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Research paper

DESIGN OF A SINGLE MAST RETRACTABLE CARPORT CANOPY

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Abstract: *Design solution to failure of carport canopy structural frame under severe weather conditions is presented. The carport is conceived to be a single mast structure supporting an overhead retractable canopy operated by screw mechanism. The retraction of the canopy deny extreme weather conditions such as strong wind or heavy snowfall a surface area on which to act upon thereby generating excessive load that may collapse the whole structure. The design process followed well established design procedure. Critical components were analyzed for functionality and safety. A proof of concept model at a reduced scale was fabricated which successfully demonstrated the efficacy of the deployment and the retracting mechanism.*

Key words: *Carport, Retractable canopy, Power screw, Polyethylene canvas, DC motor.*

1. INTRODUCTION

Carport canopies are common residential or public building structures for protection of vehicles from the elements most especially, sun rays. Extended exposure of vehicles to direct sunlight had been shown to cause premature fading of vehicle paintwork [1], while excessive interior heat may affect the quality of interior plastic parts and fabric overtime [2]. Carport covering fabric is usually fixed. However this type of design can prove dangerous in extreme weather conditions such as during heavy snowfall or strong wind. Excessive ice weight on the fabric may lead to the collapse of the support structure which is not usually design to carry additional load other than that of the canopy. The canopy can also provide undesired surface area for wind pressure to act upon leading to generation of large force that may eventually collapse the support structure. However, a solution to these problems is to make the covering fabric (the canopy) retractable so that during these type of extreme weather conditions, the surface area they act upon can be reduced to a minimum if not totally reduced to zero. Also making the canopy structure to rest on a single mast will allow easier maneuverability of the vehicle when being parked under the canopy by reducing the number of obstructions compared to when it is supported by two or four props depending on the design. This paper thus presents design of a single mast retractable carport canopy to solve the issues earlier stated. Generally the design process is both sequential and iterative. A schematic of a typical design procedure which serves as a guide for this work is as depicted in Fig. 1 based on [3- 5].

2. BASIC PARAMETERS AND THE CONCEPT

Dimensions of parking lot space for individual vehicle varied from country to country. In the United States, they typically fall between 7.5 to 9 feet (2.25 to 2.7m) wide and 10 to 20 feet (3.0 to 6.0m) long [6]. However for this design, the height of the concept carport mast was predetermined as 2.4m, while the maximum surface dimensions of the covering fabric when fully deployed is prefixed as 2.6m by 4.12m. With these basic dimensions, the concept retractable carport canopy is as depicted in Fig. 2.

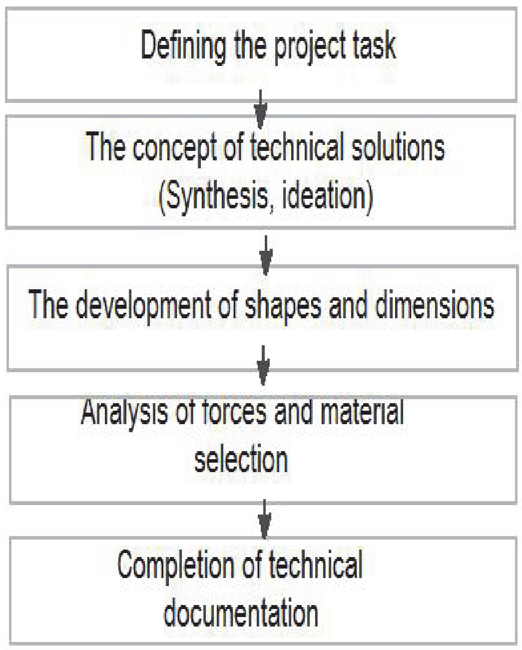

Fig.1. General procedure in machine design

The canopy is conceived to deploy and retract using power screw mechanism (Fig.2-b). Power screws are used to convert rotary motion into translation motion. In majority of power screw applications, the nut has axial motion against the resisting axial force while the screw rotates in its bearings [4]. This relative motion between

