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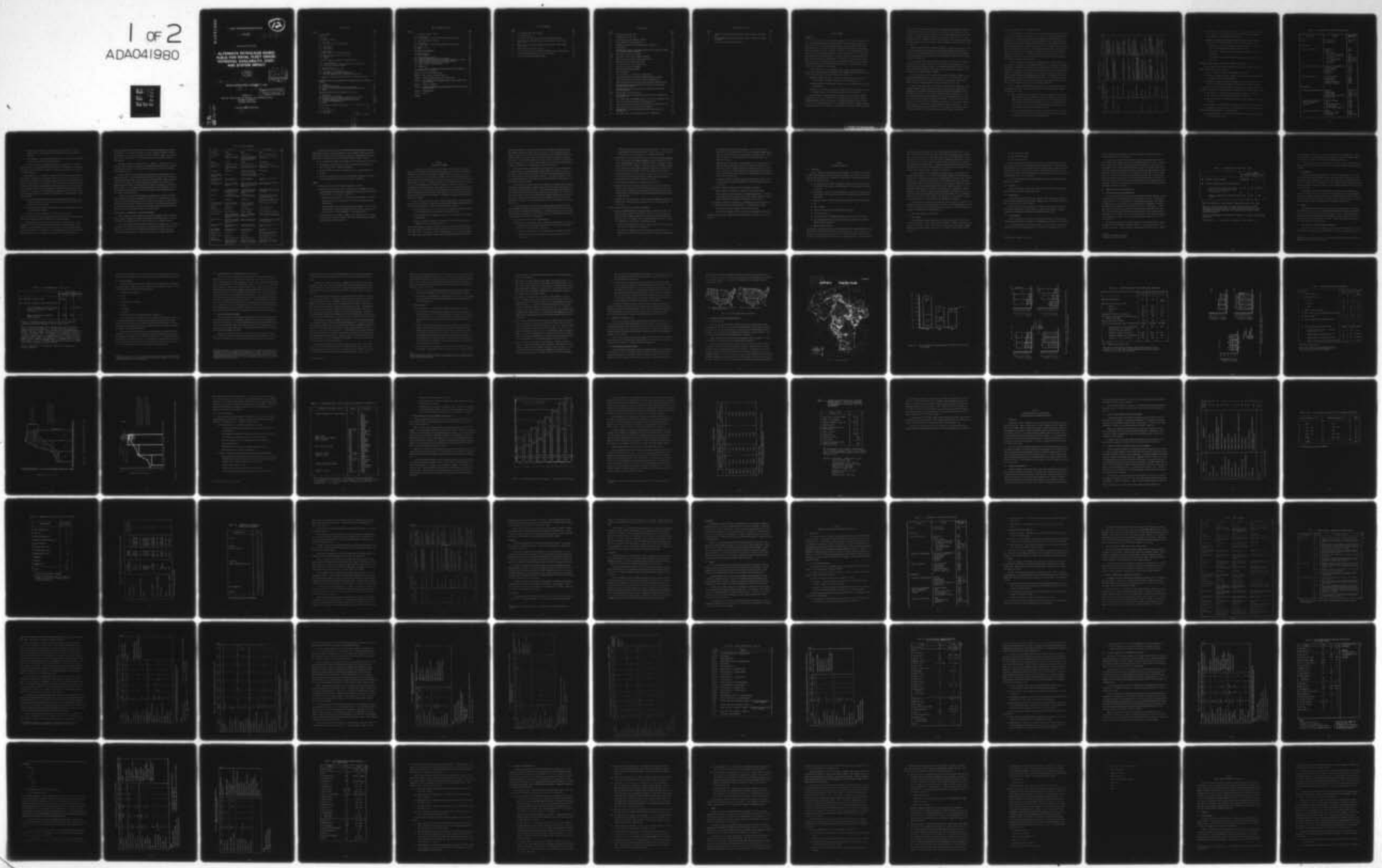

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ALTERNATE PETROLEUM BASED FUELS FOR NAVAL FLEET USAGE: POTENTIAL AVAILABILITY, COST, AND SYSTEM IMPACT.

