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Design, fabrication and testing of a Dyneema/polyethylene radome for airborne remote sensing

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ABSTRACT
Most radomes consist of a solid laminate or sandwich type structure made of fiberglass reinforced plastics. The use of Dyneema (trademark of DSM) fibers in a plyethylene (PE) matrix instead of fiberglass reinforced plastics for radomes is very interesting because of excellent radar transparency of Dyneema/PE. However, because of its sensitivity for creep, applications in aerodynamically loaded structures are limited. The key problems facing their use in radomes are how to improve the mechanical properties to an acceptable level and how to mount the radome on the radar pod.
This paper presents the development of a Dyneema/PE radome for airborne remote sensing. Several electrical properties and design aspects of the radome are discussed. The effect of the consolidation conditions on the creep behaviour and the configuration of the mounting system are described. Test flight results are evaluated.
Keywords: Dyneema/polythylene, aircraft, radome.

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DESIGN, FABRICATION AND TESTING OF A DYNEEMA/POLYETHYLENE RADOME FOR AIRBORNE REMOTE SENSING

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SUMMARY

Most radomes consist of a solid laminate or sandwich type structure made of fiberglass reinforced plastics. The use of Dyneema (trademark of DSM) fibers in a polyethylene (PE) matrix instead of fiberglass reinforced plastics for radomes is very interesting because of the excellent radar transparency of Dyneema/PE. However, because of its sensitivity for creep, applications in aerodynamically loaded structures are limited. The key problems facing their use in radomes are how to improve the mechanical properties to an acceptable level and how to mount the radome on the radar pod.

This paper presents the development of a Dyneema/PE radome for airborne remote sensing. Several electrical properties and design aspects of the radome are discussed. The effect of the consolidation conditions on the creep behaviour and the configuration of the mounting system are described. Test flight results are evaluated.
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1. INTRODUCTION

After a period of extensive studies using ground-based radars and a Sideways Looking Airborne Radar (SLAR), the Dutch remote sensing community decided to develop an airborne Synthetic Aperture Radar (SAR) with an active phased array antenna. This resulted in the PHARUS (Phased Array Universal SAR) system, developed in co-operation between the Physics and Electronics Laboratory of TNO (TNO-FEL), the National Aerospace Laboratory NLR and Delft University of Technology (DUT).

The PHARUS-concept allows airborne SAR systems to be built on a common generic basis but tailored to a specific user. This provides an economic and yet technically sophisticated solution to remote sensing or surveying. The use of an active phased array antenna provides flexibility in the design of compact lightweight instruments so it can be carried on small aircraft.

The first, experimental PHARUS system was designed for use on a Cessna Citation II research aircraft. Because of the required minimum ground clearance and the maximum weight that can be attached externally on this aircraft, the size and the weight of the radar pod was limited.

The purpose of this work was to develop a suitable radome for the PHARUS system with a minimum weight but also a minimal loss of signal and minimal depolarisation effects.

2. GEOMETRY AND ELECTRICAL ASPECTS OF THE RADOME

PHARUS is a fully polarimetric C-band system with a very flexible configuration. The active phased array radar is expandable up to four rows of 24 modules. The external radar pod contains the complete radar system and consists of a 1.5 m long aluminium box with integrated liquid cooling channels. The cross-section of the radarpod is given in figure 1.

