Evaluation of a Boron-Epoxy Reinforced Titanium Truss

NICHOLAS CORVELLI* AND ROBERT L. CARRI†
Grumman Aerospace Corporation, Bethpage, N.Y.

Theme

A SAVINGS of 24% weight is forecasted when comparing a boron/epoxy reinforced titanium tubular truss with an all-titanium design for application to the space shuttle booster thrust structure. This forecast is based on experimental results obtained by testing boron/epoxy composite cylindrical local buckling specimens, composite-to-metal bonded step joint specimens and a boron/epoxy reinforced titanium truss which failed at 118% of design ultimate load.

Contents

The demand for increased structural efficiency in aerospace vehicles can be met by the use of relatively expensive, advanced composite materials. At the same time, the rising cost of aerospace vehicles dictates that composite materials be utilized in the most effective manner. One approach which appears to offer the potential of meeting this goal is a composite reinforced metal concept.

The composite-reinforced tubular concept offers the designer a variable weight saving which is dependent upon the percentage of composite material used. As the percentage of composite is increased, both the weight saving and the unit cost of that weight saving are increased. The relation between cost and weight is shown in Fig. 1 for a typical compression member designed as a uniform boron/epoxy reinforced titanium tube. Note that the application of a small percentage of boron/epoxy reinforcement is extremely efficient in terms of weight saved per pound of boron/epoxy used. The tubular members for the truss were designed with approximately 75% boron/epoxy and 25% titanium by volume. This volume ratio was selected since a further increase in volume of composite would result in a minimal weight reduction and it was anticipated that this high ratio of composite-to-metal would exhibit the potential problem areas associated with this design concept. The composite-reinforced columns were designed with boron/epoxy reinforcement on the outside of a titanium tubular substrate. Included in the figure for comparison purposes is an all-composite minimum weight design column with a laminate orientation (60% longitudinal and 40% ± 45° plies) determined in a separate optimization study.

Demonstration truss: The space shuttle booster thrust structure was chosen as a demonstration article for this concept. The demonstration truss, shown in Fig. 2, includes a 41-in. compression member, a 25-in. tension member and a joint cluster machined from titanium 6A1-4V annealed. This truss is a segment of the $\frac{1}{3}$-scale model of a vertical planar truss shown in Fig. 2 which was chosen by NASA Marshall

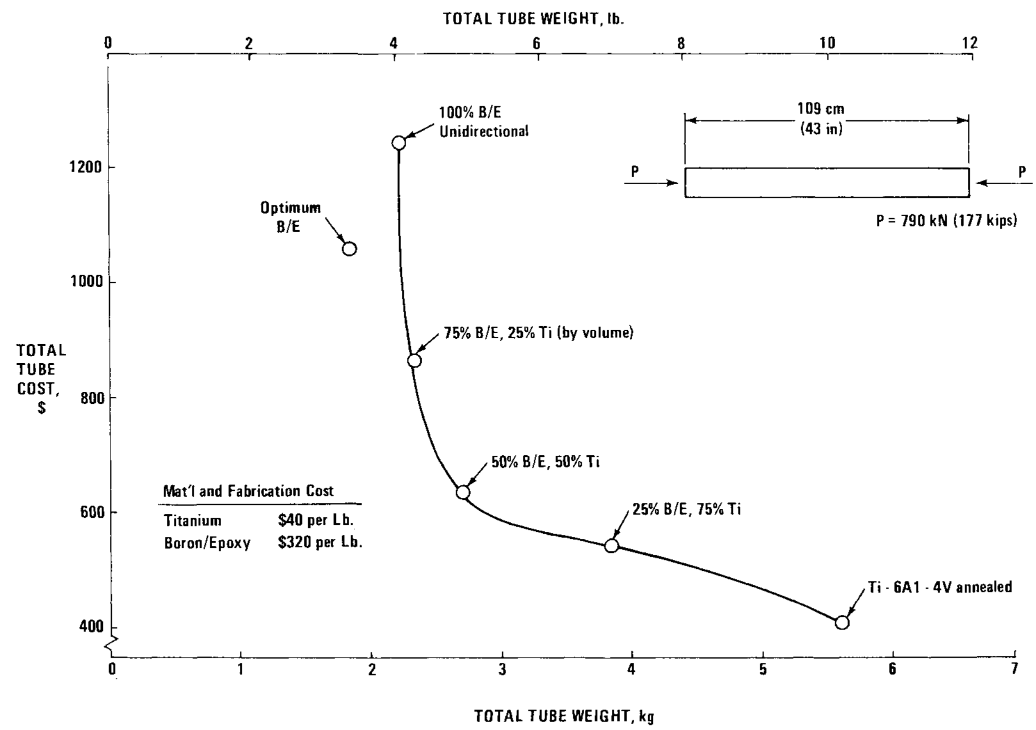

Fig. 1 Cost-weight comparison of composite-reinforced tubular columns.

