Politecnico di Torino

Master of Science in Mechanical Engineering
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Master Thesis

Design of Ultralight Inflatable Antenna for Low Earth Orbit: Lorentz Force-Based Orientation

Feasibility study

Supervisors:
Prof.ssa Raffaella Sesana
Prof. Ladislau Matekovits

Candidate:
Simone Pacetti

Topic Overview

This thesis investigates the preliminary feasibility study of a new class of ultra-light inflatable antennas with a large transmitting and receiving surface composed of metallized fabric. These antennas are designed for deployment in Low Earth Orbit (LEO), at approximately 2000 km altitude from sea level. The orientation is controlled through the interaction between the Earth's magnetic field and electric currents induced within conductive elements embedded in the antenna's structure. This innovative control method eliminates the need for traditional mechanical actuators or booms, reducing complexity, mass, and transportation cost to space, while increasing operational efficiency.

A critical challenge associated with inflatable antennas is deployment and ensuring structural integrity of the membrane. Historical NASA experiments with inflatable space antennas were conducted in the 20th century, revealing a high failure rate due to uncontrolled inflation in vacuum conditions, leading to sudden structural collapse. This thesis addresses these concerns by conducting a pre-feasibility study on suitable materials specifically selected, inflation techniques, and rigidization methods. The selected inflation strategy ensures safe and controlled deployment, while rigidization mechanisms provide long-term structural stability, reducing the effects of micrometeoroid impacts and material degradation over time.

In addition to structural considerations, this work explores power generation solutions necessary for antenna operation. Advanced photovoltaic technologies, including new generation lightweight and flexible solar cells, are evaluated as a means of supplying power to the system. These solar cells can be integrated onto the antenna's surface or deployed on an auxiliary CubeSat operating in proximity to the antenna, enabling wireless energy transfer and improving mission sustainability.

The inflatable antenna structure is designed as a spheroid, with the southern hemisphere forming a parabolic reflective surface composed of metallized fabric, while the northern hemisphere remains transparent to electromagnetic radiation. The proposed system holds significant potential for aerospace applications, including radio astronomy and deep-space communication.

Through structural simulations, material selection studies, and power system evaluations, this thesis lays the groundwork for further development of inflatable antennas for space applications. While the findings confirm the feasibility of this innovative concept, additional experimental validation and optimization are required to transition from theoretical analysis to practical implementation in orbit.

Target

This thesis focuses on several critical aspects necessary for the successful realization of the proposed antenna system. First, the structural integrity of the inflatable membrane is analyzed, considering material selection, deployment mechanisms, and rigidization techniques. The research evaluates potential materials, such as metallized Mylar and other multi-layer composites, to ensure durability against space environmental factors, including atomic oxygen, micrometeoroid impacts, and extreme thermal variations. Furthermore, different inflation and rigidization strategies are examined to achieve a stable and long-lasting operational configuration in orbit.

Furthermore, power supply solutions are examined. The integration of lightweight and high-efficiency solar arrays is analyzed to determine the feasibility of generating sufficient power for the antenna's operation. The study also evaluates whether solar cells should be mounted directly onto the antenna's surface or deployed on an auxiliary CubeSat that remains near the antenna, enabling remote control.

Another key objective of this work is the development of a control methodology capable of achieving precise orientation of the inflatable antenna. By modulating electric currents within embedded conductive elements, the structure can generate distributed electromagnetic forces sufficient to induce controlled rotational motion. Dedicated simulations have been carried out to analyze the relationship between applied current and maneuver time, with the aim of identifying optimal parameters for effective and reliable control.

Results

As part of the development of the innovative inflatable antenna, a dual-hemisphere structural configuration was designed with distinct mechanical and functional roles. The selected multilayer structure ensures high reflectivity, thermal and mechanical stability, and resistance to UV radiation, atomic oxygen, and micrometeoroid impacts. Deployment is achieved through gas inflation, chosen for its compatibility with the materials and operational simplicity. Once the antenna reaches its final shape, a UV-curing process is used to rigidize the structure without requiring continuous internal pressure. The UV-curing resin is applied to the inner Mylar layer, providing the antenna with long-term stability and structural integrity.

