LEVEL

TM 79-1 SY

AD A068637

Technical Memorandum

AIRCRAFT ENGINE DRIVEN ACCESSORY

SHAFT COUPLING IMPROVEMENTS

USING HIGH-STRENGTH NONMETALLIC ADAPTER/BUSHINGS

SECOND PROGRESS REPORT

Mr. Aleck Loker

Systems Engineering Test Directorate

20 April 1979

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NAVAL AIR TEST CENTER
PATUXENT RIVER, MARYLAND

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
-TM 79-1-SY

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
AIRCRAFT ENGINE DRIVEN ACCESSORY SHAFT COUPLING IMPROVEMENTS USING HIGH-STRENGTH NONMETALLIC ADAPTER/BUSHINGS, SECOND PROGRESS REPORT

5. TYPE OF REPORT & PERIOD COVERED

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
MR. ALECK LOKER

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
SYSTEMS ENGINEERING TEST DIRECTORATE
NAVAL AIR TEST CENTER
PATUXENT RIVER, MARYLAND 20670

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
SYSTEMS ENGINEERING TEST DIRECTORATE
NAVAL AIR TEST CENTER
PATUXENT RIVER, MARYLAND 20670

12. REPORT DATE
20 APR[redacted]979

13. NUMBER OF PAGES
47

14. MONITORING AGENCY NAME & ADDRESS (If different from Controlling Office)

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

SHAFT COUPLINGS
SPLINED SHAFTS
INVOLUTE SPLINES
CIRCULAR SPLINES
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 splined 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 their rapid wear and failure rate, NAVAIRTESTCEN has engaged in a continuing spline coupling improvement program over the past 11 years. An outgrowth of this program has been the development of the new high-strength nonmetallic spline coupling adapter/bushing technology. Previous Technical Memoranda, TM 76-1 SY and TM 78-1 SY, condensed the

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results of these coupling improvement efforts into a description of two basic spline coupling designs (crowned circular toothed and flat toothed splines), explained their apparent success, and presented limited application and manufacturing information.

This report presents a summary of the new coupling designs which have been evaluated or are planned for future tests. Previously unpublished test data and the latest applicable Military Standard Drawings are also contained therein.

Actual flight operations totaling 68,000 hr on 10 different drive shaft nonmetallic coupling designs have verified the value of this new coupling technology.

Hydraulic pump endurance testing indicates that properly applied nonmetallic spline adapters can endure millions of stress cycles.

Air turbine starter tests have established that the low cycle fatigue limit for the circular spline design approaches the static torsional limit of the nonmetallic adapter.

Wear of the metal or plastic coupling parts is negligible even when the load approaches the torsional limit of the nonmetallic adapter.

Preliminary acoustic tests of a hydraulic pump driven through a nonmetallic coupling demonstrated a 9 dB reduction in the predominant audible frequency.

New applications will continue to be tested. Performance standards, an adapter specification, and alternate nonmetallic material qualification will be emphasized in future programs.

The circular spline design (U.S. Patent Number 3,620,043 of 16 November 1971) has been assigned to ARINC Research Corporation with royalty free rights to the Department of Defense. The other nonmetallic spline coupling design (U.S. Patent Number 4,098,096 of 4 July 1978) has been assigned to the United States Government.

PREFACE

Previous Technical Memoranda, TM 76-1 SY and TM 78-1 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 additional references are included in this report for the reader who wants more extensive background information pertaining to the spline coupling problem.

The continued and growing 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 application 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

JOHN B, PARADIS
Technical Director
Naval Air Test Center

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INTRODUCTION

1. Engine driven accessories, such as generators, starters, and pumps, are commonly connected to their respective power takeoff shafts by splined couplings. NAVAIRTESTCEN has engaged in a continuing spline coupling improvement program during the past 11 years. 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. Reference 2 presented additional application oriented information such as manufacturing details and specific design information. This report presents a summary of the new coupling designs which have been evaluated or are planned for future tests. Previously unpublished test data and the latest Military Standard Drawings are also contained herein.

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 axial freedom of 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 3 through 7.

3. Figure 1 illustrates a typical example of spline wear as experienced with an aircraft hydraulic pump. 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 6, 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 8, 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 lone (1,400 hr versus 25 hr) as the standard grease lubricated spline coupling. These typical laboratory test data have been verified by more than 68,000 hr of actual flight operations on 10 different drive shaft 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.

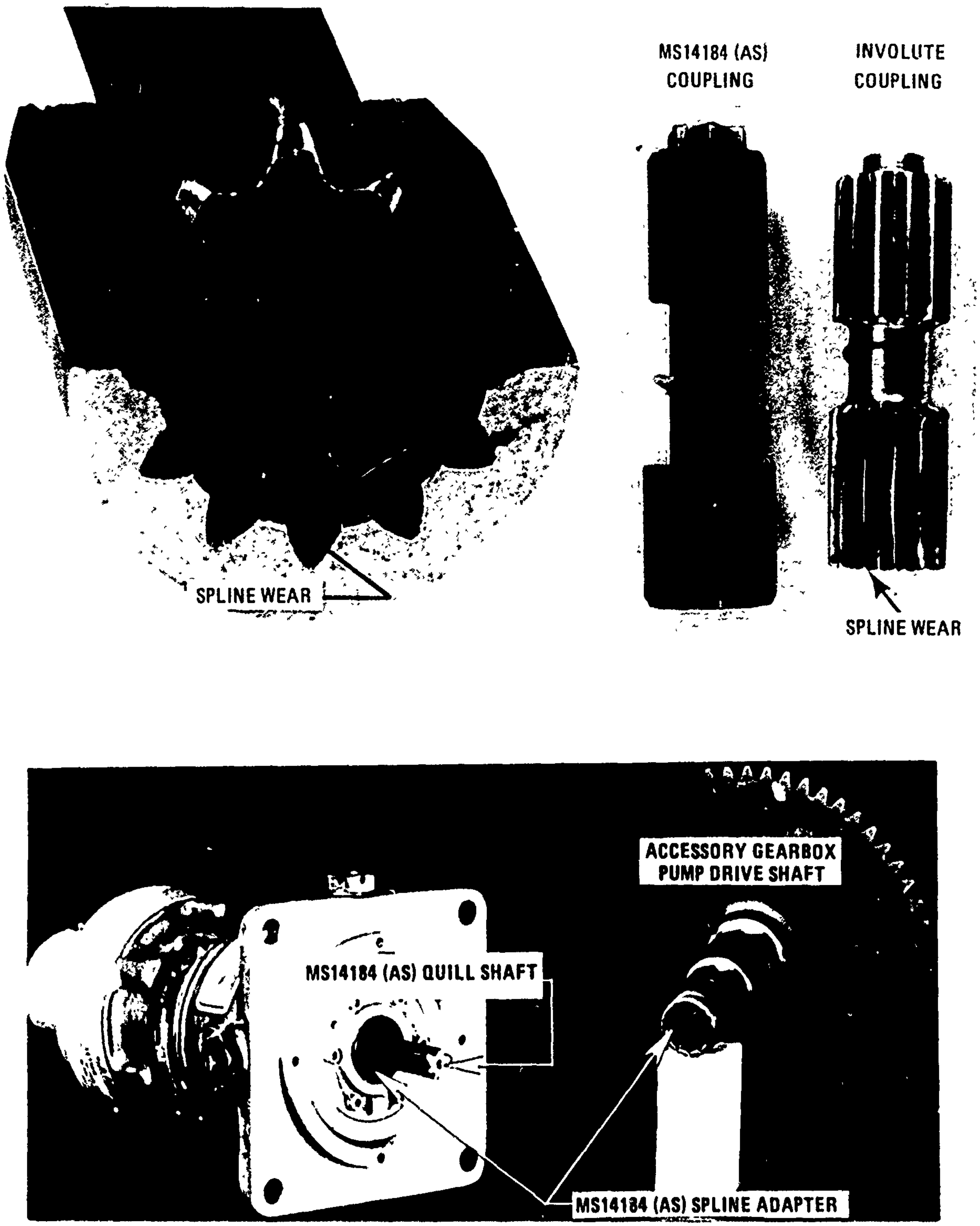


Figure 1
Aircraft Hydraulic Pump and Shaft Coupling Hardware Illustrating Typically Worn Standard Involute Splines and The New Nonmetallic Spline Modification

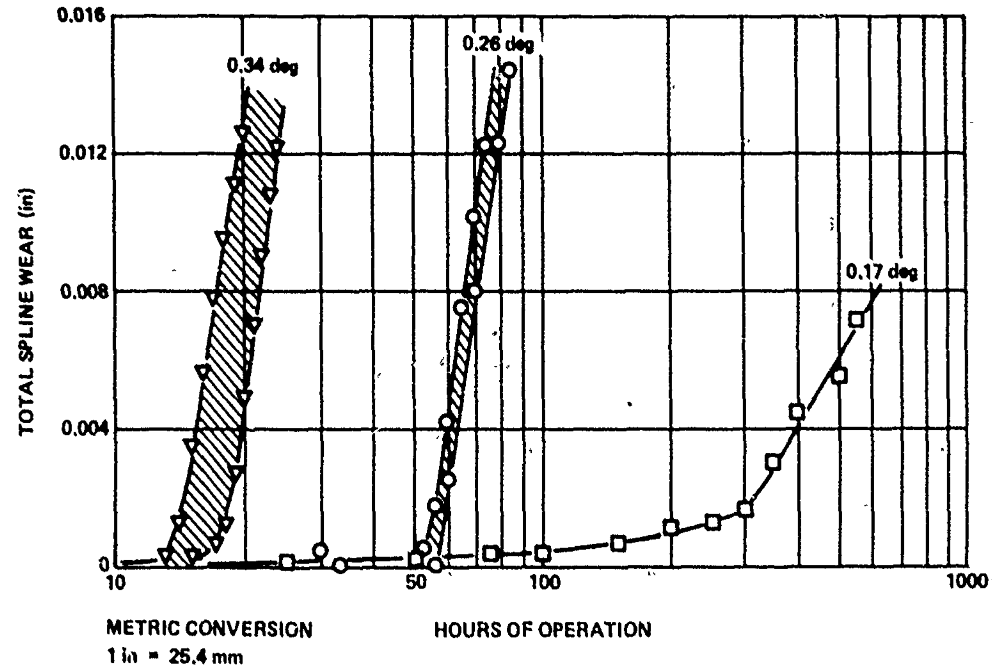


Figure 2
Laboratory Induced Spline Wear of Grease Lubricated Splines Showing the Effect of Spline Coupling Misalignment

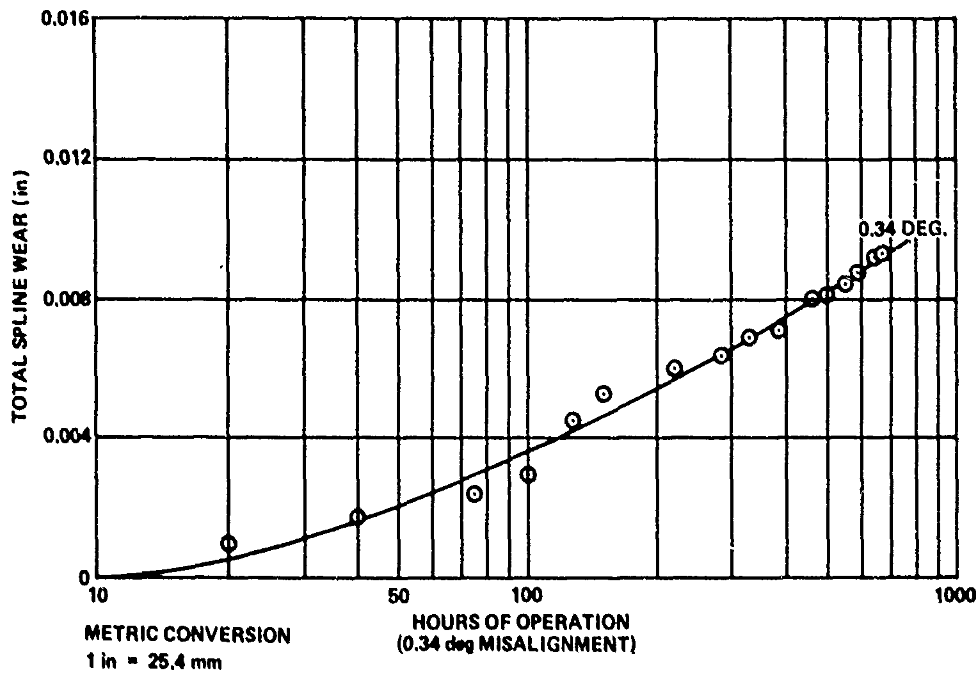


Figure 3
Laboratory Induced Spline Wear of Unlubricated, Internally and Externally Involute-Splined, Polyimide Plastic Bushing Showing the Reduction in Wear Rate

PURPOSE

4. This report presents a summary of the new nonmetallic spline coupling design applications, contains previously unpublished test data, and includes the current Military Standard Drawings.

SUMMARY OF SPLINE COUPLING APPLICATIONS

5. Twenty-two separate designs have been produced for evaluation during the course of this nonmetallic shaft coupling program. These designs can be categorized as MS14169(AS) circular splines, MS14184(AS) flat sided splines, and involute splines. Table 1 contains information on each of the 22 applications which have been or are being evaluated during laboratory or flight operations. These designs are required to transmit torques from 27 in.-lb (3 N-m) to greater than 6,000 in.-lb (565 N-m) and operate at speeds up to 26,000 RPM.

EXTERNAL SPLINE ADAPTER CONFIGURATIONS

6. In all cases, the nonmetallic adapters have been designed to be a tight fit in the accessory or gearbox splined cavity. This tight fit, which serves a dual purpose of retaining the adapter and applying a compressive prestress, has been achieved by incorporating oversized flat sided splines on the outside of the adapter. Two different methods of obtaining this fit have been used and are illustrated in figure 4. The primary difference between the two methods, side fit with root clearance and saw slots and side fit with no root clearance, reflects the need to limit installation forces on the larger diameter adapters. Consequently, the saw slots were added and the root clearance increased in the MS14169(AS) design to limit the axial force necessary to press the adapter into its mating splined cavity. The external spline geometry of the smaller MS14184(AS) adapters has been carefully selected to limit the axial installation force.

