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JP-8 AND JP-5 AS COMPRESSION IGNITION ENGINE FUEL

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For many years, aircraft turbine fuel JP-5 has been used in diesel engines as an alternate fuel for DF-2, and is listed as such in Army Regulation 703-1. Since 1965, diesel engine endurance tests have been conducted in a variety of compression-ignition engines using JP-5 or JP-8 as the fuel and comparing performances with DF-2. None of these tests showed engine failures or excessive wear attributable to the use of kerosene-type aircraft turbine fuels, although slightly reduced fuel injection delivery volumes and lower power output were experienced in most engines, due to lower viscosity and lower heat content of JP-5 and JP-8 compared to DF-2. These results not withstanding, periodically, concerns are raised about the use of JP-5 and JP-8 in diesel engines over long periods in the 500- to 1000-hour time frame, especially in new engine designs. This report is primarily an annotated bibliography of 23 references consisting of technical notes, letters, letter reports, and interim reports, on the subject of using aircraft turbine fuels JP-5 and JP-8 in diesel engines. Originator supplied keywords include:

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FOREWORD

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I. INTRODUCTION

During the mid 1970's, Army agencies were requested to consider use of Military Specification MIL-T-5624 Grade JP-5 as an "alternate fuel" for all equipment powered by compression-ignition engines. Based upon previous data developed by the Navy Civil Engineering Laboratory at Port Hueneme, CA, surveys of engine and component manufacturers, short-term testing conducted by the Army, and a comprehensive knowledge of military engine fuel requirements, the Army subsequently approved MIL-T-5624 Grade JP-5 as an alternate fuel to diesel fuel meeting Federal Specification VV-F-800. This approval was reflected in the Army Regulation AR 703-1 coal and petroleum supply and management activities, dated 6 September 1978.

Since that time, additional engine and component test data have been developed on not only differing JP-5 fuels, but more recently samples of MIL-T-83133 Grade JP-8. Both JP-5 and JP-8 are aviation kerosene turbine engine fuels which essentially differ only in their flash and freezing point requirements. These differences are summarized as follows:

	JP-5	JP-8
Flash Point, °C, min	60	38
Freezing Point, °C, max	-46	-50
Kinematic Viscosity at -20°C, max	8.5	8.0
Distillation, °C, End Point, max	290	300
Sulfur, Mass %, max	0.4	0.3

Within the past few years, concerns have been frequently raised by Army, Navy, and Marine Corps field personnel regarding use of JP-5 fuel in diesel-powered equipment and the effect it may have on the mean time between overhauls. As a result of these concerns, a need surfaced to provide a summary of all work conducted on use of aviation kerosene turbine engine fuels in diesel-powered equipment. The intent in developing this summary was to provide sufficient documentation that would (1) resolve any user concerns with existing use of JP-5 and (2) establish MIL-T-83133 Grade JP-8 as an altr ate fuel to diesel fuel meeting VV-F-800.

II. OBJECTIVE

The objective of this task was to assemble existing data and reports dealing with the use of JP-5 and JP-8 in lieu of diesel fuel for compression-ignition engines into one summary document. From these accumulated data, conclusions could then be drawn as to the likelihood of successful use of these aviation turbine fuels in military newly acquired and future-designed diesel-powered equipment.

III. APPROACH

Technical notes, letters, letter reports, and interim reports dating back to 1965 have been located which deal with the subject of this report. An annotated bibliography on 23 references has been prepared and forms the bulk of this report. In addition to those references on JP-5, recent documentation on JP-8 has also been included because of the similarity of these two turbine fuels. Based on these reports, specific conclusions have been drawn supporting the acceptability for using JP-5 and JP-8 in diesel-powered equipment.

Since JP-5, JP-8, DF-A, and DF-2 are fuels frequently discussed in this report, Table 1 compares some of the requirements for these fuels. MIL-F-16884-H, Naval Distillate Fuel (NDF) is intended for use only as a shipboard fuel and not for ground equipment. However, since it is occasionally used in vehicles, its requirements are included in Table 1 for information.

TABLE 1. COMPARATIVE REQUIREMENTS OF DIESEL AND TURBINE FUELS

Properties	VV-F-800C DF-A	VV-F-800C DF-2	MIL-F-16884-H NDF	MIL-T-5624-L JP-5	MIL-T-83133A JP-8
Flash Point, °C, min	38	52	60	60	38
Cloud Point, °C, max	-51	*	-1	NR**	NR
Pour Point, °C	Rpt	Rpt	-6	NR	NR
Freezing Point, °C, max	NR	NR	NR	-46	-50
Kinematic Viscosity at 40°C, cSt	1.1 to 2.4	1.9 to 4.1	1.7 to 4.3	NR	NR
Kinematic Viscosity at -20°C, cSt, max	NR	NR	NR	8.5	8.0
Distillation, °C					
10% recovered, max	NR	NR	NR	205	205
20% recovered, max	NR	NR	NR	Rpt	Rpt
50% recovered, max	Rpt	Rpt	Rpt	Rpt	Rpt
90% recovered, max	288	338	357	Rpt	Rpt
End Point, max	300	370	385	290	300
Residue, vol%, max	3	3	3	1.5	1.5
Sulfur, mass%, max	0.25	0.50	1.00	0.4	0.3
Cu Corrosivity					
3 hrs at 50°C, max	3	3	NR	NR	NR
2 hrs at 100°C, max	NR	NR	1	1B	1B
Ash, wt%, max	0.01	0.01	0.005	NR	NR
Accelerated Stability, mg/100 mL, max	1.5	1.5	1.5	NR	NR
Neutralization Number, mg KOH/g, max	0.05	NR	0.3	0.015	0.015
Particulate Contamination, mg/L, max	10	10	NR	1.0	1.0
Cetane Number, min	40	40	45	NR	NR

* Specified according to anticipated low ambient temperature at use location.
** NR = No requirement.

