12

DEVELOPMENT OF ARMY HIGH-ENERGY FUEL FOR DIESEL/TURBINE-POWERED SURFACE EQUIPMENT

INTERIM REPORT

AFLRL No. 120

by
W. W. Wimer
and
E. C. Owens
U.S. Army Fuels and Lubricants Research Laboratory
Southwest Research Institute
San Antonio, Texas

for

U.S. Army Mobility Equipment
Research and Development Command
Energy and Water Resources Laboratory
Fort Belvoir, Virginia

Under

Contract Nos. DAAK70-78-C-0001
and DAAK70-80-C-0001

October 1979

DISCLAIMERS

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Trade names cited in this report do not constitute an official endorsement or approval of the use of such commercial hardware, software, or products.

DDC AVAILABILITY NOTICE

Qualified requestors may obtain copies of this report from Defense Documentation Center, Cameron Station, Alexandria, Virginia 22.14.

DISPOSITION INSTRUCTIONS

Destroy this report when no longer needed. Do not return it to the originator.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS
BEFORE COMPLETING FORM

1. REPORT NUMBER

2. GOVT ACCESSION NO.
AD-A094 328

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (*and Subtitle*)
(6) Development of Army High-Energy Fuel For Diesel/Turbine Powered Surface Equipment.

5. ~~TYPE OF REPORT & PERIOD COVERED~~
(9) Interim/Technical Rept.
Oct 1977-Oct 1979,

6. ~~PERFORMING ORG. REPORT NUMBER~~
AFLRL No. 120

7. AUTHOR(s)
(10) William W./Wimer
Edwin C./Owens

(11) Oct 79

8. ~~CONTRACT OR GRANT NUMBER(s)~~
(15) DAAK70-78-C-0001, DAAK70-80-C-0001

9. PERFORMING ORGANIZATION NAME AND ADDRESS
U.S. Army Fuels & Lubricants Research Laboratory
Southwest Research Institute
San Antonio, Texas 78284

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
(16) 1L762733AH20EH;
WL-805

(17) EH

11. CONTROLLING OFFICE NAME AND ADDRESS
U.S. Army Mobility Equipment Research and Development Command, Energy and Water Resources Laboratory
Fort Belvoir, VA 22060

12. REPORT DATE
October 1979

13. NUMBER OF PAGES
(12) 116

14. MONITORING AGENCY NAME & ADDRESS(*if different from Controlling Office*)
(14) AFLRL-120

15. SECURITY CLASS. (*of this report*)
Unclassified

15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (*of this Report*)

Approved for public release; distribution unlimited

DTIC
ELECTE
NOV 3 1980
S

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*)

Ballistic Tests
Carbonaceous Fuels
Carbon Slurries
Dispersants
Exo-Tetrahydrodicyclopentadiene
High Energy Fuels
High Explosive Incendiary Tests
Microemulsions
Synthetic Liquid Hydrocarbon Fuels
Volumetric Heat of Combustion

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

This is a status report on the U.S. Army's ongoing program on high energy fuels for diesel/turbine powered surface equipment. The Army is interested in those fuels that have a high energy content per unit volume and therefore result in increased payload capabilities and/or extended operational range of their vehicles.

Two types of high energy fuels are discussed in this report. The first being the synthetic liquid hydrocarbon fuels of the polycondensed cycloparaffinic

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified 77331 10

SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*) type; the second being the powdered solids/hydrocarbon slurries.

Background information is provided on several of the synthethic liquid hydrocarbon fuels; the Air Force's and the Navy's interests in these fuels are discussed; and a brief review of their chemistry and properties are included. Examples of these fuels are JP-9, JP-10 (exo-tetrahydrodicyclopentadiene), and RJ-5.

Background material is also provided on various carbonaceous materials considered for use in slurry preparation. The selection of the carbons to be used along with their properties, are described. Also discussed are the mixing devices used in the preparation; the various dispersants considered; the stability of the various slurries; and the methods and techniques for measuring their settling rates and determining their stability.

The high-explosive incendiary tracer tests that were run on some of the high energy fuel candidates to evaluate fluid fire vulnerability are described and discussed in detail.

The engine tests that were run on the leading candidate fuels are described and discussed in detail.

In addition to the regular references in this report, a list of pertinent related references are included.

FOREWORD

The work reported herein was conducted at the U.S. Army Fuels and Lubricants Research Laboratory (AFLRL), Southwest Research Institute, San Antonio, Texas, under Contracts DAAK70-78-C-0001 and DAAK70-80-C-0001. The work was funded by the U.S. Army Mobility Equipment Research and Development Command (MERADCOM), Ft. Belvoir, VA. Contracting Officer's representative was Mr. F.W. Schaekel, Fuels and Lubricants Division, Energy and Water Resources Laboratory (DRDME-GL).

ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance provided by the staff of their organization, especially Messrs. S.R. Segura and S. Mathis for conducting the laboratory experiments; Mr. S.J. Lestz, Dr. T.W. Ryan, and Dr. W.D. Weatherford, Jr. for their many consultations; Dr. G.E. Fodor for the preparation of the aqueous JP-10 microemulsion; and Dr. D.W. Naegeli, Mr. J.W. Pryor, and Ms. E.J. Robinett for their editorial assistance. Special acknowledgment is given to Mr. M.E. LePera and Dr. M.J. Kolobielski of MERADCOM'S Fuel & Lubricants Division (DRDME-GL) and Mr. R.D. Quillian, Jr. of the U.S. Army Fuels and Lubricants Research Laboratory, Southwest Research Institute, for their helpful suggestions and encouragement.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

LIST OF TABLES

LIST OF TABLES (CONT'D)

LIST OF ILLUSTRATIONS

I. INTRODUCTION

The Army has long recognized the need and desirability of developing a fuel that could increase the payload capabilities and extend the operational range of both its tactical and combat vehicles. The development of such a fuel or fuels would need to be conventional enough that they could be used in present and future Army vehicles, yet novel enough that they contain the high-energy (per unit volume) requirement necessary to fulfill the need. The Army Scientific Advisory Panel, in its Summer Study 76,(1)* recommended a research program on high-energy fuels.

II. BACKGROUND

The Air Force and Navy are also interested in high-energy (high-density) fuel development. The Air Force at its Aero Propulsion Laboratory at Wright-Patterson Air Force Base has been actively evaluating hydrocarbon blends that are potential performance improvers for its air-breathing type missile systems. This class of fuel would be exceptionally good for use in the strategic cruise missile(2) whose maximum effectiveness depends on maximum range, minimum time to reach the target, and minimum weight. Since small missiles, such as the cruise, are volume limited, it is imperative that the fuel contains a high-energy content per unit volume. In general, an increase in the volumetric energy content of a fuel will result in the range of the missile being increased by a like percentage. Although there are several ways available to increase the energy content of a given quantity of fuel, the most applicable for missile use is to increase the fuel's density.

Because the Air Force's aircraft are often operating under extremely cold temperatures, both on the ground and at high altitudes, they require a fuel of low viscosity and high volatility. This volatility requirement results in the fuel having a low flashpoint. JP-4 has thus far satisfied their needs.

---

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

For example, the Air Force's Air Launched Cruise Missile (ALCM) is designed to be carried under the wing of the B-52 aircraft and requires a fuel that can be operational at low temperatures. On the other hand, the Navy must carry its fuel aboard its ships and has been using JP-5. This fuel meets the Navy's minimum flash point requirement of 60°C (140°F) (MIL-T-5624). It follows that the fuel for the Navy's Sea Launched Cruise Missiles (SLCM) must meet this safety requirement of a minimum flash point of 60°C for all fuels carried on board ship. Research on high-density, high-energy liquid hydrocarbon fuels by the Air Force and Navy continues. This work is being closely monitored by the U.S. Army. A few of these fuels that may be of interest to the Army are described later.

III. APPROACH

In the Army's program, a selective list was prepared of viable candidate fuels that could possibly be developed into a fuel that could increase the payload capabilities and extend the operating range of tactical and combat diesel/turbine ground vehicles. In general, the candidate fuels fell into two classes: (a) the synthetic liquid hydrocarbon fuels of the polycondensed cycloparaffinic type; and (b) powdered solids/hydrocarbon slurries. The dispersed solid could be either metallic (aluminum, boron, beryllium, etc.) or nonmetallic (carbon).

From the above mentioned list, several prime candidates were selected for further development and testing. The selection was made on certain imposed criteria and judgment and certain laboratory tests. The viable candidates were judged on their probability of success in such cases as volumetric energy content, ease of fuel preparation, fuel delivery, engine performance, combustion effectiveness, toxicity, cost, etc. Consideration was also given to problem areas and the difficulties that might be incurred in solving them.

Other fuel candidates that may emerge and have the potential of becoming prime candidates will be evaluated during the course of this program.

IV. TECHNICAL PROGRAM

A. SYNTHETIC LIQUID HYDROCARBON FUELS--DESCRIPTION

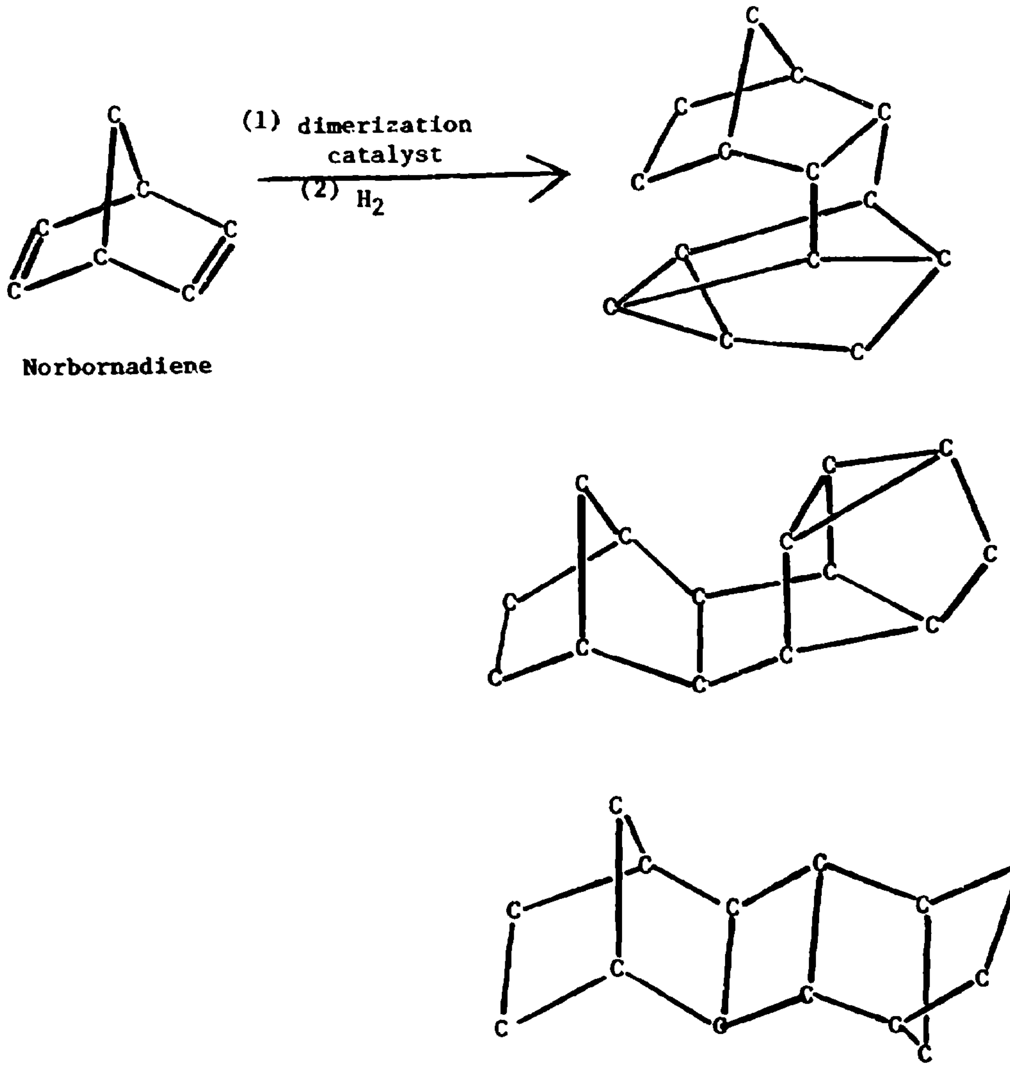
1. Shelldyne-H (RJ-5)

One of the first high-density fuels studied was of a polycondensed cycloparaffic type called Shelldyne-H. This liquid hydrocarbon fuel is formed by the catalytic dimerization of norbornadiene followed by hydrogenation to produce several stereospecific isomers (See Figure 1). First produced by Shell Development Company in the late 1950s, it has since been made by Sun Ventures (Suntech) and is currently being produced, under license, by Ashland Chemical Company.

The typical concentration range for the Shelldyne-H product(3) is 55-75 wt% of isomer I, 16-22 wt% of isomer II, and 9-20 wt% of isomer III. There is evidence for a fourth isomer, but if present, it would probably be less than one percent (3,4). The physical and chemical analyses of a sample of Shelldyne-H were reported in Table I of Reference 3, and that table is shown here as Table 1. The product now called RJ-5, and the isomer distribution has changed somewhat from the original product, especially in the Suntech product.

TABLE 1. SHELLDYNE-H CHEMICAL AND PHYSICAL ANALYSIS
(Lot No. 11410-103)

Property	Value
Density 15.6°C(60°F)	
grams/cc	1.082
pounds/gal.	9.031
Viscosity, cP at	
-53.9°C(-65°F)	18,761
-40.0°C(-40°F)	2,336
-31.7°C(-25°F)	911
Net Heat of Combustion,	
Btu/lb	17,755
Btu/gal.	160,347
Flash Point, °C(°F)	111.1 (232)
Molecular Formula	$C_{14}H_{18}$
Freezing Point,°C(°F)	-53.9(-65)



Norbornadiene

(I) Hexacyclic endo-endo dihydrodinorbornadiene

(II) Hexacyclic exo-endc dihydrodinorbornadiene

(III) Pentacyclic exo-trans-exo tetrahydrodinorbornadiene

FIGURE 1. PREPARATION AND COMPOSITION OF SHELLDYNE-H (RJ-5)

Table 1 shows that the viscosity of Shelldyne-H is relatively high, especially at the low temperatures that might be experienced in its use. However, it can for practical applications be blended with other materials, especially since it has a high volumetric heat of combustion and would increase the volumetric enthalpy of almost all resulting blends.

2. JP-10 (Exo-Tetrahydrodicyclopentadiene)

Dicyclopentadiene, the starting material for the preparation of JP-10 can be obtained from the aromatic oils that are produced when certain hydrocarbons are cracked to olefins.(5) Exo-tetrahydrodicyclopentadiene (JP-10) can be prepared by hydrogenating dicyclopentadiene to yield endo-tetrahydrodicyclopentadiene. In the presence of a special catalyst, this material can be isomerized to yield almost exclusively the exo-isomer (Figure 2 and Table 2).

3. JP-9

The Air Force has several critical specifications for the fuel used in the ALCM.(6) The high altitude encountered in this missile's flight requires a freezing point below -53.9°C (-65°F), and the viscosity must be no more than 80 cSt at -53.9°C to ensure its flow and pumpability. The fuel must be storable for at least 5 years and still perform as expected, and it cannot have any aromatic components. Lastly, a high volatility is required, since missile may be launched at high altitudes, and ignition would otherwise be difficult.

JP-10 would be acceptable as the fuel for these cruise missiles except for the high volatility requirement. The addition of methylcyclohexane to JP-10 in an amount sufficient to provide the required volatility reduces the overall fuel heating value significantly. To offset this negative effect on the volumetric heating value, a certain quantity of RJ-5 is added, so that the resulting blend meets the fuel requirement for the ALCM. This three-component blend of JP-10 (65-70 wt%), RJ-5 (20-25 wt%), and methylcyclohexane (10-12 wt%) is now called JP-9. The chemical and physical requirements, along with the test methods [MIL-P-87107A (USAF)], for both JP-9 and JP-10 are included in Appendix A.

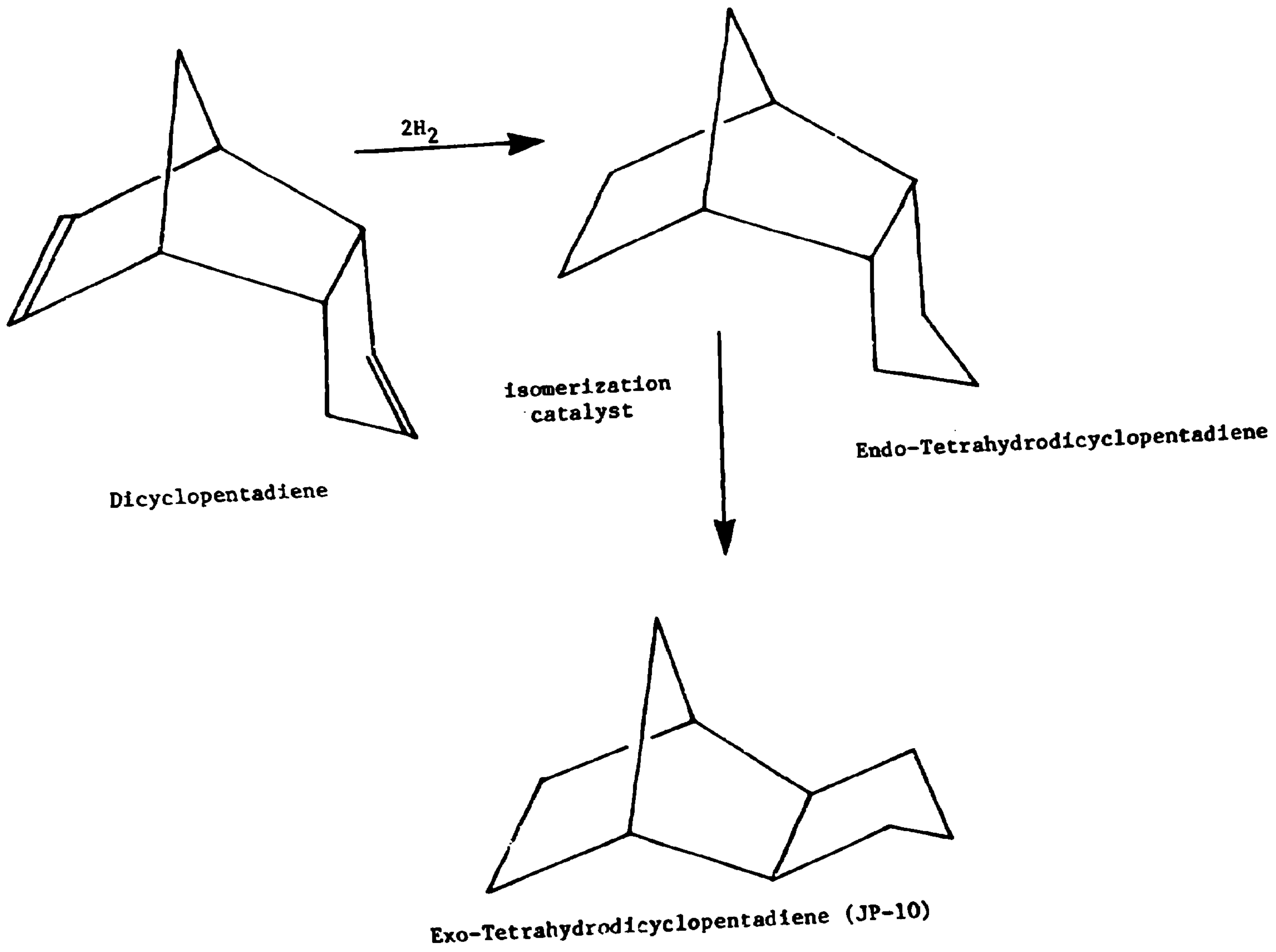
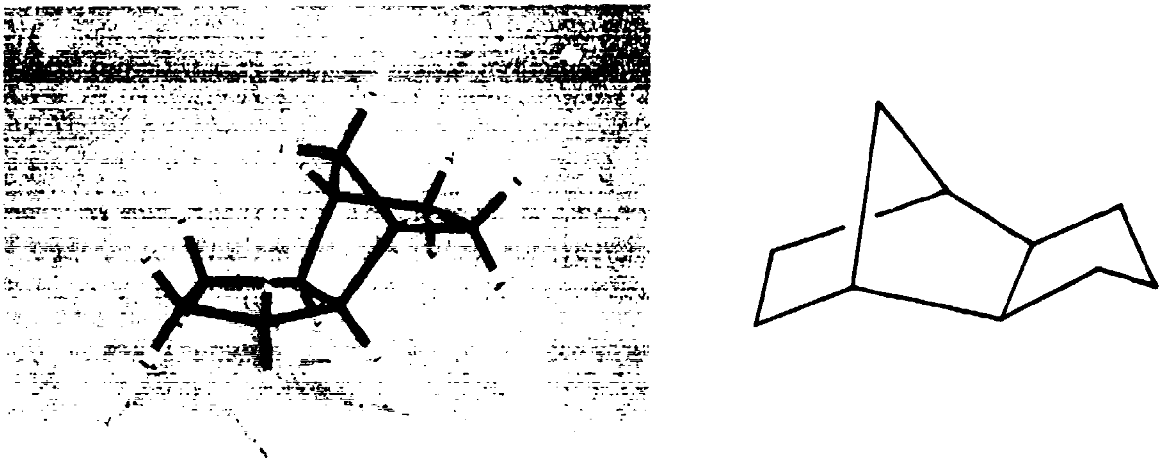


FIGURE 2. PREPARATION OF JP-10

TABLE 2. TYPICAL PROPERTIES OF JP-10



Exo-tetrahydrodicyclopentadiene ($C_{10}H_{16}$)

[JP-10]

Molecular Weight	136.2
C:H Ratio	0.62
Specific Gravity at 15.6°C (60°F)	0.94
Heating Value, Btu/gal.	142,000
Viscosity, cSt at -40°C (-40°F)	19
Freezing Point, °C (°F)	-78.9 (-110)
Flash Point, °C (°F)	57.2 (135)

4. RJ-4

Another high-density liquid hydrocarbon fuel of this type is RJ-4. This fuel was developed specifically for the Navy's cruise missile, Talos, as a replacement for JP-5. It can be synthetized from di-(methylcyclopentadiene) by hydrogenation to yield a mixture of the isomers of endo- and exo-tetrahydrodimethylcyclopentadiene.(6) Because of its availability, relatively low cost, medium heating value (140,000 Btu/gal.), and medium viscosity (60 cSt at -40°C), and because it had been used successfully in the Talos missile for over 10 years, RJ-4 was recommended as the fuel for the General Ordnance Ramjet Engine (GORJE) in 1973.(7)

5. RJ-4-I

Related to RJ-4 is RJ-4-I (RJ-4 special), which contains a larger amount of the exo-isomer of tetrahydrodimethyldicyclopentadiene. RJ-4-I has a much lower viscosity (28 cSt at -40°C) and freezing point (-51°C) than the RJ-4.(7,8) Some of the more important properties of RJ-4 and RJ-4-I are compared with Referee Grade Diesel Fuel [MIL-F-46162A (MR)] in Table 3.

6. JP-10 Microemulsions

In mid-September 1978, three samples of translucent microemulsion type fuels were prepared, consisting of 84 percent JP-10, 10 percent deionized water, and 6 percent emulsifying agent. A similar microemulsion of DF-2 and water is currently under development by the Army and is showing great promise as a fire-resistant fuel. Thus, the JP-10/H_2O microemulsion fuels were prepared to see if any fire-resistant properties might be imparted to this fuel. The results of the High-Explosive Incendiary Tracer Tests, Impact Dispersion and Mist Flash Back Tests are described in Section IV-C. In the JP-10/H_2O microemulsions, three different emulsifying agents were used, all similar in type, but with varying acid numbers. The agents, designated as EA-8, EA-12, and EA-37, had acid numbers of approximately 14, 18.5, and >20, respectively. All three were visually stable (no settling) for 1 year. After 15 months, sedimentation began to occur with the microemulsions prepared with EA-12 and EA-37. To date (after 15 months), the microemulsion prepared with EA-8 is still stable, as shown in Figure 3.

7. Other Fuels

High-energy fuels, such as RJ-5, RJ-4, and JP-10 can be blended with each other, or with other components, in order to achieve the properties for a particular application. Research in this area continues. A good example

TABLE 3. COMPARISON OF THE PROPERTIES OF RJ-4 AND RJ-4-I (SPECIAL) AND REFEREE DF-2

Property	RJ-4(a)	RJ-4-I(b)	Referee DF-2(c)
Net Heat of Combustion	41.40 Mj/kg (min) (d) 17,800 Btu/lb (min)(d) 139,500 Btu/gal. (min)(d)	41.17 Mj/kg (min) 17,700 Btu/lb (min) 139,500 Btu/gal. (min)	42.40 Mj/kg(e) 18,230 Btu/lb(e) 129,860 Btu/gal.(e)
Viscosity	30 cSt at -1°C (max)(f) 4.20 cSt at 38°C (max)(f)	35 cSt at -40°C (max) 12 cSt at -18°C (max) 9 cSt at 20°C (max)	7.33 cSt at -10°C(g) 5.24 cSt at 0°C(g) 3.12 cSt at 20°C(g) 2.11 cSt at 40°C(g)
Specific Gravity	0.92 to 0.94 (max)(h)	0.91 to 0.93	0.84 to 0.86
API Gravity (15.6°C)	22.3 (max); 19.0 (min)(h)		36.1(g)
Flash Point	60°C (min); 79°C (max)(i)	60°C (min); 79°C (max)	56°C (min)
Pour Point	-40°C(j)	-51°C [(max) freezing point]	-18°C (max)

(a) MIL-F-82522A (OS) specifications
(b) Typical Properties Reference 8, Section VI
(c) MIL-F 46162A (MR), Grade II
(d) ASTM D 2382
(e) Typical values; "report" is only requirement
(f) ASTM D 2382
(g) Typical values
(h) ASTM D 287
(i) ASTM D 93
(j) ASTM D 97

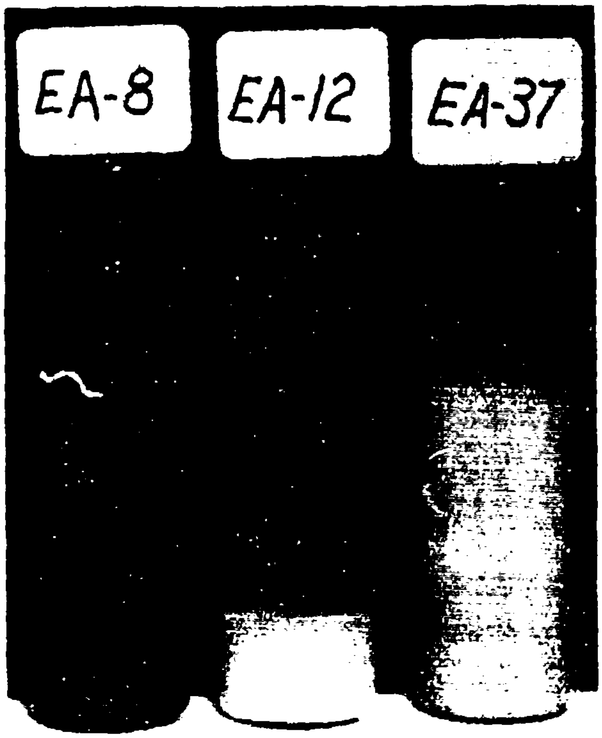


FIGURE 3. VISUAL COMPARISON OF JP-10/WATER MICROEMULSIONS PREPARED WITH DIFFERENT EMULSIFYING AGENTS. EA-8, EA-12, AND EA-37.

is a blend of 80 percent RJ-5 and 20 percent iso-butylbenzene. This blended fuel is being used in the Advanced Long Range Air to Air Missile (ALRAAM) and is known as SI-80.(9) Another example, mentioned earlier, is JP-9.

8. Summary

As previously stated, the volumetric heat content of the fuel can be raised by increasing the fuel's density. It was found that the bridged alicyclic structures, like those found in RJ-5 and JP-10, increase both the density and the volumetric heat content. The comparison of the typical properties and chemical composition of liquid hydrocarbon high-energy fuels (RJ-5, JP-9, JP-10, and RJ-4) with common jet fuels (JP-4, JP-5) was made in Reference

6. Tables 1 and 2 from that reference are combined and presented as Table 4, in which Army DF-2 diesel fuel is also shown. Although JP-4 and JP-5 have average molecular weights similar to JP-9 and JP-10 (as seen in Table 4), the higher carbon-to-hydrogen ratios and higher densities in the latter give a substantial increase in the volumetric heat content (13 to 20 percent).(6) In general, fuels with aromatic and naphthenic ring structures have low volumetric heating values, even though their C:H ratio might be very high.

Another method to increase the energy content of the fuel is to add fairly dense solids with higher volumetric heating values. Powdered metal/hydrocarbon slurry has been investigated in the past, mainly in attempting to find promising fuel with a high gravimetric heat of combustion. Slurries containing the elements beryllium, boron, carbon, magnesium, aluminum, silicon, phosphorus, titanium, yttrium, zirconium, cerium, and tungsten have all been investigated.

The upper limit for liquid hydrocarbon fuels is about 170,000 Btu/gal. (Figure 4), although most of the new multicyclic, bridged-ring structures are in the range of 140,000 to 160,000 Btu/gal.

