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A composite sprocket carrier for the Marine Corps LVT-7 amphibian vehicle has been designed under Contract No.N00167-83-C-0045 for David Taylor Naval Ship R&D Center.

The composite sprocket carrier uses a graphite/epoxy composite, produced by wet filament winding followed by compression molding at high temperature to compact and cure the matrix. Stainless steel inserts are used to resist corrosion and creep at the interfaces between the component and the vehicle.

Stress analysis of the composite component has been carried out using a NASTRAN finite element computer model. This analysis reveals generally satisfactory stress levels, with safety factors in excess of 2.5. The most highly stressed area is found to be the rim of the carrier, where the sprocket rings are mounted. When the restraining effect of the rings is taken into account, stresses in the area are considered acceptable.

The production techniques established for this design provide and economic means for the volume production of the composite sprocket carrier. Keywords:

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Report No. 83-0100

DESIGN OF A COMPOSITE SPROCKET CARRIER FOR THE LVT-7 AMPHIBIAN VEHICLE

Prepared under Contract No. N00167-83-C-0045 for
David Taylor Naval Ship R&D Center
Bethesda, Maryland 20084

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ABSTRACT

A composite sprocket carrier for the Marine Corps LVT-7 amphibian vehicle has been designed under Contract No. N00167-83-C-0045 for David Taylor Naval Ship R&D Center.

The composite sprocket carrier uses a graphite/epoxy composite, produced by wet filament winding followed by compression molding at high temperature to compact and cure the matrix. Stainless steel inserts are used to resist corrosion and creep at the interfaces between the component and the vehicle.

Stress analysis of the composite component has been carried out using a NASTRAN finite element computer model. This analysis reveals generally satisfactory stress levels, with safety factors in excess of 2.5. The most highly stressed area is found to be the rim of the carrier, where the sprocket rings are mounted. When the restraining effect of the rings is taken into account, stresses in the area are considered acceptable.

The production techniques established for this design provide an economic means for volume production of the composite sprocket carrier.

1.0 INTRODUCTION

This report details the composite sprocket carrier which has been developed under Contract No. N00167-83-C-0045, originating from Solicitation No. N00167-82-12-0254. The composite sprocket carrier has been designed in advanced composite materials to replace a steel component on the LVT-7 Marine Corps amphibian vehicle. The design has been optimized in the area of strength, weight, cost and durability, and is compatible with the existing final drive and sprocket rings of the LVT-7 vehicle.

The report also contains projected costs for production of the composite sprocket carrier in batches of 1,500 and 2,000 units, together with a description of the proposed production methods.

2.0 DISCUSSION

2.1 Design Approach

2.1.1 General Considerations

The general design approach is based on the concept of filament-wound preforms and compression molding using hard tooling mounted in a 300-ton capacity hydraulic press. This approach was chosen to combine minimum weight with low technical risk and cost for both prototype and production units.

To attain comparable stiffness to the existing steel structure within the constraints of the available envelope, the use of graphite filaments is considered essential. The use of filament-wound preform construction allows the filaments to be oriented to give a composite with optimum properties in the directions of loading. In the case of the sprocket carrier, the major loading are torsional, axial and in-plane (see Figure 1).

Resistance to torsional loads can best be achieved by the use of filaments oriented at angles of ±45° to the axis of rotation of the sprocket carrier. Fibers having this orientation are required throughout the part. Axial and in-plane loads may be resolved into bending moments along the profile of the sprocket carrier and torsional loads giving rise to shear stresses. Since the outer rim area is supported by the sprocket rings, and the hub area by the final drive interface, the most severe bending loads are encountered along the conical sides of the components. These loads are best reacted by filaments placed in a quasi-radial direction (i.e. parallel to the cone sides).

Consideration of the bearing area for reacting torsional loads between fastener holes suggests that the compressive loads seen by the composite in the area between the final-drive bolts are excessive. To avoid damage to the composite, steel shear plates are bonded to both sides of the composite to react the loads.

Composite materials often exhibit long-term creep behavior, which may lead to loss of torque in bolted joints. This problem can be avoided by the use of metallic inserts around the fastener holes. Both these inserts and the shear plates, by suitable choice of material, reduce the risk to galvanic corrosion between the graphite of the sprocket carrier and the steel mating components of the LVT-7.

2.1.2 Manufacturing Sequence and Process

The technique adopted for production of the oriented composite is based on the use of filament-wound preforms. This approach was chosen over other possible techniques such as hand lay-up because of its suitability for volume production. The preforms are obtained by winding filamentary material impregnated with resin onto suitably shaped mandrels (see Figure 2).

Two different basic types of filament orientation are required for the sprocket carrier:

(i) ±45° fibers in the rim, cone and hub areas

(ii) quasi-radial fibers in the cone area.

The ±45° fiber orientations are approximated by using a "polar winding" technique. The required mandrel represents the two cone shapes of the sprocket carrier, reversed and placed together rim-to-rim (see Figure 2a). A prototype mandrel has been fabricated of aluminum, with a steel shaft. This mandrel has proved the validity of the approach. The production mandrel will be similar in shape, but of increased thickness to withstand the pressure of compression molding.

A numerically-controlled three-axis filament winding machine is used to lay filaments onto the mandrel, achieving the required angles by wrapping filaments along the cone sides and over the polar ends, leaving an opening around the shaft at each end. The winding pattern is illustrated in Figure 3a. It should be noted that a space is left between the windings and the conical sides. This allows for the flange areas to be formed after the two mandrel halves have been separated.

The preform produced is then slit, while the resin is still in the uncured condition. To avoid slippage of the preform during cutting, the filaments are held tensioned by a pair of rings which fit over the conical sections. This is illustrated in Figure 4. Following slitting, the rings are pushed fully home against the rims of the mandrels to form the rim flange.

The quasi-radial preform is produced by a similar technique, using a cylindrical mandrel instead of the conical mandrel. The filament winding machine is again used to lay filaments in a pattern oriented at ±85° to the mandrel axis. (The angle is required to give the completed preform some integrity during handling before cure.)

The radial preform is then slit and flattened out. To aid handling during this phase, a Tedlar film is laid over the mandrel before winding. This sheet remains with the preform until the complete sprocket carrier molding charge is assembled.

The molding charge is assembled by assembling the two polar preforms "nose-to-nose", without removing them from their mandrels. Radial location of the two mandrels is achieved by the central shaft running between the two mandrel halves. The charge is completed by wrapping the radial preform around the outside of the assembled polar preforms.

At this stage, the two conical mandrels are preheated to 350°F using an inductive heater. The complete, preheated charge is then transferred to a compression mold mounted in a 300-ton press. The mold (see Figure 5) consists of the two conical mandrel halves to form the carrier inside profile, and four hydraulically-driven side-slides to form the outside profile. The mold is maintained at 350°F. De-bulking and preliminary cure of the sprocket carrier is achieved by closing the mold under pressure for 3 minutes. The part is then removed from the press and fully cured in an oven at 350°F for 10 minutes. Compression molding was chosen over other potential consolidation techniques such as vacuum bagging or autoclaving because of the high compaction pressures and high order of repeatibility which it offers.

Production of the sprocket carrier is completed by machining off excess material in the hub area, machining the required holes and bonding and inserting steel parts.

2.2 Profile Generation

2.2.1 Theoretical Profile

The critical interface dimensions for the composite sprocket carrier profile are the thicknessess and diameter at the hub and at the rim. Early in the program the design goal was set of matching the thickness of the existing steel design at these points, so that the composite part could be assembled using the same fasteners as the steel part. A further constraint was set, based on simple manual calculations, that the minimum thickness of ±45° material in the cone areas should not be less than 1/4".

Filament winding is essentially a constant-volume process, so that the variation of thickness and angle bears a definite relationship to the radius of winding. The theory of winding pattern generation is documented in Reference 1. Based on theoretical calculations, a profile for the polar windings was generated (see Figure 6). The predicted polar preform thickness varies from 0.26" at the outer rim, to 0.63" at the center. The fiber angles vary from ±30° at the rim, ±36° to ±56° over the cone area (giving a mean of ±45°), to angles approaching circumferential around the hub. (Note: Zero degrees is taken to be the sprocket axis direction.)

The profile of the radial preform is based on achieving maximum material in the outside rim area without exceeding the maximum allowed radius of 5 5/8" at the center of the sprocket. This approach gave a radial preform profile with thickness varying from about 0.4" at the center to 0.25" at the rim, with angles varying from $\pm 5^\circ$ at the center to $\pm 3^\circ$ at the rim.

The theoretical profile shown in Figure 6 was used for stress analysis.

2.2.2 Measured Profile

To verify the profiles predicted theoretically, a development glass-epoxy sprocket carrier was wound, using simply-fabricated temporary tooling (see Figure 7). Measurement of the thickness of the flat preforms produced showed general agreement (within 15%) with the theoretical profile, with the exception of the hub area. There, the composite built up to a thickness of about 1.1", compared with a theoretical 0.63". The reason for the buildup was slippage of filaments inwards towards the mandrel shaft during winding. The problem will be reduced on future preforms by "fine-tuning" of the filament winding program.

A second potential problem noted was a reduction in thickness (to 0.21" compared with 0.26") of material in the rim area. This again can be adjusted by tuning of the winding program. Should this tuning fail to achieve sufficient thickness, the mold charge could be made up by insertion of an additional ring-shaped preform in the rim area. These preforms could be wound quickly and and inexpensively using a special purpose machine evolved by CEC for winding automotive steering wheel armatures (see Figure 8). Wastage of material with this technique would be minimal.

2.3 Composite Material Choice

As has been mentioned previously, graphite-epoxy was viewed as the composite system of choice. This decision is dictated by the need to attain comparable stiffness to the steel part within small variations from the existing part envelope. Although hybrid composites of graphite and glass have attractive impact-resistant properties, it was felt that, at this stage of the program, the technical risk in reducing the component stiffness was not acceptable.

2.3.1 Filamentary Reinforcing

An evaluation of the filament properties, Table I suggested three candidates as being most suited to the application:

1. Union Carbide P55S (Pitch based precursor)
2. Union Carbide T-300 (PAN based precursor)
3. Courtaulds X-AS (PAN based precursor).

The first of the above is a high-modulus fiber and would present the best opportunity to attain high comparative stiffness within the envelope available, albeit with lower strength. Candidates 2 and 3 have intermediate moduli (18.5 - 20 msi) and higher strength. While CEC has had considerable experience with the P55S material, it is marginally more difficult to process than either T-300 or X-AS. All have comparably low cost (circa $20/lb).

Because the composite sprocket carrier is a relatively complex part to process, a preliminary decision has been taken to use the Union Carbide T-300 filaments. This decision is backed up by the stress analysis performed, which confirms that adequate stiffness can be achieved with the material. It should be emphasized, however, that a change of material can be made at a later stage of the program with little or no schedule impact should the need become apparent.

2.3.2 Resin Matrix System

Three generic resin systems, viz:

1. vinyl-ester

2. polyester

3. epoxy

were considered as resin matrix candidates. While vinyl-esters and polyesters process well and are relatively inexpensive, their inferior mechanical performance (particularly toughness) in relation to epoxies tended to eliminate them as viable candidates. CEC has had considerable experience with a number of epoxy systems that meet the requirements of MIL-12-9300 Type I and are ideally suited to the proposed process which involves wet impregnation followed by compression molding. Additionally, performance after prolonged exposure to salt water is excellent with little or no change in elastic moduli over the entire spectrum of moisture content from dry to fully saturated.

One such candidate is Celanese 30-129, an amine-free, long-pot life epoxy matrix system ideally suited to graphite reinforced composites. A 3-5 hour pot life is attainable at winding temperatures of 130 -140°C, the system demonstrating a cure speed of 15 minutes for short mold cycling in the 300F -360°F cure range. Characteristics of the resulting composite include:

a) high impact resistance

b) resistance to property degradation when exposed to high humidity or water immersion

c) maintenance of composite performance to service temperature in the 250 F -300°F range

d) resistance to a variety of chemicals.

For these reasons, a preliminary decision has been taken to use Celanese 30-129. However, as in the case of the filaments chosen, it would be possible to change the resin at a later stage in the program with little schedule impact. An in-house program of resin evaluation is in progress at CEC, and should a more suitable resin be found, this will be offered to the sprocket carrier program.

2.3.3 Properties

The manufacturer's published property data for the 30-129 Celanese resin are given in Table II. The Celion 6000 graphite used to obtain the data is very similar in properties to the Union Carbide T-300 proposed for this contract. Based on experience, CEC has used the following (reduced) properties for stress analysis:

longitudinal modulus = 18×10^6 psi

transverse modulus = 1×10^6 psi

interlaminar modulus = 1×10^6 psi

shear modulus = 0.6×10^6 psi

longitudinal tensile stress (allowable) = 180×10^3 psi

longitudinal compressive stress (allowable) = 180×10^3 psi

interlaminar normal & transverse tensile stress (allowable) = 8×10^3psi

interlaminar normal & transverse compressive stress (allowable) = 30×10^3 psi

shear stress (allowable) = 12 X 10 psi

Figures 9, 10 and 11 show the variation of modulus, allowable shear stress and allowable direct stress for the composite for variations of fiber orientations. These curves were produced using in-house computer programs at CEC.

