Paper on Wind load Estimation and truss Optimization of parabolic radio dish antenna

Mr H.S Kale, Yash Kunjir, ShlokKhaire, Chirag Gore, Apurva Kale, Dr P S Gajjal

Abstract—This paper focuses on estimation of wind load and optimization of truss structure for parabolic dish antenna using an analytical approach through computational fluid dynamics (CFD) method. CFD is a less complicated and time-efficient process in calculating the coefficient of drag and lift i.e C_D and C_L respectively. From this, we evaluated resultant wind load at varying operational angle. Ansys was used as software and CFD analysis as a tool with assuming uniform material density and wind load acting as uniform distributed load with an exemption of environment conditions. The use of truss member over single structural support resulted in weight reduction up to 10% to 20%. This method is useful to perform analytical approach using CFD for approximate theoretical wind load estimation and design of optimum truss structure.

Index Terms— Computational Fluid Dynamics, Coefficient of lift, coefficient of drag, Dish Antenna, Structural analysis, Truss optimization, Wind load.

1. INTRODUCTION

Parabolic antennas are used to collect the radio signals coming from space and other astronomical objects, bring it to focus, amplify them and make it available for analysis. The main component of dish antenna is [15]:

i. Radiating system
ii. Parabolic reflector
iii. Feed systems.

The radio telescope is more vulnerable to high wind force than an optical telescope because its accuracy decreases with an increase in deformation[16]. So due to this, accurate estimation of wind load becomes a crucial part of designing the dish antenna. Usually, wind load calculation is done using a wind tunnel, which requires high infrastructure and an accurately constructed dish model. However, it is not a time-efficient and cost-effective process. So, wind load can be estimated approximately by using K-epsilon turbulence model of CFD ANALYSIS, and by varying dish diameter different iterations can be performed and can be evaluated in a cost-effective and time-efficient manner. Spoke is a component on which parabolic reflector panel is mounted. Truss is a triangulated system of member which are organized in a definite manner for geometrical stability and rigidity to the spoke.

Using a single solid structural member as a supporting member for spoke requires more dimension to withstand high wind load, increasing its weight. So, by using truss structure dimension of spoke reduces and weight reduction up to 40-60% is achieved and improves rigidity of structure.

Yash Kunjir pursuing Bachelors in Mechanical Engineering in AISSMS College of Engineering, Pune, India. PH- 9834087341, Email- yashbr069@gmail.com

Apurva Kale pursuing Bachelors in Mechanical Engineering in AISSMS College of Engineering, Pune, India. PH- 9637001059,Email- apurvakale4799@gmail.com

2. LITERATURE REVIEW

Designing a radio antenna requires an extensive background study of the components and systems involved, including the reflector dish, the drive systems and the supporting structure. Also, for the antenna to withstand incident wind loads, the design needs high stability and resistance to bending. In the paper, 'Wind Forces on Structures, Cohen E. presents a comprehensive analysis of the various factors affecting wind speeds.

Hence, wind loading on static structures and derives empirical formulae for the same. A resolution of predicting wind forces on antennas depends upon improved knowledge of the variety of pressures and local velocities on the reflector and its supporting framework, integrated loadings, and ground effect for both solid and porous conditions.This paper aims to present the results of a recent aerodynamic study of these aspects of the problem and indicate possible applications.

In this information in determining wind loads on antennas, the wind force is particularly significant since the maximum stresses induced in the reflector are due to the application of wind pressure at varying velocities, as is the torque exerted on the drive systems. The paper develops an analytical model for calculating the wind pressure exerted on a structure taking into account the relative height, the topographical factors, seasonal wind variation, etc. Although the wind forces are dynamic, the paper is restricted to static loading on the structure. It is important to note that the data presented in the report is based primarily on the analytical calculations performed.Similarly, K. Suresh Kumar assesses the wind loads exerted on structures in metro cities in India.Traditional methods for determining the wind climate for wind engineering purposes are based on analysis of long-term surface records from a nearby meteorological station,typically measured at the height of 10 m above ground.

For this assessment, hourly surface wind data from various stations in and around the city was used. The wind speed value is typically taken from the local code of practice as specified by the Indian Metrological Department.

