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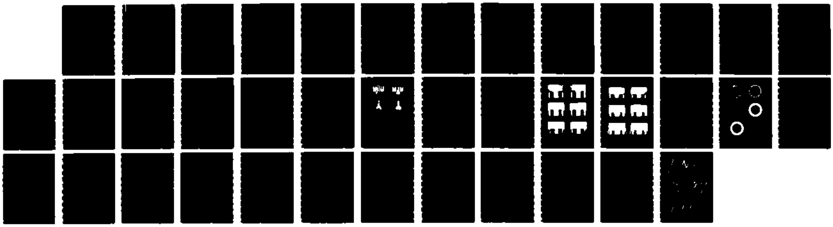

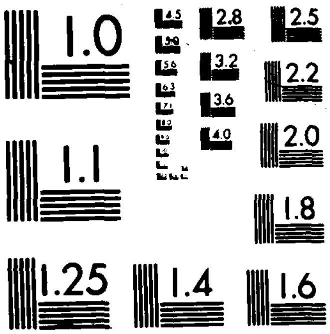

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COMPARISON OF 6.2L ARCTIC AND STANDARD FUEL INJECTION PUMPS USING JP-8 FUEL

INTERIM REPORT
BFLRF No. 218

By

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The U.S. Army is investigating the use of MIL-T-83133 JP-8 Aviation Turbine Fuel (NATO F-34) in compression-ignition engines. In previous engine-dynamometer tests, JP-8 was completely compatible with the 6V-53T and NHC-250 engines. Tests with the 6.2L engine, however, indicated that the JP-8 fuel may cause premature fuel injection pump deterioration, resulting in a change in maximum fuel delivery volume and retarding the injection timing. The fuel injection pump manufacturer has experienced premature wear problems with their pumps when operated on low viscosity fuels, such as JP-8 and DF-A in cold climates. Now an "arctic" fuel injection pump designed to operate with lower viscosity fuels is offered. The objective of this program was to determine if the arctic pump is superior to the standard pump in its ability to prevent the premature wear with JP-8 fuel observed in the engine-dynamometer testing.

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A 200-hour test was run on a bench rig in order to compare the arctic and standard pumps. The pumps were subjected to identical operating conditions, running JP-8 fuel at full rack. Test results indicate that the arctic pump performed better than the standard pump in injection timing change (caused by internal drive tang wear), while the standard pump was better in governor thrust washer wear.

Results also indicate that the arctic and standard pumps experienced the same amount of delivery volume deterioration during the 200-hour test. Based on this one test, the arctic pump is superior to the standard pump in JP-8 service. Use of JP-8 fuel with either the arctic or standard pump, however, will produce an initial maximum power loss (due to the lower heating value, viscosity, and specific gravity) and may ultimately produce an additional loss in maximum power due to deterioration of fuel delivery as a result of component wear.

EXECUTIVE SUMMARY

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FOREWORD

This work was performed at the Belvoir Fuels and Lubricants Research Facility (SwRI) located at Southwest Research Institute, San Antonio, TX, under Contract No. DAAK70-85-C-0007, for the period February 1986 through October 1986. Work was funded by the U.S. Army Belvoir Research, Development and Engineering Center, Ft. Belvoir, VA, with Mr. F.W. Schaekel (STRBE-VF) serving as contracting officer's representative. Project technical monitor was Mr. M.E. LePera, STRBE-VF.

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I. INTRODUCTION

The U.S. Army is investigating the acceptability of using MIL-T-83133 JP-8 Aviation Turbine Fuel (NATO F-34) in compression ignition engine-powered ground equipment and vehicles.(1,2)* The work is being conducted under a project entitled "Development of Accelerated Fuels Qualification Procedures (AFQP)" which was initiated in FY80 to develop more efficient and rapid military fuel qualification procedures. A basic concern in the AFQP program is to address those fuels expected to be used in the near to distant future in currently fielded military engines. Examples might include broad specification fuels, synthetic fuels, high-sulfur fuels, or the use of aviation turbine fuels in diesel-powered equipment and vehicles. There is significant concern within the NATO community to consider use of JP-8 (F-34) as an alternate to diesel fuel (F-54).(3) Using JP-8 would eliminate winter waxing, filter plugging, and other problems observed in ground equipment operating with diesel fuel.

Laboratory engine-dynamometer cyclic endurance tests were previously completed using JP-8 fuel in three different Army diesel engines which are representative of high-density fielded equipment. These are the 6V-53T, the NHC-250, and the 6.2L engines. All engine systems are found in combat and tactical vehicles.

The JP-8 fuel was completely compatible with the 6V-53T and NHC-250 engines. No fuel-related deposits, wear, or used lubricant problems were observed in either the 6V-53T (operated under a 240-hour test) or NHC-250 (operated under a 210-hour test) engines.(4-7)

Two tests were conducted using the 6.2L engine operated on JP-8 fuel. One test was conducted according to the Army/CRC 210-hour wheeled-vehicle cycle, while the other was conducted according to the 400-hour NATO qualification cycle (AEP-5).(8) The JP-8 caused fuel injection pump deterioration in both tests.(9,10)

During the 210-hour test, there was a gradual increase in fuel injection pump delivery and a gradual retarding of injection pump timing. The increase in delivery

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*Underscored numbers in parentheses refer to the list of references at the end of this report.

volume was thought to be the result of wear on the roller shoes, while the retarded timing was the result of drive tang wear.

During the 400-hour test, there was a decrease in fuel injection pump delivery rate and a loss of 8.5 percent in maximum power. The cause of the decreased fuel delivery was not determined. Drive tang wear was also evident in this test.

The manufacturer of the 6.2L fuel injection pumps has recognized that its fuel injection pumps have a premature wear problem when operated with low-viscosity fuels.(11) In order to alleviate this problem, the manufacturer now offers new pumps designated as "arctic" pumps. These pumps utilize different transfer pump liners and blades, governor thrust washers, and drive shafts. The objective of the work reported herein was to determine if the arctic fuel injection pumps are superior to the standard fuel injection pumps in preventing the premature wear problems noted in the engine-dynamometer testing.

II. APPROACH

A. Equipment

For this program, six 1986 standard fuel injection pumps were obtained through a local pump service representative. Designated as part No. 23500413, manufacturer part No. DB2829 4520, these pumps are designed for use on the Commercial Utility Cargo Vehicle (CUCV) family of Army vehicles. Of the six pumps, three were converted to arctic pumps by the pump service representative according to the appropriate service bulletin.(11) The pumps were converted because new pumps were not yet available for direct purchase. The arctic pumps received an electroless nickel-plated governor thrust washer (unplated on standard), sintered M-2 transfer pump liner and blades (tool steel on standard), and a new drive shaft with a hard chrome-plated tang (unplated on standard). The conversion resulted in three part No. 23500414, manufacturer part No. DB2829 4521 fuel injection pumps. Both the standard and arctic pumps were calibrated by the service representative to factory specifications. Calibration included checks of injection timing and volumetric delivery characteristics at a variety of speeds.

A test stand was fabricated that has the ability to run two 6.2L pumps side-by-side at the same test speed, using a common fuel supply. The stand was powered by a variable speed drive system capable of turning at speeds ranging 300 through 3600 rpm. The pumps were mounted on a flat plate using the same mounting configuration as on the engine. The pumps were gear driven from a common drive gear, using the driving and driven gears from the engine. Gears ran in an oil bath using AL-14080-L, the same Grade 30, MIL-L-2104D lubricant as had been used in the engine tests. Each pump was axially loaded using the same spring and button arrangement as is used on the engine, with spring tension adjusted by a set screw. The set screw was adjusted to obtain the same amount of spring compression as on the engine.

