GYROSCOPIC 3D PRINTED CUP HOLDER

PROJECT REPORT

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BONAFIDE CERTIFICATE

Certified that this project report **"GYROSCOPIC 3D PRINTED CUP HOLDER"** is the bonafide work of

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ABSTRACT

Consuming liquids such as coffee, juice etc. in a moving vehicle is a very difficult task as the liquid contents are bound to spill as the vehicle navigates rough roads, potholes, steep inclines. Our project aims to prevent liquid spillage within a moving vehicle by providing a cup holder with two planes of free rotation in the XZ and YZ directions. This allows the liquid and its cup to continue in their inertia whenever there is a disturbance in the vehicle, preventing spillage. This is a very cheap but effective project that can save car owners thousands of rupees spent in cleaning stains and give them great peace of mind.

CHAPTER 1

1.1 INTRODUCTION

Keeping an opened and unsecured liquid beverage in a moving vehicle is a sure recipe for disaster. The liquid will spill whenever the vehicle accelerates, decelerates, brakes suddenly or encounters any kind of incline or sudden bump in the road surface. The reason this happens is because, the vehicle has undergone a change in its state of motion suddenly. The cup which is in contact with vehicle experiences that change next. This is transferred to the layer of liquid at the very bottom of the cup. However, the upper layers of liquid experience this change later, and as a result they still have the inertia of the previous state of motion. That is why when a vehicle, hard brakes, coffee in an open cup in the vehicle continues to have forward inertia and spills over. This spillage can be minimized by converting the inertia of linear motion into inertia of circular motion by creating a gyroscopic cup holder that has 2 planes for free rotation about the center of gravity of the cup and its contents.

1.2 OBJECTIVE

The objectives of this project are:

- To present a functioning prototype of a gyroscopic, 3D - printed cup holder for use in moving vehicles of any kind.
- The design and manufacturing process should be easy, efficient and cost effective
- Make use of readily available raw materials
- Modular design to ensure portability and easy adaptability to various use cases

1.3 NEED FOR THE PROJECT

An opened cup filled with liquid, placed in a moving vehicle will surely spill its contents due to the effect of inertia on the cup contents whenever the vehicle undergoes a relatively sudden change in its state of motion.

If the cup and its contents are placed in a gyroscopic cup holder with 2 planes of free rotation, any linear inertia that the cup and its contents have at times of sudden changes to the vehicles state of motion, will be converted to rotational inertia about the cup's centre of gravity. This will prevent spillage of the liquid contents inside the vehicle.

CHAPTER 2

2.1. COMPONENTS TO BE PRINTED

1. Inner Ring
2. Middle Ring
3. Outer Ring
4. Stand / Holder

2.2. COMPONENTS DESCRIPTION

2.2.1. Inner Ring

The Inner Ring is the smallest of the 3 rings that serves the purpose of holding the container. The ring has a diameter of 7.5 cm which is in accordance to the standard size of cup holders found in vehicles. It has a thickness of less than 5mm when viewed from top view to minimize weight. It has two cylindrical shafts on diametrically opposite ends of the rings that are used to attach to the middle ring. These shafts must be smooth to avoid friction. In applications where a very heavy load is to be used, ball bearings can be employed to ensure frictionless rotation however in the case of a cup holder where the net load is less than 500g this is not necessary.

