mmA Antenna Memo No. 14

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MEMORANDUM

To: Bob Brown, Peter Napier

From: James Lamb

Subject : Visit to Composite Optics, Inc.

On 29 July 1993 John Payne, Jingquan Cheng and I visited Composite Optics, Inc. in San Diego, CA. The company specializes in fabricating mirror assemblies (mainly for centimeter wavelengths) and their support structures. Our impression was that they are a well-organized company with good design and fabrication facilities, and they have some interesting ideas that are germane to the mmA.

I append a detailed report, which recommends development funding for some specific areas. This includes three areas where some Development Contracts would be appropriate.

Report on Visit to Composite Optics, Inc.

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NRAO, Tucson
3 August 1993

1 Introduction

Composite Optics, Inc. (COI) is a San Diego company that was founded in 1976 and now has about 150 employees. Their product lines are divided into Spacecraft Structures, Stable Structures, and Antenna Systems. Capabilities include design, fabrication and testing. Their main work has been in the aerospace industry fabricating antennas, waveguides, microwave filters and horns from carbon-fiber-reinforced-plastic (CFRP) for spacecraft applications. These have been at much lower frequencies but the company potentially has the capabilities to work to the accuracies required for the mmA.

2 General Impressions

The company appears to be well organized. The members of staff whom we met were friendly, interacted well with each other, and they were competent in their areas of expertise. We were given a tour of their manufacturing plant.

3 Capabilities

3.1 Design and Analysis

Full design and analysis capabilities including NASTRAN finite-element-analysis program and PATRAN pre/post-processor.

3.2 Materials

Materials are purchased from outside companies as prefabricated composite sheets, or sheets of fibers preimpregnated with the matrix material. The prefabricated sheets may be cut and formed and the preimpregnated sheets are formed into laminates, sometimes with irregular surfaces (such as for shaped beam antenna systems). COI has good relationships with suppliers and has some feedback into the material design and production process. They have access to a wide range of materials and have extensive experience in selecting materials for particular applications. The trade-offs among stiffness, thermal expansion, isotropy, moisture absorption, and cost are well understood.

3.3 *Machining*

There are several machines that would be useful for fabricating parts for the mmA antennas:

Water-Jet Cutter:	This produces a jet of water and grit with a diameter of 0.8 mm under pressure at 65 000 psi. The head is mounted on a numerically-controlled router and can cut complex 2-D shapes in laminate sheets. It is capable of cutting up to 100 mm thicknesses in Invar.
2½-Axis CNC:	Has a capacity of 2.3 m × 1.0 m × 1.5 m and an accuracy of 25 µm end-to-end
5-Axis CNC:	On order. Will have a capacity of 6.1 m × 4.3 m × 1.2 m and an accuracy of 25 µm. A laser metrology head may be added as a retrofit.
Miscellaneous:	Several in-house built machines for forming reflector surfaces of revolution.

3.4 *Fabrication*

Facilities are available for taking the raw materials and fabricating complete assemblies. Sheets may be cut and assembled and glued into 3-dimensional structures.

Shaped surfaces may be formed on molds. Generally bulk graphite molds are used and these are purchased from a local company that machines them to specification. With the acquisition of the new 5-axis CNC machine they will be able to machine molds in-house, but intend only to act as a second source. Glass molds have also been purchased for production of high-accuracy reflectors.

Several surface coatings have been developed for various applications, such as providing conductive surfaces or protection from moisture absorption. Metallic coatings include copper, aluminum and nickel, which are applied by electrolytic or electroless processes. Non-metallic coatings can also be applied, and an ultrahigh-molecular-weight polyethylene coating has been developed for protecting metallic surfaces.

3.5 *Inspection and Testing*

Facilities include:

CMM:	Coordinate Measuring Machine with a capacity of 1.4 m × 2.0 m × 0.76 m and an accuracy of 2.5 µm.
Theodolites:	Set of three theodolites for coordinate measurement by triangulation.
CTE Measurement:	Laser optical comparator for coefficient of thermal expansion (CTE) measurements.

4 Relevance to the mmA

Composite Optics' capabilities are relevant primarily to the backing structure, panels, secondary and secondary support. The remainder of the antenna structure from the backing structure down would need to be fabricated independently. COI have experience in joining CFRP materials to metals so connections to the lower part of the structure should not be a problem, provided that the interface is properly specified.

4.1 Backing Structure and Secondary Mirror Support

Conventional backing structures are usually space truss designs. Where CFRP is used connections are made with metal nodes (steel or Invar). This type of structure is well understood, but the nodes contribute a large part of the structure weight without improving the stiffness. If they are made from steel they can also dominate the thermal expansion of the structure. In either case precision machining of the nodes is required to ensure that member axes pass through a common point, in conformance with the finite-element model. We have been considering alternative construction methods which would be more appropriate for CFRP and concluded that a box structure made from sheet would be appropriate.

