TM 78-1 SY

Technical Memorandum

AIRCRAFT ENGINE DRIVEN ACCESSORY SHAFT COUPLING IMPROVEMENTS USING HIGH-STRENGTH NONMETALLIC ADAPTER/BUSHINGS, A PROGRESS REPORT

Mr. Aleck Loker

Systems Engineering Test Directorate

31 March 1978

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AIRCRAFT POWER TRANSMISSION
RELIABILITY
GENERATOR DRIVE SHAFTS
STARTER DRIVE SHAFTS
HYDRAULIC PUMP DRIVE SHAFTS

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Engine driven accessories, such as generators, starters, and pumps, are commonly connected to their respective power takeoff shafts by spline couplings. These shaft couplings, which allow rapid installation and removal of the accessory, are capable of high torque transmission and are considered to be self-centering. However, because of the rapid wear and failure rate of these couplings, NAVAIRTESTCEN has engaged in a continuing spline coupling improvement program over the past 10 years. An outgrowth of this program has been the development of the new high-strength nonmetallic spline coupling adapter/bushing technology. A previous report, Technical Memorandum TM 76-1

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SY, condensed the results of these coupling improvement efforts into a description of two basic spline coupling designs (crowned circular toothed and flat toothed splines) and explained their apparent success.

This Technical Memorandum presents information pertaining to manufacturing techniques, contains previously unpublished test data, and includes all of the new spline designs produced and evaluated by NAVAIRTESTCEN. Extensive laboratory testing and 40,000 hr of flight on six aircraft types have demonstrated the value of the new spline designs. Some of the benefits of the new coupling technique are: (1) higher accessory power system reliability, (2) elimination of wear and premature failure, (3) reclamation of gearboxes at the organizational level, and (4) reduction of maintenance induced failures. A series of nonmetallic couplings are available for a large number of accessory equipment applications due to the expanding size/rating range of coupling designs.

The circular spline design (U.S. Patent Number 3,620,043 of November 16, 1971) has been assigned to ARINC Research Corporation with royalty free rights to the Department of Defense. The other nonmetallic spline couplings have been assigned Navy Case Number 61068 and a patent assignment to the United States Government is pending.

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PREFACE

A previous Technical Memorandum, TM 76-1 SY, described the successful elimination of spline coupling wear and the attendant reliability improvement made possible by new high-strength nonmetallic shaft couplings. This report presumes a knowledge of the basic spline coupling mechanism, the factors leading to spline wear, and the design principles which are fundamental to the new nonmetallic coupling. Appropriate references in addition to TM 76-1 SY are included in this report for the reader who wants more extensive background information pertaining to the spline coupling problem.

The interest in this new shaft coupling technique expressed by the aerospace and industrial mechanical design community has resulted in numerous requests for additional design, test, and manufacturing information. This Technical Memorandum is intended to provide an update on the spline coupling improvement efforts at NAVAIRTESTCEN and to provide application oriented design information as a supplement to the basic coupling configurations previously published.

APPROVED FOR RELEASE

J. H. Foxgrover

J. H. FOXGROVER
Commander, Naval Air Test Center

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*See Appendix A for a list of illustrations therein.

INTRODUCTION

1. Engine driven accessories, such as generators, starters, and pumps, are commonly connected to their respective power takeoff shafts by spline couplings. The NAVAIRTESTCEN has engaged in a continuing spline coupling improvement program during the past 10 yr. Reference 1 introduced the new spline technology which resulted from these efforts and explained how these nonmetallic spline couplings may improve accessory power system reliability. This report presents additional information consisting of manufacturing details, a sample of test results, and a brief description of the new coupling designs produced thus far.

BACKGROUND

2. Spline couplings have been chosen by mechanical equipment designers for connecting driven accessories to power takeoffs because of their ability to transmit high torque, their purported self-centering tendency, and freedom of axial movement which eases installation and removal. However, the demonstrated high wear rates of conventional spline couplings used with engine driven accessories, such as hydraulic and fuel pumps, generators, and engine starters, frequently cause expensive and time-consuming maintenance or overhaul action and affect propulsion system reliability. The causes of spline wear, discussed in detail in reference 1, can be summarized as an inability of the coupling to adequately accommodate misalignment, a difficulty in maintaining sufficient lubrication, and a basic susceptibility to the process of fretting. Additional background information on the application of spline couplings and their inherent limitations may be obtained from references 2 through 6.

3. Figure 1 (inset) illustrates a typical example of spline coupling wear as experienced with an aircraft electrical starter-generator. For comparison purposes, the illustration also shows one of the new series of spline couplings which have demonstrated an immunity to fretting. The new couplings require no lubrication or periodic cleaning and are tolerant of the degree of misalignment experienced in aircraft accessory installations. Figure 2 presents generally accepted laboratory data, taken from reference 5, which typifies the wear behavior of grease lubricated involute spline couplings at various levels of misalignment. In contrast, figure 3 illustrates the benefit offered by one type of nonmetallic spline coupling. These data, taken from reference 7, when compared with figure 2, illustrate the degree of wear reduction provided by the new nonmetallic spline coupling technique. Examination of figures 2 and 3 at an acceptable wear limit of 0.012 in. (0.30 mm), for a common misalignment level of 0.34 deg, demonstrates that the nonmetallic spline coupling will last 56 times as long (1,400 hr versus 25 hr) as the standard grease lubricated spline coupling. These typical laboratory test data have been verified by more than 40,000 hr of actual flight operations on seven different drive shaft applications using even more promising nonmetallic coupling designs. During these flight tests, no coupling failures have occurred, no periodic maintenance was required, and, in all cases, wear of the nonmetallic elements was negligible. Wear of the steel components was nonexistent.

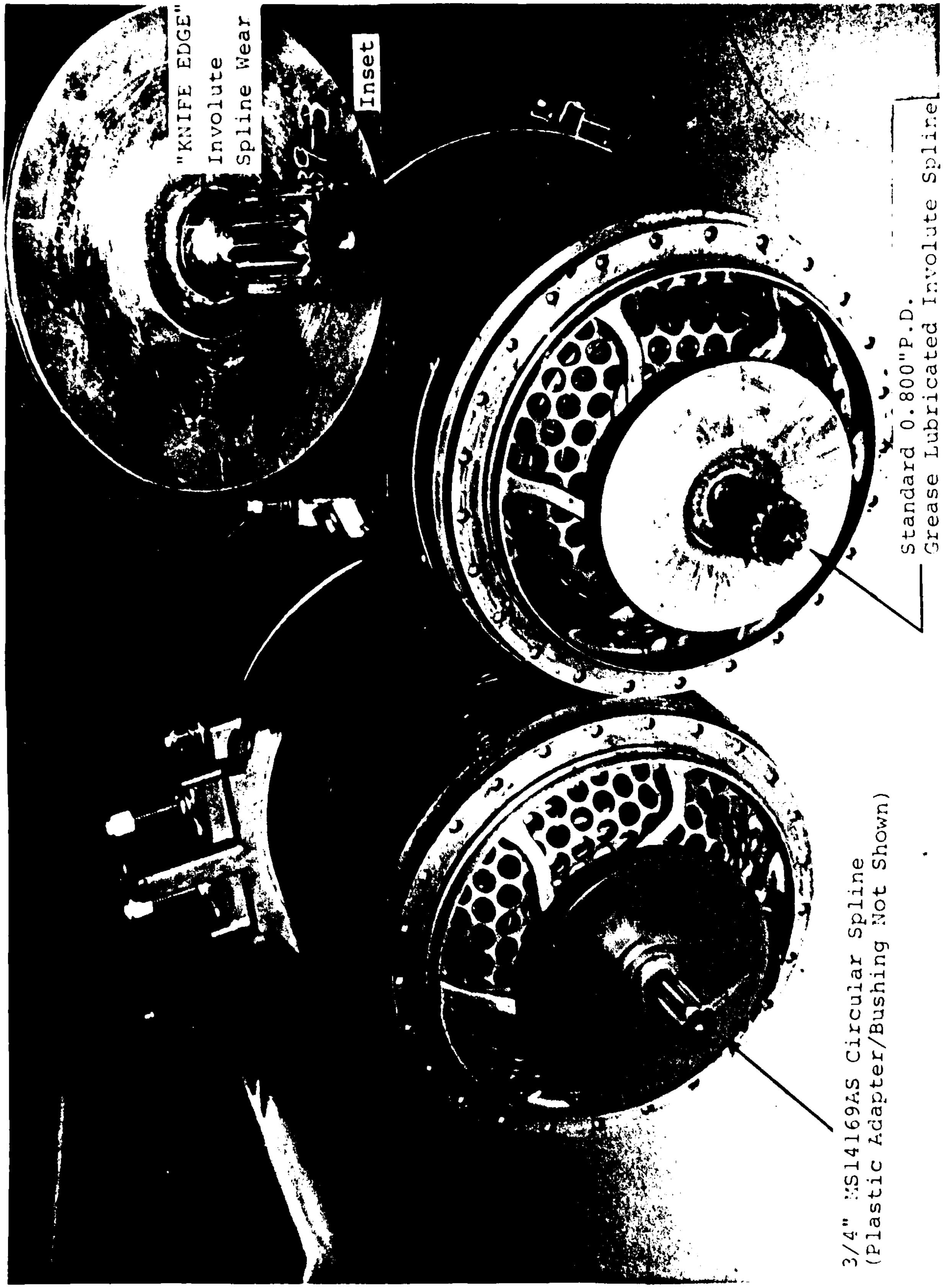


Figure 1
T-2C Starter-Generator. Comparison of Standard Spline and Circular Spline (Inset Shows Spline Wear)

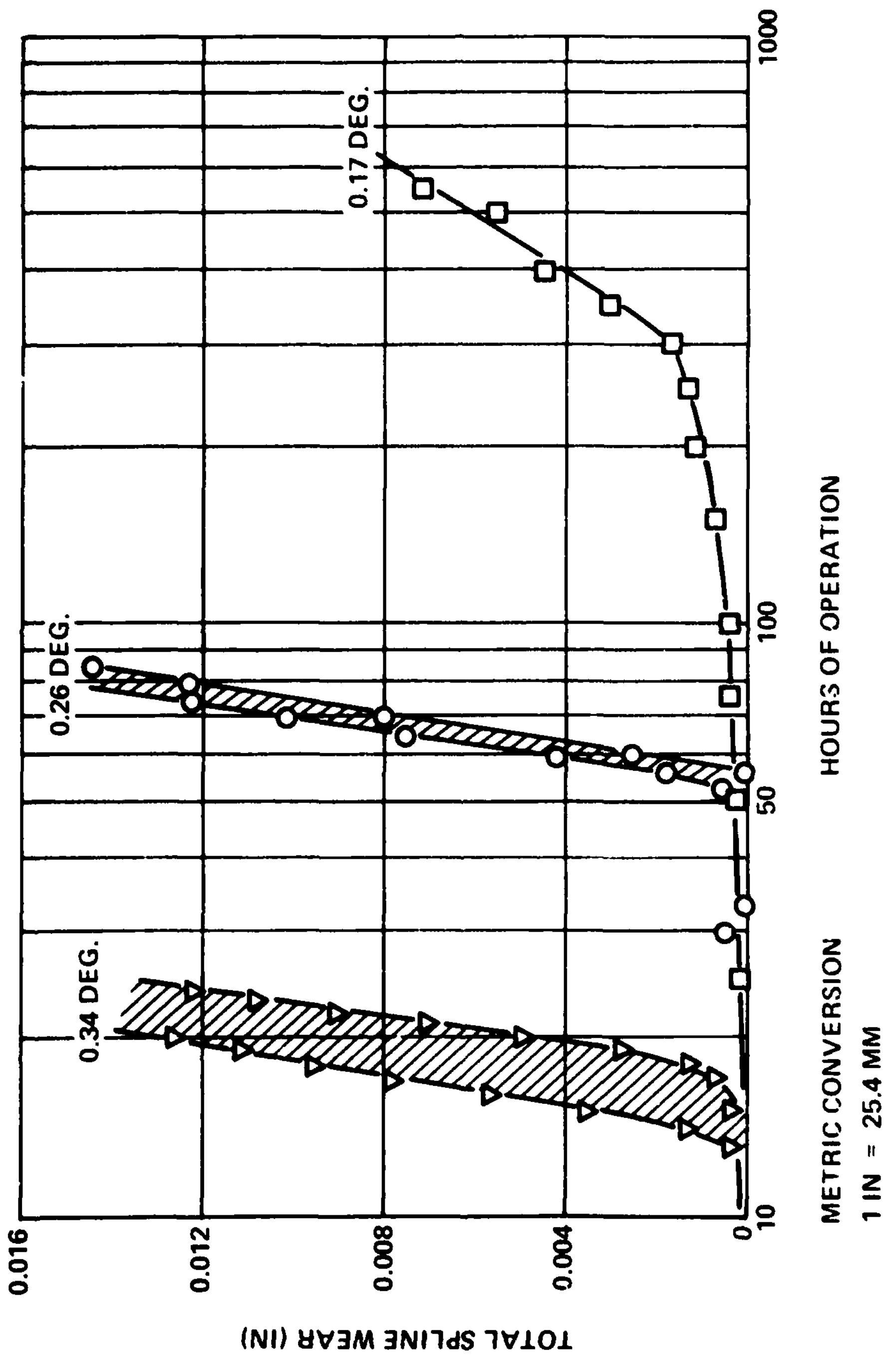


Figure 2
Laboratory Induced Spline Wear of Grease Lubricated Involute Splines
Showing the Effect of Spline Coupling Misalignment

