USAAMRDL-TR-76-6

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BS.

DEVELOPMENT OF DESIGN AND MANUFACTURING TECHNOLOGY FOR BALLISTIC-DAMAGE-TOLERANT FLIGHT CONTROL COMPONENTS

Bell Helicopter Company
P. O. Box 482
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EUSTIS DIRECTORATE POSITION STATEMENT

This report gives the results of one of three contractual efforts undertaken to develop manufacturing methods for ballistically tolerant flight control components. Two previous programs were conducted by Whittaker Corporation. One program, reported in USAAMRDL-TR-73-20, covered a group of CH-47 flight control components; the other, reported in USAAMRDL-TR-75-49, covered two UH-1 flight control components. This contract differed from the others in the incorporation of ballistically tolerant bearings in the flight control components. The main purpose of this program was to develop the manufacturing methods for the ballistically tolerant bearings, rod ends, and retention pins.

This project was accomplished as part of the U. S. Army Aviation Manufacturing Technology Program. The primary objective of this program is to develop, on a timely basis, manufacturing processes, techniques, and equipment for use in the production of Army materiel.

The manufacturing technology presented in this report is considered to be ready for production items.

Philip J. Haselbauer of the Technology Applications Division served as project engineer for this effort.

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Two components in the AH-1G antitorque control system were chosen for samples. These parts were redesigned to be ballistic-damage-tolerant and were then fabricated with specially designed tooling. The completed parts were mechanically, ballistically, and environmentally tested to prove soundness of design and fabrication.

The program showed that manufacturing could be done on a production basis, resulting in parts that are very satisfactory in quality and performance.

PREFACE

This report was prepared by Bell Helicopter Company (BHC), Fort Worth, Texas, 76101, under U. S. Army Contract DAAJ02-73-C-0063, "Development of Design and Manufacturing Technology for Ballistic-Damage-Tolerant Flight Control Components." The contract was administered under the direction of the Eustis Directorate, USAAMRDL, Fort Eustis, Virginia, by Contracting Officer Mr. F. G. McGraw and Technical Representative Mr. Philip J. Haselbauer. Contracted work began in May 1973, and was completed through verification testing in December 1974. Technical tasks in this program were conducted under the direction of Mr. Sam Aker, BHC Research Project Engineer. He was assisted by Mr. Peter Alukonis.

Dr. Ken Berg and Mr. J. Hilzinger of Whittaker Research Company were responsible for the fabrication of the molded graphite/epoxy inner races for the bearings. Mr. R. Matt and Mr. R. Thompson at Fafnir Bearing Company were responsible for the fabrication of the bearings.

The investigators in this program would like to express appreciation to Mr. Philip Haselbauer for his guidance and support.

SUMMARY

This report presents the results of a USAAMRDL program to develop manufacturing technology for the production of ballistic-damage-tolerant flight control components.

The objectives of this program were to:

- Provide manufacturing methods technology for producing ballistic-damage-tolerant flight control components for the AH-1G. These components are to have a high degree of reliability and a relatively low cost, and are to be made of fiber-reinforced composite materials using automated fabrication techniques.

- Establish appropriate manufacturing processes, quality assurance methods, and a manufacturing technology data package, to ensure repeatable production of composite material flight control components with inherent high reliability and quality characteristics.

To meet these objectives, it was necessary to design sample components which could be proven to be ballastic damage tolerant and functionally reliable without sacrificing producibility.

One bellcrank and one clevis in the AH-1G antitorque control system were selected as the sample parts. To accommodate verification testing, the support and the control tube, which mate with the samples, were redesigned. To accommodate flight testing, local structure was slightly redesigned. A complete set of production drawings was prepared for the fabrication of parts.

At the same time that design was in progress, the manufacturing techniques were examined and design changes were made for compatibility. After the redesigning of parts was completed, design and fabrication of tools began. Fabrication of parts followed, and the resulting components were very satisfactory in quality.

The amount of verification testing was reduced from original plans to just those tests deemed to be most significant (static and oscillatory load, ballistic, and fungus). The components survived all of these, exceeding specified requirements.

The oscillatory load tests were the most significant tests performed, consisting of a combination of tests performed in series. After a static proof load test, the assembly was operated at normal loads for one million cycles. Upon completion of this test, the assembly was moved to the BHC Ballistic Laboratory where the static load was applied and a .30-caliber round, in a tumbled state, was fired through the joint. Then the assembly was returned to the oscillatory load fixture and cycled under load for sixteen hundred cycles, and then cycled an additional four hundred cycles at an increased load. Following the completion of the oscillatory load, a static test to failure was performed.

The significant results of this program are as follows:

- Composite flight control components which met the design requirements were consistently produced.

- Automated techniques were used in a number of the steps in fabrication, and additional automation is possible.

- A ballistic-damage-tolerant joint was demonstrated.

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LIST OF ILLUSTRATIONS - Concluded

1.0 INTRODUCTION

The concept of making ballistic-damage-tolerant aircraft control components from composite materials that incorporate multiple load paths has been demonstrated by several programs sponsored by USAAMRDL. It has been shown that these components can be made strong enough to carry a significant load and to continue to function after being hit by a .30-caliber APM2 projectile. However, the rotating joints were still considered to be vulnerable. These joints, when struck, would either separate or jam.

The possibility of making ballistic-damage-tolerant components has been proven, but only on a prototype basis. Their usefulness for aircraft depends upon whether it is possible to produce them at a high rate as low-cost, flightworthy parts. Consequently, an objective of this program was to develop and demonstrate the producibility of such components, and then to prove that the manufacturing methods chosen produced good parts.

Two parts in the AH-1G antitorque control system (a bellcrank and a clevis) were selected as the samples on which the concept would be demonstrated. The sample components chosen were the 209-001-754-1 Bellcrank and the clevis on the 209-001-063-17 Control Tube. To accommodate these parts for verification testing, the following connecting parts were also redesigned: the 209-001-064-7 Control Tube and the 209-001-717 Support. Consideration of future flight testing made it necessary to modify the 209-030-104 Bulkhead and the 209-030-159 Beam Cap. Figure 1 shows the redesigned components and accompanying parts installed in the AH-1G antitorque control system.

While the objectives of this program were primarily to develop a manufacturing technology for ballistic-damage-tolerant control components, it will be seen that a significant amount of engineering work was done also. The reasons for this were:

- To ensure that the resulting parts would pass the rigorous testing which was specified.

- To be confident that the best compromises between functional requirements and producibility were made.

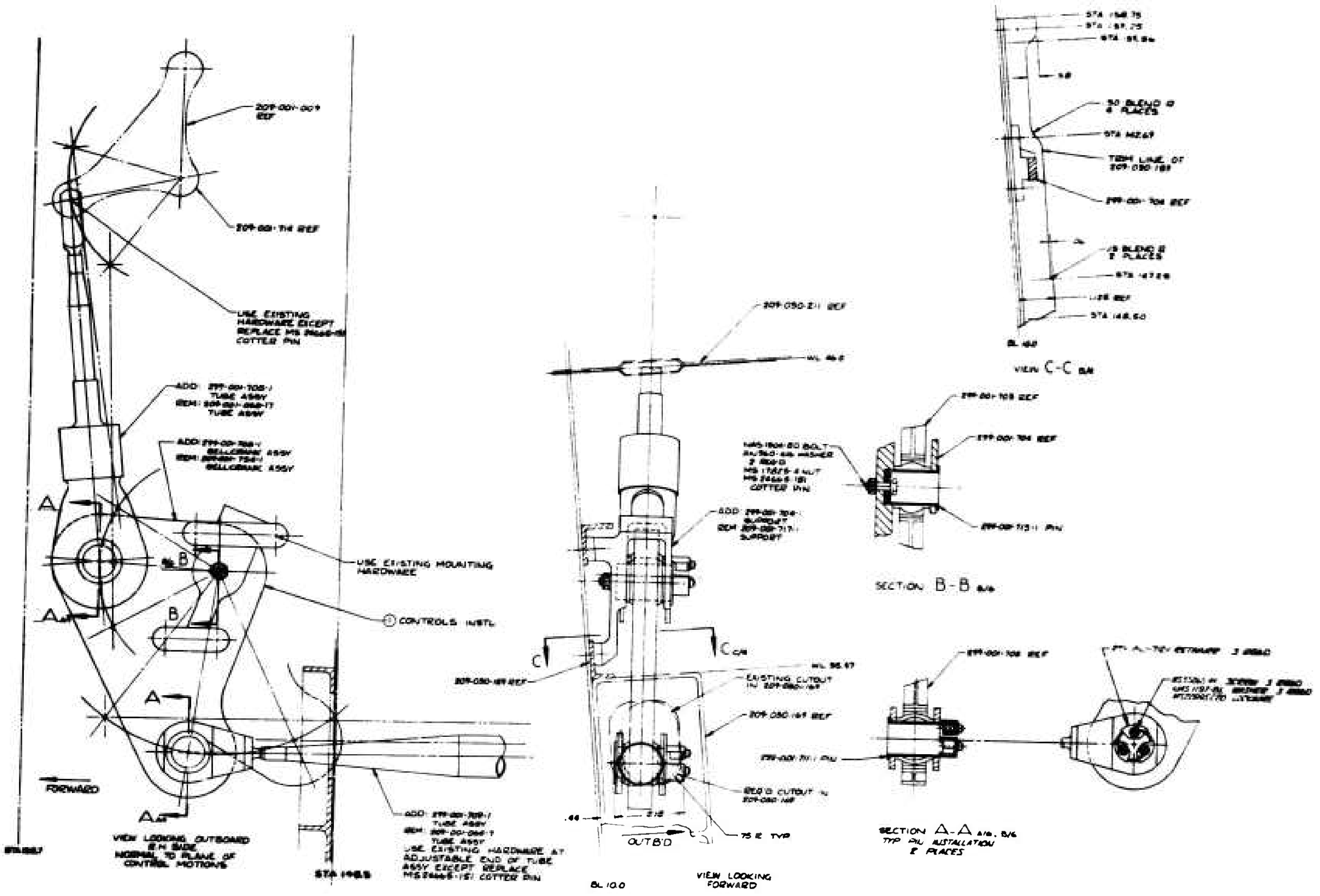


Figure 1. Controls installation, antitorque, ballistic tolerant.

To reach the goals of the program, the overall task was conducted in five phases, as follows:

Phase I

- Design of Components
- Ballistic Screening Test
- Evaluation of Manufacturing Techniques
- Tool Design
- Tool Fabrication

PHASE II

- Fabrication

PHASE III

- Quality Assurance Planning

PHASE IV

- Verification Tests
  - Cyclic Test
  - Proof Test
  - Ballistic Test
  - Post-Ballistic Cyclic Test
  - Ultimate Load Test
- Environmental Test

PHASE V

- Preparation of Manufacturing Package
- Final Report

2.0 DESIGN

2.1 DESIGN CONCEPTS

To summarize the design goals, the components must:

- Be capable of functioning after being damaged by a fully tumbled .30-caliber APM2 projectile.
- Be designed to be manufactured by mass-production concepts at relatively low costs.
- Maintain a structural integrity comparable to the existing aircraft components with a minimum weight penalty.

The basic design of the bellcrank and the bearings were developed in an earlier research program at Bell. This earlier work, which is presented in Bell Helicopter Company Report 299-199-085, "Gunfire Tests of Helicopter Components," was done between January 1971 and April 1972. In this concept, ballistic-damage tolerance is achieved by using low-density materials, multiple load paths, and parts of a larger size.

Because of the low density, the resistance to penetration is minimal. This results in less energy absorption upon impact and consequently, less damage. For this reason, fiberglass and graphite composites were selected as the materials best suited for the fabrication of the components.

Because of the larger sizes and multiple load paths, enough material of sufficient strength remains after penetration to ensure continued functioning.

2.2 BEARING DESIGN

Two types of bearings are used: self-aligning and nonself-aligning (see Figures 2 and 3). They are larger than conventional bearings and the ball is designed with a hollowed-out section on the base of the inner race to reduce the thickness in that area. This reduction in thickness assures the minimum resistance to the round, thus minimizing ballistic damage. The two types of bearings are similar in design having large diameter inner races made from chopped graphite/epoxy molding compound. The self-aligning bearing is made with a spherical inner race, while the nonself-aligning bearing features a toroidal section with aligning shoulders on each end. Both bearings have a glass fiber filament-wound outer race. This outer race is fabricated by first applying a Teflon fabric liner over the inner race and then winding glass filament over the liner.

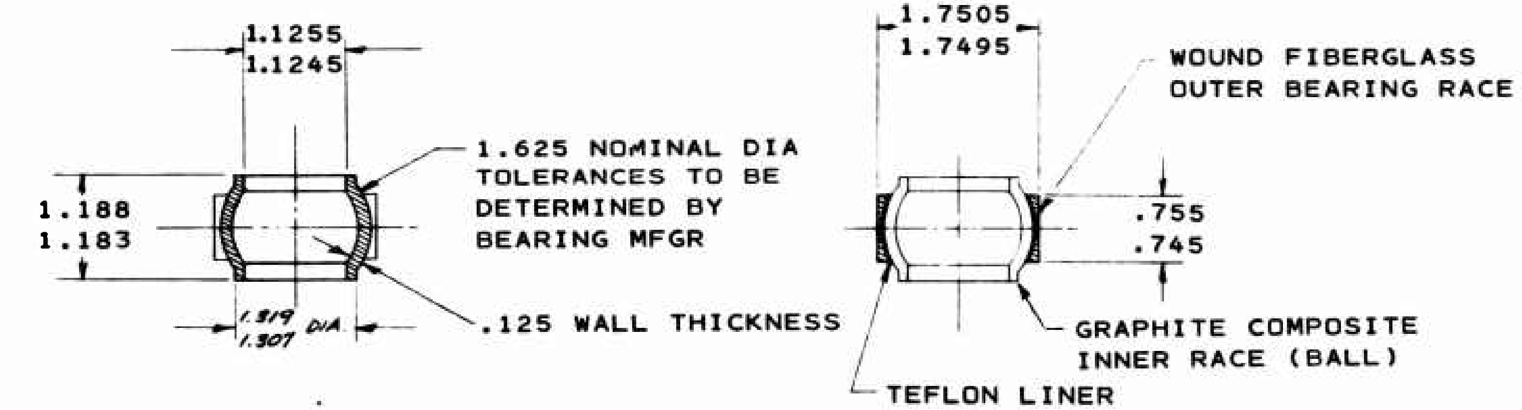


Figure 2. Bearing, self aligning.