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EXECUTIVE SUMMARY

INTRODUCTION

In recent years, particularly since the Oil Embargo of 1973, all major fuel consuming sectors in the United States Navy have become increasingly aware of the limited supply and high cost of petroleum fuels. Fuel is currently consumed by the Navy at the rate of 230,000 barrels per day. Energy conservation is one method to reduce this demand on petroleum resources and the resulting high annual expenditures for fuel. In addition, conservation is in the long-term interests of the country, since it assists nationwide efforts to "stretch" our remaining oil reserves. Alternatives to petroleum-based fuels are another option. One of these, shale oil, is being evaluated by the Navy in their 100,000 barrel oil shale experiment. Yet another option could be the use of fuels which do not meet all the requirements of military specifications (MILSPECS) for fuels, but which could be burned without significantly impairing naval operations. This approach could increase fuel availability and reduce costs to the Navy.

To assess the feasibility of using non-MILSPEC fuels in Navy combustion equipment, the David W. Taylor Naval Ship Research and Development Center ~~(DTNSRDC)~~ engaged the Aerotherm Division of Acurex Corporation to perform a study with the following objectives:

- 1) Determine whether there exists a large supply of fuel beyond that currently being procured for the Navy, which meets, or nearly meets, military specifications,
- 2) Determine whether any such comparable "nonspec" fuel is less expensive than the currently approved product, and
- 3) Assess, using all available information, the viability of storing, handling, and burning comparable "nonspec" fuels in naval systems, even if only on a limited basis.

Using procurement data obtained from DFSC and production data collected from a variety of government agencies, this study confirmed earlier investigations which indicated that the Navy's world-wide consumption of DFM is about 2 percent of the domestic production of middle distillate. For jet aircraft its total consumption of JP-5 is approximately 7 percent of the domestic production of kerosine-based jet fuel. The investigation also determined that shortages of MILSPEC fuels have occurred in the past, although they have been localized, temporary, and unpredictable. Moreover, JP-5 shortages will become worse if the other services (especially the Air Force) switch to JP-8. Therefore, it is prudent to assume that shortages will recur with increasing frequency, even though availability currently exceeds Navy demand at various times in some parts of the world. Since a substantial quantity of "comparable" commercial fuel is available, a Navy program to explore further any potential impacts on their fuel systems and combustion equipment of using these alternates would be justified.

Because civilian and military procurement procedures are, of necessity, different, we could not present any definitive conclusions about cost relationships between MILSPEC and comparable civilian fuels. Although any incremental costs that could be related to the special requirements imposed by the MILSPEC are not predictable, they currently appear to account for only a relatively small part of the total cost.

To indicate what options might be available to the Navy in a specific situation, Aerotherm identified possible substitutes for DFM and JP-5 that could be available to Navy facilities at Norfolk, Virginia, and San Diego, California. We then assessed the potential impacts that use of these readily available, comparable civilian fuels might have on the safety, performance, or maintainability of Navy ship-based combustion equipment.

This report contains, in addition to data which substantiates the above statements, a large amount of detailed information on fuel usage by fiscal year (FY 74 to 76) and location, civilian and military fuel prices, specific examples of additional fuel availability or spot shortages, refinery capacities, world-wide suppliers of middle distillate fuels, and the like.

To begin to assess the viability of using other fuels Aerotherm first compared naval marine equipment (shipboard combustion systems and ship-based aircraft) and operating requirements with corresponding civilian systems to determine why these two user groups place somewhat different requirements on their fuel. We then identified differences between the characteristics of fuels which satisfy the MILSPECS (Diesel Fuel Marine (DFM) for ship propulsion and hotel services and JP-5 for ship-based jet aircraft) and comparable civilian fuels. In each case military fuels were compared to civilian fuels which (1) satisfy ASTM specifications, (2) satisfy select oil refiners' specifications, or (3) have had their properties measured on samples of delivered fuel. These findings are summarized here and clearly show the need for a procedure to quantify the impact on naval combustion systems of using fuels which do not satisfy all elements of the MILSPEC.

DIFFERENCES BETWEEN NAVY AND CIVILIAN COMBUSTION SYSTEMS

Combustion equipment is used on Navy ships to provide both propulsive power and ship service (hot water, space heating, and electricity). For many years, marine propulsion has been supplied by steam turbines and large-bore diesel engines. These two types of combustion equipment will continue to supply fleet marine propulsion through the foreseeable future, although more recently aircraft-derivative marine gas turbines have entered fleet service to provide marine propulsion. The use of marine gas turbines will continue to grow, relative to steam turbines and diesel engines, but is not expected to be a major factor. The situation is different, however, for aircraft propulsion, due to the emphasis on jet aircraft for fleet aviation missions. Here gas turbines are the major source of propulsion. The smaller aircraft-derivative marine gas turbines are also beginning to be used for auxiliary power and hotel services, even though small- to medium-sized diesel engines have been the traditional source.

