Faculty of Engineering, Environment & Computing
School of Mechanical Engineering,
School of Future Transport Engineering

Coventry University

6052/6053 MAA Mechanical Product Innovation
Interim Presentation

Project Title: City Vehicle Door/Car Park Friendly Door

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Declaration: The work described in this report is the result of our own investigations. All sections of the text and results that have been obtained from other work are fully referenced. I understand that cheating and plagiarism constitute a breach of University Regulations and will be dealt with accordingly.

Signed:	Date:

City Vehicle Door/Car Park Friendly Door

- **Delivery Plan**

1. Concept Generation.
2. Final Design.
3. Ergonomics.
4. Design Validation and Optimisation.
5. DFM, DFA and DFMEA.
6. Material Selection and Costing.
7. Sustainability.

Fig 1: *lambo-DooredV8 Range Rover Stromer Concept.*

City Vehicle Door/Car Park Friendly Door

- Concept Generation

Design Requirements:

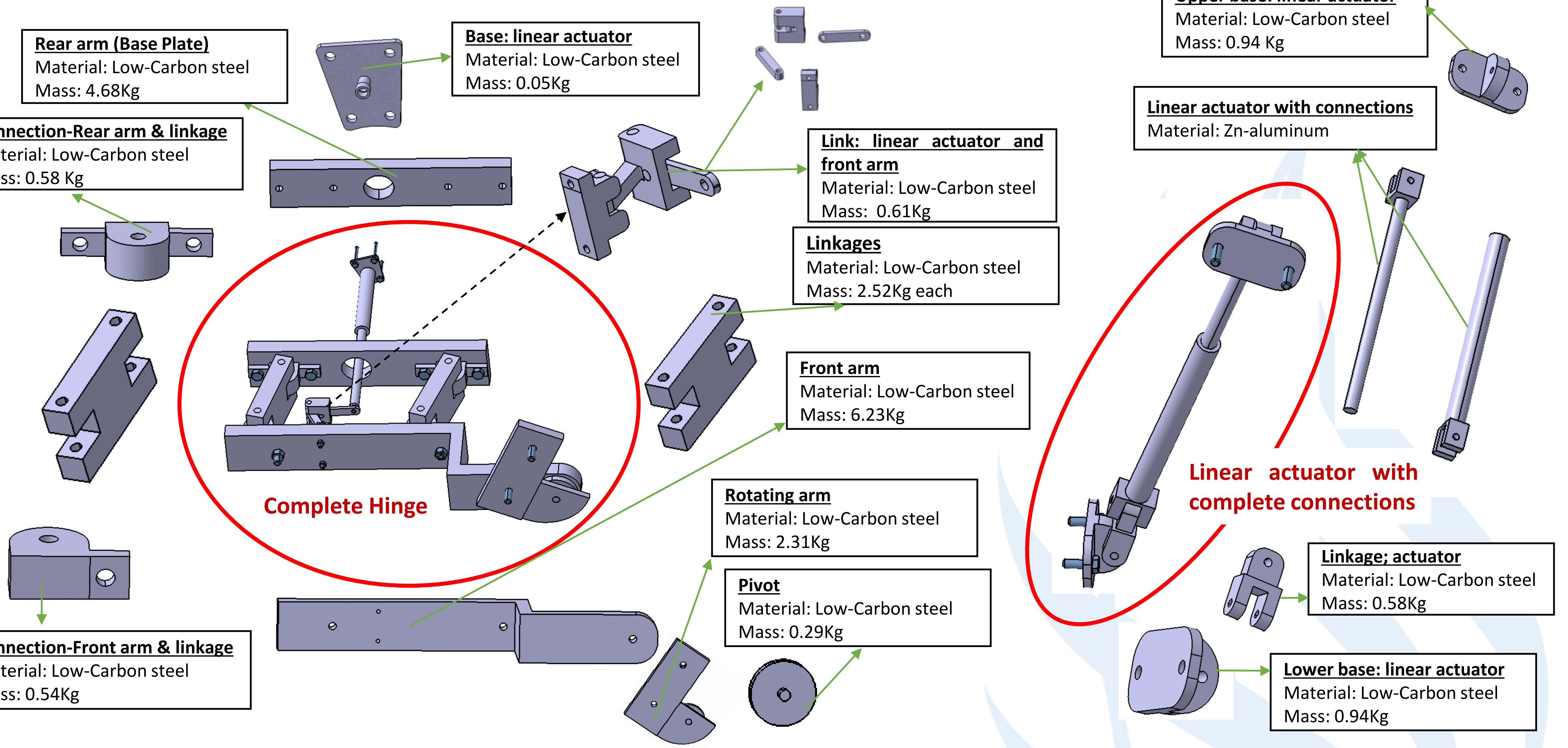
- Ability to open the door in a space of width 2500mm.
- Give unobstructed access to rear load space.
- Option to be powered or manual.
- Premium feeling-smooth operation.
- Function at acceptable speed.
- Low vibration and noise level.
- Quality finish and appearance.
- Meet expected shut line gaps when close.

Initial Design Procedures:

- Kano Model.
- QFD.
- Morphological Analysis.

City Vehicle Door/Car Park Friendly Door

- **Exploded View-Hinge Components and Linear Actuator**



Rear arm (Base Plate)
Material: Low-Carbon steel
Mass: 4.68Kg

Base: linear actuator
Material: Low-Carbon steel
Mass: 0.05Kg

Upper base: linear actuator
Material: Low-Carbon steel
Mass: 0.94 Kg

Connection-Rear arm & linkage
Material: Low-Carbon steel
Mass: 0.58 Kg

Linear actuator with connections
Material: Zn-aluminum

Link: linear actuator and front arm
Material: Low-Carbon steel
Mass: 0.61Kg

Linkages
Material: Low-Carbon steel
Mass: 2.52Kg each

Front arm
Material: Low-Carbon steel
Mass: 6.23Kg

Rotating arm
Material: Low-Carbon steel
Mass: 2.31Kg

Pivot
Material: Low-Carbon steel
Mass: 0.29Kg

Linkage; actuator
Material: Low-Carbon steel
Mass: 0.58Kg

Connection-Front arm & linkage
Material: Low-Carbon steel
Mass: 0.54Kg

Lower base: linear actuator
Material: Low-Carbon steel
Mass: 0.94Kg

City Vehicle Door/Car Park Friendly Door

- ## Conceptual Design

Mechanism-Closed

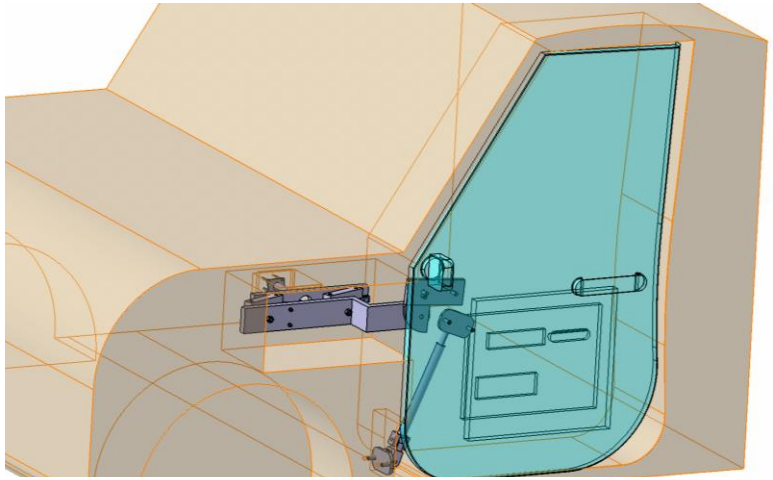


Fig 2: *Door lateral view during closed state*

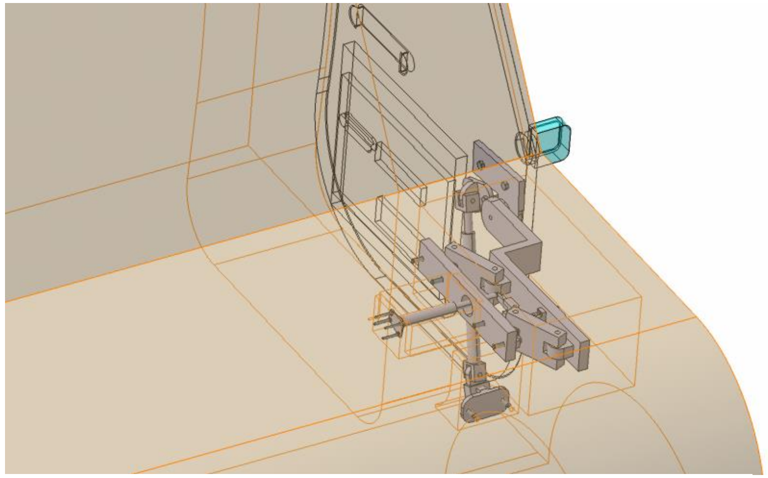


Fig 3: *Back view of the mechanism*

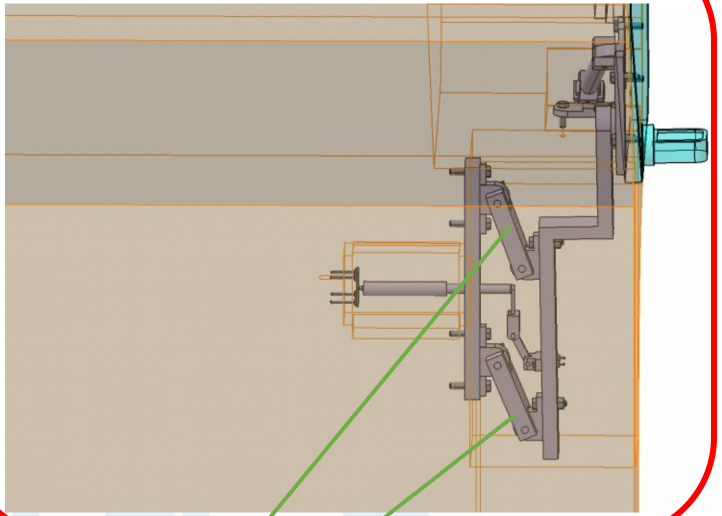


Fig 4: *Top view*

- Electric motor used to engage and disengage latch locking mechanism
- Can be locked and unlocked using button on car keys or buttons on interior of car.

- Linkages at 30° angle at closed-door condition.
- Linear actuator is at normal state.