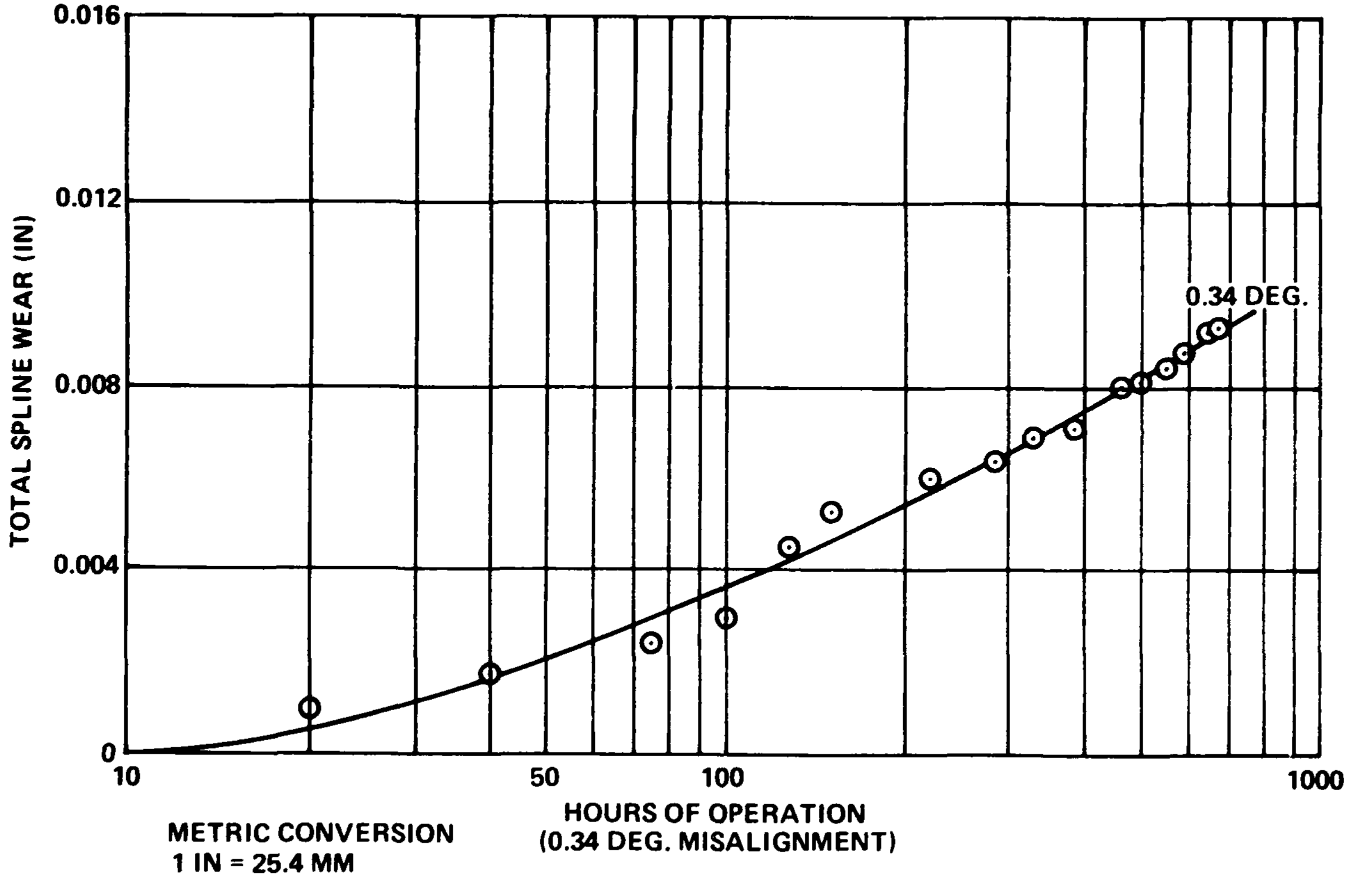


Figure 3
Laboratory Induced Spline Wear of Unlubricated, Internally and Externally Involute Splined, Polyimide Plastic Bushing Showing the Reduction in Wear Rate

PURPOSE

4. This report describes the manufacturing procedures used to produce the test couplings which have been successfully flight tested, contains previously unpublished laboratory test data, and presents each of the specific designs built and tested to date.

MANUFACTURING PROCEDURES

5. All of the new spline couplings share the common technique of interposing a nonmetallic or plastic element (adapter/bushing) between a metal splined bore and a metal inner torque shaft. The components of these couplings are readily manufactured using standard machining practices. Figures 4 through 7 illustrate the manufacturing of circular spline couplings in accordance with reference 8. Figure 4 shows a mill, equipped with a flycutter of the appropriate circular shape, cutting the crowned, circular cross-section spline teeth on a shaft held in an indexing fixture supported on a pivoting bed plate. The pivoting bed plate allows the machinist to apply the spline crowning as the circular cross-section teeth are cut on the cylindrical blank. Figure 5 gives a closer view of the flycutter details. Figure 6 shows the boring operation which results in circular cross-section spline gooves in the plastic adapter/bushing. The slotting saw, which cuts the 0.020 in. (0.51 mm) grooves in the plastic adapter external spline lands, is shown in figure 7. These fabrication methods obviously apply to small production lots of no more than 50 pieces and are inefficient for full scale production. Several manufacturers have successfully produced larger quantities of the circular splined shafts and plastic adapter/bushings using production machining techniques, such as hobbing for the shafts and broaching for the plastic adapter/bushing internal splines.

6. The smaller flat-sided spline couplings, with simpler geometry and no crown, offer less challenge to the manufacturer. Standard milling cutters produced the flat-sided splines on the test sample metal shafts and plastic adapters. The internal multitoothed splines in the plastic adapters resulted from a simple, single-pass broaching operation illustrated in figure 8. One manufacturer has produced plastic adapter/bushings at significantly lower cost using a combined "direct forming" and broaching operation. In this case, the adapter external spline diameter and internal bore are die formed in one operation as part of the process which produces the adapter blank. The adapter internal and external splines are then broached in a secondary machining step. As with the circular spline, automated production methods applied to these smaller coupling components will result in attendant cost savings.

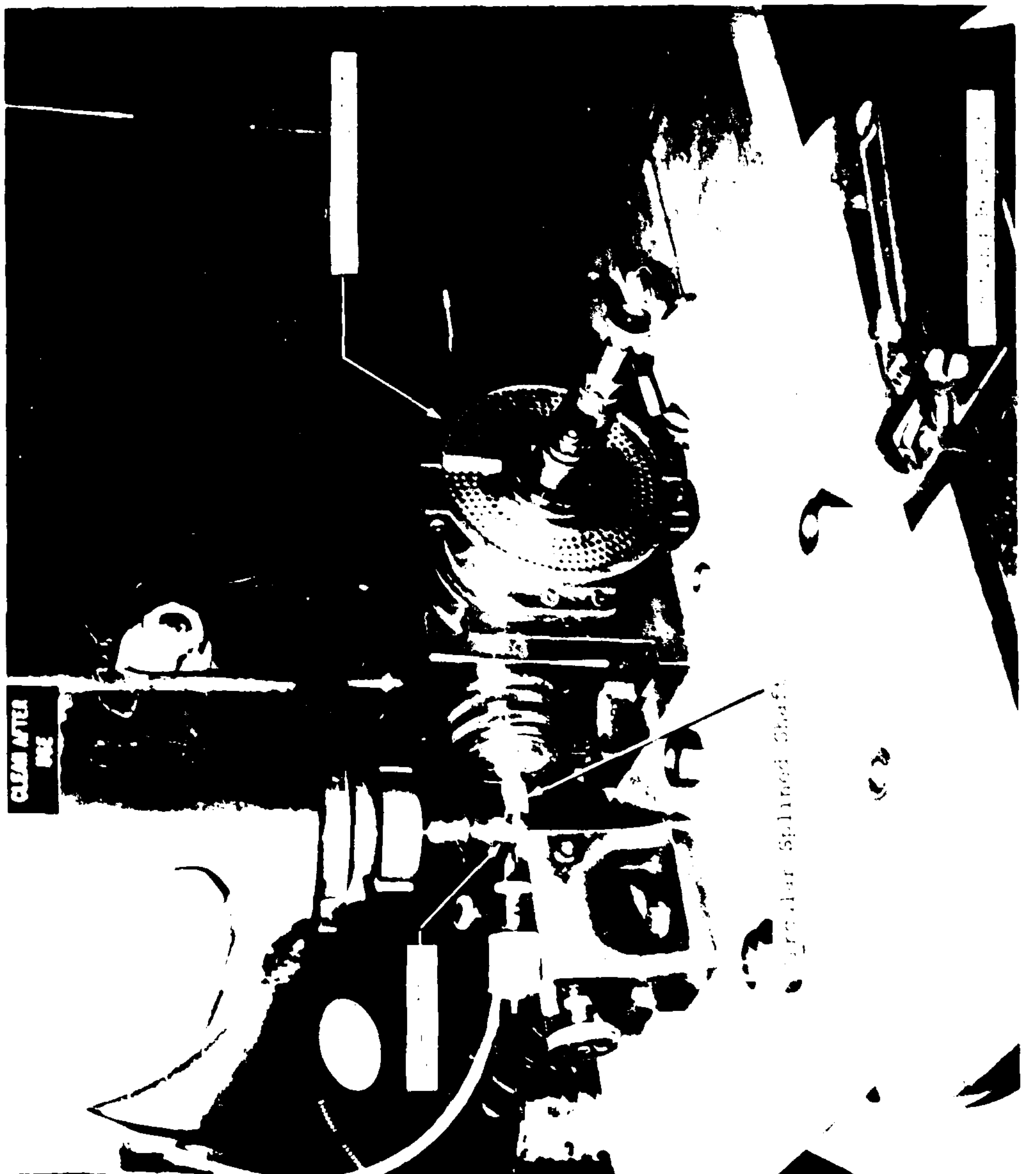


Figure 4
Milling Operation: Cutting Crowned, Circular Splines on Drive Shaft Blank

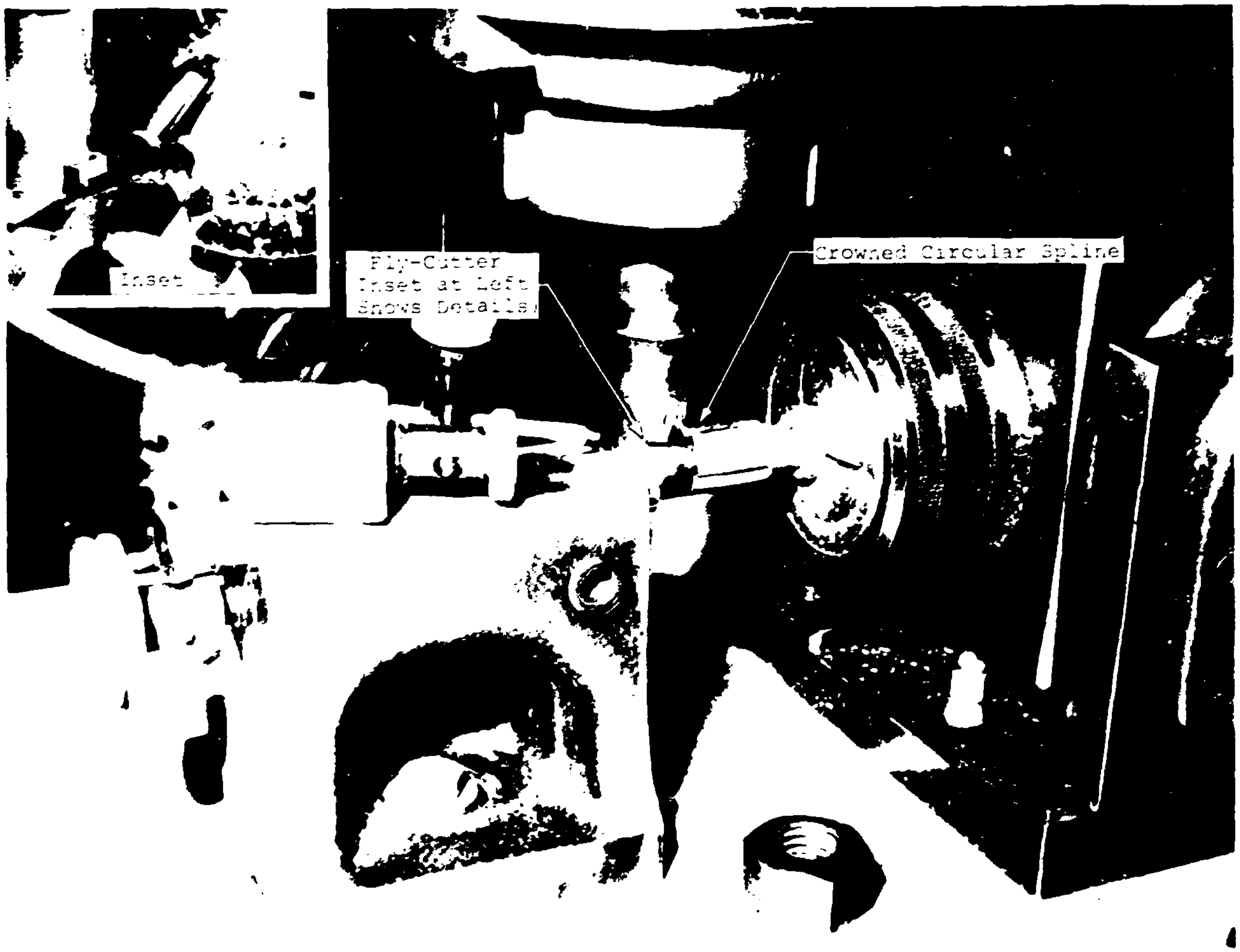


Figure 5
Milling Operation: Close-Up of Cutting Circular Splines on Drive Shaft Blank

