SIMULATION DRIVEN ANTENNA DESIGN TO MEET ENVIRONMENTAL SPECIFICATIONS

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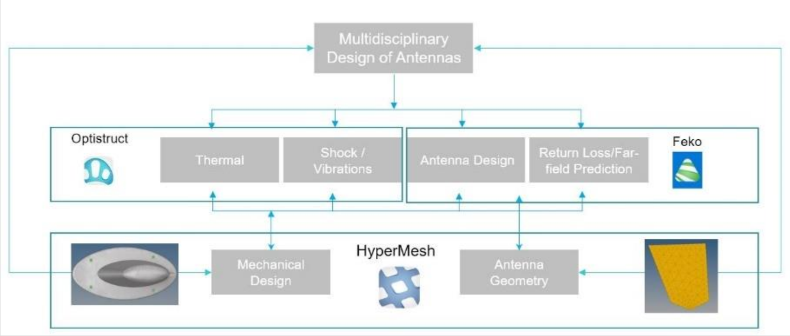


Introduction

With growing communications, nowadays there are increasingly sophisticated antenna systems that are mission critical. Advances in electromagnetic (EM) simulation tools such as Altair Feko [1] have significantly improved the design process for such systems, resulting in reduced testing time and costs. To meet the system requirements, antennas are designed for factors such as return loss, gain, polarization, bandwidth etc. Once the basic structure of the antenna is designed, it is handed over to mechanical engineers to certify the ability to withstand the physical demands placed on the antenna by the environment. The ability of antennas to survive and continue to function as designed is critical for long-term deployments on various platforms such as aircrafts, ships, ground vehicles, IoT/M2M applications as well as for safety purposes. Specifically, during flight operations, antennas are routinely subjected to uncompromising operating conditions such as extremely low/high temperatures, vibrations, shock etc. to meet specifications as defined in standards such as MIL-STD 810 [2]. Normally, mechanical design of antennas is done by experience, intuition and following rules of thumb. Once a prototype is made, it is tested physically for environmental suitability at testing facilities such as [3,4], resulting in many design iterations before the antennas pass all environmental specifications. This a very expensive and time-consuming process leading to increased costs and delays in product development. In this paper, we illustrate a simulation-driven workflow process using Altair HyperWorks Suite [5] for antennas to meet environmental specifications during the design process so time taken for test and certification can be minimized and thus, cost savings and faster product development cycles.

Simulation Driven Multiphysics Design of Antennas

To illustrate Altair's approach for simulation-driven Multiphysics design of antennas, a blade antenna is chosen as an example. Blade antennas are widely used in aerospace industry. Several antennas are required on an aircraft, whether it is a general aviation aircraft, or high-performance military aircraft or commercial passenger aircraft. An example of various antennas on a commercial aircraft is shown in Figure 1. Blade antennas, like the one shown in Figure 2 are widely used for various applications such as VHF/UHF Communications, DME (Distance Measuring Equipment), transponders etc.

To meet the environmental specifications as stipulated by MIL-STD 810, those antennas are typically enclosed in a radome. Blade antennas they are typically filled with a material such as polyurethane foam.

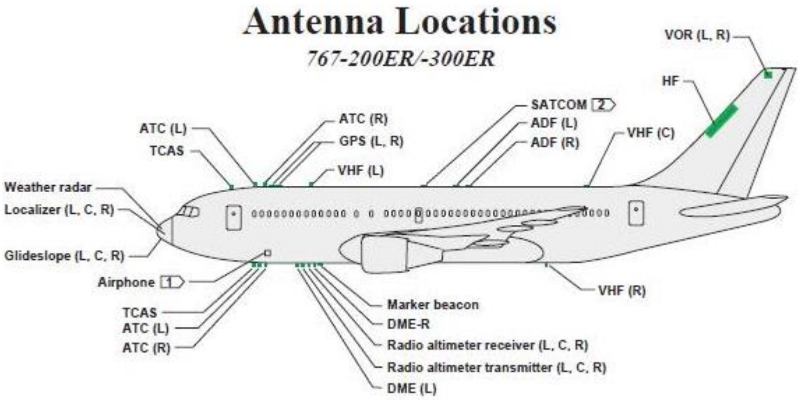


Figure 1 - Antenna Locations on Boeing 767-200ER / -300ER

(Source: https://aviation.stackexchange.com/questions/48077/which-antenna-on-an-commercial-airline-airplane-is-used-for-the-transponder-ssr)

Figure 2 – A typical blade antenna mounted on the fuselage of the aircraft.