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- **Conceptual Design**

Mechanism-Half Opened

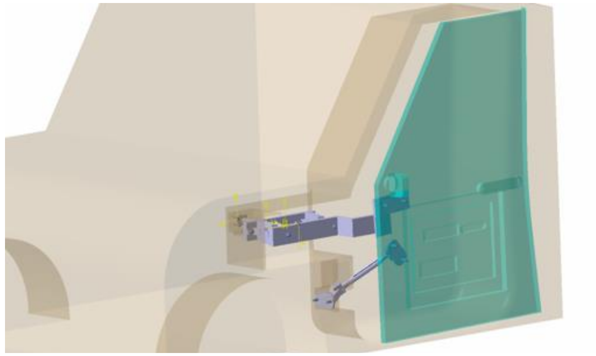
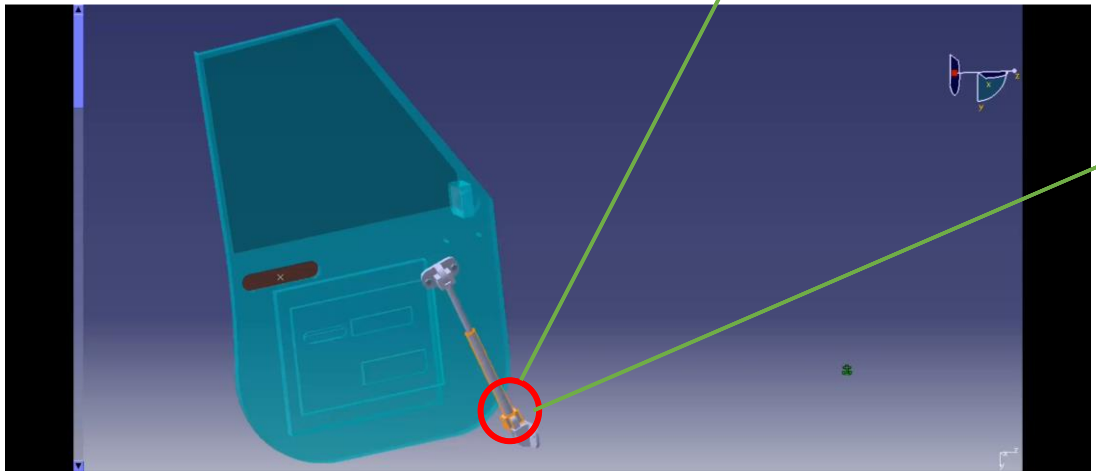
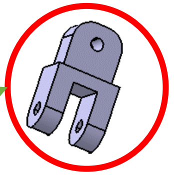


Fig 5: Door lateral view during closed state

- Linkages at 80° angle at half-open condition.
- Linear actuator expands by 130 mm.

- Lateral shifting of bigger linear actuator along with the movement of linkages.





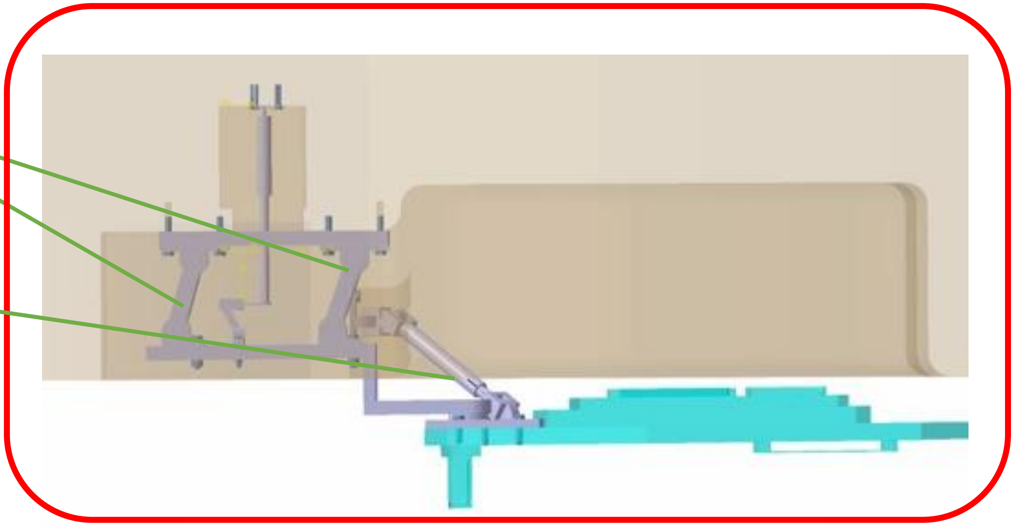


Fig 7: Top view of the mechanism

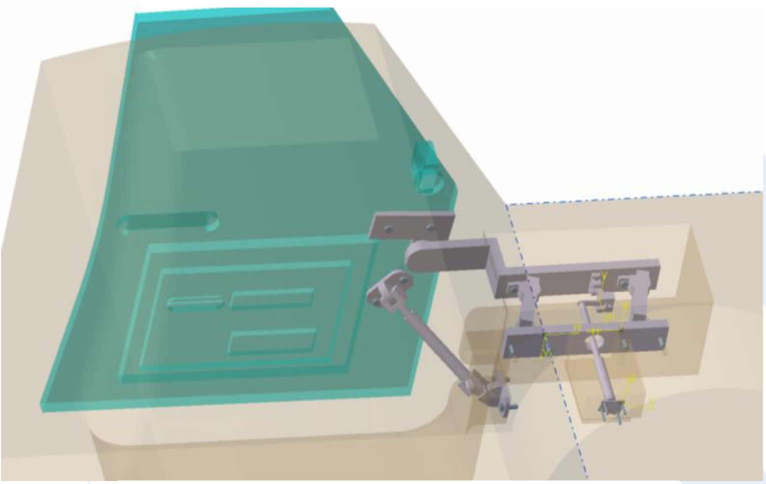


Fig 6: Back view of the mechanism

City Vehicle Door/Car Park Friendly Door

- ## Conceptual Design

Mechanism-Complete Open

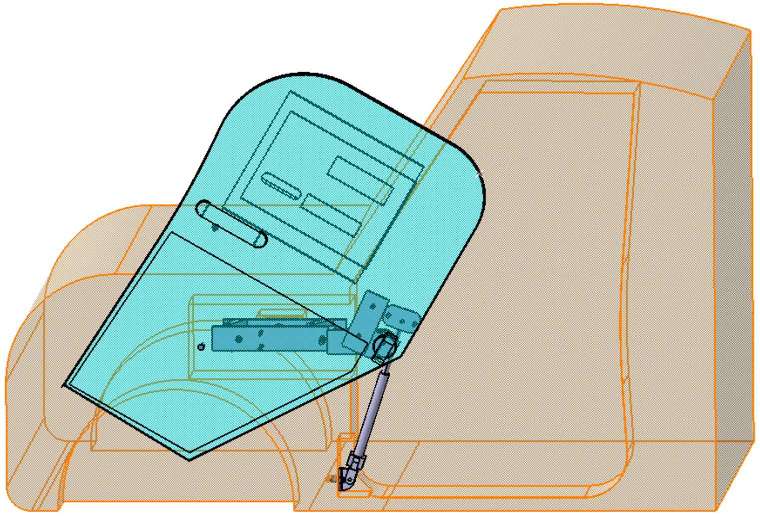


Fig 8: Door lateral view during closed state

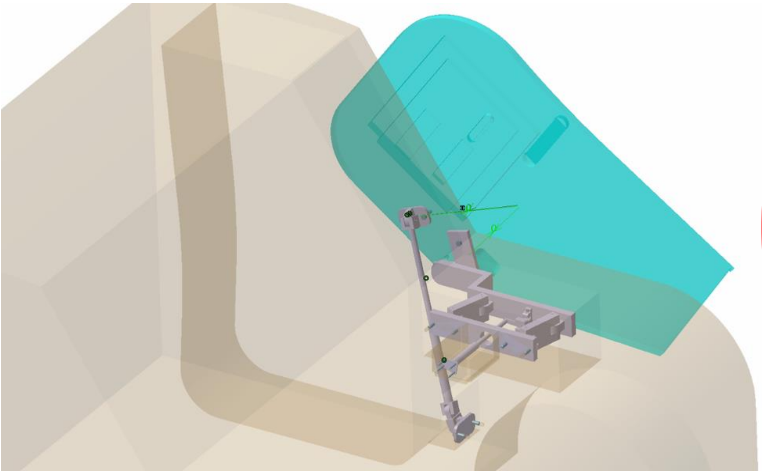


***Fig 9:** Back view of the mechanism*

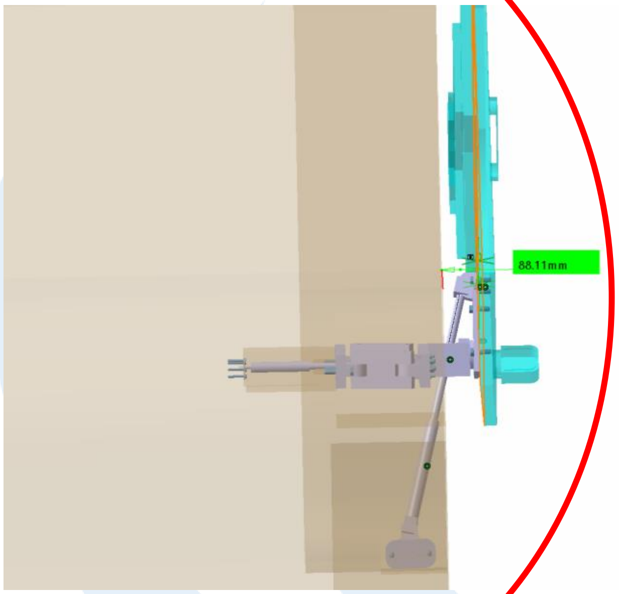


***Fig 10:** Top view of the mechanism*

- ➢ Upward rotational movement of door.
- ➢ Linear Actuator extends by 350mm maximum
- ➢ Ultrasonic and passive infrared sensors will prevent linear actuator movement from collisions with nearby people or objects

- ➢ Electric
- ➢ key Controlled

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- **Manual operation of the door**

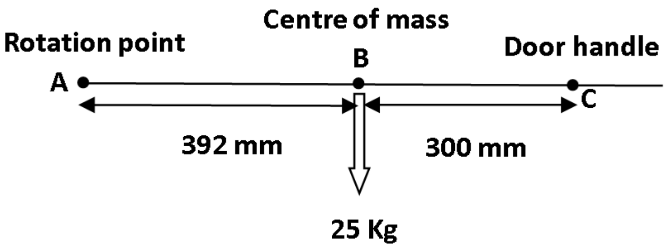

Fig 11: *Free body diagram the hinge from rotation point to the door handle.*

- $kinetic\ coefficient\ of\ friction\ of\ low\ carbon\ steel\ (\mu) = 0.2$
- $Perependicular\ distance\ to\ the\ handle\ from\ rotation\ point\ (d) = 692\ mm$
- $Reaction\ force\ at\ rotation\ point\ (F_N) = 25 * 0.392 = 9.8\ N$
- $Frictional\ force\ at\ rotation\ point\ (F_f) = \mu * F_N = 1.96\ N$
- $Frictional\ moment\ (M_f) = F_f * d = 1.35\ N$
- $Moment\ without\ friction\ (M) = F_N * d = 6.78\ Nm$
- $Net\ moment\ required\ (M_{net}) = 6.78 + 1.35 = 8.13\ Nm$

$Since, the\ net\ moment\ required\ to\ lift\ the\ door\ with\ hand\ is\ 8.13\ N$ $which\ is\ easier\ to\ apply\ by\ female, male\ or\ any\ aged\ group\ except\ kids.$