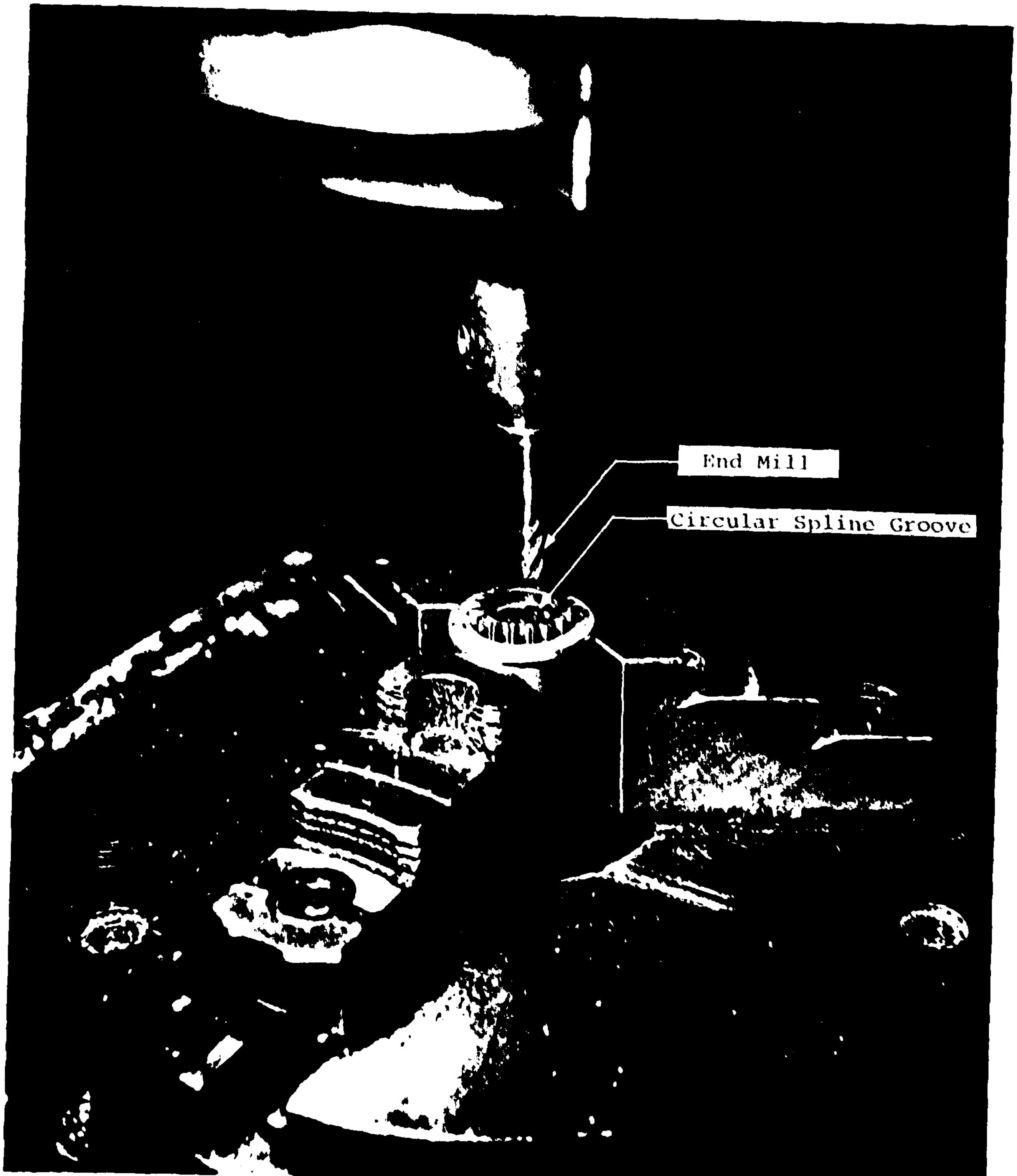


Figure 6
Milling Operation: Boring Internal Circular Spline Grooves in Plastic Adapter/Bushing

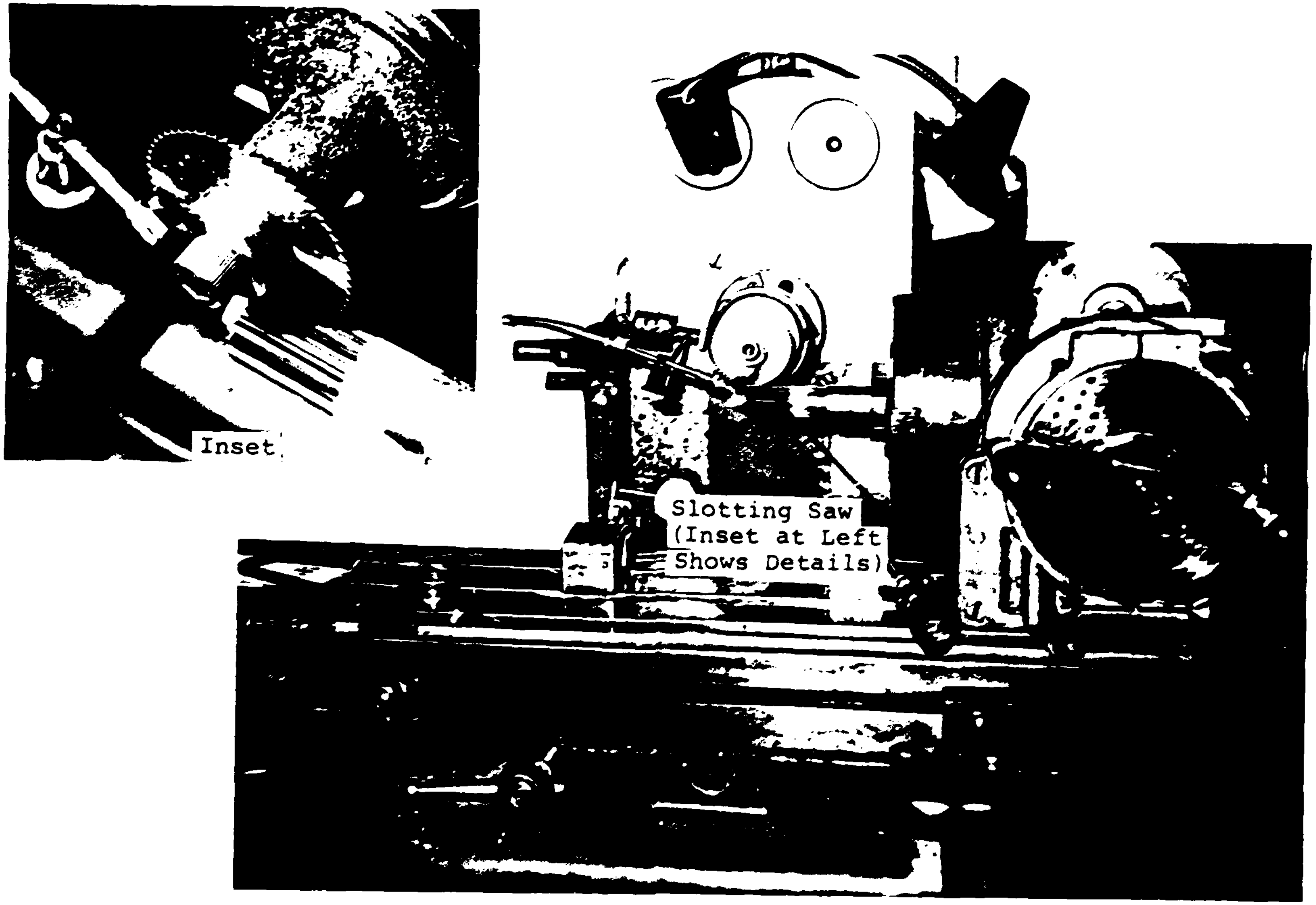


Figure 7
Milling Operation: Slotting-Saw Cutting 0.020 Inch (0.51 mm) Grooves
in Plastic Adapter/Bushing External Splines

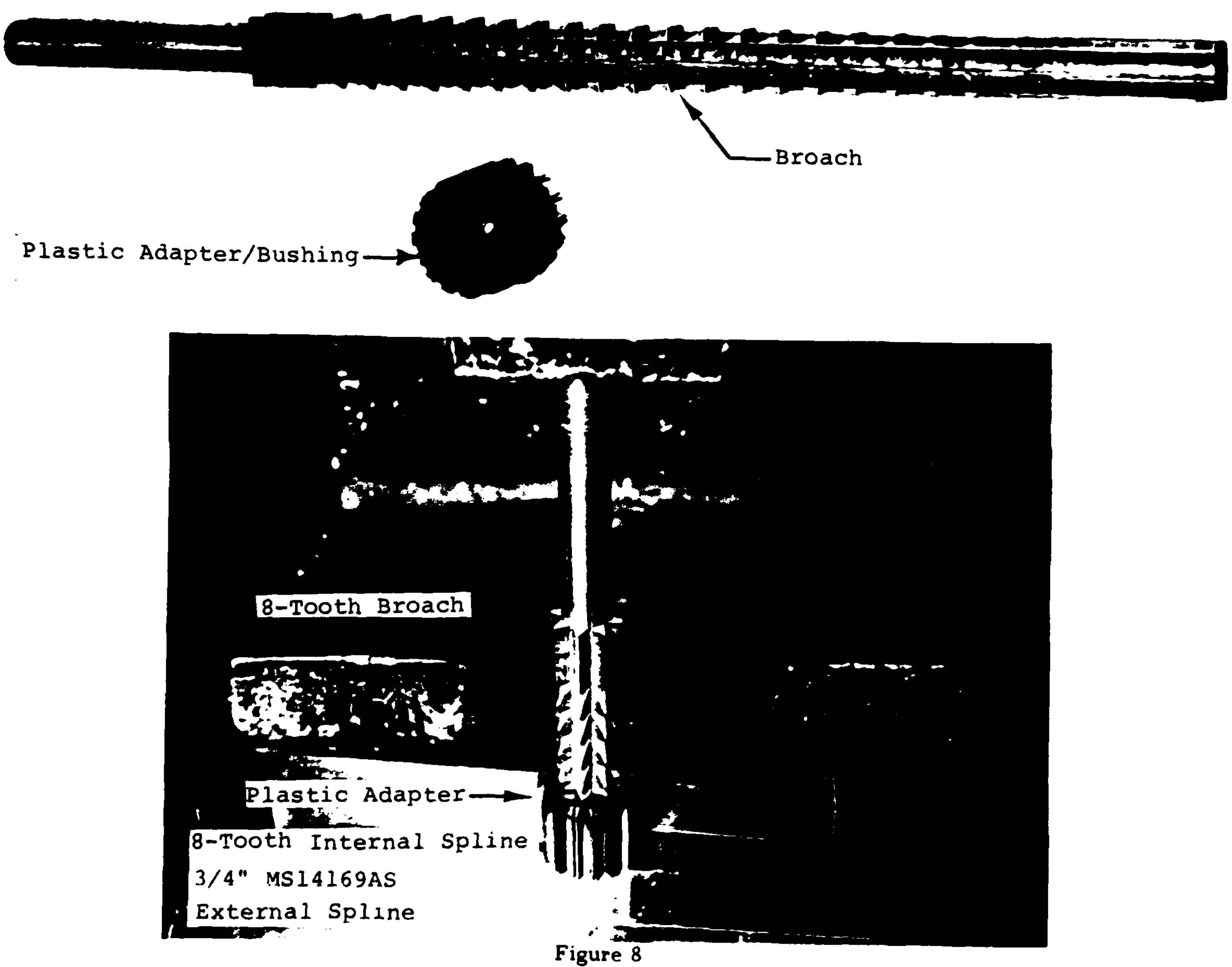


Figure 8
Mock-Up of Internal Spline Broaching Operation

LABORATORY TEST DATA

7. Previous publications, references 9 through 17, have described most of the laboratory tests conducted by NAVAIRTESTCEN, ARINC Research Corporation, and Bendix Corporation on the new nonmetallic shaft couplings. As part of a continuing investigation of the mechanical properties of plastic adapter/bushings, various tests on several types and brands of high-strength plastic materials are being conducted. Since DuPont VESPEL® SP-1 Polyimide plastic is the material in use at this time, material tests have concentrated on determining the properties of plastic adapters manufactured from this material. Reference 18 contains basic material properties of isotropic (or isostatic) VESPEL® SP-1 plastic in standard material test configurations. The previously unpublished data which is being compiled (some of which is contained herein) is intended to augment the DuPont data and to be applicable to splined adapters for use in drive shaft couplings. Material properties of other types of plastics will be published as the information becomes available.