B. CARBON SLURRIES--PREPARATION AND DESCRIPTION

1. Carbon/Synthetic Liquid Hydrocarbon Slurries

The probability of finding or synthesizing a missile fuel with higher volumetric heat content and acceptable properties (i.e., viscosity, pour point, etc.) than those presently used is low. The renewed interest in slurried fuels can be attributed to the recognition of this fact. The Air Force has funded a slurried fuel program because of the high potential benefits of utilizing high-energy fuels in volume-limited vehicles. The Air Force has found that the targeted value of 180,000 Btu/gal. (net) could be achieved with 65 wt% carbon black and 35 wt% JP-10 (~50/50 by volume).(10)

TABLE 4. COMPARISON OF THE COMPOSITION AND TYPICAL PROPERTIES OF JP-4, JP-5, and DF-2 WITH VARIOUS SYNTHETIC HIGH-ENERGY FUELS

	JP-4	JP-5	JP-10	JP-9	RJ-4	RJ-5	DF-2
Avg Chemical Formula	$C_{9.5}H_{18.9}$	$C_{10}H_{16}$	$C_{10}H_{16}$	$C_{10.6}H_{16.2}$	$C_{12}H_{20}$	$C_{14}H_{18}$	$C_{13.3}H_{25.1}$
Carbon:Hydrogen Ratio	0.50	0.53	0.62	0.65	0.60	0.78	0.53
Specific Gravity at 15.6°C	0.77	0.83	0.94	0.94	0.94	1.08	0.844
Approximate Heating Value, Btu/gal. (Net)	118,000	125,000	142,000	142,000	140,000	160,000	130,000
Viscosity, cSt at -40°C	4.5	17	19	24	60	2000	7.3(-10°C)
Freezing Point, °C	<-58	<-46	<-79	<-54	<-40	>-18	-18(Pour Pt)
Flash Point, °C	-29	66	57	24	66	110	56

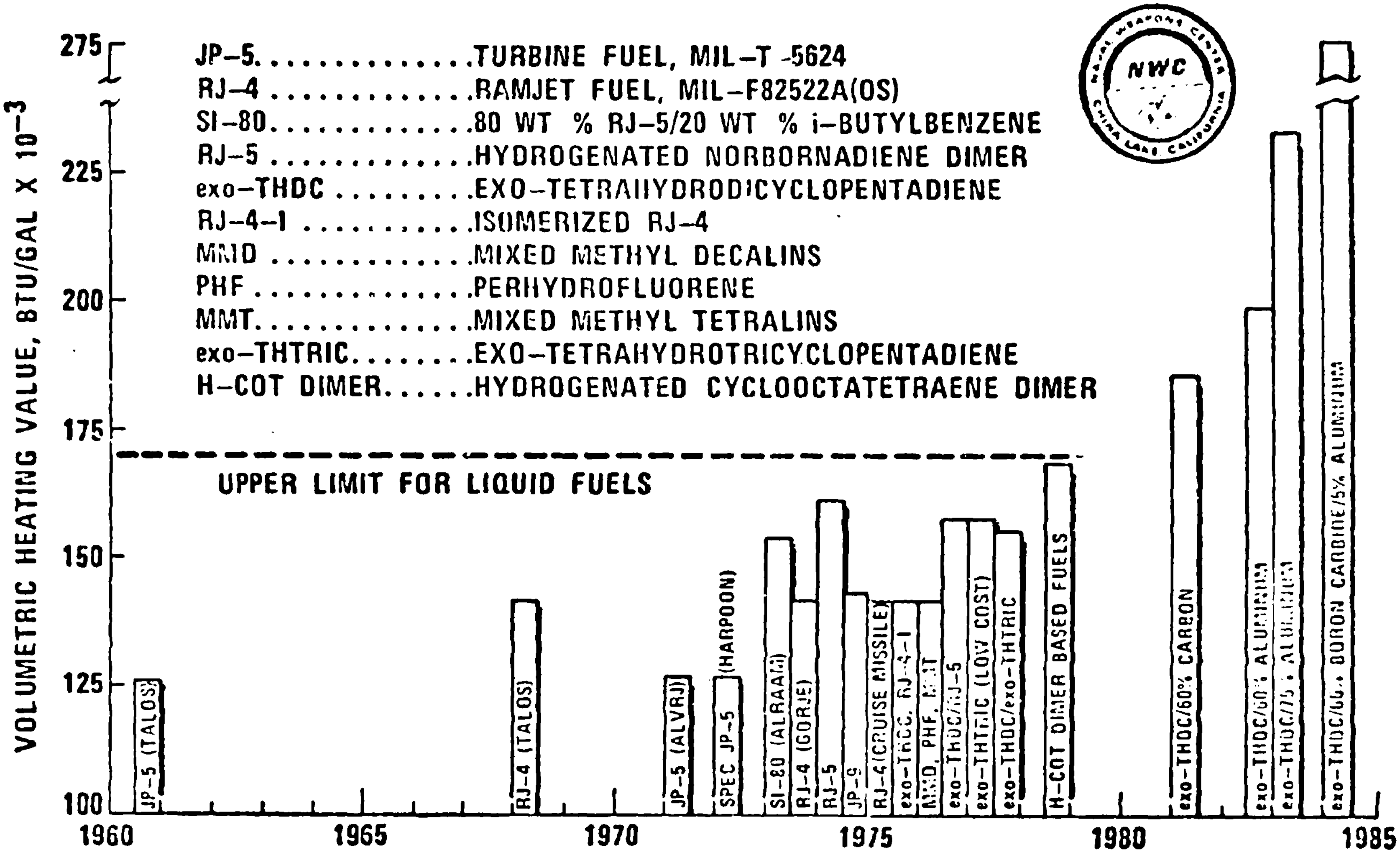


FIGURE 4. THE NAVY'S LIQUID HYDROCARBON FUELS

Figure 5 shows the net effect of carbon black dispersion on the net volumetric heat of combustion in RJ-5 and JP-10, and is reproduced here from Reference 10.

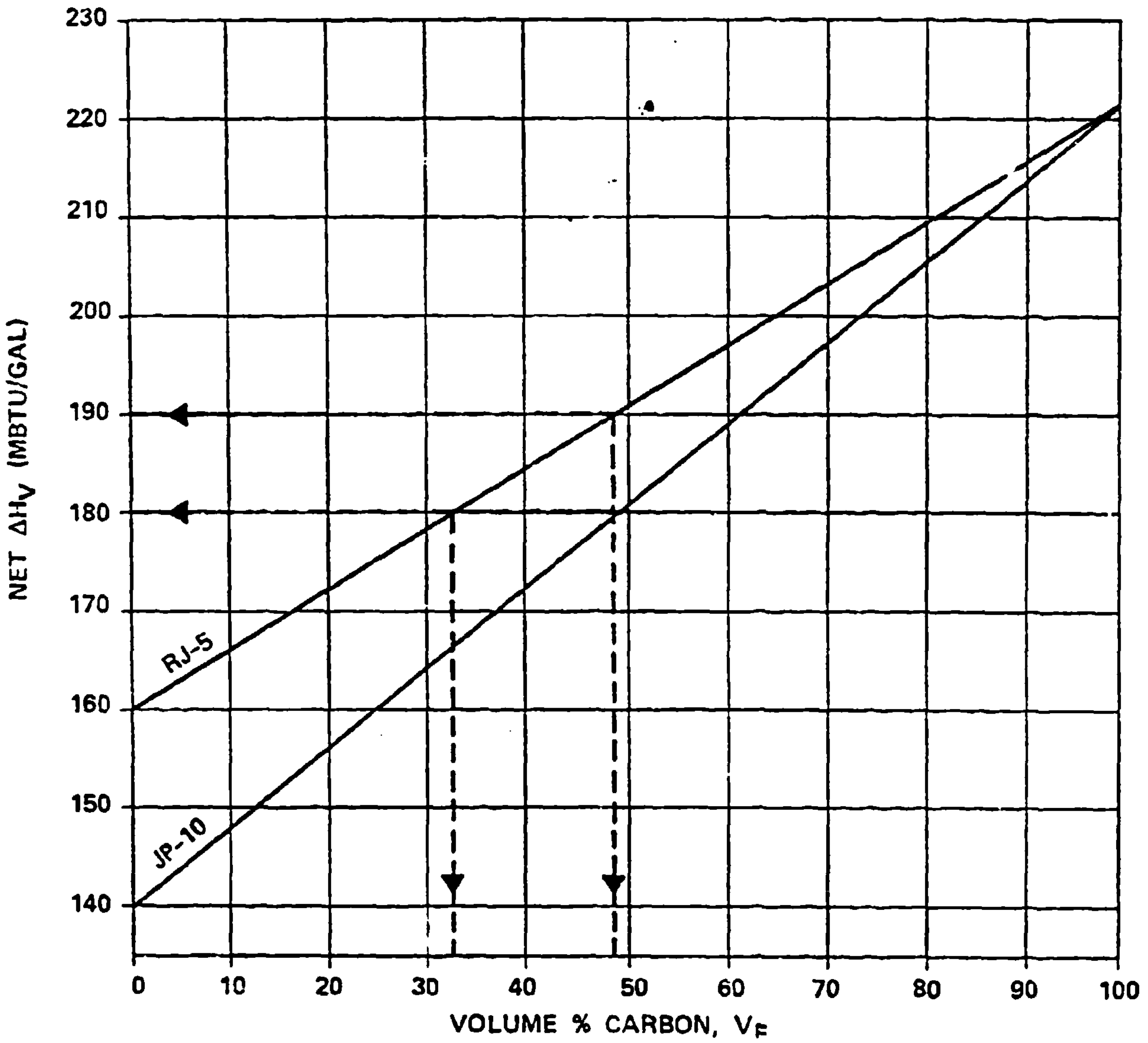


FIGURE 5. CARBON SLURRY FUELS NET VOLUMETRIC HEAT OF COMBUSTION

2. Carbon/Diesel Fuel Slurries

a. Carbonaceous Materials (Sources and Background)

At the Army Fuels and Lubricants Research Laboratory (AFLRL), carbon slurries have been prepared mainly in diesel fuel. Table 5 lists various carbonaceous materials that were considered for use in the preparation of carbon slurries. Of the petroleum-derived channel blacks, Superspectra and Superba, Superba is no longer manufactured. Raven 410, 1000, and 1170 are furnace blacks.

A brief description of some of the carbonaceous material listed in Table 5 is included in this section. The ash and heating values were determined at AFLRL using ASTM D 482-79 and ASTM D 240-76.

Carbon samples from a variety of sources were obtained. One source of carbon is petroleum. Its production is usually based on the heavy residual oils from the solvent extraction process and/or vacuum distillation step.(11) Several types of carbon blacks are possible, depending on the process by which they are made.

Furnace black is the result of incomplete combustion, and its formation takes place under controlled turbulence conditions. The thermal black is produced from a cyclic process, in the absence of oxygen, where hot checker bricks are used to thermally decompose the natural gas from which it is being made. The carbon particles are large.

The channel black, so called because of the steel channels that chill the gas flame and from which it is then collected, yields the smallest particles and has the best tinting power.(12) It is an incomplete combustion process and the black is exposed to oxidizing temperatures after its formation.

Lampblack (soot), formed from the incomplete combustion of carbonaceous materials, is inferior in its tinting strength and coloring qualities when compared to the other blacks.(13) This type of carbon sample was not examined since it may vary in its purity; it was desirable to study the more homogeneous samples.

TABLE 5. CARBONACEOUS MATERIALS
(AFLRL Experimental Values)

Carbon Origin	Trade Name*	Ash, % **	Btu/lb***	mj/Kg	Process
Petroleum	RAVEN 410	0.69	14,415	33.53	Furnace Black
Petroleum	RAVEN 1000	0.86	13,360	31.63	Furnace Black
Petroleum	RAVEN 1170	0.47	13,875	32.27	Furnace Black
Petroleum	Super Spectra	0.36	13,665	31.78	Channel Black
Petroleum	Superba	0.06	11,600	26.98	Channel Black
Wood Fines	MCB	2.84	13,345	31.04	Wood Charcoal, Fine
Wood	MCB Charcoal	4.43	13,170	28.30	Wood Charcoal, Lump
Wood	DARCO KB	3.16	10,330	24.02	Wood Charcoal
Lignite	DARCO S-51	19.00	10,540	24.51	Lignite Charcoal
Lignite	DARCO G-60	1.40	12,990	30.22	Lignite Charcoal
Coke	Asbury	0.74	13,935	32.41	Coke Flour
Graphite	Asbury	1.72	13,770	32.03	Calcined Petroleum Coke with Coal Tar Pitch Binder
Anthracite Coal	Asbury	18.53	11,630	27.05	Anthracite Coal
Coconut Shells	Fisher	4.22	12,540	29.17	Coconut Charcoal
Sugar	Fisher	0.06	6,285	14.62	Sugar Charcoal

---

* The addresses of the manufacturers/distributors of these materials are in Appendix B.
** Method ASTM D 482-79.
*** Method ASTM D 240-76.

Wood charcoal is formed by the destructive distillation of wood.

Lignite, often called "brown coal," is a low-grade, brownish-black coal closely related to peat. When mixed, the coal contains 20 to 45 percent moisture and has a heating value between 5500-8300 Btu/lb. The principal lignite deposits in the United States are in the Dakotas, Montana, Texas, Louisiana, Mississippi, and Arkansas.(14)

Graphite, abundant naturally in deposits of varying purity in many places in the world (Madagascar, Ceylon, Mexico, etc.), can also be produced synthetically by heating petroleum coke to 3000°C in an electric resistance furnace. It is characterized by its crystalline allotropic form of carbon in a hexagonal arrangement of carbon atoms.(14)

From the list in Table 5, AFLRL selected a furnace black (Raven 1170) and a wood charcoal (fine) for further study of fuel slurries. The selection was made after a careful study of the properties, availability, and cost of the carbons, a review of the literature, and consultation with technical personnel from several of the carbon black manufacturers.

b. Preparation, Material and Technique

(1) Mixing (and grinding)

(a) Types of Mixing Devices

Essentially all slurry fuels were prepared using diesel fuel as the base fuel. Four types of mixing devices were tested during the program. Described below, these devices included a magnetic stirrer, blender, homogenizer, and an attritor.

[1] Magnetic Stirrer and Bar

In the early phase of the program, the magnetic stirrer and bar was used. This device was adequate for some of the small preparations and screening experiments. The magnetic stirrer was Fisher Scientific's Round Flexa-Mix, which operates at speeds from near standstill (at "low" setting) to maximum speed of 1650 rpm under maximum load. It is capable of 2700 rpm without load at the "high" setting.

[2] Blender

A Waring blender with a 940 milliliter mixing vessel and speeds exceeding 20,000 rpm was tried. Its use was limited because of small working capacity (<500 milliliters) and numerous problems with air entrainment.

[3] Homogenizer

Also utilized was the Gifford Wood Homogenizer-Mixer manufactured by Gifford Wood, Inc., Hudson, New York, which employs a turbine-stator mechanism to create stable emulsions and suspensions. As the turbine rotates at high speeds, a pressure differential is created between the bottom of the mixing head and the material charged. This differential causes the unrefined product to be drawn continuously from the bottom and forced through very restricted passages existing between the stator and turbine. The product is broken down to smaller particle sizes by the intense forces of impact and hydraulic shear. This process is followed by the discharge of the product in an upward direction against a baffle adjusted to deflect the rising current toward the vessel's side; the product then falls back into the mixing area, where the cycle is repeated.

The homogenizer-mixer could be run at speeds greater than 12,000 rpm. However, several problems were encountered with the homogenizer. The vigorous mixing action caused the temperature of the slurry to rise, and corrective measures had to be taken (ice bath around slurry, or off-time to permit cooling) during its operation. Air entrainment was also encountered.

[4] Attritor

The attritor Model No. 1-S manufactured by Union Process, Inc., Akron, Ohio was the most versatile device for slurry preparation. The Attritor has a stationary grinding tank [9.5 liters (2.5 gal.) capacity] that is filled to a workable level with 0.48 cm (3/16 in.) carbon balls as a grinding medium. An agitator, capable of speeds to 550 rpm, keeps the whole charge in a continuously agitated condition that results in intensive interaction. A jacket, which surrounds the stationary grinding tank to provide temperature control, can be heated or cooled as desired. The attritor is equipped with facilities for discharging by dumping, but it also has a bottom discharge ball valve that is more convenient and more commonly used. The average size of the batch preparation is approximately four liters.

(b) Experimental

A series of experiments were conducted to compare these mixing devices on the basis of their effectiveness in the preparation of stable slurries. Settling data were collected and used as the criteria for determining stability, and hence effectiveness, of the mixing apparatus. All the slurries were of the same composition (20 percent carbon black, 1 percent lecithin in DF-2); all were mixed the same length of time (30 minutes); and all were allowed to settle for the same period (48 hours). Because of the many variables involved, some judgments regarding the conditions under which the experiments were run were necessary. A carbon concentration of 20 percent was selected because previous work had shown that stable slurries could be prepared at this concentration. Slurries with carbon concentration less than 20 percent are not as desirable for useful application, while flow properties become a problem at the higher carbon concentrations. The 30-minute mixing time was chosen because studies with the attritor had indicated that this length of time was adequate for the preparation of slurries. The settling time of 48 hours was selected because it would give a good indication of the slurry's stability over a reasonable time frame.

The settling was measured by freezing a tubular section of the slurry and dividing it into sections to be analyzed, a method discussed in a subsequent section of this report. The data are tabulated in Appendix C and illustrated graphically in Figure 6. These results show that the blender is the most effective, followed closely by the attritor and the homogenizer. The magnetic stirrer was found to be inferior to the other devices. The attritor was selected to do most of the mixing in the slurry preparation work because

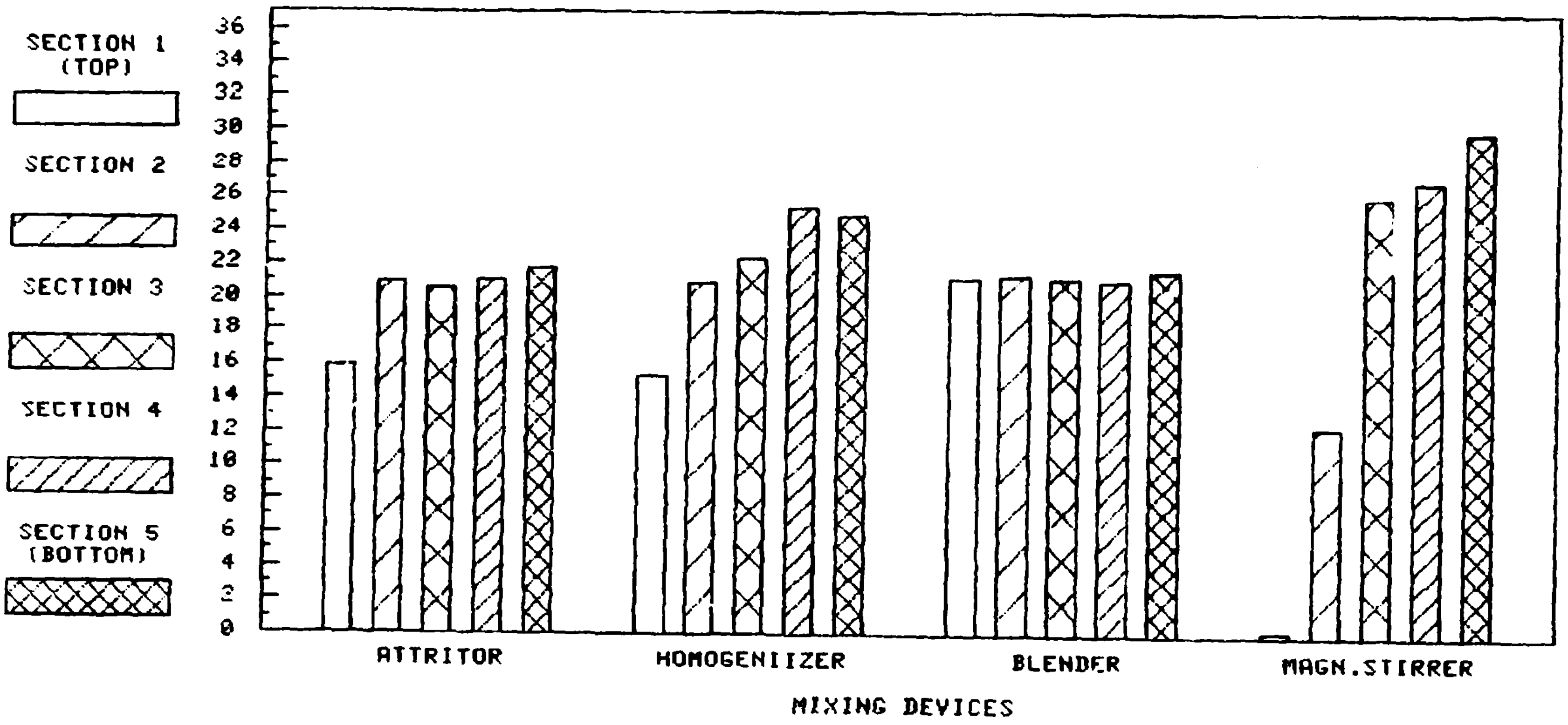


FIGURE 6. COMPARISON OF VARIOUS MIXING DEVICES AND THEIR EFFECT ON THE STABILITY OF CARBON SLURRIES.
(20% Carbon, 1% Lecithin in DF-2; 30 Min. Mixing, 48 Hr. Settling Period.)

of its capacity (4-liter charge) and its ease of preparation (can be run unattended).

(2) Carbon

(a) Selection

The two carbons chosen for the slurry preparations were a furnace black (Raven 1170) and a wood charcoal. The properties of these two carbons are shown in Table 6. Raven 1170 is an industrial product manufactured by the Columbian Division of Cities Service Company with a mean particle diameter of 24 nm. Actually, the particles are clustered in groups of 50 to 100 or more units, and the diameter stated is that of the individual unit.

TABLE 6. PROPERTIES OF CARBONS SELECTED FOR SLURRY PREPARATIONS

Raven 1170	Columbian Div., Cities Service Co.
H_c, Btu/lb x 10^3	13.9
Ash, wt%	0.5
Particle Diameter, NM	24.0
Specific Gravity, Approx.	1.80
Pounds Per Solid Gal.	15.00
Fixed Carbon Analysis,% (Moisture Free)	99.0
Volatile Matter,% (Moisture Free)	1.0
Surface Area, sq. meters/g	102.0

Wood Charcoal	Matheson, Coleman and Bell
H_c, Btu/lb x 10^3	13.3
Ash, wt%	2.8

The diameter of the agglomerate is usually greater than one micrometer. Photomicrographs of several different carbon blacks are shown in Figure 7. A photomicrograph of a petroleum coke is included for comparative purposes. It offers another possible carbonaceous material for incorporating into a slurry formulation, but would require extensive grinding before it could be effectively used. The carbon particles in the slurry should be small enough that effective combustion can take place, although the optimum size for maximum combustion efficiency in the engine has not yet been determined. If the carbon particles become too small, the flow properties become unsatisfactory, i.e., the fuel tends to take on "gel type" characteristics.

(b) Effect of Carbon Concentration on Stability

A series of experiments was run to compare the effect of various carbon concentrations on the slurry stability. Settling data were collected and used as the criteria. Five carbon slurries were prepared with carbon concentrations of 1, 5, 10, 20, and 35 wt% in DF-2. All the slurries used the same dispersant (lecithin), all were mixed over the same time period (30 minutes) using the same mixing device (homogenizer), and all were allowed to settle for the same period of time (48 hours). The settling in all samples was then measured by the freezing tube method. The data plotted in Figure 8 indicate that the most stable slurry was that containing 35 percent carbon, followed by slurries of 20, 10, and 5 percent carbon concentrations. The least stable concentration was the 1 percent. The conditions that exist at any given slurry concentration varies greatly, and the physical environments of the individual carbon particles in the slurry are very complex. An over-simplified explanation would be that as the carbon concentration is increased, the amount of sedimentation decreases because of the hindered settling caused by particle interactions. The tables from which the plotted data of Figure 8 are derived are in Appendix C.

(3) Dispersants and Stabilizers

(a) Selection

The selection of dispersants and suspending agents that would be screened for use in the preparation of the carbon slurries was based on the following

Courtesy of Cities Service
Co. Columbian Division

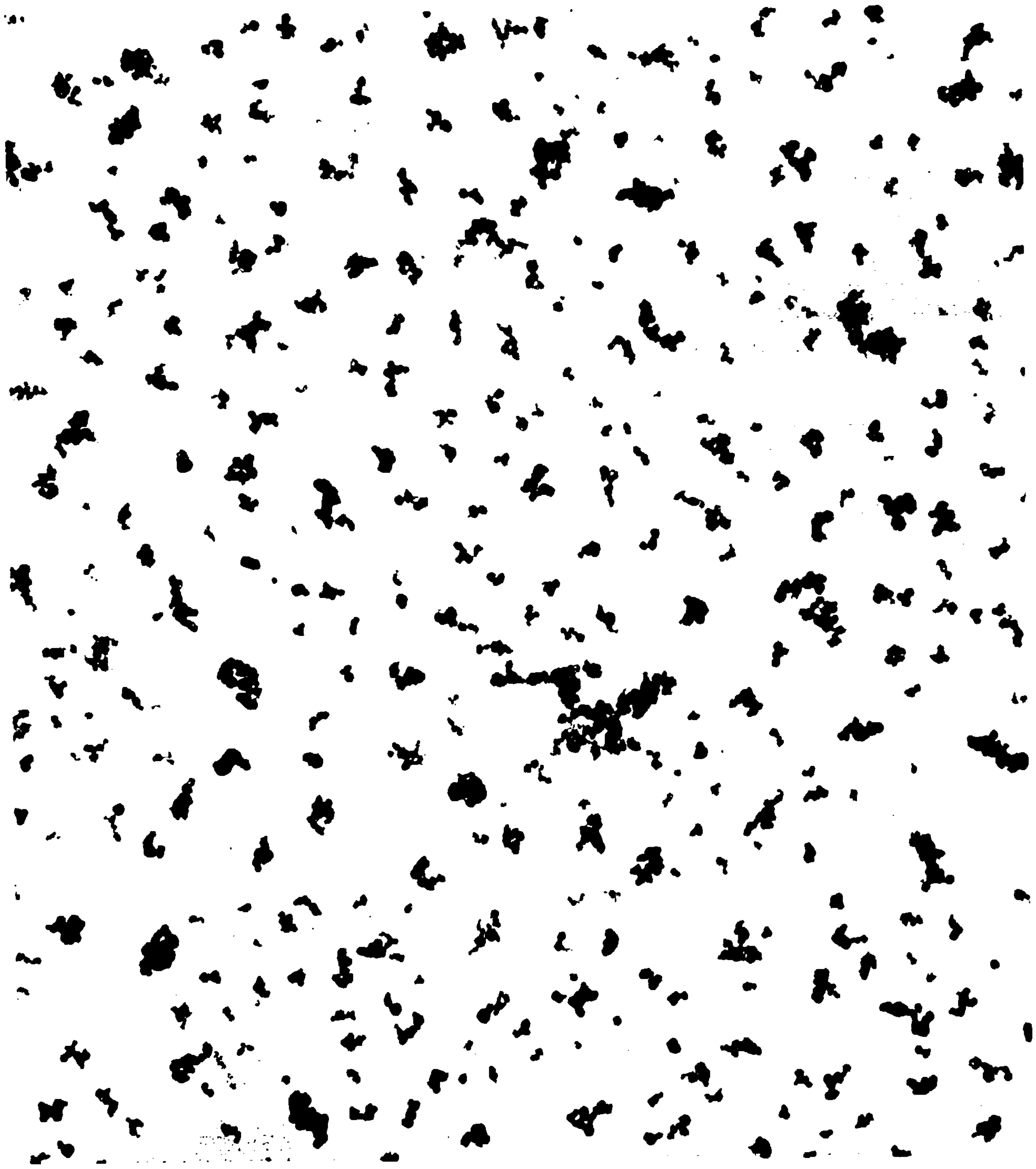
a. Carbon Black, Raven 410 (X50,000)

FIGURE 7. PHOTOMICROGRAPHS OF CARBON BLACKS

Courtesy of Cities Service
Co. Columbian Division

b. Carbon Black, Raven 430 (X50,000)

FIGURE 7. PHOTOMICROGRAPHS OF CARBON BLACKS (CONT'D)



Courtesy of Cities Service
Co. Columbian Division

c. Carbon Black, Raven 1170 (X50,000)

FIGURE 7. PHOTOMICROGRAPHS OF CARBON BLACKS (CONT'D)

d. Petroleum Coke D-14 (X50,000)

FIGURE 7. PHOTOMICROGRAPH OF PETROLEUM COKE (CONT'D)

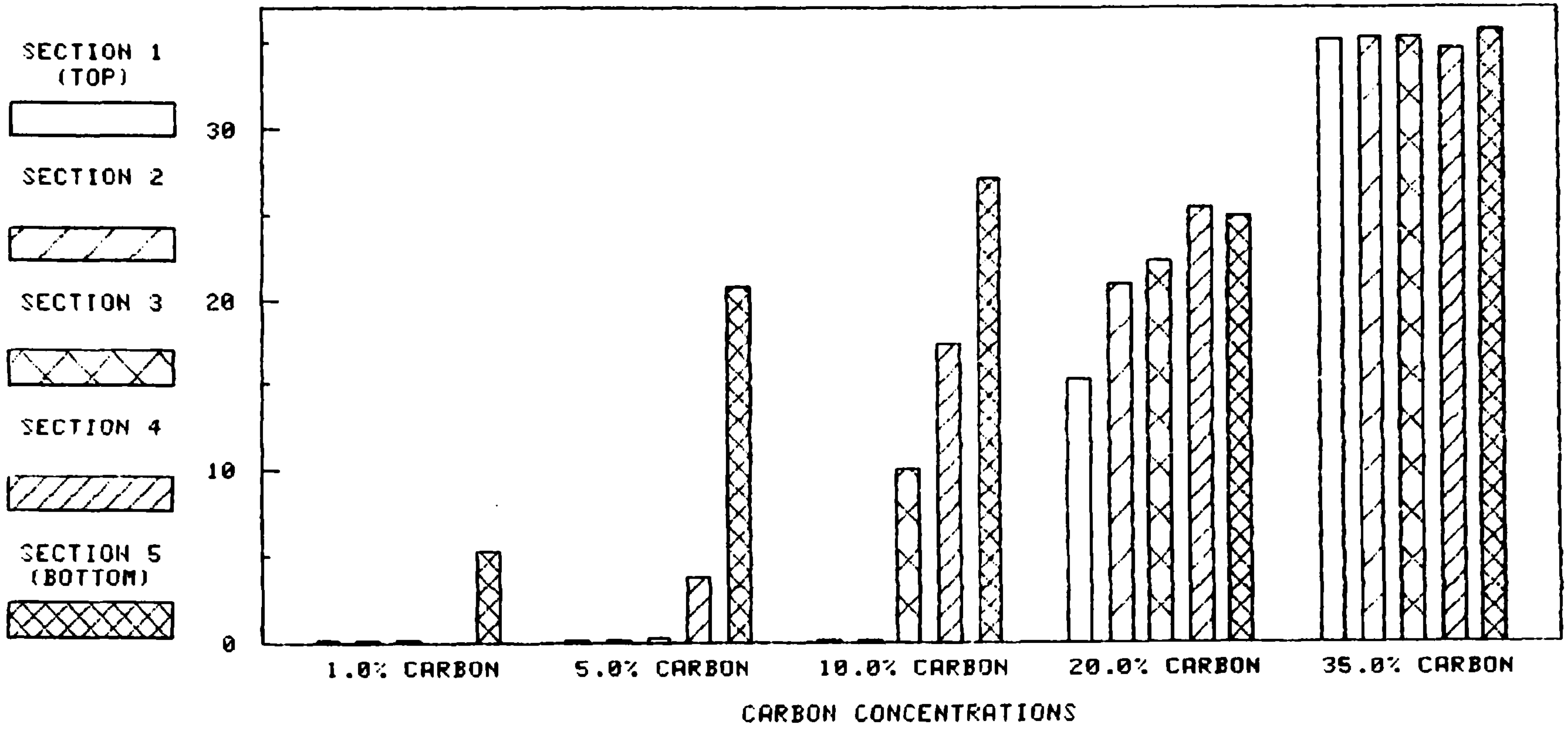


FIGURE 8. COMPARISON OF VARIOUS CARBON CONCENTRATIONS AND THEIR EFFECT ON THE STABILITY OF CARBON SLURRIES.
(20% Carbon, 1% Lecithin, in DF-2; 30 Min. Stirring (Homogenizer) 48 Hr. Settling Period).

information: the chemistry of the system; the available literature; consultations with researchers working in this area; consultations with manufacturers of dispersants and suspending agents; and consultations with manufacturers of carbon black.