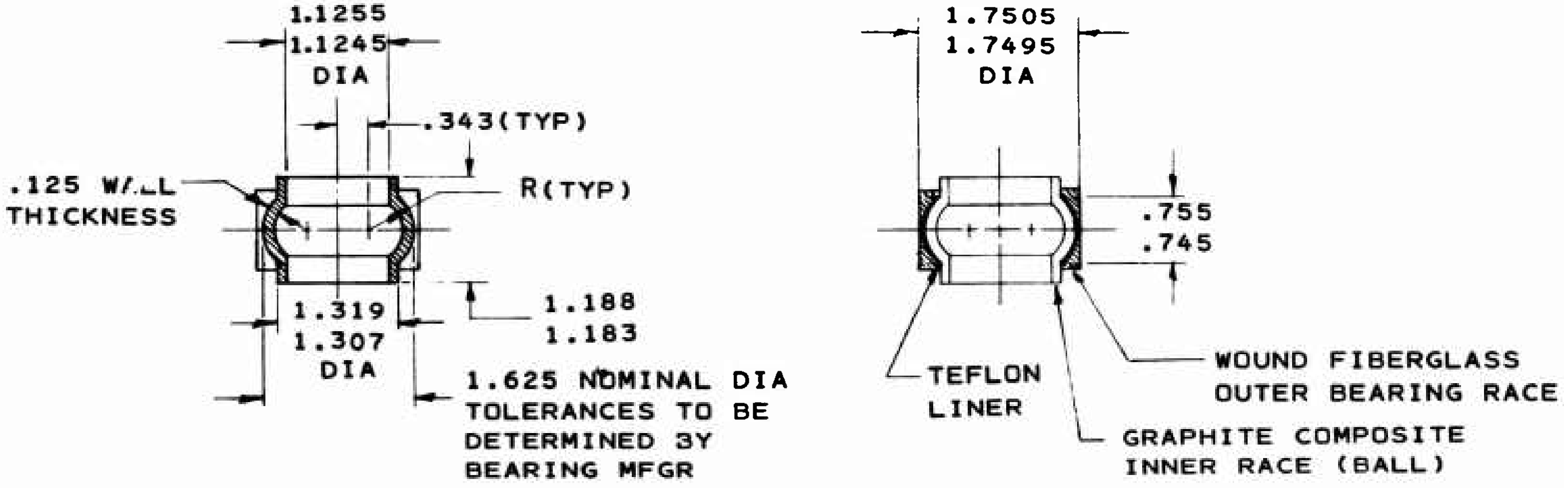


Figure 3. Bearing, nonself-aligning.

The bearings are purchased parts of BHC design, manufactured by the Fafnir Bearing Company. They are designed to withstand usage comparable to that of the usual metallic bearing of this configuration.

2.3 BELLCRANK DESIGN

The ballistic-damage-tolerant bellcrank (Figure 4) is designed to kinematically replace the 209-001-754-1 Bellcrank (Figure 5). The bellcrank has been sized to permit penetration by a tumbled .30-caliber projectile at any point and leave sufficient material to withstand single-pilot effort loads. Redundant load paths are provided in all areas of the part by two fiberglass bands which run around each of the three pivot points. Any band can be completely severed by a projectile and the remaining band will react the required loads. The density of the bellcrank is minimized by the use of low-density materials and thin sections throughout. The thin sections can be used because of the larger size and redundant load paths.

Ballistic-damage-tolerant bearings are used in the bellcrank at the pivot point and at the push-pull tube attach points. Figure 6 shows an exploded view of the bellcrank. The web is made of laminated prepreg fiberglass cloth. The inner and outer bands and the bearing sleeves are of unidirectional (wound) fiberglass. An overlay of fiberglass cloth is used to reinforce the bands to the web. The web, bands, sleeves and overlay cloth are assembled by bonding in a heated mold. Draft is provided to facilitate extraction from the mold.

2.4 CLEVIS DESIGN

A ballistic-damage-tolerant clevis (Figure 7) is incorporated in the replacement push-pull tube for P/N 209-001-063-17. The clevis is fabricated from fiberglass cloth using the large-size, low-density concept. Each clevis lug is flat in the vicinity of the bolt. This blends into a conical bead as the flat area transitions into a circular section at the adapter. This arrangement provides high compressive strength without using additional material.

Ballistic-damage tolerance is terminated at the adapter. The machined metal adapter provides a means of attaching the large diameter to a conventional-size tube (5/8-inch diameter).

Figure 8 shows an exploded view of the clevis. Each lug is bonded to the adapter and then reinforced by a winding of unidirectional fiber.

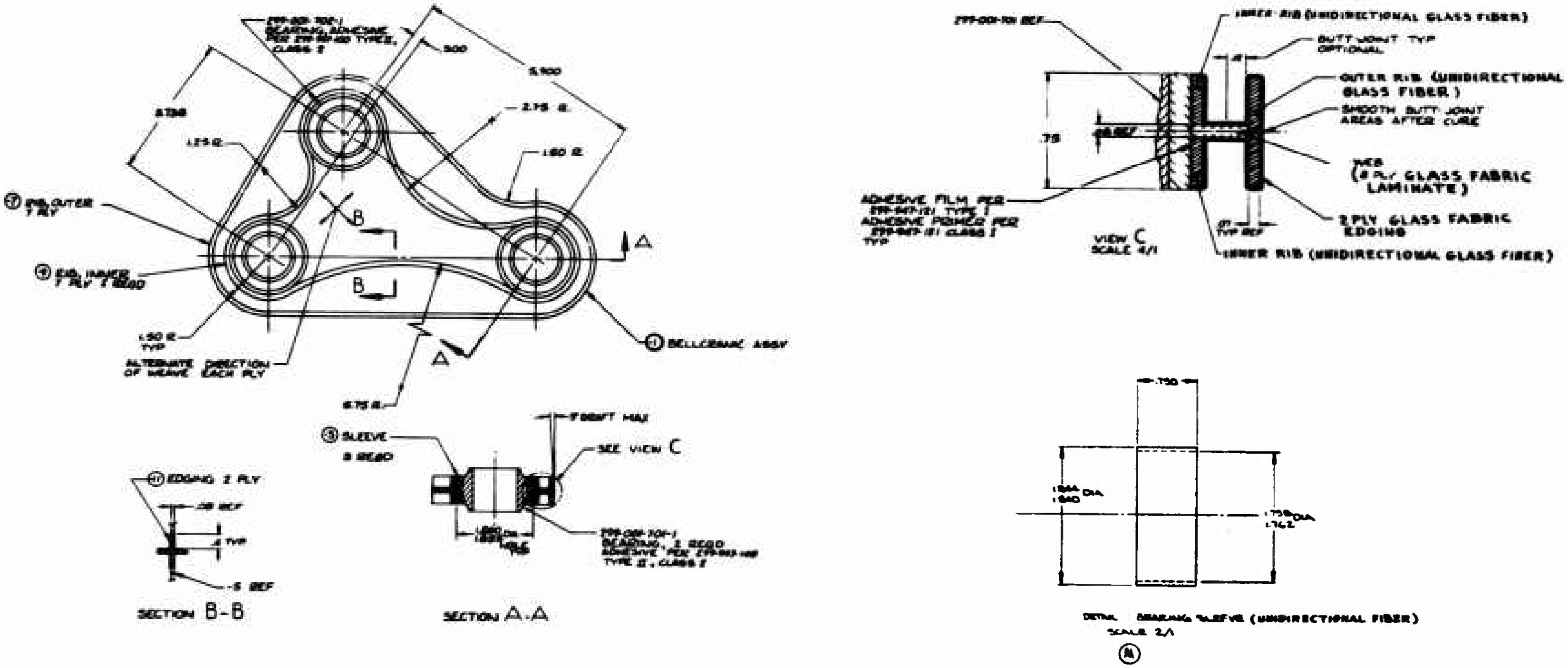


Figure 4. Bellcrank assembly, antitorque controls.

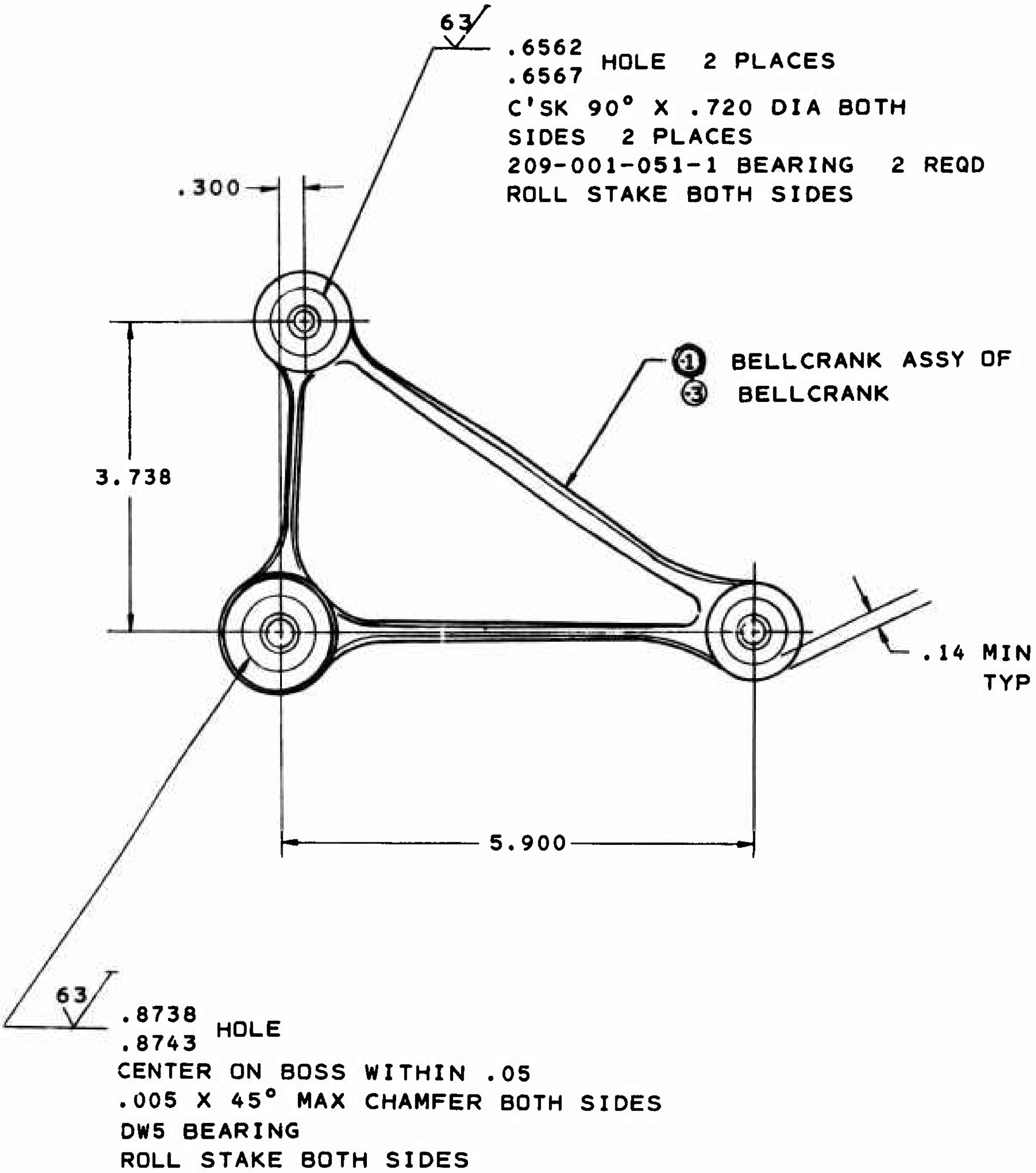


Figure 5. P/N 209-001-754-1 aluminum alloy bellcrank.