Process Description

The process involves both electromagnetic and mechanical design of the antenna. The workflow process is illustrated in Figure 3. Electromagnetic design is accomplished using Altair Feko and mechanical design is accomplished using Altair HyperMesh in conjunction with the structural simulation solver Altair OptiStruct.

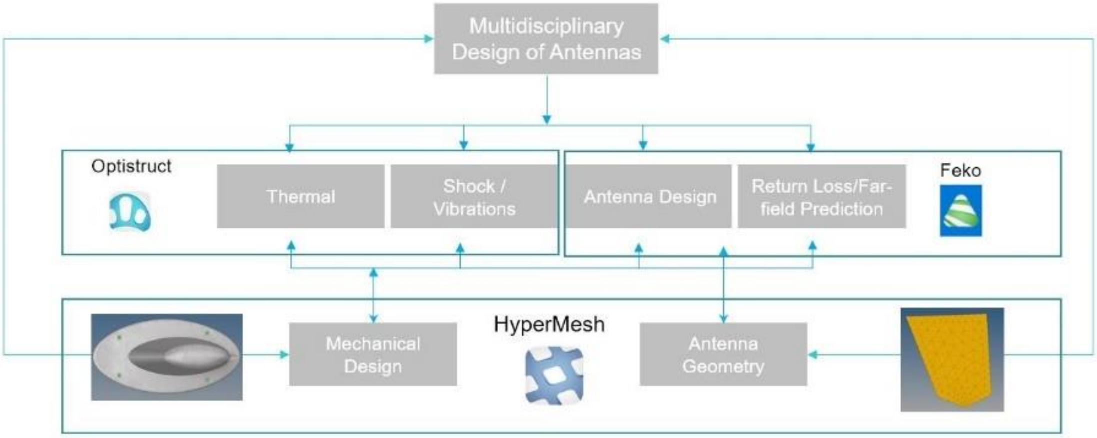


Figure 3 – Workflow process for simulation-driven multiphysics design of antenna

Electromagnetic Design of the Blade Antenna

Airborne communication Systems require broadband antennas with light weight and aerodynamic shape to decrease the wind resistance. Monopole antennas are simple and usually light weight structures that can achieve wide bandwidth. The low wind drag coefficient, light weight, simplicity of fabrication, and wide bandwidth make the blade antenna a preferred antenna structure in airborne applications. Blade antennas are monopoles that utilize the following two techniques to improve the impedance bandwidth.

1) Lowering the length (l) to diameter (d) ratio (l/d) of the antenna
2) Defining antenna structure by angle: conical and triangular sheet antennas are broadband structures that utilize this technique.

The geometry of the blade antenna without the protective radome is shown in Figure 4 and its dimensions are W =53mm, W1=27mm , H=87mmm and H1=11mm. It is mounted on the infinite ground plane for the sake of Feko simulations. Dimension H determines the lower frequency in the band. For frequencies where H is less than λ/4 (λ is the free space wavelength) the radiation resistance of the antenna decreases, and the input impedance of the antenna becomes capacitive with large imaginary part. A wire port is used for the excitation of the blade antenna.

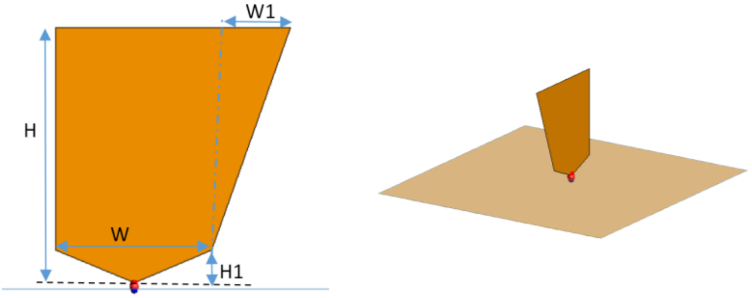


Figure 4 – Blade antenna geometry without the protective radome

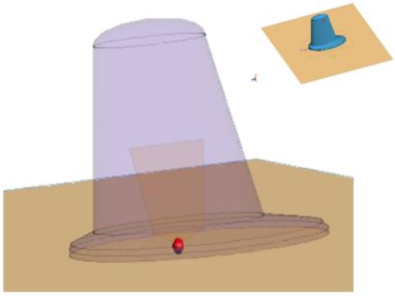


Figure 5 – Blade antenna geometry with the protective radome potting material.

