University of Nottingham
MMME2044
Design, Manufacture and Project

TRASL CDR REPORT

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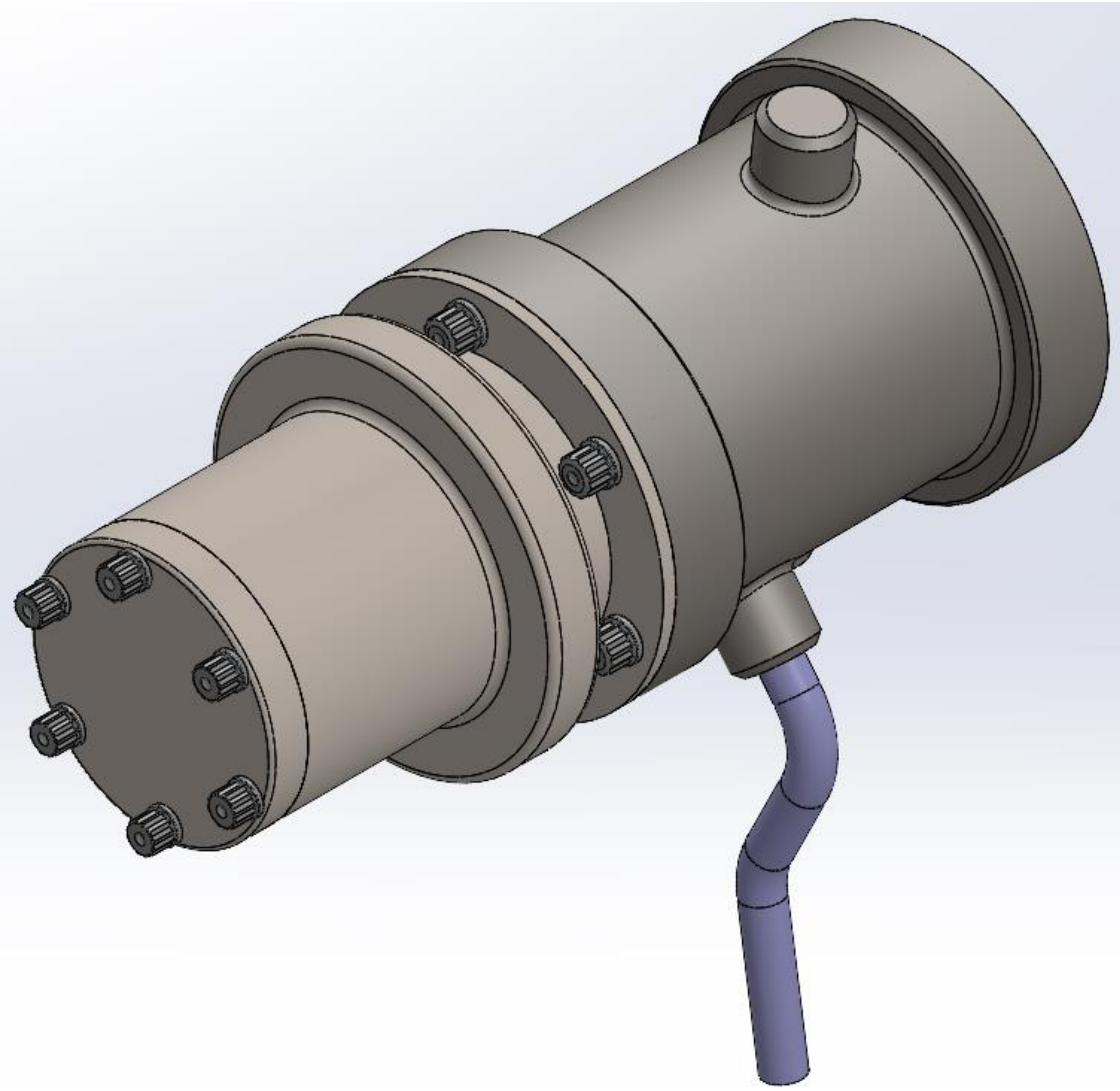

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Executive Summary

To complete the design task set out, a Trust Reversal Actuator System Lock (TRASL) was designed. To ensure proper function, hydraulic pressure is used to unlock the system while disc springs are used to lock the system. As the springs are passive, they function as a safety system in the event of loss of pressure.

The axial force was calculated to be 5938.46N, which includes a safety factor of 1.5. From this maximum force, the piston diameter and housing minimum thickness were calculated to be 23.87mm and 11.93mm, respectively. Once these design calculations were conducted, disc springs and O ring seals were calculated by using data in provided tables. The O ring seal selected was BS0456-24.

As weight is key in aerospace designs, the system was designed to be as small as possible and use lighter materials such as aluminium alloys. As a failure of the system can have catastrophic results, the assembly is kept simple to ensure the system can be maintained easily without human error, this reduces the chance of the system failing while being used. Additionally, to reduce costs of manufacturing, the components are manufactured by using a lathe.

General Assembly and detailed drawings of the system and parts can also be found in this report. They are drawn to BS8888 standard.

Design Rationale and Engineering

The final design of the TRASL completed all the requirements stated in the PDR. These include:

1. The thrust reversal actuation system (TRAS) should fit both the locking actuators and the third lock
    a. This means that the system should have a common coupling system.
2. In case of failure, the maximum torque the system can provide must not pass 120Nm
3. 13.79MPa (20000psi) of hydraulic supply in all three hydraulic
4. The total mass of the system, excluding fluids, should not exceed 3.5kg
    a. A target weight of 3kg has been selected.
5. Reserve stress factors should not be less than 1.5
6. M6 x 20 Aerospace Waspalloy fasteners should be used to secure the locking actuators
    a. This is for maintenance purposes
7. The minimum size of any fasteners should be M5.

For the final design to be successful – all the requirements must be achieved. A compliance statement matrix is drawn to deduce if the final design completes all the requirements.

Compliance Statement

No	Requirement	Outcome
1	The TRASL must be common and fit both locking actuators and the third lock.	The design uses the same coupling that will fit both the locking actuators and the third lock. Additionally, fasterns which are common for both the locking actuators and third lock are used.
2	The maximum torque in the failure case is 120Nm.	Axial force was calculated using 120Nm.
3	The hydraulic supply is 13.79MPa in all three hydraulic systems.	13.79 MPa was used in the calculations when calculating maximum thickness. The oil pump has not been changed.
4	The total mass of the TRASL, excluding fluids, shall not exceed 3.5Kg with a target weight of 3Kg.	Mass of the TRASL is 1.6Kg which is less than 3Kg.
5	Reserve stress factors shall not be less than 1.5.	K=1.5, which is used in the force calculations.
6	For maintenance purposes the unit shall be secured to the locking actuators and thirds lock using M6x20 Aerospace Wasalloy fasterns.	6 M6x20 Aerospace Wasalloy fasterns are used to secure the housing to the third lock.
7	The minimum size of any other fasteners shall be M5.	Other fasterns are M5
8	There shall be appropriate means for sealing the TRASL with hydraulic supply of 13.79 MPa pressure.	Housing is secured onto the lock using the 6 M6x20 Aerospace Wasalloy fasterns and an O Ring is used to seal the inside of the housing.
9	Considerations are given to appropriate design features for selected manufactured processes.	See Manufacturing and Assembly section of this report.
10	There is an established procedure for the assembly of the TRASL unit. .	See Manufacturing and Assembly section of this report.

Table 1 – The Compliance statement table, used to see if the statement of requirements has been completed.

The compliance statement table shows how all the requirements, and more, have been achieved. As the design has completed all the requirements, this design task can be called a success. Notable improvements from the initial design include the final weight being 1.6Kg - Almost halving the target weight.

Morphology Chart

Function Number	Function	Final TRASL Design
1	To transmit torque to lock	Hirth Serration Coupling
2	To lock in case of failure	Disc Springs
3	To reduce weight	Small assembly and lightweight materials
4	To power the mechanism	Hydraulic Pressure/Elastic potential energy
5	To be common for both actuators and lock	Same Hirth Serration Coupling and fasteners used
6	To provide linear movement	Linear piston movement
7	To seal mechanism	O ring

Table 2 – An updated morphology chart, used to understand how the concept will complete seven distinct functions.

Design Rationale

Ockham's razor states "The simplest designs are often the best designs". This concept drove the initial design philosophy of this project. The final design had to be as simple as possible while still maintain all the functions required. To achieve this, the body was kept as small as possible, and the number of parts were kept to a minimum. Not only does this decrease manufacturing, but it also decreases cost for the airlines as less fuel is needed to transport the TRASL while in flight. [6]

To unlock the TRASL, hydraulic oil (incompressible fluid) is injected into the space between the two couplings. This creates a force pushing the couplings away from each other, thus unlocking the device. The oil is maintained inside this space to stop the couplings from coming together. Additionally, the oil contacts the hirth coupling thus decreasing wear as the two couplings will be lubricated. The shape of the hirth coupling is not changed.

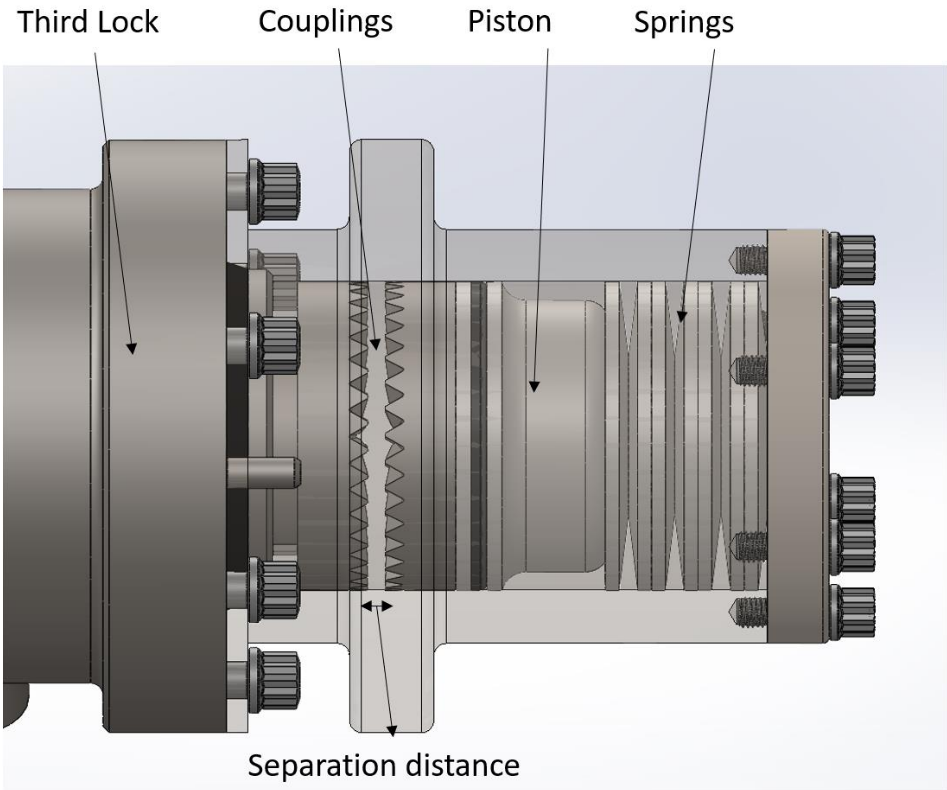


Diagram 1– The TRASL in the unlocked position. Parts are label in accordance with the labelling in the GA Drawings/Bill of Materials (BOM)

To lock the TRASL, the hydraulic oil is allowed to leave the space between the two couplings. A force generated by the disc springs behind the piston pushes the couplings together thus moving the hydraulic oil out of the way. The disc springs maintain the lock position until hydraulic oil is injected back into the system. In the event of oil leakage or failure of the oil pump, the passive design of the springs will ensure the device is kept in the locked position.