IV. DISCUSSION

A tabulation of all the engine tests reported in the reference contained in the Annotated Bibliography was prepared and is shown as Table 2. The test periods ranged from 240 to 500 hours, and no unusual wear or damage to engines was observed in any of the test programs.

In the referenced reports where the performance of JP-5 or JP-8 is compared to that of DF-2, the aircraft turbine fuels show power output values up to 6 percent lower than observed with the diesel fuel. This is due to the lower volumetric heat content of the jet fuels and the lower viscosity of these fuels, which contributes to reduced delivery rates in the fuel injection system (Reference 19 summarizes these product differences). Diesel fuel arctic grade (DF-A) has viscosity and boiling range very similar to JP-5 and JP-8; therefore, a comparable reduction in power output would be expected when DF-A is used in compression-ignition engines.

Non-winterized diesel fuels (i.e., Grade DF-2 or NO. 2-D) generally have relatively high pour and cloud points; therefore, it has been the practice in Alaska to use DF-A or Jet A-1 (JP-8) year-round in all diesel-powered equipment, especially in Fairbanks and Northern regions. For example, all equipment operating on the Alaskan Pipeline during its construction used Jet A-1 with no problems being reported (M.E. LePera, US Army Mobility Equipment Research and Development Center, Trip Report, 20 February 1975).

Table 2 summarizes the engine endurance testing conducted with JP-5 and JP-8 that were reviewed in this report.

None of the reports summarized above indicate any direct experience with the newer engines being introduced in the Military fleet, such as the Detroit Diesel 6.2L engine; however, 500-hour tests have been run at NCEL on other diesel engines using JP-5 with no apparent adverse effects. Moreover, the satisfactory 500-hr testing on the 50-kW sets with MP-1 (Reference 3) which represents a fuel

TABLE 2. ENGINE-DYNAMOMETER TESTING OF JP-5 AND JP-8 FUELS

Engine	Injection System	Fuel	Test Hrs.	Results	Conducted by	Ref. No.
Continental Mtrs SD-802	Roosa Master Pump CAV Injectors	JP-5	500	No damage or unusual wear	NCEL*	1
Continental Mtrs SD-802	Roosa Master Pump CAV Injectors	DF-2	359	Timing gear failed-no damage or unusual wear	NCEL	1
Detroit Diesel 3-71	GMC Unit Injectors	JP-5	500	No damage or unusual wear	NCEL	1
Detroit Diesel 3-71	GMC Unit Injectors	DF-2	500	No damage or unusual wear	NCEL	1
International UD-18A	IHC Injection System	JP-5	500	No damage or unusual wear	NCEL	1
International UD-18A	IHC Injection System	DF-2	500	No damage or unusual wear	NCEL	1
Cummins Model JT-6	Cummins PT Injection	JP-5	500	No damage or unusual wear	NCEL	1
Cummins Model JT-6	Cummins PT Injection	DF-2	500	No damage or unusual wear	NCEL	1
Caterpillar 50-kW	Caterpillar Injection	DF-A	500	Parts in excellent condition 0.8% loss in pumping capacity	NCEL	3
Caterpillar 50-kW	Caterpillar Injection	MP-1	500	Parts in excellent condition 2.0% loss in pumping capacity	NCEL	3
CUE+ 1790	Am. Bosch APE1BB	JP-5	250	Less wear and deposits than with DF-2	AFLRL**	11
AVDS-1790-2C (RISE)	Am. Bosch Rotary	JP-5	400	Performance was satisfactory	TCM***	12
DD6V-53T	GMC Unit Injectors	JP-8	240	No damage or unusual wear	AFLRL	21

* NCEL - U.S. Naval Engineering Laboratory, Port Hueneme, CA
** AFLRL - U.S. Army Fuels and Lubricants Research Laboratory
*** TCM - Teledyne Continental Motors
\+ Cooperative Universal Engine

of "lower lubricity" than JP-5 provided direct support to this issue. There have been undocumented reports that lubricating oil has been added to JP-5 to reduce wear of injection equipment. The extensive work summarized here indicates that this practice is not necessary. Both MIL-T-5624L and MIL-T-83133 require the addition of a corrosion inhibitor to JP-5 and JP-8 aircraft turbine fuels, and the corrosion inhibitors on the qualified products list are known to impart lubricity characteristics to the fuel.

V. CONCLUSIONS

The investigations summarized briefly in this document are reported in 23 references dating from 1965 to the present. These references indicate that JP-5 and JP-8 are acceptable alternates for DF-2 as fuels in all vehicles and stationary equipment powered by compression-ignition engines. JP-5 and JP-8 do have lower viscosity and lower volumetric heat content than DF-2. Because of this, slightly reduced fuel injection delivery volumes and lower power output are experienced in most engines when using JP-5 or JP-8 in place of DF-2. These differences are no more than would be experienced when using DF-A in locations where climatic conditions require its use. JP-5 and JP-8 that meet the requirements of Military Specifications MIL-T-5624L and MIL-T-83133A, respectively, including the required amount of corrosion inhibitor, should not cause undue wear in engines operating on this fuel for extended periods. Although experiences with kerosene-type aircraft turbine fuels beyond 500 hours were not reported in the references reviewed, operation for longer periods should not cause problems.