Fig 11: *Picture showing manual door operation.*

City Vehicle Door/Car Park Friendly Door

- **Material Comparison Graph**

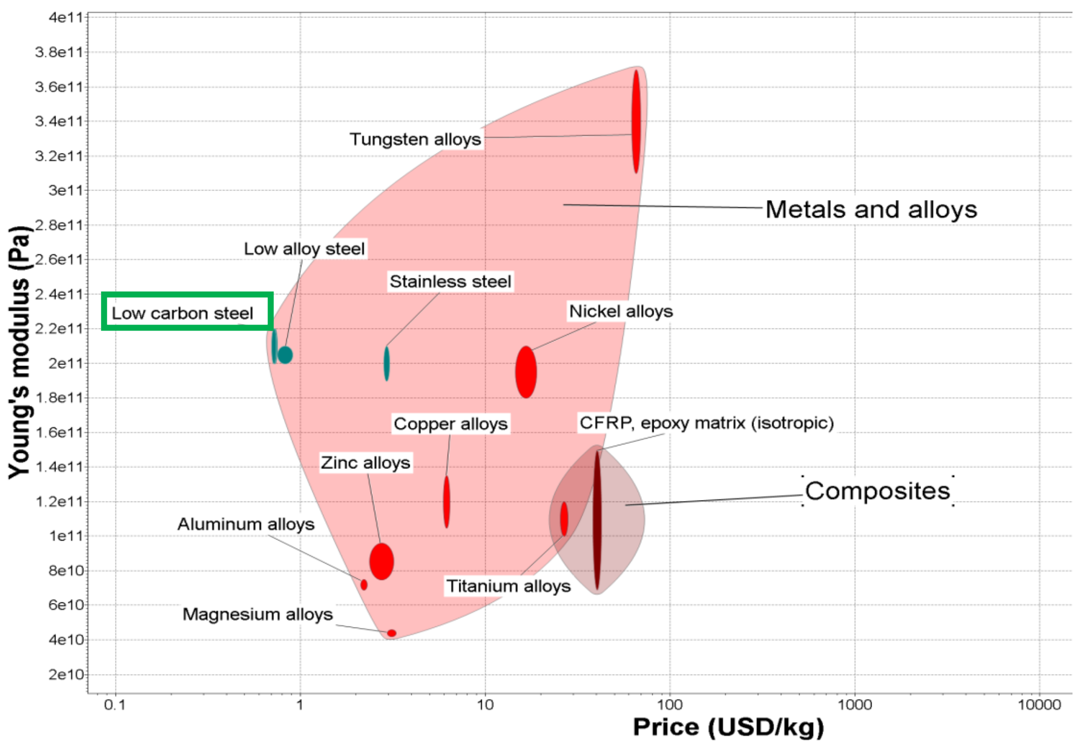

***Fig 12:** Young's modulus Vs Price graph of different Metals and Composites.*

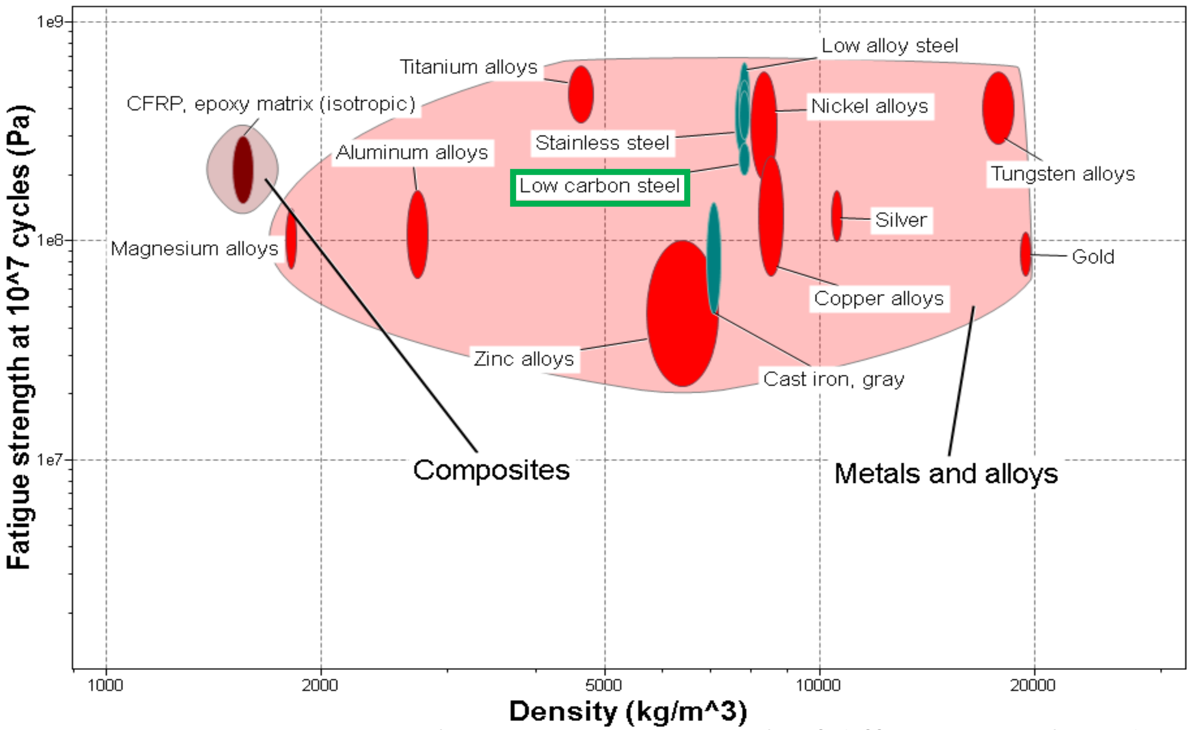

***Fig 13:** Fracture Toughness Vs Density graph of different Metals and Composites.*

City Vehicle Door/Car Park Friendly Door

- **Material Comparison Graph**

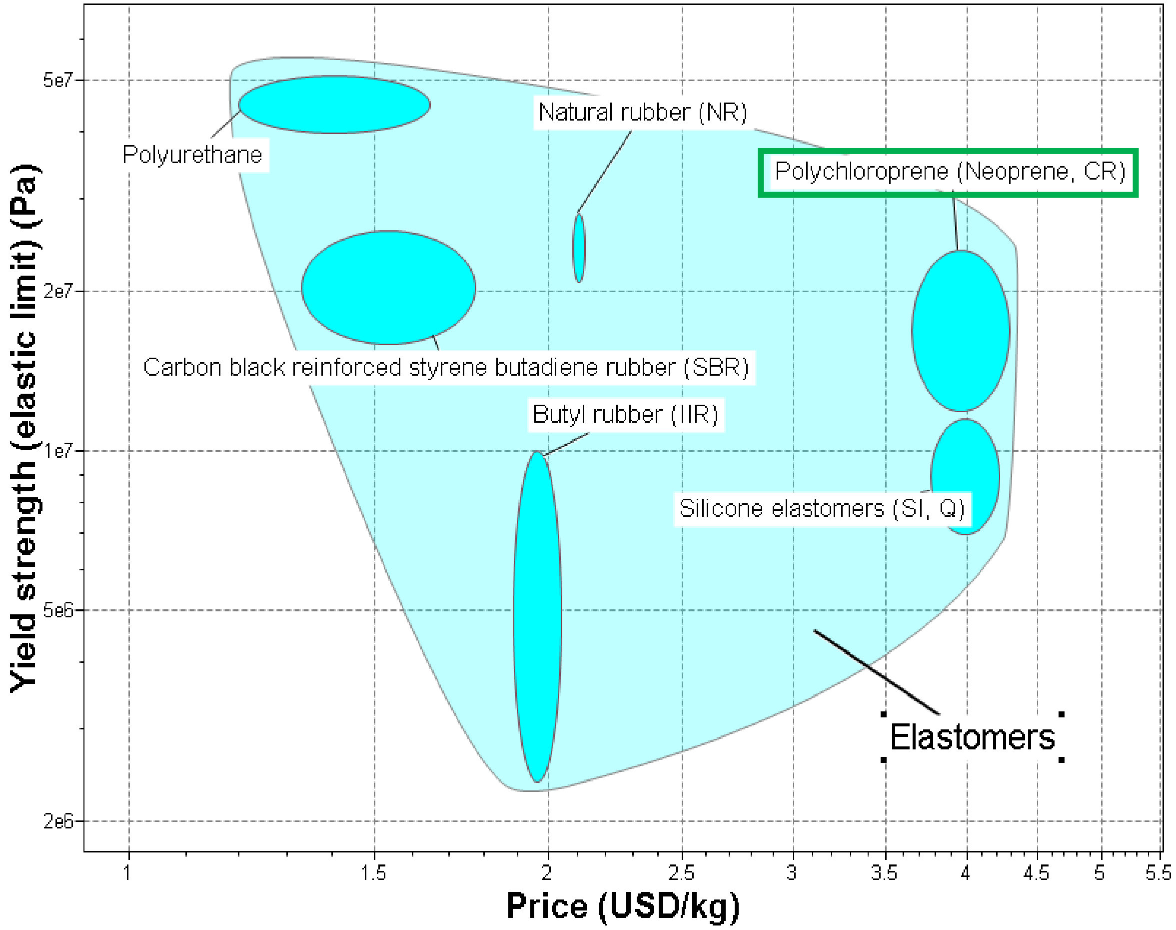

Fig 14: *Yield Strength Vs Price of Elastomers.*

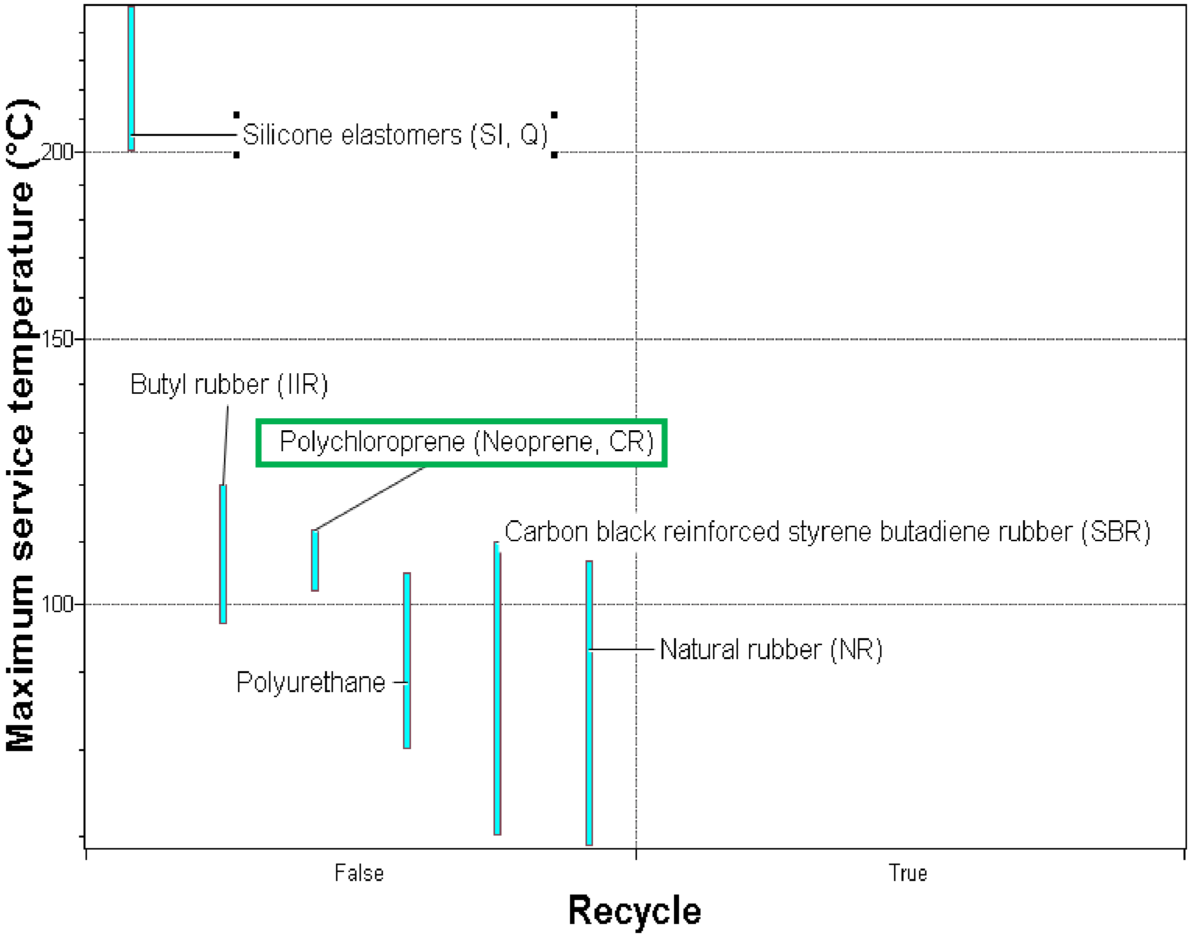

Fig 15: *Maximum temperature Vs Recycle of various Elastomers*

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- **Material Comparison Graph**