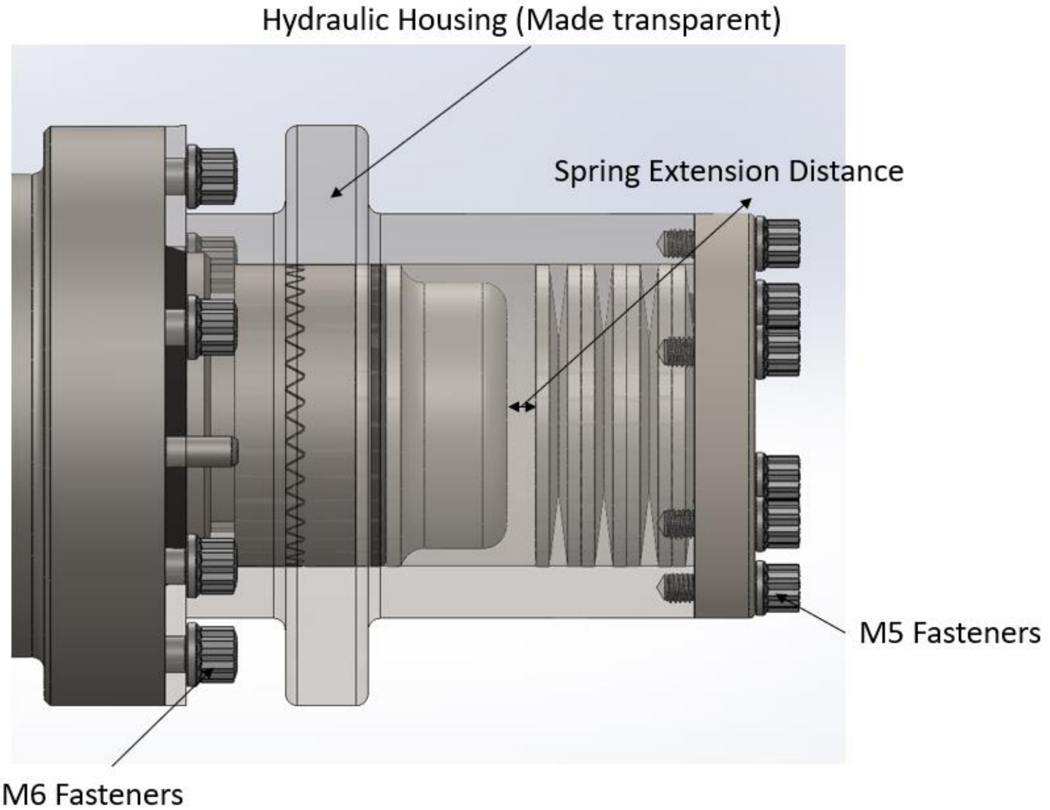


Diagram 2 – The TRASL in the locked position – Note: for the springs to be fully defined, they cannot move with the piston. In the real world – they would be extended (in accordance with the spring extension distance), mating with the piston.

The thicker section of the housing ensures the minimum thickness of the cylinder is maintained for the section where the oil is injected into. To reduce weight, all other sections of the housing are slimed down.

Calculations

Torque and Force Calculations

Safety Factor

A reserve factor of 1.5 is chosen. Therefore:

$$k = 1.5$$

Torque and Force

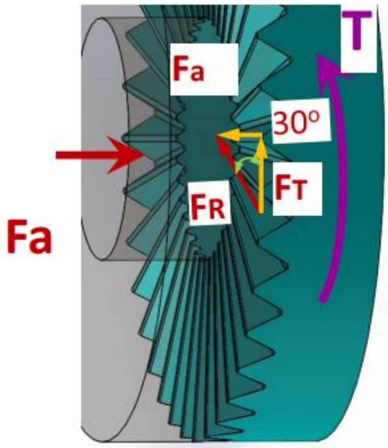


Diagram 3 – A diagram of the forces acting on the coupling.

$$To\ find\ the\ axial\ force\ needed:$$

$$F_{Tangential} = F_T = \frac{Torque}{radius} = \frac{120Nm}{0.0175m} = 6857.14N$$

$$Faxial = Fa = Fr * \tan\left(\frac{\pi}{6}\right) * k = 6857.14N * \tan\left(\frac{\pi}{6}\right) * 1.5 = 5938.46N$$

$$5938.46N\ is\ required\ to\ lock\ the\ system$$

Tightening Torque of Fasteners

	Maximum Torque (Nm)	Induced Load (kN)
M5	*9.5*	*10.3*
M6	*16.5*	*14.5*

Table 3 – The table used to calculate maximum torque and induced load of the M5 and M6 fasteners used.

$$9.5 * 6 = 57$$
$$10.3 * 6 = 61.8$$
$$16.5 * 6 = 99$$
$$14.5 * 6 = 87$$

6 M5 Bolts secure the lower cap to the housing. Therefore, a maximum torque of 57Nm and a maximum load of 61.8kN. As the springs induce a load of *5.2*kN, which is lower than the maximum load of the bolts. The 6 M5 fasteners will secure the lower cap to the housing.

On the other hand, 6 M6 bolts secure the housing to the third lock. Therefore, a maximum torque of 99Nm and a maximum load of 87kN. As the hydraulic force induces a load of 5938.46N, which is lower than the maximum load of the bolts. The 6 M6 fasteners will secure the lower cap to the housing.

All fasteners to be dipped in engine oil and torque fastened.

Design Calculations

Sizing of the Piston and Cylinder

$$To\ find\ the\ minimum\ diameter\ of\ the\ piston\ (D)$$

$$Area\ of\ piston = \frac{Force\ required}{pressure}$$

$$\frac{\pi D^2}{4} = \frac{F}{p} => D = \sqrt{\frac{4F}{\pi p}} = \sqrt{\frac{4 * 5938.46N}{\pi * 13.27\text{MPa}}} = 0.02387022499\text{m} = 23.87\text{mm}$$

$$Thickness\ of\ cylinder\ (t)\ is\ calculated\ by\ considering\ circumferntial\ stress:$$

$$Circumferential\ stress = \sigma_H = \frac{Force}{cross-sectional\ area} = \frac{5938.46N}{4.4751 * 10^{-4}m^2}$$

$$= 13270000.2Nm^{-2}$$

$$Thickness\ of\ cylinder = t = \frac{pD}{2\sigma_H} = 0.01193499982m = 11.93mm$$

The minimum diameter of the piston is calculated to be 23.87mm while the minimum thickness of the housing is 11.93mm. These values will aid the computer aided design (CAD) of the assembly.

Selection of Disc Springs

Dimensions						Design Force, Deflection and Stresses Based on E = 206 kMPa and μ = 0.3																						
						Preload, $s = 0.15\ h_o$					$s = 0.25\ h_o$					$s = 0.5\ h_o$					$s = 0.75\ h_o$					$s = h_o$		
D_e	D_i	t	l_o	h_o	h_o/t	s	l_t	F	σ_{II}	σ_{III}	s	l_t	F	σ_{II}	σ_{III}	s	l_t	F	σ_{II}	σ_{III}	s	l_t	F	σ_{II}	σ_{III}	s	F	σ_{OM}
50.0	25.4	2.25	3.75	1.50	0.67	0.23	3.53	1,821	165	312	0.38	3.38	2,905	292	508	0.75	3.00	5,249	675	959	1.13	2.63	7,217	1,147	1,353	1.50	8,997	-1,697

Table 4 – The table used to dimension the disc springs [1]

Seven of the shown springs in *table 4* will lock the system. Seven springs deployed in series with a 50% preload will result in a total deflection of:

$$7 * 0.75mm = 5.25mm$$

Which is above the target separation. Additionally, as the springs are in series, the total force is equal to the force of a single disc and is therefore 5249N.

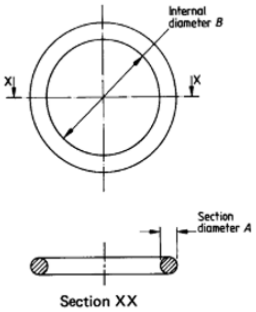
$$Fa = 5938.46 > 5249$$

The spring system will yield to the force produced by the hydraulic system.

Finally, as the thickness is less than 1.25mm, the standard material of high carbon steel is used to manufacture the springs.

Selection of Seals

As the design uses cylindrical shapes, an O ring is chosen instead of a quad/U ring.



All dimensions in millimetres

"O"-ring ref. no (see note)	"O"-ring dimensions				Nominal housing dimensions (see Figure 2 and 4.1)	
	Internal diameter B	Internal diameter tolerance	Section diameter A	Section diameter tolerance	Shaft diameter d_1	Cylinder diameter D_1
0316-24	31.6		2.4		32[b]	36
0346-24	34.6		2.4		35	39
0356-24	35.6		2.4		36[b]	40[b]
0376-24	37.6		2.4		38	42
0396-24	39.6	± 0.3	2.4	± 0.08	40[b]	44
0416-24	41.6		2.4		42	46
0446-24	44.6		2.4		45[b]	49
0456-24	45.6		2.4		46	50[b]

Table 5 – The table used to choose the dimensions of the O-Ring used. [2]

For nominal cylinder diameter = 50mm, use BS0456-24.

