Design and Fabrication of a Lighter than Air Wind Turbine

Saket Singh, Samridh Mehta, Rishi Jain, K. Vishnu Kiran, Utkarsh Bajpai, and K. B. Ravichandra Kumar

Abstract The Lighter than Air (LTA) Wind Turbine system utilizes the stronger wind currents at higher altitudes to generate electricity. Suspended in the air with the help of tethers, this system is capable of rotating about its axis which further actuates an onboard AC generator that transfers the current to the ground, where the alternating current is transformed into useful direct current. The envelope and wing design of the system is such that it can operate under conditions with wind flow from two directions and a spherical envelope further increases the balloon's stability in turbulent weathers due to an acting Magnus effect. Such systems have the efficacy of being used very efficiently in metropolitan cities where the establishment of conventional wind turbines is not feasible due to space constraints. Such lighter than air systems have a huge latent potential in building a sustainable future and this project works towards the manifestation of the same. This paper offers an alternative which can be further worked upon to make a viable solution for this concept.

Keywords Lighter than air · Wind energy · Sustainability · Fabrication · Design

Nomenclature

g	Gravitational constant (m.s-1)
p	Pressure (N.m-2)
L	Lift (N)
r	Radius (m)
h	Altitude (m)
I	Moment of Inertia (m4)

S. Singh (✉) · S. Mehta · R. Jain · K. V. Kiran · U. Bajpai · K. B. R. Kumar
SRM Institute of Science and Technology, Chennai, India
e-mail: singhsaket625@gmail.com

V. Edwin Geo and F. Aloui (eds.), *Energy and Exergy for Sustainable and Clean Environment, Volume 2*, Green Energy and Technology,
https://doi.org/10.1007/978-981-16-8274-2_3

Greek letters

α Angular Acceleration (rad/sec2)
ρ Density (kg/m3)
μ Viscosity (Pa.s)
τ Torque (Nm)

Subscripts

s Static

1 Introduction

Wind is the fastest growing energy source in the world and one of the lowest priced renewable energy technologies today, at a cost of 4–6 cents per kW hour. "There is enough energy in high altitude winds to power civilization 100 times over; and sooner or later we're going to learn to tap into the power of winds and use it to run civilization." The life cycle for the energy gained from wind turbines is simple if the physical parts last. The generation of electricity from wind power takes place in several steps. It requires a rotor, usually consisting of 2–3 blades, mounted atop a tower; wiring; and "balance of power" components such as converters, inverters and batteries Wind turbines at ground level produce at a rate of 20–25%, but when placed at altitudes from 600–1000 feet, energy output can double.

The existing methods of efficiently harnessing wind energy to electrical energy primarily involve a wind turbine.

Horizontal and Vertical axis wind turbines are the two dominant classes of wind turbines. Small turbines are predominantly utilized as auxiliary power units for battery charging of low power equipment like traffic warning signs, streetlights, and consumer vehicles. Larger turbines can contribute to the domestic power supply while excess power can be returned to the utility by net metering. Wind farms-arrays of exceptionally large turbines are an important source of intermittent renewable energy. These are strategically deployed by many nations at scale to reduce fossil fuel consumption. One assessment claimed that, as of 2009, wind had the "lowest relative greenhouse gas emissions, the least water consumption demands and the most favorable social impacts" compared to coal, gas and even renewable resources like—photovoltaic, geothermal energy and hydro power.

Airborne wind turbines are conceptualised as a wind turbine that has its rotor supported in the air without a tower. Such a design benefits from higher velocity and persistence of wind at high altitudes, diverse mechanical and aerodynamic options, reduction in overall cost due to lack of tower construction or the need for slip rings or yaw mechanism. While the caveats include safely suspending and maintaining the turbine at altitudes of hundreds of meters in turbulent winds, transferring the generated power back to earth, and interference with aviation.

Airborne wind turbines are part of a wider class of Airborne Wind Energy Systems (AWES). They may operate in low or high altitudes or on top of skyscrapers. Tethering is a core part of AWESs. A non-conducting tether may be used when the generator is ground-based. But when the generator is aloft, then a conductive tether would be used to transmit energy to the ground. AWESs suffer from some disadvantages—Kites and helicopters are grounded when there is insufficient wind; kytoons and blimps may resolve the matter. Other disadvantages for our system are: Bad weather like lightning or thunderstorms could temporarily suspend use of the machines, requiring them to be brought back down to the ground. Some schemes may require a long power cable and that may interfere with aircraft operations.