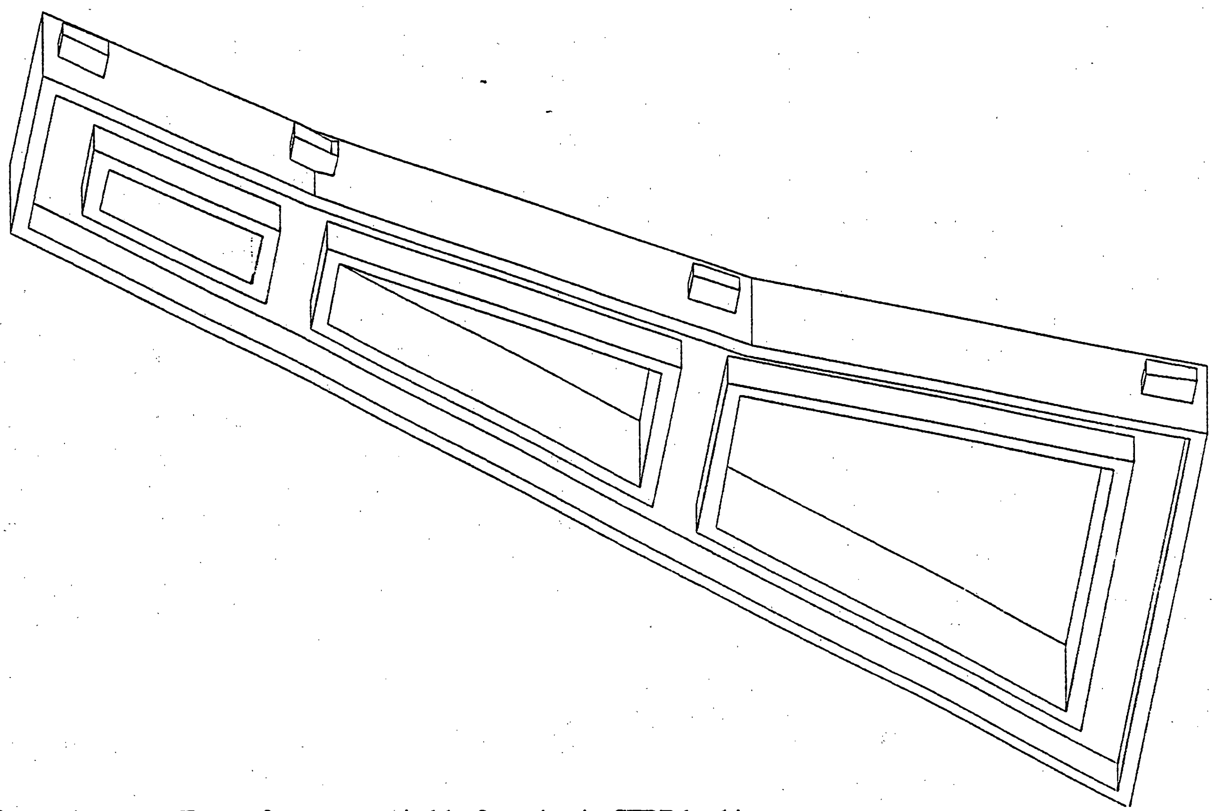

Figure 1 Type of structure suitable for using in CFRP backing structure.

COI have studied such a construction method in connection with the SAO antennas and have gone as far as making a scale model. They have a patented mortise-and-tenon technique which results in strong joints. Figure 1 represents the type of structure being considered (actually more elegant than this representation). Although they claim that the structure is easier to analyze than a truss structure, we have some reservations about this. A truss structure can be analyzed by considering each strut as an element and the nodes as point connections. This relies on accurate machining of nodes to ensure a common intersection point for all the members. For the box-type truss, the flat sheets need to be divided up into a mesh with an appropriate granularity, requiring a large amount of computing. COI have reduced this problem by modeling the beams as joints and connecting elements as for the truss structure. The effective "strut" and "joint" properties are computed separately by gridding these separately and then modeling them as simple elements. Measurements and finite-element-analysis predictions of structural eigenfrequencies agree to 1%, but it is not clear this accuracy is obtainable for static as well as dynamic analysis. 1% of a 300 μm absolute deflection is acceptable, but 10% is not. It may be that the structure is stiffer, in which case 10% of a 30 μm deflection would be acceptable, for example. This is an area which we think would be fruitful for further study.

COI had some interesting ideas about using different materials in the trusses and would consider how to use the stiffer and more expensive composites sparingly and using the cheaper materials where possible.

4.2 Panels and Secondary Mirror

Most of the reflector surfaces which the company have made are much less accurate than we require (by an order of magnitude). Recently they have been making advances in more accurate fabrication, for the SAO proposal, for example. For this they have used glass molds rather than the bulk graphite ones. They believe that they should be able to achieve the required accuracy.

