Design and Development of an easily Deployable indoor Finless airship

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***Abstract*—Airships have an upper hand over multi-rotor drones when it comes to endurance and sound of operation for surveillance in an indoor environment. This paper discusses the design methodology and fabrication of an easily deployable finless airship for indoor surveillance and advertisement. The design of the airship discussed in this paper is driven by factors such as longevity, assembling time, dismantling time and control authority over the flight. The propulsion system employed in the airship uses two swivel-able motors with differential thrust thereby providing sufficient control authority over the attitude and velocity of the airship. The airship was assembled and flown indoors. A *Pixhawk PX4* autopilot was installed on-board whose function is to collect data on attitude which could later be used to validate airship flight dynamics model and to study the flight characteristics of the airship.**

I. Introduction and Background

Application of drones for indoor surveillance is quite rare, primarily because commercial available multirotor drones are noisy and have low endurance. Airships provide an elegant and feasible solution for crowd monitoring in an enclosed environment such as gymnasiums, metro stations and exhibitions since they provide higher endurance than a conventional drone. Analogous to a multirotor drones, airship can host a camera and on the contrary airships are less noisier than the multirotor drones. However, airships are voluminous compared to conventional drones. But their gargantum size could be used for effective advertising and marketing. Moreover, airships are safer in an indoor environment even in case of malfunction they will not crash but descent gradually.

For the past two decades several remote controlled (RC) blimps have been designed, developed and flown. The first recorded RC airship *Blimp Simon* was built over two decades ago as a research project [1]. The start of 21st century rekindled the interest in RC blimps. Several blimps were designed and fabricated for a variety of applications such as aerial photography, surveillance, product promotion and advertisement, agricultural applications such as spraying insecticides, weather monitoring system, etc. Several airships have been designed and built for a variety of applications at the Lighter-Than-Air (LTA) Systems Laboratory, IIT Bombay since 2002 [2]–[5]. Two airship designs, [5] and [6] have been studied carefully and a design methodology was tailored for the airship to be built.

The work presented in this paper is focussed on developing a low cost, easily deployable airship for indoor applications. The airship is to be designed to have sufficient control over it's speed, altitude and attitude consuming as little power as possible. The design requirements for the blimp are displayed in Table 1,

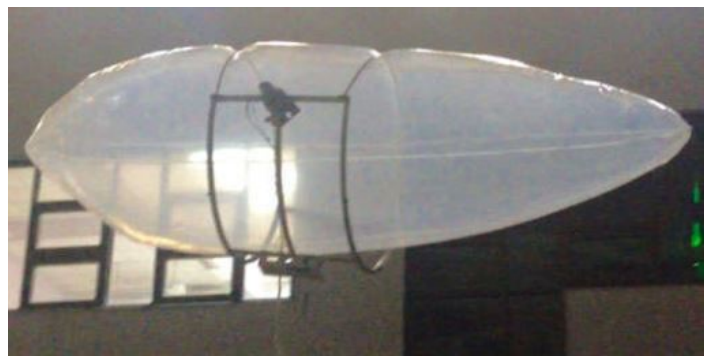

Fig. 1: Finless Airship developed by Mistri & Pant [5]

Fig. 2: SSTAB developed by Manas & Pant [6]

II. Envelope Design and Fabrication

Methodology for design of a conventional airship has been outlined in [1]–[5]. The airship is to be operated at a maximum of 3 m/s in an indoor environment. Hence zero wind conditions were assumed for the design. Airship size is primarily determined by its envelope material and the shape. Sections(II-A) and (II-B) discuss the implications of choosing an envelope shape and fabric over the airship design.

Parameter	Value	Description / Justification
Lifting Gas	Helium	Operational safety
Max. Length	4 m	Ease in storage and handling
Max. Diameter	1.2 m	
Max. Envelope Volume	3 m^3	Reduce cost of operation by using less Helium
Payload	100 g	Onboard camera system/ Data acquisition unit
Hover Endurance	1 hour	Higher than commercially available drones
Endurance @ 1 m/s	30 minutes	
Max. Speed	3 m/s	Operation only in an indoor environment
Budget	£400	Low cost for higher endurance
Manhours for Fabrication	30 hours	Easy to fabricate and reduce labor cost
Deployment Time	10 minutes	Quick deploymeny and shorter assembly time