Table I

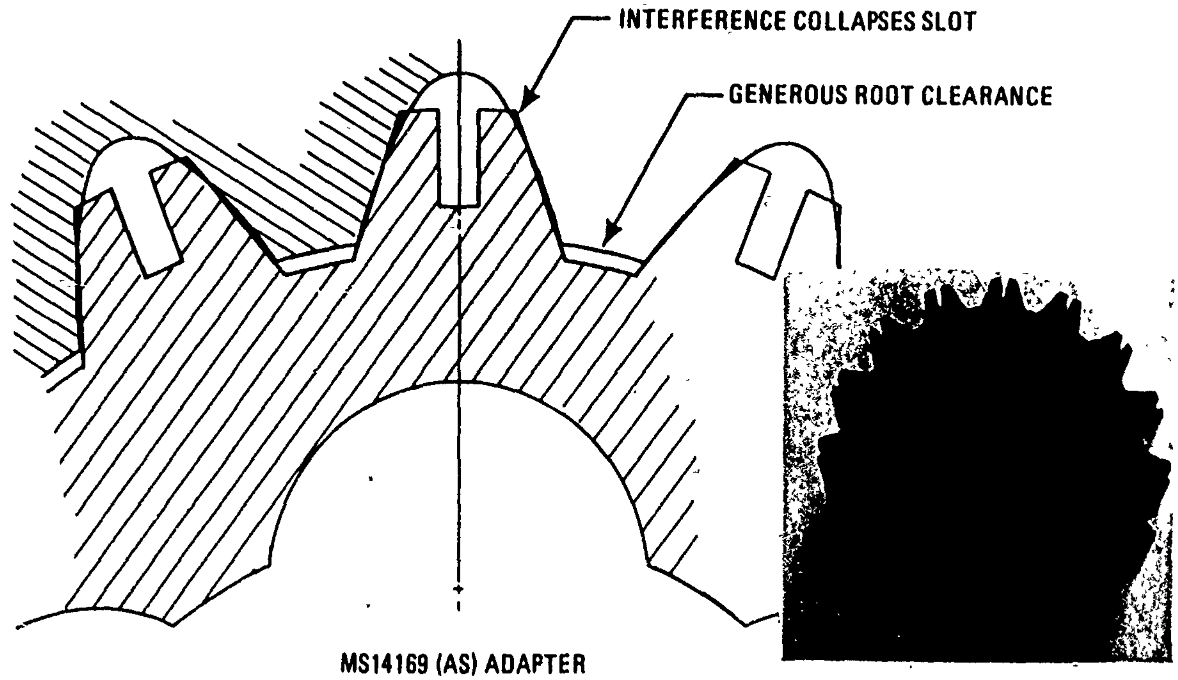
Status of Nonmetallic Shaft Coupling Applications

Test Application Aircraft	A-4	F-4	P-3	P-3	EC-130	EC-130	EC-130	T-2C	T-2C	CH-53D	CH-53E	CH-53E
Accessory	28B-139 Generator	30AGD03 CSD	28B95 Generator	A-24 Starter	2CM9ACF TACH Gen	2CM342 Generator	2CM355 Generator	30B45 Start/Gen	30B45 Start/Gen	65WB02003 Hyd Pump	28B58 Generator	Various Pumps
Configuration	Circular 0.800 in.	Circular 1.200 in.	Circular 1.200 in.	MS14169(AS) 1.200 in.	Square 0.244 in.	MS14169(AS) 1.200 in.	MS14169(AS) 1.200 in.	MS14169(AS) 0.800 in.	MS14169MOD 0.800 in.	MS14184(AS) 0.600 in.	MS14169(AS) 1.200 in.	MS14184(AS) 0.6875/0.800
Laboratory Test Running Time	2702	2267	7266	1040	0	0	75	12	2	700	200	650
High Time (1)	600	1450	4704	1040	0	0	40	12	2	350	200	400
Load Cycles	N.A.	N.A.	N.A.	1200	0	0	2065	1479	216	3735	N.A.	4.3×10^6
No. of Samples	7	2	4	1	0	0	2	1	1	2	1	2
Flight Test Flight Time (2)	670	2965	27,800	457	7889	22,882	1851	542	203	3530	0	0
High Time (1)	326	679	2635	186	1006	5500	993	98	78	639	0	0
Load Cycles	N.A.	N.A.	N.A.	130	N.A.	N.A.	N.A.	371	157	N.A.	0	0
No. of Samples	3	8	25	4	8	7	2	9	3	9	0	0
Date (3)	12-74	12-76	10-78	1-79	2-79	10-78	2-79	3-78	2-79	10-78	3-78	9-78

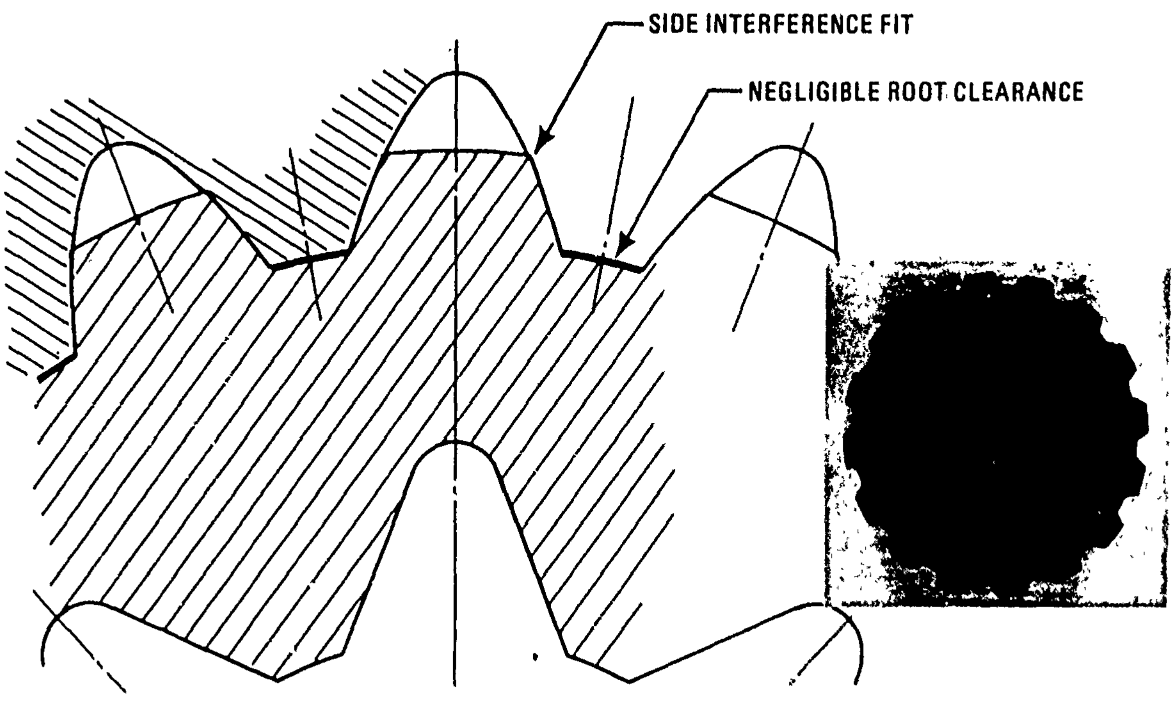
Test Application Aircraft	NAPC Trenton	Air Force SA ALC	T-76	F-14	H-53	A-4	A-7	F/A-18	F/A-18	A-7
Accessory	Engine Tst Fixture	KC-1186-8 Tst Stand	868510-6 Fuel Pump	A-28 Starter	66YF400 Pump	2CM-381 Generator	Fuel Pump	Generator	Starter	CSD
Configuration	Involute 1.200/0.800	Involute 1.375/1.100	Involute 0.4583/0.275	MS14169(AS) 1.200 in.	Involute 0.6750/NATC	MS14169(AS) 1.200 in.	MS14169(AS) 0.800 MOD	MS14169(AS) 1.200 in.	Involute	MS14169(AS) 1.700 in.
Laboratory Test Running Time	375	N.A.	0	40	0	0	0	0	0	0
High Time (1)	375	N.A.	0	40	0	0	0	0	0	0
Load Cycles	843	300	0	1200	0	0	0	0	0	0
No. of Samples	1	1	0	1	0	0	0	0	0	0
Flight Tests Flight Time (2)	0	0	0	0	0	0	0	0	0	0
High Time (1)	0	0	0	0	0	0	0	0	0	0
Load Cycles	0	0	0	0	0	0	0	0	0	0
No. of Samples	0	0	0	0	0	0	0	0	0	0
Date (3)	10-78	10-78	10-78	1-79	10-78	10-78	2-79	2-79	2-79	2-79

NOTES: (1) Largest number of hours accumulated by a single sample.
(2) Total hours accumulated by the number of samples
(3) Date of latest available flight and/or laboratory test information.

TOTALS
15,329 Laboratory Hours
68,789 Flight Hours
84,118 Total Test Hours



MS14169 (AS) ADAPTER



MS14184 (AS) ADAPTER

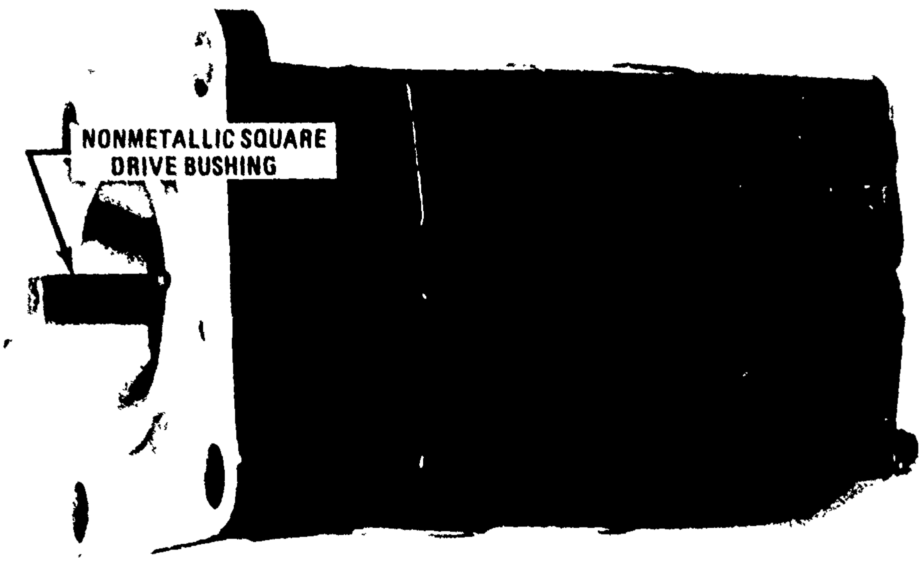
Figure 4
A Comparison of Two Types of Nonmetallic Shaft Couplings Noting the Two Preferred Methods of Achieving Retention and Compressive Preload

INTERNAL SPLINE ADAPTER CONFIGURATIONS

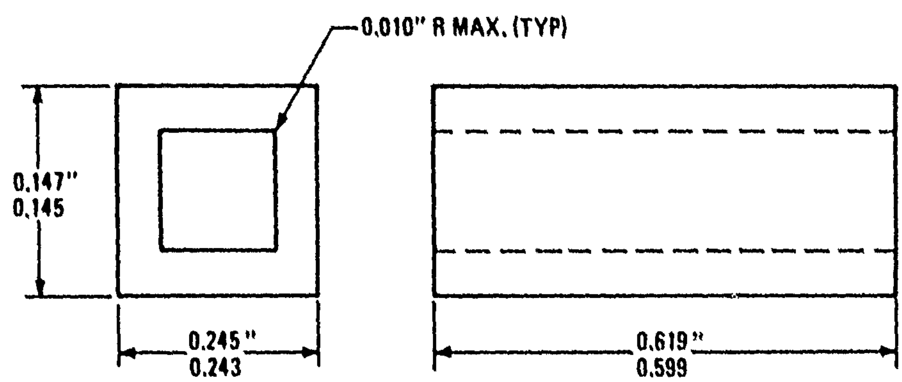
7. The internal splines are circular in cross section for all generators, constant speed drives (CSD's), and most starters. However, the proposed F/A-18 starter nonmetallic coupling design will use an involute spline profile since, in this case, the torque capacity is considered of greater importance than misalignment capability. Some additional involute designs have been produced for applications in which compatibility with existing hardware and tooling is the major concern. The hydraulic pump coupling designs have used the flat sided internal spline design in accordance with MS14184(AS). In most cases, this profile has a greater torque capacity than the closest standard involute design. Finally, because of the wide variety of fuel pump spline sizes, circular splines, as well as involute splines, have been proposed for fuel pump applications.

TACHOMETER GENERATOR SQUARE DRIVE SHAFT

8. One notable exception to the spline coupling configurations described above is included in the summary presented in table 1. The 2CM9ACF tachometer tests, which are applicable to all T-56 engine installations, have been conducted on shafts built in accordance with figure 5. In the strictest sense, this shaft coupling is not a splined coupling. Furthermore, the nonmetallic bushing used here is designed to fit loosely into the matching gearbox shaft cavity and is bonded to the tachometer shaft using an epoxy adhesive. However, since it is a type of nonmetallic coupling, it is included in the summary for completeness. Three different coupling configurations have been used in the T-56 engine driven tachometer generator: steel shaft, steel shaft with NYLON® bushing, and steel shaft with VESPEL® bushing. The latter two designs are being compared in flight tests in the EC-130 aircraft to determine if the additional VESPEL® strength will eliminate the observed tendency of the NYLON® to cold flow and ultimately fail. Prior flight experience demonstrated that the NYLON® bushing prevents the fretting wear of the square drive and mating gearbox shaft cavity experienced with the original all steel shaft coupling.



TACHOMETER - GENERATOR



NOTES:
1. MATERIAL - VESPEL SP-1
2. BUSHING ATTACHED WITH ECCOBOND 104 EPOXY ADHESIVE CURED FOR 6 HOURS AT 250° F.

