Design, Fabrication and Field Testing of an Aerostat system

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Abstract

Aerostats have so far been realized worldwide for several applications e.g., aerial surveillance and photography, product promotion, atmospheric sampling and for related experimentation purposes. The paper provides details of a methodology for design and analysis of the performance of the aerostat, and examining the sensitivity of various operational parameters. The methodology is a systematic collation of various design approaches and concepts, which were examined during the ongoing design and field trial exercises related to remotely controlled airships and aerostats at the Lighter-Than-A Systems Laboratory of the institute. The various design decisions were driven by the availability of local materials for different components. This paper discusses most of the aspects for design and fabrication of aerostats of 70 m^3 and 100 m^3 envelope sizes that can carry payload in the range of 10-15 kg to raise it to 100-300 m above ground level respectively. The paper will also share the field testing experience in carrying out experiment to serve the aerostat as a platform for carrying wireless communication platform to make the system as low cost as possible.

Nomenclature

LTA	=	Lighter Than Air
PADS	=	Procedure for Aerostat Design and Sizing
ISA	=	International Standard Atmosphere
MSL	=	Mean Sea Level
AGL	=	Above Ground Level
HAPS	=	High Attitude Platforms
LOS	=	Line of Sight
$Lift_{net}$	=	Net lift [kg]
V_e	=	Envelope Volume [m^3]
ρ_{air}	=	air density at off standard design pressure altitude [kg/m^3]
ρ_{LTA}	=	contained gas density at off standard design pressure altitude [kg/m^3]
Pu_{LTA}	=	percentage purity of the contained gas [%]
C_{DV}	=	Volumetric drag coefficient

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C_p	=	pressure coefficient
l	=	Length of the envelope [m]
d	=	Diameter of the envelope [m]
Re	=	Reynolds number
D	=	Drag on the envelope [N]
V	=	wind speed [m/s]
Cx	=	force coefficient in the x direction
Cy	=	force coefficient in the y direction
c	=	chord
dt	=	time step
Fx	=	X component of the resultant pressure force acting on the vehicle
Fy	=	Y component of the resultant pressure force acting on the vehicle
f, g	=	generic functions
h	=	height
i	=	time index during navigation
j	=	waypoint index
K	=	trailing-edge (TE) nondimensional angular deflection rate

I. Introduction of the Concept

Modern day technology lays emphasis on development of platforms that support rapid exchange of data. A major step in this direction has been the introduction of Internet. Over the last decade, a large chunk of the urban population has especially benefited from this. However, in many developing nations, the rural population is still devoid of internet connectivity. While poor infrastructure and high installation costs are obvious reasons behind the digital divide, the intrinsic property of rural areas to be sparsely populated further complicates the problem. Wired connection to each and every household becomes an economically unviable option.

A novel solution to this problem based on latest wireless technology was proposed, which aims to employ wireless bridges that can span distances to the tune of 10 km. The basic approach is to mount antennas (typically directional) on a high tower which is then connected to the wireless bridge. These antennas now look at client side antennas through line of sight (LOS) connectivity for internet access. It is the cost of high towers (50 to 100 meters) at the base station which makes deployment of wireless networks (say WiFi) expensive. To overcome the cost barrier of high towers, use aerostats tethered to the ground has been proposed and also in execution, which will reach heights exceeding 100 meters in the air to ensure that disturbance free LOS is available. This system aims to connect the far-flung rural communities to the urban areas, for knowledge and information sharing, using a mechanism that is easily re-locatable, and requires very low expenditure on fixed infrastructure, when compared to other options.

Grace et al. [1] have discussed the application of High Altitude Platforms (HAPs) operating in the stratosphere, 20 to 22 km above the ground for meeting the ever increasing demand for capacity for future generation multimedia applications, by utilizing the frequency allocations in the mm wave bands e.g. those specified for local multi-point distribution systems (LMDS). These frequency bands are capable of delivering considerably higher data rate services, due to the larger frequency allocations available. However, in these frequency bands, signals experience high attenuation due to line of sight (LOS) obstructions, and also to rain, which requires appropriate link margins to be used in order to guarantee availability and quality of service. HAPs are ideal in tackling both these problems effectively, i.e., LOS obstructions and rain attenuation. Such platforms have the potential capability to serve a large number of users, situated over a large geographical area, using considerably less communications infrastructure than that required if delivered by a terrestrial network.

Several patents have also been granted recently for innovative applications of aerostats. For instance, Knoblach and Frische [2] have proposed the creation of an airborne constellation with a system of individual lighter-than-air platforms spaced apart above a contiguous geographical area within a predetermined altitude range, so that proper line of sight of coverage of the geographic area is provided. Each of the LTA platforms further includes a signal transmitting device attached to the enclosure by which the signals from the platform may be transmitted to the contiguous area. In another patent, a distributed elevated Radar antenna system has been proposed by Halsey and Boschma [3], which is an airborne radar antenna system for detecting a target in a volume that includes a tethered aerostat and an antenna that is supported above ground by the aerostat. The aerostat-based antenna is used for transmitting and receiving a radar beam into the volume to detect the target. Additionally, the system includes a ground-based transmitter that generates a beacon signal which monitors the antenna configuration at the aerostat. The current system is also one of the possible innovative applications of LTA systems technology, and is quite similar to these two systems.

The Aerostat will be raised centrally to an altitude of around 50-70 m (165-230 ft) AMSL, on which a payload consisting of a router box and omni directional antenna will be mounted. The router circuitry receives the signals from a router box located away from the Aerostat, which in turn will be directed to the client antennas located in the surrounding villages within around 10 km range. This solution is ideal for the situation where there are villages scattered around a central village, which has the internet connectivity. The base station is chosen at this central village to maximize the reach of the wireless network. Also, the base station is such that safety of the aerostat is ensured. Also, it should have good physical accessibility and basic amenities like electricity, for proper working of the network. Power supply for the access point is provided from the ground over the PoE cable which doubles up as a data cable. Access point is a bridge between the Ethernet and wireless interface at the base station. This bridge will transmit the data packets wirelessly to the client side, from the omni-directional antenna mounted on top of the aerostat.

At the client side, flat panel antenna receives these data packets with the Line of sight connectivity maintained (otherwise there will be loss of data packet). This becomes an important factor as flat panel antennae on client side are directional and has limited beam-width in horizontal and vertical direction. Once the connectivity is established between base station and client side, internet connectivity to many other nodes can be also provided, by setting up a local area network using a hub.

Figure 1 shows a schematic diagram of the proposed system. The various components of the system are explained in the next section.