TABLE 1: Primary Design Requirements

A. Envelope Profile

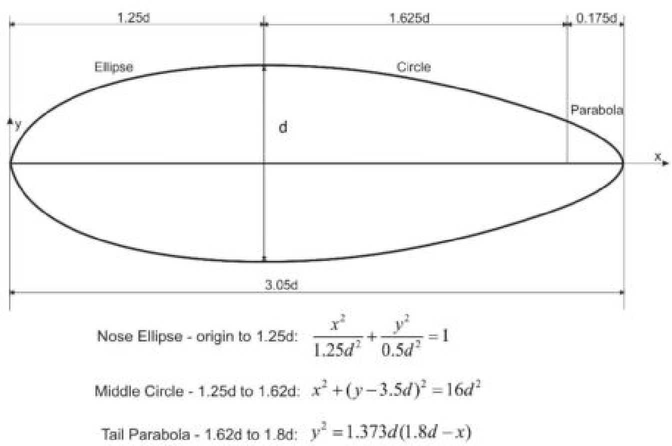

Fig. 3: GNVR Profile [6]

The envelope is the largest component of the airship and also the most crucial component. The envelope determines the lifting capacity, aerodynamics, and the dynamic behavior of the airship. In principle, the envelope should have a high volume to surface area ratio and low aerodynamic drag [7]. For the given volume, spherical envelope would have the highest volume to surface area ratio. However, a spherical envelope is aerodynamically inefficient and exhibits a huge drag. Since the airship was to be designed for low operating airspeed, GNVR profile was chosen as it exhibited the highest volume to surface area ratio, even though it is not the most aerodynamic envelope shape. Since, the GNVR profile (Fig. 3) is parameterized in terms of it's diameter, volume and surface area computation was rendered relatively simple. The aerodynamic data for GNVR aerostats were readily available in [8] and [9].

The length (L), volume (V), surface area (SA) and centre of volume location from the nose (CV) for the GNVR envelope can be determined as a function of diameter (D) using the following relations,

$$L = 3.05 \ D \tag{1}$$

$$V = 1.47926 \ D^3 \tag{2}$$

$$SA = 7.4488 \ D^2 \tag{3}$$

$$CV = 1.3834741 \ D \tag{4}$$

B. Envelope Materials

It is quite essential to choose the right material for the airship envelope as it retains the lifting gas within the envelope and support the gondola. The weight of the envelope accounts approximately about 38% of the airship empty weight. Apart from low fabric density of the material, it is desirable to have the following properties in the envelope material.

- High strength to mass ratio.
- High tear resistance.
- Maximum impermeability to gas, achievable within a limited mass.
- High resistance to degradation due to UV rays, hydrolysis, abrasion and other environmental factors.
- Ease of fabrication i.e. radio frequency (RF), thermal, and adhesive sealability.

Typically, a single material is unable to exhibit all the above properties. Hence a laminated layer of different materials is manufactured. However, since the airship is meant to be used in an indoor environment, some of the properties such as effect of UV rays may be compromised and the more significance was given to the fabric density.

In order to study the effect of material density over the airship size, envelope shape was fixed as GNVR. By varying the fabric density of the material, airship lengths were determined for neutral buoyancy for each of the fabric density values. As seen in Fig. 4, airship size varies linearly with respect to fabric density. Hence for an efficient design it is advisable to chose a fabric with the lowest density among the list of acceptable envelope materials.

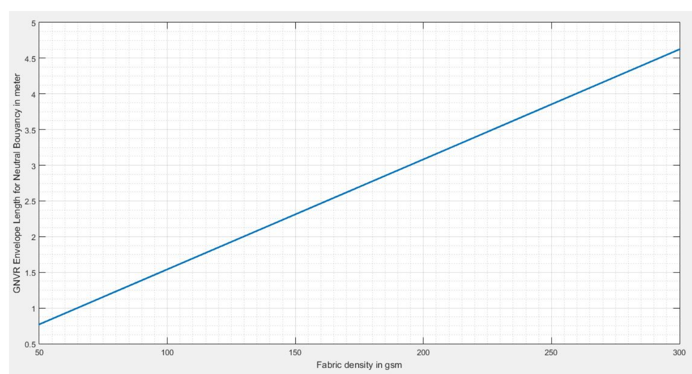

Fig. 4: GNVR Envelope Length for neutral bouyancy wrt to change in fabric density

Several single layer materials which exhibited most of the desirable properties were studied, based on which the following materials were shortlisted:

- PVC - Polyvinyl Chloride
- LDPE - Low Density Polyethylene
- PET - Poly Ethylene Terephthalate
- MPET - Metalized Poly Ethylene Terephthalate
- Mylar/ VMPET - Vaccuum Metalized Poly Ethylene Terephthalate [1]
- PU - Polyurethane [1]

It is to be noted that all these materials ensured excellent impermeability to helium/ hydrogen. A qualitative comparison of material strength and tear resistance is recorded in [10]. Table 2 summarizes the material properties.