Since the word surfactant is an abbreviated term for a surface active agent that usually affects the interfacial tension between two liquids, surfactants may also be used as dispersing agents. In a recent paper on the use of additives to stabilize coal-oil mixtures, it was reported that approximately 1300 types of surfactants (nonionic, anionic, catonic) were tested.(15) By definition, dispersing agents (sometimes referred to as suspending agents) are added to promote and keep the individual fine particles separated. The term is often used interchangeably with emulsifying agents.

Table 7 lists all the dispersants that were considered. The dispersants manufacturers' names, addresses, and telephone numbers are included in Appendix D. The trade names of the dispersants are also included, when applicable. Most of the agents were tested for systems of carbon dispersed in diesel fuel, although a limited number were tested for carbon dispersed in water or alcohol. After screening and evaluation, the list was narrowed to the ones described below. Since both the Air Force (10,16) and Navy(9) are actively engaged in research and development work with carbon slurries, only a limited effort was made at this time to find the "perfect" agent.

It was felt that the knowledge that will be gained from the Air Force and Navy programs will be very beneficial. As stated previously, the available dispersing agents are almost unlimited, and there should be no problem in finding a suitable one if any of the carbon slurry fuel formulations show a high potential for further development.

[1] Aluminum Octoate

[a] Background Aluminum soaps have many uses, as in the stabilizing of emulsions, the thickening of hydrocarbon oils, and the manufacturing of paint.

TABLE 7. LIST OF DISPERSING AGENTS SCREENED

No.	Class or Formula	Physical State (20°C)*	Type**	HLB***
1.	2-Amino-2-methyl-1-propanol	S	N	
2.	Alkylphenoxy polyoxyethene ethanol	L	N	
3.	Octylphenoxy poly(ethyleneoxy) ethanol	L	N	18.0
4.	Octylphenoxy polyethoxyl ethanol	L	N	13.5
5.	Propoxylated butanols	L	N	
6.	Lecithin 90%	L		
7.	Alkanolamides	L	N	
8.	Diethanolamides	L	N	
9.	Diethanolamide of coconut fatty acids	L	N	
10.	N,N'-ethylenebisstearamide	S		
11.	Fatty alkylolamide condensate	L	N	
12.	Alkyl aryl sulfonate	L	N	11.7
13.	Glycerol monolaurate	L	N	6.8
14.	Lanolin derivative	S(Paste)	N	
15.	Oleyl alcohol ethoxylate	L	N	
16.	Polyethylene glycol monolaurate		N	6.0
17.	Polyethylene glycol monostearate		N	0.9
18.	Polyoxyethylene (20) sorbitan monooleate	L	N	15.0
19.	Sorbitan monooleate	L	N	4.3
20.	Sorbitan trioleate	L	N	1.8

---

* L = Liquid, S = Solid

** AMP = amphoteric, A = Anionic, C = Cationic, N = Nonionic

*** HLB = Hydrophile-lipophile balance

TABLE 7. LIST OF DISPERSING AGENTS SCREENED (Cont'd)

No.	Class or Formula	Physical State (20°C)*	Type**	HLB***
21.	Sorbitan trioleate	L	N	4.3
22.	Sorbitan tristearate	S	N	2.1
23.	Sorbitan partial fatty esters	L	N	4.3
24.	Polyoxyethylene sorbitol oleate-polyoxyethylene amine blend	L	N	12.5
25.	Mono- and diglycerides from the glycerolysis of edible fats	S	N	3.5
26.	Mono- and diglycerides from the glycerolysis of edible fats	S	N	2.8
27.	Polyoxyalkylene fatty ester	L	N	
28.	Chlorinated hydrocarbon	L	N	
29.	Guar gum derivatives	S		
30.	Amine salt (95%)	L	C	
31.	Amine salt of dodecyl benzene sulfonic acid	L		
32.	Ammonium lauryl sulfate	L	A	
33.	Calcium lignosulfonate	S	A	
34.	Sodium salt of polymeric carboxylic acid (25%)	L	A	
35.	Sodium salt of polymerized alkyl naphthalene sulfonic acids	S	A	
36.	Sodium lauryl sulfate (30%)	L	A	
37.	Sodium lauryl sarcosinate	S	A	
38.	Sodium dioctyl sulfosuccinate	S	A	
39.	Dioctyl sodium sulfosuccinate 60%-water 20%-isopropyl alcohol 20%	L	A	
40.	Lignosulfonic acid salts	S	A	

---

* L = Liquid, S = Solid

** AMP = amphoteric, A = Anionic, C = Cationic, N = Nonionic

*** HLB = Hydrophile-lipophile balance

TABLE 7. LIST OF DISPERSING AGENTS SCREENED (Cont'd)

No.	Class or Formula	Physical State (20°C)*	Type**	HLB***
41.	Poly(methyl vinyl ether/maleic anhydride)	S	A	
42.	Free acid of complex organic phosphate ester	L	A	
43.	Heterocyclic tertiary amine	S	C	
44.	Quaternary amine	L	C	
45.	Fatty imidazoline 1-C_2H_4-OH, 2-undecyl imidazoline	L	C	
46.	Substituted oxazoline	S(Wax)	C	
47.	Priority product (Blend of nonionic and cationic agents)	L	C	
48.	Dicarboxylic capric derivative triethanolamine salt	L	AMP	
49.	Decarboxyl lauric derivative sodium salt (37%)	L	AMP	
50.	Alumagel	S		
51.	Aluminum octoate	S		
52.	Aluminum stearate	S		
53.	Ammonium stearate	S		
54.	Lead octoate	S		
55.	Lead stearate	S		
56.	Lithium stearate	S		
57.	Zinc stearate	S		
58.	Mono alkene thiophosphonate	L		
59.	LV 1776 alkyd	L		

---

* L = Liquid, S = Solid
** AMP = amphoteric, A = Anionic, C = Cationic, N = Nonionic
*** HLB = Hydrophile-lipophile balance

Aluminum soaps are usually mono- or di-soaps; i.e., they have either one or two free hydroxyl groups. The aluminum octoate used to stabilize the carbon slurries was actually aluminum hydroxydioctoate, but will be referred to henceforth in this report as aluminum octoate. When such soaps are used in organic solvents, aggregates are formed, aided largely by the intermolecular bonds associated with the free hydroxyl groups.(17) Fowkes(17) pointed out that the high viscosities observed with aluminum soaps would seem to suggest high molecular weight filamentous aggregates which reform spontaneously if broken by stirring. These high molecular weight aggregates have been postulated by some workers(18,19) to be linear polymers in the case of aluminum stearate (Figure 9). Gray and Alexander(20) present a good case for ruling out this type of structure for aluminum mono- and di-soaps. Ludke, et al.(21) present excellent and convincing reasons why Figure 10 represents the true picture.

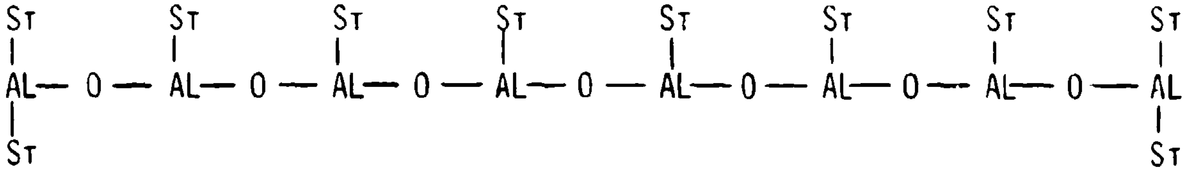


FIGURE 9. PROPOSED STRUCTURE FOR ALUMINUM STEARATE

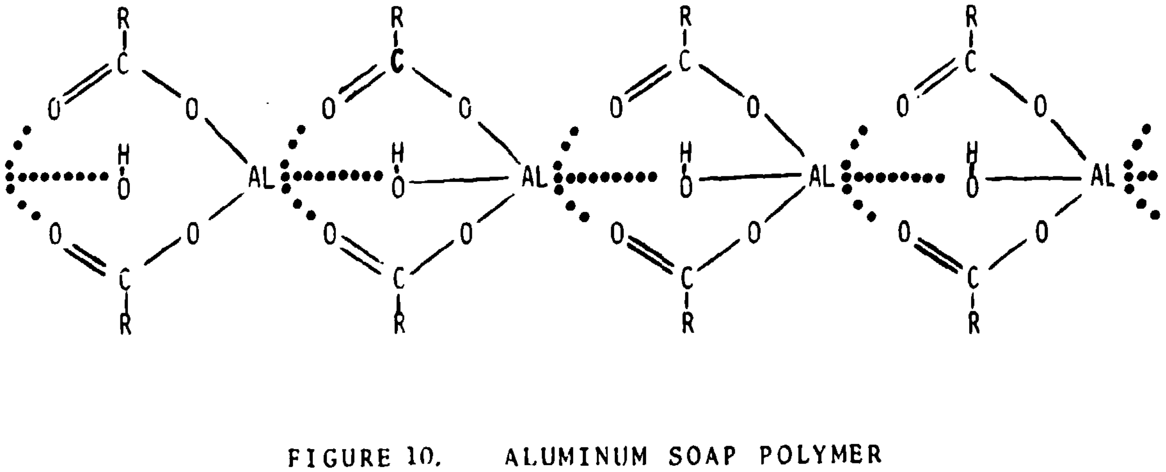


FIGURE 10. ALUMINUM SOAP POLYMER

[b] Experimental Aluminum octoate is a white powder at room temperature. As a precautionary measure, it was dried for at least 4 hours at 100°C (212°F) prior to its use.

When aluminum octoate is heated in diesel fuel, with stirring, to about 79°C, a gel is formed. It was found that it was more convenient to make a supply of aluminum octoate in diesel fuel at concentrations of 1 to 2 wt%, and then when the aluminum octoate was needed, to dilute it with diesel fuel to the desired lower concentrations. Aluminum octoate at concentrations greater than a few percent is difficult to handle.

Additionally, it was found that the best procedure was to add, with stirring, an increment of aluminum octoate "concentrate" to an amount of diesel fuel to give the desired final concentration. This procedure was then followed, with continued stirring, by the slow addition of the carbon black. For a 200-milliliter preparation of 20 wt% carbon slurry, the carbon addition time averaged 30 minutes.

Observations were made on a gel that was formed when 1 wt% aluminum octoate was heated to 79.4°C (175°F) in diesel fuel over a period of 30 minutes. It was found that the life of the gel was approximately 30 days. The gel could be rejuvenated by again heating to 79.4°C (175°F), but this secondary gel was not nearly as good as the original in its properties, nor did it have as long a life (only a few days). This short life could be a problem for storage over one month. Another concern was the Al_2O_3 ash that might be formed as a combustion product when burned in an engine. It was calculated that 0.2 wt% aluminum octoate could yield 0.03 wt% Al_2O_3.

[c] Slurry Preparation In the slurry preparations, the aluminum octoate was used at concentrations of 0.1 to 0.5 wt%. In Figure 11 and in Table 8, one can compare the effectiveness of aluminum octoate at two concentrations (0.1 wt%, 0.2 wt%) in a typical slurry of carbon (20 wt%) in DF-2, using settling data as the indicator. The settling was measured by the simplified method discussed earlier. Therefore, only the top three fractions (sections) were examined. It is evident from the plotted data that 0.1 wt% aluminum octoate is ineffective at times greater than 8 hours. The figure also shows that with this concentration almost all of the carbon

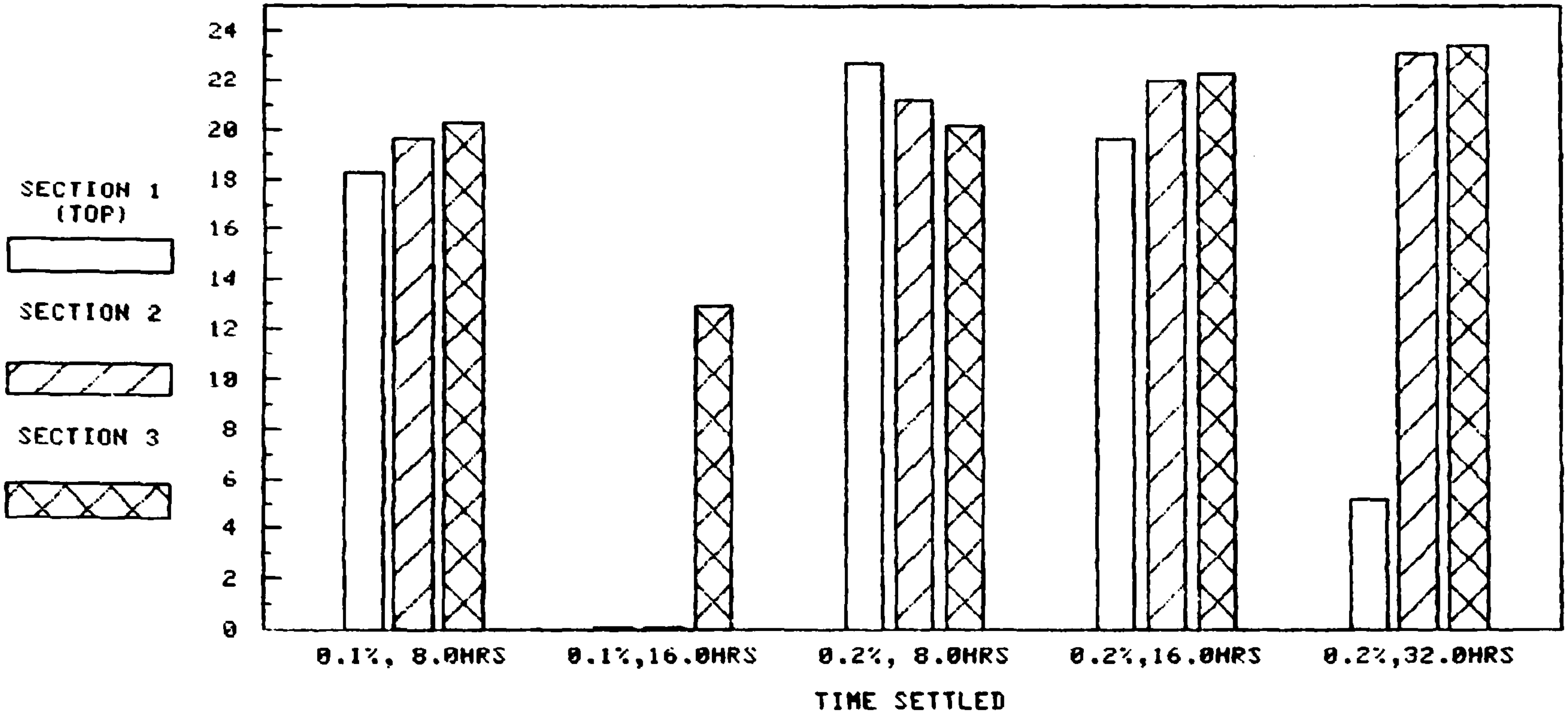


FIGURE 11. EFFECT OF ALUMINUM OCTOATE CONCENTRATIONS (0.1% VS. 0.2%) ON THE STABILITY OF CARBON SLURRIES.
(20% Carbon in DF-2; 30 Min. Stirring (Magnetic stirrer and bar))

TABLE 8. EFFECT OF ALUMINUM OCTOATE CONCENTRATION OF SLURRY STABILITY (SETTLING(a) DATA AND PROPERTIES(b) OF CARBON/DF-2 SLURRIES)

Mixture		Settling Time (hrs)	% Carbon in Fractions			Viscosity cSt(37.8°C)	Density g/ml (15°C)	ΔH_C	
			Fract. 1	Fract. 2	Fract. 3			Btu/lb	Btu/gal.
Carbon (Raven 1170)	20.0%	16.0	19.6	22.0	23.3	204.5	0.942	18,100	142,030
Aluminum Octoate	0.2%	32.0	5.2	23.1	22.5				
Diesel Fuel-2	79.8%								
Wood Charcoal	20.0%	8.0	22.7	21.2	20.2	33.6	0.934	17,950	139,650
Aluminum Octoate	0.2%	16.0	20.6	20.2	20.3				
Diesel Fuel-2	79.8%								
Carbon (Raven 1170)	20.0%	8.0	18.2	19.6	20.3				
Aluminum Octoate	0.1%	16.0	0.04	0.04	12.9				
Diesel Fuel-2	79.8%								
Diesel Fuel-2	100.0%	-	-	-	-	3.26	0.855	19,110	136,100

(a) The settling rates were measured by filling a 100-ml graduate with a thoroughly mixed sample of known concentration, and then allowing it to settle for a predetermined period of time. The amount of carbon in the first three 20-ml fractions was measured and used as an indication of the settling rate. The top fraction is fraction 1.

(b) The experimental determinations of properties were done on freshly prepared samples.

had settled from the top two sections after 16 hours. After 32 hours, the slurry containing the 0.2 wt% aluminum octoate showed signs of settling. It should be pointed out that the slurries used in the above study were prepared using the magnetic stirrer. It has been demonstrated that this type of mixing was the least effective of the four devices tried in producing stable slurries. Undoubtedly these slurries would have shown greater stability if other methods of preparation had been used.

[2] Lecithin

[a] Background Lecithin(22) shown in Figure 12, is composed of a group of phosphatides, any of which are found in all plant and animal tissues. Its general composition is approximately $CH_2(R)CH(R^1)CH_2OPO(OH)O(CH_2)_2N(OH)(CH_3)_3$, where R and R^1 are fatty acid groups. The phosphatides are mixtures of diglyceride residues from fatty acids (oleic, $C_{17}H_{33}COOH$; palmitic $C_{15}H_{31}COOH$; stearic, $C_{17}H_{35}COOH$). The diglyceride residues of the fatty acids are bound to the choline ester of phosphoric acid.(14)

Lecithin is produced commercially from egg yolk, soybean, and corn and is used in the processing of foods, pharmaceuticals, cosmetics, paint, ink, rubber, and plastics.(23)

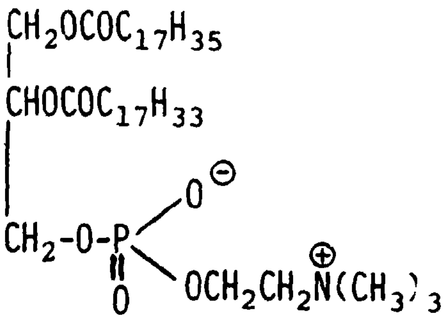


FIGURE 12. TYPICAL STRUCTURE OF LECITHIN

The lecithin described in this report was manufactured by Troy Chemical, Newark, New Jersey, and called Lecithin W.D. It contains 90 percent lecithin and 10 percent nonionic surfactants, with an average molecular weight of approximately 780. Lecithin W.D. was suggested as a possible stabilizer by researchers at PERC (Pittsburgh Energy Research Center), where it was used to help stabilize coal oil mixtures.(24) It is also being used at Union Process, Inc., Akron, Ohio, in some of its work.

[b] Experimental The lecithin had an experimentally determined heating value of 13,740 Btu/lb and a measured density of 1.0263. For this program, 15 gallons of diesel fuel containing 17 wt% carbon black (Raven 1170) and 1 wt% lecithin were blended in the attritor. Settling rates were negligible over an 840-hr (35-day) period.

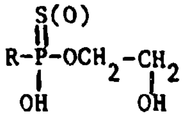
[3] D-5200 (Amergy)

[a] Background A consortium of 27 organizations, headed by General Motors Corporation, made a 2-year research effort to demonstrate that coal oil mixtures could be prepared on a full-scale operation and burned in an industrial boiler.(25) One phase of the development program examined the concept of homogenizing water and No. 6 fuel oil. Because of economic consideration, the additives limit was set at 0.2 wt% of the final mixture. For various reasons, the researchers decided on a 6.5 wt% water content. Of the various additives tried, the best results were obtained with D-5200, manufactured by Drew Chemical Corporation, Parsippany, New Jersey. With 0.2 wt% of this additive, a 50 percent coal oil mixture at 66°C (150°F) showed a 32 percent settling rate after one week. At lower concentrations of D-5200, the stability decreased.

[b] Experimental This additive, D-5200 (or Amergy 5200), was found in initial studies to be ineffective in 20 wt% carbon slurries, with almost immediate settling. However, preparations using D-5200 were made using the magnetic stirrer as the mixing mode. As has already been demonstrated (Figure 6), the magnetic stirrer is not very effective for this type of preparation. D-5200 should be considered for use in future preparations, especially in systems containing water.

[4] TLA-202

[a] Background TLA-202, an additive manufactured by Texaco, Inc., Beacon, New York, is a complex mono alkene thiophosphonate characterized as



$$\mathrm{R{-}\overset{\overset{S(O)}{\|}}{\underset{\underset{OH}{|}}{P}}{-}OCH_2{-}\underset{\underset{OH}{|}}{CH_2}}$$

It is an ashless phosphonate dispersant. The typical inspection data furnished by Texaco are listed below:

Pounds per gallon at 60/60°F	7.6
Flash, COC, °F	345.
Pour, °F	+10
Viscosity at 210°F, SUS	240
Phosphorus, wt%	1.0
Sulfur, wt%	0.7
OH Number	15
Ash (Metallic)	NIL

TLA-202 was used by Ashland Chemical Company contract in their work that was contracted by McDonnell Douglas Astronautics Company-East (MDAC-E) to perform ramjet fuels research in support of an Air Force contract entitled, "Supersonic Long Range Missile Integration Study."(26) TLA-202 (2 percent) was used by Ashland in the preparation of slurries containing high concentrations of carbon blacks (40 to 70 percent) in RJ-5. The viscosities reported by Ashland were described as "like wet clay," "similar to wet tar," "comparable to honey" and "SAE 30 motor oil." The Ashland researchers used a Roll Mill to prepare these high-viscosity slurries.

[b] Experimental. Only limited testing was performed with TLA-202, as early indications were that slurries prepared using this dispersant were not as stable as those prepared using lecithin. As with D-5200, the early preparations were made using the magnetic stirrer for mixing, while those preparations with lecithin as the dispersant were made with the attritor. Recent results indicate that further studies with TLA-202 may be warranted.

(b) Experimental and Conclusions

A series of experiments were conducted to obtain a comparison of four dispersants on the basis of their effectiveness in producing stability of slurries. Settling data were collected and used as the criteria for determining stability. All the slurries were of the same composition (20 percent carbon black in DF-2), all were mixed for 30 minutes using the homogenizer, and all were allowed to settle for 48 hours. All the dispersants were used at the 1 wt% level except aluminum octoate (0.3 wt%). Aluminum octoate, if used at the 1 wt% level, would have raised the viscosity to an unacceptable level. The settling was measured by the freezing tube method. Under the conditions set forth above, the data showed no overwhelming preference for any of the four dispersants, although TLA-202 and aluminum octoate appear slightly better (Figure 13). The tables from which the plotted data in Figure 13 are derived can be found in Appendix C.

Lecithin was chosen as the dispersant to be used in most of the carbon slurry preparations because earlier settling rate studies indicated good stability for at least 35 days or 840 hours (Table 9). It should be noted, however, that in these studies, the slurry was prepared in the attritor. In the dispersant comparison study (Figure 13), an homogenizer was used as the mixing device, and the settling measurements were made after 48 hours. Although homogenizers are classified by many as "grinders," they do very

TABLE 9. SETTLING RATE OF CARBON IN DIESEL FUEL
[Raven 1170 (17 wt%), Lecithin (1%) In Diesel Fuel]

Fractions (wt% Carbon)	16 hr	64 hr	168 hr	336 hr	840 hr
Control	17.0	17.3	17.4	17.4	18.7
1st Fraction	16.8	16.8	15.3	15.1	14.2
2nd Fraction	16.8	17.0	17.0	16.9	20.3
3rd Fraction	17.0	17.1	17.0	17.1	20.0

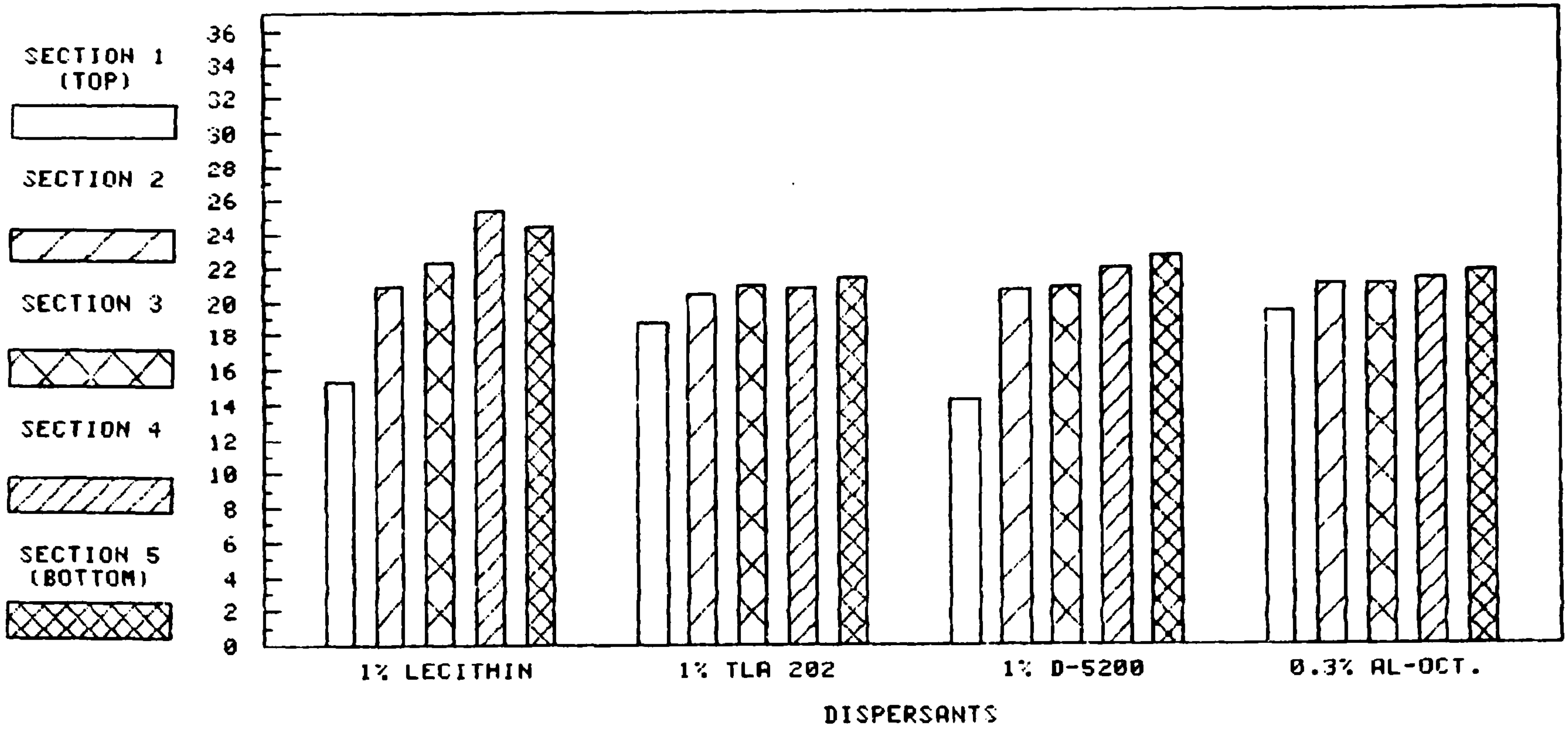


FIGURE 13. COMPARISON OF VARIOUS DISPERSANTS AND THEIR EFFECT ON THE STABILITY OF CARBON SLURRIES.
(20% Carbon in DF-2, 30 Min.Stirring (Homogenizer); 48 Hr. Settling Period.)

little actual grinding. They operate on the principle of high speed fluid shear and are most valuable in the degradation of agglomerates, such as carbon.(27)

The attritor, on the other hand, is a true grinding device. In a comparison of various attrition time periods, the greater stability was found, as expected, in those samples that were attrited for the longer time (Figure 14). The tables from which this plotted data are derived can be found in Appendix C.