Antenna reflectors are of various types, varying in size, shape and composition. Mithun Kumar C. N. and Venkateshmurthy have developed a paper on the different composite materials used in constructing antenna structures. Succinctly put, unidirectional carbon/epoxy and glass/epoxy composite laminates are highly orthotropic, w. The inductivity and permittivity are strongly dependent on the incident angle relative to the fibre orientation—the paper deals with the structural analysis of the composite reflectors which are subjected to high wind loads. The displacement stress and mass of the Antenna Reflector are found by varying the thickness of the antenna Truss and analysing them.

The paper develops a systematic, step-by-step approach to modelling, discretizing and analyzing the reflector truss for obtaining an idea of the effect of wind loads on dishes of different material compositions[1,16]. Modelling is done using CATIA/CAD software according to given dimensional specifications. The file is then imported into Hypermesh for discretisation. The element type is chosen based on the complexity of the geometry under consideration. Further, after applying boundary conditions, the file is solved using NASTRAN as a solver and Hyperview as a post-processor.

Mr Govind Swarup developed the SMART concept to construct radio antennas in his paper on the Giant Meter wave Radio Telescope. This novel idea incorporates stretched mesh attached to rope trusses, which helps achieve a meagre solidity ratio since a series replaces the conventional backup structure.

In the search for more economical design solutions, engineers today rely on optimization processes to find concepts that might not otherwise be logical or require numerous analytical calculations[3,4]. The constraints limiting the search-space maximal allowed stress and maximally allowed displacement are generally found in the literature. In order to maintain construction stability, dynamic restrictions for buckling must also be implemented. Tejani et al conducted simultaneous sizing, shape and topology optimization of planar and space trusses without considering buckling. Their approach did, however, account for possible unacceptable topologies using Grubler's criterion. Researchers in compared sizing, topology and shape optimization results of planar and space trusses to sequential optimization of these three criteria and simultaneous optimization of all three.

Results showed remarkable improvements in outcomes of simultaneous optimization compared to initial models and single aspect optimization. However, these examples did not include Euler buckling constraints. Gonçalves et al have used discrete sizing variables with buckling constraints on 10, 37, and 20 bar truss examples in a few combinations of optimization types with excellent results. Authors in included dynamic N. Petrović et al. / Applied Engineering Letters Vol.5, No.2, 39-45 (2020) 40 constraints for buckling in their research using various optimization methods to optimize different aspects of examples.

Researchers in presented the need for using buckling constraints on sizing optimization examples of planar and space trusses. Authors in conducted global buckling and frequency analyses on 2D and 3D trusses. In showed the influence of using discrete cross-section variables in optimization, which provide useable results. However, the complexity of these problems requires optimisation methods that can operate with a small number of known inputs and navigate the vast search space. Roof truss structures are a particularly interesting area of research for truss optimization, as there is a lot of possibility for practical application.

YEILD STRENGTH

Yield strength refers to an indication of maximum stress that can be developed in a material without causing plastic deformation[12]. It is the stress at which a material exhibits a specified permanent deformation and is a practical approximation of the elastic limit.

WIND LOAD

Windload is the load in pounds per square foot; placed on the exterior of a structure by wind. It depends on angle by which wind strikes the structure and shape of structure[11].

COEFFICIENT OF LIFT

The lift coefficient is dimensionless quantity that relates the lift generated by a lifting body to the fluid density around the body, the fluid velocity and an associated reference area.

COEFFICIENT OF DRAG

It is dimensionless quantity that is used to quantify the drag or resistance of an object in a fluid environment, such as air or water[9].

CFD

Computational fluid dynamics is branch of fluid mechanics that uses numerical analysis and data structures to analyze and solve problems that involve fluid flows[10].

MODULUS OF SECTION

Section modulus is a geometric property for a given cross-section used in the design of beams or flexural members. Other geometric properties used in design include tension and shear, the radius of gyration for compression, and moment of inertia and polar moment of inertia for stiffness.

MOMENT OF AREA

The first area is commonly used in engineering applications to determine the centroid of an object or the statical moment of the site[13]. The second moment of site, also known as moment of inertia of plane area, or second area moment, is a geometrical property of a place that reflects how.

STRESS CONCENTRATION

A stress concentration (also called a stress raiser or a stress riser) is a location in an object where the stress is significantly greater than the surrounding region[14]. Stress

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concentrations occur when there are irregularities in the geometry or material of a structural component that cause an interruption to the flow of stress. This arises from such details as holes, grooves, notches and fillets. Stress concentrations may also occur from accidental damage such as nicks and scratches.

