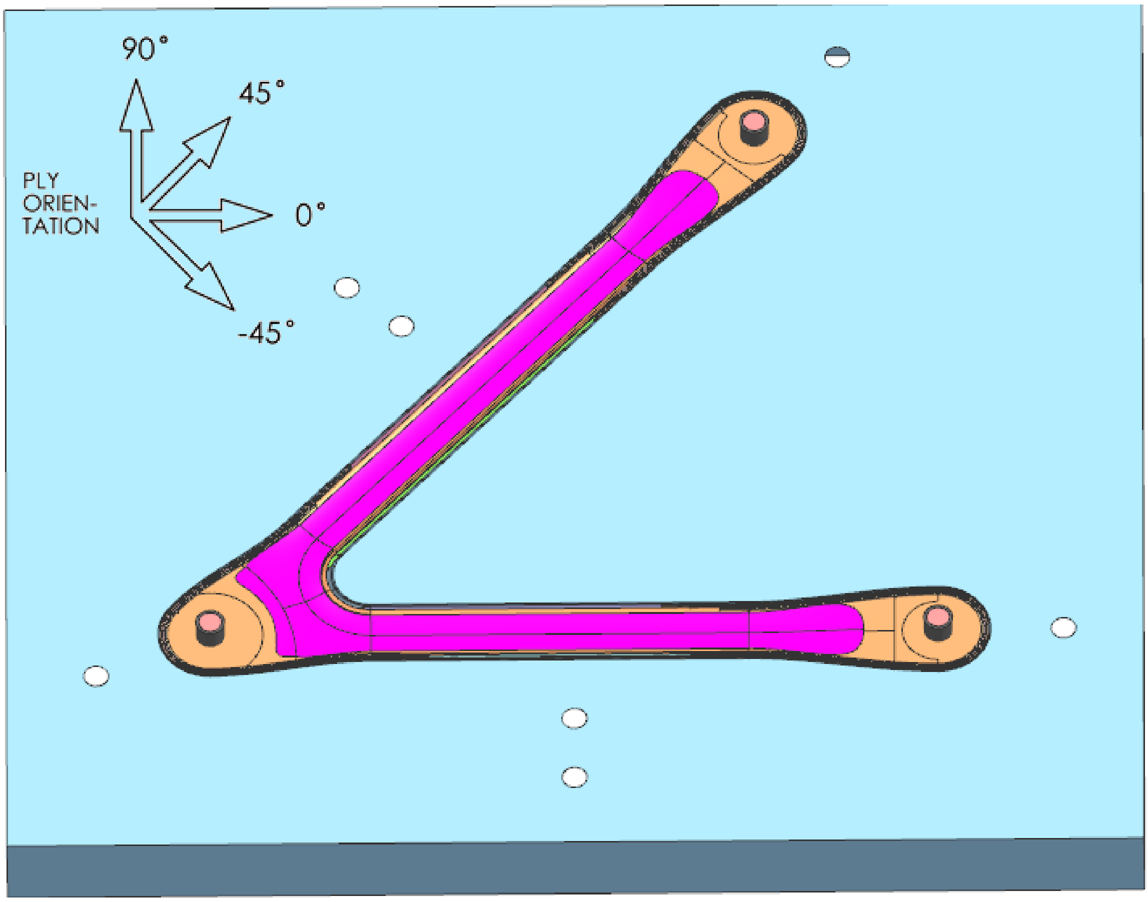
OP No.	Material Spec.	Orientation	Comments	Laminator
29	MTC400-1-C200T-M40J-42%RW-1250	45	Lay as shown.	

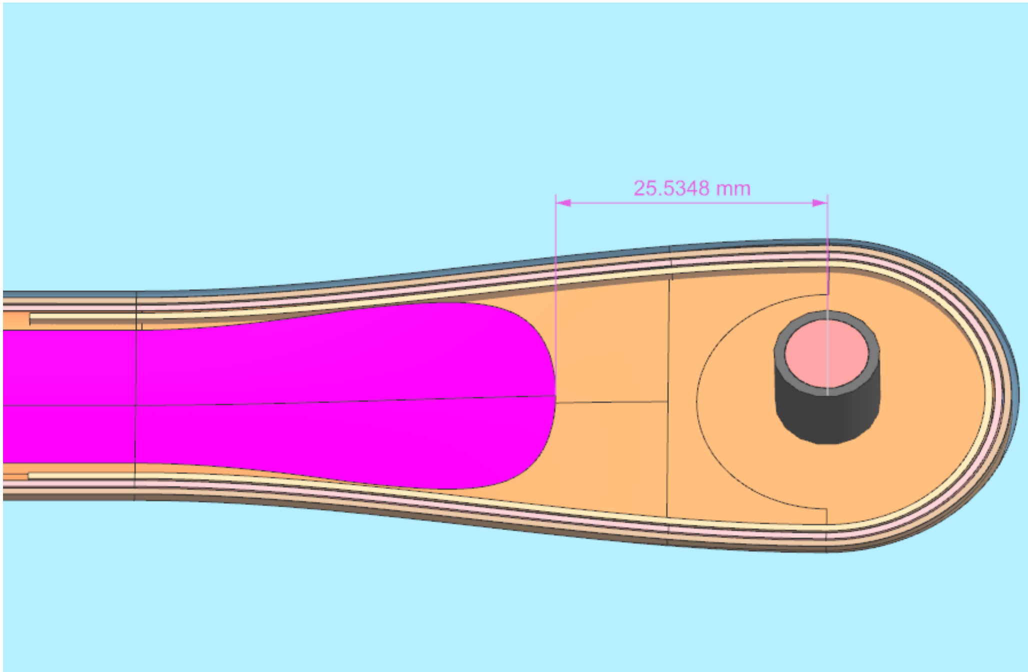


OP No.	Material Spec.	Orientation	Comments	Laminator
30	MTC400-1-C200T-M40J-42%RW-1250	0/90	Lay as shown.	

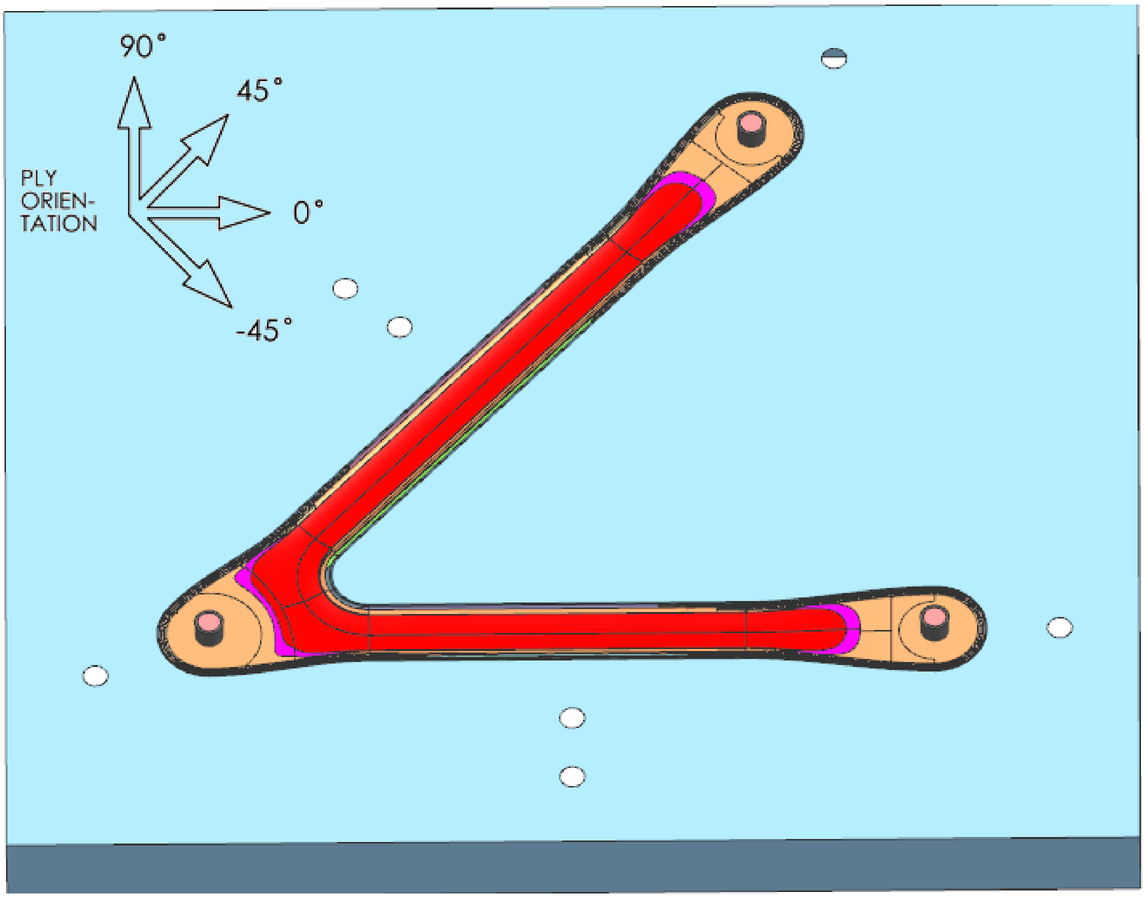


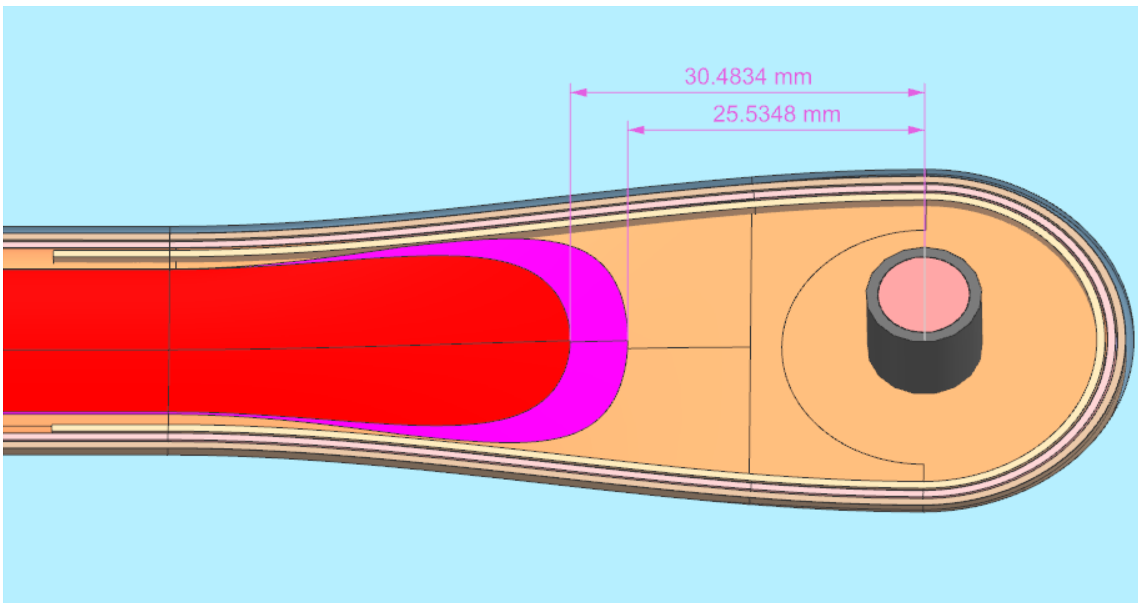
OP No.	Material Spec.	Orientation	Comments	Laminator
31	MTC400-1-C200T-M40J-42%RW-1250	0/90	Lay as shown. Trim excess material post debulk	
32	Room Temperature Debulk – 15 min			



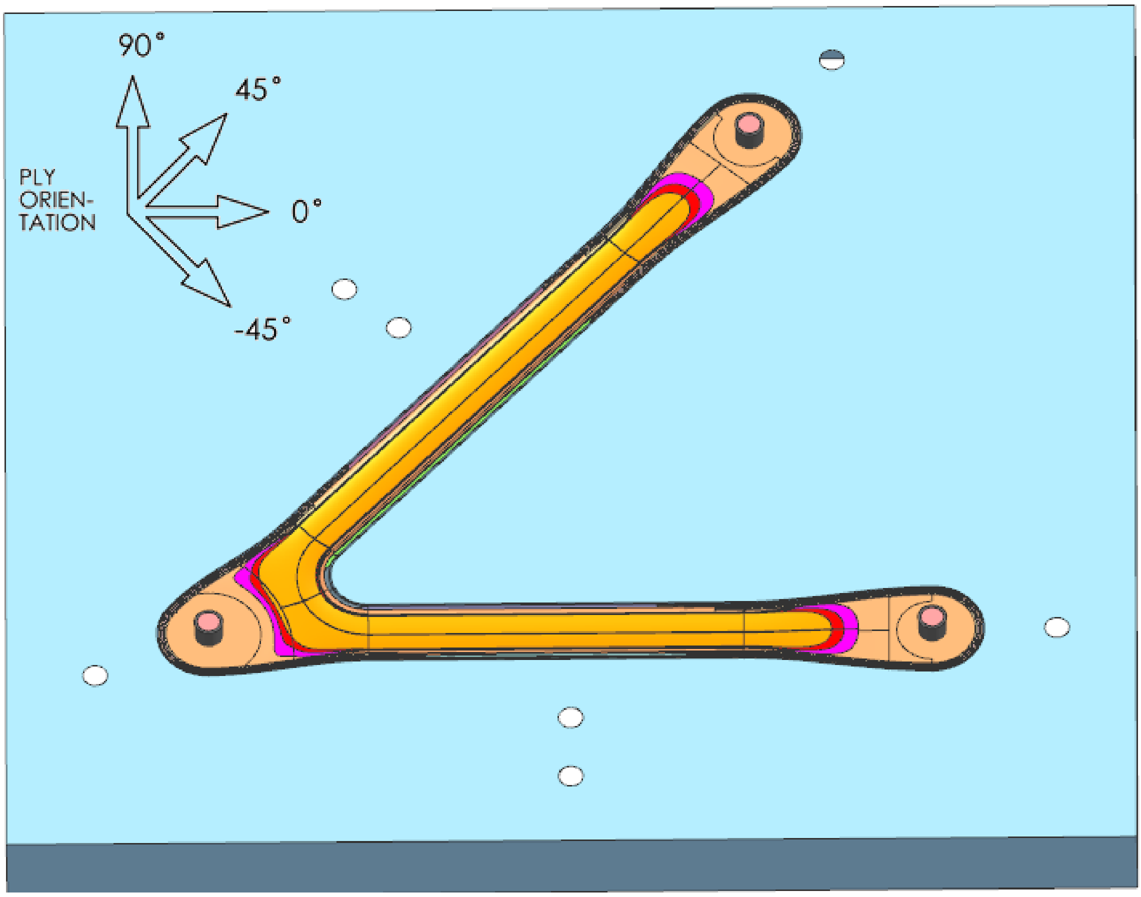


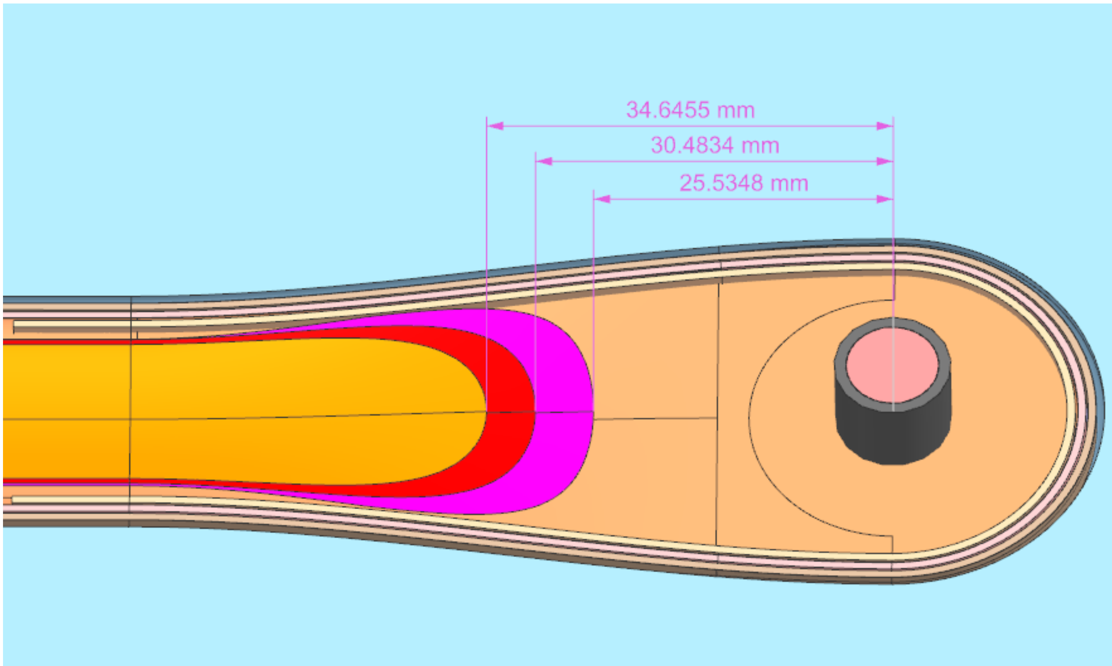
OP No.	Material Spec.	Orientation	Comments	Laminator
33	MTC400-1-C200T-M40J-42%RW-1250	0/90	Lay as shown.	



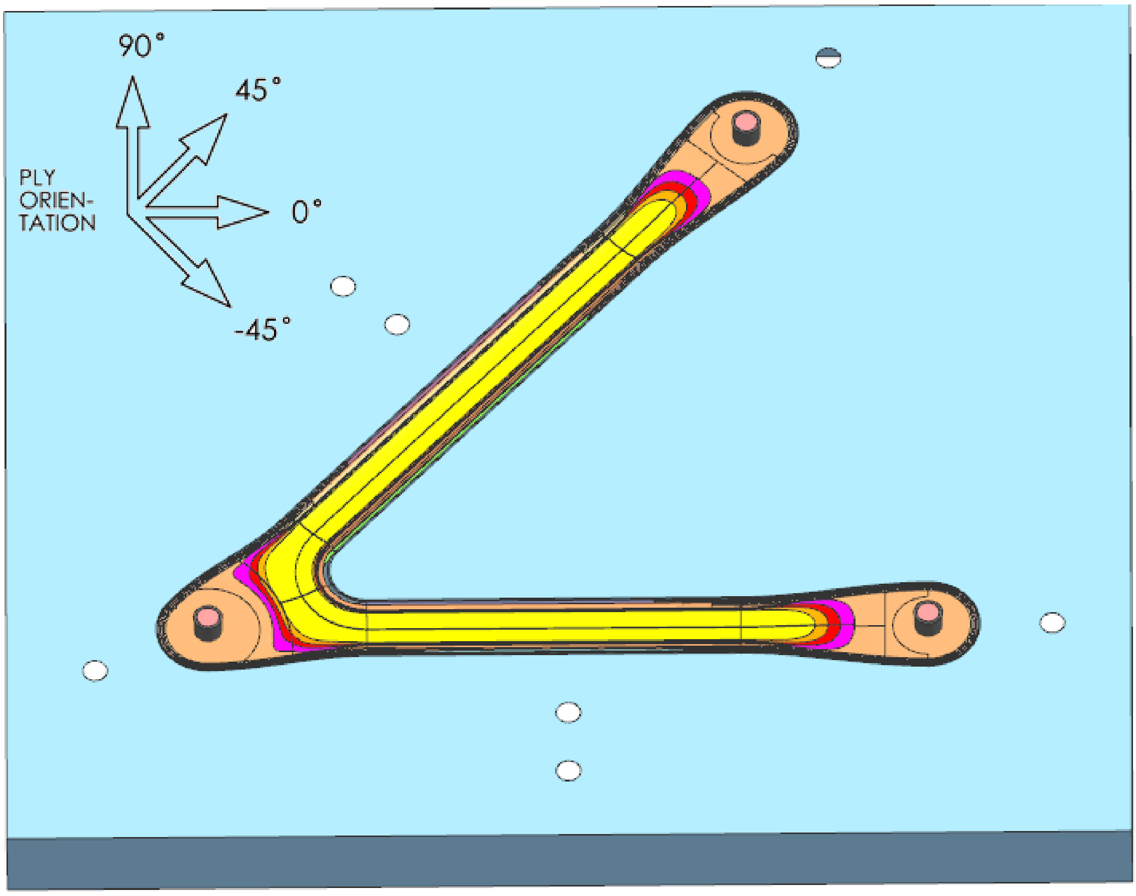


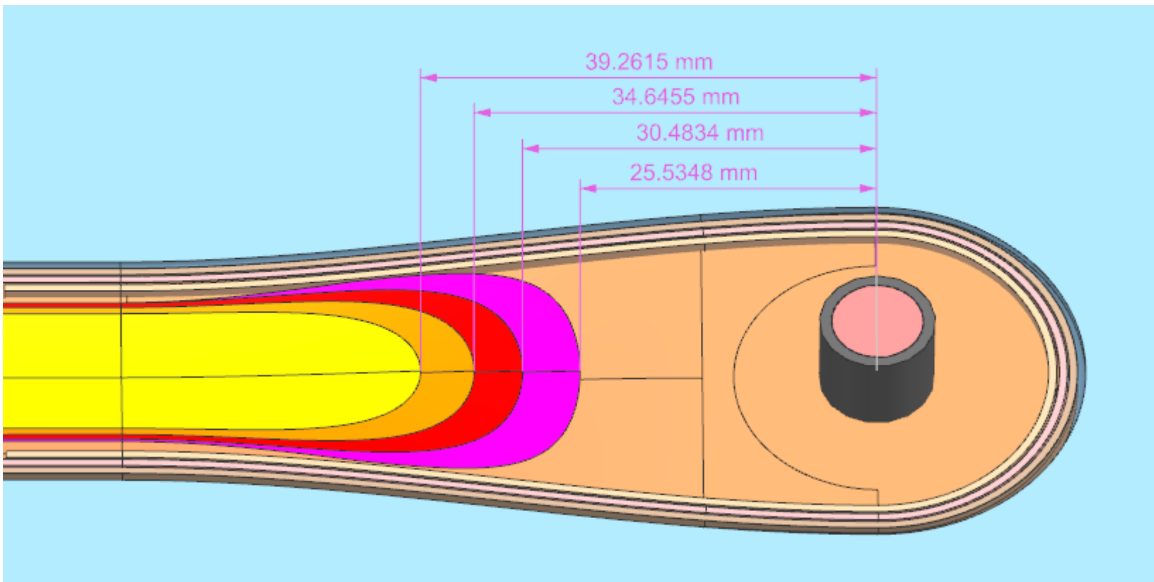
OP No.	Material Spec.	Orientation	Comments	Laminator
34	MTC400-1-C200T-M40J-42%RW-1250	0/90	Lay as shown.	



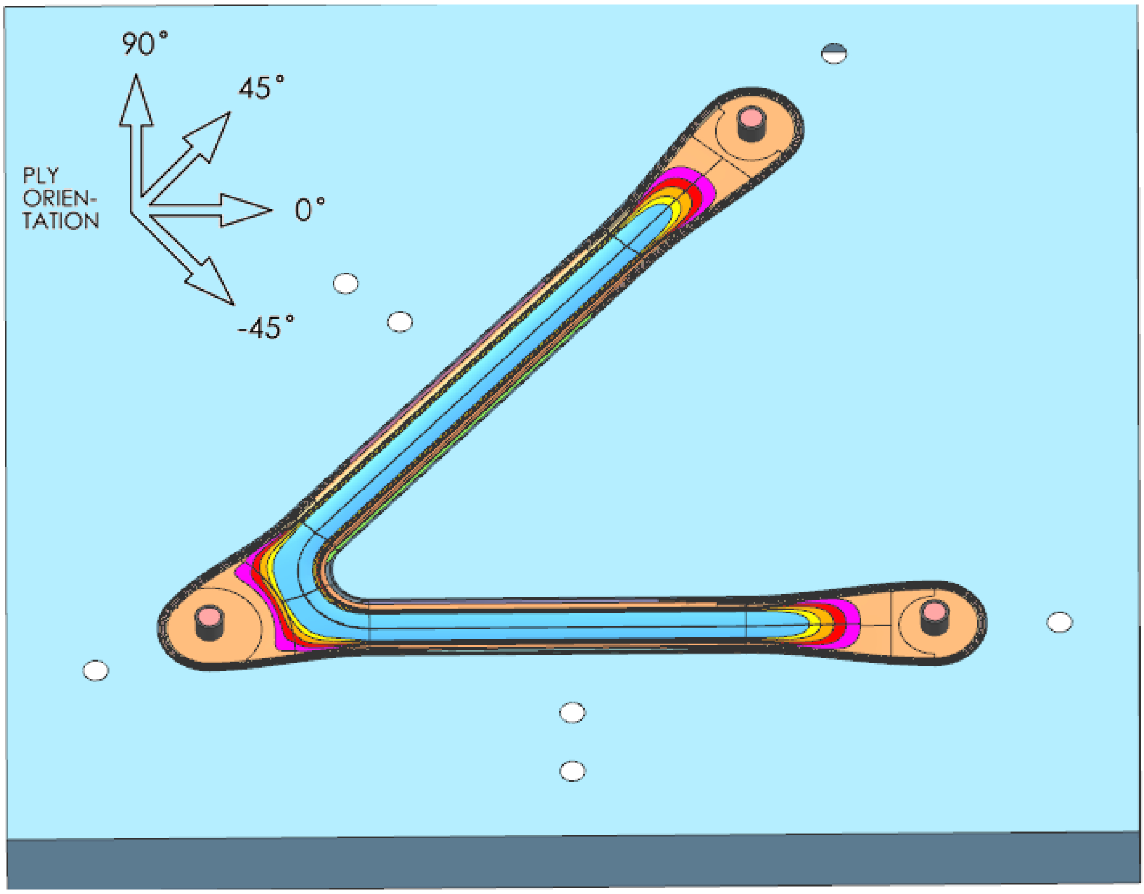


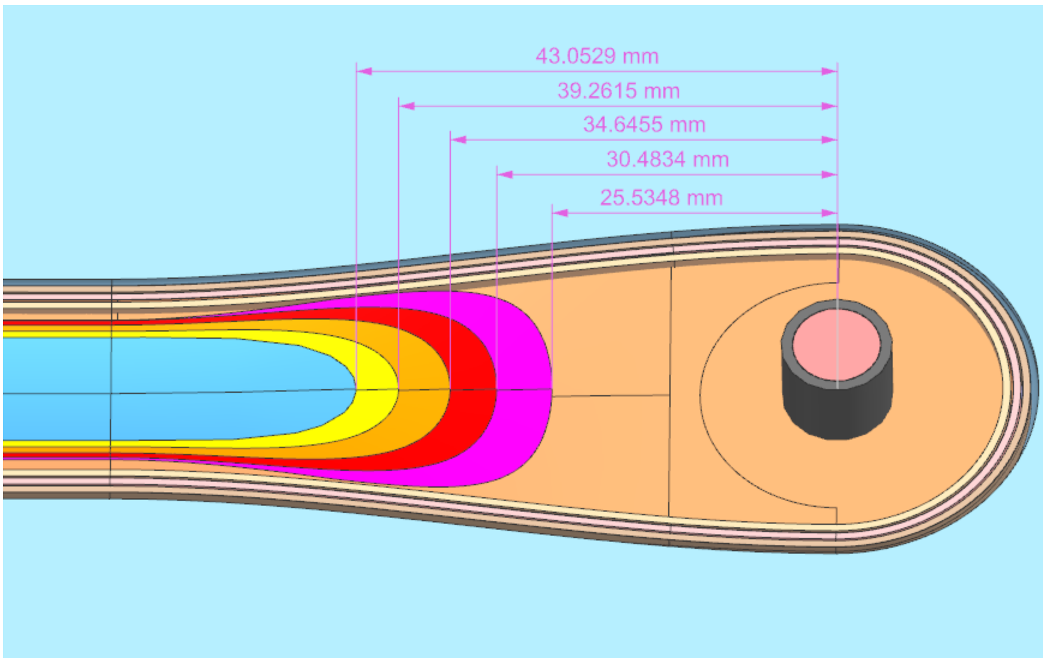
OP No.	Material Spec.	Orientation	Comments	Laminator
35	MTC400-1-C200T-M40J-42%RW-1250	45	Lay as shown.	