Experience with the new 6.2L diesel engine using JP-5 or JP-8 has not been reported. Based on the successful use of these fuels in a variety of other diesel engines, JP-5 or JP-8 should be adequate fuels for the 6.2L diesel-powered high mobility multipurpose wheeled vehicles (HMMWV) and commercial utility and cargo vehicles (CUCV).

VI. RECOMMENDATIONS

Based on the documents reviewed in this report and the extensive experience with the problem-free use of JP-5 and JP-8 in diesel engines within the Army and Navy, it is recommended that JP-8 be considered an alternate to diesel fuel DF-2, in the same manner that JP-5 is now approved as an alternate fuel as reflected in Army Regulation AR 703-1.

VI. ANNOTATED BIBLIOGRAPHY

Throughout the Annotated Bibliography section, the reference is given first followed by a summary of the document. Many of the references listed in the Annotated Bibliography are available as follows: Those references giving an AD number may be obtained from Defense Technical Information Center; those from NCEL may be obtained by contacting the Technical Library at the Naval facility; the letter reports may be available from the sources. Other references listed as letters are not available. Where included, the authors' comments on the references follow and are set apart from the report summary by bolded text.

1. Watson, W.W.; Wise, J.J., "Substitution of JP-5 for Diesel Fuel Ashore," Technical Note N-660, U.S. Naval Civil Engineering Laboratory, Port Hueneme, California, 15 February 1965.

Severe logistic problems outside CONUS made it necessary to reduce the number of fuels carried in Navy stock. The Naval Civil Engineering Laboratory, therefore, was directed to conduct a series of tests to determine the suitability of JP-5 aviation turbine fuel as a replacement for DF-2 diesel fuel in construction-type equipment.

Contact was made with every important United States manufacturer of diesel engines and diesel fuel injection equipment, all major oil company laboratories, and appropriate Government agencies. These organizations were asked for their recommendations concerning the use of JP-5 as a fuel in diesel engines.

Although the overwhelming majority of answers to this survey reported that JP-5 is a satisfactory substitute for diesel fuel in automotive and construction equipment diesel engines, there was also general agreement that the following undesirable side effects may result.

a. Inasmuch as the JP-5 specification does not control cetane rating, there is always the chance of obtaining a supply of low cetane fuel which could cause engine starting and operating difficulties.

b. The reduced viscosity of JP-5 may result in a somewhat shorter length of time between injection equipment overhauls. The general consensus was, however, that this should not prove serious providing that reasonable precautions are taken.

Four matched pairs of diesel engines were operated under load for 500 hours. These engines included two Continental Motors SD-802 engines with Roosa Master injection pumps and CAV injectors, two Detroit Diesel 3-71 engines with GMC unit injectors, two International UD-18A engines with IHC injection equipment, and two Cummins Model JT-6 with a Cummins PT injection system. One engine of each pair ran on JP-5 aviation turbine fuel while the other ran on DF-2 diesel fuel. After this run, the injection equipment from each engine was disassembled and inspected for evidence of scoring, damage, unusual wear, or malfunction. This inspection revealed no damage due to operation on JP-5.

Preliminary findings disclosed that the JP-5 fuels currently available on the West Coast can be successfully used in the diesel engines assigned to the Naval Construction Forces without the use of additives or precautions, other than increased attention to the cleanliness of the fuel and the fuel system.

2. Wise, J.J.; Phelps, S., "Heavy Equipment Operators' Evaluation: JP-5 Versus DF-2," Technical Note N-693, U.S. Naval Civil Engineering Laboratory, Port Hueneme, California, 13 May 1965.

The results of previous tests showed that JP-5 aviation turbine fuel is a suitable substitute for DF-2 diesel fuel in diesel engines powering the equipment of the Naval Construction Forces. However, several conflicting opinions were expressed concerning the alleged variation in performance which might be detected by heavy equipment operators while using the substitute fuel. Therefore, it was decided to conduct a series of tests to determine if experienced operators could, indeed, discern a difference in performance between equipment fueled with JP-5 and the same equipment fueled with DF-2.

The results of this experiment indicated that well-trained operators could sometimes detect a very slight power loss with JP-5, but that otherwise engine operation is completely normal and adequate. This slight power loss is primarily due to increased leakage of the less viscous JP-5 around the fuel injection plungers. The loss does not appear to be of sufficient magnitude to warrant any change in injector rack settings.

3. Watson, W.W.; Wise, J.W., "MP-1 as a Fuel for Diesel Engines (Ambient Temperature Phase)," Technical Note N-742, U.S. Naval Civil Engineering Laboratory, Port Hueneme, California, 17 September 1965.

The specification for a multipurpose fuel, MP-1 (MIL-F-23188), was developed by the Bureau of Naval Weapons for use at Antarctica in aircraft turbines, diesel engines, and space heaters, and received prior approval for use in C-130 and C-135 aircraft. This study was undertaken to determine its suitability for use as a fuel in compression-ignition engines.