TURBULENCE

Turbulence or turbulent flow is fluid motion characterized by chaotic changes in pressure and flow velocity. It is in contrast to a laminar flow, which occurs when a fluid flows in parallel layers, with no disruption between those layers.

2.1 PROBLEM STATEMENT

Wind load estimation for a 3.2m dish antenna subjected to 80kmph survival wind speed using CFD analysis and truss structure design and optimization for 0.2mm maximum deformation.

SYMBOL	REPRESENATTION
ϱ	DENSITY OF AIR
V	SURVIVAL WIND SPEED
C_L	LIFT COEFFICIENT
C_D	DRAG COEFFICIENT
L	LIFT FORCE
D	DRAG FORCE
S	AREA OF DISH ANTENNA
α	ELEVATION ANGLE
θ	ANGLE BETWEEN LIFT AND DRAG FORCE
Ft	RESULTANT FORCE
Fs	FORCE ACTING ON EACH SPOKE
dh	HUB DIAMETER
ds	DIAMETER OF DISH
Ms	BENDING MOMENT OF SPOKE
Zp	MODULUS OF SECTION
σsy	YEILD STRENGTH
W	WEIGHT OF SPOKE
E	YOUNGS MODULUS
I	MOMENT OF INERTIA
lm	MOMENT ARM OF REMOTE FORCE
ls	LENGTH OF SPOKE
m_T	MASS OF TRUSS
m_2	MASS OF SPOKE (CASE 2)
m_s	MASS OF SPOKE (CASE 1)
I_{XX}	MOMENT OF AREA
Ymax	MAXIMUM DEFORMATION
y	DISTANCE FROM THE NEUTRAL AXIS TO THE MOST EXTREME FIBRE
m%	MASS PERCENTAGE REDUCTION

List of Symbols

3. WIND LOAD CALCULATIONS:

1. Two primary forces act on dish due to wind load of

a) Lift force: Lift force always acts perpendicular to surface and given by formula[11]:

$$L = 0.5 * \varrho * V^2 * Cl * S$$

Only variable quantity w.r.t elevation angle is (Cl) which is estimated bye performing CFD analysis and lift force is calculated for each elevation angle.

b) Drag force: Drag force always acts parallel to the direction of wind which is horizontal w.r.t surface for every elevation angle. Drag force is given by formula[11]:

$$D = 0.5 * \varrho * V^2 * Cd * S$$

(Cd) is the only variable quantity w.r.t elevation angle which is estimated by performing CFD analysis at respective elevation angle.

2. Resultant force acting on the dish at particular elevation angle (α) is the resultant force of lift and drag at that angle which is given by the formula [9]:

$$f_t = \sqrt{L^2 + D^2 + 2 * L * D * \cos(\theta)}$$

where θis the angle between lift and dragforce which is given by[9]:

$$\theta = (90 - \alpha)$$

3. Given data for wind load estimation is

a) Velocity of wind = Survival wind speed = 80kmph

$$V = 80kmph = 22.22\ m/s$$

b) Density of air = ϱ = 1.223kg/m³ at 1atm (sea level)

c) Area of dish antenna = S = $(\pi/4) * (d_s)^2$

where (d_s) = diameter of dish = 3.2m

$$S = (\pi/4) * (3.2)^2 = 8.034m^2$$

3.1 CFD ANALYSIS:

CFD analysis is performed by using k-epsilon turbulence model with 5% turbulent intensity and turbulent viscosity ratio of 10 at various elevation angles from 0˚-90˚. For every 10˚ interval values of Cl & Cd are calculated[10].

Meshing type	Meshing size	Input velocity	No. of iterations	No. of elements
Tetrahedron	2 mm	22.22 m/s	500	47220

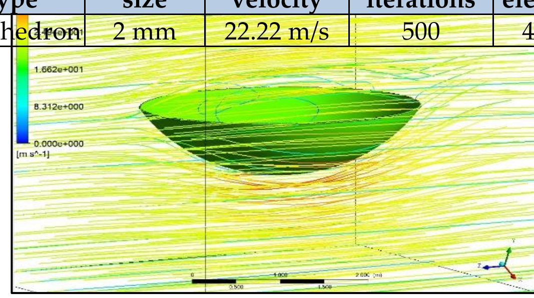
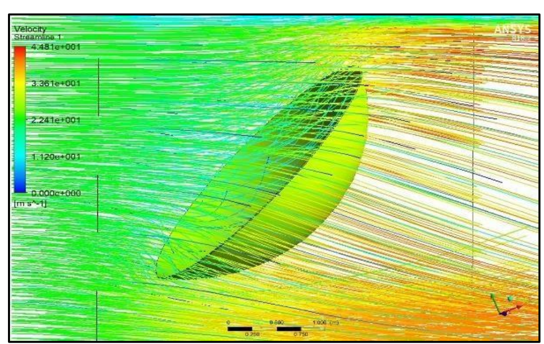