2 Design Inspiration

Several profound disadvantages make it harder to implement the technology as the go to energy harnessing source. These include:

- Wind turbines can be large, reaching over 140 m (460 ft) tall and with blades 55 m (60 yd) long, and people have often complained about their visual impact.
- Environmental impact of wind power includes effect on wildlife Thousands of birds, including rare species, have been killed by the blades of wind turbines.
- Energy harnessed by wind turbines is sporadic and not a "dispatchable" source of power; its availability is based on whether the wind is blowing, not whether electricity is needed.
- Turbines can be placed on ridges or bluffs to maximize the access of wind they have, but this also limits the locations where they can be placed.
- To maximize the energy output enough to power a city, a large area of land (known as wind farm) needs to be acquired. Due to the large length of wind blades, two windmills cannot be located at proximity. Hence, a much larger land area is required to accommodate a greater number of windmills.
- Lighter than Air Wind Turbines mitigates most of the technological disadvantages mentioned above. Some of the advantages of LTAs over traditional windmills are:
- Unlike the traditional windmills, the design of Lighter than air wind turbines are such that they are capable of rotation irrespective of the wind direction i.e. they are aerodynamically efficient.
- LTAs are usually suspended in the air with tether cables. They don't require large independent structural towers. The structural requirements of LTAs are less as compared to windmills.
- LTAs are cheaper and easier to manufacture and transport. They also require less maintenance due to less mechanical parts involved in the design.

- LTAs are smaller in size and therefore, does not require huge acres of wind farm to generate electricity. Instead, many LTAs can be placed close to each other. LTAs can also be placed individually over tall skyscrapers.
- It is a known fact that at higher altitudes, wind blows more faster than at low altitudes. It will be easier for a tether attached LTA to harness the wind energy at those higher altitudes when compared with tower mounted traditional windmills.

3 Generator Selection and Output

3.1 Generator Selection

The generator selected for the final design is a 12–24 V 36 W Mini Wind Turbine Generator. Due to the low weight of the generator, and the subsequent performance with large torque, this generator perfectly suits our necessities for the balloon to generate adequate electricity (Fig. 1 and Table 1).

Fig. 1 12–24 V 36 W mini wind turbine generator

Table 1 Specifications of 12–24 V 36 W mini wind turbine generator

Power	40 W
Speed	12V3000 turn/24V5000 transfer
DC generator time by	Maximum 36 W (DC)

3.2 *Generator Output*

As simulated using Simulink, a graphical programming environment for modelling, simulating and analyzing multidomain dynamical systems, the following data was collected (Fig. 2) (Tables 2 and 3).

Practically, the data that was collected from the generators are.

4 Transmission Mechanism

The objective of the mechanism is the transmission of power from the LTAWT to the generator.

The LTAWT was fabricated using PVC material. It is completely sealed to prevent any leakages of gas molecules. As the cost of Helium was exorbitant, the Lighter than Air Wind Turbine had to be tested in front of the Open Jet Wind Tunnel in

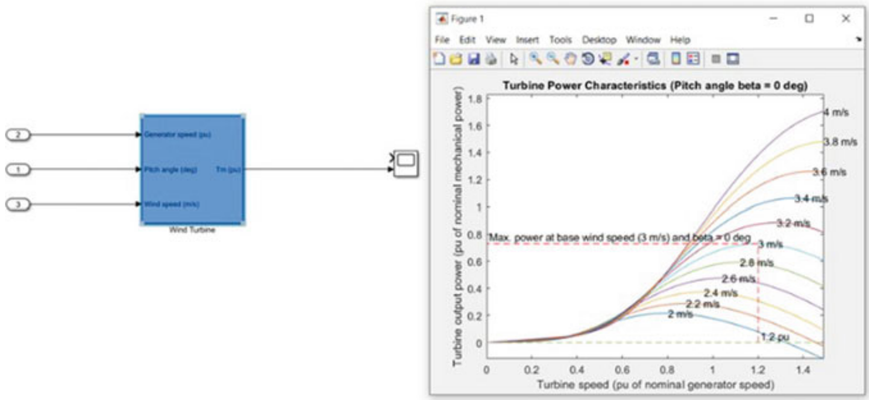


Fig. 2 Simulink analysis showcasing the generator output

Table 2 Theoretical data collected using simulink analysis of 12-24 V 36 W mini wind turbine generator

Torque	0.1 N-m
Maximum RPM	3000RPM
Power generated (2 generators)	80 W

Table 3 Practical data collected of 12 V–24 36 W mini wind turbine generator

Generator current	4A
Generator Voltage	23 V
RPM	2950RPM
Calculated power	92 W

the Aerospace Hangar at SRM Institute of Science and Technology. However, tether cables would be unable to keep the LTAWT in place in front of the wind tunnel. To mitigate this problem, a platform was design and fabricated for the sole purpose of testing the LTAWT in front of the open jet wind tunnel.