The fuel system for the test is depicted in Fig. 1. Fuel supply was from a 55-gallon drum provided with a band heater. The band heater was used for startup only, in order to provide fuel at test temperature. Fuel was pumped from the drum using a centrifugal pump with bronze impeller and internal pressure regulator. This pump

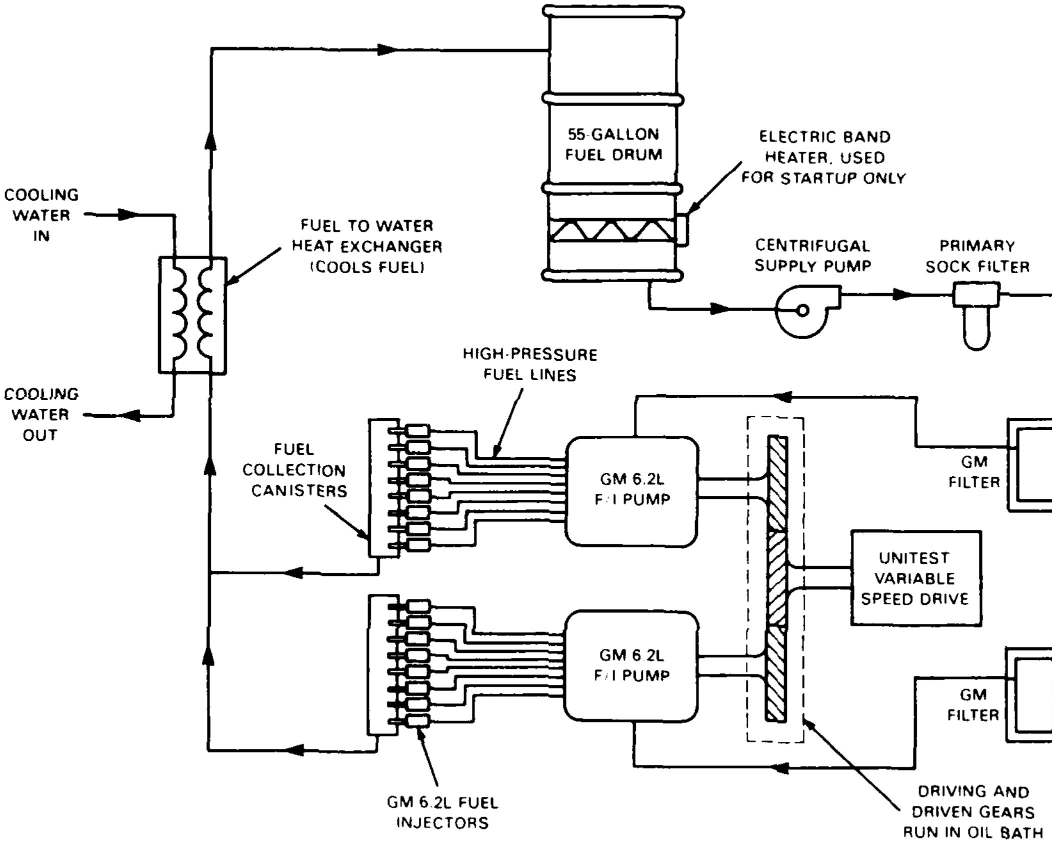


Figure 1. Fuel system schematic

was selected in order to preclude the introduction of any iron wear particles into the fuel. The fuel then flowed through a primary (sock) filter and then through individual cartridge filters (paper). The cartridge filters were the same as the ones used on the 6.2L engines. Supply pressure of the fuel was measured at the pump inlets and was maintained at 3 psig throughout all tests. Supply lines from the drum to the primary filter were 1/2-in. diameter, from the primary filter to the secondary filters were 3/8-in. diameter, and from the secondary filters to the pumps were 1/4-in. diameter. Each of the pumps was connected through high-pressure fuel lines of 24-7/8 in. length to fuel injectors from 6.2L engines. Each of the injectors from an individual pump emptied into a fuel collection canister. A valve was provided at the exit of each fuel collection canister in order to obtain fuel delivery volumes throughout the test. After leaving the fuel collection canisters, the fuel flowed through a fuel-to-water heat exchanger and then returned to the fuel drum. The fuel-to-water heat exchanger was used throughout the test to maintain a fuel temperature at the injection pump inlet of 105°F (91°C). Internal fuel pressure (transfer pump pressure) was measured throughout the test by replacing the inlet port locking screw with a combination locking screw and pressure tap.

Fuel temperature was measured at the pump inlet using a type J thermocouple and a chart recorder. Fuel supply pressure was measured for each pump using a 0- to 15-psig gauge. Internal transfer pump pressure was measured for each pump using a 0- to 100-psig gauge. Speed was measured using a magnetic pickup on one of the driven gears and a digital readout. The entire rig was equipped with safety shutdowns that would turn off the drive motor in the event of low fluid level in the supply drum, low or high fuel temperature, low or high transfer pump pressure, or fire. The intent of the emergency shutdown capability was to allow the rig to safely run unattended overnight, greatly shortening the test period and reducing the manhours spent on a test.

B. Materials

The test fuel for these evaluations was AL-14216-F, the same JP-8 fuel used in the engine-dynamometer tests. Properties of the test fuel are shown in Table 1. A break-in fuel (Caterpillar 1-H/1-G) was used in the test apparatus since the supply of JP-8 was limited, and the purpose of the break-in run was to test the device, not the fuel. The gearbox of the test apparatus was filled with AL-14080-L, the same Grade 30, MIL-L-2104D lubricant as had been used in the engine-dynamometer tests.

C. Test Procedure

After receiving the fuel injection pumps at Belvoir Fuels and Lubricants Research Facility (BFLRF) at Southwest Research Institute, each pump was visually inspected for obvious differences between the arctic and standard pumps. The pumps were identical except for the identification plate attached by the pump service representative. Each of the six pumps was coded with a number. The code numbers are shown in Table 2.

TABLE 1. Test Fuel Properties, AL-14216-F, JP-8

Property	Method	Result	MIL-T-83133A Spec. Limit
Saybolt Color	D 156	+15	Report
Total Acid Number, mg KOH/gm	D 3242	0.005	0.015 max
Flash Point, C	D 93	55.5	38 min
Freezing Point, C	D 2386	-55.0	-50 max
Specific Gravity at 60°C	D 1298	0.8100	NR
Gravity, °API	D 1298	40.3	37 to 51
K. Vis at -20°C, cSt	D 445	4.14	8.0 max
at 40°C, cSt	D 445	1.26	NR
at 50°C, cSt	D 445	1.12	NR
at 100°C, cSt	D 445	0.67	NR
Distillation Temp., °C			
IBP 0.5%	D 2887	136.2	Report
5%	D 2887	157.1	NR
10%	D 2887	166.9	186 max
20%	D 2287	178.3	Report
30%	D 2287	188.6	NR
40%	D 2287	197.9	NR
50%	D 2287	205.2	Report
60%	D 2887	212.5	NR
70%	D 2887	220.3	NR
80%	D 2887	230.0	NR
90%	D 2887	239.0	Report
99.5%	D 2887	262.6	330 max
100%	D 2887	323.3	NR
Residue, vol%	D 2887	0.0	1.5 max
Lubricity Wear Scar Dia., mm	BOCLE	0.3	NR
Copper Corrosion, 2 hr at 100°C	D 130	1A	1B max
Sulfur, wt%	XRF	<.01	0.3 max
Mercaptan Sulfur, wt%	D 3227	0.00016	0.001 max
Iron Content, ppm	XRF	<10	NR
Cetane Number	D 613	41.5	NR
Net Heat of Combustion, Btu/lb	D 240	18532	18400 min
Hydrogen, wt%	D 3178	13.7	13.5 min
Smoke Point, mm	D 1322	22.2	19.0 min
Thermal Stability, JFTOT	D 3241	Pass	NR
Existent Gum, mg/100 mL	D 381	0.2	7.0 max
Water Reaction	D 1094	1	1B max
Water Separation Index	D 2550	NP	85 min
Fuel System Ice Inhib, vol%	FTM 5340	0.04	0.10 to 0.15
Electrical Conductivity, pS/m	D 2624	170	200 to 600
Particulate Matter, mg/L	D 2276	1.1	1.0 max
Aromatics, vol%	D 1319	19.0	25.0 max
Olefins, vol%	D 1319	0.0	5.0 max
Saturates, vol%	D 1319	81.0	NR

NR = Not Required
NP = Not Performed

TABLE 2. Fuel Injection Pump Code Sheet

Code No.	Pump Type	Serial No.
1	Arctic	5113925
2	Standard	5113921
3	Standard	5113920
4	Arctic	5113931
5	Arctic	5113935
6	Standard	5113919

Each pump was then checked for full-power performance characteristics by running it on a GM 6.2L engine coupled to a dynamometer. This procedure was followed in order to assure that each pump was calibrated correctly and to establish before-test baseline performance. Each pump was mounted to the engine in the same timing orientation, with the timing line on the pump aligned with the timing line on the engine. During the power determinations, injection timing was checked with a Snap-On luminosity/magnetic timing meter No. MT480.