METRIC CONVERSION

1 in = 25.4 mm

Figure 5
Engine Driven Tachometer-Generator Illustrating the Nonmetallic Square Drive Bushing Installation

SUMMARY OF RECENT TEST RESULTS

9. The evaluation of the 22 separate designs generally has led to or will result in separate NAVAIRTESTCEN Reports of Test Results giving the details of each design test program. References 9 to 17 present the specific results from some of these coupling test programs. The information presented below is contained herein because it is of general interest, illustrative of the nonmetallic coupling capability, and, in some cases, is previously unpublished.

CH-53E HYDRAULIC PUMP FATIGUE TEST

10. Figure 6 shows a test setup used to subject drive shafts to large numbers of cyclic torque loads. The apparatus consists of an aircraft electrical starter which drives the test specimen through a torque transducer. One end of the test shaft is locked so that it cannot rotate. The other end of the test sample is twisted in a controlled torque application produced by energizing the electrical starter from a regulated current source. Candidate design shafts and nonmetallic adapters are subjected to repeated load cycles in this apparatus to determine their torsional fatigue strength. In the case of the CH-53E hydraulic pump drive shafts, various configurations of nonmetallic coupling shafts and adapters were fatigue tested to achieve the maximum strength possible in a 0.6875 in. (17.5 mm) pitch diameter (P.D.) application. A sample trace of load cycles applied to prototype CH-53E hydraulic pump drive shafts is shown in figure 7. The torque peak of 85 ft-lb (11.5 N-m) is followed by a damped oscillation caused by the release of stored energy in the twisted shaft when the starter electrical current is interrupted. The selected CH-53E shaft design was subjected to 30,000 such torque application cycles (not counting the negative torque peaks or damped oscillations) without failure. The CH-53E pump spline test coupling is illustrated in figure 8 and conforms to the requirements of MS14184(AS).

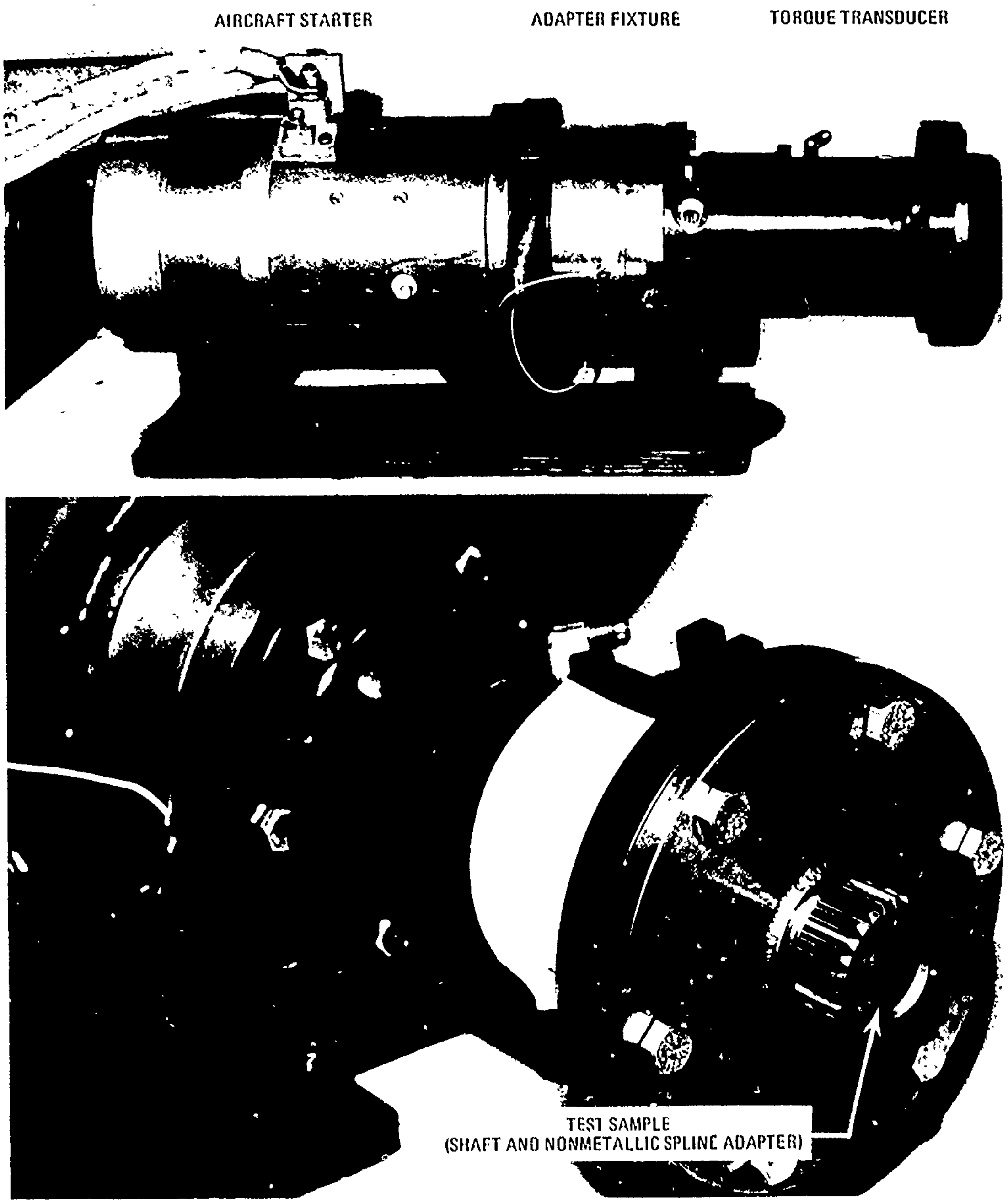
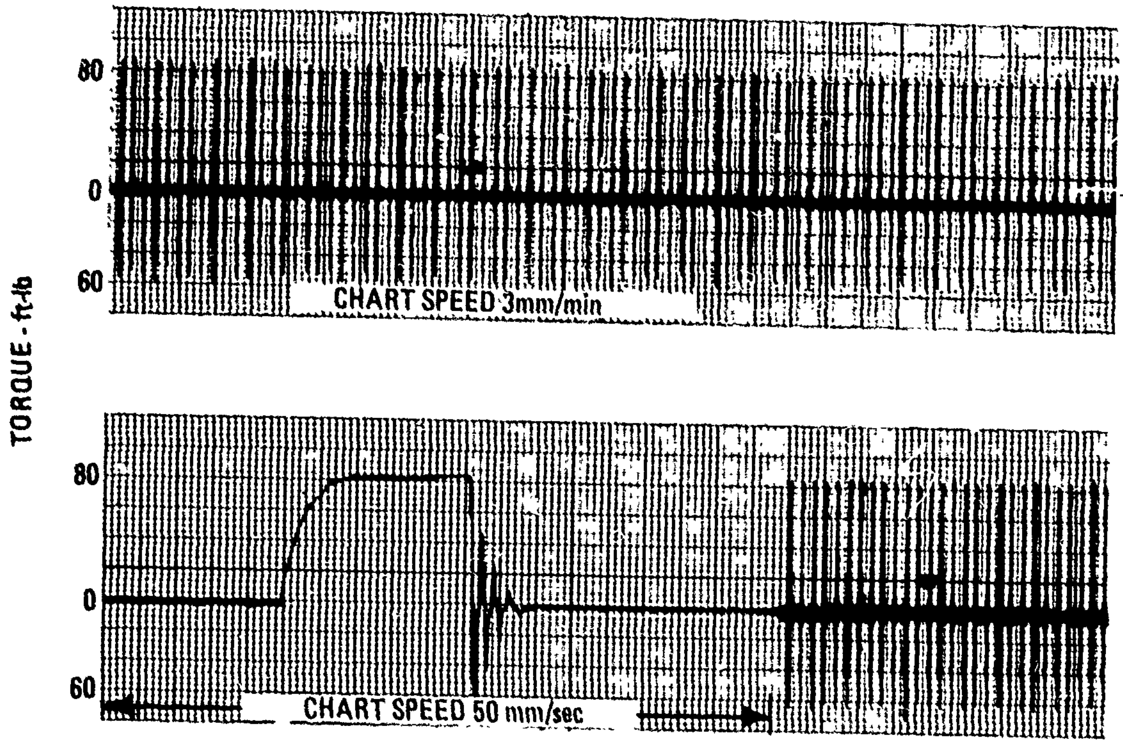
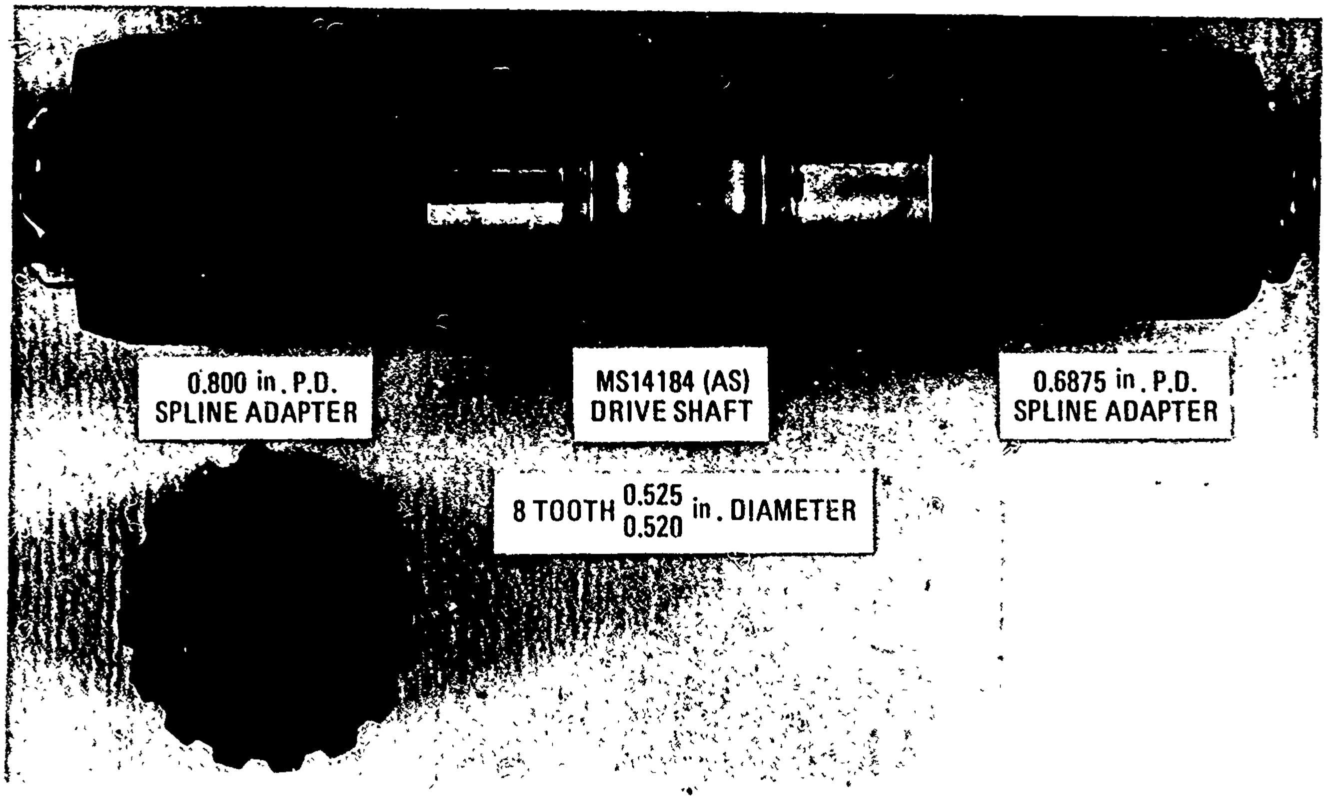


Figure 6
Shaft Torsional Fatigue Test Apparatus Using an Aircraft Electrical Starter as the Prime Mover



METRIC CONVERSION
1 ft·lb = 1.356 N·m

Figure 7
Typical Torsional Load Cycles Applied to Test Shaft Couplings During Shaft Torsional Fatigue Evaluations



METRIC CONVERSION

1 in. = 25.4 mm

Figure 8
Proposed Aircraft Hydraulic Pump Nonmetallic Shaft Couplings as Tested for the CH-53E

CH-53E HYDRAULIC PUMP SHAFT ENDURANCE TEST

11. Following successful completion of the shaft fatigue test, the proposed CH-53E hydraulic pump was equipped with a second identical shaft test sample. The pump was installed in the test configuration shown in figure 9, and the hydraulic circuit was connected in accordance with figure 10. During 400 hr of operation, the pump was automatically loaded and unloaded in a simulation of the expected CH-53E operating scenario. Pump loads were varied throughout the test at a rate of 3 Hz since the aircraft automatic flight control servo system is expected to vary its demand at that average rate. Figure 11 shows the actual recorded load profile. In addition to the profile shown, the pump was stopped and restarted (accelerated to 3700 RPM) 100 times to simulate the interval between flights. In figure 12, the recording speed was increased so that individual load cycles could be defined. Drive shaft torque can be observed to vary from 15 to 36 ft-lb (20 to 49 N-m) during the "normal" servo load condition of 4 to 11 GPM (0.2 to 0.7 l/s). During startup, the pump drive shaft torque increased to a peak of 66 ft-lb (89.5 N-m) at which point the automatic pump piston stroke control

reduced the torque load to the 15 to 36 ft-lb (20 to 49 N-m) range. A sample start trace showing this condition is presented as figure 13. At the end of the 400 hr test, the shaft was removed, visually inspected, and magnafluxed. The appearance of the shaft had not changed and no cracks were found. The adapters showed very little deformation, no apparent wear, and had a polished appearance in the shaft bores. The 0.6875 in. (17.5 mm) P.D. pump spline adapter had cracked longitudinally at three of the thin sections between the external teeth as shown in figure 14. Cracks of this nature do not significantly affect the strength or wear life of the adapter since the adapter is restrained by the enveloping outer shaft spline. An attempt was made to break the shaft to check the shear section, but the internal teeth of the 0.6875 in. (17.5 mm) P.D. adapter failed at 183 ft-lb (248 N-m). A second attempt was made using a 0.800 in. (20.3 mm) P.D. adapter at each end of the shaft. This adapter with its slightly longer internal splines failed at 201 ft-lb (272 N-m). No attempt was made to break the shaft without the adapters because it was felt that uniform loading on the shaft teeth could not be obtained by other means. It should be noted that during the 400 hr test, the shaft was subjected to 4.3×10^6 torsional load cycles.

