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Finite Element Analysis of Typical Ground Based Composite Sandwich Radome

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ABSTRACT
Radome encapsulates the Radar and serves as radio frequency transparent shield to the antenna. Radome protects the antenna from external environments which are detrimental to the Electromagnetic performance of the radar. Ground based radomes which house the ground based radars are generally large spherical truncated structures constructed with composite sandwich panels. Essentially, geometry and material selection of the radome is driven by the Electromagnetic design and performance. The structural design of the radome is mainly based on the aerodynamic loads on the radome.In this thesis, based on detailed literature survey, technical specifications of a typical ground based radome is considered. The aerodynamic loads on the radome are assumed as per appropriate standards. Detailed FE analysis considering sandwich composite material with varying aerodynamic loads and actual boundary conditions is carried out. The pre-processing and post processing of the FE model are carried out using Hypermesh and MSC Nastran is used as the Solver. The results are extracted from the FE analysis and detailed Failure Analysis of the composite structure is carried out.
Keywords:aerodynamic loads,finite element analysis,sandwich composite material, failure Analysis

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I. INTRODUCTION

"Radome" comes from the contraction of two English words (radar and dome). A Radome is a structural, weatherproof enclosure used to protect a Microwave Antenna. It functions as protective covers for antenna systems for minimizing the Electro-magnetic losses during transmission and receiving. The Radome mainly protects the antenna from Air loads and other Environmental Impacts such as snow, ice, hail impact, salty weather conditions, etc. Radomeincreases the useful life of the antenna and decrease overall maintenance costs for the system. A Radome also allows the antenna system to use lighter duty and less expensive components such as drive motors and smaller lessexpensive foundations by eliminating wind loads from the antenna.

Poor Radome layout can even cause unwanted sensitivity on the backside of the sensor. The cover material can act as a lens and focus or disperse the radarwaves. This is why it should have a constant thickness within the area used for transmission. The radome is constructed of material thatminimally attenuates the electromagnetic signal transmitted or received by the antenna. Historically, a variety of materials have been used for constructing radomes, including balsa and plywood in early structures. Modern groundbasedradomes are manufactured using composite materials such as fiberglass, quartz, and aramid fibers held together with polyester, epoxy, and other resins. Radomes come in variety of shapes and sizes and protect a wide range of antenna types including weather radar, communications and navigation systems, and various sensors.Radomes are usually truncated sphere consisting of curved panels.Truncation is usually between 80% and 90% of the radome's diameter.

II. MAJOR LOADS ON GROUND BASED RADOME STRUCTURE

The Structural Design of the Radome is dictated by the Aerodynamic Loads.Based on the Literature Survey, in the present work the Radome Structure is designed for a maximum wind speed of 220 kmph.

As per the Aerodynamic principles, the flow over a sphere is considered. We could see that there is a suction at the top of the sphere and the Lift force is more. Also there exists a Drag force at the right hand side of the sphere. And there exists a net imbalance in force which creates a moment.

Lift Force $L= C_L q_\infty S$

Here,

C_L = Coefficient of Lift = 1.5 (considered)

Dynamic pressure $q_\infty = ½\rho V^2$

S = Wetted Surface area, m^2

where,

ρ = Air density, Kg / m^3

V =Velocity of Air, m/s

Similarly, drag Force D= $C_D\, q_\infty\, S$

Here,

C_D = Coefficient of Drag = 1 (considered)

The above forces are the driving parameters in the design and analysis of the Radome structure, definition of panel bolts and the grouting scheme of the Radome.

III. FE ANALYSIS OF SANDWICH COMPOSITE RADOMES

Many works have been carried out in design,analyzing and optimizing the sandwich composite structures.The works include stress analysis of radome panels, buckling analysis, impact analysis, frequency and model analysis etc. Some of the literature work carried out in the past on analysis of radome structures are discussed.

- Ch. John Marie Britto and S. Vijaya Kumar has done work on 'Design and Study of Different Parameters of A Submarine Radome By Using ANSYS', estimated the stresses acting on different materials and also have arrived at the displacement and frequencies for the load applied.
- N. V. Srinivasulu, Safeeruddin Khan and S. Jaikrishna has done work on 'Design and Analysis of Submarine Radome', arrived at estimating the Von-mises stresses at the corner of the hole using Stress Concentration Factor method;
- Hyonny Kim has done experiment and Finite Element Analysis using ABAQUS on 'Impact Damage Formation on Composite Aircraft Structures' and has studied the GSE BluntImpact, Ice Impact and Large Radius Metal Tips.
- TadeuszNiezgodzinski presented the results of finite element method calculations of stability of thinwalled spherical shells. The local and global buckling behaviour of thin spherical shells are studied using finite element analysis with FEM ANSYS 12.1. An isotropic material is considered with appropriated numerical values.
- Niranjan Murthy, V. et.all studied the finite element analysis of radome for airborne satellite communication radar. In this work, a Sandwich construction of radomeis considered and the displacement, stress and Tsai-Wu index plots of the radome under aerodynamic loading conditions were analysed.