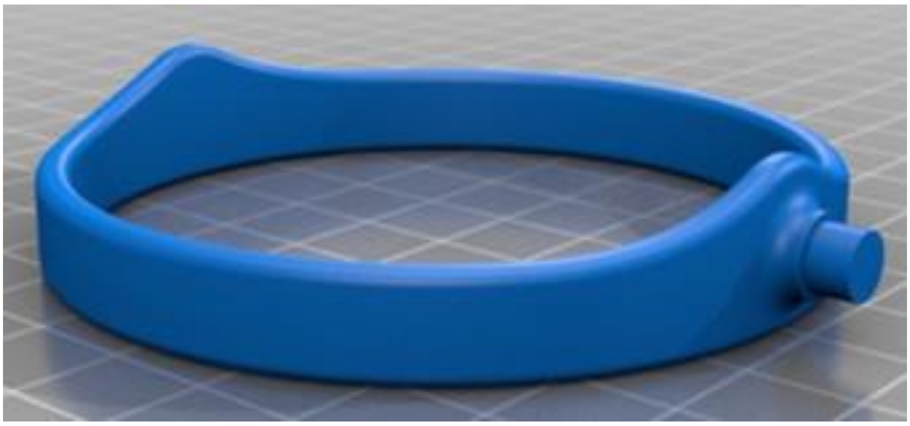

FIGURE 2.1 INNER RING

2.2.2. Middle Ring

The Middle Ring is the crucial ring that enables the cup to attain self-balancing or self-levelling properties. It is fundamentally similar to the Inner ring but has a larger diameter of 8.6 cm and also has two holes that support the shafts of the inner ring. It also has two shafts of its own that it uses to attach to the outer ring.

It is critical that the imaginary line joining its shaft and the imaginary line joining its holes are exactly perpendicular to each other. This allows the rings to convert the random rotation of the external source into the rotation along the X and Y axis

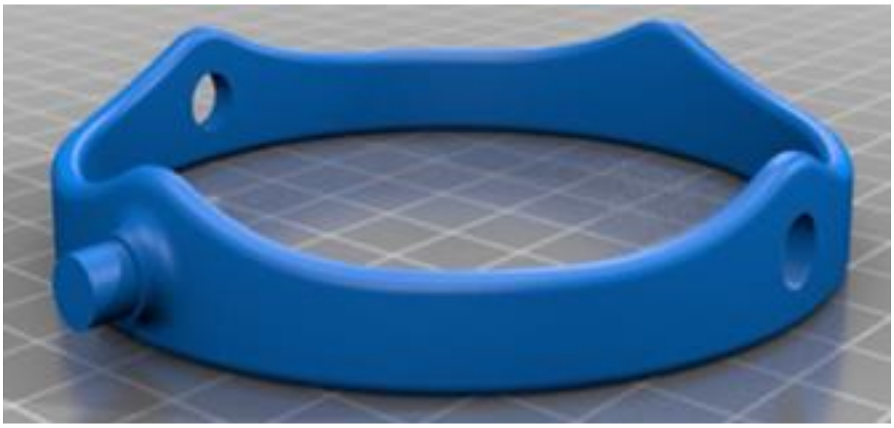

FIGURE 2.2 MIDDLE RING

2.2.3. Outer Ring

The Outer Ring acts as the main supporting structure that unites the rings to the stand. It has the largest diameter among the other rings of 10.4 cm and consists of two holes that support the shaft of the middle ring. It also connects to the stand via a removable interface. Unlike the other rings it is not necessary to produce a completely circular ring and a semi-circular ring is preferred as it reduces the overall weight, materials required and cost of production. The ring-stand interface can support different types of stands such as leg based stand, suction based and handle bar stand to adapt for different vehicles.

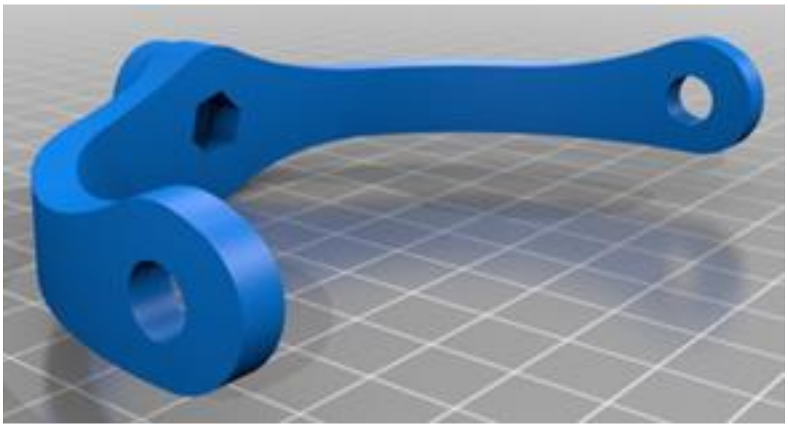

FIGURE 2.3 OUTER RING

2.2.3. Stand

The Stand is the main structural unit of the cup holder and is designed to be strong yet simple. Based on the type of scenario various different types of stands can be used. However their common goal is to support the rings. It is designed to be foldable and removable while also being able to withstand the torque generated by the weight of the rings and container. The one shown in the figure, and is also used in the prototype is broken down into 3 separate parts for portability and reusability of parts.