2.4 Insert Design

Material Choice

As described earlier, composite materials are susceptible to creep under load, leading to loss of tension in threaded fasteners (see Figure 12). This problem can be overcome by the use of metallic inserts around the fastener holes. Graphite acts cathodically with most metals to cause galvanic corrosion. Considerable literature on this subject exists, particularly MIL-HDBK-721(MR) (Reference 2) and MIL-STD-1568A (USAF) (Reference 3). These authorities suggest that austenitic stainless steel is the most cost-effective material to use with graphite (see Table III).

An ASM report on stainless steels (Reference 4) suggests that AISI 316 stainless steel is the optimum for corrosion resistance, while AISI 302 is also good. Both materials have high strength and hardness, but are not heat-treatable.

To confirm the resistance to corrosion of austenitic stainless steel with graphite/epoxy, a pair of samples, representative of the types of bushing to be used in the sprocket carrier, have been assembled into representative graphite/epoxy test panels. These panels are undergoing a salt-spray test (see Figure 13). This test has been running for approximtely two weeks, with no visible damage to the specimens beyond surface discoloration. At the conclusion of the test, the specimens will be sectioned to check for internal corrosion.

2.4.2 Bushing Dimensions

Two different bushings have been designed (see Figure 14), for the different-sized fastener holes for the sprocket ring and for attachment of the sprocket carrier to the final drive. In the case of the outer, (sprocket ring) bushes, the chief problem was to retain adequate material between the edge of the bush and the rim of the sprocket carrier. A further requirement was for the bush to be shouldered to bring the thickness locally around the hole to the same thickness as the original steel sprocket carrier. These constraints resulted in the design shown in Figure 16a. The clearance in the rim area is maximized by the choice of a relatively fine (16-pitch) thread on the bushing. To enable the bushing to withstand high clamping loads from the sprocket ring bolts, hardened AISI 302B stainless steel is selected as the material. The center hole diameter and tolerance is the same as for the existing steel sprocket carrier.

In the case of the inner (final drive fastener) bushings, the bush is required to fit flush into the sprocket carrier hub. For this reason, the head is countersunk. Because more material is available around these bushings, the thread chosen is a relatively coarse 8-pitch. The material chosen is, again, AISI 302B and the hole diameter and tolerance are again the same as the existing steel sprocket carrier.

The feasibility of machining the graphite/epoxy composite to accept these bushings was proved during the production of the corrosion test samples mentioned earlier. However, there remains a small risk that damage to the composite may occur during machining. Potential design remedies for this problem are either use of a finer pitch thread, or use of an unthreaded, tapered bushing design.

2.4.3 Shear Plates

To provide a barrier against galvanic corrosion between the machined face of the sprocket carrier hub region and the vehicle final drive, and also to guard against any damage of excessive bearing stresses between holes in the area, stainless steel shear plates are bonded to the sprocket carrier hub on both sides. To optimize corrosion resistance in these less highly stressed plates, the material chosen is annealed AISI 316 stainless steel.

The shear plates are retained in position both by bonding and by the countersunk heads of the inner bushings. To retain both plates, alternate bushings are entered from opposite sides of the hub (see Figure 15). The holes in the shear plates are controlled within tight tolerance limits to ensure a good match between the large central bore and the bore of the composite sprocket carrier. This is essential to maintain radial location on the vehicle.

2.4.4 Bonding

The bonding agent chosen to attach the bushing and shear plates to the sprocket carrier is M&T Chemicals "Uralane" 5757A/B. This is a semi-flexible urethane adhesive, which was chosen in preference to epoxies because of its high toughness and resilience (see Table IV). The stainless steel components are prepared for bonding by degreasing and acid etching.

Tests to verify the integrity of the bonding procedure will be carried out during the development of the sprocket carrier.

2.5 Stress Analysis

2.5.1 Description of Technique

The basis for the stress analysis of the composite sprocket carrier was a three-dimensional model prepared using the NASTRAN finite element computer program.

The sprocket carrier was modelled using the CHEXA and CPENTA solid elements. The defined loading conditions permitted the analysis of a symmetric half model (Figure 16). Material properties are varied linearly from the fork to the base of the rim beginning with a crossply angle of ±56° degrees. The hub section material angle was arbitrarily set at ±56° degrees. This angle was justified on the grounds that the assumed fixity at the inner bolt ring eliminates any structural contribution from the two innermost element groups where the material angle would be changing dramatically. The orientation of the radial reinforcement was assumed to be ±5° degrees. The element-numbering system used is shown in Figure 17.

Two loading conditions were specified:

1. 40,000 lb track tension

2. 39,500 lb/ft torque from the drive.

The torque-loading case, which would be equivalent to a track-tension of greater than 40,000 lb/ft, is the more severe. Consequently, the torque loading case was used for design. The load was applied as a reaction at two sprocket ring bolt holes to the point tangential load on a sprocket tooth. The direction and magnitude of the reaction loads was such as to satisfy the conditions of equilibrium at the point of load application. An additional case, in which a nominal axial load was applied, was also submitted to obtain axial stiffness data.

The boundary conditions were as follows: symmetric conditions on the Y-Z plane (X, RY, RZ restrained), full restraint for all nodes with radial coordinate equal to 4.1875 (interior bolt hole ring) and full radial constraint for all nodes along the central bore.

2.5.3 Stress Data

The model described above was first run using 100% graphite/epoxy as the material. The maximum stresses for each element group, together with the minimum factor-of-safety, are presented in Table V and shown graphically in Figure 18. The Tsai-Hill combined stress criterion is used to evaluate the factor for in-place stresses, while the maximum stress criterion is used for interlaminar stresses. In both cases, the unfactored design allowables used are those listed in Paragraph 2.3.3 of the report, and the factors of safety are evaluated using in-house computer programs to generate the allowable for various fiber orientations. The stresses listed represent the longitudinal, transverse and interlaminar direct and shear stresses for each element in psi.

From Figure 18 and Table V, it can be seen that the design in 100% graphite is generally conservative, with safety factors in excess of 2.5. In all areas of the sprocket carrier where they are present, the ±5° sections of composite, resulting from the radial preforms, are the more highly loaded. The only area of real concern is in the rim section, where the transverse and interlaminar stresses are high, leading to unsatisfactory factors-of-safety. However, in a vehicle installation, these areas are rigidly constrained in all directions by the steel sprocket rings. This constraint would almost certainly prevent the composite from deflecting enough to generate the high theoretical stresses.

The computer model was also run using a hybrid material of 80% graphite/epoxy and 20% S2-glass epoxy. The stress data for the hybrid is presented in Table VI and Figure 18. It can be seen that the factors of safety are generally about 30% lower than for the all-graphite component. The major problem area is, again, in the rim area, but, for the hybrid, the excessive stresses extend into the cone area. For these reasons, the use of the glass/graphite hybrid is not recommended without further design work.

2.5.4 Stiffness Data

The torsional stiffness of the sprocket carrier is difficult to define because of the manner in which the component is loaded with a two-point direct load rather than a uniform torsional load. However, considering a point on the rim, at the radius of the outer bolt holes, and midway between the two loaded bolts, the following data is obtained from the NASTRAN model:

Material	Max. Deflection (in)	Torsional Stiffness
100% graphite/epoxy	0.057	6.8×10^7 lb in/rad
80% graphite/epoxy 20% glass/epoxy	0.059	6.6×10^7 lb in/rad

It was not considered feasible at this stage to calculate accurately the out-of-plane stiffness of the sprocket carrier, since lateral loads on the composite will be transmitted from the vehicle tracks in a very complex way, dependent on the interaction between sprocket carrier, sprocket ring and track. An analysis based on consideration of the cross section of the sprocket carrier, and disregarding 3-dimensional stiffening effects, suggests a "worst case" out-of-plane stiffness of around 5×10^6 lb/in.

2.6 Weight Estimate of Sprocket Carrier

On the basis of the design given in Figure 15 and the use of the filamentary reinforcement/matrix defined, the weight breakdown for the proposed sprocket carrier design is a follows:

Graphite/epoxy molded structure (after machining)	23.50 lbs
Hub hole bushings (10), stainless steel	1.23 lbs
Hub shear rings (2), stainless steel	1.30 lbs
Sprocket ring hole bushings (22), stainless steel	1.00 lbs
TOTAL COMPONENT WEIGHT	27.03 lbs

2.7 Manufacturing Analysis

The general method of manufacture has been referred to previously in this report. The basic approach will be valid for both the prototypes and any subsequent production. More detailed estimates will be available when the first representative carrier has been produced. The steps for manufacturing the carrier are essentially as follows:

1) Prepare winding machine, resin impregnation system and spool tension control system for winding preforms.

2) Mount winding mandrel into the winding machine and wind preforms.

3) Slit preforms and remove from mandrel.

4) Heat up mold (mounted in 300-ton press) and insert preform charges onto the top and bottom of the mold and the four-side slides.

5) Close mold and hold for required cycle time.

6) Open mold and eject part.

7) Deflash.

8) Mount component in holding fixture and jig-bore holes for bolt bushings.

9) Machine flat mounting surfaces

10) Following surface treatment of all stainless-steel parts, bond and insert bushings and shear plates.

11) Test and inspect.

A typical manufacturing flow sequence is indicated in Figure 21.

2.7.1 Estimates of Production Cost for 500 & 2000 Units

The following is a summary estimate of production costs for production runs of 500 and 2000 units:

Case 1. 500 Units

Labor (Hours)

- Operation Filament winding of preform and removal from mandrel:

  Center Sections (2) 0.75

  Rim Section (1) 0.50

- Operation: Inserting preform charges and compression molding:

  Insert charge 0.20

  Molding cycle 0.30

  Remove part and prepare mold 0.10

o Operation: Deflashing and preparation for machining:

Deflàsh,grind	0.20

o Operation: Machine holes and mounting surfaces:

Drill	0.50
Grind	0.30

o Operation: Inserting bushing and bonding rings:

Inserting bushings	0.50
Surface treatments	0.50
Bonding plates	0.50

o Operation: Quality control/inspection

In process/final	0.50

<u>TOTAL LABOR = 4.25 MANHOURS</u>

<u>Material Costs</u>

Assumptions: a) Graphite/epoxy molded structure (including 10% scrap at center section, etc.)

b) *Weight fraction* (60% *volume fraction*:
Filaments 16 lbs (at \$22.00/lb)
Matrix resin 7 lbs (at \$3.75/lb)

A. <u>Composite Structure</u>

Cost of composite from b)	\$ 379
Filaments	352
Resin	27

B. <u>Stainless Steel Components</u>

Inner bolt ring inserts (10)	14
Outer bolt ring inserts (22)	31
Inner bolt ring plates (2)	12

C. Miscellaneous

Adhesive, etc.	10

TOTAL MATERIAL COSTS = $446

Tooling Costs

Compression Mold (1)	$35,000
Mandrels (6)	1,800
Holding Plate (1)	1,400
Bonding Fixtures, Misc. (1)	3,500

TOTAL TOOLING COSTS = $41,700

Summary

Assuming (for comparative purposes only) a total effective average labor cost of $50.00/hour (DL + OH + G&A + PROFIT), the total unit cost (excluding tooling) would be:

Material	$ 446
Labor	243

Tooling $31,200

Case 2: 2,000 Units

o Operation: Filament winding of preform and removal from mandrel:

Center Sections (2)	0.45
Rim Section (1)	0.30

o Operation: Inserting preform charges and compression molding:

Insert charge	0.10
Molding cycle	0.30
Remove part & prepare mold	

o Operation: Deflashing and preparation for machining:

Deflash, grind	0.20

o Operation: Machining holes and mounting surfaces:

Drill	0.20
Grind	0.20

o Operation: Inserting bushings and bonding rings:

Inserting bushings	0.20
Surface treatment	0.10
Bonding plates	0.20

o Operation: Inspecting component:

Inspection	0.30

TOTAL LABOR = 2.65 MANHOURS

Material Costs

Assume 15% quantity discount for larger purchase on graphite/epoxy and 25% reduction in stainless steel component cost.

TOTAL MATERIAL COST = $372

Tooling Costs ($)

Tooling (as previously)

Summary

Assuming (for comparative purposes) only a total effective average labor cost of $46/hour (DL + OH + G&A + PROFIT), the total unit cost (excluding tooling) would be

Material	$ 372
Labor	122
	$ 494/Unit
	22
	$516

Tooling $41,700

3.0 SUMMARY

A sprocket carrier for the Marine Corps LVT-7 amphibian vehicle utilizing advanced composites in its construction, is currently under development by Compositek Engineering Corporation/Kelsey-Hayes Company, for David Taylor Naval Ship R&D Center under Contract Number N00167-83-C-0045. This report details the composite component which has been designed, describes the development and analysis work which has been carried out in evolving the design, and estimates production costs for large batch production.