Injection timing was checked at 700 rpm, no-load; 1500 rpm, 100 lb-ft load; and 1600 rpm, full-load. Cylinder No. 3 was used as the indicating cylinder. The timing specification obtained from GM was 3 to 4 degrees after top dead center (TDC) at 1600 rpm, full-load, and 1 to 2 degrees after TDC at 1500 rpm, 100 lb-ft load. Although 700 rpm, no-load was not a factory specification point, timing was checked at this point because it could easily be checked on a vehicle. Table 3 lists the timing data from the full-power performance determinations.

Results of the before-test, full-power performance determinations indicated that pump No. 1 exhibited noticeably less power than the other pumps throughout the speed range. This is shown graphically in Fig. 2. In addition, the injection timing of pump No. 1 appeared to be advanced by 1.5 to 3.5 degrees when compared to the other pumps. Because of this, pump No. 1 was returned to the pump service representative for re-calibration.

Each pump was also checked for internal backlash using an in-house developed apparatus. The device consisted of a small locking pin inserted through the

TABLE 3. Injection Timing Measurements

Pump No.	Type	Before Test 700 rpm	Before Test 1500 rpm	Before Test 1600 rpm	After Test 700 rpm	After Test 1500 rpm	After Test 1600 rpm
		Injection Timing, Degrees After TDC					
1	*Arctic	0.0	1.0B	3.5B	NM	NM	NM
1	Arctic	2.0	0.0	0.5	2.0	2.0	0.5
2	Standard	3.5	0.5	0.0	3.5	1.0	0.5
3	Standard	2.0	0.5	0.0	NM	NM	NM
4	Arctic	2.5	1.0	0.0	5.0	1.5	0.0
5	Arctic	0.5	0.5	0.0	NM	NM	NM
6	Standard	3.5	0.5	0.5B	NM	NM	NM

* = These timing measurements are before re-calibration by pump representative.
B = Before TDC
NM = Not Measured

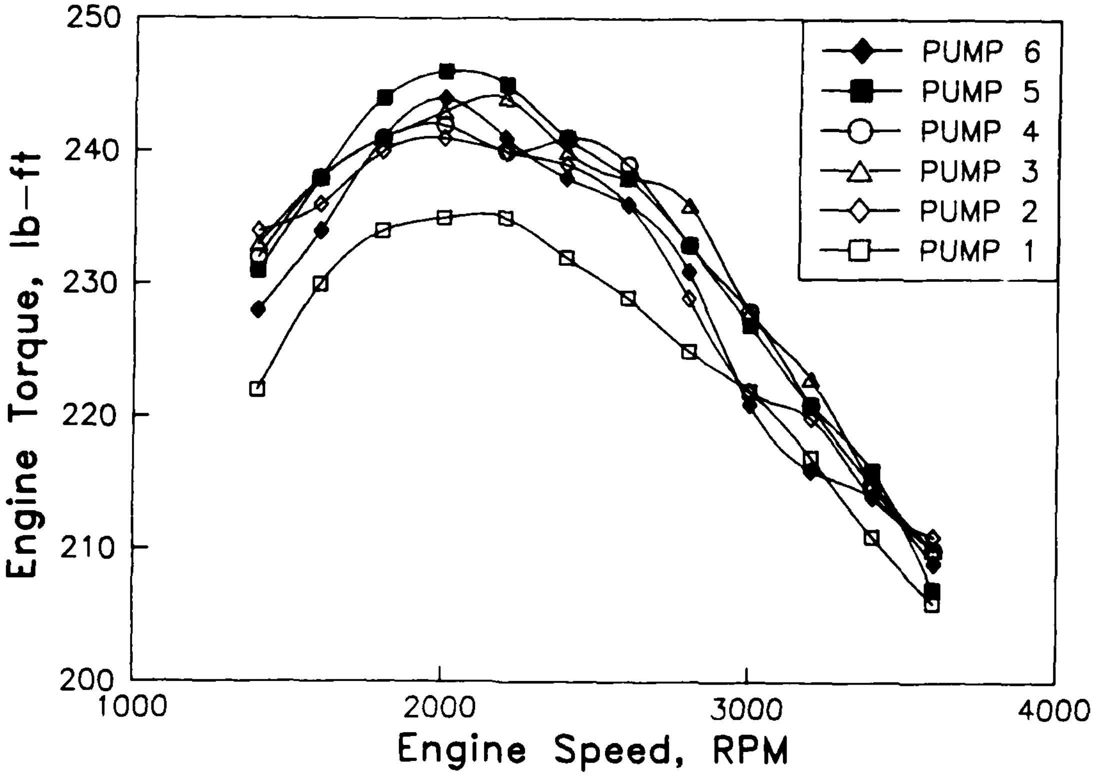


Figure 2. Before test torque curve with VV-F-800 DF-2 fuel

timing hole (side cover) of the pump, an 8-in. arm fastened to the drive flange of the pump, and a dial indicator to measure the deflection of the arm. The locking pin effectively prevented the internal rotor from moving by engaging the case and an Allen head bolt on the rotor. The deflection of the arm (rotation of the drive flange) was measured using the dial indicator at an 8-in. radius under light hand pressure. An attempt was made to use a spring scale to deflect the arm, but light hand pressure yielded more repeatable results. The resultant internal backlash numbers represent the total angular freedom of the input shaft with respect to the case when the rotor is locked. This angular freedom is mainly the result of play between the drive shaft tang and the rotor and, to a lesser extent, the result of drive shaft bearing radial movement. This measurement was deemed important because it permitted the quantification of the drive tang wear before and after the test. Drive tang wear was apparent in the previously mentioned engine-dynamometer tests. The pump manufacturer has apparently recognized this as a problem since the arctic pumps have a hard chrome plating on the drive tangs. Drive tang wear results in a shift in injection timing that is double the angular wear experienced. The shift in injection timing could retard the combustion event, leading to power loss and possible overheating of engine components and lubricant.

The test rig was run on a shakedown run for 5 hours using nontest fuel injection pumps and Caterpillar 1-H/1-G test fuel. During the shakedown, one fuel injection line broke. The line was replaced, and the test continued. No other operational difficulties were experienced during the shakedown run. The pumps were run at 1800 rpm (equivalent to 3600 rpm engine speed) at full rack with a supply pressure of 3 psig and a fuel temperature of 105°F (91°C). The fuel temperature was chosen to coincide with the fuel temperature from the engine tests.