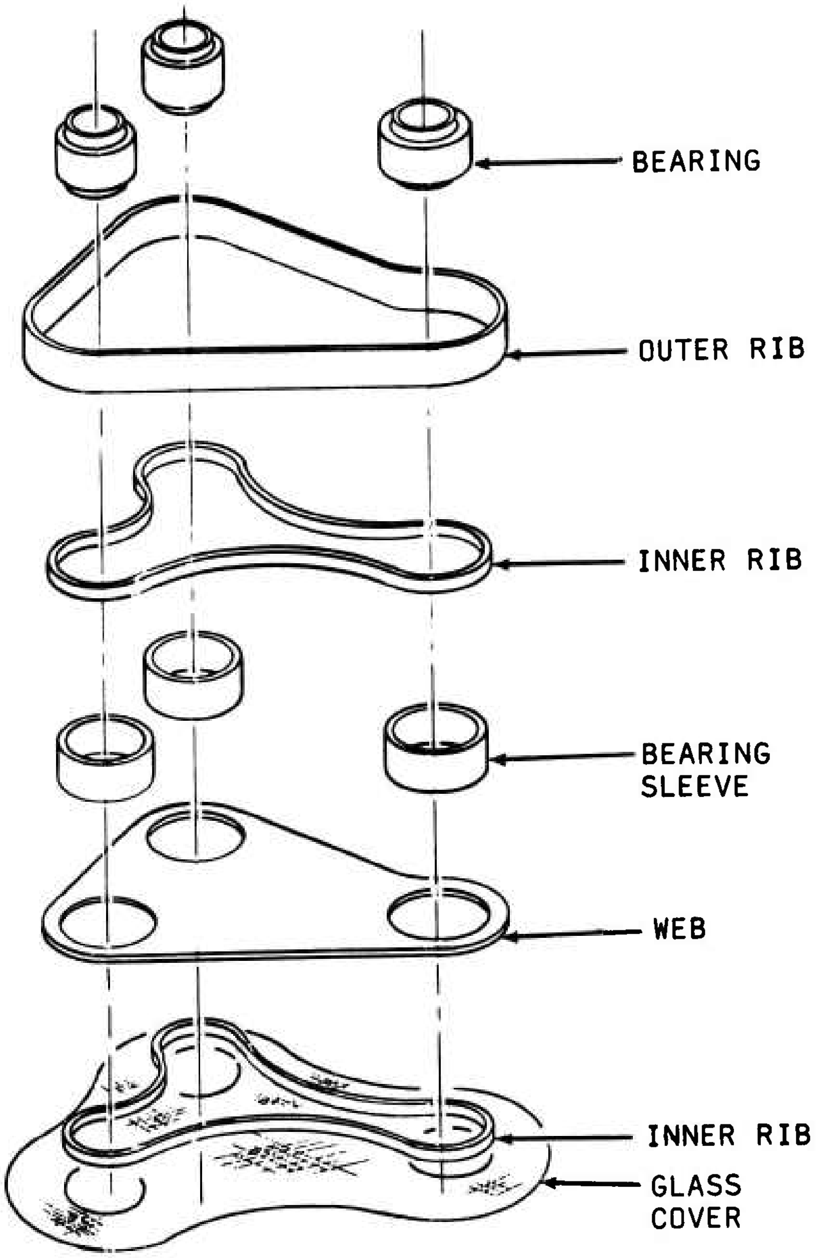


Figure 6. Exploded view of bellcrank assembly.

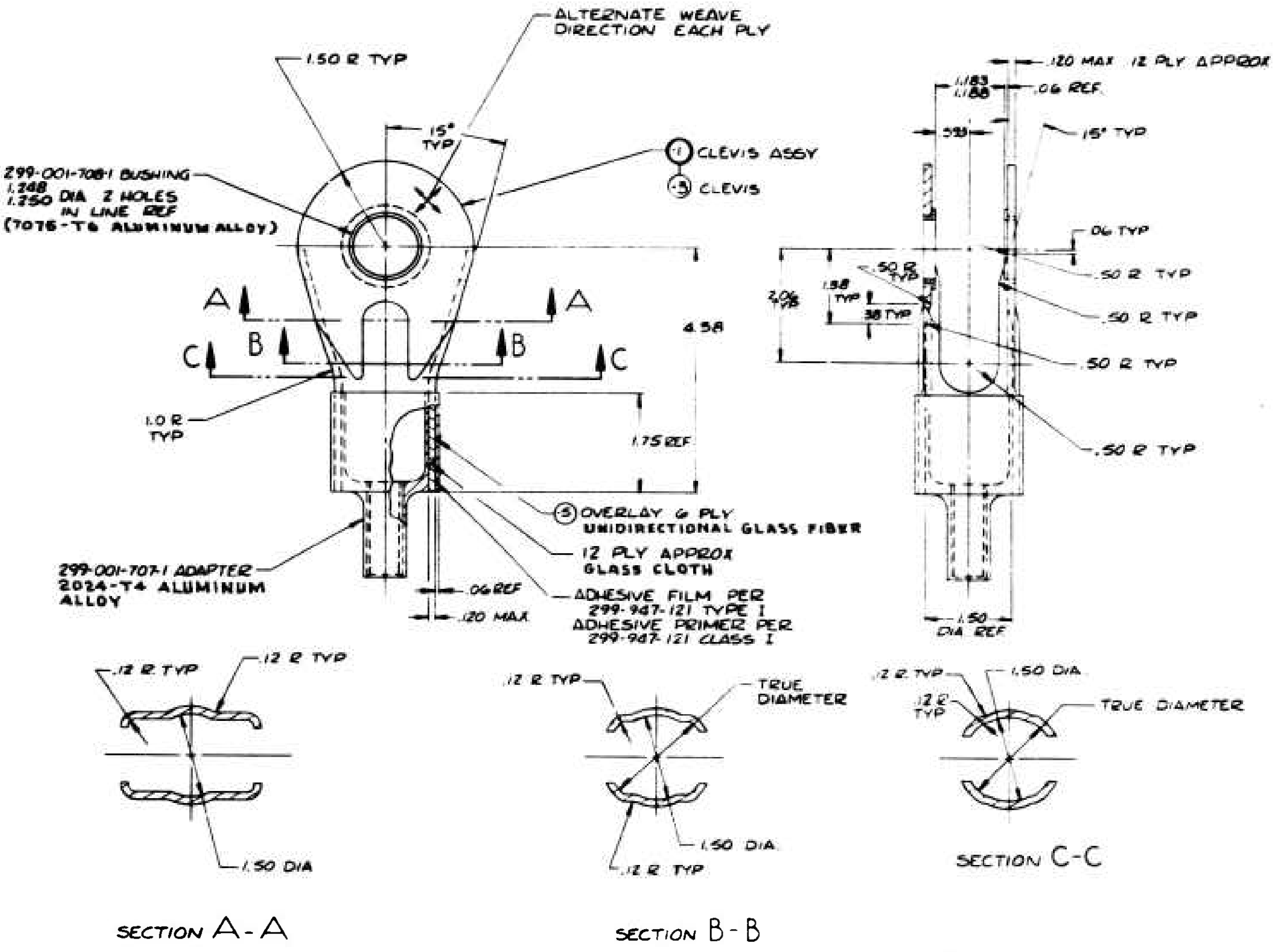


Figure 7. Clevis assembly, antitorque controls.

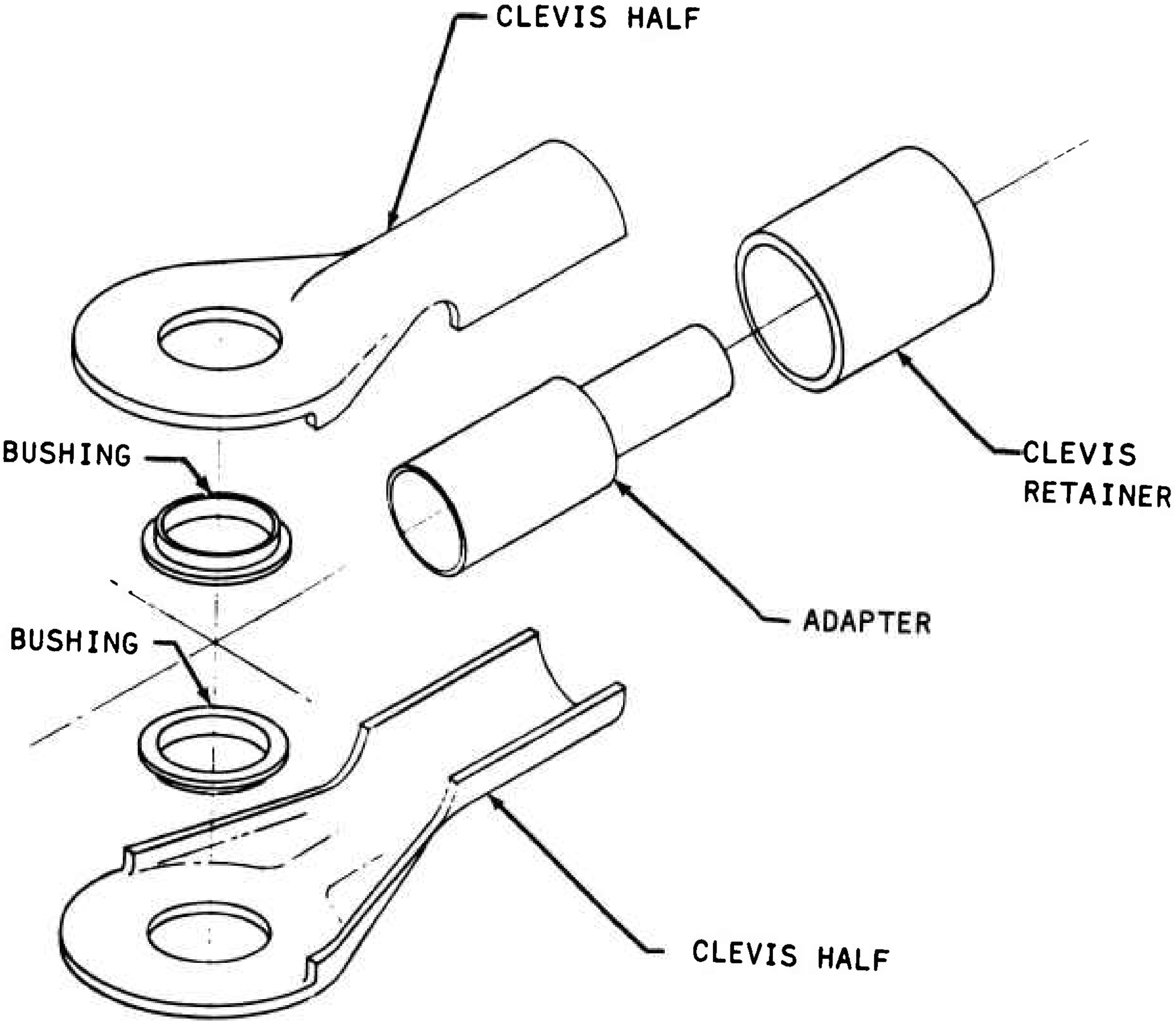


Figure 8. Exploded view of clevis assembly.

2.5 PIVOT PIN DESIGN

The pin configuration used (Figures 9 and 10) is the most successful version of two which were tried in the ballistic screening tests (see Appendix A for another configuration). It consists, basically, of a large-diameter, thin-wall aluminum alloy tube with a head on one end and three threaded receptacles on the other. The receptacles are for attachment of retainers which lock the pin into the assembled crank and clevis, and to provide clamp-up on the bearing. (See Figure 1 for the joint assembly.)

With the conventional bolt type configuration, the round would rip the nut from the bolt thread, leaving the pin loose. In the pin configuration developed in this program, a set of three separate retainers is used to achieve redundancy. No more than two retainers can be shot off at one time, leaving one retainer which is sufficient to keep the joint assembled. In addition to the redundant retainers, the pin features a lightweight, thin tubular section to minimize resistance to the passage of a round.

2.6 AIRFRAME MODIFICATIONS

The control components selected for this program were chosen because their alteration had minimum effect on existing airframe and control systems. However, some local modifications to the airframe in the area of the new components, and some modification of the control linkage leading to and away from these components were required. These changes are itemized below and shown in Figure 1.

- Support P/N 209-001-717-1 was removed and replaced with an aluminum alloy hog-out. The new support attaches to the airframe using the same mounting holes and hardware.

- Control Tube P/N 2J9-001-063-17 was removed and replaced with a tube having the ballistic-damage-tolerant clevis.

- Control Tube P/N 209-001-064-7 was removed and replaced with a tube having a new rod end clevis to fit the new bellcrank.

- The following airframe changes are required if flight testing of the above components is desired:

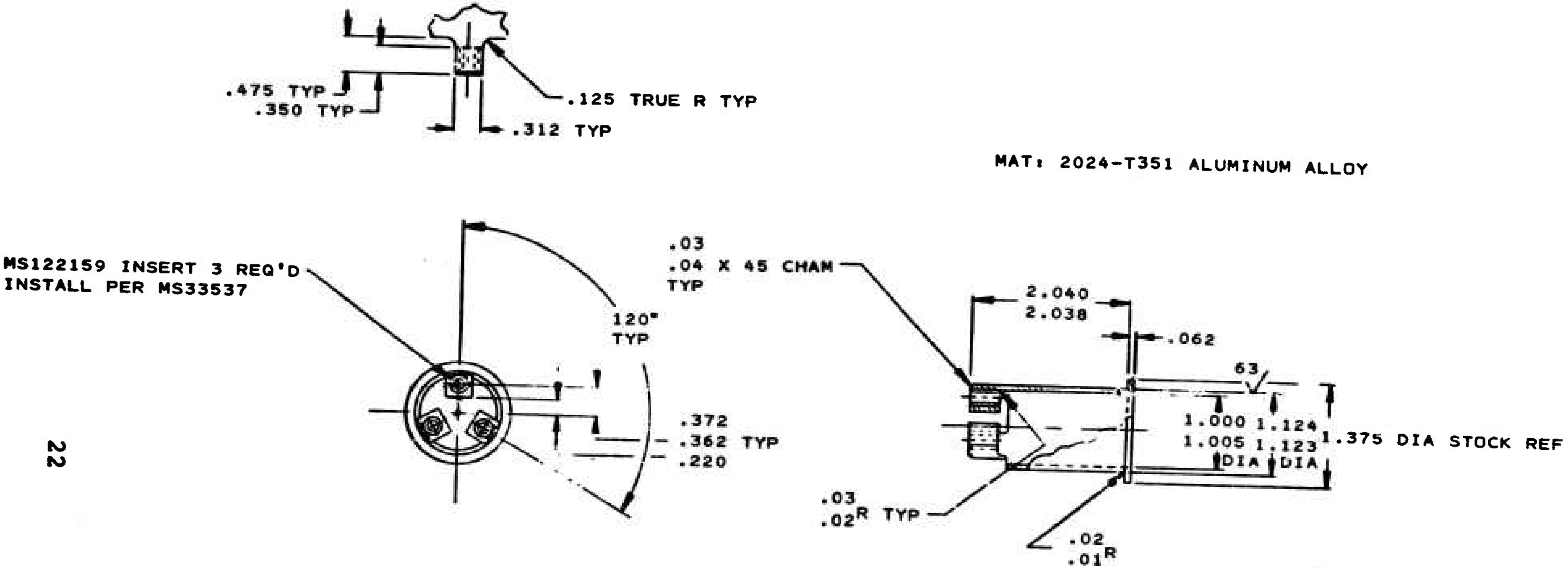


Figure 9. Pin assembly.