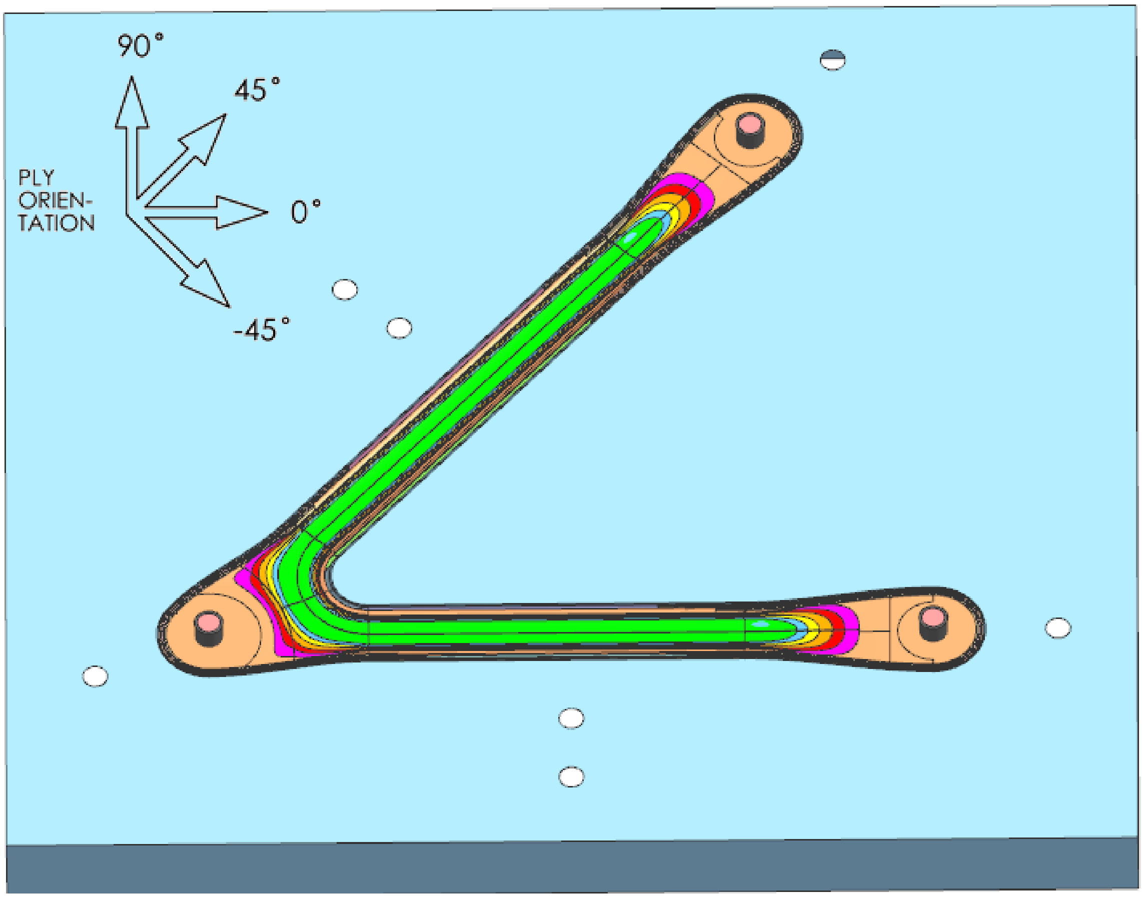


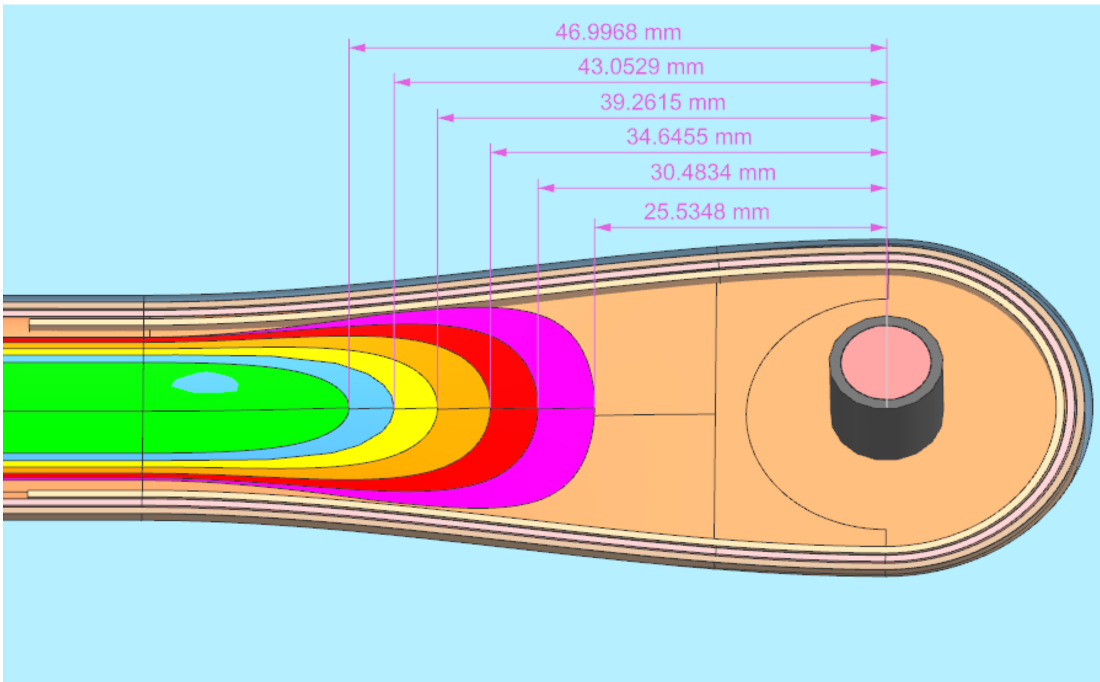
OP No.	Material Spec.	Orientation	Comments	Laminator
36	MTC400-1-C200T-M40J-42%RW-1250	0/90	Lay as shown. Trim excess material post debulk	
37	Room Temperature Debulk – 15 min			



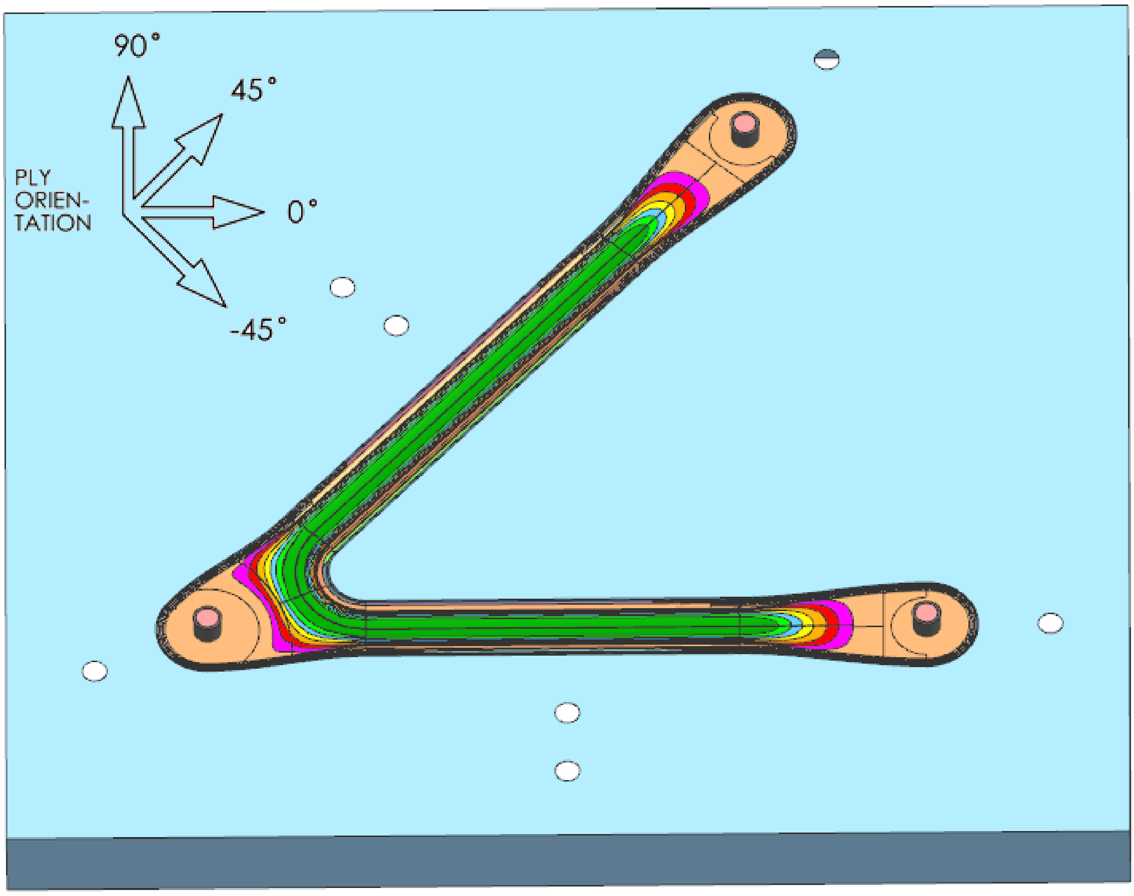


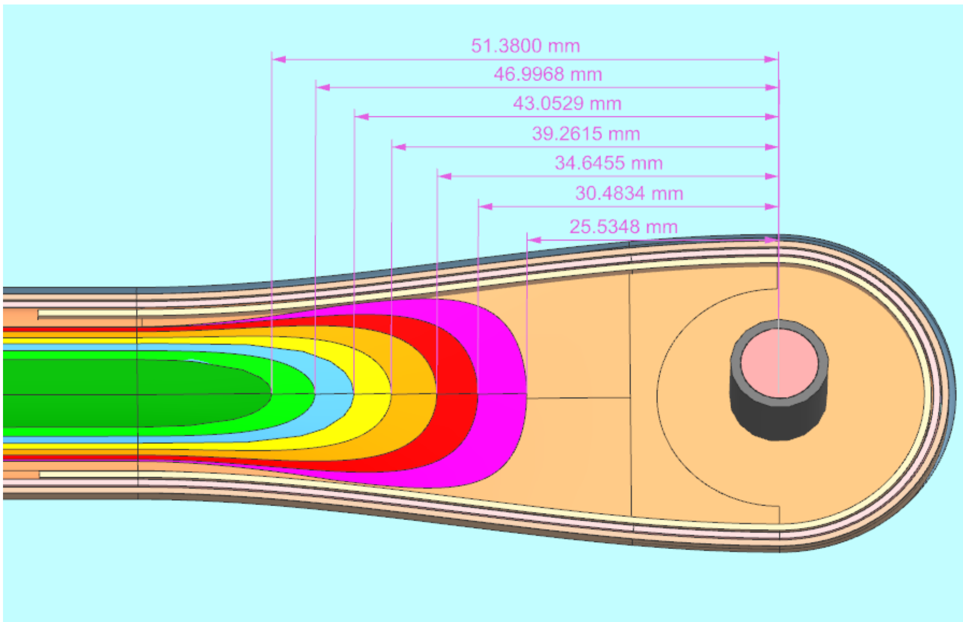
OP No.	Material Spec.	Orientation	Comments	Laminator
38	MTC400-1-C200T-M40J-42%RW-1250	45	Lay as shown.	



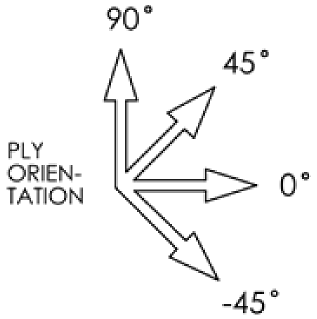


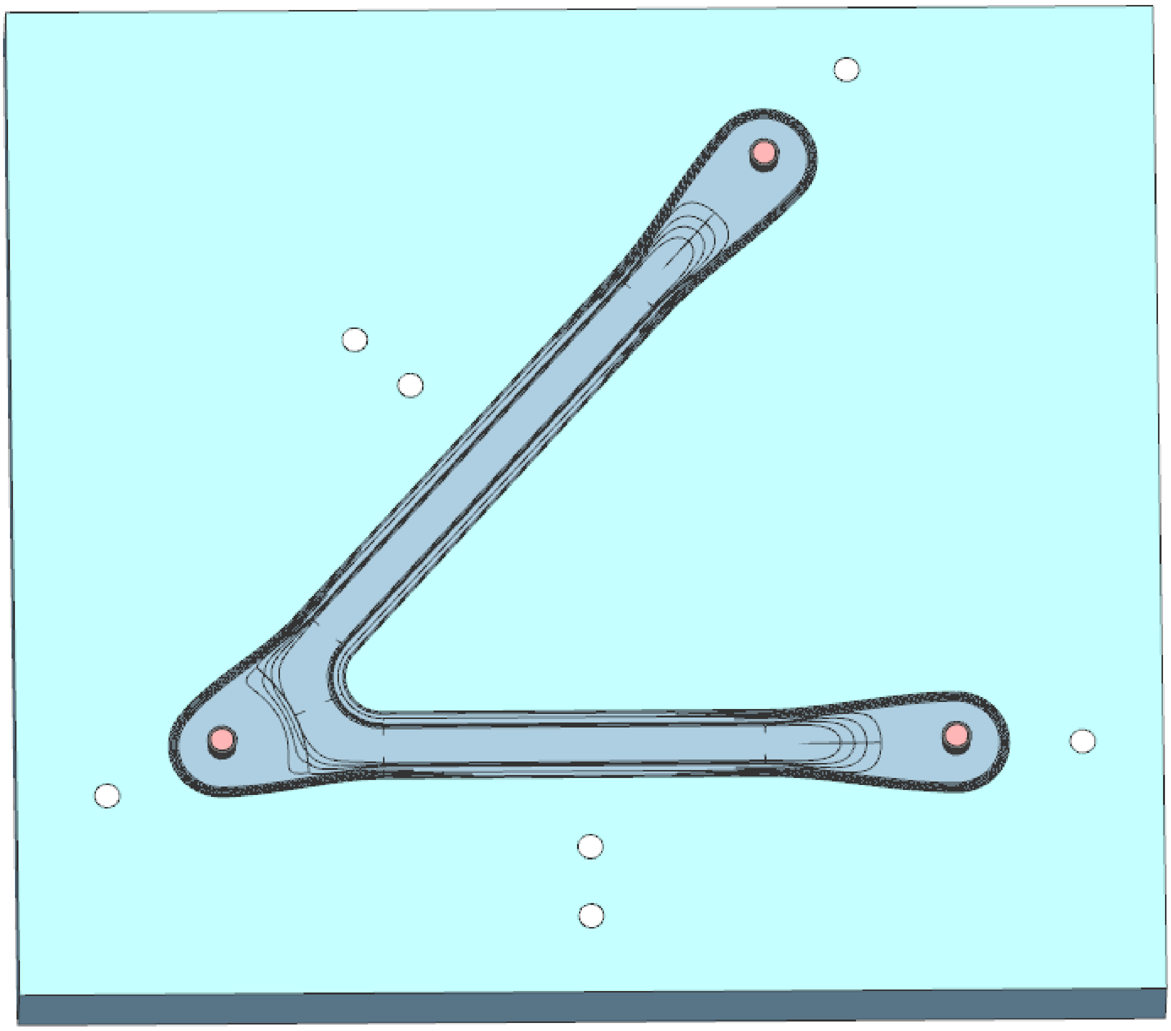
OP No.	Material Spec.	Orientation	Comments	Laminator
39	MTC400-1-C200T-M40J-42%RW-1250	0/90	Lay as shown.	



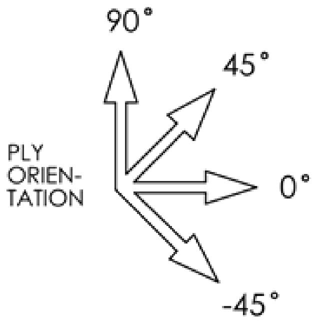


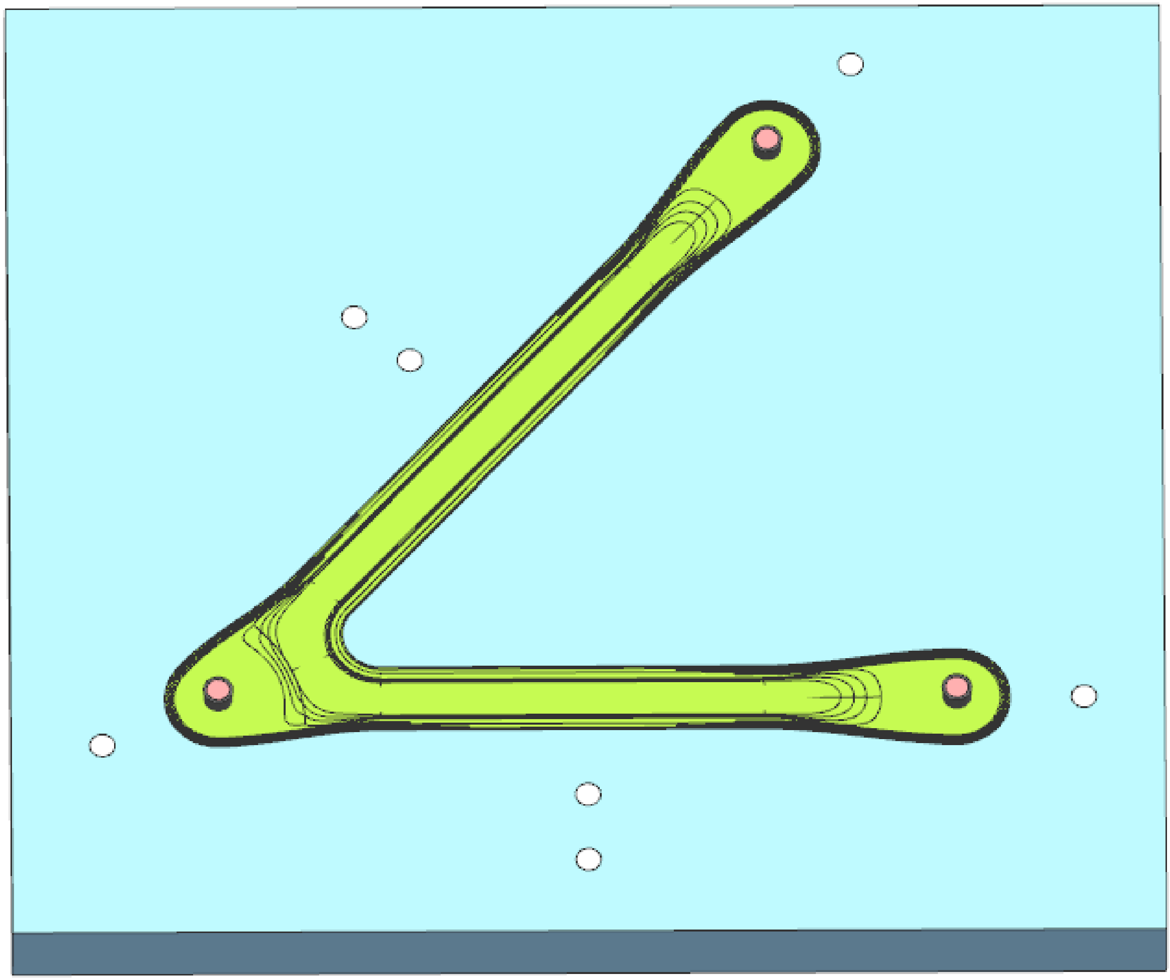
OP No.	Material Spec.	Orientation	Comments	Laminator
40	MTC400-1-C200T-M40J-42%RW-1250	45	Lay as shown. Trim excess material post debulk	
41	Room Temperature Debulk – 15 min			



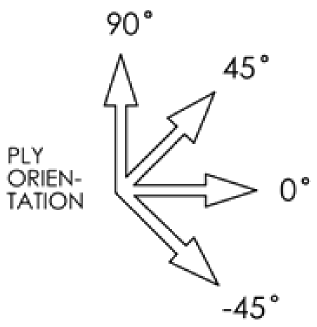


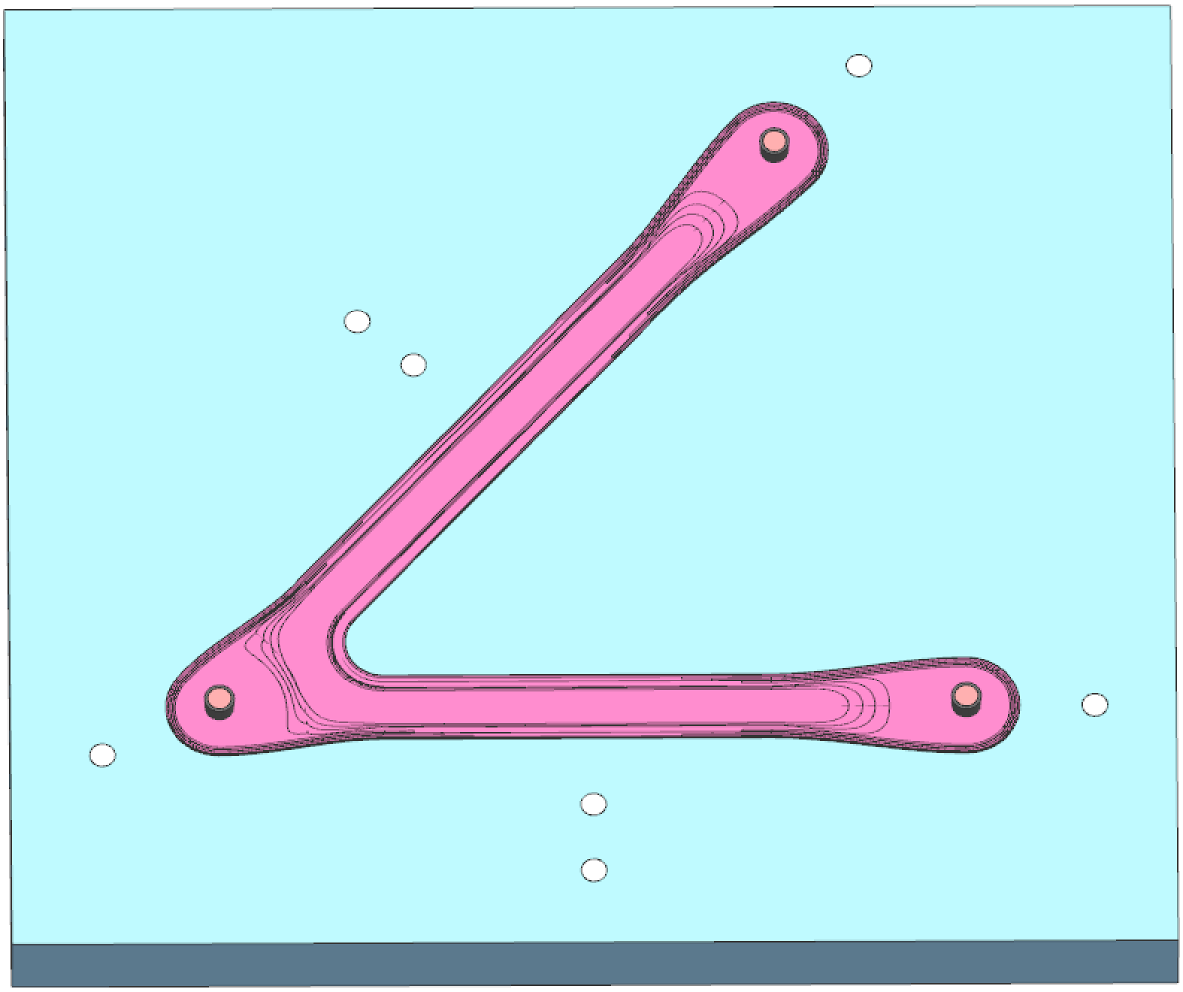
OP No.	Material Spec.	Orientation	Comments	Laminator
42	MTC400-1-C200T-M40J-42%RW-1250	0/90	Lay as shown.	