	PVC-1	PVC-PET Blend	LDPE	PET	MPET - 1	MPET - 2
Fabric Density (gsm)	200	180	75	95	100	105
Strength	Excellent	Excellent	Poor	Poor	Good	Excellent
Sealing Technique	RF	RF/ Heat	Heat	Heat	Heat	Heat
Wear Resistance	Good	Good	Poor	Poor	Good	Satisfactory

TABLE 2: Airship Envelope Material Properties

As seen from Table 2, MPET-2 exhibited most desirable properties and hence this material was chosen for the airship.

C. Variation of Net Lift with respect to Airship Size

An airship envelope becomes neutrally buoyant when the total aerostatic force is equal to the envelope weight. For a GNVR shaped envelope with a fabric density of ρ_{fab} , the diameter D to attain neutral buoyancy may be determined as follows,

$$V\rho_{specific} = (SA)\rho_{fab} \tag{5}$$

$$1.47926\ D\rho_{sp} = 7.4488\ \ \rho_{fab} \tag{6}$$

$$\implies \quad D = \frac{5.035\ \ \rho_{fab}}{\rho_{sp}} \tag{7}$$

where, $\rho_{sp} = \rho_{air} - \rho_{lta}$ is the specific lifting capacity of the LTA gas. Fig.5 shows the variation of net lift with change in envelope length, L for a GNVR shaped envelope with a fabric density of $105\ \ gsm$. It could be seen from Fig.5, that for the given parameters the neutral buoyancy is attained around a length of $1.6\ \ m$. It can also be noted that after the envelope reaches neutral buoyancy, a small change in size would cause a huge net lift.

[1]Samples for these materials could not be obtained due to unavailability in the market.

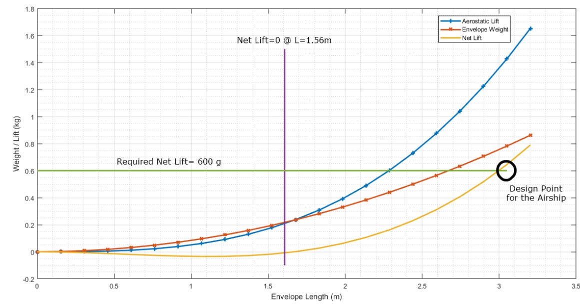

Fig. 5: Variation of Net Lift for a GNVR envelope wrt to Airship Length ($105\ \ gsm$)