Two Caterpillar 50-kW diesel-electrical generating sets were operated under load for 500 hours. One engine ran on diesel fuel - arctic, while the other used MP-1. A few of the properties of MP-1 are compared to DF-A and JP-5 as follows:

PROPERTIES OF MP-1 FUEL COMPARED TO DF-A AND JP-5

	MP-1 (3)	DF-A '64 (3) Procurement	DF-A '65 (3) Procurement	JP-5 (13) Typ. Values
Cetane No.	42.7	38.1	39.9	35 to 47
Kinetic Viscosity,				
cSt at 100°F	1.06	1.42	1.40	1.5 to 1.9
Sulfur, wt%	0.02	0.10	0.11	0.4 max.
Distillation, °F				
10% recovered	333	403	402	401 max.
End Point	390	524	526	554 max.
Freezing Point, °F	Below -76	-74	-64	-51 max.

Results of a 500-hour endurance run and a series of dynamometer tests indicate that MP-1 fuel is an entirely acceptable substitute for DF-A fuel in medium- and high-speed diesel engines, under temperate weather conditions.

Note that in terms of viscosity and volatility, the MP-1 fuel used in this test program would be expected to produce higher injection system wear and a greater likelihood of pump filling and power reduction problems. However, successful use of the MP-1 fuel provides further support for the successful use of JP-5 fuels.

4. Watson, W.W., "The Use of JP-5 Aviation Turbine Fuel in Large-Bore, Low-Speed Diesel Engines," Technical Note N-743, U.S. Naval Civil Engineering Laboratory, Port Hueneme, California, 15 November 1965.

In view of substantial economies anticipated in the field of fuel logistics, an investigation was conducted to determine the feasibility of substituting JP-5 aviation turbine fuel for standard DF-2 diesel fuel in large-bore, low-speed diesel engines.

The investigation included:

1. Consultation with engineering and service representatives of engine and injection equipment manufacturers.

2. Detailed examinations of typical engines following lengthy operation on JP-5 fuel.

3. On-the-spot inspection and analysis of reported large-bore engine-fuel difficulties.

From this investigation, it was concluded that JP-5 can be substituted for DF-2 in large-bore, low-speed diesel engines with no appreciable ill effects to the engine or injection equipment, provided that:

1. The fuel is water-free and filtration down to at least the 5-micron level is carefully maintained.

2. Corrections, when necessary, are made in injection nozzle sizes, injection pressures, and/or injection timing, in order to attain optimum fuel spray penetration in the combustion chambers.

3. A 6- to 7-percent correction in rack setting is made when maximum power output is essential.

5. Lestz, S.J., "Comparison of DF-2 and JP-5 in GMC Detroit Diesel 6V-53T Performance Evaluation," Letter to Headquarters U.S. Marine Corps, Major Lee, 15 March 1972.

Comparative fuel performance evaluation of JP-5 and DF-2 were conducted in a GMC Detroit Diesel 6V-53T engine. Analysis of the data indicates that a power reduction of from 2.5 percent to 6.5 percent can be expected over the operating range of this engine when switching from No. 2 diesel fuel to JP-5 fuel. The 6.5 percent power reduction is in line with the 5.2 percent reduction in fuel heating value. The brake specific fuel consumption data indicate that the power decrease is offset by a modest increase in fuel economy at engine speeds above the peak torque--the normal operating range for the engine. To summarize, unless the engine were to be modified, a slight power reduction is to be expected accompanied by a slight improvement in fuel economy.

6. Ammlung, H.L., "Use of JP-5 Fuel in Lieu of Diesel Fuel," Letter to Headquarters, U.S. Army Materiel Command, Mr. W. J. Horton, 20 March 1972.

In 1972, the US Army Coating and Chemical Laboratory at Aberdeen Proving Ground conducted a survey of major diesel engine and fuel system manufacturers to solicit their comments regarding the substitution of a JP-5 fuel for diesel fuel. The survey included five major engine companies and the three largest fuel system builders. The basic letter requested their comments in regard to any effects resulting from the substitution of JP-5 fuels in place of diesel fuel currently procured under VV-F-800A, DF-2 for all diesel-powered Army equipment.

Based on the survey, it was recommended that for procurement of fuel meeting MIL-T-5624H, Grade JP-5, to be used in Japan, the following specification requirements be applied to the subject fuel:

Inspection Test	Minimum Requirement
Cetane Number	40
Kinematic Viscosity @ 100°F	1.3 cSt

For those engines equipped with fuel density compensators (or other devices allowing for changes in gravity, density, or viscosity), alternate use of diesel and/or JP-5 would be permitted once readjustments to the fuel delivery systems had been completed. However, with other engine systems (namely

Caterpillar and International Harvester), the alternate use of diesel was not permitted once readjustments to the fuel delivery systems had been completed. This prohibiting of alternate diesel should be maintained for other engine systems to minimize the possibility of damage for the engines in question, due to potential over-fueling.

In view of the data available from previous studies and even the responses obtained in this survey, the recommendations to limit the use of JP-5 to compensator-equipped (multifuel) engines seem overly restrictive. There are no available records indicating that any problems were experienced as a result of JP-5 substitution in Japan during that period. This restriction was later removed as a result of the following work.

7. Garabrant, A.R., "Lubricity of JP-5 and Diesel Fuels," Final Technical Report, from Exxon Research and Engineering Company for U.S. Army Mobility Equipment Research and Development Center, DAAD05-73-C-0563, December 1974.