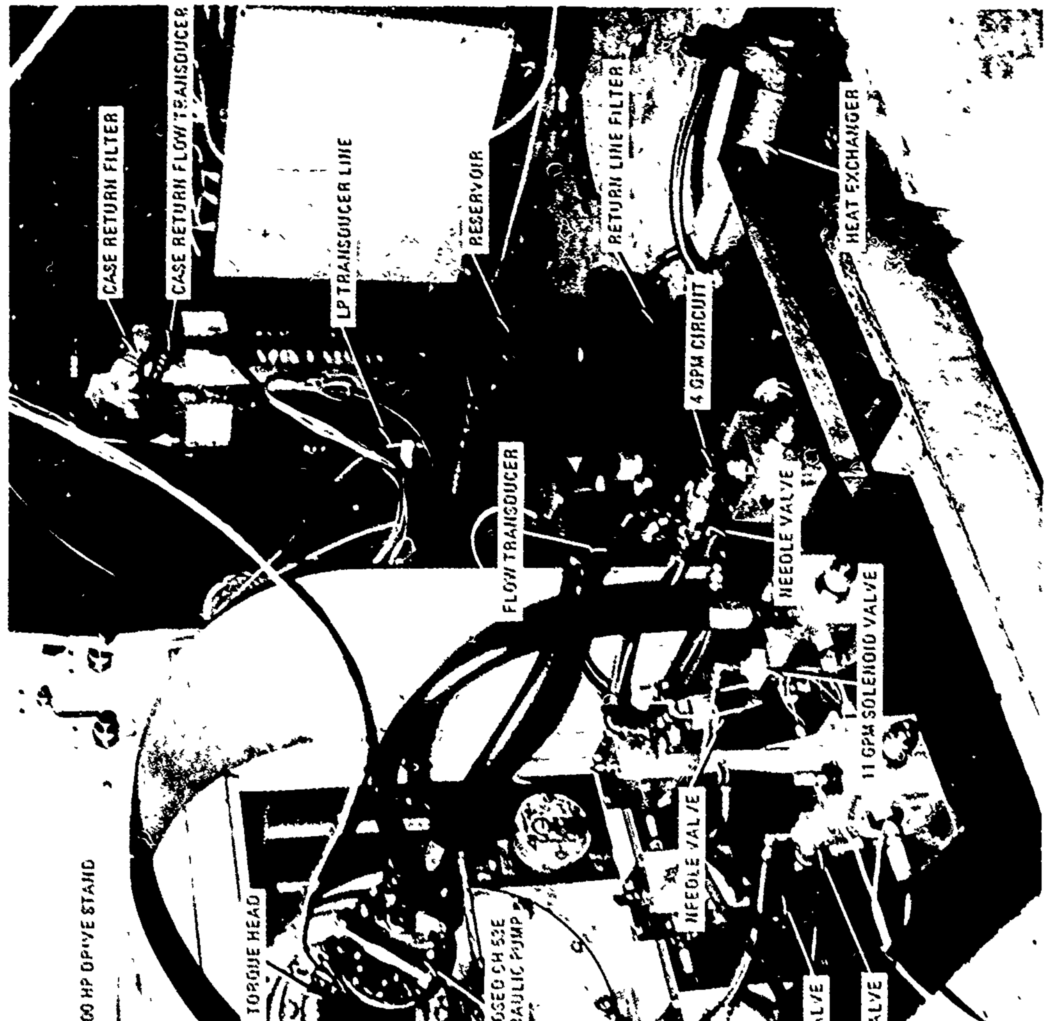


Figure 9
CH-53E Hydraulic Pump Endurance Test Laboratory Installation
Illustrating the Various Hydraulic Components

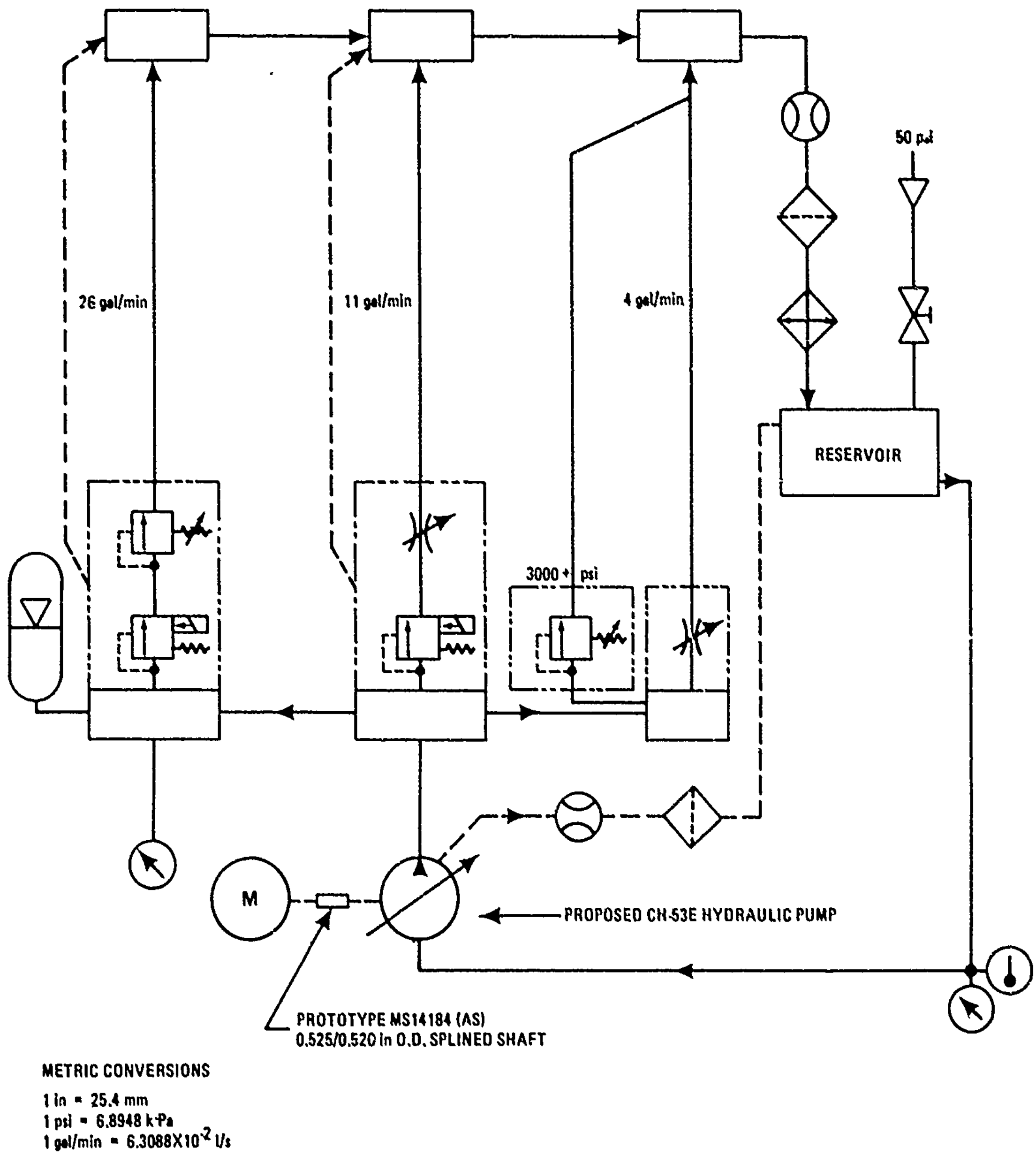
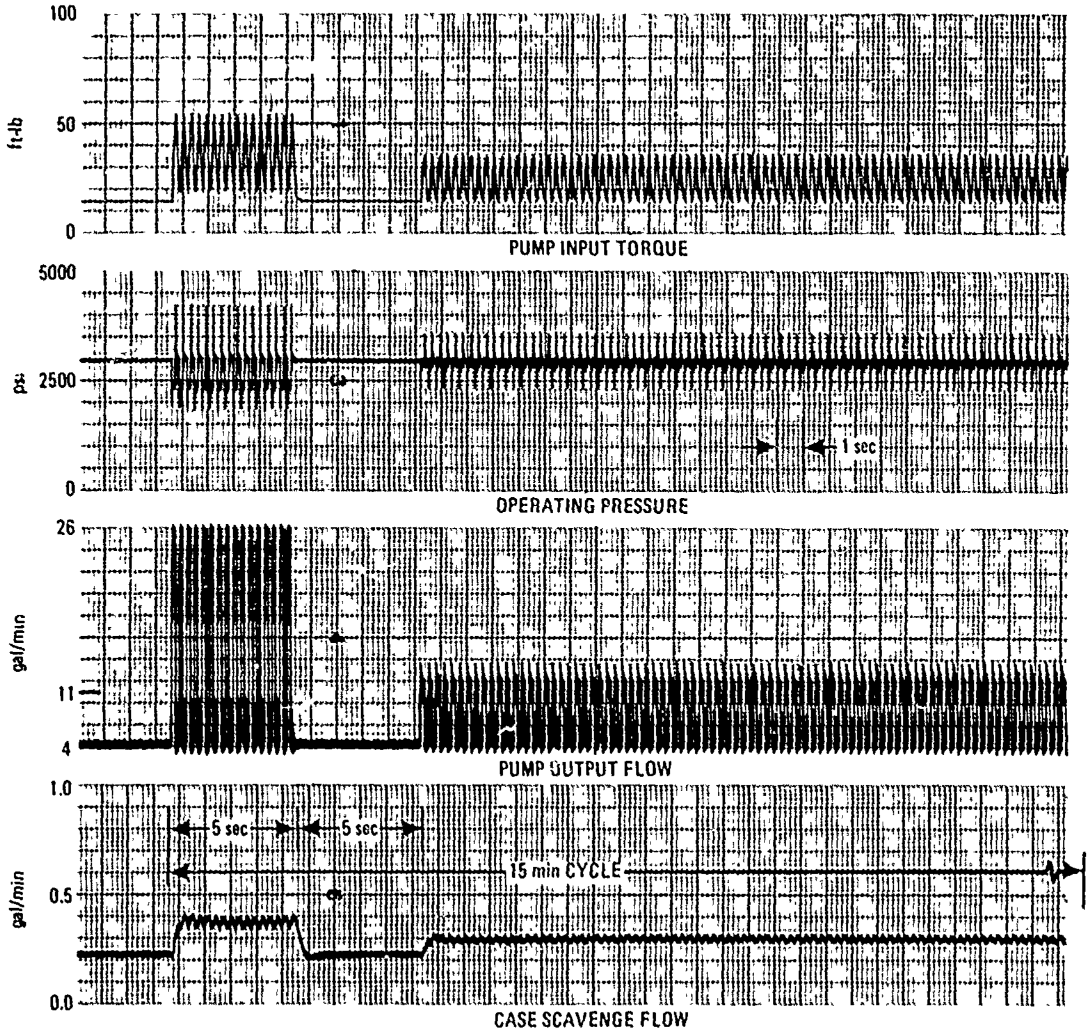


Figure 10
CH-53E Hydraulic Pump Endurance Test Diagram Showing the Relationship of the Various Hydraulic Components



METRIC CONVERSIONS

1 ft-lb = 1.356 N·m

1 gal/min = 6.3088×10^{-2} l/s

1 psi = 6.8948 k·Pa

Figure 11

CH-53E Hydraulic Pump Endurance Test Recorded Load Profile Showing the Cyclic Variation of the Test Parameters

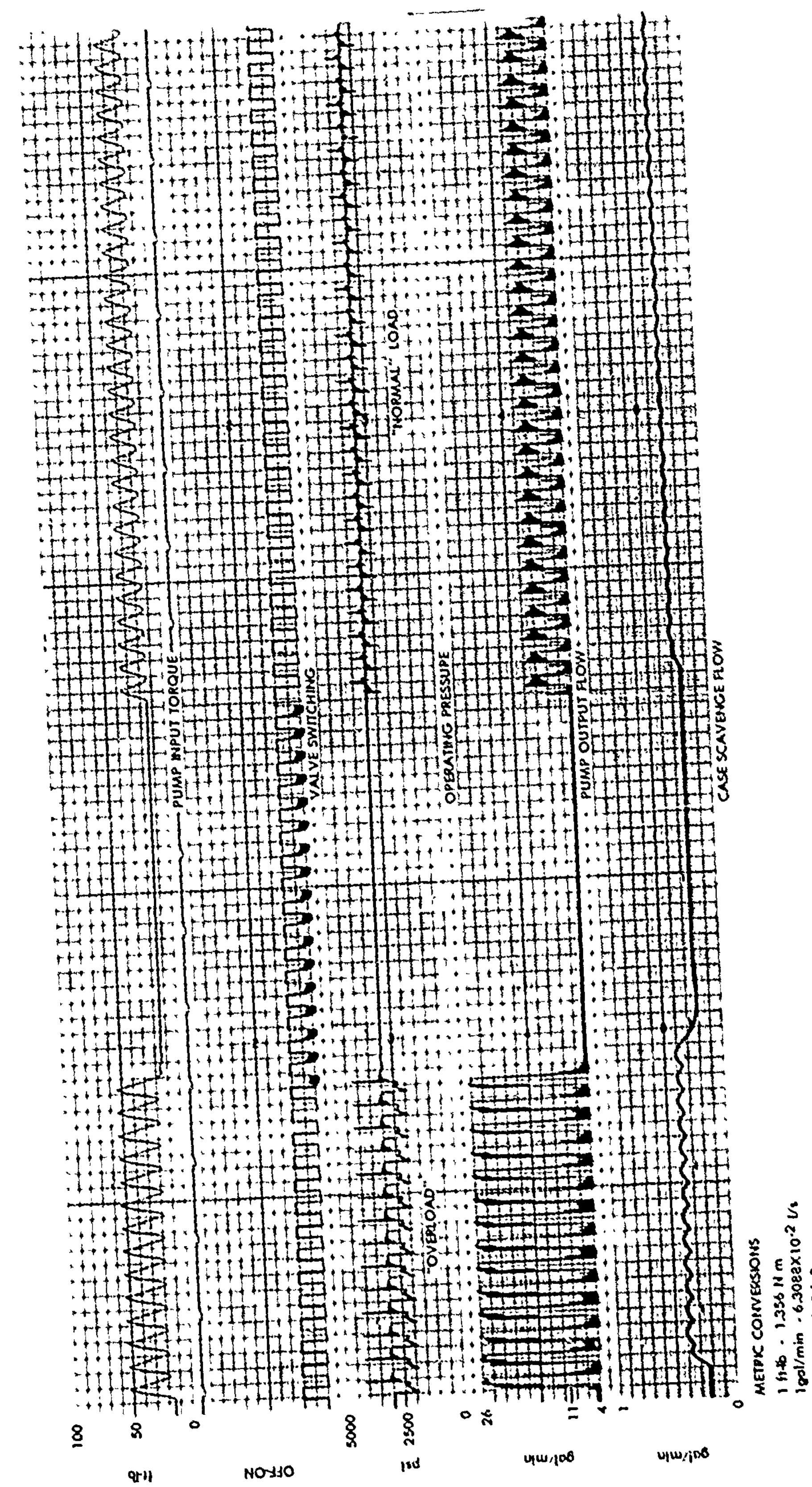


Figure 12
CH-53E Hydraulic Pump Endurance Test Recorded Load Profile, Time Domain Expanded to Show Individual Load Cycles