The blade antenna is encased with a suitable protective radome potting material (Polyurethane foam with dielectric constant 2.1 and loss tangent 0.01) and is shown in Figure 5 resulting in overall maximum dimensions of height 210mm, length 260mm and width 110mm.

Feko simulations are carried out for the blade antenna shown in Figure 4 and show an operating bandwidth over the frequency range of 1.06GHz to 2.1GHz with less than -10dB return loss (reflection coefficient) and with a center frequency of 1.8GHz as shown in Figure 6 (blue curve). It is observed that the reflection coefficient response is shifted up in the frequency due to the introduction of radome potting material (green curve in Figure 6). The blade antenna dimensions are changed so that the reflection coefficient response is similar to that of the blade antenna without radome material. The dimensions of the blade antenna are modified to be W =56mm, W1=28mm , H=91mm and H1=12mm bringing the center frequency back to 1.8GHz (red curve in Figure 6).

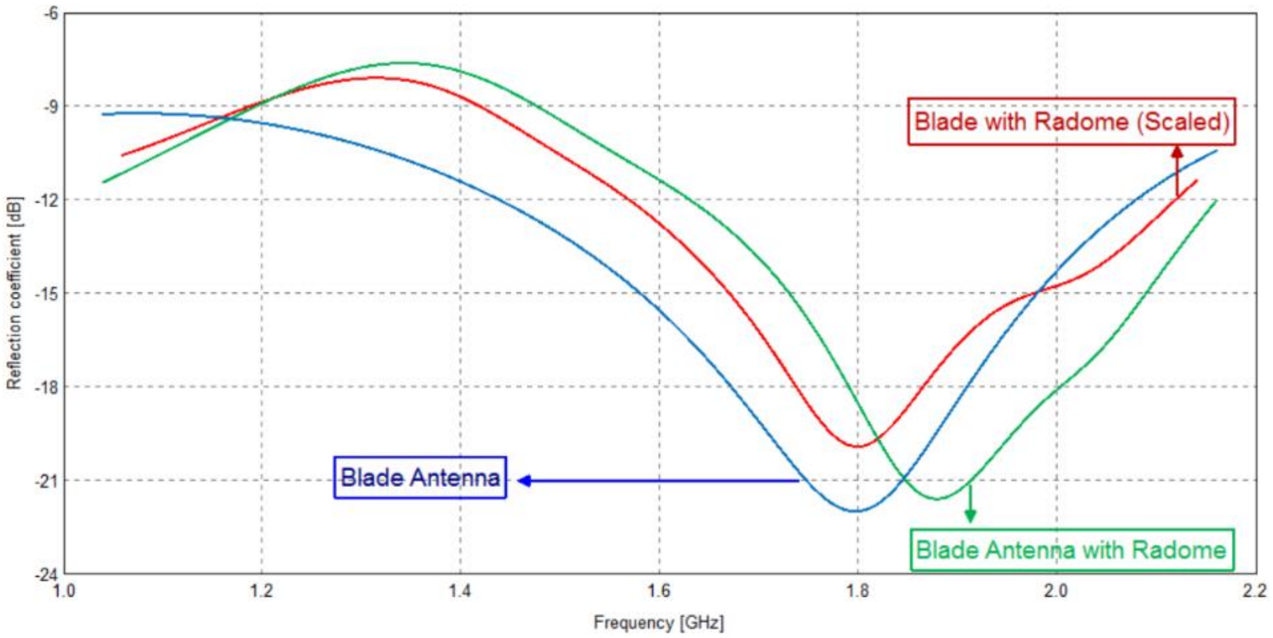


Figure 6 – Reflection coefficient responses of blade antenna (blue curve) and with radome (green curve) and the scaled version (red curve).