This leads to a section diameter of 2.4mm, and an internal diameter of 45.6mm. A section diameter of 2.5mm was chosen for the design to increase the safety of the system.

The pressure inside the system is greater than 100 Bar (=10000000Pa = 10Mpa) therefore a back-up ring could be necessary. However, as the piston is not in direct contact with the hydraulic pressure, a backup ring is not necessary.

Tolerance Calculations

Tolerance Housing

A clearance fit is needed for the piston to freely rotate within the housing. From the *BS Selected ISO Fits – Hole Basis chart* [5], a fitting and tolerance can be selected.

Nominal sizes		Tolerance		Tolerance		Tolernnce		Tolerance		Tolerance		Tolernnce	
Over	To	H11	c11	H9	d10	H9	e9	H8	f7	H7	g6	H7	h6
mm	mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm
—	3	+ 60 0	− 60 − 120	+ 25 0	− 20 − 60	+ 25 0	− 14 − 39	+ 14 0	− 6 − 16	+ 10 0	− 2 − 8	+ 10 0	− 6 0
3	6	+ 75 0	− 70 − 145	+ 30 0	− 30 − 78	+ 30 0	− 20 − 50	+ 18 0	− 10 − 22	+ 12 0	− 4 − 12	+ 12 0	− 8 0
6	10	+ 90 0	− 80 − 170	+ 36 0	− 40 − 98	+ 36 0	− 25 − 61	+ 22 0	− 13 − 28	+ 15 0	− 5 − 14	+ 15 0	− 9 0
10	18	+ 110 0	− 95 − 205	+ 43 0	− 50 − 120	+ 43 0	− 32 − 75	+ 27 0	− 16 − 34	+ 18 0	− 6 − 17	+ 18 0	− 11 0
18	30	+ 130 0	− 110 − 240	+ 52 0	− 65 − 149	+ 52 0	− 40 − 92	+ 33 0	− 20 − 41	+ 21 0	− 7 − 20	+ 21 0	− 13 0
30	40	+ 160 0	− 120 − 280	+ 62 0	− 80 − 180	+ 62 0	− 50 − 112	+ 39 0	− 25 − 50	+ 25 0	− 9 − 25	+ 25 0	− 16 0
40	50	+ 160 0	− 130 − 290										
50	65	+ 190 0	− 140 − 330	+ 74 0	− 100 − 220	+ 74 0	− 60 − 134	+ 46 0	− 30 − 60	+ 30 0	− 10 − 29	+ 30 0	− 19 0
65	80	+ 190 0	− 150 − 340										

Table 6– Part of the table used to deduce tolerances and fits [5]

H7/h6 is chosen for the housing as it is the tightest clearance fit. While free rotation is needed, the piston should still provide linear movement inside the housing. From the table, we can deduce that the housing should have +0.0030mm tolerance and -0.0019mm fitting. This is for the housing.

Tolerance Piston

A clearance fit is needed for the piston to freely rotate within the housing. From the *BS Selected ISO Fits – Shaft Basis chart* [5], a fitting and tolerance can be selected.

Nominal sizes		Tolerance		Tolerance		Tolerance		Tolerance		Tolerance		Tolerance	
Over	To	h11	C11	h9	D10	h9	E9	h7	F8	h6	G7	h6	H7
mm	mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm
—	3	0 − 60	+ 120 + 60	0 − 25	+ 60 + 20	0 − 25	+ 39 + 14	0 − 10	+ 20 + 6	0 − 6	+ 12 + 2	0 − 6	+ 10 0
3	6	0 − 75	+ 145 + 70	0 − 30	+ 78 + 30	0 − 30	+ 50 + 20	0 − 12	+ 28 + 10	0 − 8	+ 16 + 4	0 − 8	+ 12 0
6	10	0 − 90	+ 170 + 80	0 − 36	+ 98 + 40	0 − 36	+ 61 + 25	0 − 15	+ 35 + 13	0 − 9	+ 20 + 5	0 − 9	+ 15 0
10	18	0 − 110	+ 205 + 95	0 − 43	+ 120 + 50	0 − 43	+ 75 + 32	0 − 18	+ 43 + 16	0 − 11	+ 24 + 6	0 − 11	+ 18 0
18	30	0 − 130	+ 240 + 110	0 − 52	+ 149 + 65	0 − 52	+ 92 + 40	0 − 21	+ 53 + 20	0 − 13	+ 28 + 7	0 − 13	+ 21 0
30	40	0 − 160	+ 280 + 120	0 − 62	+ 180 + 80	0 − 62	+ 112 + 50	0 − 25	+ 64 + 25	0 − 16	+ 34 + 9	0 − 16	+ 25 0
40	50	0 − 160	+ 290 + 130										
50	65	0 − 190	+ 330 + 140	0 − 74	+ 220 + 100	0 − 74	+ 134 + 60	0 − 30	+ 76 + 30	0 − 19	+ 40 + 10	0 − 19	+ 30 0
65	80	0 − 190	+ 340 + 150										

Table 7 – Part of the table used to deduce tolerances and fits [5]

H7/h6 is chosen for the housing as it is the tightest clearance fit. While free rotation is needed, the piston should still provide linear movement inside the housing. From the table, we can deduce that the housing should have -0.0019mm tolerance and +0.0030mm fitting. This is for the piston.

Material Selection and Manufacturing Processes

Material Selection

- Titanium alloys were initially selected; however, alumina has a much lower mass density than titanium. Therefore, Alumina is used for the lower cap and hydraulic housing due to its lightweight yet durable material properties. A high tensile strength of 300N/mm^2 ensures that housing will not yield to the pressure inside.
- The springs are made from plain-carbon steel to improve their lifetime (thus decreasing maintenance). Additionally, plain-carbon steel has good machining and thus easier to manufacture.
- Commercially pure CP-Ti UNS R50700 Grade 4 (SS) titanium alloy is used for the piston. As the piston transmits the force between the springs and coupling, a strong yet lightweight material is needed.
- Epichlorohydrin rubber (ECO) is used for the O ring as it achieves a *"very-good"* score in the James Walker material selection matrix as seen in *table 10*. [4]

All the materials selected also have high chemical resistance.

Material Properties

Alumina Properties

Property	Value	Units
Youngs Modulus	370000	N/mm^2
Mass Density	3960	Kg/m^3
Tensile Strength	300	N/mm^2
Compressive Strength	3000	N/mm^2

Table 8 – A table demonstrating the materials properties of alumina, the chosen material for the housing and lower cap. [3]

Plain Carbon Steel Properties

Property	Value	Units
Youngs Modulus	210000	N/mm^2
Mass Density	7800	Kg/m^3
Tensile Strength	399.826	N/mm^2
Yield Strength	220.594	N/mm^2

Table 9 – A table demonstrating the material properties of plain carbon steel, the chosen material for the springs. [3]

Titanium Alloy Properties

Property	Value	Units
Youngs Modulus	105000	N/mm2
Mass Density	4510	Kg/m3
Tensile Strength	550	N/mm2
Yield Strength	500	N/mm2

Table 10 – A table demonstrating the material properties of the titanium alloy, the chosen material for the piston. [3]

Epichlorohydrin Rubber Properties

Property	Value	Units
Mass Density	1505.2	Kg/m^3

Table 11 – A table demonstrating the material properties of Epichlorohydrin rubber, the chosen material for the O-ring. [3]

MATERIAL TYPE		Air or oxygen	Water – up to 80°C	Water – above 80°C	Dilute acids	Dilute alkalis	Lower alcohols	Aldehydes	Amines	Chlorinated solvents	Ethers	Ketones	Hydrocarbons – aliphatic	Hydrocarbons – aromatic	Leaded petrol (gasoline)
Epichlorohydrin	ECO	2	1	2	3	2	2	4	1	4	4	4	3	4	1

MATERIAL TYPE	Kerosene	Animal oils and fats	Fuel oils and diesel oils	Lubricating oils – mineral	Lubricating oils – synthetic	Silicone oils and grease	Vegetable oils	Hydraulic fluids – mineral based	Hydraulic fluids fire resistent: Chlorinated	Oil in water emulsions	Water in oil emulsions	Water – glycol based	Phosphate esters – aliphatic	Phosphate esters – aromatic
Epichlorohydrin	1	1	1	1	4	1	1	1	4	2	2	2	4	4

MATERIAL TYPE	Temperature range (°C): Low	High – continuous	High – intermittent	Hardness range IRHD	Available to the latest issue of the following specifications
Epichlorohydrin	–30	150	175	70 - 90	

Table 12 – Part of the James Walker material selection matrix

Total Weight

By using Solidworks, the total weight was calculated to be 1635.53 grams (1.635Kg). This means the requirement of the target weight being less than 3kg and the maximum weight of 3.5Kg has been achieved.

Reserve Factor

Max stresses are calculated using Von Mises and Tresca yield criteria.

Material	Yield Strength N/m2	Max Stresses
Alumina	500000000	13270000
Titanium	500000000	270000000

Table 13 – A table comparing the yield strength and max stresses for both materials used in the piston and housing

$$Reserve\ Factor\ (Alumina) = RF_A = \frac{500 * 10^6}{13.2 * 10^6} = 37.8$$

$$Reserve\ Factor\ (Titanium) = RF_T = \frac{500 * 10^6}{270 * 10^6} = 1.85$$

$$37.8\ and\ 1.85\ are\ both\ greater\ than\ 1.5, the\ minimum\ reserve\ factor$$

Manufacturing and Assembly

Through harden all metallic parts to increase the strength and hardness of the material.

As the parts are circular, turning with a lathe will be the preferred option in manufacturing these parts. To cut the equal spaced holes in the Hydraulic Housing and Lower Cap, a milling machine will be used.