The high strength and stiffness requirements for the composite sprocket carrier have dictated the use of graphite/epoxy material, utilizing oriented fibers to optimize load-bearing capacity. The production technique selected uses wet filament winding of preforms having the required fiber orientation, followed by compression molding to achieve precise dimensions and excellent compaction during cure. Fiber orientations are a mix of ±45° orientations to best withstand torsional loading, and and quasi-radial orientations to withstand out-of-plane loading. Metallic inserts are used at interface areas to overcome potential creep and corrosion problems.

The manufacturing sequence commences with wet-winding ± 45° preforms using a polar winding technique, and quasi-radial preforms using a cylindrical winding technique. The preforms are assembled into a charge, then compression molded at 350°F to cure the resin matrix. Production is completed by machining the molded component and the bonding of steel parts.

The profile of the molded part has been defined theoretically. Development work is continuing to produce prototype components to confirm the theoretical profile prior to ordering the molding tooling. Preliminary work indicates correlation within 15%.

Based on previous company experience, Union Carbide T-300 graphite filaments in a Celanese 30-129 epoxy resin matrix have been selected as the composite materials to be used. Design allowable stresses for this material have been defined based on experience and limited test data. Austenitic stainless steel has been selected for the insert material on the basis of its excellent corrosion resistance and high strength. The insert bushings are threaded directly into the composite, and bonded in place with a 2-part urethane adhesive.

Stress analysis of the composite sprocket carrier has been performed using a NASTRAN finite element computer model. Under the maximum torsional loading case of 39,500 ft/lb, safety factors in excess of 2.5 have been computed throughout most of the component. The only areas of concern are in the rim area, where high transverse stresses appear. It is considered that in a vehicle installation, the deflections leading to these stresses would be restrained by the steel sprocket rings so that the stresses computed would not occur. The computer model predicts a torsional stiffness of 6.8×10^7 lb in/rad for the composite sprocket carrier, with a maximum tangential deflection of 0.057 in under the design load of 39,500 lb/in. A preliminary assessment of the composite sprocket carrier out-of-plane stiffness suggests a value of around 5×10^6 lb/in.

The estimated weight for the composite sprocket carrier complete with steel inserts is 27.03 lbs. The estimated production costs at the time are estimated to be $679 per unit in batches of 500, and $494 per unit in batches of 2000. These figures will be defined more exactly as development proceeds.

4.0 CONCLUSION

The design for the composite sprocket carrier has been successfully completed in the areas of design concept, processing, material selection and stress analysis. It is recommended that work proceed on fabrication of representative prototype components.

5.0 REFERENCES

1. Bookhart, T.W., Fowler, A.H.: "Geodesic Paths on Surfaces of Revolution", Union Carbide Corporation Report, New York - 1660, November 1968.

2. MIL-HDBK-721(MR): "Corrosion and Corrosion Protection of Metals", November, 1965.

3. MIL-STD-1568A(USAF): "Materials and Processes For Corrosion Prevention and Control in Aerospace Weapons Systems", October 1979.

4. ASM Committee on Corrosion of Stainless Steels: "The Selection of Stainless Steel for Atmospheric Marine Corrosion Service".

Table I. Typical Properties For Graphite/Epoxy Composites

System	Tensile Modulus E_L (msi)	Tensile Strength F_L^{tu} (ksi)	Compressive Strength F_L^{cu} (ksi)	Shear Strength F_{LT}^{su} (ksi)	Fiber Density (lb/ft^3)	Fiber Cost ($/lb)
Union Carbide						
P55S (Pitch)	28.0	105	75	9.5	0.073	18.00
P65S (Pitch)	36.0	110	68	9.0	0.073	43.50
T-300 (PAN)	20.0	225	230	12.0	0.063	21.00
Courtaulds						
HM-S	28.0	220	-	9.3	0.067	40.00
XAS	18.5	275	-	14.5	0.065	22.00
Celanese						
Celion	21.4	240	220	10.8	0.064	24.00
Hercules						
HM-S	29.7	158	-	13.2	0.066	65.00

TABLE II

PROPERTIES OF 0° FILAMENT WOUND FIBER REINFORCED COMPOSITES[1] BASED ON MATRIX SYSTEM 30-129

Fiber:	**E-GLASS**	**Celion® 6000 Graphite**
Tensile Strength @ 23°C		
0°	155,000 psi	274,000 psi
90°	6,000 psi	5,700 psi
Tensile Elongation @ 23°C		
0°	2.4%	1.3%
90°	0.3%	0.5%
Ultimate Flexural Strength[2]		
@ 23°C	219,000 psi	221,000 psi
@ 121°C	138,000 psi	158,000 psi
@ 149°C	112,000 psi	129,000 psi
Initial Flexural Modulus[2]		
@ 23°C	6.50×10^6 psi	18.6×10^6 psi
@ 121°C	5.54×10^6 psi	18.5×10^6 psi
@ 149°C	5.68×10^6 psi	17.4×10^6 psi
Short Beam Shear Strength[2]		
@ 23°C	12,600 psi	12,100 psi
@ 121°C	8,000 psi	7,600 psi
@ 149°C	6,600 psi	6,600 psi
Compressive Strength[2]	107,000 psi	140,000 psi
Percent Absorption		
24 hr water boil	0.27	0.33
7 day water boil	0.41	0.48
Short Beam Shear Strength[2] Following 24 hr. water boil		
@ 23°C	11,700 psi	11,100 psi
@ 121°C	6,100 psi	6,700 psi
Fatigue Resistance[3] Load bearing loss after 500,000 cycles	< 2%	

(1) Contact mold cured for 8 minutes @ 177°C. No post cure
(2) Values normalized to 6[illegible]% fiber volume content
(3) Cycled between 1000 psi and 90,000 psi fiber stress at 5Hz

End	Material
Anodic End	Magnesium
	Magnesium Alloys
	Zinc
	Alclad
	Aluminum 6053
	Cadmium
	Aluminum 2024
	Cast Iron
	Wrought Iron
	Mild Steel
	13% Chromium Steel Type 410 (Active)
	18-8-3 Chromium Nickel Stainless Steel Type 316 (Active)
	18-8 Chromium Nickel Stainless Steel Type 304 (Active)
	Tin
	Lead
	Lead Tin Solders
	Naval Brass
	Manganese Bronze
	Muntz Metal
	76 Ni-16 Cr-7 Fe Alloy (Active)
	Nickel (Active)
	Silicon Bronze
	Copper
	Red Brass
	Aluminum Brass
	Admiralty Brass
	Yellow Brass
	76 Ni-16 Cr-7 Fe Alloy (Passive)
	Nickel (Passive)
	Silver Solder
	70-30 Cupro-Nickel
	Monel
	Titanium
	13% Chromium Steel Type 410 (Passive)
	18-8-3 Chromium Nickel Stainless Steel Type 316 (Passive)
	18-8 Chromium Nickel Stainless Steel Type 304 (Passive)
	Silver
	Graphite
	Gold
Cathodic End	Platinum

TABLE III ELECTROMOTIVE SERIES FOR POTENTIAL ELECTRODES

M&T CHEMICALS INC.
FUNCTIONAL PLASTICS DIVISION

FURANE PRODUCTS

INFORMATION SHEET

URALANE 5757-A/B

HIGH STRENGTH
URETHANE ADHESIVE

EP-80-19-A

DESCRIPTION: URALANE 5757-A/B is a two part urethane adhesive which cures at room temperature in 5-7 days or with heat for shorter cure time. It forms tough, heat resistant bonds between various metal substrates.

MIX RATIO: To 100 PBW URALANE 5757-A, add 50 PBW URALANE 5757-B

WORK LIFE:
20 minutes @ R.T. - Spreadable
25 minutes @ R.T. - Spreadable but stiff
30 minutes @ R.T. - Gelled

CURE: 7 Days @ R.T. OR 2 hr. @ 180°F. + 3 days @ R.T., OR R.T. Gel + 16 hrs. @ 150°F.

TYPICAL PROPERTIES:

Viscosity, Part A	4500 cps
Part B	225 cps
Initial Mixed	2500 cps
Specific Gravity, Part A	1.05
Part B	1.27
Mixed Flow Characteristics	Semi-thixotropic, non-flow

	CURE 7 Days R.T.	CURE 16 hr. 180°F.
Etched Aluminum		
Lap Shear, psi @ -65°F.	3000	7000
@ R.T.	2000	2400
@ 150°F.	900	1200
@ 250°F.	450	700
After Aging 30 days @ 160°F. and 95% R.H.		1500
After Aging 30 days Dry Heat @ 250°F.		3600

T-Peel Strength, pli AL/AL		
100/50 PBW	50	75
100/58 PBW ratio	-	150
Polycarbonate		
Lap Shear, psi	600	600
T-Peel Strength, pli	8	8
ABS		
Lap Shear, psi	-	950
Polysulfone		
Lap Shear, psi	-	1500
Reversion Resistance, 28 days @ 160°F. 95% R.H.		
Durometer Hardness D		
Initial	45/42	
14 Days	45/42	
28 Days	46/38	

CLEANLINESS AND SAFETY: Avoid contact of the resin or hardener with the skin and apply under conditions of good ventilation. Request and examine Safety Bulletin EP-54-B.

FOR INDUSTRIAL AND PROFESSIONAL USE ONLY.

TABLE IV. PROPERTIES OF URALANE 5757 ADHESIVE

TABLE V. 100% AS-Graphite/Epoxy Sprocket Carrier- Maximum Element Midpoint Stresses for 39500 lb/ft Loading

Element Group		L	T	I	LT	I	Factor Of Safety
HUB	1 & 2	0	0	0	0	0	-
	3	± 2000	± 1700	± 200	9200	500	5.0
	4	± 2000	± 3000	± 700	7700	1600	6.3
	5	± 2300	± 6300	± 900	2400	4000	3.0
CONE	6	± 500	± 4400	± 500	4600	4400	2.7
	7	± 4100	± 2000	±2000	1200	2100	3.4
	8	± 1300	± 3600	± 300	3800	900	8.0
	9	± 6600	± 1600	± 800	3000	1600	3.3
	10	± 1400	± 4100	± 100	4000	800	7.0
	11	± 6600	± 1300	± 100	3200	1000	3.5
	12	± 2000	± 4600	± 100	4300	600	6.8
	13	± 6600	± 1200	± 100	3200	900	3.6
	14	± 2900	± 2400	± 200	4500	600	10.7
	15	± 6700	± 1000	± 100	3300	700	3.7
	16	± 3700	± 5500	± 200	4700	600	7.0
	17	± 6300	± 900	± 100	3300	600	3.7
	18	± 4600	± 6300	± 200	5100	500	6.4
	19	± 6000	± 1300	± 100	3500	300	3.3
	20	± 6200	± 6900	± 500	5400	500	5.9
	21	± 5300	± 1800	± 200	3700	600	2.8
	22	± 5900	± 7200	± 600	5600	900	5.9
	23	± 4300	± 2400	± 300	4300	900	2.2
	24	± 6200	± 8300	± 800	6200	1400	5.0
	25	± 3800	± 3000	± 300	5100	1000	1.8
	26	± 6300	± 9200	± 900	6900	900	4.3
	27	± 5600	± 3700	± 900	6100	1800	1.5
	28	± 5600	± 9400	± 700	4800	6700	1.8
	29	± 10000	± 4500	± 700	7900	2100	1.2
	30	± 6400	± 9400	± 700	6300	4800	4.3
	31	± 11000	± 4600	± 500	7200	1600	1.2
RIM	32	± 5100	± 9200	± 300	8100	1600	1.4
	33	± 13000	± 7500	± 600	7100	1800	0.9
	34	± 6900	± 16100	± 700	9000	2200	0.6
	35	± 20400	± 11200	± 800	7200	1300	0.7
	36	± 23100	± 27600	±1500	4500	2000	0.5
	37	± 17800	± 14500	±1400	2500	1300	0.5
	38	± 15600	± 27300	±1000	2600	1700	0.5
	39	± 13000	± 16300	±1300	1400	2000	0.4

TABLE VI. 80% AS-Graphite/Epoxy, 20% S-2 Glass/Epoxy Sprocket Carrier
Maximum Element Midpoint Stresses for 39500 lb/ft Loading