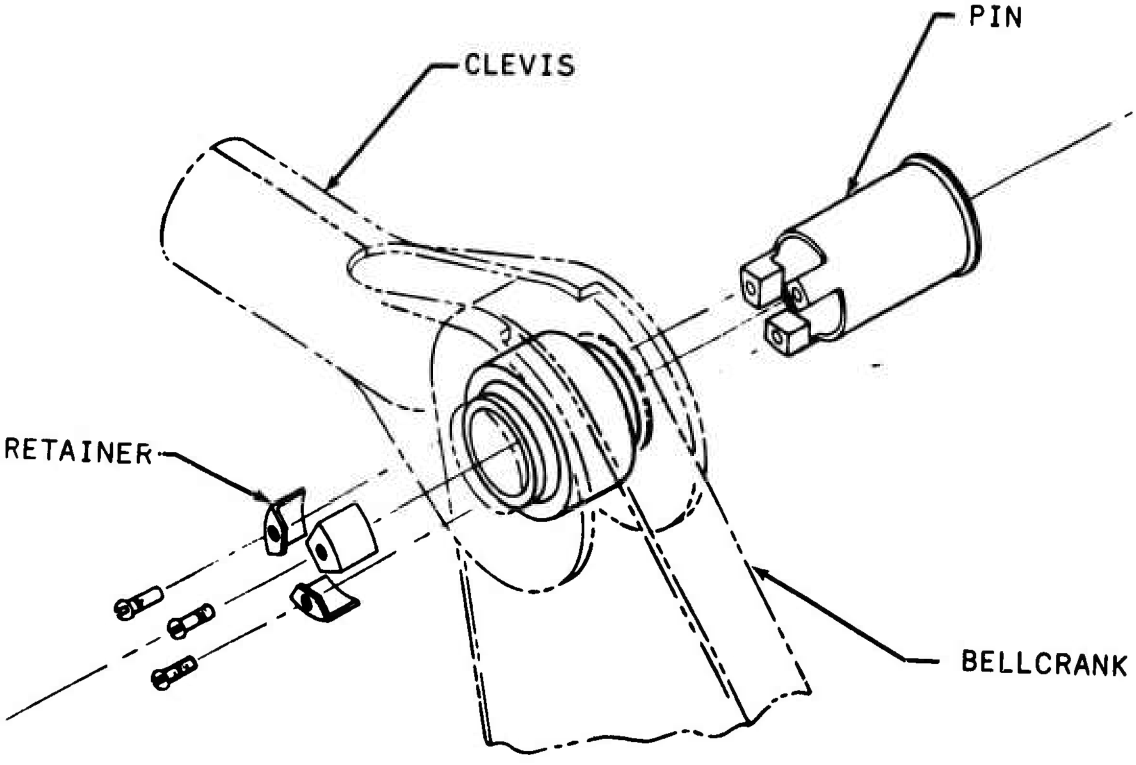


Figure 10. Exploded view of pin assembly.

- A portion of the cap must be removed between stations 138.7 and 148.5 to provide clearance for the rod end clevis when it is in the extreme travel position.
- The clearance hole in the 209-030-169 support must be enlarged to provide additional clearance for the end of the new bellcrank.

3.0 MANUFACTURING

3.1 MANUFACTURING CONCEPT

The tools and dies used in this program are shown in Figures 11 through 17. The basic philosophy was to minimize tooling costs.

For high-volume production, it is recommended that the bond fixtures incorporate heating elements and cooling coils to facilitate faster curing. It is further recommended that the mandrels for the inner and outer ribs of the bellcrank consist of a series of detachable sections so that each section is made to the exact dimensions of the rib and that any number of ribs can be cured at one time.

3.2 BEARING FABRICATION (299-001-701 and 299-001-702)

The bearings were manufactured by the Fafnir Bearing Company to Bell Helicopter specifications. Fabrication of this bearing, as originally conceived, would allow the graphite balls to be used in the "as-molded" condition. In the course of manufacture, however, it was found that the ball sphericity and smoothness could not be held within the required limits. This problem was resolved by grinding the ball prior to assembly of the bearing.

3.3 MANUFACTURING OF BELLCRANK ASSEMBLY (299-001-703-1)

The bellcrank was made from epoxy prepreg laminated material. Manufacture of the bellcrank was divided into four steps consisting of fabrication of the web, bearing sleeves, and ribs, and the assembly of these details. An exploded view of the bellcrank assembly is shown in Figure 6.

To manufacture the 299-001-703-5 web, a 2 x 4 foot multilayer laminate of woven prepreg fabric (Hexcel Corp. Coast Mfg. Div. No. F180-1/2P181 per MIL-C-9084, Type VIII, VIIIA or VIIIB as an alternate) was laid up on a flat plate, bagged, and heat cured under pressure in an autoclave. The web elements were cut to size from the cured laminate with the steel blank and pierce die.

The bellcrank requires one 299-001-703-7 outer rib and two symmetrical 299-001-703-9 inner ribs (see Figure 6). The ribs were fabricated as follows. First, the mandrel was coated with a release agent. Next, the 1-inch wide tapes of unidirectional prepreg fibers (Scotchply 250SF1 per MIL-R-9300) were wound on the mandrel; the tapes were separated by rows of cork/neoprene rubber (see Figure 12). This vinyl bagging was applied, and the ribs were heat cured under pressure in an autoclave. After

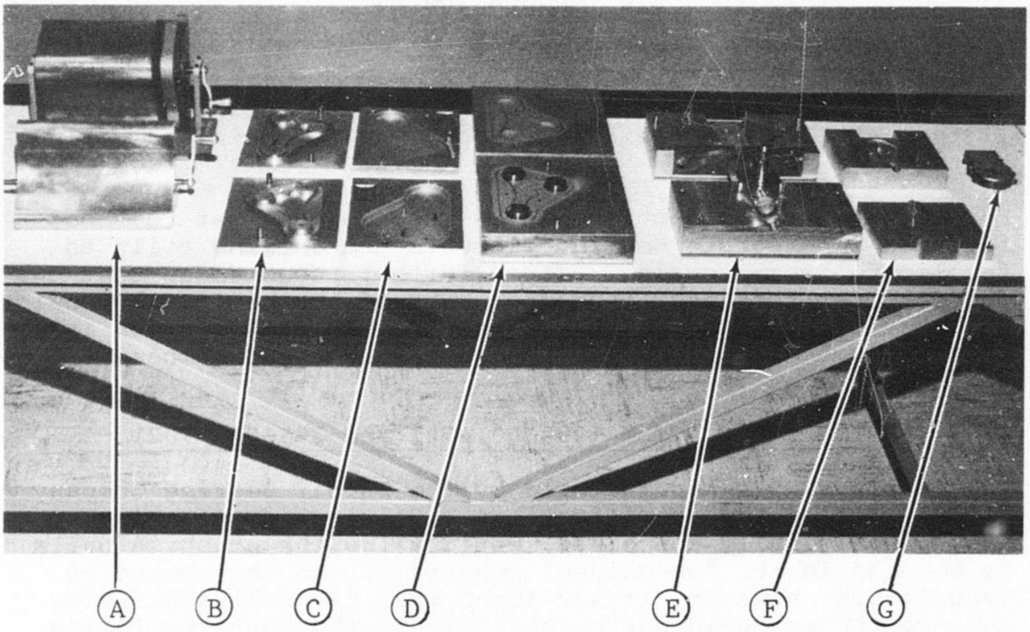


Figure 11. Tool and die family.

Ⓐ Mandrels for forming inner and outer ribs

Ⓑ & Ⓒ Dies for forming silicone rubber inserts for bellcrank cavity bond fixture

Ⓓ Bellcrank cavity bond fixture

Ⓔ Clevis cavity bond fixture

Ⓕ Dies for forming silicone rubber inserts for clevis cavity bond fixture

Ⓖ Steel rule die for blanking out woven fabric for clevis halves

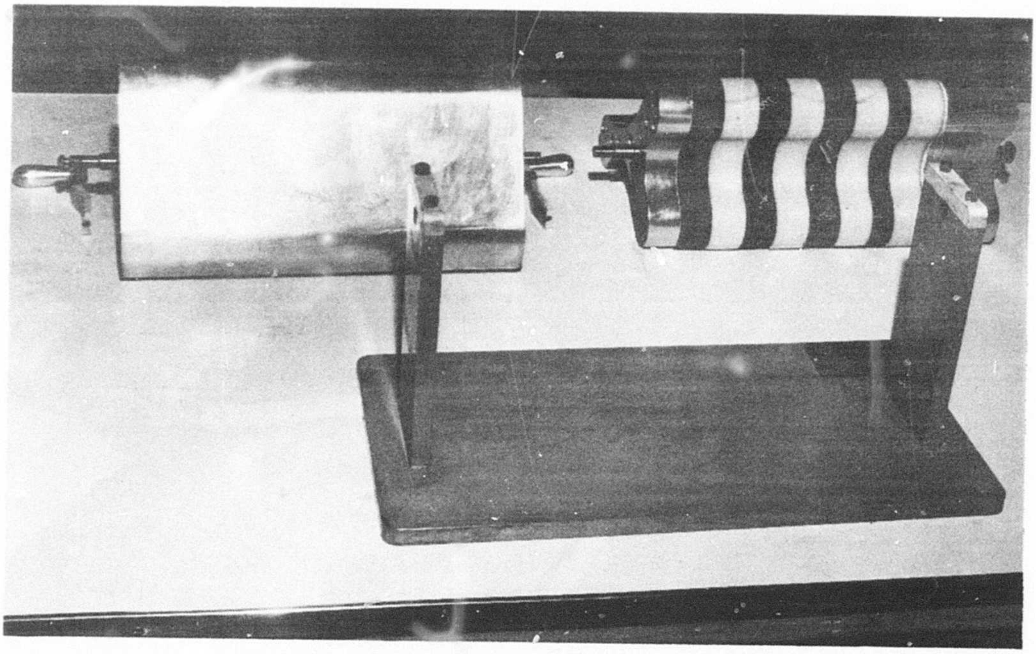


Figure 12. Mandrels for outer and inner ribs.

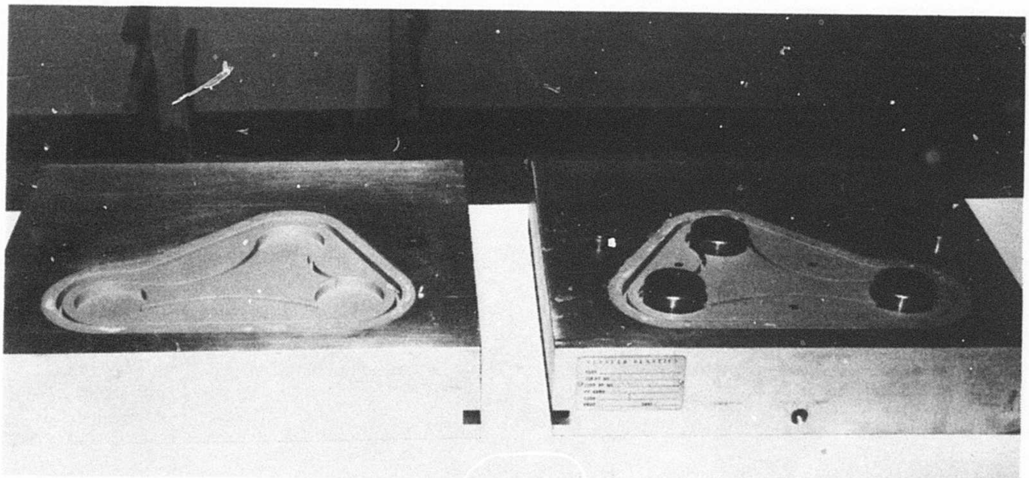


Figure 13. Bellcrank cavity bond fixture.