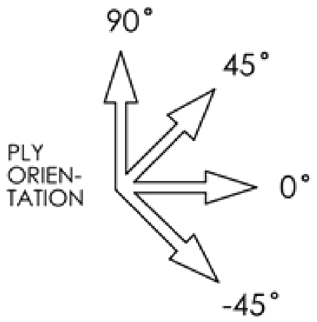


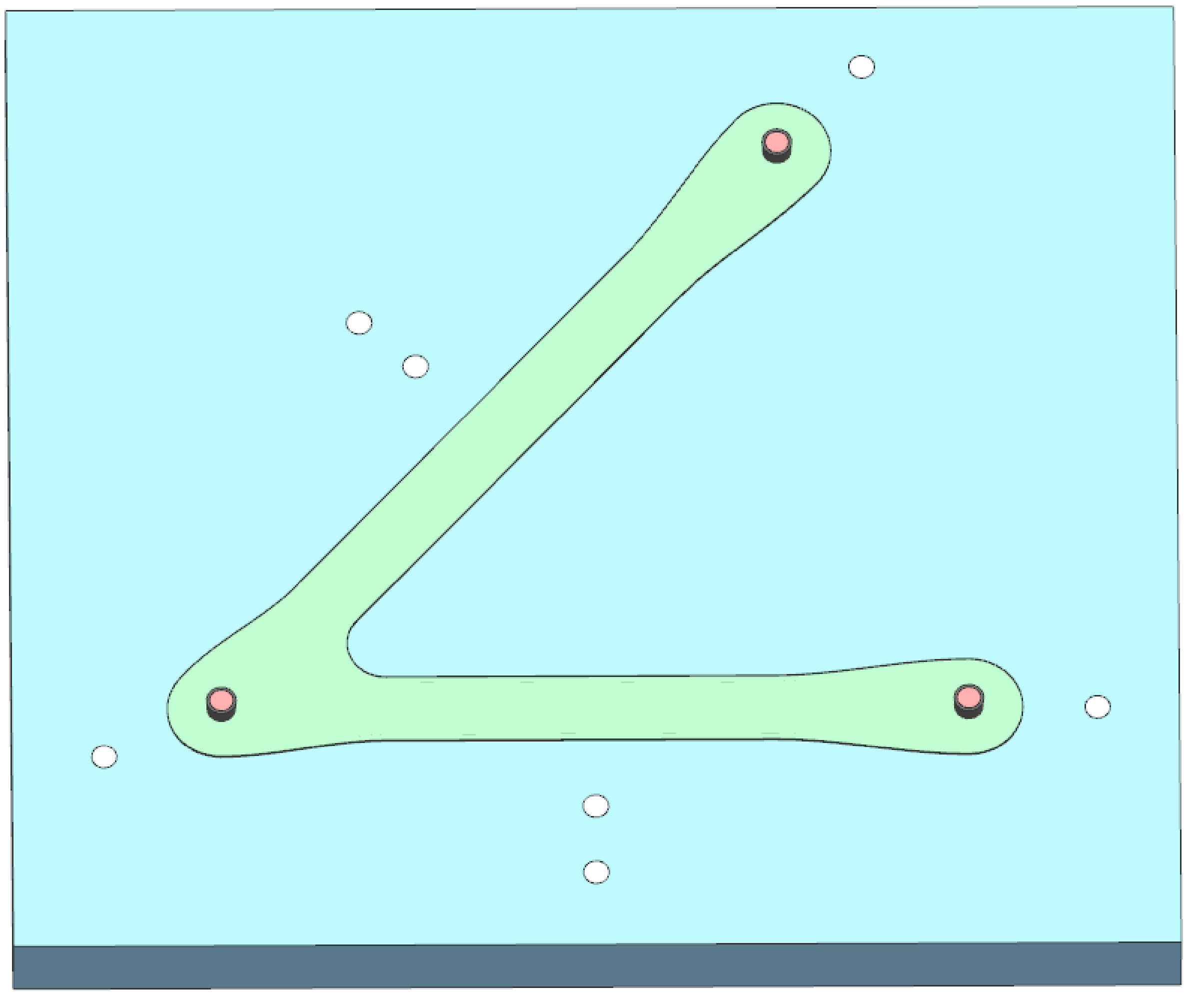
OP No.	Material Spec.	Orientation	Comments	Laminator
43	MTC400-1-C200T-M40J-42%RW-1250	0/90	Lay as shown.	
44	Room Temperature Debulk-15mins			



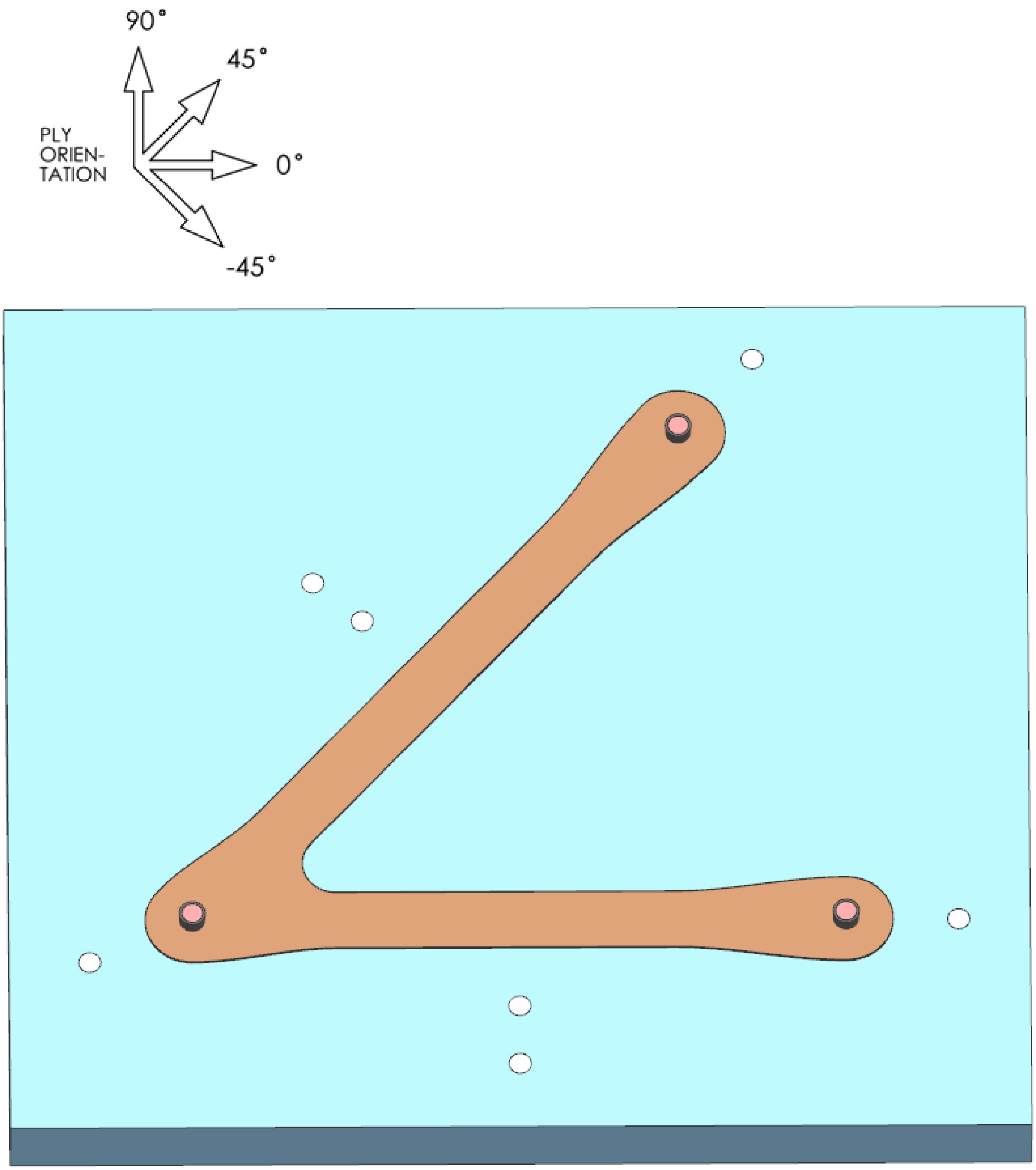


OP No.	Material Spec.	Orientation	Comments	Laminator
45	MTC400-1-C200T-M40J-42%RW-1250	0/90	Lay as shown. Trim excess material post debulk	





OP No.	Material Spec.	Orientation	Comments	Laminator
46	MTC400-1-C200T-M40J-42%RW-1250	0/90	Lay as shown. Trim excess material post debulk	



OP No.	Material Spec.	Orientation	Comments	Laminator
47	MTC400-1-C200T-M40J-42%RW-1250	0/90	Lay as shown. Trim excess material post debulk	

Layup Checklist

OP No.	Material Spec.	Orientation	Comments	Laminator
01		-	Orientate mould as shown and note rosette.	
02	MTC400-1-C200T-M40J-42%RW-1250	-	Install pre-released dowels and wrap 4x around diameter.	
03	MTC400-1-C200T-M40J-42%RW-1250	+-45	Star ply around dowels and lay over dowel	
04	Room Temperature Debulk – 15 min			
05	MTC400-1-C200T-M40J-42%RW-1250	0/90	Star ply around dowels and lay over dowel	
06	MTC400-1-C200T-M40J-42%RW-1250	+-45	Star ply around dowel and lay over dowel	
07	MTC400-1-UD140-M46J-33%RW-300P	0	Do not overlap ply onto dowels.	
08	MTC400-1-UD140-M46J-33%RW-300P	0	Do not overlap ply onto dowels. Butt plys as shown.	
9	MTC400-1-UD140-M46J-33%RW-300P	0	Do not overlap ply onto dowels. Butt plys as shown	
10	MTC400-1-UD140-M46J-33%RW-300P	0	Butt plys as shown	
11	MTC400-1-UD140-M46J-33%RW-300P	0	Fill remaining area as shown. Do not overlap plys	
12	MTC400-1-UD140-M46J-33%RW-300P	0/90	Transfer preforms onto job. NB: Dimensions +-2mm	
13	Room Temperature Debulk - 15 min			
14	MTC400-1-UD140-M46J- 33%RW-300P	0	Butt plys as shown. Op 7-10 as reference	
15	MTC400-1-UD140-M46J-33%RW-300P	0	Butt plys as shown. Op 7-10 as reference	
16	MTC400-1-UD140-M46J-	0/90	Transfer preforms onto job. NB: Dimensions +-2mm	

	33%RW-300P			
17	Room Temperature Debulk - 15 min			
18	MTC400-1-UD140-M46J-33%RW-300P	0	Butt plys as shown. Op 7-10 as reference	
19	MTC400-1-UD140-M46J-33%RW-300P	0	Butt plys as shown. Op 7-10 as reference	
20	MTC400-1-UD140-M46J-33%RW-300P	0/90	Transfer preforms onto job. NB: Dimensions +-2mm	
21	Room Temperature Debulk - 15 min			
22	MTC400-1-UD140-M46J-33%RW-300P	0	Butt plys as shown. Op 7-10 as reference	
23	MTC400-1-UD140-M46J-33%RW-300P	0	Butt plys as shown. Op 7-10 as reference	
24	MTC400-1-C200T-M40J-42%RW-1250	0/90	Lay as shown. Trim excess material post debulk	
25	Room Temperature Debulk – 15 min			
26	MTC400-1-C200T-M40J-42%RW-1250	0/90	Lay as shown.	
27	MTC400-1-C200T-M40J-42%RW-1250	45	Lay as shown. Trim excess material post debulk	
28	Room Temperature Debulk – 15 min			
29	MTC400-1-C200T-M40J-42%RW-1250	45	Lay as shown.	
30	MTC400-1-C200T-M40J-42%RW-1250	0/90	Lay as shown.	
31	MTC400-1-C200T-M40J-42%RW-1250	0/90	Lay as shown. Trim excess material post debulk	
32	Room Temperature Debulk – 15 min			
33	MTC400-1-C200T-M40J-42%RW-1250	0/90	Lay as shown.	
34	MTC400-1-C200T-M40J-42%RW-1250	0/90	Lay as shown.	
35	MTC400-1-C200T-M40J-42%RW-1250	45	Lay as shown.	
36	MTC400-1-C200T-M40J-42%RW-1250	0/90	Lay as shown. Trim excess material post debulk	
37	Room Temperature Debulk – 15 min			
38	MTC400-1-C200T-M40J-42%RW-1250	45	Lay as shown.	
39	MTC400-1-C200T-M40J-42%RW-1250	0/90	Lay as shown.	
40	MTC400-1-C200T-M40J-42%RW-1250	45	Lay as shown. Trim excess material post debulk	
41	Room Temperature Debulk - 15 min			

42	MTC400-1-C200T-M40J-42%RW-1250	0/90	Lay as shown.	
43	MTC400-1-C200T-M40J-42%RW-1250	0/90	Lay as shown.	
44	Room Temperature Debulk-15mins			
45	MTC400-1-C200T-M40J-42%RW-1250	0/90	Lay as shown.	
46	MTC400-1-C200T-M40J-42%RW-1250	0/90	Lay as shown.	
47	MTC400-1-C200T-M40J-42%RW-1250	0/90	Lay as shown. Trim excess material post debulk	
48	Room Temperature Debulk-15mins			
49	Cure : 2h @ 110°C 6bar autoclave pressure			

Appendix G – Lye Testing

Due to the premature yielding of the lug at approximately 275 MPa, compared with the more typical expected value of around 400 MPa, there was uncertainty regarding the aluminium alloy supplied for manufacture. A sodium hydroxide lye test was therefore considered as a simple qualitative check of the material.

Sodium hydroxide reacts with aluminium by breaking down the oxide layer and chemically attacking the surface. However, this method cannot reliably confirm the exact alloy grade or temper. It can only provide an indicative comparison, as 7075 aluminium is expected to react more vigorously and darken more noticeably than some other aluminium alloys.

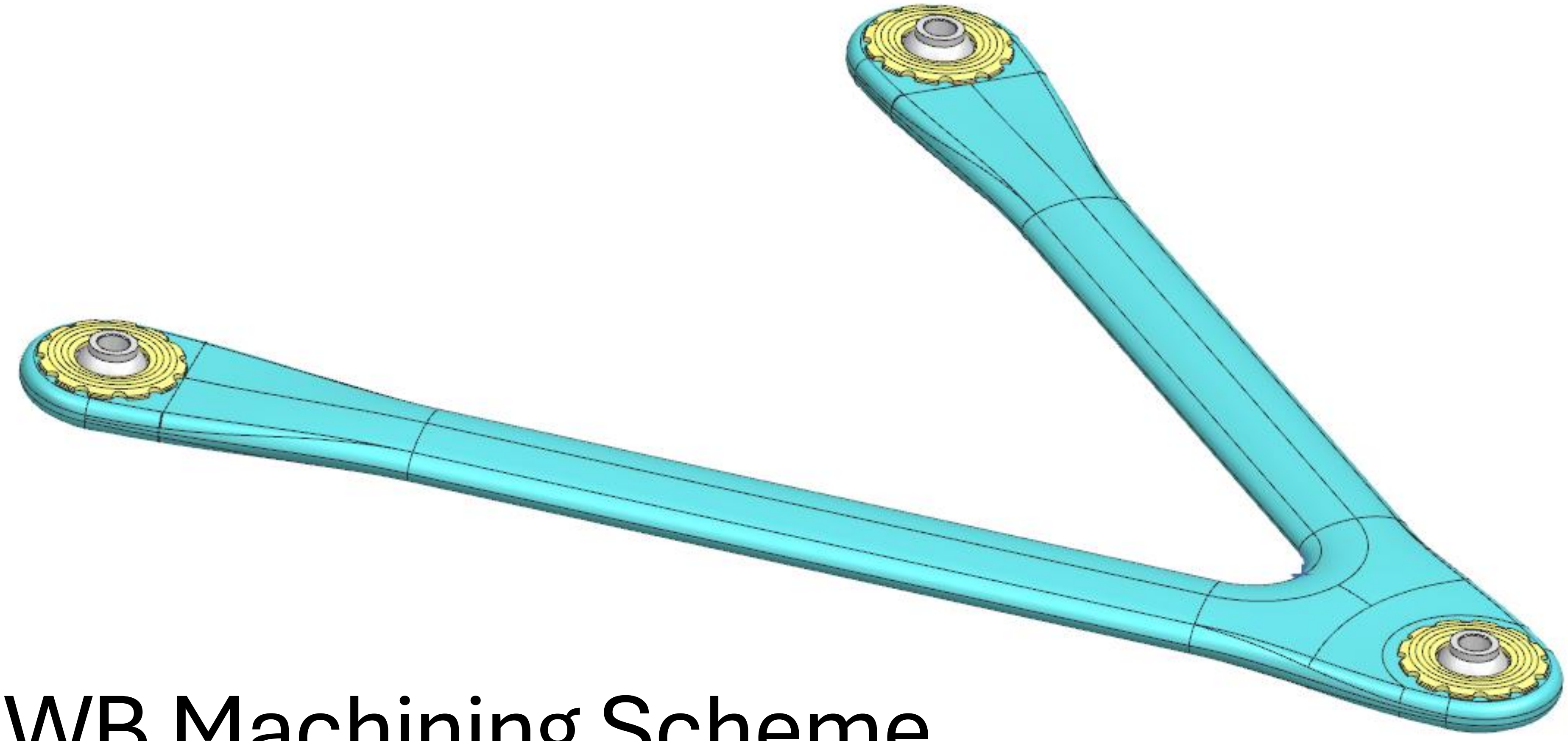
Figure 18: Aluminium samples; 7075 on the left, 5083 on the right.

Figure 19: Reaction of sample; 7075 on the left, 5083 on the right.

Samples of known 7075 and 5083 aluminium alloy were first cut into small strips and exposed to a 10% NaOH solution to compare their reactions. The 7075 sample produced a noticeably more vigorous reaction and darkened to a black surface finish, providing a baseline response for comparison.

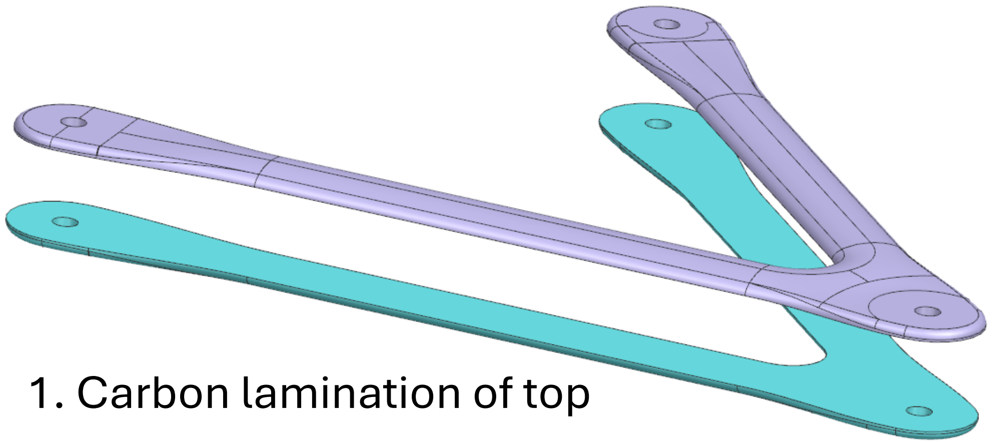
Small sections were then cut from the tested lug and placed into the same solution. The lug samples did not show the same reaction intensity or blackening observed in the known 7075 sample (Figure 20). This suggested that the tested lug material has not been 7075 aluminium, supporting the earlier concern raised by the unexpectedly low yield strength measured during tensile testing.

Figure 20: Lug material in NaOH.

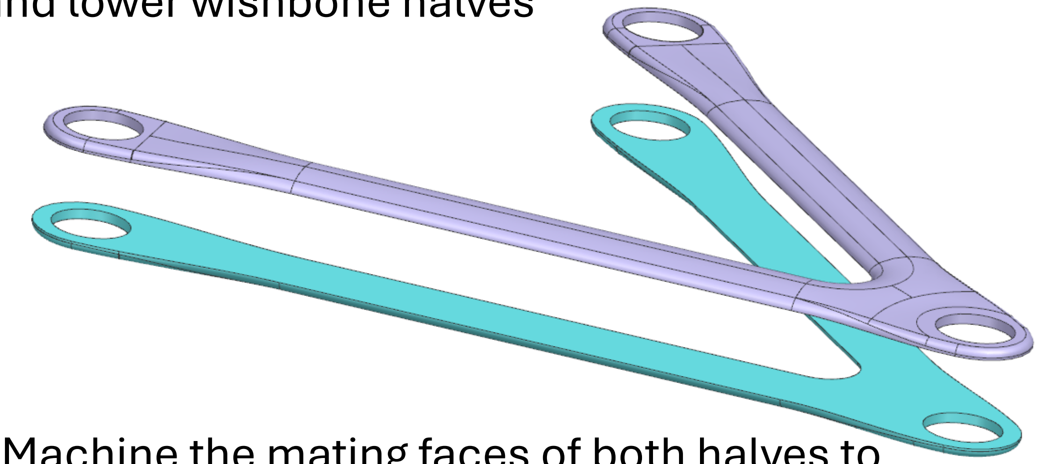


FUWB Machining Scheme

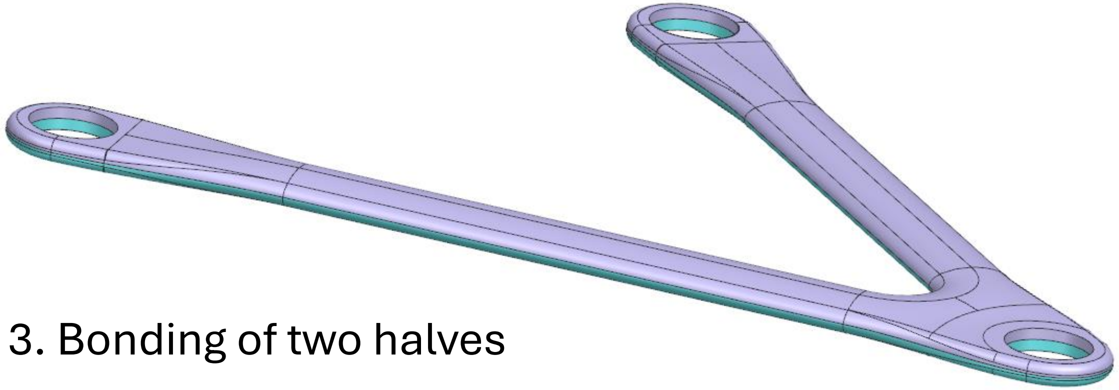
Manufacturing Stages



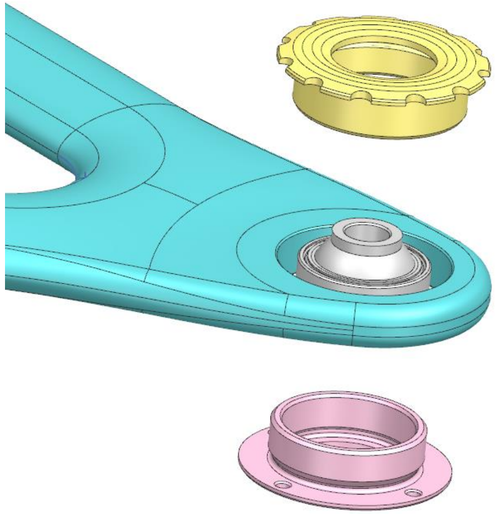
1. Carbon lamination of top and lower wishbone halves



2. Machine the mating faces of both halves to remove excess material, followed by boring of the bearing slots

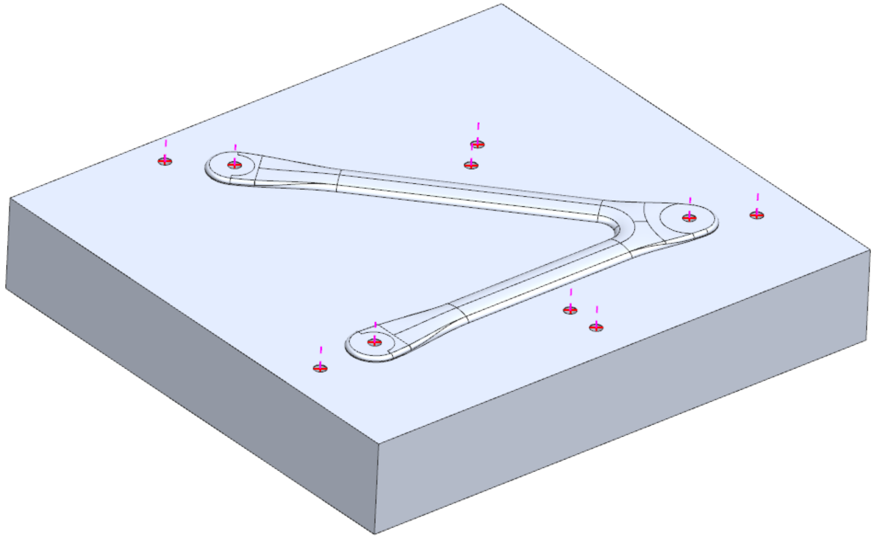


3. Bonding of two halves together

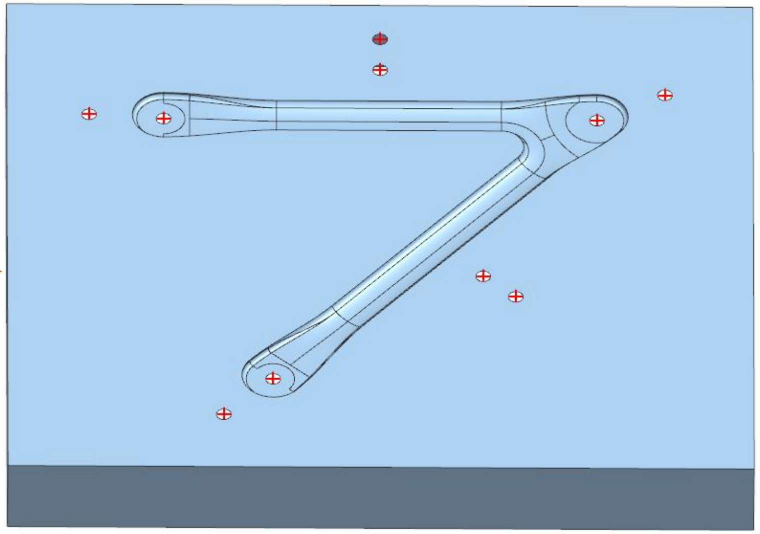


4. Installation of bearing retaining top hats.

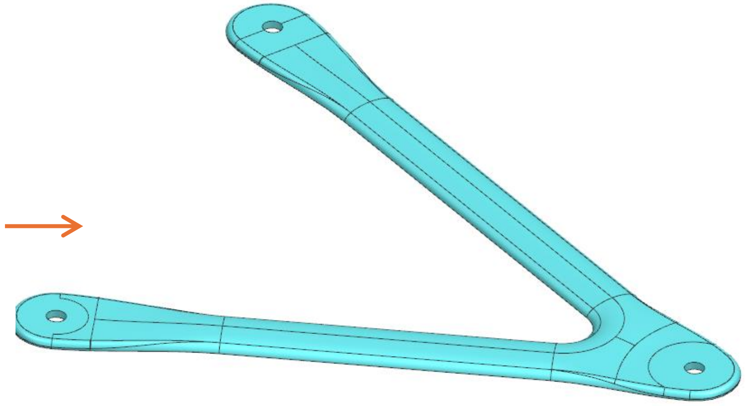
1. Lamination



1. Machined tooling board used as a male pattern



2. Carbon female mould created from pattern



3. Carbon wishbone half laid and cured on carbon mould

1. Lamination – Test Piece Example

Resin male pattern

Mould layup into pattern

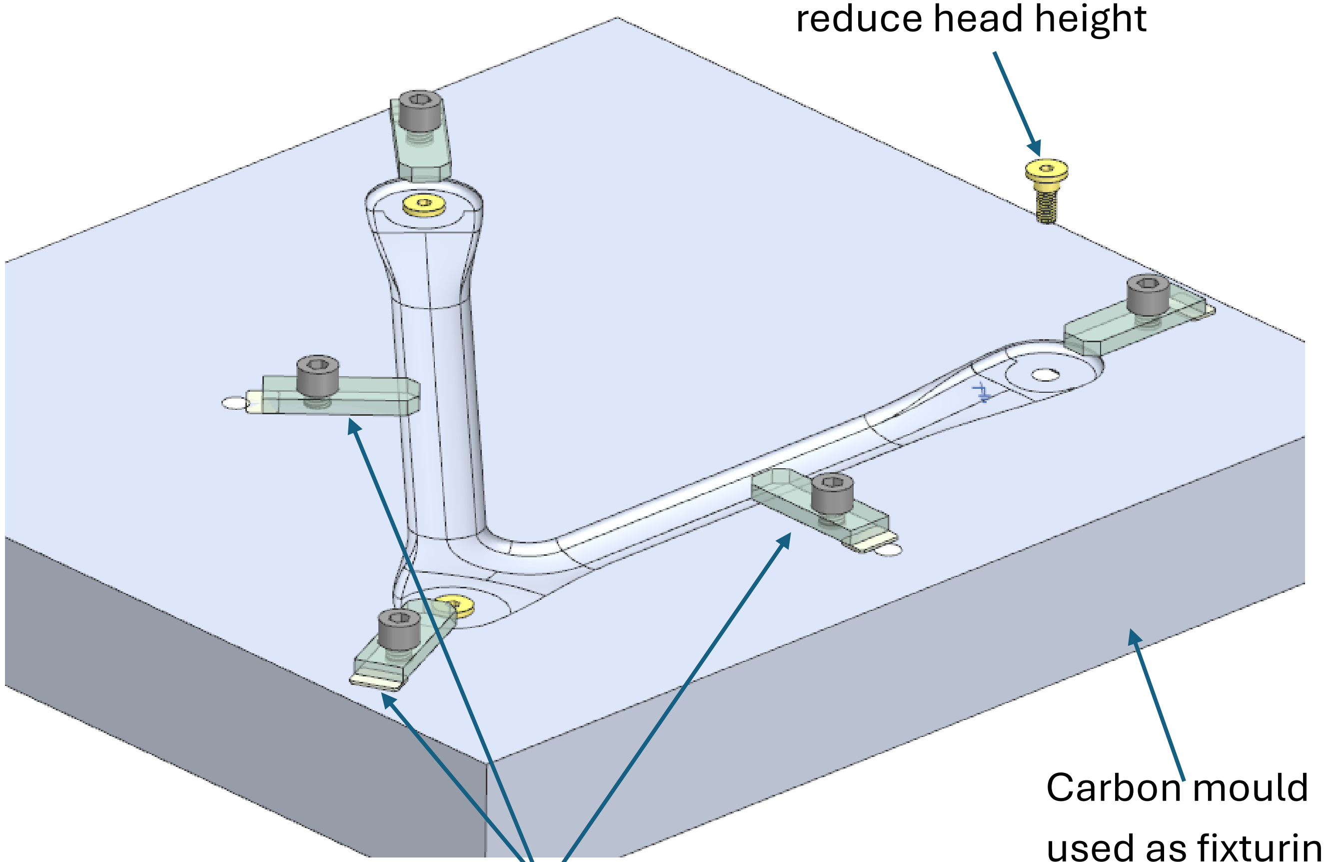
Cured female mould

Wishbone half cured (untooled faces)