Element Group		L	T	I	LT	I	Factor Of Safety
HUB	1 & 2	0	0	0	0	0	-
	3	± 2000	± 1600	± 200	9600	500	3.4
	4	± 2000	± 3500	± 1300	8000	1600	4.3
	5	± 2300	± 600	± 1900	2800	6700	1.5
CONE	6	± 300	± 3800	± 800	4700	4400	2.3
	7	± 4100	± 2100	± 2200	1200	2200	2.5
	8	± 1200	± 3900	± 400	3900	900	5.4
	9	± 6700	± 1700	± 800	3100	1700	2.3
	10	± 1400	± 4300	± 100	4000	800	5.0
	11	± 6600	± 1300	± 100	3400	1100	2.5
	12	± 2000	± 4600	± 100	4400	600	4.9
	13	± 6600	± 1200	± 100	3400	900	2.6
	14	± 2800	± 2500	± 200	4600	600	6.9
	15	± 6700	± 1100	± 100	3400	700	2.7
	16	± 3700	± 5500	± 200	4800	500	4.5
	17	± 6400	± 900	± 100	3400	500	2.9
	18	± 4500	± 4600	± 300	5200	400	4.9
	19	± 6000	± 1300	± 200	3500	400	2.5
	20	± 5200	± 6900	± 400	5500	600	3.8
	21	± 5300	± 1900	± 200	3700	500	2.0
	22	± 5800	± 7300	± 600	5800	900	5.5
	23	± 4200	± 2500	± 300	4400	900	1.6
	24	± 6100	± 8400	± 800	6300	1400	5.7
	25	± 3600	± 3100	± 400	5200	1000	1.3
	26	± 6100	± 9300	± 900	7100	900	4.4
	27	± 5100	± 3800	± 900	6300	1800	1.1
	28	± 5400	± 9600	± 800	5000	6400	1.6
	29	± 9400	± 4700	± 600	8200	2100	0.8
	30	± 6200	± 9700	± 700	6500	4600	2.2
	31	± 10300	± 4700	± 500	7600	1600	0.9
RIM	32	± 4800	± 9400	± 300	8300	1600	0.9
	33	± 12300	± 2900	± 600	7500	1800	1.1
	34	± 6000	± 16500	± 700	9300	2200	0.5
	35	± 19500	± 11800	± 900	-7600	1300	0.4
	36	± 22100	± 28000	± 1700	4600	1900	0.3
	37	± 17900	± 15300	± 1400	2600	1400	0.3
	38	± 14500	± 27600	± 1100	2700	1800	0.3
	39	± 12700	± 17200	± 1300	1400	1400	0.3

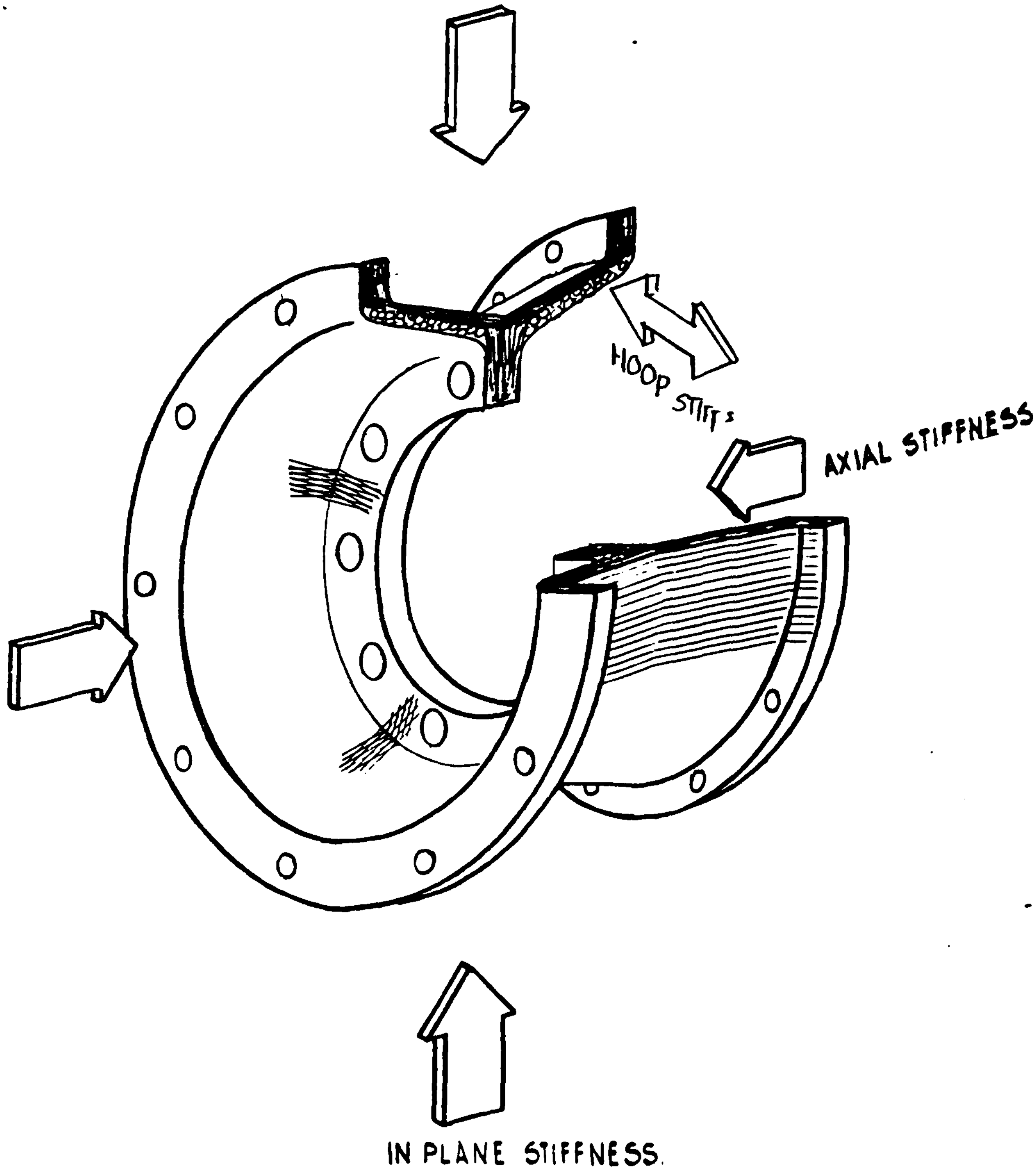
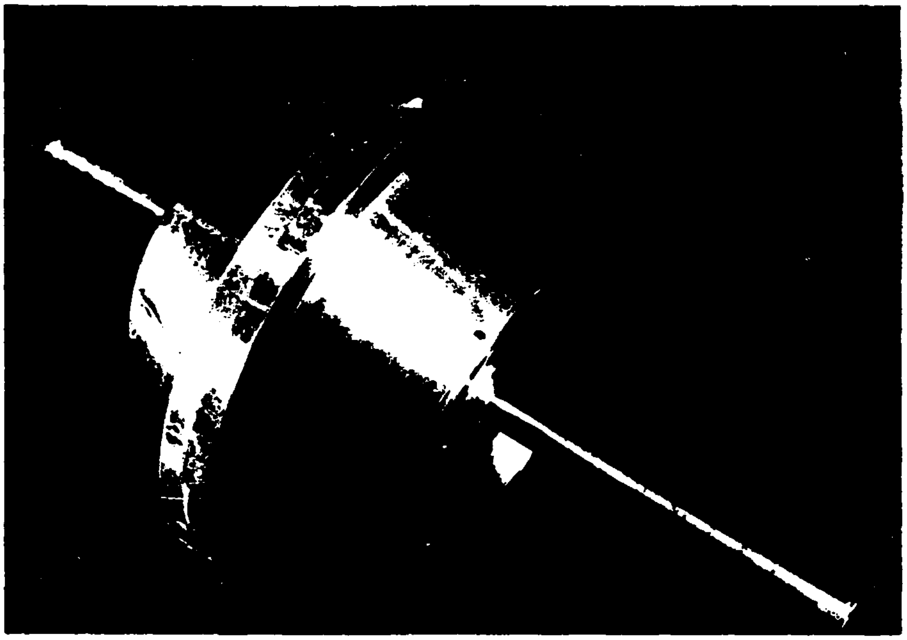


FIGURE 1. ILLUSTRATION OF LOADING

a)



b)

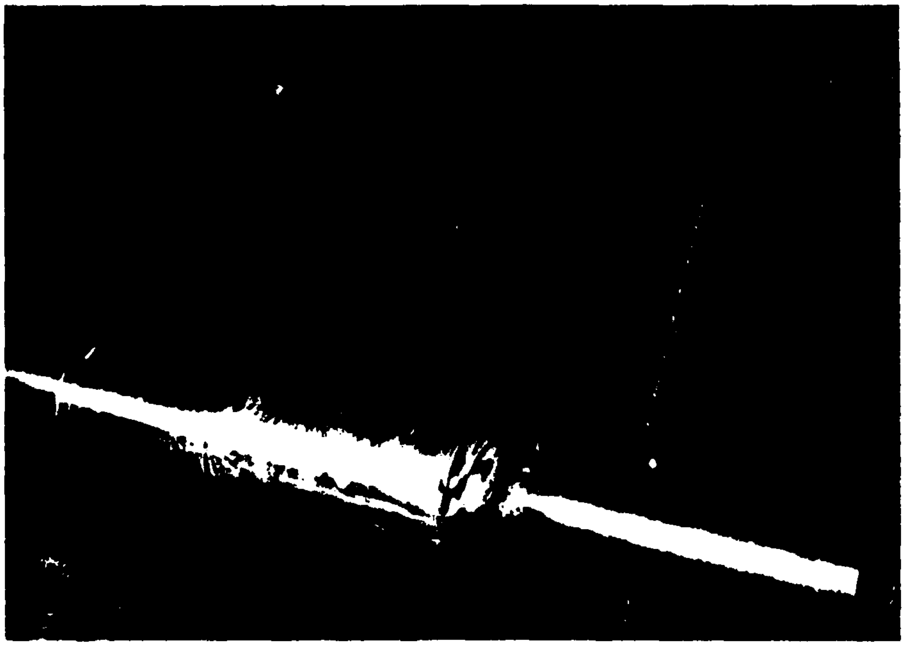


FIGURE 2. WINDING MANDRELS (DEVELOPMENT)