4.1 Shaft and Platform

The shaft design is inspired from the Twin Spool arrangement which is like the Jet Engines. A Stainless-Steel shaft is kept stationary and is concentrically mounted to a 3D Printed Pipe (Fig. 3) (Table 4).

This entire shaft with pipe mounting is coupled to the balloon. This entire structure is further mounted to a platform with the help of Ball Bearings (Table 5).

Fig. 3 The 3D printed pipe incorporated with the stainless-steel shaft

Table 4 Dimensions of the shaft design

Stainless steel shaft diameter	8 mm
3D printed pipe inner diameter	19 mm
3D printed pipe outer diameter	25 mm

Table 5 Dimensions of the interior ball bearing

Inner diameter	8 mm
Outer diameter	19 mm

Table 6 Dimensions of the platform ball bearing

Inner diameter	25 mm
Outer diameter	37 mm

The supporting platform was made 1150 mm high from the ground. The platform has Ball Bearing to hold the pipe (Table 6).

The Ball Bearing was push fitted inside the Plywood which is directly crafted on the platform. The Generator is mounted with a 3D Printed Hub as shown in the Figure. 3D Printed Gears were used with a gear ratio of 3:1 to proliferate the RPM Output (Figs. 4 and 5) (Table 7).

The mechanism can be segregated into two divisions:

(1) Stationary parts: The 8 mm Stainless-steel shaft which passes through the LTAWT holds the complete body. The tethers are attached to both the ends of this shaft. The Generator is also stationary which is mounted on the shaft with the 3D printed mount.

Fig. 4 Gear 1

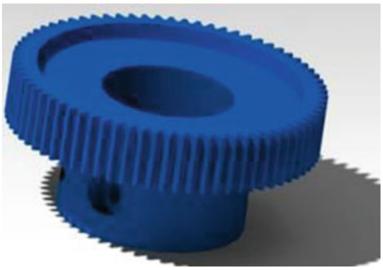


Fig. 5 Gear 2

Table 7 Dimension of the gears

Gear 1		Gear 2	
Inner diameter	25 mm	Inner diameter	8 mm
Outer diamter	60 mm	Outer diamter	20 mm

Fig. 6 3D printed pipe and the stainless-steel shaft mounted on the balloon, generator in its mount, CAD model for the translation mechanism

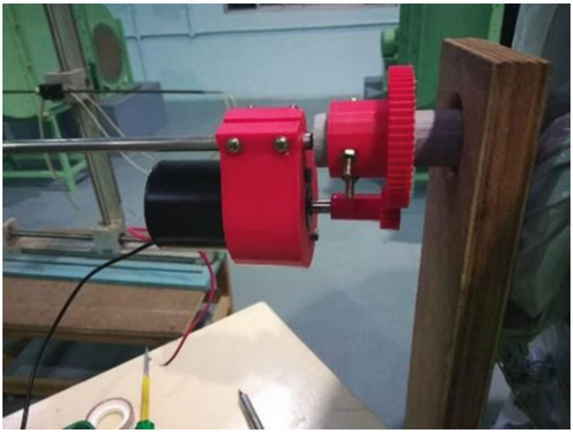


Fig. 7 Translation mechanism for mark III

(2) Dynamic parts: All other parts of the design exhibit motion. The inside plate in the platform has ball bearings attached to it. The inner plate is stationary and outer plate is rotating. The inside plate is attached to the rubber gasket, 3D printed coupler. The coupler couples the inside plate with the pipe.

This pipe is concentric with the stationary shaft. The Spur gear is mounted on this pipe which transmits the power to the Generator.

The gear on the pipe is meshed with another gear on the generator.

Thus, the power is transmitted from the rotating balloon to the generator and energy is produced (Figs. 6 and 7).

4.2 *Structural Analysis of the Shaft*

The stainless-steel shaft is a crucial component of the mechanism as it carries the complete load of the balloon and the Generators. A detailed structural analysis on the shaft is conducted in ANSYS Workbench 15.0 (Structure).

Given parameters:

- 1600 mm long Stainless-Steel Shaft
- Uniformlydistributedloadswherethe generator is mounted
- 50 mm-300 mm
- 1300 mm-1450 mm
- Fixed Supports at 300 mm and 1300 mm, where Ball Bearings are mounted.

After successfully running the solver, the results obtained are (Figs. 8 and 9).