Tooled faces

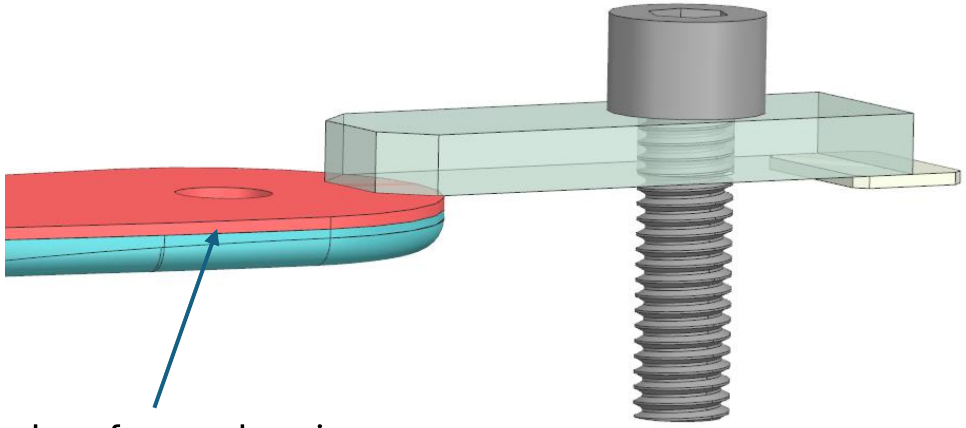
2. Machining- Fixturing

Modified M8 shoulder screws to reduce head height



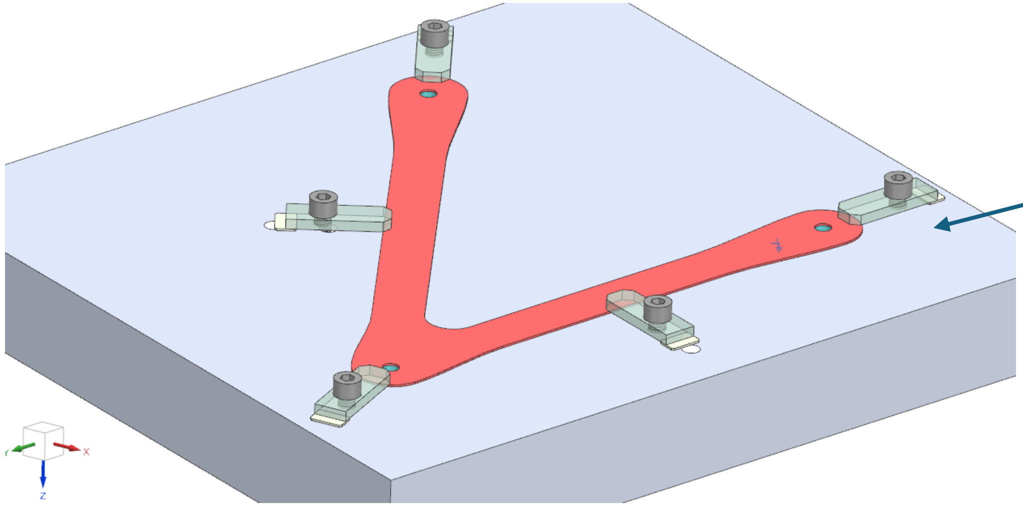
Carbon mould used as fixturing

Fixturing clamps around wishbone circumference

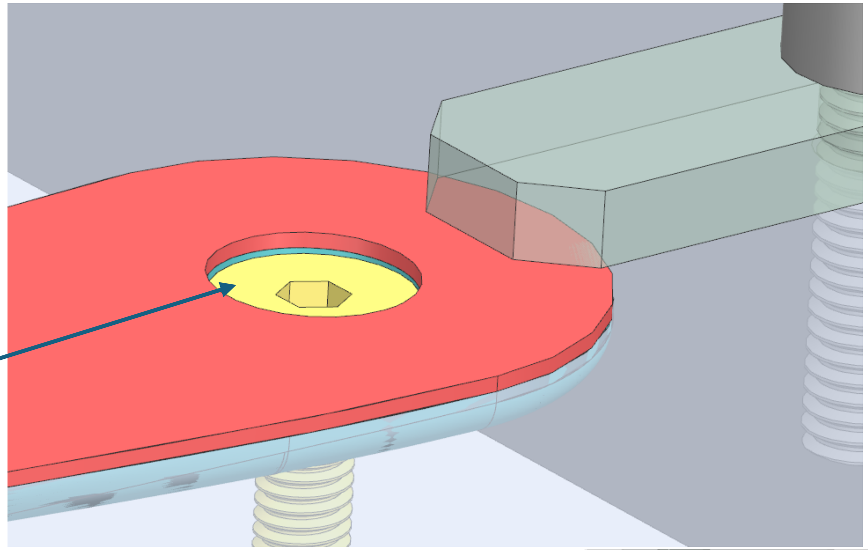


Red surfaces showing excess material

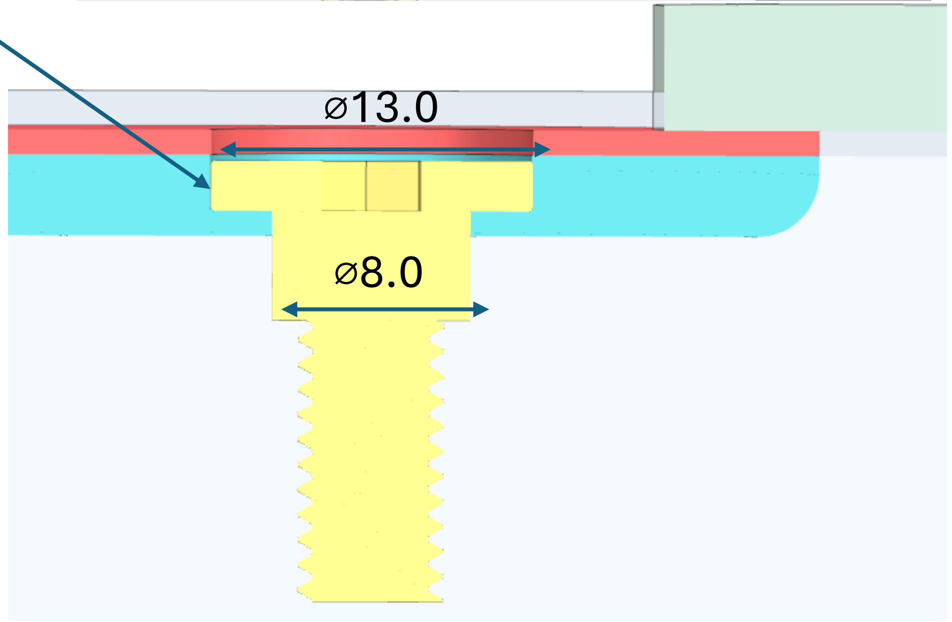
2. Machining- Boring



Wishbone half placed back into mould and clamped



C’bore drilled to fit the modified shoulder bolt sub flush to the post machined surface.



Proposed tool used

EPNC-C10 08-25C08F63 IC02

SOLIDMILL
PREMIUM LINE

ITEM #	BRAND:	MFR#:	UNSPSC:
ISC5622851	Iscar	5622851	23241614

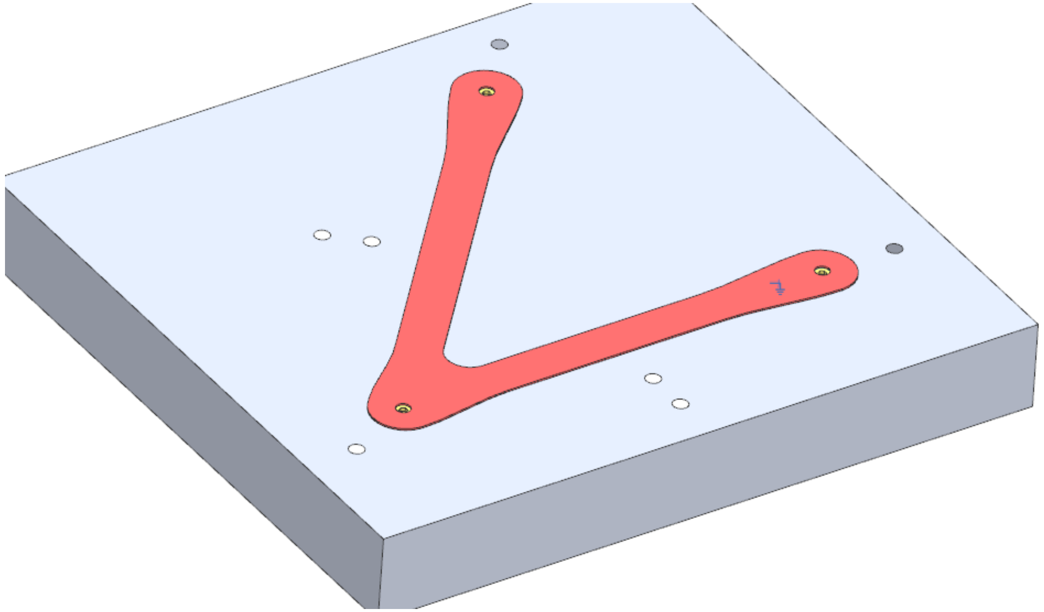
List Price: £66.70 each

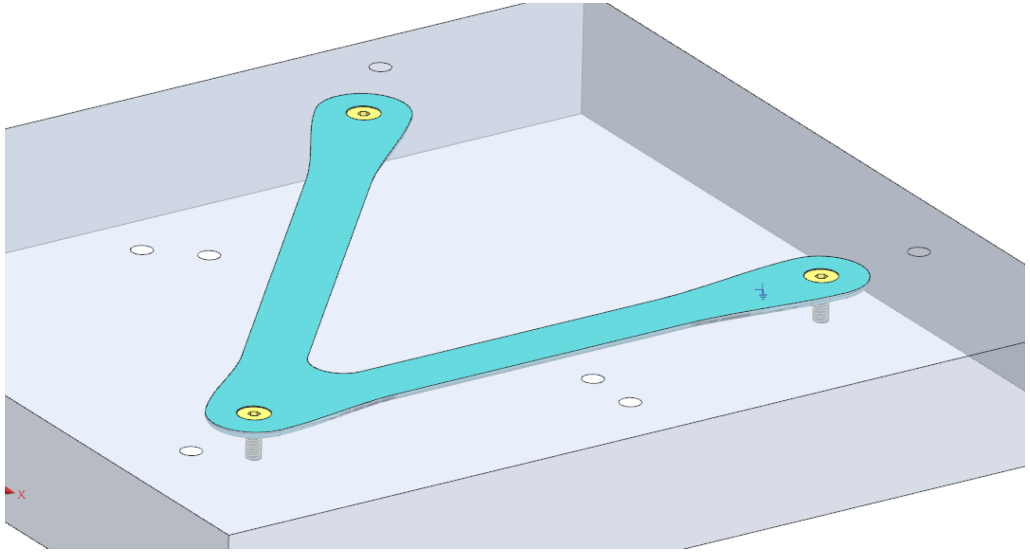
1 Add to Cart

Quantity Available

Manufacturer stock 14

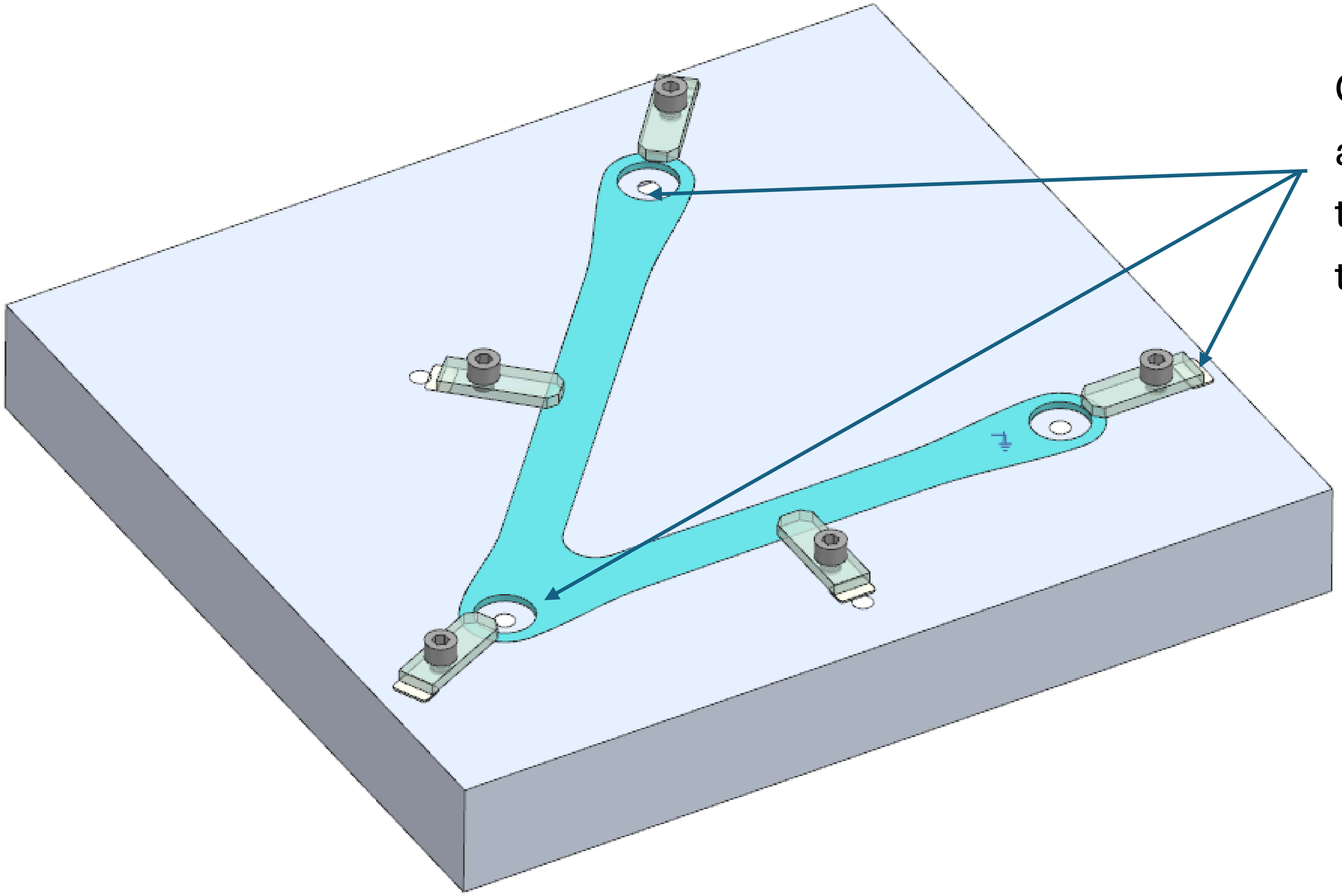
2. Machining-





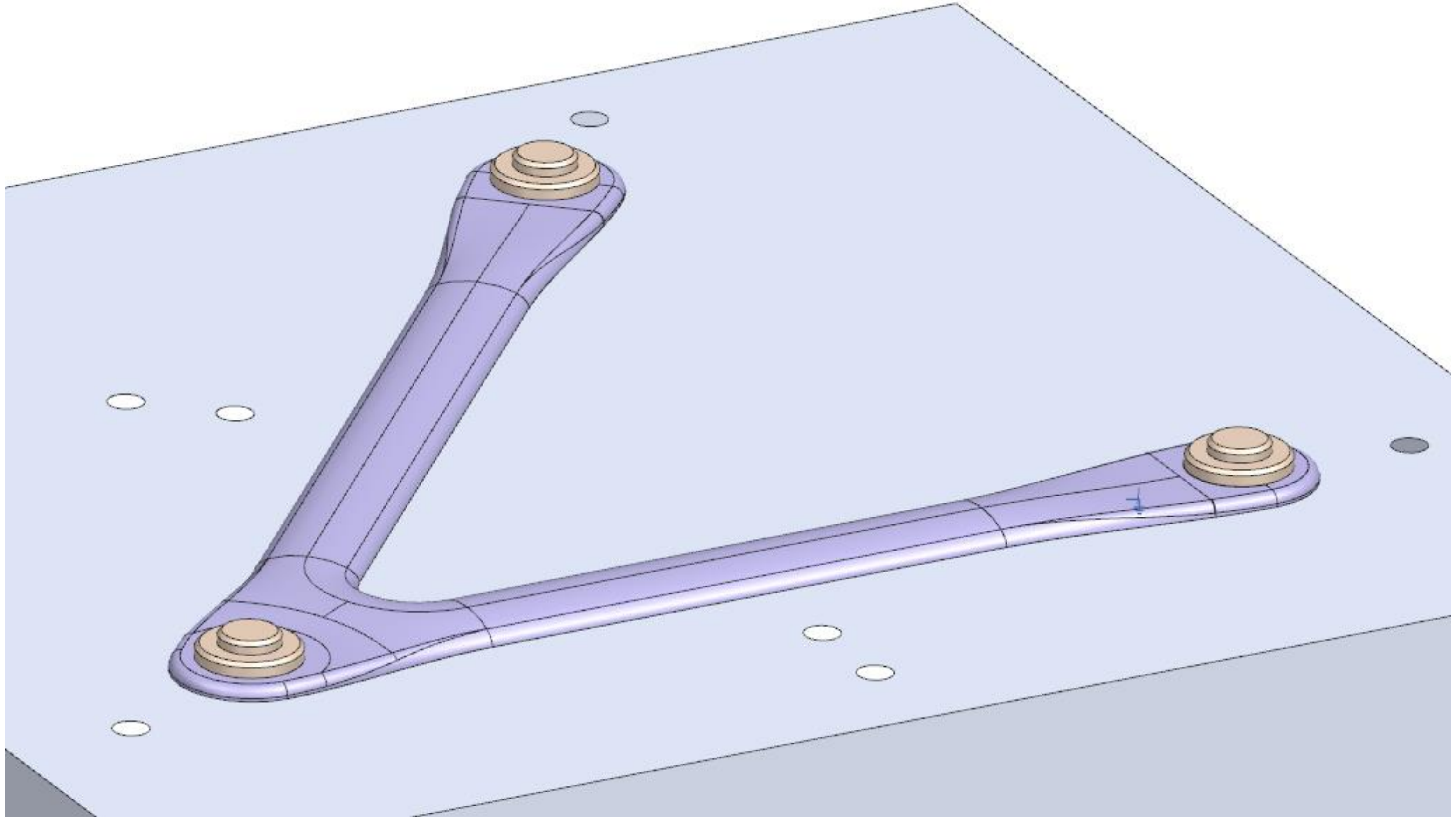
Remove clamps and torque the shoulder bolts to the fixture

2. Machining- Boring



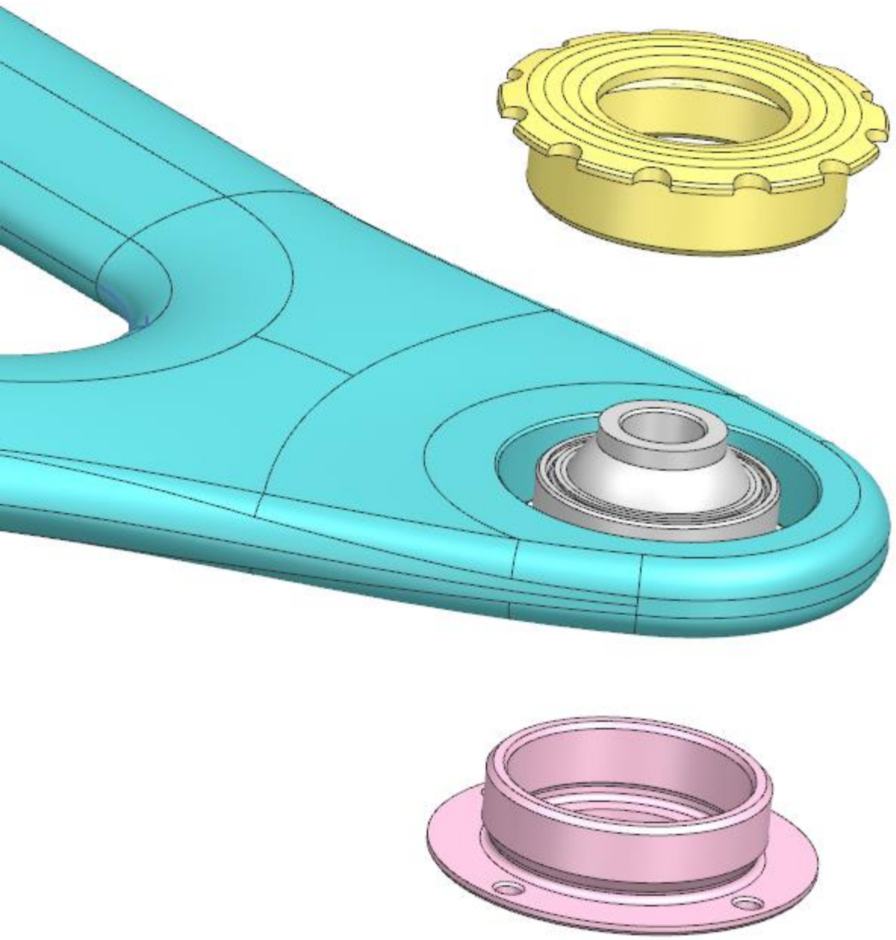
Clamps re-installed and screws removed to bore out the holes to final ⌀ 24.6 mm.

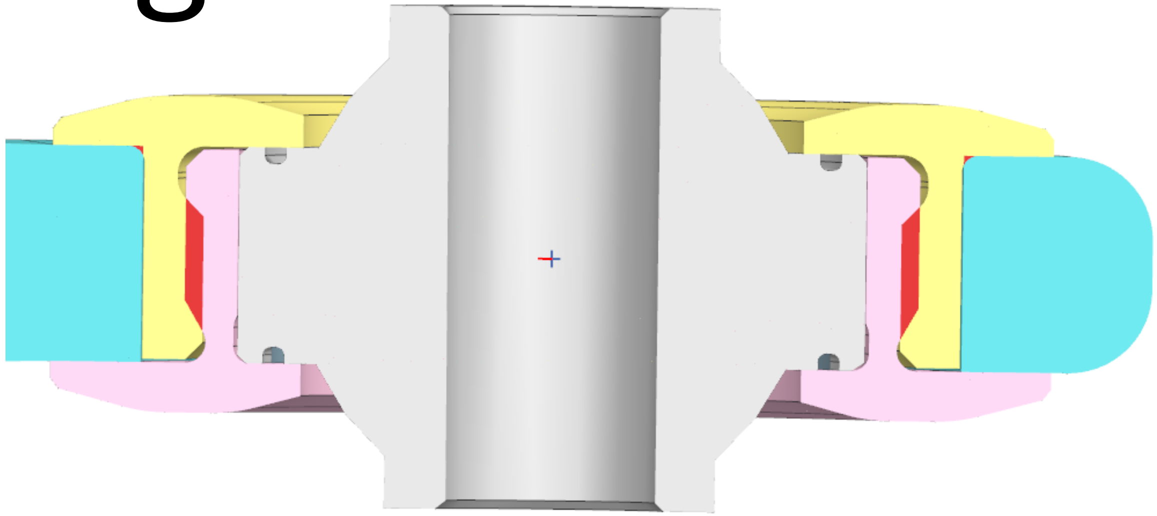
3. Bonding



The lower wishbone half is placed in the mould, followed by installation of the upper half using three locating bushes. The adhesive bond line thickness is controlled by 0.25 mm glass beads.