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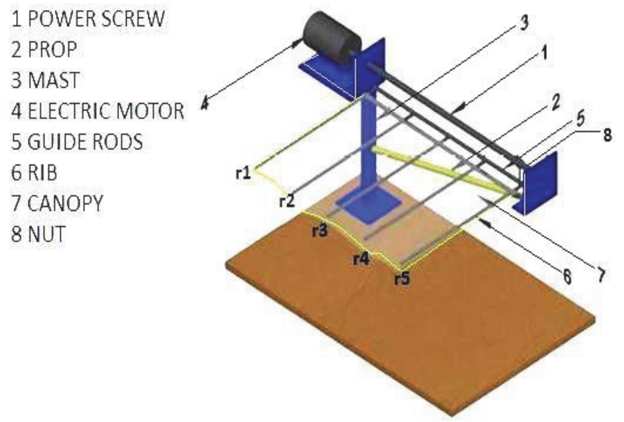
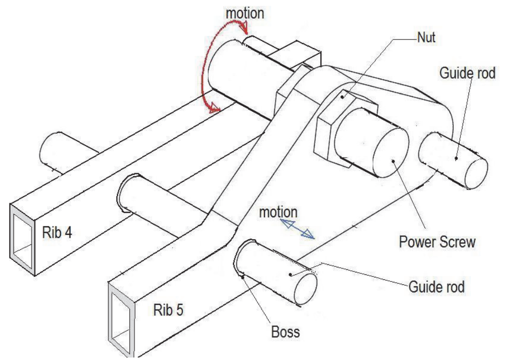
screw and nut is at the heart of the operating mechanism of this present design. The power screw is rotated by an electric motor in its bearing. The screw's nut with the



(a)



(b)

Fig.2. Conceptual sketch of the retractable carport canopy (a) and the details of the screw mechanism (b).

outermost rib (r5) integral to it is advanced back or forth depending on the screw direction of rotation. The ribs r2 to r4 are dummy mobile ribs, while rib r1 closest to the motor is fixed. Ribs r2-r5 slides on two parallel guide shafts which pass through the bosses on the canopy ribs [Fig. 2-b]. When the powered rib (r5) is driven outward from the motor, it drags the fabric along from its limp form till it become tight, and then the stretched portion of the fabric starts to drag along rib 4. The process continues for the rest of the ribs (r2 and r3) until the canopy is fully deployed over the parking space. Retraction is actualized when the power screw rotates in the opposite direction and slides the ribs back towards the mast. A plastic cover extending along the entire length of the screw mechanism and partially wrapped round it protect it from the elements. The ribs are to be made from aluminum alloy (6063) for strength and comparative lightweight, the rest of the metallic parts (mast, guide rod etc) from rust resistant structural steel, the screw cover from a suitable plastic, while the canopy is made from high quality, waterproof polyethylene canvas.

3. DESIGN CALCULATIONS OF IMPORTANT COMPONENTS

The following sub-sections present design calculations for the main components of the carport.

3.1. Screw Forces Analysis and Motor Sizing.

The screw forces analysis diagram is as shown in Fig. 3. The screw thread was based on ACME thread form. ACME threads are commonly used when rapid movement is required or large forces are transmitted. This thread is the most common form used in screw mechanisms for industrial machines [7].

The force F required to slide the canopy and rib subassembly over the steel guide rods is given by

$F=\mu_s W$ (1)

Where μ_s is coefficient of static friction for steel on steel dry surface taken as 0.6 [8], F= F_f (force to overcome friction) and W = Fn (the normal reaction).

$W = (Wc + Wr)g$ (2)

Where Wc is the mass of canopy (kg), Wr is the mass of the four mobile ribs(kg), and g is acceleration due to gravity(m/s^2). Wc = (weight/unit area of canopy X area of canopy).

Weight/unit area of canopy is taken as $500 g/m^2$ [9].

Wc = 5.36kg.

$Wr = \rho.l.x.y.n$ (3)

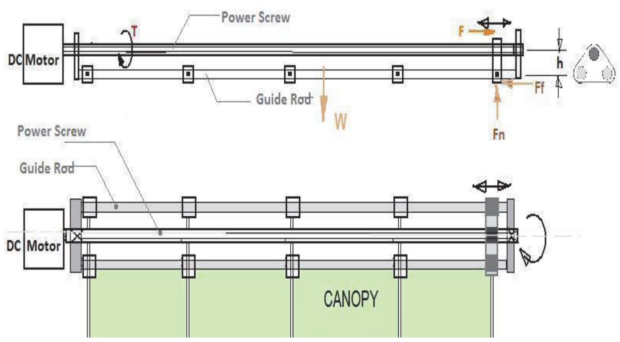


Fig.3. Screw forces analysis diagram

Where ρ is density of aluminum alloy 6063 (rib material) taken as 2720 kg/m^3 [10], l is length (2.4m), x is the width (60mm) and y is the depth (60mm) of the rib (if the rib is initially assumed for now to be a prismatic bar of rectangular section), and n is the number of mobile ribs (four in number).