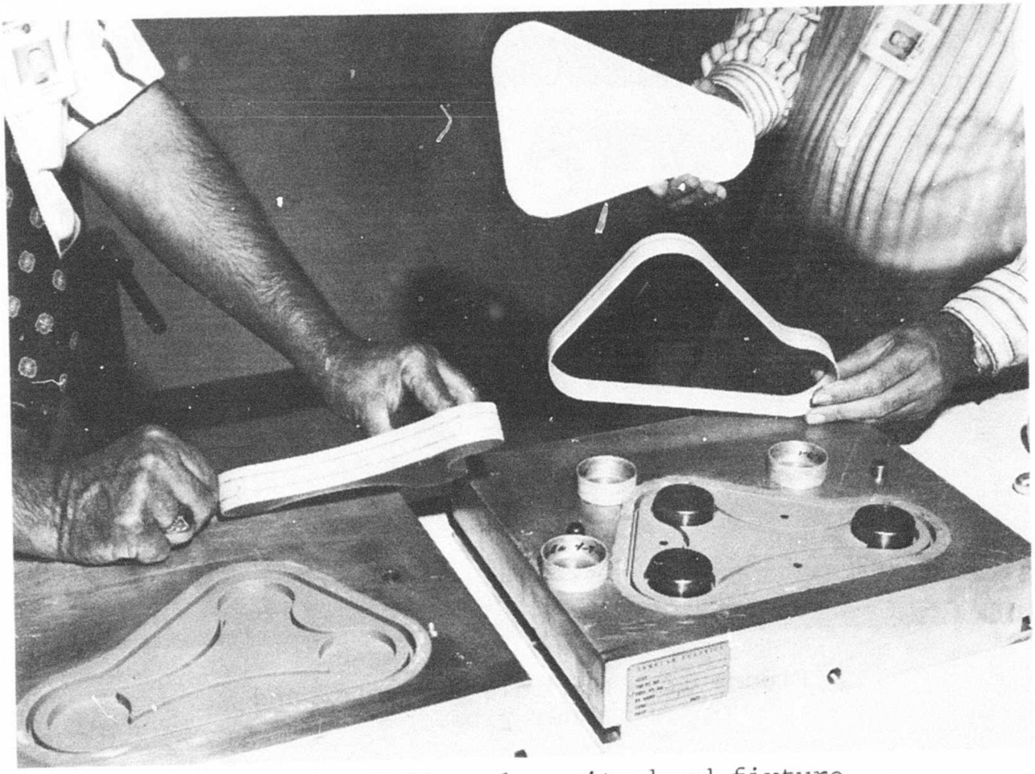


Figure 14. Bellcrank cavity bond fixture with subassembly details.

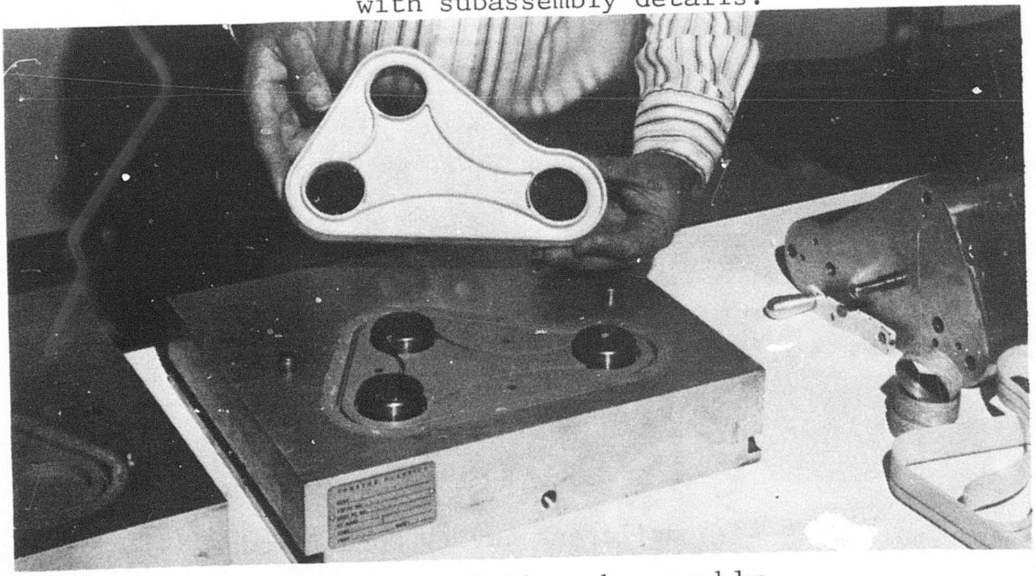


Figure 15. Bellcrank assembly (without bearings).

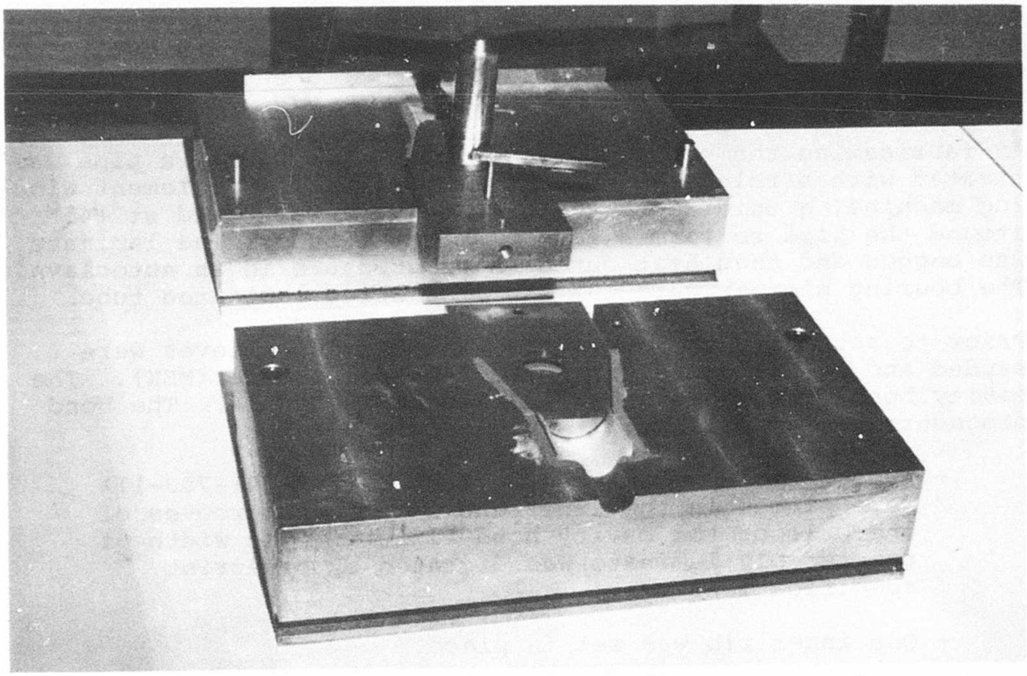


Figure 16. Clevis cavity bond fixture, view 1.

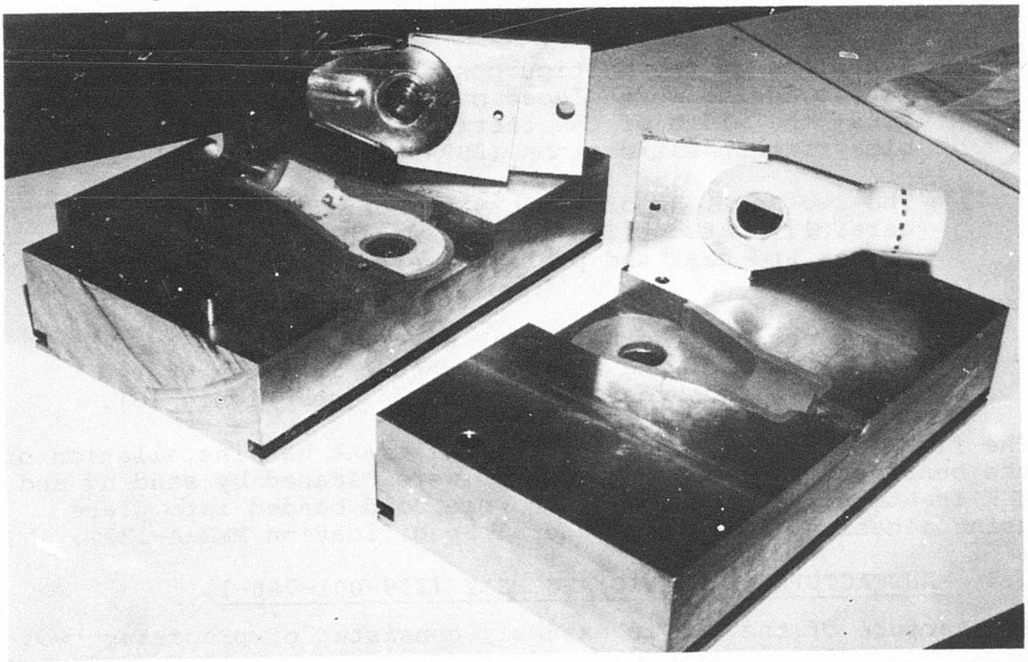


Figure 17. Clevis cavity bond fixture, view 2.

being cured, the parts were trimmed to size. The tools were designed so that the correct configuration was obtained when the tool was thermally expanded during the heat cure cycle. Contraction of the tool on cooling permitted easy removal of the cured part.

In fabricating the bearing sleeves (299-001-703-3), a pipe was treated with a release agent; and, by means of a filament winding machine, a unidirectional prepreg yarn was wound at ±45° around the pipe to form a long, laminated tube. The laminate was bagged and then heat cured under pressure in an autoclave. The bearing sleeves were cut from the cured laminated tube.

Prior to assembly, the web, ribs, and bearing sleeves were sanded and then cleaned with methol eythol ketone (MEK). The cavity bond fixture is shown in Figures 13 and 14. The bond procedure was as follows:

- Two plies of woven prepreg fabric (299-001-703-11) were placed in the inner and outer band grooves of one-half of the cavity bond fixture. The width of the two-ply laminate was dictated by blueprint specifications.

- One inner rib was set in place.

- The web, outer rib, and bearing sleeves were set in place.

- Two plies of the multipurpose adhesive, laminate fabric edging were placed over the inner and outer ribs; the width of the fabric was again based on blueprint specifications (299-001-703-11).

- The two sections of the cavity bond fixture were carefully mated. The fixture was placed in a platen press, and heat and pressure were applied to effect curing.

- After curing, the bellcrank was removed from the mold, trimmed, and abrasive sanded in areas where excessive squeezeout had occurred (see Figure 15).

The final step in fabricating the bellcrank was installation of the bearings. The bearing sleeves were cleaned by sanding and MEK treatment, and the bearings were cold bonded into place using adhesive (EA934 per Federal Specification MMM-A-132).

3.4 MANUFACTURE OF CLEVIS ASSEMBLY (299-001-706-1)

Manufacture of the clevis assembly consisted of preparing two symmetrical clevis halves and two aluminum bushings and then mating these items with an aluminum adapter. An exploded view of the clevis assembly is shown in Figure 8.

The 299-001-708-1 bushings and the 299-001-707-1 adapter were fabricated by machining; the bond surfaces were treated by vapor blasting, cleaning with MEK, and then coating with an adhesive primer. Blanks of woven prepreg fabric (299-001-706-3) were formed using a steel rule die (Figure 11). The bushings, blanks, and adapter were placed into one-half of the cavity bond fixture (Figures 16 and 17). The two halves of the fixture were joined and the fixture was placed in a platen press. The prepreg material was cured at the required temperature and pressure. After curing, the clevis was extracted from the bond fixture and the flashing was removed.

The clevis assembly was completed by applying a reinforcing wrap. The bonding surfaces were sanded, cleaned with MEK, and air dried. By means of a filament-winding machine, a prepreg unidirectional yearn was wound to form the outer reinforcement wrap. Heat-shrinkable nylon film was wrapped around the reinforcement, and the resin was cured at the proper temperature in an oven. After cure, the flashing was trimmed. Finished parts are shown in Figure 18.

3.5 QUALITY CONTROL METHODS

In general, the Bell Helicopter Quality Assurance Plan is as follows. The plan, in detail, is presented in Appendix A. Bell Helicopter Process Specifications govern the control of processes. Physical inspections are specified in work instructions, such as Production Planning and Assembly Inspection Logs, at appropriate points in the production cycle and in accordance with instructions provided to Production Planning by the Quality Department. Acceptance criteria are provided for all required inspections and for monitoring significant elements of production cycles.

Designs were reviewed for quality assurance provisions and technical definitions for control purposes.

Production planning was reviewed to verify:

- The existence of adequate numbers of inspection checkpoints and their incorporation at appropriate points in the manufacturing cycle.

- Adequacy of step-by-step fabrication, machining, and assembly instructions.

- Traceability to the worker for each manufacturing operation and to the inspector for each inspection operation.

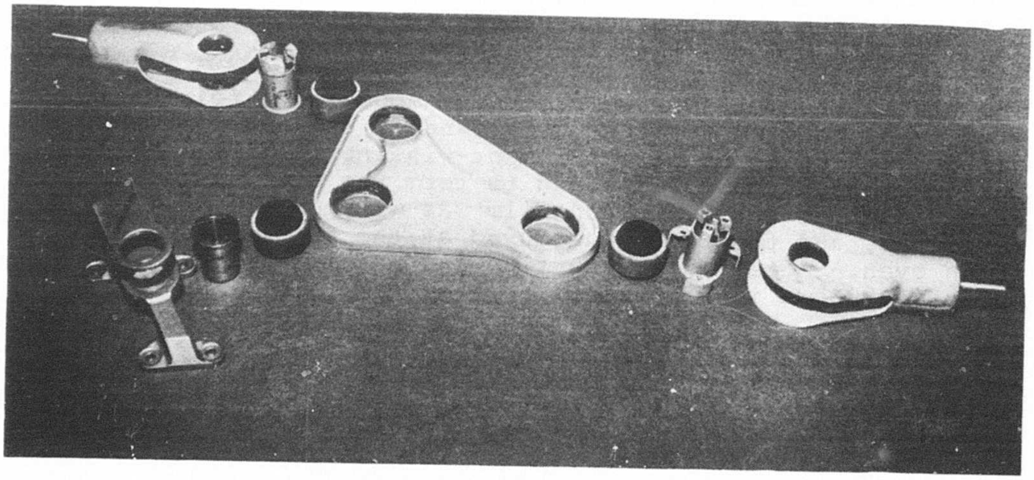


Figure 18. Finished detail parts.