IV. PROBLEM DEFINITION & METHODOLOGY

OVERALL GEOMETRY

Spherical Diameter = Ø 6.7 m
Centre Height = 1.8 m
Ground Flange Length = 0.150 m
Ground Flange thickness = 0.040 m
Truncation Ratio = 80%
Number of Panels considered = 22

Material

The material chosen for the design of Radomes are Sandwich composites.

- Skin : Composite E-Glass Fibre Reinforced Plastic (GFRP) - Bidirectional cloth
- Core : PU Foam

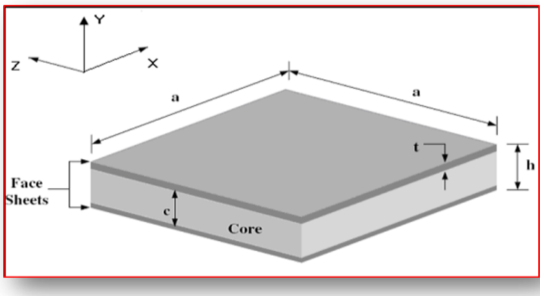

Fig 1 A typical sandwich panel construction

Material Thickness

Panel:

The panel is comprises of 9 layers. Among these 9 layers, top and bottom 4 layers are GFRP and the core material is PU Foam.

Top 4 layer: 0.25 mm thick GFRP
Core layer: 15 mm of PU Foam
Bottom 4 layer: 0.25 mm thick GFRP

Base panel:

The base panel s assumed to be consisting of 20 mm Laminate for a thickness of 0.25 mm, so total of 80 layers of GFRP laminates are taken for consideration.

Loads :

The Loads considered to be acting on the Radome are only the Aerodynamic Loads based on the Environmental conditions prevailing in our geographic zone.

As discussed earlier the pressure distribution around the Radome Surface is continuously varying due to the air flow around the Radome structure. Because of this, different region of the Radome is subjected to different normal pressure. The Pressure distribution can be approximated.

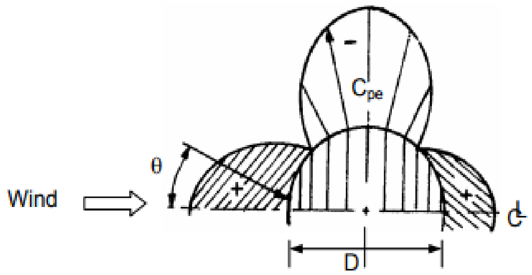

Fig2 External Pressure Distribution coefficients around spherical structures

Here different sections on the Radome surface along the direction of the wind flow are considered. The coefficient of pressure on these section are found to be approximately same. Hence it is conveniently assumed that the coefficient of pressure is constant for a given section and the Cp value for different sections are assumed and given in the Table 1.

Table 1 External Pressure Distribution coefficients around spherical structures

Position of Periphery, *θ* in Degrees	C_{pe}	Remarks
0	+1.0	C_f = 0.5 for $DV_z < 7$
15	+0.9	= 0.2 for $DV_z \geq 7$
30	+0.5	
45	-0.1	where D is the diameter of the sphere
60	-0.7	
75	-1.1	
90	-1.2	
105	-1.0	
120	-0.6	
135	-0.2	
150	+0.1	
165	+0.3	
180	+0.4	

The total pressure at a specified point along the Radomeis given by $P = C_P \times q_\infty$

Wind Dynamic Pressure is given by $q_\infty = \frac{1}{2}\rho V^2$

C_P = Coefficient of Pressure

S = Wetted Surface area, m^2

ρ = Air density, Kg/m^3

V = Velocity of Air, m/s

Using the above Table 1, the C_P values on individual sections are extracted. Using the C_P values the total Pressure assumed to be action on the particular section is calculated. The same pressure value is applied on the appropriate section of the Finite Element Mesh by selecting the elements by Geometry (Surface).The load considered here is only the wind loads. Based on the Literature survey an Aerodynamic Load of Maximum wind speed of V= 220Kmph (61.10m/s) is considered.