Wr = 93.66 kg, hence

W = 971.30N.

Thus, F= 582.80 N.

The canopy is expected to fully deploy in a minute. The total length of the active section of the screw is fixed at 4.12 m (length of canopy). ACME thread Steel screw of nominal diameter 40mm is selected. In practice power screws are provided by specialist suppliers who provide technical literature which includes all the necessary data for selecting power screws from their range [11]. From [4] the pitch p of 40mm ACME thread screw is given as 6mm. For deployment time t in minute, the screw speed N in revolution per minute (rpm) is given by

$N = l/pt$ (4)

N = 687 rpm. The speed (ω) in angular notation is given by

$\omega = 2\pi N,$ (5)

$\omega=72$ rad/s.

The torque T required to turn the screw under the force F is given by;

T= P (d/2) (6)

Where d is the mean diameter of the screw and the tangential force P of the screw circumference is given by [4];

$$P = F\frac{\tan\alpha + \tan\phi}{1-[\tan\alpha\tan\phi]} \quad (7)$$

tan ϕ = 0.1 [4],

$$\tan\alpha = pitch/(\pi d) = 0.0516 \quad (8)$$

P is determined as 88.51 N. The torque is determined as 1.64 Nm. The power of the motor to turn the screw is given by;

$$Power = T\omega \quad (9)$$

The minimum value of the motor power is determined as 117.90 W. The motor is to be a DC permanent magnet electric motor. The motor selected is IMPERIAL ELECTRIC permanent magnet motor P56 SD 113 rated 700W and 1070 rpm with VAC integral rectified to VDC. The motor shaft is capable of rotating in either direction (data sheet available at *www.imperialelectric.com*).

3.2. Rib Boss Sizing

For non interference of the power screw on the ribs sliding on the guide rod, the screw is elevated by height h above the parallel guide rods (Fig.4). To prevent jamming of the rib bosses while sliding on the guide rods under force F which is not collinear with friction force F_f, the bosses, and by extension, the rib must have a minimum width x. x is 60mm (section 3.1), thus h is given by [8]as;

$$h = \frac{x}{2\mu k} \quad (10)$$

Where μ_k is coefficient of kinetic friction for steel on steel dry surface taken as 0.4 [8]. Thus h=75mm.

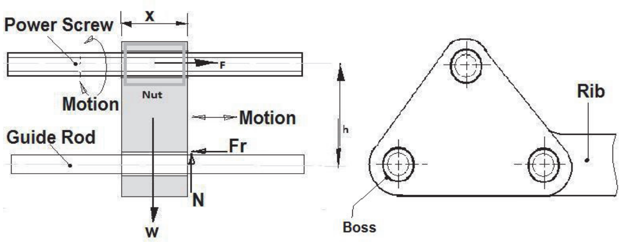


Fig.4. Schematic of rib boss analysis.

3.3. Canopy Rib(s) Cross-Sectional Shape and Dimensions.

Due to the weight of the canopy, the screw force F as well as its own weight, the ribs are subjected to both transverse and longitudinal deflections (Fig.5). The ribs are fashioned from hollow square section aluminum alloy pipe 60mm by 60mm with thickness 6mm. The cantilevered length L of the ribs had been pre-fixed at 2.4m (overall length is 2.6m). The forces acting on the ribs are as depicted in Fig.5. Force F and W (section 3.1) are taken to be evenly spread along the length of the cantilever with values f=0.0606N/mm and w=0.01011 N/mm respectively. The deflection δf and δw respectively caused by F and W were determined thus [12];

$$\delta f = fL^4/8EI \quad (11)$$

$$\delta w = -wL^4/8EI \quad (12)$$

Where E is the modulus of elasticity for aluminum taken as 71000N/mm^2 [13] and I is section modulus calculated as637632 mm^4. The deflections δf and δw were obtained as 5.55 mm and 0.93 mm respectively. Both values are within the predetermined maximum safe deflection value of up to 10mm.

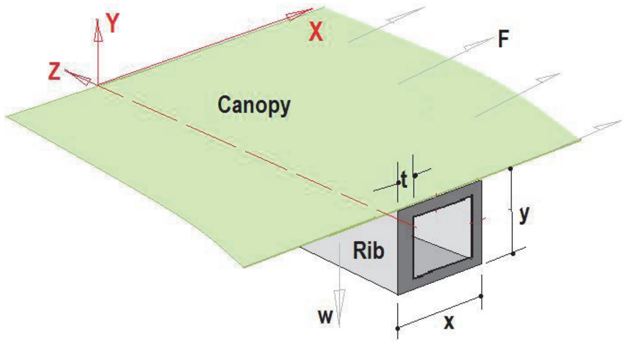


Fig.5. Deflection forces acting on the ribs.