Table 1 Material multi-layer with relative thickness, from inner to outer

Reflective Section			**Transparent Canopy**		
Layer	**Material**	**Thickness**	**Layer**	**Material**	**Thickness**
Core Structural layer	Mylar	12,5 µm	**Core Structural layer**	Mylar	12,5 µm
Reflective Coating	Aluminum	200 nm	**Outer Protective Layer**	Silicon Dioxide	100 nm
Outer Protective Layer	Silicon Dioxide	100 nm			

The structural analysis conducted using Ansys demonstrates the mechanical viability under the operational conditions in orbit. Simulations were performed to evaluate the behavior of the structure under inflation pressure and thermal variations, focusing on the hot and cold cases. The results were compared with the maximum allowable stress and strain values to verify the compliance of the design with the material's limitations. For the hot case, considering applying an inflation pressure of 12 Pa with a temperature of 85°C, the maximum Von Mises stress was determined to be 27,88 MPa, slightly below the allowable stress limit of 30.32 MPa. The strain values also remained within the elastic range, confirming the structural stability of the material under these conditions. Even though, the train value of 1,08% is slightly below the allowable limit ($\varepsilon_{allow} = 1{,}14\%$), the situation is not critical since has been adopted a safety factor of 2. The thermal strain, resulting from the expansion due to temperature, was included in the analysis to ensure a realistic assessment of the antenna's behavior.