The U.S. Army was considering the potential replacement of diesel fuel by aviation turbine fuel, since certain areas historically supplied by the U.S. Navy have been required to switch from diesel fuel to JP-5 fuel. Concurrent with this, the U.S. Army was pursuing development of a universal fuel in which certain lubricity parameters are needed. Inasmuch as the properties of aviation turbine fuels differ from those of diesel fuels, the possibility of adverse wear effects upon the engine's fuel system and fuel-handling equipment must be considered. The U.S. Army Materiel Command has the overall responsibility for determining the suitability of these fuels for use in diesel engines. The Exxon Research and Engineering Company was retained to evaluate the wear and friction characteristics of selected jet engine and diesel engine fuels and to correlate their lubricity characteristics with their physical and chemical properties, as part of the Materiel Command's effort.

The wear and friction characteristics of eleven selected fuels were evaluated with aid of the Exxon Research and Engineering Company's Ball-on-Cylinder Machine test. Limited additional testing of some of the fuels was also done with the aid of the Vickers Vane Pump test.

Fuel nitrogen and sulfur levels, as well as back end volatilities and viscosities, are factors in wear phenomena. Relative humidity of the ambient air, or water content of the fuels, has a significant effect upon the fuels' lubricity properties. There is an apparent correlation between the origin of the fuels and their bench test performance; however, this may well be the result of manufacturing operations or crude types rather than actual geographic location of the fuels' sources. Wear phenomena observed with the Ball-on-Cylinder Machine and the Vickers vane pump are correlatable. While the Ball-on-Cylinder Machine is more sensitive to fuel quality than the Vickers vane pump, it is also less precise than the vane pump.

As a result of this work, in 1974 the U.S. Army Materiel Command recommended unrestricted substitution of JP-5 for diesel fuel in Army equipment operating in Japan.

8. Marvin, F.R., "Performance Curves, DDA Engines, JP-4, JP-5, and No. 2 Diesel Fuel," Letter to Headquarters U.S. Marine Corps, Attention: Code LME (Mr. C. Jackson), from Detroit Diesel Allison Division, General Motors Corporation, 3 January 1974.

At the request of the U.S. Marine Corps, performance curves for seven Detroit Diesel Allison Division engine-injector combinations were forwarded in this letter. The author did not comment on the data; however, examination of the curves indicates a reduced power output with the JP-5 compared to DF-2 which is due to the lower volumetric heat content of the JP-5.

9. Bowden, J.N.; Wimer, W.W., "Universal Fuel Requirements," U.S. Army Mobility Equipment Research and Development Center, Report AFLRL No. 67, AD A016157, DAAK02-73-C-0221, May 1975.

Critical examination of diesel and ground turbine engine requirements for fuels led to recommended properties for a universal fuel that would satisfy both types of engines. These properties represent essentially a merger of JP-8 with DF-A specifications with allowance for expansion of the boiling range of both.

10. Bowden, J.N., "JP-8 for Ground Equipment," Letter to U.S. Army Mobility Equipment Research and Development Command, Mr. M.E. LePera, 23 March 1979.

The operation of jet aircraft in the European area on JP-8 prompted an inquiry with respect to the potential utilization of this fuel in diesel-powered ground equipment and in burners. Since JP-8 and JP-5 are similar fuels, the principal difference being in the higher flash point required of JP-5 for shipboard use, this letter summarized the information available at that time on the use of JP-5 as a diesel engine fuel. It was concluded that most JP-8 fuels should have adequate viscosities and cetane numbers for satisfactory operation in diesel engines.

11. Moon, R.B., "Evaluation of JP-5 Turbine Fuel in the Single Cylinder CUE-1790 Diesel Engine," U.S. Army Mobility Equipment Research and Development Command, Final Report AFLRL No. 119, AD A078666, DAAK70-79-C-0060, November 1979.

Performance and 250-hour endurance tests of JP-5 turbine fuel in a single-cylinder assembly (CUE "Cooperative Universal Engine" 1790) from the Teledyne Continental Motors 12-cylinder AVDS 1790-2C (RISE) 4-cycle diesel engine were conducted at AFLRL. The performance test compared fuel consumption and horsepower of the CUE 1790 when operating on JP-5 turbine

fuel in place of diesel fuel, while the endurance test compared engine wear and deposits when operating the CUE 1790 on JP-5 instead of diesel fuel.

The performance test indicated no change in power and a 3±1-percent increase in fuel consumption. The endurance test indicated no change to slightly less wear, fewer deposits, no change in the oil consumption rate, and nothing unusual in the used oil analyses. Analysis of the JP-5 indicated a cetane number within diesel fuel specifications.

Although further tests are necessary to define the effect of random variables on the test results, from this test it was concluded that the use of JP-5 in the CUE 1790 resulted in no appreciable loss in performance or service life. As a result, JP-5 was considered to be a satisfactory alternative fuel for use in the AVDS 1790-2C diesel engine.

12. Lee, J.R., "JP-5 Fuel Compatibility Test (400-Hour Mission Profile)," Technical Report No. AVDS-1790-2C-204, Teledyne Continental Motors, General Products Division, Muskegon, Michigan, DAAE07-78-C-1369, December 1979.

This report contains the test data and results of a 400-hour durability test conducted with an AVDS-1790-2C (RISE) engine using JP-5 as the fuel. Conclusions from the test at Teledyne indicated that maximum horsepower at rated engine speed with JP-5 was 2.6 percent below that obtainable with DF-2 for a new engine, and 3.5 percent below after 400 hours. The JP-5 fuel was compatible with the AVDS-1790 engine. Engine durability was excellent as no incident of component failure was observed. Visual inspection of all major components after teardown showed them to be in excellent condition. The recommendations in this report state that JP-5 with cetane numbers in the range of 48 to 53 can be used in the AVDS-1790 engine.