3.4 Mast

The mast carries the weight of all other components; hence its structural integrity under both the steady and dynamic loadings of the deployment and retraction process is very critical. With the imposed loads and boundary conditions, FEM simulations were carried out for the mast to determine the stresses and displacements (Fig. 6).

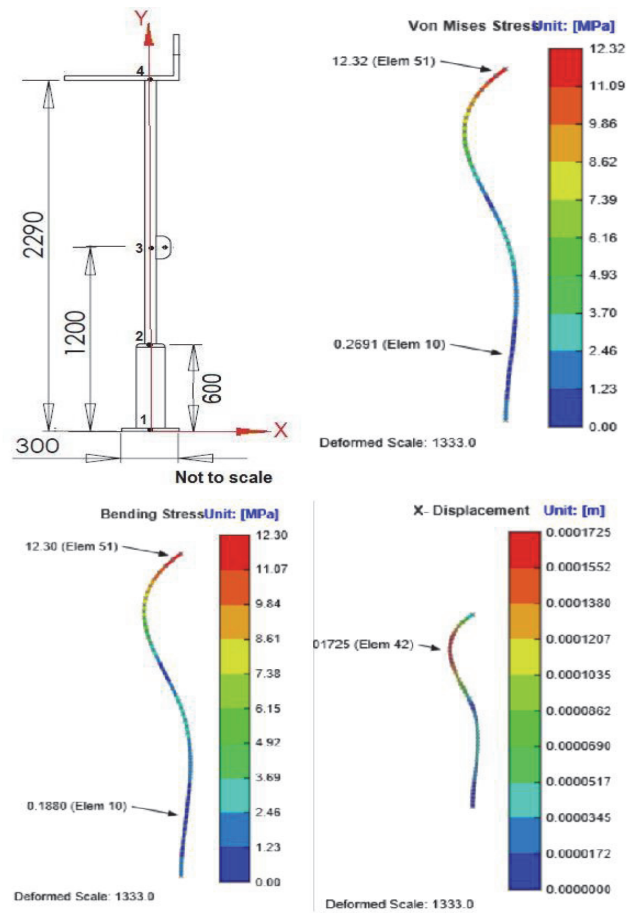


Fig.6. Mast FEM simulations showing results for Von Mesis stress, Bending stress and displacement.

The upper section of the mast is made from 15mm (6'') rust resistant steel pipe; while the lower portion is fashioned from 220mm (9'') pipe. The maximum bending stress results obtained from the simulations is 12.60 MPa which is less than the ultimate tensile strength and yield stress of 448MPa and 345 MPa respectively for the material [10]. The maximum deformation (or displacement) is 0.17 mm. This implies that there is no risk condition of overloading leading to excessive deformation or failure of the mast.

4. ORTHOGRAPHIC DRAWING OF NON STANDARD COMPONENTS

The fully dimensioned orthographic drawings of the main components are as shown in Fig 7-13. All dimensions are in mm. The orthographic and isometric views of the assembled retractable carport canopy are depicted in Fig.14 completed with part list. The drawings were produced using SOLIDWORKS.

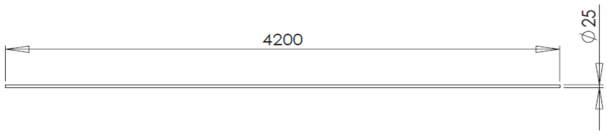


Fig.7. Guide rod(s)

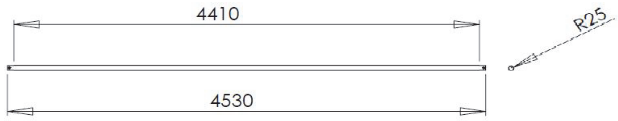


Fig.8. The Prop

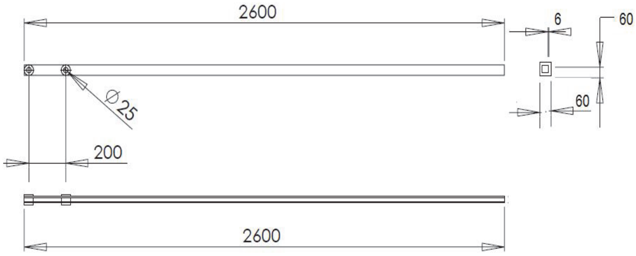


Fig.9. The Rib(s)