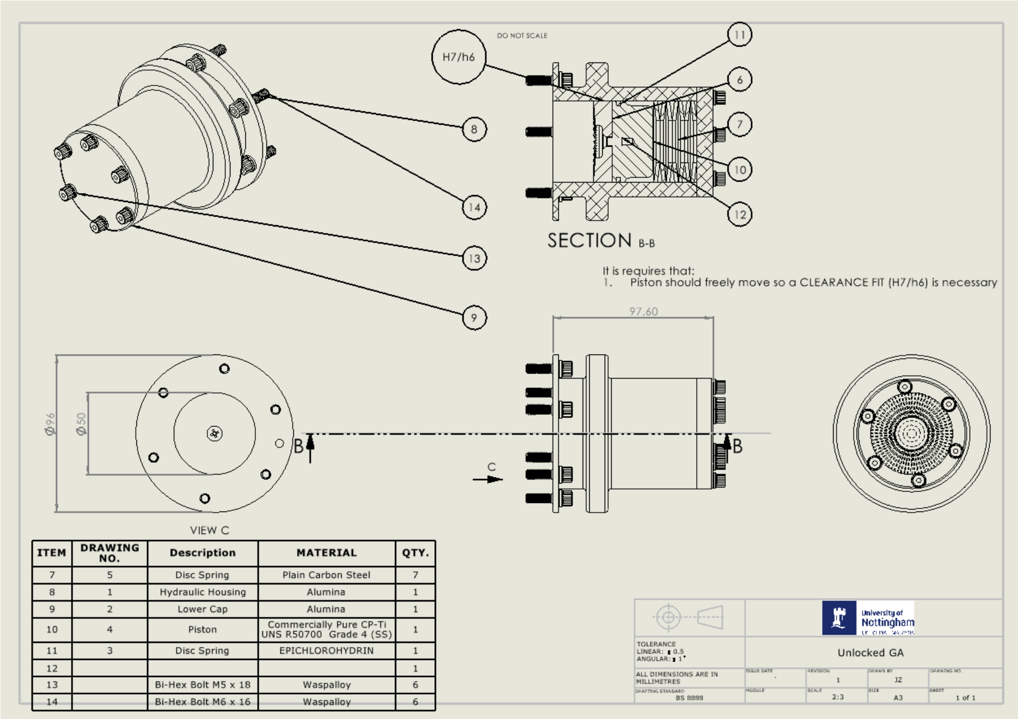
To assemble the TRASL:

1. Secure the O-Ring onto the piston head.
2. Screw the hirth serration coupling onto the piston.
    a. A screwdriver can be used.
3. Screw the lower cap into the hydraulic housing.
    a. An Alan key/spanner can be used.
4. Insert the springs into the hydraulic housing.
    a. Ensure that the springs are orientated in the correct way.
5. Place the piston connected to the coupling and O-ring on top of the springs
    a. Ensure the coupling is pointing away from the springs.
6. Secure the assembly to the third lock or the locking actuators.
    a. An Alan key/spanner can be used.
7. Test parts by injecting hydraulic fluid at operating pressure to ensure no leaks.

General Assembly (GA) Drawings

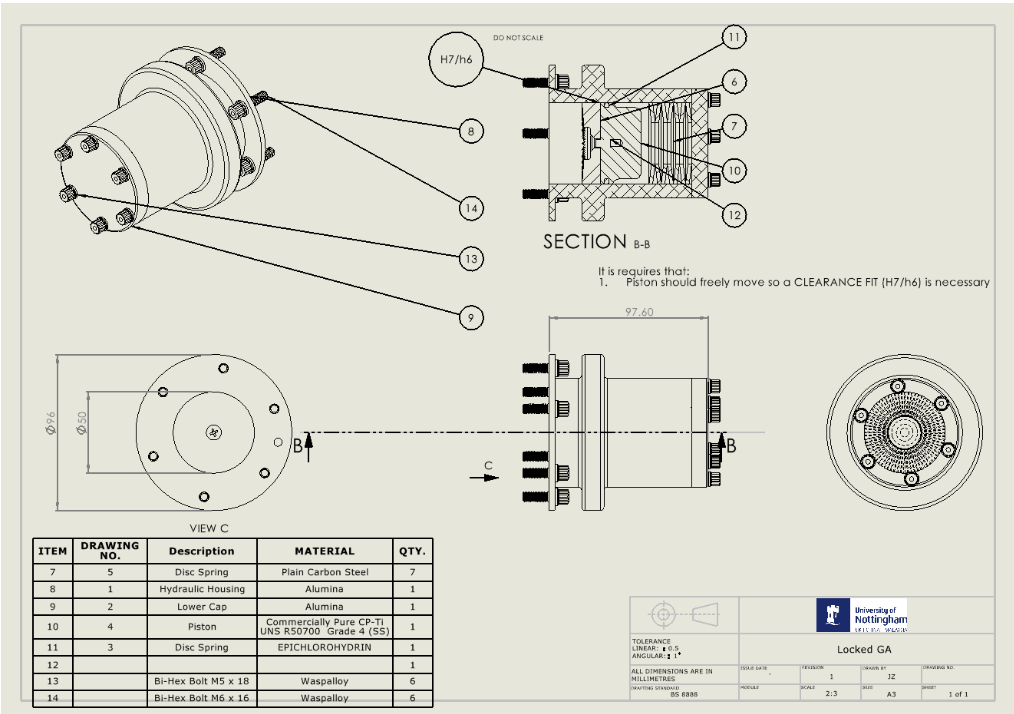
The piston and Springs fit inside the housing. To allow the piston to move linearly, a clearance fit is needed between the piston and the inner diameter of the housing. H7/g6 is necessary to allow for the movement.

TRASL Locked



Drawing 1.1 – A GA of the TRASL in the locked position

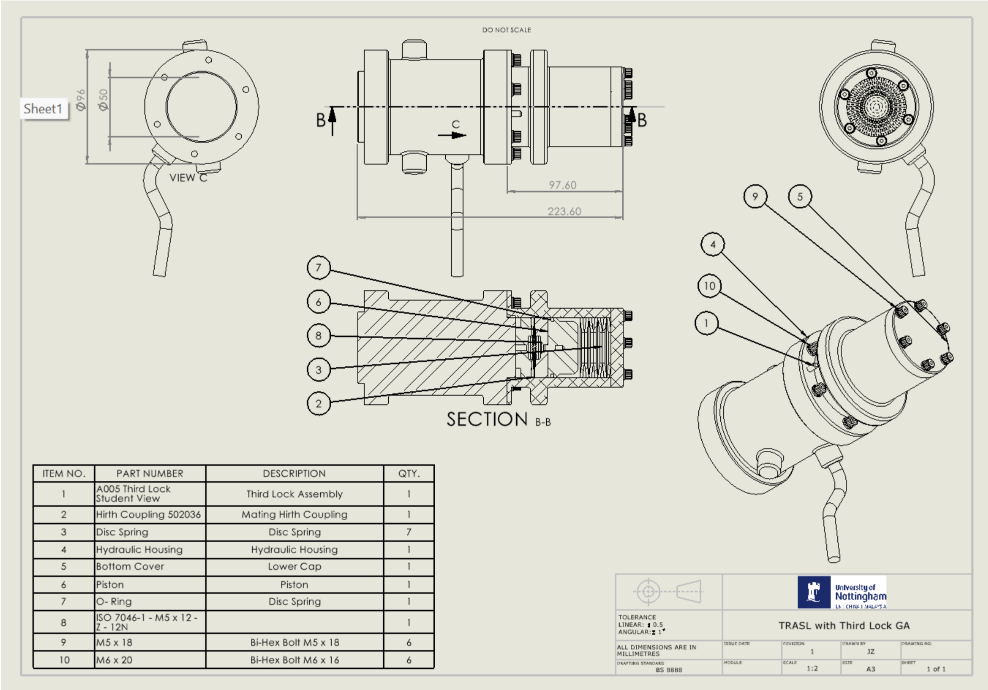
TRASL Unlocked



Drawing 1.2 – A GA of the TRSAL in the unlocked position

Note: for the springs to be fully defined, they cannot move with the piston. In the real world – they would be extended, mating with the piston.

TRASL with Third Lock

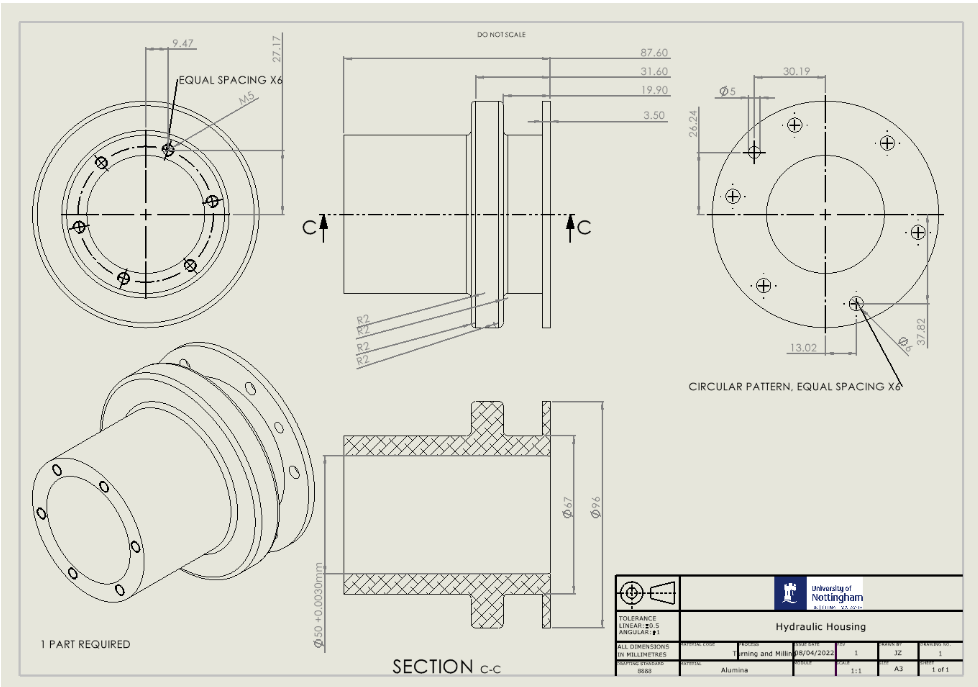


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	A005 Third Lock Student View	Third Lock Assembly	1
2	Hirth Coupling 502036	Mating Hirth Coupling	1
3	Disc Spring	Disc Spring	7
4	Hydraulic Housing	Hydraulic Housing	1
5	Bottom Cover	Lower Cap	1
6	Piston	Piston	1
7	O- Ring	Disc Spring	1
8	ISO 7046-1 - M5 x 12 - Z - 12N		1
9	M5 x 18	Bi-Hex Bolt M5 x 18	6
10	M6 x 20	Bi-Hex Bolt M6 x 16	6