D. Envelope Sizing Methodology

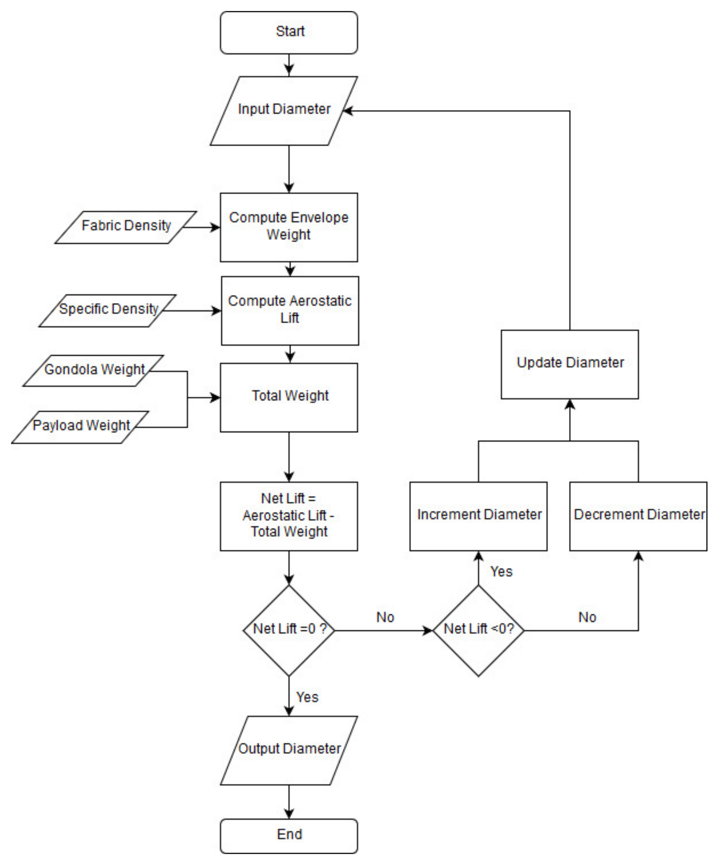

Fig. 6: Flowchart of the procedure for envelope sizing

The envelope size for the airship can be determined by equating the aerostatic force produced by the lifting gas contained within the envelope and the weight of the envelope, the gondola and the payload. The design methodology used in determining the size of the airship envelope has been depicted in the flowchart in Fig.6. For a gondola weight budget of $500\ \ g$ and a payload of $100\ \ g$, the design methodology yielded a GNVR profile with diameter of $1\ m$. The CAD model of the airship is as shown in Fig.7.

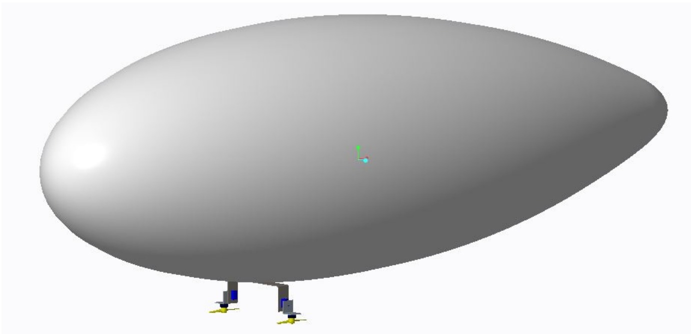

Fig. 7: CAD model of the Finless Airship

E. Envelope Fabrication

Envelope fabrication is perhaps the most tedious task in airship fabrication. Yet, envelope has to be fabricated with precision so as to avoid gas leaks and in order to maintain the desired envelope shape. There are various methods to fabricate an airship envelope. These methods have been discussed in several papers such as [2], [3], [11].

Fig. 8: Envelope Petal

Gore design method as discussed in [5] was used for the envelope fabrication. Six petals (Fig.8) were made and then welded together using the heat sealing machine. Hooks (Fig.9) were sealed on the bottom petal for gondola mounting. Once the fabrication was complete, the envelope was tested for leaks initially by filling it with air and then using a helium leak detector.

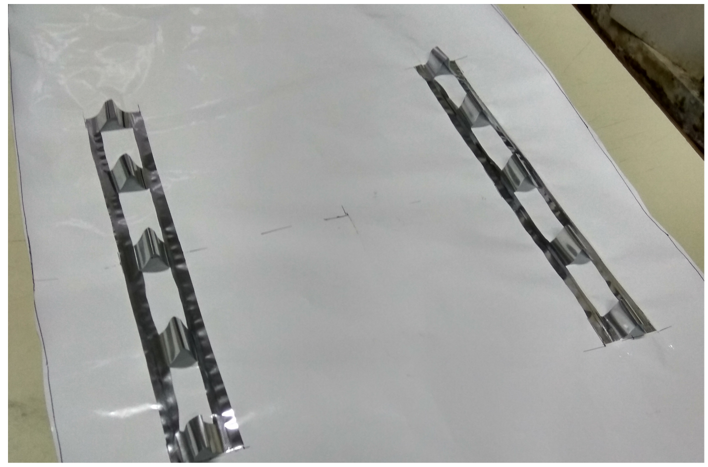

Fig. 9: Hooks to mount Gondola

F. Permeability Test

Once the envelope was fabricated, it had to be tested for permeability to determine the loss of aerostatic lift per day. The airship was filled with the LTA gas and the lifting capacity of the envelope was recorded every day for a span of 10 days. The percentage loss of net aerostatic lift for 8 days is shown in Fig.10.