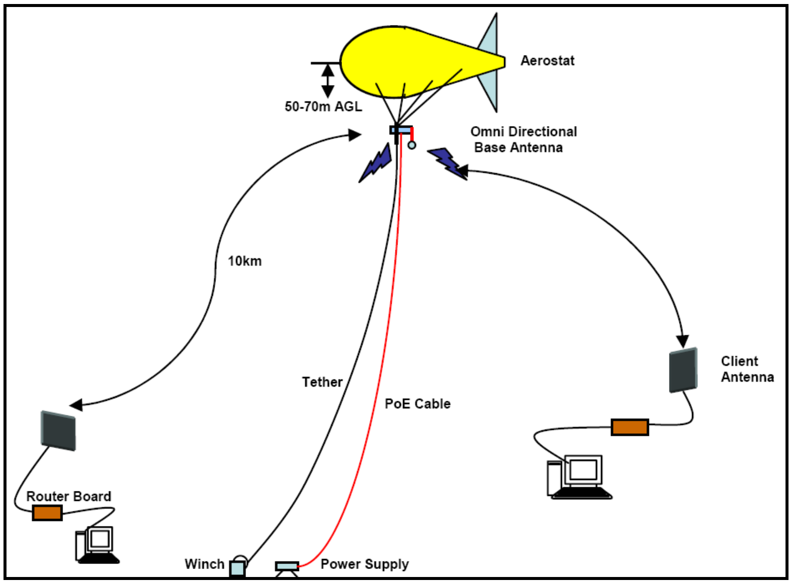


Figure1: Conceptual sketch of the Aerostat based wireless communication system

A communication system based on Aerostat has the following advantages over tower networks.

1) The system can be relocated to any required place where tower erection is sometimes practically not possible.
2) The height of the payload can be easily adjusted depending on requirements, which is not possible once the tower is erected.
3) A cost saving of 10 to 15 times the cost incurred in the tower fabrication and erection is possible with Aerostat based communication system.
4) This includes flood areas, earthquake areas, and other natural disaster affected areas where communication network is not yet established, or severely disrupted.
5) Commercial mobile services, television services can be quickly set up on the platform at required sites.

6) Aerostats can be lowered to put any heavy payload, where as it has to raised by some means to put it on tower which may be a cumbersome job. Same is the case when maintenance or modifications of the systems is required; on aerostat based system is much easy to maintain.

Another aspect of this concept was demonstrated during the trials conducted at Pune in August – September 2007. Here the aerostat system was used as a platform to conduct aerial surveillance and for recording various parameters like wind speed, altitude, blow by and airborne time using a video transmission downlink device and a GPS receiver, respectively. The aerostat was launched separately to a height of 300m AGL in order to record these parameters and establish the functionality of the whole system as an aerial surveillance platform.

II. Aerostat Design Methodology

Depending on the payload, range of surveillance, and operational time at station, aerostats have been launched to an operating altitude of around 4600 m from sea level. As per published literature, aerostats have been successfully deployed by commercial companies to carry payload such as Surveillance radars of all sizes and capabilities, Signal Intelligence (SIGINT) collection equipment, Gyro-stabilized daylight, low-light level and infra-red video cameras, Direct television broadcast and relay, FM radio broadcast and relay, VHF/UHF, Ground Control Intercept (GCI) and microwave communications, and Environmental monitoring equipment.

A methodology for initial sizing and conceptual design of an aerostat system has been developed to arrive at the required geometrical parameters and detailed mass breakup of an aerostat system, given the values of some operation, configuration, and performance related parameters. This methodology implements spread sheet form of MS-EXCEL™ and named as PADS.

PADS accepts all the input parameters, constant parameters, and some geometrical and operation related options such as envelope profile selection, Gas pressure management by Ballonets or symmetrically expandable elastic strip, and type of LTA gas used. The objective behind providing this facility for selection of optional parameters was to make the methodology more flexible and adaptive for any future modification in the aerostat system, and also to make sensitivity analyses much more comprehensive.

In an aerostat the geometry of the envelope has a profound effect on its aerodynamic characteristics, and hence on the stability and payload carrying ability. Some standard shapes of the aerostat envelopes exist and their profiles were incorporated in the input part of the PADS which are explained in the next section.

A. Various modules in PADS

PADS is designed in a modular fashion and contains 48 spread sheets with separate modules that cover the calculations related to LTA gas properties in the atmosphere, and sizing of envelope, petal, tether and fins. It also has modules that carry out calculations related to LOS error angle calculation, pivot and safety-system attachment. The fabrication process plans, including that of a small winch are worked out and cost calculations are carried out. Design flow is described in a modular way which enables to understand the contribution of each module for the design and sizing in subsequent steps.

The design procedure is based on the flow chart shown in Fig. 2.

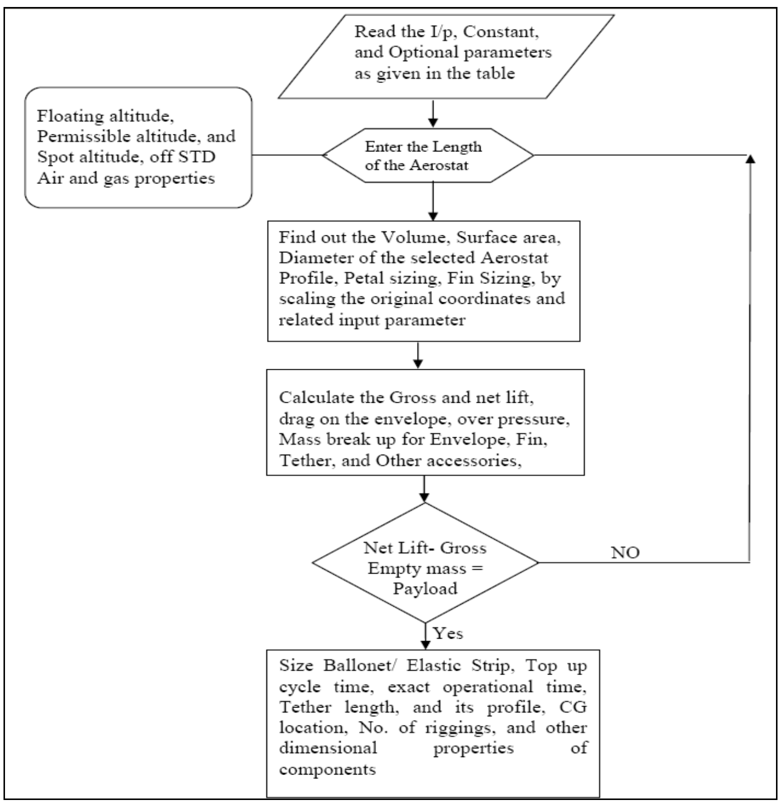


Figure 2: Design Methodology Flow chart

B. Database and Options for Design Initialization

Database and Options module contains various information and options required to carry out specific looped task to size major components of the aerostat. This mainly includes options like choice of contained gas viz., Helium, Hydrogen; choice of envelope shape viz., NPL, GNVR, SAC, and Optimum, with normalized coordinates, and fin dimensions; tether C_D calculation chart for various Reynolds numbers; tether material and specification up to 2 km AGL. Strength properties of envelope material are also added that includes breaking strength in warp and weft directions, He/ H_2 permeability rate, and surface density. There is scope for adding various options and database in the same module in future.