A colloid is defined as a suspension of finely divided particles, approximately 5 to 5000 Angstroms in size, in a continuous medium that is thermodynamically stable and can not be easily filtered.(23) It would therefore follow that as the carbon particles are ground down and approach colloidal size, the stability of the slurry would increase. Although dispersants are helpful, the physical means by which slurries are prepared is probably the most important factor.

(4) Methods and Techniques for Measuring Settling Rates

(a) Simplified Method

The method of measuring settling rate at the beginning of the program was simple, which did cause some drawbacks. For example, the settling rates could not be determined with confidence because of the sampling difficulties described below. However, later results using another method indicated that the earlier values were good approximations of the settling.

In the simplified method, the settling rates were measured by carefully filling a 100-milliliter graduate with a thoroughly mixed sample of known concentration and then allowing it to settle, undisturbed, for a predetermined period of time. The first three 20-milliliter fractions were removed by pipette. The diesel fuel was extracted from each fraction by washing several times with pentane and then removing the pentane by decanting after centrifugation. The sample was then dried in an oven at 100 C for at least 30 minutes, then in a desiccator overnight and weighed. The disadvantage of this

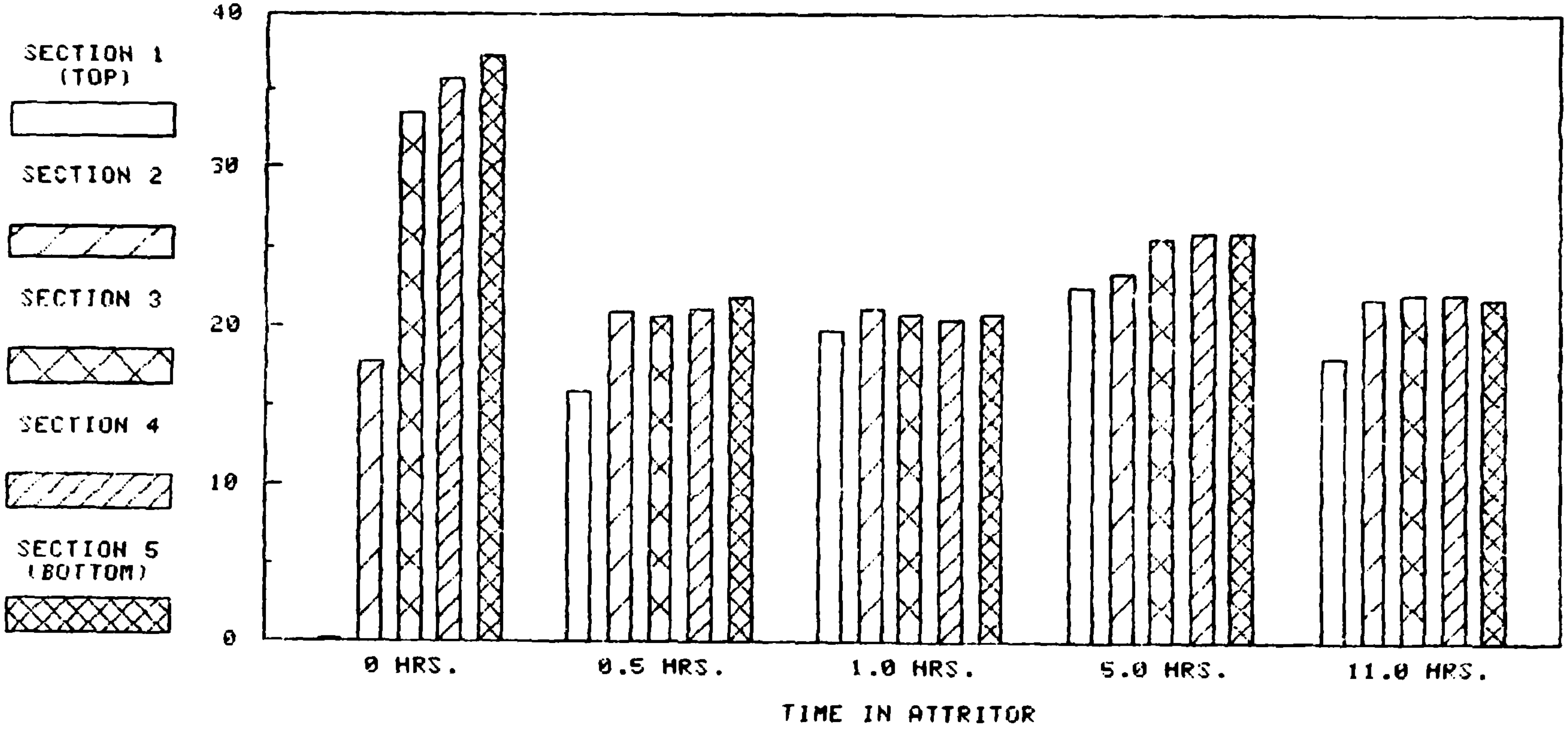


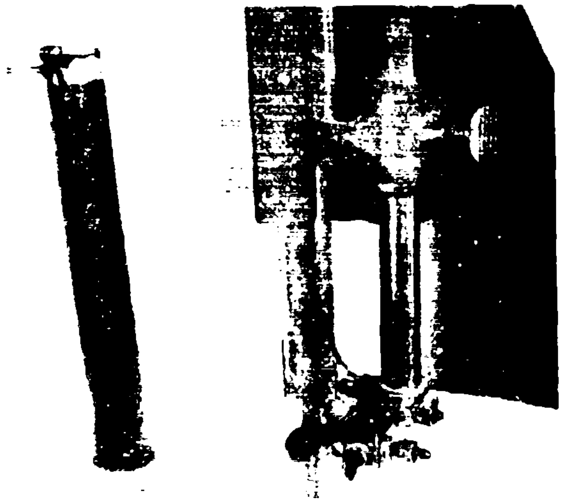
FIGURE 14. COMPARISON OF VARIOUS ATTRITION TIMES AND THEIR EFFECT ON THE STABILITY OF CARBON SLURRIES.
(20% Carbon, 1% Lecithin in DF-2; 48 Hr. Settling Period)

method was that the last two 20-milliliter fractions could not be analyzed because of difficulties encountered in the sampling. However, if the concentration of the top three fractions did not differ significantly from the initial homogeneous concentration, it was assumed to be stable.

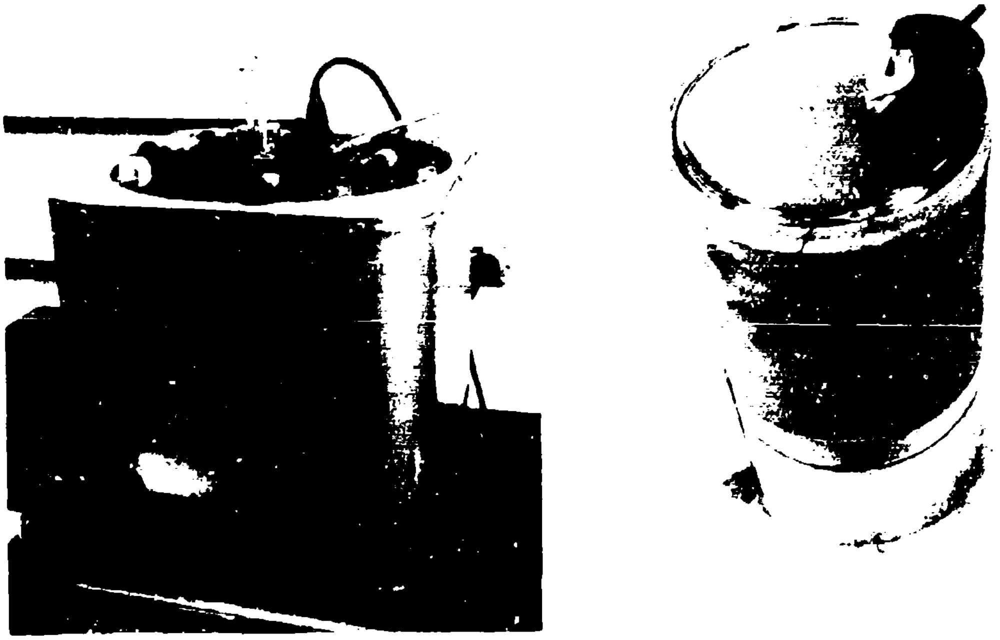
(b) Freezing Tube Method

In this AFLRL-developed method, the prepared samples of known concentration were placed in plastic tubes (4.5-cm OD, 3.8-cm ID, 0.32-cm wall, and approximately 31 cm in length) which were plugged at the bottom with a No. 8 rubber stopper (Figure 15a). Almost all the data were taken at room temperature; however, a controlled temperature bath could be used for future samples if settling rates at other temperatures are desired (Figure 15b). After the desired time period for settling, the tubes were frozen at approximately -80°C (-112°F) (Figure 15c), and each tube cut into six segments (Figures '5d and 15e) and measured by length. After each segment has thawed, it was thoroughly stirred to give a uniform sample. A small 5- to 10-gram sample was removed and then analyzed for solids (carbon) by a modified ASTM D 893-78 procedure, the standard test for insolubles in (used) lubricating oils. The procedure, as modified, consists of weighing the sample in a centrifuge tube, washing it three times with 75 to 100 ml of pentane per wash, and removing the pentane by decanting after centrifugation. The sample is dried in an oven at 104°C (220°F) for at least 30 minutes, cooled in a desiccator, and then weighed.

Although a good method, it is time consuming and it tends to give slightly high values for the recovered carbon. Although the values appear to be high, they are correct relative to each other, a phenomenon which might be caused by the incomplete removal of the last trace of diesel fuel adsorbed by the carbon black. Although the method is not yet quantitative, it is an excellent indicator of stability, since all samples are prepared in an identical fashion.



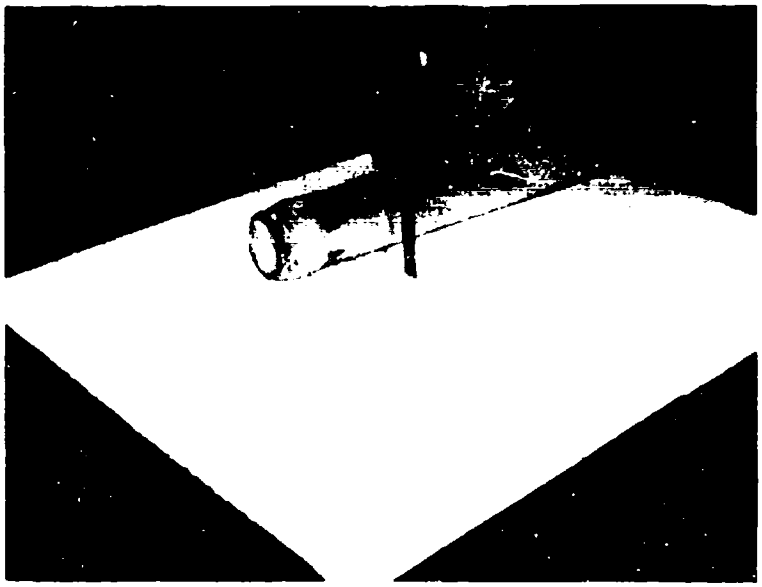
a. Tube Containing the Carbon Slurry



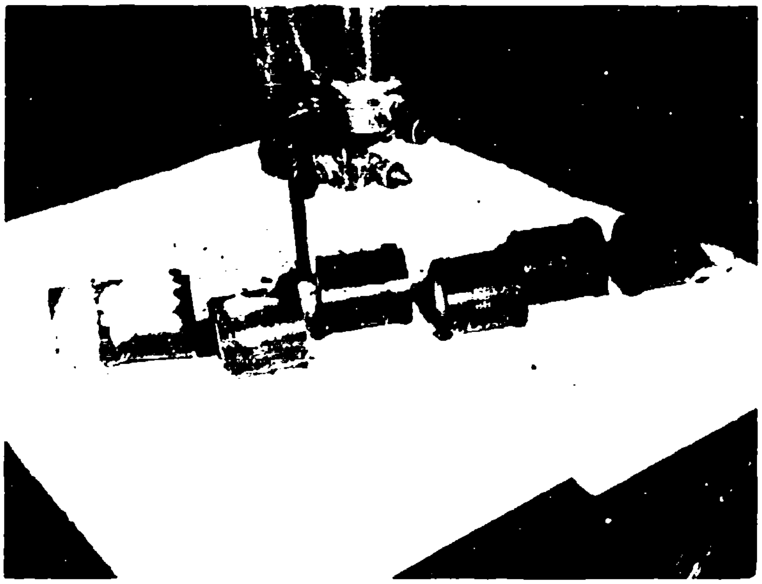
b. Tube in Controlled Temperature Bath

c. Tube Frozen in -80°C Bath

FIGURE 15. FREEZING TUBE METHOD FOR MEASURING CARBON SEDIMENTATION



d. Frozen Tube Just Prior to Slicing



e. The Six Resulting Segments After Slicing

FIGURE 15. FREEZING TUBE METHOD FOR MEASURING CARBON SEDIMENTATION (CONT'D)

(C) Capacitance Measuring Method (Under Development)

A method currently under development consists of measuring the capacitance through the slurry at six equidistant locations over a height of 42 centimeters. The capacitance of known carbon concentrations will be measured to establish a standard curve. When developed, this method should drastically reduce the time needed for analyzing the carbon concentrations from approximately one day to several minutes.

3. Carbon/Water and Carbon/Methanol Slurries

A cursory study was made toward preparing stable suspensions of carbon in water. During this study, methanol slurries were also briefly explored. The carbon/water slurry could be the first step in preparing a slurried fuel of carbon in water/diesel fuel emulsion.

a. Experimental

A magnetic stirrer and bar was used in these screening studies. The most stable slurry of carbon in water was prepared by adding 0.3 percent CMPH, a guar gum derivative (see No. 29, Table 7) to distilled water. Guar gum is a high molecular weight carbohydrate polymer that causes thickening in the water. The carbon black (Raven 1170) was added after the thickening had occurred, and the resulting slurry (89.7 percent H_2O, 10.0 percent carbon, 0.3 percent CMPH) was stable for at least 16 hours (visual observations). A similar preparation, using methanol rather than water, settled rapidly. Other screening tests of this study are summarized in Table 10.

C. HIGH-EXPLOSIVE INCENDIARY TRACER TESTS

1. Background

It would be a distinct advantage to have the high-energy fuels developed for use by the Army to also qualify as fire-resistant fuels. Therefore, a series of high-explosive incendiary tracer tests were run on some of the candidates.

TABLE 10. SCREENING TESTS OF VARIOUS ADDITIVES FOR USE IN PREPARING CARBON SLURRIES IN WATER/OR METHANOL

Composition	Observations
10.0% Carbon, 89.0% Water, 1% Gantrez AN-169	Settled out upon standing overnight
10.0% Carbon, 89.7% Water, 0.3% Jaguar CMHP	Appears to be a stable mixture
10.0% Carbon, 89.7% Methanol, 0.3% Jaguar CMHP	Settled out
10.0% Carbon, 89.7% Methanol, 0.3% Amino 0	Settled out rapidly
10.0% Carbon, 89.7% Water, 0.3% Tamol (25%)	Some settling overnight
5.3% Carbon, 93.6% Water, 1.1% Marasperse CB	Some settling
10.0% Carbon, 89.0% Methanol, 1.0% Marasperse CB	Settled out overnight
10.0% Carbon, 85.8% Water, 3.0% DF-2, 1% Ethanolamine, 0.2% Gantrez AN-169	Settled out
12.1% Carbon, 87.5% Water, 0.4% CBOs-3	Settled out

There are two 20-mm High-Explosive Incendiary Tracer (HEIT) test procedures (ballistic tests) that are available at AFLRL to evaluate fluid fire vulnerability. The first test procedure, developed for fuels, requires a relatively large sample for testing [75.7 liters (20 gallons]. The second procedure was developed for testing hydraulic fluids. This procedure requires a smaller sample (~2 liters), and it is run under hydraulic fluid system conditions (i.e., pressure). The initial studies conducted at AFLRL were run under pressure. The experimental setup of the ballistic range is shown in Figure 16 and the hydraulic cylinder target assembly is illustrated in Figure 17. A complete detailed description of both test procedures, the ballistic facilities, test sequence, and ballistic evaluation can be found in Reference 28. A brief synopsis of this ballistic test can be found in Appendix E.

In the studies reported here, the results were recorded on color 16-mm film, using real time (24 frames/sec) and slow motion (800 frames/sec) cameras. The cameras and firings were remotely controlled.

Since the fuels to be tested were either expensive (~$25 per gal for JP-10) or difficult to clean up (carbon black slurries), the HEIT procedure for evaluating hydraulic fluids was selected because of the minimum fluid requirement i.e., 2 liters vs 20 gal. for the full ballistic test. Because this HEIT procedure was designed to test hydraulic fluids, which are normally used in pressurized systems, it called for the target cylinder containing the sample to be pressurized to 67.5 atm (1000 psig) with nitrogen for each test. However, some of the later tests were conducted at atmospheric pressure to minimize misting effects.

2. Experimental

The tests reported here were made at various times during this program. In an attempt to confirm the results of some tests conducted earlier in the program, the HEIT ballistic tests were repeated.

The data from all the tests are summarized in Table 11. Examination of the data reveals apparent inconsistencies between the earlier tests and

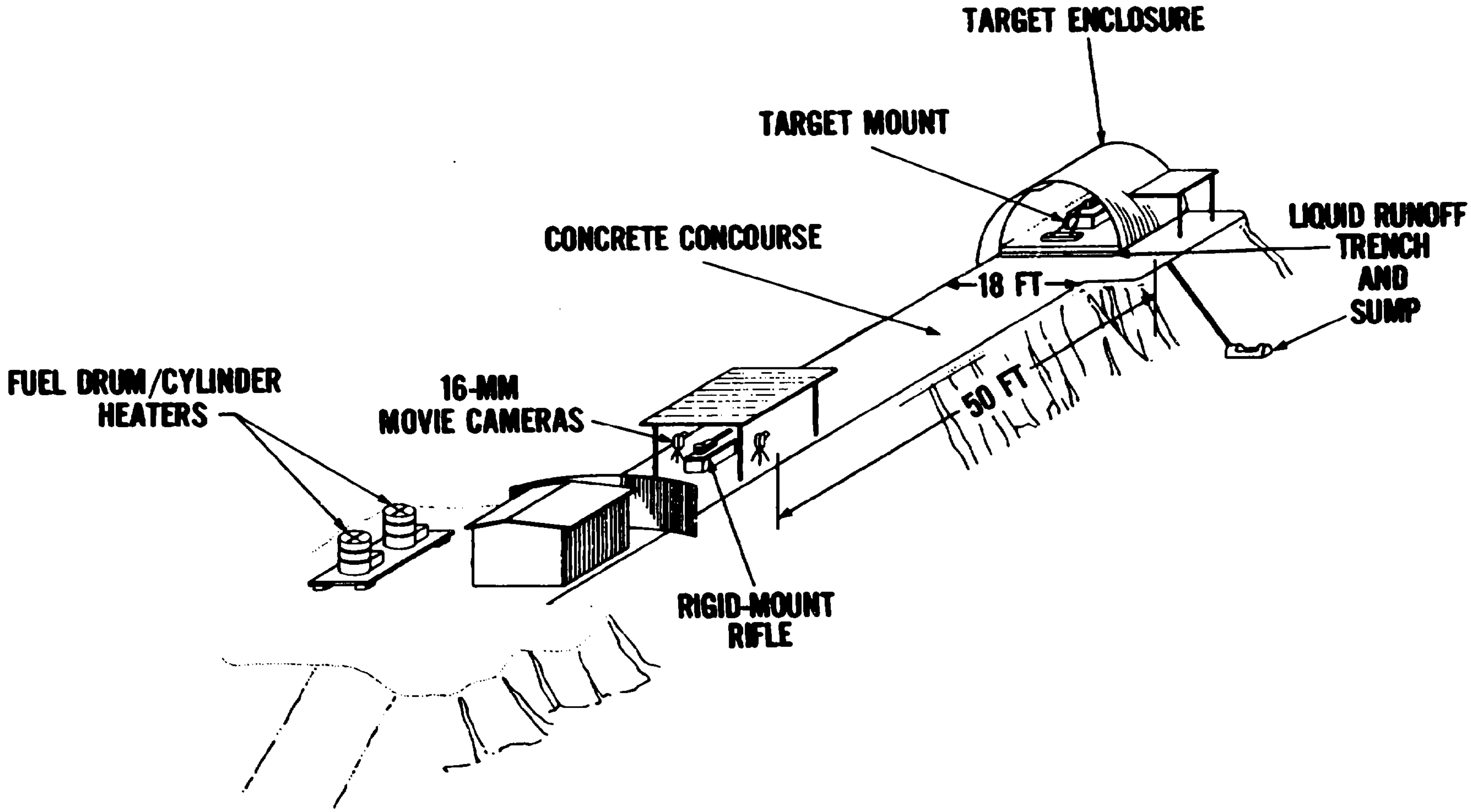


FIGURE 16. ILLUSTRATION OF BALLISTIC RANGE

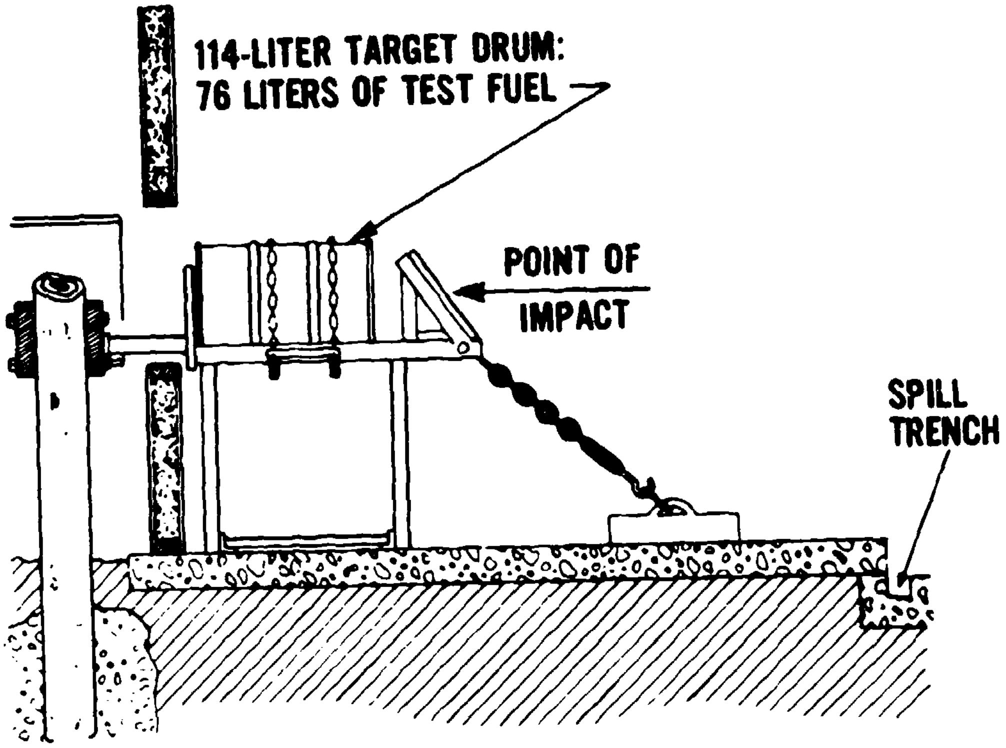


FIGURE 17. ILLUSTRATION OF HYDRAULIC CYLINDER TARGET ASSEMBLY

TABLE 11. RESULTS OF 20-mm HIGH-EXPLOSIVE INCENDIARY TESTS USING TEST PROCEDURES DEVELOPED FOR EVALUATING HYDRAULIC FLUIDS(a)

Test No.	Date of Test	Hydraulic Fluid	Pressure (psig)	HEIT(b) Rating
21	2-21-79	JP-10	1000	BD
29	5-15-79	JP-10	1000	A
30	5-13-79	JP-10	0	ABCDF
22	2-21-79	JP-10/H_2O(c)	1000	A
31	5-15-79	JP-10/H_2O(c)	1000	ABCF(d)
195	12-1-78	DF-2	1000	ABC
32	5-17-79	DF-2	1000	A
33	5-17-79	DF-2	0	BE
196	12-1-78	DF-2/carbon black(e)	1000	A
35	5-17-79	DF-2/carbon black(e)	1000	ABF
36	5-23-79	DF-2/carbon black(e)	1000	AB
37	5-23-79	DF-2/carbon black(e)	C	BF
34	5-17-79	DF-2/H_2O(f)	1000	A

(a) For details of this test, please see Reference 28.

(b) Code for HEIT Ballistic Test
A = Incendiary Flash and Fireball
B = Mist Fireball
C = Transient Ground Fire
D = Sustained Ground Fire
E = Residual Transient Burning in Target Cylinder
F = Residual Sustained Burning in Target Cylinder

(c) 80% JP-10; 10% Deionized H_2O; 6% Emulsifying Agent (EM-12)

(d) Incendiary flash had nearly extinquished before igniting the mist fireball

(e) 82% DF-2; 17% Carbon Black; 1% Lecithin

(f) 84% DF-2; 10% Deionized H_2O; 6% Emulsifying Agent (EA-37)

those conducted later. For example, JP-10 (neat) had a mist fireball and a severe sustained ground fire in the earlier tests (Test No. 21), but later showed only the incendiary flash and fireball (Test No. 29). The same type of results was noted with the JP-10/H_2O emulsified fuels (Test No. 22 vs Test No. 31) and with carbon black-diesel fuel slurry (Test No. 196 vs Tests

Nos. 35 and 36). A possible explanation of these inconsistencies is that when the system is pressurized, the fuel mist velocity, under certain conditions, is greater than the fuel flame velocity. In such cases, any mist ignition could not propagate back to the test vessel. Certainly, the impact dispersion and mist flashback data on the JP-10 (neat) (see Table 12) would indicate that HEIT Test No. 21 was more representative of the true flammability properties than HEIT Test No. 29. The procedures for mist flashback and the impact dispersion tests are described in Appendix E. The best evidence collected to support the hypothesis that the fuel mist can be accelerated too fast to sustain ignition can be seen when viewing the slow motion film of HEIT Test No. 31. The test is almost identical to its earlier counterpart (Test No. 22), except that the mist cloud is ignited after the incendiary fireball is nearly extinquished.

In order to establish the effect of the pressurization on the sample, several HEIT tests were conducted at 0 psig (Table 11, Test Nos.30, 33, 37). If the pressure caused the mist to accelerate faster than the fire in some of the previous tests, this condition should not exist when the cylinder is at atmospheric pressure. These tests give credence to the proposed explanation for the observed results. Some other variables of this HEIT ballistic test are the location of the impact point on the cylinder and the manner in which the cylinder ruptures. Since the pressurized test successfully evaluates hydraulic fluid ballistic fire vulnerability but gives inconsistent results with the less viscous fuels, any future fuel tests will be conducted without pressurizing the sample.

D. ENGINE TESTS

1. Synthetic Liquid Hydrocarbon Fuels

Of the high density fuels evaluated, the three fuels selected for engine testing were RJ-5, JP-9 and JP-10. The first parameter to be evaluated was cetane number, since this value would be expected to be lower than that normally required for diesel engines which usually require cetane numbers of at least 40. All of the synthetic liquid high-density hydrocarbon fuels that were evaluated had excessively low cetane numbers (Table 13), precluding their use in many current tactical vehicles without preliminary fuel treatment.