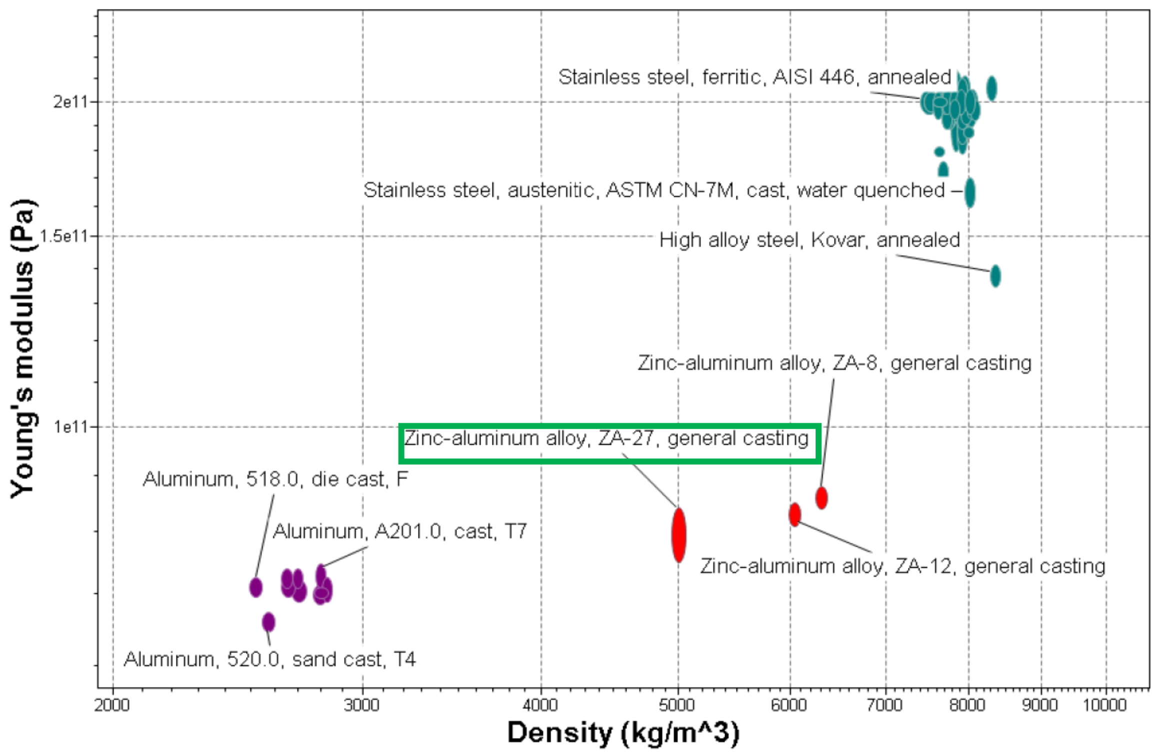


Fig 16: Yield Strength Vs Density of various metals.

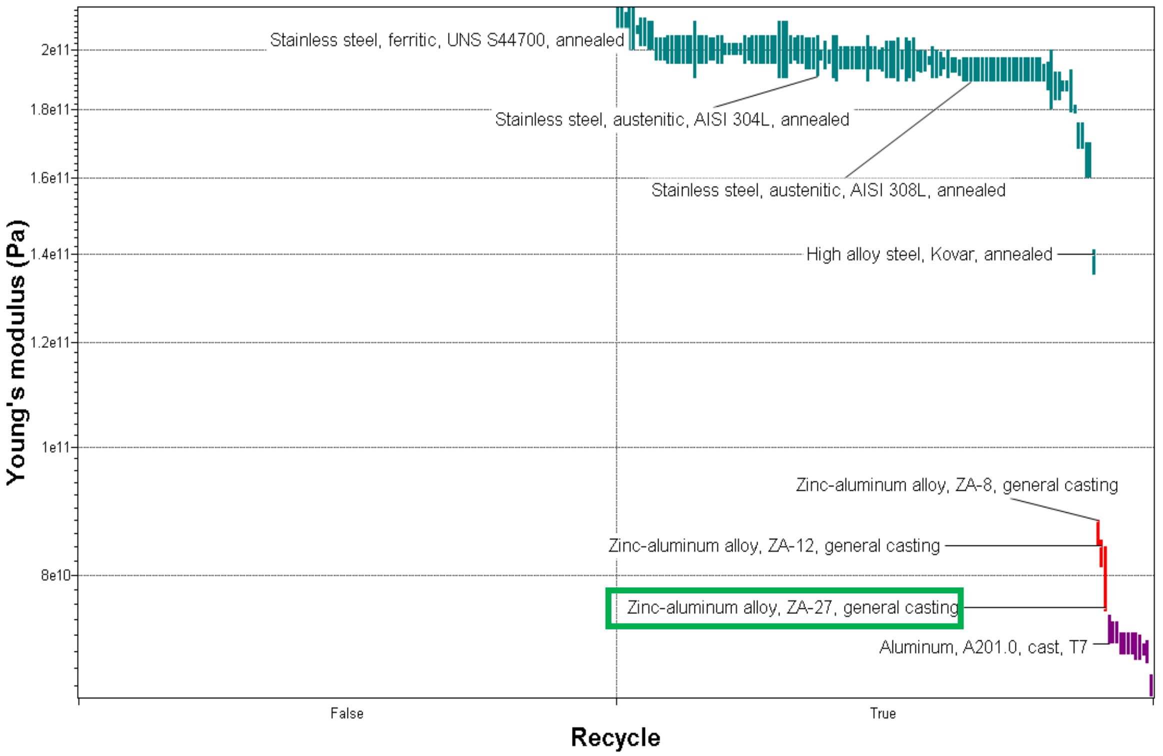


Fig 17: Yield Strength Vs Recycle of various metals.

Describe in term of price

City Vehicle Door/Car Park Friendly Door

- **Material Selection:**

Hinge

Linear actuator

Table 1: *Material specification Table*

	AISI 1025-C	SA216 (Type WCC)	ZA-27	Aluminium 7050
Price [GBP/kg]	0.582-0.646	0.662-0.726	1.8-2.05	3.07-3.46
Density [kg/m^3]	7820-7900	7810-7840	4950-5050	2810-2840
Yield Strength [MPa]	248-274	228-241	235-395	359-414
Tensile Strength [MPa]	379-419	434-462	290-445	427-483
Specific Strength [kN.m/kg]	31.5-34.9	29.1-30.8	47-79	127-147
Flexural Strength [modulus of rupture] [MPa]	248-274	228-241	235-395	359-414
Fatigue Strength at 10^7 cycles [MPa]	203-293	207	100-175	130-150
CO2 footprint, primary production [typical grade] [kg/kg]	1.33-1.55	1.33-1.55	4.88-5.52	7.86-9.17

City Vehicle Door/Car Park Friendly Door

▪ Material Selection:

- ❑ Neoprene/EPDM foam strips selected for sealing.
- ❑ This material passes the 3c08 requirements, but the majority polymer is EPDM.
- ❑ Neoprene provides high resistance against oils, acids, alkalis.
- ❑ EPDM has good weathering, heat and ozone resistance

Table 2: *Material specification Table*

Specification	Test Method	Required Limits	Test Results
Compression @25% Deflection (kPa)	ASTM D1056-00	35 – 65	43
Compression @50% Deflection (kPa)	ASTM D1056-00	80 – 160	112
Compression Set @50% 22h 20°C (kPa)	ASTM D1056-00	25% Max	19.1%
Water Absorption, max. change in weight (%)	ASTM D1056-00	10	0.8
Heat Aging, Change in Compression, 168h @ 70°C		±30%	Pass
Density (kg/M³)	ISO 845-95	120 ± 20	122
Flammability	FMVSS 302	Burn Rate < 100mm	Pass
Flammability	UL94 HBF		Pass
Elongation at Break (%)	ISO 1798-7		>180
Tensile Strength (KN/M²)	ISO 1798-7		>500
Temperature Range (°C)			-40°C to 85°C
High Intermittent			+100°C
Resistance to Air + UV			Excellent
Resistance to Oil			Poor
Resistance to Acids			Good
Environmental Protection			CFC and HFC free / Fully Recyclable
Specification		ASTM D1056-00 AFNOR 99-211	2A2 B2C 2C08/3C08 B3 C2

City Vehicle Door/Car Park Friendly Door

- **DFM- total manufacturing cost: 563.79 pence**

COMPONENT DETAILS					$M_c = V \times C_{mt} \times W_c$			A		$R_c = C_{mp} \times C_c \times C_s \times C_{ft}$									B	A + B
PART No. ID	PART DESCRIPTION	MATERIAL	PRIMARY PROCESS	SHAPE COMP.	VOLUME V [mm3]	C_{mt}	W_c	M_C	P_C	C_{mp}	C_c	C_s	Tolerance [mm]	C_t	Surface Finish [μm]	C_f	C_{ft}	R_C	$(P_C \times R_C)$	M_i
1	Eco Worthy 12 V Linear Actuator	Aluminum	AM	A1	278978.248	0.0005	1.6	221.4	1.3	4	1	1	0.12	1.34	0.4	2.3	2.3	9.2	11.96	233.36
2	M12x40 steel grade C hexagon head screw	stainless steel	AM	A2	6616.976	0.0018	2	24.218	1.3	4	1.2	1	0.06	1.15	0.8	1.5	1.5	7.2	9.36	33.578
3	M6x40 steel grade A hexagon head screw	stainless steel	AM	A2	1414.548	0.0018	2	5.1772	1.3	4	1.2	1	0.06	1.15	0.8	1.5	1.5	7.2	9.36	14.537
4	M12x50 steel grade A hexagon head bolt	stainless steel	AM	A2	8684.573	0.0018	2	31.264	1.3	4	1.2	1	0.06	1.15	0.8	1.5	1.5	7.2	9.36	40.624
5	M6x50 steel grade A hexagon head bolt	stainless steel	AM	A2	1727.174	0.0018	2	6.2178	1.3	4	1.2	1	0.06	1.15	0.8	1.5	1.5	7.2	9.36	15.578
6	Door Hinge	low-carbon steel	IC	A2	145953.8055	0.0004	1	64.22	11.2	1	1.2	1.5	0.06	2.1	0.6	1.8	2.1	3.78	42.336	106.56
7	Arm connected with hinge	low-carbon steel	IC	A1	49730.34295	0.0004	1	19.892	11.2	1	1	1.5	0.08	1.8	0.4	1.6	1.8	2.7	30.24	50.132
8	M6 steel grade A hexagon nut	stainless steel	AM	A2	349.263	0.0018	2	1.2783	1.3	4	1.2	1	0.06	1.15	0.8	1.5	1.5	7.2	9.36	10.638
9	M12 steel grade A hexagon nut	stainless steel	AM	A2	2150.733	0.0018	2	7.8717	1.3	4	1.2	1	0.06	1.15	0.8	1.5	1.5	7.2	9.36	17.232
10	M12x60 steel grade C hexagon head screw	stainless steel	AM	A2	8796.841	0.0018	2	32.196	1.3	4	1.2	1	0.06	1.15	0.8	1.5	1.5	7.2	9.36	41.556
																			Total Cost (p)	563.79

