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AERODYNAMIC CHARACTERISATION OF TORUS SHAPED AEROSTAT

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ABSTRACT:

Manufacturers can make balloons into variety of shapes, most common are spherical and ellipsoidal tether balloon and constant volume balloon have been in use for years but it is not common to see both in combination. In preliminary development and evaluation of the tether balloon system of angle and shape .Torus envelope could be viable but the envelope must be very large to withstand low to moderate winds. In this thesis the main criteria is to reduce the volume and increase stability.

The flow characterization can be done by ANSYS and the comparison is made with wind tunnel results.

Hoop stress is the force exerted circumferentially in all directions on every particle in the cylinder wall. When the vessel has closed ends the internal pressure acts on them to develop a force. The outside and inside experience the same total strain which however is distributed over different circumferences. This hoop stress is analyzed using NASTRAN and PATRAN and is minimized.

Keywords: ANSYS,NASTRAN,PATRAN

INTRODUCTION:

As materials and technology have evolved, aerostats have increased in reliability, safety, size and carrying capacity. They can carry payloads—ranging from communications sensors to signals intelligence (SIGINT) and electronic intelligence (ELINT) systems, radars and day and night (cooled IR) cameras—with ever-higher reliability, range, quality and resolution. When evaluating the various systems for conservation work, potential users should keep their mission in mind (e.g. survey a reserve entry point, detect human intruders, relay communication, provide a 24/7 view of forest canopy, carry weather gauges or other research equipment) to effectively assess necessary coverage, mobility and permits from local air traffic control.NavinMahto (2017), the design of a tethered aerostat system that can possibly utilized for animal and bird hazard mitigation. This system incorporates bio-acoustic devices as a payload to mitigate the bird and animal hazards in agricultural areas. Such a re-locatable, re-deployable and versatile system can be tailored to meet the specific hazard that is present and can be very helpful for agricultural applications. The results of sizing of such a system are also presented through a case study. It is capable of carrying a payload of 50 kg, and requires a minimal LTA gas refill once a month.Jonathan 1. Miller(2005), The goal of

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this research was to design an aerostat that could be deployed for very long periods, thus reducing operating costs and interruptions in data acquisition. Existing designs and fabrication techniques were first reviewed and replicated in the construction of a 2.5 m diameter spherical aerostat. The constructed balloon was then flown outdoors to observe its operational qualities. A low-cost data acquisition system was assembled to characterize the balloon's dynamics. The results were used to inform a Finite Element Analysis model evaluating the critical stresses in a 10.15 m diameter balloon' s envelope and its tendency to "dimple" when subjected to high wind speeds. A second model was created to appraise the performance of an aerostat with a partially hard shell, made of carbon fiber, in highly loaded areas. An average drag coefficient of 0.88 was calculated for aIl the flights.Shawn T. Petersen(2005), A mooring system that is highly mobile with the safety of a three-point, weathervaning platform. A system flexible enough for multiple inflation/deflation cycles but rugged enough for long term deployment. An aerostat designed to carry various payloads: cameras, antennas or radars.Kazuhisa Chiba(2017), investigate the influence of aerodynamic factors on the static behavior of a tethered high-altitude lighter-than-air platform. The system design comprised a lighter-than-air vehicle and a tether cable, and the conceptual platform configuration of such a system is studied herein. Governing equations were derived to model the static behavior of the system, and the effects of aerodynamic lift and buoyancy were parametrically analyzed based on the advection distance of the platform under storm conditions.Thomas Pink(2007), the investigation of the potential use of aerostats for the recovery of heavy military vehicles such as Main Battle Tanks and other heavy military or relief equipment deployed from a Sea Base. A capability gap was identified for vehicles within the Marine Corp and Army inventory. High value vehicles that will need to be recovered but couldn‘t be lifted by the heavy lift helicopter CH-53 were identified. Past and current aerostats were researched and the most suitable type, which satisfied most of the key requirements, was identified.

Materials and Equipment

Material development is a continuing process. Some desirable properties for airship textile materials are mentioned below:

- High strength: Strength of the material determines the maximum possible envelope size
- High strength to weight ratio: To minimize the weight of the envelope
- Resistance to the environmental degradation(temperature, humidity, ultraviolet light).
- High tear resistance to give damage tolerance.
- Low permeability to minimize helium loss. Helium loss results in loss of operational capability and increased operational costs.
- Joining techniques that reduces strong and reliable joints not subjected to creep rupture.

Winch: force 5 guide line winch	Storage drum capacity : 5262ft or 7/8 rope. Max pulling force: 3400lbf
Tether: spectra tether, nylon6-6	Breaking strength: 800lbf Line weight:10 lbf Diameter : 8 mm
Envelope fabric: polyurethane coated	Tear strength: 0.8 gpa

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nylon	Fabric density: 200gms/m2
Lifting gas: helium	Density: 0.18 kg/m3 at sea level
Bridle lines: nylon or spectra tether	Breaking strength: 800 lbf
	Line weight : 10 lbf
	Diameter : 8 mm
Suspension lines: nylon or spectra tether	Breaking strength: 800 lbf
	Line weight : 10 lbf
	Diameter : 8 mm
Bearing swivels	Type: clevis and clevis
Adhesive backed tie down rings	Working load : 260 lbf

METHODOLOGY;

DESIGN;

Computational fluid dynamics (CFD) is a powerful tool used to model the real life behavior of fluids. It allows the optimization of design parameters without the need for the costly testing of multiple prototypes. What is more, it is also a powerful graphical tool for visualizing flow patterns that can give insight into flow physics that otherwise would be very difficult and costly to discover experimentally, if possible at all. Governing equations exist to model fluid behavior, but it is not always possible to apply them to many of the complex flow patterns we see in the real world directly as there would be too many unknown variables.The modeling process consists of first taking the real world fluid geometry and replicating this in the virtual environment. From here, a mesh can be created to divide the fluid up into discrete sections. Boundary conditions must then be entered into the model to designate parameters such as the type of fluids to be modeled or the details of any solid edges or flow inlets/outlets.