Structural/thermal finite element model

As described in the previous section, the structural overall maximum dimensions of the antenna with the polyurethane potting material are height 210mm, length 260mm and width 110mm. The blade structure (Figure 4) is assumed to be made of copper. The structural finite element (FE) model of the antenna is shown in Figure 7.

The radome is fixed on the fuselage using several bolts. Finding the optimal number of bolts as well as their location will be the subject of the next chapters. The number of bolts must be minimized while the structural design must be safe to satisfy the environmental specifications.

Material Data: For the structural FE analysis we will need the material properties for copper and polyurethane potting material and are extracted from Altair Material Data Center [6]. Copper material data is given in Table 1.

Table 1 – Material Properties of copper to be used in Structural finite element analysis of the antenna

Density	**8.90 t/m3**
Young’s Modulus	150000 MPa
Poisson’s ratio	0.33
Maximum admissible stress	202 MPa
Thermal Coefficient of Expansion	17.0 E-6 m/m/K

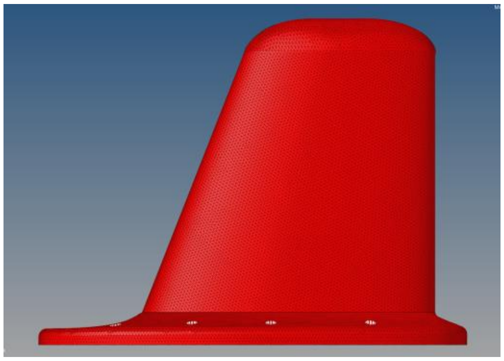


Figure 7 – Structural finite element model of the antenna.

Polyurethane material data is given in Table 2 along with the stress vs strain curve in Figure 8.

Table 2 – Material Properties of polyurethane to be used in the structural finite element analysis of the antenna

Density	**1.30 t/m3**
Young's Modulus	1300 MPa
Poisson's ratio	0.1
Maximum admissible stress	15 MPa
Thermal Coefficient of Expansion	20.0 E-6 m/m/K

Structural Analysis: The finite element model was created using Altair HyperMesh [7] and the finite element structural simulations are done with Altair OptiStruct [8], both from Altair HyperWorks software suite [5]. The structural FE mesh is created with 2mm tetrahedral elements resulting in 550,000 elements (Figure 9). This number varies depending on the number of bolts.

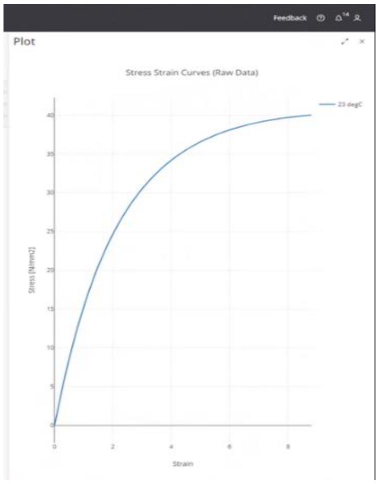


Figure 8 – Stress vs Strain Curve of polyurethane material.

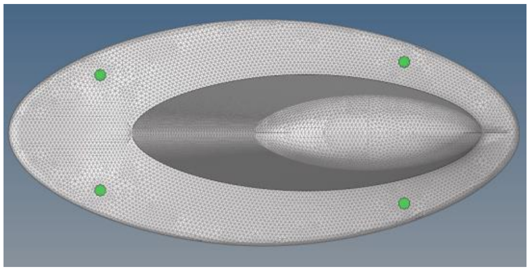


Figure 9 – Finite element model of the antenna with radome

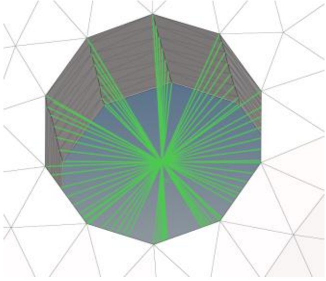


Figure 10 – Bolt modeling

The bolts are modeled with rigid body connections (RBE2) (Figure 10): all the nodes of the hole behave as a single undeformable body (the hole cannot change shape). Each RBE2 master node is fixed (the bolt cannot move).