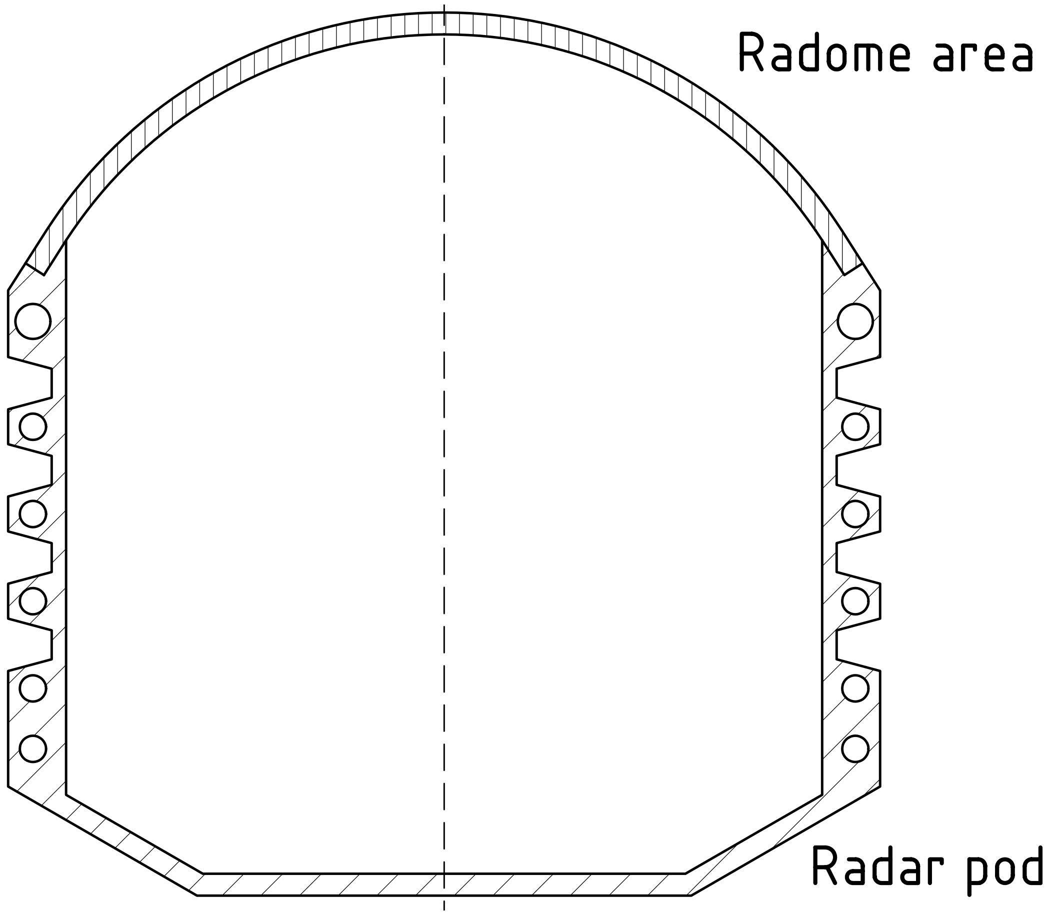

Fig. 1 Cross-section of the radar pod

Since the depolarisation effects are minimal when the shape of a half lambda line is approached, the ideal radome for this long and narrow configuration is half a cylinder. However, the height of the radome above the frame is restricted to a maximum of 100 mm to prevent ground contact. Furthermore the frame width and the position of the antenna in relation to the frame were constrained.

Because of the fact that a half cylinder could be approached better with a thin radome and that a sandwich radome would cause more depolarisation (ref. 2), a relatively thin solid laminate radome was preferred above a sandwich type. Research at TNO-FEL learned that a single layer radome with a radius of 207.5 mm and a thickness up to 4 mm of Dyneema/PE would be the best achievable compromise for this specific radome (ref. 1). In this case, due to the good radar transparency of Dyneema/PE the reflection loss would be less then 0.4 dB and the maximum cross-polar deterioration would be 1.5 dB.

3. DESIGN ASPECTS

The experimental PHARUS system is designed to be mounted externally on a Cessna Citation II aircraft. This twin jet business aircraft was chosen for high resolution SAR imagery because of its high operating speed, up to 250 m/s, and its high maximum altitude of 12 km.
To prevent condensation problems the radar pod is hermetically sealed and kept at an inside pressure of 1 bar. The maximum operational height is 14 km, giving a pressure difference of more then 0.75 bar on the radar pod and the radome. Deformations caused by this pressure difference are not allowed to exceed 2.3 mm.
The operational temperatures range from +50°C to -60°C. In order to prevent ice accretion, composite cones are mounted on the front and back end. The allowed total mass of the radar pod is 240 kg. Because of the relative heavy radar pod this means a maximum mass of 4.5 kg for the radome.
Due to the internal pressure, the radome is loaded in tension. Depending on the mounting interface, also some bending will occur. Furthermore, expansion of the aluminium radar pod can be expected due to the integrated cooling system for the radar.
Solid laminates of Dyneema/PE can be obtained by film stacking with Dyneema fabric and PE film. For the radome, the Dyneema SK65 fiber with easy available low density PE (LDPE) film was chosen. Dyneema SK65 fibers do have a potential tensile strength of 3 GPa and a potential modulus of 95 GPa at room temperature. These properties increase at sub-zero temperatures, but decrease at higher temperatures. The coefficient of thermal expansion for the Dyneema fiber is -12E-6/K.
Although the short term tensile properties look promising, on a laminate level they are strongly reduced due to the poor adhesion of the matrix on the fiber, the low matrix properties and the creep sensitivity. Typical properties, provided by DSM for Dyneema/LDPE laminates with a fibervolume of 80%, consolidated at 125°C and 25 bar are a yield stress of 40 MPa and a modulus of 8 GPa.
To avoid creep and secondary loads due to thermal expansion, it was decided to apply a quasi-isotropic laminate of 3.8 mm Dyneema SK65/LDPE. Including the mounting interface, this would result in a radome mass of about 4.4 kg, which is below the allowed maximum mass.