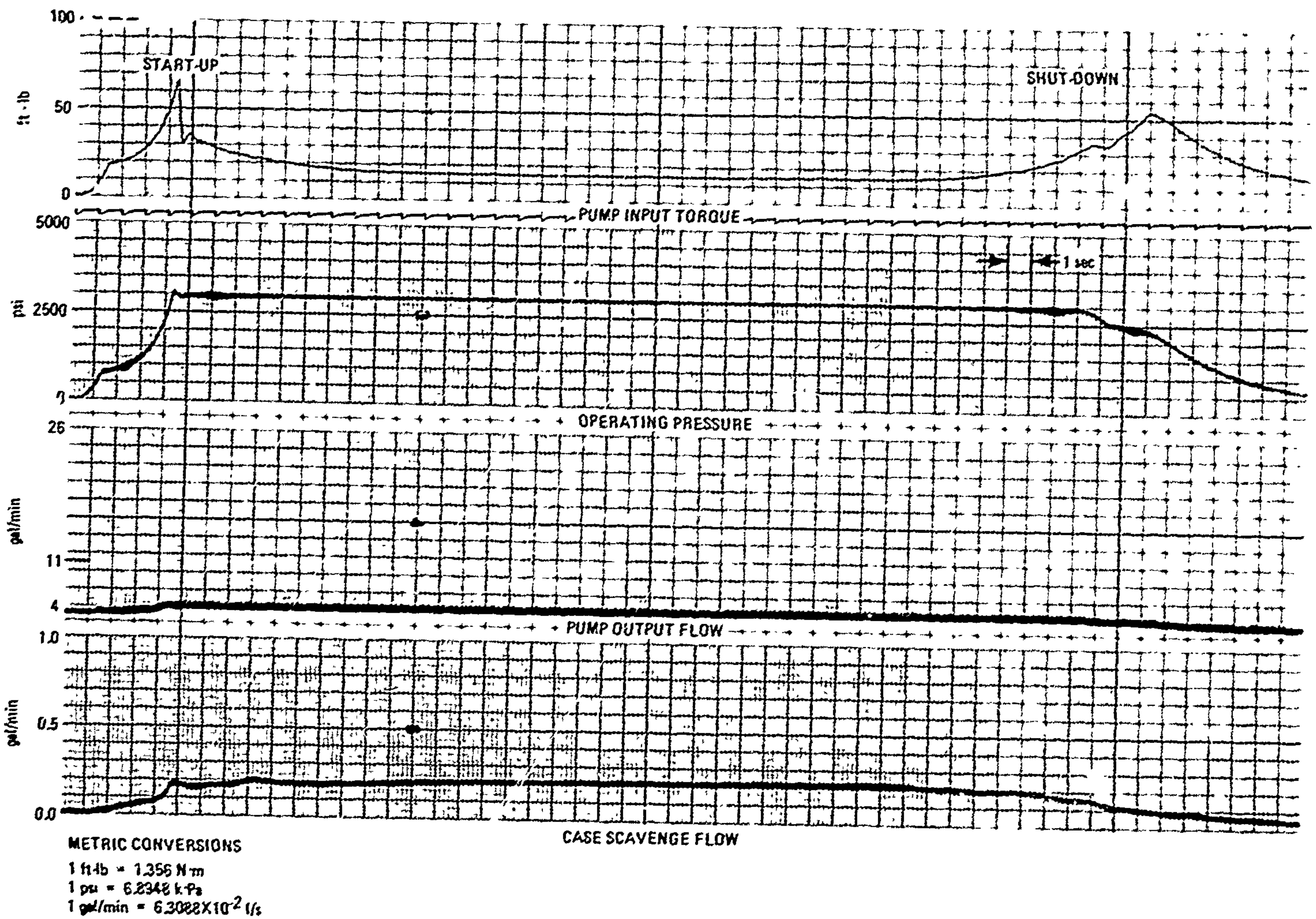
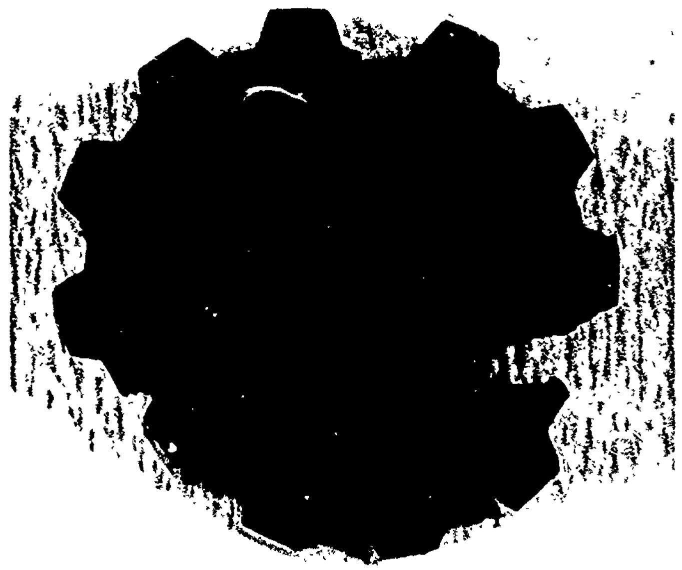


Figure 13
CH-53E Hydraulic Pump Endurance Test Recorded Load Profile
Showing the Torque Peak Experienced During Simulated
Engine Start-up and Shut-down



NOTE: The axial cracks do not significantly affect the strength or wear rate of the adapter since the adapter is restrained by the enveloping outer shaft.

Figure 14
0.6875 in. (17.5 mm) Pitch Diameter Spline Adapter Removed from the Enveloping Outer Shaft Spline Following 4.3 Million Torsional Load Cycles

HYDRAULIC PUMP ACOUSTIC TEST

12. During the course of testing the CH-53E pump drive shaft, various technicians commented that the pump ran audibly quieter with the nonmetallic coupling than with the standard steel drive shaft coupling. Consequently, at the end of the endurance test, acoustic measurements were made using a tripod mounted, noise intensity meter as shown in figure 15. These measurements were taken after all other rotating or noise producing equipment (except for the pump drive stand) was shut down to minimize the background noise. Furthermore, the noise data were recorded with the pump driven through the steel shaft and also through the nonmetallic coupling configurations twice to verify that the acoustic signatures were repeatable. Figure 16 gives the results of this test. The acoustic measurements were significantly lower when the pump was driven by the nonmetallic coupling. The most noticeable noise reduction of 9 dB occurred at 500 Hz, which is in the frequency range of normal conversation. The frequency of the peak noise level corresponds to the frequency generated by the product of the nine pistons and the rotational rate of 62 Hz (3,720 RPM). Torque measurements

shown in figure 17 were also taken with the standard steel shaft and with the nonmetallic coupling. A comparison of the torque measurements at four different pump test conditions indicates that the nonmetallic adapter dampens the inherent pump torsional oscillations and may in turn dampen the pressure pulsations generated by each piston. This damping is suspected as the cause of the noise reduction.

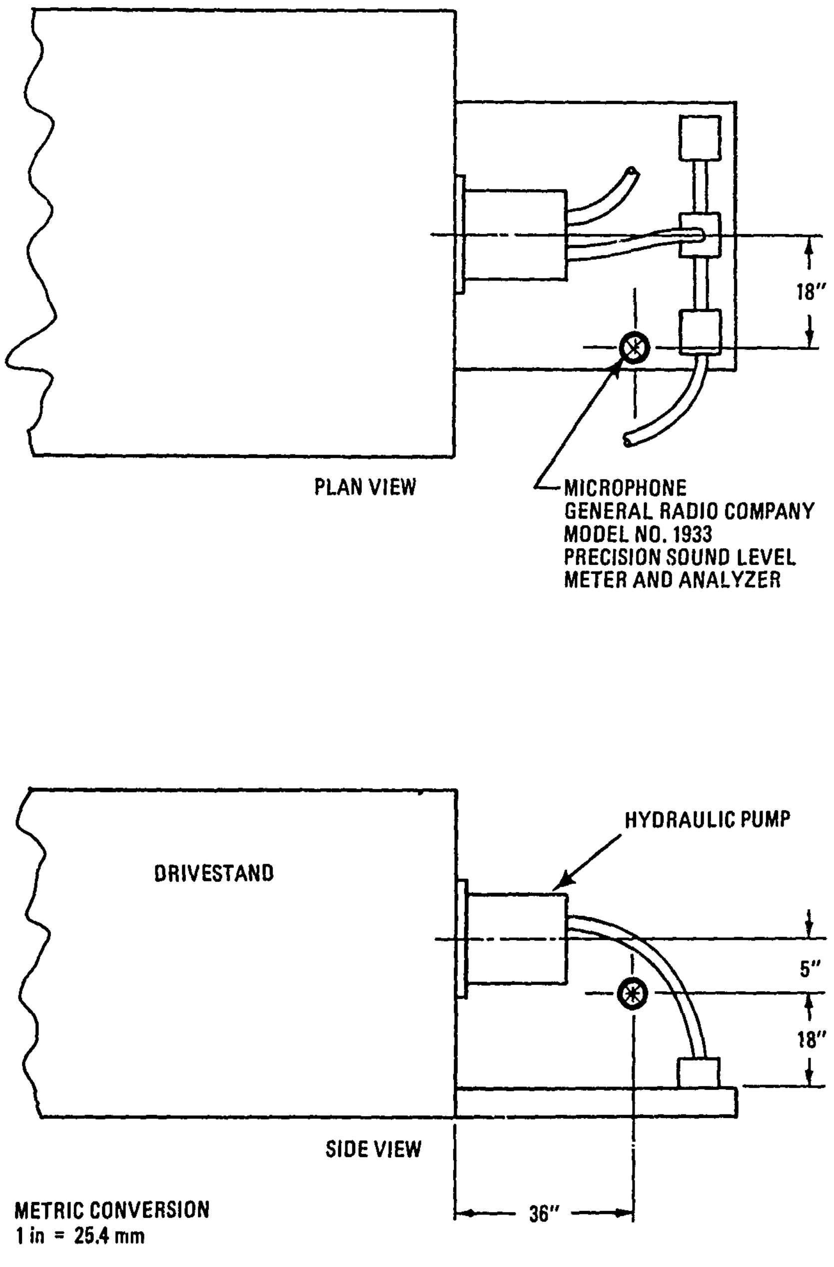
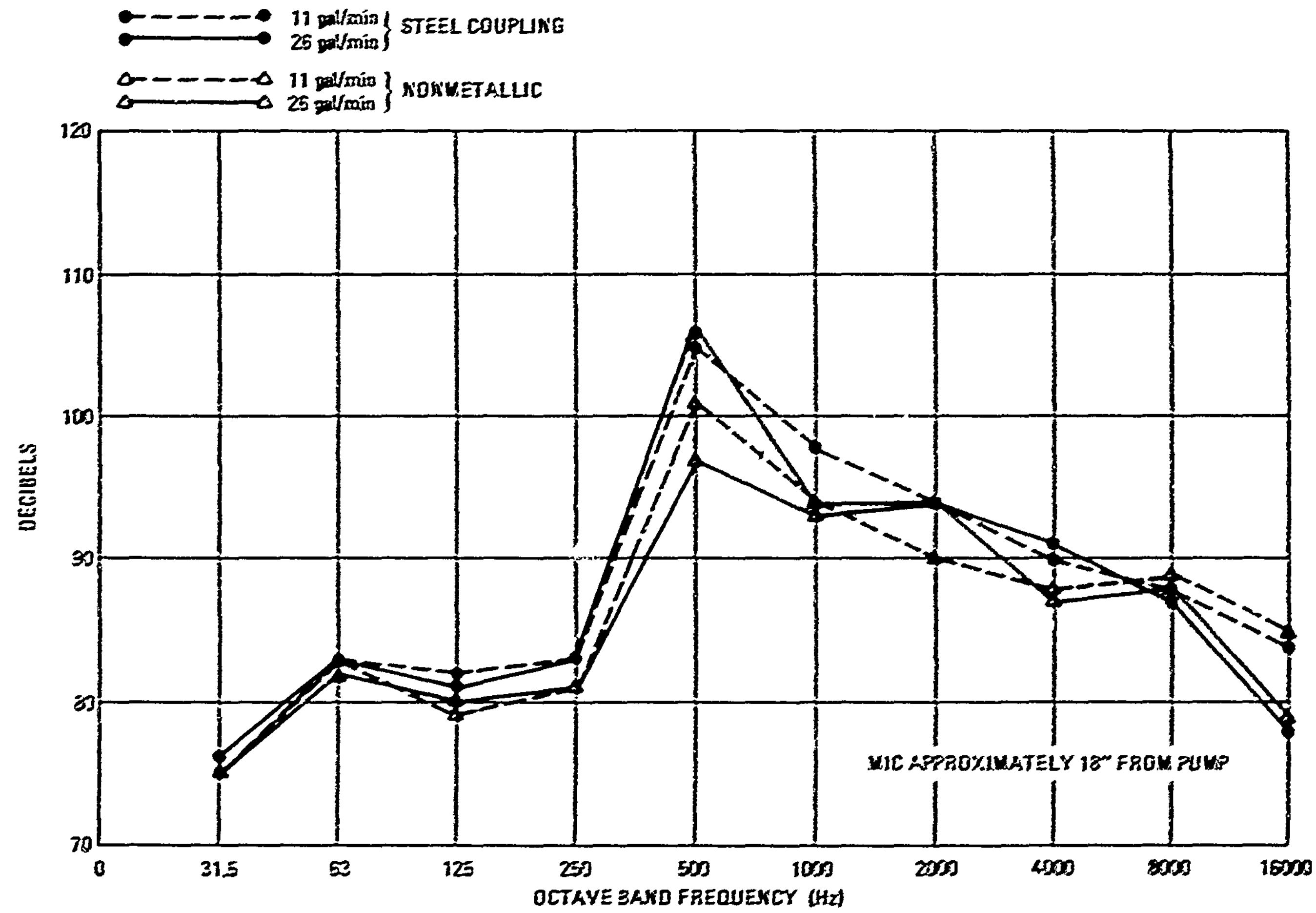