TABLE 12. RESULTS OF THE IMPACT DISPERSION (DROP TEST)(a) AND MIST FLASHBACK TESTS(b) WITH JP-10 (NEAT) AND JP-10/H_2O (MICROEMULSIFIED) FUELS

	Impact Dispersion Test					Mist Flashback Test	
						Mist Flashback Rating	
	Sample Temp, °C	Drop Plate Temp, °C	Self-Extinquishing	Remarks (Drop Test)	Drop Test(c) Rating	Centimeters	(In.)
JP-10	77	77	No	Large Fire	E	24.1	(9.5)
JP-10	24	24	Yes	No Ground Fire	D	----	-----
JP-10% H_2O(d)	77	77	No	Reduced Fireball; then large fire	E	18.3	(7.2)
JP-10% H_2O(d)	24	25	Yes	No Ground Fire	D	----	-----

(a) For details of this test, please see outline in Appendix E.

(b) For details of this test, please see Reference 29 or outline in Appendix E.

(c) Code for rating Drop Test
A = No Pilot Flame Enlargement
B = Pilot flame dimensions less than doubled
C = Pilot flame dimensions more than doubled
D = Pilot flames totally obscured by transient mist fireball
E = Coalesced fireball with simultaneous pool burning

(d) 84% JP-10; 10% Deionized Water; 6% Emulsifying Agent (EA-12)

TABLE 13. CETANE NUMBERS OF HIGH ENERGY FUELS

	Cetane No. (neat fuel)	Cetane No. (0.5 wt% Amyl Nitrate	Cetane No. (0.87 wt% Amyl Nitrate)
RJ-5	23.6	30.7	--
JP-9	21.1	31.8	--
JP-10	19.7	32.9	42

To improve the cetane number, amyl nitrate was added at the 0.5 wt% concentration. The effects of these additions are shown in Table 13. Although these cetane values are lower than normally accepted, this was considered adequate for these tests.

a. CLR Engine Studies

The three fuels containing the cetane improver were run in the CLR direct injection engine (Table 14) and compared against neat DF-2 at 1500 rpm,

TABLE 14. CLR OIL TEST ENGINE

Configuration	Direct Injection
Bore, cm (in.)	9.65 (3.80)
Stroke, cm (in.)	9.53 (3.75)
Displacement, cm^3($in.^3$)	696.5 (42.5)
Compression ratio	16.36:1
Valve timing (IN)	5° BTC to 38° ABC
(EX)	55° BBC to 20° ATC
Fuel injection system	Bosch APE
Barrel and plunger	10 mm
Injector	Sims NL-141, 4-hole

18° BTC beginning of injection, and an intermediate rack position (2 percent opacity smoke). The engine was fitted with a four-hole Sims 141 injector, and a 10-mm barrel and plunger were used in the fuel injection pump. The engine was stabilized on DF-2. The engine was then switched to a high-density synthetic fuel (containing 0.5 wt% amyl nitrate) without changing the rack setting, resulting in an almost constant volume fuel delivery rate. The change in engine power output was noted, along with any minor fuel rate changes. Combustion chamber pressure was measured using a piezoelectric pressure transducer and an oscilloscope.

These data indicate that without modification to engine variables (timing, injection hardware, fuel rate setting) but with some compensation for low cetane number via fuel additives, both power and thermal efficiency can be increased with these high-energy fuels (Table 15). These improvements may be a direct result of the low cetane number of the fuel. No attempt to evaluate this contribution was undertaken.

TABLE 15. COMPARISON OF FUEL PERFORMANCE OF HIGH-ENERGY FUELS WITH DIESEL FUEL AT CONSTANT VOLUMETRIC DELIVERY

	Fuel Rate (lb/hr)	Horsepower	Thermal Efficiency (%)	Gal/Hp-hr	Smoke
DF-2	2.35	4.28	23.9	1.75×10^{-4}	2.0
JP-9	2.95	5.71	27.3	1.44×10^{-4}	0.4
JP-10	2.82	5.43	27.0	1.46×10^{-4}	0.3
RJ-5	3.80	7.00	26.1	1.32×10^{-4}	8.0

It should be noted that efficiency increased with RJ-5 more than with other fuels, an anticipated fact since the fuel viscosity and density were significantly different from DF-2 (see Table 4). The increased viscosity would be expected to degrade droplet formation in the spray and reduce mixing while the increased density would lead to greater penetration with possible impingement on cylinder walls or piston. Because of these increases, various engine parameters can be optimized for this fuel and yield further improvements in performance.

A brief attempt at determining timing and fuel delivery rate effects was then undertaken. The effects of variation in injection timing are given in Table 16, where the data were recorded after a 6-mm barrel and plunger were installed in the injection pump instead of the 10-mm unit used in the previous tests. Certain combinations of injection timing and fuel rates resulted in abnormal engine operation, and the fuel delivery rate was changed (increased or decreased) to obtain normal operation. As a result, the data in Table 16 were not obtained at constant fuel flow rates. Due to the limited fuel supply, no attempt was made to diagnose these difficulties.

TABLE 16. EFFECT OF INJECTION TIMING ON RJ-5 PERFORMANCE

	Beginning of Injection	Fuel Rate (lb/hr)	Horsepower	Thermal Efficiency (%)	Gal./Hp-hr
RJ-5	15°	2.70	6.00	31.5%	1.10×10^{-4}
RJ-5	17°	2.60	5.97	32.5%	1.06×10^{-4}
RJ-5	22°	2.93	6.43	31.1%	1.11×10^{-4}

Over the timing range examined, the sensitivity to timing changes was minimal, due in part to the very low cetane number of the fuel, which was evident during engine operation. However, the change in fuel delivery rate due to barrel and plunger variation (10- to 6-mm) increased the efficiency from 26 to 32 percent at 17° timing, with a corresponding efficiency increase, 24 to 30 percent, with DF-2. Since this was an initial investigation with a limited quantity of test fuel, no other modifications were undertaken. The low cetane number, even after addition of 0.5 wt% amyl nitrate, caused some operational difficulties and a further cetane number increase would have been desirable.

Since these data were generated at partial rack settings, there was excess air available for combustion. These high-density fuels, at the same fuel volume delivery rates, would thus be expected to produce additional power. At maximum rack settings, where the engine nears air-limited combustion, the additional mass of fuel delivered may not produce additional power.

To investigate this possibility, the CLR was operated with DF-2 at conditions representative of full rack settings in a normally-aspirated engine (ϕ = 0.70 based on exhaust composition). Blends of DF-2 with varying quantities of RJ-5 were then tested at the same volume flow rate. A blend of 50 wt% DF-2, 49.75 wt% RJ-5 and 0.25 wt% amyl nitrate produced a 10-percent increase in horsepower at equal rack settings. This blend, which had a 14-percent density increase relative to neat DF-2, also showed an unexplained increase in volume delivery rate at the fixed rack setting, and yielded a 3-percent increase in power per gallon of fuel. This small increase in power, relative to the density increase, could be an indication of the limited air availability. In addition, the smoke increased from 3.5-percent opacity to 9 percent.

After evaluation of this data, along with the physical properties of the three fuels, their relative costs, availability, and other factors, it was decided that additional research would be concentrated on JP-10.

A brief startability test was conducted in the CLR engine using JP-10 without cetane improver. With the engine warm, 68°C (155°F) water jacket and 71°C (160°F) oil sump, it could be started and operated normally. However, after allowing the engine to cool for two days and stabilize at ambient conditions [23°C (73°F) water and oil temperature], starting with JP-10 was achieved with great difficulty and poor operation.

As a result, 0.87 wt% (1.0 vol%) of amyl nitrate was added to the JP-10 before further operation. The fuel was then examined at 1000, 1500 and 2500 rpm, and at full, three-quarters, and one-half of rated power engine loadings at each speed. Table 17 details the data obtained. This data were obtained using the gross heat of combustion for the fuels. When recalculated using the net heats of combustion, no significant changes were noted. Operation with the JP-10 was completely satisfactory, although there was slight evidence of low cetane number even after the amyl nitrate had been added. The cetane number effect was not believed to be significant enough to expect any field operational difficulties.

TABLE 17. CLR ENGINE PERFORMANCE COMPARISON OF JP-10$^{(B)}$ WITH DF-2$^{(A)}$

Test No.	Test Fuel	Engine Speed (rpm)	Engine Load (lb/ft)	Mass Fuel Rate (lb/hr)	Horsepower (obs)	BSFC (lb/bhp-hr)	Vol Fuel Rate (gal./hr)	Spec Range (hp-hr/gal.)	Thermal Eff (%)	Smoke (% Opacity)
1	A	1500	23.0	3.29	6.57	0.501	0.461	14.22	25.5	4.5
2	A	2500	22.4	5.35	10.66	0.502	0.751	14.19	25.4	4.8
3	A	1000	22.0	2.10	4.19	0.501	0.295	14.20	25.5	5.0
4	A	1500	23.0	3.29	6.57	0.501	0.462	14.22	25.5	5.0
5	B	1500	23.0	2.95	6.57	0.448	0.377	17.43	29.8	2.0
6	A	1500	23.0	3.26	6.57	0.496	0.458	14.35	25.7	5.5
7	A	1500	17.25	2.40	4.93	0.486	0.336	14.65	26.3	2.0
8	B	1500	17.25	2.32	4.93	0.471	0.297	16.59	28.4	1.5
9	A	1500	17.25	2.41	4.93	0.489	0.338	14.56	26.1	3.0
10	A	1500	11.5	1.84	3.28	0.561	0.258	12.71	22.8	1.0
11	B	1500	11.5	1.82	3.28	0.555	0.233	14.10	24.1	0
12	A	1500	11.5	1.83	3.28	0.558	0.257	12.78	22.9	1.0
13	A	1000	22.0	2.14	4.19	0.511	0.301	13.94	25.0	5.5
14	B	1000	22.0	1.96	4.19	0.468	0.251	16.70	28.6	2.0
15	A	1000	22.0	2.17	4.19	0.518	0.305	13.75	24.6	5.5
16	A	1000	16.5	1.67	3.14	0.532	0.235	13.40	24.0	4.0
17	B	1000	16.5	1.58	3.14	0.503	0.202	15.54	26.6	1.25
18	A	1000	16.5	1.62	3.14	0.516	0.228	13.81	24.8	4.0
19	A	1000	11.0	1.23	2.09	0.589	0.173	12.13	21.7	1.5
20	B	1000	11.0	1.14	2.09	0.545	0.146	14.36	24.6	.05
21	A	1000	11.0	1.23	2.09	0.589	0.173	12.13	21.7	1.5
22	A	2500	22.4	5.95	10.66	0.558	0.836	12.76	22.9	7.0
23	B	2500	22.4	5.47	10.66	0.513	0.700	15.23	26.0	2.0
24	A	2500	22.4	5.76	10.66	0.540	0.809	13.18	23.6	6.5

Fuel A = Base DF-2
Fuel B = JP-10

TABLE 17. CLR ENGINE PERFORMANCE COMPARISON OF JP-10$^{(B)}$ WITH DF-2$^{(A)}$ (CONT'D)

Test No.	Test Fuel	Engine Speed (rpm)	Engine Load (lb/ft)	Mass Fuel Rate (lb/hr)	Horsepower (obs)	BSFC (lb/bhp-hr)	Vol Fuel Rate (gal./hr)	Spec Range (hp-hr/gal.)	Thermal Eff (%)	Smoke (% Opacity)
25	A	2500	16.8	4.31	8.00	0.539	0.605	13.21	23.7	2.0
26	B	2500	16.8	4.16	8.00	0.520	0.532	15.02	25.7	1.5
27	A	2500	16.8	4.31	8.00	0.539	0.605	13.21	23.7	2.4
28	A	2500	11.2	3.14	5.33	0.589	0.441	12.09	21.7	2.0
29	B	2500	11.2	3.14	5.33	0.589	0.402	13.27	22.7	2.0
30	A	2500	11.2	3.19	5.33	0.498	0.448	11.90	21.3	2.0
31	A	1500	11.5	1.85	3.28	0.564	0.260	12.64	22.7	1.0
32	B	1500	11.5	1.85	3.28	0.564	0.237	13.87	23.7	1.0
33	A	1500	11.5	1.82	3.28	0.555	0.256	12.85	23.0	1.5
34	A	1500	17.25	2.41	4.93	0.489	0.338	14.56	26.1	2.5
35	B	1500	17.25	2.41	4.93	0.489	0.308	15.97	27.3	N.D.
36	A	1500	17.25	2.41	4.93	0.489	0.338	14.56	26.1	2.0
37	A	1500	23.0	3.21	6.57	0.489	0.451	14.57	26.1	5.5
38	B	1500	23.0	2.88	6.57	0.438	0.369	17.82	30.5	1.5
39	A	1500	23.0	3.24	6.57	0.493	0.455	14.44	25.9	6.0
40	A	1000	11.0	1.23	2.09	0.589	0.173	12.13	21.7	1.5
41	B	1000	11.0	1.28	2.09	0.610	0.164	12.79	21.9	0
42	A	1000	11.0	1.22	2.09	0.584	0.171	12.22	21.9	1.0
43	A	1000	16.5	1.64	3.14	0.522	0.230	13.64	24.5	4.0
44	B	1000	16.5	1.53	3.14	0.487	0.196	16.05	27.4	1.0
45	A	1000	16.5	1.58	3.14	0.503	0.222	14.16	25.4	3.5
46	A	1000	22.0	2.20	4.19	0.525	0.309	13.56	24.3	7.0
47	B	1000	22.0	2.08	4.19	0.496	0.266	15.74	26.9	4.5
48	A	1000	22.0	2.16	4.19	0.516	0.303	13.81	24.8	5.5

Fuel A = Base DF-2
* JP-10
Hc = 19,045 Btu/lb
density = 0.9384 @ 60°F

Fuel B = JP-10
DF-2
Hc = 18,935 Btu/lb
density = 0.8551 @ 60°F

Post-test analysis of the JP-10 data showed a significant increase in the specific range of this fuel, which is defined as the number of horsepower-hours that can be obtained per gallon of fuel. The JP-10 fuel showed an increase of approximately 20 percent in range compared to the base diesel fuel at high speeds and loads. This fell to approximately 10 to 15 percent increased range at lower speeds and loads and would provide an extension of the vehicle driving distance of approximately these percentages. In addition, use of the JP-10 showed a consistent reduction in smoke emissions relative to the diesel fuel. This reduction was apparent throughout the speed and load range, but was most evident at the high-load conditions. A consistent increase in thermal efficiency was noted for the JP-10 fuel. Since the reason(s) for this increase are not completely understood, more analysis of these data and combustion data are in order.

b. DD3-53 Engine Studies

An engine performance comparison of JP-10 with DF-2 was also made in the Detroit Diesel 3-53, Table 18. As in the CLR testing, 0.87 wt% (1.0 vol%) of the cetane number-improving additive amyl nitrate was added to this fuel.

The JP-10 and the DF-2 fuels were examined at 1800, 2200, and 2800 rpm and at full and three-quarters of rated power engine loadings at each speed. Table 19 details the data obtained.

Post-test analysis of the JP-10 data showed the specific range to be approximately equal to the expected value based on the volumetric heat of combustion of this fuel except for the data obtained at 1800 rpm and full-rack. At this engine setting, an unexplained reduction in the thermal efficiency occurs. If the volumetric fuel rates are plotted graphically against the observed powers for these two fuels at 1800, 2200, and 2800 rpm, three pairs of consistent relationships should be obtained (Figures 18a, 18b, and 18c). These relationships should illustrate the effect of the increased energy content of JP-10 compared to DF-2 on the engine performance at a given fuel rate. The nonparallelism noted in the 1800-rpm data set (Figure 18a) makes these data suspicious.

During the engine test runs, the JP-10 test fuel was allowed to remain in

TABLE 18. DD3-53 ENGINE CHARACTERISTICS

Engine Type	Normally Aspirated, two-cycle compression ignition, direct injection, uniflow scavenging
Weight (dry), kg (lb)	431 (950)
No. of cylinders, arrangement	3 in line
Displacement, liter (cu. in.)	2.6 (159)
Bore and stroke, cm (in.)	9.84 x 11.43 (3-7/8 x 4-1/2)
Cylinder block material	cast iron (case iron liners)
Rated power, kW (hp)	72.3 (97) at 2800 rpm
Maximum torque, Nm (lb/ft)	278 (205) at 1800 rpm
Compression ratio	21 to 1
Fuel system	Unit injector (N 50 needle valve) (primary and secondary engine filters)
Governor	Variable speed with throttle controls
Oil filter	Full-flow single filter
Oil cooling	Integral heat exchanger using 100 percent jacket-coolant flow capacity 13.2 l (14 qt)
Piston description	
Material/design	Cast iron/trunk type
Ring configuration	1 - Fire ring (rectangular) 3 - Compression rings (rectangular) 2 - Oil rings
Piston cooling	From jet in top of connecting rod

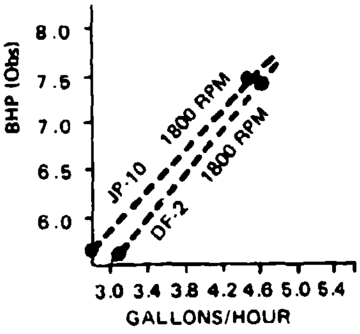
TABLE 19. DD3-53 ENGINE PERFORMANCE COMPARISON OF JP-10 WITH DF-2

Test No.	Test Fuel	Engine Speed (rpm)	Engine Load (lb/ft)	Rack Position	Mass Fuel Rate (lb/hr)	Bhp (obs)	BSFC (lb/bhp-hr)	BSVC (gal./bhp-hr)	Spec Range (hp-hr/gal.)	Thermal Eff (%)	Vol Fuel Rate (gal./hr)
1	JP-10	1800	125	Full	35.5	75.0	0.473	0.061	16.45	29.5	4.51
1a	JP-10	1800	125	Full	34.9	75.0	0.465	0.060	16.67	30.1	
2	JP-10	1800	94	3/4	21.8	56.4	0.387	0.050	20.16	36.2	2.81
2a	JP-10	1800	94	3/4	22.1	56.4	0.392	0.050	19.87	35.7	
3	JP-10	2200	124	Full	38.6	90.9	0.424	0.055	18.18	32.9	5.05
3a	JP-10	2200	125	Full	40.2	91.7	0.439	0.056	17.75	31.9	
4	JP-10	2200	93	3/4	27.1	68.2	0.397	0.051	19.59	35.2	3.47
4a	JP-10	2200	74*	3/4	22.3	54.3	0.411	0.053	18.94	34.0	
5	JP-10	2800	100	Full	39.0	93.2	0.418	0.054	18.63	33.5	5.02
5a	JP-10	2800	102	Full	39.3	95.2	0.413	0.053	18.86	33.9	
6	JP-10	2800	73	3/4	29.3	70.0	0.419	0.054	18.60	33.4	3.78
6a	JP-10	2800	76	3/4	29.6	70.9	0.417	0.054	18.66	33.5	
1	DF-2	1800	124	Full	32.1	74.4	0.431	0.061	16.29	32.4	4.60
1a	DF-2	1800	126	Full	32.7	75.6	0.433	0.062	16.26	32.3	
2	DF-2	1800	93	3/4	20.6	55.8	0.369	0.053	19.04	37.8	3.11
2a	DF-2	1800	93	3/4	22.1	55.8	0.396	0.056	17.76	35.3	
3	DF-2	2200	122	Full	36.4	89.5	0.407	0.058	17.28	34.3	5.19
3a	DF-2	2200	125	Full	36.7	91.7	0.400	0.057	17.57	34.9	
4	DF-2	2200	91	3/4	25.5	66.7	0.382	0.054	18.40	36.5	3.61
4a	DF-2	2200	91	3/4	25.4	66.7	0.381	0.054	18.47	36.7	
5	DF-2	2800	100	Full	37.1	93.3	0.398	0.057	17.69	35.1	5.39
5a	DF-2	2800	102	Full	38.8	95.2	0.408	0.058	17.25	34.3	
6	DF-2	2800	75	3/4	29.1	70.0	0.416	0.059	16.91	33.6	4.19
6a	DF-2	2800	75	3/4	30.0	70.0	0.429	0.061	16.41	32.6	

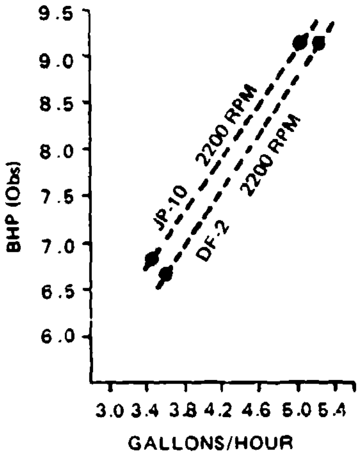
JP-10 ΔH_c (net) 18,195 Btu/lb
142,176 Btu/gal.
Density 0.938 g/ml at 15°C

DF-2 ΔH_c (net) 18,222 Btu/lb
128,420 Btu/gal.
Density 0.8445 g/ml at 15°C

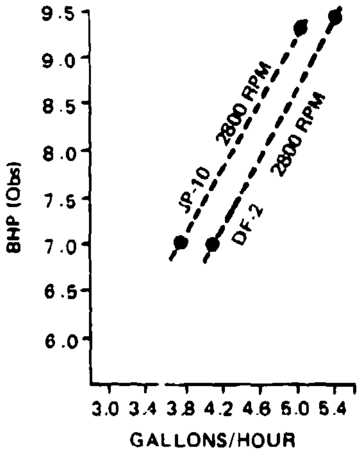
* *Probably an error in reading; possibly should be 94 instead of 74.*



a. 1800 RPM Data



b. 2200 RPM Data



c. 2800 RPM Data

FIGURE 18. EFFECT OF THE INCREASED ENERGY CONTENT OF JP-10 COMPARED TO DF-2 ON THE ENGINE PERFORMANCE

the engine over the weekend, and the engine was then started cold without any difficulty.

c. LD-465 Engine Studies

A similar performance comparison of JP-10 with DF-2 was made in the LD-465 engine, Table 20. Unlike the previous studies conducted with the DD3-53 and CLR engines, no cetane improver additive was necessary in the test using the LD-465 engine, due to the cetane number tolerant design of this multifuel engine family.

TABLE 20. LD-465 CHARACTERISTICS

No. of Cylinders	6
Bore, cm (in.)	1.80 (4.56)
Stroke, cm (in.)	1.92 (4.87)
Displacement, l (in^3)	7.83 (4.78)
Compression Ratio	22:1
Fuel Injection System	Bosch Rotary Distributor with density compensation
Piston Type	Annulus

With the LD-465 engine, the JP-10 and the DF-2 fuels were examined at 1700, 2000, 2300, and 2600 rpm, and at full, three-quarter, and half of rated engine loading at each speed. Table 21 details the data obtained.

Within the limits of experimental error, the JP-10 showed a 4- to 6-percent increase in power, a 4- to 11-percent decrease in the average BSVC, and a 0- to 2-percent decrease in the thermal efficiency. The JP-10 also showed a significant increase in specific range of approximately 4 to 11 percent.

2. Carbonaceous Fuels

A series of diesel fuels containing carbon were prepared for operation in the CLR direct injection diesel engine. The carbon suspensions appeared stable with a slight increase in viscosity, but when attempting to operate the engine on these fuels, it was found that the fuels thickened with time.

TABLE 21. LD-465 ENGINE PERFORMANCE COMPARISON OF JP-10 WITH DF-2

Test No.	Test Fuel	Engine Speed (rpm)	Engine Load (lb/ft)	Rack Position	Mass Fuel Rate (lb/hr)	Bhp (obs)	BSFC (lb/bhp-hr)	BSVC (gal./bhp-hr)	Spec Range (hp-hr/gal.)	Thermal Eff (%)
1	JP-10	1703	325	Full	47.9	105.4	0.455	0.0580	17.2	30.5
2	JP-10	1701	231	3/4	29.9	74.8	0.400	0.0510	19.6	34.7
3	JP-10	1699	154	1/2	23.0	49.8	0.462	0.0589	17.0	30.0
4	JP-10	2002	315	Full	54.0	120.1	0.450	0.0574	17.4	30.8
5	JP-10	2000	225	3/4	36.6	85.7	0.427	0.0545	18.4	32.5
6	JP-10	2004	150	1/2	25.7	57.2	0.449	0.0573	17.4	30.9
7	JP-10	2300	300	Full	60.5	131.4	0.461	0.0588	17.0	30.1
8	JP-10	2299	213	3/4	40.3	93.2	0.432	0.0552	18.1	32.1
9	JP-10	2299	142	1/2	30.1	62.2	0.484	0.0618	16.2	28.6
10	JP-10	2600	277	Full	67.4	137.1	0.492	0.0627	16.0	28.2
11	JP-10	2603	199	3/4	45.0	98.6	0.456	0.0582	17.2	30.4
12	JP-10	2600	133	1/2	34.2	65.8	0.519	0.0663	15.1	26.7
1a	DF-2	1700	308	Full	42.5	99.7	0.426	0.0605	16.5	32.8
2a	DF-2	1697	231	3/4	29.2	74.6	0.391	0.0555	18.0	35.7
3a	DF-2	1701	154	1/2	21.5	49.9	0.431	0.0611	16.4	32.4
4a	DF-2	2000	300	Full	47.7	114.2	0.418	0.0592	16.9	33.4
5a	DF-2	2001	225	3/4	34.2	85.7	0.399	0.0566	17.7	35.0
6a	DF-2	1999	150	1/2	25.8	57.1	0.452	0.0641	15.6	30.9
7a	DF-2	2300	284	Full	53.6	124.4	0.431	0.0611	16.4	32.4
8a	DF-2	2301	213	3/4	39.2	93.3	0.420	0.0596	16.8	33.2
9a	DF-2	2301	142	1/2	29.9	62.2	0.481	0.0682	14.7	29.1
10a	DF-2	2600	266	Full	60.8	131.7	0.462	0.0655	15.3	30.2
11a	DF-2	2600	199	3/4	44.8	98.5	0.447	0.0633	15.8	31.3
12a	DF-2	2600	133	1/2	33.7	65.8	0.512	0.0726	13.8	27.3

JP-10 ΔH_c (net) 18,355 Btu/lb
Density 0.939 g/ml at 15°C

DF-2 ΔH_c (net) 18,222 Btu/lb
Density 0.8445 g/ml at 15°C

The gear-type fuel transfer pump would cause the carbon-containing fuels to thicken quickly and finally solidify with pumping. As a result, the fuel would change during the engine operation period. To alleviate this problem, the CLR fuel system was modified to deliver the carbon-containing fuels to the fuel injection pump using pressurized air. This modification appeared to allow reasonable engine operation, and further optimization of engine-operating conditions and engine hardware was undertaken. After some initially promising results, difficulty was again experienced with the fuels, possibly due to deterioration of the aluminum octoate suspending agent. After a period of time, the carbon fuels would become unstable and separate, again causing problems in determining actual performance of the fuels within the engine. This problem of carbon separation from the diesel fuel was finally resolved by modifying the blending procedure and formulation. Following these changes, the slurries operated satisfactorily, although the air-assisted fuel supply system was still required. A 17 percent carbon black in DF-2 blend was evaluated in the CLR, and Table 22 gives the results of these initial tests. At 1200 rpm, the carbon fuel produced a higher

TABLE 22. CLR PERFORMANCE WITH 17 PERCENT CARBON BLACK IN DF-2

Fuel	Base	17% Carbon	Base	17% Carbon
Engine Speed, RPM	1200	1200	1800	1800
Power, bhp	5.14	5.03	8.23	9.17
BSFC, lb/bhp-hr	0.512	0.555	0.580	0.605
bhp-hr/gal.	13.82	13.79	12.20	12.65
n, Thermal Efficiency	0.260	0.246	0.230	0.226
Exhaust Temp, °F	830	830	1060	1080
Ignition Delay, °CA	5.0	5.0	6.3	6.4
Avg Rate Press. Rise, psi/°CA	94	100	111	111
Est % Carbon Burned*	--	68	--	90

---

* Based on equal thermal conversion efficiency and normal DF-2 combustion in both cases.

specific fuel consumption on a mass or volume basis. Assuming that the carbon black would have the same thermal conversion efficiency as the reference DF-2 test, the thermal efficiency achieved indicates that 68 percent of the carbon black was utilized at this condition.

The percent of carbon utilized was estimated by assuming that the diesel fuel portion of the slurry was burned with the thermal efficiency of the bracketing base fuel. It was also assumed that the fraction of carbon burned had the same thermal conversion efficiency. Any loss in overall thermal efficiency was due to some portion of the carbon not undergoing combustion. Based on these assumptions, the percent of carbon burned can be calculated. However, due to the nature of the fuel and fuel-handling system, these assumptions would be expected to be high (numerically). Thus the percent carbon burned would be a pessimistic estimate of the actual percentage of carbon utilized.

At 1800 rpm, the calculated percentage of carbon consumed had increased to 90 percent, and the fuel showed a slight improvement in volumetric specific fuel consumption relative to the base fuel. Since higher engine speeds reduce the time available for combustion, this increase in conversion efficiency indicates that the combustion of carbon is mixing-limited. Thus, the increased air swirl at increased speeds may be responsible for the improvement noted.

Some mechanical difficulties were noted when using this fuel. Because of the limited fuel availability and the uncertain effects of fuel recycle, the recycling of fuel from the injection pump was stopped. This action resulted in excessive heating of the injection pump and unstable fuel-delivery rates, which was alleviated somewhat by cooling the pump with dry ice. In addition, use of the carbon fuel produced injector nozzle difficulties and required periodic replacement of the fuel injection nozzles.