Input geometry:An input geometry is drawn using CATIA V5

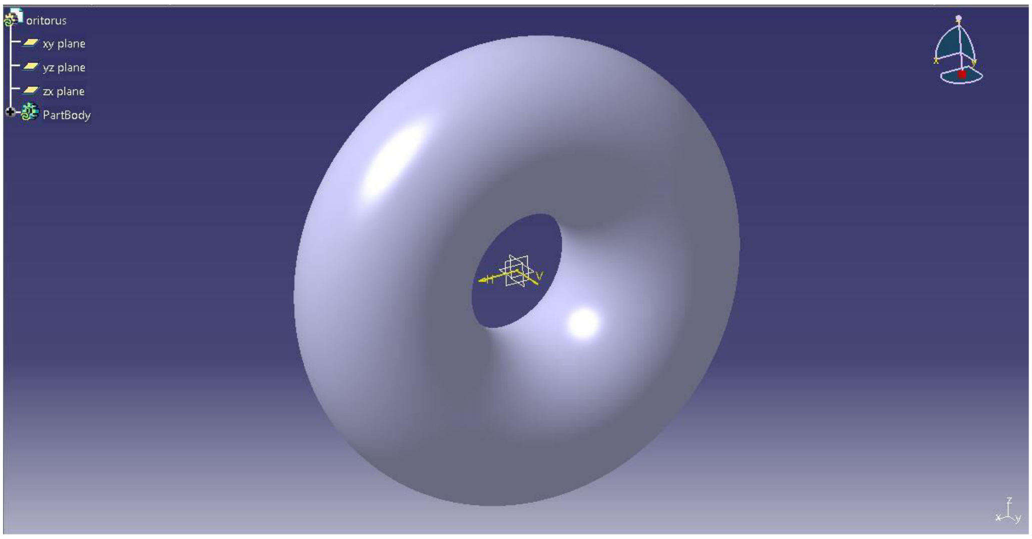

Figure 6 -Design of torus

Mesh preparation;

ANSYS so meshing could begin. Models were imported as torus.igs files, which was the geometry file from CATIA that was compatible with ANSYS. Once imported, the geometry

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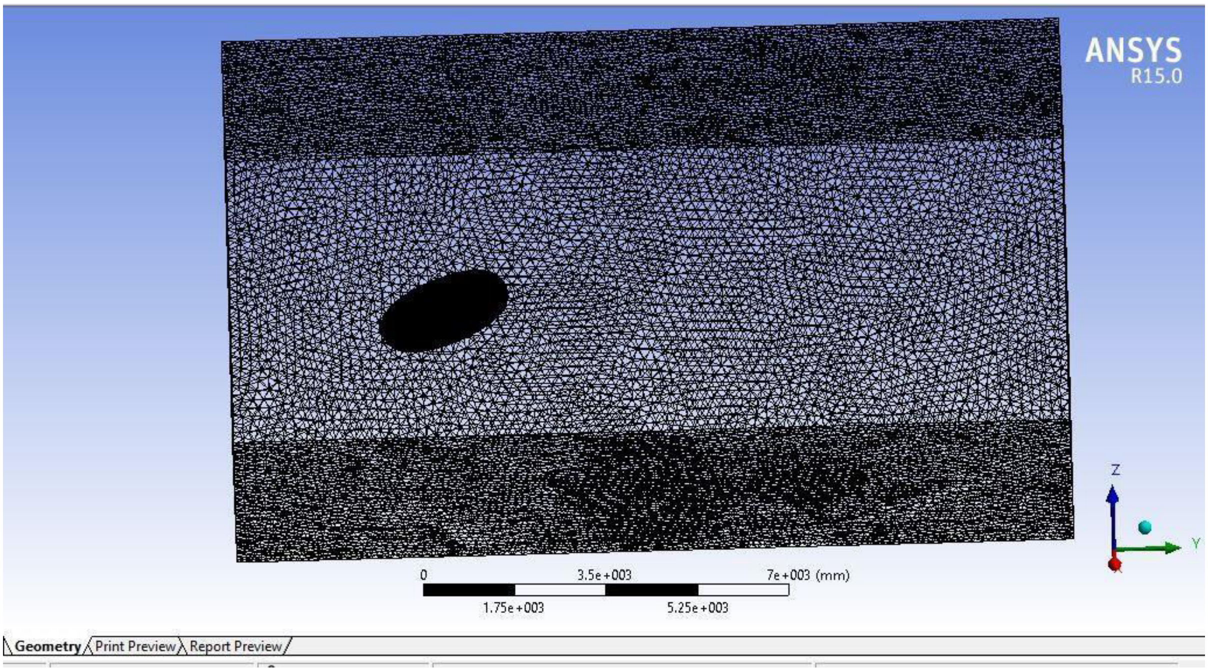
could be used to define the volume through which fluid flow would be occurring. This was accomplished by inverting the CATIA geometries to leave behind the fluid, or void space. In other words, the geometry acted as a mould for creating the volume.The default category included physics preference, solver preference, and relevance. The physics preference was CFD (Computational fluid dynamics) due to the project goal specification that CFD be performed. CFX was chosen as the solver preference for reasons similar to the choice that led to using CFD as the physics preference.

The sizing category was mainly kept as the given default conditions. The two main differences included turning off the advanced sizing features for the empty channel and specifying the relevance center as fine. The advanced sizing features added complexity to the problem that was not needed and resulted in a less uniform mesh overall.



Boundary condition
then the solution might result in blunders and if they are not utilized wisely, them the problem solving time may increase manifold. Transient problems require one more thing , initial conditions where initial values of flow variables are specified at nodes in the flow domain.