Boundary Conditions

The Radome is firmly fixed with the concrete foundation using specified number of base panel bolts to sustain the heavy Bending moment developed at the Radome Base. The base panel is made out of solid laminates of sufficient thickness, so in this problem the base panel thickness is considered as 20 mm solid Glass Fiber Reinforced Plastic laminate. It is also assumed that the Radome is fixed with the foundation using 16 number of M20 bolts.To simulate the base panel bolts on the Radome Finite Element model, Hard Points are created in the FE model using the defeaturing option in Auto-Mesh. During meshing the nodes are automatically created at these hard points. On these nodes all the 6 Degrees of Freedom (DOF) are constrained to simulate the bolt condition.

V. FE ANALYSIS OF A SANDWICH RADOME STRUCTURE

Pre-processing of the FE Model

The pre-processing of the FE model is carried outin Hypermesh software. The radome is assumed as a 2D surface geometry and the thickness of the panel and base panel are assumed appropriately. Nastran 2D elements i.e. Quad and Tria elements are used meshing. The step by step procedure carried out in pre-processing stage is presented below**.**

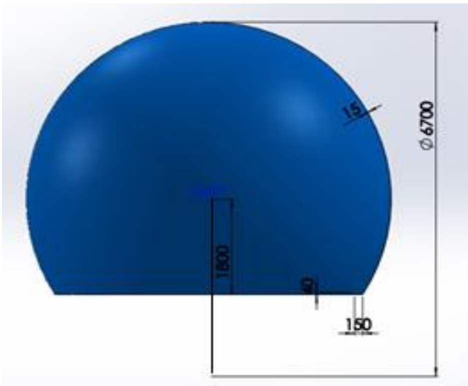

Fig 3 Panel arrangement in a Radome

FE Model geometry

The Geometry for the Finite Element Model of the Radome is made in Solidworks. A step file is considered taking only the mid surface of the model. The file is imported into the Hypermesh 9.0 version.

The edges are cleaned for removing the unnecessary lines in the surface model. This is best to make the surface as clear as possible. The surface is sliced into various strips to make necessary arrangements to apply the loads acting on the hemispherical Radome surface.

Material Property and Component Collectors
Material Property :

The Radome is designed as a bi-directional sandwich panel. The facesheets are made up of GFRP and the core is made of PU Foam.
In order to analyse we need to create appropriate material collectors. Hence two different material collectors are created. The material name, colour, type of material and Material cords are chosen corresponding the region of study.

1. GFRP:
The Material name: GFRP
Type of Material: Orthotropic
Card: MAT8
2. PU Foam
The Material name: PU Foam
Type of Material: Isotropic
Card: MAT1

Property Collector :

The next step in the analysis is to create the Property collector. Similar to the material collector the Property collector has to be created for the respective region of study. For the present analysis two different property collectors are created, one for the GFRP material and the other for the PU Foam. The Property collector has the details about the Material properties like Young's modulus, Poisson's ratio, Thickness, Density, etc.

Component Collector :

The component collector is one of the step where a group of elements is created which belongs to have particularproperty collector and material collector. So, once the mesh is createdthese collectors will be assigned to the corresponding elements in order to fulfill our analysis requirements.

Finite Element Mesh

The Finite element mesh is created on the Radome surface by using the Automesh Option. The element type is 2D shell element. The meshing is generated with Quad 4 and Tria 3 elements of Nastran. The mesh is checked for the presence any free edges. The element size is chosen as 100 mm in size.

Load Collectors :

Load collectors are the ones which determines the type of load acting on the elements on the mesh that are created. In this analysis two different load collectors are created, one is for the applied aerodynamic load and the other one is boundary conditions of the Radome.

As discussed in the previous sections the radome outer surface is modelled with different segments to impose different aerodynamic loads to simulate the pressure distribution around the radome. The dynamic wind pressure load calculated as per the equation .

$q_\infty = \frac{1}{2}\rho v^2$ N/m^2
Considering
$\rho = 1.22$ kg / m^3
and wind velocity V as 300 km / hr, the wind dynamic pressure is calculated to be
$q_\infty = 4216$ N/ m^2
Varying wind loads are assumed on the radome surface with respect to Table 1 and the appropriate region of the radome surface is applied with total wind pressure.
It can be noted that the pressure around the radome surfaces are both compressive as well as suction type.The bolt locations are modelled as hard points in the FE geometry. The Boundary conditions are created at these hard points where all the six degrees of freedom are arrested. SPC (Single Point Constraint) load type is applied on the base panel bolts.

FE Solution using MSC Nastran

The load steps are defined accordingly considering the pressure load and the single point constraint loads. A linear static analysis is performed on this model.