8. The adapter/bushing test configuration illustrated in figure 9 has been subjected to various fuels, lubricants, hydraulic fluids, and other liquids to determine their effect on VESPEL® SP-1. The test fluids consisted of: JP-4 and JP-5 (fuels), MIL-L-23699 (turbine oil), MIL-H-5606 and MIL-H-83282 (hydraulic fluid), MIL-C-43616B (cleaning compound), and Methyl-Ethyl-Ketone (solvent). The plastic adapters' outside diameters and lengths were accurately measured and recorded prior to immersion in the test fluids. Following 216 hr (9 days) of fluid immersion at laboratory ambient temperatures, the dimensions were measured and compared with the original measurements to determine if the plastic adapters had been altered by the test fluid. Following the dimensional checks, the adapters were each placed in a special torque test fixture and torsionally loaded until shear rupture occurred. The ultimate torsional strength of each adapter was thus determined and compared with a "control" adapter manufactured in the same lot but not exposed to the test fluids. The control adapter ultimate strength was 84 ft-lb (114 N-m). Only one fluid (MIL-C-43616B cleaning compound) produced a notable change in adapter dimensions or ultimate torsional strength. This fluid, which is the corrosion control wash rack detergent, was used full strength for these tests rather than highly diluted as is normal practice during aircraft washing. The plastic adapter dimensions were reduced 3% on the length, 2% on the diameter, and the ultimate torsional strength was reduced 19% by exposure to the full strength cleaning compound. The plastics manufacturer, DuPont, attributes this phenomenon to attack of the SP resin by the potassium hydroxide present in the cleaning compound. The potassium hydroxide causes the fluid to be strongly basic (ph 10-11). DuPont does not recommend the use of SP-1 plastic parts where they may be exposed to fluids with a ph greater than 10. The VESPEL® SP-1 plastic adapters used in engine driven accessories are adequately isolated from exposure to the cleaning compound. Obviously, cleaning splined cavities and drive shaft hardware with such high ph fluids should be avoided, not only to protect the coupling, but also to protect shaft seal materials which could be equally vulnerable. The use of VESPEL® SP-1 adapter/bushings in areas subject to continuous or intermittent exposure to high ph fluids should be carefully evaluated before implementation.

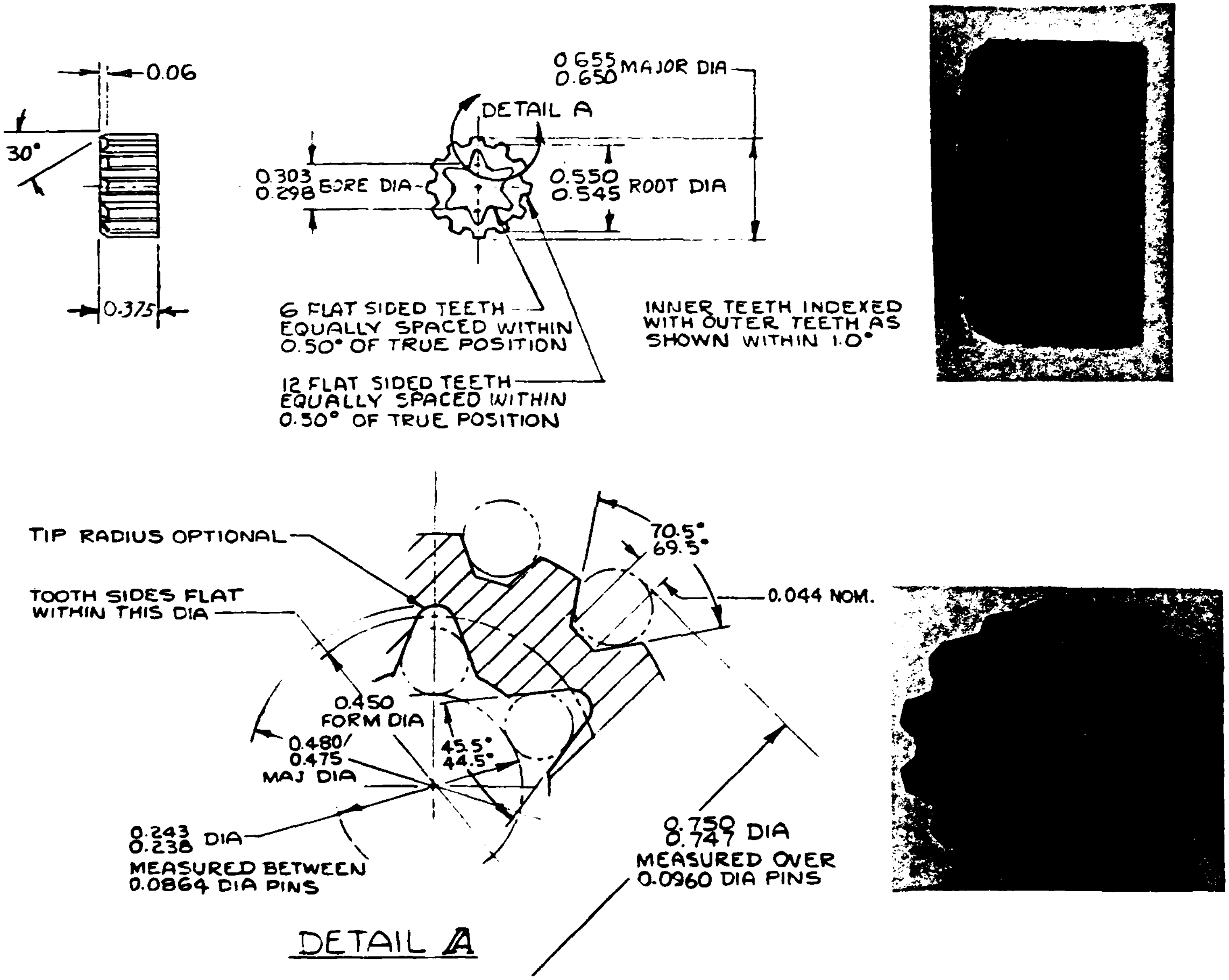


Figure 9
Fluid Compatibility and Operating Temperature Plastic Bushing Test Sample Configuration

9. Figures 10 and 11 show the results of a second series of tests to determine the effect of operating temperature on the ultimate strength of VESPEL® SP-1 plastic adapters. The test sample configuration and the torsional test fixture were identical to the hardware used in the fluid immersion tests. The procedure consisted of installing the plastic adapter/bushing and the torsional fixture in an oven or refrigerated chamber with thermocouple type instrumentation to determine when thermal equilibrium was reached. The fixture with the plastic adapter installed was then quickly removed from the chamber, installed on the torque loading and measuring device, and the plastic adapter was torsionally loaded until shear rupture occurred. Figure 10 contains the results of tests of VESPEL® SP-1 isotropic material. These data show that the ultimate torsional strength of the adapter is reduced at elevated temperatures and increases as the operating temperature is lowered in approximately a straight line relationship between 0°F and 700°F (-18°C to +370°C). The strength increases at a greater rate between 0°F and -60°F (-18°C to -51°C). However, as with most high-strength materials, the increase in ultimate strength at low temperature is accompanied by a tendency to become brittle. Figure 11 presents similar data for VESPEL® SP-1 Direct Formed adapters which exhibit an approximate 10% reduction in ultimate torsional strength. These direct formed adapters offer significant savings in cost since they require minimal secondary machining and should be considered where the 10% reduction in strength can be tolerated.

10. Some limited tests to determine the effect of plastic adapter/bushing wall thickness have resulted in rather interesting observations. Ultimate torsional strength tests similar to the procedures described above were conducted on test sample configurations depicted in figure 12. The results of strength determinations on adapters (data also shown on figure 12) seem to indicate that the basic plastic adapter becomes weaker as the wall thickness increases. However, the effect of compressive preload, controlled by the degree of interference fit on the outside of the plastic adapter, must also be taken into account. Sufficient tests have not been completed to conclude if the observed reduction in strength is due to the change in material thickness, the change in compressive preload (hoop stress), or a combination of both. Consequently, the observations are offered merely for consideration by other coupling designers.

NEW NONMETALLIC COUPLING DESIGNS

11. Since the inception of the new nonmetallic coupling techniques, many different configurations have been built and tested. The design drawings and photographs contained in Appendix A present each new coupling design configuration with additional information pertaining to its test application and its predicted room temperature ultimate strength when built from VESPEL® SP-1 isotropic material. Where available, accumulated flight hours and other significant events are also included.

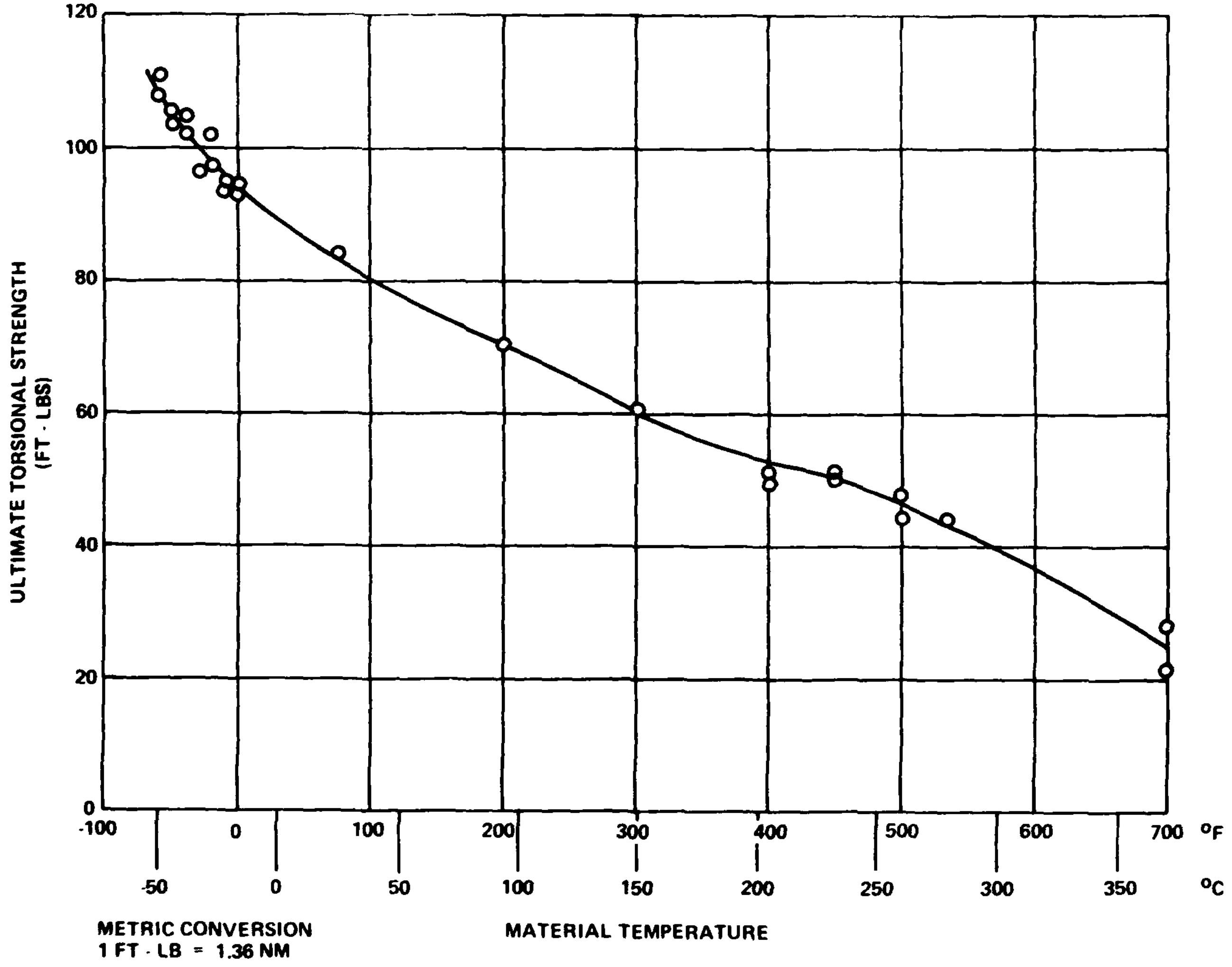


Figure 10
Effect of Operating Temperature on the Ultimate Torsional Strength of Plastic Spline Coupling Adapter/Bushings (VESPEL® SP-1 Isotropic Plastic)