To expand upon these data, a slurry composed of 16 percent carbon black in standard diesel fuel was then formulated for further testing in the CLR engine. The slurry was examined at 1000, 1500, and 2500 rpm, and at full, three-quarters, and one-half of rated power engine loadings at each speed. Table 23 details the data obtained. Although a compressed air system had to be used for fuel delivery, and the injection nozzles had to be replaced

TABLE 23. CLR ENGINE PERFORMANCE OF 16-PERCENT CARBON BLACK IN DF-2 COMPARED AGAINST DF-2

Test No.	Test Fuel	Engine Speed (rpm)	Engine Load (lb/ft)	Rack Position	Mass Fuel Rate (lb/hr)	Bhp (obs)	BSFC lb/bhp-hr	Est % Carbon Burned	Spec Range hp-hr/gal.	Thermal Eff (%)	Smoke (% Opacity)
1	D	1500	23.0	1	2.98	6.57	0.454		15.62	31.0	5.0
2	C	1500	23.0	1	3.26	6.57	0.496	65.6	15.66	29.4	8.0
3	D	1500	23.0	1	2.95	6.57	0.449		15.77	31.1	6.5
4	D	1500	17.25	2	2.41	4.93	0.489		14.48	28.7	4.0
5	C	1500	17.25	2	2.50	4.93	0.507	92.6	15.22	28.7	5.0
6	D	1500	17.25	2	2.35	4.93	0.477		14.85	29.4	2.0
7	D	1500	11.50	3	1.65	3.28	0.502		14.10	28.0	1.5
8	C	1500	11.50	3	1.84	3.28	0.560	78.3	13.79	26.0	2.5
9	D	1500	11.50	3	1.78	3.28	0.542		13.07	25.9	1.0
10	D	1000	22.0	1	2.08	4.19	0.497		14.27	28.3	6.0
11	C	1000	22.0	1	2.49	4.19	0.594	17.5	13.00	24.5	7.0
12	D	1000	22.0	1	Injector Leaking						
13	D	1000	16.5	2	1.58	3.14	0.503		14.09	27.9	3.8
14	C	1000	16.5	2	1.88	3.14	0.598	27.2	12.91	24.4	7.0
15	D	1000	16.5	2	1.61	3.14	0.512		13.82	27.4	4.0
16	D	1000	11.0	3	1.19	2.09	0.568		12.47	24.7	2.5
17	C	1000	11.0	3	1.46	2.09	0.697	13.5	11.08	20.9	5.0
18	D	1000	11.0	3	1.23	2.09	0.587		12.06	23.9	2.5
19	D	2500	22.4	1	5.35	10.66	0.502		14.12	28.0	5.5
20	C	2500	22.4	1	5.76	10.66	0.540	88.8	14.30	27.0	9.5
21	D	2500	22.4	1	5.55	10.66	0.521		13.61	27.0	5.5
22	D	2500	16.8	2	4.28	8.00	0.535		13.24	26.2	1.5
23	C	2500	16.8	2	4.62	8.00	0.578	83.2	13.37	25.2	6.0
24	D	2500	16.8	2	4.36	8.00	0.545		12.99	25.8	2.0
25	D	2500	11.2	3	3.19	5.33	0.598		11.84	23.5	2.0
26	C	2500	11.2	3	3.75	5.33	0.703	44.3	10.98	20.7	5.0
27	D	2500	11.2	3	3.40	5.33	0.638		11.11	22.0	1.5

Fuel D = Diesel Fuel
Fuel C = Carbon Slurry

TABLE 23. CLR ENGINE PERFORMANCE OF 16-PERCENT CARBON BLACK IN DF-2 COMPARED AGAINST DF-2 (CONT'D)

Test No.	Test Fuel	Engine Speed (rpm)	Engine Load (lb/ft)	Rack Position	Mass Fuel Rate (lb/hr)	Bhp (obs)	BSFC lb/bhp-hr	Est % Carbon Burned	Spec Range hp-hr/gal.	Thermal Eff (%)	Smoke (% Opacity)
28	D	1000	11.0	3	1.26	2.09	0.602		11.78	23.3	3.0
29	C	1000	11.0	3	1.54	2.09	0.735	7.1	10.51	19.8	5.5
30	D	1000	11.0	3	1.26	2.09	0.602		11.78	23.3	2.0
31	D	1000	16.5	2	1.60	3.14	0.509		13.91	27.6	3.0
32	C	1000	16.5	2	1.87	3.14	0.595	32.6	12.98	24.5	6.0
33	D	1000	16.5	2	1.61	3.14	0.512		13.82	27.4	3.0
34	D	1000	22.0	1	2.04	4.19	0.487		14.55	28.8	5.0
35	C	1000	22.0	1	2.32	4.19	0.554	55.2	13.95	26.3	8.0
36	D	1000	22.0	1	2.11	4.19	0.504		14.06	27.9	4.5
37	D	1500	11.5	3	1.84	3.28	0.560		12.65	25.1	1.0
38	C	1500	11.5	3	2.00	3.28	0.609	55.1	12.69	23.9	3.0
39	D	1500	11.5	3	1.74	3.28	0.530		13.37	26.5	1.0
40	D	1500	17.25	2	2.20	4.93	0.447		15.86	31.5	2.0
41	C	1500	17.25	2	2.50	4.93	0.507	57.8	15.22	28.7	4.5
42	D	1500	17.25	2	2.30	4.93	0.467		15.17	30.1	2.0
43	D	1500	23.0	1	3.15	6.57	0.480		14.77	29.3	9.0
44	C	1500	23.0	1	3.75	6.57	0.571	23.6	13.53	25.5	14.0
45	D	1500	23.0	1	3.19	6.57	0.486		14.59	28.9	8.0
46	D	2500	11.2	3	3.19	5.33	0.598		11.84	23.5	1.0
47	C	2500	11.2	3	3.44	5.33	0.645	74.0	11.97	22.6	4.0
48	D	2500	11.2	3	3.16	5.33	0.593		11.95	23.7	1.0
49	D	2500	16.8	2	4.16	8.00	0.520		13.62	27.0	1.5
50	C	2500	16.8	2	5.0	8.00	0.625	39.0	12.36	23.3	4.5
51	D	2500	16.8	2	4.54	8.00	0.568		12.48	24.7	2.0
52	D	2500	22.4	1	5.85	10.66	0.549		12.91	25.6	9.0
53	C	2500	22.4	1	6.25	10.66	0.586	73.7	13.18	24.9	13.0
54	D	2500	22.4	1	5.68	10.66	0.533		13.30	26.4	10.0

Fuel D = Diesel Fuel	Fuel C = Carbon Slurry
Hc (gross) 19,315 Btu/lb	Hc (gross) 18,442 Btu/lb
Hc (net) 18,114 Btu/lb	Hc (net) 17,448 Btu/lb
Density = 0.8507 @ 15.6°C (60°F)	Density = 0.9277 @ 15.6°C (60°F)

Net heats of combustion were used in the calculations.

several times during the operation, the engine could again be operated satisfactorily on this carbon slurry fuel.

Analysis of the data reveals a 4- to 12-percent loss in the thermal efficiency in these test runs, with the calculated specific range varying from an 8-percent loss to a 2-percent gain. At a constant fuel injection rate per cycle (constant rack setting), the utilization of the carbon generally increases and approaches 100 percent as the speed increases. It is estimated that the carbon utilization under these test conditions may have varied from a low of 7 percent up to 92 percent or higher. The carbon slurry would thus be expected to give better performance in a more turbulent engine design.

V. CONCLUSIONS AND RECOMMENDATIONS

A. GENERAL CONCLUSIONS

- The potential of high-energy fuels for Army ground equipment has been confirmed
- Several promising high-energy compositions now deserve accelerated development efforts.

B. SPECIFIC CONCLUSIONS

1. Synthetic Liquid Hydrocarbon Fuels

- Use of synthetic liquid hydrocarbn high-density fuels, with proper control of cetane number, can increase the maximum smoke-limited power available from current tactical vehicles. However, such power increases will impose an additional load on the vehicle's cooling system.

- These high-density fuels can be used to extend the vehicle range between refuelings wihtout a loss of vehicle performance. This could be accomplished by readjusting the vehicle fuel system to reduce the maximum fueling rate.

- These fuels appear to improve engine thermal efficiency relative to the reference fuel. No attempt was made to separate cetane number effects from other fuel effects.

- Since there was no attempt to optimize the engine design and operating parameters for these high-energy fuels, it would be anticipated that such engine optimization would improve the performance of these fuels.

2. Carbonaceous Fuels

- The most important factor in obtaining stable carbon dispersions is the physical means by which they are prepared and dispersed.

- The extreme viscosity of the carbon fuel slurries, combined with the tendency to thicken on pumping, makes these fuel difficult to use in current engine fuel handling equipment.

- By modification to the fuel transfer and fuel handling equipment, these carbon fuels can be used in current combustion systems for short periods of time.

- Based on these results, a significant fraction of carbon contained in these fuels can be burned in current high-speed diesel engines. The combustion of this carbon appears to be dependent on mixing rate, and therefore high turbulence combustion chambers should improve carbon utilization.

- Before these carbon fuels will be practical for field use, major changes to the design of the engine fuel handling and combustion systems will be required.

B. RECOMMENDATIONS

It is recommended that:

- Close monitoring of the research being conducted by the Air Force and Navy continue, especially in the area of slurry preparation and synthetic liquid hydrocarbon fuels in order that no duplication of effort occurs.

- The use of carbon black in JP-10 and diesel microemulsion fuels should be explored as high-energy, fire-resistant fuel possibilities.

- Full-scale HEIT ballistic tests similar to those developed at AFLRL employing 76 liters of test fuel should be run on carbon slurried fuels and JP-10 microemulsions. The HEIT tests described in this report were inconclusive. The limited availability of samples at that time necessitated the use of a procedure that required a relatively small sample. Results from the tests indicated that this procedure was not entirely adaptable to the fuels tested.

- Studies should be initiated on carbon dispersions (10- to 20-percent) in JP-10 to supplement the Air Force and Navy on-going programs.

- Other high energy candidates that emerge during this program or from the research of others should be examined and evaluated.

- Further work on dispersants and surfactants to stabilize carbon slurries should be limited until a fuel has been formulated that demonstrates a high potential for further development. Since the list of dispersing agents and surfactants are almost limitless, no problem is anticipated in finding such an agent.

- The development of the capacitance method for measuring the sedimentation rate of slurries should be completed.

- Methods for improving the cetane number of the synthetic liquid hydrocarbon fuels should be investigated.

- The thermal efficiency increases observed with the combustion of the synthetic liquid hydrocarbon fuels in the engines should be investigated. If the efficiency increase cannot be fully explained by this cetane number effects, then this efficiency improvement deserves further study.

- The impact of the synthetic liquid hydrocarbon fuels on vehicle signature should be more thoroughly evaluated since these polycondensed cycloparaffic materials may increase smoke emissions.

- The relationship between combustion chamber turbulence and carbon utilization noted in the engine studies should be better defined.

VI. REFERENCES

1. Army Scientific Advisory Panel, "Mobility Systems Subgroup Report," Summer Study 76, Vol. 5, September 1976.

2. Tsipis, K., "Cruise Missiles," Scientific American, Vol. 236, No. 2, February 1977.

3. Lander, H.R., "High Density Fuel Development," U.S. Air Force Aero Propulsion Laboratory, Wright-Patterson AFB, OH, 1977.

4. Butler, R.D., "Chromatographic Examination of Shelldyne-H and Related Materials," Report No. AFAPL-SFF-TM-73-9, November 1973.

5. Hahn, A.V., The Petrochemical Industry. Market and Economics. McGraw-Hill Book Company, Inc., New York, NY, Chapter 9, p. 580, 1970.

6. Burdette, G.W., Lander, H.R., and McCoy, J.r., "High Energy Fuels for Cruise Missiles," AIAA 16th Aerospace Science Meeting, Huntsville, AL, January 1978.

7. Burdette, G.W., Bryant, J.T., and Wood, S.E., "New Liquid Hydrocarbon Fuels for Ramjets and Liquid Propellant Guns," Naval Weapons Center, China Lake, CA, November 1977.

8. Ashland Chemical Company, "High Energy Fuels for Volume Limited Missiles and Aircraft," Bulletin No. 1383, Ashland Chemical Company, Chemical Products Division, Columbus, OH.

9. Brudette, G.W. and Reed, R., "High Density Fuels for Navy Air Breathing Missiles," 16th JANNAF Combustion Meeting, Monterey, CA, September 1979.

10. Bruce, T.W., et al., "Formulation Properties and Combustion of Carbon-Slurry Fuels," 16th JANNAF Combustion Meeting, Monterey, CA, September 1979.

11. Mantell, C.L., "Petroleum Based Carbons," Chapter 2, Petroleum Derived Carbons, M.L. Deviney and T.M. O'Grady, editors, ACS Symposium Series No. 21, American Chemical Society, Washington, D.C., 1976.

12. Nelson, W.L., Petroleum Refinery Engineering, 4th Edition, Sixth Impression, McGraw-Hill Book Company, New York, NY, Chapter 22, pp. 830, 843, 1958.

13. Shreve, R.N., The Chemical Process Industries, First Edition, Sixth Impression, McGraw-Hill Book Company, New York, NY, Chapter 9, p. 144.

14. Rose, A. and Rose, E., The Condensed Chemical Dictionary, Fifth Edition, Reinhold Publishing Corporation, New York, NY, p. 651, 1958.

15. Naka, A., "The Use of Additives to Stabilize Coal-Oil Mixtures," Second International Symposium on Coal-Oil Mixture Combustion, Danvers, MA, November 1979.

16. Salvesen, R.H. and Blazowski, W.S., "High Density Carbon Dispersion Fuels - Initial Program Results," 16th JANNAF Combustion Meeting, Monterey, CA, September 1979.

17. Fowkes, F.M., "The Interactions of Polar Molecules, Micelles, and Polymers in Nonaqueous Media," Chapter 2, Solvent Properties of Surfactant Solutions, K. Shinoda, editor, Vol. II of Surfactant Science Series, Marcel Dekker, Inc., New York, NY, 1967.

18. Eigenberger, E. and Eigenberger-Bittner, A., "Aluminum Stearate," Kollid-Z, 91 287, 1940.

19. Eigenberger, E., "Aluminum Salts of Higher Fat Acids," Fette u. Seifen 49, 505, 1942.

20. Gray, V.R. and Alexander, A.E., "Studies of Aluminum Soaps II. The Composition, Structure, and Gelling Properties of Aluminum Soaps," 22nd National Colloid Symposium, Cambridge, MA, June 1948.

21. Ludke, W.O., et al., "Mechanism of Peptization of Aluminum Soap - Hydrocarbon gels Based Upon Infrared Studies," Journal of Physical Chemistry, Vol. 59, 222, 1955.

22. Fieser, L.F. and Fieser, M., Advanced Organic Chemistry, Second Printing, Reinhold Publishing Corporation, New York, NY, Chapter 10, p. 1005, 1962.

23. Morris, W. (Editor), The American Heritage Dictionary of the English Language, 4th Printing, American Heritage Publishing Co., Inc., New York, NY, and Horighton Mifflin Company, Dallas, TX, p. 745, 1970.

24. Ruppel, T.C., Private Communication, August 15, 1976.

25. Brown, A. (Editor), "Final Report of the General Motors Corporation Powdered Coal-Oil Mixtures (COM) Program," FE 2267-2, General Motors Corporation, GM Technical Center, Warren, MI, October 1977.

26. Frainer, L.J. and Colling, P.M., "Ramjet Fuels Analysis Support for the Supersonic Long Range Missile Integration Study. Final Report," Ashland Chemical Company, Research and Development Division, November 1977.

27. Perry, R.H. and Chilton C.H. (Editors), Chemical Engineer's Handbook, Fifth Edition, McGraw-Hill Book Company, New York, NY, Chapter 8, p. 42, 1973.

28. Wright, B.R. and Weatherford, W.D., Jr., "A Technique for Evaluating Fuel and Hydraulic Fluid Ballistic Vulnerability," Interim Report AFLRL No. 89, U.S. Army Fuels and Lubricants Research Laboratory, Southwest Research Institute, San Antonio, TX, December 1977.

29. Wright, B.R., Stavinoha, L.L., and Weatherford, W.D., Jr., "A Technique for Evaluating Fuel Mist Flammability," Interim Report AFLRL No. 25, U.S. Army Fuels and Lubricants Reserch Laboratory, Southwest Research Institute, San Antonio, TX, December 1973.

VII. BIBLIOGRAPHY

1. Adel-Hadadi, M., Lesikar, A.V., Moynihan, C.T., "Shear Viscosities of C_{10} Saturated Hydrocarbon Mixtures," Technical Report No. 2 (NAVAIR), Vitreous State Laboratory, Catholic University of America, Washington, D.C., April 1979.

2. Aklert, R.C., et al., "Optimization of Fuel Selection for External Burning Applications," AD 886127, March 1970.

3. Antoine, A.C., "Evaluation of the Application of Some Gas Chromatographic Methods for the Determination of Properties of Synthetic Fuels," NASA Technical Memorandum 79035, Technical Paper presented at the Aerospace Meeting, Society of Automotive Engineers, San Diego, CA, November 1978.

4. Arenberg, C.A. and Cohen, P., "Application Studies of High Energy Fuels to Gas Turbine Systems," AD 139754, April 1957.

5. Atkins, J.H., "Porosity and Surface Area of Carbon Black," Carbon, 3, 299, December 1965.

6. Back, K.C., "Toxicology of Ramjet Fuels : An Overview," 1978 JANNAF Propulsion Meeting, Incline Village, NV, February 1978.

7. Bakhman, N.N. and Belyaev, A.F., "Combustion of Heterogeneous Condensed Systems," AD-670440, Institute of Chemical Physics, Moscow, U.S.S.R., (Translated from Russian), November 1967.

8. Ban, L.L. and Hess, W.M., "Microstructure and Morphology of Carbon Blacks," Chapter 26, Petroleum Derived Carbons, M.L. Deviney and T.M. O'Grady, editors, ACS Symposium Series No. 21, American Chemical Society, Washington, D.C., 1976.

9. Bartick, H., et al., "CLAM Systems - Fuels Performance Studies," AD 348865, Atlantic Research Corp., Alexandria, VA, February 1964.

10. Bartick, H., et al., "CLAM Systems - Fuels Performance Studies," AD 352540, Atlantic Research Corp., Alexandria, VA, June 64.

11. Bartick, H., et al., "CLAM Systems - Fuels Performance Studies," AD 356418, Atlantic Research Corp., Alexandria, VA, December 1964.

12. Bartick, H., et al., "CLAM Systems - Fuels Performance Studies," AD 364457, Atlantic Research Corp., Alexandria, VA, June 1965.

13. Bartick, H.A., "Research and Development on an Advanced Slurry Fuel for Navy Applications," ARC Report TR-PL 9869, Atlantic Research Corp., Alexandria, VA, November 1969.

14. Becher, P., "Emulsification," Chapter 18, Nonionic Surfactants, Vol. 1, M.J. Schick, editor, Surfactant Science Series, Marcel Dekker, Inc., New York, NY, 1966.

15. Black, F. and High, L., "Methodology for Determining Particulate and Gaseous Diesel Hydrocarbon Emissions," Society of Automotive Engineers, AD 790422, March 1979.

16. Brupbacher, J.M., et al., "Combustion of High Density Fuels," AD B015805, Martin Marietta Laboratories, Baltimore, MD, November 1976.

17. Brupbacher, J.M. and McCall, M.T., "Combustion Properties of High Density Fuels," MML 77-72C, Martin Marietta Laboratories, Baltimore, MD, November 1977.

18. Brupbacher, J.M., McCall, M.T., and Morgenthaler, T., "Ramjet Fuels: Autoignition of RJ-5," 1978 JANNAF Propulsion Meeting, Incline Village, NV, February 1978.

19. Bryant, J.T. and Burdette, G.W., "Ramjet Fuel Studies, Part 1, Carbon," NWC TP 4810, Naval Weapons Center (NWC), China Lake, CA, July 1971.

20. Burdette, G.W., et al., "Status Report on Notsgel-A" NWC TP 3891, Naval Weapons Center (NWC), China Lake, CA, March 1970.

21. Burdette, G.W. "Navy Ramjet Fuel Candidates," Reg. No. 4544-1031, Naval Weapons Center, China Lake, CA, June 1973.

22. Burdette, G.W. and Bryant, J.T., "Ramjet Fuel Studies, Part 2, Aluminum, Boron, and Carbide," (NWC TP 4810, Part 2), China Lake, CA, July 1973.

23. Burnette, L.W., "Nonionics as Ionic Surfactant Intermediates," Chapter 11, and "Miscellaneous Nonionic Surfactants," Chapter 12, Nonionic Surfactants, Vol. 1, M.J. Schick, editor, Surfactant Science Series, Marcel Dekker, Inc., New York, NY, 1966.

24. Cadle, R.D., Particle Size Determination, Interscience Publishers, Inc., New York, NY, 1955.

25. Cities Service Company, "Carbon Blacks for Rubber," Bulletin No. 2, Cities Service Company, Columbian Division, Akron, OH, July 1974.

26. Clark, G., "Turbine Engine Powers Army's New Battle Tank," Diesel and Gas Turbine Progress, February 1977.

27. Coffin, K.P. and Brokaw, R.S., "A General System for Calculating Rates of Particles and Drops and Comparison of Calculated Burning Rates for Carbon, Boron, Magnesium, and Isooctane," Technical Note 3929, National Advisory Committee for Aeronautics, Washington, D.C., 1957

28. Colling, P. and Norton, R., "Manufacture of High Density Fuels for Air Breathing Missiles," 1978 JANNAF Propulsion Meeting, Incline Village, NV, February 1978.

29. Crowell, C.J. and Googins, G.C., "Final Report on Development of Solid Fuel for Ramjet Sustainer Motor," Tech Memorandum No. NMC-TM-66-7, U.S. Naval Missile Center, May 1966.

30. Davies, R., "Particle Size Analysis," *Ind. Eng. Chem.*, Vol *62*, 87, 1970.

31. Elliott, S.B., *The Alkaline-Earth and Heavy-Metal Soaps*, American Chemical Society Monograph Series, Reinhold Publishing Corp., New York, NY, 1966.

32. Essenhigh, R.H., "Predicted Burning Times of Solid Particles in an Idealized Dust Flame," *J. Inst. Fuel*, Vol. 34, 239, 1961.

33. Faith, L.E., et al., "Hydrocarbon Fuels for Advanced Systems," Shell Development Co. Annual Technical Report No. 2, Sept. 1, 1970 to Aug. 31, 1971, AD 737372, Emeryville, CA, 1971.

34. Frainier, L.J., "Development of a Process for Producing the High-Energy Missile Fuel, Tetra-Hydro-Norbornadiene Dimer," Interim Report 15, April 15, 1974 - April 15, 1975, Ashland Oil Inc., Dublin, OH, May 1975.

35. Friedenstein, H., Davis, B., and Eppel, C., "Literature of Chemical Technology," Chapter from *Literature of Chemical Technology*, Advances in Chemistry Series No. 78. American Chemical Society, Washington, D.C., 1968.

36. Godsave, G.A.E., "The Combustion Rates of Solid Fuel Particles," National Gas Turbine Establishment, AD-6658, November 1952.

37. Gordon, S. and McBride, J., "Computer Program for Calculation of Complex Chemical Equilibrium Compositions, Rocket Performance, Incident and Reflected Shocks, and Chapman-Jouquet Detonations," NASA SP-273, National Aeronautics and Space Administration, Washington, D.C., 1971.

38. Harkins, W.S., et al., "Analytical Experimental Investigations of Chemical Ramjet Engine Components for Low Altitude Application," AD 358879, The Marquardt Corp., Van Nuys, CA, November 1964.

39. Heckman, F.A., "Microstructure of Carbon Black," *Rubber Chemistry and Technology*, Vol. 37, No. 5, 1245, December 1964.

40. Heins, A.E., Jr., Reed, G.J., and Woodgrift, K.E., "Hydrocarbon Scramjet Feasibility Program, Part I. Fundamental Investigations of Bi-liquid Pilots for Hydrocarbon Fueled Scramjet," Report No. MR-S-959-PT-1, Marquardt Co., Van Nuys, CA, November 1970.

41. Howard, J.B. and Kausch, W.J., Jr., "Soot Control by Fuel Additives," Final Report ESL-TR-79-32, Dept. of Chemical Engineering, Massachusetts Institute of Technology, Cambridge, MA, September 1979.

42. Hutchinson, E. and Shinoda, K., "An Outline of the Solvent Properties of Surfactant Solutions," Chapter 1, *Solvent Properties of Surfactant Solutions*, K. Shinoda, Editor, Vol. II of Surfactant Science Series, Marcel Dekker, Inc., New York, NY, 1967.

43. Jaarsma, F., "Impact of Future Fuels on Military Aero-Engines," N75-16981, National Aerospace Laboratory, the Netherlands, Advisory Group, Aerospace Research and Development (AGARD), Annual Meeting, Paris, France, September 1974.

44. Kelley, K.M., et al., "Combustion Kinetics of Particulate Boron," Technical Report DEN-I-PU, Denver Research Institute, Denver, CO, 1970.

45. Kiproff, P., "High Density Fuel Applications in Selected Navy Missions," AD 531340, Naval Air Development Center, September 1974.

46. Kolobielski, M., "High Energy Fuels - Literature Survey," Report 2221, U.S. Army Mobility Equipment Research and Development Command, Fort Belvoir, VA, September 1977.

47. Lander, M.R. and Strouse, A.S., "Viscosity Measurements of Potential High Density Hydrocarbon Fuel Blends," Report AFAPL-TR-76-17, Air Force Aero Propulsion Laboratory (AFAPL), Wright-Patterson AFB, OH, June 1976.

48. Macek, A. and Semple, J., "Combustion of Boron Particles at Atmospheric Pressures," Comb. Sci. and Tech., Vol. 1, 181, 1969.

49. Macek, A. and Semple, J., "Combustion of Boron Particles at Elevated Pressures," Technical Report ARC-13-PU, Atlantic Research Corp., Alexander, VA 1970.

50. Macek, A. and Semple, J., "Combustion of Boron Carbide," Final Report on Contract No. N00123-69-C-2365, Atlantic Research Corp., Alexander, VA, 1970.

51. Maggitti, L., "High Energy Fuels for Gas Turbine Engines," NAPTC-LR-75-30, Naval Air Propulsion Test Center (NAPTC), July 1975.

52. Marshall, H.P. and Walters, D.C., Jr., "An Experimental Investigation of a Coal-Slurry Fueled Diesel Engine," SAE Paper 770795, September 1977.

53. McCarty, R.S. and Brandys, E.L., "Evaluation of Shelldyne-H Fuel for Gas Turbine Engine Use," AD 703691, AiResearch Manufacturing Co. of AZ, March 1970.

54. McLain, W.H., et al., "Identification of Exhaust Species from the Combustion of LM and LMH Fuels," AD 808681, Denver Research Institute, Denver, CO, December 1966.

55. Medalia, A.I. and Hagopian, E., "Rheology of Dispersant-Free Aqueous Slurries of Carbon Black," Rheologica Acta 3, 100, December 1963.

56. Medalia, A.I. and Hagopian, E., "Dispersant-Free Aqueous Slurries of Carbon Black," I&EC Product Research and Development, Vol. 3, 120, June 1964.

57. Medalia, A.I. and Heckman, F.A., "Morphology of Aggregates. II. Size and Shape Factors of Carbon Black Aggregates From Electron Microscopy," Carbon, Vol. 7, 567, October 1969.

58. Medalia, A.I. and Heckman, F.A., "Morphology of Aggregates. VII. Comparison Chart Method for Electron Microscopic Determination of Carbon Black Aggregate Morphology," J. Colloid and Interface Science, 36, 173, June 1971.

59. Medalia, A.I., Heckman, F.A., and Harling, D.F., "Morphology of Aggregates, IV. Particle Size and 'Structure' of Carbon Black from Electron Micrographs," Journal of the Rubber Research Institute of Malaya, 22 (4), 381, 1969.

60. Medalia, A.I., et al., "Characterization of New Technology Carbon Blacks," Rubber Chemistry and Technology 46 (5), 1239, December 1973.

61. Moynihan, C.T., Schnaus, U.E., and Czaplak, D., "Viscosities of Hydrogenated Norbornadiene Dimers and Their Mixtures. A Free Volume Interpretation," Vitreous State Laboratory, Catholic University of America, Technical Report No. 5, Contract No. N0019-77-C-0065, Washington, D.C., November 1977.

62. Moynihan, C.T., Schnaus, U.E., H., and Czaplak, D., "Physical Properties of Hydrogenated Dimers of Norbornadiene and Exo-Tetrahydrodicyclopentadiene and Their Mixture," Final Report November 8, 1976 ot November 7, 1977, Vitreous State Laboratory, Catholic University of America, Washington, D.C., December 1977.

63. Moynihan, C.T. and Adel-Hadadi, M., "Non-Additivity in Shear Viscosities of C_{10} Saturated Hydrocarbon Mixtures," Vitreous State Laboratory, Catholic University of America, Report No. 1, Contract No. N0019-76-C-0366, Washington,D.C., November 1978.

64. Mrowca, J.J., "Catalysis of a Cycloaddition Reaction by Rhodium on Carbon," American Chemical Society, 88, 40, 1966.

65. Mulcahy, M.F.R. and Smith, I.W., "Kinetics of Combustion of Pulverized Fuel: A Review of Theory and Experiment," Rev. Pure and Appl. Chem., Vol. 19, 81, 1969.