In general, Navy equipment and operating requirements place more stringent constraints on fuels than do the corresponding civilian equipment and operations. Navy equipment is more compact and operates at higher combustion intensities than civilian equipment. It also must supply greater peak power and is subject to larger and more frequent fluctuations in power level. Moreover, Navy equipment must operate more quietly, produce less visible exhaust, and be able to perform under hostile conditions without subjecting personnel to undue hazard. It must also be able to handle contaminated fuel, since naval fleet handling practices can result in contamination of fuels by water. In addition, Navy fuels must have a longer storage stability than civilian fuels, because Navy fuels must be capable of being stored for years without deteriorating.

Table S-1 summarizes those differences between Navy and civilian systems which may prevent the Navy from using civilian fuels under normal conditions. The major operating or equipment differences are as follows:

- Safety: Requirements are more stringent for Navy fuels because the ships may operate under hostile conditions. To reduce the risk of igniting leaked fuel, or at least to retard ignition, the MILSPEC for fuel carried on ships (i.e., DFM and JP-5) requires a higher flash point (60°C) than do specifications for civilian or land-based military fuels (e.g., No. 2 diesel or JP-4, which can have flash points of 40°C or lower). For JP-5, the MILSPEC also includes an explosiveness criterion.
- Storage: The Navy currently stores some fuel as a reserve for emergencies. Since this fuel must not degrade when stored for long periods, restrictions have to be placed on the composition of the fuel and the permissible additives.

TABLE S-1. NAVY AND CIVILIAN COMBUSTION EQUIPMENT[a]

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Equipment	Component or Condition That Is Different	Navy/Civilian Difference	Potential Impact From Use of Civilian Fuels
All Types of Equipment	All components	All Navy equipment is exposed to ordnance from military opponents; *civilian* operations are not	Navy fuel systems may be subjected to higher ambient temperatures and mechanical shocks which can induce fuel to burn/explode
All Marine Equipment	Fuel supply system	Navy ships have deactivated (or removed) preheaters and have changed pumps => fuel systems made comparable with DFM	Navy ships cannot use the heavier grades of fuels
Steam Boilers	Feedwater temperature	~ 120°C/≥ 137°C	Navy feedwater *temperature* is below acid *dewpoint* => corrosion of economizers in Navy equipment
	Superheater tube clearance	Clearance in Navy equipment is ~ 75 percent of that in civilian equipment	Navy equipment is more susceptible to fouling and clogging from contaminants in fuel
	Soot blowers	Do not exist on some Naval ships/usually present on civilian ships	Where soot blowers are missing, carbon deposits can build up to problem levels
	Refractory	From 50 to 400 percent more refractory in Navy ships	Combination of these two differences can lead to more thermal shock spalling and hot corrosive reactions in Navy ships
	Combustion intensity	*Navy boilers at 30 percent load (cruise)* generate ~90000 Btu/hr-ft^3, while commercial boilers at full load generate 70000 to 80000 Btu/hr-ft^3	
Diesel Engines	Power demands	Naval ships can require more frequent power changes over greater ranges	May cause excessive stack smoke in Navy ships
	Injector size	Nozzle size in Navy injectors may be ~ 70 percent of that in civilian equipment	May cause clogging and coking at the injector ports of Navy equipment
Marine GT	Operating conditions	Navy equipment may operate at higher power and greater combustion intensities than civilian equipment	Higher hot gas path temperatures (~ 38°C) accelerate sulfidation and other corrosion problems in Navy equipment
Aircraft GT	Operating conditions	See marine GT	See marine GT
	Nozzles per burner	Navy equipment may have multiple nozzles per burner	Smaller nozzle orifices in Navy engines => increase potential for coking in Navy engines
	Environment	Navy aircraft engines may operate at higher altitudes than civilian equipment	Navy fuel systems are more susceptable to low temperature effects

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[a] Sources: Personal communications with equipment vendors, users, and other cognizant sources (Reference 17).