SOLVER AND SIMULATION;

A CFD simulation is done by using CFX solver. A simulation is done for finding the aerodynamics characterization of torus while torus immersed in flow field. A flow visualization is carried out by 3m/s velocity and different angle from vertical position. A flow field Reynolds number is nearly 12000, for Reynolds number calculation we have to take outer diameter of torus.

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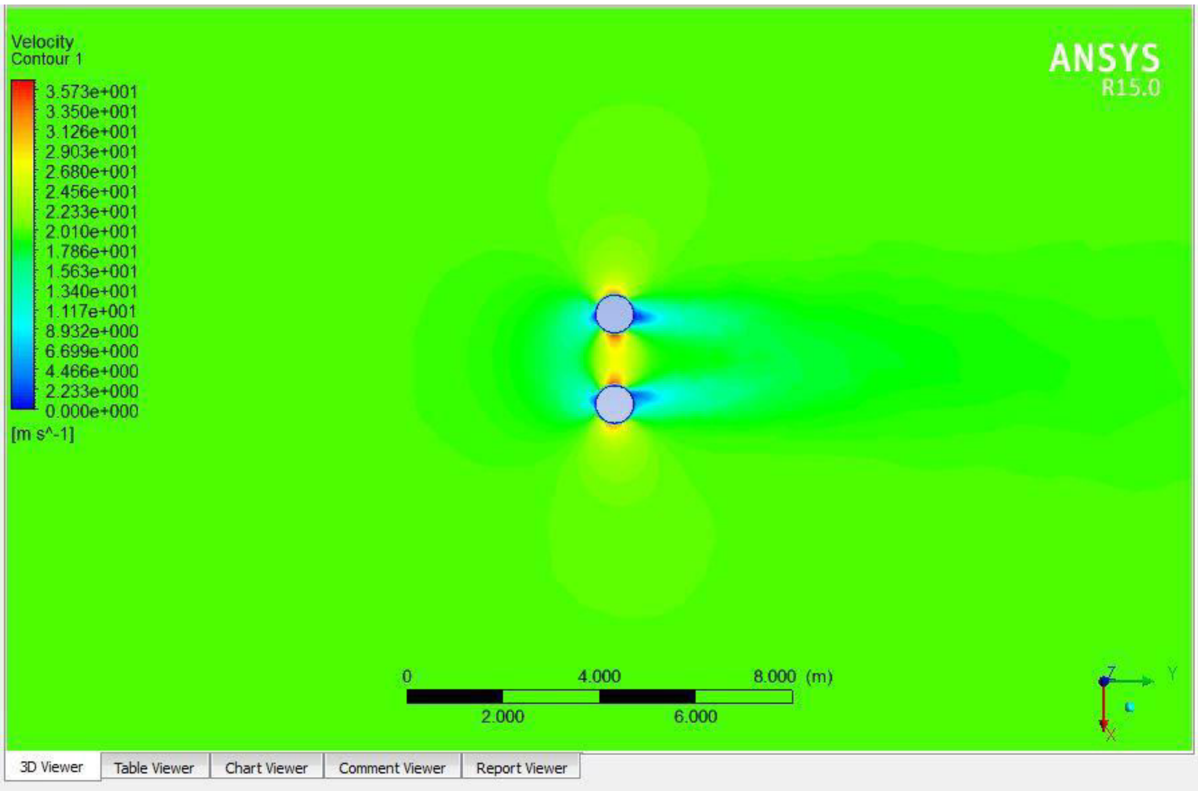