Drawing 1.3 – A GA of the TRSAL with the Third Lock

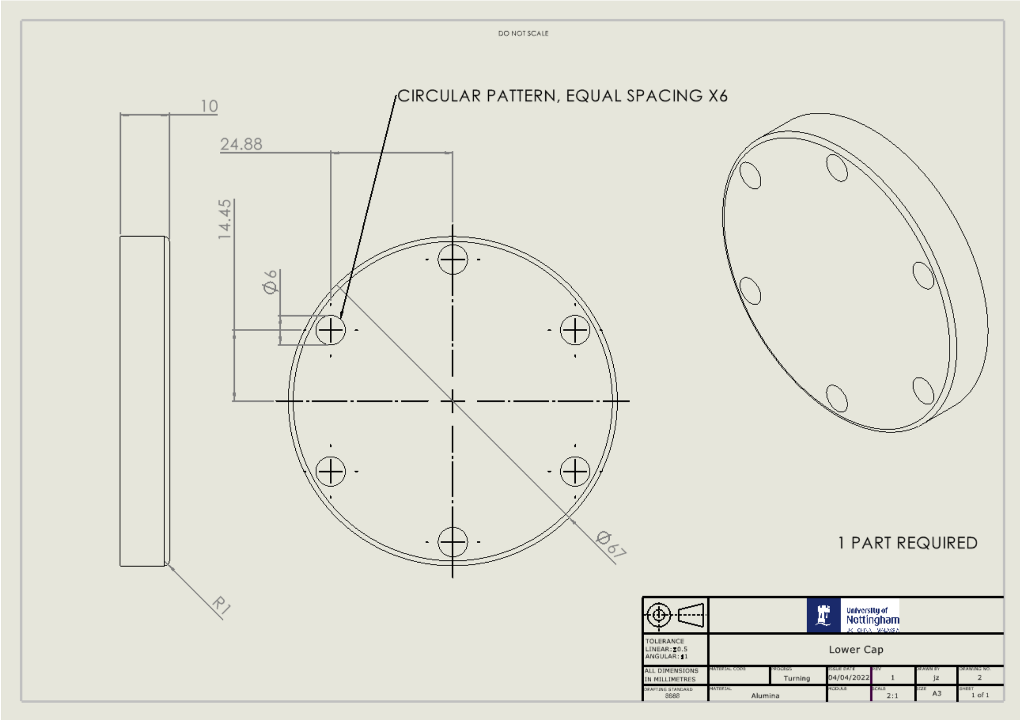
Detail Drawings

Hydraulic Housing



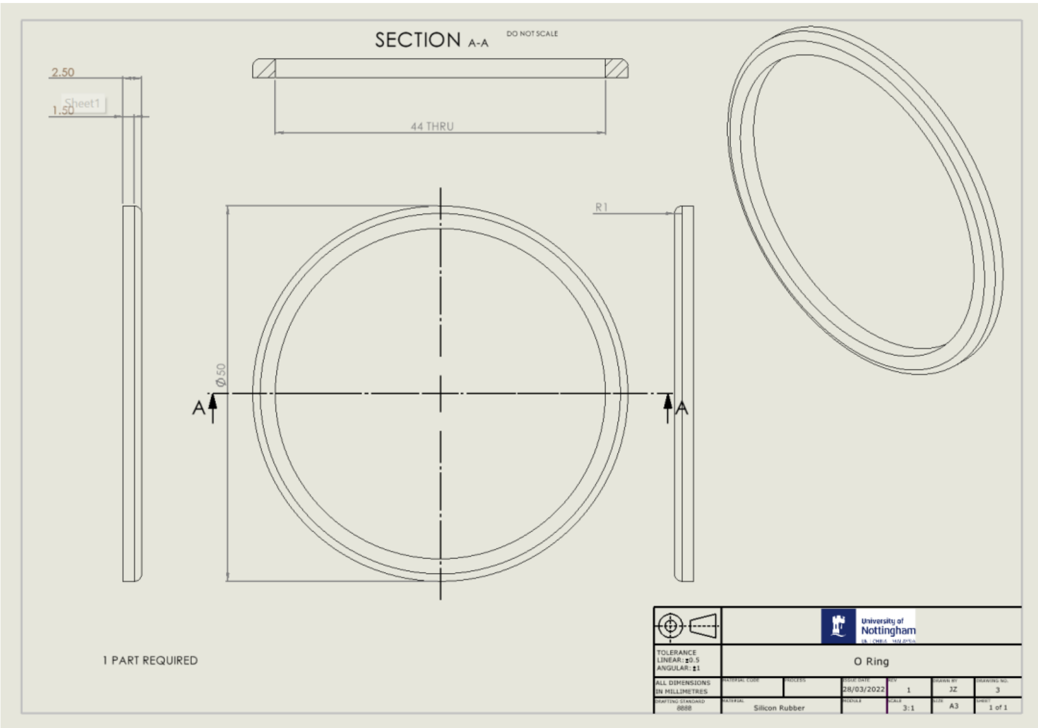
Drawing 2.1 – A detailed drawing of the Hydraulic Housing

Bottom Cover



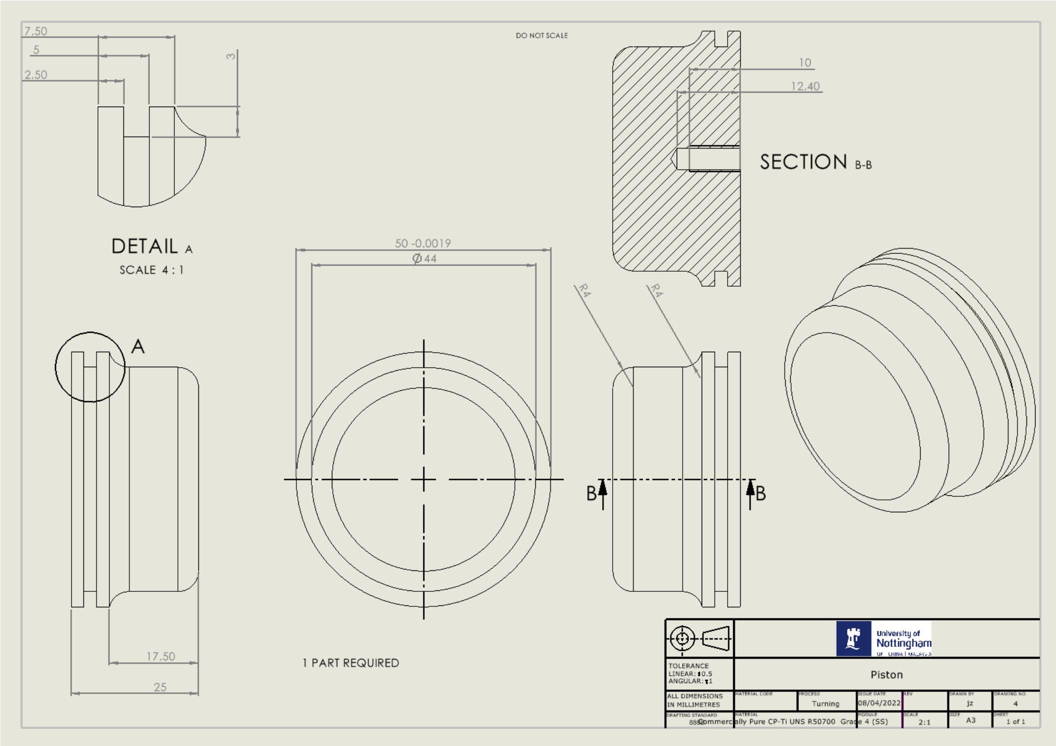
Drawing 2.2 – A detailed drawing of the Lower Cap

O – Ring



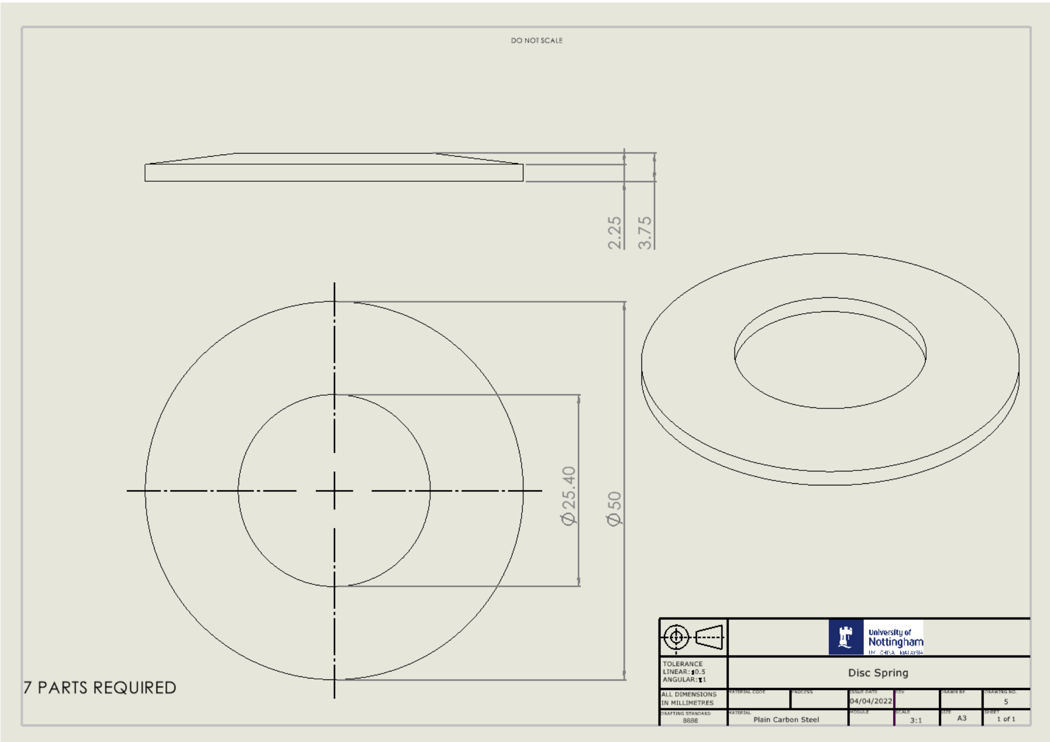
Drawing 2.3 – A detailed drawing of the O Ring