The blade antenna mesh is exported from Feko and imported into HyperMesh with material properties of copper and meshed with 2 to 12mm triangular elements with element thickness of 0.1mm resulting in 202 elements.

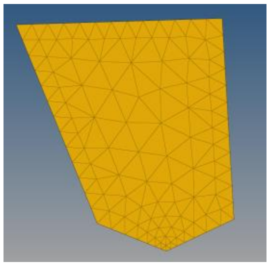


Figure 11 – Blade antenna (copper) FE model

The connection between the radome material and the antenna is done through tied contact. The displacement of the antenna follows the local displacements of the radome. Tied contact makes the model building process easier because there is no need for the antenna mesh to be coincident with the radome mesh. Therefore, different antenna and radome designs can be meshed and simulated together with no additional effort.

Vibration Specification: As per MIL- STD 810E, the vibration loading is a power spectral density (PSD) applied in three successive directions (x, y and z). The maximum amplitude is 0.3 g^2/Hz.

The PSD loading curve (g^2 vs Hz) is shown in Figure 12. The response is calculated for all frequencies equal to the eigenfrequencies of the structure between 0 and 1000 Hz as well as frequencies amounting to 20%, 40%, 60% and 80% of those values. The damping coefficient is set to 5%.

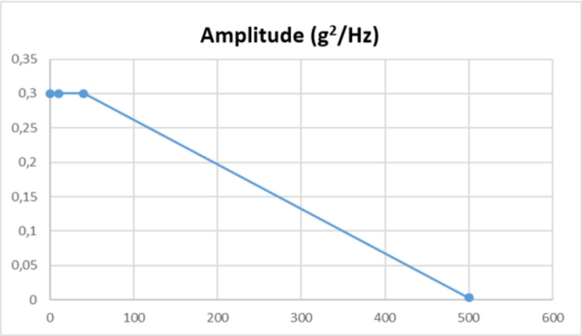


Figure 12 – PSD Loading of the antenna as per MIL-STD 810E

Mechanical Shock Specification: The mechanical shock loading is based on three 15g, 11 ms impacts calculations, one in each direction. A global loading of 15g is applied for 11 ms in each direction and the response of the structure is analyzed. The simulation performed is a transient modal response analysis. The frequencies considered are the same as for the vibration analysis

Thermal Specification: The standard MIL-STD-810C, method 504.1 PROC.I defines the certification of the device to thermal variations. Given the length of the phenomenon, hence their quasi-static nature, this can be defined as two static simulations with the antenna at -54 and 55°C. Once again, the VonMises stresses are checked. The main areas to be checked are the holes around the radome and the contact zone between the antenna and the radome as the differences in thermal expansion coefficients between copper and polyurethane material may create stress. The calculation is performed using Optistruct on the same numerical model as for mechanical loads, only the load case is modified.

Antenna Models: Four different antenna models were considered by changing the number and position of the bolts. By increasing the number of bolts, it is expected that the stress due to vibrations and shocks will be reduced, but the thermal stresses are likely to increase as this limits the dilatation of the radome around the holes. In addition, the number of bolts must be minimized due to weight, maintenance, costs, and design simplicity considerations.

(a) 2 bolts

(b 10 bolts

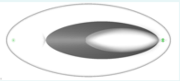
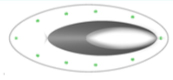
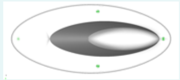
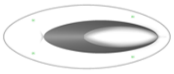
(c) 4 bolts

(d) 4 bolts (2 on each side)

Figure 13 – Antenna design variations with different bolt configurations

Vibration and Shock Loading Results: Several simulation iterations were performed varying the number and positions of the bolts as shown in Figure 13. The main criteria are the maximum Von-Mises stress over the radome. It must be checked that it does not exceed 15 MPa to avoid irreversible damage to the antenna. Similarly, VonMises stresses over the blade (copper) are limited to 202 MPa. Table 3 lists all results according to load cases and design. The most critical cases are vibrations and shock in y direction.