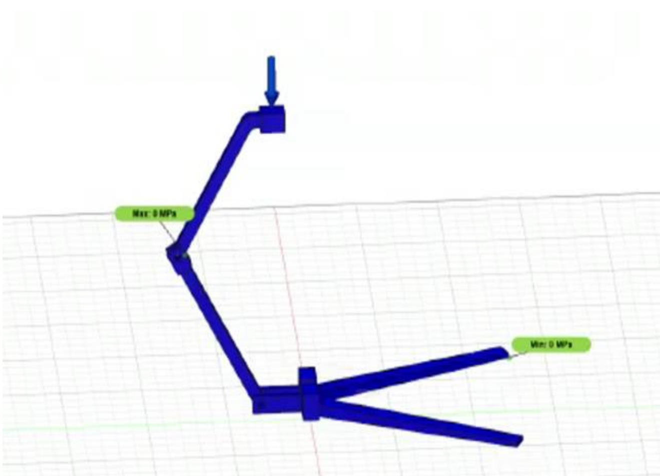

FIGURE 2.4 LEG TYPE STAND

2.3. MECHANICAL GYROSCOPES

A mechanical gyroscope essentially consists of a spinning mass that rotates around its axis. In particular, when the mass is rotating on its axis, it tends to remain parallel to itself and to oppose any attempt to change its orientation. This mechanism was invented in 1852 by physicist Léon Foucault during his studies of the Earth's rotation. If a gyroscope is installed on gimbals that allow the mass to navigate freely in the three directions of space, its spinning axis will remain oriented in the same direction, even if it changes direction.

A mechanical gyroscope shows a number of physical phenomena, including precession and nutation. In the following sections, the main operating principles of the mechanical gyroscopes are reported, with reference to the Inertial Navigation Systems.

2.3.1. Principle of Mechanical Gyroscopes: Gyroscopic Effects

The basic effect upon which a gyroscope relies is that an isolated spinning mass tends to keep its angular position with respect to an inertial reference frame, and, when a constant external torque (respectively, a constant angular speed) is applied to the mass, its rotation axis undergoes a precession motion at a constant angular speed (respectively, with a constant output torque), in a direction that is normal to the direction of the applied torque (respectively, to the constant angular speed).

However by using the force generated by the gravity of earth that intrinsically applies a force on the centre of mass of any object that acts perpendicularly to the earth's surface we are able to avoid any dependencies on rotational inertia. This eliminates the need for any electronic motors and actuators.

2.3.2. Rotational Axes of independence

The gyroscope converts its rotation into its X and Y axis rotational components. When there is rotation along the X axis the inner ring will rotate in an equal amount in the opposite direction with the middle ring effectively cancelling out the rotation along that axis. When there is rotation along the Y axis the middle ring will rotate in an equal amount in the opposite direction with the outer ring again cancelling out the rotation along that axis. When combined this setup is able to eliminate any external rotation.

This phenomenon is due to the inertia of the object and rings and the weight of the container acting along the centre of mass in a fixed downward direction. The container will always tend to be in its state of rotational equilibrium and the two degrees of rotational freedom enable it to do so thereby balancing the cups.

2.4. DESIGN

The design of the gyroscope has needs to balance form and function. The components must be designed to enable quick and easy 3D printing with less material wastage and weight. This is achieved by minimizing the thickness of the structure.