Figure 3.1.1 Velocity Streamline at 0˚



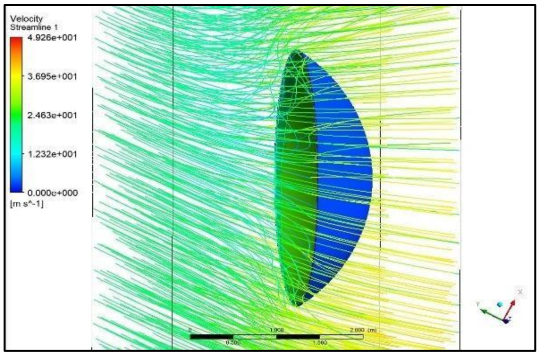


Figure 3.1.3 Velocity Streamline at 90˚

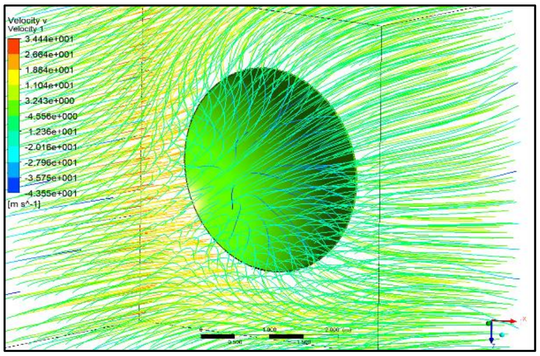


Figure 3.1.4 Velocity Streamline at 90˚

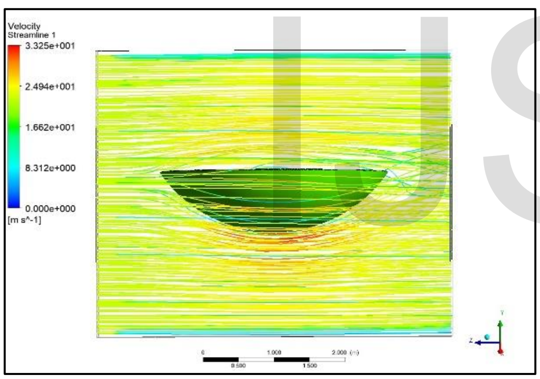


Figure 3.1.5 Velocity Streamline at 0˚

Wind Load and Cl & Cd values are given as follows:

Sr No.	α	θ	Cl	Cd	L (N)	D (N)	f_t(N)
1	0	90	0.23	0.205	557.88	497.24	556.68
2	10	80	0.24	0.210	582.14	509.37	729.98
3	20	70	0.26	0.215	630.65	521.50	1042.23
4	30	60	0.28	0.220	679.16	533.62	235.95
5	40	50	0.3	0.250	727.67	606.39	1322.43
6	50	40	0.28	0.280	679.16	679.16	554.30
7	60	30	0.14	0.300	339.58	727.67	849.15
8	70	20	0.1	0.350	242.56	848.95	973.46
9	80	10	0.01	0.400	24.25	970.23	949.97
10	90	0	0.003	0.470	7.27	1140.25	1147.3

From above wind load calculation, it is clear that at elevation angle (α = 40) wind load acting on dish is maximum,