1) Maximum Deflection = **0.3mm**

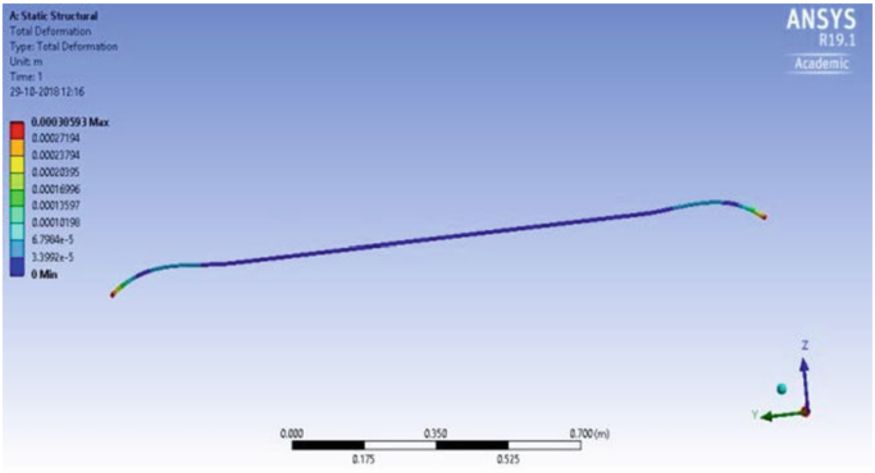


Fig. 8 Total deformation on the shaft

2) Maximum Stress = 5.4178e7 Pa

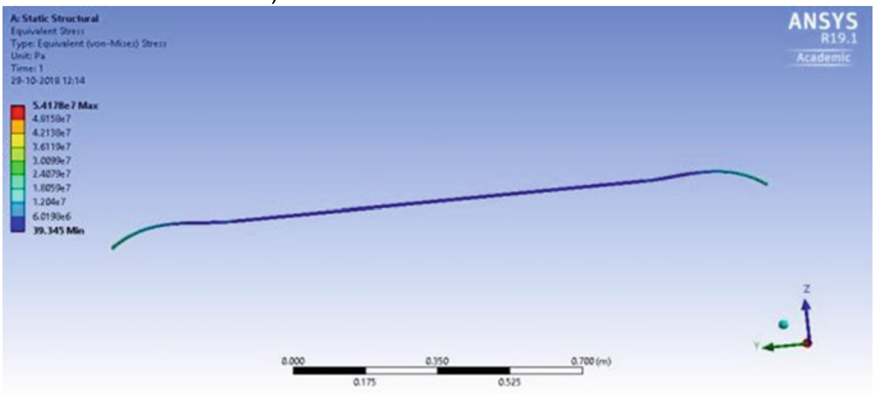


Fig. 9 Maximum stress on the shaft

5 Windspeed Calculations and Baloon Sizing

5.1 Windspeed Calculations

The design of the lighter than air wind turbine will majorly be dictated by operating wind conditions at the operating altitude. The subsequent wing design and the lift generated by them to create a rotating torque is also governed by the wind speed and hence deciding an operating altitude is an integral part of the design phase.

As environmental wind flow over cities and other terrains are also shear flows in nature, there exists a wind gradient as we move upwards. Much like a traditional boundary layer over external geometries, a planetary boundary layer is seen to form over Earth's surface. This is naturally caused because of a shear layer with the terrain and vertically extends up to the point where the gradient of flow velocity is the same as the freestream. In addition to this, daytime heating from the sun leads to increased mixing of the boundary layer and the freestream. This mixing leads to a significant increment in the boundary layer thickness and must be taken into consideration.

For Wind Turbine Engineering, a polynomial variation between the altitude and wind speed can be defined by,

$$\left(\frac{v}{v_0}\right) = \left(\frac{H}{H_0}\right)\alpha$$

where,

α	Hellman's Constant = Friction Coefficient
v	Windspeed at operating altitude
v_0	Windspeed on ground (i.e. 10 m)
H	Required Altitude
H_0	10 m

The Hellman exponent is parametrically derived from various environmental constraints such as the location of the coast, if there are peaks in the terrain below and also the stability of the air around. Considering the application to be over the coastal area of Chennai, India, we can consider a Hellman's Coefficient of 0.4 for the subsequent wind speed calculations.