Figure 15
Location of the Acoustic Measurement Equipment with Respect to the CH-53E Hydraulic Pump and Drive Stand



METRIC CONVERSIONS
1 in = 25.4 mm
1 gal/min = 6.3088X10^-2 l/s

Figure 16
Comparison of Octave Band Analysis of Acoustic Data Recorded with CH-53E Hydraulic Pump Driven Through a Standard Steel Involute Coupling and Through a Nonmetallic Coupling

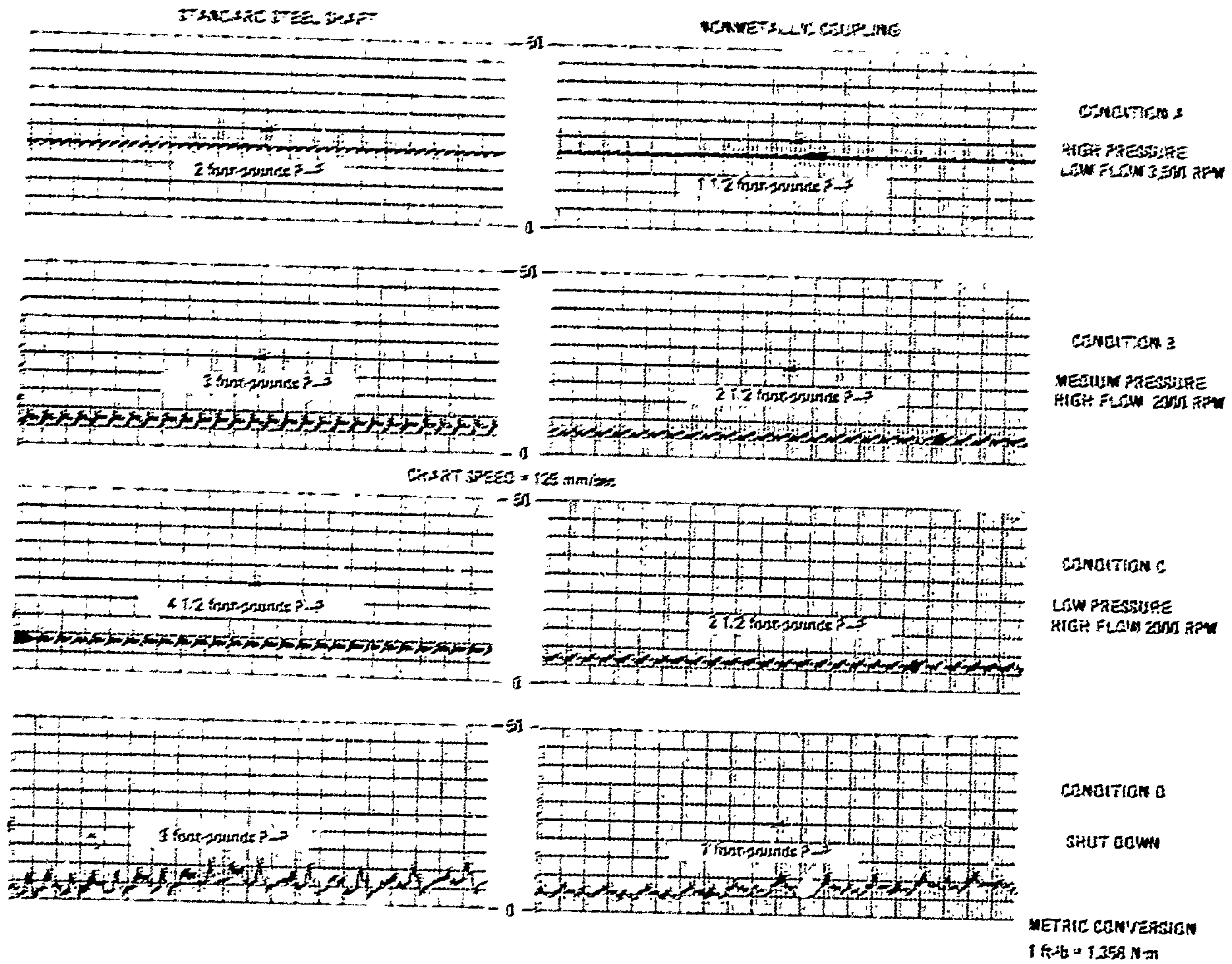


Figure 17
Comparison of Torsional Oscillations with the CH-53E Hydraulic Pump Driven Through a Standard Steel Involute Coupling and Through a Nonmetallic Coupling

AIR TURBINE STARTER TESTS

13. Recent test of air turbine starters equipped with MS14169(AS) circular splines have demonstrated the design's resistance to low cycle fatigue. The T-56 engine air turbine starter listed in table I as the P-3, A-24 starter was subjected to 1200, 61 ft-lb (82.7 N-m) engine start cycles during laboratory tests at the Naval Air Propulsion Center (NAVAIRPROPCEN), Trenton. Following the start cycles, the starter was motored at 14,000 RPM for 1,000 hr to simulate the over-running condition experienced during flight. The nonmetallic coupling was in excellent conditions at the end of the test, exhibiting a minor amount of wear/deformation as shown in figure 18.

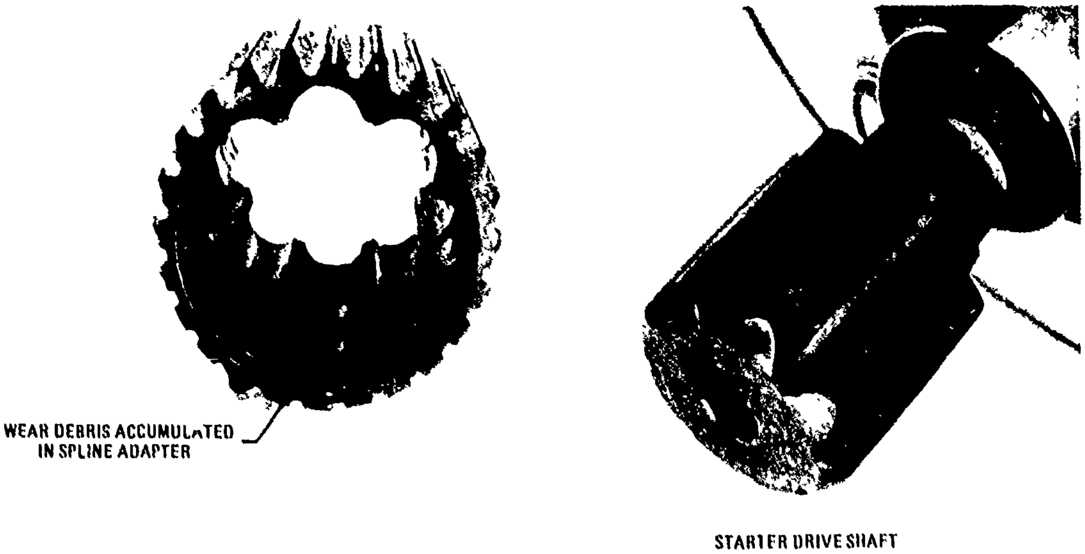


Figure 18
T-56 Engine Air Turbine Starter Nonmetallic Coupling Components Following 1200 Start Cycles and 1000 Hr Continuous Operation at 14,000 RPM

14. A similar test of the F-14, A-28 air turbine starter with an equivalent circular spline was less successful. The F-14 starter was subjected to 1200, 450 ft-lb (610 N-m) engine start cycles at NAVAIRPROPCEN. The nonmetallic coupling exhibited no cracks and minimal deformation when examined after 497 starts. However, when examined after 1200 start cycles, the nonmetallic adapter showed severe deformation with cracks underlying the internal teeth. The condition of this adapter is shown in figure 19 (taken following the 1200 start cycles). The results of the F-14 air turbine starter nonmetallic spline modification indicate the upper limit for the basic size 1 circular spline. It should be noted that the static torsional limit for the size 1 circular spline adapter was previously determined to be 567 ft-lb (768 N-m). In this light, the results of the starter endurance test are encouraging. These tests will be resumed with a nonmetallic adapter made from a stronger polymeric plastic material.

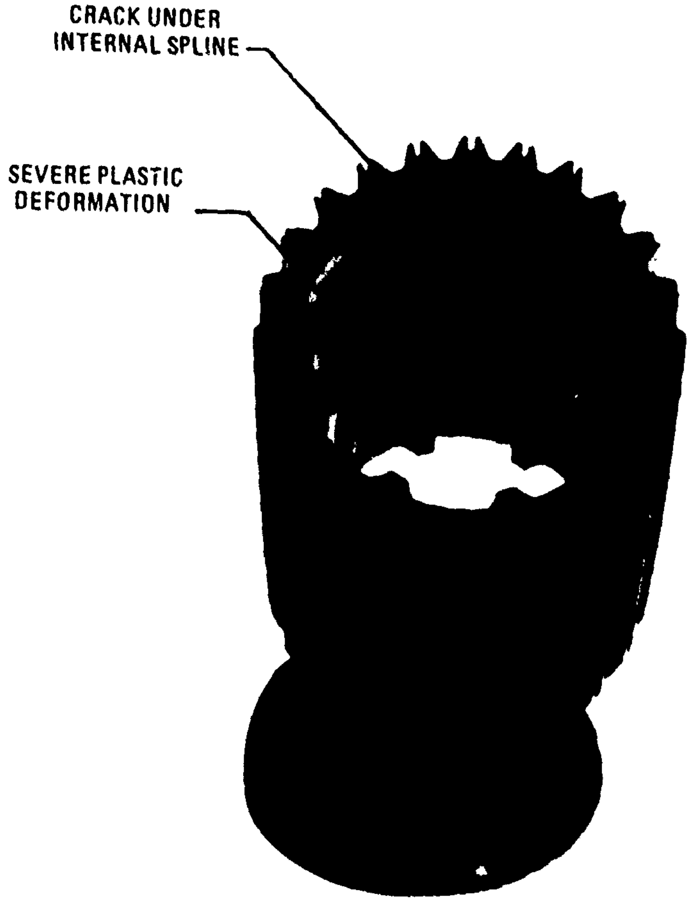


Figure 19
Nonmetallic Adapter Damaged During 1200 Cycles of the F-14 Engine Air Turbine Starter

ADDITIONAL NONMETALLIC SPLINE ADAPTER DATA

15. Ultimate torsional strength data are being compiled for various sizes and combinations of the MS14169(AS), MS14184(AS), and certain special nonmetallic adapters. Table II presents the available data for the configurations which have been tested. The listed ultimate torsional strengths result from measurements of the static torsional stress which causes failure of the nonmetallic adapter at room temperature. In some cases, the failure is characterized by fracturing at the base of the internal spline teeth. In other cases, the failure exhibits the appearance of excessive slip and compressive deformation. Figure 20 illustrates these two types of adapter failure. In general, the type of failure appears to be due to the way the torque load is transposed to shear and compressive stresses by the spline geometry of the nonmetallic part. Figure 21 shows that the torque load results in substantial shear stress in the circular spline, whereas the compressive stress predominates in the flat sided or involute shaped splines. Consequently, in the circular spline, slippage and compressive deformation should predominate, whereas fracture of the internal splines should predominate in the flat sided and involute teeth. Figure 21 also contains various design parameters which indicate the relative merits of the three different spline shapes. The product of the number of teeth (N) times the area per unit length (A) gives the total spline load bearing area (N-A). This area has been maximized in the MS14184(AS) flat-sided splines at the expense of the steel inner shaft strength. The reduction in the steel inner shaft strength is due to the relatively deep root diameter of the flat-sided splines. This analysis indicates:

a. MS14169(AS) circular splines should be used for moderate torque load applications in which misalignment due to tolerance stackup, overhung moment, and flight dynamics is probable.

b. MS14184(AS) flat-sides splines should be chosen when per-unit-area load must be minimized to limit wear due to high frequency cyclic loads, when misalignment is not severe, and when the relatively weaker inner shaft will provide an adequate safety margin.

c. Involute splines with nonmetallic adapters should be used when the steel inner shaft is severely limited in diameter relative to the transmitted torque load making use of the circular or flat-sided splines impractical.