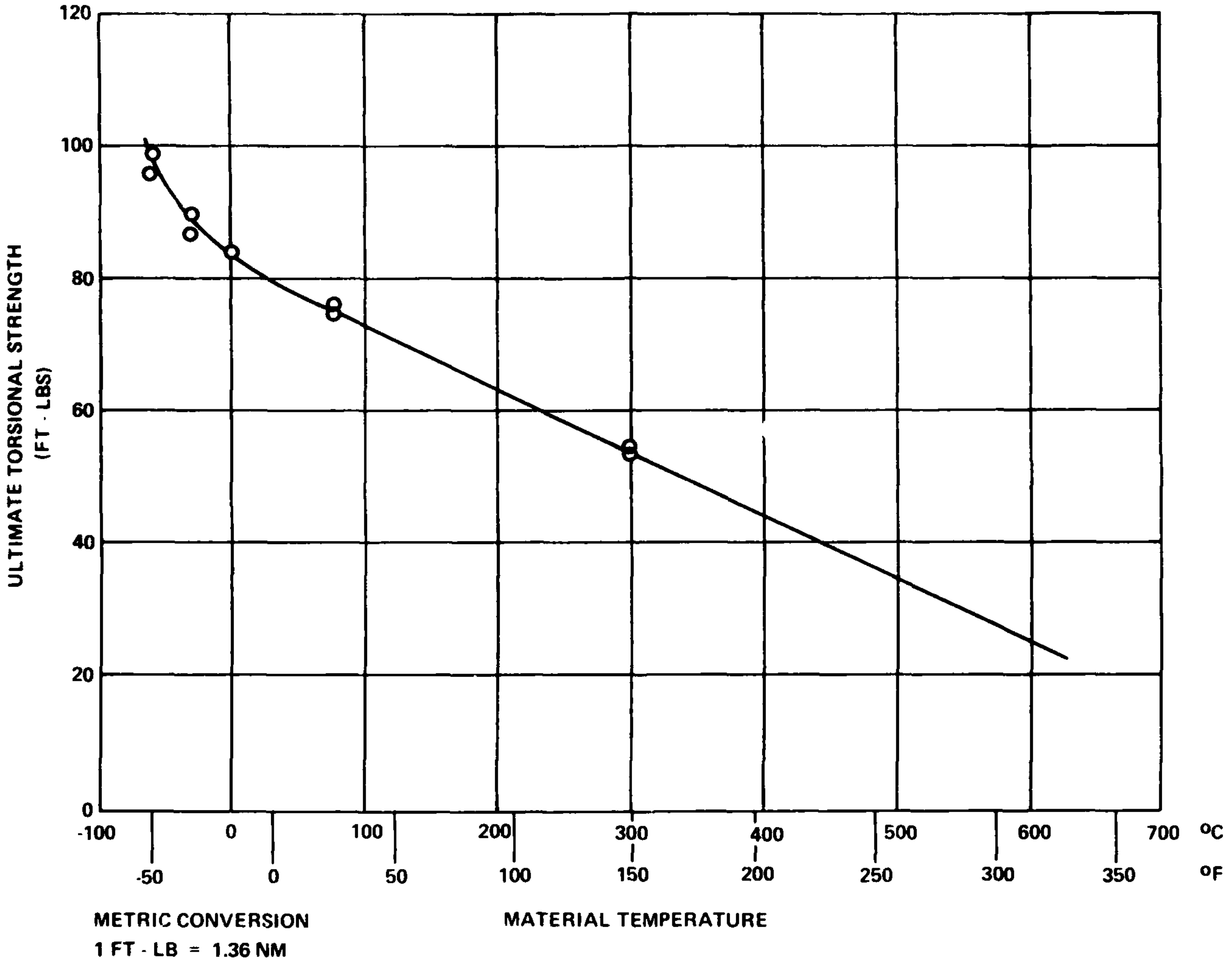


Figure 11
Effect of Operating Temperature on the Ultimate Torsional Strength of Plastic Spline Coupling Adapter/Bushings (VESPEL® SP-1 Direct Formed Plastic)

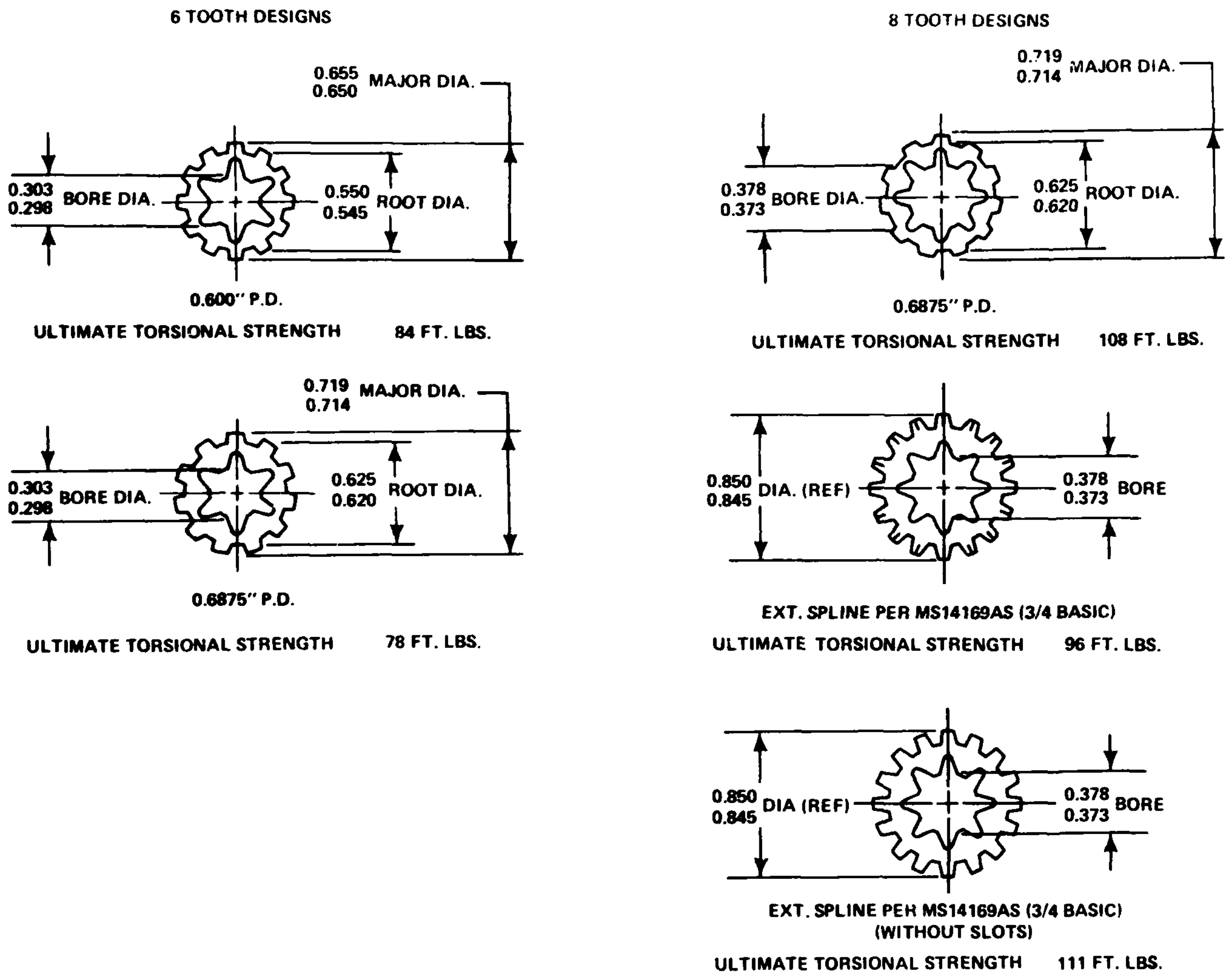


Figure 12
Comparison of Torsional Strength of 0.375 Inch (9.52 mm) Long VESPEL® SP-1
(Isotropic) Plastic Bushings Showing the Effect of Wall Thickness and Compressive Preload

CONCLUSIONS

12. Extensive laboratory testing and in excess of 40,000 hr of flight testing on six aircraft types have demonstrated the value of the new nonmetallic spline couplings.

13. This spline coupling technique provides higher accessory power system reliability by eliminating excessive coupling wear and premature failure.

14. The substitution of high-strength nonmetallic shaft couplings for the standard involute couplings reclaims otherwise serviceable engine driven gearboxes. Since this change, involving removal and replacement of the accessory drive shaft, takes place at the organizational maintenance level, significant savings in maintenance manpower and resources are possible.

15. These nonmetallic shaft couplings require no periodic inspection, cleaning, or lubrication. The elimination of periodic coupling inspection reduces maintenance induced failures

16. A series of nonmetallic couplings is available for a large number of accessory equipment applications due to the expanding size/rating range of coupling designs.

APPENDIX A

NEW NONMETALLIC COUPLING DESIGNS

APPENDIX A

LIST OF ILLUSTRATIONS

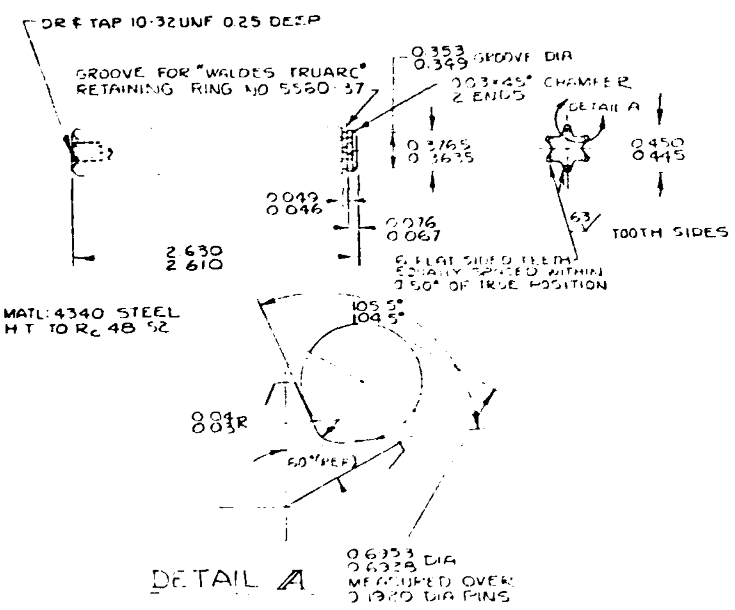


Figure 1
0.600 Inch (15.2 mm) P.D. Nonmetallic
Spline Coupling, Six Tooth Torque Shaft Design