Table 3 – Summary of results : Maximum stress in MPa according to load case and design

	Vibrations x	Vibrations y	Vibrations z	Shock x	Shock y	Shock z
	14.8	72.7	19.6	15.8	92.0	19.12
	1.1	3.6	0.33	2.6	4.0	2.9
	**6.5**	**13.9**	**2.3**	6.5	12.2	7.2
	**7.6**	**11.4**	**2.1**	4.6	6.8	4.1

The best design is the “4 bolt design” with two bolts on each side (Figure 13 (d)). This bolt configuration is the optimal one: the number of bolts is minimized while the safety margin is optimized (11.4 MPa max stress).

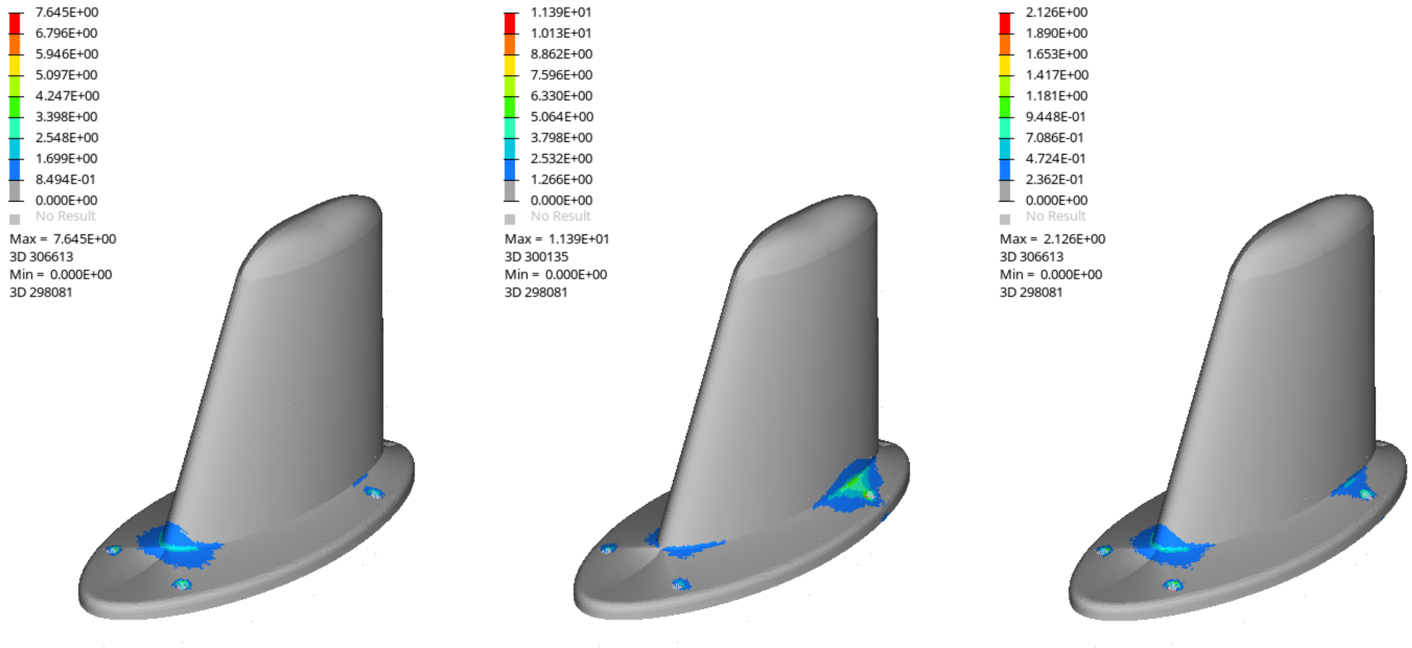
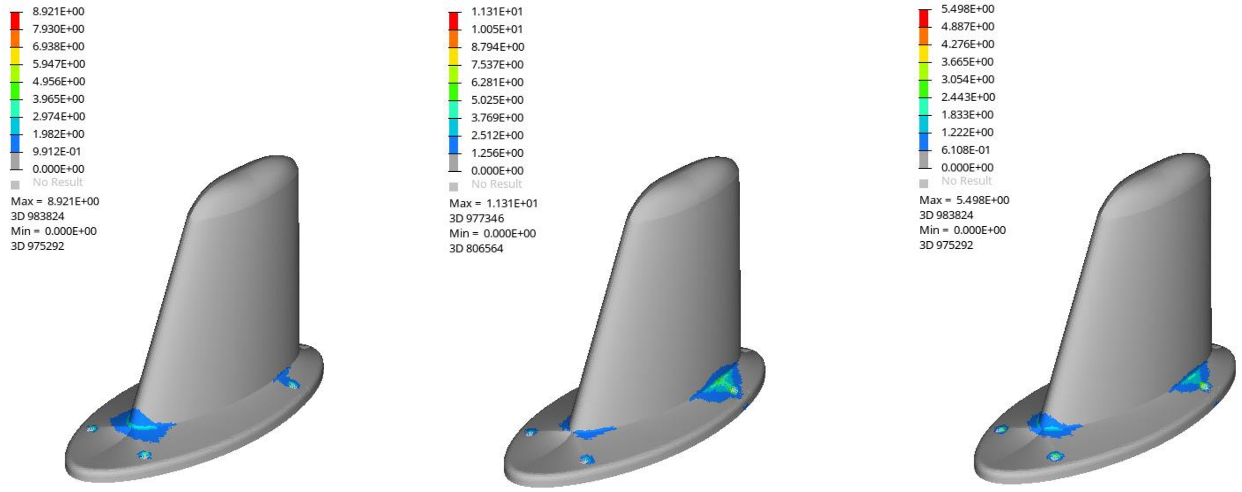