Table II

Ultimate Static Torque Load for Various Nonmetallic Adapter Configurations (Room Temperature Performance, Values in ft-lb)

Test Sample Type (VESPEL SP-1 Material)				Sample Length (in.) .375	Sample Length (in.) Other
MS14169(AS)					
Size 3/4				68-72	
Size 1				205 (CALC)	137 (.250)
MS14184(AS)					
Outside PD(1)	Outside DP(2)	Inside T(3)	Inside FD(4)		
.6000	20/40	6	.450	84	
.6875	16/32	6	.450	75-81	
.6875	16/32	8	.525	108-109	
.8000	20/30	8	.525	111	183 (.700)
.8000	20/40	8	.525	109-113	201 (.800)
.8000	20/40	8	.615		
SPECIAL					
Outside		Inside			
MS14169 Size 3/4		8T .525 FD MS14184		94-98	211 (.750)
MS14169 Size 3/4		8T .615 FD MS14184		124	
MS14169 Size 1		MS14169 Size 3/4		62	
MS14169 Size 1		16T .800 PD 20/30 INVOL		190 (CALC)	127 (.250)
11T .4583 PD		11T .275 PD 40/80 INVOL		22 (CALC)	19 (.325)
21T .8750 PD		6T .450 FD MS14184		64	
21T .8750 PD		8T .615 FD MS14184		125	
MS14184 .8000 20/30		MS14169 Size 3/4		79	

NOTES: (1) PD indicates Pitch Diameter in inches.
(2) DP indicates Diametral Pitch.
(3) T indicates the Number of Teeth.
(4) FD indicates the Form Diameter in inches.

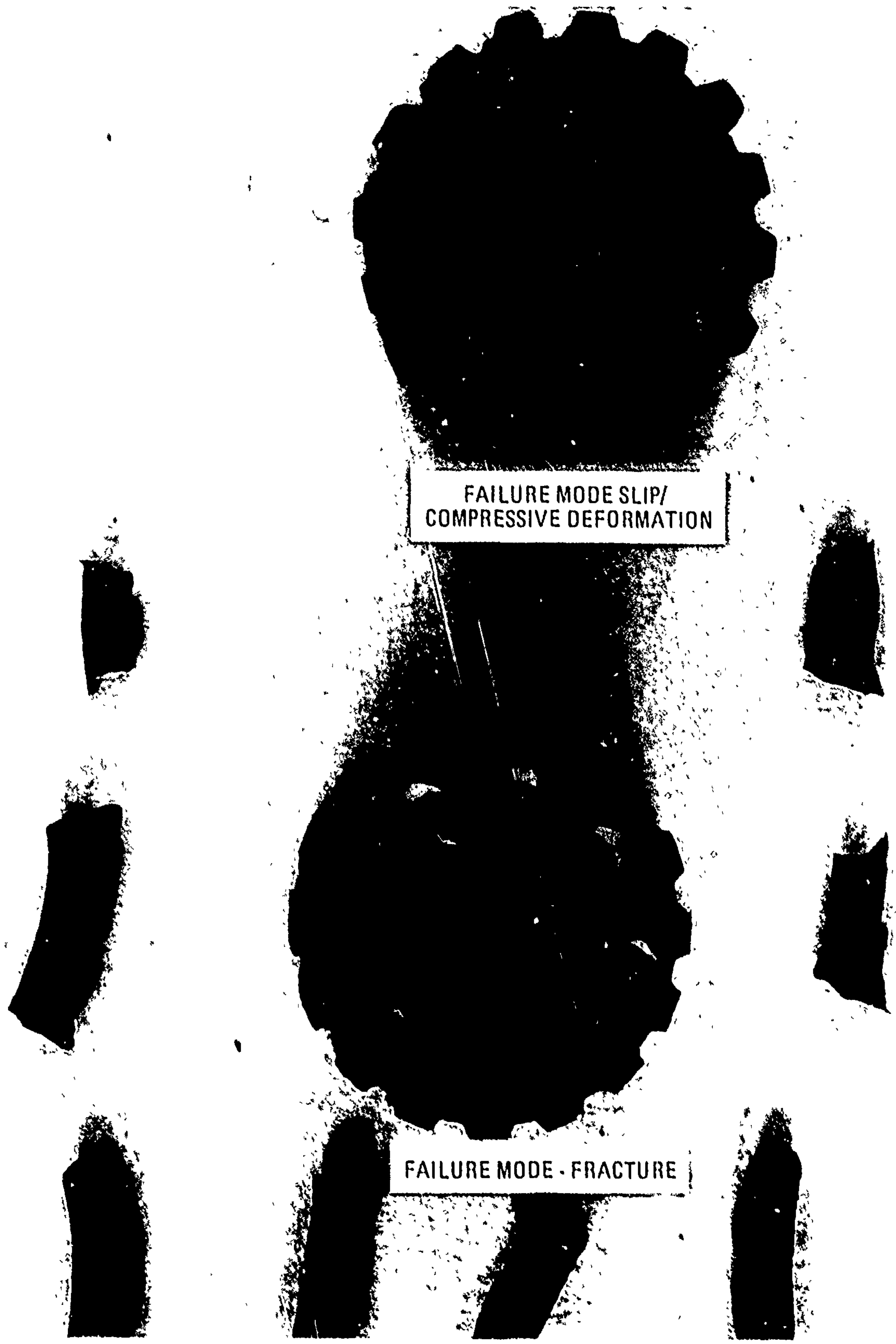
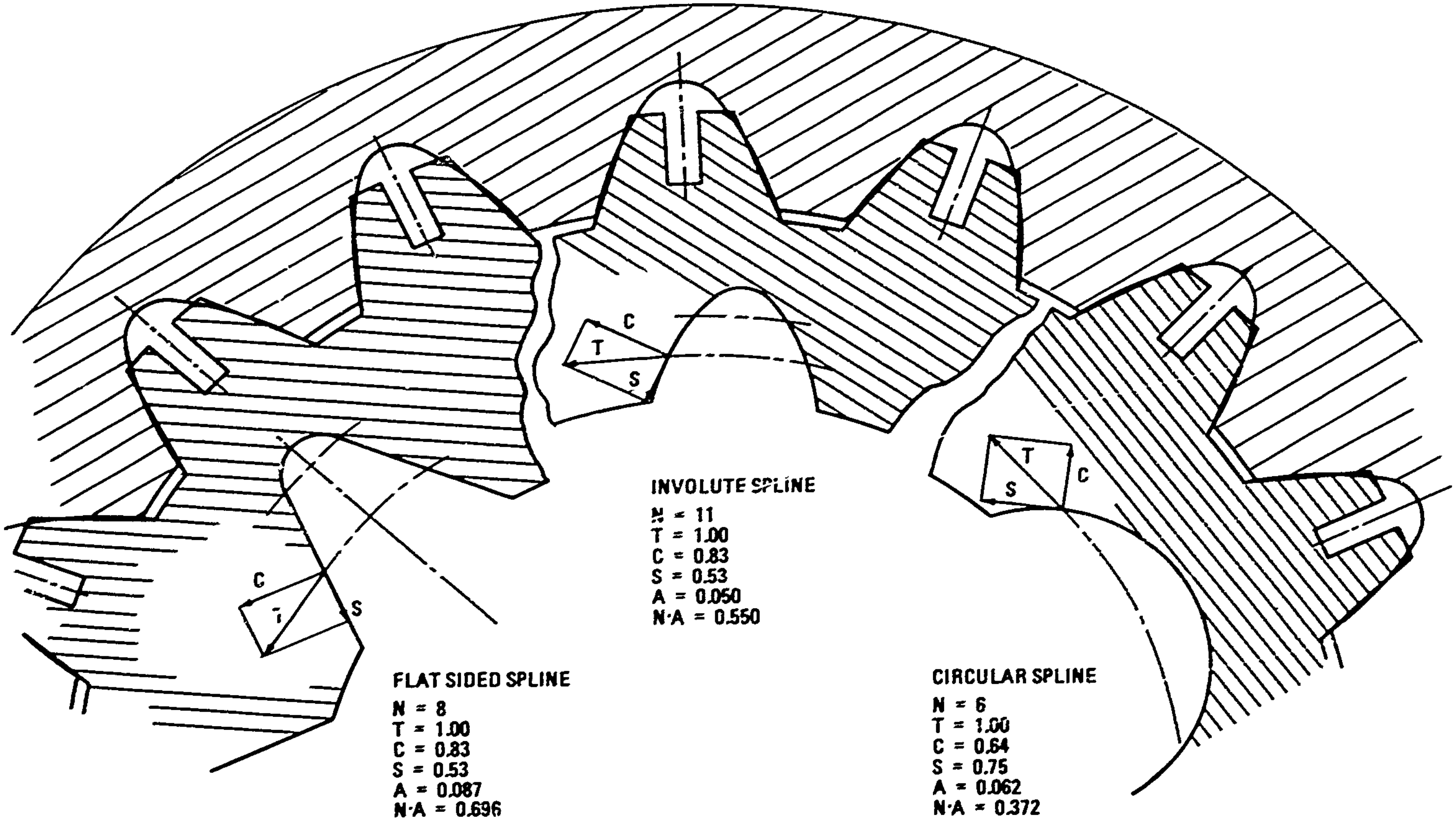


Figure 20
Comparison of the Two Typical Nonmetallic Adapter Failure Modes: Slip/Compressive Deformation Associated with the Circular Splines and Fracture Associated with the Flat-sided Splines



NOTE:

N = NUMBER OF TEETH
T = TORQUE VECTOR MAGNITUDE
C = COMPRESSIVE STRESS MAGNITUDE
S = SHEAR STRESS MAGNITUDE
A = UNIT AREA PER SPLINE
N·A = TOTAL COUPLING UNIT AREA

Figure 21
Illustration of the Torque, Compressive and Shear Loads Inherent in Three Spline Types Showing the Relatively Higher Shear Load Resulting from the Circular Spline and Showing the Load Bearing Area Available in Each Design

MILITARY STANDARD DRAWINGS

16. MS14169(AS) gives the recommended circular spline coupling geometry and manufacturing tolerances for three basic sizes which replace the 0.800 in. (20.3 mm) 16 tooth, 1.200 in. (30.5 mm) 24 tooth, and 1.625 in. (41.3 mm) 26 tooth involute spline couplings. MS14184(AS) contains similar data describing six different flat-sided spline coupling combinations which replace the 0.600 in. (15.2 mm) 12 tooth, 0.6875 in. (17.5 mm) 11 tooth, and 0.800 in. (20.3 mm) 16 tooth involute spline couplings. Appendix A contains copies of the latest issue of each of these Military Standard Drawings. The special involute splined nonmetallic adapters referred to previously were designed using standard involute spline data taken from AS84B and AS972, published by the Society of Automotive Engineers, Incorporated.

CONCLUSIONS

17. Actual flight operations totaling 68,000 hr on 10 different drive shaft nonmetallic coupling designs have verified the value of this new technology.

18. Hydraulic pump endurance testing indicates that properly applied nonmetallic adapters can endure millions of stress cycles.

19. Air turbine starter tests have established that the low cycle fatigue limit for the circular spline design approaches the static torsional limit of the nonmetallic adapter.

20. Wear of the metal or plastic coupling parts is negligible even when the load approaches the torsional limit of the nonmetallic adapter.

21. Preliminary acoustic tests performed on a hydraulic pump equipped with a nonmetallic spline coupling determined a 9 dB reduction in the predominant audible frequency.

PLANS

22. New applications will continue to be examined during laboratory and flight tests.

23. Future programs will emphasize the establishment of nonmetallic coupling performance standards, preparation of a nonmetallic adapter military specification, and the qualification of alternate nonmetallic materials.

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15. Evaluation of the Circular Spline Coupling for EC-130Q Aircraft 40/50 KV Generators, Interim Report No. SY-164R-76, 24 August 1976, by J. Bortzfield, Naval Air Test Center, Patuxent River, Maryland.

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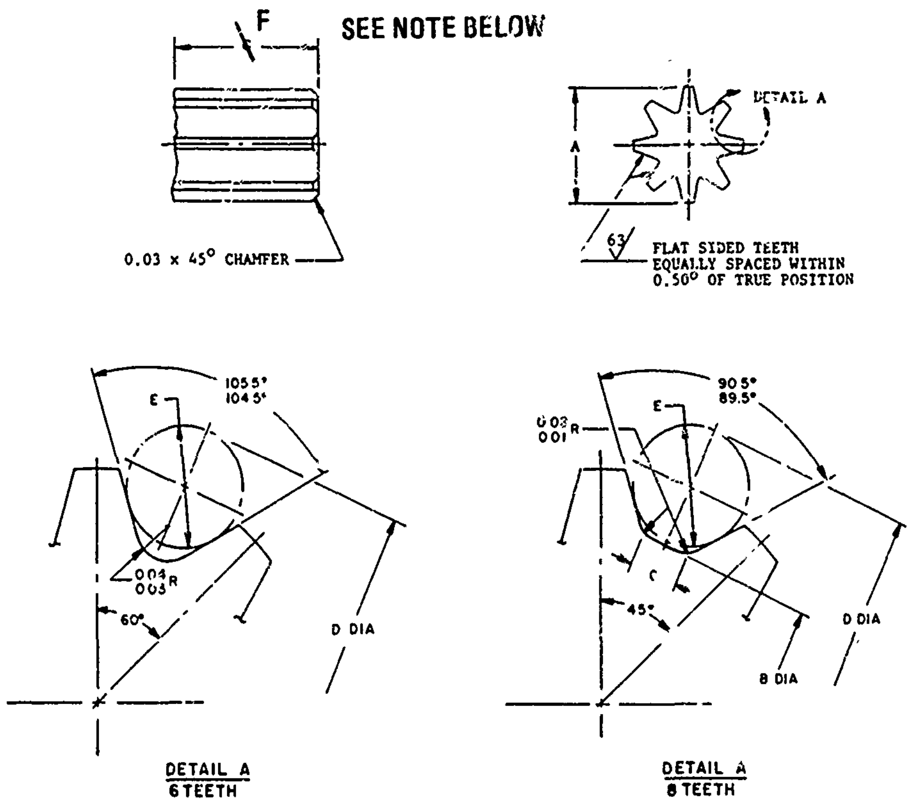
NONMFTALLIC SPLINE COUPLING MILITARY STANDARD DRAWINGS