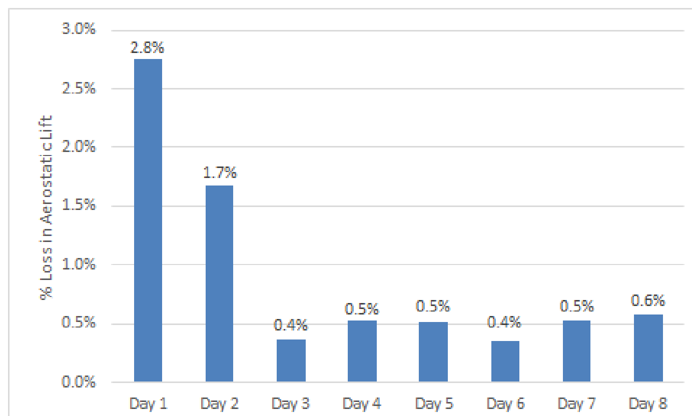

Fig. 10: Net aerostatic lift loss per day

The maximum lift loss of about 3% which accounts to about $22\ g$ occurs on the first day, and then drops gradually. This is obviously due to the high pressure inside the envelope when it is fully inflated. As the pressure inside the envelope, drops the LTA leak rate reduces and drops down. This leak rate is acceptable as only a small fraction of aerostatic lift is lost per day.

III. Gondola Design and Fabrication

Gondola, like a fuselage in an aircraft houses the payload and propulsion units in an airship. It is placed at the bottom of the gondola. A weight budget of $500\ g$ was set for the gondola. This budget was inclusive of the structure, propulsion units and battery. This constraint over the gondola weight made it necessary to make the gondola design as compact as possible. It was decided to fabricate the gondola framework out of 1 mm thick and 30 mm wide aluminum strips. Several gondola designs were considered before the one shown in Fig.11 was finalized.

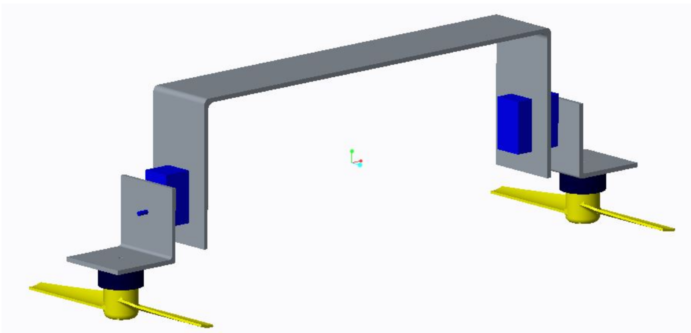

Fig. 11: CAD Model of the Gondola

A. Propulsion System

As per the design requirements, the maximum speed of the airship is 3 m/s. Approximating the airship envelope as an ellipsoid, the coefficient of drag along the longitudinal axis, C_D is 0.38 [12]. The drag acting on the airship at an airspeed of the 3 m/s can be determined as follows,

$$Drag = \frac{1}{2} C_D S_{ref} \rho_{air} V^2 \tag{8}$$

where $S_{ref} = \frac{\pi D^2}{4}$ is the frontal area of the ellipsoid, $\rho_{air} = 1.225\ kg/m^3$ is the air density and $V = 3m/s$ is the required air speed. This yields a drag of 1.65 N or 165 g. Since RC airships operate in a slight negative buoyancy condition, an upward thrust of about 100 g would be necessary to maintain altitude. Hence the total thrust required for the airship is 192 g. Since there are 2 propulsive units the thrust per motor is approximated to about 100 g. Conventionally, a low kV motor with long propellers are used in airships as they require less power. However, since the motors would be mounted close to the envelope, a high rpm motor (*EMAX RS2205-S 2300KV*) with a 5×4 tri-blade propeller configuration was chosen.

The chosen motor propeller configuration was coupled to a *Hitec HS-85MG* servo motor in a way that the line of thrust could be swivelled for both altitude and speed control. The propulsion unit can be seen in Fig.11 and 12.

B. Endurance Calculation

Thrust required per propulsive unit for altitude hold is 50 g and as per the datasheet of the motor propeller configuration[1] this would consume about 1 A current when used with a 3 cell lithium polymer battery. It is assumed that the two servos in total would consume about 1 A. Hence the total current required for hover is about $3A$. The design requirement dictates that the airship should be able to hover for a period of 1 hour. Hence a battery of 3000 mAh would deliver and endurance of 1 hour. A 3 cell lithium polymer battery of $3300mAh$ was chosen.

[1] http://gettbs.in/index.php?route=product/product&product_id=134.

C. Gondola Assembly

The total weight of the assembly was about 50 g heavier than the set limit as the airship had to be made slightly heavier than air. The fabricated gondola is shown in Fig.12.