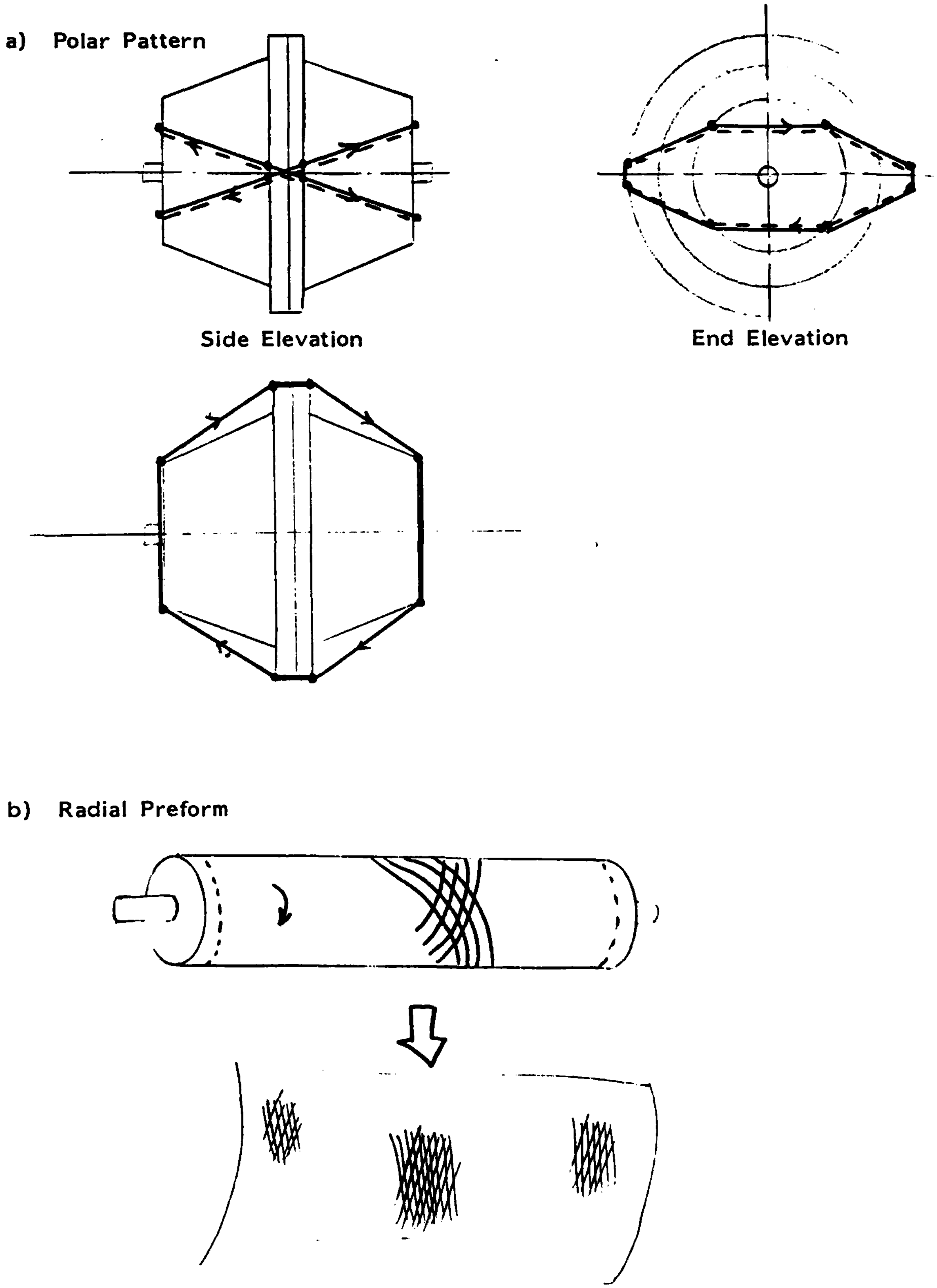


FIGURE 3. WINDING PATTERNS

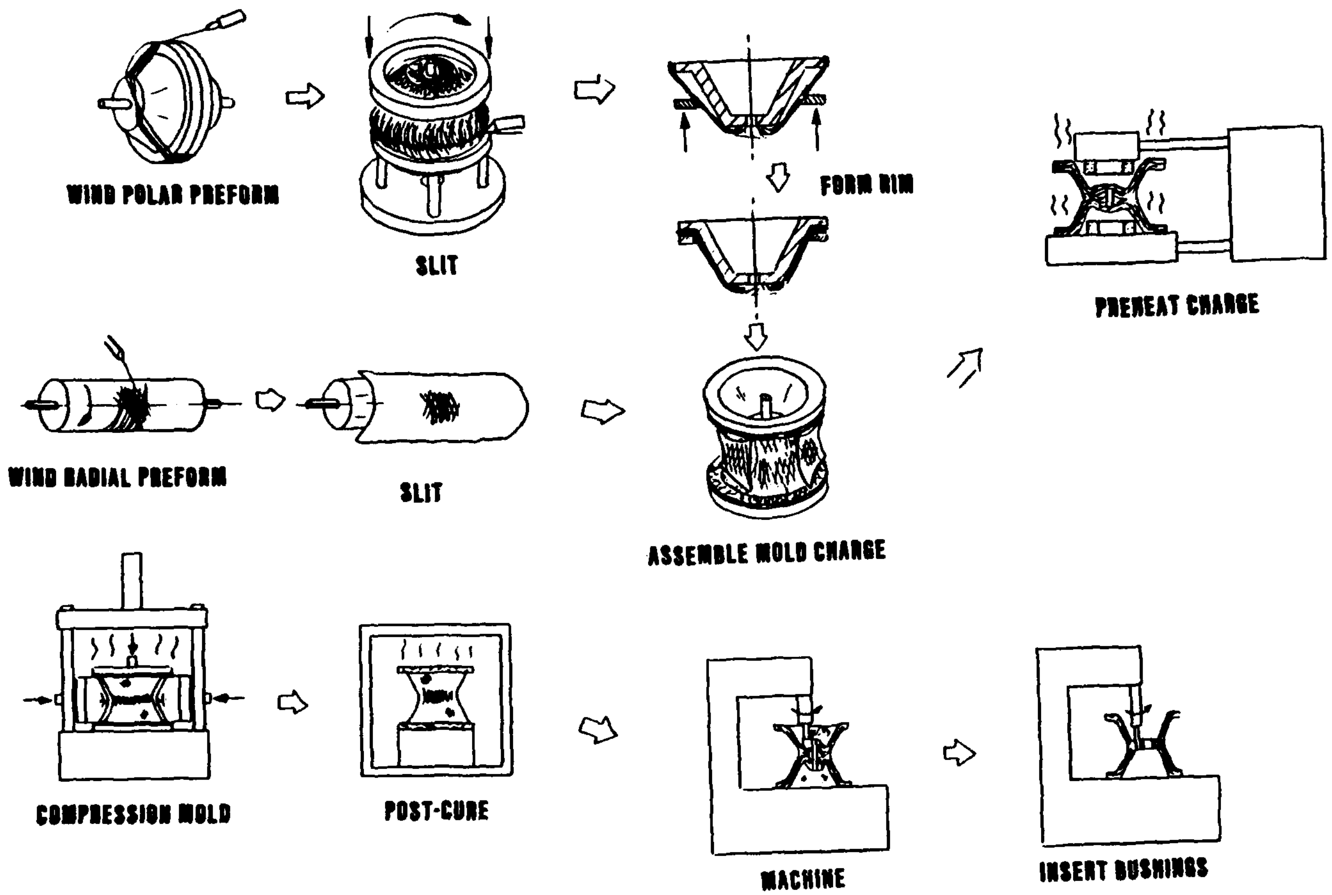


FIGURE 4. MANUFACTURING PROCESS

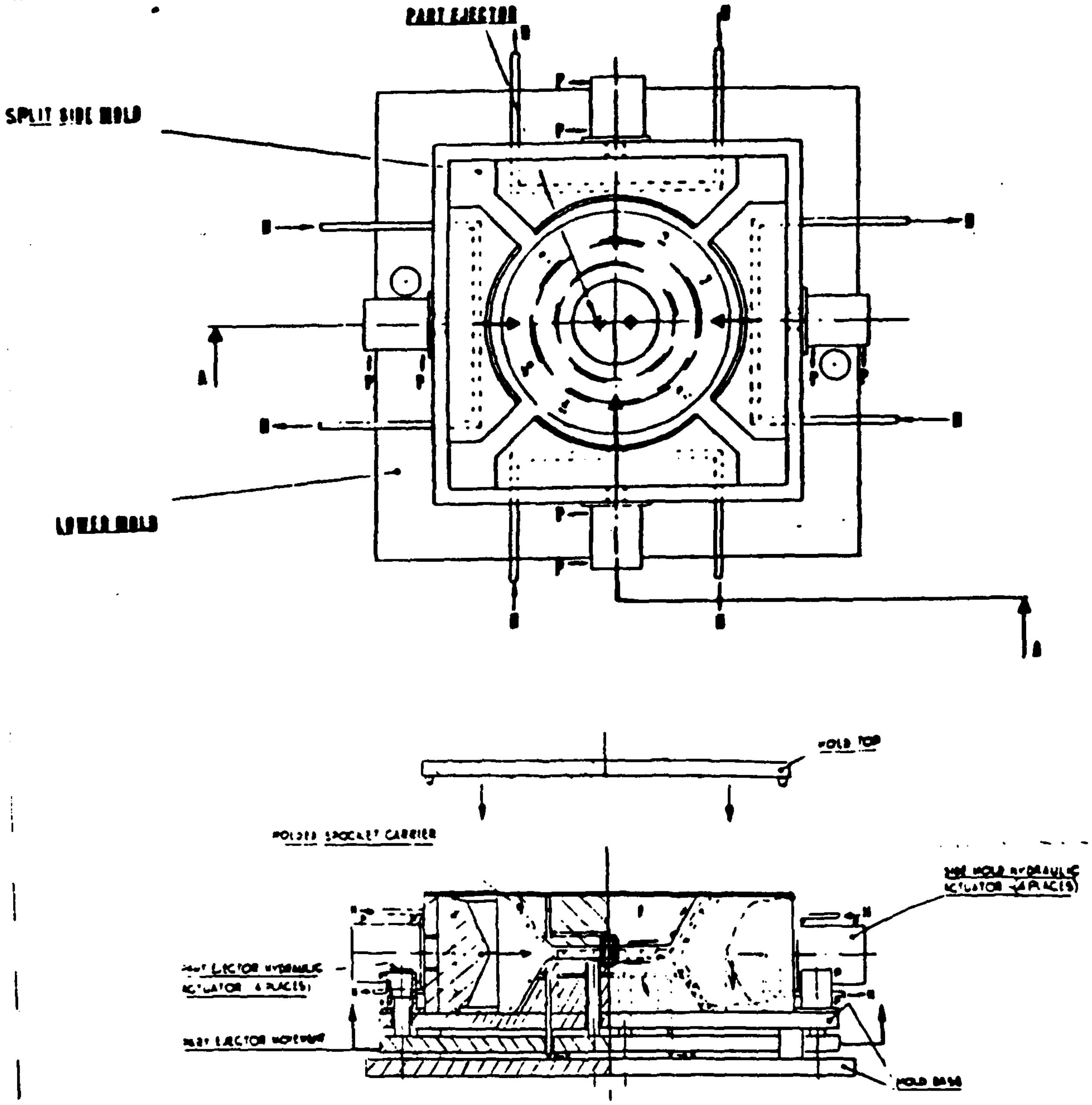


FIGURE 5. MOLD TOOL

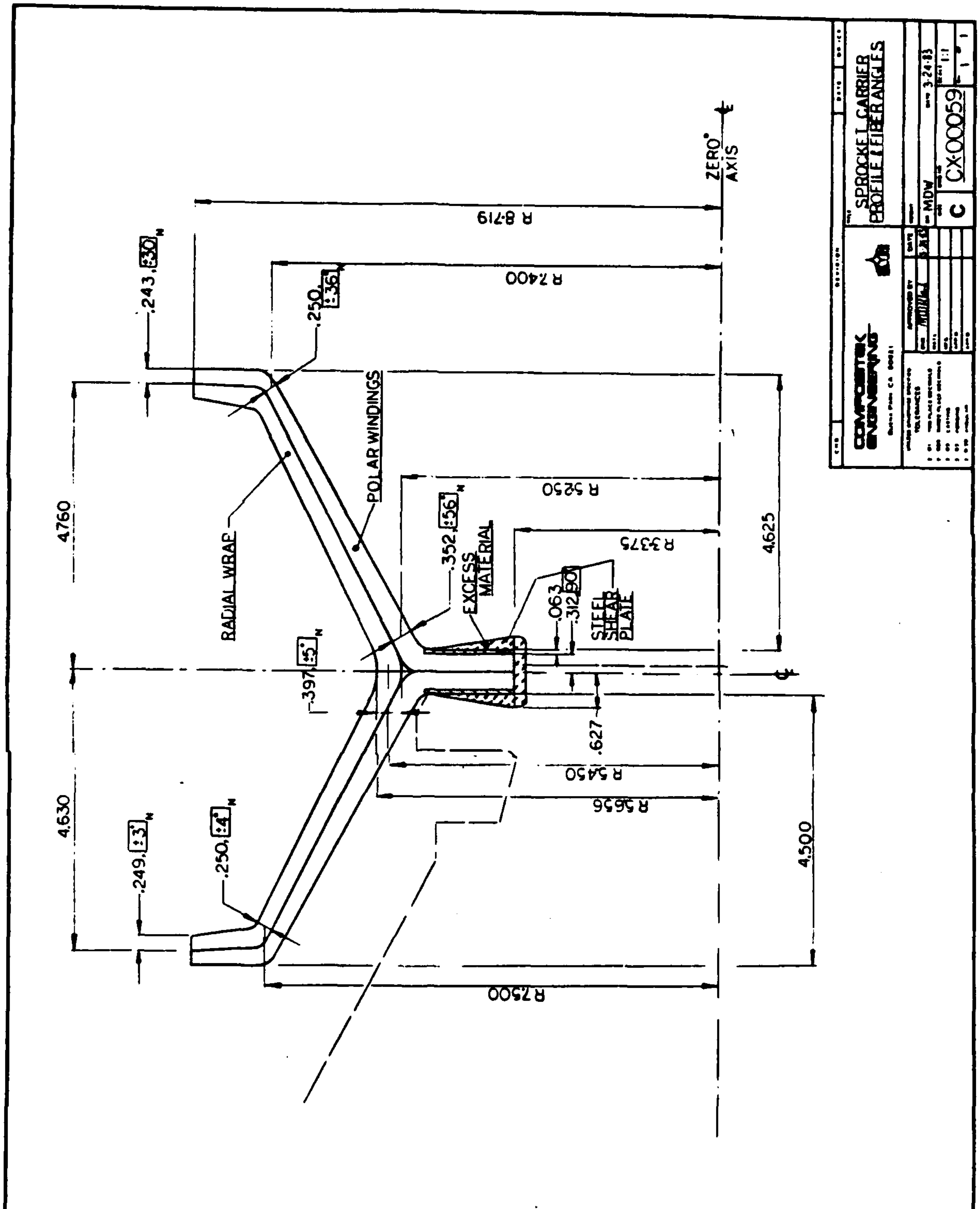


FIGURE 6. THEORETICAL PROFILE