After the shakedown run, the fuel system was flushed with the test fuel (AL-14216-F, JP-8) and the filters changed. A sample of the test fuel was analyzed as shown in Table 1. Pump Nos. 5 and 6 (arctic and standard, respectively) were placed on the test rig. The standard pump was placed on the right side of the injection rig when viewed from the drive side. The fuel drum was preheated to 105°F. Fuel viscosity at 105°F was 1.25 cSt. The test was initiated late in the afternoon and set to run overnight. At 0.5 test hours, a fuel injection line began to leak. The unit was brought down manually, and the test was continued. At 4.0 test hours, another fuel injection line broke, shutting the unit down in the automatic mode from low fuel level in the supply drum. Possible vibration problems were investigated, and fuel injection lines were ordered from a second supplier. Injection line quality and/or vibration problems were suspected since the upset end of the fuel injection line had broken off, and cracks in the end fittings appeared to be the problem with the first two failures. The line was replaced the next day, the fuel preheated, and the unit started. Since the unit had shut down automatically the day before, the speed control lever was necessarily in the full-speed position at startup. Normal startup procedure was to start with the speed at minimum (600 rpm) and idle for approximately 3 minutes to allow the pump time to warm up.

After an emergency shutdown, however, the speed control lever remains in the full-speed (1800 rpm) position until the operator can manually crank it down to 600 rpm at the next startup. This is a function of the design of the variable speed drive system which will not allow speed changes while the unit is stationary. Pump No. 6 (a standard pump) failed at startup at 4.6 test hours. The failure mode was a broken drive shaft in the necked down area of the drive shaft. Disassembly and inspection of the failed pump revealed a locked rotor with severe galling at the outlet ports of the rotor. The local pump service representative could assign no positive reason for the failure except to suggest that contamination in the fuel may have caused the failure.

No post-test full-power determinations or internal backlash determinations were performed on pump No. 6 since the broken drive shaft made such tests impossible. Pump Nos. 3 and 4 were then mounted on the test stand. This time the arctic pump (No. 4) was placed on the right side of the injection rig when viewed from the drive side. The test was started and ran well until it was shut down by a faulty temperature sensor 3 hours into the test. The rig was started in the high speed mode the following day (since it had shut down automatically the day before) and pump No. 3 (standard) failed almost immediately in the same failure mode as the previous pump. The local pump service representative could offer no reason for the failure. Fig. 3 and 4 depict the split rotors and stators and broken drive shafts from the failed pumps. Again, no after-test, full-power curves or internal backlash measurements were taken on the failed set of pumps.

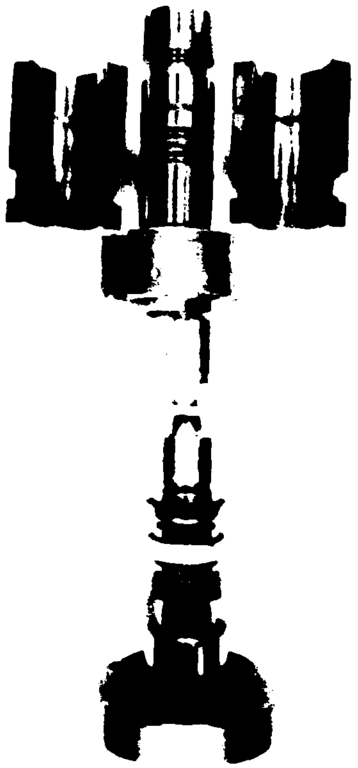


Figure 3. Broken drive shaft, rotor and split stator from pump No. 3

Figure 4. Broken drive shaft, rotor and split stator from pump No. 6

Pump Nos. 1 and 2 were next mounted on the test stand. At this point, it was decided to monitor the rigs continuously and run only 8 hours per day. This procedure would allow the operator to bring the rig down manually in the event of any problem and to avoid any high-speed startups. This approach was successful, with the rig completing 200 hours of operation.

During the run, several problems were encountered, the most serious of which was fuel injection line failure. The original fuel injection lines used on the rig failed frequently during the test. The lines would begin to leak at the injector end and would stop leaking upon tightening. This did not appear to be a vibration loosening problem since the lines were still snug when they were leaking. During the course of the test, five lines were replaced. The original lines were 24-7/8 in. in length with a 0.090-in. diameter bore. They had a pressed on ferrule on the pump end and a pressure swaged head on the injector end. The failures were occurring at the swaged end and took the form of cracking at the tube-swage interface. The pump service representative supplied BFLRF with replacement lines 24-1/2 in. in length and 0.090 in. inside diameter. The replacement lines had brazed or silver soldered heads on both ends. The original lines were replaced with the new lines on an attrition basis. No problems were experienced with the new lines.

Minor fluctuations in speed were experienced during the test. This was caused by worn drive belts on the variable speed drive system. It was not feasible to replace the belts during test since replacement belts were available only with a 4-week lead time and required a complete teardown of the rig for installation. Belt dressing on the drive belts minimized the speed fluctuations to approximately 50 rpm at infrequent intervals.

At hourly intervals throughout the test, an operator logged the date, time, test hour, fuel temperature, supply pressure, internal transfer pump pressure, and speed for both pumps. At 10-hour intervals, a composite fuel delivery was measured for each pump by routing the return fuel from the fuel collection canisters to a graduated cylinder and measuring the flow time. This provided a measure of delivered volume as the test progressed. Fuel samples were taken at 0, 100, and 200 test hours and tested for wear metals and lubricity (BOCLE). No significant changes in fuel lubricity or wear metals were found in the 100- or 200-hour samples. The test was completed, full-power performance curves were run, and internal backlash measurements were made on each pump. Throughout the tests, the identity of the test pumps were masked, making it impossible to distinguish between arctic and standard pumps. This was important in order to minimize experimental bias in favor of either pump. All of the injectors used in the test were checked for proper spray pattern and jerk pressure both before and after test.

After the test was completed, all pumps were disassembled for inspection. Photographs were taken of the governor thrust washers from all six pumps. Surface profiles were run on all six washers at four locations equally spaced on the surface of each washer. Photographs were taken of the split stators, rotors, and drive shafts from the failed standard pump Nos. 3 and 6. Photographs were taken of all six drive shaft tangs. Photomicrographs were taken of the roller shoes from all six pumps.

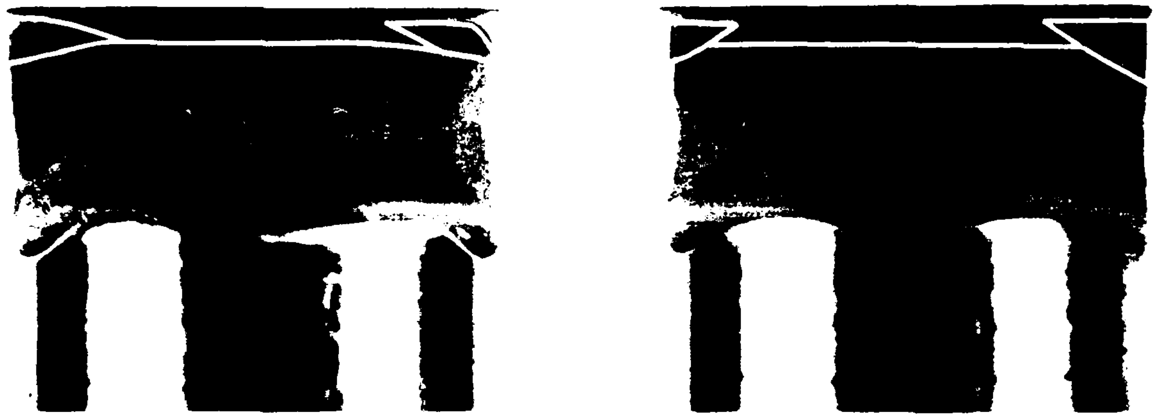
III. DISCUSSION OF RESULTS

Results from the first two tests (pump Nos. 3, 4, 5, and 6) represent only a few hours of run time but are, nonetheless, comparable in terms of wear. The fact that both standard pumps failed and both arctic pumps survived is disturbing. The probable cause for the standard pumps failing was the high-speed startup procedure used for the first two tests. The arctic pump drive shafts may have undergone a slightly different manufacturing process than the standard pump shafts (in addition to the hard chrome plating) and, therefore, been less prone to failure from shock loading. Minor differences in the transfer pumps or assembly technique may have contributed to the arctic pumps surviving and the standard pumps failing.