Piston



Drawing 2.4 – A detailed drawing of the Piston

Disc Spring



Drawing 2.5 – A detailed drawing of the individual washer spring

Appendix

DIN Series	Dimensions D_e	D_i	t	l_o	h_o	h_o/t	Preload, $s = 0.15\,h_o$: s	l_t	F	σ_{II}	σ_{III}	$s = 0.25\,h_o$: s	l_t	F	σ_{II}	σ_{III}	$s = 0.5\,h_o$: s	l_t	F	σ_{II}	σ_{III}	$s = 0.75\,h_o$: s	l_t	F	σ_{II}	σ_{III}	$s = h_o$: s	F	σ_{OM}
	Design Force, Deflection and Stresses Based on E = 206 kMPa and $\mu = 0.3$																												
C	35.5	18.3	0.90	2.05	1.15	1.28	0.17	1.88	303	-12	264	0.29	1.76	458	2	427	0.58	1.48	712	108	786	0.86	1.19	832	320	1,078	1.15	884	-1,042
B	35.5	18.3	1.25	2.25	1.00	0.80	0.15	2.10	464	91	251	0.25	2.00	731	168	409	0.50	1.75	1,277	416	766	0.75	1.50	1,699	743	1,073	1.00	2,059	-1,258
A	35.5	18.3	2.00	2.80	0.80	0.40	0.12	2.68	1,139	230	249	0.20	2.60	1,864	393	409	0.40	2.40	3,576	837	785	0.60	2.20	5,187	1,332	1,128	0.80	6,747	-1,611
	40.0	14.3	1.25	2.65	1.40	1.12	0.21	2.44	591	44	251	0.35	2.30	904	98	406	0.70	1.95	1,459	319	750	1.05	1.60	1,780	664	1,033	1.40	1,984	-1,213
	40.0	14.3	1.50	2.80	1.30	0.87	0.20	2.61	760	118	245	0.33	2.48	1,188	218	398	0.65	2.15	2,040	542	743	0.98	1.83	2,668	973	1,034	1.30	3,184	-1,351
	40.0	14.3	2.00	3.05	1.05	0.53	0.16	2.89	1,112	227	214	0.26	2.79	1,800	393	349	0.53	2.53	3,363	855	664	0.79	2.26	4,769	1,387	943	1.05	6,096	-1,455
	40.0	16.3	1.50	2.80	1.30	0.87	0.20	2.61	783	107	265	0.33	2.48	1,224	199	430	0.65	2.15	2,102	503	802	0.98	1.83	2,749	911	1,118	1.30	3,281	-1,392
	40.0	16.3	2.00	3.10	1.10	0.55	0.17	2.94	1,222	216	246	0.28	2.83	1,972	375	402	0.55	2.55	3,663	825	764	0.83	2.28	5,169	1,349	1,084	1.10	6,580	-1,571
	40.0	18.3	2.00	3.15	1.15	0.58	0.17	2.98	1,355	209	285	0.29	2.86	2,182	365	466	0.58	2.58	4,030	810	883	0.86	2.29	5,656	1,338	1,252	1.15	7,171	-1,712
C	40.0	20.4	1.00	2.30	1.30	1.30	0.20	2.11	375	-15	261	0.33	1.98	565	-4	422	0.65	1.65	876	98	776	0.98	1.32	1,017	305	1,063	1.30	1,072	-1,024
B	40.0	20.4	1.50	2.65	1.15	0.77	0.17	2.48	702	108	265	0.29	2.36	1,109	196	431	0.58	2.08	1,953	474	810	0.86	1.79	2,621	835	1,136	1.15	3,201	-1,359
	40.0	20.4	2.00	3.10	1.10	0.55	0.17	2.94	1,348	203	296	0.28	2.83	2,175	354	484	0.55	2.55	4,041	783	920	0.83	2.28	5,701	1,288	1,307	1.10	7,258	-1,733
A	40.0	20.4	2.25	3.15	0.90	0.40	0.14	3.02	1,428	229	246	0.23	2.93	2,336	392	403	0.45	2.70	4,481	835	774	0.68	2.47	6,500	1,328	1,112	0.90	8,456	-1,595
	40.0	20.4	2.50	3.45	0.95	0.38	0.14	3.31	2,045	275	284	0.24	3.21	3,351	470	466	0.48	2.98	6,453	997	896	0.71	2.74	9,390	1,579	1,290	0.95	12,243	-1,871
C	45.0	22.4	1.25	2.85	1.60	1.28	0.24	2.61	689	-13	307	0.40	2.45	1,041	4	497	0.80	2.05	1,620	134	914	1.20	1.65	1,891	389	1,253	1.60	2,007	-1,227
B	45.0	22.4	1.75	3.05	1.30	0.74	0.20	2.86	963	119	266	0.33	2.73	1,524	214	433	0.65	2.40	2,701	512	814	0.98	2.07	3,646	892	1,144	1.30	4,475	-1,396
A	45.0	22.4	2.50	3.50	1.00	0.40	0.15	3.35	1,695	224	234	0.25	3.25	2,773	383	384	0.50	3.00	5,320	815	737	0.75	2.75	7,716	1,296	1,059	1.00	10,037	-1,534
	45.0	24.4	2.25	3.40	1.15	0.51	0.17	3.23	1,610	200	287	0.29	3.11	2,607	346	469	0.58	2.83	4,887	759	893	0.86	2.54	6,949	1,239	1,273	1.15	8,902	-1,679
	50.0	18.4	1.50	3.15	1.65	1.10	0.25	2.90	761	42	229	0.41	2.74	1,166	93	370	0.83	2.33	1,890	294	684	1.24	1.91	2,319	605	942	1.65	2,600	-1,104
	50.0	18.4	2.00	3.65	1.65	0.83	0.25	3.40	1,419	137	263	0.41	3.24	2,229	251	428	0.83	2.83	3,868	610	800	1.24	2.41	5,114	1,079	1,116	1.65	6,163	-1,471
	50.0	18.4	2.50	4.15	1.65	0.66	0.25	3.90	2,424	232	298	0.41	3.74	3,870	409	486	0.83	3.33	7,002	926	916	1.24	2.91	9,643	1,552	1,291	1.65	12,038	-1,839
	50.0	20.4	2.00	3.50	1.50	0.75	0.23	3.28	1,243	136	244	0.38	3.13	1,966	244	397	0.75	2.75	3,478	578	745	1.13	2.38	4,687	1,000	1,045	1.50	5,745	-1,371
	50.0	20.4	2.50	3.85	1.35	0.54	0.20	3.65	1,862	215	240	0.34	3.51	3,008	373	393	0.68	3.18	5,601	817	746	1.01	2.84	7,919	1,334	1,060	1.35	10,098	-1,543
	50.0	22.4	2.00	3.60	1.60	0.80	0.24	3.36	1,427	125	286	0.40	3.20	2,247	228	466	0.80	2.80	3,924	556	872	1.20	2.40	5,222	985	1,220	1.60	6,329	-1,511
	50.0	22.4	2.50	3.90	1.40	0.56	0.21	3.69	2,023	209	270	0.35	3.55	3,261	364	442	0.70	3.20	6,044	806	838	1.05	2.85	8,510	1,324	1,190	1.40	10,817	-1,653
C	50.0	25.4	1.25	2.85	1.60	1.28	0.24	2.61	565	-11	254	0.40	2.45	854	2	410	0.80	2.05	1,328	106	755	1.20	1.65	1,550	312	1,035	1.60	1,646	-1,006
	50.0	25.4	1.50	3.10	1.60	1.07	0.24	2.86	808	32	276	0.40	2.70	1,242	74	447	0.80	2.30	2,028	250	828	1.20	1.90	2,512	528	1,145	1.60	2,844	-1,207
B	50.0	25.4	2.00	3.40	1.40	0.70	0.21	3.19	1,226	128	264	0.35	3.05	1,949	230	430	0.70	2.70	3,491	537	810	1.05	2.35	4,762	923	1,140	1.40	5,898	-1,408
	50.0	25.4	2.25	3.75	1.50	0.67	0.23	3.53	1,821	165	312	0.38	3.38	2,905	292	508	0.75	3.00	5,249	675	959	1.13	2.63	7,217	1,147	1,353	1.50	8,997	-1,697
	50.0	25.4	2.50	3.90	1.40	0.56	0.21	3.69	2,154	204	302	0.35	3.55	3,473	355	494	0.70	3.20	6,437	789	938	1.05	2.85	9,063	1,301	1,332	1.40	11,519	-1,760
A	50.0	25.4	3.00	4.10	1.10	0.37	0.17	3.94	2,594	249	249	0.28	3.83	4,255	424	409	0.55	3.55	8,214	897	787	0.83	3.27	11,976	1,418	1,135	1.10	15,640	-1,659
C	56.0	28.5	1.50	3.45	1.95	1.30	0.29	3.16	966	-17	299	0.49	2.96	1,458	-4	483	0.98	2.48	2,259	112	889	1.46	1.99	2,622	350	1,218	1.95	2,766	-1,174
B	56.0	28.5	2.00	3.60	1.60	0.80	0.24	3.36	1,213	94	255	0.40	3.20	1,910	173	415	0.80	2.80	3,335	428	778	1.20	2.40	4,438	765	1,090	1.60	5,379	-1,284
A	56.0	28.5	3.00	4.30	1.30	0.43	0.20	4.11	2,539	216	247	0.33	3.98	4,142	371	404	0.65	3.65	7,895	795	775	0.98	3.32	11,388	1,274	1,110	1.30	14,752	-1,565
	60.0	20.5	2.00	4.20	2.20	1.10	0.33	3.87	1,650	58	272	0.55	3.65	2,528	125	440	1.10	3.10	4,097	386	812	1.65	2.55	5,026	784	1,119	2.20	5,636	-1,346
	60.0	20.5	2.50	4.70	2.20	0.88	0.33	4.37	2,657	149	303	0.55	4.15	4,151	276	491	1.10	3.60	7,102	688	916	1.65	3.05	9,255	1,237	1,273	2.20	11,008	-1,682
	60.0	25.5	2.50	4.40	1.90	0.76	0.29	4.12	2,181	143	277	0.48	3.93	3,447	259	451	0.95	3.45	6,081	616	847	1.43	2.98	8,175	1,072	1,187	1.90	9,997	-1,527
	60.0	25.5	3.00	4.65	1.65	0.55	0.25	4.40	2,786	213	254	0.41	4.24	4,495	369	414	0.83	3.83	8,352	812	787	1.24	3.41	11,784	1,330	1,117	1.65	15,002	-1,592
	60.0	30.5	2.50	4.50	2.00	0.80	0.30	4.20	2,578	128	347	0.50	4.00	4,059	236	564	1.00	3.50	7,088	583	1,058	1.50	3.00	9,432	1,041	1,481	2.00	11,433	-1,747
	60.0	30.5	3.00	4.70	1.70	0.57	0.26	4.45	3,155	204	307	0.43	4.28	5,083	356	502	0.85	3.85	9,407	793	953	1.28	3.43	13,226	1,309	1,353	1.70	16,792	-1,782
	60.0	30.5	3.50	5.00	1.50	0.43	0.23	4.78	4,039	255	288	0.38	4.63	6,591	437	472	0.75	4.25	12,574	937	905	1.13	3.88	18,153	1,499	1,297	1.50	23,528	-1,834