- Bunkering practices: Navy operations expose fuels to more water than do civilian practices. This places limits on additives to insure that the water can be removed effectively and does not react chemically with the additive.
- Equipment: Differences between Navy and civilian combustion systems which affect fuel requirements can be adequately characterized by basic equipment types, as follows:
  - Steam boilers: Smaller tube clearances and higher combustion intensities lead to more stringent requirements for allowable contamination levels
  - Diesel engines: More severe load variation requirements lead to stricter limits on cetane number
  - Aircraft gas turbines: Higher altitude operations lead to more stringent limits on freeze point

DIFFERENCES BETWEEN CHARACTERISTICS OF NAVY AND COMPARABLE CIVILIAN FUELS

To compare fuels on the basis of their properties, it is useful to group the specification elements into the following three categories:

- Safety — elements which specify the hazard potential of the fuel
- Performance — elements which specify the fuel's ability to deliver the required output and its compatibility with handling equipment
- Maintenance — elements which specify the contamination levels of the fuel and, hence, its potential to degrade the performance of the fuel supply or combustion equipment

Table S-2 lists all the elements of the MILSPECS for DFM and JP-5, grouped into these three categories. The performance specifications group is subdivided further into the following subgroups:

- Basic properties -- those which define the distillation fraction of the petroleum from which the fuel is derived and associated basic physical properties
- Combustion properties — those which define the heat content and combustion characteristics of the fuel
- Other properties — those which define the ability of the fuel to flow in the liquid phase

The maintenance specification group can also be subdivided for clarity in highlighting and understanding differences among fuels. These subgroups are:

- Corrosion contaminants — those which induce corrosion, either along the hot gas path or within the fuel supply system

TABLE S-2. CATEGORIES OF SPECIFICATION ELEMENTS

Category	Element	Applicable MILSPEC
Safety	Flash point	DFM, JP-5
	Explosiveness	JP-5
Performance		
Basic Properties	Appearance	DFM
	Color	DFM
	Distillation	
	10 percent fraction	JP-5
	90 percent fraction	DFM
	End point	DFM, JP-5
	Loss and Residue	DFM, JP-5
	Viscosity	DFM, JP-5
	Gravity	JP-5
Combustion Properties	Net heat of combustion	JP-5
	Cetane number	DFM
	Smoke point	JP-5
	Aromatics	JP-5
	Olefins	JP-5
Other Properties	Freezing point	JP-5
	Pour point	DFM
	Cloud point	DFM
	Demulsification	DFM
	Thermal stability	JP-5
Maintenance		
Corrosion Contaminants	Sulfur	DFM, JP-5
	Mercaptans	JP-5
	Acid number	DFM, JP-5
	Copper strip corrosion	DFM, JP-5
	Neutrality	DFM
Erosion Contaminants and plugging or fouling	Carbon residue	DFM
	Ash	DFM
	Particulate matter	JP-5
	Existent gum	JP-5
	Accelerated stability	DFM
Other Contamination	WSIM	JP-5
	Filtration time	JP-5
	Additives	DFM, JP-5

- Erosion or fouling contaminants — those which can plug small openings, foul heat exchanger surfaces, or erode materials that are exposed to the fuel or its products of combustion
- Other contaminants — those contaminants and additives that can block the fuel flow within the supply system or otherwise compromise operation

Thus, Table S-2 illustrates a framework which can be used to compare fuels by their specifications, showing the differences between the MILSPECS and the requirements made of corresponding civilian fuels, and identifying each difference as it affects safety, performance, or maintenance of combustion equipment.

When comparing fuels it is important to recognize that civilian fuels may meet a number of specifications. The most general are the ASTM specifications. Most fuels must also satisfy the specifications of the company that refines them, and those specifications are frequently more stringent than the ASTM, especially for some elements. Both of these types of specifications are limits, and analyses of actual fuel samples generally show that the fuels surpass even the company specification. Therefore, Aerotherm assessed the differences between MILSPEC and corresponding civilian fuels by a set of comparisons. First, the MILSPECS were compared to the ASTM specifications, then to several company specifications, and finally to actual analyses of civilian fuel samples. These comparisons showed:

- How currently acceptable Navy fuels differ from the guaranteed characteristics of comparable civilian fuels (at least most domestic and many foreign fuels, which are sold conforming to ASTM specifications)
- How the same Navy fuels differ from the minimum quality fuel that several petroleum companies will guarantee to supply
- How Navy fuels differ from typical fuels delivered to civilian users

The first two comparisons are based on guarantees and show the biggest possible differences between Navy and civilian fuels, while the last comparison shows current differences.