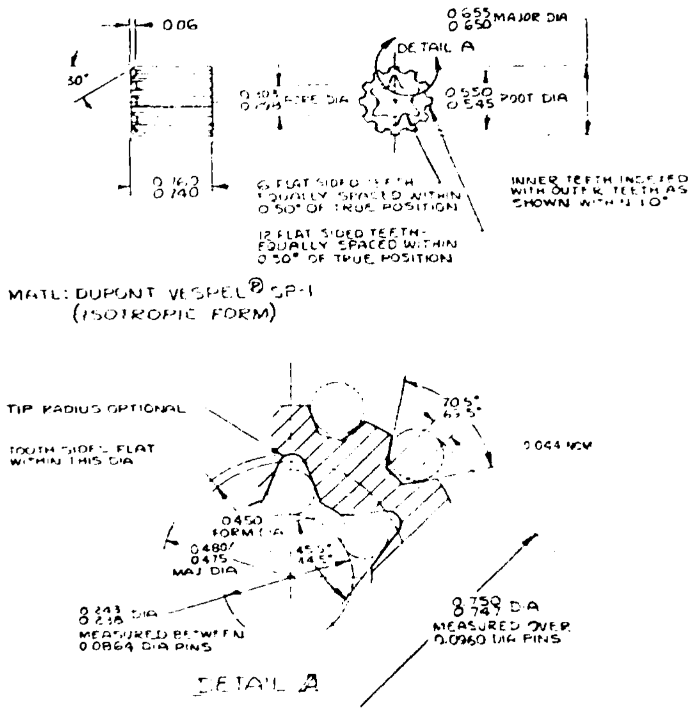
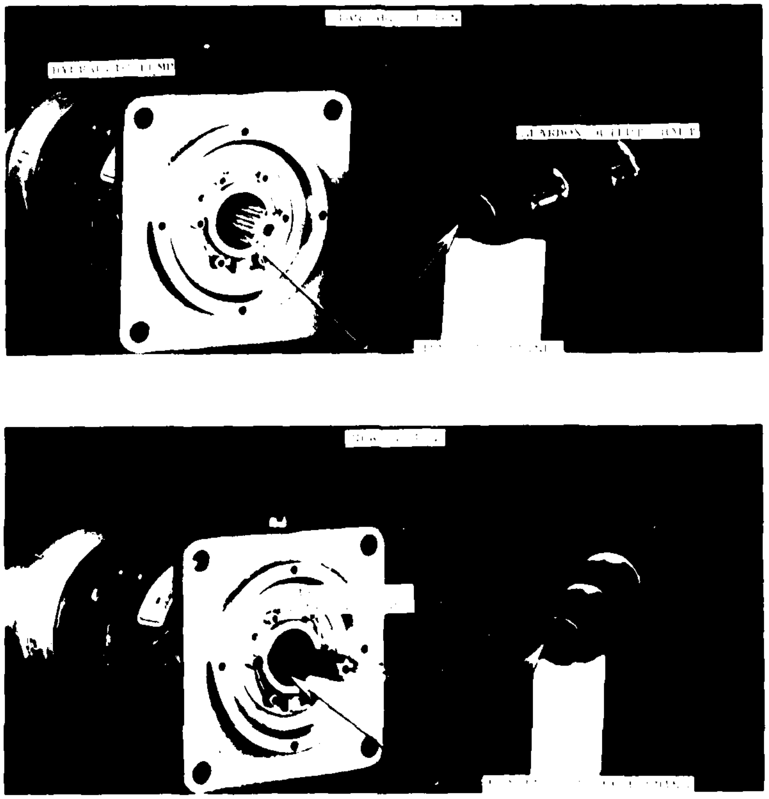


Figure 2
0.600 Inch (15.2 mm) P.D. Nonmetallic
Spline Coupling, Six Tooth to Twelve Tooth
Plastic Adapter/Bushing Design



TEST APPLICATION:

Aircraft	CH-53D
Accessory	New York Air Brake P/N 65WB02093 First Stage Hydraulic Pump

FLIGHT TESTS:

Flight Time(1)	1,830 Hours
Operations	N.A.
High Time(2)	339 Hours
Number of Samples	9
Date(3)	13 February 1978

ULTIMATE TORSIONAL STRENGTH

Predicted for VESPEL® SP-1 Isotropic (70°F, 21°C)	2,016 In.-Lb (228 N-m)

(1) Total time accumulated by the Number of Samples
(2) Largest number of hours accumulated by a single sample
(3) Date of latest available Flight Test information

Figure 3
0.600 Inch (15.2 mm) P.D. Nonmetallic Spline Coupling,
CH-53D First Stage Hydraulic Pump Modification for Flight Test

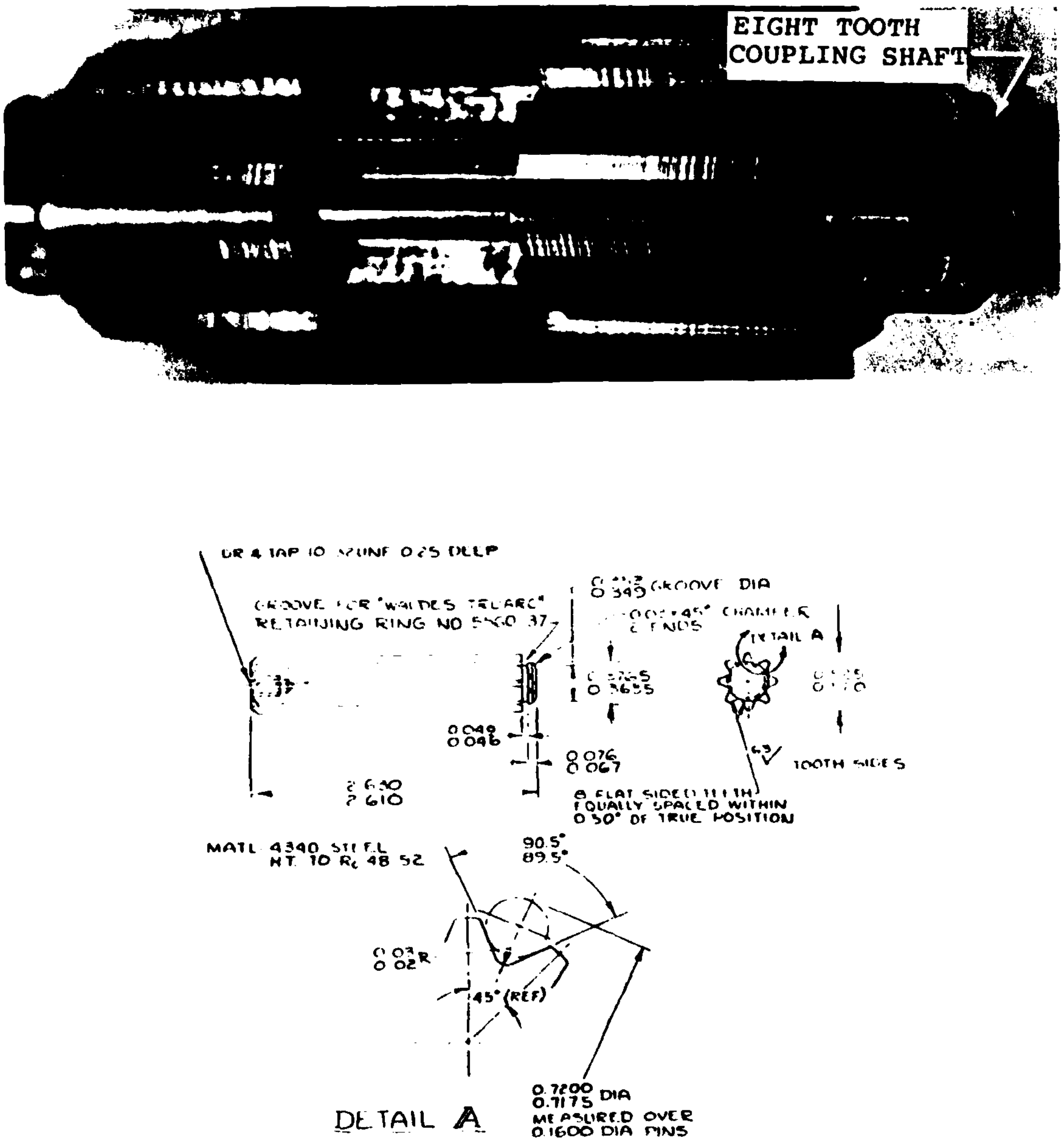
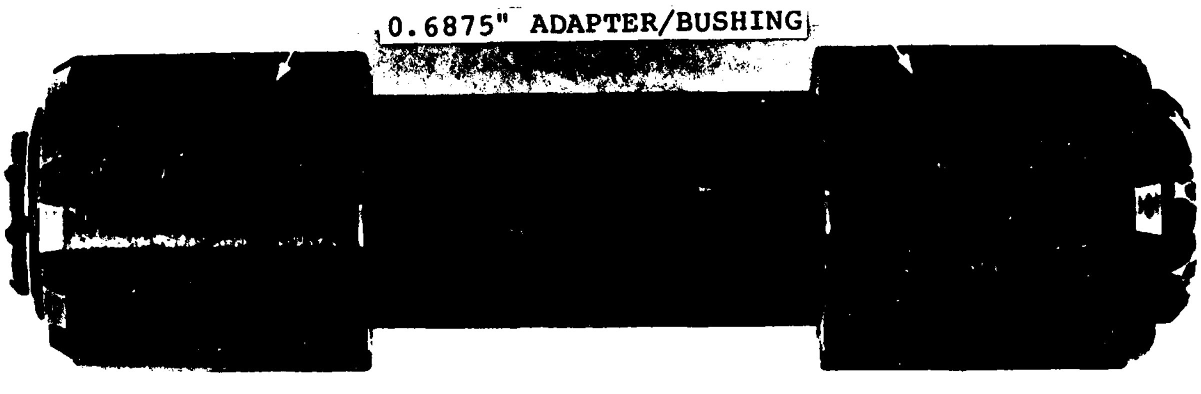


Figure 4
0.6875 Inch (17.5 mm) P.D. Nonmetallic Spline Coupling, Eight Tooth Torque Shaft Design



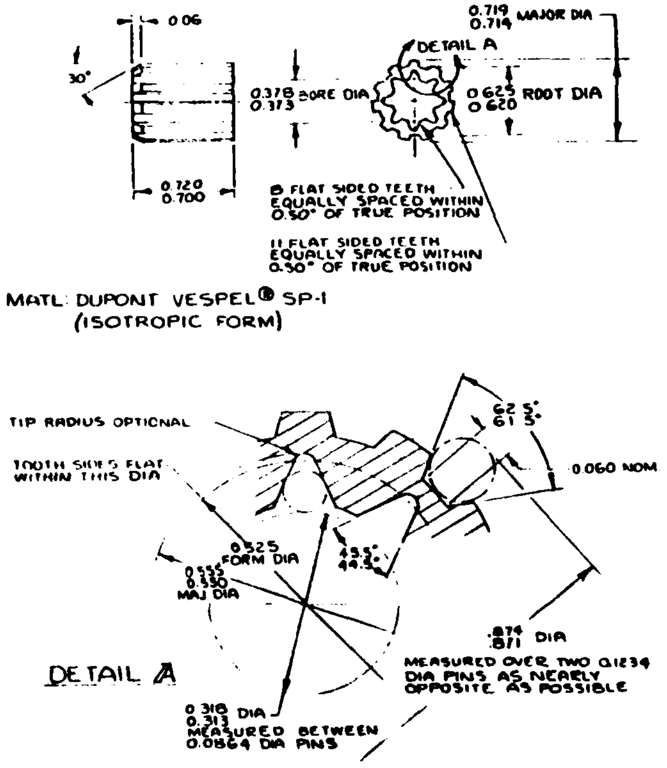


Figure 5
0.6875 Inch (17.5 mm) P.D. Nonmetallic Spline Coupling, Eight Tooth to Eleven Tooth Plastic Adapter/Bushing Design

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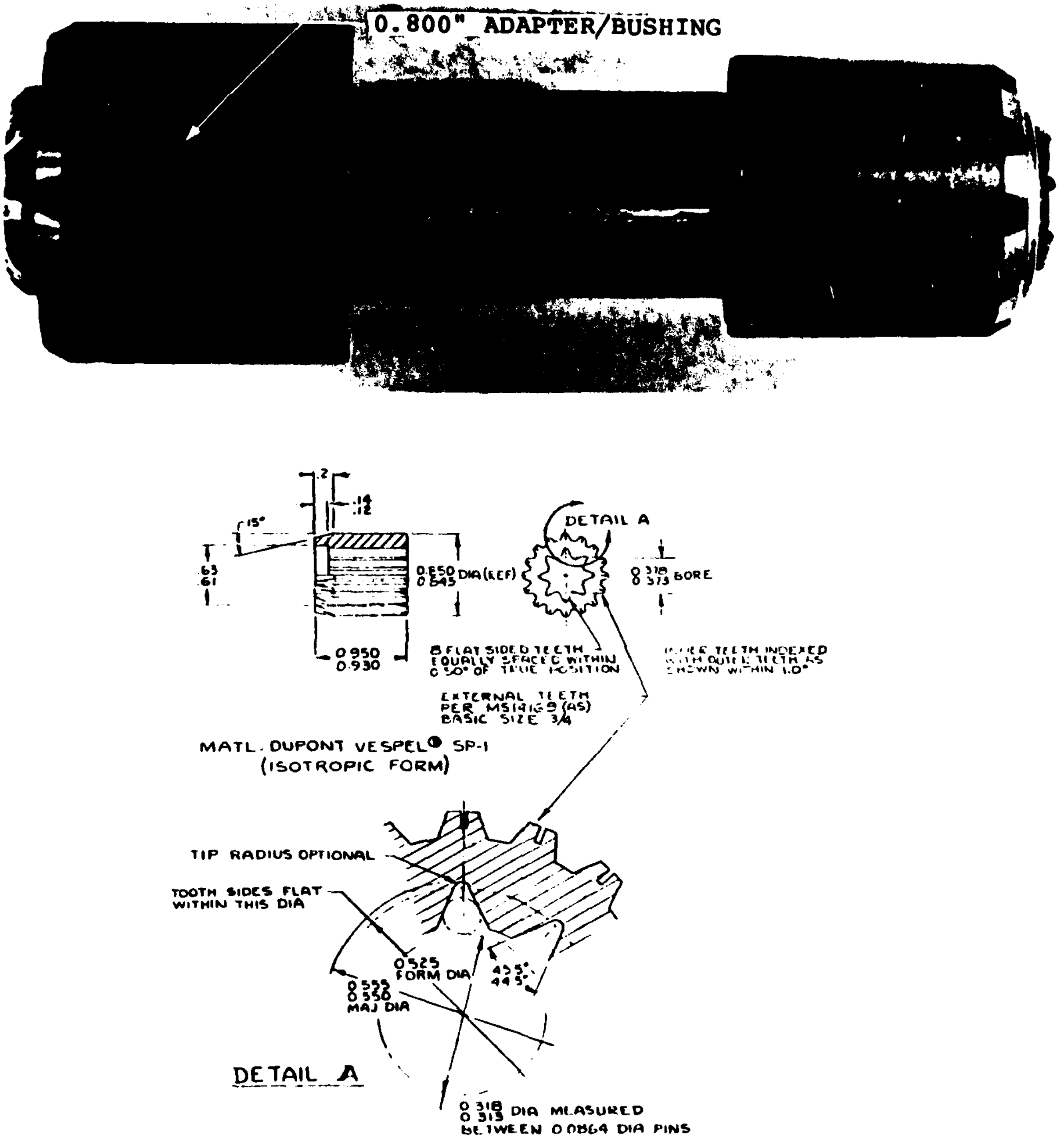