After due literature surveys, it was judged that an operating altitude of 300 ft would be apt for the design. This decision was made after considering trade-off that although a higher altitude would provide very lucrative operating conditions, such an operating height would exponentially demand a bigger balloon size due to the added tether weight. An exponentially bigger envelope size would then cubically demand more lifting gas volume to lift the enter system up. Finally, as Helium is one of the primary and ideal lifting gases and happens to be one of the rarest on earth as well, its use becomes very constrained. Hence, it is a penultimate task of selecting an operating altitude that is optimum from the sizing as well as cost point of view.

The average wind speed on ground in Chennai is 8 kmph or 2.22 m/s as per the metrological department. The wind speed at 300 ft is found with the help of the relation given above.

$$\frac{v_{300\mathrm{ft}}}{2.22} = \left(\frac{91.44}{10}\right)^{0.4}$$

Hence, $v_{300\,ft} = \mathbf{5.38\,m/s}$

The subsequent wing calculations and design have been done in accordance to this wind speed. This wind speed is streamlined as compared to planetary flow near the surface as there are no disturbances to distort it. This will facilitate better lift generation over the wings.

5.2 Weight Estimation and Baloon Sizing

To find an optimum size for the envelope enough to lift the entire setup, it is imperative to estimate the weight of the envelope, the wings attached to it, the onboard payload and the tether along with an additional extra static lift. The total lift needs to be quantified to ensure enough buoyancy for the envelope to pick the entire system up. Once an initial total system weight has been estimated, the balloon is sized and iterated for until an optimum value has reached. An initial benchmark for the onboard payload was taken as 3 kg and the envelope and wing weight as 2 kg.

The envelope was chosen to be spherical in shape because of its high volume to surface area ratio. A high volume to surface area ratio is preferred in order to facilitate the largest lifting gas volume possible to lift up as much weight as possible. A higher volume to surface area ratio also implies a lower surface area that means that the envelope weight also is towards the lower end. This is another important aspect as a lower surface area would directly reduce the mass of the envelope material. The Surface Area to Volume ratios of various 3d geometries are given as follows (Table 8).

The sizing of the envelope is governed majorly by the Archimedes Principle and the fundamentals of buoyancy. This can be simply done by equating two known physical aspects for any floating object. Since for such a floating wind turbine, the buoyant force comes from the displacement of its weight, and lift being a difference between this buoyant force and displaced gas, the sizing relationship is.

$$L_s = B - W_{\mathrm{gas}}$$

$$L_s = W_{\mathrm{air}} - W_{\mathrm{gas}}$$

$$L_s = V_g(\rho_{\mathrm{air}} - \rho_{\mathrm{gas}}) \tag{1}$$

Table 8 Surface area to volume ratios of various 3D geometries

Shape		Characteristic Length a	Surface Area	Volume	SA/V ratio	SA/V ratio for unit volume
Tetrahedron		side	$\sqrt{3}a^2$	$\frac{\sqrt{2}a^3}{12}$	$\frac{6\sqrt{6}}{a} \approx \frac{14.697}{a}$	7.21
Cube		side	$6a^2$	a^3	$\frac{6}{a}$	6
Octahedron		side	$2\sqrt{3}a^2$	$\frac{1}{3}\sqrt{2}a^3$	$\frac{3\sqrt{6}}{a} \approx \frac{7.348}{a}$	5.72
Dodecahedron		side	$3\sqrt{25+10\sqrt{5}}a^2$	$\frac{1}{4}(15+7\sqrt{5})a^3$	$\frac{12\sqrt{25+10\sqrt{5}}}{(15+7\sqrt{5})a} \approx \frac{2.694}{a}$	5.31
Capsule		radius (R)	$4\pi a^2 + 2\pi a * 2a = 8\pi a^2$	$\frac{4\pi a^3}{3} + \pi a^2 * 2a = \frac{10\pi a^3}{3}$	$\frac{12}{5a}$	5.251
Icosahedron		side	$5\sqrt{3}a^2$	$\frac{5}{12}(3+\sqrt{5})a^3$	$\frac{12\sqrt{3}}{(3+\sqrt{5})a} \approx \frac{3.970}{a}$	5.148
Sphere		radius	$4\pi a^2$	$\frac{4\pi a^3}{3}$	$\frac{3}{a}$	4.83515

where, $V = 4/3\pi r^3$.