$f_t(max) = 1322.43$ N

4. TRUSS OPTIMIZATION:
4.1 CASE 1]

1. Designing spoke structure for handling f_t = 1322.43N.
   So according to NCRA standards[16] 16 spoke skeleton is used to support reflector panels. So, force acting on each panel is given by,
   $f_s = f_t / 16 = 1322.43 / 16$
   $f_s = 82.65$ N
2. Spoke is subjected to a UDL (wind load) which can be converted into remote force (f_s = 82.65 N) acting on the midpoint of the spoke[13].
3. Hub diameter (d_h) is given by NCRA standards as[15],
   $d_h = d_s / 4$
   $d_h = 0.8$ m
4. Spoke is subjected to B.M by wind load due to moment arm from hub joint to location of remote force which is given by,
   $l_m = (d_s / 4) – (d_h / 4)$
   $l_m = 0.6$ m = 600 mm
5. B.M acting on spoke is given by[12],
   $M_s = f_s * l_m$
   $= 82.65 * 600$
   $M_s = 49.59 * 10^3$ N-mm
   By using NCRA standards design for stress[13],
   $(\sigma_{sy} / F.O.S) \le [M_s / (Zp)_s]$
   where σ_{sy} = 250 MPa [14] for Mild Steel
   $(250 / 2) = [(49.59 * 10^3) / (Zp)_s]$
   $(Zp)_s = 396.72$ mm^3
   By using westermans table [14], suitable cross-section with minimum mass per length is selected as (ISNT30)
   m_s = 1.8kg/m & Y = 8.2mm
   So, weight of spoke is given by,
   $W = m_s * l_s * g$
   $= 1.8 * 1.35 * 9.8$
   $W = 23.82$ N
   So total force acting on truss structure is given by,
   $f_t = f_s + W$
   $= 23.82 + 82.65$
   $f_t = 106.464$ N
6. By (NCRA) standards maximum deformation at tip of spoke should not exceed 0.2 mm[15,16].
7. For given spoke with cross-section of [ISNT30] maximum deformation at tip is given by[12],
   $Y_{max} = [(f_t * l_m^3) / (3EI)] + [l_m * \tan(\theta_s)]$
   $(\theta_s \to 0 \therefore \tan(\theta_s) \approx \theta_s)$
   $Y_{max} = [(f_t * l_m^3) / (3EI_{XX})] + [(f_t * l_m^3) / (2EI_{XX})]$
   $Y_{max} = [(106.46 * 600^3) / (3 * 200 * 10 * I_{XX})] + [(106.46 * 600^3) / (2 * 200 * 10^3 * I_{XX})]$
   $(I_{XX} / y) = (Zp)_s$
   $I_{XX} = 8.2 * 800 = 6560$ mm^4
   $Y_{max} = 14.6$ mm
   Here (Y_{max}> 0.2 mm) so we need extra support of truss structure to reduce deformation up to 0.2

mm.

8. Design process for truss is largely iterative. Various iterations are performed by changing length, angle and cross-section of truss elements[3].
9. Four different iterations are performed per cross-section. Cross-sections used are given below:
   i. (40 * 4) mm^2
   ii. (30 * 4) mm^2
   iii. (20 * 4) mm^2

   Structural analysis is performed on all 12 iterations by applying remote force on midpoint of the spoke. Fixed support is given to two attachments of truss structure and deformation and stress concentration is observed[4].

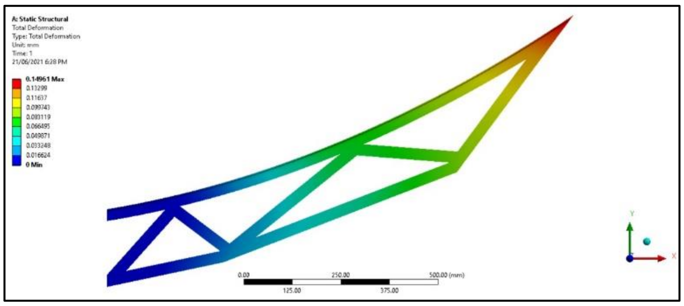


Figure 4.1.1Iteration No. 7 (30 * 4) mm^2

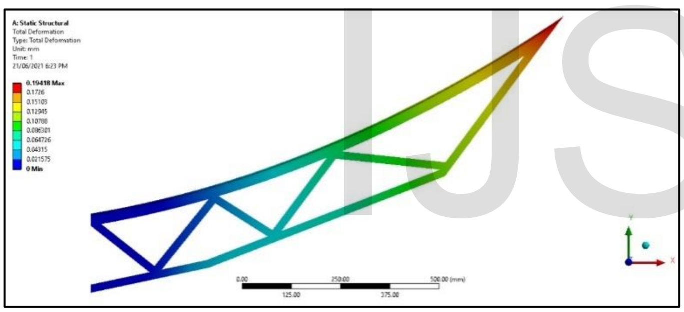


Figure 4.1.2 Iteration No. 10 (20 * 4) mm^2

Meshing type	Meshing size	Input force	Type of Support	No. of elements
Tetrahedron	5 mm	212.921 N	Fixed	47220