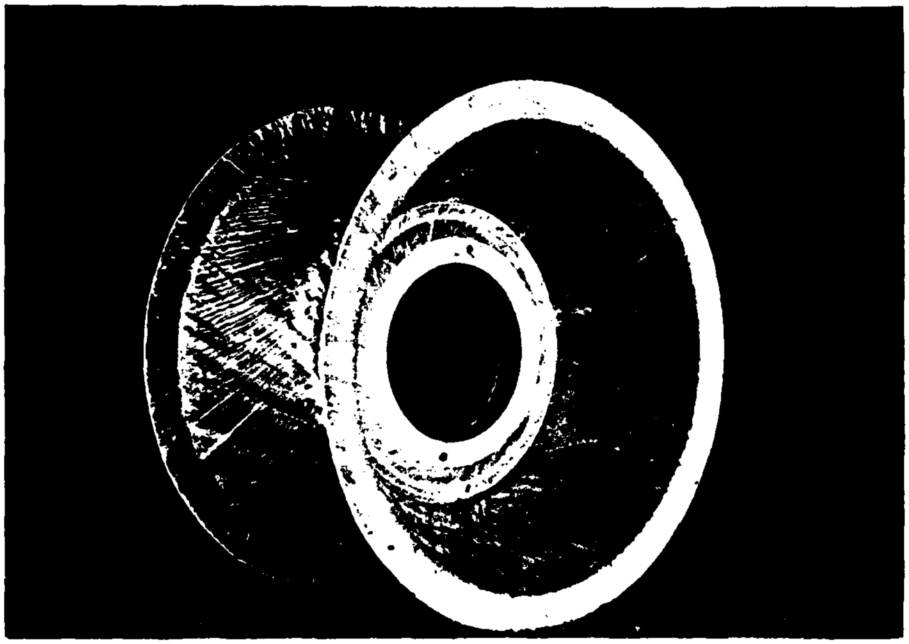


FIGURE 7. DEVELOPMENT GLASS/EPOXY SPROCKET CARRIER

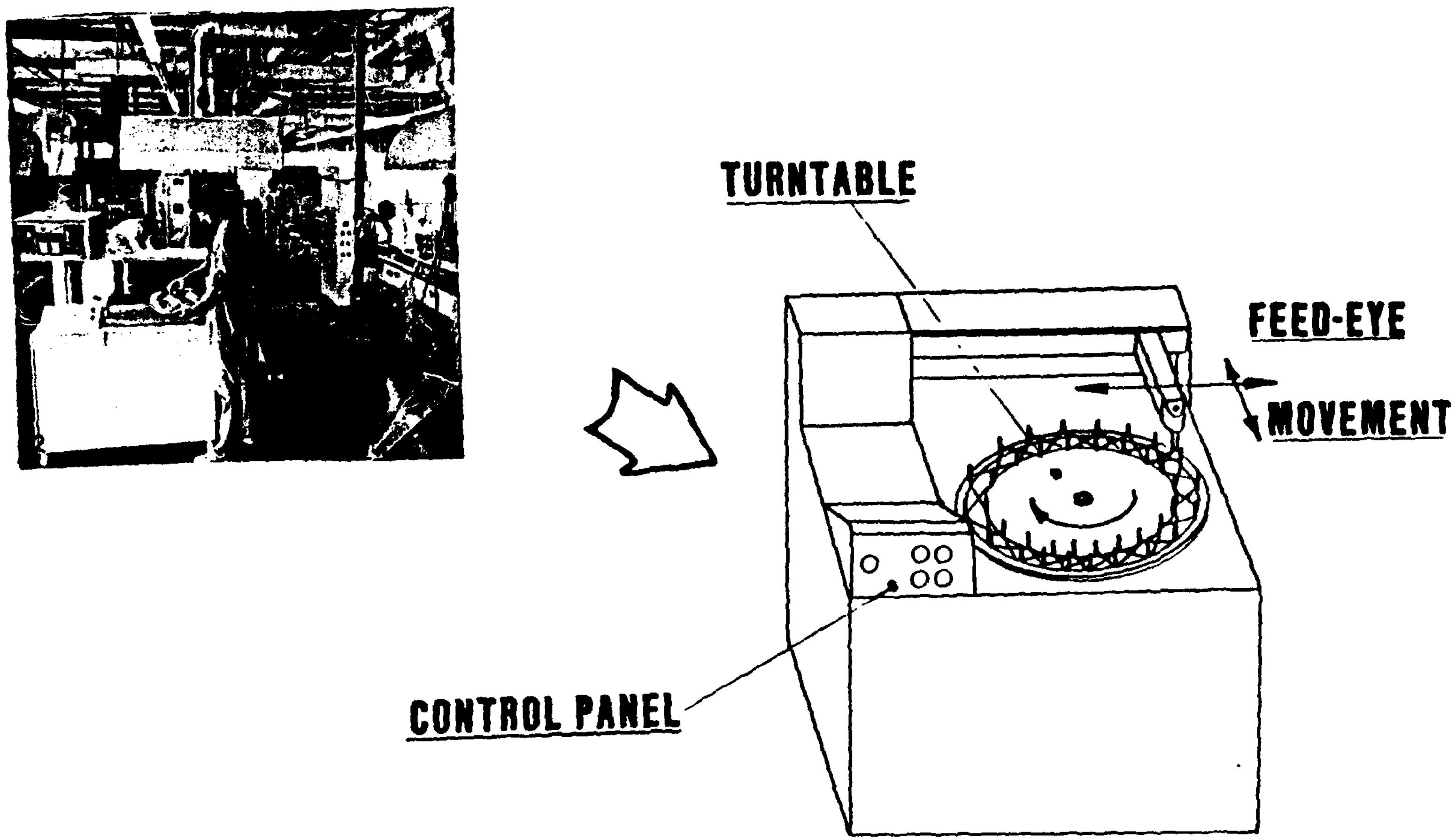


FIGURE 8. METHOD OF WINDING ADDITIONAL RIM MATERIAL

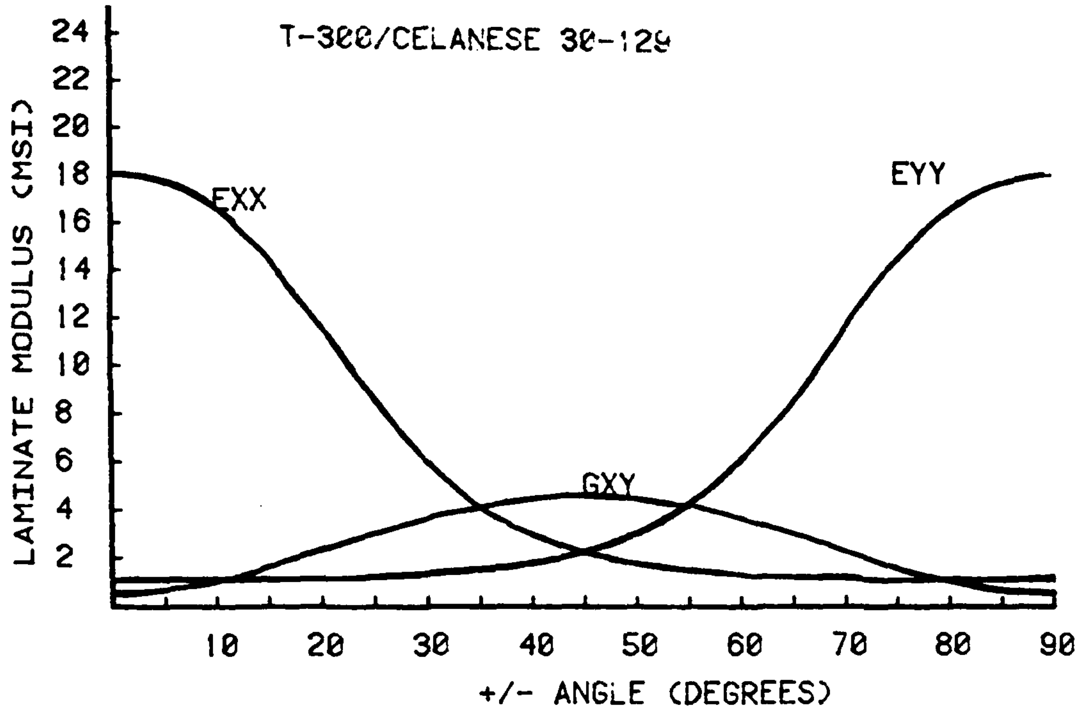


FIGURE 9. VARIATION OF MODULUS WITH CROSSPLY ANGLE (GRAPHITE/EPOXY)