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Table 14 – The full table used to select dimensions for the disc springs [1]

MATERIAL TYPE		Air or oxygen	Water – up to 80°C	Water – above 80°C	Dilute acids	Dilute alkalis	Lower alcohols	Aldehydes	Amines	Chlorinated solvents	Ethers	Ketones	Hydrocarbons – aliphatic	Hydrocarbons – aromatic	Leaded petrol (gasoline)	Kerosene	Animal oils and fats	Fuel oils and diesel oils	Lubricating oils – mineral	Lubricating oils – synthetic	Silicone oils and grease	Vegetable oils	Hydraulic fluids – mineral based	Hydraulic fluids fire resistent: Chlorinated	Oil in water emulsions	Water in oil emulsions	Water – glycol based	Phosphate esters – aliphatic	Phosphate esters – aromatic	Temperature range (°C): Low	High – continuous	High – intermittent	Hardness range IRHD	Available to the latest issue of the following specifications
Acrylic	ACM	2	4	4	4	4	4	4	4	3	3	4	1	3	1	1	1	1	1	2	1	1	1	4	4	4	4	4	4	–20	150	175	80	
Aflas®	FEPM	1	1	1^F	1	1	1	1	1	3	4	4	1	3	2	1	1	1	1	2	1	1	1	2	1	1	1	1	2	0	200	230^F	70 - 90	
Butyl	IIR	1	1	2	1	1	1	1	1	4	4	1	4	4	4	4	2	4	4	4	1	3	4	4	4	4	1	2	2	–35	120	150	60 - 70	BS 3227
Chlorosulphonyl polyethylene	CSM	2	1	3	4	1	1	3	4	4	4	4	3	4	4	4	3	3	4	4	1	2	2	4	4	3	1	4	4	–30	120	150	65 - 80	
Elast-O-Lion®	HNBR	1	1	1	1	2	1	2	1	2	4	4	1	3	2	1	1	2	1	1	1	1	1	4	2	2	2	3	4	$–25^A$	150	170	50 - 90	DEF STAN 02-337
Epichlorohydrin	ECO	2	1	2	3	2	2	4	1	4	4	4	3	4	1	1	1	1	1	4	1	1	1	4	2	2	2	4	4	–30	150	175	70 - 90	
Ethylene-propylene	EPM/EPDM	1	1	1	2	1	1	1	2	4	3	1	1	4	4	4	2	4	4	4	1	3	4	4	4	4	1	1	2	–45	120	150^B	50 - 90	BS F 156, 162
Fluolion®	PTFE	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	–200	250			
Fluoroelastomers	FKM	1	1	3	1	2	4^C	4^C	4^C	1	3^C	4^C	1	1	1	1	1	1	1	2	1	1	1	2	1	1	2	1	1	$–15^D$	200	230^D	50 - 98	DEF STAN 02-337, *DTD 5543, 5603, 5612, 5613.
Fluorosilicone	FVMQ	1	1	2	3	2	1	4	4	2	3	4	1	1	2	1	1	2	1	2	1	1	2	2	2	2	2	3	3	–60	180	200	60 - 80	BS F 154
Kalrez®	FFKM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	–40	325		70 - 95	SAE AMS 7257
Natural rubber	NR	3	1	2	3	2	2	3	2	4	4	4	4	4	4	4	4	4	4	4	1	4	4	4	4	4	3	4	4	–50	100	120	40 - 85	BS 1154
Neoprene	CR	1	1	2	3	1	1	3	2	4	4	4	2	4	3	2	2	3	2	3	1	3	3	4	4	4	3	4	4	–40	120	150	40 - 90	BS 2752
Nitrile	NBR	2	1	2	3	2	1	3	2	3	4	4	1	3	2	1	1	2	1	2	1	1	1	4	3	3	1	4	4	$–30^A$	120	150	40 - 90	BS 2751, 6996, 6997, DEF STAN 02-337, *DTD 5509, 5594, 5595, 5606, 5607.
Polyurethane	AU/EU	1	4	4	4	4	4	4	4	3	2	4	2	4	2	2	2	3	2	4	1	2	1	4	4	4	4	4	4	–15	85	100	$55 - 95^E$	
Silicone	VMQ	1	1	2	3	2	1	2	2	4	4	3	3	4	4	4	2	4	3	3	4	1	4	3	3	4	2	2	3	–65	200	250	40 - 80	BS F 152, 153, 159

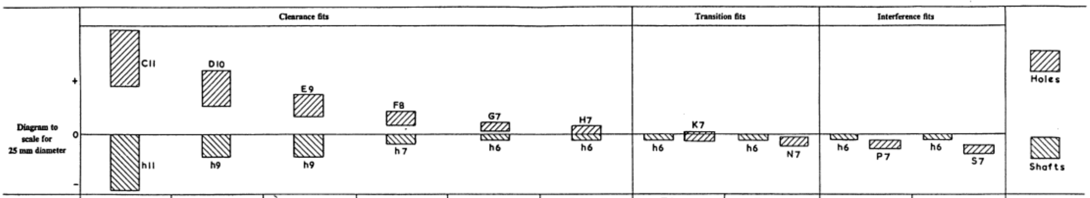
Table 15– The full table used to deduce which material is used for the O ring. [4]

Extracted from BS 4500 : 1969

BRITISH STANDARD

SELECTED ISO FITS—SHAFT BASIS

Data Sheet 4500B
Issue 1, February 1970



Nominal sizes		Tolerance		Tolerance		Tolerance		Tolerance		Tolerance		Tolerance		Tolerance		Tolerance		Tolerance		Tolerance		Nominal sizes	
Over	To	h11	C11	h9	D10	h9	E9	h7	F8	h6	G7	h6	H7	h6	K7	h6	N7	h6	P7	h6	S7	Over	To
mm	mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	mm	mm
—	3	0 - 60	+ 120 + 60	0 - 25	+ 60 + 20	0 - 25	+ 39 + 14	0 - 10	+ 20 + 6	0 - 6	+ 12 + 2	0 - 6	+ 10 0	0 - 6	0 - 10	0 - 6	- 4 - 14	0 - 6	- 6 - 16	0 - 6	- 14 - 24	—	3
3	6	0 - 75	+ 145 + 70	0 - 30	+ 78 + 30	0 - 30	+ 50 + 20	0 - 12	+ 28 + 10	0 - 8	+ 16 + 4	0 - 8	+ 12 0	0 - 8	+ 3 - 9	0 - 8	- 4 - 16	0 - 8	- 8 - 20	0 - 8	- 15 - 27	3	6
6	10	0 - 90	+ 170 + 80	0 - 36	+ 98 + 40	0 - 36	+ 61 + 25	0 - 15	+ 35 + 13	0 - 9	+ 20 + 5	0 - 9	+ 15 0	0 - 9	+ 5 - 10	0 - 9	- 4 - 19	0 - 9	- 9 - 24	0 - 9	- 17 - 32	6	10
10	18	0 - 110	+ 205 + 95	0 - 43	+ 120 + 50	0 - 43	+ 75 + 32	0 - 18	+ 43 + 16	0 - 11	+ 24 + 6	0 - 11	+ 18 0	0 - 11	+ 6 - 12	0 - 11	- 5 - 23	0 - 11	- 11 - 29	0 - 11	- 21 - 39	10	18
18	30	0 - 130	+ 240 + 110	0 - 52	+ 149 + 65	0 - 52	+ 92 + 40	0 - 21	+ 53 + 20	0 - 13	+ 28 + 7	0 - 13	+ 21 0	0 - 13	+ 6 - 15	0 - 13	- 7 - 28	0 - 13	- 14 - 35	0 - 13	- 27 - 48	18	30
30	40	0 - 160	+ 280 + 120	0 - 62	+ 180 + 80	0 - 62	+ 112 + 50	0 - 25	+ 64 + 25	0 - 16	+ 34 + 9	0 - 16	+ 25 0	0 - 16	+ 7 - 18	0 - 16	- 8 - 33	0 - 16	- 17 - 42	0 - 16	- 34 - 59	30	40
40	50	0 - 160	+ 290 + 130																			40	50
50	65	0 - 190	+ 330 + 140	0 - 74	+ 220 + 100	0 - 74	+ 134 + 60	0 - 30	+ 76 + 30	0 - 19	+ 40 + 10	0 - 19	+ 30 0	0 - 19	+ 9 - 21	0 - 19	- 9 - 39	0 - 19	- 21 - 51	0 - 19	- 42 - 72	50	65
65	80	0 - 190	+ 340 + 150																	0 - 19	- 48 - 78	65	80
80	100	0 - 220	+ 390 + 170	0 - 87	+ 260 + 120	0 - 87	+ 159 + 72	0 - 35	+ 90 + 36	0 - 22	+ 47 + 12	0 - 22	+ 35 0	0 - 22	+ 10 - 25	0 - 22	- 10 - 45	0 - 22	- 24 - 59	0 - 22	- 58 - 93	80	100
100	120	0 - 220	+ 400 + 180																	0 - 22	- 66 - 101	100	120
120	140	0 - 250	+ 450 + 200																	0 - 25	- 77 - 117	120	140
140	160	0 - 250	+ 460 + 210	0 - 100	+ 305 + 145	0 - 100	+ 185 + 85	0 - 40	+ 106 + 43	0 - 25	+ 54 + 14	0 - 25	+ 40 0	0 - 25	+ 12 - 28	0 - 25	- 12 - 52	0 - 25	- 28 - 68	0 - 25	- 85 - 125	140	160
160	180	0 - 250	+ 480 + 230																	0 - 25	- 93 - 133	160	180
180	200	0 - 290	+ 530 + 240																	0 - 29	- 105 - 151	180	200
200	225	0 - 290	+ 550 + 260	0 - 115	+ 355 + 170	0 - 115	+ 215 + 100	0 - 46	+ 122 + 50	0 - 29	+ 61 + 15	0 - 29	+ 46 0	0 - 29	+ 13 - 33	0 - 29	- 14 - 60	0 - 29	- 33 - 79	0 - 29	- 113 - 159	200	225
225	250	0 - 290	+ 570 + 280																	0 - 29	- 123 - 169	225	250
250	280	0 - 320	+ 620 + 300	0 - 130	+ 400 + 190	0 - 130	+ 240 + 110	0 - 52	+ 137 + 56	0 - 32	+ 62 + 17	0 - 32	+ 52 0	0 - 32	+ 16 - 36	0 - 32	- 14 - 66	0 - 32	- 36 - 88	0 - 32	- 138 - 190	250	280
280	315	0 - 320	+ 650 + 330																	0 - 32	- 150 - 202	280	315
315	355	0 - 360	+ 720 + 360	0 - 140	+ 440 + 210	0 - 140	+ 265 + 125	0 - 57	+ 151 + 62	0 - 36	+ 75 + 18	0 - 36	+ 57 0	0 - 36	+ 17 - 40	0 - 36	- 16 - 73	0 - 36	- 41 - 98	0 - 36	- 169 - 226	315	355
355	400	0 - 360	+ 760 + 400																	0 - 36	- 187 - 244	355	400
400	450	0 - 400	+ 840 + 440	0 - 155	+ 480 + 230	0 - 155	+ 290 + 135	0 - 63	+ 165 + 68	0 - 40	+ 83 + 20	0 - 40	+ 63 0	0 - 40	+ 18 - 45	0 - 40	- 17 - 80	0 - 40	- 45 - 108	0 - 40	- 209 - 272	400	450
450	500	0 - 400	+ 880 + 480																	0 - 40	- 229 - 292	450	500