4. Bearing Housing

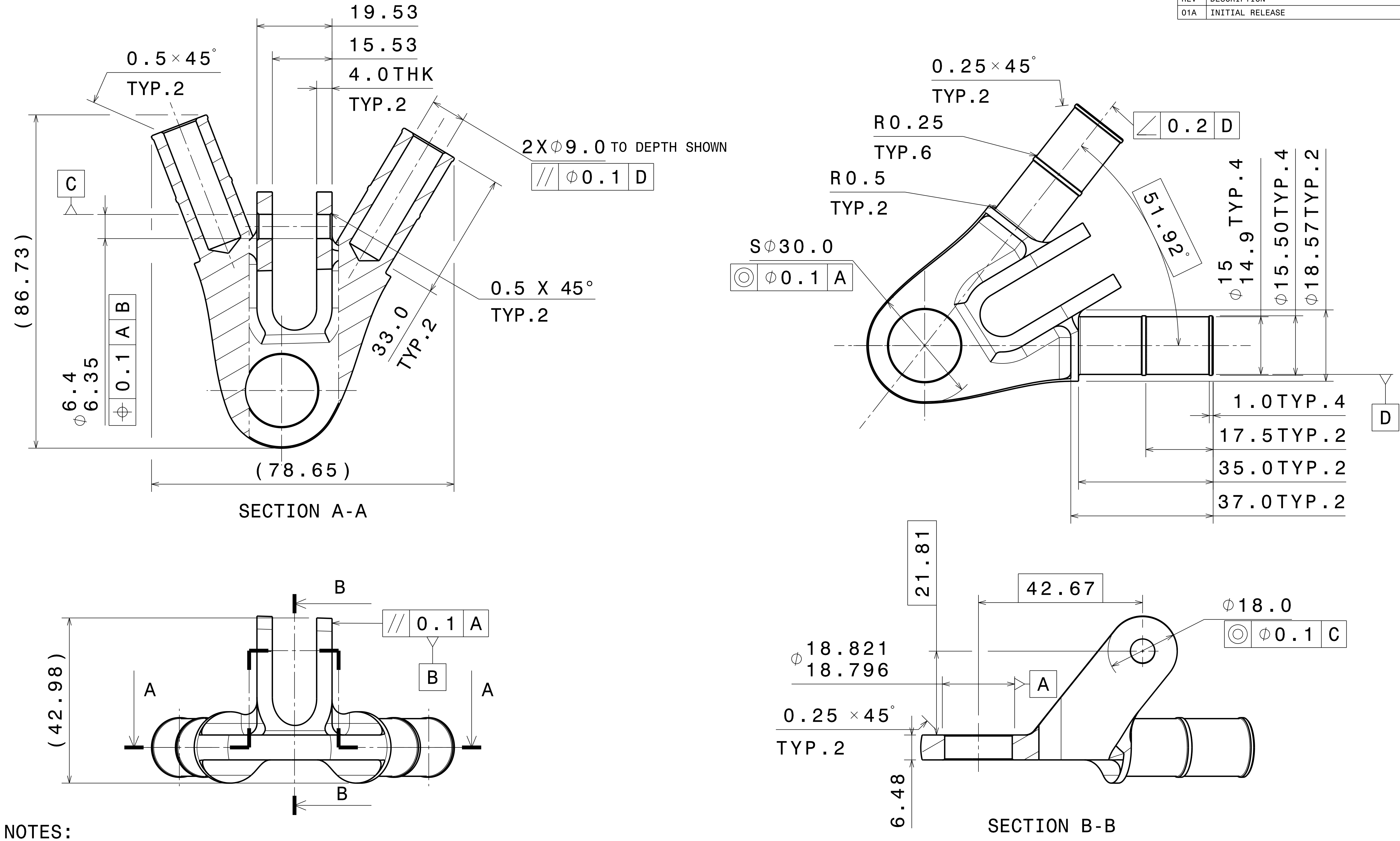




The bearing is retained by two top-hat inserts. Mating M22 X 1.0 threads provide the required preload to withstand

Appendix I – Technical Drawings

REV	DESCRIPTION	INIT	DATE
01A	INITIAL RELEASE	MAS	08.03.26



NOTES:
LH PART SHOWN, RH SYMMETRICALLY OPPOSITE.

RH PART IS UBR29-FS-008-01-COWBELL INSERT-FLWB-RH

1. MACHINE ALL UNDIAMENSIONED FEATURES TO CAD DATA.

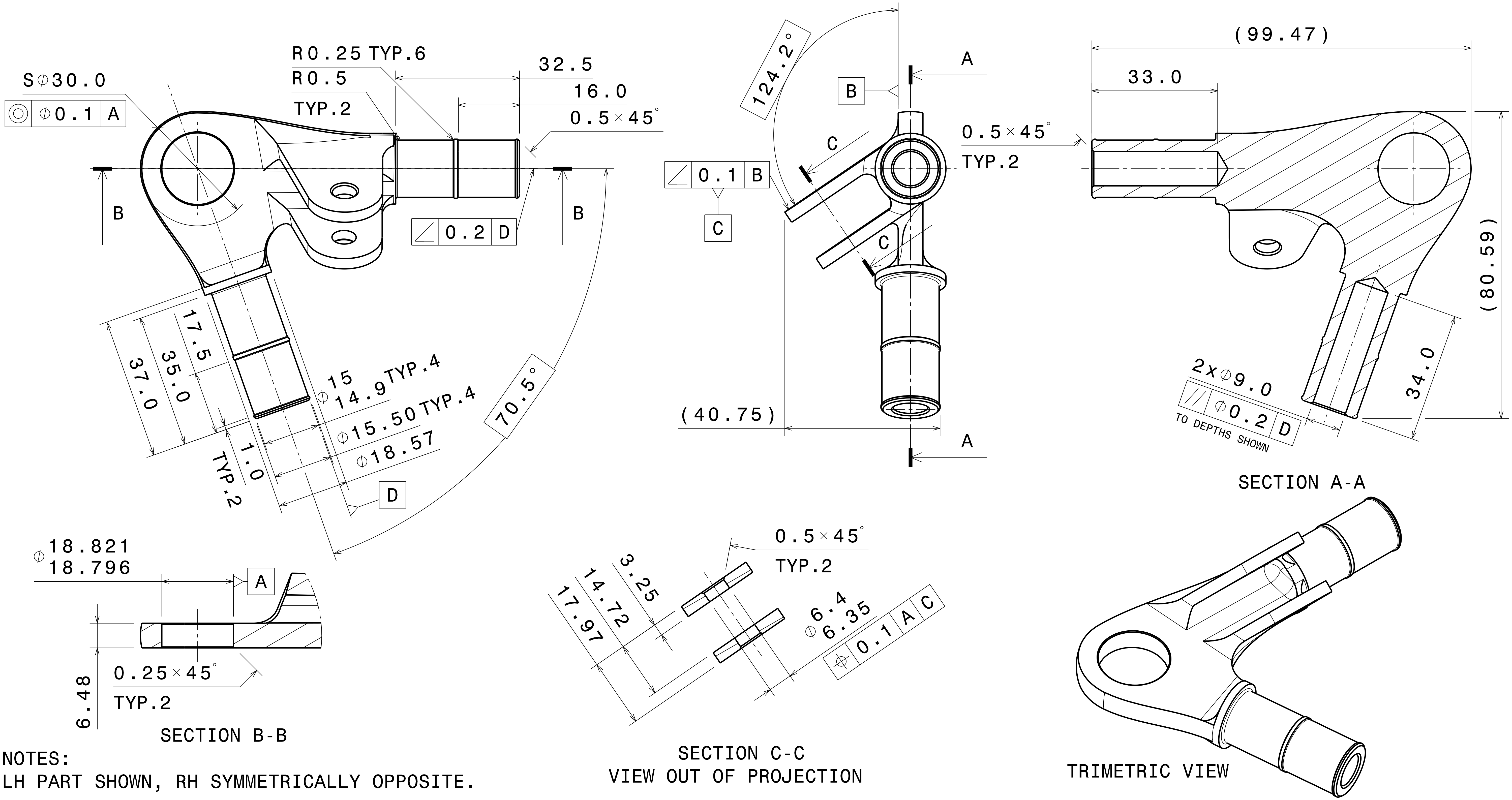
2. DEBURR ALL SHARP EDGES.

3. INSPECT TO DIMENSIONS SHOWN.

UBRacing		MATERIAL CERTIFICATE REQUIRED DIMENSIONS IN MILIMETRES U.O.S 0 DECIMAL PLACES ±0.50 1 DECIMAL PLACE ±0.25 2 DECIMAL PLACES ±0.10 3 DECIMAL PLACES ±0.02 GENERAL CONCENTRICITY 0.1 TIR ANGULAR TOLERANCE ±0.25° REMOVE BURRS AND SHARP EDGES
A3	IF IN DOUBT - ASK DO NOT SCALE	
TEL.	+44 (0)121 414 4218	
E-MAIL.	ubracing@gmail.com	

COMPONENT MASS (kg)	0.063	MATERIAL SPEC	7075
		HEAT TREATMENT	T6
DRAWN BY		SURFACE TREATMENT	N/A
MAS		DESCRIPTION	COWBELL INSERT-FLWB-LH
SCALE	1:1	SHEET 1/1	PART NUMBER UBR29-FS-007-01

REV	DESCRIPTION	INIT	DATE
01A	INITIAL RELEASE	MAS	09.03.26



NOTES:
LH PART SHOWN, RH SYMMETRICALLY OPPOSITE.

RH PART NUMBER IS UBR29-RS-003-01-COWBELL INSERT-RLWB-RH

1. MACHINE ALL UNDIAMENSIONED FEATURES TO CAD DATA.

2. DEBURR ALL SHARP EDGES.

3. INSPECT TO DIMENSIONS SHOWN.

UBRacing

A3 — IF IN DOUBT - ASK — DO NOT SCALE

TEL. +44 (0)121 414 4218

E-MAIL. ubracing@gmail.com

MATERIAL CERTIFICATE REQUIRED

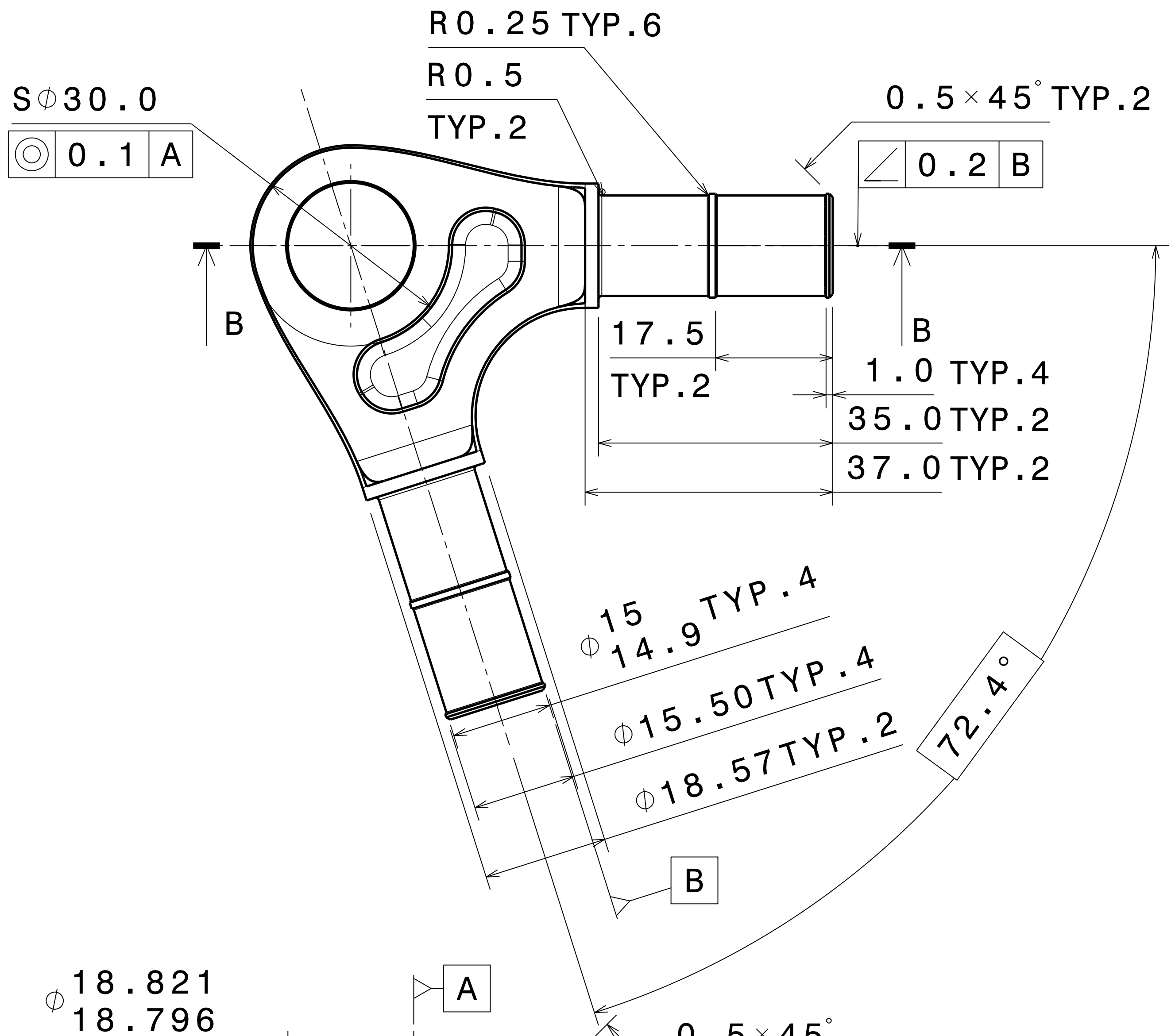
DIMENSIONS IN MILIMETRES U.O.S

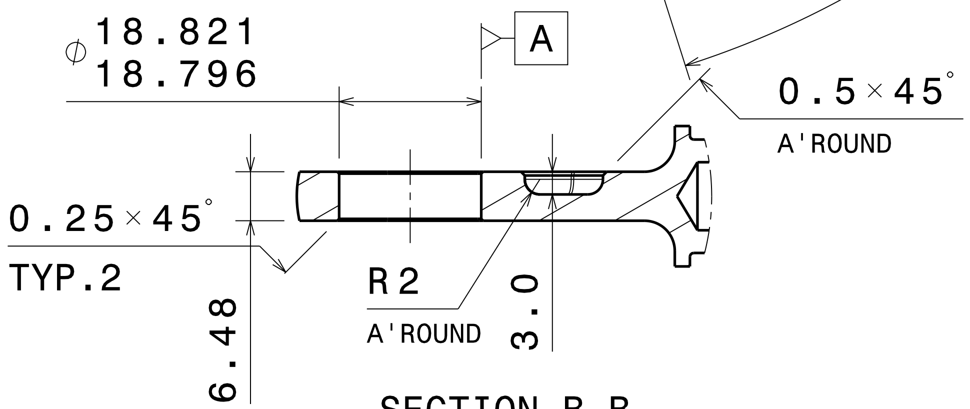
0 DECIMAL PLACES	±0.50
1 DECIMAL PLACE	±0.25
2 DECIMAL PLACES	±0.10
3 DECIMAL PLACES	±0.02
GENERAL CONCENTRICITY	0.1 TIR
ANGULAR TOLERANCE	±0.25°

REMOVE BURRS AND SHARP EDGES

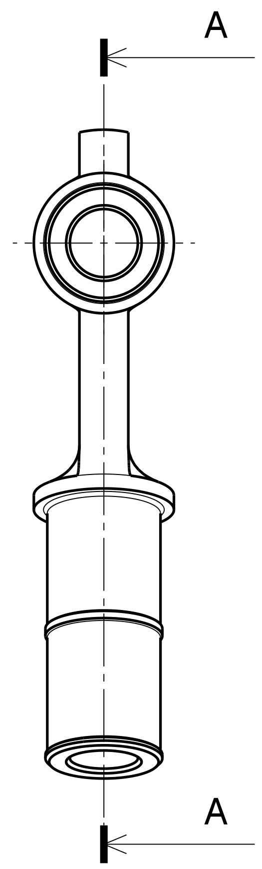
COMPONENT MASS (kg)	0.066
DRAWN BY	MAS
MATERIAL SPEC	7075
HEAT TREATMENT	T6
SURFACE TREATMENT	N/A
DESCRIPTION	COWBELL INSERT-RLWB-LH
SCALE	1:1
SHEET	1/1
PART NUMBER	UBR29-RS-002-01

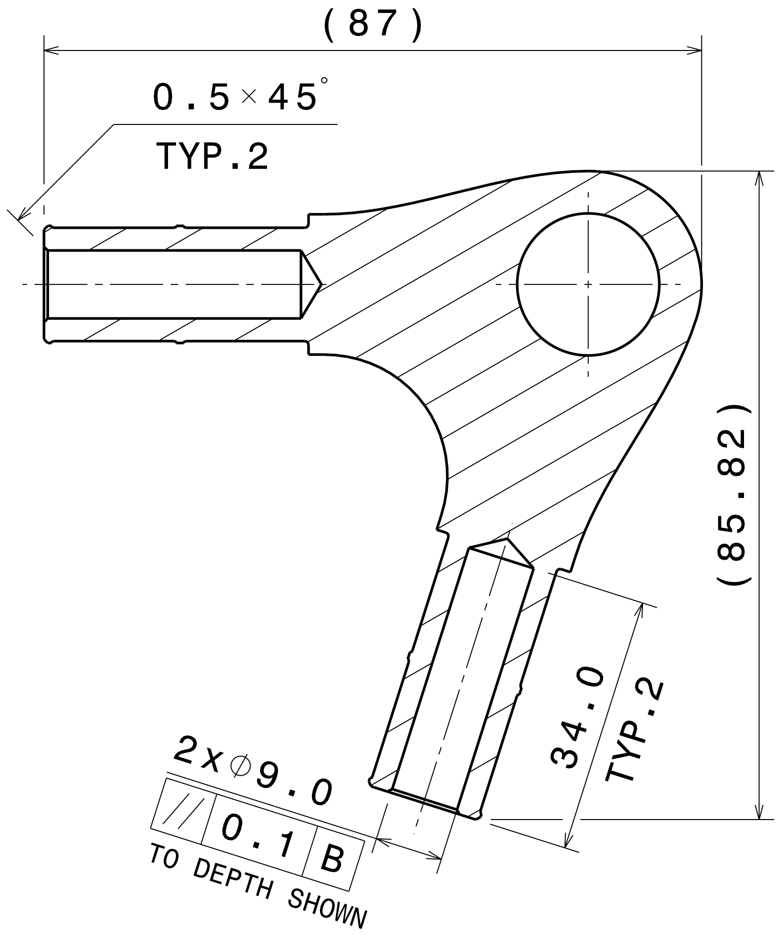
REV	DESCRIPTION	INIT	DATE
01A	INITIAL RELEASE	MAS	09.03.26



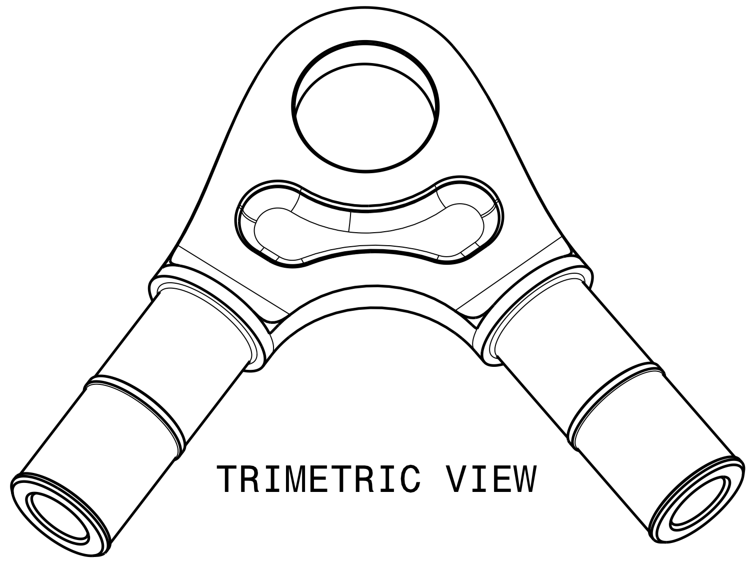


SECTION B-B





SECTION A-A


TRIMETRIC VIEW

NOTES:
LH PART SHOWN, RH SYMMETRICALLY OPPOSITE.

RH PART IS UBR29-RS-006-01-COWBELL INSERT-RUWB-RH

1. MACHINE ALL UNDIAMENSIONED FEATURES TO CAD DATA.

2. DEBURR ALL SHARP EDGES.

3. INSPECT TO DIMENSIONS SHOWN.

UBRacing

A3 | IF IN DOUBT - ASK | DO NOT SCALE

TEL. +44 (0)121 414 4218

E-MAIL. ubracing@gmail.com

MATERIAL CERTIFICATE REQUIRED

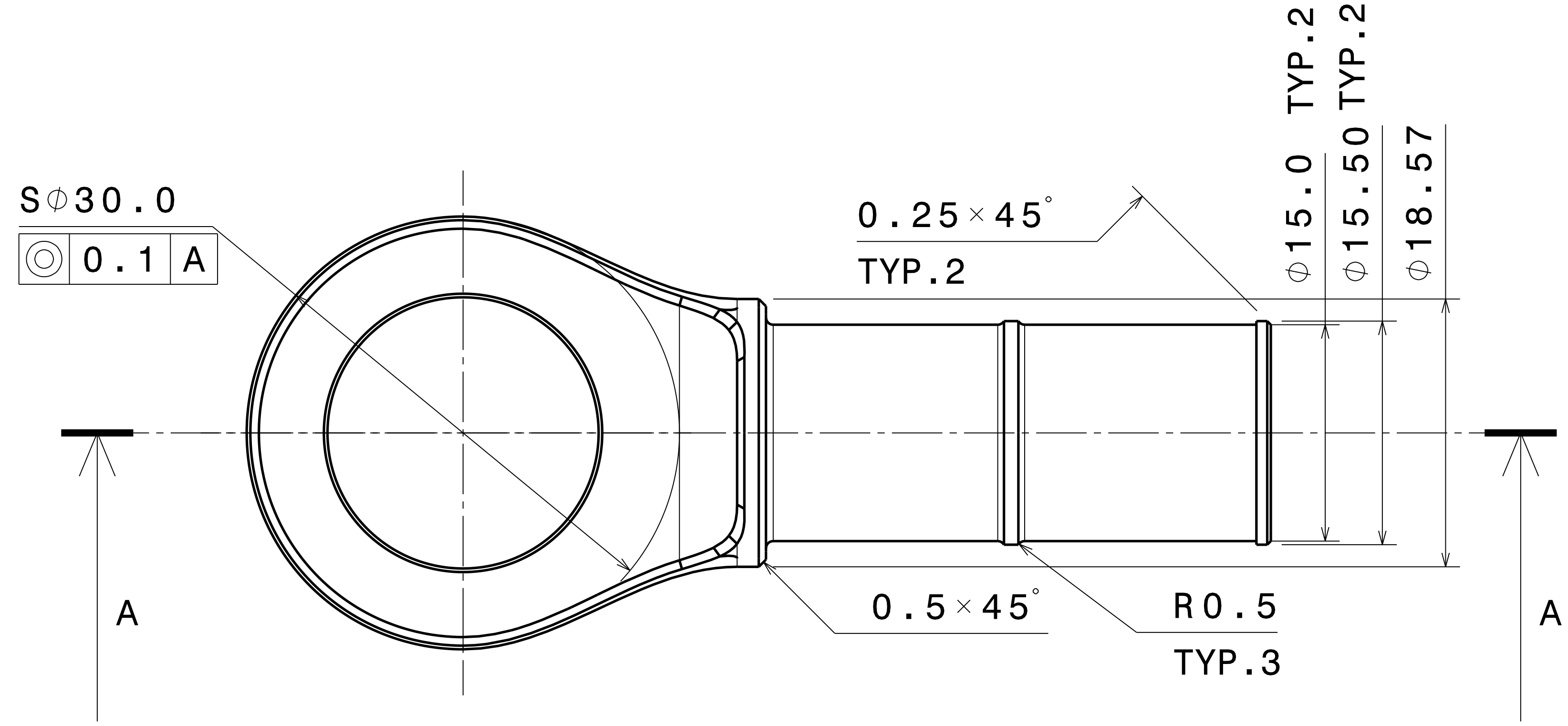
DIMENSIONS IN MILIMETRES U.O.S

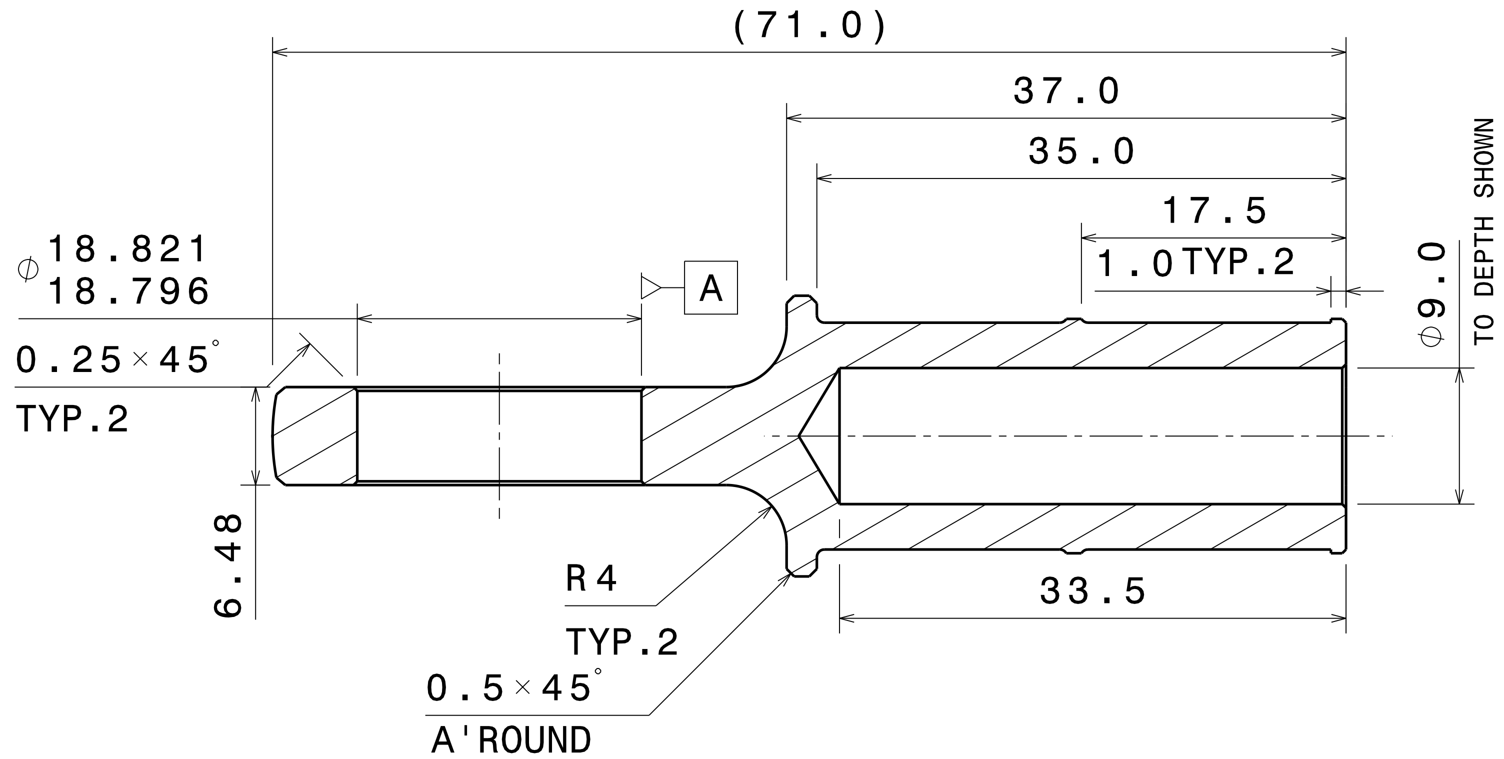
0 DECIMAL PLACES	±0.50
1 DECIMAL PLACE	±0.25
2 DECIMAL PLACES	±0.10
3 DECIMAL PLACES	±0.02
GENERAL CONCENTRICITY	0.1 TIR
ANGULAR TOLERANCE	±0.25°