The cetane number recommendation proposed by Teledyne-Continental (TC) in this report reflected a misunderstanding in relation to defining military engine fuel requirements. The problem is that cetane number is not a specification requirement for JP-5 and would not be routinely available for stocks of JP-5 as it is not normally reported. This recommendation, if taken at face value, would preclude the use of JP-5 because the information required to determine acceptability would not be available. Moreover, the limits proposed by TCM were without technical justification. Rather, these limits appear to be derived from the cetane number of the particular test fuel and the reproducibility of the cetane measurement procedure.

13. Owens, E.C., "Inspection of AVDS-1790 Engine Operated on JP-5 fuel at Teledyne Continental Motors," Letter to U.S. Army Mobility Equipment Research and Development Command from AFLRL, 7 February 1980.

    The AVDS-1790-2D which was operated on JP-5 for 400 hours in a durability test was inspected by personnel from AFLRL. The inspection report stated in summary that there was no evidence of fuel incompatibility or fuel-related distress that would seriously shorten the engine life or otherwise adversely affect engine operation.

14. Christians, J.A., "AVDS-1790-2C Engine Dynamometer Compatibility Test Using MIL-T-5624, JP-5," Letter to Office of Project Manager, M60 Tanks, Attn: DRCPM-M60-E (Mr. DeGroot), 15 January 1980.

    A review of events is presented in this letter related to the conducting of a 400-hour mission profile test on a new AVDS-1790-2C engine, operating on JP-5 fuel conforming to MIL-T-5624.

    Based upon this test, the single-cylinder CUE-1790 (Reference 11), and the subsequent review of JP-5 samples worldwide, the U.S. Army recommended the USMC accept MIL-T-5624 JP-5 as an alternate fuel for diesel-powered equipment.

15. Bowden, J.N.; Owens, E.C.; Naegeli, D.W.; Stavinoha, L.L., "Military Fuels Refined From Paraho-II Shale Oil," U.S. Army Mobility Research and Development Command, Interim Report AFLRL No. 131, AD A101069, DAAK70-80-C-0001, March 1981.

Shale-derived JP-5, JP-8, aviation turbine fuels and marine diesel fuel were analyzed for compliance with military specifications and evaluated for storage stability, corrosion tendencies, additive response, compatibility with petroleum fuels and microbiological growth susceptibility. The shale fuels behaved very much like petroleum-derived fuels. Turbine combustor evaluation showed a likeness to petroleum-derived Jet A fuel. Performance tests of the shale fuels conducted in four diesel engines also indicated a similarity with the same tests performed with petroleum-derived fuels. The JP-5 met all the requirements for Military Specification MIL-T-5624L, Turbine Fuel, Aviation, Grade JP-5, with exception of the requirements of the copper corrosion test and smoke point. The shale JP-5 in the Detroit Diesel 6V-53T engine showed a 6-percent average loss in maximum power output when compared to the reference diesel fuel. This approximates the 6.5-percent power loss observed in the same engine with petroleum-derived JP-5. The shale-derived JP-5 and DFM performed in the CUE-1790 engine as might be expected from the similar petroleum-derived fuels.

16. LePera, M.E., "Use of JP-5 in Lieu of DF-2," Letter to Commander, 200th Theater Army Materiel Management Center, 31 August 1981.

Specification changes that occurred with the revision of VV-F-800B to the C version did not affect the recommended use of JP-5 in diesel engines and burners under specified conditions. No field problem had been reported resulting from use of JP-5 as diesel fuel.

17. Montemayor, A.F.; Naegeli, D.W.; Dodge, L.G.; Owens, E.C.; Bowden, J.N., "Fuel Property Effects on Diesel Engine and Gas Turbine Combustor Performance," U.S. Army Mobility Equipment Research and Development

Command, Interim Report AFLRL No. 149, AD A120879, DAAK70-82-C-0001, December 1981.

In this program, four military engines and a gas turbine combustor were run to determine the effects of fuel properties on combustion performance. Eighteen test fuels were prepared with properties extending beyond the range of the specifications of diesel fuels. Diesel engine performance data were analyzed statistically, and regression equations were obtained for each engine expressing load in terms of speed, energy input, cetane number, kinematic viscosity, 10-percent boiling point, and aromatic content. Combustion performance measurements in the T-63 gas turbine combustor included flame radiation, exhaust smoke, gaseous emissions (THC, CO and NO_x), combustion efficiency, and ignition properties. The atomizing characteristics of the test fuels were examined with a particle sizing system based on forward-angle diffraction, and the results were correlated with the ignition properties of the fuels. Flame radiation and exhaust smoke were correlated with H/C ratio of the fuel. Viscosity and end point were used as correlating parameters for THC and CO emissions, and combustion efficiency. Under the operating conditions listed and over the range of fuel properties tested, the Cummins NTC-350 and Caterpillar 3208T proved to be more fuel tolerant than either the Detroit Diesel 4-53T or the LDT-465-1C. The adverse effects (loss of power) associated with high aromatics (for the DD 4-53T) and low 10-percent boiling point (for the LDT-465-1C) are small and probably would not be noticed by a vehicle operator.

The 18 test fuels in this program included three with properties similar to those of JP-5.

18. Russell, J.A.; Cuellar, J.P.; Tyler, J.C.; Erwin, J.; Alvarez, R.A.; Knutson, W.K.; et al., "Development of Accelerated Fuel-Engines Qualification Procedures Methodology, Volume I," U.S. Army Mobility Equipment Research and Development Command, Interim Report AFLRL No. 144, AD A113461, DAAK70-81-C-0209, December 1981.