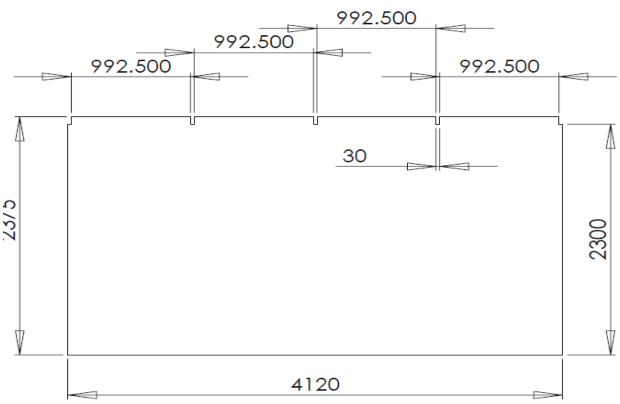


Fig.10. Canopy canvass cutting instruction

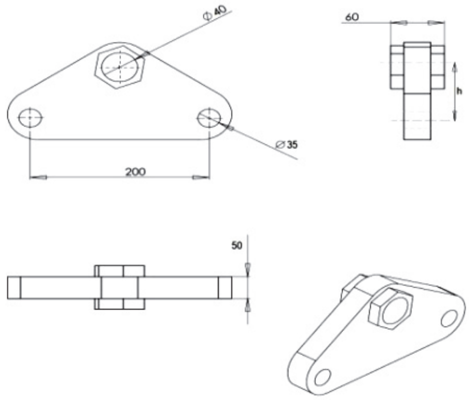


Fig.11. The Nut sub-assembly

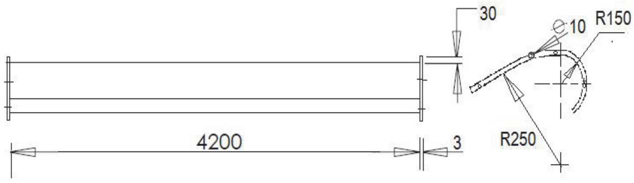


Fig.12. Screw mechanism protective cover

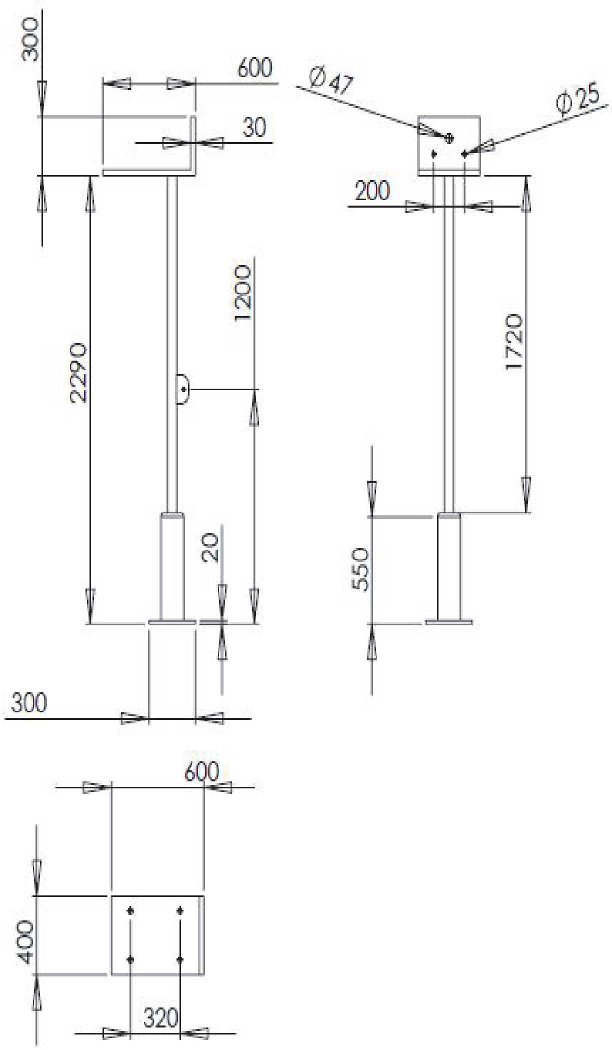
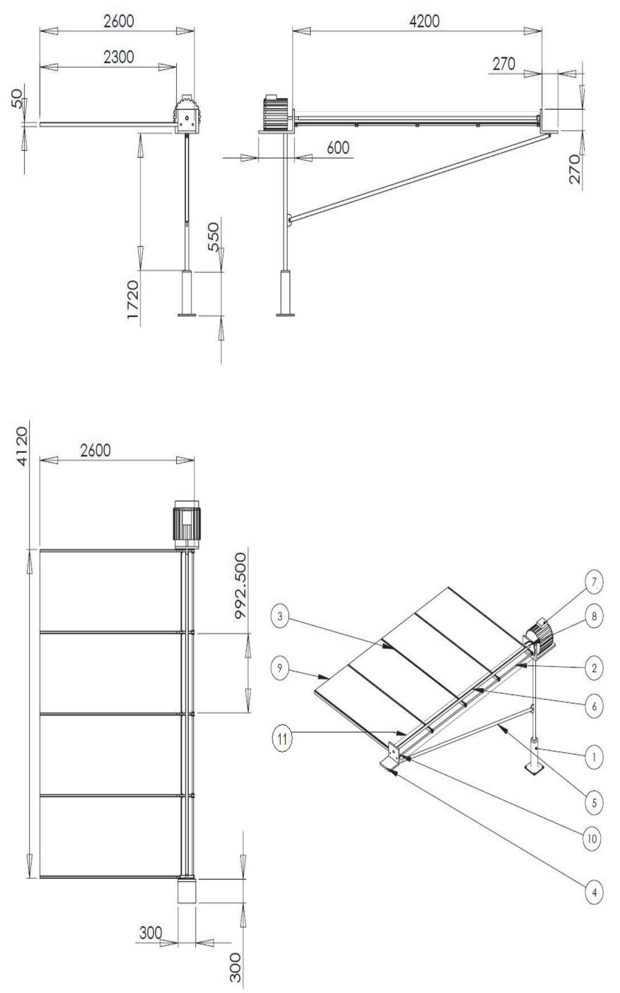