Presented as Paper 72–393 at the AIAA/ASME/SAE 13th Structures, Structural Dynamics, and Materials Conference, San Antonio, Texas, April 10–12, 1972; submitted May 8, 1972; synoptic received July 18, 1972; revision received August 15, 1972. Full paper available from AIAA Library, 750 Third Avenue, New York, N. Y. 10017. Price: Microfiche, $1.00; hard copy, $5.00. **Order must be accompanied by remittance.** Full paper (NASA TN D-6778) also available from National Technical Information Service, Springfield, Va., 22151, as N72-24942 at the standard price (available upon request). This work was performed by Grumman Aerospace Corporation engineers assigned to NASA Langley Research Center under the Grumman-Langley Research Associate Program. Over-all program guidance, hardware manufacture, and test support were provided by Langley Research Center personnel.

Index category: Structural Composite Materials (including Coatings).

* Structural Mechanics Engineer.

† Structural Analysis Engineer.

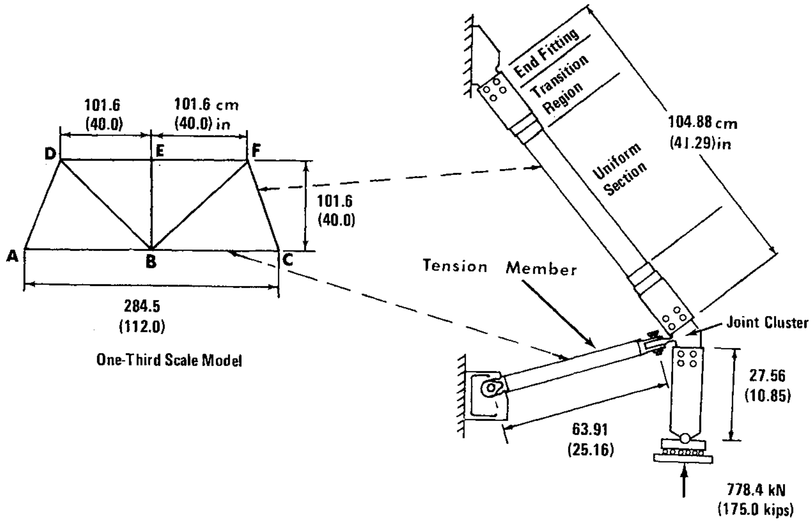

Fig. 2 Demonstration truss.

Space Flight Center for use in an earlier cost weight study. To account for scaling the applied load of 175 kips shown in Fig. 2 is $\frac{1}{3}$ of the full scale truss load. To facilitate loading, the demonstration truss was rotated so that the resultant applied load was vertical. The angle between the compression and tension members of the demonstration truss is identical to that of the model.

The compression member of the demonstration truss consists of 16 layers of boron/epoxy $(\pm 45/0_{14})$ on a 3.6-in. o.d., 0.026-in. wall titanium 6A1-4V annealed tube. Five additional plies of boron/epoxy are contained in the transition region to obtain a 15% margin of safety. The end fittings of the tube are rolled sheet stock chem-milled to final dimensions. For assembly, the shims were expanded slightly and slipped into position over the boron/epoxy and film adhesive. The discontinuities in the shims were staggered around the tube.

The tension member of the truss was fabricated by curing 18 layers of boron/epoxy $(\pm 45/0_{16})$ on a 2-in. o.d., 0.033-in. wall titanium 6A1-4V annealed tube. The titanium substrate was butt-welded to machined end fittings prior to the addition of the boron/epoxy.

The demonstration truss failed at a load of 206 kips, 118% of design ultimate load. Failure occurred in the center section of the tension member shown in Fig. 2. A tension failure of the composite material apparently initiated the fracture and debonding between the boron/epoxy and the titanium substrate. It is unlikely that the failure started in the titanium because it was stressed to less than 80% of its ultimate stress. The failure continued through the titanium substrate at a location near the butt weld. After testing, a visual inspection revealed no evidence of failure in the compression member or the joint cluster. Strain gage data recorded during the test indicate that the compression member had been loaded to 113% of design ultimate load.

Projected weight saving: Weight estimates for a full-size planar truss of the configuration shown in Fig. 2 are included in Table 1 for an all-titanium design and a boron/epoxy-reinforced-titanium design. The composite-reinforced members had a basic section of 75% boron/epoxy and 25% titanium by volume similar to those of the demonstration truss.

Table 1 Projected weights and weight savings for full scale-planar truss

	Weight, lb		
Truss members	Titanium design	B/E Reinforced design	Saving
AD & CF	187.4 lb	134.6 lb	52.8 lb
BE	99.5	71.3	28.2
DE & EF	144.0	102.4	41.6
AB & BC	153.6	105.8	47.8
BD & BF	139.2	96.2	43.0
Subtotal	723.7 lb	510.3 lb	213.4 lb
Joint clusters			
A & C	73.2 lb	63.7 lb	9.5 lb
B	85.7	71.7	14.0
D & F	101.4	91.1	10.3
E	65.3	59.0	6.3
Subtotal	325.6 lb	285.5 lb	40.1 lb
Total	1049.3 lb	795.8 lb	253.5 lb

The weights of the end fittings and joint clusters required to attach the composite reinforced tubular members to each other into a truss are included in Table 1. The end fitting weights are included in the member weights. The weights were estimated by scaling up for size and load the appropriate designs of the demonstration truss.

A weight saving of 213 lb was calculated for the members with an additional 40 lb for the joint clusters. This additional saving resulted from the fact that the optimum titanium compression members were of a larger diameter than the composite-reinforced designs and therefore required larger connectors. The total weight saving for the full-scale planar truss amounts to 24% of the truss weight.