- **DFA- total assembly cost: 15.31 pence**

COMPONENT DETAILS			Handling Index H = Ah + [∑Po + ∑Pg]						Fitting Index F = Af + [∑Pf + ∑Pa]											C_l (F + H)
PART No. ID	PART DESCRIPTION	ASSY PROCESS	Ah	Po1	Po2	∑Po	∑Pg	H	Af	Pf1	Pf2	Pf3	Pf4	Pf5	Pf6	∑Pf	∑Pa	F	Line Total (F + H)	CMA (cost in pence)
1	Eco Worthy 12 V Linear Actuator	HAND/FIT	1.5	0.1	0.1	0.2	0	1.7	1	0	0.7	0	0	0	0	0.7	0	1.7	3.4	1.05
2	M12x40 steel grade C hexagon head screw	HAND/FIT	1.5	0.1	0	0.1	0	1.6	4	0	0	0	0	0	0.1	0.1	0	4.1	5.7	1.77
3	M6x40 steel grade A hexagon head screw	HAND/FIT	1.5	0.1	0	0.1	0	1.6	4	0	0	0	0	0	0.1	0.1	0	4.1	5.7	1.77
4	M12x50 steel grade A hexagon head bolt	HAND/FIT	1.5	0.1	0	0.1	0	1.6	4	0	0	0	0	0	0.1	0.1	0	4.1	5.7	1.77
5	Door Hinge	HAND/FIT	1.5	0.1	0.1	0.2	0	1.7	1	0	0.7	0	0	0	0	0.7	0	1.7	3.4	1.05
6	Arm connected with hinge	HAND/FIT	1.5	0.1	0.1	0.2	0	1.7	1	0	0	0	0	0	0	0	0	1	2.7	0.84
7	M12 steel grade A hexagon nut	HAND/FIT	1.5	0.1	0	0.1	0	1.6	4	0	0	0	0	0	0.1	0.1	0	4.1	5.7	1.77
8	M12x60 steel grade C hexagon head screw	HAND/FIT	1.5	0.1	0	0.1	0	1.6	4	0	0	0	0	0	0.1	0.1	0	4.1	5.7	1.77
9	M6x50 steel grade A hexagon head bolt	HAND/FIT	1.5	0.1	0	0.1	0	1.6	4	0	0	0	0	0	0.1	0.1	0	4.1	5.7	1.77
10	M6 steel grade A hexagon nut	HAND/FIT	1.5	0.1	0	0.1	0	1.6	4	0	0	0	0	0	0.1	0.1	0	4.1	5.7	1.77
																			Total Time 49	Total Assy Cost 15.31

City Vehicle Door/Car Park Friendly Door

- **Sustainability**

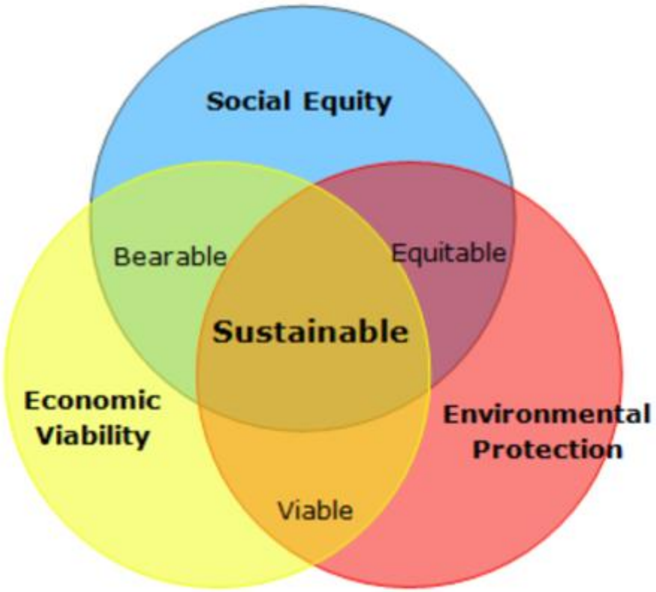


Fig 18: *Three Pillar of Sustainability*

- **Availability of materials.**
- **Life-cycle of materials.**
- **Transportation.**
- **Manufacturing Process and,**
- **Cost.**

City Vehicle Door/Car Park Friendly Door

- **DFMEA**

Item	Function	Potential Failure Mode	Potential Effects of Failure	Severity	Potential Causes of Failure	Occurance	Current Controls for Prevention	Detection	Detection	RPN	Recommended Action	Responsibility and Target Completion Date	Action Results				
													Action Taken	Svrty	Ocrnc	Dtctn	RPN
Hinge	connect two components keeping them alligned while supporting the weight of the door	Hinge Fracture	Door could come off and injure surrounding people	9	Bad material selection and excessive loading	3	Ensure Suitable material is selected by comparing properties such as Young's Modulas and Ultimate tensile strength of materials.	calculating forces resulting from the weight of the door, wind resistance.	2	54	Complete tensile, compressive and fatigue tests to determine stregth values for materials. Use of extra support.	20/03/2023	calculation of forces acting on the hinge. Double linkage introduced instead of one.	7	2	2	28
Linear Actuator	Push/pull the door	fails to keep/push door in primary position and failure to keep/pull into secondary position	Door will not operate fully	7	insufficient power provided by motor and faulty wiring, control communication error	2	Ensure motor in the linear actuator has sufficient capacity to lift door, use of high quality electrical components	buzzing noise from component, inspect wiring	2	28	Choosing appropriate shock and vibration testing standards of linear actuator such as IEC.	20/03/2023	Linear actuator with 8-35V 1500N Motor selected after calculation of force required to operate door	7	1	2	14
	act as secondary support of the door	Door weight no longer fully supported	Door may become loose	6	Excessive loading and side loading	2	Ensure the linear actuator of suitable material is selected by comparing properties such as Young's Modulas and Ultimate tensile strength of materials	Door will have slow and eratic operation	2	24	Complete tensile, compressive and fatigue tests to determine stregth values for materials	20/03/2023	Zinc-Aluminium alloy selected as a material due to its high yield strength.	6	1	2	12
Sealing	Waterproofing, Noise reduction, pressure control, climate control inside of the car	Tear in car seal	reduced fuel efficiency due to increased aerodynamic drag	6	Incorrect installation and not the correct use of adhesive	5	Ensure proper seal selection by considering system operating pressure, seal material compatibility with fluid and fluid operating temperature, resistance against extrusion, expected service life	Direct observation of the sealing in the frame of the car door. loud popping sound	2	60	Proper material selection for the sealing. Incase of tear replace sealing.	20/03/2023	Black closed cell neoprene/epdm foam strips used	6	3	2	36
			leakage of water and air inside car, increased noise.	6	Wear and tear overtime due to regular use	5	Tensile strength tests for different materials,	Partial or total sealing off of the frame	2	60	Use protective coating to help prevent damage from UV rays, moisture, and other environmental factors.	20/03/2023	Use of silicone coating	5	3	2	30

City Vehicle Door/Car Park Friendly Door

- ## Cost Estimation

Linear Actuators:

-Eco worthy Linear Actuator 6-inch- £63.99

-Eco worthy Linear Actuator 12inch - £68.99

Neoprene/EPDM foam strips:

10m roll-£16.25

- Roll length- 10m
- Thickness- 25mm
- Width- 25mm

Objective: Door opening within 5 sec.

- $linear\ actuator\ extension\ (d) = 0.35\ m$
- $required\ time\ (t) = 5\ sec$
- $mass\ of\ the\ door\ (m) = 25\ kg$
- $Power\ required\ (P) = ?$

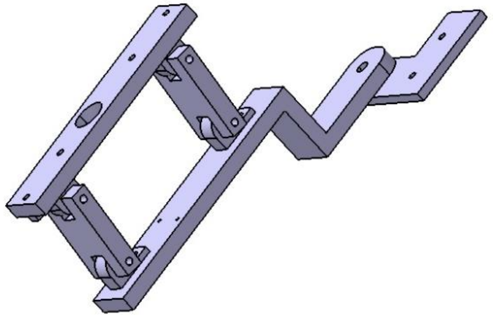
➢ $P = Force\ (F) * velocity(v) \quad where,\ v = \frac{d}{t}$

➢ $P = 17.16\ w$

Since, the power required by the linear actuator to open the door within 5 sec is 17.16 w

Hinge-AISI 1025 carbon steel:

- Cost: 5.1e3 GBP/m^3 = £5100/m^3
- Cost of manufacturing= 156.66 pence
- Cost of assembly= 15.31 pence
- Volume = 3389000mm3
- Price = £18.96



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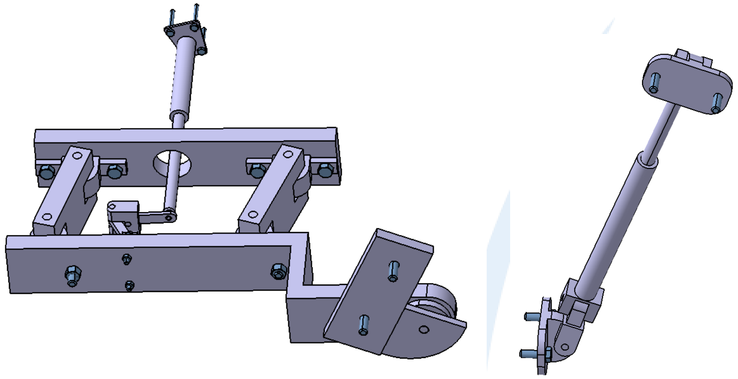
Cost Estimation:

Component	Price	Quantity
M12x40 steel grade C hexagon head screw	£2.20	4
M12x60 steel grade C hexagon head screw	£1.06	4
M6x40 steel grade A hexagon head screw	£1.65	4
M12x50 steel grade A hexagon head bolt	£1.53	2
M12x50 steel grade A hexagon head bolt	£2.86	2
M12 steel grade A hexagon nut	£1.15	2
M6 steel grade A hexagon nut	£0.61	2