C. Design Requirements

The main module is the heart of PADS, all the inputs and options can be selected and design and analysis can be performed within this module. A case as in the Table 1 shows the structure of the spread sheet for input parameters. PADS are designed for SI units.

Table 1: Sample input of Main module of the PADS

INPUT PARAMETERS			
General	**Symbol**	**SI Unit**	**Typical Value**
Payload	W_pay	[kg]	7.00
Floating Altitude (From Sea Level)	H_float	[m]	740.81
Spot Altitude from Sea Level	H_Spot	[m]	560.00
Design Wind Speed	v_wind	[m/s]	15.00
Off Standard Temperature	ΔT_ISA	[^{o}C]	20.00
Operational Time	Ti_station	[days]	15.00
Diurnal Temperature range	ΔT_diurnal	[^{o}C]	10.00
Free Lift Permissible	Per_freelift	%	15.00
Permissible Reduction in Altitude	Always +ve	±DH	5.00
Constant Parameters			
Contained Gas Initial Purity	Per_Purity	[%]	99.50
Option for Envelope Material (PVC-1, Other-2)		PVC	1.00
Rate of Gas Permeability thru Envelope fabric	R_leak	[ltr/m2/day]	2.50
PoE Cable Specific Length	Ro_PoE	[kg/m]	0.04
Low Loss Cable Specific Length	Ro_LLC	[kg/m]	0.00
Elastic Strip Specific Length		[kg/m]	0.02
Available PVC Fabric density	Ro_PVC	[kg/m2]	0.21
Permissible Blow by and Excess Length for all the cables Design altitude AGL		%	20.00
Centre of pressure for Aerostat (0.3-0.35)		[-]	0.33
Options			
Profile Configuration (NPL-1, GNVR-2, SAC-3, Optimum-4, TCOM360Y-5)	Profile	SAC	3

Petal Configuration (1-Single, 2-Double)		Double	2
Rear Gore Petals (No. of Petals)	No_RearGore	[-]	10.00
Front Gore Petals	No_FrontGore	[-]	20.00
Contained Gas (He-1, H2-2)	Contain Gas	Helium	1
Include Integrated Balloonet OR Elastic Strips (Ballonet-1,El Strip-2)	Ballonet	El. Strip	2
Fin fabrication (Inflatable-1, Rigid outline with cover-2)			1
Mass specific length of PVC pipe		gm/m	125.00

The spreadsheet like form of PADS also helps in carrying out extensive sensitivity studies. In order to resize the aerostat of a given configuration and material for different operating conditions, only the operating parameters have to be changed. The Main module in the PADS is linked other modules to other module for design and sizing of various components of the Aerostat viz., Atmosphere, Envelope, Fin, Petals for the envelope, Pivot and safety, and accessories such as winch. The required output/s from these modules is posted back to Main module.

D. Envelope sizing, estimation of net Lift and Drag

PADS starts by inputting all the required input data as mentioned in the Table 1 in the specified units. A starting value for the envelope length is specified which invokes the envelope sizing module to multiply the normalized coordinates of the selected profile from Database and Options module. With numerical integration method, program calculates the volume and surface area of selected profile with inputted length of the envelope; this in turn used to calculate CG and CB. A detailed layout of the envelope profile, reference fin geometry and the single gore petal is collectively shown in the Fig.3 as below. All the features shown are gathered from different modules.

Simultaneously, Atmosphere module starts calculating the required off standard air properties not only at the design altitude, but also at the permissible lower, and ground altitudes by considering the ISA standard properties at MSL as the reference properties of air, viz., pressure, temperature and density. In addition to these properties, this module also calculates the Dynamic viscosity and Reynolds number at the design altitude. All the required formulae to calculate these air properties are taken from Anderson [6] and Khoury and Gillett [4]. Similarly, properties for the L-T-A gas chosen are also calculated at all the required altitudes. This module can calculate the properties up to stratopause which is 47 km from ISA MSL.