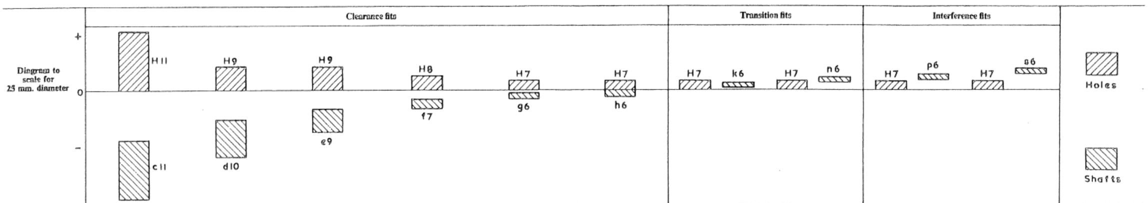
Table 16– The full table used to deduce which tolerances to use in the design for the piston[5]

Extracted from BS 4500 : 1969

BRITISH STANDARD

SELECTED ISO FITS—HOLE BASIS

Data Sheet 4500A
Issue 1. February 1970
Confirmed August 1985



Nominal sizes		Tolerance		Tolerance		Tolerance		Tolerance		Tolerance		Tolerance		Tolerance		Tolerance		Tolerance		Tolerance		Nominal sizes	
Over	To	H11	c11	H9	d10	H9	e9	H8	f7	H7	g6	H7	h6	H7	k6	H7	n6	H7	p6	H7	s6	Over	To
mm	mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	0·001 mm	mm	mm
—	3	+ 60 0	- 60 - 120	+ 25 0	- 20 - 60	+ 25 0	- 14 - 39	+ 14 0	- 6 - 16	+ 10 0	- 2 - 8	+ 10 0	- 6 0	+ 10 0	+ 6 + 0	+ 10 0	+ 10 + 4	+ 10 0	+ 12 + 6	+ 10 0	+ 20 + 14	—	3
3	6	+ 75 0	- 70 - 145	+ 30 0	- 30 - 78	+ 30 0	- 20 - 50	+ 18 0	- 10 - 22	+ 12 0	- 4 - 12	+ 12 0	- 8 0	+ 12 0	+ 9 + 1	+ 12 0	+ 16 + 8	+ 12 0	+ 20 + 12	+ 12 0	+ 27 + 19	3	6
6	10	+ 90 0	- 80 - 170	+ 36 0	- 40 - 98	+ 36 0	- 25 - 61	+ 22 0	- 13 - 28	+ 15 0	- 5 - 14	+ 15 0	- 9 0	+ 15 0	+ 10 + 1	+ 15 0	+ 19 + 10	+ 15 0	+ 24 + 15	+ 15 0	+ 32 + 23	6	10
10	18	+ 110 0	- 95 - 205	+ 43 0	- 50 - 120	+ 43 0	- 32 - 75	+ 27 0	- 16 - 34	+ 18 0	- 6 - 17	+ 18 0	- 11 0	+ 18 0	+ 12 + 1	+ 18 0	+ 23 + 12	+ 18 0	+ 29 + 18	+ 18 0	+ 39 + 28	10	18
18	30	+ 130 0	- 110 - 240	+ 52 0	- 65 - 149	+ 52 0	- 40 - 92	+ 33 0	- 20 - 41	+ 21 0	- 7 - 20	+ 21 0	- 13 0	+ 21 0	+ 15 + 2	+ 21 0	+ 28 + 15	+ 21 0	+ 35 + 22	+ 21 0	+ 48 + 35	18	30
30	40	+ 160 0	- 120 - 280	+ 62 0	- 80 - 180	+ 62 0	- 50 - 112	+ 39 0	- 25 - 50	+ 25 0	- 9 - 25	+ 25 0	- 16 0	+ 25 0	+ 18 + 2	+ 25 0	+ 33 + 17	+ 25 0	+ 42 + 26	+ 25 0	+ 59 + 43	30	40
40	50	+ 160 0	- 130 - 290																			40	50
50	65	+ 190 0	- 140 - 330	+ 74 0	- 100 - 220	+ 74 0	- 60 - 134	+ 46 0	- 30 - 60	+ 30 0	- 10 - 29	+ 30 0	- 19 0	+ 30 0	+ 21 + 2	+ 30 0	+ 39 + 20	+ 30 0	+ 51 + 32	+ 30 0	+ 72 + 53	50	65
65	80	+ 190 0	- 150 - 340																	+ 30 0	+ 78 + 59	65	80
80	100	+ 220 0	- 170 - 390	+ 87 0	- 120 - 260	+ 87 0	- 72 - 159	+ 54 0	- 36 - 71	+ 35 0	- 12 - 34	+ 35 0	- 22 0	+ 35 0	+ 25 + 3	+ 35 0	+ 45 + 23	+ 35 0	+ 59 + 37	+ 35 0	+ 93 + 71	80	100
100	120	+ 220 0	- 180 - 400																	+ 35 0	+ 101 + 79	100	120
120	140	+ 250 0	- 200 - 450																	+ 40 0	+ 117 + 92	120	140
140	160	+ 250 0	- 210 - 460	+ 100 0	- 145 - 305	+ 100 0	- 84 - 185	+ 63 0	- 43 - 83	+ 40 0	- 14 - 39	+ 40 0	- 25 0	+ 40 0	+ 28 + 3	+ 40 0	+ 52 + 27	+ 40 0	+ 68 + 43	+ 40 0	+ 125 + 100	140	160
160	180	+ 250 0	- 230 - 480																	+ 40 0	+ 133 + 108	160	180
180	200	+ 290 0	- 240 - 530																	+ 46 0	+ 151 + 122	180	200
200	225	+ 290 0	260 550	+ 115 0	- 170 - 355	+ 115 0	- 100 - 215	+ 72 0	- 50 - 96	+ 46 0	- 15 - 44	+ 46 0	- 29 0	+ 46 0	+ 33 + 4	+ 46 0	+ 60 + 31	+ 46 0	+ 79 + 50	+ 46 0	+ 159 + 130	200	225
225	250	+ 290 0	- 280 - 570																	+ 46 0	+ 169 + 140	225	250
250	280	+ 320 0	- 300 620	+ 130 0	- 190 - 400	+ 130 0	- 110 - 240	+ 81 0	- 56 - 108	+ 52 0	- 17 - 49	+ 52 0	- 32 0	+ 52 0	+ 36 + 4	+ 52 0	+ 66 + 34	+ 52 0	+ 88 + 56	+ 52 0	+ 190 + 158	250	280
280	315	+ 320 0	330 - 650																	+ 52 0	+ 202 + 170	280	315
315	355	+ 360 0	360 - 720	+ 140 0	- 210 - 440	+ 140 0	- 125 - 265	+ 89 0	- 62 - 119	+ 57 0	- 18 - 54	+ 57 0	- 36 0	+ 57 0	+ 40 + 4	+ 57 0	+ 73 + 37	+ 57 0	+ 98 + 62	+ 57 0	+ 226 + 190	315	355
355	400	+ 360 0	400 760																	+ 57 0	+ 244 + 208	355	400
400	450	+ 400 0	- 440 840	+ 155 0	- 230 - 480	+ 155 0	- 135 - 290	+ 97 0	- 68 - 131	+ 63 0	- 20 - 60	+ 63 0	- 40 0	+ 63 0	+ 45 + 5	+ 63 0	+ 80 + 40	+ 63 0	+ 108 + 68	+ 63 0	+ 272 + 232	400	450
450	500	+ 400 0	480 880																	+ 63 0	+ 292 + 252	450	500

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Table 17 - The full table used to deduce which tolerances to use in the design for the housing [5]

All dimensions in millimetres

"O"-ring ref. no.	Internal pressure		J	External pressure			H	R
	d (max.)	D		D (min.)	d	K		(max.)
0316-24	29.5	36.4		38	32			
0346-24	32.5	39.4		41	35			
0356-24	33.5	40.4		42	36			
0376-24	35.5	42.4	0.16	44	38			
0396-24	37.5	44.4		46	40			
0416-24	39.5	46.4		48	42	0.16		
0446-24	42.5	49.4		51	45			
0456-24	43.5	50.4		52	46			
0476-24	45.5	52.4		54	48			
0496-24	47.5	54.4		56	50			
0516-24	49.5	56.4		58	52			
0546-24	52.5	59.4		61	55			
0556-24	53.5	60.4		62	56			
0576-24	55.5	62.4		64	58			
0586-24	56.5	63.4		65	59			
0596-24	57.5	64.4	0.19	66	60			
0616-24	59.5	66.4		68	62	0.19		
0626-24	60.5	67.4		69	63			
0646-24	62.5	69.4		71	65			
0676-24	65.5	72.4		74	68			
0696-24	67.5	74.4		76	70			

Table 18 – Key part of the full tables used to dimension the O Rings [2]

References

[1] Spirol® Disc Spring catalogue, https://www.spirol.com/assets/files/SPIROL-Disc-Springs-us.pdf.

[2] BS 4518:1982+A2:2014, Specification for metric dimensions of toroidal sealing rings ('O'-rings) and their housings, BSI website https://bsol.bsigroup.com/ via NUSearch.

[3] Solidworks CES Tables, Solidworks.

[4] James Walker_O-ring_guide, https://www.moodle.nottingham.ac.uk

[5] Selected ISO Fits-Hole/Shaft Basis, https://www.moodle.nottingham.ac.uk

[6] Concept of Tsiolkovsky's rocket equation, https://en.wikipedia.org/wiki/Tsiolkovsky_rocket_equation