2.4.1. Rings

The rings are designed to be light weight and low thickness. The surface finish in the holes and shafts must be smooth to enable frictionless rotation. The weight distribution must be uniform across the entire volume of the rings. The centre of mass of the rings must be exactly at the geometric centre of the rings.

2.4.2. Stand

The stand is designed to be foldable and variable angle. This is to enable easy transport and setup. The base consists of two long legs placed 45 degrees apart from each other. The stand comprises of smaller parts that are combined together using screws. This reduces the printing time and reduces wastage of materials while also allowing the stand angle to be variable.

2.5 3D PRINTING

3D printing, or additive manufacturing, is the construction of a three-dimensional object from a CAD model or a digital 3D model. The term "3D printing" can refer to a variety of processes in which material is deposited, joined or solidified under computer control to create a three-dimensional object, with material being added together (such as plastics, liquids or powder grains being fused together), typically layer by layer.

2.5.1 Types of 3D Printing

There are several types of 3D printing, which include:

- Stereo lithography (SLA)
- Selective Laser Sintering (SLS)
- Fused Deposition Modeling (FDM)
- Digital Light Process (DLP)
- Multi Jet Fusion (MJF)
- Poly jet
- Direct Metal Laser Sintering (DMLS)
- Electron Beam Melting (EBM)

2.5.2 The five 3D Printing Considerations

The 5 important factors to be considered before selecting a suitable printing technique or machine are,

- Budget
- Mechanical requirements
- Cosmetic appearance
- Material selection
- Geometry

2.5.3 Fused Deposition Modelling (FDM)

Fused filament fabrication (FFF), also known as fused deposition modelling (with the trademarked acronym FDM), or called filament freeform fabrication, is a 3D printing process that uses a continuous filament of a thermoplastic material. Filament is fed from a large spool through a moving, heated printer extruder head, and is deposited on the growing work.

The 3D printer head or 3D printer extruder is a part in material extrusion additive manufacturing responsible for raw material melting and forming it into a continuous profile. A wide variety of filament materials are extruded, including thermoplastics such as acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), polyethylene terephthalate glycol (PETG), polyethylene terephtathalate (PET), high- impact polystyrene (HIPS), thermoplastic polyurethane (TPU) and aliphatic polyamides (nylon).

2.6 3D PRINTING PLASTICS

2.6.1 Acrylonitrile butadiene styrene (ABS)

Acrylonitrile butadiene styrene (ABS) (chemical formula $(C_8H_8)_x \cdot (C_4H_6)_y \cdot (C_3H_3N)_z$) is a common thermoplastic polymer. Its glass transition temperature is approximately 220 °F (104 °C). ABS is amorphous and therefore has no true melting point.

ABS is a terpolymer made by polymerizing styrene and acrylonitrile in the presence of polybutadiene. The proportions can vary from 15% to 35% acrylonitrile, 5% to 30% butadiene and 40% to 60% styrene.

2.6.2 Polylactic acid (PLA)

Polylactic acid (PLA), also known as polylactide, is a thermoplastic polyester with backbone formula $(C_3H_4O_2)$, formally obtained by condensation of lactic acid $(C(CH_3)(OH)HCOOH)$ with the loss of water.

PLA has become a popular material due to it being economically produced from renewable resources. In 2010, PLA had the second highest consumption volume of any bioplastic of the world, although it is still not a commodity polymer. Its widespread application has been hindered by numerous physical and processing short comings. PLA is the most widely used plastic filament material in 3D printing.

Properties*	ABS	PLA
Tensile Strength**	27 MPa	37 MPa
Elongation	3.5 - 50%	6%
Flexural Modulus	2.1 - 7.6 GPa	4 GPa
Density	1.0 - 1.4 g/cm^3	1.3 g/cm^3
Melting Point	N/A (amorphous)	173 °C
Biodegradable	No	Yes, under the correct conditions
Glass Transition Temperature	105 °C	60 °C
Spool Price*** (1kg, 1.75mm, black)	$USD 21.99	$USD 22.99
Common Products	LEGO, electronic housings	Cups, plastic bags, cutlery

Table 2.1 Comparison between ABS and PLA plastic

2.7 3D PRINTER

2.7.1 Creality Ender 3 FDM 3D Printer

Creality Ender 3 is fused deposition modelling (FDM) based 3D printer, suited for hobbyists. It has a build volume of 220mm x 220mm x 250mm, a Build-Tak-like heated build plate, power recovery mode, and a tight filament pathway that makes it easier to print with flexible materials.