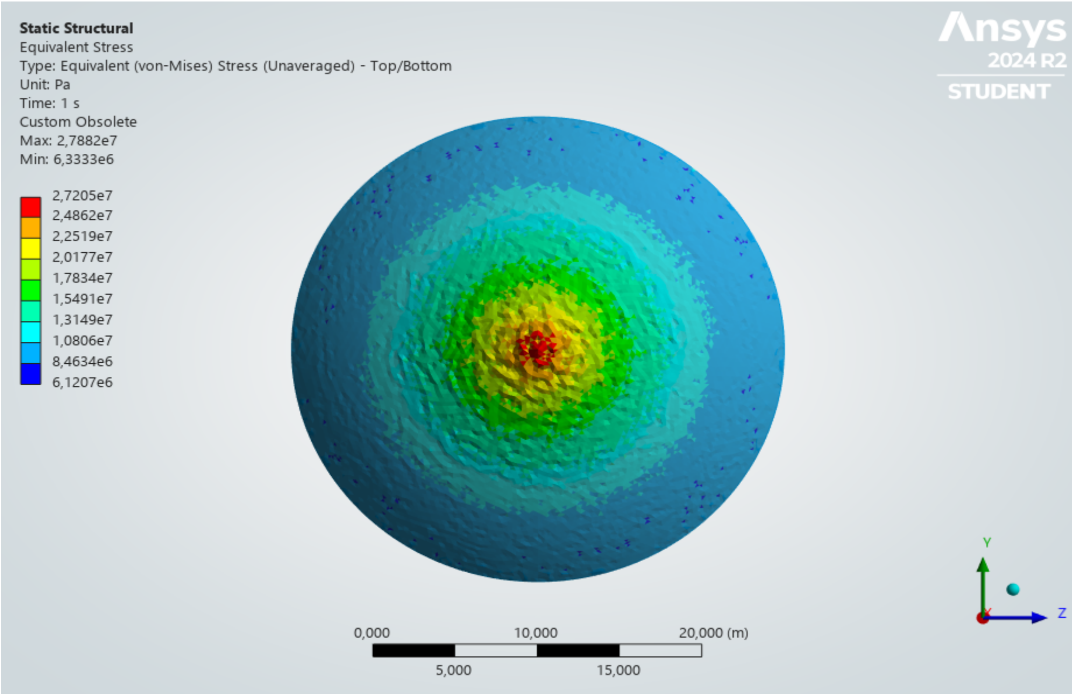

Figure 1 Equivalent Von Mises stress distribution in Hot Case – Reflector

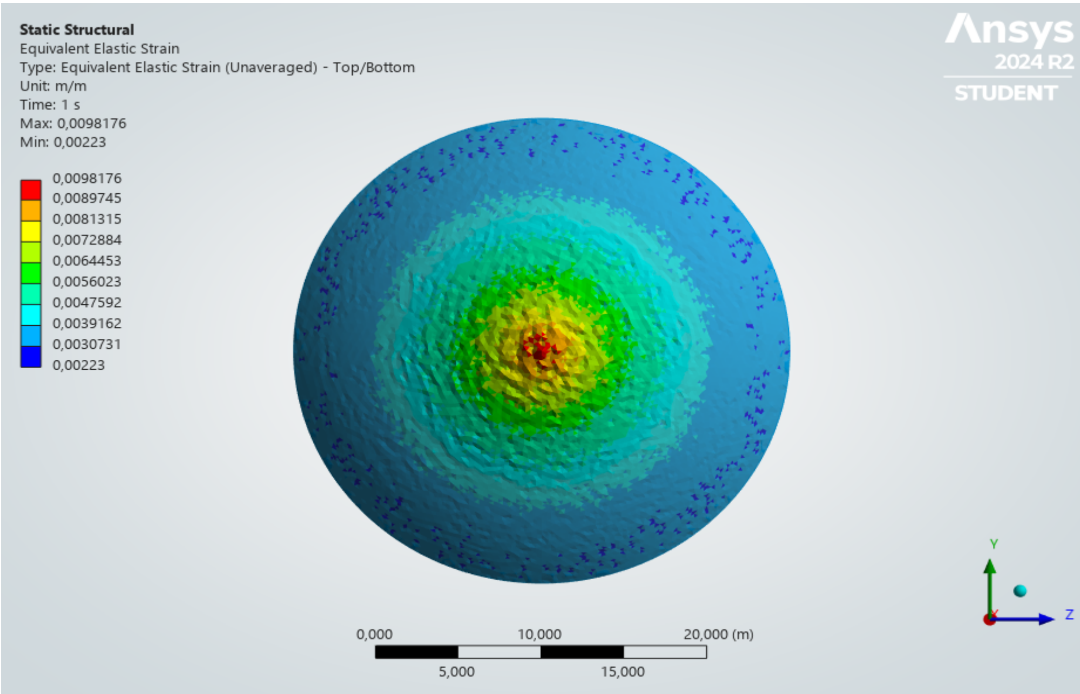

Figure 2 Equivalent Elastic Strain in Hot case – Reflector

In the cold case, corresponding to -85°C and inflation pressure of 6,25 Pa, the maximum Von Mises stress reached 14,52 MPa, remaining well within the allowable limit of 42.02 MPa. The strain values were similarly evaluated. With a total strain value of 0,13%, the safety limit of 0,92% is respected confirming that the material maintained its elastic behavior even at low temperatures. Stress distribution across the structure was largely uniform, with minor concentrations near critical points such as the central point of the reflective section and the edge of the canopy, which were within acceptable limits.