It became evident during the early stages of the study that the distillate fuels, such as the Numbers 1 and 2 fuel oils and diesel fuels, satisfied many of the MILSPEC elements for DFM. Therefore, these fuels could be used in lieu of DFM, at least for a short time, without having to replace or modify equipment. In addition, JP-5 and the corresponding civilian fuel Jet A/A1 appear to be reasonably similar. Hence, these fuels, all middle distillate, were considered to be preferred alternates and were emphasized in both the availability/cost analyses and the detailed fuel comparisons. In fact, analyses of actual fuel samples of preferred alternates for DFM show that some fuels exist whose measured properties all satisfy the MILSPEC. However, some properties (demulsification time, neutrality, and permitted additives) were not measured and could deviate from the MILSPEC.

Analyses of heavy fuel oil alternates to DFM (e.g., Numbers 4, 5, and 6 fuel oils), on the other hand, confirm the impression given by the corresponding ASTM specifications that they deviate from the MILSPEC in many areas. The most significant deviations are viscosity and contaminants (particulate matter, etc.).

Both fuel suppliers and the Bartelsville Energy Research Center (ERDA) reported results of property tests on Jet A. These data showed that several samples from among all those tested satisfied all the MILSPEC requirements for those properties which were measured. However, explosiveness, olefin content, acid number, and particulate matter were not measured, nor was the presence or absence of any additives noted. Although the important flashpoint criteria was not satisfied by a number of samples, (i.e., those where all the measured properties did not meet MILSPECS), all the fuels analyzed met the MILSPEC criteria for distillation properties, most combustion properties, and a number of contamination levels.

In summary, then, certain readily and commercially available civilian fuels in the middle distillate range nearly satisfy the requirements for MILSPEC fuel. As will be noted in the next section, the precise quantitative impact of using such fuels in naval systems is not known, although the general nature and direction of the impact can be assessed. Since these "preferred alternates" are so readily available, prudence dictates that the Navy should conduct a program to quantify the potential impacts on their combustion systems of using such alternates.

QUALITATIVE IMPACT OF NONCOMPLIANCE WITH SPECIFICATION ELEMENTS

Table S-3 identifies how each element affects combustion equipment by noting the qualitative impact on combustion equipment of individual noncompliance with each MILSPEC element. These potential impact(s) are noted separately for the three basic types of naval combustion equipment.

For some specification elements the potential impact(s) vary with equipment type. For example, cetane number has an impact only on diesel engines, while explosiveness impacts only aircraft gas turbines. These variations should be considered when determining the conditions under which a civilian fuel could be substituted for a MILSPEC fuel in a given type of combustion equipment.

TABLE S-3. IMPACT OF ELEMENTS

Element	Boilers	Diesels	Gas Turbines
Flash point	Safety	Safety	Safety
Explosiveness	Not applicable	Not applicable	Safety for aircraft gas turbines
Viscosity	Pumpability, incomplete combustion, and lubricity	Pumpability, incomplete combustion, power loss due to injection pump and injector leakage, and lubricity	Pumpability, incomplete combustion, and lubricity
Gravity	Endurance	Endurance	Endurance/range
Appearance/color	Plugging and/or corrosion	Plugging and/or corrosion	Plugging and/or corrosion
Demulsification	Potential corrosion, clogging due to organic slimes	Potential corrosion, clogging due to organic slimes	Potential corrosion, clogging due to organic slimes
Cetane number	Not applicable	Ignition speed → smoke and increased fuel consumption	Not applicable
Distillation temperature, 10 percent recovered	Start up	Start up, response to rapidly fluctuating load/speed demands	Start up
Distillation temperature, 90 percent recovered	Elimination of hard to vaporize fractions	Elimination of hard to vaporize fractions	Elimination of hard to vaporize fractions
Distillation temperature, end point	Similar to distillation temperature, 90 percent recovered	Similar to distillation temperature, 90 percent recovered; piston ring and combustion chamber deposits	Similar to distillation temperature, 90 percent recovered
Freezing point Cloud point	Low temperature formation of ice/wax crystals can clog filters and other small passages	Low temperature formation of ice/wax crystals can clog filters and other small passages	Low temperature formation of ice/wax crystals can clog filters and other small passages
Pour point	Low temperature limit for gravity flow from storage	Low temperature limit for gravity flow from storage	Low temperature limit for gravity flow from storage; not applicable for aviation gas turbines
Olefins	Not applicable	Not applicable	Aviation gas turbine fuel storage; favorable lubricity characteristics
Sulfur (when combined with sodium, potassium, etc.)	Corrosion of tubes and other hot-side metallic surfaces	Corrosion of injectors, piston pins, and rings; liner wear; deposits	Hot-gas path corrosion of metals
Mercaptans	Not applicable	Not applicable	Attacks elastomers; odors
Copper corrosion	Not applicable	Copper alloy corrosion	Copper alloy corrosion
Acid number neutrality	Corrosion of metals	Corrosion of metals	Corrosion of metals and elastomers
Carbon residue	Fouling, clogging, smoke, radiation increases wall and heat transfer surface temperatures	Fouling, clogging, smoke, radiation increases wall temperatures	Fouling, clogging, smoke, radiation increases wall and liner temperatures
Particulate matter Ash	Erosion and wear on pumps, deposits on heat transfer surfaces, tube wall clogging	Erosion on injectors, pumps, pistons, rings; deposits	Fuel system wear and clogging, potential turbine corrosion due to erosive removal of protective coatings
Accelerated stability, insolubles	Storage stability erosion fouling, deposits, sticking	Storage stability erosion fouling, deposits, sticking	Storage stability erosion fouling, deposits, sticking
Water separation index, modified	Polar material present → disarms coalescers	Polar material present → disarms coalescers	Polar material present → disarms coalescers
Fuel system icing inhibitor	Not applicable	Not applicable	Lowers flash point, polar characteristics can disarm coalescers
Corrosion inhibitor	Not applicable	Not applicable	Degrade stability during storage
Antioxidant	Degrade thermal stability	Degrade thermal stability	Degrade thermal stability
Metal deactivator	Degrade stability during storage, source of nutrients for organics → slime clogging	Degrade stability during storage, source of nutrients for organics → slime clogging	Degrade stability during storage, source of nutrients for organics → slime clogging