3D Printer
Fig 2.5

2.7.2 Creality Ender 3 FDM 3D Printer Technical Specifications

Modeling Technology: Fused Deposition Modeling (FDM)

Printing Size: 220mm x 220mm x 250mm

Printing Speed: 180mm/s

Filament: 1.75mm PLA, TPU, ABS

Working Mode: Online or SD offline

Compatible File Formats: STL, OBJ, G-code

Machine Size: 440mm x 440mm x 465mm

Net Weight: 8kg

Power Supply: 100-265V, 50-60 Hz

Output: 24V, 15A, 270W

2.7.3 Creality Ender 3 FDM 3D Printer Extruder Hardware Technical Specifications

Layer Thickness: 0.1-0.4mm

Nozzle Diameter: 0.4mm

Printing Accuracy:± 0.1mm

Nozzle Temperature: 255°C

2.7.4 SOFTWARE USED

- AUTODESK fusion 360
- AUTODESK Inventor

2.8 FINAL PROTOTYPE IMAGES

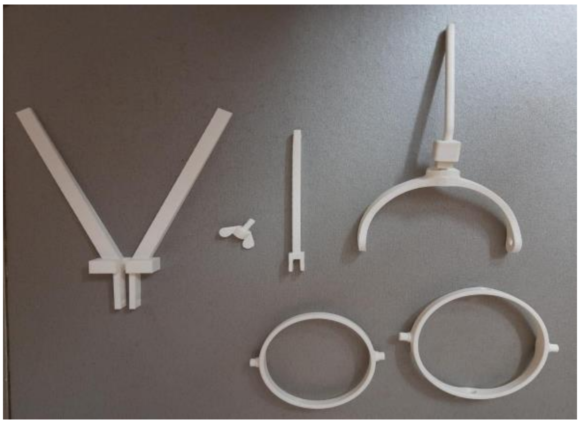

Fig 2.6 Components Top View

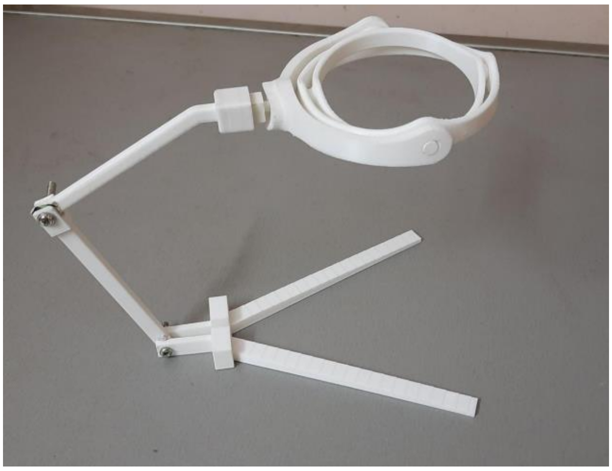

Fig 2.7 Assembled View

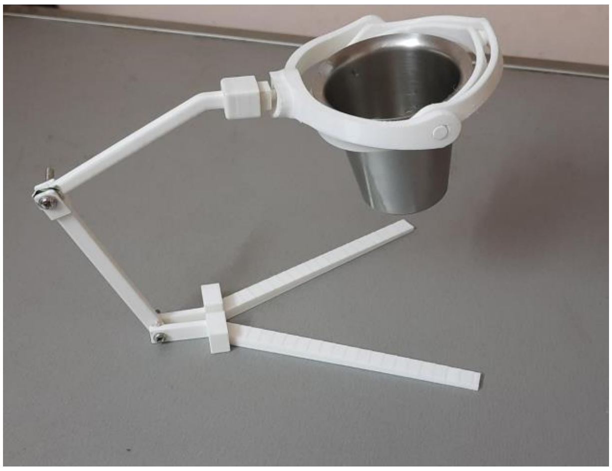

Fig 2.8 Under Load

CHAPTER 3

3.1 COST ESTIMATION

S. NO	COMPONENTS	WEIGHT (grams)	COST (Rs 1.12 per gram)
1	Inner Ring	14	15.68
2	Middle Ring	17	19.04
3	Outer Ring	16	17.92
4	Stand Link 1	18	20.16
5	Stand Link 2	16	17.92
6	Base	27	30.24
7	Wing Nuts	16	17.92
8	Wastage	10	11.2
	TOTAL	**134**	**150.08**

Table 3.1 Cost of prototyping

3.2 STATIC STRESS TEST

3.2.1 Damping Mesh

Average Element Size (% of model size)	
Solids	10
Scale Mesh Size Per Part	No
Average Element Size (absolute value)	-
Element Order	Parabolic
Create Curved Mesh Elements	No
Max. Turn Angle on Curves (Deg.)	60
Max. Adjacent Mesh Size Ratio	1.5
Max. Aspect Ratio	10
Minimum Element Size (% of average size)	2

Table 3.2 Damping mesh stress test results

3.2.2 Adaptive Mesh Refinement

Number of Refinement Steps	0
Results Convergence Tolerance (%)	20
Portion of Elements to Refine (%)	10
Results for Baseline Accuracy	Von Mises Stress

Table 3.3 Mesh Refinement

3.2.3 ABS Plastic

Density	1.06E-06 kg / mm^3
Young's Modulus	2240 MPa
Poisson's Ratio	0.38
Yield Strength	20 MPa
Ultimate Tensile Strength	29.6 MPa
Thermal Conductivity	1.6E-04 W / (mm C)
Thermal Expansion Coefficient	8.57E-05 / C
Specific Heat	1500 J / (kg C)

Table 3.4 ABS plastic properties

3.2.4 Load Constraints

Type	Force
Magnitude	1.47 N
X Value	6.808E-19 N
Y Value	3.346E-15 N
Z Value	-1.47 N
Force Per Entity	No