Figure 14 – Vibration loading Stress plots for the optimal 4-bolt configuration (Figure 13 (d)).

Figure 15 gives the maximum stress for shock loading in all three directions for the optimal design. The mechanical shock loading is less critical than the vibration responses.



X direction
max stress = 8.92 MPa

Y direction
max stress = 11.3 MPa

Z direction
Max stress = 5.5 MPa

Figure 15 – Shock loading Stress plots for the optimal 4-bolt configuration (Figure 13 (d)).

Blade Antenna Behavior: The blade antenna (copper) is not subjected to large deformation during the mechanical loadings, therefore, there is no risk of failure and electromagnetic performances will not be affected. Maximum stress and relative displacements of blade antenna (copper) are shown in Figure 16.

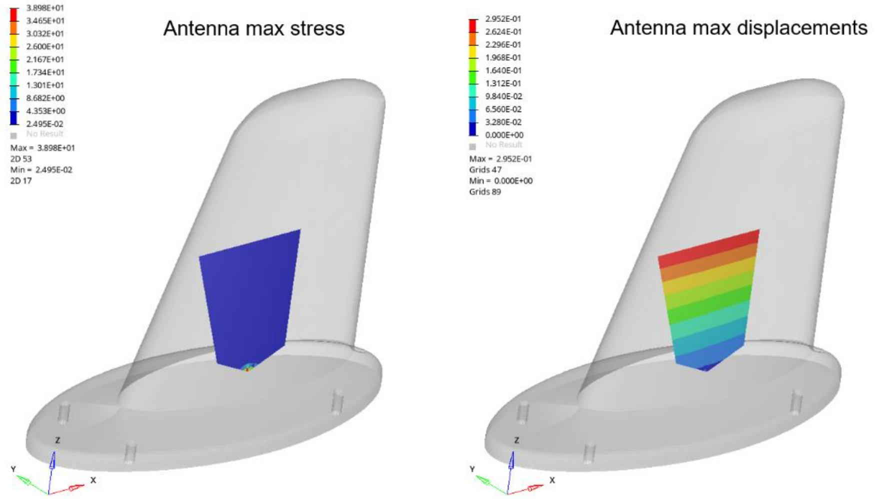


Figure 16 – Max stress and relative displacements of the blade antenna

Thermal Results: The thermal loading is critical with a compromise to be made as a high number of bolts reduces the stress due to fixations but increases the thermal stress by locally preventing material dilatation. As a consequence, the thermal material properties and especially the thermal expansion coefficients play a critical role. Thermal simulation results are shown in Figure 17 for all four bolt configurations shown in Figure 13.