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A limited amount of more quantitative information was obtained from combustion equipment vendors about the impact of variable fuel properties on their combustion and fuel supply systems. Based on the survey conducted to obtain these data, it appears that the manufacturers and users of these systems are concerned mainly about a small number of potential impacts. These are:

- The correlation shown between reduced flashpoint and increased instances of aircraft fire
- The importance of being within a prescribed viscosity range to avoid problems with lubricity, flame stability, pumping, and atomization
- The need to minimize sulfur levels to reduce corrosion in all types of combustion equipment
- The fact that insolubles can foul not only primary combustion equipment, but may also clog fuel flow passages and filters that are designed to remove them

SUMMARY

The main conclusions of Aerotherm's study can be summarized as follows:

- Commercial fuels exist which are similar to MILSPEC fuels; these commercial fuels are used in comparable applications and have properties which may differ from those required of military fuels in only a few areas. Specifically:
    - Some civilian counterpart fuels, as delivered, satisfy most elements of the MILSPEC
    - Delivered civilian fuels vary by supplier, but a given supplier tends to have a consistent fuel
    - Differences generally are restricted to the following parameters: safety (flash point and explosiveness), additives, and properties for which limits are specified by the military but not the civilian standards (i.e., "unmeasured properties")
- A substantial quantity of "comparable" commercial fuel is available, and a Navy program to explore further any potential impacts on their fuel systems and combustion equipment from using these alternates is justified

SECTION 1

INTRODUCTION AND SUMMARY

In recent years, particularly since the Oil Embargo of 1973, all major fuel consuming sectors in the United States Navy have become increasingly aware of the limited supply and high cost of petroleum fuels. These fuels are essential to operate the Navy's forces afloat, its aircraft, and its shore facilities, and they are currently consumed at the rate of 230,000 barrels per day. Energy conservation is one method to reduce this demand on petroleum resources and the resulting high annual expenditures for fuel. In addition, conservation is in the long-term interests of the country, since it assists nationwide efforts to "stretch" our remaining oil reserves. Alternatives to petroleum-based fuels are another option. One of these, shale oil, is being evaluated by the Navy in its 100,000 barrel oil shale experiment. Yet another option could be the use of fuels which do not meet all the requirements of military specifications (MILSPECS) for fuels, but which could be burned without significantly impairing naval operations. This approach could increase fuel availability and reduce costs to the Navy.