4.0 TESTING

4.1 GENERAL

The original amount of required testing was very comprehensive, but late in the program. The amount of testing was reduced to only the most significant tests. This resulted in the omission of the fit and function test and all of the environmental tests except for the fungus test. The remaining tests were as follows:

- Preliminary oscillatory load test
- Proof test
- Ballistic test
- Post-ballistic oscillatory load test
- Ultimate load test
- Fungus test

For the mechanical tests, two of each of the following were used as test specimens: a 299-001-705-1 Tube Assembly, a 299-001-703-1 Bellcrank Assembly, a 299-001-710-1 Clevis, and a 299-001-704-1 Support. Of these, only the clevis on the tube assembly and the bellcrank are ballistic-damage tolerant.

All mechanical testing was performed in the Bell Helicopter Mechanical Test Laboratory at Fort Worth, Texas, between November 15 and December 5, 1974.

4.2 PRELIMINARY OSCILLATORY LOAD TEST

The test machine used for the oscillatory loads tests is shown in Figure 19. The machine was designed to test two sets of controls simultaneously. Motion was applied to the controls by means of a hydraulic servo cylinder connected in a manner to produce oscillatory rotary motion about the nonself-aligning bearings. The controls were mounted in the machine so that their relative motion duplicated that of the helicopter installation. Reaction to the motion of the controls, to introduce the proper force in the system, was provided by adjustable cantilever, leaf-type springs. The length of the springs was adjusted to apply the proper force at the maximum displacement from the neutral position. An electromechanical counter was used to record the accumulated cycles and to shut off the machine automatically when the desired number of cycles was

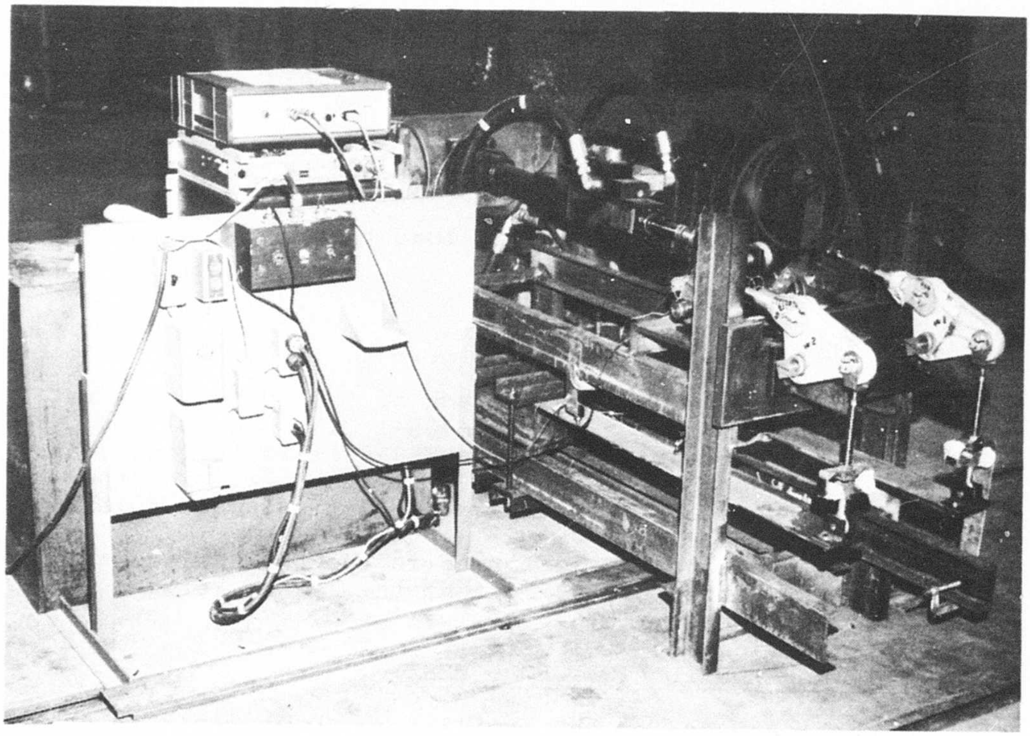


Figure 19. Cyclic test fixture.

reached. Limit switches and vibrator switches were positioned to shut off the machine in case of a failure in either the specimen or the machine.

The test load for the preliminary oscillatory loads test was the cyclic load resulting from the application of ±10 pounds at the rudder, which produced an alternate tension and compression load in the controls. The controls were moved through their full travel at 2 cps for one million cycles.

No failures or significant deterioration of the control was noted during the preliminary tests. A creaking noise was noted in specimen No. 1 during initial start-up, so the test was stopped and the specimen examined. No binding or stiffness was noted, and upon restart, the noise was gone and it never reappeared. The bearings ran slightly warm to the touch during the test. The bellcrank in specimen No. 2 had a small amount of material extending from the pivot bearing between the inner and outer race, but after completion of the test no signifcant deterioration of the bearing, as evidenced by lateral or radial looseness, was noted.

4.3 PROOF TEST

The fixture used for performing the proof test is shown in Figure 20. The controls were positioned in the fixture at the most critical loading position. Tensile load was applied by means of a hydraulic cylinder using a hand pump with a calibrated pressure gage. See Appendix B for test loads.

No failures were experienced during proof testing.

4.4 BALLISTIC TEST

For the ballistic test, the controls were mounted as shown in Figure 21. A .30-caliber, fully tumbled round was fired into the bearing at the junction of the 299-001-705-1 tube and the 299-001-703-1 bellcrank assembly, as shown in Figures 21 and 22. The projectile entered broadside at 45° obliquity. A deadweight load of 20 pounds was applied to the controls during the test. Specimen No. 2 was heated to 160°F by heat lamps directed at both sides of the controls and was at this temperature at the time of the ballistic test. Specimen No. 1 was not heated prior to the test.

Figure 21 shows the damage sustained by specimen No. 1, while Figures 22 and 23 show the damage to specimen No. 2 during the ballistic test. Both specimens moved freely at the damaged junction and did not exhibit any significant amount of slack either laterally or radially.

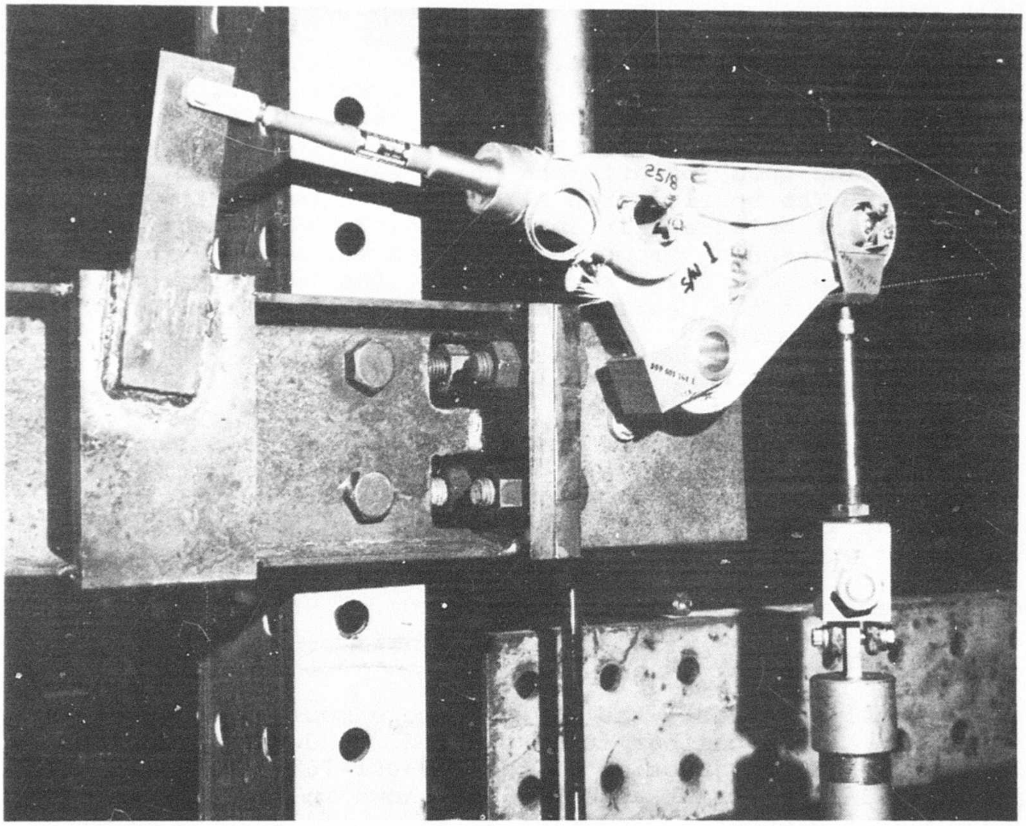


Figure 20. Static load test fixture.

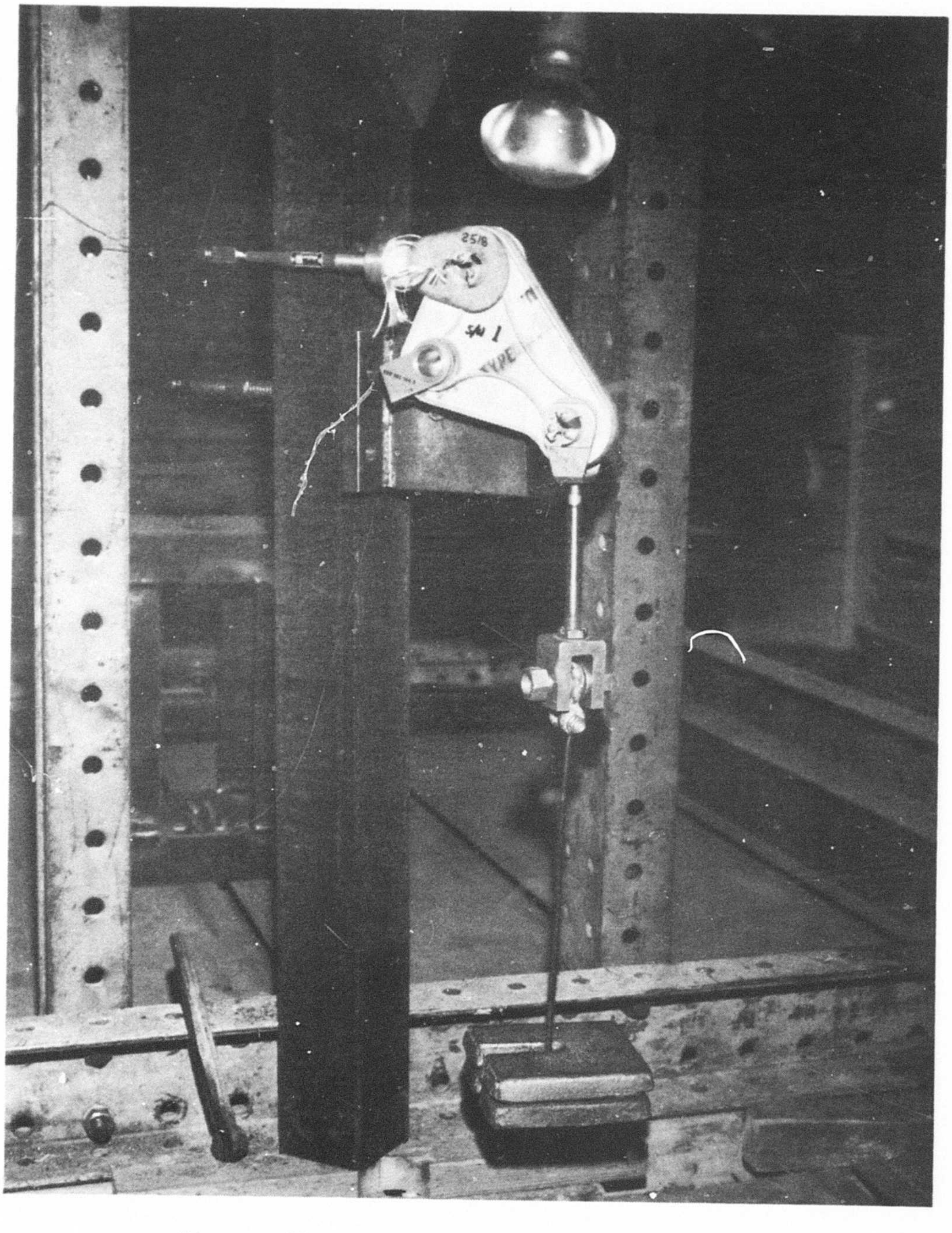


Figure 21. Ballistic test fixture and specimen no. 1 after impact.

