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Composite Applications for Radio Telescopes

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Abstract. Development of construction techniques for composite reflectors is an active R&D focus at the National Research Council's Dominion Radio Astronomical Observatory (DRAO), near Penticton, Canada. The team at DRAO constructed and tested its first 10-m diameter prototype reflector in 2007 and is currently incorporating improvements in performance and manufacturability for the next prototype to be built in the spring of 2008. Composite materials offer a range of benefits over traditional metal structures in the construction of large ($>$ 10 m diameter) reflectors. The high specific modulus of composite materials results in the construction of lighter and stiffer reflectors and the low CTE of these materials yields thermally stable structures. A lighter stiffer reflector allows higher accelerations with a given power input and the thermal stability allows for high performance over wide operating temperature ranges. New developments in composite manufacturing processes have the potential to make composites a cost effective alternative for reflector antennas.

1. Introduction

The Composite Applications for Radio Telescopes (CART) project at the Herzberg Institute of Astrophysics' (HIA) Dominion Radio Astrophysical Observatory (DRAO) in Penticton, Canada is an ongoing effort to investigate the potential application of composite materials to radio telescope structures. The primary motivation is to provide cost-effective collecting area for the Square Kilometre Array (SKA) telescope, but several other potential radio astronomy projects could benefit from the unique properties of composite materials including VLBI 2010.

1.1. Composite Material Properties

Composite materials have a wide variety of properties, allowing them to be tailored very precisely to a given application. Of particular interest to radio telescopes are high specific stiffness, high specific strength, and low coefficient of thermal expansion. While composite materials do have a high specific cost (\$/kg), the mass of structures is low, so the overall cost can be competitive.

Composite structures have been in use for over 30 years in high UV, marine environments, and advances in material coatings and processes in recent years have improved the quality and longevity of composite structures.

1.2. Composite Fabrication Processes

Until recently none of the available composite fabrication processes were appropriate to the manufacture of large radio reflectors. The vacuum infusion process (VIP) now offers a viable alternative: fabric and core materials are laid dry in a mold, and sealed under a vacuum tight bag. Resin is then drawn into the part under vacuum. The size of the part is limited only by the height to which the resin can be drawn, $\sim 6\,\mathrm{m}$, allowing diameters up to $\sim 100\,\mathrm{m}$.

VIP requires very little capital investment, typically a couple of large vacuum pumps, various common shop tools, and a facility with a moderate degree of climate control. For large structures, the mold and equipment to handle the completed structure are the major expenses, but with moderate production quantities these are quickly amortized. The simple infrastructure requirements allow the fabrication to take place at or near the site.

2. The CART Project

The CART project aims to demonstrate the cost-effective fabrication of high-performance, one-piece composite radio reflector. A 10 m diameter was selected as it is typical of reflectors under consideration for upcoming projects.

2.1. Prototype Design

The following prototype specifications were chosen:

Reflector Diameter: 10 m	Design Wind Speeds
Optics: Centre-fed parabolic reflector	Operating: 35 km/h (10 m/s)
f/D Ratio: 0.45	Slew to stow: 50 km/h (14 m/s)
Max operating frequency: $\sim 10\,\mathrm{GHz}$	Survival: 160 km/h (44 m/s).

To select a reflective surface material, the reflectivity of various materials was tested using a closed cavity method developed by JPL [1]. Several alternatives were identified that offered noise temperatures only a factor of 2 higher than aluminum ($\sim 0.13\,\mathrm{K}$).

The reflector structure was designed using finite-element methods to meet the specifications for deflection and strength. The design chosen used a reflective surface with a rim and integral structural beams on the backside.

Infusion flow modelling was performed in order to ensure that the structure would fill evenly and within a reasonable time. This involved a mix of measurement of flow properties of the particular materials and laminate schedules to be used in the structure, and computer modelling.

The surface accuracy that can be realized in the final part is dependent on the surface accuracy of the mold. The mold used was measured to have 0.015 mm RMS and a maximum deviation of 1.8 mm.

2.2. Results

The first 10 m CART prototype was constructed in mid-2007. Fig. 1 shows the completed reflector on the mount. The final mass of the reflector was measured to be 1 tonne, which includes all of the back structure.

Figure 1. The completed reflector on the mount

The reflector was measured using both laser-tracking and holography. The laser tracking was performed at an elevation of 90° with the tracker mounted at the center of the reflector. The holography (at 12 GHz) employed a geostationary satellite signal at elevation 34°. Both results are shown in Fig. 2. The strong similarity despite the large elevation difference attests to the stiffness of the structure.

The RMS deviation of the surface compared to the best-fit parabola is 1 mm, and the maximum deviation is ~ 4 mm, with the best-fit parabola having a focal length 22 mm shorter than the design because of shrinkage.

Note that there are some high regions between 2 and 4 o'clock and 8 and 10 o'clock. These are believed to arise because of differential cure in the large structural beams, which were infused subsequent to the surface, rim, and smaller beams. Fig. 3 shows the layout of the beams superimposed on the measurement results. The heavy black lines indicate the beams added in the second infusion.