Total Cost of Screw, Nuts, and Bolts: £31.94

Total Cost of door mechanism: £199.47



LSD door kit: £1096.67

City Vehicle Door/Car Park Friendly Door

- **Stress and Displacement Analysis-Static Analysis**

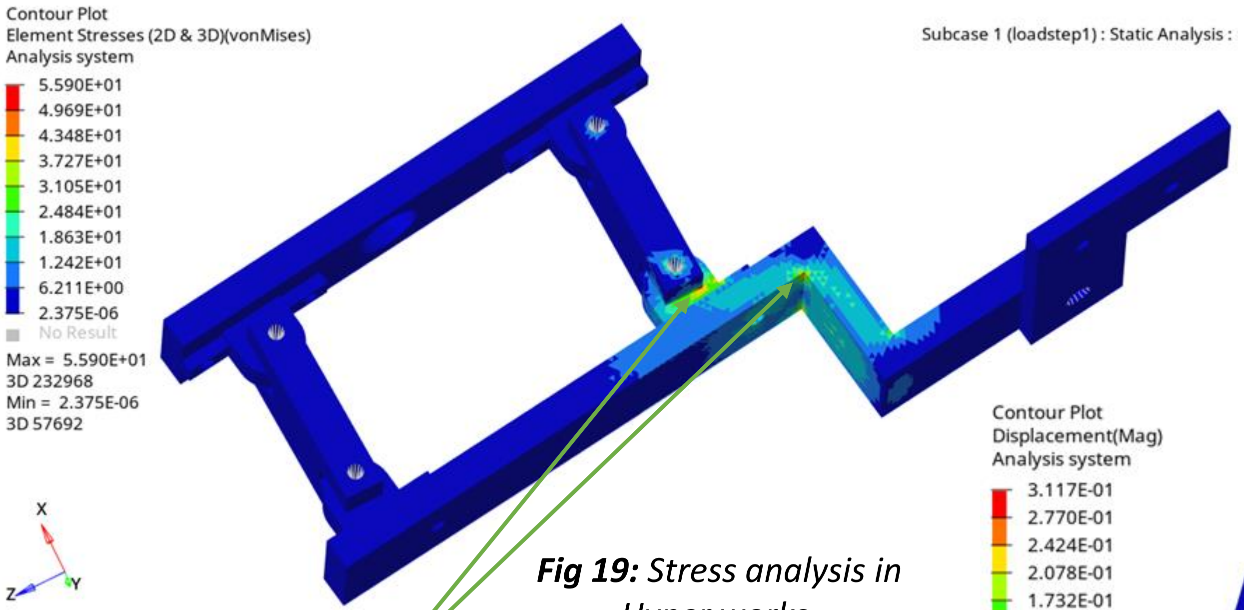


Fig 19: *Stress analysis in Hyper works.*

Assumptions:

- **Mass of the door: 25 Kg.**
- **Mass taken account: 4 x 25 Kg (door mass) + 50 Kg (extra mass) = 150Kg.**

- **Max Displacement: 0.3 mm**

- **Max Stress: 55.9 MPa**

- **Yield stress of low carbon: 255 MPA**
- **Factor of Safety: 4.56**

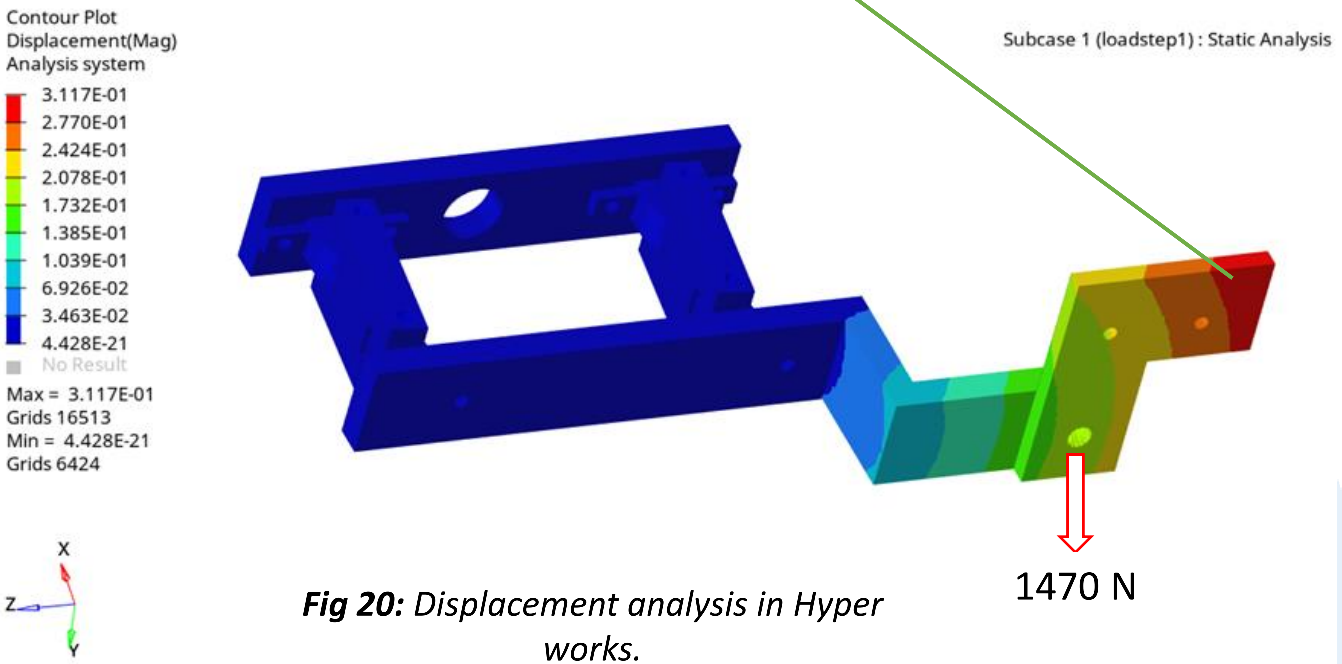


Fig 20: *Displacement analysis in Hyper works.*

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▪ Mesh Convergence Study

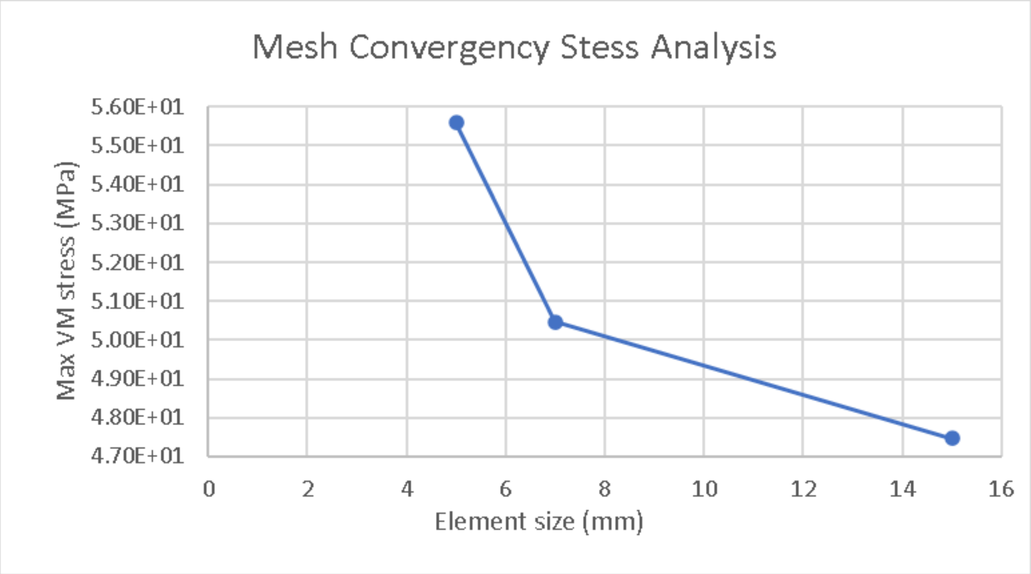

Fig 21: Mesh convergence stress analysis.

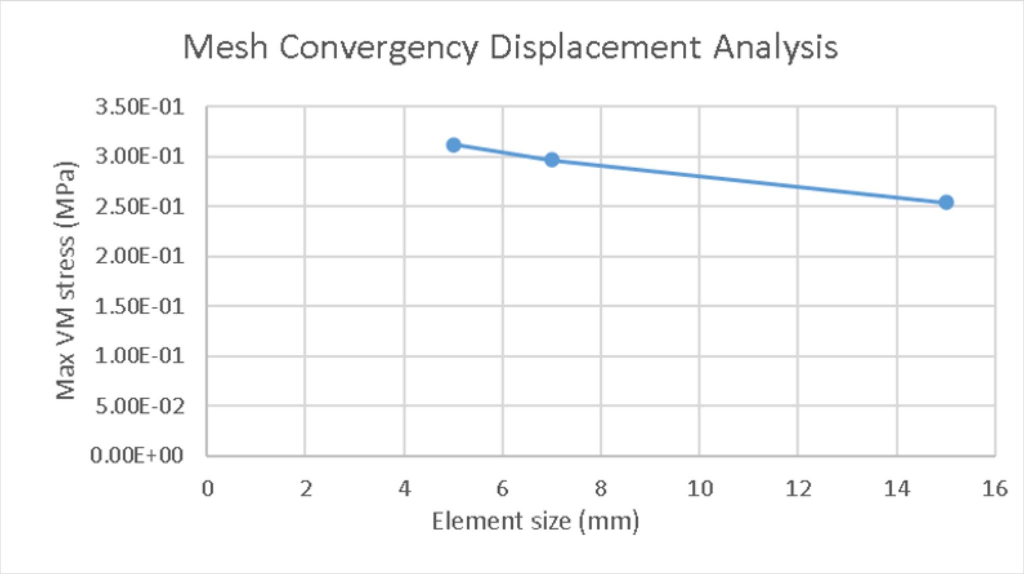

Fig 22: Mesh convergence displacement analysis.

- Different Models with Mesh size: **5,7 and 15 (mm)**
- Smaller results are showing more accuracy.
- Max stress lower than the yield strength.