REMOVE BURRS AND SHARP EDGES

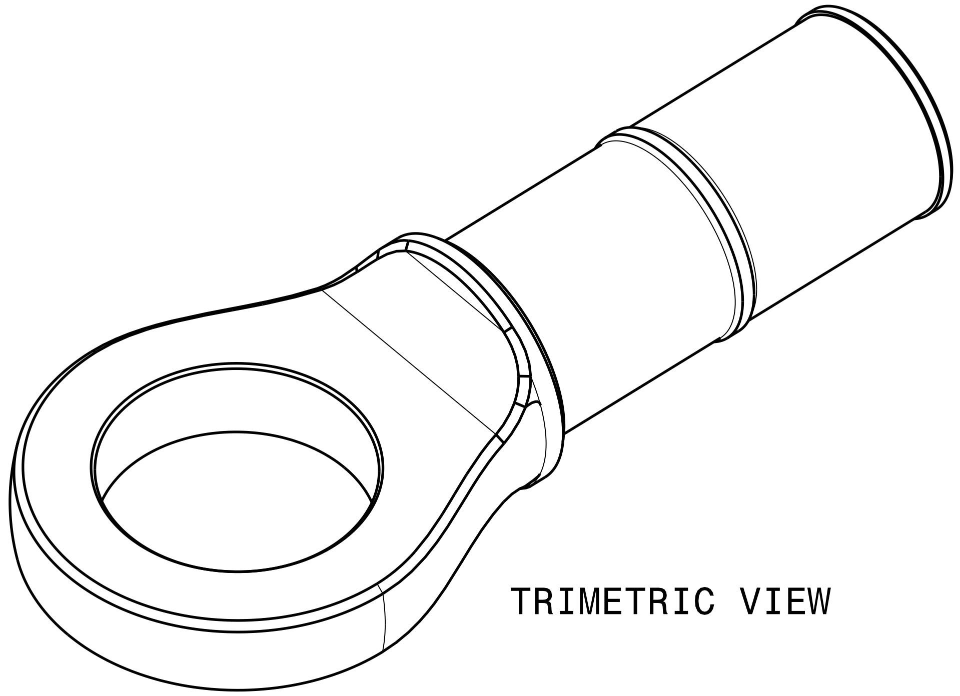
COMPONENT MASS (kg)	0.048
DRAWN BY	MAS
MATERIAL SPEC	7075
HEAT TREATMENT	T6
SURFACE TREATMENT	N/A
DESCRIPTION	COWBELL INSERT-RUWB-LH
SCALE	1:1
SHEET	1/1
PART NUMBER	UBR29-RS-005-01

REV	DESCRIPTION	INIT	DATE
01A	INITIAL RELEASE	MAS	20.03.26





SECTION A-A



TRIMETRIC VIEW

NOTES:

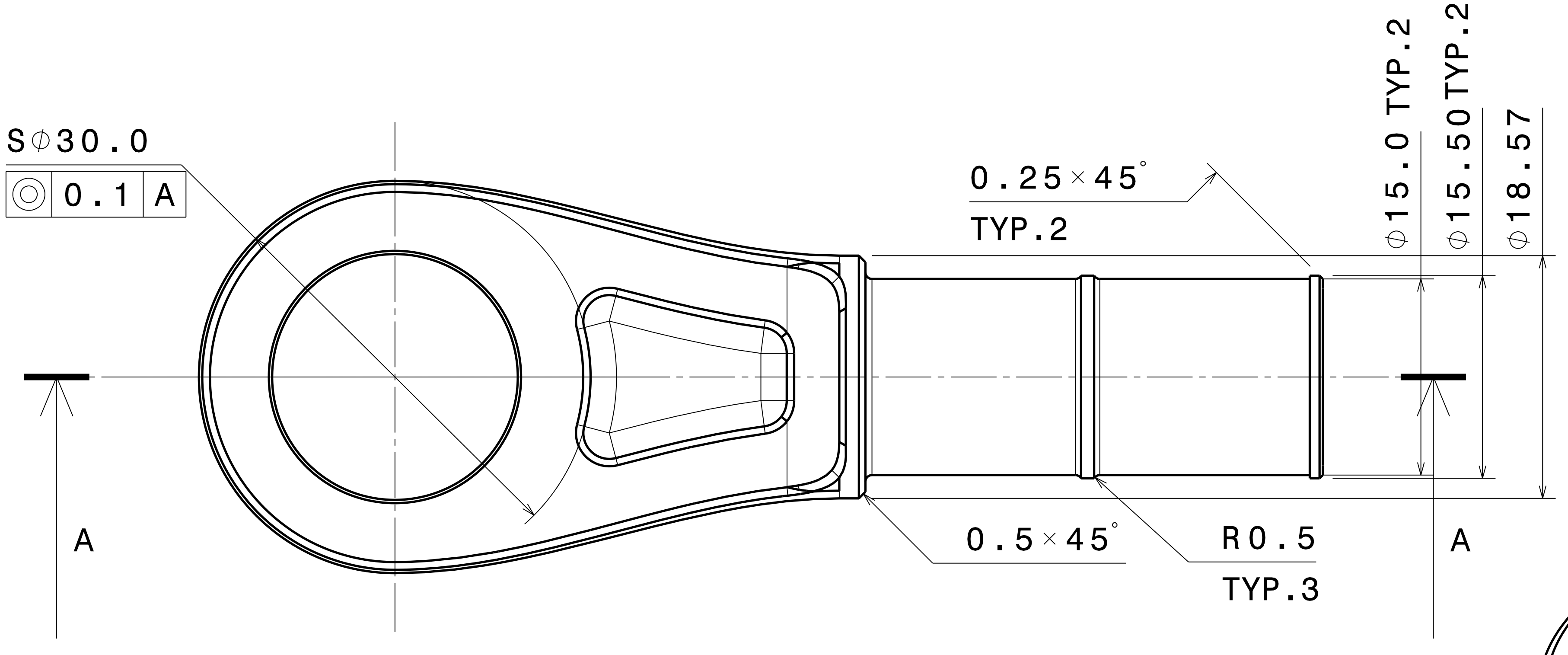
1.MACHINE ALL UNDIMENSIONED FEATURES TO CAD DATA.

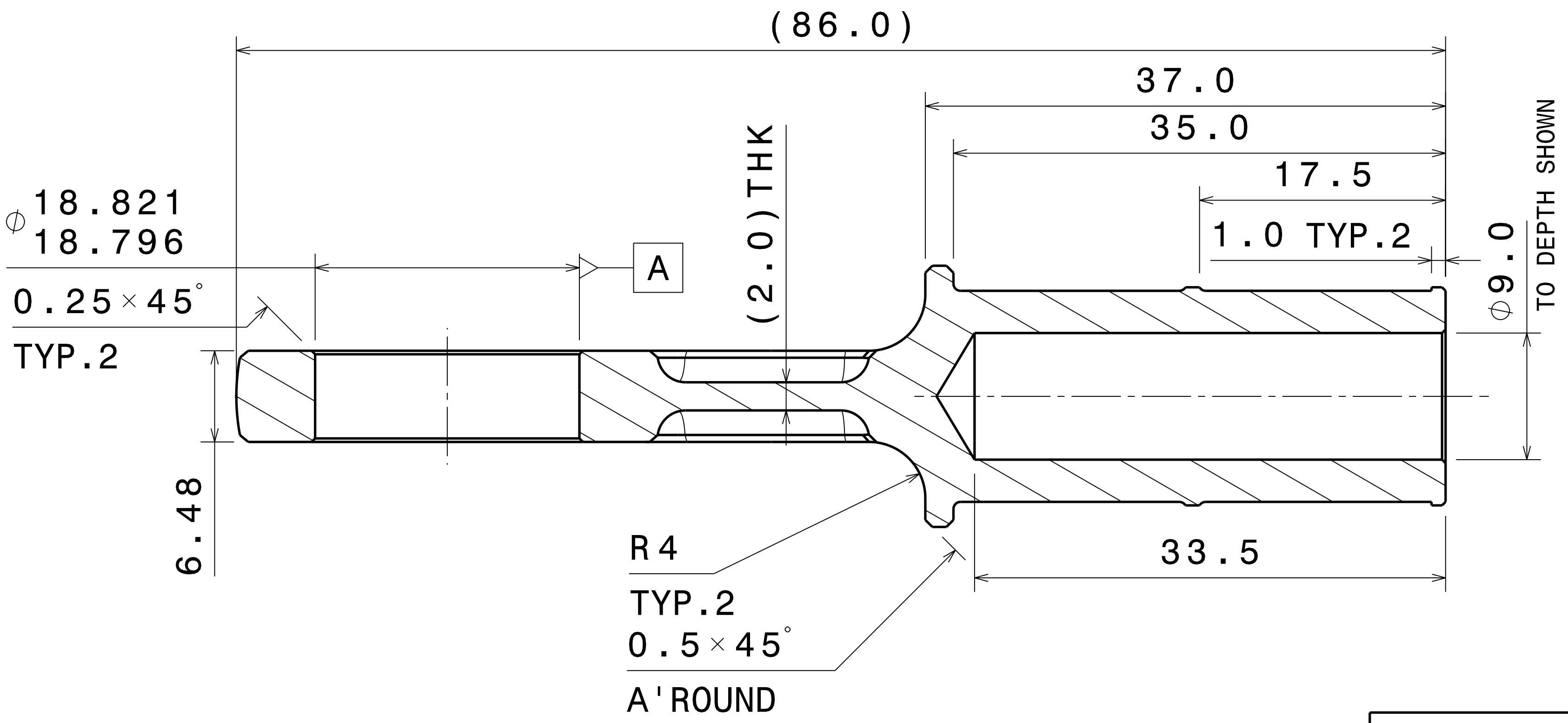
2.DEBURR ALL SHARP EDGES.

3.INSPECT TO DIMENSIONS SHOWN.

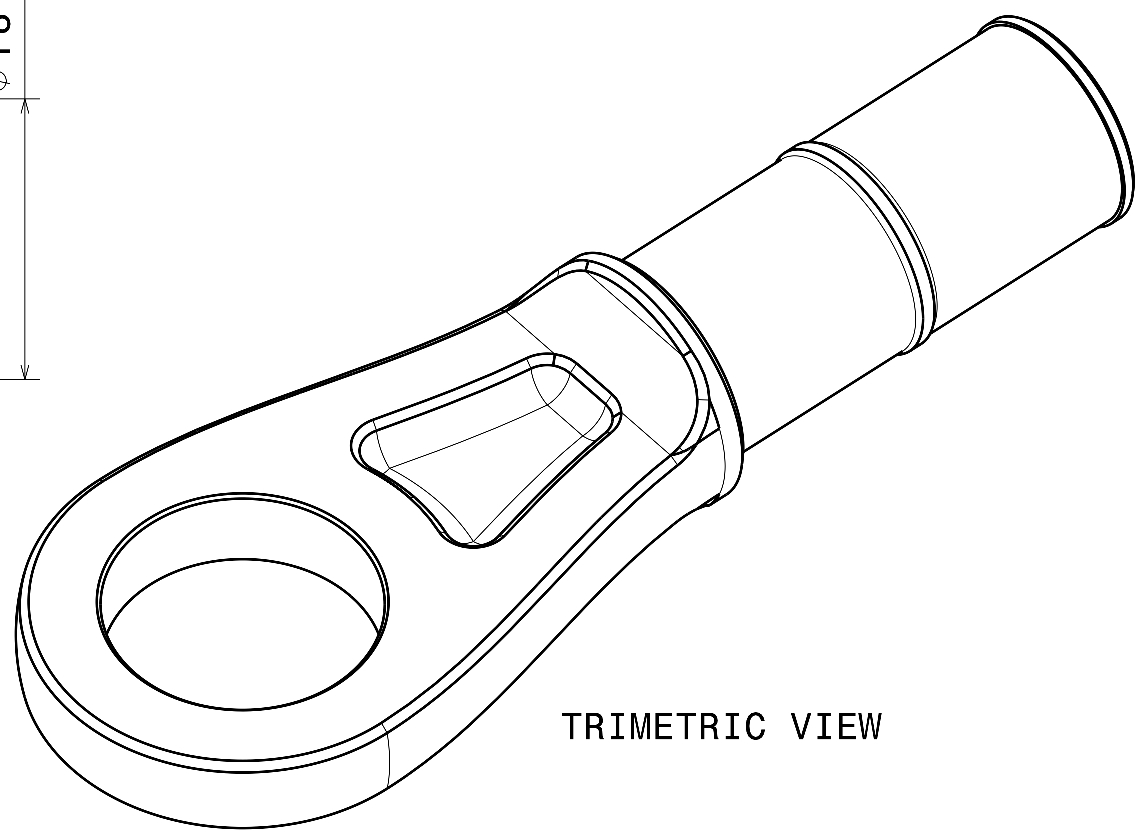
UBRacing	MATERIAL CERTIFICATE REQUIRED DIMENSIONS IN MILIMETRES U.O.S	COMPONENT MASS (kg)	0.022	MATERIAL SPEC: 7075 HEAT TREATMENT: T6
A3	IF IN DOUBT - ASK DO NOT SCALE	0 DECIMAL PLACES ±0.50 1 DECIMAL PLACE ±0.25 2 DECIMAL PLACES ±0.10 3 DECIMAL PLACES ±0.02 GENERAL CONCENTRICITY 0.1 TIR ANGULAR TOLERANCE ±0.25°	DRAWN BY	MAS
TEL.	+44 (0)121 414 4218		SURFACE TREATMENT	N/A
E-MAIL.	ubracing@gmail.com	REMOVE BURRS AND SHARP EDGES	DESCRIPTION	INNER LUG-WISHBONE
SCALE	2:1	SHEET 1/1	PART NUMBER	UBR29-FS-013-01

REV	DESCRIPTION	INIT	DATE
01A	INITIAL RELEASE	MAS	21.03.26





SECTION A-A



TRIMETRIC VIEW

NOTES:

1.MACHINE ALL UNDIMENSIONED FEATURES TO CAD DATA.

2.DEBURR ALL SHARP EDGES.

3.INSPECT TO DIMENSIONS SHOWN.

UBRacing	
A3	IF IN DOUBT - ASK DO NOT SCALE
TEL.	+44 (0)121 414 4218
E-MAIL.	ubracing@gmail.com

MATERIAL CERTIFICATE REQUIRED

DIMENSIONS IN MILIMETRES U.O.S

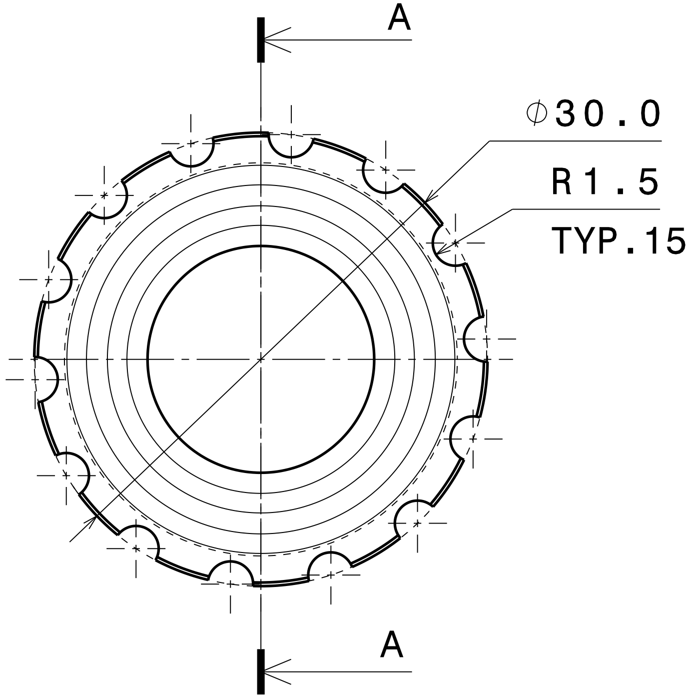
0 DECIMAL PLACES	±0.50
1 DECIMAL PLACE	±0.25
2 DECIMAL PLACES	±0.10
3 DECIMAL PLACES	±0.02
GENERAL CONCENTRICITY	0.1 TIR
ANGULAR TOLERANCE	±0.25°

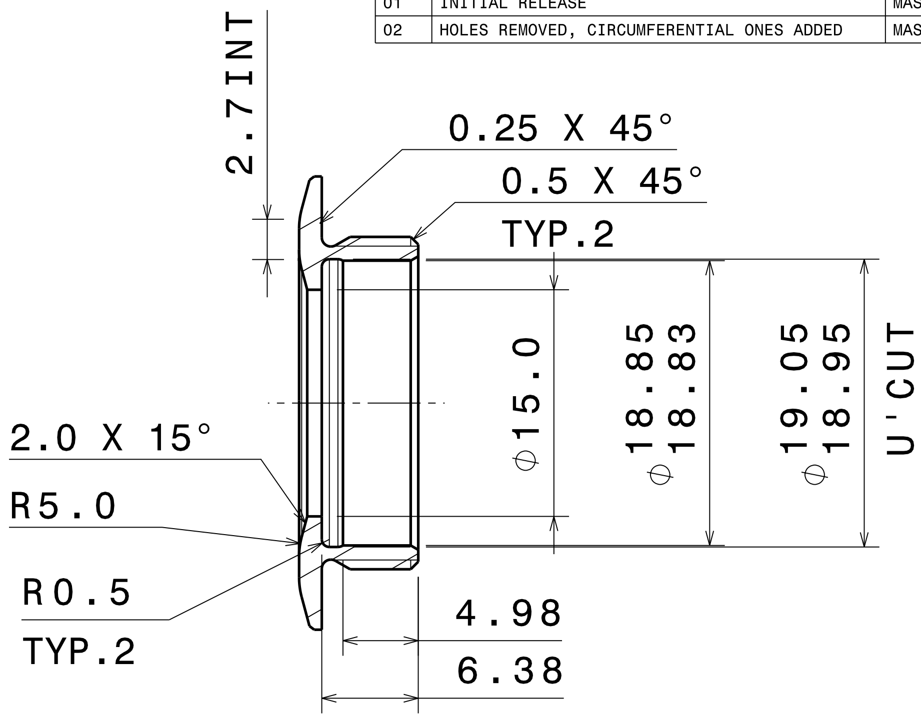
REMOVE BURRS AND SHARP EDGES

COMPONENT MASS (kg)	0.027
DRAWN BY	MAS
SCALE	2:1

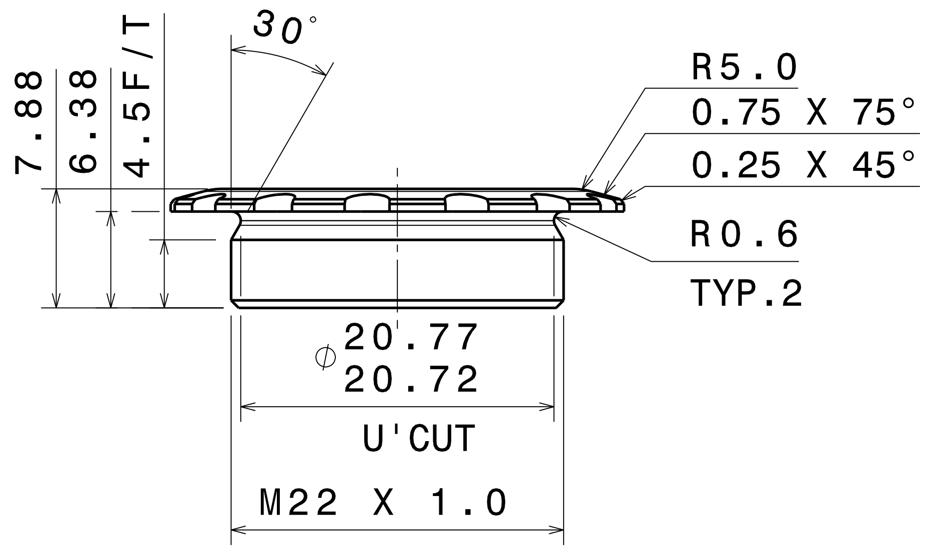
MATERIAL SPEC	7075
HEAT TREATMENT	T6
SURFACE TREATMENT	N/A
DESCRIPTION	INBOARD LUG-RLWBRL
SHEET	1/1
PART NUMBER	UBR29-RS-014-01

REV	DESCRIPTION	INIT	DATE
01	INITIAL RELEASE	MAS	22.01.26
02	HOLES REMOVED, CIRCUMFERENTIAL ONES ADDED	MAS	06.02.26





SECTION A-A



NOTES:

1. MACHINE TO CAD DATA.
2. DEBURR ALL SHARP EDGES.
3. COAT IN OIL AND PLACE IN PART MARKED BAG.

UBRacing

MATERIAL CERTIFICATE REQUIRED

DIMENSIONS IN MILIMETRES U.O.S

0 DECIMAL PLACES	±0.50
1 DECIMAL PLACE	±0.25
2 DECIMAL PLACES	±0.10
3 DECIMAL PLACES	±0.02
GENERAL CONCENTRICITY	0.1 TIR
ANGULAR TOLERANCE	±0.25°

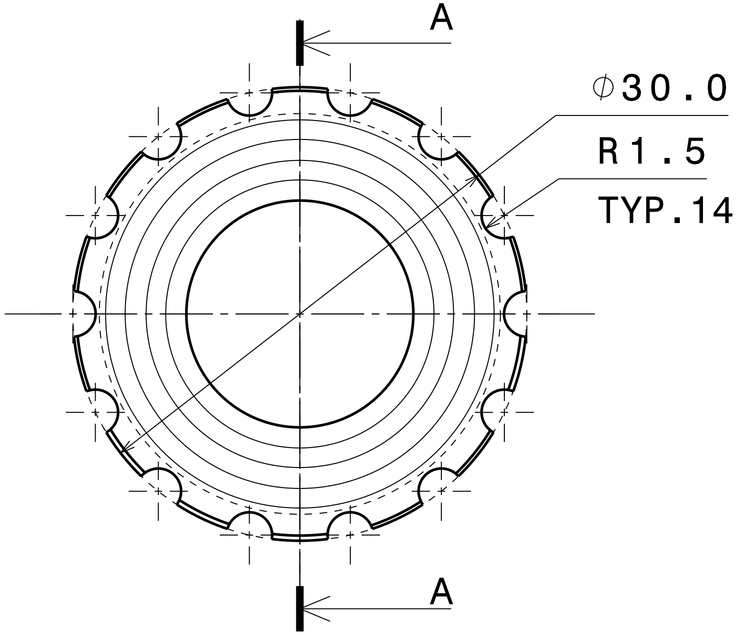
REMOVE BURRS AND SHARP EDGES

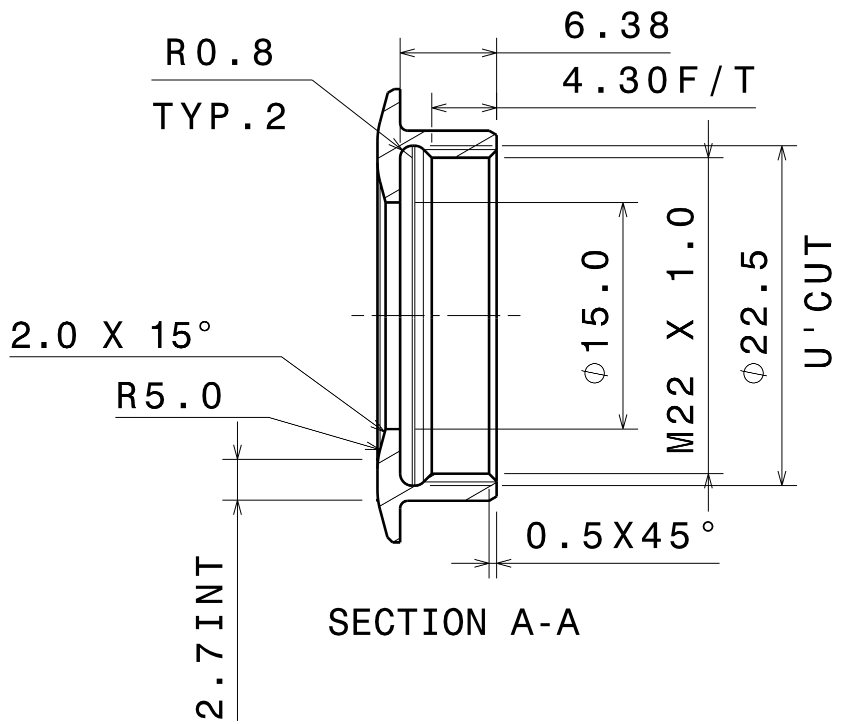
A4 — IF IN DOUBT - ASK — DO NOT SCALE

TEL. +44 (0)121 414 4218
E-MAIL. ubracing@gmail.com

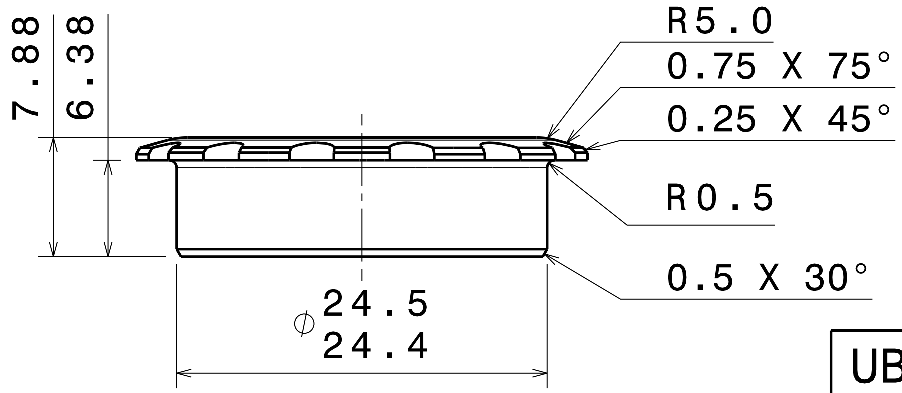
COMPONENT MASS (kg)	0.009
DRAWN BY	MAS
MATERIAL SPEC	EN24T
HEAT TREATMENT	N/A
SURFACE TREATMENT	N/A
DESCRIPTION	LWR BEARING HOUSING-FUWB
SCALE	2:1
SHEET	1/1
PART NUMBER	UBR29-FS-003-02