Figure 6
Proposed 0.800 Inch (20.3 mm) Nonmetallic Spline Coupling, Eight Tooth to Sixteen Tooth Plastic Adapter/Bushing Design

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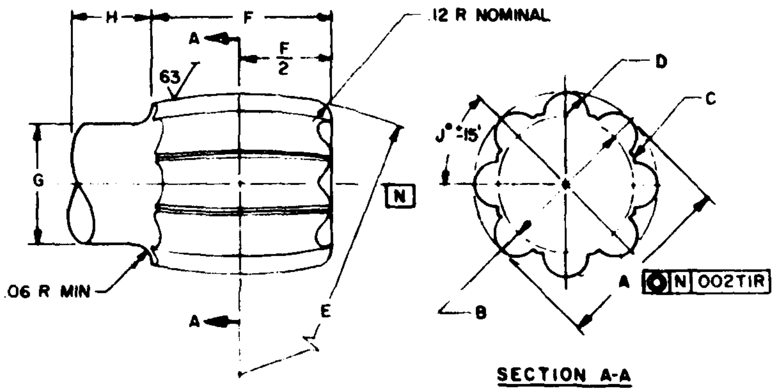
METRIC CONVERSION

1.00 in. = 25.4 mm



CIRCULAR SPLINE

SPLINE DESIGN DATA

BASIC SIZE	NO. OF TEETH	SPLINE DIA A	FORM DIA B	ROOT DIA MAX C	TOOTH RADIUS D	CROWN RADIUS E	SPLINE LENGTH F	SHAFT DIA MAX G	SHAFT LENGTH MIN H	TOOTH INDEX ANGLE J
3/4	6	0 600 0 598	0 513 BASIC	0 470	0 093 0 091	10 0 8 0	0 85 0 65	0 438	0 31	60°
1	8	1 000 0 998	0 750 BASIC	0 800	0 124 0 122	15 0 13 0	1 10 0 90	0 670	0 44	45°
[illegible]	5	1 [illegible]0 1 [illegible]8	0 917 BASIC	1 000	0 155 0 153	16 0 14 0	1 35 1 15	0 910	0 44	[illegible]

NAVY DESIGN STANDARD FOR CIRCULAR SPLINE COUPLINGS USED IN AIRCRAFT ELECTROMECHANICAL ACCESSORIES.

Ⓑ REVISED AND REDRAWN

APPROVED 6 MAY 1976 REVISED (A) 31 JULY 1977 (B) [illegible] 1978

This military standard is approved by NAVAL AIR SYSTEMS COMMAND, Department of the Navy and shall be used by that activity. All other military activities are required to employ this standard where applicable.

P A NAVY - AS Other Cust	TITLE CIRCULAR SPLINE & ADAPTER DETAILS ENGINE DRIVEN ACCESSORIES	MILITARY STANDARD MS14169 (AS)
PROCUREMENT SPECIFICATION	SUPERSEDES:	SHEET 1 OF 1

DD FORM 1 JAN 72 672-1 (Limited coordination) PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE Project No 6115-N611 PLATE NO 25071

Figure 7
MS14169AS Circular Spline Drive Shaft Design Details

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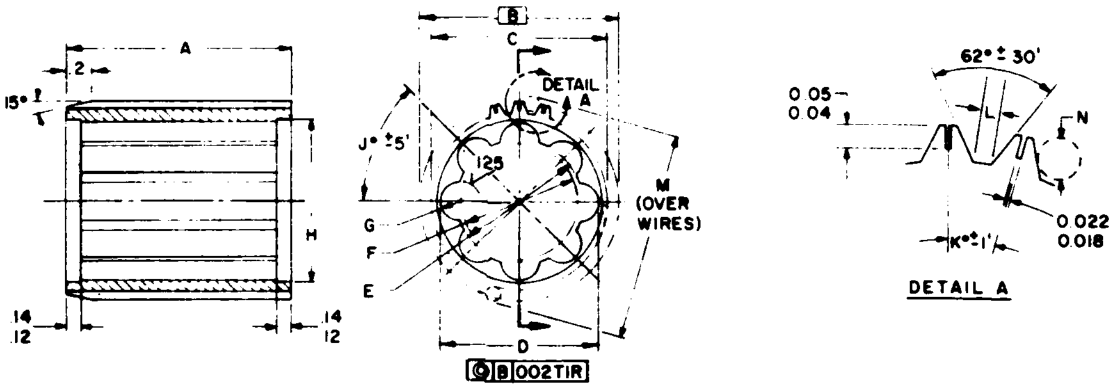
METRIC CONVERSION



SPLINE ADAPTER DESIGN DATA

BASIC SIZE	NO. OF TEETH	MIN LENGTH A	MAJOR DIA B	ROOT DIA C	SPLINE DIA D	MINOR DIA E	FORM DIA F	TOOTH RADIUS G	COUNTER BORE DIA H	INTER INDEX ANGLE J	EXTER INDEX ANGLE K	NOM ROOT WIDTH L	OVER WIRES DIA M	WIRE DIA N
[illegible]	6 int 16 ext	[illegible]	[illegible]	[illegible]	0.604 0.602	0.475 0.47[illegible]	0.413 BASIC	0.095 0.094	0.63 0.61	60°	[illegible] 30'	0.034	1.016 1.014	0.12000
[illegible]	8 int [illegible] ext	[illegible]	[illegible]	[illegible]	1.004 1.002	0.811 0.809	0.750 BASIC	0.126 0.125	1.03 [illegible]	45°	15° 0'	0.034	1.418 1.415	0.12000
[illegible]	8 int 26 ext	[illegible]	[illegible]	[illegible].554 [illegible].543	1.254 1.252	1.015 1.01[illegible]	0.937 BASIC	0.157 0.156	1.24 1.2[illegible]	45°	[illegible] 51'	0.054	1.842 1.839	0.13091

APPROVED 6 MAY 1976 REVISED (B) FOR CHANGES SEE SHEETS 1 THRU 3

This military standard is approved by NAVAL AIR SYSTEMS COMMAND, Department of the Navy and shall be used by that activity. All other military activities are required to employ this standard where suitable.

P A NAVY - AS Other Cust	TITLE CIRCULAR SPLINE & ADAPTER DETAILS ENGINE DRIVEN ACCESSORIES	MILITARY STANDARD MS 14169 (AS)
PROCUREMENT SPECIFICATION	SUPERSEDES:	SHEET 2 OF 3

DD FORM 1 MAR 72 672-1 (Limited coordination) PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE PLATE NO 23071

Figure 8
MS14169AS Circular Spline Adapter/Bushing Design Details

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NOTES

1. DIMENSIONS
All linear dimensions are in inches except roughnesses which are in microinches.

2. APPLICATION
The specified adapters may be used only with involute splines having 30 degrees pressure angles.

3. SPLINES
Male Shaft splines shall have a minimum surface hardness of 34 Rockwell C to a minimum case depth of 0.035 inches.

4. FINISH
All burrs and sharp edges shall be removed.

5. APPLICATION AND INSTALLATION
Circular spline couplings may be used as replacements for worn involute spline couplings without modification or replacement of the aircraft accessory drive pad shaft (female splines). Prior to retrofit, the female spline shall be thoroughly cleaned to remove sediment and grease. The design results in an interference fit of the spline adapter into the involute spline and a sliding fit of the circular spline shaft into the adapter.

6. MATERIAL SELECTION
The plastic spline adapter shall be fabricated from high strength, self lubricating polymeric materials having ultimate compressive strengths of a minimum of 28,000 psi. Typical materials include the polyimide, aramid and polyamide-imide resins, belonging to the Dupont Vespel and Amoco Torlon families. The process of material selection should consider strength, fatigue and aging properties, fluid compatibility, thermal exposure, dimensional stability, and forming properties.

7. SHEAR SECTION
The shaft shall include a shear section allowing the shaft to shear at the torque specified by the specification for the accessory equipment.

8. PATENT RESTRICTION
Under the conditions of patent number 3,620,043, "Spline-Type Pivots, Universal Joints and Flexible Couplings", dated November 16, 1971, ARINC Research Corporation has granted to the United States Government a royalty-free license to use the described circular spline coupling design for governmental purposes only.

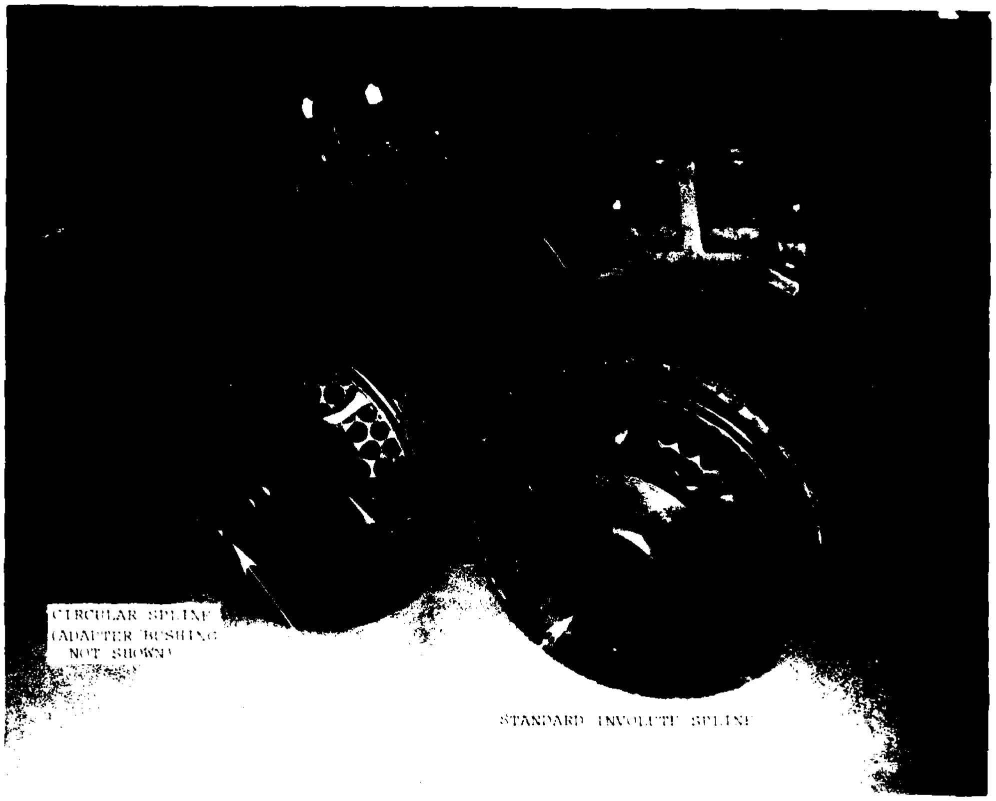
APPROVED 6 MAY 1976 REVISED Ⓑ FOR CHANGES SEE SHEETS 1 THRU 3

This military standard is approved by Naval Air Systems Command, Department of the Navy and shall be used by that activity. All other military activities are required to employ this standard where suitable.