4. DESIGN OF THE MOUNTING INTERFACE AND FABRICATION OF THE DYNEEMA/PE RADOME

The compression properties of Dyneema/PE laminates are very poor. Because the material is also creep sensitive, no reasonable bearing strength properties can be expected. Therefore a mounting interface had to be designed which does not depend on bolted joints. In order to avoid load concentrations a wedge-shaped mounting interface with line contact over the circumference of the radome was designed, see figure 2.

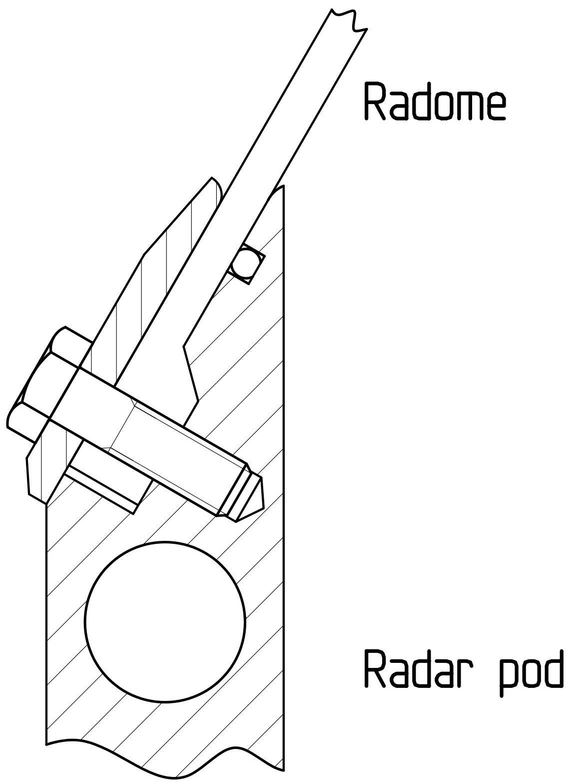

Fig. 2 Wedge-shaped mounting interface with clamping strip.

The bolts used for the clamping strip run through the laminate of the radome. Because the laminate is enclosed in the wedge, it is loaded in shear and in compression perpendicular to the fiber-plane. In order to verify the creep behaviour of this mounting interface, a number of specimens were tested. A picture of the test configuration is given in figure 3.