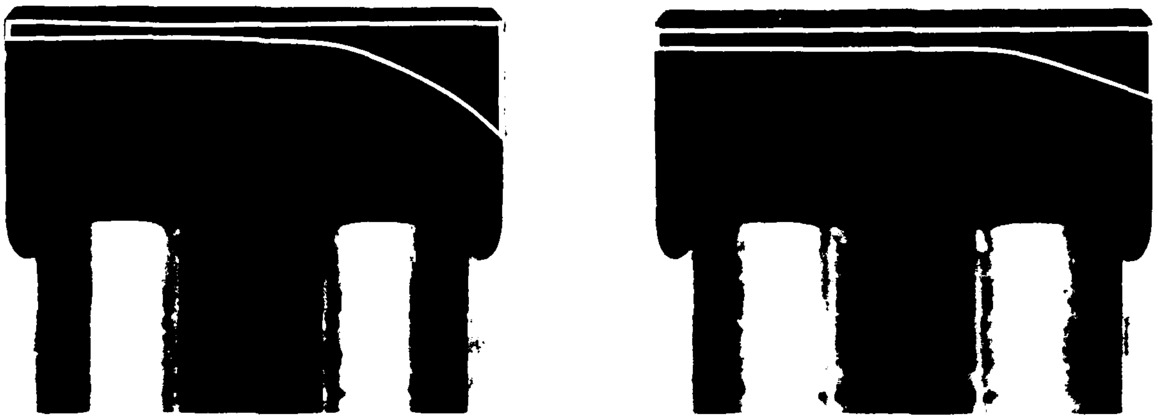
Fig. 5 depicts the wear on the drive tangs from pumps 1 through 6. Worn areas are highlighted with white lines for better comparison. Note that in all cases, the standard tangs have noticeably more worn area than the arctic tangs. This wear, when coupled with any rotor wear in the mating area, can effectively retard the injection timing of the engine. The fact that the hard chrome plating decreased the wear in this area indicates that this aspect of the arctic conversion was an improvement over the standard pumps. Before and after test internal backlash measurements for all pumps are tabulated in Table 4.

TABLE 4. Internal Backlash Measurements

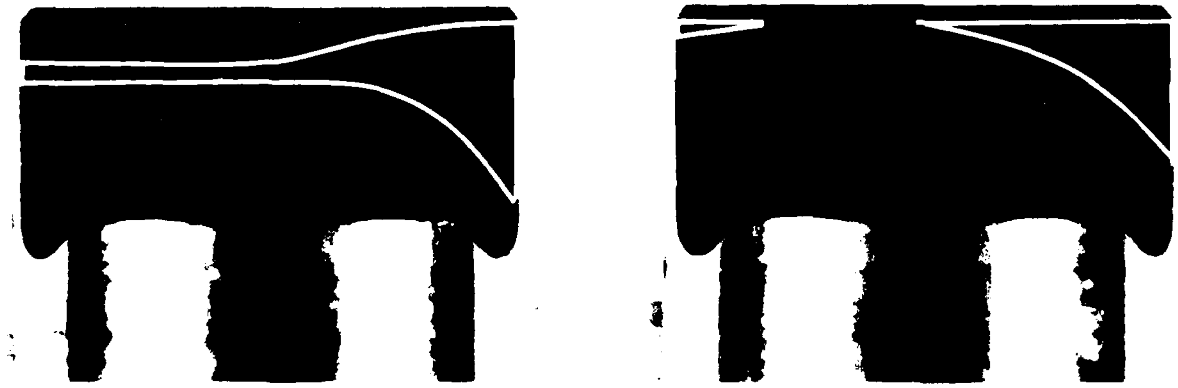
Pump No.	Type	Lash, Degrees	
		Before	After
1	Arctic	0.394	0.458
2	Standard	0.272	0.859
3	Standard	0.294	Broken
4	Arctic	0.430	Not Meas.
5	Arctic	1.884	0.344
6	Standard	1.719	Broken



a. Pump 1 (Arctic)

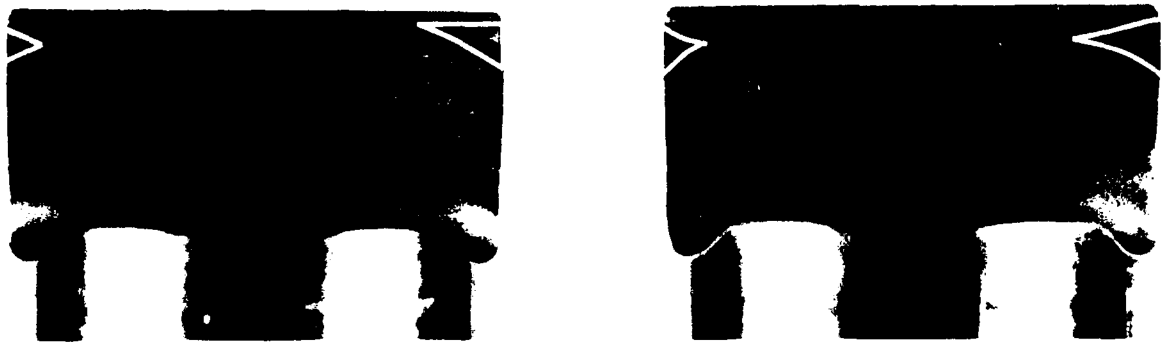


b. Pump 2 (Standard)

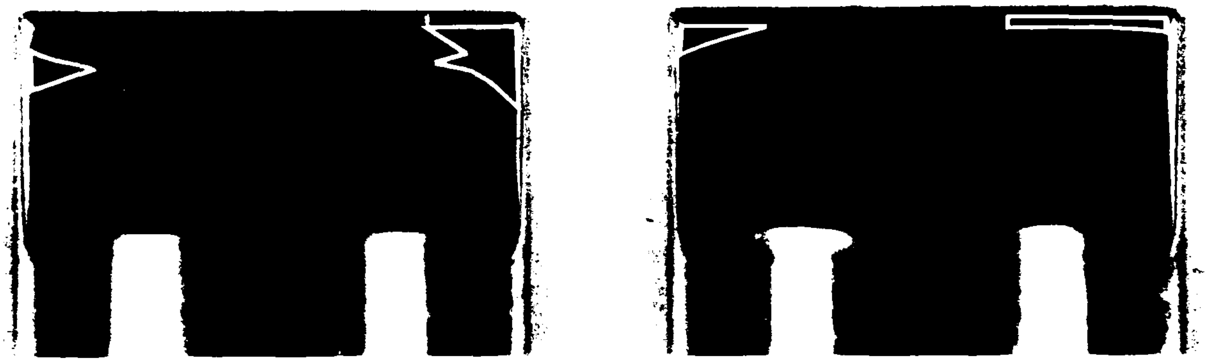


c. Pump 3 (Standard)

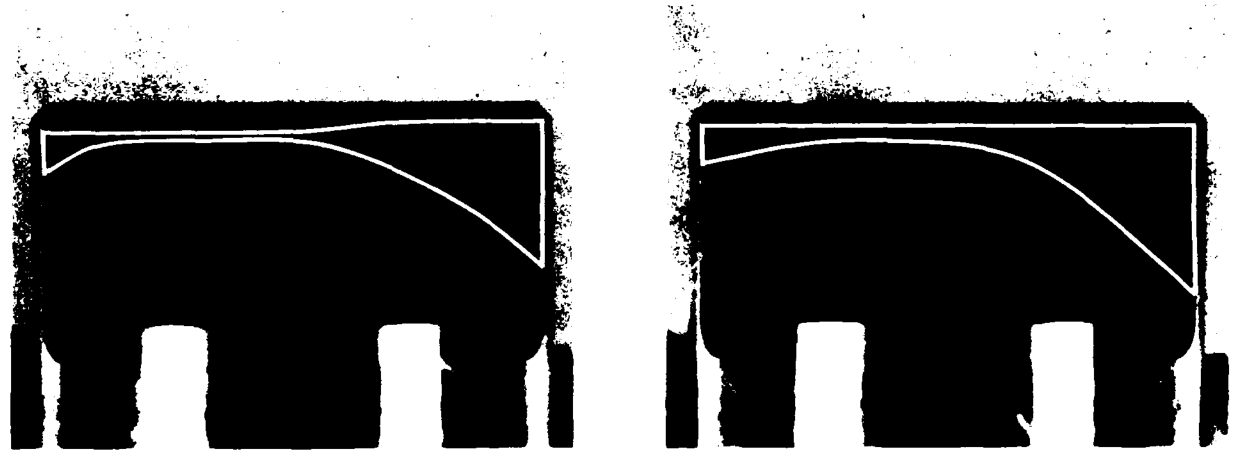
Figure 5. Drive tangs
(Areas within white lines show wear)



d. Pump 4 (Arctic)



e. Pump 5 (Arctic)