The SPC loads are assigned as constraints and the varying aerodynamic pressure are assigned as loads for the analysis.

Different outputs like, displacement, element stress, element strain, element forces etc. are requested in the FE model. The model is saved asa Nastran input file in .bdf format and solved using MSC Nastran solver. The results of the Nastran solver is extracted and stored in .pch file. The displacement and stress values available in the .pch file are extracted into the result file .res file using the translator in Hypermesh.

The results is loaded and superimposed on the FE model an displacement and stress results are extracted. Using the composite analysis, overall displacement plot of the structure can be plotted. Also different stresses like normal stress, shear stress etc., at each and every layer of the composited panel can be extracted and plotted.

Results of the FE Analysis
Displacement analysis :
From the FE analysis it is found that the maximum displacement at 300 km/hr wind speed is found to be 64.2 mm at the top portion of the radome.
Normal stress in longitudinal direction in the radome surface:

Top layer of the panel or the bottom layer of the panel will only experience the maximum normal stresses on the radome surface. Hence the normal stresses on the top and bottom layers of the panel are extracted. Figure 4shows the normal stress distribution along the longitudinal direction on bottom layers of the panel accordingly.

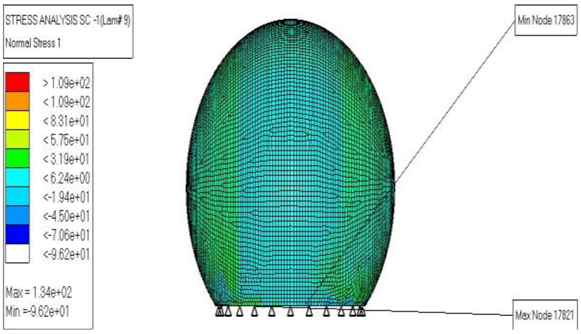

Fig 4 Normal Stresses σ_1 on the bottom panel

From the plots, the maximum tensile stress in the longitudinal direction is found to be 134 MPa and the maximum compressive stress in the longitudinal direction is found to be 96.2 MPa.

From the results of the FE analysis detailed failure analysis of the composite sandwich structure is carried out. The general failure modes of fibre portion of the panels are

1. Face Yielding
2. Face wrinkling

Face Yielding :

Failure analysis for Face Yielding is performed. The maximum tensile stresses are acting on the bottom layer.

Allowable Maximum Tensile stress in the Longitudinal direction:380 MPa

Actual Maximum Tensile stress in the Longitudinal direction:134.4 MPa

Even at 300 km/hr wind speed, the allowable Maximum Tensile stress in the Longitudinal direction of the skin is much greater than the applied Maximum Tensile stress on the skin of the panel, hence the radome structure design is acceptable.

Face Wrinkling :

Failure analysis for Face Wrinkling is performed. The maximum tensile stresses are acting on the bottom layer.

Allowable maximum compressive stress in the Longitudinal direction: 360 MPa

Actual Maximum Compressive stress in the Longitudinal direction:96.6 MPa

The allowable maximum compressive stress in the Longitudinal direction of the skin is greater than the actual Maximum Compressive stress on the skin of the panel, hence the radome structure design is acceptable.

Normal stress in lateral direction in the radomesurface :

From the plots, the maximum tensile stress in the longitudinal direction is found to be 74 MPa and the maximum compressive stress in the longitudinal direction is found to be 72.8MPa.From the failure analysis, it is found that the allowable maximum stresses in the lateral direction of the skin is greater than the actual maximum stresses on the skin of the panel, hence the radome structure design is acceptable.

Shear stress in the core of the radomepanel :

The core of the sandwich fails due to shear stress induced due to applied loading. Figure 5shows the shear stress distribution of the core of the sandwich panel.

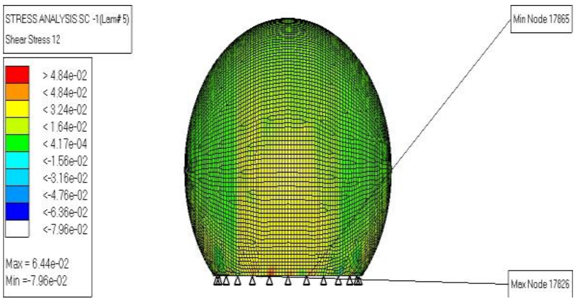

Fig 5 Shear Stresses on the core panel

From the plot, the maximum shear stress in the radome panel core is found to be 0.079 MPa.