66. Nestor, L.J., "High Energy Fuels for Gas Turbine Engines. Final Report," NAPTC-LR-30, Naval Air Propulsion Test Center (NAPTC), Trenton, NJ, July 1975.

67. Olson, W.J. and Gibbons, L.C., "Status of Combustion Research on High-Energy Fuels for Ramjets," NACARM E 51 D 23, National Advisory Committee for Aeronautics, Cleveland, OH, October 1951.

68. Olson, W.T., et al., "A Review of National Advisory Research Through 1954 on Boron Compounds as Fuels for Jet Aircrafts," NACA Research Memorandum E 55 B01, Lewis Flight Propulsion Laboratory, April 1957.

69. Ottewill, R.H., "Effect of Nonionic Surfactants on the Stability of Dispersions," Chapter 19, Nonionic Surfactants, Vol I, M.J. Schick, Editor, Surfactant Science Series, Marcel Dekker, Inc., New York, NY, 1966.

70. Owens, E.C. and Wright, B.R., "Engine Performance and Fire-Safety Characteristics of Water-Containing Diesel Fuels," AD A036011, Southwest Research Institute, San Antonio, TX, December 1976.

71. Pederson, J.J., "Small Turbine Engine Performance Evaluation of High Density Fuels," AD A008784, Air Force Rocket Propulsion Laboratory, March 1975.

72. Phillips, D.S., Levin, H., and Murphy, B.R., "Slurry Fuel Research Program for Advanced Navy Application," TMC, Report 25, 190, The Marquardt Corporation, Van Nuys, CA, January 1966.

73. Pierce, W.C., "Operational Characteristics of a Five (5) Diesel Driven Generator Set," Test Report No. E 7132, U.S. Army Mobility Equipment Research & Development Center, Fort Belvoir, VA, October 1977.

74. Pinkel, I.I., "Alternative Fuels for Aviation," N75-16980, Advisory Group Aerospace Research & Development (AGARD), Annual Meeting, Paris, France, September 1974.

75. Pinns, M.L., et al., "NACA Research on Slurry Fuels," NACA Report 1388, National Advisory Committee for Aeronautics, Cleveland, OH, 1958.

76. Reese, B.A. and Carbone, H.M., "Studies of Slurry Fueled Propulsion Systems: Sixth Semiannual Progress Report," Report TM-73-4, Thermal Sciences & Propulsion Center, Purdue University, February 1973.

77. Reese, B.A. and Carbone, H.M., "Studies of Slurry Fueled Propulsion Systems: Seventh Semiannual Progress Report," Report TM-73-5, AD 784362 Thermal Sciences & Propulsion Center, Purdue University, September 1973.

78. Rivin, D., "Surface Properties of Carbon," Rubber Chemistry and Technology, 44(2), 307, April 1971.

79. Ryan, T.W., et al., "The Use of Hybrid Fuel in a Single Cylinder Diesel Engine," Paper No. CSS/CI-80-06, Central State Sections/ The Combustion Institute, Baton Rouge, LA, March 1980.

80. Ryan, T.W., et al., "Hybrid Fuels For Highway Transportation," DOE Second Annual Technical Progress Report/1 June 1979-1 June 1980, Under Contract No. DEAC04-79CS54240, prepared by Mobile Energy Division, Southwest Research Institute, San Antonio, TX, June 1980.

81. Sargent, D.H., "Advanced Fuel Systems for Ramjet-Powered Vehicles," AD 738634, Atlantic Research Corp., Alexandria, VA, February 1972.

82. Schneider, A., et al., "Air-Breathing Missile Fuel Development," AD 922786, Sun Ventures, Inc., Marcus Hook, PA, May 1974.

83. Schneider, A., et al., "Air-Breathing Missile Fuel Development," AFAPL-TR-74-44, Vol. II, Sun Ventures, Inc., Marcus, Hook, PA, June 1975.

84. Schneider, A., et al., "Air Breathing Missile Fuel Development," AFAPL-TR-74-44, Vol. III, Sun Ventures, Inc., Marcus, Hook, PA, November 1976.

85. Shinoda, K., "Solvent Properties of Nonionic Surfactants in Aqueous Solutions," Chapter 2, *Solvent Properties of Surfactant Solutions*, Vol. 2, K. Schinoda, Editor, Surfactant Science Series, Marcel Dekker, Inc., New York, NY, 1967.

86. Smith, E.Q., Jr., "A Proposal for a Unique Solution to Energy Problem From Aerospace Technology for Private Vehicles," AD B004554L, U.S. Naval Missile Center, March 1975.

87. Smoot, L.D., "Mixing and Combustion Processes in Air Breathing Propulsion Systems," AD 778664, Brigham Young University, May 1974.,

88. Spalding, D.B., "Combustion of Fuel Particles," *Fuel* *30*, 121, 1951.

89. Street, P.J., Twanley, C.S., and Webster, J.M., "Studies of the Rapid Combustion of Single Fuel Particles," *The Journal of Photographic Science*, *18*, 113, 1970.

90. Taylor, W.F. and Hall, H.J., "Future Synthetic Fuels," Scientific and Technical Application Forecast, Contract No. DAAD05-73-C-0059, Department of the Army, 1975.

91. Tyler, J.C., et al., "Hybrid Fuels for Highway Transportation," DOE First Annual Technical Progress Report/1 June 1978 - 1 June 1979, under Contract No. EM-78-C-04-4240, prepared by Mobile Energy Division, Southwest Research Institute, San Antonio, TX, June 1979.

92. Warner, C.F., "Studies of Slurry Fueled Propulsion Systems: Fifth Semiannual Progress Report," Report TM-72-5, Jet Propulsion Center, Purdue University, September 1972.

93. Wicke, E., "Contribution to the Combustion Mechanism of Carbon," Fifth International Symposium on Combustion, The Combustion Institute, Pittsburgh, PA, p. 245, 1955.

MIL-P-87107B(USAF)
1 March 1979
SUPERSEDING
MIL-P-87107A(USAF)
29 July 1977

MILITARY SPECIFICATION

PROPELLANT, HIGH DENSITY SYNTHETIC HYDROCARBON TYPE, GRADES JP-9 AND JP-10

This specification is approved for use by the Department of the Air Force and is available for use by all Departments and Agencies of the Department of Defense.

1. SCOPE

1.1 Scope. This specification covers two grades of high density synthetic hydrocarbon type propellant.

GRADE	DESCRIPTION
JP-9	High density hydrocarbon fuel, composed of three different components.
JP-10	High density hydrocarbon fuel, composed solely of *exo*-tetrahydrodi(cyclopentadiene).

2. APPLICABLE DOCUMENT

2.1 Issues of documents. The following documents of the issue in effect on date of invitation for bids or request for proposal form a part of this specification to the extent specified herein.

SPECIFICATIONS

FEDERAL

TT-E-485	Enamel, Semi-gloss, Rust Inhibiting
PPP-D-729	Drums, Shipping and Storage, Steel, 55-Gallon (208 Liters)

MILITARY

MIL-I-27686	Inhibitor, Icing, Fuel System

Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: ASD/ENESS, Wright-Patterson AFB, Ohio, 45433 by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

FSC 9135

STANDARDS

FEDERAL

FED-STD-313	Material Safety Data Sheets, Preparation and Submission of
FED-STD-791	Lubricants, Liquid Fuel and Related Products, Methods of Testing

MILITARY

MIL-STD-105	Sampling Procedures and Tables for Inspection by Attributes
MIL-STD-129	Marking for Shipment and Storage

(Copies of specifications, standards, drawings, and publications required by contractors in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

2.2 Other publications. The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

American Society for Testing and Materials Standards

ASTM D 93	Flash Point by Pensky-Martens Closed Tester
ASTM D 156	Saybolt Color of Petroleum Products (Saybolt Chromometer Method)
ASTM D 240	Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter Test
ASTM D 270	Sampling Petroleum and Petroleum Products
ASTM D 381	Test for Existent Gum in Fuels by Jet Evaporation
ASTM D 445	Viscosity of Transparent and Opaque Liquids (Kinematic and Dynamic Viscosities)
ASTM D 1298	Test for Density, Specific Gravity, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
ASTM D 1655	Aviation Turbine Fuels Standard Specification
ASTM D 2276	Tests for Particulate Contaminant in Aviation Turbine Fuels
ASTM D 2382	Test for Heat of Combustion of Hydrocarbon Fuels by Bomb Calorimeter (High-Precision Method)
ASTM D 2386	Test for Freezing Point of Aviation Fuels
ASTM D 3241	Test for Thermal Oxidation Stability of Aviation Turbine Fuels (JFTOT Procedure)
ASTM D 3243	Test for Flash Point of Aviation Turbine Fuels by by Setaflash Closed Tester
ASTM E 29	Recommended Practices for Indicating Which Places of Figures Are To Be Considered Significant in Specified Limiting Values

(Copies of these standards may be obtained from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA, 19103.)

Department of Transportation

49 CFR 170-189	Department of Transportation Rules and Regulations of the Transportation of Explosives and Dangerous Articles

(Copies of these documents may be obtained from the Superintendent of Documents, U. S. Government Printing Office, Washington, DC 20402.)

3. REQUIREMENTS

3.1 Materials. Except as otherwise specified herein, Grade JP-9 fuel shall consist completely of a mixture of three specific hydrocarbon compounds, and Grade JP-10 shall consist solely of *exo*-tetrahydrodi(cyclopentadiene).

3.2 Chemical and physical requirements. The chemical and physical requirements of the finished fuel shall conform to those listed in table 1. Requirements contained herein are not subject to corrections for test tolerances. If multiple determinations are made, results falling within any specified repeatability and reproducibility tolerances may be averaged. For rounding off of significant figures, ASTM E 29 shall apply to all tests required by this specification.

3.3 Additives. The additives listed shall be used in combination in amounts not to exceed those specified. The type and amount of each additive used shall be reported.

3.3.1 Antioxidants. The following active inhibitors shall be blended separately or in combination into the fuel in total concentration of 90 parts per million (minimum) to 110 parts per million (maximum), by weight, not including weight of solvent,in order to prevent the formation of polymeric oxidation products:

a. 2,6-di-*tert*-butyl-4-methylphenol

b. 6-*tert*-butyl-2,4-dimethylphenol

c. 2,6-di-*tert*-butylphenol

3.3.2 Fuel system icing inhibitor. The fuel system icing inhibitor shall conform to MIL-I-27686.

3.4 Workmanship. The finished fuel blend shall be visually free from undissolved water, sediment or suspended matter and shall be clean and bright at the ambient temperature or at 21°C (70°F), whichever is higher.

QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspections. Unless otherwise specified in the contract, the contractor is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified in the contract, the contractor may use his own or any other facilities suitable for performance of the inspection requirements specified herein, unless disapproved by the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

TABLE I. Chemical and physical requirements and test methods.

Property	JP-9		JP-10		ASTM Standards
	Min	Max	Min	Max	
Color, Saybolt	+25		+25		D 156
Chemical Analysis, wt percent					1/
methylcyclohexane	10.0	12.0			
exo-tetrahydrodi(cyclopentadiene)	65.0	70.0	98.5	100.0	
perhydrodi(norbornadiene)	20.0	25.0			
other hydrocarbons		1.5		1.5	
Iron, parts per million		10.0		10.0	2/
Flash point, °C (°F)	16 (60)	27 (80)	52 (125)		D 93, D 3243
Specific gravity, (60/60F)	0.935	0.955	0.935	0.943	D 1298
Freezing point, °C (°F)		-54 (-65)		-79 (-110)	D 2386 3/
Viscosity, centistokes at°C (°F)					D 445
-54 (-65)		50		40	
-18 (0)		12		10	
Net heat of combustion					D 240, D 2382
MJ/kg (Btu/lb)	42.0 (18,050)		42.1 (18,100)		
MJ/m³ (Btu/gallon)	39,600 (142,000)		39,400 (141,500)		
Thermal stability					D 3241 4/
change in pressure drop, mm Hg		10		10	
heater tube deposit visual rating		code 2		code 2	
Existent gum, mg/liter		50		50	D 381
Particulate matter, mg/liter		1.0		1.0	D 2276
Fuel system icing inhibitor, vol percent	0.10	0.15	0.10	0.15	5/

1/ Test procedure and required equipment outlined in Appendix A.

2/ Test procedure and required equipment outlined in Appendix B. This test is waived for Grade JP-10.

3/ This test is waived for Grade JP-10.

4/ See 4.7.1.1 for D 3241 test conditions and test limits.

5/ Test shall be performed using method 5327 of FED-STD-791.

4.2 Quality conformance inspection. For acceptance purposes, individual lots shall be examined as specified herein and subject to tests for all requirements cited in section 3.

4.3 Inspection lot

4.3.1 Bulk lot. A bulk lot shall consist of an indefinite quantity of a homogeneous mixture of material offered for acceptance in a single isolated container.

4.3.2 Packaged lot. A packaged lot shall consist of an indefinite number of 55-gallon drums or small unit packages of identical size and shape offered for acceptance and filled from the isolated tank containing a homogeneous mixture of material.

4.4 Sampling

4.4.1 Sampling for verification of product quality. Each bulk or packaged lot of material shall be sampled for verification of product quality in accordance with ASTM D 270, except where individual test procedures contain specific sampling instructions.

4.4.2 Sampling for examination of filled containers for delivery. A random sample of filled containers shall be selected from each lot in accordance with MIL-STD-105 at inspection level II and acceptable quality level (AQL) of 2.5 percent defective. The samples shall be examined in accordance with 4.6.3

4.5 Inspection. Inspection shall be performed in accordance with method 9601 of FED-STD-791.

4.6 Examinations

4.6.1 Examination of product. Samples selected in accordance with 4.4.1 shall be visually examined for compliance with 3.5.

4.6.2 Examination of empty containers. Prior to filling, each empty unit container shall be visually inspected for cleanliness and suitability.

4.6.3 Examination of filled containers. Samples taken as specified in 4.4.2 shall be examined for conformance to MIL-STD-105 with regard to fill, closure, sealing, leakage, packaging, packing, and markings. Any container having one or more defects under the required fill shall be rejected. If the number of defective or underfilled containers exceeds the acceptance number for appropriate plan of MIL-STD-105, the lot represented by the sample shall be rejected.

4.7 Test methods. Test to determine conformance to chemical and physical requirements shall be conducted in accordance with FED-STD-791, ASTM standards, or in the case of unique requirements, the test procedures as outlined in table I and described in the attached Appendix.

4.7.1 Thermal stability

4.7.1.1 ASTM D 3241. The thermal stability test shall be conducted using ASTM D 3241 (JFTOT). The heater tube shall be rated visually.

4.7.1.1.1 ASTM D 3241 test conditions

a. Heater tube temperature at maximum point: 300°C (572°F)

b. Fuel system pressure: 3.43 MPa (500 psig)

c. Fuel flow rate: 3.0 ml/minute

d. Test duration: 150 minutes

4.7.1.1.2 Results. The fuel sample is acceptable if all the following criteria are met:

a. The maximum differential pressure across the test filter does not exceed 10 millimeters

b. The maximum visual rating of the heater tube deposits is a Code 2, and the visual rating of the heater tube shows neither peacock type deposits (code P) nor abnormal type deposits (code A).

4.7.1.1.3 ASTM D 3241 reported data. The following data shall be reported:

a. Differential pressure in millimeters of mercury at 150 minutes, or time to differential pressure of 10 millimeters of mercury, whichever comes first

b. Heater tube deposit Visual Rating Code at the end of the test

c. If a Mark 8A Tube Deposit Rater (TDR) is available, the maximum SPUN TDR rating shall be reported.

4.8 Test report. Test data required by 4.7 shall be reported in accordance with ASTM D 1655, using the standard ASTM form entitled "Inspection Data on Aviation Turbine Fuels" or AFTO Form 476 (see 6.2.1).

5. PACKAGING

5.1 Packaging. Packaging shall be level B.

5.2 The fuel shall be in 55 gallon drums conforming to requirements of PPP-D-729, Type II. Each drum shall contain 54 gallons of product. Outside of drums need not be phosphatized. Exterior coating shall conform to TT-E-485. Bungs need not be painted. Cap seals shall be applied to each bung and vent.

5.3 Blocking and bracing. When specified, blocking and bracing of shipments in designated conveyances shall be in accordance with Department of Transportation (DOT) regulations and best commercial practice.

5.4 Marking and labeling. Marking shall be in accordance with MIL-STD-129. Drums shall be labeled in accordance with DOT regulations for flammable liquids. Flash point shall be stenciled on each drum.

6. NOTES

6.1 Intended use. The fuel covered by this specification is intended for use in gas turbine engines or ramjet engines for missile application.

6.2 Ordering data. Procurement documents should specify;

a. Title, number, and date of this specification

b. Quantity required and size containers desired

c. Level of packing required (see 5.1).

d. When blocking and bracing is specified (see 5.2).

e. When Material Safety Data Sheet is required in accordance with FED-STD-313.

6.2.1 Contract data requirements. Data as required by 4.8 to be submitted as stated on DD 1423 and incorporated in the contract.

6.2.1.1 Type and amount of additive (3.3).

6.3 Precaution of mixing inhibitors. To prevent any possible reaction between the concentrated forms of the different inhibitors (see 3.3) the fuel contractor is cautioned not to commingle inhibitors prior to their addition to the fuels.

Custodians: Air Force - 11	Preparing activity: Air Force - 11
Review activities: Air Force - 68	Project Nr. 9135-F094

APPENDIX B

NAMES AND ADDRESSES OF THE MANUFACTURERS OR DISTRIBUTORS OF THE CARBONACEOUS MATERIALS LISTED IN TABLE 5

No.	Trade Name	Manufacturer or Distributor	Address	Telephone No.
1	RAVEN 410	Cities Services Co. Columbian Div.	3200 West Market St. Fairlawn Village Akron, OH 44313	216/867-5800
2	RAVEN 1000	Cities Services Co. Columbian Div.	3200 West Market St. Fairlawn Village Akron, OH 44313	216/867-5800
3	RAVEN 1170	Cities Services Co. Columbian Div.	3200 West Market St. Fairlawn Village Akron, OH 44313	216/867-5800
4	Super Spectra	Cities Services Co. Columbian Div.	3200 West Market St. Fairlawn Village Akron, OH 44313	216/867-5800
5	MCB	Matheson Coleman and Bell Manufacturing Chemists	2909 Highland Ave. Norwood, OH 45212	513/631-0445
7	MCB Charcoal	Matheson Coleman and Bell Manufacturing Chemists	2909 Highland Ave. Norwood, OH 45212	513/631-0445
8	DARCO KB	ICI United States Inc. Specialty Chemicals Div.	New Murphy Rd & Concord Pike Wilmington, DE 19897	302/658-9311
9	DARCO S-51	ICI United States Inc. Specialty Chemicals Div.	New Murphy Rd & Concord Pike Wilmington, DE 19897	302/658-9311

APPENDIX B

NAMES AND ADDRESSES OF THE MANUFACTURERS OR DISTRIBUTORS OF THE CARBONACEOUS MATERIALS LISTED IN TABLE 5

No.	Trade Name	Manufacturer or Distributor	Address	Telephone No.
10	DARCO G-60	ICI United States Inc. Specialty Chemicals Div.	New Murphy Rd & Concord Pike Wilmington, DE 19897	302/658-9311
11	Asbury	Asbury Graphite Mills, Inc.	Asbury Warren County, NJ 08802	201/537-2155
12	Asbury	Asbury Graphite Mills, Inc.	Asbury Warren County, NJ 08802	201/537-2155
13	Asbury	Asbury Graphite Mills, Inc.	Asbury Warren County, NJ 08802	201/537-2155
14	Fisher	Fisher Scientific Co.	711 Forbes Ave. Pittsburgh, PA 15219	412/562-8300
15	Fisher	Fisher Scientific Co.	711 Forbes Ave. Pittsburgh, PA 15219	412/562-8300

APPENDIX C

DATA USED IN THE PREPARATION OF FIGURES 6, 8, 13 AND 14

I. MIXING DEVICES

Composition:

20.0 wt% Carbon Black (Raven 1170)
79.0 wt% DF-2 (AL-6766F)
1.0 wt% Lecithin (AL-7619A)

Mixing Time: 30 minutes
Settling Period: 48 hours

	Attritor, % C	Homogenizer, % C	Blender, % C	Magnetic Stirrer & Bar % C
Sections:				
1 (Top)	15.9	15.3	21.2	0.31
2	20.8	21.0	21.3	12.4
3	20.5	22.2	21.2	26.0
4	21.0	25.4	21.1	27.0
5 (Bottom)	21.7	24.8	21.6	30.0

II. CARBON CONCENTRATIONS

Mixing Device: Homogenizer
Mixing Time: 30 minutes
Settling Period: 48.0 hours

	Wt. Percent Carbon Charged				
	(1%)	(5%)	(10%)	(20%)	(35%)
Sections:	% C	% C	% C	% C	% C
1 (Top)	0.18	0.16	0.09	14.2	35.1
2	0.11	0.16	0.10	20.6	35.3
3	0.20	0.24	10.0	20.8	35.3
4	0.03	3.78	17.3	21.8	34.7
5 (Bottom)	5.35	20.8	26.9	22.6	35.7

DATA USED IN THE PREPARATION OF FIGURES 6, 8, 13 AND 14 (CONT'D)

III. DISPERSANTS

Compositions:

20.0 wt% Carbon (Raven 1170)
79.0 wt% DF-2 (AL-6766F)
1.0 wt% Dispersant

} In All Blends except when Al-Octoate is used

or

20.0 wt% Carbon (Raven 1170)
79.7 wt% DF-2 (AL-6766F)
0.3 wt% Aluminum octoate

Mixing Device: Homogenizer
Mixint Time: 30 minutes
Settling Period: 48.0 hours

	Dispersants			
	Lecithin	TLA	D-5200	Al-octoate
Sections:	% C	% C	% C	% C
1 (Top)	15.3	18.7	14.2	19.3
2	21.0	20.3	20.6	21.0
3	22.2	20.8	20.8	20.9
4	25.4	20.8	21.8	21.1
5 (Bottom)	24.8	21.2	22.6	21.6

IV. ATTRITION TIME

Composition:

20.0 wt% Carbon (Raven 1170)
79.0 wt% DF-2 (AL-6766F)
1.0 wt% Lecithin

Mixing Device: Attritor
Settling Period: 48.0 hours

	Attrition Time hours				
	0.0	0.5	1.0	5.0	11.0
Sections	% C	% C	% C	% C	% C
1 (Top)	0.12	15.9	19.7	22.5	18.1
2	17.8	20.8	20.9	23.4	21.7
3	33.5	20.5	20.7	25.5	22.0
4	35.7	21.0	20.4	26.0	22.0
5 (Bottom)	37.3	21.7	20.6	25.9	21.7

APPENDIX D

TRADE NAMES OF DISPERSANTS LISTED IN TABLE 7 AND THE MANUFACTURERS' NAMES AND ADDRESSES

No.*	Trade Name	Manufacturer	Address	Telephone No.
1	AMP	IPM Chemical Group Inc.	1331 S. 1st St. Terre Haute, IN 47808	812/232-0121
2	Makon	Stepan Chemical Co.	Edens & Winnetka Roads Northfield, IL 60093	312/446-7500
3	Igepal CA 890	GAF Corp.	Chemical Products 140 W. 51st St. New York, NY 10020	212/582-7600
4	Triton X-100	Rohm & Haas Co.	Independence Mall West Philadelphia, PA 19105	215/592-3000
5	Ucon Fluid	Union Carbide Corp.	Chemicals & Plastics 270 Park Avenue New York, NY 10017	212/551-5344
6	Lecithin WD	Troy Chemical Corp.	1 Avenue L Newark, NJ 07105	201/589-2500
7	Richamide	The Richard Co.	2400 East Devon Ave. Suite 187 Des Plaines, IL 60018	312/297-0154
8	Clindrol	Clintwood Chemical Co.	4342 S. Wolcott Ave. Chicago, IL 60609	312/927-1071
9	Clindrol Super 100CG	Clintwood Chemical Co.	4342 S. Wolcott Ave. Chicago, IL 60609	312/927-1071
10	Kemamide	Humko Sheffield Chemicals	Division Kraftco P.O. Box 398 Memphis, TN 38101	901/682-9111

* Numbers listed here correspond with numbers of dispersants listed in Table 7.

APPENDIX D

TRADE NAMES OF DISPERSANTS LISTED IN TABLE 7 AND THE MANUFACTURERS' NAMES AND ADDRESSES (Cont'd)

No.*	Trade Name	Manufacturer	Address	Telephone No.
11	Alrosol-O	Ciba-Geigy Corp.	Geigy Chemical Corp. P.O. Box 11422 Greensboro, NC 27409	919/292-7100
12	Atlas G-3300	I.C.I.United States Inc.	Atlas Chemicals Div. New Murphy Rd & Concord Pike Wilmington, DE 19899	302/575-3000
13	Aldo MLD	Glyco Chemicals Inc.	51 Weaver St. Greenwich, CT 06830	203/661-1000
14	Amerchol	Amerchol (CPC International Inc.)	Amerchol Park Edison, NJ 08817	201/287-1600
15	Ameroxol	Amerchol(CPC International Inc.)	Amerchol Park Edison, NJ 08817	201/287-1600
16	Pegosperse 100-ML	Glyco Chemicals Inc.	51 Weaver St. Greenwich, CT 06830	203/661-1000
17	Pegosperse 50-MS	Glyco Chemicals Inc.	51 Weaver St. Greenwich, CT 06830	203/661-1000
18	Tween 80	ICI United States Inc.	Atlas Chemicals Div. New Murphy Rd & Concord Pike Wilmington, DE 19899	302/575-3000
19	Span 80	ICI United States Inc.	Atlas Chemicals Div. New Murphy Rd & Concord Pike Wilmington, DE 19899	302/575-3000

* Numbers listed here correspond with numbers of dispersants listed in Table 7.

APPENDIX D

TRADE NAMES OF DISPERSANTS LISTED IN TABLE 7 AND THE MANUFACTURER'S NAMES AND ADDRESSES (Cont'd)

No.*	Trade Name	Manufacturer	Address	Telephone No.
20	Span 85	ICI United States Inc.	Atlas Chemical Division New Murphy Rd & Concord Pike Wilmington, DE 19899	302/575-3000
21	Artacel 85	ICI United States Inc.	Atlas Chemical Division New Murphy Rd & Concord Pike Wilmington, DE 19899	302/575-3000
22	Span 65	ICI United States Inc.	Atlas Chemical Division New Murphy Rd & Concord Pike Wilmington, DE 19899	302/575-3000
23	Atpet	ICI United States Inc.	Atlas Chemical Division New Murphy Rd & Concord Pike Wilmington, DE 19899	302/575-3000
24	Atlas G2090	ICI United States Inc.	Atlas Chemical Division New Murphy Rd & Concord Pike Wilmington, DE 19899	302/575-3000
25	Atmul 124	ICI United States Inc.	Atlas Chemical Division New Murphy Rd & Concord Pike Wilmington, DE 19899	302/575-3000
26	Atmul 80	ICI United States Inc.	Atlas Chemical Division New Murphy Rd & Concord Pike Wilmington, DE 19899	302/575-3000
27	Nonisol	GIBA-Geigy Corp.	444 Saw Mill River Rd. Ardsley, NY 10502	914/478-3131

* Numbers listed here correspond with numbers of dispersants listed in Table 7.

APPENDIX D

TRADE NAMES OF DISPERSANTS LISTED IN TABLE 7 AND THE MANUFACTURER'S NAMES AND ADDRESSES (Cont'd)

No.*	Trade Name	Manufacturer	Address	Telephone No.
28	Amergy 5200	DREW Chemical Corp.	701 Jefferson Rd. Parsippany, NJ 07054	201/263-7600
29	Jaguar CMHP	Stein Hall and Co., Inc.	605 Third Ave. New York, NY 10016	212/764-8830
30	Richamate 3555	The Richardson Co.	Organic Chemical Div. 2400 East Devon Ave. Suite 187 Des Plaines, IL 60018	312/297-3570
31	Richonic Acid B	The Richardson Co.	Organic Chemical Div. 2400 East Devon Ave. Suite 187 Des Plaines, IL 60018	312/297-3570
32	Richonol AM	The Richardson Co.	Organic Chemical Div. 2400 East Devon Ave. Suite 187 Des Plaines, IL 60018	312/297-3570
33	Lignox	NL Baroid Div.	National Lead Co. 2404 SW Freeway Houston, TX 77001	713/527-1149
34	Tamol 731	Rohm and Haas Co.	Independence Mall West Philadelphia, PA 19105	215/592-3000
35	DAXAD 11G	WR Grace and Co.	Organic Chemicals Div. 55 Hayden Ave. Lexington, MA 02173	617/861-6600

* Numbers listed here correspond with numbers of dispersants listed in Table 7.