It should be noted that for windy operating conditions, the current floating wind turbine must have a net positive lift. The reason for this is to prevent the turbine from dropping its altitude due to any possible downward push from the turbulent or windy freestream. This net positive aerostatic lift should allow for a stable recovery of the original operating altitude of the wind turbine. For the tethered aerostat system, this design condition can be met by the following equation.

$$L_s = W_{\text{env}} + W_{\text{tether}} + W_{\text{payload}} + L_{\text{excess}} \quad (2)$$

From Eqs. (1) and (2), we get

$$V_g(\rho_{\text{air}} - \rho_{\text{gas}}) = W_{\text{env}} + W_{\text{tether}} + W_{\text{payload}} + L_{\text{excess}}$$

$$\frac{4}{3}\pi r^3 g(\rho_{air} - \rho_{gas}) = W_{env} + W_{tether} + W_{payload} + L_{excess}$$

Here, W_{tether}, W_{payload} and L_{excess} are fixed values. The Only variables are the volume of the lifting gas (V) and W_{env} that are cubically and exponentially dependent on the radius of the envelope, respectively. The volume of the wings has been neglected as they are accountable for little lift generation. That is,

$$\frac{4}{3}\pi r^3 g(\rho_{\text{air}} - \rho_{\text{gas}}) = (k.4\pi r^2) + W_{\text{fixed}}$$

$$W_{\text{env}} = W_{\text{tether}} + W_{\text{payload}} + L_{\text{excess}}$$

Here, k is the mass per square meter (kg/m2) of the envelope material and hence multiplying this with the surface area of the sphere will give us W_{env}.

ρ_{air} and ρ_{gas} are found for the operating altitudes of 300 ft (91.44 m). Air density variation with altitude can be derived as follows:

$$T = 59 - (0.00356 \times h)$$

$$P = 2116 \times [(T + 459)] \times 5.256$$

where the temperature is given in Fahrenheit degrees, the pressure in pounds/square feet, and h is the altitude in feet. Finally,

$$\rho = \frac{P}{[1718 \times (T + 459.7)]}$$

On calculating further,

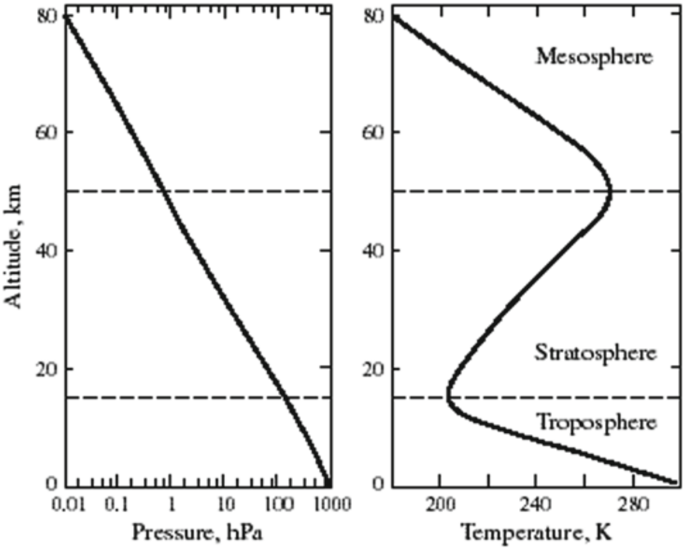


Fig. 10 Graphs representing pressure and temperature variation with altitude

$$\rho_{air} = 1.218\,\text{kg/m}^3 \text{ at } 300\text{ft.}$$

Similarly,

$$\rho_{helium} = 0.16085\,\text{kg/m}^3 \text{ at } 300\text{ft}$$

Conversely, these values can simply be found by referring to the already established charts of the respective temperature, pressure and density variations with respect to altitude (Fig. 10).

Substituting the values of ρ_{air} and ρ_{helium}, we get,

$$49.7614r^3 = \left(k^4.\frac{\pi}{3}r^2\right) + W_{fixed}$$

The selected material for the envelope has a gram per square centimetre value of 450 g/cm^3 which represents the value ‘k’. Also, W_{fixed} represents the sum of weights of the tether and payload.

W_{tether} can be found by multiplying the rope’s mass per meter with the altitude that it needs to cover. Standard breaking strengths and mass per unit length of commercial ropes can be found on their data sheet itself. A ¼ inch diameter nylon rope seems to be a viable option considering its failure load of 56.167 kg after a Factor of Safety of 12. With a mass per unit length value of 0.023, the mass of such a tether comes out to be,

$$W_{tether} = 0.023 \times 91.44$$

$$W_{tether} = \mathbf{4.103kg\ for\ two\ tethers}$$

$W_{payload}$ was estimated to be 2 kg after design on CAD platforms. The design has been discussed extensively on in the subsequent chapters.