REV	DESCRIPTION	INIT	DATE
01	INITIAL RELEASE	MAS	22.01.26
01A	R1.5 HOLES COUNT INCREASE, WAS 12 OF	MAS	06.02.26





SECTION A-A



NOTES:

1. MACHINE TO CAD DATA.
2. DEBURR ALL SHARP EDGES.
3. COAT IN OIL AND PLACE IN PART MARKED BAG

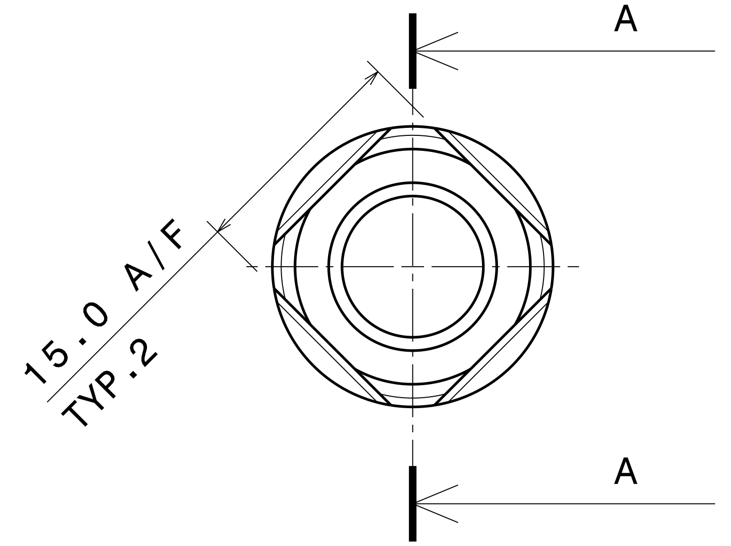
UBRacing

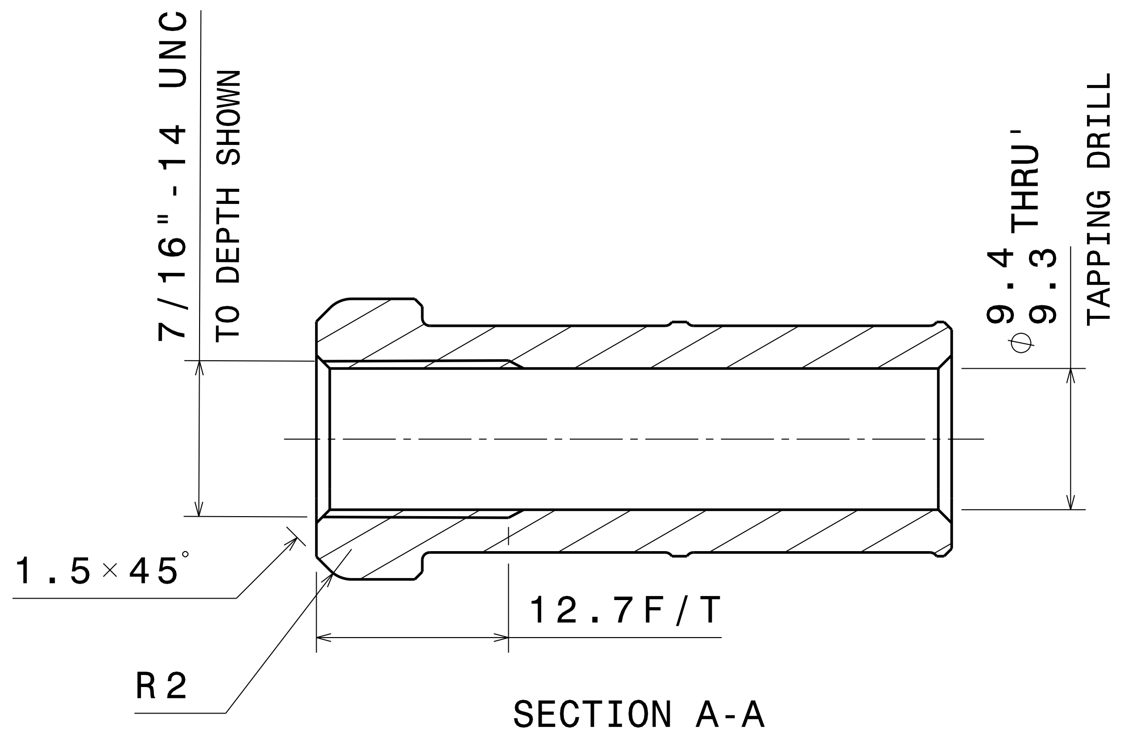
MATERIAL CERTIFICATE REQUIRED		MATERIAL SPEC	EN24T
DIMENSIONS IN MILIMETRES U.O.S		HEAT TREATMENT	N/A
0 DECIMAL PLACES	±0.50	SURFACE TREATMENT	N/A
1 DECIMAL PLACE	±0.25		
2 DECIMAL PLACES	±0.10		
3 DECIMAL PLACES	±0.02		
GENERAL CONCENTRICITY	0.1 TIR		
ANGULAR TOLERANCE	±0.25°		
REMOVE BURRS AND SHARP EDGES			

A4 — IF IN DOUBT - ASK — DO NOT SCALE

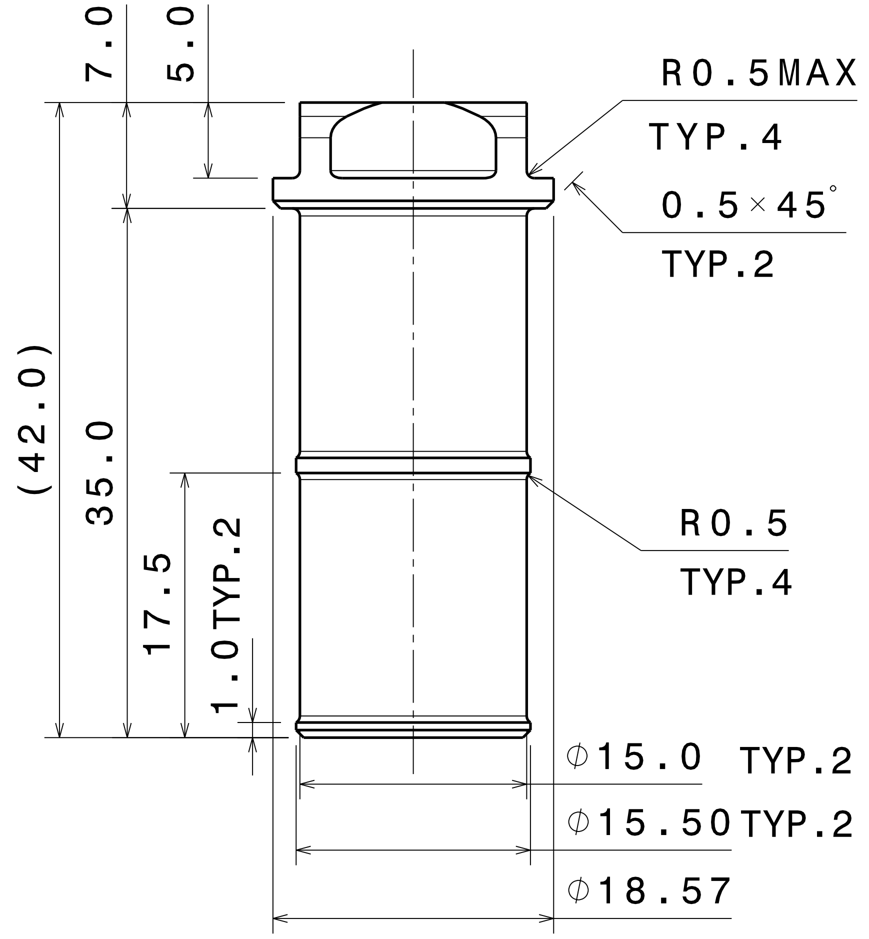
TEL.	+44 (0)121 414 4218
E-MAIL.	ubracing@gmail.com
COMPONENT MASS (kg)	0.011
DRAWN BY	MAS
DESCRIPTION	UPR BEARING HOUSING-FUWB
SCALE	2:1
SHEET	1/1
PART NUMBER	UBR29-FS-004-02

REV	DESCRIPTION	INIT	DATE
01A	INITIAL RELEASE	MAS	20.03.26





SECTION A-A

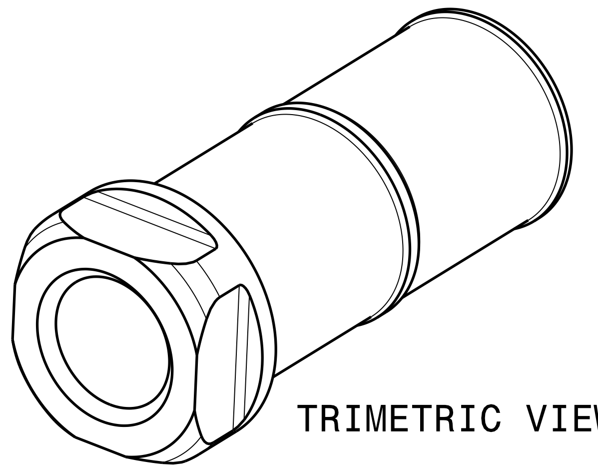


NOTES:

1. MACHINED TO CAD DATA.

2. DEBURR ALL SHARP EDGES.

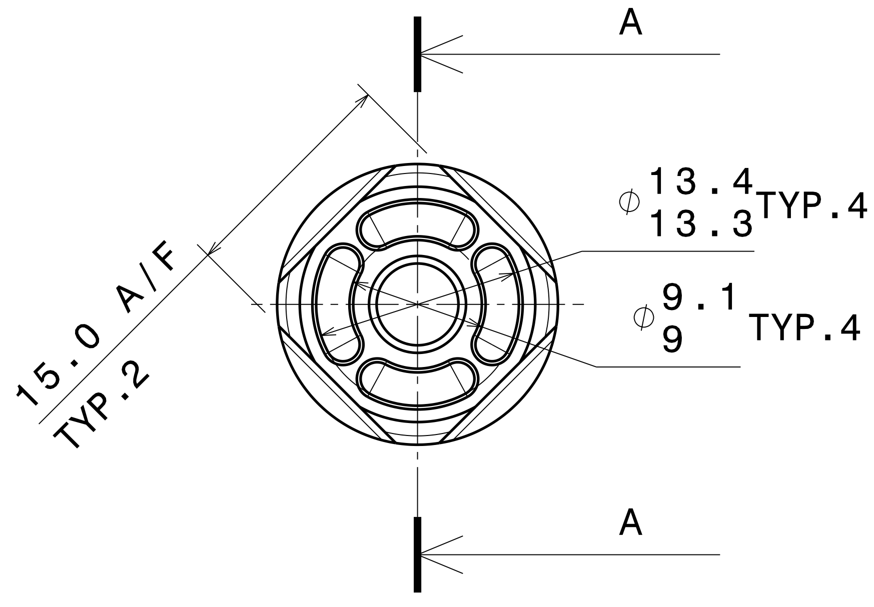
3. INSPECT TO DIMENSIONS SHOWN.

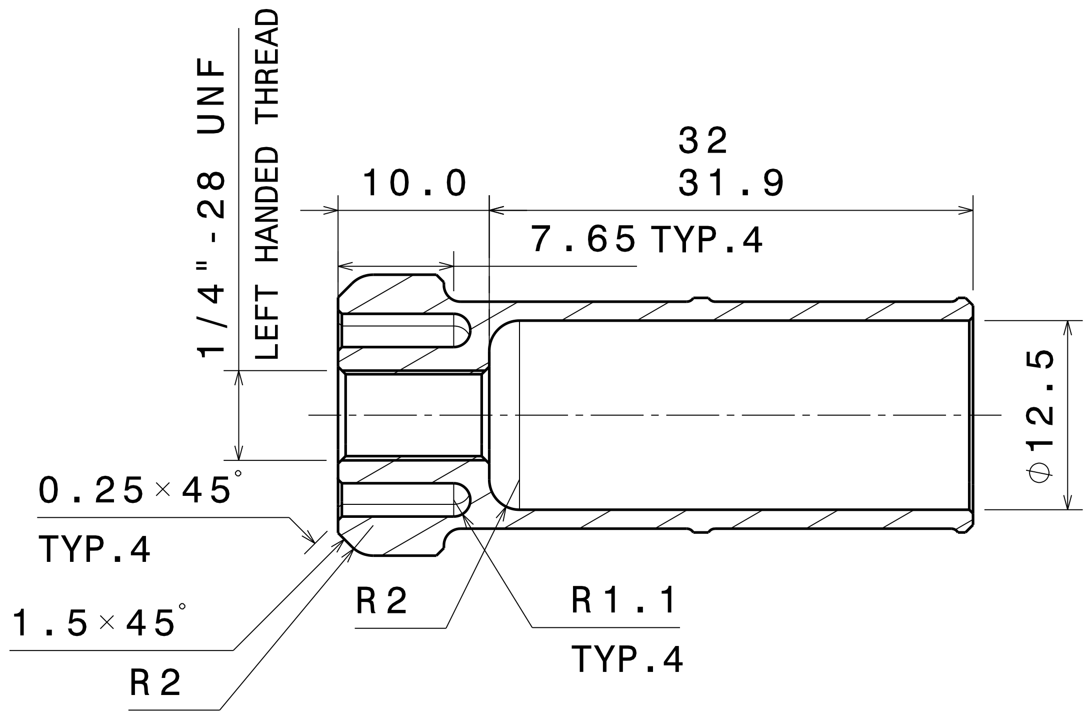


TRIMETRIC VIEW

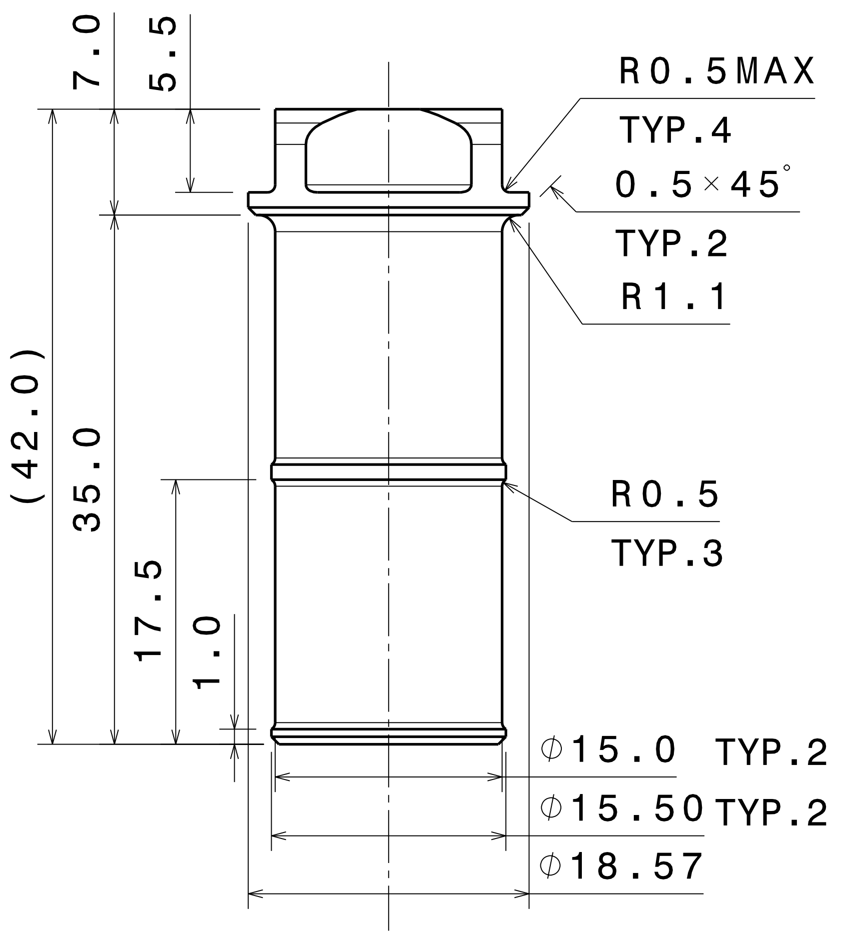
UBRacing	MATERIAL CERTIFICATE REQUIRED DIMENSIONS IN MILIMETRES U.O.S	COMPONENT MASS (kg): 0.013	MATERIAL SPEC	7075
			HEAT TREATMENT	T6
A3 — IF IN DOUBT - ASK / DO NOT SCALE	0 DECIMAL PLACES ±0.50 1 DECIMAL PLACE ±0.25 2 DECIMAL PLACES ±0.10 3 DECIMAL PLACES ±0.02 GENERAL CONCENTRICITY 0.1 TIR ANGULAR TOLERANCE ±0.25°	DRAWN BY: MAS	SURFACE TREATMENT	N/A
TEL. +44 (0)121 414 4218			DESCRIPTION	INSERT-TRACKROD-RH
E-MAIL. ubracing@gmail.com	REMOVE BURRS AND SHARP EDGES			
This drawing and the copyright herein are the property of UBRacing. It is private & confidential and is issued on the express condition that it is not modified,copied or communicated to any other party without the written consent of UBRacing.		SCALE 2:1	SHEET 1/1	PART NUMBER UBR29-FS-023-01

REV	DESCRIPTION	INIT	DATE
01A	INITIAL RELEASE	MAS	20.03.26



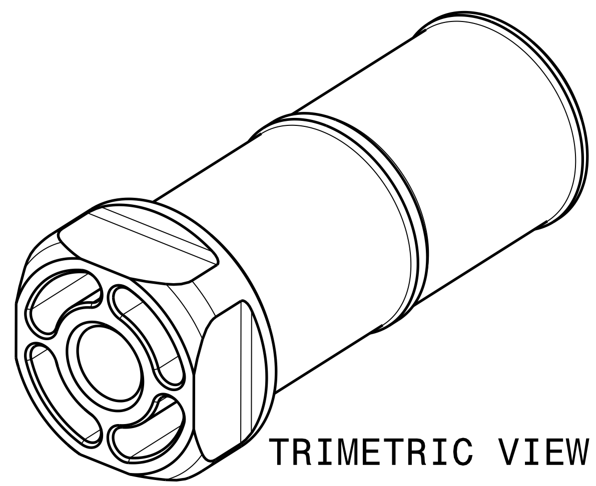


SECTION A-A



NOTES:

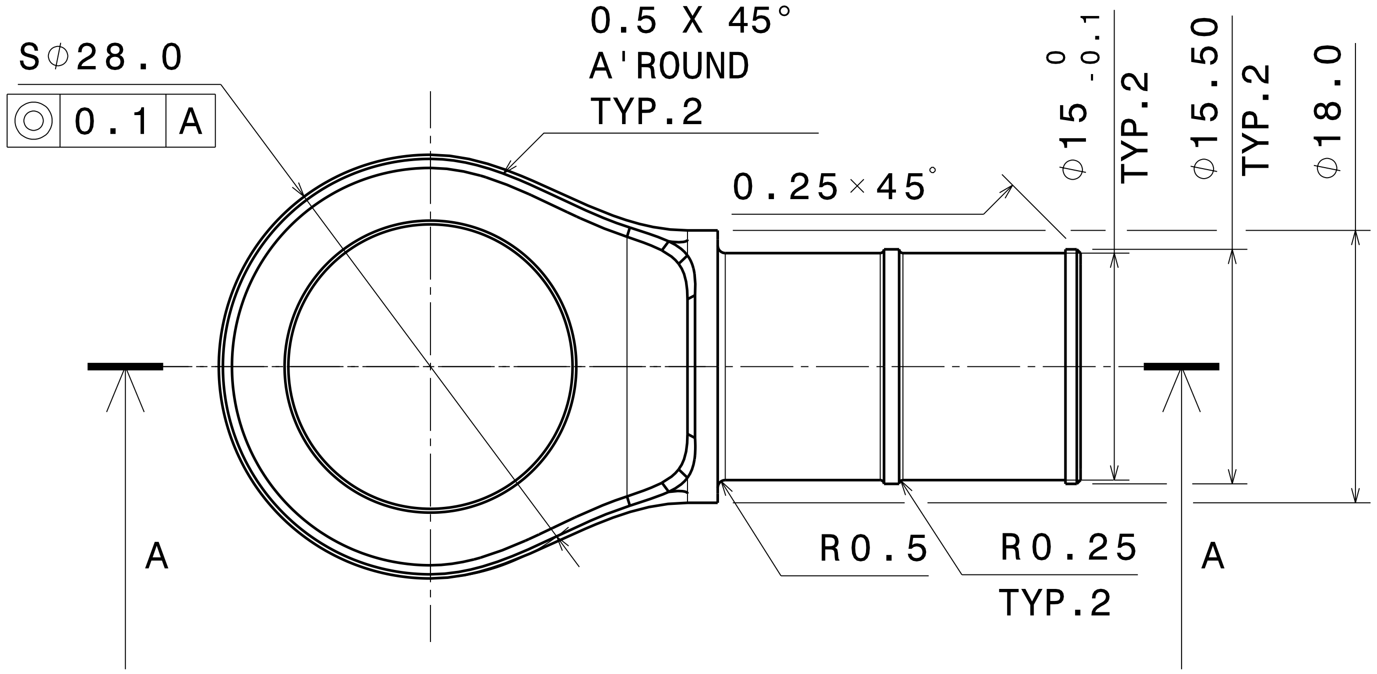
1. MACHINED TO CAD DATA.
2. 1/4"-28 THREAD IS LEFT HANDED.
3. DEBURR ALL SHARP EDGES.
4. INSPECT TO DIMENSIONS SHOWN.