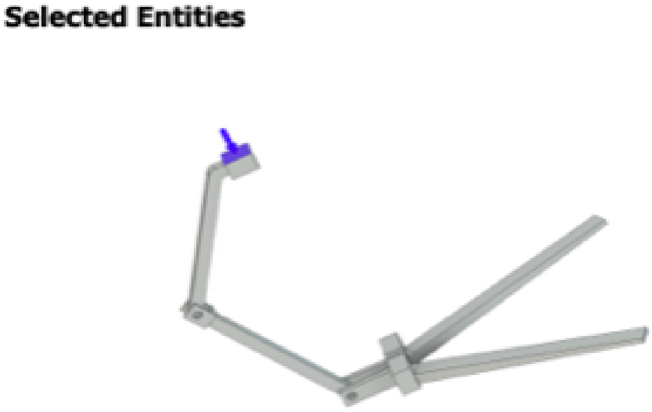

Fig 3.1 Load constrains

3.2.5 Loads

Type	Fixed
Ux	Fixed
Uy	Fixed
Uz	Fixed

Fig 3.2 Loads

3.2.6 Results Summary

Name	Minimum	Maximum
Safety Factor		
Safety Factor (Per Body)	2.258	15
Stress		
Von Mises	8.526E-11 MPa	8.859 MPa
1st Principal	-0.4605 MPa	4.738 MPa
3rd Principal	-8.947 MPa	0.4826 MPa
Normal XX	-1.971 MPa	1.414 MPa
Normal YY	-2.642 MPa	2.526 MPa
Normal ZZ	-6.834 MPa	3.154 MPa
Shear XY	-1.432 MPa	0.7664 MPa
Shear YZ	-1.446 MPa	2.291 MPa
Shear ZX	-2.046 MPa	3.914 MPa
Displacement		
Total	0 mm	2.6 mm
X	-0.06786 mm	0.004325 mm
Y	-3.687E-04 mm	2.236 mm
Z	-1.327 mm	0.3299 mm
Reaction Force		
Total	0 N	0.1684 N
X	-0.1023 N	0.06656 N
Y	-0.08546 N	0.04558 N
Z	-0.0538 N	0.1264 N
Strain		
Equivalent	4.936E-14	0.006402
1st Principal	3.457E-14	0.004303
3rd Principal	-0.006508	-1.712E-14
Normal XX	-6.214E-04	0.001332
Normal YY	-0.001092	8.011E-04
Normal ZZ	-0.002644	0.001232
Shear XY	-0.001765	9.444E-04
Shear YZ	-0.001781	0.002823
Shear ZX	-0.002521	0.004822