Activities and findings are reported for a 12-month program aimed at the development of procedures for accelerating the qualification of new fuels on Army equipment, emphasizing those derived from oil shale and coal. Principal activities were identification of key tactical and combat surface and air vehicles, power plants, and fuels systems components; identification of critical properties peculiar to new fuels anticipated to have significant impact upon Army materiel; laboratory evaluations of materials compatibility and fuels characteristics (including lubricity, elastomer compatibility, thermal stability, and corrosion); full-scale fuel systems component testing, and an overall review and evaluation of existing engine/fuel system qualification procedures. Conclusions and recommendations are presented in terms of methodology and criteria which will realistically address key peculiarities of alternative fuels and thus serve to accelerate their qualification for field Army use.

Criteria defining satisfactory or unsatisfactory fuel lubricity as measured by the Ball-on-Cylinder Machine (BOCM) are generally unavailable. Based on a limited number of operational incidents, the Navy has established tentative guidelines for JP-5 aircraft turbine fuels shown here:

Good		WSD* < 0.42 mm
Marginal	0.43 <	WSD < 0.48 mm
Poor		WSD > 0.49 mm

* WSD - Wear Scar Diameter

The applicability of these criteria in ranking other fuel types or for nonaeronautical engines has not been established.

BOCM RESULTS FOR VARIOUS BASE FUELS

Fuel Description	No. of Runs	Average WSD, mm	Std Dev., mm
JP-5	2	0.28	0.02
Diesel Fuel	4	0.27	0.04

This work found that the two JP-5 samples examined had lubricity ratings equal to that of the diesel fuels, all of which were considered good.

19. Bowden, J.N.; Stavinoha, L.L., "Emergency Fuels Technology," U.S. Army Mobility Equipment Research and Development Command, Interim Report AFLRL No. 155, AD A125275, DAAK70-82-C-0001, June 1982.

Different types of engines in the military system require specific fuels for normal operation. Spark-ignition engines require gasoline, while compression-ignition engines and ground gas turbine engines require diesel fuel. The requirements of each engine type are listed in Army Regulation 703-1 as primary, alternate, and emergency fuels. The work reported here identifies other combustible liquids that, in extreme emergency scenarios, could be used as field emergency fuels (FEF), either as extenders of the primary fuel supply, or as acquired. Correlations are presented that permit estimating the fuel blend properties considered to be crucial for operation of engines at a minimal performance level.

Compression-ignition engines that use VV-F-800, DF-2, as the primary design fuel and JP-5 and commercial diesel fuels as alternate fuels can operate in an emergency on kerosene, JP-8, commercial jet fuels, DFM, gas turbine fuels, FO-1, FO-2, commercial burner fuels, ASTM D 975 4-D diesel fuel, and Navy distillate. The order listed is presumed to be the ranking according to anticipated performance in the compression-ignition engines.

Analyses of numerous worldwide samples of kerosene-type jet fuels showed that 4 of the 23 JP-5 samples had cetane numbers below 40, the lowest value being 34.8; three of the 44 Jet A/A-1 samples had cetane numbers below 40, the lowest value being 34.7. The following table compares the average properties of the JP-5 samples to DF-2 diesel fuel requirements.

AVERAGES AND RANGE OF VALUES FOR PROPERTIES
OF 23 JP-5 SAMPLES

	Average	High	Low	DF-2 Requirements CONUS	DF-2 Requirements OCONUS
Gravity, °API	40.7	44.1	36.3	NR*	NR
Density at 15°C, kg/L	0.8213	0.8428	0.8054	NR	0.815-0.860**
Flash point, °C	65	73	65	52 min	56 min
Viscosity at 40°C, cSt	1.5	1.7	1.3	1.9 to 4.1	
at 20°C, cSt					1.8 to 9.5
Cetane number	42.0	47.5	34.8	45 min**	45
Cetane index	41.7	47.2	36.5	NR	NR
Distillation, D 86, °C					
10% Recovered	196	204	188	NR	NR
50% Recovered	214	223	204	Report	Report
90% Recovered	241	267	226	338 max	357 max
Aromatics, FIA, vol%	20.8	25.0	15.0	NR	NR
Cloud point, °C	-	-45	<-60	+	-13
Freezing point, °C	-	-46	-74	NR	NR
Hydrogen, mass%	13.59	13.84	13.34	NR	NR
Neat heat of combustion, MJ/L	35.40	36.10	34.71	36.43++	NR

* NR = No requirement.
** 40 min cetane number is currently accepted for DF-2.
\+ At or below anticipated ambient temperature at location of use. (See Appendix A of VV-F-800C for guidance).
++ Typical value for a reference diesel fuel.

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20. Westbrook, S.R.; Stavinoha, L.L.; Bundy, L.L., "Summary of Stability Additive Package Evaluation in Partially Fueled Vehicles on Board USMC Ships at Diego Garcia," U.S. Army Belvoir Research and Development Center, Letter Report AFLRL No. 174, DAAK70-82-C-0001, 13 March 1984.