APPENDIX D

TRADE NAMES OF DISPERSANTS LISTED IN TABLE 7 AND THE MANUFACTURER'S NAMES AND ADDRESSES (Cont'd)

No.*	Trade Name	Manufacturer	Address	Telephone No.
36	Sarkosyl NL-30	Ciba-Geigy Corp.	Dyestuff & Chemicals Div. P. O. Box 11422 Greensboro, NC 27409	919/292-7100
37	Sarkosyl NL-97	Ciba-Geigy Corp.	Dyestuff & Chemicals Div. P. O. Box 11422 Greensboro, NC 27409	919/292-7100
38	Aerosol OT	Mona Industries Inc.	65 E. 23rd St. Paterson, NJ 07542	201/274-8220
39	Triton GR 5M	Rohm and Haas Co.	Independence Mall West Philadelphia, PA 19105	215/592-3000
40	Marasperse CB	American Can Co.	Chemical Products Dept. American Lane Greenwich, CN 06830	203/552-3785
41	Gantrez AN-169	GAP Corp.	Chemical Division 140 West 51st St. New York, NY 10020	212/582-7600
42	Gafac	GAF Corp.	Chemical Division 140 West 51st St. New York, NY 10020	212/582-7600
43	Amine - O	Ciba-Geigy Corp.	Dyestuff & Chemical Div. P. O. Box 11422 Greensboro, NC 27409	919/292-7100

* Numbers listed here correspond with numbers of dispersants listed in Table 7.

APPENDIX D

TRADE NAMES OF DISPERSANTS LISTED IN TABLE 7 AND THE MANUFACTURER'S NAMES AND ADDRESSES (Cont'd)

No.*	Trade Name	Manufacturer	Address	Telephone No.
44	Quaternary - O	Ciba-Geigy Corp.	Dyestuff & Chemical Div. P. O. Box 11422 Greensboro, NC 27409	919/292-7100
45	Unamine - C	Lonza Inc.	22-10 Route 208 Fair Lawn, NJ 07410	201/791-7500
46	Alkaterge - T	IMC Chemical Group Inc.	1331 S. 1st St. Terre Haute, IN 47808	812/232-0121
47	Schercomul - B	Scher Chemicals Inc.	P. O. Box 538 Allwood Station Clifton, NJ 07012	201/471-1300
48	Miranol S2M-TEA	Miranol Chemical Co., Inc.	277 Coit St. Irvington, NJ 07111	201/399-7000
49	Miranol J2M	Miranol Chemical Co., Inc.	277 Coit St. Irvington, NJ 07111	201/399-7000
50	Alumagel	Witco Chemical Corp.	Organics Div. 277 Park Ave. New York, NY 10017	212/826-1000
51	Aluminum Octoate	Witco Chemical Corp.	Organics Div. 277 Park Ave. New York, NY 10017	212/826-1000
52	Aluminum Stearate	Witco Chemical Corp.	Organics Div. 277 Park Ave. New York, NY 10017	212/826-1000

* Numbers listed here correspond with numbers of dispersants listed in Table 7.

APPENDIX D

TRADE NAMES OF DISPERSANTS LISTED IN TABLE 7 AND THE MANUFACTURER'S NAMES AND ADDRESSES (Cont'd)

No.*	Trade Name	Manufacturer	Address	Telephone No.
53	Ammonium Stearate	Diamond Shamrock Corp.	Process Chemical Div. 350 Mt. Kemble Ave. Morristown, NJ 07960	201/267-1000
54	Lead Octoate	Pfaltz & Bauer Inc.	375 Fairfield Ave. Stamford, CT 06902	203/357-8700
55	Lead Stearate	Witco Chemical Corp.	Organic Division 277 Park Avenue New York, NY 10017	212/826-1000
56	Lithium Stearate	Witco Chemical Corp.	Organic Division 277 Park Avenue New York, NY 10017	212/826-1000
57	Zinc Stearate	Witco Chemical Corp.	Organic Division 277 Park Avenue New York, NY 10017	212/826-1000
58	TLA 202	Texaco, Inc.	P. O. Box 430 4800 Fournace Place Bellaire, TX 77401	713/666-8000
59	LV 1776 Alkyl	Lawter Chemicals, Inc.	990 Skokie Boulevard Northbrook, IL 60062	312/498-4700

* Numbers listed here correspond with numbers of dispersants listed in Table 7.

APPENDIX E. PROGRAM BRIEF

Program Title: Development of Mist Flashback Fluid Flammability Test

Sponsor: U.S. Army MERADCOM

Contract No.: DAAD05-70-C-0250

SwRI Project No.: 10-2798

Start/Complete Dates: 1970/1972

Reports or Publications: Weatherford, W. D., Jr., and Schaekel, F. W.,"Emulsified Fuels and Aircraft Safety," AGARD/NATO 37th PEP Meeting "Aircraft Fuels, Lubricants, and Fire Safety," The Hague, Netherlands, May 1971 (AGARD-CP-84-71, pp. 21,1-21,12).

Weatherford, W. D. Jr., and Wright, B. R., "Status of Research on Antimist Aircraft Turbine Engine Fuels in the United States," AGARD/NATO 45th PEP Meeting "Aircraft Fire Safety," Rome, Italy, AFLRL No. 69, April 1975 (AGARD-CP-166, pp. 2, 1-2, 12, DDC No. AD-A011341).

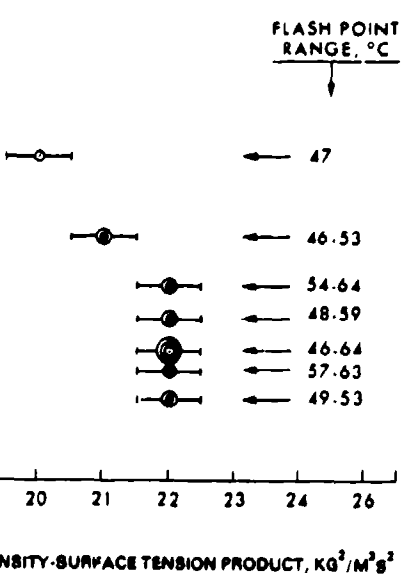
PROGRAM SYNOPSIS

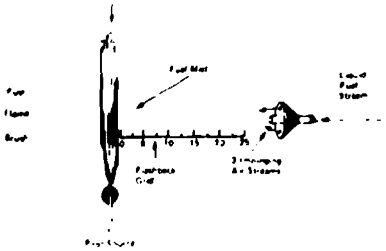
Technical Objectives: Develop a quantitative bench-scale laboratory technique for assessing differences in mist flammability characteristics among various flammable liquids.

Approach: Fuel is delivered through a capillary at a controlled rate, and three impinging air streams form a mist at the point of impingement. The fuel mist passes through an overwhelming ignition source to avoid marginal ignition problems. The extent of flashback from the ignition source toward the fuel capillary is interpreted as a measure of mist flammability. Flashback is recorded utilizing a video camera and tape recorder. These results can then be carefully evaluated at some later time by measuring directly from a graduated scale located beyond the flame.

Accomplishments: A mist flashback rating, expressed as a mean distance of flashback, is assigned to the fuel. This average rating is based on triplicate experiments, each conducted at three different misting air rates (ranging from relatively low to extremely high shear conditions), i.e., the average of nine values.

The sensitivity of this measurement technique is best illustrated by describing results obtained with a series of fourteen base-fuel samples, all meeting Jet-A or the tentative JP-8 specification. The extent of mist flashback with various JP-8 neat fuels ranges from 16.5 cm (6.5 in.) to greater than 20 cm (8.2 in.). It should be noted that JP-4 produces a mist flashback of 21 cm (8.2 in.) in this test procedure. Hence, the most flammable JP-8 fuel shown in this figure is almost indistinguishable from JP-4 under misting conditions. On the other hand, the majority of the fuel samples were significantly less flammable in the mist form than this most flammable JP-8 fuel. As illustrated in the lower right, the flash points of these various samples ranged from 46° to 64°C (114° to 148°F), and no correlation between flash point and mist flashback is evident. The data are presented in terms of the product of surface tension and density; however, it is emphasized that the controlling physiocochemical properties for mist flammability in this apparatus have not yet been established, and the presentation is made on this basis only as a graphical convenience.





APPENDIX E. PROGRAM BRIEF

Program Title: Development of Impact Dispersion Fluid Flammability Test

Sponsor: U.S. Army MERADCOM

Contract No.: DAAD05-67-C-0354/DAAD05-70-C-0250/DAAK-73-C-0221/
DAAG53-76-C-0003/DAAK70-78-C-0001

SwRI Project No.: 10-2078/10-2798/10-3630/10-4296/10-5070

Start/Complete Dates: 1969/1978 Continuing Refinement of Facility and Procedures

Reports or Publications: Weatherford, W. D., Jr., and Schaekel, F. W., "Emulsified Fuels and Aircraft Safety," AGARD/NATO 37th PEP Meeting "Aircraft Fuels, Lubricants, and Fire Safety," The Hague, Netherlands, May 1971 (AGARD-CP-84-71, pp. 21, 1-21, 12).

Weatherford, W. D., Jr., and Wright, B. R., "Status of Research on Antimist Aircraft Turbine Engine Fuels in the United States," AGARD/NATO 45th PEP Meeting "Aircraft Fire Safety," Rome, Italy, April 1975 (AGARD-CP-166, pp. 2, 1-2, 12, DDC No. AD-A011341).

Weatherford, W. D. Jr., and Schaekel, F. W., "U.S. Army Helicopter Modified Fuel Development Program—Review of Emulsified and Gelled Fuel Studies," prepared by Southwest Research Institute, U.S. Army Fuels and Lubricants Research Laboratory, under U.S. Army Contract No. DAAK02-73-C-0221, AFLRL No. 69, June 1975 (DDC No. AD-A023848).

PROGRAM SYNOPSIS

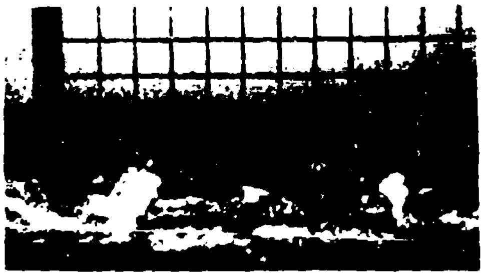
Technical Objectives: Develop a repeatable bench-scale laboratory technique for assessing fire-safety characteristics of various flammable liquids.

Approach: Impact dispersion experiments are conducted in a well ventilated enclosed facility developed for this purpose. These tests involve allowing a 2-liter glass vessel, containing about 1.2 kg of fuel, to fall freely 6 meters onto a steel target plate, originally embedded in concrete and surrounded on two sides by gas pilot flames. In the present facility, the target plate comprises a horizontal, elevated 2.5 cm-thick steel plate with electric surface heaters attached to its under side so that its surface temperature can be adjusted and controlled independently.

The relatively low vertical velocity of 11 meters per second developed by the glass vessel during this free fall corresponds to total occupant survivability during a vertical helicopter crash, but it is near the onset of marginal survivability. The glass containers are filled to an ullage of about 2 percent of the total volume for each test. A television camera (with zoom lens) is located about 6 meters from the impact point, and this is used to document the test results on video tape. A background grid provides a dimensional frame of reference, and subsequent examination of the video tape by slow motion (and stop action) provides reduced data. Tests are conducted at several different temperature levels, from about 25° to 99° by preheating the fuel sample and the steel target plate to the desired temperatures.

Accomplishments: The following data reduction system placed the impact dispersion results on a semiquantitative basis. A rating from "A" through "E" is assigned to the results of each experiment, depending upon the observed flammability characteristics. These range from "no pilot flame enlargement" for highly effective antimist fuels through "pilot dimensions less than doubled," "pilot flames totally obscured by transient mist fireball" (neat, low-volatility fuels), to "coalesced fireball with simultaneous pool burning" (volatile liquid fuels). This method of quantifying the results of impact dispersion tests has proved usable and correlatable with other experimentally measured flammability properties.

Heated Impact Pad, Gas Pilot Array, and Fluid Container With Solenoid Release (Lowered for Photograph)



Peak Splash With No Fireball (Typical of Antimist Fuels)

Peak Mist Fireball

APPENDIX E. PROGRAM BRIEF

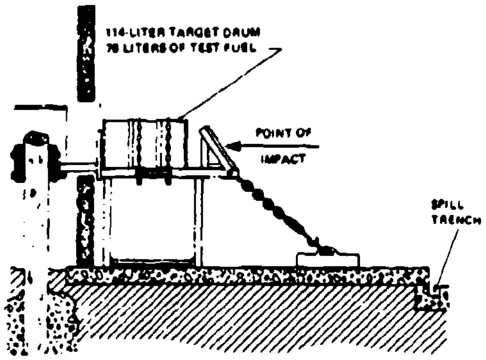
Program Title:	Development of Simulated Full-Scale Ballistic Test for Evaluation of Fluid Fire Vulnerability
Sponsor:	U.S. Army; MERADCOM
Contract No.:	DAAG53-76-C-0003, DAAK70-78-C-0001, DAAK70-80-C-0001
SwRI Project No.:	10-4296, 10-5070, 10-5857
Start/Complete Dates:	1976/present
Reports or Publications:	Wright, B. R. and Weatherford, W. D., Jr., "A Technique for Evaluating Fuel and Hydraulic Fluid Ballistic Vulnerability," Interim Report AFLRL No. 89, prepared by U.S. Army Fuels and Lubricants Research Laboratory, Southwest Research Institute, Government Accession No. AD AO55058, April 1975.

PROGRAM SYNOPSIS

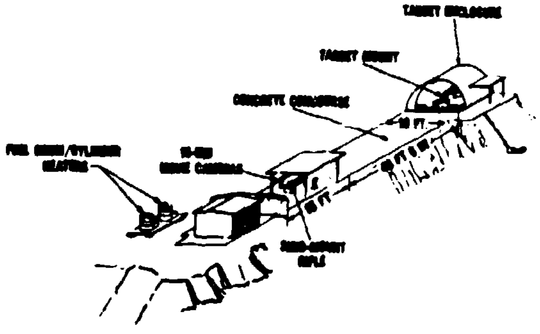
Technical Objectives: To develop a ballistic test that evaluates the effectiveness of fire-resistant-fuel formulations and to compare flammability characteristics of various hydraulic fluids.

Approach: A relatively inexpensive ballistic test procedure has been developed for evaluating the relative fire vulnerability of various fluids of interest for Army applications. The technique employs 20-mm HEIT projectiles fired into partially filled fluid containers, and yields repeatable results which establish both transient fireball effects and residual burning tendencies. Appropriate experimental procedures and conditions, such as target fluid temperature, were established, and efficacy and repeatability were evaluated by conducting a total of 184 experiments. These latter experiments were conducted with fire-resistant fuel (FRF) and fire-resistant hydraulic fluid (FRH) candidates. The resulting experimental data agree with flammability measurements made with laboratory and bench-scale techniques and provide an apparently realistic assessment of ballistic vulnerability.

Accomplishments: A new flammability test procedure has been developed that will span the gap between laboratory scale and full-scale ballistic tests. The 20-mm HEIT projectile has proven to be a very energetic and repeatable ignition source, and results have correlated well with subsequent testing using 3.2-inch precision shaped charges.



Fuel Drum Target Assembly



Ballistic Range

DISTRIBUTION LIST

DEPARTMENT OF DEFENSE

DEFENSE DOCUMENTATION CTR
CAMERON STATION 12
ALEXANDRIA VA 22314

DEPT OF DEFENSE
ATTN: DASA(MRA&L)-ES(MR DYKEMAN) 1
WASHINGTON DC 20301

COMMANDER
DEFENSE LOGISTICS AGY
ATTN DLA-SME (MRS P MCLAIN) 1
CAMERON STATION
ALEXANDRIA VA 22314

COMMANDER
DEFENSE FUEL SUPPLY CTR
ATTN: DFSC-T 1
CAMERON STA
ALEXANDRIA VA 22314

COMMANDER
DEFENSE GENERAL SUPPLY CTR
ATTN: DGSC-SSA 1
RICHMOND VA 23297

DEPARTMENT OF THE ARMY

HQ, DEPT OF ARMY
ATTN: DALO-TSE 1
DAMA-CSS-P (DR BRYANT) 1
DAMA-ARZ (DR CHURCH) 1
DAMA-SMZ 1
WASHINGTON DC 20310

CDR
U.S. ARMY MOBILITY EQUIPMENT R&D COMMAND
Attn: DRDME-GL 10
FORT BELVOIR VA 22060

CDR
US ARMY MATERIAL DEVEL&READINESS COMMAND
ATTN: DRCLDC (MR BENDER) 1
DRCMM-SP (LTC O'CONNER) 1
DRCQA-E (MR SMART) 1
DRCDE-DG (MR MCGOWAN) 1
DRCIS-S (MR SPRAGUE) 1
DRCIS-C (LTC CROW) 1
5001 EISENHOWER AVE
ALEXANDRIA VA 22333

CDR
US ARMY TANK-AUTOMOTIVE R&D CMD
ATTN DRDTA-NW (TWVMO) 1
DRDTA-RG (MR HAMPARIAN) 1
DRDTA-NS (DR PETRICK) 1
DRDTA-J 1
WARREN MI 48090

CDR
US ARMY TANK-AUTOMOTIVE MATERIAL READINESS CMD
ATTN DRSTA-G (COL MILLS) 1
DRSTA-M 1
DRSTA-GBP (MR MCCARTNEY) 1
WARREN MI 48090

DIRECTOR
US ARMY MATERIAL SYSTEMS ANALYSIS AGENCY
ATTN DRXSY-CM 1
DRXSY-S 1
DRXSY-L 1
ABERDEEN PROVING GROUND MD 21005

CDR
US ARMY APPLIED TECH LAB
ATTN DAVDL-ATL-ATP (MR MORROW) 1
DAVDL-ATL 1
FORT EUSTIS VA 23604

HQ, 172D INFANTRY BRIGADE (ALASKA)
ATTN AFZT-DI-L 1
AFZT-DI-M 1
DIRECTORATE OF INDUSTRIAL OPERATIONS
FT RICHARDSON AK 99505

CDR
US ARMY GENERAL MATERIAL & PETROLEUM ACTIVITY
ATTN STSGP-FT (MS GEORGE) 1
STSGP-PE 1
STSGP (COL HILL) 1
NEW CUMBERLAND ARMY DEPOT
NEW CUMBERLAND PA 17070

CDR
US ARMY ARRCOM, LOG ENGR DIR
ATTN DRSAT-LEM (MR MENKE) 1
ROCK ISLAND ARSENAL IL 61299

CDR
US ARMY COLD REGION TEST CENTER
ATTN STECR-TA (MR HASLEM) 1
APO SEATTLE 98733

CDR
US ARMY RES & STDZN GROUP
(EUROPE)
ATTN DRXSN-E-RA 1
BOX 65
FPO NEW YORK 09510

HQ, US ARMY AVIATION R&D CMD
ATTN DRDAV-D (MR CRAWFORD) 1
DRDAV-N (MR BORGMAN) 1
DRDAV-E (MR LONG) 1
P O BOX 209
ST LOUIS MO 63166

CDR
US ARMY FORCES COMMAND
ATTN AFLG-REG (MR HAMMERSTROM) 1
AFLG-POP (MR COOK) 1
FORT MCPHERSON GA 30330

CDR
US ARMY ABERDEEN PROVING GROUND
ATTN STEAP-MT 1
STEAP-MT-U (MR DEAVER) 1
ABERDEEN PROVING GROUND MD 21005

CDR
US ARMY YUMA PROVING GROUND
ATTN STEYP-MT (MR DOEBBLER) 1
YUMA AR 85364

MICHIGAN ARMY MISSILE PLANT
OFC OF PROJ MGR, XM-1 TANK SYS
ATTN DRCPM-GCM-S 1
WARREN MI 48090

MICHIGAN ARMY MISSILE PLANT
PROG MGR, FIGHTING VEHICLE SYS
ATTN DRCPM-FVS-SE 1
WARREN MI 48090

PROJ MGR, M60 TANK DEVELOPMENT
ATTN DRCPM-M60-E 1
WARREN MI 48090

PROG MGR, M113/M113A1 FAMILY
OF VEHICLES
ATTN DRCPM-M113 1
WARREN MI 48090

PROJ MGR, MOBILE ELECTRIC POWER
ATTN DRCPM-MEP-TM 1
7500 BACKLICK ROAD
SPRINGFIELD VA 22150

OFC OF PROJ MGR, IMPROVED TOW
VEHICLE
US ARMY TANK-AUTOMOTIVE R&D CMD
ATTN DRCPM-ITV-T 1
WARREN MI 48090

CDR
US ARMY EUROPE & SEVENTH ARMY
ATTN AEAGC-FMD 1
APO NY 09403

PROJ MGR, PATRIOT PROJ OFC
ATTN DRCPM-MD-T-G 1
US ARMY DARCOM
REDSTONE ARSENAL AL 35809

CDR
THEATER ARMY MATERIAL MGMT
CENTER (200TH)
DIRECTORATE FOR PETROL MGMT
ATTN AEAGD-MM-PT-Q (MR PINZOLA) 1
ZWEIBRUCKEN
APO NY 09052

CDR
US ARMY RESEARCH OFC
ATTN DRXRO-EG 1
DRXRO-CB (DR GHIRARDELLI) 1
P O BOX 12211
RSCH TRIANGLE PARK NC 27709

DIR
US ARMY R&T LAB
ADVANCED SYSTEMS RSCH OFC
ATTN MR D WILSTED 1
AMES RSCH CTR
MOFFITT FIELD CA 94035

CDR
TOBYHANNA ARMY DEPOT
ATTN SDSTO-TP-S 1
TOBYHANNA PA 18466

DIR
US ARMY MATERIALS & MECHANICS
RSCH CTR
ATTN DRXMR 1
WATERTOWN MA 02172

CDR
US ARMY DEPOT SYSTEMS CMD
ATTN DRSDS 1
CHAMBERSBURG PA 17201

CDR
US ARMY WATERVLIET ARSENAL
ATTN SARWY-RDD 1
WATERVLIET NY 12189

CDR
US ARMY LEA
ATTN DALO-LEP 1
NEW CUMBERLAND ARMY DEPOT
NEW CUMBERLAND PA 17070

CDR
US ARMY GENERAL MATERIAL &
PETROLEUM ACTIVITY
ATTN STSGP-PW (MR PRICE) 1
SHARPE ARMY DEPOT
LATHROP CA 95330

CDR
US ARMY FOREIGN SCIENCE & TECH
CENTER
ATTN DRXST-MT1 1
FEDERAL BLDG
CHARLOTTESVILLE VA 22901

CDR
DARCOM MATERIAL READINESS
SUPPORT ACTIVITY (MRSA)
ATTN DRXMD-MS 1
LEXINGTON KY 40511

HQ, US ARMY T&E COMMAND
ATTN DRSTE-TO-O 1
ABERDEEN PROVING GROUND, MD 21005

HQ, US ARMY ARMAMENT R&D CMD
ATTN DRDAR-SCM-OO (MR MUFFLEY) 1
DRDAR-TST-S 1
DOVER NJ 07801

HQ, US ARMY TROOP SUPPORT &
AVIATION MATERIAL READINESS
COMMAND
ATTN DRSTS-MFG (2) 1
DRCPO-PDE (LTC FOSTER) 1
4300 GOODFELLOW BLVD
ST LOUIS MO 63120

DEPARTMENT OF THE ARMY
CONSTRUCTION ENG RSCH LAB
ATTN CERL-EM 1
P O BOX 4005
CHAMPAIGN IL 61820

HQ
US ARMY TRAINING & DOCTRINE CMD
ATTN ATCD-SL (MR RAFFERTY) 1
FORT MONROE VA 23651

DIRECTOR
US ARMY RSCH & TECH LAB (AVRADCOM)
PROPULSION LABORATORY
ATTN DAVDL-PL-D (MR ACURIO) 1
21000 BROOKPARK ROAD
CLEVELAND OH 44135

CDR
US ARMY NATICK RES & DEV CMD
ATTN DRDNA-YEP (DR KAPLAN) 1
NATICK MA 01760

CDR
US ARMY TRANSPORTATION SCHOOL
ATTN ATSP-CD-MS 1
FORT EUSTIS VA 23604

CDR
US ARMY QUARTERMASTER SCHOOL
ATTN ATSM-CD-M 1
ATSM-CTD-MS 1
ATSM-TNG-PT (COL VOLPE) 1
FORT LEE VA 23801

HQ, US ARMY ARMOR SCHOOL
ATTN ATSB-TD 1
FORT KNOX KY 40121

CDR
US ARMY LOGISTICS CTR
ATTN ATCL-MS (MR A MARSHALL) 1
FORT LEE VA 23801

CDR
US ARMY FIELD ARTILLERY SCHOOL
ATTN ATSF-CD 1
FORT SILL OK 73503

CDR
US ARMY ORDNANCE CTR & SCHOOL
ATTN ATSL-CTD-MS 1
ABERDEEN PROVING GROUND MD 21005

CDR
US ARMY ENGINEER SCHOOL
ATTN ATSE-CDM 1
FORT BELVOIR VA 22060

CDR
US ARMY INFANTRY SCHOOL
ATTN ATSH-CD-MS-M 1
FORT BENNING GA 31905

CDR
US ARMY AVIATION CTR & FT RUCKER
ATTN ATZQ-D 1
FORT RUCKER AL 36362

DEPARTMENT OF THE NAVY

CDR
NAVAL AIR PROPULSION CENTER
ATTN PE-71 1
PE-72 (MR D'ORAZIO) 1
P O BOX 7176
TRENTON NJ 06828

CDR
NAVAL SHIP ENGINEERING CTR
CODE 6101F (MR R LAYNE) 1
WASHINGTON DC 20362

CDR
DAVID TAYLOR NAVAL SHIP R&D CTR
CODE 2830 (MR G BOSMAJIAN) 1
CODE 2831 1
ANNAPOLIS MD 21402

JOINT OIL ANALYSIS PROGRAM -
TECHNICAL SUPPORT CTR 1
BLDG 780
NAVAL AIR STATION
PENSACOLA FL 32508

DEPARTMENT OF THE NAVY
HQ, US MARINE CORPS
ATTN LPP (MAJ SANBERG) 1
LMM (MAJ GRIGGS) 1
WASHINGTON DC 20380

CDR
NAVAL AIR SYSTEMS CMD
ATTN CODE 52032E (MR WEINBURG) 1
CODE 53645 1
WASHINGTON DC 20361

CDR
NAVAL AIR DEVELOPMENT CTR
ATTN CODE 60612 (MR L STALLINGS) 1
WARMINSTER PA 18974

CDR
NAVAL RESEARCH LABORATORY
ATTN CODE 6170 (MR H RAVNER) 1
CODE 6180 1
CODE 6110 (DR HARVEY) 1
WASHINGTON DC 20375

CDR
NAVAL FACILITIES ENGR CTR
ATTN CODE 1202B (MR R BURRIS) 1
CODE 120B (MR BUSCHELMAN) 1
200 STONEWALL ST
ALEXANDRIA VA 22322

CHIEF OF NAVAL RESEARCH
ATTN CODE 473 (DR R MILLER) 1
ARLINGTON VA 22217

CDR
NAVAL AIR ENGR CENTER
ATTN CODE 92727 1
LAKEHURST NJ 08733

CDR
NAVY FACILITIES ENGRG CMD
CIVIL ENGR SUPPORT OFC
CODE 15312A (ATTN EOC COOK) 1
NAVAL CONSTRUCTION BATTALION CTR
PORT HUENEME CA 93043

CDR, NAVAL MATERIAL COMMAND
ATTN MAT-08T3 (DR A ROBERTS) 1
CP6, RM 606
WASHINGTON DC 20360

CDR
NAVY PETROLEUM OFC
ATTN CODE 40 1
CAMERON STATION
ALEXANDRIA VA 22314

CDR
MARINE CORPS LOGISTICS SUPPORT
BASE ATLANTIC
ATTN CODE P841 1
ALBANY GA 31704

DEPARTMENT OF THE AIR FORCE

HQ, USAF
ATTN RDPT 1
WASHINGTON DC 20330

HQ AIR FORCE SYSTEMS CMD
ATTN AFSC/DLF (LTC RADLOF) 1
ANDREWS AFB MD 20334

CDR
US AIR FORCE WRIGHT AERONAUTICAL LAB
ATTN AFWAL/POSF (MR CHURCHILL) 1
AFWAL/POSL (MR JONES) 1
WRIGHT-PATTERSON AFB OH 45433

CDR
USAF SAN ANTONIO AIR LOGISTICS CTR
ATTN SAALC/SFQ (MR MAKRIS) 1
SAALC/MMPRR (MR ELLIOT) 1
KELLY AIR FORCE BASE, TX 78241

CDR
US AIR FORCE WRIGHT AERONAUTICAL LAB
ATTN AFWAL/MLSE (MR MORRIS) 1
AFWAL/MLBT 1
WRIGHT-PATTERSON AFB OH 45433

CDR
USAF WARNER ROBINS AIR LOGISTIC CTR
ATTN WR-ALC/MMIRAB-1 (MR GRAHAM) 1
ROBINS AFB GA 31098

OTHER GOVERNMENT AGENCIES

US DEPARTMENT OF TRANSPORTATION
ATTN AIRCRAFT DESIGN CRITERIA BRANCH 2
FEDERAL AVIATION ADMIN
2100 2ND ST SW
WASHINGTON DC 20590

US DEPARTMENT OF ENERGY
DIV OF TRANS ENERGY CONSERV 2
ALTERNATIVE FUELS UTILIZATION BRANCH
20 MASSACHUSETTS AVENUE
WASHINGTON DC 20545

DIRECTOR
NATL MAINTENANCE TECH SUPPORT CTR 2
US POSTAL SERVICE
NORMAN OK 73069

US DEPARTMENT OF ENERGY
BARTLESVILLE ENERGY RSCH CTR
DIV OF PROCESSING & THERMO RES 1
DIV OF UTILIZATION RES 1
BOX 1398
BARTLESVILLE OK 74003

SCI & TECH INFO FACILITY
ATTN NASA REP (SAK/DL) 1
P O BOX 8757
BALTIMORE/WASH INT AIRPORT MD 21240