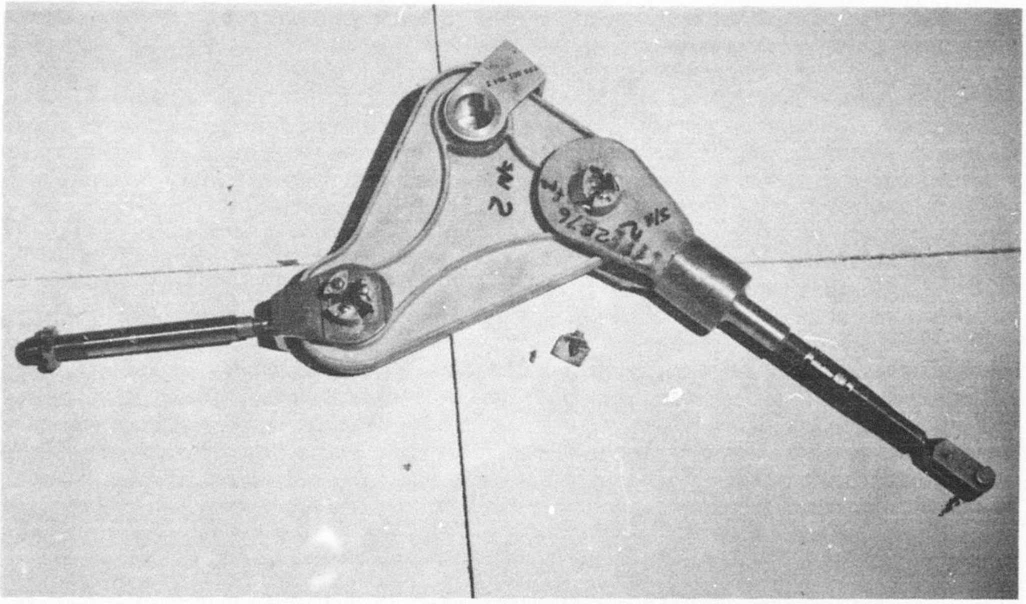


Figure 22. Results of ballistic test on specimen no. 2 - entry side.

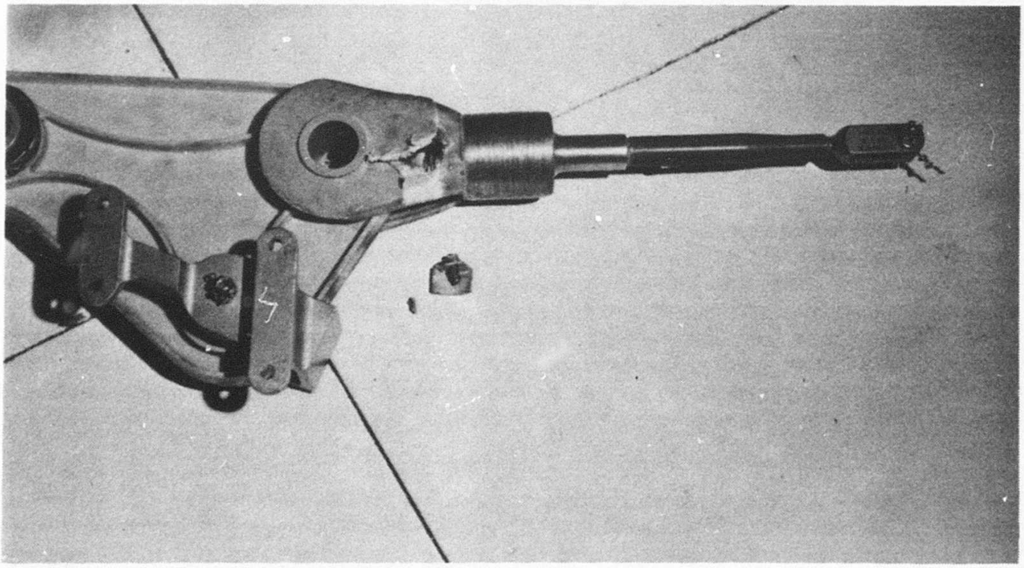


Figure 23. Results of ballistic test on specimen no. 2 - exit side.

4.5 POST-BALLISTIC OSCILLATORY LOADS TEST

Following the ballistic test, the damaged specimens were returned to the oscillatory loads test machine. The specimens were cycled at a load equivalent to ±10 pounds at the rudder pedals for 1600 cycles. Then, the load was increased to an equivalent of ±18 pounds on the pedals for an additional 400 cycles. Both specimens survived this test without significant loss of functioning capability.

4.6 ULTIMATE LOAD TEST

The specimens were reinstalled in the fixture used for the proof test. The load was applied as before except that it was continually increased until failure occurred.

Specimen no. 1 failed under a maximum tensile load of 1841 pounds. Failure occurred from lateral buckling of the bellcrank and subsequent cracking around the pivot bearing.

On specimen no. 2, the side of the clevis that had been partially severed during the ballistic test failed at 312 pounds applied tensile load. The other side of the clevis fractured at 525 pounds applied tensile load, resulting in a complete loss of load-carrying capability. Limit load is 424 pounds.

4.7 FUNGUS TEST

The assembled bellcrank and clevis were fungus tested in accordance with MIL-STD-810B, Method 508, Procedure I, using the following spores:

- Aspergillus niger
- Aspergillus flavus
- Aspergillus versicolor
- Penicillium funiculosum
- Chaetomium globosum

The assembly was hung in the fungus chamber (see Figure 24) for one day of stabilization. Then the chamber door was opened and the control samples and assembly were inoculated with the fungus spore suspension. The chamber was closed and the temperature was maintained above 84°F (29°C) and 95 percent relative humidity. After 14 days, the chamber was opened to allow inspection of the control samples. After the full 28 days from inoculation, the chamber was opened and the control samples and all parts of the assembly were inspected for fungus growth. No growth was noted upon inspection of the assembly.

The testing was performed at Environ Laboratories, Inc.
Dallas, Texas.

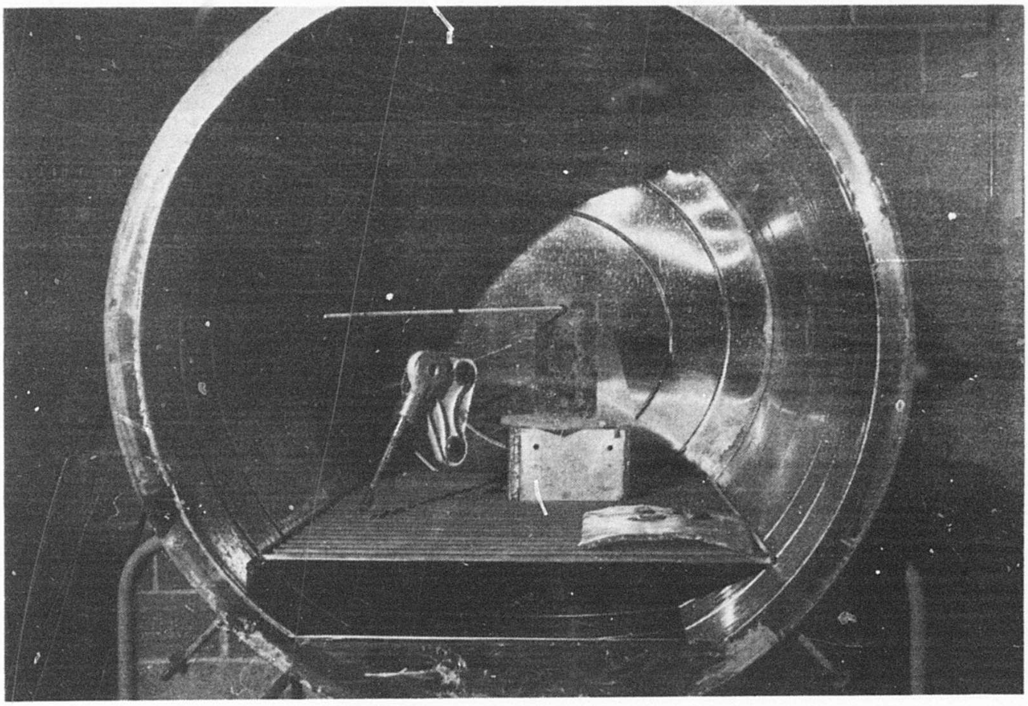


Figure 24. Fungus test chamber.

5.0 COST

During the design phase of this program, a cost analysis was performed. The analysis considered the original tooling concept. Figure 25 shows the fabrication time required for units of the bellcrank on a 95 percent experience curve. All time required in the fabrication of details of the bellcrank assembly is included, except for the bearings. The amortized cost of the bearings is contained in Figure 26. Unit costs are based on quotations obtained from the bearing vendor during 1973. Tables 1 and 2 contain the estimated nonrecurring costs and recurring cost of unit number 1 of the bellcrank and clevis, respectively. Figure 27 shows the unit fabrication time for the clevis on a 95 percent experience curve.

Adjustments to these cost data become necessary due to a change in the tooling concept. Capacity of the belt tools was decreased and the integral heating feature of the belt and assembly tools was eliminated. These changes were predicted on budgetary considerations.

Only the bellcrank is treated in the new cost analysis since it alone has reasonable prospects of future production. (It is not likely that the clevis would be produced except as a part of a composite link assembly.)

Figure 28 shows the man-hours required for fabrication of the bellcrank with as-built tools. The plot is based on an 87 percent experience curve instead of the 95 percent used previously. The rationale for using the 87 percent curve is that considerably more labor would be involved in the first article, and the slope of the curve would be steeper due to the greater amount of hand labor.

Table 3 contains the recurring fabrication time for unit number 1 of the 299-001-703 bellcrank assembly according to the amended analysis. Using data from Figures 26 and 28, material costs (exclusive of bearings) of $7.20, and a labor rate of $22.00/hour, the estimated cost of the 299-001-703 bellcrank assembly is $205.96 for the 250th unit of a 500 part production order. Components of this cost are:

Labor (2.47 hrs @ $22.00)	$ 54.34
Bearings (3 @ $48.14)	144.42
Other material	7.20
Total	$205.96

For comparison purposes, it should be noted that the current spares cost of the 209-001-754-1 bellcrank assembly (metal) is approximately $60.00.

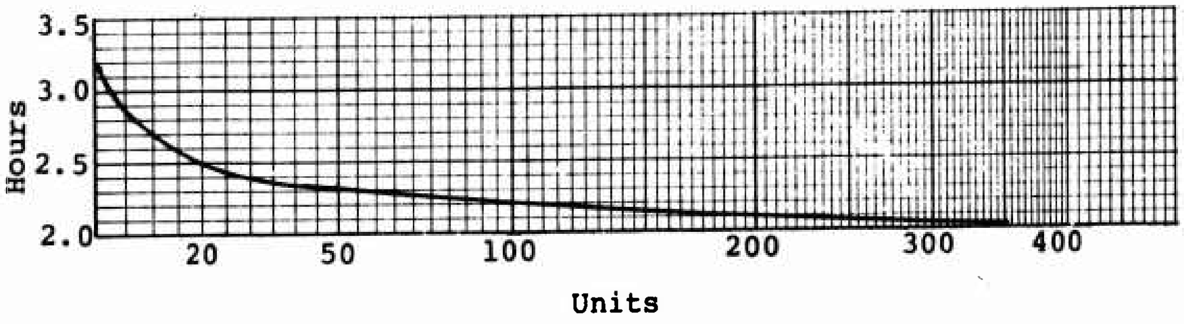


Figure 25. Bellcrank unit fabrication time (95% experience curve).

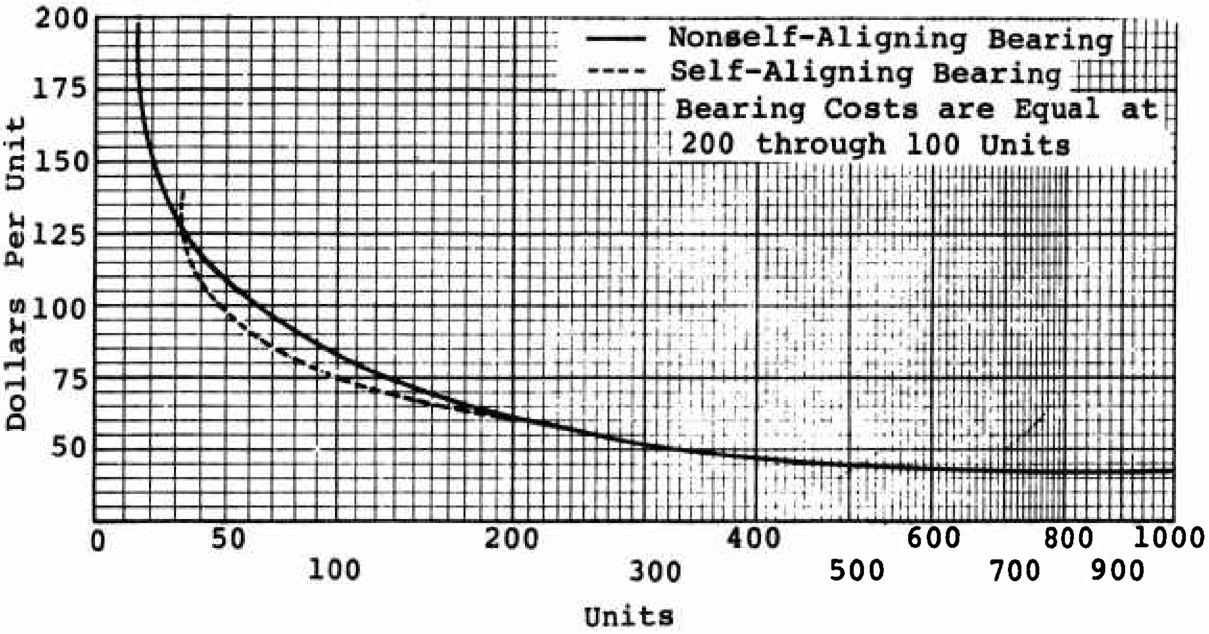


Figure 26. Bearing, amortized cost per unit.