P.A. NAVY - AS Other Cust	TITLE CIRCULAR SPLINE & ADAPTER DETAILS ENGINE DRIVEN ACCESSORIES	MILITARY STANDARD MS 14169 (AS)
PROCUREMENT SPECIFICATION	SUPERSEDES:	SHEET 3 OF 3

DD FORM 672-1 (Limited coordination) PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE. PLATE NO. 8807

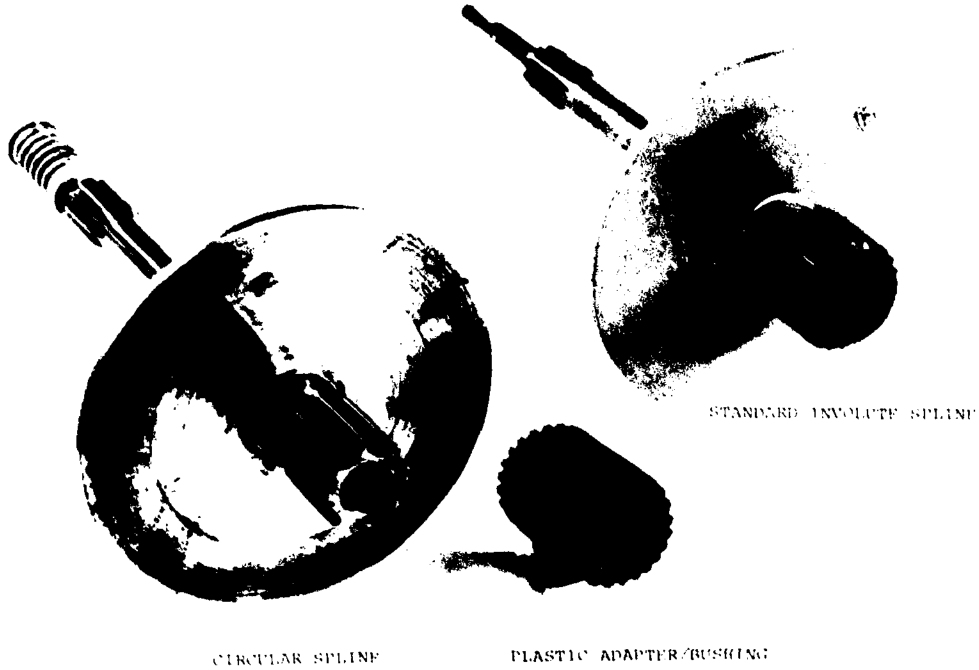
Figure 9
MS14169AS Circular Spline Drive Shaft and Adapter/Bushing Notes



TEST APPLICATION:	
Aircraft	T-2C
Accessory	Bendix 30B45 Starter/Generator
FLIGHT TESTS:	
Flight Time(1)	365.5 Hours
Operations	245 Starts
High Time(2)	97.7 Hours
Number of Samples	10
Date(3)	28 February 1978
ULTIMATE TORSIONAL STRENGTH	
Predicted for VESPEL® SP-1 Isotropic (70°F, 21°C)	1,680 In.-Lb (190 N-m)

(1) Total time accumulated by the Number of Samples
(2) Largest number of hours accumulated by a single sample
(3) Date of latest available Flight Test information

Figure 10
0.800 Inch (20.3 mm) P.D. MS14169AS Circular Spline Modification
of the T-2C Aircraft DC Starter/Generator

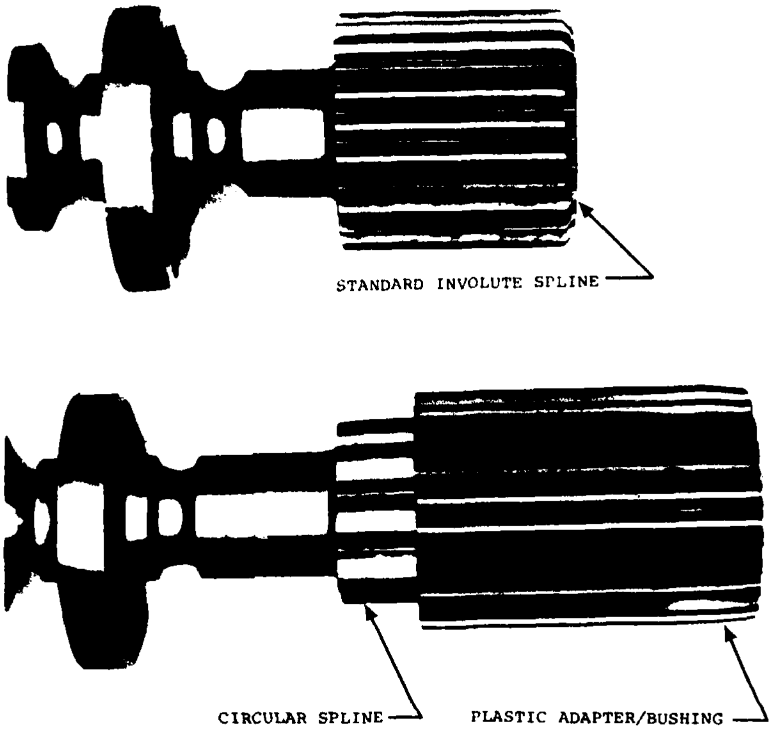


TEST APPLICATION:	
Aircraft	P-3
Accessory	Bendix 28B95 Generator
FLIGHT TESTS:	
Flight Time(1)	20,635 Hours*
Operations	N.A.
High Time(2)	2,287 Hours
Number of Samples	25*
Date(3)	28 February 1978
ULTIMATE TORSIONAL STRENGTH	
Predicted for VESPEL® SP-1 Isotropic (70°F, 21°C)	6,800 In.-Lb (768 N-m)

(1) Total Time accumulated by the Number of Samples
(2) Largest Number of hours accumulated by a single sample
(3) Date of latest available Flight Test information

* Includes an estimated 8,130 hours on 18 samples in Patrol Wing Five and Patrol Wing Eleven aircraft.

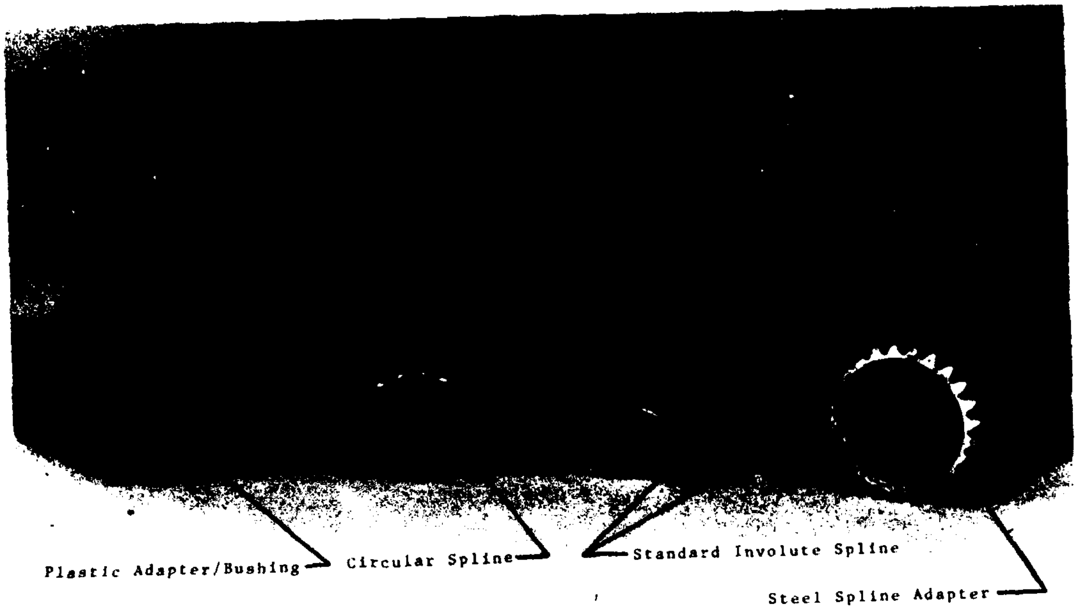
Figure 11
1.200 Inch (30.5 mm) P.D. MS14169AS Circular Spline
Modification of the P-3 Aircraft 60 KVA Generator Drive Shaft



TEST APPLICATION:	
Aircraft	EC-130
Accessory	General Electric 2CM 342 40/50 KVA Generator
FLIGHT TESTS:	
Flight Time(1)	16,382 Hours
Operations	N.A.
High Time(2)	3,539 Hours
Number of Samples	7
Date(3)	2 March 1978
ULTIMATE TORSIONAL STRENGTH	
Predicted for VESPEL® SP-1 Isotropic (70°F, 21°C)	6,800 In.-Lb (768 N-m)

(1) Total time accumulated by the Number of Samples
(2) Largest number of hours accumulated by a single sample
(3) Date of latest available Flight Test information

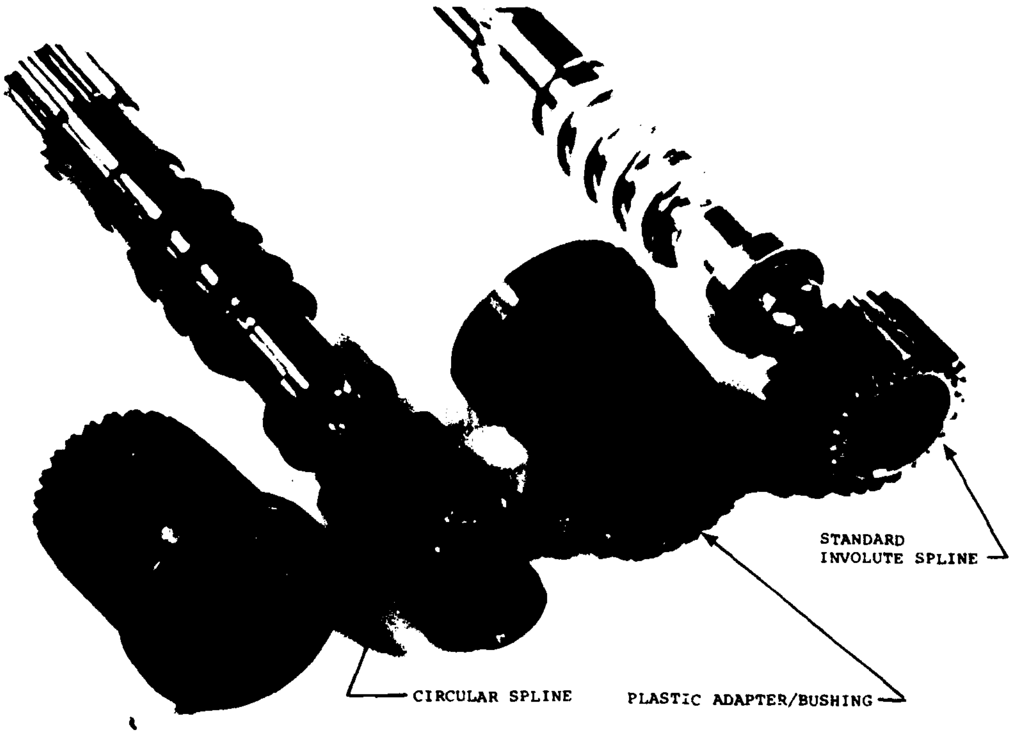
Figure 12
1.200 Inch (30.5 mm) P.D. MS14169AS Circular Spline
Modification of the EC-130 Aircraft 40/50 KVA Generator Drive Shaft



TEST APPLICATION:	
Aircraft	EC-130
Accessory	General Electric 2CM 355 60/90 KVA Generator
FLIGHT TESTS:	
Flight Time(1)	1,102 Hours
Operations	N.A.
High Time(2)	628 Hours
Number of Samples	2
Date(3)	2 March 1978
ULTIMATE TORSIONAL STRENGTH	
Predicted for VESPEL® SP-1 Isotropic (70°F, 21°C)	6,800 In.-Lb (768 N-m)

(1) Total time accumulated by the Number of Samples
(2) Largest number of hours accumulated by a single sample
(3) Date of latest available Flight Test information

Figure 13
1.200 Inch (30.5 mm) P.D. MS14169AS Circular Spline
Modification of the EC-130 Aircraft 60/90 KVA Generator Drive Shaft



TEST APPLICATION:	
Aircraft	F-4
Accessory	Sundstrand 30AGD03 *Constant Speed Drive*
FLIGHT TESTS:	
Flight Time(1)	2,965 Hours
Operations	N.A.
High Time(2)	679 Hours
Number of Samples	8
Date(3)	December 1976
ULTIMATE TORSIONAL STRENGTH	
Predicted for VESPEL® SP-1 Isotropic (70°F, 21°C)	6,800 In.-Lb (768 N-m)

(1) Total time accumulated by the Number of Samples
(2) Largest number of hours accumulated by a single sample
(3) Date of latest available Flight Test information

Figure 14
1.200 Inch (30.5 mm) P.D. MS14169AS Circular Spline
Modification of the F-4 Aircraft Constant Speed Drive Input Shaft

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