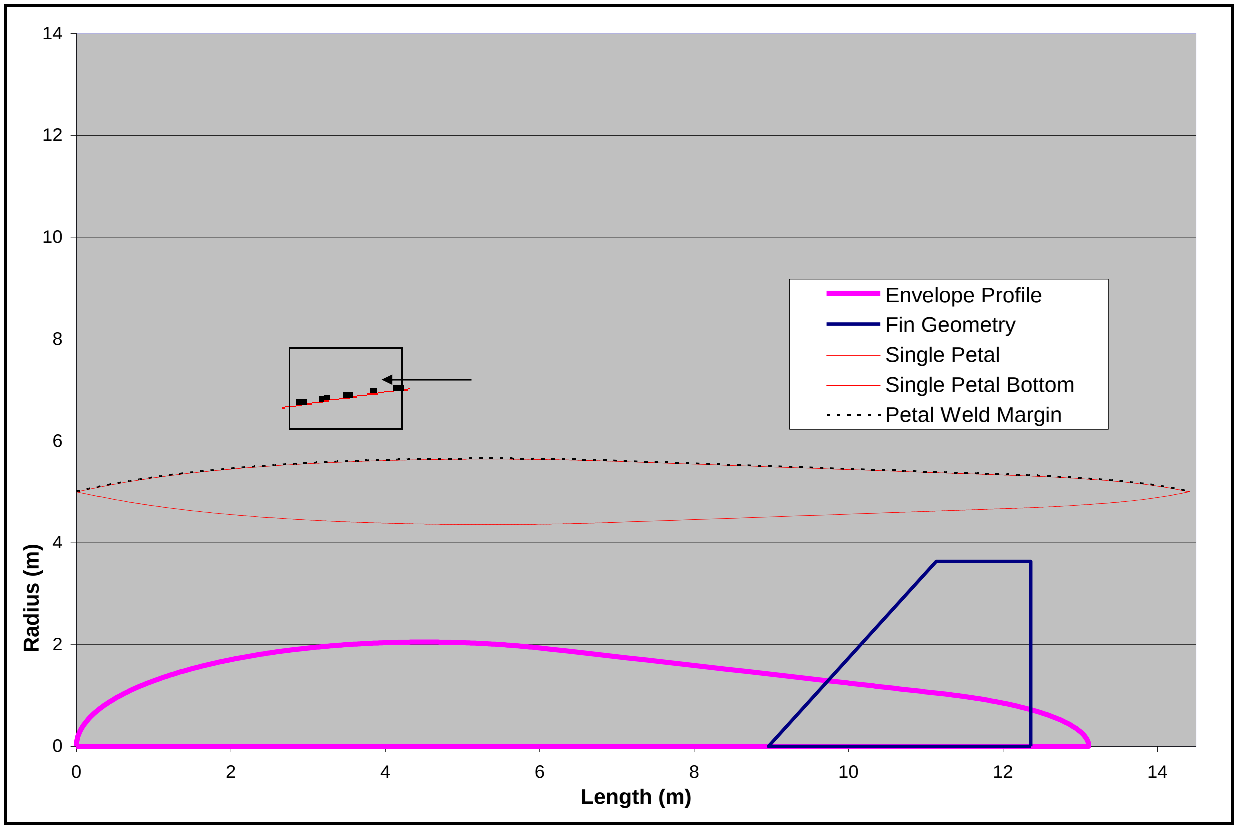


Figure 3: PADS generated combined output for envelope profile and reference fin geometry

The Main Module receives the required properties of air and LTA gas and calculates the Net disposable lift with volume of envelope, purity of LTA gas which is shown as below.

$$Lift_{net} = V_e \times \left[\rho_{air} - \left(\rho_{LTA} \cdot \left(\frac{Pu_{LTA}}{100} \right) + \left(1 - \left(\frac{Pu_{LTA}}{100} \right) \right) \cdot \rho_{air} \right) \right]$$

In order to seek the drag of the aerostat like body where lift is directly related to the volume; C_{DV} is calculated as per the formula quoted by Khoury [4].

$$C_{DV} = \left[0.712 \cdot \, {}^{l}\!/_{d}{}^{\,1/3} + 0.252 \cdot \, {}^{d}\!/_{l}{}^{\,1/2} + 1.032 \cdot \, {}^{d}\!/_{l}{}^{\,2.7} \right] \cdot \mathrm{Re}^{-1/6}$$

Based on the above equation, drag on the envelope is calculated as below

$$D = \frac{1}{2} \cdot \rho_{air}^{a} \cdot v^2 \cdot V^{2/3} \cdot C_{DV}$$

This value is used in tether module along with other parameters for calculating the expected blow by which is explained later.

E. Internal Pressure Estimation

In order to maintain positive pressure inside the envelope, three main loadings have to be considered, viz., the loading due to dynamic pressure, aerodynamic loading, and hydrostatic pressure. A brief description of these three components of the module is as given below.

<u>Loading due to dynamic pressure</u> which acts on the front portion of the aerostat envelope and tries to make a depression on the envelope surface, its diameter depends on the region of highly stressed area which is normally 7 to 9 % of the envelope length. To maintain the shape of the envelope, the internal pressure is kept slightly higher than dynamic pressure, normally 15% as suggested by Gupta & Malik [5] as shown in the equation below.

$$\Pr_{dyna} = 1.15 \cdot \left(\frac{1}{2} \cdot \rho_{air}^{a} \cdot v^{2} \right)$$

<u>Aerodynamic loading</u> results from applying the stability conditions to the aerostat. Aerostat is operated at certain angle of attack, (normally 2 to 2.5 degrees) which results in aerodynamic loading. Coefficient of pressure, as observed normally for such envelope profiles is in the range of 0.30 to 0.35 from the leading edge, but normally for such shapes it is assumed at the maximum diameter. Following equation is used for calculating the pressure due to this loading.

$$\Pr_{aero} = C_{p} \cdot \left(\frac{1}{2} \cdot \rho_{air}^{a} \cdot v^{2} \right)$$

<u>**Hydrostatic pressure:**</u> This is due to the difference between the height of the top and bottom of aerostat and could be quite substantial of the aerostat diameter in large. The hydrostatic pressure as observed at mean centerline axis of the envelope is calculated at maximum diameter using the following formula

$$\Pr_{hydro} = \quad \rho_{air}^{a} - \rho_{LTA}^{a} \quad \cdot g \cdot \frac{d}{2}$$

Thus, a sum of pressure due to afore three loadings gives the total required internal pressure.

Since the aerostat envelope diameter is more than twenty times of the thickness of the material; it can be considered as a very thin shell and hence hoop stress is calculated in terms of the circumferential unit load as shown in the following equation. Normally, this value is expressed in terms of kg/5cm of circumferential length of maximum diameter of envelope material fiber. This gives the allowable load that the envelope material fiber of 5 cm length, aligned in circumferential fashion can bear as:

$$\sigma_{c} = \Delta p \cdot \frac{d}{2}$$

Value from the above equation is then compared with the database module value of the selected fabric. A factor of safety of 4 (four) has normally been kept in selection of envelope fabric. This is required to take care of the inaccuracies in the calculation of diurnal temperature variations, degradation in the envelope material due to handling and prolonged exposure to atmospheric conditions, and changes in gas properties due to superheat.

Further, the Main module continues to calculate the total system mass breakdown in terms contained gas, Envelope group, Fin group, tether group, and other accessories group. All the sub group parameters are received from respective module.

F. Gore petal sizing

In most of the aerostats, petals are shaped depending on size of the envelope and the available form of material. PVC rolls, normally, are available in the local market in a flat pipe form (double layers) of 26" width with 50 ft length. In order to achieve more accurate shape after inflation, a large number of petals are employed, if the welding length is not a constraint. For operational benefits, however, a wider material with fewer welds is always preferable from leakage view point. But lesser number of petals leads to a improper shape of the envelope, especially at the ends. Usually less petals and greater curvatures at the nose portion, lead to many folds and thus affects the shape of the envelope and also the surface quality. In order to reduce these folds, a novel technique is incorporated based on the ADRDE's work experience [5], in this technique; a single petal is divided at certain appropriate location near the maximum diameter (normally 40% from the nose) in to two symmetric petals as shown in Figure 4. Thus, a single petal remains single at maximum diameter and subsequently at rear ends, in the region of maximum diameter, and also gets double at the nose portion to avoid folds. This technique ensures weld joints in only required area and thus leads to minimum weld lengths.