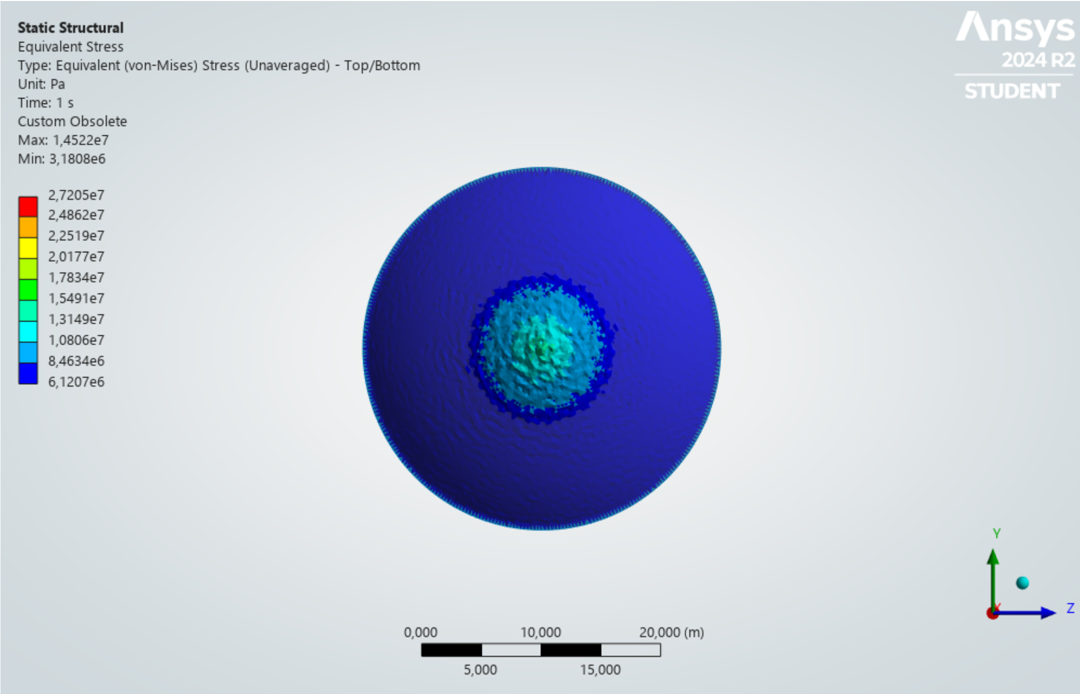

Figure 3 Equivalent Von Mises stress distribution in Cold Case – Reflector

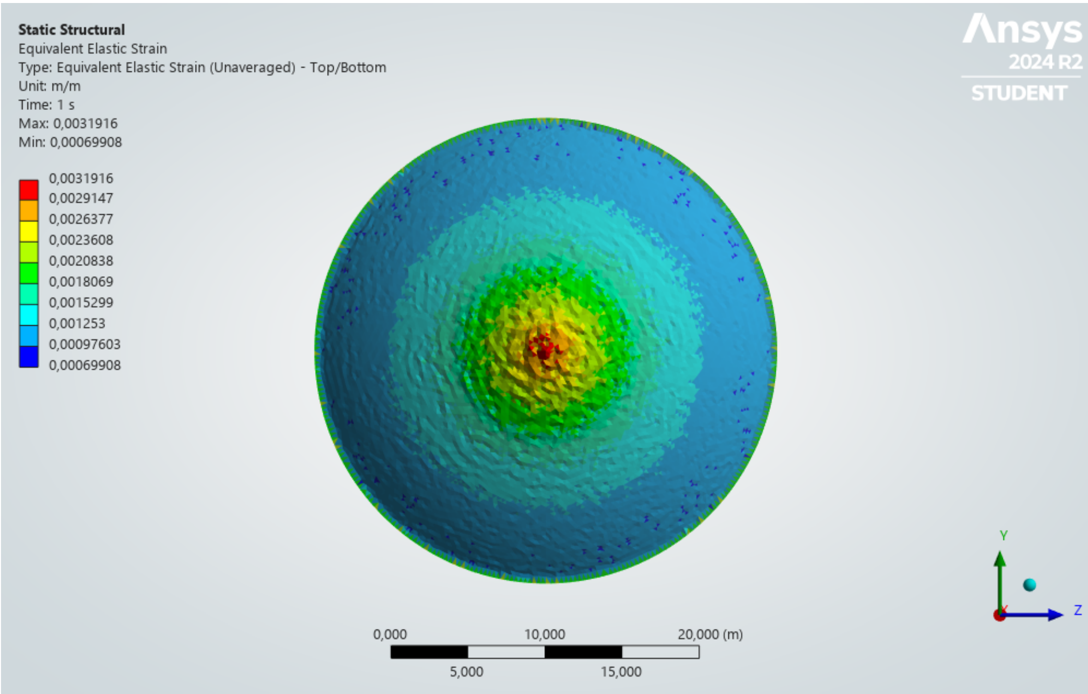

Figure 4 Equivalent Elastic Strain in Cold case – Reflector