Hence, $W_{fixed} = 2.103 + 2$

$$W_{fixed} = 6.206\,\text{kg for two tethers}$$

Substituting the value of W_{fixed} and 'k', we get,

$$49.7614\,r^3 = 5.652\,r^2 + 8.206$$

Solving this cubic equation for 'r', we get,

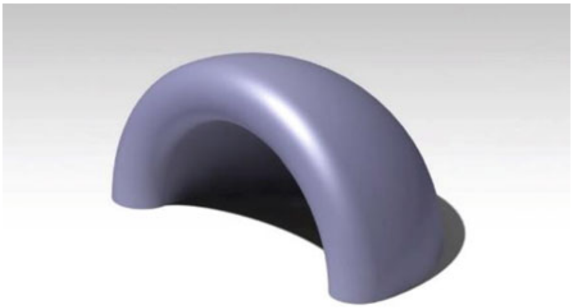
$$\mathbf{r = 0.588\,m{\sim}0.6m}$$

6 Wing Design

Two wing designs were considered based on the feasibility and ease of fabrication, cost, torque generation and wing efficiency. The two options that were considered were a fixed wing and a drag bucket. However, manufacturing the fixed wing and mounting it on the envelope wasn't feasible and demanded a lot of time and money. Hence, to make things easier and equally effective, a drag bucket type wing was made and directly pasted on to the envelope. Once wind flows into the bucket, a lot of parasitic and form drag is created and this enables the balloon to spin about its axis.

This drag bucket has a diameter of 0.62 m and has a thin sheet of fabric behind it. The design was tested using CFD tools and a total drag of 1.524 N. For a moment arm of 0.7 m, the torque being generated comes out to be (Fig. 11).

Fig. 11 The drag bucket designed on a CAD platform



$$\text{Torque} = \text{Drag} \times \text{Moment Arm}$$

$$\text{Torque} = 1.524 \times 0.7$$

$$\mathbf{Torque = 1.067Nm}$$

Hence, for 4 such drag buckets,

$$\begin{aligned}\text{Total torque} &= 1.067 \times 4 \\ &= \mathbf{4.268N - m}\end{aligned}$$

At 4.268 N-m, the balloon rotates at,

$$\alpha = \frac{4.268}{1.48872}$$

Since,

$$(\alpha = \tau)$$

Hence, **Angular Acceleration = 2.8669 rad/sec^2.**
Also,

$$n = \frac{(\alpha \times t \times 30)}{\pi}$$

Therefore,

$$n = \frac{(2.8869 \times 5 \times 30)}{3.14}$$

n = **136.9 rpm** (considering torque from all four buckets)

7 Fabrication

7.1 Material Selection

The project is related to Lighter than Air mechanisms. Hence, for the fabrication only the lightest weighted material possible with enough rigidity to support the entire weight of the mechanism had to be selected. To achieve this rationale for the LTAWT,

Table 9 Physical properties of polyvinyl chloride (PVC)

Density	1.35~1.45 specific gravity
Economics	PVC is readily available and cheap
Melt temperature	100–260°C
Tensile strength	• Flexible PVC: 6.9–25 MPa (1000–3625 PSI) • Rigid PVC: 34–62 MPa (4930–9000 PSI)

we selected Polyvinyl Chloride (PVC) sheets to be the material for the balloon, the reasons for which are stated as follows (Table 9).

7.2 Fabrication

The fabrication for the LTAWT was separated into two distinct domains:

(1) Balloon Fabrication,
(2) Mechanism Fabrication.

7.2.1 Fabrication of Baloon

The word balloon gives a general image in mind but here we are talking about a turbine. Using the balloon designing and sizing explained in V: Balloon Design and Sizing, we fabricated the balloon using various methods and came across several iterations.

Since the balloon is the wind turbine itself, we needed to take great care while selecting the fabricating methods for it. The balloon is analogous to the propeller in the design. The major factors on which the design was based are;

(1) Low surface area of the balloon to use minimum material for lowest possible weight,
(2) High volume of the balloon to fill maximum amount of helium gas for maximum possible lift force,
(3) Balloon shape for Magnus Effect to act on it for stability.

The major factors for fabrication of the balloon are;

(1) Light weight material,
(2) Material requires strong adhesion as balloon must be fabricated in parts to be joined together,
(3) Material should have enough strength to be able to hold the air pressure inside it without bursting.

Hence, the method of heat sealing was decided as the primary method to fabricate the balloon, as it was the best way to encompass all the adjourning factors required for the balloon (Fig. 12).