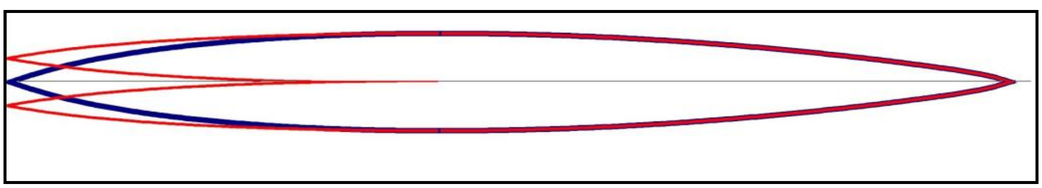


Figure 4: Single and split petal layout for GNVR envelope shape

The exact output from PADS looks as shown in the Fig. 5.

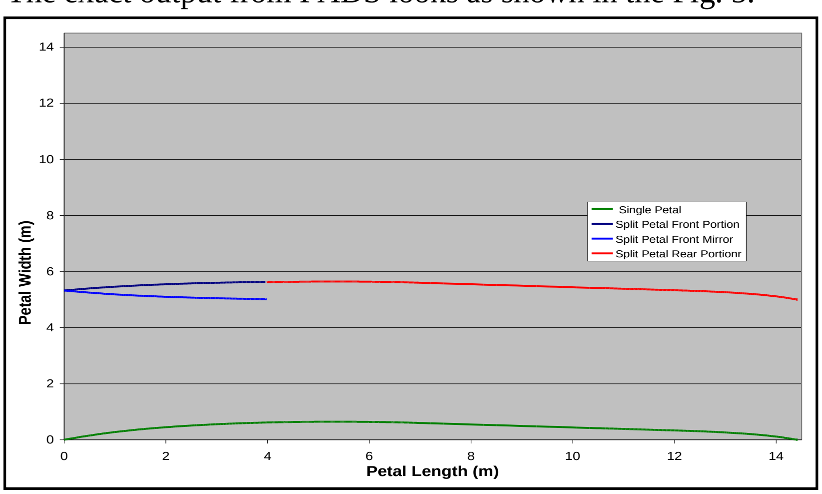


Figure 5: PADS output for Single and Split petals for SAC envelope profile.

G. Fin Sizing

Fin module of PADS accepts the fin sizing parameters as soon as the selected envelope is scaled to inputted length in envelope sizing module. PADS's fin sizing and mass estimation are based on the reference fin area. As shown in the Figure 6, the root chord is taken on the centerline of the aerostat. Based on the selected profile from Database module, a ratio of each part of the fin geometry to the envelope length (Root chord, Tip chord, Average half span, and the location of the trailing edge from the nose of the aerostat, to the length of the aerostat) is calculated. This then multiplied with the length with which the main calculation is initiated. Thus a linear scaling is performed on all the parameters so as to get the exact plan form geometry of the fin for the instantaneous envelope length.

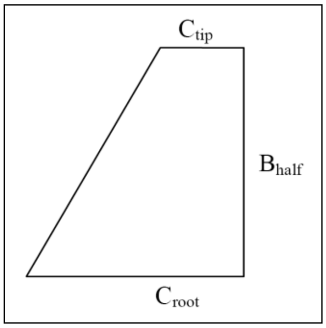


Figure 6: Sketch of Reference fin

PADS does the fin sizing structurally for two types of fin, one is the conventional inflatable structure with symmetric airfoil and other is the framed PVC structure. NACA 0018, aerofoil cross section is commonly used as a default cross section for all the fins of various envelope profiles available in the PADS Database and Options module; Coordinates of this airfoil are extracted from [7]. For inflatable fin, it is necessary to join the flexible ribs made of the same material as of fin to get the reasonably accurate shape of the fin structure as that of the airfoil after inflation. Knowledge on the number of ribs was gained from David et. al. [8], a structure of fin used in one of the experimental prototype is shown in Fig. 7. The schematic of how the fin will look like at tip and root sections is shown in Figure 7. Figure 8 shows the inflated wing structure that was used during the first trials at Lonere. The trailing edge can either be cut or can be aligned properly by means of harder plastic so as to maintain the contour.

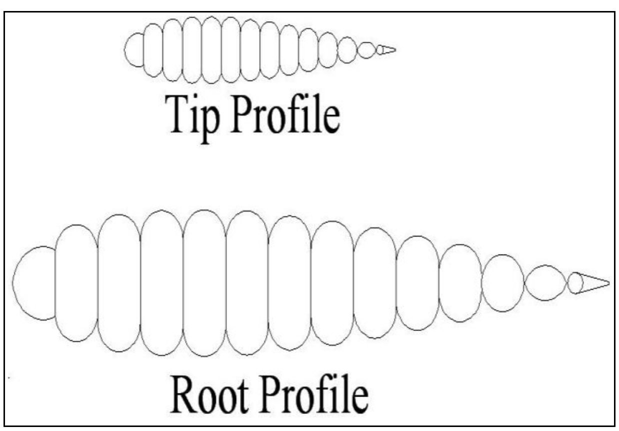


Figure 7: NACA 0018 as seen in inflatable fin structure at root and tip levels [3]


Figure 8: Inflated fin structure used during the first trial conducted at Lonere

For the rib sizing and its mass is made interactive with two CAD tools viz., AutoCAD2004™ and Solidworks2005™. Whole 3-D fin is firstly converted in to a flat 2-D structure by knowing the perimeter of the profile at both root and tip levels separated by the reference half span. This gives the area which is then multiplied with surface density of cover material to get the mass of the cover. As shown in Fig. 7, width of each rib is calculated by dividing the root and tip airfoils at appropriate intervals and getting the local thickness. A margin for weld is always added to this thickness. Length of each rib is calculated directly by joining the rib from tip at one point to the corresponding point at root locations as shown in the Fig.8. PADS do this for any number of ribs. Thus knowing the length and width at root and tip for each fin, surface area of all the ribs is calculated by multiplying it with the material surface density. Thus, mass of cover and the ribs is then added to get the complete mass of the fin which in turn multiplied by three for complete empennage mass. A factor of 1.1 is used to take care of additional attachments on the fin.