To assess the desirability and feasibility of using non-MILSPEC fuels in Navy combustion equipment, the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) engaged the Aerotherm Division of Acurex Corporation to perform a study with the following objectives:

- Determine whether there exists a large supply of fuel beyond that currently being procured for the Navy, which meets, or nearly meets, military specifications
- Determine whether any such comparable "non-spec" fuel is less expensive than the currently approved product
- Assess, using available information, the viability of storing, handling, and burning comparable "non-spec" fuels in naval systems

Early results indicated that substantial quantities of fuel which nearly meet the MILSPECS were, in fact, being produced. These findings justified an evaluation of the viability of using such other fuels, even if only on a limited basis. To provide the background for such an evaluation, Aerotherm first compared naval marine equipment (shipboard combustion systems and ship-based aircraft) and operating requirements with corresponding civilian systems to determine why these two user groups place somewhat different requirements on their fuel (Section 3). We then identified differences between the characteristics of fuels which satisfy the MILSPECS (Diesel Fuel Marine (DFM) for ship propulsion and hotel services and JP-5 for ship-based jet aircraft) and comparable civilian fuels. In each case, military fuels were compared to civilian fuels which (1) satisfy civilian ASTM specifications, (2) satisfy select oil refiners' specifications, or (3) have had their properties measured on samples of delivered fuel. These comparisons are presented in Section 4.

Thus, Sections 2 through 4 present general data on availability, cost, fuel characteristics and potential impacts. To indicate what options might be available to the Navy in a specific situation, Section 5 identifies possible substitutes for DFM and JP-5 that could be available to Navy facilities at Norfolk, Virginia, and San Diego, California. It then considers the extent to which use of these comparable civilian fuels might affect the safety, performance, or maintainability of Navy ship-based combustion equipment.

As implied above, this study was restricted to alternates for ship-based combustion equipment: steam boilers, reciprocating engines, and marine gas turbines for propulsion or ships service, and gas turbines in carrier-launched jet aircraft. The boilers and engines now burn mostly DFM, the aircraft are fueled with JP-5, and the marine gas turbines can burn either DFM or JP-5. In Section 4, we will show, in detail, the similarities and differences between the Number 2 fuels (both fuel oil and diesel fuel) and DFM. Likewise, comparisons will be presented between Jet A (and its arctic equivalent, Jet A1) and JP-5. The Jet A/A1 fuels are used by civilian jet airliners and are comparable to JP-5.

This study looks only at the similarities and differences between the military fuels and existing, commercially available civilian fuels; it does not consider possibilities for increasing fuel availability by changing refinery configurations. In addition, because of the paucity of data on fuel availability and properties outside the United States, only general comments and broad-based data are presented for the regions outside the CONUS.

The main conclusions of this study are summarized below:

- Commercial fuels exist which are similar to MILSPEC fuels; these commercial fuels are used in comparable applications and have properties which may differ from those required of military fuels in only a few areas. Specifically:
  - Some civilian counterpart fuels, as delivered, satisfy most elements of the MILSPEC
  - Delivered civilian fuels vary by supplier, but a given supplier tends to have a consistent fuel

  - Differences generally are restricted to the following parameters: safety (flash point and explosiveness), additives, and properties for which limits are specified by the military *but not the civilian standards (i.e., "unmeasured properties")*

- Careful analysis of DFSC data confirmed the belief that the Navy's worldwide consumption of DFM is about 2 percent of the domestic production of middle distillate; for jet aircraft its total consumption of JP-5 is approximately 7 percent of the domestic production of kerosine-based jet fuel. Therefore, a substantial quantity of "comparable" commercial fuel is available, and a Navy program to explore further any potential impacts on their fuel systems and combustion equipment of using these alternates would be justified.
- Fuel shortages have been localized, temporary, and unpredictable. The conservative view is that this problem will recur with increasing frequency, even though availability exceeds Navy demand at various times in some parts of the world.
- JP-5 shortages will become worse if the other services switch to JP-8
- Attempts to alleviate future shortages of middle distillate fuels, such as DFM or JP-5, by turning to West Coast refineries which process Alaskan crude will not succeed with current refinery configurations; sufficient advanced refinery capacity does not now exist on the West Coast to process enough of the heavy Alaskan crude to meet the total demand for middle distillate
- Incremental fuel costs that could be related to the special requirements imposed by the MILSPEC are not predictable; currently they account for only a relatively small part of the total cost

Based on these conclusions we make the following recommendations:

- Develop a standardized procedure to evaluate the impact of using non-spec fuels. This procedure should be capable of meeting specific needs, such as to test the potential impact on Navy fuel systems and combustors of using petroleum-based fuels which satisfy most, but not all of the MILSPECS, as well as the general needs of the shale oil program. This recommendation is based largely on the following findings:
  - Shortfalls in MILSPEC fuels have occurred in the past and are likely to occur again, even if only on a temporary and localized basis
  - Fuels which could probably be used in naval combustion systems with little or no impact appear to be available in quantities that greatly exceed current Navy consumption