Fig. 12 Mark III inflated with compressed air

7.2.2 Fabrication of Transmission Mechanism

The mechanism's main objective was transmission of power from the balloon to the generator. We had decided to use gears for power transmission. Based on our calculations we came up with the gear ratio to be 3:1. The components required for mechanism are:

(1) Ball bearing
(2) Stainless-steel shaft
(3) 3D Printed Hollow pipe with Surface Coupling
(4) Gears
(5) Generator
(6) Generator Mount
(7) Circlips
(8) Inner and Outer Circlip Plier
(9) Nuts and Bolts

The gears, hollow pipe with surface coupling and generator mounts were fabricated using 3D Printing technique (Fig. 13).

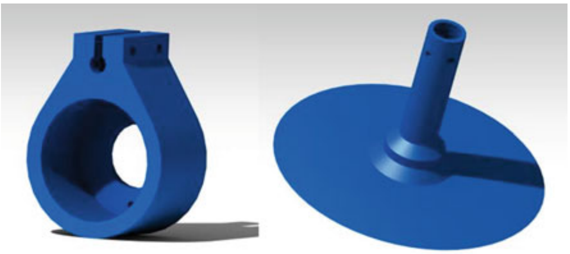


Fig. 13 CAD Models of the mount and the hollow pipe

Fig. 14 Mark III

The shaft was divided into two parts which is mounted on both the sides forming a cantilever. To support this cantilever, we have provided 2 supports with ball bearings. The final mechanism was coupled with the balloon with the help of anabond adhesive and was very strong without any slippage between the balloon and the mechanism (Fig. 14).

8 Fabrication

The testing of the LTAWT was done in front of the Open Jet Wind Tunnel inside the Aerospace Hangar of SRM Institute of Science and Technology. In an ideal case, helium would be used to inflate the balloon for it to rise in the air and rotate at an altitude, which was the basic case for the design which was proposed. Although, after a lot research, helium was found to be expensive and hydrogen is too volatile to be used for this purpose. Hence an improvised stand was fabricated for the balloon to be tested in front of the Open Jet Wind Tunnel in the Aerospace Hangar, with the balloon being inflated using compressed air (Table 10).

Table 10 Results derived from testing

Distance of the balloon from the ground	1500 mm
Distance of the balloon from the wind tunnel	2000 mm
Wind speed	~ 20 m/s
RPM of the balloon	36
RPM of the generator (3:1)	108
Electricity produced by 2 generators	2 V

9 Future Scope

The prototype was built to utilize the powerful winds blowing at higher altitudes for the purpose of generating electricity. The balloon works the way it is supposed to. The aim was to check if the design truly worked as per the standards and as the report suggests, good results have been acquired. However, there exist certain deficits in the prototype which did not produce practical results similar to the ones produced theoretically.

Talking about the scope, there exists a much bigger picture than the existing prototype's, which is but the starting point and a substantial success towards an even better future of electricity generation. The succeeding prototype can be iterated on a number of parameters.

1. **A bigger balloon size**: a bigger balloon will be heavier hence can support better generators and ensure the utilization of a greater volume of the blowing winds, thereby permitting the model to produce greater amounts of electricity.
2. **A more versatile transmission system**: Presently only two gears are being used. The prototype can be levelled up to implement planetary gear systems in entirety, which will further facilitate a feature of toggling the RPM produced by the gears when the model is stationary. This will enable operating the prototype to work more efficiently in accordance to the wind patterns to produce an increased throughput. A versatile translation system will also ensure increased torque even if the balloon is operating on a lower RPM.
3. **Increased gear to teeth ratio:** The greater the ratio, the greater the rpm and hence the greater the torque. This will ensure better performances and increased electricity generation.
4. **Incorporating smart devices**: Using raspberry pi with smart generator technology the prototype can be taken to whole new levels,

a. This will enable smart toggling of rpm even when it is operational, however the mechanical aspect will be quite arduous to make this possible, as every gear would need a variety of connections;
b. Relevant sensors can help to analyse the temperature at different heights and record the corresponding speed of the winds, thereby allowing the prototype to adjust to the current conditions and working in accordance to the most suited functionality for a given condition;
c. Integrating the mechanical aspect to the tech-driven ones by making a user-friendly application that can enable the developer to make changes to the behaviour of the operational prototype at any time, from the ground level.

The parameters listed above have been devised only theoretically. While some seem doable, others may require more knowledge (which may be out of the current scope) to up the current levels to a whole new high. Fixing and bettering the mechanical aspect of the prototype shall be the topmost priority of the successor.

Initially, the aim of the project will be to ensure an increase in the throughput by working on the gear systems which are the major setbacks to good electricity generation as per the most recent observations.

From there, putting the renewed prototype to a challenging testing environment in order to test its durability, in case the weather goes south, will be the following step. If everything goes well, the prototype should be able to power at least one complete household as its lower bound.