Fig.13. The Mast sub-assembly



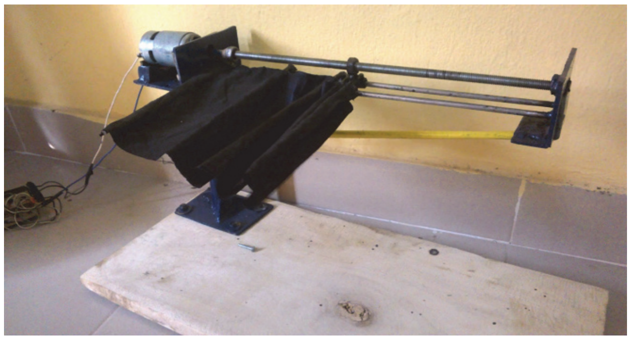
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Mast	Rust Free Steel Pipe	1
2	Guide Rod	Rust Free Steel Pipe	2
3	Rib	Square section Aluminum hollow pipe	5
4	Supporting Plate	Rust Free Steel Pipe	1
5	Prop	Rust Free Steel Pipe	1
6	Power Screw		1
7	DC Electric Motor	-	1
8	AFBMA 12.1.4.1 - 0350-47 - 28,DE,NC,28_68	Bearings	2
9	Retractable Canvass	waterproof polyethylene fabric	1
10	Nut		1
11	Screw Cover	Plastic	1

Fig.14. The assembly drawing

5. PROOF OF CONCEPT MODEL

A 1/10 working model of the design (the DC motor is not in proportional with the physical scaled size) was fabricated using materials similar to those specified in the design and operated to serve as a proof of concept (Fig. 15). The approximate speed of the motor used under test conditions was 550 rpm while the screw's pitch is 0.8mm. The deployment time for the model under these conditions was 51 seconds as expected based on Equation 4. Figure 13 shows the proof of concept model carport canopy when fully deployed, and when partially retracted.

(a)



(b)

Fig.15. The proof of concept model carport canopy (a) when fully deployed, (b) when partially retracted.

6. CONCLUSIONS

The design of the retractable single mast carport canopy is a worthwhile project going by high cost due to car damage that may occur during extreme weather conditions. The design met the project task criteria initially set. The components involved in the construction are readily source locally and fabrication processes required are well established in industry, this shall make the overall cost of production to be comparatively low and cost effective. The proof of concept model at a reduced scale successfully demonstrated the efficacy of the deployment and the retracting mechanism. The next step is the construction of a full scale prototype in orders to asses its real life performance and to note area of which further improvements may be required.

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