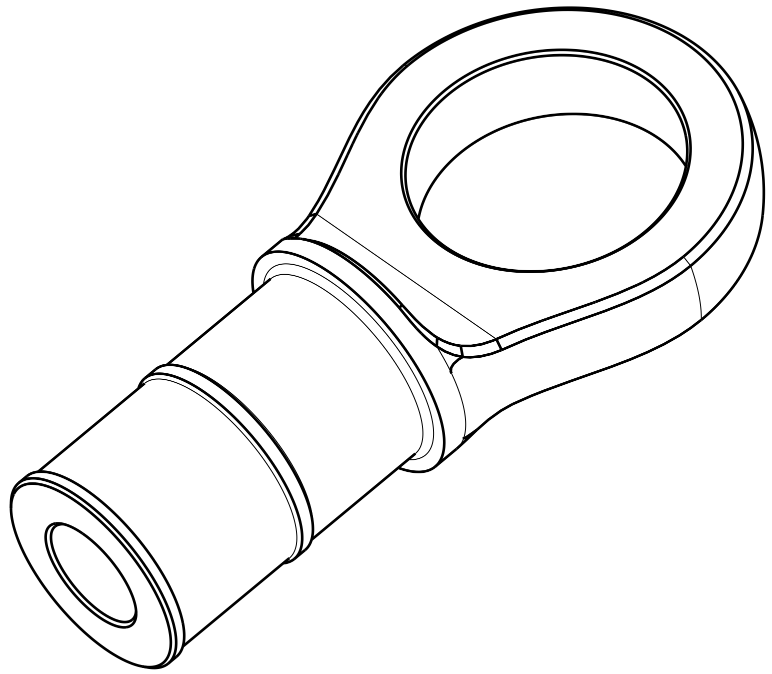


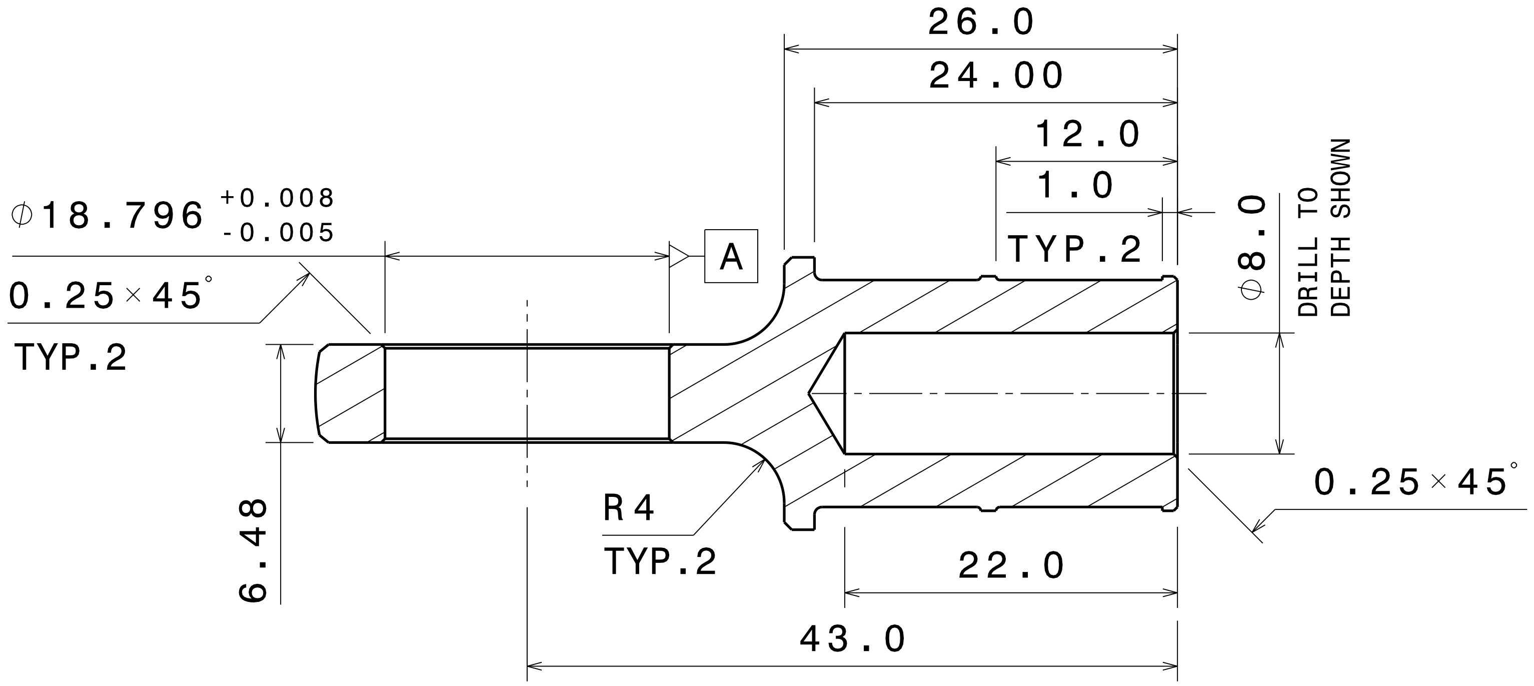
TRIMETRIC VIEW

UBRacing	MATERIAL CERTIFICATE REQUIRED DIMENSIONS IN MILIMETRES U.O.S	COMPONENT MASS (kg)	0.024	MATERIAL SPEC: #45 HEAT TREATMENT: N/A
A3 — IF IN DOUBT - ASK DO NOT SCALE	0 DECIMAL PLACES ±0.50 1 DECIMAL PLACE ±0.25 2 DECIMAL PLACES ±0.10 3 DECIMAL PLACES ±0.02 GENERAL CONCENTRICITY 0.1 TIR ANGULAR TOLERANCE ±0.25°	DRAWN BY MAS		SURFACE TREATMENT: N/A DESCRIPTION INSERT-TRACKROD-LH
TEL. +44 (0)121 414 4218				
E-MAIL. ubracing@gmail.com	REMOVE BURRS AND SHARP EDGES			
This drawing and the copyright herein are the property of UBRacing. It is private & confidential and is issued on the express condition that it is not modified,copied or communicated to any other party without the written consent of UBRacing.		SCALE	2:1	SHEET 1/1 — PART NUMBER UBR29-FS-024-01

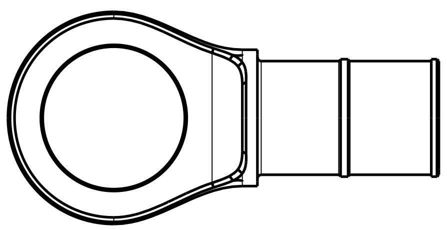
REV	DESCRIPTION	INIT	DATE
01A	INITIAL RELEASE	MAS	26.10.25







Section view A-A



Scale: 1:1

NOTES:

1. MACHINE ALL UNDIMENSIONED FEATURES TO CAD DATA.

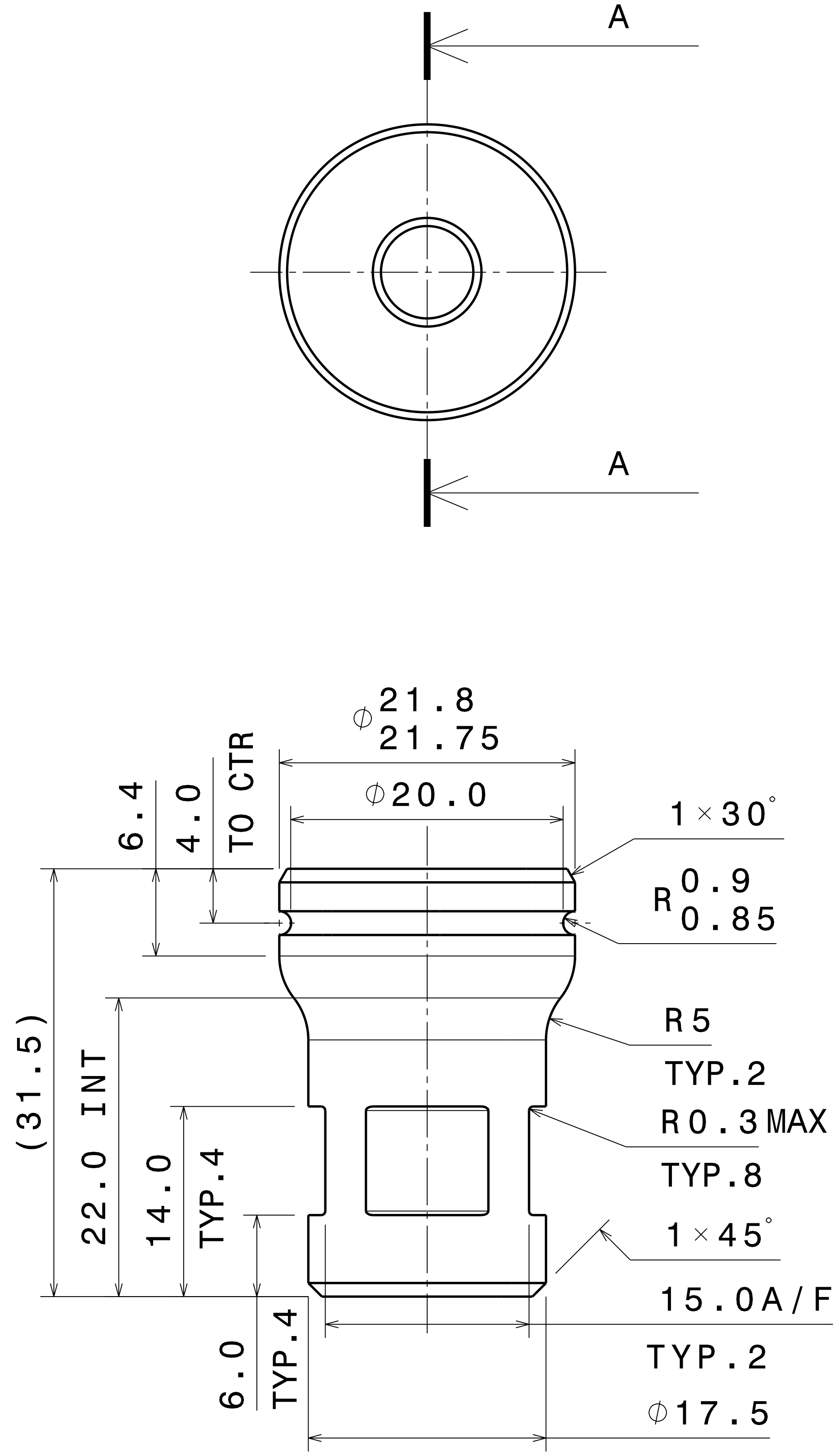
2. DEBURR ALL SHARP EDGES.

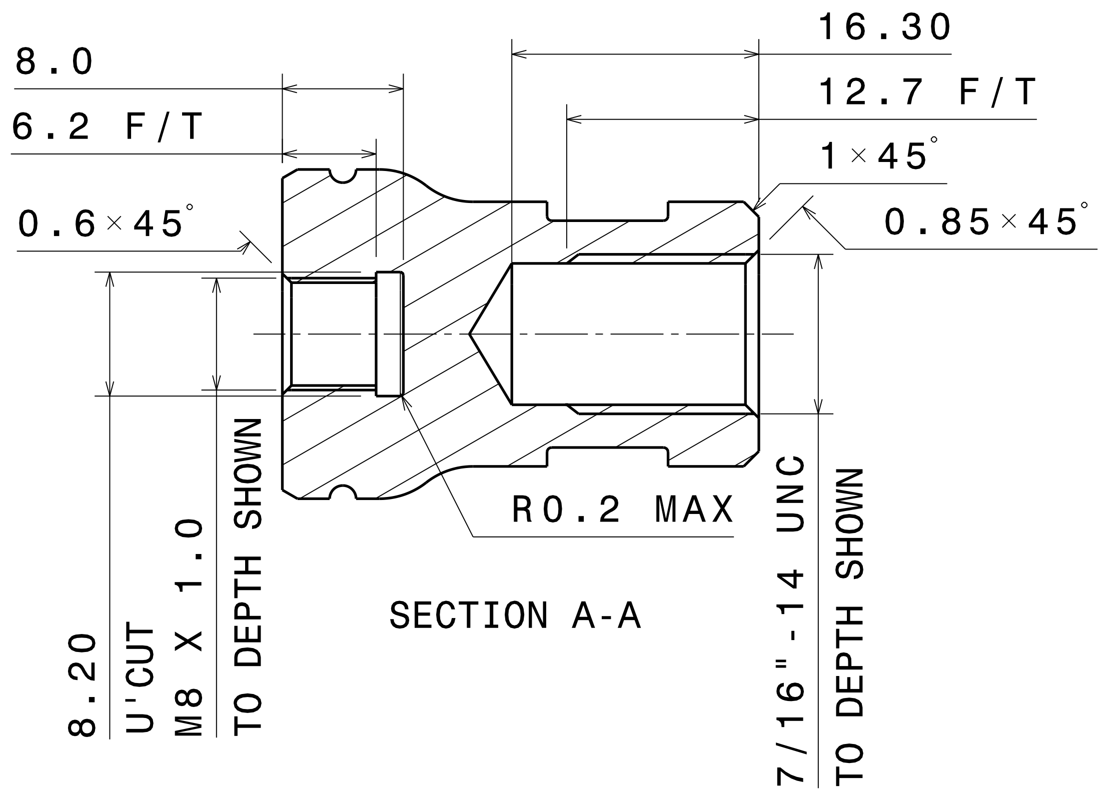
3. INSPECT TO DIMENSIONS SHOWN.

4. PLACE IN PART MARKED BAG.

UBRacing	DIMENSIONS IN MILIMETRES U.O.S 0 DECIMAL PLACES ±0.50 1 DECIMAL PLACE ±0.25 2 DECIMAL PLACES ±0.10 3 DECIMAL PLACES ±0.02 GENERAL CONCENTRICITY 0.1 TIR ANGULAR TOLERANCE ±0.25° REMOVE BURRS AND SHARP EDGES	COMPONENT MASS (kg): 0.017	MATERIAL SPEC: ALUMINIUM 7075
A3	IF IN DOUBT - ASK DO NOT SCALE	DRAWN BY: MAS	HEAT TREATMENT: T6
TEL.	+44 (0)121 414 4218		SURFACE TREATMENT: N/A
E-MAIL.	ubracing@gmail.com		DESCRIPTION: INBOARD-LUG
SCALE	2:1	SHEET 1/1	PART NUMBER: UBR29-FSD-006-01

REV	DESCRIPTION	INIT	DATE
01	INITIAL RELEASE	MAS	10.02.26
01A	5mm RAD ADDITION	MAS	16.04.26





SECTION A-A

NOTES:

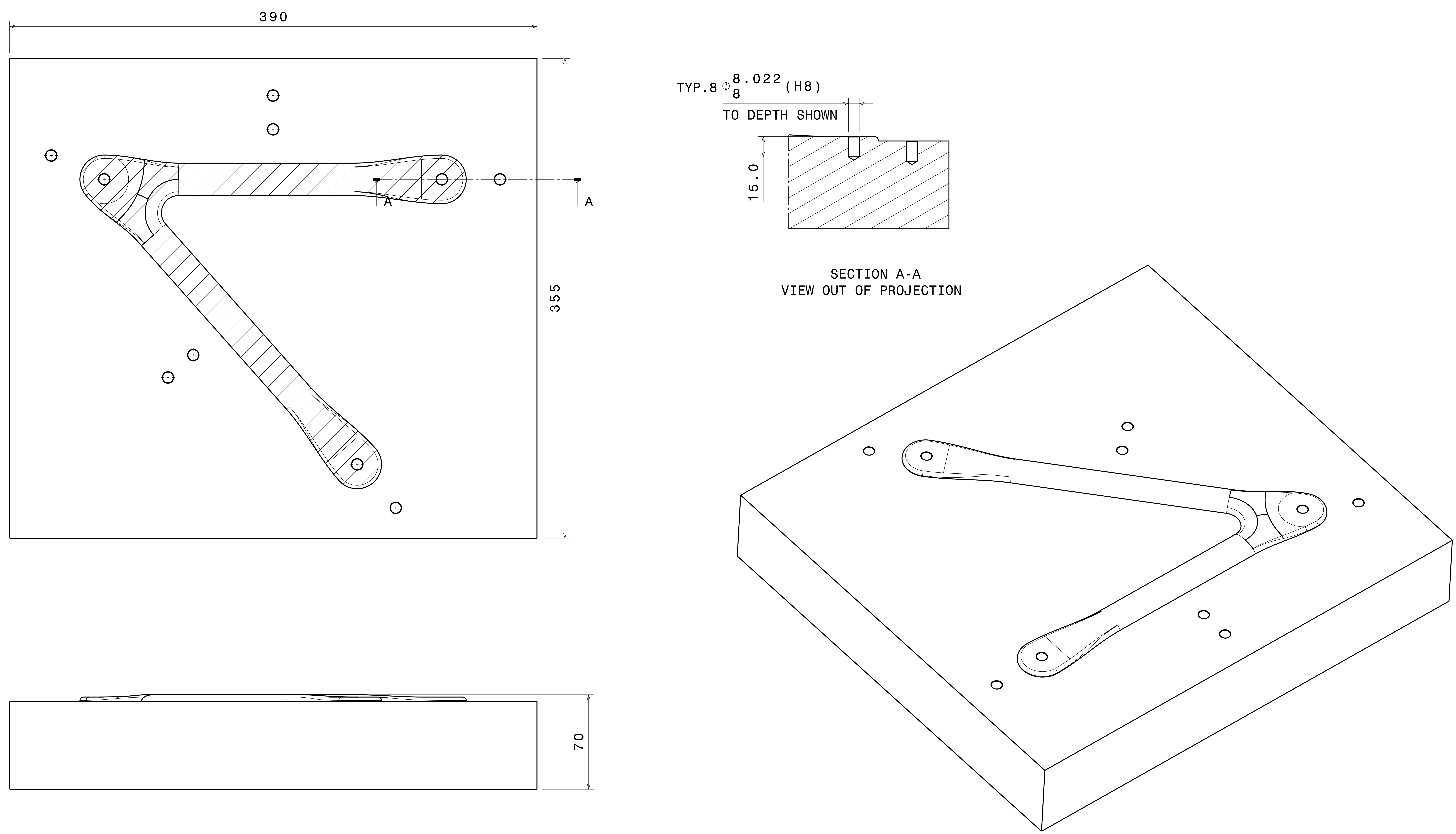
1. MACHINE TO CAD AND INSPECT TO DWG.

2. DEBURR ALL SHARP EDGES.

3. PLACE IN PART MARKED BAG.

UBRacing	MATERIAL CERTIFICATE REQUIRED DIMENSIONS IN MILIMETRES U.O.S	COMPONENT MASS (kg)	0.019	MATERIAL SPEC	7075
				HEAT TREATMENT	T6
A3 / IF IN DOUBT - ASK DO NOT SCALE	0 DECIMAL PLACES ±0.50 1 DECIMAL PLACE ±0.25 2 DECIMAL PLACES ±0.10 3 DECIMAL PLACES ±0.02 GENERAL CONCENTRICITY 0.1 TIR ANGULAR TOLERANCE ±0.25°	DRAWN BY	MAS	SURFACE TREATMENT	N/A
TEL. +44 (0)121 414 4218				DESCRIPTION	SPRING RETAINER-DAMPER
E-MAIL. ubracing@gmail.com	REMOVE BURRS AND SHARP EDGES				
		SCALE	2:1	SHEET 1/1	PART NUMBER UBR29-RS-021-02

REV	DESCRIPTION	INIT	DATE
01A	INITIAL RELEASE	MAS	19.01.26



NOTES:

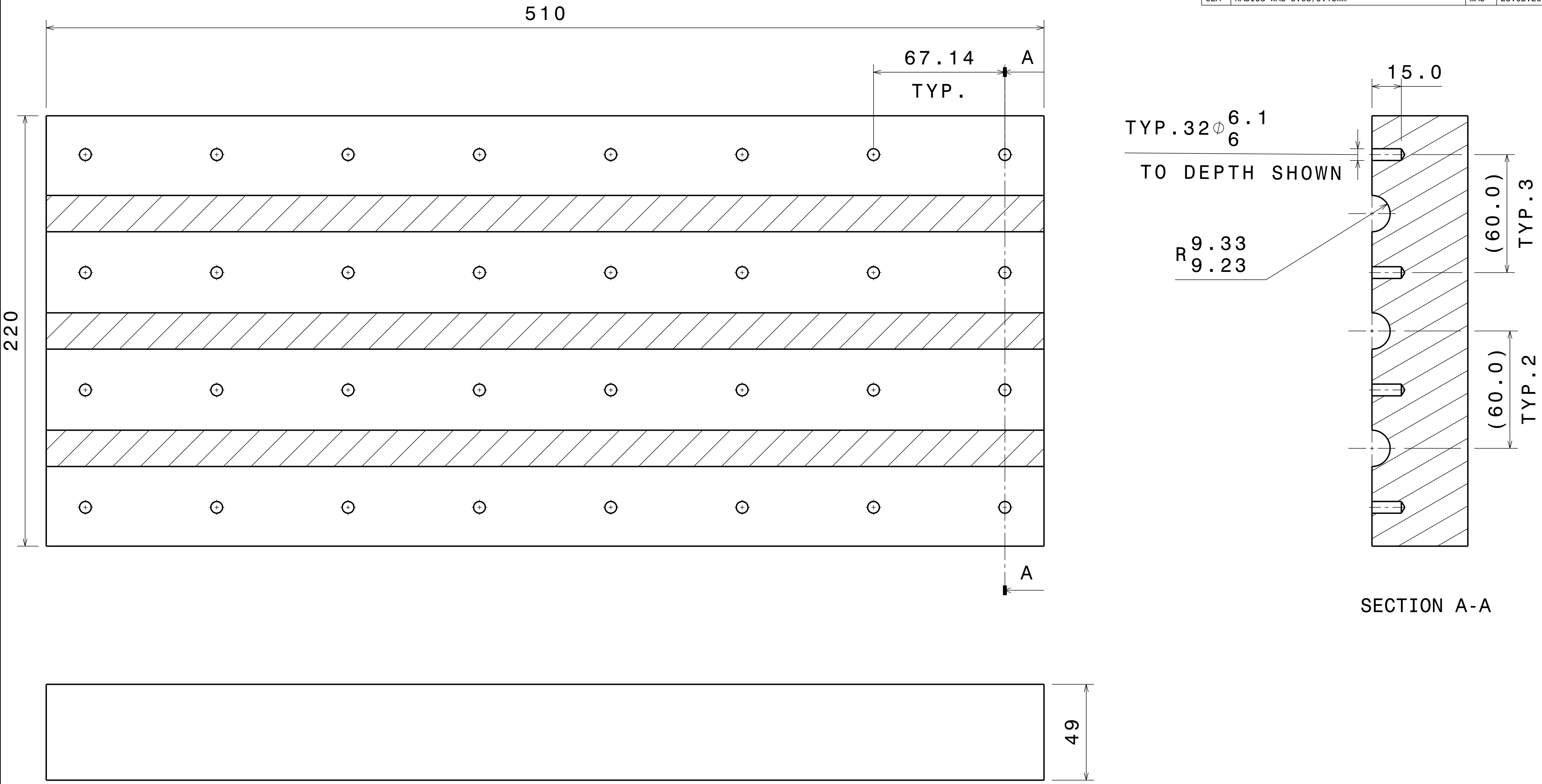
LH PART SHOWN, RH SYMMETRICALLY OPPOSITE

1. MACHINE ALL SURFACES TO CAD DATA.

2. HATCHED REGION MACHINED TO ⌓ 0.2

UBRacing	MATERIAL CERTIFICATE REQUIRED DIMENSIONS IN MILIMETRES U.O.S	COMPONENT MASS (kg)	7.200	MATERIAL SPEC	BE368
				HEAT TREATMENT	N/A
A2 / IF IN DOUBT - ASK DO NOT SCALE	0 DECIMAL PLACES ±0.50 1 DECIMAL PLACE ±0.25 2 DECIMAL PLACES ±0.10 3 DECIMAL PLACES ±0.02 GENERAL CONCENTRICITY 0.1 TIR ANGULAR TOLERANCE ±0.25°	DRAWN BY	MAS	SURFACE TREATMENT	N/A
TEL. +44 (0)121 414 4218				DESCRIPTION	PATTERN-FUWB-LH
E-MAIL. ubracing@gmail.com	REMOVE BURRS AND SHARP EDGES				
		SCALE	1:2	SHEET 1/1	PART NUMBER UBR29-FST-010-01

REV	DESCRIPTION	INIT	DATE
01A	INITIAL RELEASE	MAS	19.01.26
02A	RADIUS WAS 9.08/9.13mm	MAS	23.02.26



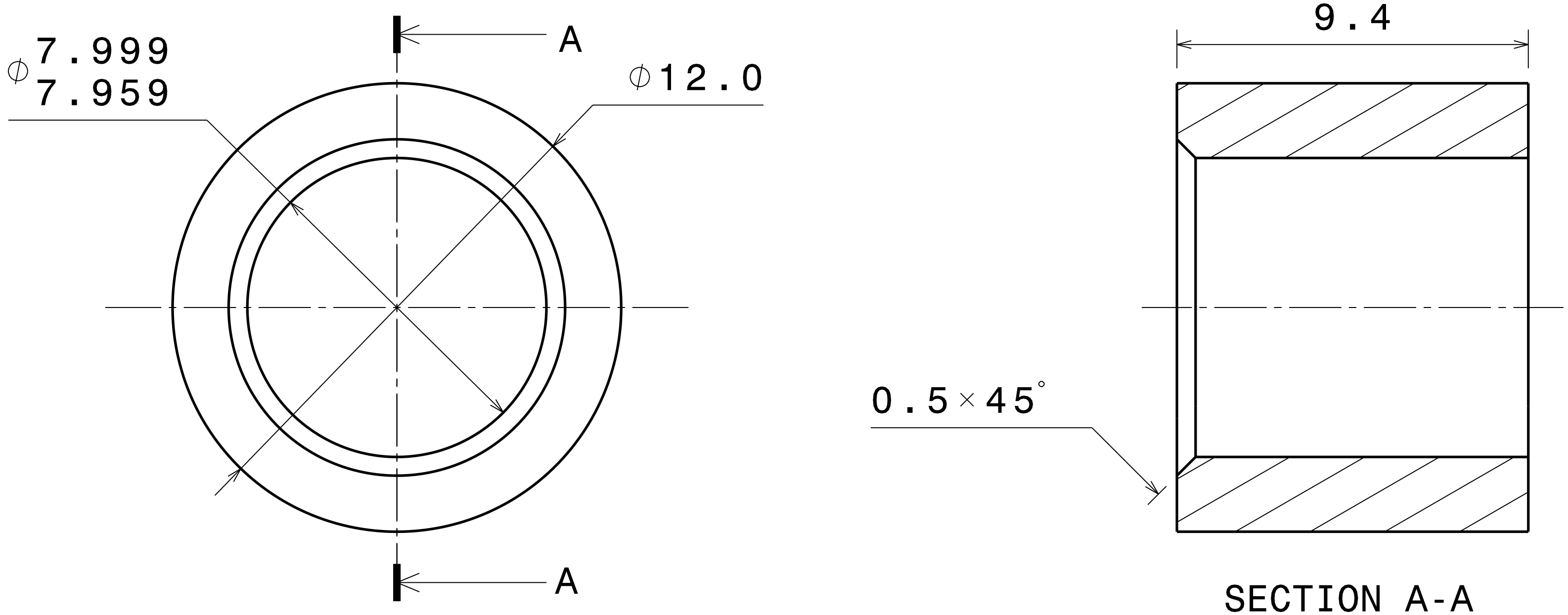
NOTES:

1. MACHINE ALL SURFACES TO CAD DATA.

2. HATCHED REGION MACHINED TO ⌓ 0.2

UBRacing	MATERIAL CERTIFICATE REQUIRED DIMENSIONS IN MILIMETRES U.O.S	COMPONENT MASS (kg)	4.22	MATERIAL SPEC	BE368
				HEAT TREATMENT	N/A
A3	IF IN DOUBT - ASK DO NOT SCALE	0 DECIMAL PLACES ±0.50 1 DECIMAL PLACE ±0.25 2 DECIMAL PLACES ±0.10 3 DECIMAL PLACES ±0.02 GENERAL CONCENTRICITY 0.1 TIR ANGULAR TOLERANCE ±0.25°	DRAWN BY MAS	SURFACE TREATMENT	N/A
TEL.	+44 (0)121 414 4218			DESCRIPTION	PATTERN-WISHBONE LEGS
E-MAIL.	ubracing@gmail.com	REMOVE BURRS AND SHARP EDGES			
SCALE	1:2	SHEET 1/1	PART NUMBER	UBR29-FST-012-02	

REV	DESCRIPTION	INIT	DATE
01A	INITIAL RELEASE	MAS	13.10.2025



SECTION A-A

NOTES:

1. DEBURR ALL SHARP EDGES.
2. INSPECT TO DIMENSIONS SHOWN.
3. COAT IN OIL AND PLACE IN PART MARKED BAG.

UBRacing		MATERIAL CERTIFICATE REQUIRED DIMENSIONS IN MILIMETRES U.O.S	COMPONENT MASS (kg)	0.0046	MATERIAL SPEC: STEEL HEAT TREATMENT: N/A
A4	IF IN DOUBT - ASK DO NOT SCALE	0 DECIMAL PLACES ±0.50 1 DECIMAL PLACE ±0.25 2 DECIMAL PLACES ±0.10 3 DECIMAL PLACES ±0.02 GENERAL CONCENTRICITY 0.1 TIR ANGULAR TOLERANCE ±0.25°	DRAWN BY	MAS	SURFACE TREATMENT: N/A DESCRIPTION: BUSH-8ID-TOOLING
TEL.	+44 (0)121 414 4218				
E-MAIL.	ubracing@gmail.com	REMOVE BURRS AND SHARP EDGES			
SCALE	5:1	SHEET 1/1	PART NUMBER	UBR29-FST-001-01	