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Forces at nodes

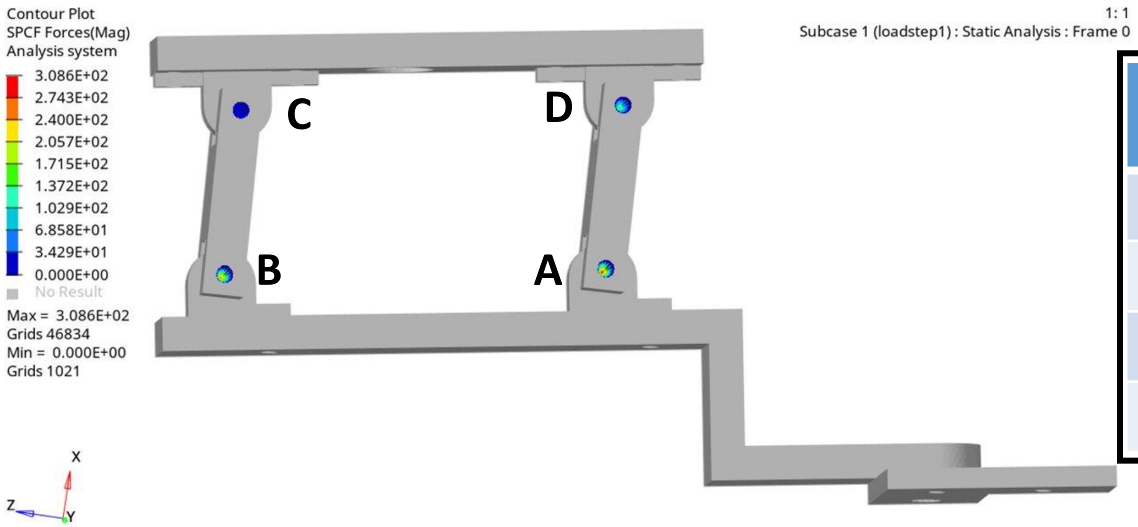

Fig 23: *Reaction forces at the nodes found using Hyper work.*

Node ID	Reaction forces [N]
A	308.6
B	272.5
C	34.6
D	158.1

Fig 24: *Results obtained using Hyper work.*

A_y	B_y	C_y	D_y
300.54 N (upward)	150.54 N (downward)	150.54 N (upward)	300.54 N (downward)

Fig 26: *reaction forces obtained Hand Calculation*

Percentage Error:

➢ $\frac{902.17-776.8}{902.17} * 100\% = 13.9\%$

Fig 27: *Percentage error between numerical approach and hand calculation*

Validation using Hand calculations:

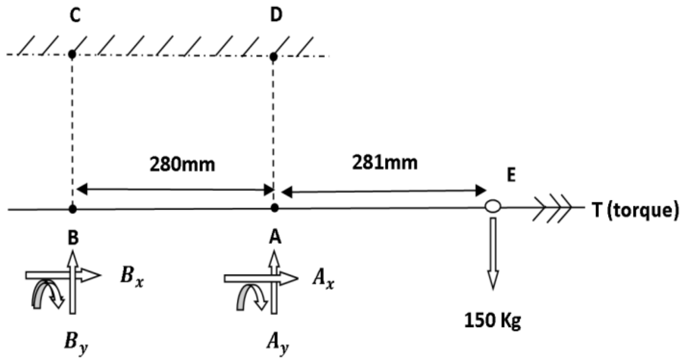

Fig 25: *Free body diagram of the hinge*

Assumptions:

- ➢ Straight arm.
- ➢ Linkages are held straight at half-open condition. Since, the forces at front and rear pin connection Experiences equal and opposite forces.

$\sum F_y = 0$

- $A_y + B_y - 150 = 0$ ------------------→ equation: 1

$\sum M_{B_y} = 0$

- $A_y * 280 - 150 * (281 + 280) = 0$ → equation: 2

$A_y = 300.54\ N$ (force reacting in upward direction)

$B_y = -150.54\ N$ (force reacting in downward direction)

$A_y = -D_y$ (*The force in A and D should be equal and opposite to balance the hinge*)

$-B_y = C_y$ (*The force in B and C should be equal and opposite to balance the hinge*)

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- **Modal Shapes at different Frequencies.**

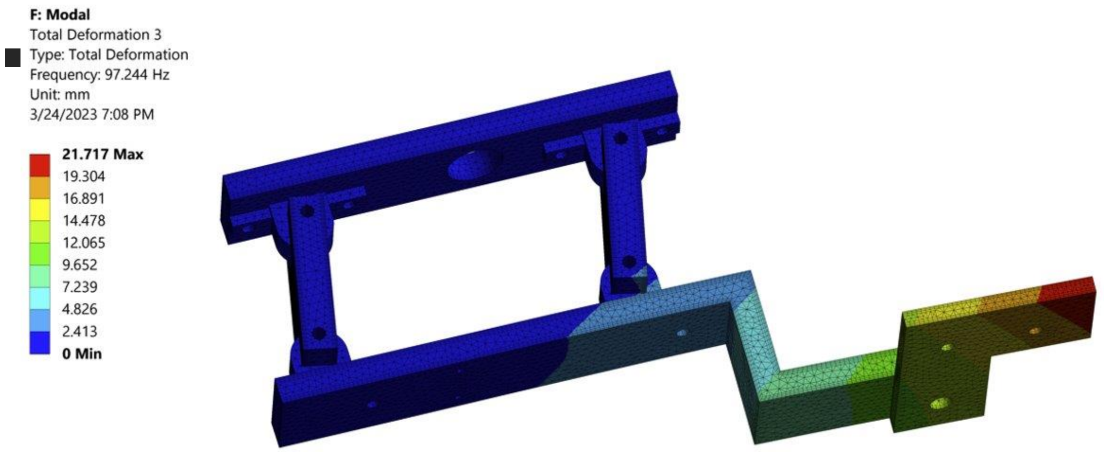

Fig 28: *Modal Shape of hinge at frequency* ***97.244*** *Hz*

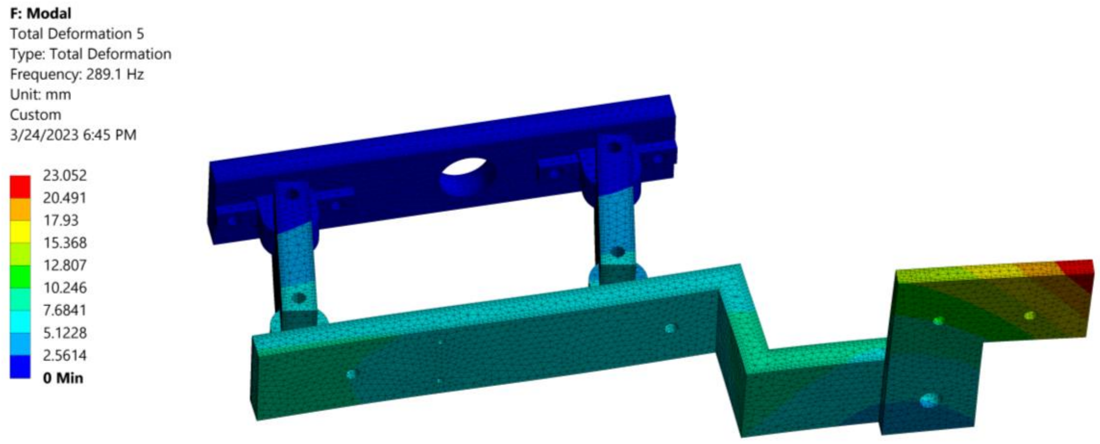

Fig 29: *Modal Shape of hinge at frequency* ***289.1*** *Hz*

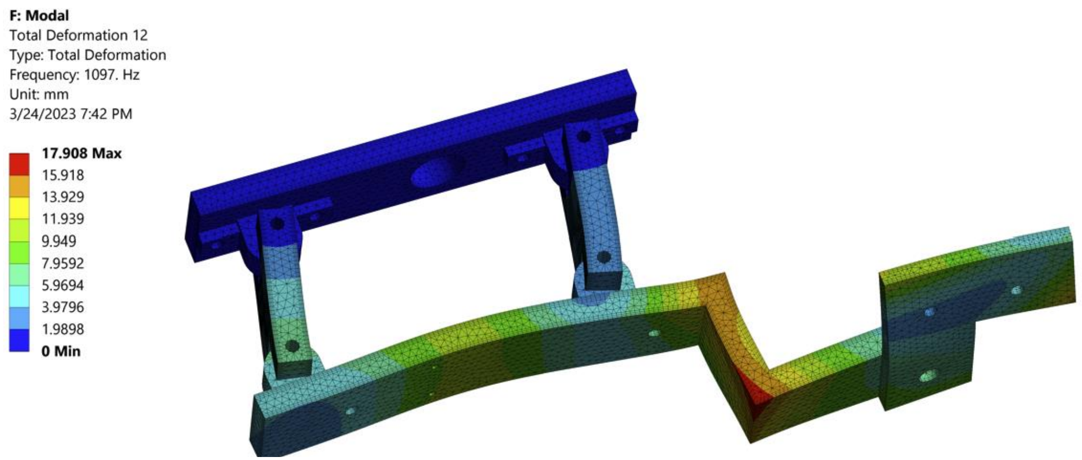

Fig 30: *Modal Shape of hinge at frequency* ***1097*** *Hz*

- **Deformation starts at frequency: 97.244 Hz**
- **Max displacement: 21.717 mm**

- **At frequency 289.1 Hz**
- **Max Displacement: 23.052 mm**

- **At frequency 1097 Hz**
- **Max Displacement: 17.908 mm and high deformation in the middle section in comparison.**

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- ## Design Optimization

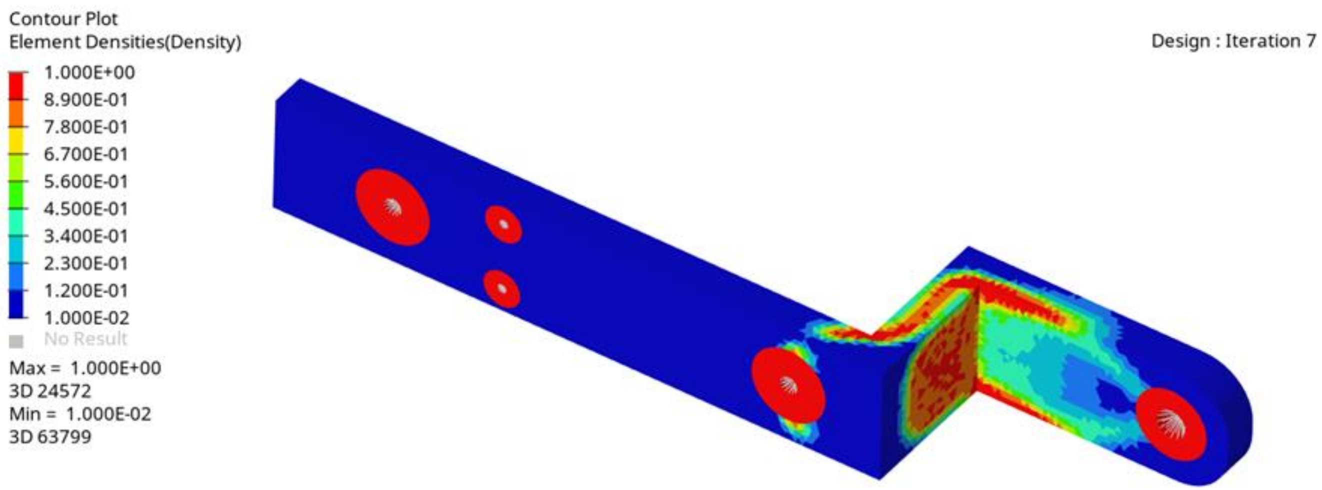

Fig 31: *Counter plot showing density change*

Part Considered
- ➢ Front arm

Objectives
- ➢ Minimize stress and minimize deformation.
- ➢ Volume, material reduction.