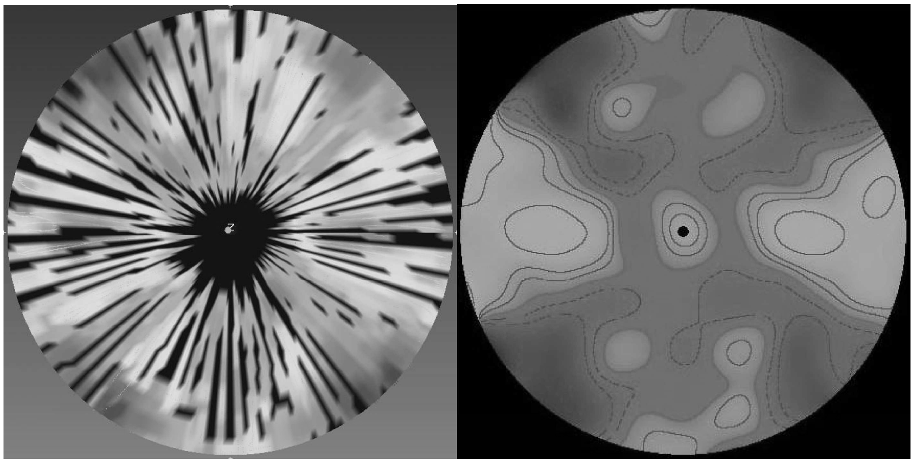

Figure 2. Laser tracker (left) and holography (right) results

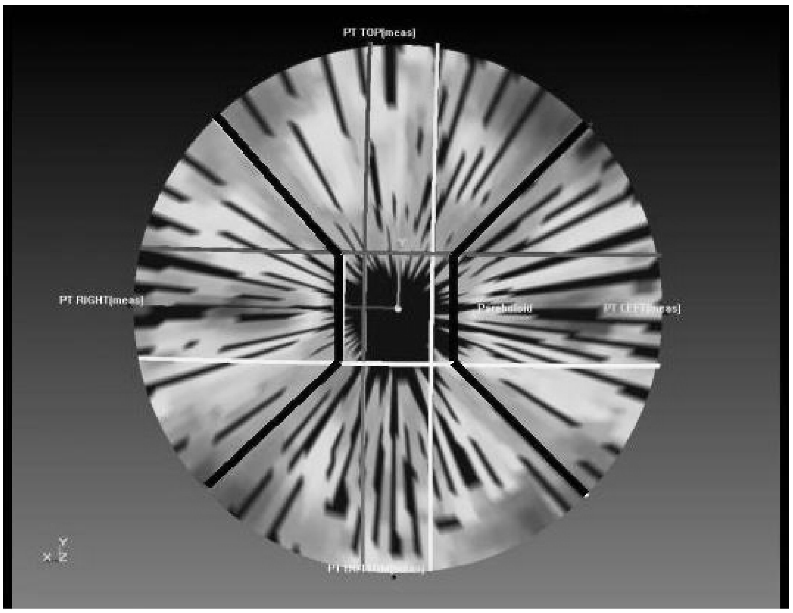

Figure 3. The layout of the beams superimposed on the measurement results

3. Future Plans

The CART Mk2 program is underway at DRAO to design and build a second prototype. The goals of the Mk2 program are to improve the structural design, design for production, and improve process design and control.

The Mk2 design is shown in Fig. 4. The surface and rim will be infused on the mold in one piece, eight beams and a hub will be fabricated separately and bonded on while it is still on the mold. The symmetry of the surface and rim will maintain symmetrical shrinkage during cure and the beams and hub will hold the surface in shape. The predicted mass is slightly less than that of the first prototype.

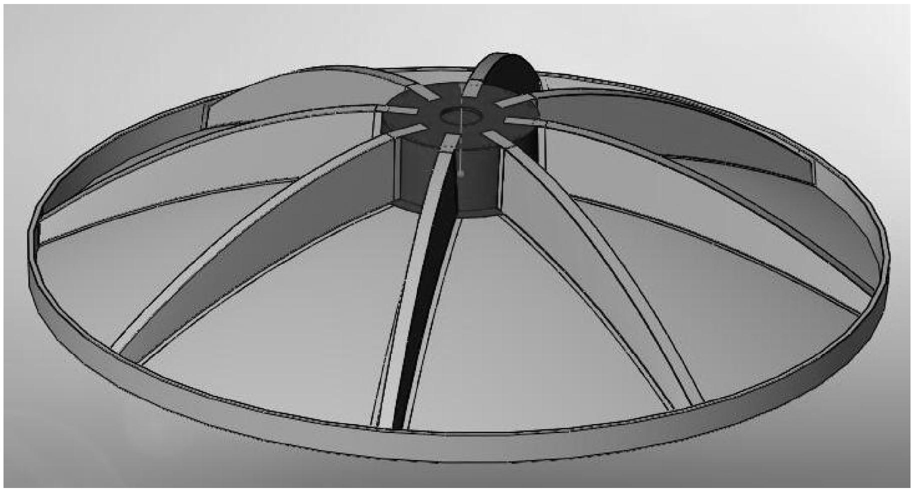

Figure 4. The Mk2 design

4. Conclusions

Composite materials have properties that make them very attractive for use in radio telescopes; lightweight, stiffness, and low coefficient of thermal expansion. New processes show promise for cost effective production of large accurate structures using composites. The Composite Applications for Radio Telescopes project has successfully produced its first 10 m prototype reflector. The mass of this reflector is 1 tonne including backing structure. The RMS deviation of the surface with respect to the best-fit parabola is 1 mm, but the deviations are not random. The cause of the major components of the deviations has been identified and development of a second prototype is underway to address these issues.

References

[1] Clauss, R., P.D. Potter. Jet Propulsion Labs Communications Elements Research Section, Improved RF Calibration Techniques: A Practical Technique for Accurate Determination of Microwave Surface Resistivity. JPL Technical Report 32-1526, v. XII.