Figure 9 - CFD for 900 inclination

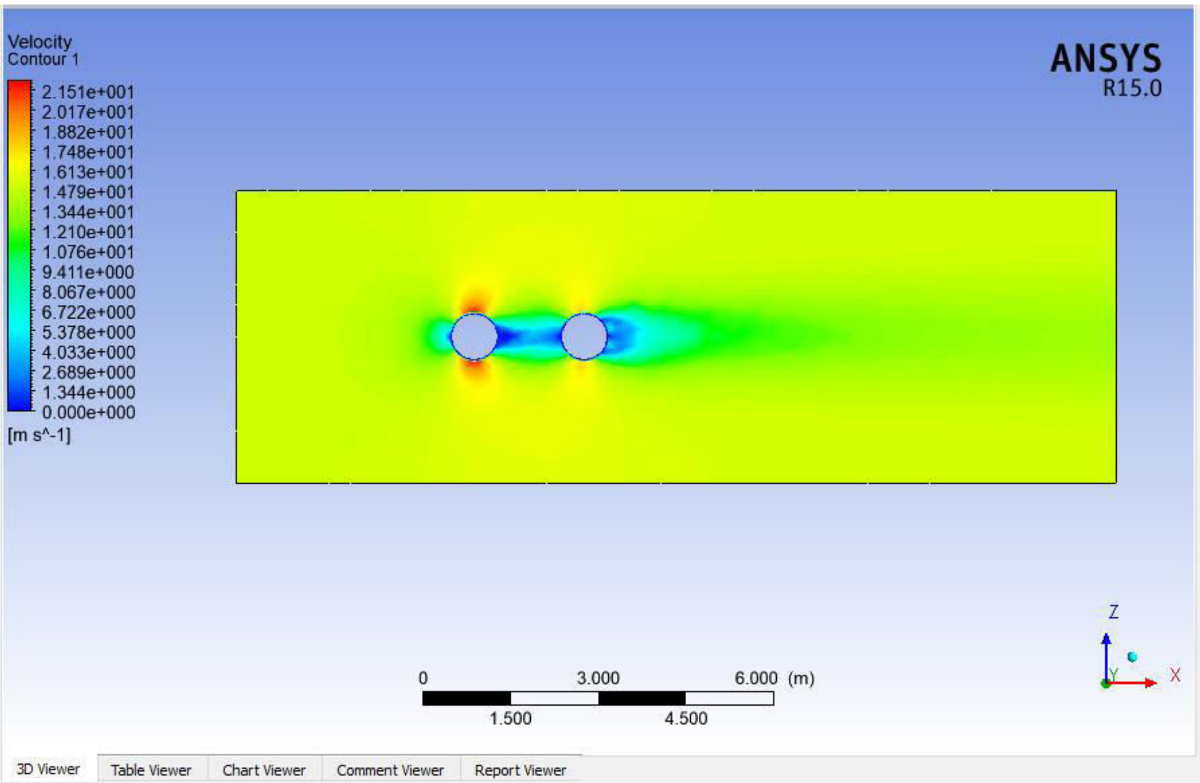

Figure 10 - CFD for 00inclination

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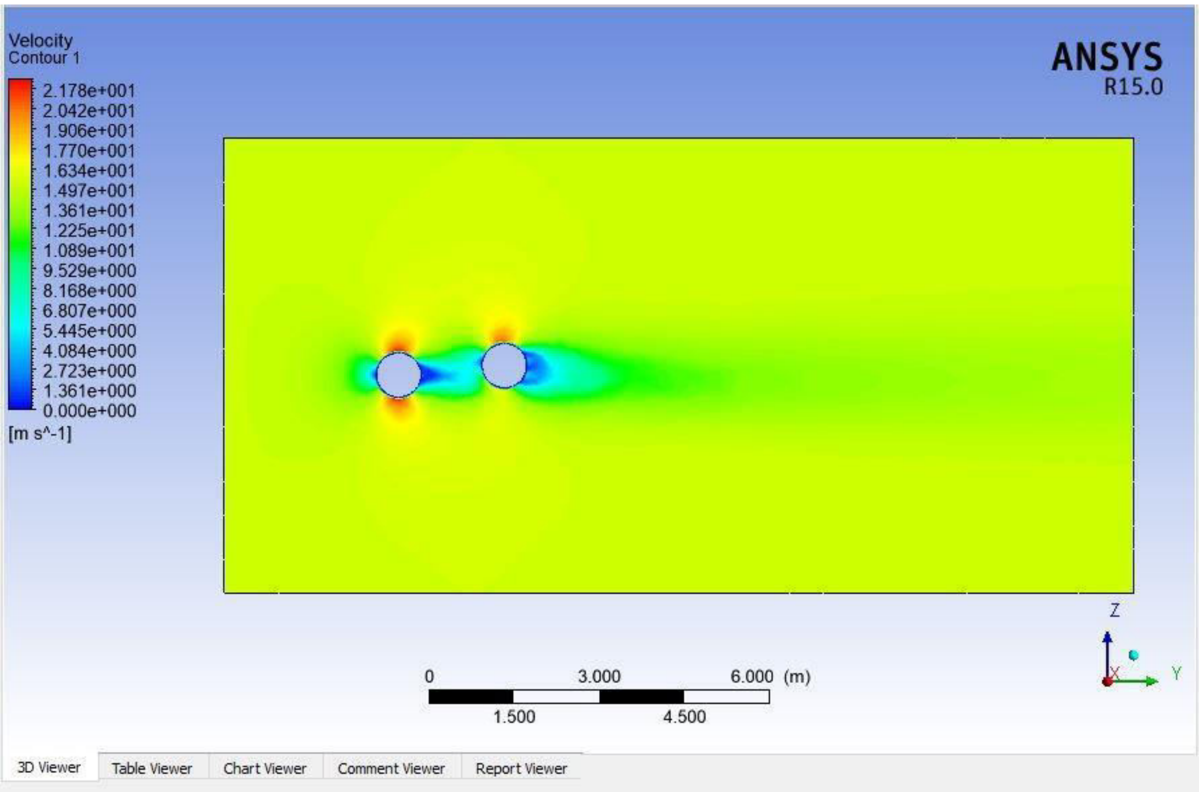