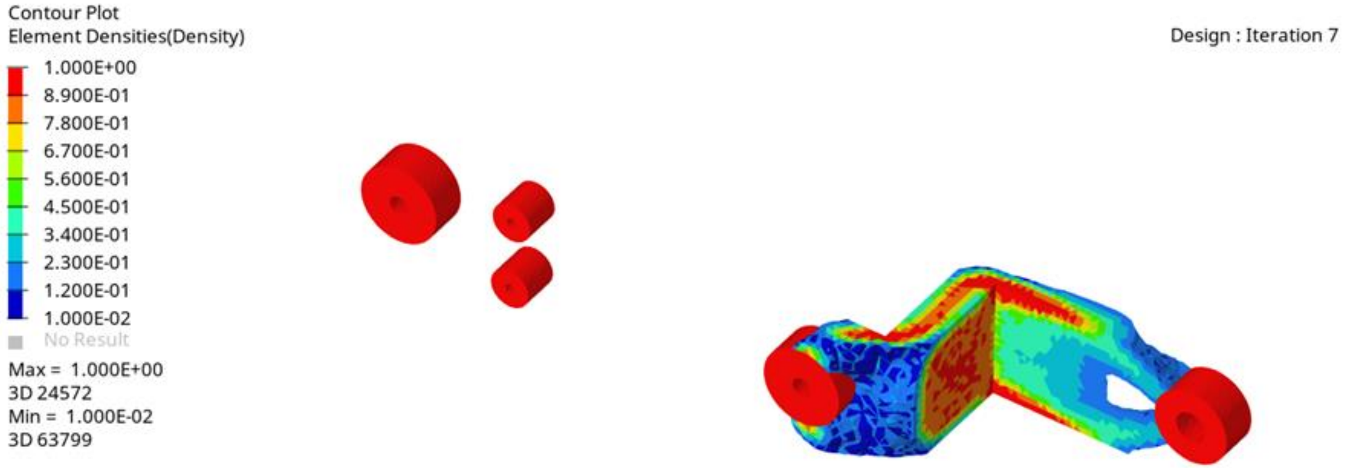

Fig 32: *Iso View of counter plot showing density change*

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▪ Design Validation

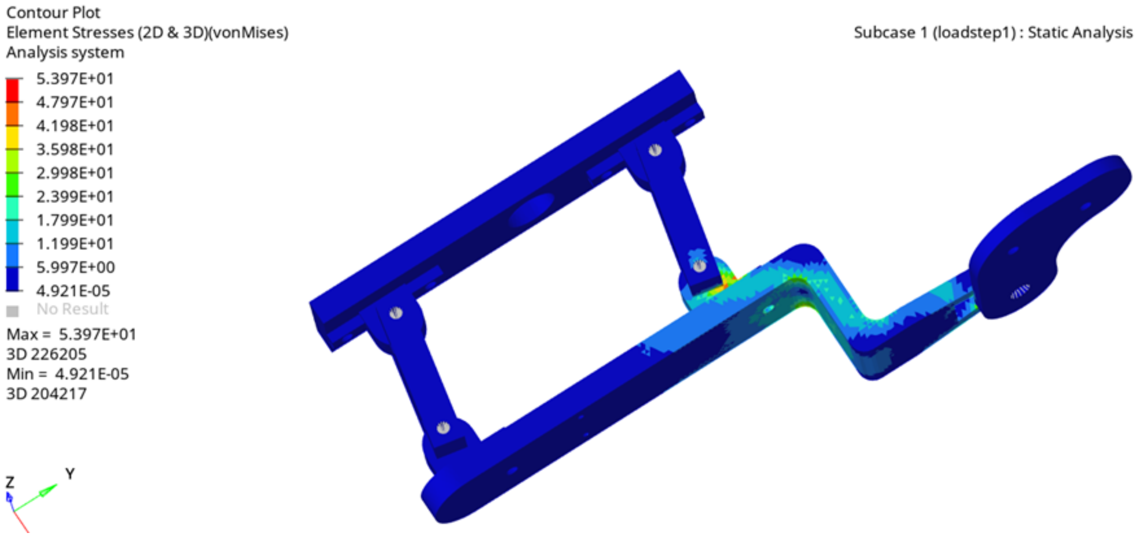

Fig 33: *Stress analysis after design validation.*

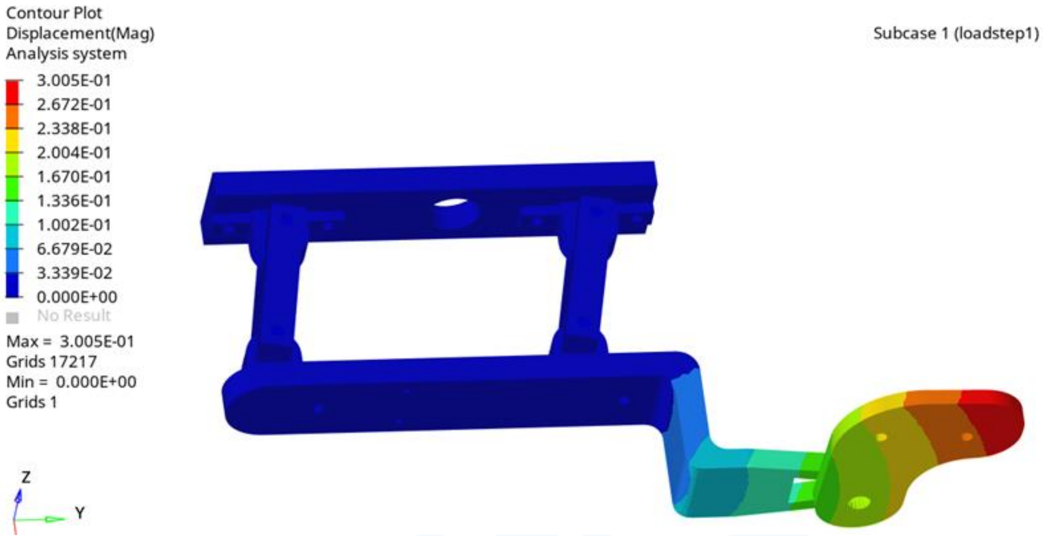

Fig 34: *Displacement analysis after design validation.*

- **Max stress: 53.9 MPa**
- **Max Displacement: 0.3 mm**

- **Mass of arm before optimization: 1371.933 g**
- **Mass of the arm after optimization: 1193.716 g**

Factor of Safety = 4.73

- **Stress Difference before and after optimization: 2 MPa**
- **Displacement difference before and after optimization: 0.11 mm**

Could achieved better results optimising all the highly stressed components.

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- **Ergonomics**

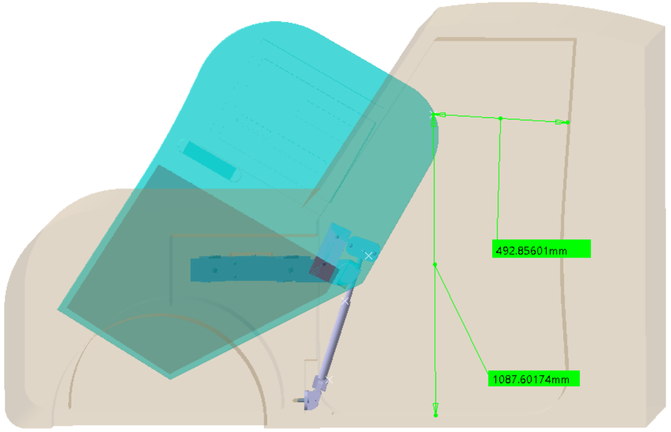

Fig 35: *Design showing the width of opening, and height of the door when door is opened.*

- Maximum opening of 1325.31mm in height and 492.86mm in width.
- A 95th percentile male has a hip breadth of 376.5mm and a sitting height of 971.9mm

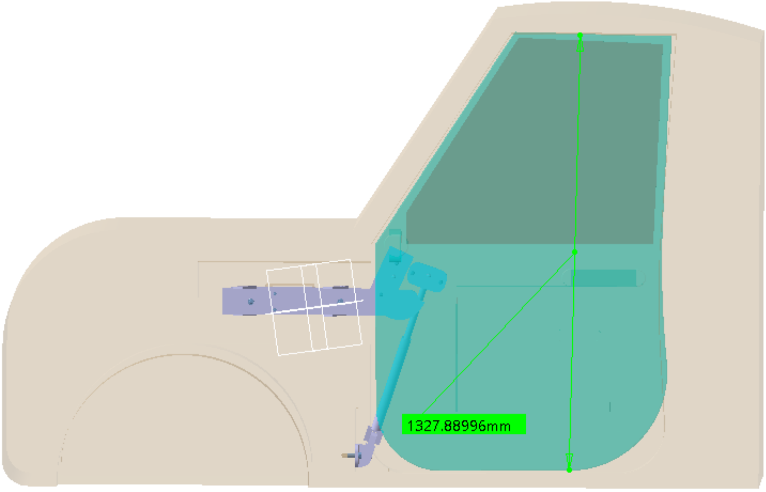

Fig 36: *Design showing height of the door*

- Car side pockets have a cover which remains constantly shut unless held open to prevent objects from falling while operating the door

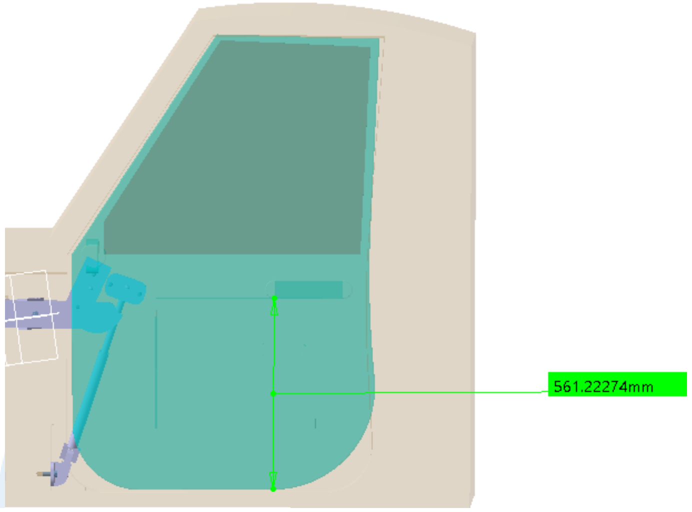

Fig 37: *Design showing the height from bottom of the door to handle*

- A 5th percentile female standing shoulder height (124cm)
- A 95th percentile male has a wrist height of (63cm)
- Door handle height (561mm) + Ride height of the door (219mm)= 78cm

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References

- Linear Actuator – Eco Worth linear actuator
  https://www.accu.co.uk/hexagon-nuts/7896-HPN-M12-A2?uk_google_shopping=1&c=3&gclid=Cj0KCQjwlPWgBhDHARIsAH2xdNfEO5YgEE73Miikp6QsEuMY8U7rapFImRAaILbOKePcH53tdH5Iu3saArX4EALw_wcB
- Sealing – Neoprene/EPDM foam strip
  https://www.polymax.co.uk/rubber-sheet/sponge-epdm-neoprene-foam-strips-sab
- Neoprene/EPDM foam strip property table
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- LSD door kit
  https://www.demon-tweeks.com/uk/lsd-lambo-look-door-kit-kwa50080014/
- *lambo-DooredV8 Range Rover Stromer Concept*
  https://www.youtube.com/watch?v=1xrJDsOVzBw&ab_channel=TopGear

Thank you for listening

Any Questions?