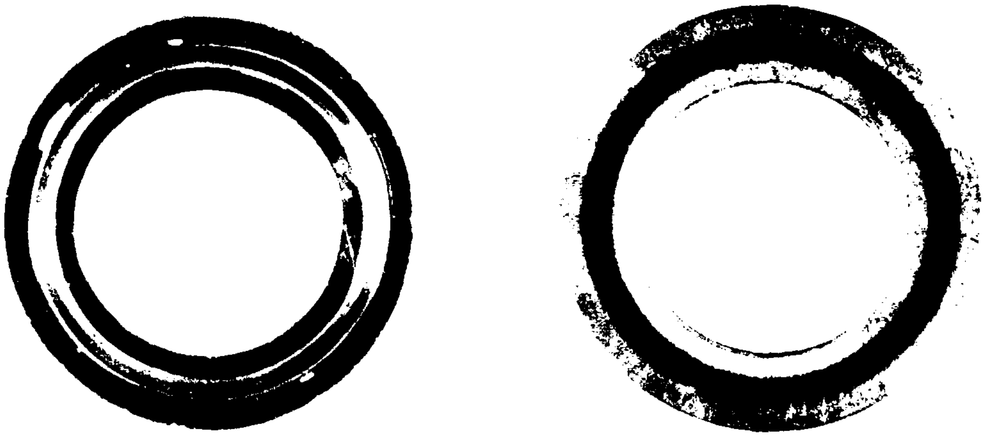
f. Pump 6 (Standard)

Figure 5. Drive tangs (Cont'd)
(Areas within white lines show wear)

The data in Table 4 are comparable only in pairs (1-2, 3-4, 5-6), since only pairs of pumps experienced the same running conditions. The lash figures are measures of total angular movement of the drive shaft with the rotor locked. This is the sum bearing movement, seal flexure, and tang wear. These data are very limited since only pump Nos. 1 and 2 completed the test intact and were, therefore, comparable. Note that the arctic pump experienced a 0.064 degree increase in lash while the standard pump experienced a 0.587 degree increase in lash. The 0.587 degree increase in pump lash demonstrated by the standard pump should equate to a 1.174 degree retardation of engine timing since the pump turns at half engine speed. This retardation was measured with the snap-on timing light as 0.5 degrees difference before and after test on pump No. 2. The 0.064 degree increase in arctic pump No. 1 should equate to a 0.128 degree change in engine timing. The measured value from the engine was 2 degrees retarding at 1600 rpm, full-load, and no change at 1500 rpm, 100 lb-ft load. Two other anomalies are worthy of note in Table 4. Pump Nos. 5 and 6 exhibited initial lashes approximately six times higher than the other pumps. This was very surprising and was checked a number of times to minimize measurement error. The cause of the increased readings is not known. Pump No. 5 exhibited less lash after running for 4 hours. One possible reason for this decrease might be that seal swelling dominated the lash measurement and masked any tang wear.

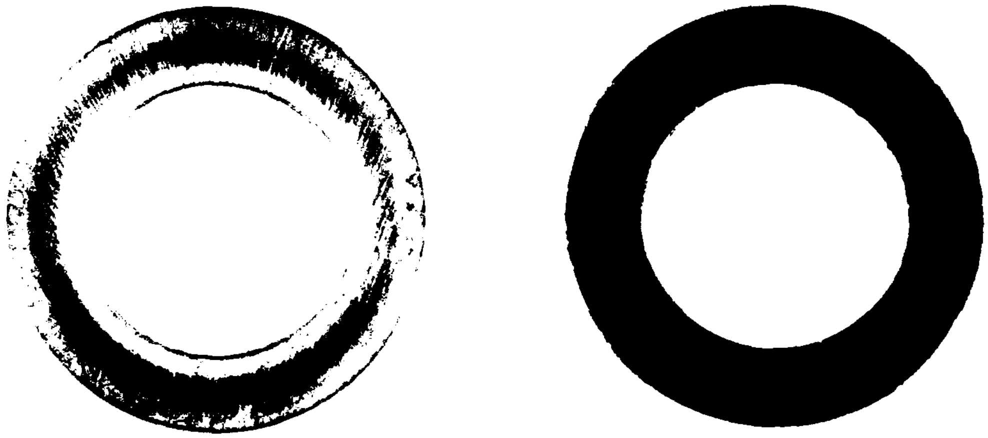
Fig. 6 shows the governor thrust washers from each of the pumps. This is one of the parts changed on the arctic pumps. The arctic washers are electroless nickel plated and, hence, have a gold coloration. In addition, the arctic washers have a small bevel on one edge that is designed to provide clearance for the governor weights. The wear scar appears to be deeper for all arctic pumps when compared to their standard counterparts. The wear on arctic thrust washer No. 1 is markedly deeper than its standard counterpart No. 2. Table 5 shows average wear scar depth at the deepest part of the wear scar. These data were computed from surface profiles run with a Talysurf Model 10 at four equispaced locations on the surface of each washer. The change to the electroless nickel plating does not appear to improve the wear characteristics of the governor thrust washers and may actually accelerate it under similar running conditions.

Fig. 7 depicts the composite fuel delivery volume from pump Nos. 1 and 2 plotted against test hour. The one high point in the arctic curve may be operator error, or



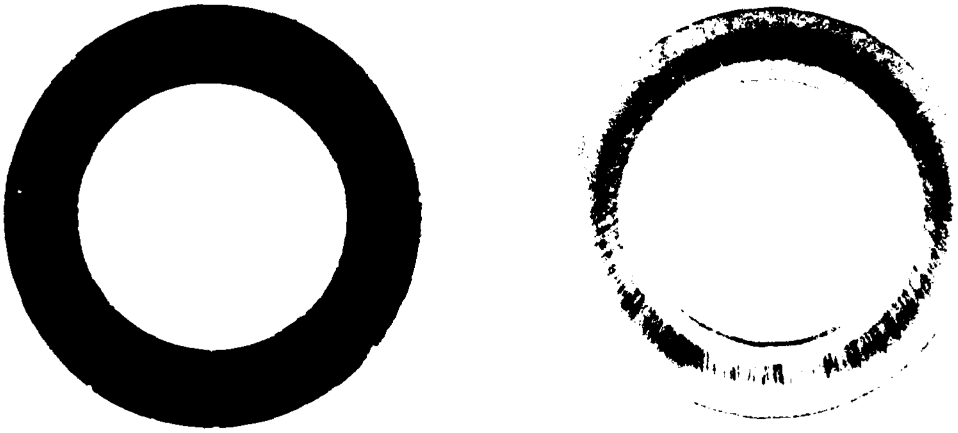
a. Pump 1 (Arctic)

b. Pump 2 (Standard)



c. Pump 3 (Standard)

d. Pump 4 (Arctic)



e. Pump 5 (Arctic)

f. Pump 6 (Standard)

Figure 6. Governor thrust washers

TABLE 5. Average Deepest Wear Scar Depths on Governor Thrust Washers

Pump No.	Kind	Depth, mm
1	Arctic	0.0329
2	Standard	0.0037
3	Standard	0.0
4	Arctic	0.0025
5	Arctic	0.0068
6	Standard	0.0