Figure 11 - CFD for 5^0inclination

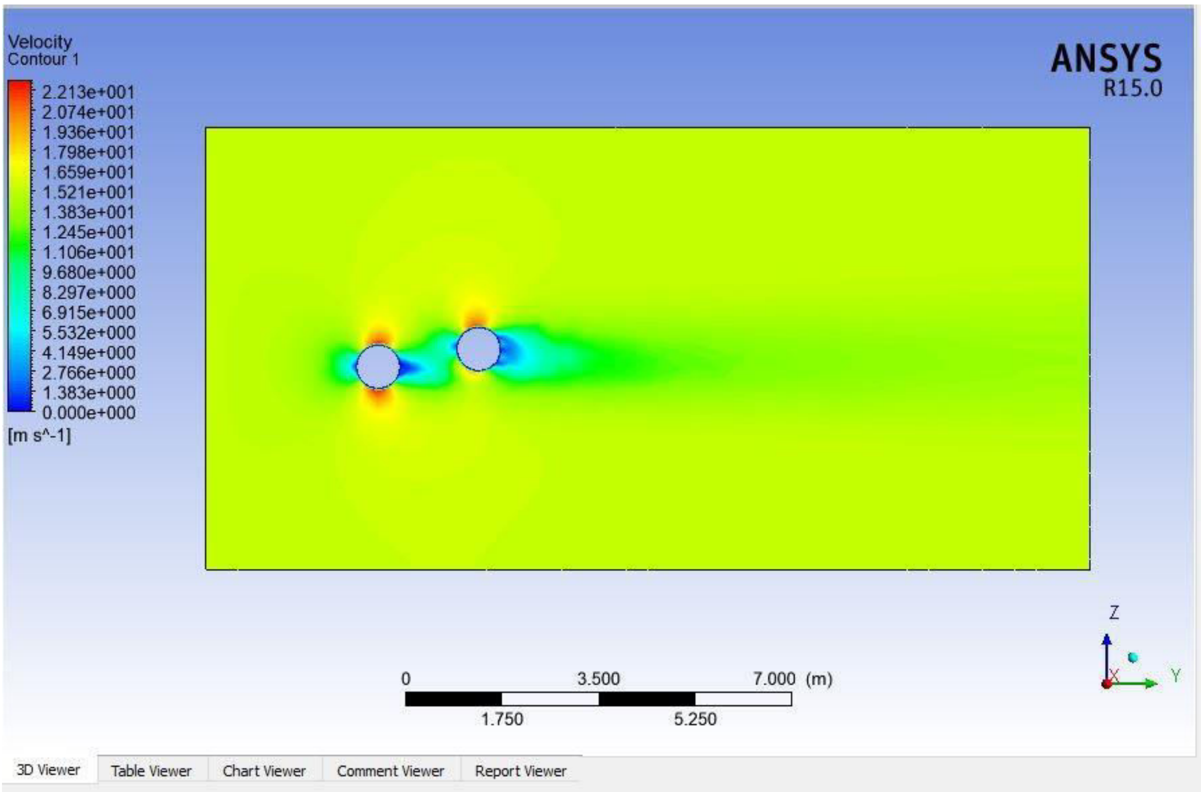

Figure 12 - CFD for 10^0 inclination

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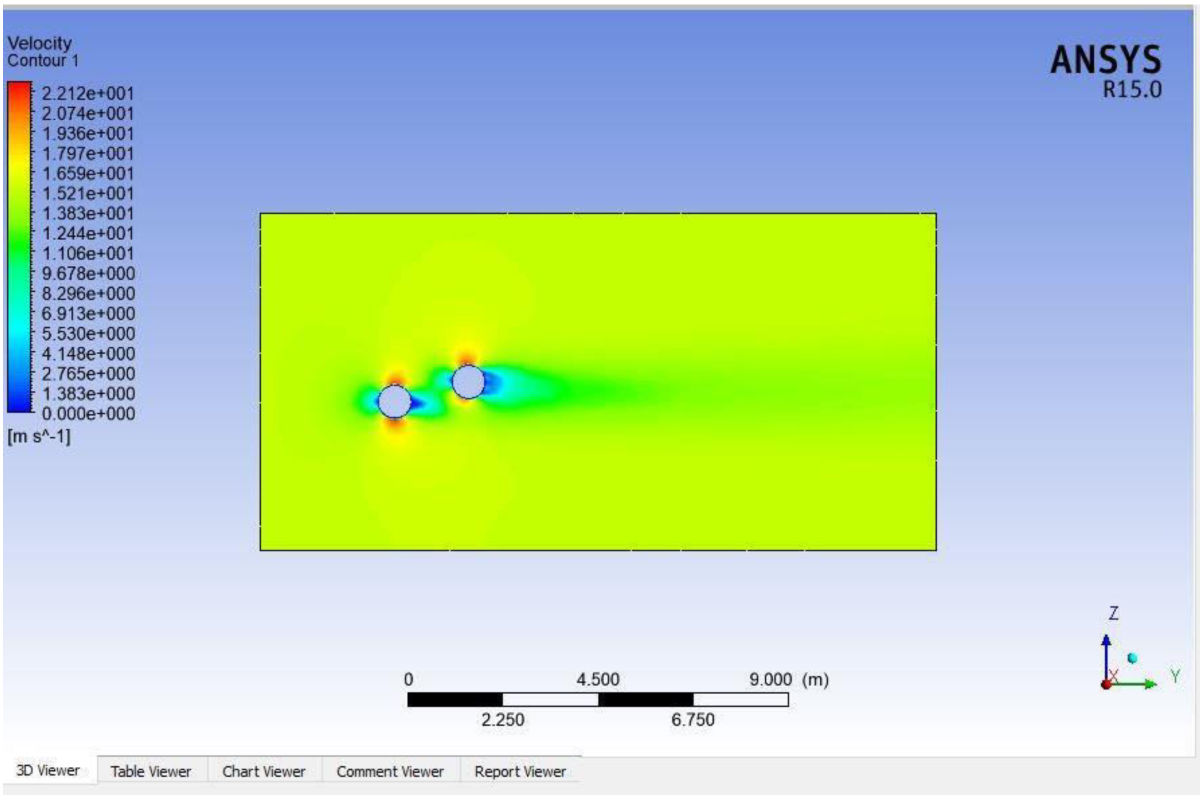