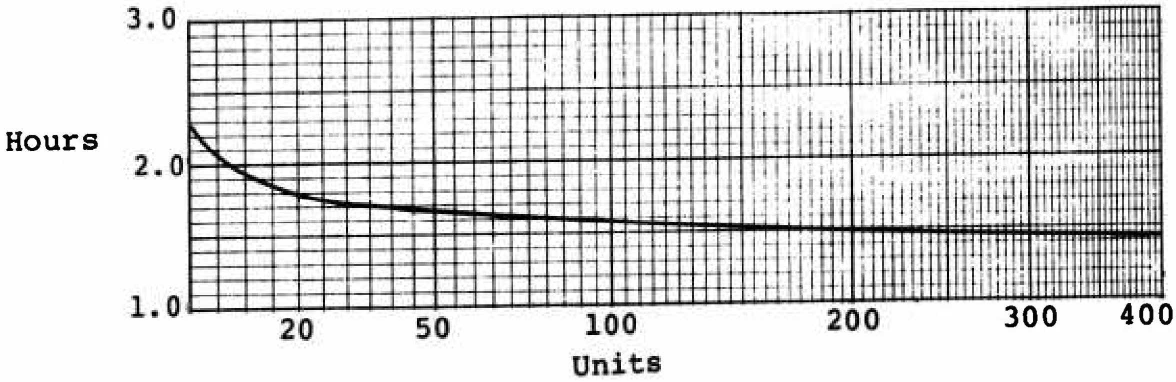


Figure 27. Clevis unit fabrication time (95% experience curve).

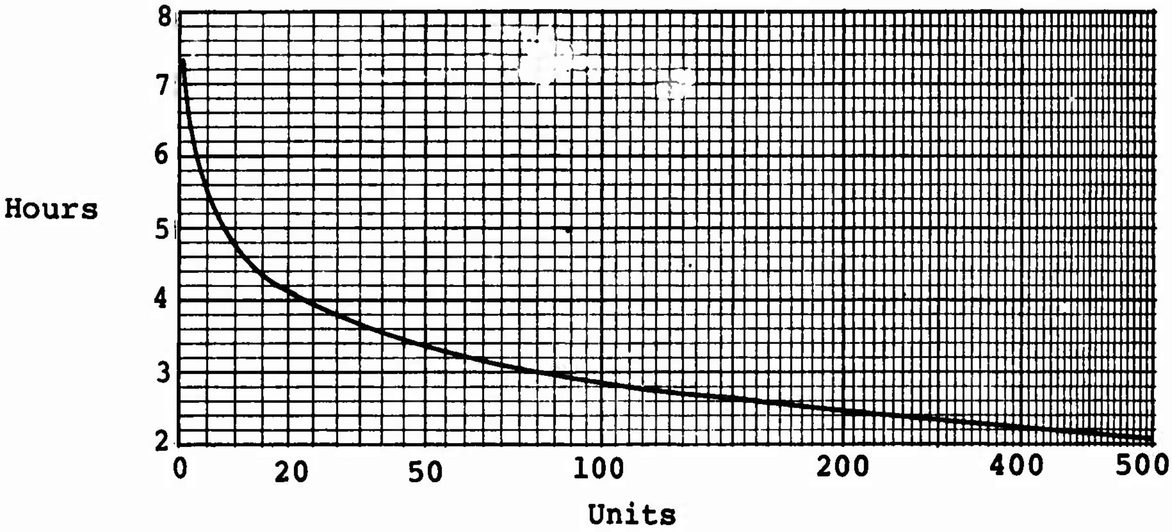


Figure 28. 299-001-703 bellcrank assembly unit fabrication time (87% experience curve).

TABLE 1. BELLCRANK - COST ANALYSIS (1973)

NONRECURRING COSTS

Tooling	Hours
Belt mandrel-outer	100.0
Belt mandrel-inner	130.0
Web blank die	50.0
Web laminating plates	48.0
Bond fixture	200.0
Insert molds (2)	50.0
Bearing bond fixture	24.0
Tool design	120.0
	722.0
Planning & development	460.0
Total	1182.0
Tooling material:	$2160.00

RECURRING COSTS

Fabrication Unit No. 1	Hours
Fabricate belts	.09
Fabricate web blank	.04
Prepare brg. liners	.45
Prepare prepreg details	.30
Assemble det's. & cure	1.13
Clean up	.30
Cold bond brgs.	.80
	3.11
Silicone inserts (2) 4.0 hrs @ 50 cycle life	.08
Total	3.19

Material	
Bearing liners	$ 4.50
Prepreg & filiment	6.00
Self-align brgs. (30 pcs)2	276.34
Nonself-align brg (15 pcs)	196.34
Unit No. 1 total	$483.17

TABLE 2. CLEVIS - COST ANALYSIS (1973)

NONRECURRING COSTS		RECURRING COSTS	
Tooling	Hours	Fabrication-Unit No. 1	Hours
Steel rule die	8.5	Stack prepreg for blank	.07
Bond fixture	280.0	Blank two halves	.07
Insert molds (2)	50.0	Assemble det's. to mandrel	.60
Tool design	80.0	Load in bond fixt. & cure	.60
	418.0	Prepare assem. for outer wrap	.30
		Apply outer wrap & cure	.45
		Clean up	.15
			2.24
Planning & Development	440.0		
Total	858.5		
		Silicone inserts (2) 4.0 Hrs @ 50 cycle life	.08
		Total	2.32

Material

Tooling ----$1300.00

Part ------ $7.20

TABLE 3. RECURRING FABRICATION TIME
299-001-703 BELLCRANK ASSEMBLY
UNIT NO. 1

Task	Man-Hours
Fabricate belts	1.62
Fabricate web blank	.72
Prepare bearing liners	.45
Prepare pre-preg details	.60
Assemble details and cure	2.90
Clean up	.30
Cold bond bearings	.80
	7.39
Silicone inserts (2) 4.0 hours @ 50 cycle life	.08
Total man-hours	7.47

6.0 CONCLUSIONS

There were no unresolved design or manufacturing problems remaining at the conclusion of the program. Fabrication proceeded basically as planned, and the resulting parts were high in quality and were in conformity with the engineering requirements.

The test results verified the quality of the manufacturing techniques used. Both sets of the ballistic-damage-tolerant controls successfully completed all phases of the mechanical, ballistic, and environmental tests. Residual static strength in both specimens was adequate for the control of a helicopter after damage from a .30-caliber projectile.

Weight and bulkiness will be problems in control systems containing BDT components such as these. The weight of the BDT bellcrank (.74 pound) is approximately twice that of its metallic counterpart (.44 pound). The weight of BDT pushrods will not be known without further study, but it is expected that they too would be heavier due to the increased bulk. Because of bulk, modifications to the AH-1G airframe structure are required in order to accommodate the components. For this reason, incorporation of BDT controls into existing helicopters would be difficult. In addition, certain areas of the helicopter would become so congested as to preclude the wide separation of parts that is desirable for survivability.

7.0 RECOMMENDATIONS

The endurance of the parts made in this program, particularly the bearings, was better than expected. More work should be done in developing composites for aircraft control systems, not only for ballistic-damage-tolerant parts, but for conventional size parts to replace the present metallic components. It can be seen in Section 5.0 that the cost of a composite bellcrank with conventional bearings would be comparable to the cost of a metal bellcrank.

Additional effort is recommended to investigate materials and processes which reduce the cost of bearings used in this particular ballistic-damage-tolerant controls concept.

Because of the problems associated with the bulkiness and weight of BDT components, it is recommended that BDT control systems be considered primarily for new helicopter designs where sufficient space can be provided.

APPENDIX A

QUALITY ASSURANCE PLAN

A1.0 INTRODUCTION

The purpose of this plan is to identify those tasks that must be accomplished in order to control the procurement, testing, storage, fabrication, verification and assembly of Ballistic-Damage-Tolerant Flight Control Components. The plan is based on MIL-Q-9858 and oriented to the specific requirements of Contract DAAJ02-73-C-0063 Phase I - Development of Manufacturing Process, Section F, para. (3), and Phase III - Quality Assurance Plan, Section F.

A2.0 PRODUCT ASSURANCE PLAN

The Project Assurance Plan complies with the intent of Military Specifications for quality programs, primarily MIL-Q-9858A, and other Product Assurance specifications as required. Implementing programs, procedures, inspection instructions and other necessary Quality Control document action will be generated to assure program effectiveness.

A2.1 Applicable Documents

The following documents of the issue listed form a part of this plan to the extent specified herein:

A2.2 Specifications:

Military

MIL-Q-5858A, Quality Programs Requirements
MIL-C-45662A, Calibration Systems Reauirements
MIL-A-8623A, Adhesive, Epoxy Resin
MIL-P-9400A, Plastic Laminate Materials

A3.0 SPECIFIC PRODUCT ASSURANCE REQUIREMENTS FOR BALLISTIC-DAMAGE-TOLERANT CONTROL COMPONENTS.

A3.1 Control of Services and Supplies

It is the responsibility of Product Assurance to ensure that the Purchasing Department maintains an effective procurement program.

A3.1.1 Area Control

Product Assurance will ensure that area controls are adhered to with specific attention to:

- Atmosphere controls
- Work surfaces
- Storage areas
- Handling of materials

A3.1.2 Surface Preparation

Ensure that surfaces are prepared for bonding in accordance with accepted cleaning procedures. An inspection buy-ff on shop work sheets will be required.

A3.1.3 Product Testing

Product Assurance will audit production testing per specifications.

A3.1.4 Material Protection

Product Assurance will perform a daily audit to ensure protection of materials prior to use.

A3.1.5 Material Use Limit

Product Assurance will ensure that the accumulated time for materials released from refrigerated storage does not exceed the specified time for each material.

A3.1.6 Nondestructive Testing

Nondestructive test of Flight Control Components will include tapping and visual inspection of bond quality. All finished control components will be penetrant inspected. Acceptance limits will be established.

A3.1.7 Destructive Testing

Destructive testing procedures will be established. Product Assurance will correlate destructive test results with NDT requirements of para A3.1.6.

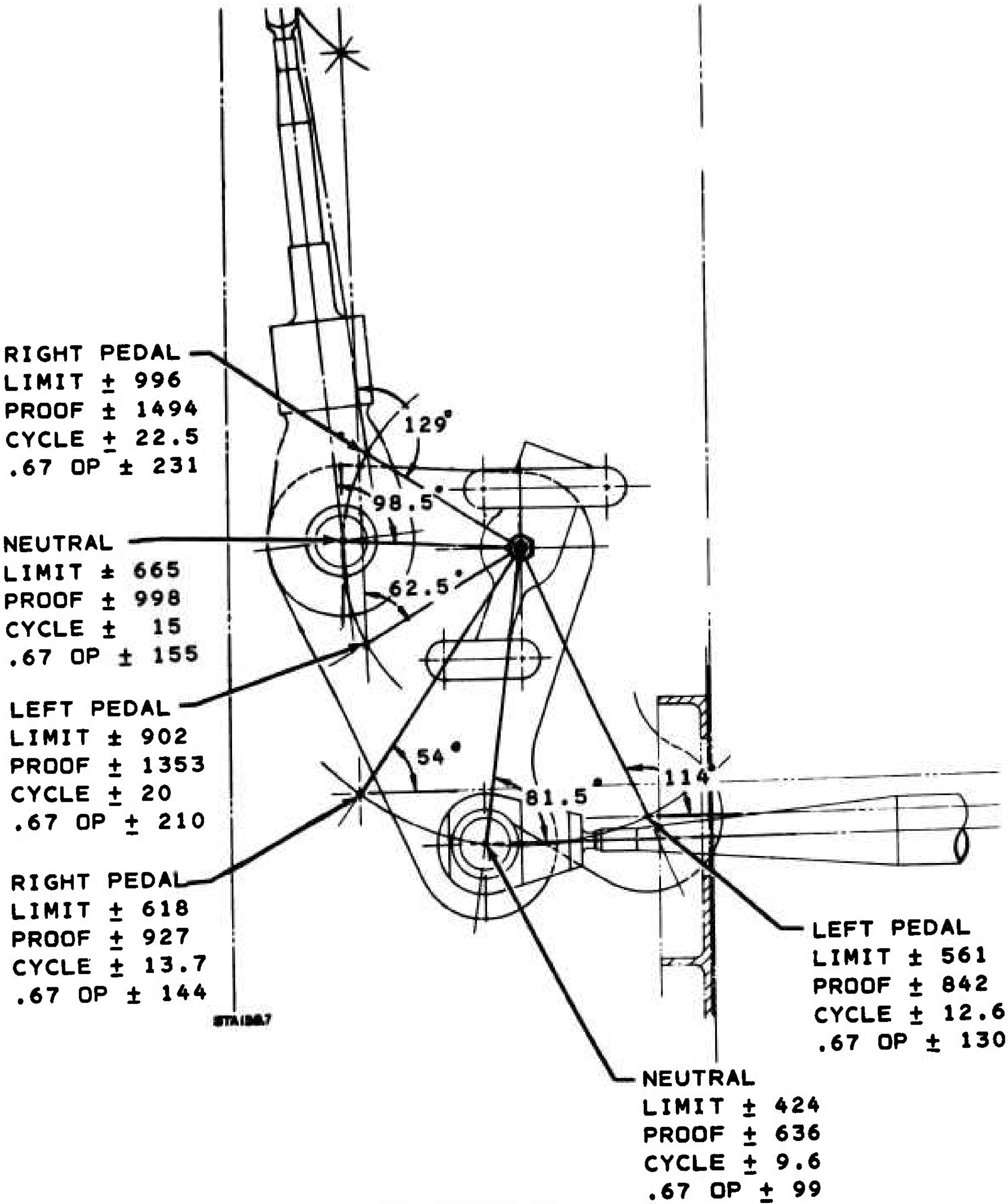
A3.2 DEFECTS

Product Assurance will use the methods of inspection required to detect and locate the following type defects.

- Internal voids

- Blisters
- Wrinkles
- Delaminations
- Foreign Objects
- Cracks

APPENDIX B
TEST LOADS



VIEW LOOKING OUTBOARD
R.H. SIDE
NORMAL TO PLANE OF
CONTROL MOTIONS

APPENDIX C

ALTERNATE PIN CONFIGURATION