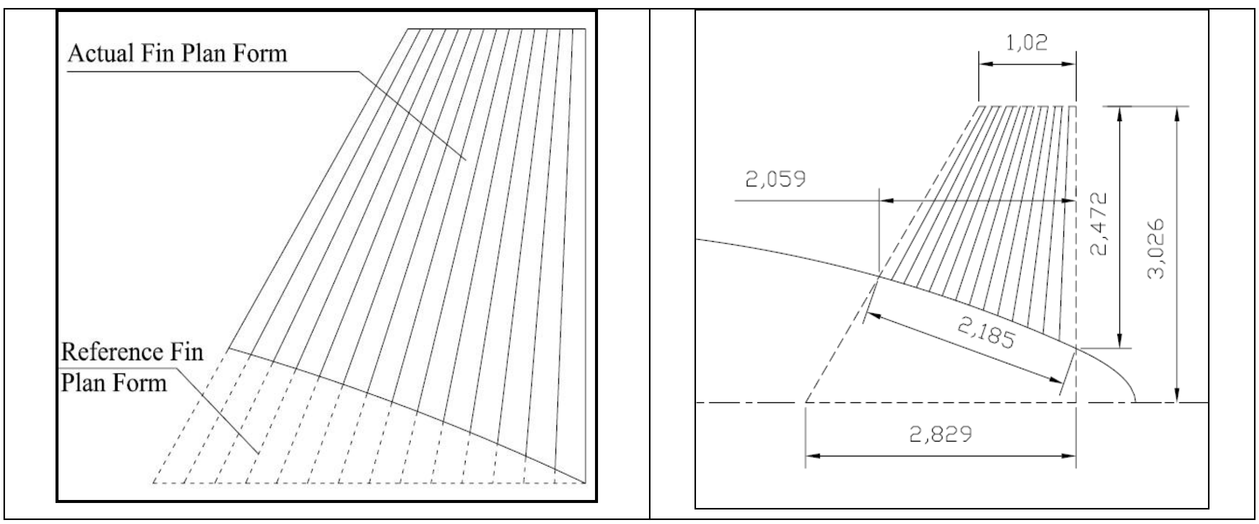


Figure9: Sketch of reference and actual fin plan form for fin mass estimation

H. Tether sizing and Profile generation

A tether module is developed in PADS to calculate the exact length of the combination of tether and PoE cable required for given design altitude, wind speed, permissible blow by, and permissible free lift in the aerostat at the design altitude. This sizing if based on the method suggested by Wright [9], which

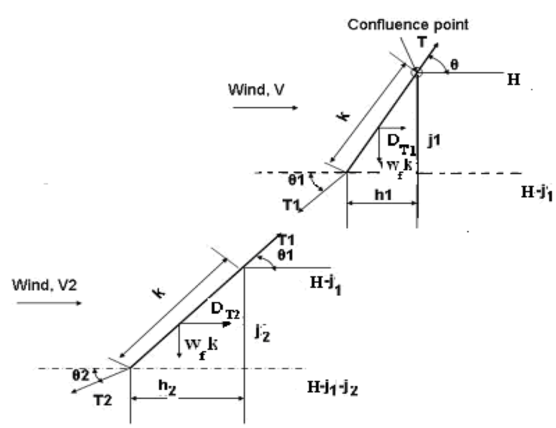


Fig.10: Free body diagram of discretized elements of tether

determines blow by of the aerostat and tether profile, given the tether tension and the tether angle at the confluence point. In this method, the tether is dis-cretiesed into elements of equal lengths and starting from the confluence point, the tension and inclination angle of each subsequent element below is determined by solving for the equilibrium of forces as shown in the Fig. 9.

The tether module also predicts the profile taken by the tether at various ambient wind speeds. Mass of the tether which is a combination of load and PoE cable is calculated by knowing the length AGL multiplied by the specific mass of the individual cable. Tether module also takes other issues in to account, such as load due to PoE cable, LDC to distribute the load on the envelope at various locations, and Pivot frame etc. LDC mass is taken as 1 % of the envelope mass, and the pivot frame is taken based on the payload space requirements.

I. Gas pressure management

This module provides two options; the ballonets or Elastic Strips for managing the gas internal over pressure. In case of ballonets, knowing the net positive lift at ground level, the volume of air to maintain aerostat both at ground and design altitudes is calculated. In addition to this volume, some additional air volume is calculated to maintain the platform performance at the design altitude in the effect of diurnal temperature variation at the local condition. Thus, once the total volume of air that is to be available in the ballonets is calculated, material for one or two ballonet bags which are to be kept within envelope for this air is calculated. It is obvious that before ballonet calculation, the volume calculated for the envelope is not enough to raise the payload to the design altitude.

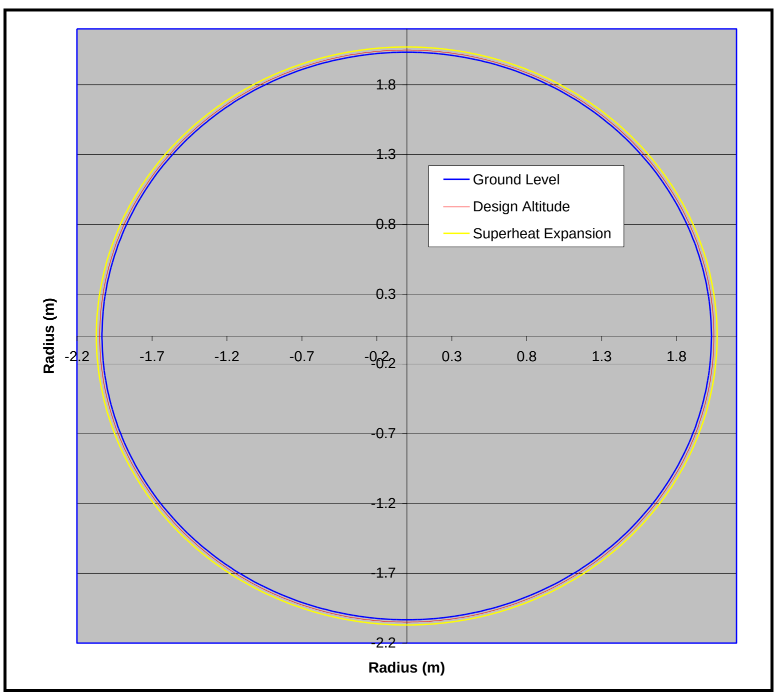


Fig. 11: PADS output for expansion of max. diameter at ground, design and superheat conditions

Hence, resizing is carried out by changing length with which envelope was calculated prior to the ballonet sizing.

In case of Elastic strips, sizing and mass estimation is carried out by calculating the expansion of the gas from ground to the design altitude. This varies the maximum diameter circumference which is recorded by Gas pressure management module as shown in the Fig. 10, with some room for expansion and contraction to take care of the envelope in the diurnal temperature variations.