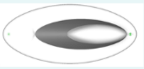
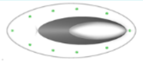
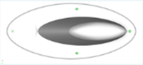
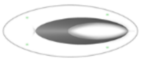
	Radome -54°C	Antenna -54°C	Radome 55°C	Antenna 55°C
	15.9	37.3	7.5	17.7
	49.7	54.3	23.6	202
	15.1	40.5	2.1	17.5
	**14.3**	**38.2**	**6.8**	18.1

Figure 17 – Thermal simulation results for all four bolt configurations shown in Figure 13.

Thermal results for the 4-bolt configuration in Figure 13 (d) is shown in Figure 18.

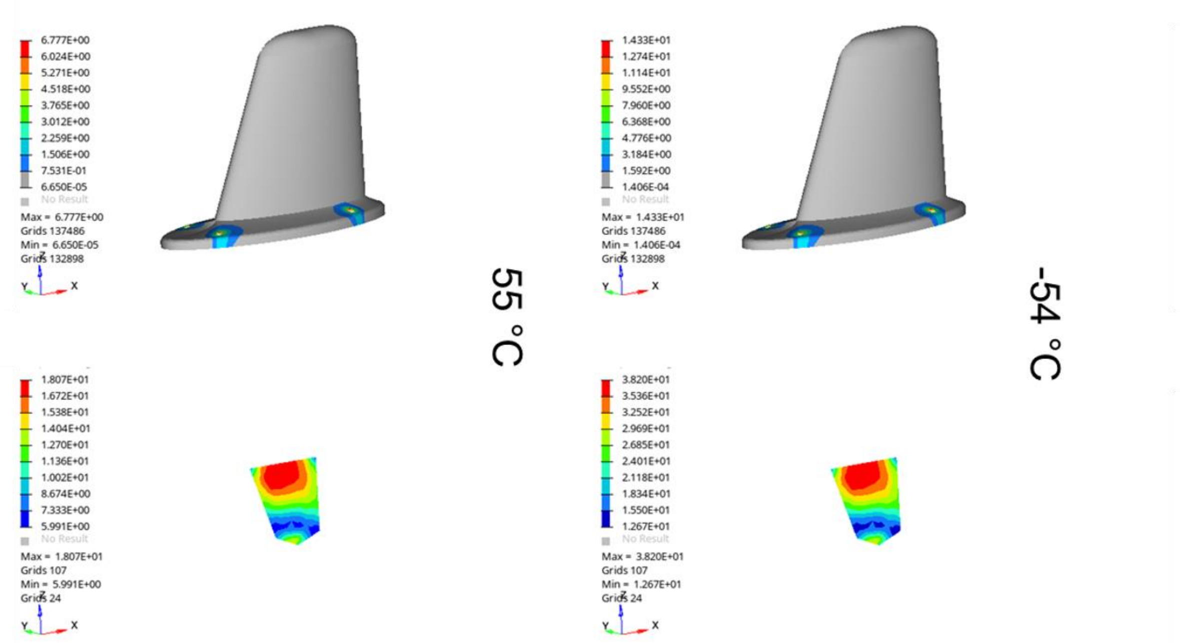


Figure 18 – Thermal simulation results for the 4-bolt configuration shown in Figure 13(d).

Summary of thermal results for the 4-bolt configuration (Figure 13(d)) is given in the table 4.

Table 4 – Thermal simulation summary for the 4-bolt configuration shown in Figure 13(d).

	Max admissible value	-54 °C	55°C
Radome	15.0 MPa	14.3 MPa	6.8 MPa
Antenna	202.0 MPa	38.2 MPa	18.1 MPa

The calculations show that the design narrowly passes the criteria. It is highly dependent on the thermal material property of the radome made of polyurethane foam.

Conclusions

In this paper, we demonstrated a simulation-driven antenna design process not only to meet the electromagnetic performance of the antenna, but also the environmental specifications for vibration, shock, and temperature. Using Altair Feko, HyperMesh and OptiStruct (all part of Altair HyperWorks Suite), we illustrated a workflow process that can be easily adapted for any antenna type. It was easy to perform a preliminary analysis of the antenna with radome and propose and modify the design for an optimal solution minimizing the number of bolts while keeping the antenna structure according to the environmental specification with a good safety margin.

This work could be conducted at early stages of the design process and can be very quickly updated if any design change is made at all stages of the design hence saving the time and cost in the antenna product development.

References

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[8] Altair OptiStruct - https://www.altair.com/optistruct/