Core Failure :

Allowable shear of PU Foam: 0.6 MPa
Shear stress at the core PU Foam: 0.0796 MPa

Even at 300 km/hr wind speed, the allowable Shear Stress of PU Foam is greater than the actual shear stress on the core of the sandwich, hence the structural design radome structure is safe.

Parametric Study

In the above FE analysis a core thickness of 20 mm is considered. A detailed parametric study has been carried out, to understand the effect of core properties on the normal stress of the skin and shear stress of the core of the radome sandwich material. In this approach, FE analysis was carried out keeping all the pre-processing parameters unchanged except selected core properties. That is, model geometry, FE Mesh, loads, boundary conditions, material properties of the skin, number of layers and skin thickness etc. are kept constant. Core thickness of the PUF are varied with appropriate step size to understand the effect in skin stress values and core shear stress values. The core thickness of the sandwich material is varied from 5 mm to 35 mm in 5 mm step size and all other parameters of the analysis are kept unchanged.

Effect of core thickness on skin normal stress :

The core thickness of the sandwich material is varied from 5 mm to 35 mm in 5 mm step size and all other parameters of the analysis are kept unchanged. The maximum normal stress on the radome panel is extracted in each analysis and the effect of change in core thickness is studied.

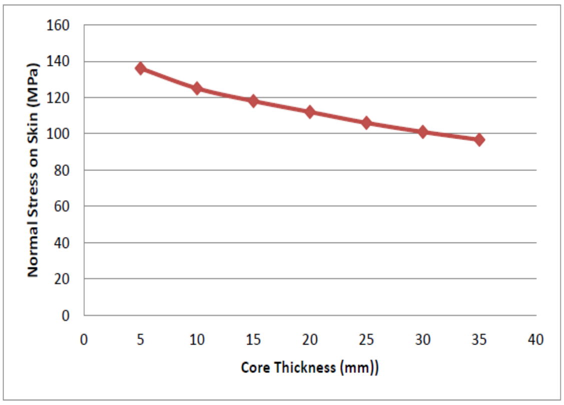

Fig 6 Normal stress on skin for varying core thickness

Figure 6 shows the effect of core thickness on the normal stresses of the skin. It can be seen that as the as the core thickness decreases the normal stress in the skin increases almost linearly.

Effect of core thickness on shear stress of the core:

The effect of the core shear stress with the change in the core thickness is studied. Figure 7 shows the effect of core thickness on the shear stress of the core.

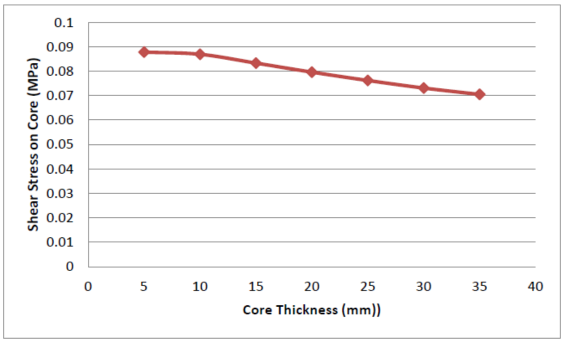

Fig 7 Shear stress on core for varying core thickness

It can be seen from Figure 7 that the core shear stress varies almost linearly with the variation in the core thickness of the sandwich material.

VI. CONCLUSION

- A detailed literature survey on ground based radomes are carried out. The general construction of radome, radome materials, panel configuration, panel joint configurations are studied in detail. The selection of composite sandwich material on the electromagnetic and structural performance of the radome are also studied.
- Based on the literature survey, a typical ground based radome is assumed with appropriate geometrical configurations. Material of the radome, thickness and mechanical properties are assumed with respect to standard literatures. The aerodynamic loads are assumed according to IS 875 and the varying pressure loads around the radome surface are modelled appropriately.
- The FE analysis of double curved panel is verified with analytical solutions considering isotropic material with uniformly distributed external pressure load. The same analysis is extended for varying aerodynamic load for composite sandwich material. From the detailed finite element analysis, the layer wise stresses are extracted.
- The layer wise stresses are found to be much less than the allowable stresses Glass fibre composite material. For the sandwich core the shear stress on the material is checked and the shear stress is found to less than the allowable shear stress of the material.
- The loads considered in the work is for 300 km/hr wind speed. As the wind load is proportional to the square of the wind velocity, the wind pressure at lower wind speeds are substantially less than thewind loads considered in this work. Even at this very high wind speed the stress levels on the GFRP fibre materials are well within the allowable stress levels of the material. According to the failure analysis of the radome composite panel, considering the stresses and deflections, the configuration of the spherical truncated composite sandwich ground based radome is safe.

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