Ten M60A1 battle tanks and ten LVTP7 personnel carriers were stored, in a partially fueled configuration, on board two separate ships (ten vehicles per ship), for 26 months. Ten of the vehicles contained DF-2 and ten contained JP-5. The fuel in 12 of the 20 vehicles was additive treated (six of each fuel type). The fuel in the remaining 8 vehicles was not additive treated. The additive package now described as MIL-S-53021 (stabilizer additive, diesel fuel) consisted of a biocide (BIOBOR-JF) at a concentration of 270 parts per million (ppm) and a polyfunctional additive (FOA-15), which acts as a dispersant, an antioxidant, a metal deactivator, and a corrosion inhibitor, at a concentration of 25 pounds/1000 barrels. The laboratory data for the base fuels indicated that the DF-2 used for testing was neither clean nor stable at the time the test was initiated. It was noted that this DF-2 could possibly show less favorable characteristics than a fuel that at least meets specification limits. Although the additive package has proved to be effective in reducing corrosion, fuel degradation, and microbiological growth with proper use, the additive package will not rectify an already existing problem with unusable fuel; they are preventive-type additives only. Consequently, the additive-treated DF-2 showed approximately the same degradation as the neat DF-2 due to the unstable nature of the diesel fuel. The JP-5 exhibited better stability characteristics in both the neat and the additive-treated fuel samples.

21. No author, "Engine-Lubricant Compatibility Test 240-Hour, Tracked-Vehicle Cycle Using DD 6V-53T Diesel Engine" (Fuel JP-8), Test Report for U.S. Army Belvoir Research and Development Center by AFLRL, 14 March 1984.

A 240-hour test on the DD 6V-53T engine was conducted using a reference lubricant REO-203 and JP-8 aircraft turbine fuel as the test fuel. After the 240 hours of operation, moderately high levels of liner scuffing and ring face demerits were observed. Due to the low viscosity of JP-8 compared to DF-2, pumping losses in the injectors were high. Because of this and the lower volumetric heat content of JP-8, proportionately less power was produced. This is reflected in the lower fuel consumption and lower power output of the engine when operated on JP-8. One fuel injector stuck in the open position at 5.5 test hours. The cause for this was not immediately determined, and the test was completed with no subsequent failures. No unusual piston deposits were noted. Injector tips were normal on the exterior and showed about the same deposits as a previous test on high-sulfur fuel. No unusual valve deposits or distress was noted. Bearings were normal throughout the engine. One injector showed no pop-off pressure and poor atomization after the test;

however, after cleaning in an ultrasonic cleaner, normal pop-off pressure and atomization were observed. No significant differences in fuel delivery were noted after the test. Air flow tests of the injector nozzles indicated that some hole plugging had occurred. Cleaning the used tips improved their air flow characteristics but not up to the new tips level.

Data comparing wear and deposits for four 240-hour 6V-53T engine tests, using the same reference lubricant and three different fuels are shown below. Tests 33 and 37 used Cat 1-H/1-G reference DF-2 fuel, test 38 used a high-sulfur (1 wt%) diesel fuel, and test 39 used the JP-8 fuel.

SUMMARY OF 6V-53T TEST RESULTS*

Test No.	33	37	38	39
Lubricant	REO-203	REO-203	REO-203	REO-203
Fuel	Cat 1-H/1-G	Cat 1-H/1-G	High Sulf	JP-8
Test Hours	240	240	158	240
Piston WTD	230	237	211	245
2&3 Ring Face Demerits	17.8	14.8	36.3	16.3
Liner Scuffing, %	28.4	18.9	63.1	32.8
Valve Burning	0	0	2	0
Fire Ring End Gap Change, in	0.007	0.004	0.013	0.002
#2 Ring End Gap Change, in	0.003	0.003	0.002	0.001
#3 Ring End Gap Change, in	0.002	0.002	0.001	0.001

* All numbers represent the average of six parts at test completion.

22. Project Manager for Mobile Electric Power (Col M.S. Higgins), Letter, AMCPM-MEP-T, 10 August 1984, to Commanding General Marine Corps Logistic Base. Subject: Use of JP-5 as an Alternate Fuel for the DoD MEP Diesel Engine Driven (DED) Generator Sets.

This provides user approval <u>from</u> the Project Manager for Mobile Electric Power to use JP-5 in DoD DED Generator Sets.

23. LePera, M.E., STRBE-VF, Letter, 14 November 1984, to S.J. Lestz, AFLRL.

Because of the nonavailability of diesel fuel (VV-F-800) in the Panama area, the U.S. Army operating out of Fort Clayton has been using MIL-T-5624 Grade JP-5 from approximately 1980 to 1983 in lieu of MIL-F-16884. Because of a recent agreement during late FY83 and FY84, the Navy Petroleum Office has agreed to monitor the sulfur content of MIL-F-16884 procurement going into the Panama area to enable Army equipment to utilize this in lieu of JP-5. The point to be made is that all Army equipment operating in the Panama area has utilized JP-5 during 1980 through 1983 with again no reported problems.

VIII. ABBREVIATIONS USED

AFLRL	Army Fuels and Lubricants Research Laboratory
AR	Army Regulation
AVDS	Air-Cooled, Vee-Configured, Direct Injection, Supercharged
CAT	Caterpillar
CAV	Charles Andrew Vanderbilt (from Lucas CAV)
CONUS	Continental United States
CUE	Cooperative Universal Engine
DDA	Detroit Diesel Allison Division
DTIC	Defense Technical Information Center
FO	Fuel Oil
GMC	General Motors Corporation
IHC	International Harvester Corporation
NCEL	Navy Civil Engineering Laboratory
OCONUS	Outside Continental United States
REO	Reference Engine Oil
THC	Total Hydrocarbons
USMC	US Marine Corps
WTD	Weighed Total Demerit

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