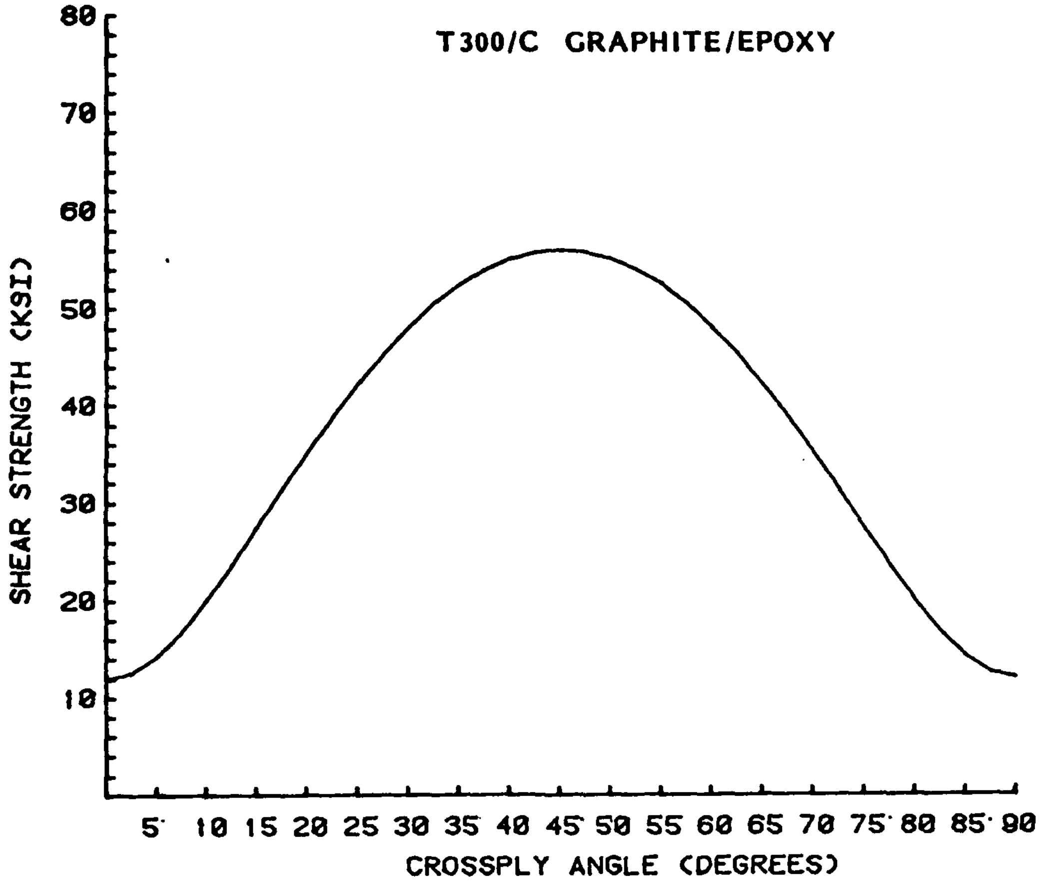


Figure 10. Ultimate Shear Strength As A Function Of Crossply Angle

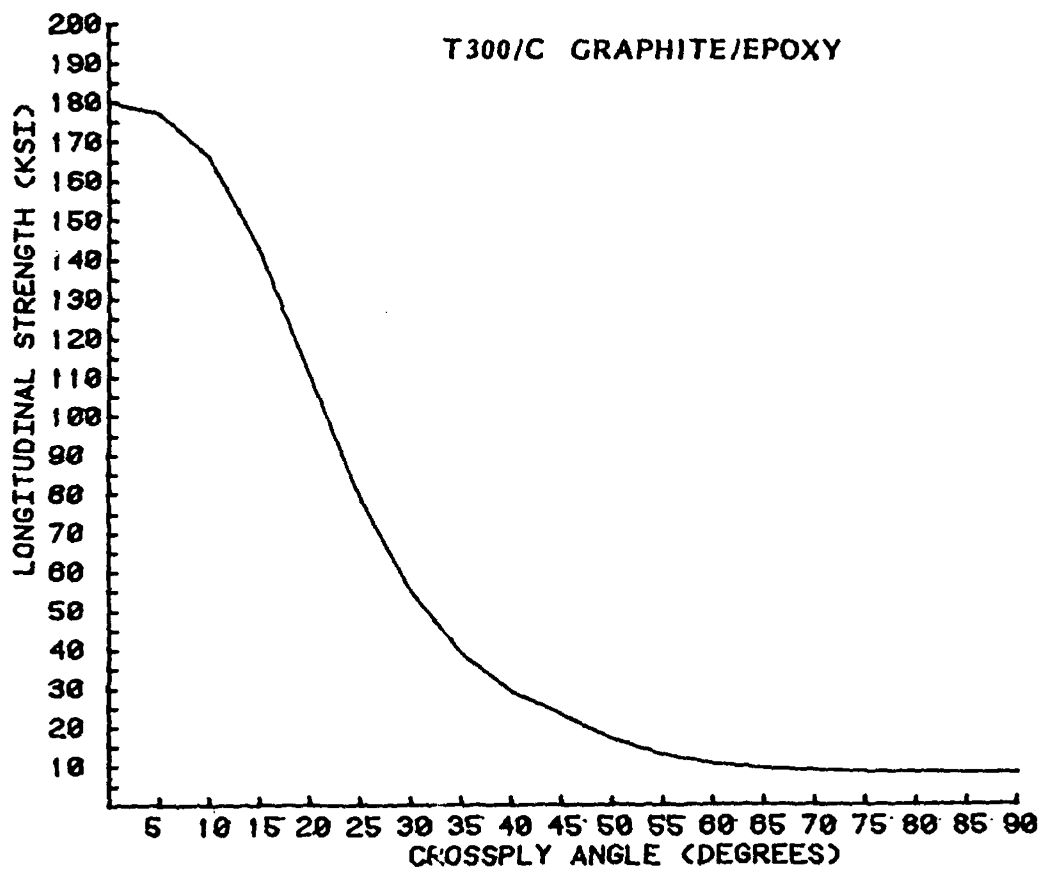


Figure 11. Ultimate Longitudinal Strength As A Function Of Crossply Angle

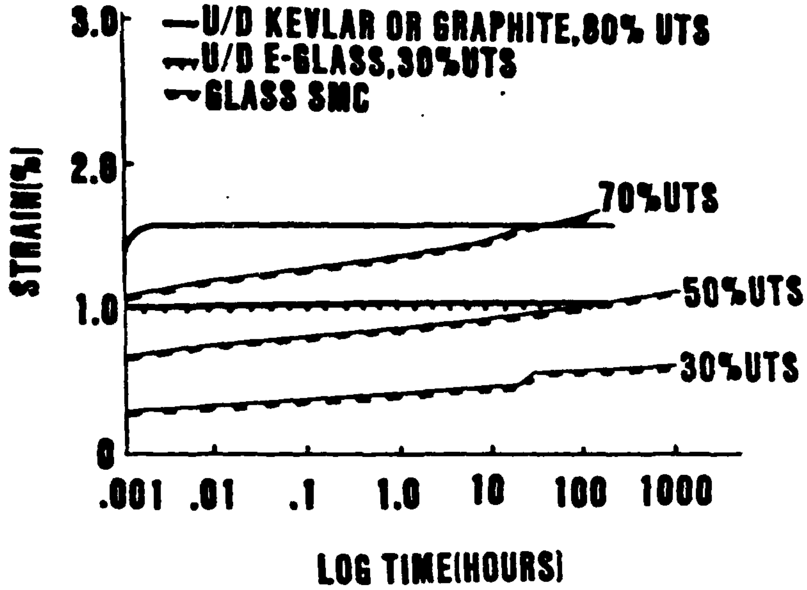


FIGURE 12. GENERALIZED CREEP DATA

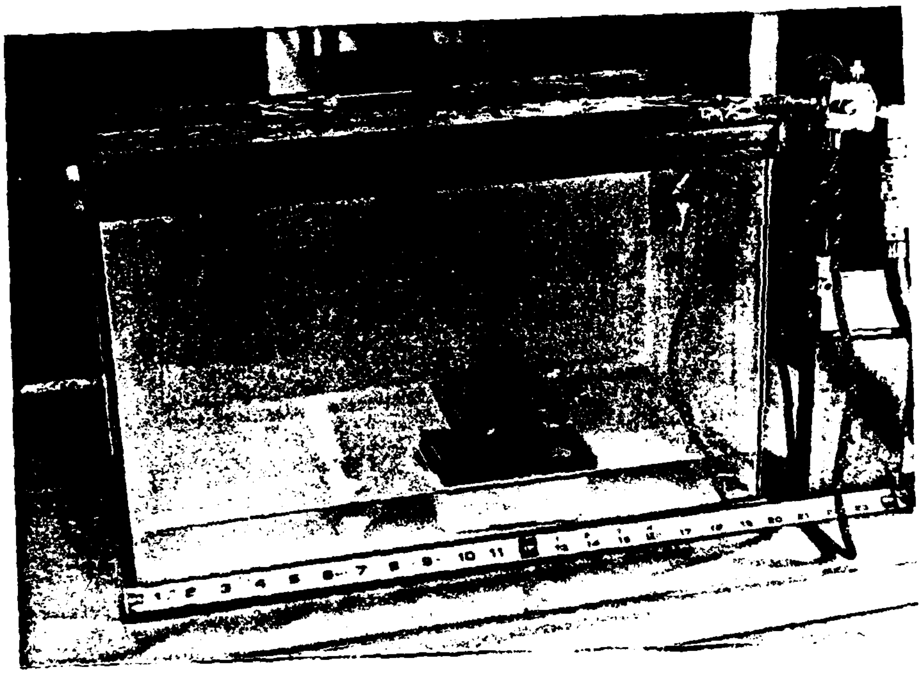
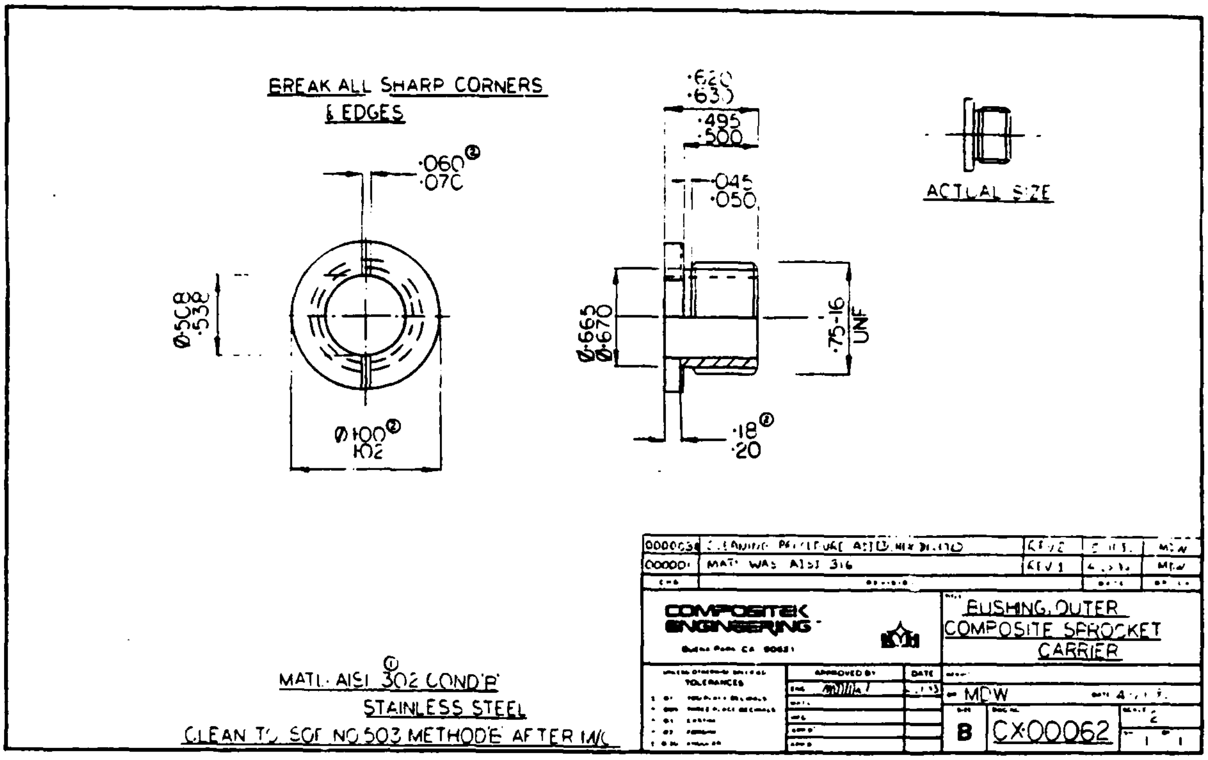


FIGURE 13. SALT-SPRAY TEST RIG

(a)

a)



b)