Figure 13 - CFD for 15^0inclination

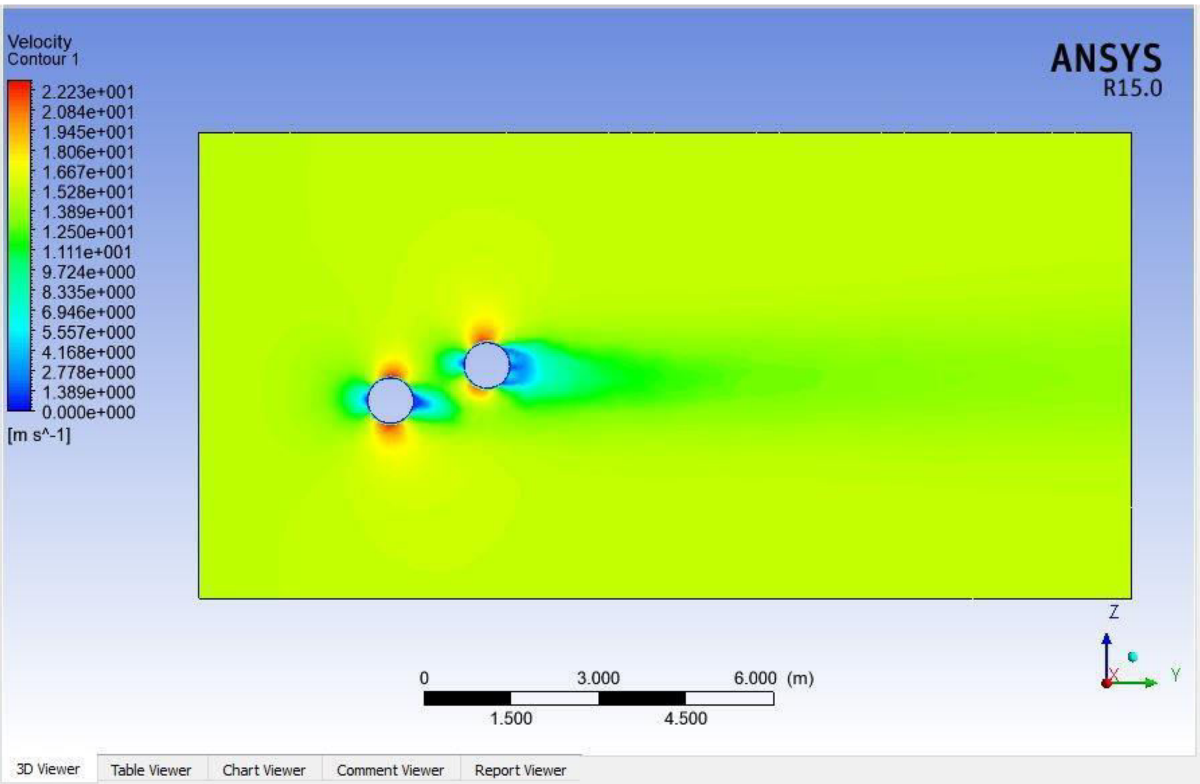

Figure 14 - CFD for 20^0inclination

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A 3m/s of laminar flow is passed through the torus, here we can see two sets of flow field. when the torus in vertical position it will obstruct the flow in two areas is top and bottom of the torus tube also a torus having allowance in center area a flow will be laminar before and after theobject.

FLAT PATTERN DEVELOPMENT OF A TORUS;

Generative shape design is carried out and flat pattern is developed using CATIA V5. Details and other important criteria are presented in this report.

Envelope details and calculation

Torus shape is selected for aerostat model. The outer diameter of torus envelope is 4.13m (radius = 2.065m), and the inner diameter of the torus is 1.1m (radius = 0.55m). the torus is divided into 16 gores in longitudinal way.
Calculation
$S = \pi 2 (R+r1) (R-r1)$
$S = 39.04$ m2
Volume of torus
$V = \frac{1}{4} \pi 2(R+r1) (R-r1)2$
$V = 14.809$ m3
Circumference of torus
$C = \frac{1}{2}(R+r)$
$C = 1.60$m
Length of each gore
$L= 4.713$m
Maximum width of each gore

$W= 0.876$m
Each Gore is again subdivided into panels, as it is the width of the fab

Drafting
Each panel is then cut and the panels are drafted to get the dimensions of each panel.
We can fabricate the torus by using this drafting sheet for avoiding material wastage.

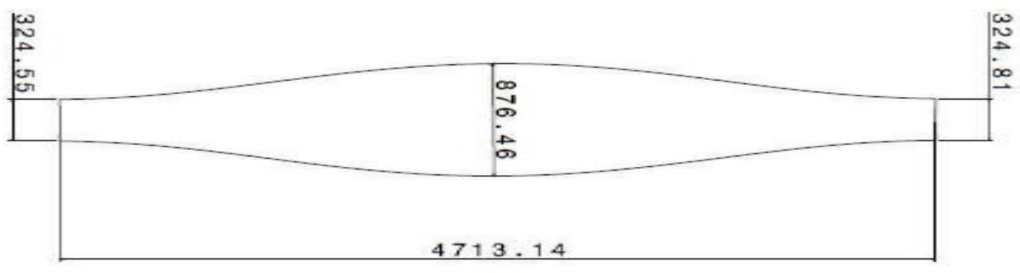

Figure 19 – Drafting of flat pattern

Aerostat sizing

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Using the literature review and data given by the company guide for general calculations. 120 GSM materials was taken and respective radius was calculated by using surface area.

1. Surface area

$S = \pi 2 (R+r1) (R-r1)$
$S = (3.14)^2(2.165)*(1.515)$
$S = 39.06102\ m2$

2. Volume of torus

$V = \pi 2/4 (R+r1) (R-r1)2$
$V = (3.14)2 *(1.515)2 *(2.165)$
4
$V = 14.7343\ m3$

Envelope weight:
We take the material weight is 120 gms/m2 so the weight of the torus is depend on surface area.
Envelope weight = 120* 39.06
= 4.68 Kg
Wene= 4.68* 9.81
Wene= 45.91 N
Total weight = 3Kg
= 3*9.81
Wtet= 29.43 N
Payload fixed = 1Kg

Wfix= 9.81 N
Aerostatic lift, $Ls = vg (\rho air – \rho gas)$
Ls = 14.79*9.81(1.125-0.18)
Ls = 137.10 N
Lexcess= $vg (\rho air – \rho gas)$ – KS – lwTL- Wfixed
Lexcess= 137.10 – 45.91 – 29.43 – 9.81
Lexcess= 51.95 N
In a zero wind condition excess lift is act as tension by Newton‘s third law

Lift = Tension Parameter	Value
Inner radius(m)	0.55m
Outer radius(m)	2.065m
Cross sectional distance(m)	1.60m
Surface area (S)	39.06102 m2
Volume (V)	14.7943 m3
Aerostatic lift (N)	137.10 N
Excess aerostatic lift(N)	51.95 N
Total weight of the envelope(N)	85.15N
Total weight to be lifted(N)	51.95N

Table 3 - Physical measurements of torus

RESULT AND DISCUSION:

A torus shape aerostat will affect from high aerodynamic load and tension, in this test is made up of 25 (m/s) velocity nearly storm condition, when the wind is blowing over a torus a tension will increase, a tension value depend on drag when a wind blowing over a torus,

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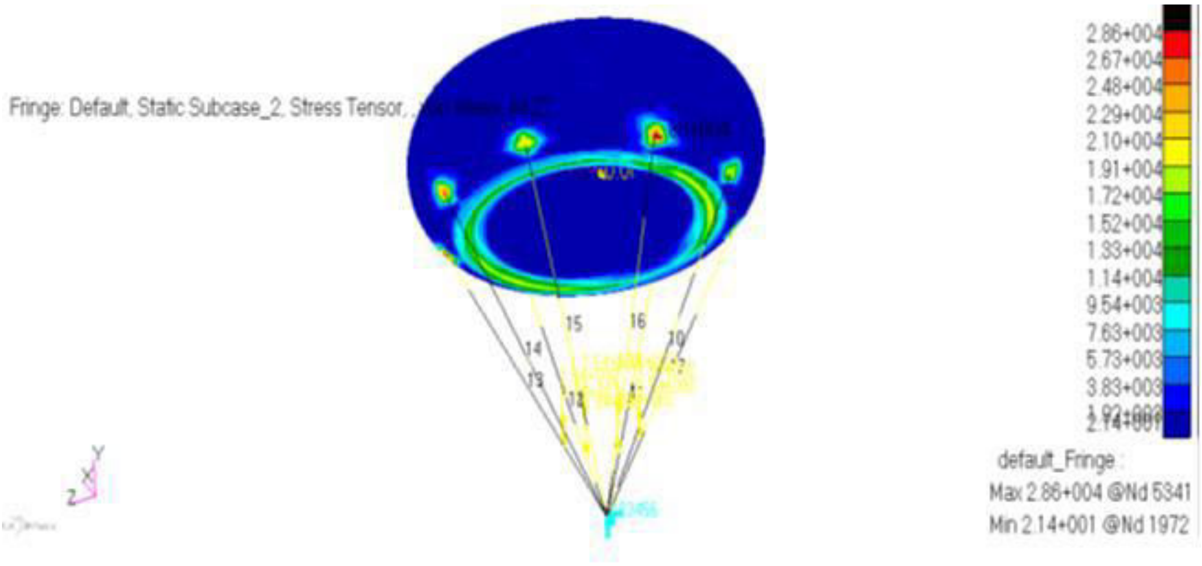