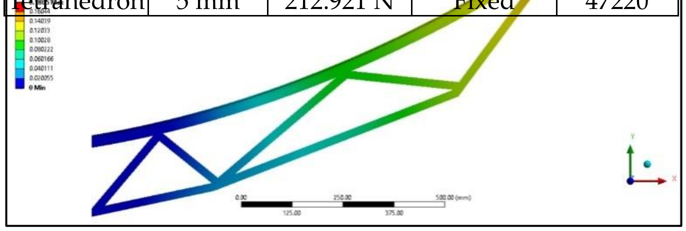


Figure 4.1.3 Iteration No. 11 (20 * 4) mm^2

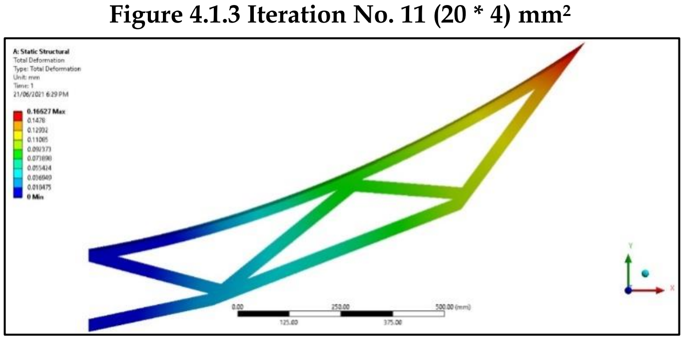


Figure 4.1.4 Iteration No. 8 (30 * 4) mm^2

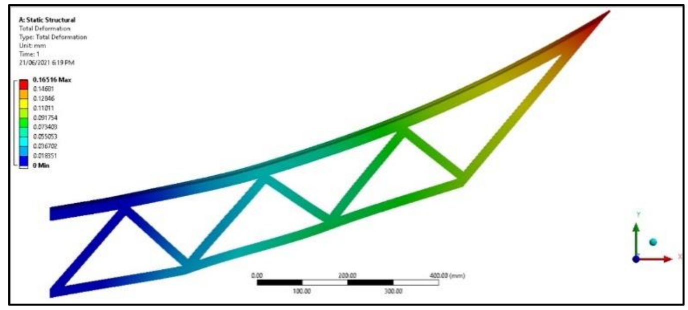


Figure 4.1.5 Iteration No. 9 (20 * 4) mm^2

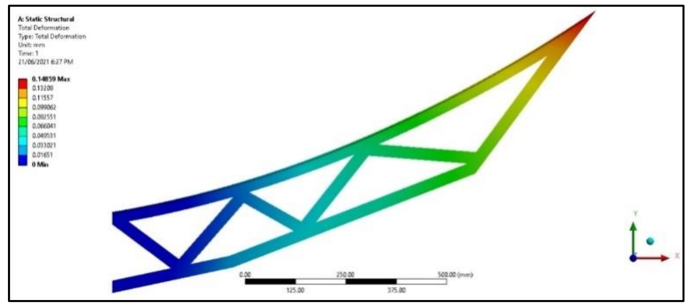


Figure 4.1.6 Iteration No. 6 (30 * 4) mm^2

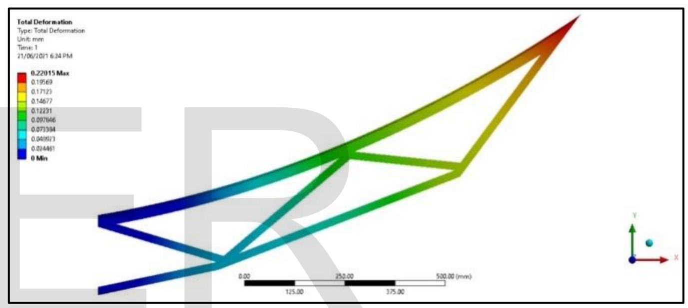


Figure 4.1.7 Iteration No. 12 (20 * 4) mm^2

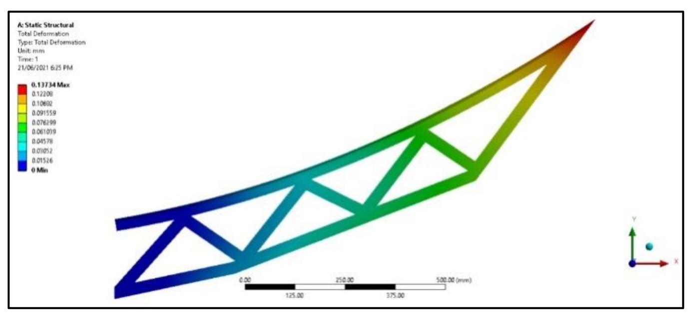


Figure 4.1.8 Iteration No. 5 (30 * 4) mm^2

Result Table:

Iteration No.	Cross-Section (mm^2)	Deformation (mm)	Mass (kg)
1	40 * 4	0.119	4.94
2	40 * 4	0.122	4.80
3	40 * 4	0.128	4.74
4	40 * 4	0.133	4.60
5	30 * 4	0.137	4.48
6	30 * 4	0.148	4.39
7	30 * 4	0.149	4.37
8	30 * 4	0.166	4.28
9	20 * 4	0.165	3.78
10	20 * 4	0.194	3.71
11	20 * 4	0.181	3.69
12	20 * 4	0.221	3.63

Iteration no. 11 is selected considering deformation criteria and minimum mass (m_T = 3.69 kg)

4.2 CASE 2]

1. In this case no truss structure is provided. Instead, single solid structural support is given to reflector panels in form of spoke so we designed this structure bye deformation criteria of 0.2 mm which will automatically satisfy the stress criteria[12].

$Y_{max} = 0.2mm \geq [(f_t * l_m^3) / (3EI_{XX})] + [(f_t * l_m^3) / (2EI_{XX})]$

$0.2 = [(106.46 * 600^3) / (3 * 200 * 10 * I_{XX})] + [(106.46 * 600^3) / (2 * 200 * 10^3 * I_{XX})]$

$I_{XX} = 479 * 10^3 \ mm^4$

Standard cross section selected from westermans chart [14] for given I_{XX} is (ISLT 250)

$m_2 = 6.1 * 1.35$

$m_2 = 8.23$ kg

Percentage reduction in mass due to truss structure is given by,

$m\% = [(m_2 – m_T) / m_2] * 100$

$m\% = 55.16$ %

5. CONCLUSION:

CFD analysis using the K-epsilon turbulence model is a relatively simple and faster process for evaluating approximate wind load and finding the value of the lift coefficient and coefficient of drag for a dish of any diameter. As lift coefficient increases with an increase in elevation angle up to 40 degrees and decreases drastically with a further increase in elevation angle due to the flow separation phenomenon. On the other hand, the drag coefficient increases as the elevation angle increases and has a maximum value at 90 degrees. In this research paper, the authors performed different iterations at different elevation angle and found a wind load value maximum at 40 degree, which is 1322.43N. This research paper is recommended for students, researchers, and educational institutes without wind tunnel facilities.

Further design and optimization of truss structure for maximum wind load calculation; two cases were considered.

CASE1: Truss structure is designed and optimized for given wind load condition by performing 12 iterations. This best-suited iteration was selected for weight and deformation criteria; this resulted in a mass of truss (m_t)= 3.69kg and deformation as (Y_{max})= 0.181mm.

CASE 2: Instead of truss structure, we provided a single solid spoke structure of cross-section (ISLT 250). This resulted in cross-section having mass (m_2) = 8.23kg

From the above 2 cases, it was concluded that the use of truss structure resulted in a weight reduction of 55.16% as compared to a single solid spoke structure.

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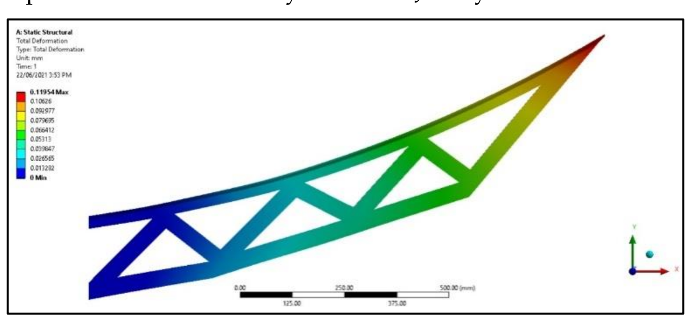

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