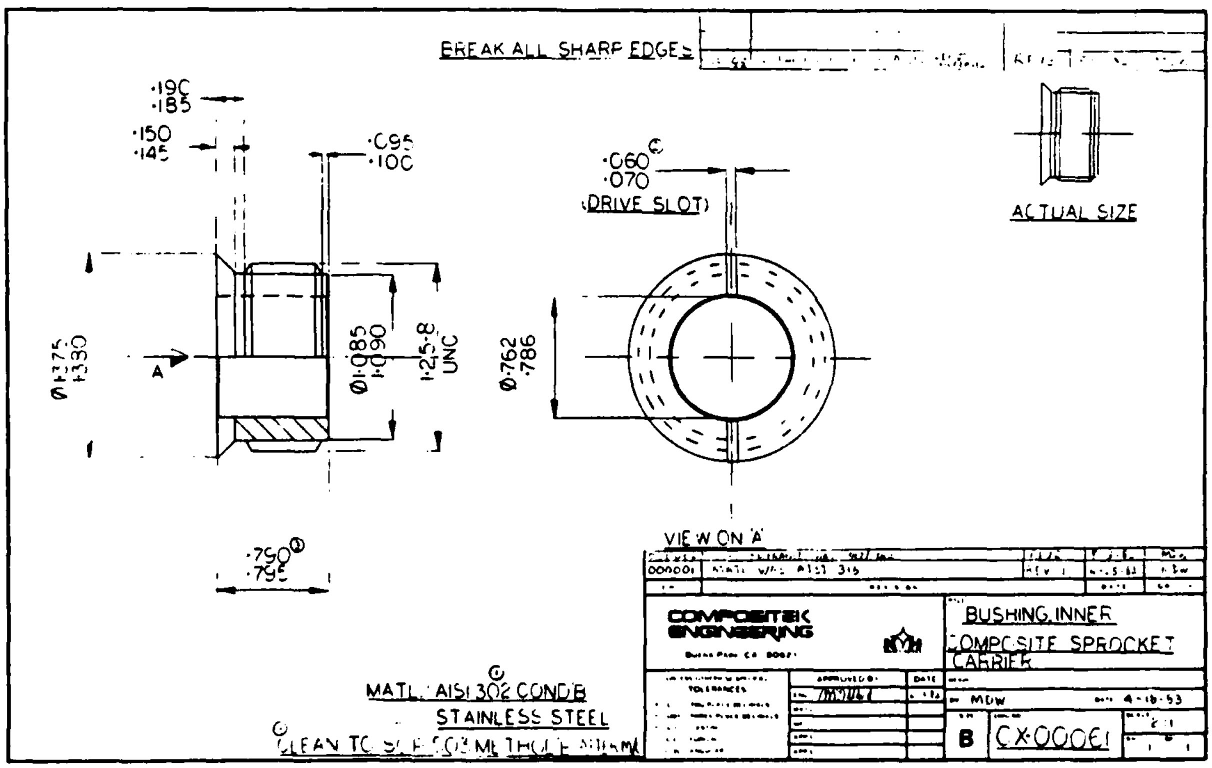


FIGURE 14. BUSHING DESIGNS

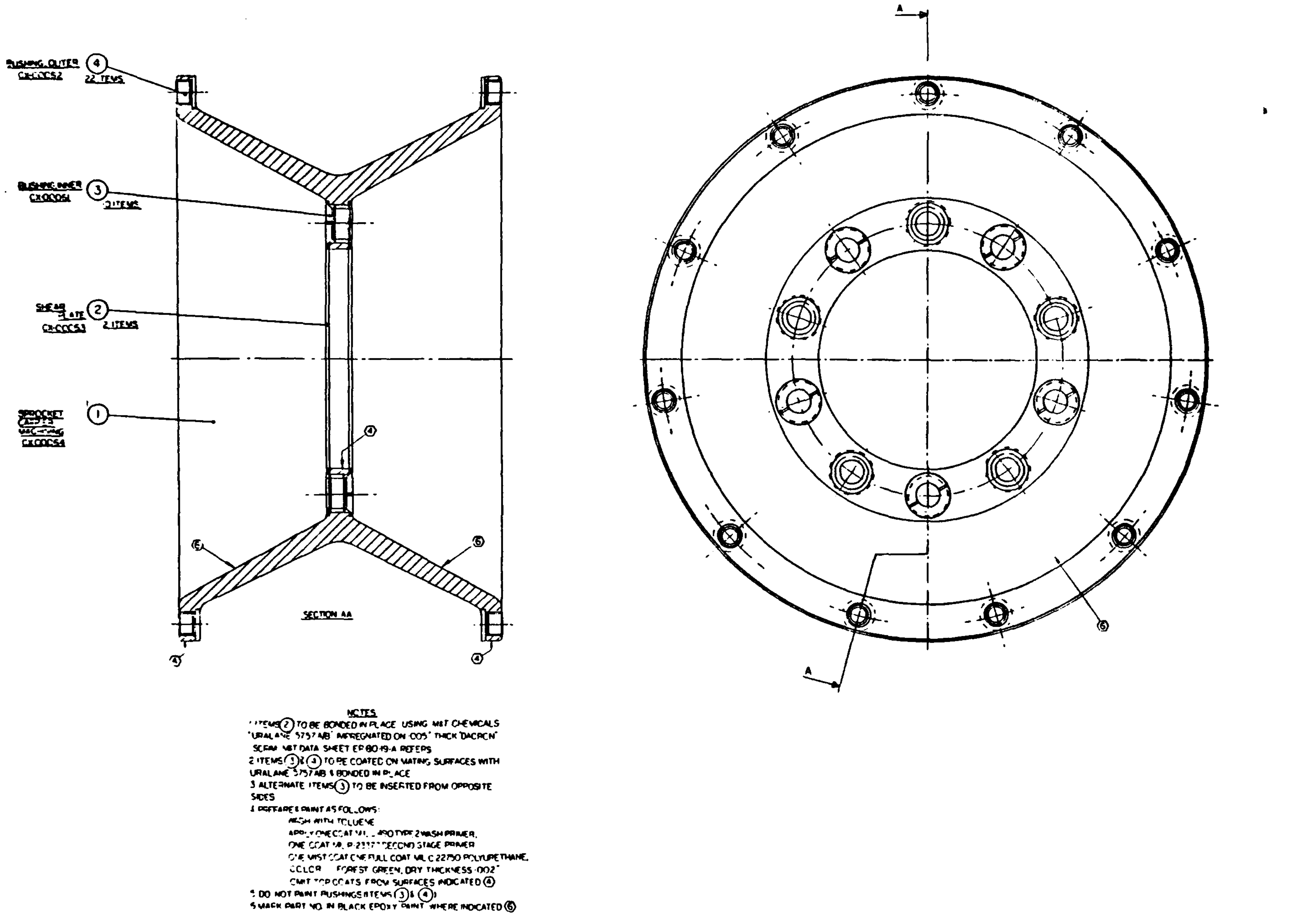


FIGURE 15. SPROCKET CARRIER ASSEMBLY

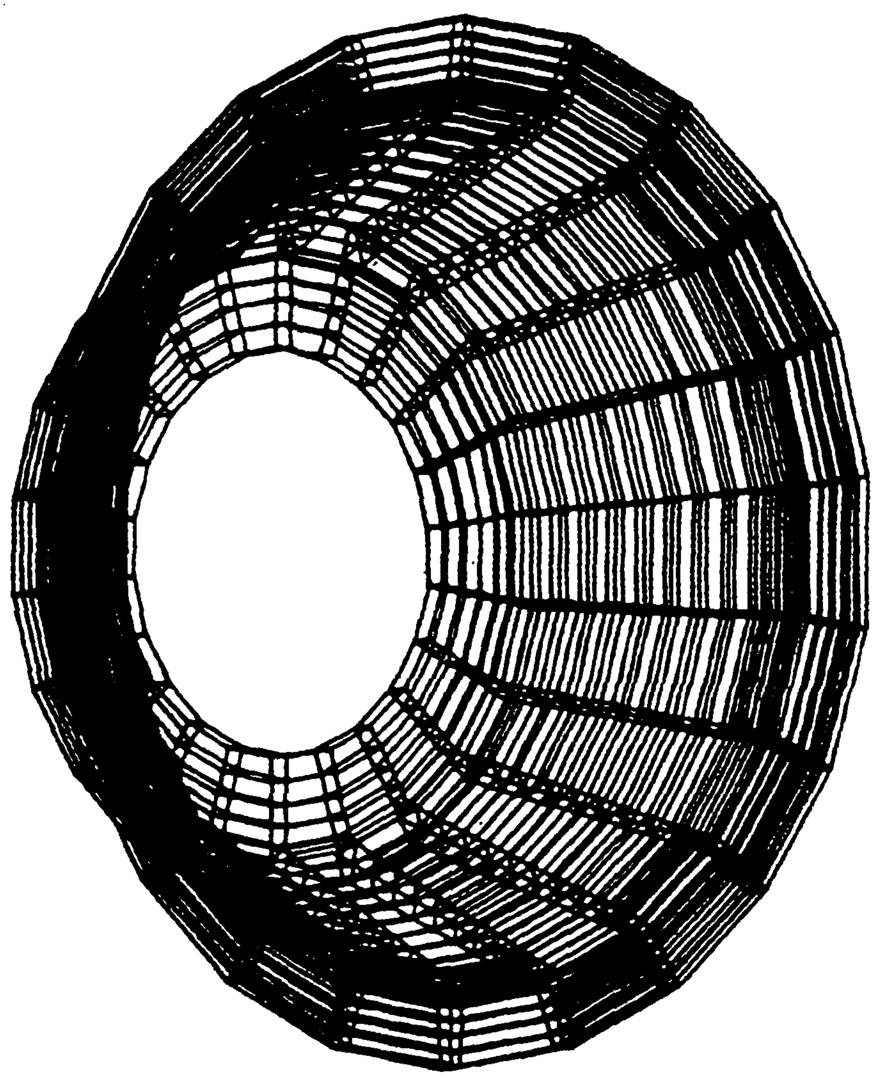


FIGURE 16. SPROCKET CARRIER FINITE ELEMENT MODEL (NASTRAN)

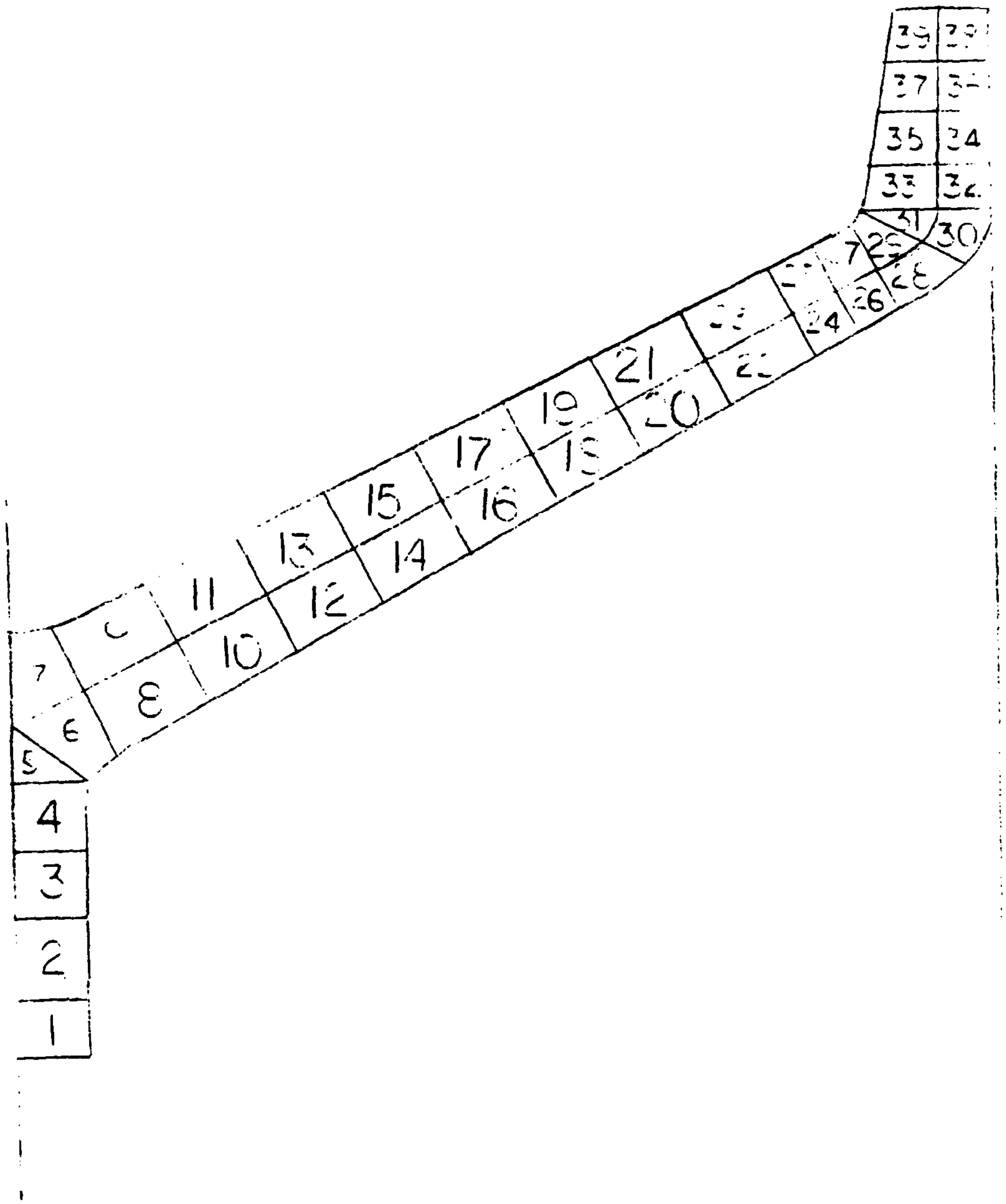


FIGURE 17. ELEMENT NUMBERING WITHIN SPROCKET CARRIER CROSS-SECTION

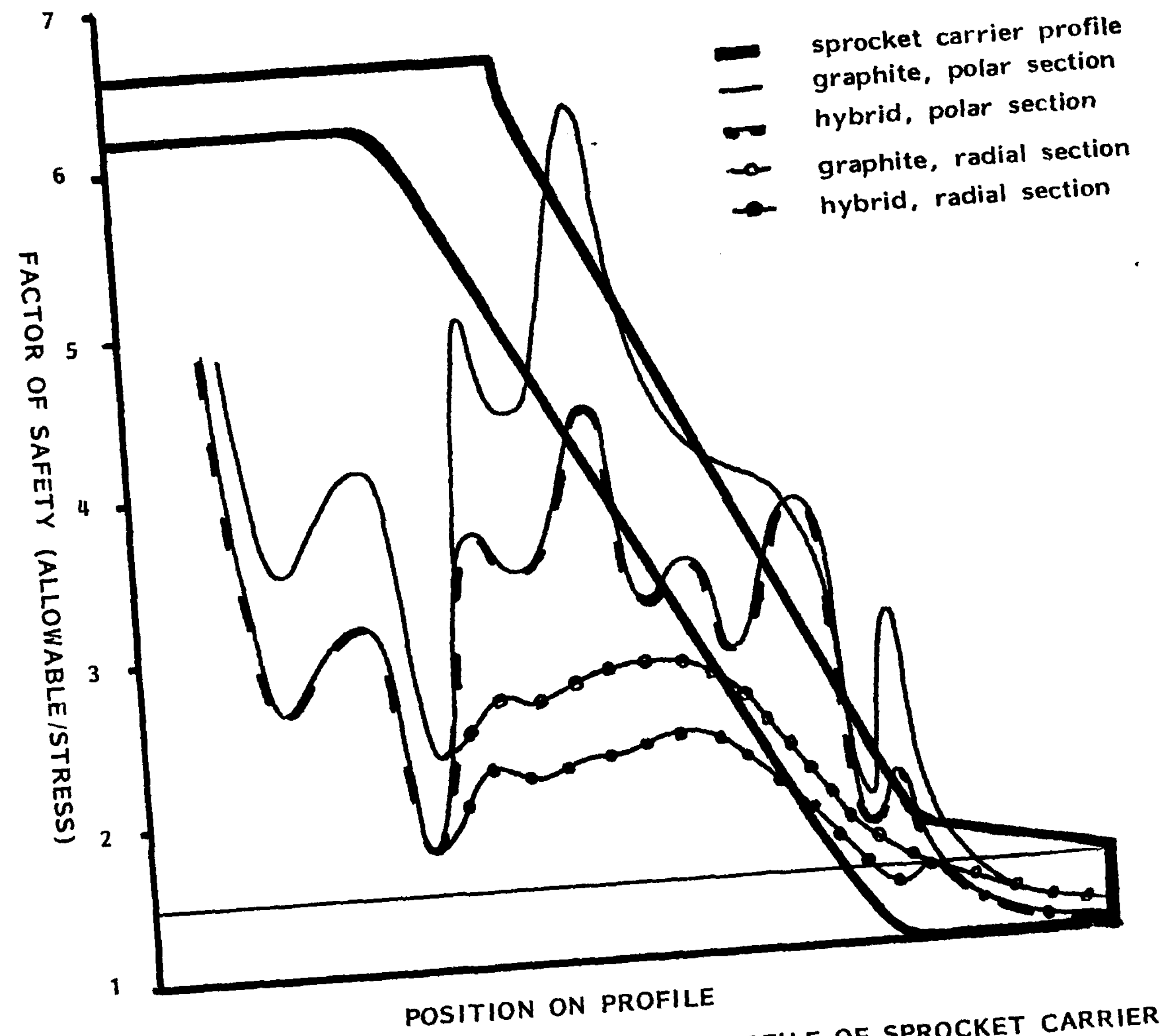


FIGURE 18. VARIATION OF SAFETY FACTOR ALONG PROFILE OF SPROCKET CARRIER