While launching the aerostat, envelope is filled with the lifting gas slightly less by an amount of expansion till it goes to the design altitude which is given by the calculations in the Main module. Elastic strips maintain the tightness in the envelope. As it goes up, elastic strips allow the gas to expand and thus envelope remains tight at any altitude within the design range. Thus, knowing the volume at ground level and at design altitude, the required circumference at maximum diameter of the envelope is calculated. The difference in the circumference gives the maximum width of the elastic region, and it is maintained proportionately on front and rear portion of the maximum diameter along the petal profile. Usually the elastic region is kept 30% of the envelope length. The dead length is the length of the elastic strip which gives maximum stretchable length more than that of required circumferential expansion. Thus, width of the maximum expandable length to take care of expansion under circumferential unit load is the sum of difference in circumference of maximum diameter at superheat volume of the envelope to ground level volume along with dead length of the strip depending on the properties. A factor of 1.5 is used for safety reasons, above dead length, knowing the fact that the envelope contraction can be managed but the expansion is quite undesirable. Further, knowing the maximum width and maximum length of the elastic region total length required, specific mass, mass of the hooks to maintain a zigzag fashion in the region and other mass of attachments are calculated.

J. Weight Estimation of Various groups

Mass of the contained gas: For the particular volume that has been calculated by initializing a certain amount of length, mass of the gas filled inside is calculated by deducing the Net lift from the gross lift that is generated for this volume.

Mass of Envelope Group: The breaks up is estimated in terms of envelope, and other external attachments to it such as riggings, patches, and hooks, nose battens, gas filling port/opening. Envelope mass is primarily calculated as summation of total material used for envelope including weld margin and multiplied by the surface density of the material. Mass of other groups in connection with the envelope are assumed to be a percentage of envelope mass as suggested in [3, 5], as mentioned below. Table 3 shows the detailed percentages of envelope weight used for rigging, hooks, patches, nose battens and Gas filling hose/port/opening

Mass of Gas Pressure Management group: Since PADS is tuned to use ballonets only if the design altitude exceeds 500 m above MSL, the current case gives the weight for this group for elastic strips only as shown in the table. Table 3 shows the mass breakup of each group and its values for the case shown in the Table 1.

Group Name	Sub Group	Criteria / Module output	Value kg
	Contained Gas	-	15.18
Envelope	**Envelope Group**		30.98
	Envelope	$W_e = \rho_{fabric} \cdot S_e$	26.3
	Rigging, Hooks and Patches	$0.06 \cdot W_e$	1.58
	Nose Battens	$0.1 \cdot W_e$	2.63
	Gas Filling Hose/Port/Opening (s)	$0.02 \cdot W_e$	0.53
Elastic strips	**Elastic Strips group**		2.62
	Mass of the elastic strip	$l_{el-s} \cdot \rho_{el-s}$	0.91
	Mass of corner hooks	$10/1000 \cdot 2 \cdot No_{zigzag}$	1.61
	Mass of support patch for elastic region	$25/1000 \cdot 2 \cdot l_{el-R}$	0.10
Fin	**Mass of Fin Group**		13.22
	Mass of PVC Cover	Fin Module*	3.65
	Mass of total spars	Fin Module*	0.588
	Total fin Mass	Fin Module*	4.24
	Total Empennage mass	$3 \cdot W_{fin}$	
Tether	**Tether Group**		23.13
	Tether	$l_t \cdot \rho_t$	10.85
	PoE Cable	$l_{PoE} \cdot \rho_{PoE}$	8.68
	Pivot with payload frame	Fixed	3.34
	Confluence lines Support Distribution Wires (1% of Envelope Mass)	$0.01 \cdot W_e$	0.26
	Other Accessories	Fixed	0.70
	Night Visibility System (Five Pin Lights)	Fixed	0.50
	GPS Receiver	Fixed	0.20
	Gross Take off Empty Mass		70.64

Table2: Weight distribution as obtained from PADS with conditions used

K. Winch Design and development:

The winch was designed using an ‘open ended approach’ so that it could be continuously upgraded during its development cycle. Details of winch design are presented in [10]; the specific design requirements for winch design were arrived from one of the modules described in PADS. This included parameters like expected tether tension, drum size, tether winding rate, and tether profile, power requirements for winding,

The first field trial revealed that the winch was toppling due to high line pull on the tether due to low weight of the winch. Therefore, a toppling arrester was developed and attached to the winch. This arrester has four studs housed in a barrel which is connected to the frame of the winch at four corners. Once the winch is placed at the launch location, these studs are pierced inside the ground for firm grip and thus arrest the toppling of winch. The design of the toppling arrester takes into consideration the tether tension at drum location for all possible movement patterns of the aerostat due to ambient wind conditions. Further, the winch is powered by a single phase induction motor that drives a pulley system which in turn drives the gear pairs for rotating the main tether drum during recovery. A separate drum has also been provided to release and wind a data cable from the ground to a payload mounted on the aerostat which could be a communication system, still/ video camera or a data logger etc. This drum is also powered by an inversion of four bar link mechanism that draws power from main drum shaft.

The winch is designed to arrive at a cost effective design, with main emphasis on local availability of material and fabrication techniques.

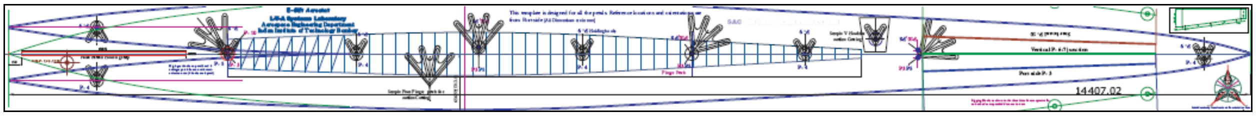
III. Fabrication

The fabrication of the aerostat system consisted of three major parts namely fabrication of envelope, fin and the winch. Detailed prototype fabrication techniques are mentioned as below.

A. Envelope fabrication:

Production drawings for the envelope were generated on a vinyl banner which worked as a master petal template with all location and orientation markings for all external attachments viz., hooks for nose rings, nose batten, guy ropes, riggings and finger patches for confluence lines. Fig 15 shows a cut view of master petal that was developed for the aerostat of 100 m^3 envelope volume.