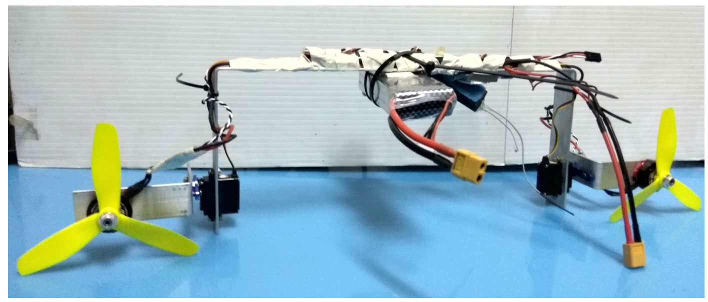

Fig. 12: Fabricated Gondola

IV. Flight Test and Results

The airship assembly took about 15 minutes which includes the envelope inflation and the gondola attachment to the envelope. The airship was flown at the Lecture Hall complex at IIT Bombay as shown in Fig. 13.

Fig. 13: Flight of the Airship

A *Pixhawk PX4* module was installed onboard the airship to collect the flight data. The aim was to study the attitude response to control input.

A. Results and Concluding Remarks

The airship flight data for altitude, pitch and roll in performing a circular trajectory is shown in Fig. 14-16.

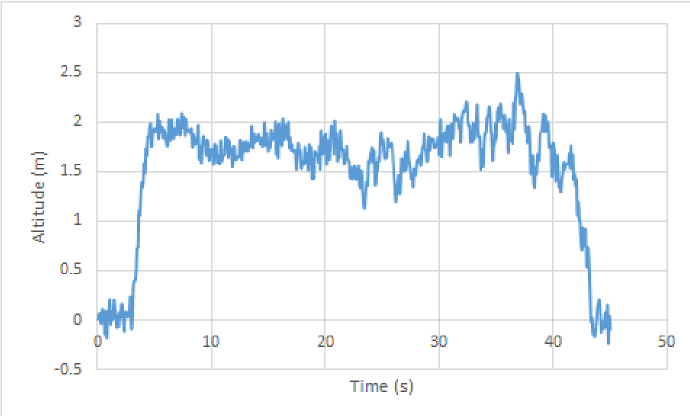

Fig. 14: Altitude data of the airship

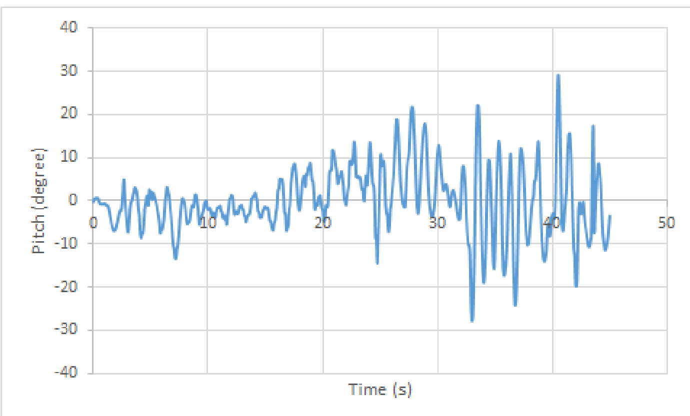

Fig. 15: Pitch data of the airship

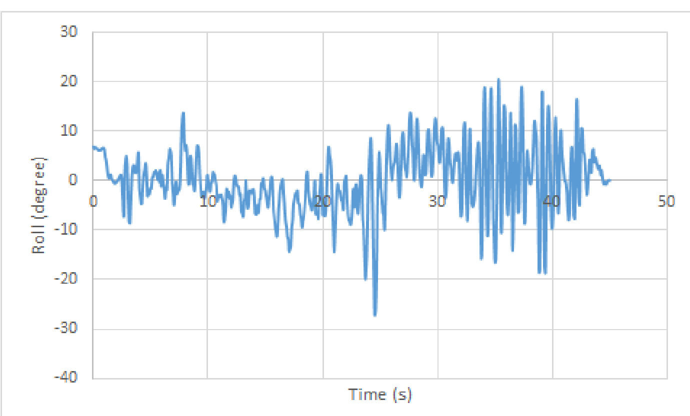

Fig. 16: Roll data of the airship

As seen from Fig. 15 and Fig. 16, it was observed that the control authortity over roll and pitch of the airship was not satisfactory. Use of two propulsive units does not provide effective control over the airship pitch and roll. This problem could be addressed by adding control surfaces like elevator or aileron. However, this approach would still be ineffective in lower airspeeds as the dynamic pressure is lower. An effective control for pitch and roll could be achieved by installing two additional propulsive units. This work would be continued and the use of four propulsive units for airship control would be investigated.

Acknowledgements

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