MS14184(AS)
NONMETALLIC SHAFT-COUPLING DETAILS
ENGINE DRIVEN ACCESSORIES
8 SEPTEMBER 1978

MS14169(AS), REVISION B
CIRCULAR SPLINE AND ADAPTER DETAILS
ENGINE DRIVEN ACCESSORIES
22 FEBRUARY 1978

DIST. SUP CLASS
6115



SPLINE DESIGN DATA

NO. OF TEETH	MAJ. DIA. A	ROOT DIA. B	NOM ROOT WIDTH C	OVER 2 WIRES DIA D	WIRE DIA E	ENGAGM'T LENGTH MIN. F
6	0.450 0.445	NA	NA	0.6953 0.6928	0.1920	0.700
8	0.525 0.520	0.405 0.395	0.067	0.7700 0.7675	0.1800	0.700
8	0.615 0.610	0.455 0.445	0.063	0.8230 0.8205	0.1800	0.750

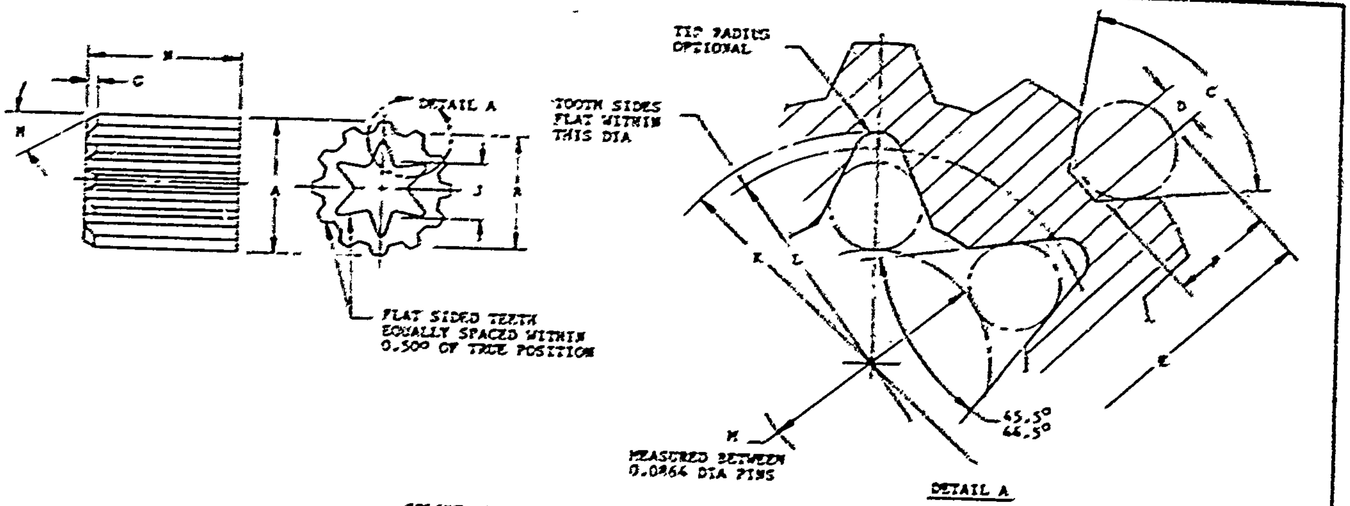
APPROVED 8 SEPT 1978 REVISED

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 NONMETALLIC SHAFT-COUPLING DETAILS, ENGINE DRIVEN ACCESSORIES	MILITARY STANDARD MS14184(AS)
PROCUREMENT SPECIFICATION	SUPERSEDES	SHEET 1 OF 3

DD FORM 1 MAR 72 672-1 (Limited coordination) PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE PROJECT NO. 6115-N423 PLATE NO 20071

NOTE: G IS AN ERROR.
AMENDED DRAWING WILL
IDENTIFY LENGTH AS F.



SPLINE ADAPTER DESIGN DATA

EXTERNAL SPLINE									INTERNAL SPLINE					
NO. OF TEETH	TO FIT INVOLUTE P.D.	OUTSIDE DIA A	ROOT DIA B	CUTTER ANGLE C	NOM ROOT WIDTH D	DIA OVER 2 WIRES E	WIRE DIA F	CHAMFER G / H	NO. OF TEETH	BORE DIA J	MAJ DIA K	FORM DIA L	DIA BETWEEN 2 WIRES M	MIN LENGTH N
12	0.5000	0.655 / 0.650	0.550 / 0.545	70.5° / 59.5°	0.044	0.750 / 0.747	0.0960	0.05 / 30°	6	0.303 / 0.298	0.480 / 0.475	0.450	0.243 / 0.238	0.700
11	0.6875	0.719 / 0.714	0.625 / 0.620	52.5° / 51.5°	0.060	0.876 / 0.871	0.1234	0.06 / 30°	6	0.303 / 0.298	0.480 / 0.475	0.450	0.263 / 0.238	0.700
									8	0.410 / 0.405	0.555 / 0.550	0.525	0.318 / 0.313	0.700
15	0.300 (20/40 DP)	0.317 / 0.312	0.750 / 0.742	70.5° / 59.5°	0.044	0.33[illegible] / 0.332	0.0960	0.20 / 15°	6	0.303 / 0.298	0.480 / 0.475	0.450	0.263 / 0.238	0.700
									8	0.410 / 0.405	0.555 / 0.550	0.525	0.318 / 0.313	0.700
	0.300 (20/30 DP)		0.733 / 0.725	52.5° / 61.5°	0.033	0.336 / 0.333			8	0.460 / 0.455	0.649 / 0.644	0.615	0.375 / 0.370	0.750

FED. SUP CLASS 6115

APPROVED 8 SEPT1978 REVISED

P.A. NAVY - AS
Other Cust

TITLE
NONMETALLIC SHAFT-COUPLING DETAILS, ENGINE DRIVEN ACCESSORIES

PROCUREMENT SPECIFICATION

SUPERSEDES

MILITARY STANDARD

MS14184(AS)

SHEET 2 OF 3

DD FORM 672-1

FED SUP CLASS
6115

REQUIREMENTS

1. SPLINES. MALE SHAFT SPLINES SHALL HAVE A MINIMUM SURFACE HARDNESS OF 34 ROCKWELL C TO A MINIMUM CASE DEPTH OF 0.035 INCHES

2. MATERIAL SELECTION. THE PLASTIC SPLINED BUSHING 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

3. 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

NOTES

1. DIMENSIONS ALL LINEAR DIMENSIONS ARE IN INCHES EXCEPT ROUGHNESSES WHICH ARE IN MICROINCHES

2. APPLICATION THE SPECIFIED BUSHINGS MAY BE USED ONLY WITH INVOLUTE SPLINES HAVING 30 DEGREE PRESSURE ANGLES

3 FINISH ALL BURRS AND SHARP EDGES SHALL BE REMOVED

4. APPLICATION AND INSTALLATION THIS COUPLING IS DESIGNED TO BE USED AT THE INTERFACE OF AIRCRAFT ACCESSORIES AND THE OUTPUT SHAFT OF THE AIRCRAFT ENGINE DRIVE PAD WITHOUT MODIFICATION OR REPLACEMENT OF THE EXISTING FEMALE OUTPUT SHAFT THE FEMALE SHAFT SPLINE SHALL BE THOROUGHLY CLEANED TO REMOVE SEDIMENT AND GREASE BEFORE INSTALLATION OF THE BUSHING THE DESIGN RESULTS IN AN INTERFERENCE FIT OF THE BUSHING INTO THE INVOLUTE SPLINE AND A SLIDING FIT OF THE NEW ACCESSORY SHAFT INTO THE BUSHING.

APPROVED 8, SEPT 1978 REVISED

P.A. NAVY - AS Other Cust	TITLE NONMETALLIC SHAFT-COUPLING DETAILS ENGINE DRIVEN ACCESSORIES	MILITARY STANDARD MS14184(AS)
PROCUREMENT SPECIFICATION	SUPERSEDES	SHEET 3 OF

DD FORM 672-1 (Limited coordination)

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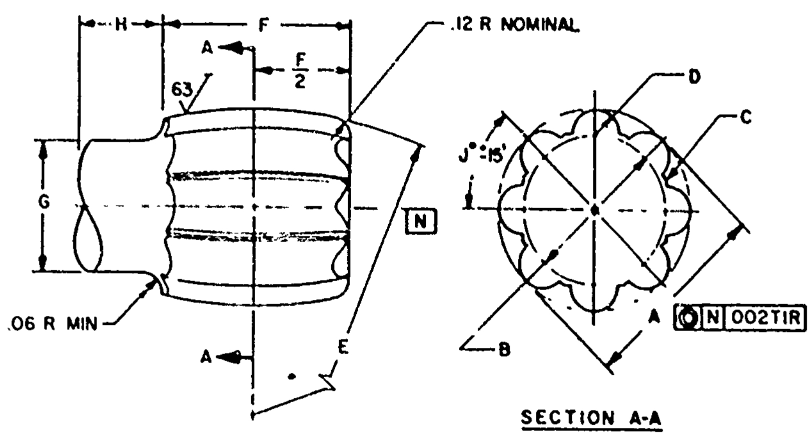
METRIC CONVERSION

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.[illegible]13 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°
1 1/2	8	1.250 1.248	0.937 BASIC	1.000	0.155 0.153	16.0 14.0	1.35 1.15	0.910	0.44	45°

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

(B) REVISED AND REDRAWN

APPROVED 6 MAY 1976 REVISED (A) 31 JULY 1977 (B) 22 Feb 1978

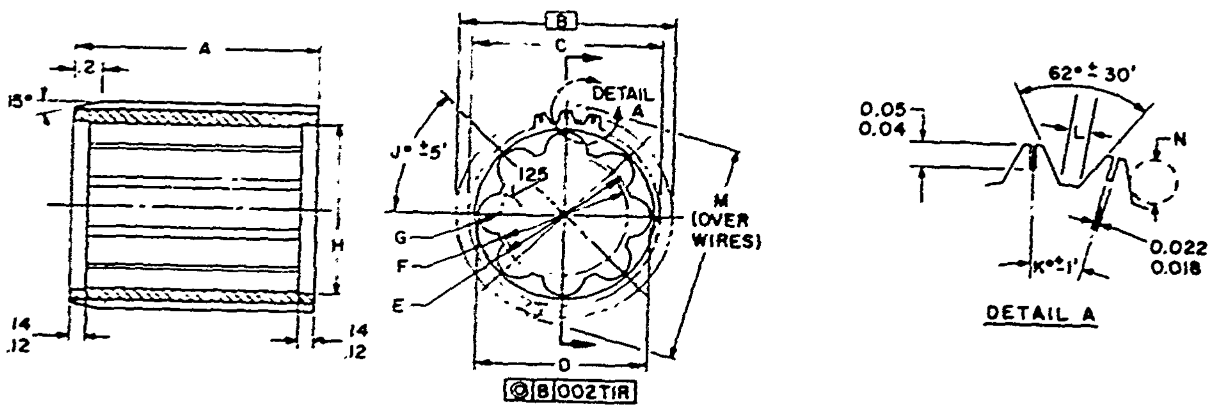
P A NAVY - AS Other Cust	TITLE CIRCULAR SPLINE & ADAPTER DETAILS ENGINE DRIVEN ACCESSORIES	MILITARY STANDARD MS14169 (AS)
PROCUREMENT SPECIFICATION	SUPERSEDES:	SHEET 1 OF 3

DD FORM 672-1 (Limited coordination) PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE. PLATE NO 15071

FED SUP CLASS 6115

METRIC CONVERSION

1.00 in = 25.4 mm



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
3/4	6 int 16 ext	1 25	0 850 0 845	0 723 0 714	0 604 0 602	0 475 0 473	0 413 BASIC	0 095 0 094	0 63 0 61	60°	22° 30'	0.034	1 016 1 014	0.12000
1	8 int 24 ext	1 75	1 270 1 265	1 124 1 113	1 004 1 002	0 811 0 809	0 750 BASIC	0 126 0 125	1 03 1 01	45°	15° 0'	0 033	1 418 1 415	0.12000
1 1/2	8 int 26 ext	2 00	1 700 1 695	1 554 1 543	1 254 1 252	1 015 1 013	0 937 BASIC	0 157 0 156	1 28 1 26	45°	13° 51'	0 056	1.842 1.838	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 requested to employ this standard where applicable.

P A NAVY - AS

Other Cust

PROCUREMENT SPECIFICATION

TITLE

CIRCULAR SPLINE & ADAPTER DETAILS
ENGINE DRIVEN ACCESSORIES

SUPERSEDES:

MILITARY STANDARD

MS 14169 (AS)

SHEET 2 OF 3

DD FORM 1 MAR 75 672-1 (Limited coordination)

PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE

PLATE NO 25071

FED. SUP CLASS 6115

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 spline). 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 (B) FOR CHANGES SEE SHEETS 1 THRU 3

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 1 MAR 73 672-1 (Limited coordination) PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE. PLATE NO 23071

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NAVAIR (PMA-256)	(1)
NAVAIR (PMA-257)	(1)
NAVAIR (PMA-261)	(1)
NAVAIR (PMA-265)	(1)
NAVAIR (AIR-03)	(1)
NAVAIR (AIR-330)	(1)
NAVAIR (AIR-340)	(1)
NAVAIR (AIR-04)	(1)
NAVAIR (AIR-05)	(1)
NAVAIR (AIR-510)	(1)
NAVAIR (AIR-520)	(1)
NAVAIR (AIR-530)	(1)
NAVAIR (AIR-536)	(1)
NAVAIR (AIR-5364)	(1)
NAVAIRTESTCEN (CT02)	(1)
NAVAIRTESTCEN (CT84)	(1)
NAVAIRTESTCEN (CT08)	(1)
NAVAIRTESTCEN (SY01)	(1)
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NAVAIRTESTCEN (SY41)	(1)
NAVAIRTESTCEN (SA01)	(1)
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