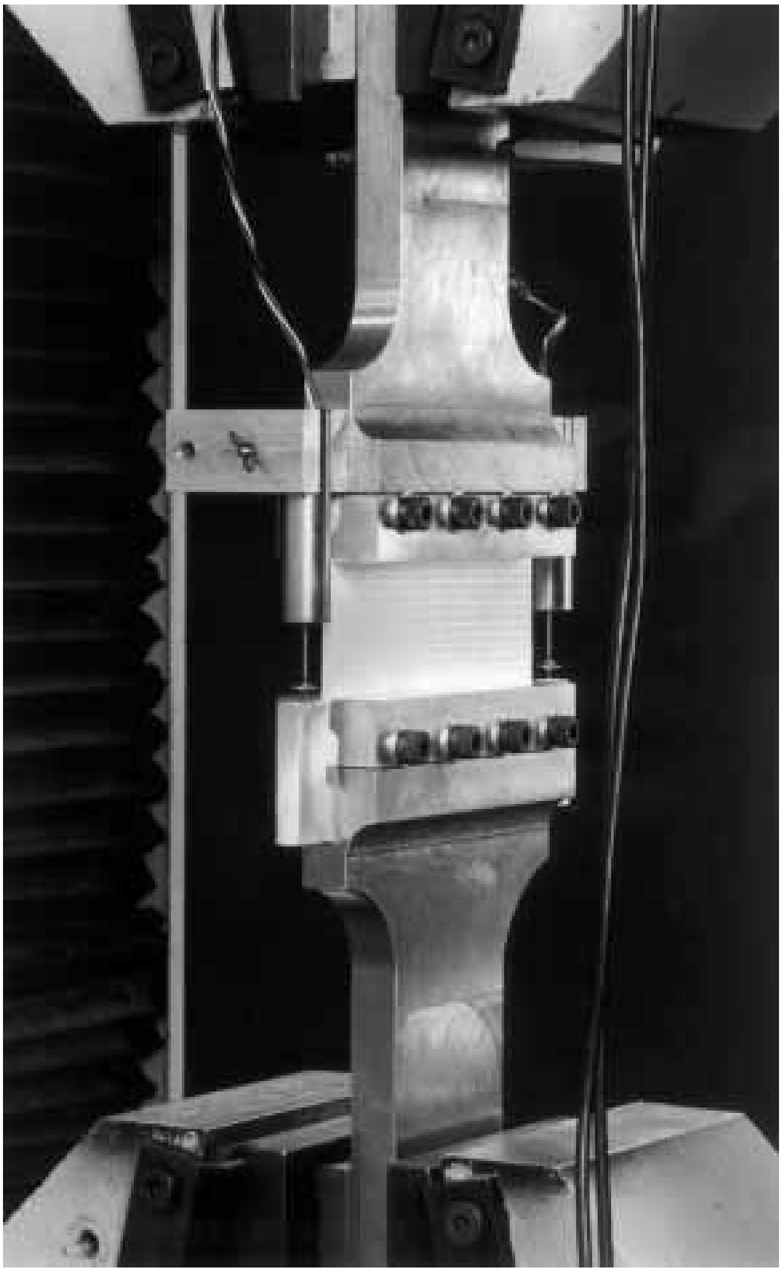

Fig. 3 Testing the creep behaviour of Dyneema/PE

At first, the specimens were consolidated at 135°C and 20 bar pressure, according to the recommendations of DSM. Static tests on these specimen gave poor results, the yield stress was about 30 MPa with a modulus of 3 GPa. Because of the poor quality no fatigue tests were performed.

To improve the performance it was decided to consolidate another set of specimens at a temperature of 145°C. This temperature is very close to the melt temperature of Dyneema, so proper temperature control had to be performed. The pressure of 20 bar could not be increased because this pressure was the maximum pressure capability of the autoclave in which the radome had to be made.
The increased consolidation temperature gave a significant improvement of the mechanical properties. The material was much more homogeneous and the hardness was much higher. With the same number of plies a 10% thinner laminate was made. The yield stress of the quasi-isotropic laminate was 43 MPa and the modulus was 9 GPa.
Static tests at room temperature using a load multiplication factor of 4 were performed successfully on specimens with a laminate thickness of 3.8 mm. Fatigue tests at room temperature did show a little creep, but no permanent lengthening within 4 hours flight time. Fatigue tests with the same load but also simulated temperatures showed a creep of only 0,12 %. This was acceptable. Therefore it was decided to use Dyneema SK65/LDPE with a consolidation temperature of 145°C and a pressure of 20 bar for the radome.

5. PERFORMANCE OF THE RADOME

Generally a Spectra (trademark of AlliedSignal) or Dyneema/vinylester radome (ref. 3) is considered to have the lowest combination of dielectric constant (≈2.7) and loss tangent (≈0.003). With a dielectric constant of 2.25 and a loss tangent of 0.0002, the Dyneema/PE radome has far better transmission properties. The reflection loss is also depending on the thickness of the radome, but because of the very low loss tangent of Dyneema it will perform better, even for increased thicknesses.
If necessary the mechanical properties of Dyneema/PE can be improved further by using high density polyethylene (HDPE) matrix material instead of the applied LDPE. A higher pressure, up to 50 bar would also improve the mechanical properties.

The PHARUS system has performed its first test flight on September 22, 1995 and has provided good quality data since. The radome is performing in a satisfactory manner, and did not show any mechanical or electrical distortion yet. Figure 4 shows the Cessna Citation II of NLR with the PHARUS system during one of the test flights.

Fig. 4 The Cessna Citation II with the PHARUS system

6. CONCLUSIONS

Although the mechanical properties of Dyneema/PE composites are low, they are interesting for solid laminate radomes because of the good transmission properties. Compared to glassfiber reinforced plastic radomes a greater thickness is needed, but for aerodynamically loaded radomes the reflection loss of a Dyneema/PE radome is still very low while the transmission loss is negligible.
The mechanical properties of Dyneema/LDPE become significantly better when they are consolidated at 145°C. This temperature is very close to the melt temperature of Dyneema, so proper temperature control has to be performed.
The properties can be improved further by using a higher consolidation pressure and high density polyethylene.
Mounting problems with Dyneema/PE due to the low compression and bearing stress properties can be overcome by using a wedge-shaped mounting interface with line contact over the circumference of the radome.

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