For CFRP/Al-honeycomb panels the surface has to be coated with a reflective material. They can plate with copper (which may not be sufficiently corrosion resistant), aluminum (which may also suffer from exposure on a mountain site), or nickel (which has one-third the conductivity of aluminum). Coatings of ultrahigh-molecular-weight polyethylene (UMPE) may be applied for protection against a hostile environment. Questions to be answered are: How tough are the unprotected metallic coatings?; What would the effects of the UMPE coating be?; Is a nickel surface acceptably conductive? These are all potential topics of collaborative studies.

5 Comments on Costs

Some interesting points regarding costs were made. Note that these are not to be construed as accurate estimates or commitments by COI, but they recorded here to give at least an approximate idea of costs.

Material Costs: From \$10 kg^{-1} to \$2 000 kg^{-1}, depending on properties (alignment of fibers, epoxy/fiber ratio, matrix material, *etc.*). Higher strength materials are more expensive. For the backing structure the cost would probably be around \$60 kg^{-1}.

Backing Structure: Guesstimate \$0.25 M, materials and fabrication.

Factors: Could save ~25% by not overconstraining the design. Save 10% for quantity. Material costs not expected to come down much in the foreseeable future.

6 Time Scale

The company believed that construction of 1 antenna per month is feasible. It would not be more than a factor of two slower, but detailed study would be needed to give a firm estimate.

7 Possible Study Contracts

There are several possible study contracts which we could give to COI:

PANEL STUDY

Are we still interested in CFRP panels? Machined cast aluminum panels appear to be gaining in popularity so we need to compare the two technologies. At this point the comparisons are:

Cost:	Aluminum *possibly* cheaper.
Thermal:	Both acceptable in terms of error due to gradients in the panel. CFRP preferable when mounted on a CFRP backing structure (shape change matches backing structure change better).
Gravity:	Self-weight of CFRP panels possibly slightly less, but both acceptable.
Weight:	CFRP panels are much lighter.
Manufacturing:	Need comparison study.
Ruggedness:	Aluminum panels would be acceptably resistant to a mountain-top environment. It is not clear that CFRP panels would be.

Because of the thermal and weight considerations the CFRP panels have some advantages and it would be wise not to rule them out at this stage. The resistance to degradation by wind, snow, *etc.*, could be tested on some samples. The following Study Contract is proposed:

Proposal I:

COI should provide a set of samples of surfaces for testing. These would have metallic coatings of various thicknesses and compositions (Cu, Al, Ni, *etc.*), with and without dielectric protecting layers of various thicknesses (*e.g.*, UMPE). These would be specified by NRAO based on RF requirements. Samples need be only 100-300 mm in size and no special surface accuracy is required. COI can organize accelerated testing, NRAO could monitor samples at relevant sites, such as the VLBA antenna on Mauna Kea.

Comment: Other companies may have similar or better capabilities in this area. Since the cost should be relatively low, more than one company could be commissioned to do similar tests or provide NRAO with test panels. Hexcel is an obvious alternative.

BACKING STRUCTURE ANALYSIS

Because of the reservations about the accuracy of modelling the box structure numerically we feel that it would be essential to convince ourselves that a performance prediction would be reliable.

Proposal II:

COI to construct a scale model of a prototype backing structure truss. Analysis of structure by COI to be verified by NRAO. Static testing of model (*e.g.*, add weights at various points and directions and measure deflections) by COI and/or NRAO. Compare predicted and measured results and resolve any discrepancies. Change analysis method or construction method to achieve reliable modeling if necessary.

REFLECTOR DESIGN

We would like to build a prototype antenna. COI has the capabilities to construct all of the antenna above the slant-axis bearing. Before building we need to have a design and cost estimate.

Proposal III:

Design complete backing structure, reflector surface, secondary mirror support, secondary mirror. Demonstrate that it conforms to thermal, gravitational, wind and other specifications by numerical analysis and scale model testing.

8 Comments and Recommendations

At this point we have not decided whether we will use CFRP or not. It looks as though a steel structure may be marginal and would at least require sunshades and air circulation. If we REALLY want to meet the antenna specifications at all times, day and night, for reasonable wind conditions then the CFRP design looks attractive. A detailed design study would give a close estimate for the cost of using this design so that the cost/benefit tradeoffs could be properly assessed.

Proposal I: Panel samples should be ordered as soon as possible. The cost is likely to be low enough that samples could be ordered from other companies such as Hexcel.

Proposal II: The proposed backing structure design has some features which are proprietary to COI so a contract for analyzing the contract should be placed with them. Again this is not likely to be an expensive undertaking and should be done as soon as possible.

Proposal III: Design of a complete backing structure is a bigger undertaking. Before a contract is let we would need to get a proposal from COI as to how they would proceed, what their particular expertise is, and what the cost would be. Similar requests could be made of other companies.

In connection with the last point it should be noted that only preliminary contact has been made with other companies and these should be expanded ion a similar way. They include: Hexcel, TIW, Coast Steel, Harris, MAN, Vertex.