Figure 38 - Maximum tension value

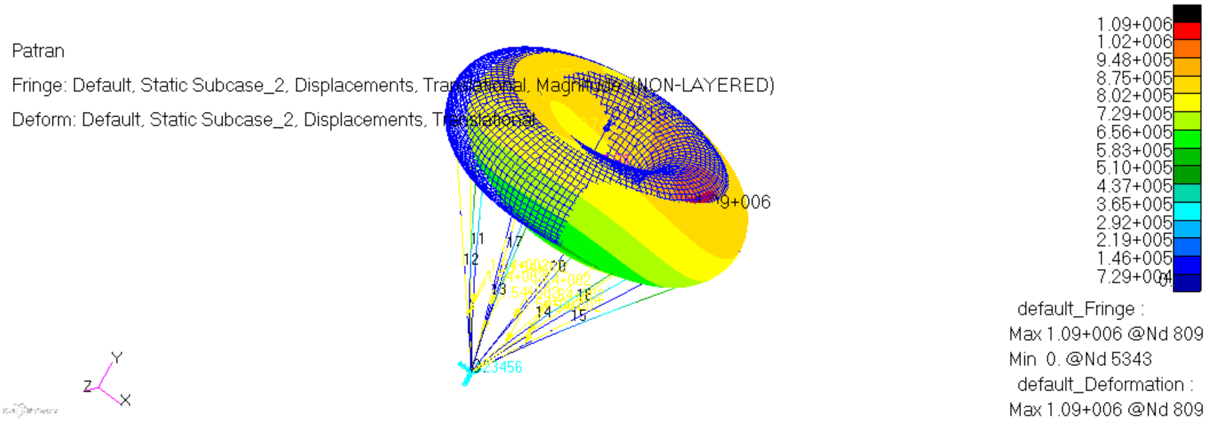

Figure 39 - Maximum displacement

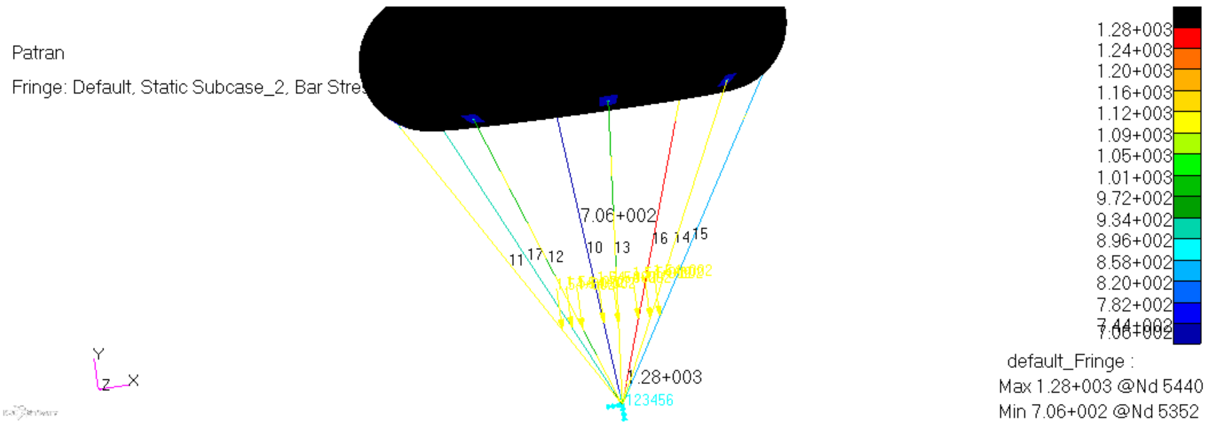

Figure 40 - Maximum bar stress on red rope

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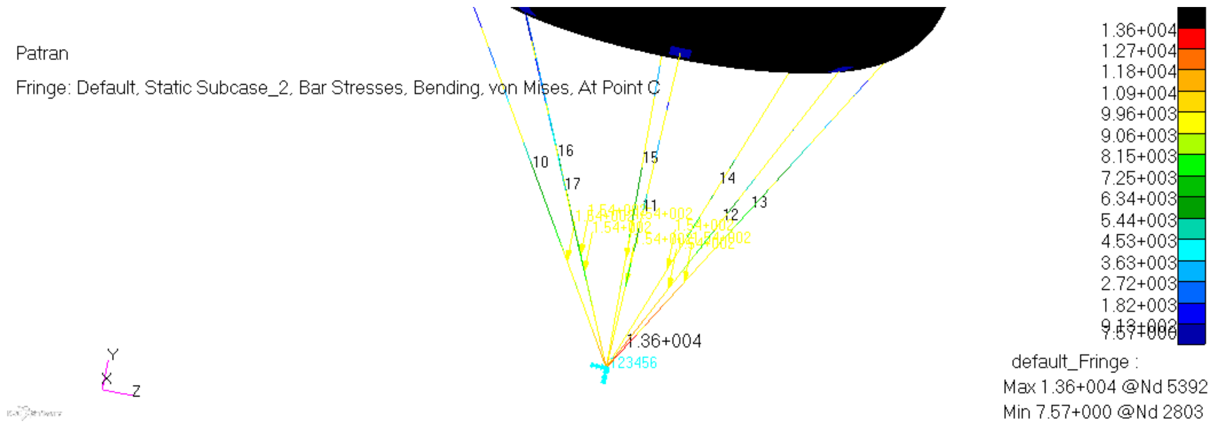

Figure-41 Maximum bending stress on red rope

the above four figure shows the maximum stress on a patch, and maximum displacement, bending stress on rope, axial bar stress on rope these high values are indicated by red Color.

Parameters	Value
Maximum tension (N/m2)	2.86*104
Maximum displacement (N/m2)	1.9*106
Maximum bar stress (N/m2)	1.28*103
Maximum bending stress (N/m2)	1.36*104

11.1 Loads on Torus

Calculating values

Calculating for Lift and tether force are done from the earlier mentioned equations.

For a Torus, buoyant force is given by

Buoyancy force:

$Fb = \rho*g*v$

$Fb = 1.1255* 9.81* 14.79$

$Fb = 163.22$ N

Net static lift of the aerostat, FL , is given by

$Ls = vg (\rho air- \rho gas)$

$Ls = 14.09*9.81 (1.125 – 0.18)$

$Ls = 137.11$N

Assuming a wind acting 25m/s over the torus so the loads are

Internal pressure:

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Pinter = ½ ρ*V2*1.15
Pinter = 0.5*1.125*252*1.15
Pinter = 404.29 N/m2
Aerodynamic loading:
Paero= ½ ρ* V2*Cp
Co-efficient of Pressure id Cp = P – Po/q
P = static pressure
Po = static pressure at the point of intersect
q = dynamic pressure
Cp = 0.28
Paero= 101425 – 101325/351.56
Paero= 100 N/ m2
Drag force and Thrust force on Torus
D = ½ ρ*V2*V2/3 *Cd
D = 0.5*0.6*1.125*252*39.06
D = 1230N
(Co-efficient of drag on this shape was obtained from CFD analysis)
While wind acting on torus will produce the drag, it will pull the torus into some direction and distance, so we have to know the distance and angle of tether cable.
ΣFx= D – T sinϕ
ΣFY = Ls – W – T cosϕ
tan φ = D/(Ls– W) = ½ Cd ρairυ∞2 V2/3 /(vg (ρair- ρgas) – W)
T = √(Ls – W)2 +D2
From above formula,

tan φ = 1230/51.95
tan φ = 23.67
φ = 87.58o
And the tension is,
T = √(Ls – W)2 +D2
T = 1231 N
11.2 Hoop stress
The envelope of the tethered aerostat system can be treated as a pressure vessel. It encloses a lifting gas which imposes pressure on the envelope material causing stresses in three directions, but of most concern is the hoop direction. If the stress due to a particular pressure of the lifting gas exceeds the envelope material‘s strength, the envelope will burst. It is important to make sure that for all planned flight conditions, the envelope stress remains at or below the appropriate factor of safety limit. In this document a classical formula for torus hoop stress determines the maximum expected stresses for the envelope.
σhoop =Pr/2t[2rbend – r/rbend− r]
P = pressure difference between internal and ambient pressure at a speed and altitude
rbend= bending radius of tube
r = tube radius
σhoop = (14526.52*0.75/2*0.0004)*((2*1.30)-(0.75))/(1.30-0.75)
σhoop = 13618612.5*(1.85/0.55)
σhoop= 45808060.2 N/m2
the above value is obtain in storm condition, a hoop stress value depend on ambient pressure and thickness of the material, in this value is obtain in 0.0004 m thickness material and 351.56 pa ambient pressure, when we increase the material thickness the hoop stress value will decrease.

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CONCLUSION:

- A torus flow behaviour is better than sphere it will stand a moderate wind condition.
- Drag value of torus is low when compare to sphere
- A drag can produce the lift with respect to angle, a body which produce the lift and drag equally it will applicable.
- A high stress value will be occur on any rope or patch at high wind condition this stress value will be controlled by the well designed patch.
- In this aerostat can used in storm condition.
- In this aerostat manufacturing is easier than sphere aerostat.

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