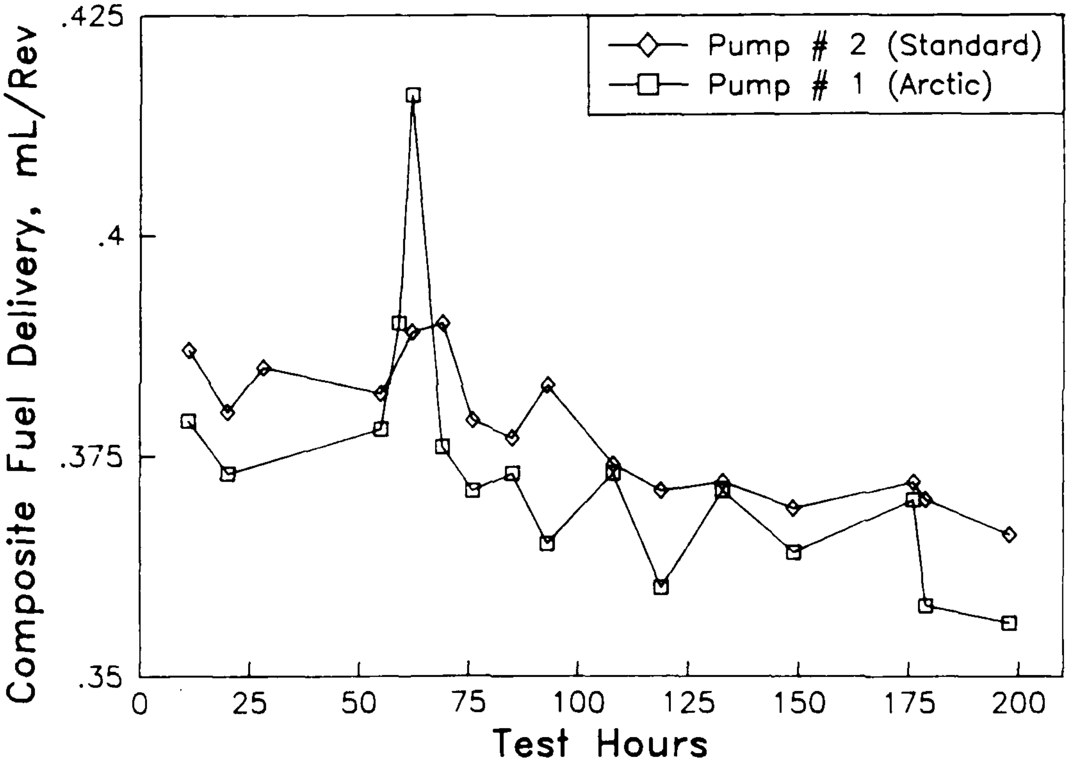


Figure 7. Composite fuel delivery on test rig with JP-8 fuel

it may be an actual temporary increase in fuel delivery. In any event, the trend for both the arctic and standard pump is a gradual decrease in maximum fuel delivery.

The decrease in delivered volume shown in Fig. 7 was reflected in engine fuel delivery as shown in Fig. 8. Note that the standard and arctic pumps experienced

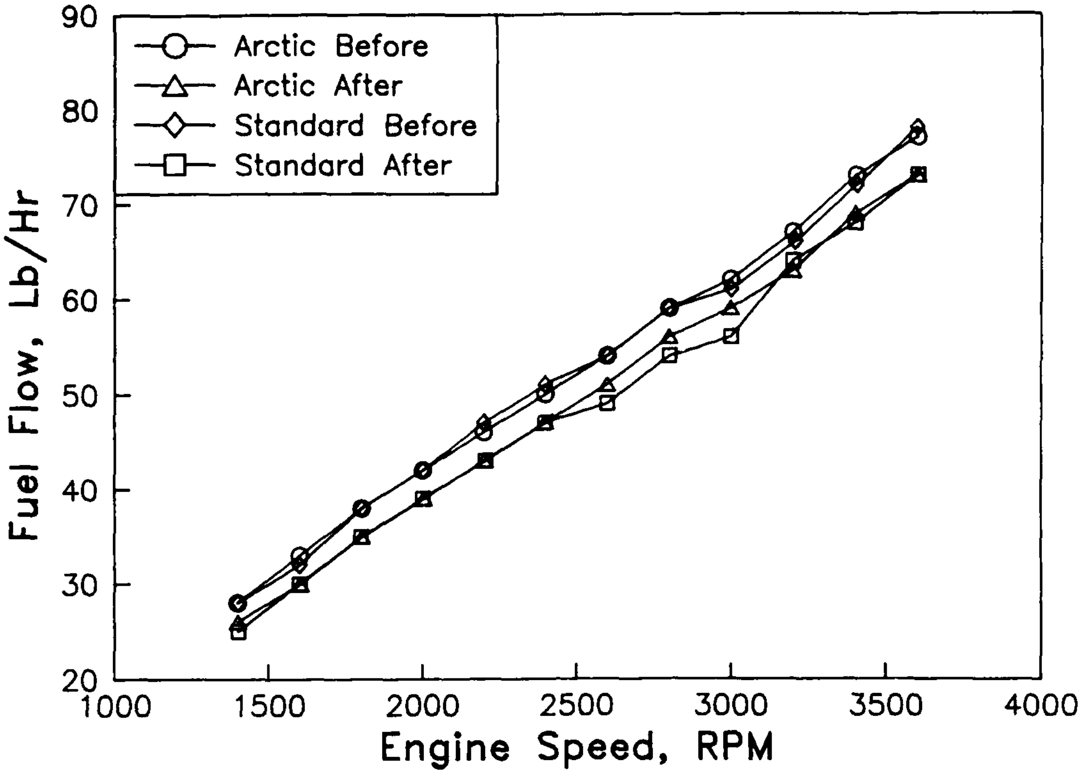


Figure 8. Full-load fuel flow

about the same amount of decreased fuel flow from before to after test. The fuel deliveries shown in Fig. 8 were taken from pre- and post-test full-load performance determinations.

The decrease in fuel flow produced a decrease in maximum load that the engine would produced. Fig. 9 shows the observed load versus speed curves for the arctic and standard pumps (1 and 2) both before and after test. Note that the before-test arctic curve was taken after the re-calibration by the pump service representative and is different from that shown in Fig. 1. Both the arctic and standard pumps experienced about the same amount of deterioration in maximum torque.

Exhaust common temperatures for the arctic and standard pumps before and after test are shown in Fig. 10. Note that there are five apparent anomalies in the arctic after-test curve. The causes of these high readings are unknown. Again,