Once the master petal template was ready the same dimensions were transferred onto equivalent amounts of PVC sheets. The same were cut as per dimension and prepared for the next task of joining these individuals into an envelope. A RF sealing machine was used for welding these PVC petals together. A set of linear, circular, and arc dies made from brass were used. Heat is used to diffuse the material on the inner interface in order to obtain a gas leek proof joint. Adequate amount of overlap is provided between two joints in order to ensure a completely leek proof joint.



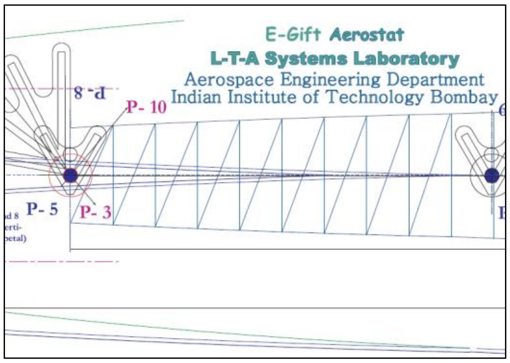


Figure 12: Master petal template used for the fabrication of envelope from ten petals

The additional pouches required for insertion of the nose baton strips along with the finger patches are fabricated to the requisite petals during the envelope fabrication itself. Figure 16 shows the fabrication process.

Figure 13: Snap shots of envelope fabrication process

B. Fin fabrication:

The inflatable fin comprises of many ribs and thus necessitates maximum number of welded joints. For the 70 m^3 aerostat fin, the total weld length for a single fin was around 68 m within a surface area of 9.52 m^2. In the envelope, total weld length is over 320 m in 91.6 m^2 area. Thus, fin has more than double the weld length per square meter of area (7.14 m/ m^2 as compared to 3.5 m/ m2 for the Envelope). Hence, it is possible that more leakages may occur in the fin. Care has been taken in the present design to maintain the welding current for proper merging of multiple folds of the material. There is a provision of three hooks on either side of the fin at a location 2/3rd of the average half span from the root level. This is for holding the fin on the envelope from top portion. For fixing of fin at root level, a flexible flange with around 70 (Seventy) holes hardened by means of metal eyelets are attached, and same part is also attached on the envelope at same location. While attaching the fin, high strength Mylar thread is passed through both the Flanges. This arrangement is the same as the one used in Shoe laces, which results n a very firm attachment. Figure 17 shows photographs of fin under fabrication.

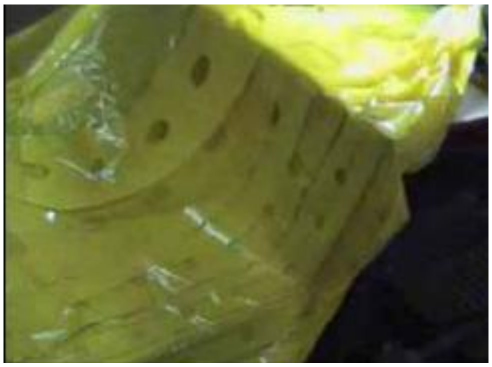


Figure14: Fin fabrication pictures with rib joining, provision on the envelope for attachment, inflated fin

IV. Field testing of 70 m^3 and 100m^3 Aerostat systems:

A. 70m^3 Envelope field trial at B.A.T.U. Lonere, Raigad

The field trial for the 70m^3 aerostat was done at Babhasaheb Ambedkar Technological Institute, Lonere, Raigad. This trial was conducted in May ‘07. The objective of the first trial was mainly to establish the working of the aerostat system as a successful communication platform.

The Aerostat was raised centrally to an altitude of around 50-70 m (165-230 ft) AMSL on which a payload consisting of a router box and omni directional antenna was mounted. The router circuitry received signals from a router box located away from the Aerostat, which in turn was directed to the client antennas located in the surrounding villages within around 10 km range. The maximum range achieved was at 7 km. The base station was chosen so as to maximize the reach of the wireless network. The safety of the aerostat is ensured taking into consideration the location of the base station. Power supply for the access point is provided from the ground over the PoE cable which doubles up as a data cable.

Fig 15: Aerostat being integrated and prepared for launch.

Access point is a bridge between the Ethernet and wireless interface at the base station. This bridge will transmit the data packets wirelessly to the client side, from the omni-directional antenna mounted on top of the aerostat.

At the client side, flat panel antenna receives these data packets with the Line of sight connectivity maintained (otherwise there will be loss of data packet). This becomes an important factor as flat panel antennae on client side are directional and has limited beam-width in horizontal and vertical direction. Once the connectivity is established between base station and client side, internet connectivity can be provided to many more nodes, by setting up a local area network using a hub.

The above concept was successfully executed during the first trial conducted at B.A.T.U., Lonere, Raigad.

B. 100m^3 Envelope field trial conducted at Pune Gliding Centre, Hadapsar, Pune

The field trial for 100m^3 envelope was conducted at Pune Gliding Centre at Hadapsar, Pune. Since the aerostat system had already been successfully proved as a platform for wireless communication during the first trial, the urge to try something new was on the minds of all of the team members. Hence it was collectively decided that the aerostat system would be used to establish its functionality as a surveillance platform. The same was achieved by mounting a Video downlink transmission device along with a GPS device.

The aerostat was launched to a height of 300m above ground level. Using the Video downlink transmission device, images were captured from a height of nearly 250m. This successfully proved the usability of the aerostat system as an aerial surveillance device.

Fig 16: Aerostat filled with lighter than air gas ready for launch.

Once the aerostat was launched to its maximum height i.e. 300m ~ 1000ft, the GPS device was used to record various parameters such as wind speed, airborne time, altitude, blowby, etc. This simply proved that in case of a natural disaster the aerostat could be successfully used as a platform for gathering essential and critical data which would help the concerned officials to speed up rescue efforts. Thus the trials conducted proved the functionality our aerostat system so as to serve different purposes during operation.

V. Conclusions:

The methodology quoted in PADS found very useful in generating the drawings for fabrication work and during the field testing of two experimental prototypes. Since, PADS is in modular fashion, it is very user friendly in getting the values and graphical representation of results of individual module. Winch system performed as desired, the braking system positively regulated the ascending rate of the aerostat despite of tremendous line pull due to free lift which actually came out to be 70 kg in the field. Since the inflatable fin was designed to be attached externally, there was no provision in the fin to manage the internal over pressure in the fin during launch and diurnal temperature variation. There is still much scope to make PADS for a complete design and analysis of aerostat and even airships with integration of CAD and CAM tools. The basic design intent of arriving at a cost effective aerostat system for wireless communication has so far been realized in two field trials. Also the variety of functions that the aerostat system could be subjected to was realized during the trials.

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