Table 3.5 Results Summary

3.2.7 Safety Factor (Per Body)

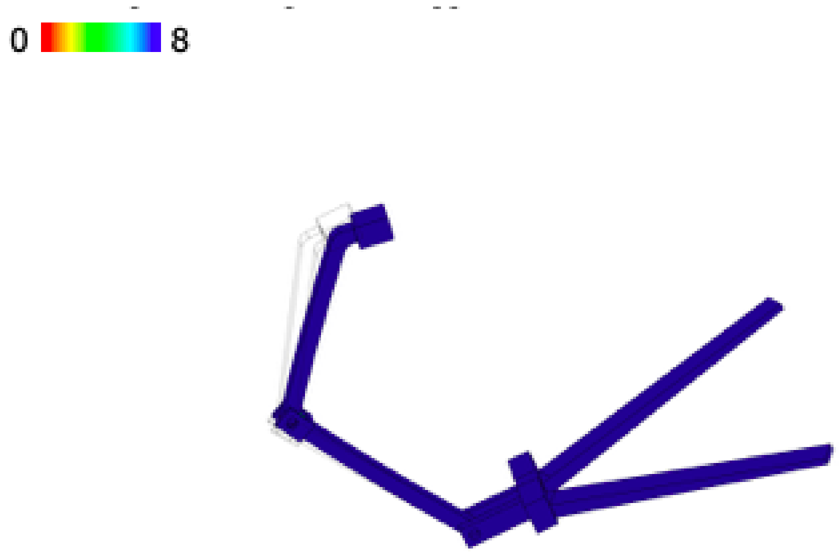

Fig 3.3 Safety Factor of stand

3.2.8 Von Mises Stress

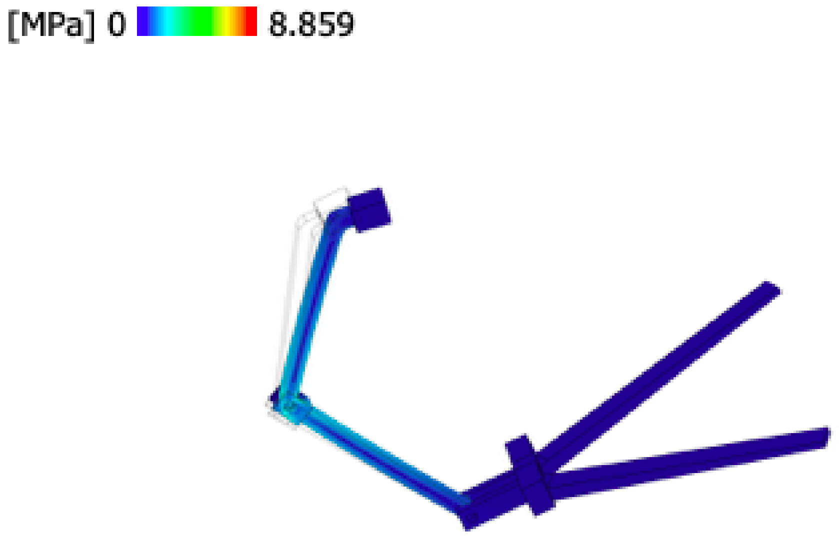

Fig 3.4 Von Mises Stress of stand

3.2.9 1st Principal Stress

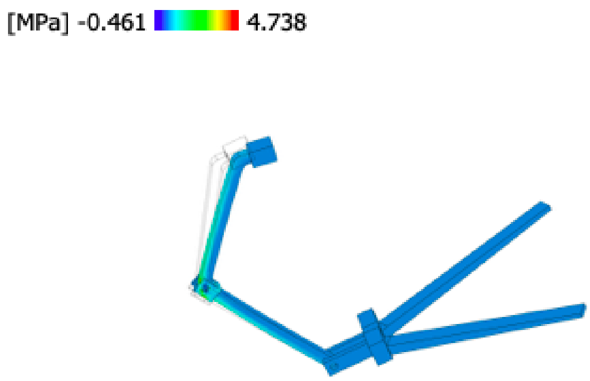

Fig 3.5 First Principle Stress

3.2.10 3rd Principal Stress

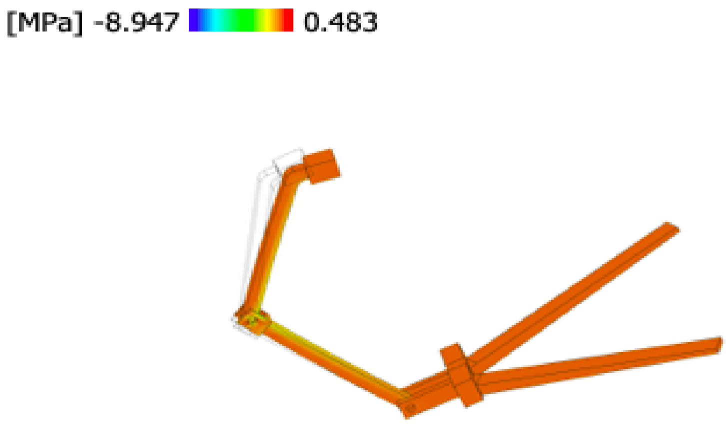

Fig 3.6 Third Principle Stress

3.2.11 Total Displacement

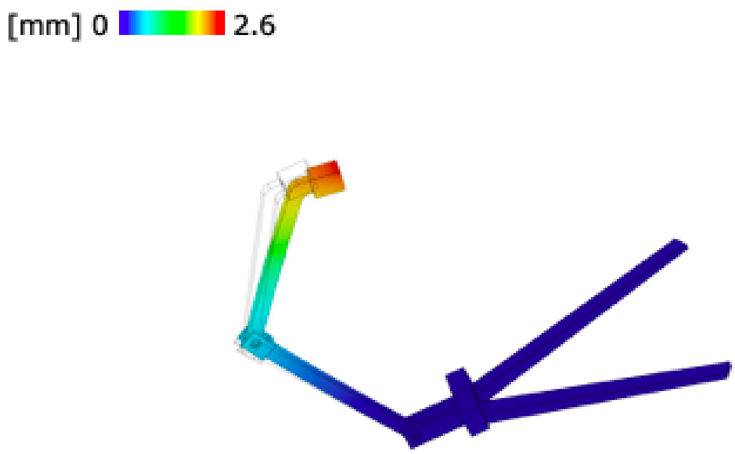

Fig 3.7 Total displacement under load

CHAPTER 4

4.1 CONCLUSION

The prototype is found to perform as expected in various conditions and orientations. This allows it to be used in vehicles of all types such as bikes, cars or trucks, preventing spillage of beverages and avoiding unwanted cleanup and maintenance costs. The stand can be customized for the vehicle type or attaching method. Additionally the stand is foldable and variable angle which allows quick setup, dismantling and transport. Due to low cost of production, it can be easily considered as a mass market product.

The Stress and Load analysis is performed on the stand and is found to be suitable for supporting loads without failure. The Properties of the 3D printer, 3D printing plastics and the process of low cost and wastage 3D printing are utilized to minimize the unwanted costs and weight in the final print.

CHAPTER 5

5.1 REFERENCES

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