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Impact behavior of composite antenna array that is conformed around cylindrical bodies

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ABSTRACT

In this paper, one structurally integrated array that is conformed around cylindrical bodies has been designed and fabricated for a part of the aircraft outer skin. The effects of the mechanical topology are considered in the antenna design, confirming the optimal integration without compromising either the mechanical or the electrical performance. The measured results show that the radiation pattern is strongly dependent on the radius of curvature. The results of a study of the response and failure characteristics subjected to low-speed impact damage are presented; they indicate that the value of the contact force decreases as the radius of curvature decreases. As the impact energy was increased, the specimens experienced significant damage consisting of a dent localized in the region of impact. These results suggest that the radius of curvature is an important electrical and mechanical parameter in the design of conformal arrays.

1. Introduction

Modern military aircrafts offer few locations where a large, high-gain antenna may be installed without severely increasing aerodynamic drag. To meet this challenge, significant amount of research has been undertaken on the embedding of antennas in load-bearing structural surfaces of aircrafts to improve both structural efficiency and antenna performance [1–3]. Structure, material and antenna designers have joined forces to develop this new high payoff technology called Conformal Load-bearing Antenna Structure (CLAS) [3]. Innovative integration of antenna elements should significantly improve the reception quality and manufacturability of this type of vehicles.

In order to accurately represent and design such a load-bearing antenna structure, we have proposed the antenna-integrated composite structure, shown in Fig. 1 [4–6]. This structure was designed using the high-gain condition that involves the multi-layer geometry of composite structure [7,8].

Moreover, antenna engineers from military laboratories and aerospace industry are examining a class of highly sophisticated antennas on non-planar surfaces called "conformal arrays" very commonly integrated with the outer skin of the aircraft. While conformal arrays have existed for years [9,10], antenna engineers have started only recently to develop revolutionary new designs, which hug the outer mold-line of military aircraft. Engineers can install conformal arrays, up to a few inches thick, directly on the skin of aircraft. However, the most advanced conformal arrays are structurally load-bearing arrays, whose elements are embedded flush with the skin of the aircraft and must bear high dynamic mechanical loads while radiating or receiving electromagnetic energy.

In the present paper, one structurally integrated array, termed "composite array", is proposed. A sandwich composite consisting of glass/epoxy facesheet and honeycomb core is used as a basic mechanical structure, in which an antenna array is embedded around cylinders with various radius of curvature. The radiation patterns are measured in an anechoic chamber to investigate the effect of cylindrical geometry on antenna performances and the correction in the excitation phase is presented in order to obtain a main beam in a fixed direction.

Serving in primary load-carrying components in aircraft and aerospace structures, composite array is subjected to impacts such as tool drops, hail, bird strikes, and runway debris. Predictions of the effects of low-velocity impact damage are difficult and are still relatively immature. For this reason, experimental studies have been performed to characterize the damage created by low-velocity impacts. Most of the studies of the effects of low-speed impact damage reported in the literature have focused on flat sandwich composite [11–14]. There is very limited information in the literature that addresses the low-speed impact response of curved sandwich composite with thin facesheet that is typical of fuselage skins.

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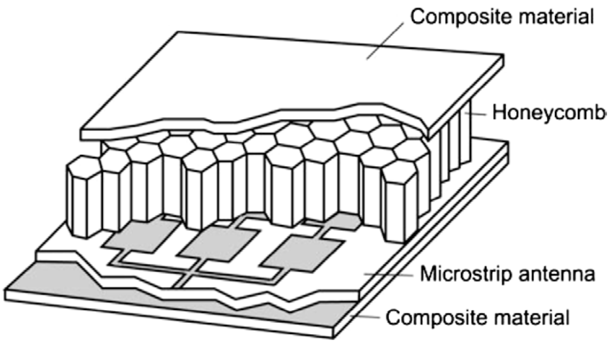

Fig. 1. Basic geometry of composite array.

It has been shown that composite plates with curvature and certain combinations of plate dimensions exhibit a nonlinear "softening" response when impacted with dropped-weight impactors [15,16].

Understanding the nature of the structural responses and damage characteristics as a function of structural and impact parameters is essential for designing impact-safe and electrically effective composite arrays. The present paper presents the results of a study of the effect of low-speed impact events on the response of cylindrically curved composite arrays with different radii. The influence of the curvature on the impact response of the structure and the impact energy levels necessary to cause significant damage are also discussed in detail.