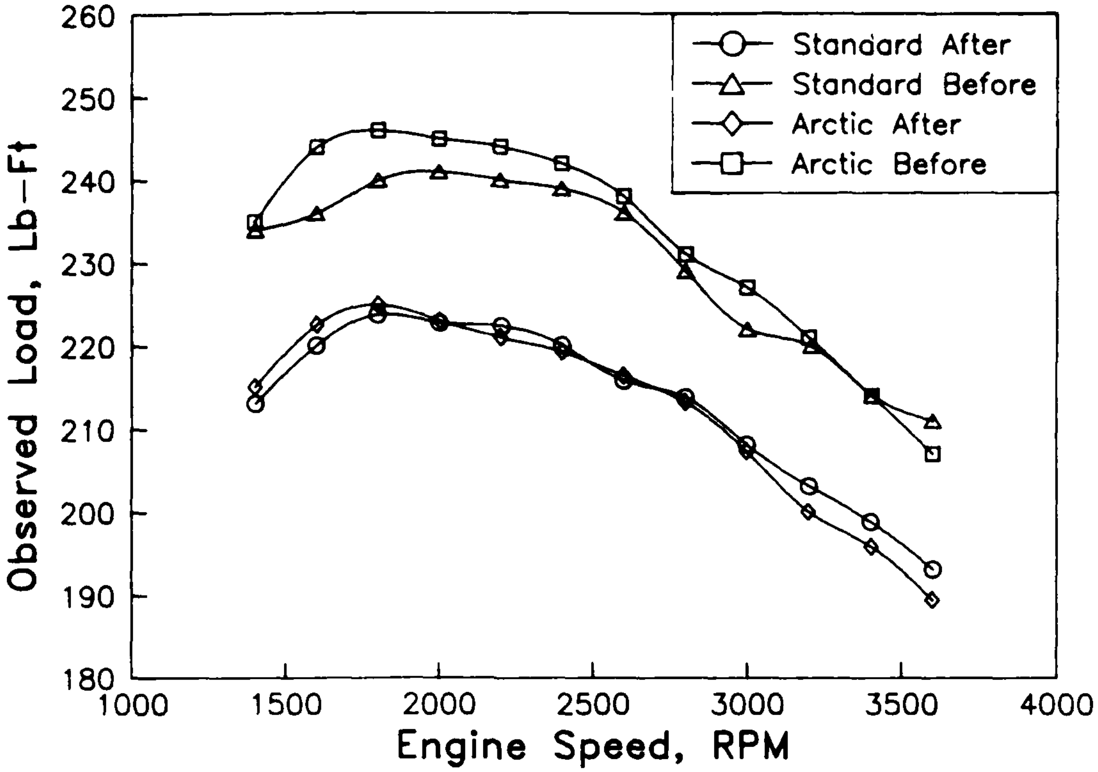


Figure 9. Full load performance with VV-F-800 DF-2 fuel

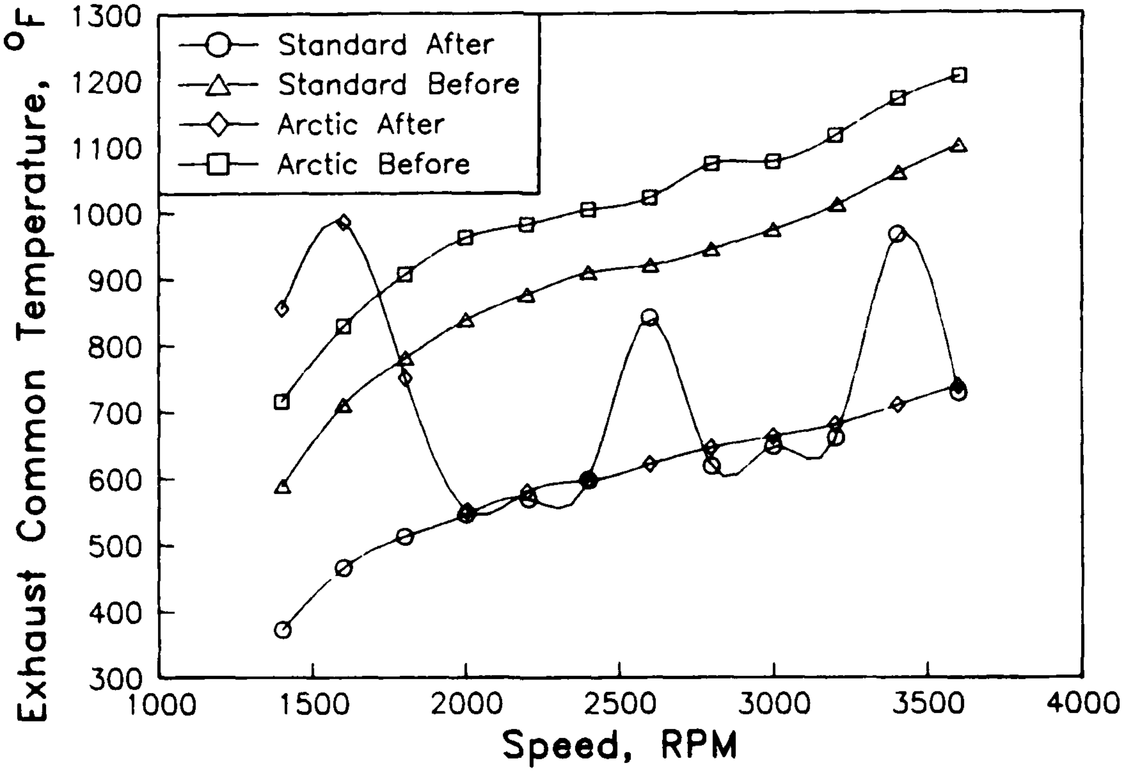


Figure 10. Exhaust temperature with VV-F-800 DF-2 fuel

the exhaust temperatures were taken from full-load performance determinations both before and after test. Both the arctic and standard pumps experienced drops in exhaust temperature when compared to pre-test values.

Other parts examined for wear were the transfer pump liners, cam ring, and rollers. No significant wear was evident in these areas. Transfer pump pressure remained essentially constant throughout the three tests, indicating that there was either minimal wear in the transfer pump or that flow was adequate to feed the built-in pressure relief valve.

IV. CONCLUSIONS

- The arctic pumps for the 6.2L engine exhibit less drive tang wear than the standard pumps in JP-8 service under full-rack full-speed conditions. If allowed to progress, drive tang wear could lead to ignition timing retardation in the engine and a resultant decrease in engine efficiency.

- The arctic pumps experience more governor thrust washer wear under the same conditions.

- Both the arctic and standard fuel injection pumps exhibited a decrease in maximum fuel delivery throughout the test. This decrease equates to a maximum power loss for the engine. The cause of the decrease in fuel flow has not yet been determined.

- Visual inspection of the transfer pumps reveal no significant distress for either the arctic or standard pumps. Transfer pump pressure remained essentially constant throughout the test.

- On engine ignition timing may be a means to compensate for the effects of drive tang wear. This would require cooperation with the engine manufacturer to develop a procedure for measuring timing change and compensating for it.

- These results were obtained at full-output conditions, which are believed to be the most severe for the wear behavior studied. Actual vehicle service conditions may reduce the rate of wear significantly. At this time, the data do not allow estimation of when the observed pump wear would become apparent in actual service.

- Results from these tests are very limited since data from only one dual 200-hour run and two short failed runs were available.

V. RECOMMENDATIONS

- Additional testing using a statistically significant number of arctic and standard pumps should be undertaken to quantify wear effects. This testing could take the form of bench tests similar to those reported herein, or could be a controlled field test.

- JP-8 should be used in 6.2L engines with the understanding that it will produce an initial loss in maximum power (due to viscosity and heating value effects) and may ultimately produce an additional loss in power due to fuel injection pump deterioration.

- The engine manufacturer should be queried for a procedure to check ignition timing in the fielded Commercial Utility Cargo Vehicles and High-Mobility Multipurpose Wheeled Vehicles. Vehicles in cold climates currently using DF-A should be checked for retarded injection timing. This could provide field data on when (or if) potential problems may occur.

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CDR
WARNER ROBINS AIR LOGISTIC
CTR
ATTN: WRALC/MMTV (MR GRAHAM) 1
ROBINS AFB GA 31098

CDR
USAF 3902 TRANSPORTATION
SQUADRON
ATTN: LGTVP (MR VAUGHN) 1
OFFUTT AIR FORCE BASE NE 68113

CDR
DET 29
ATTN: SA-ALC/SFM 1
CAMERON STATION
ALEXANDRIA VA 22314

OTHER GOVERNMENT AGENCIES

NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION 1
LEWIS RESEARCH CENTER
CLEVELAND OH 44135

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
ATTN: AWS-110 1
800 INDEPENDENCE AVE, SW
WASHINGTON DC 20590

US DEPARTMENT OF ENERGY
CE-151, ATTN:
MR ECKLUND 1
FORRESTAL BLDG.
1000 INDEPENDENCE AVE, SW
WASHINGTON DC 20585

ENVIRONMENTAL PROTECTION
AGENCY
AIR POLLUTION CONTROL 1
2565 PLYMOUTH ROAD
ANN ARBOR MI 48105

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