2. Composite array

The basic geometry of the composite array is a sandwich composite in which a microstrip antenna is embedded, as shown in Fig. 1. Sandwich construction [17,18] involves two relatively dense and stiff facesheets that are bonded to either side of a low-density core. The facesheets carry bending-induced axial loads, and the core sustains shear stresses as well as compressive stresses normal to the plate. The presence of the core moves the facesheets away from the neutral axis, enhancing the bending resistance provided by the facesheets, the properties of which, despite being necessary to sustain the structural load, must not impair antenna performance.

In Refs. [7,8], the effects of multi-layer (3D) geometries on microstrip antennas have been investigated for the design of composite arrays. Changes in the gain of antenna due to the laminated geometry have been determined using a transmission line analogy and the design of high-gain antennas in a specific bandwidth is proposed away from structural resonance. Composite arrays in this paper have been designed using the high-gain condition that involves the sandwich geometry. Fig. 2 presents the mechanical and electrical advantages of the geometry in composite array. It requires integrated product development from disparate technologies, including structures, electronics, materials, and manufacturing. The classic of division between structures and antennas is bridged in composite array, and the technical challenge is to satisfy structural and electrical requirements that often conflict.

3. Design and fabrication

For an effective structural performance, glass/epoxy laminate was used as the facesheet material, and non-metallic honeycomb of rectangular cell shape as the core material. The honeycomb was manufactured from high temperature resistant aramid paper, and coated with a phenolic resin. The combination of aramid paper and phenolic resin gives the superior strength, toughness and chemical resistance. The honeycomb cell shape is normally hexagonal for optimum mechanical properties, but in this effort it has a rectangular cell shape to provide improved drapeability for the production of curved parts. This honeycomb has "air-like" dielectric properties, transparent to radio and radar waves. The RT/duroid 5880 is used as the antenna substrate. Table 1 shows the mechanical and electrical properties of the materials used in this composite array.

The final geometry is presented in Fig. 3. The array consists of 4×1 patches and the elements are all uniformly excited in amplitude and phase. The antenna patches were designed at the resonant frequency of 12.5 GHz. Since we designed this thin composite array so as it can be easily integrated into the skin of an aircraft, the benchmarking mounting cylindrical structures were formed with four practical radii of curvature, *R*, of 50, 100, 150, and 200 mm.

The manufacturing of the composite array is a sequential process. The antenna layer is processed and integrated into the designed sandwich composite. Each layer is bonded on the top or bottom of another one in a designed sequence, using epoxy film adhesive. The assembly is performed on a cylindrical mold of designated radius. After being covered by a vacuum bag, the curved panel is

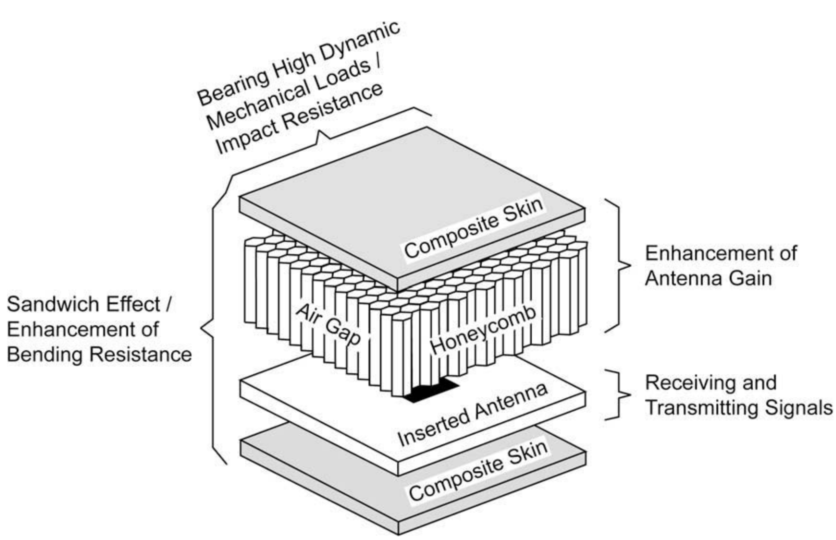

Fig. 2. Mechanical and electrical advantages in composite array.