  - Limited experience with some of these alternates (i.e., No. 2 fuel oil and No. 2 diesel fuel in lieu of DFM and Jet A/A1 for JP-5) and/or engineering judgment suggests that they could be used, if necessary, by Navy ships and ship-based aircraft. Data do not exist, however, to verify this supposition nor to identify the extent of any impacts that may occur.
  - Characteristics of civilian fuels of a given grade (e.g., No. 2 diesel fuel) vary from supplier to supplier (even though they tend to be uniform for a given supplier for long periods of time). Therefore, each supplier's potential alternate to a military fuel will probably differ from the MILSPEC in a different way than do other suppliers' fuels. This means that many fuels might have to be evaluated and, hence, a standardized procedure would be appropriate.
  - A standardized procedure is especially timely now given the Navy's interest in shale oil and the concomitant need for a methodology to identify any potential impacts of using that fuel
- Extend the problem definition phase of the fuels availability program to:
  - Measure properties of alternate fuels (especially foreign) where not known
  - Further explore flexibility restrictions on a company-by-company basis. This should include indentification of companies whose civilian counterpart fuel meets, or nearly meets, the MILSPECS and determination of the availability of such fuels.
- Conduct R&D to determine how the Navy could use alternate fuels which are available in large quantities and nearly satisfy the MILSPEC. Such approaches could include:
  - Minor equipment changes to shipboard fuel and combustion systems
  - Identification of emergency conditions for which existing alternates can be used now

More detailed conclusions and recommendations are presented throughout the report and, as a group, in Section 6.

SECTION 2

FUEL AVAILABILITY AND COST

2.1 INTRODUCTION

Planning — whether for contingencies or long-range purposes — must be based on accurate data. The types of data required are directly influenced by the planning goals. The goal for this study was to provide accurate data on fuel flexibility for future planning. Therefore, Aerotherm sought answers to the following questions:

- What types and amounts of fuel has the Defense Fuel Supply Center (DFSC) been supplying to the Navy? To what locations has DFSC delivered fuel to the Navy? What has DFSC paid for the fuel?
- Which suppliers in these locations have comparable civilian fuels and in what quantities? What have been civilian prices at these locations for comparable fuels during the same time periods?

To answer these questions, Aerotherm collected and analyzed data from the following sources:

- DFSC
- Platt's Oilgram
- Refineries, both domestic and foreign (through direct queries)
- The Oil and Gas Journal
- Energy Statistics Office, Department of Economic and Social Affairs, United Nations
- Federal Energy Administration, Bureau of Mines, Bureau of Labor Statistics and other government agencies and offices
- American Petroleum Institute

The selection of data from these sources was based upon data availability and upon Aerotherm's initial identification of preferred alternative fuels (discussed in Section 4). Thus, although the types and quantities of fuel that DFSC has been supplying to the Navy were determined, these data were not available in finer detail than by DFSC reporting region. Production data on civilian fuels were also available only by reporting regions, in this case those of the Bureau of Mines for the U.S. and of the U.N. for the rest of the "Free World". None of these regions corresponded to those used by the DFSC. As a result, the bulk of the availability comparisons are based on aggregate data for the U.S. and/or the rest of the Free World. These overall data are supplemented by the few specific examples we could obtain from DFSC and fuel suppliers of known shortfalls in MILSPEC fuels or of potential local availabilities of equivalent fuels. Together these data enabled us to reach useful conclusions about the potential for shortfalls and the availability of fuels which could be used with little or no impact on Navy combustion systems in the event of such shortfalls.

A similar situation was found when attempting to compare cost data. DFSC reports only its mean cost for each fuel type – i.e., its costs for the product averaged over all procurements over the fiscal year. Furthermore, these costs are for products delivered to DFSC tank farms. DFSC then charges a user, such as the Navy, this average price plus an additional sum which is the prorated share (based on volume of fuel obtained) of the total cost of running DFSC – administrative and procurement costs plus those of operating the tank farms and fuel transportation systems. In other words, when the Navy obtains fuel from DFSC, it pays an amount which is independent of location. Therefore, it is not meaningful to compare prices between MILSPEC fuels supplied by DFSC to a particular ship or facility and comparable civilian fuels that are available locally. The comparisons presented in this section will show, instead, how the mean DFSC cost for each fiscal year compares with the range of fuel prices throughout the U.S. for comparable civilian products.

The following discussion then, first delineates the scope of the study, as it applies to fuel availability and cost, and the methodology used to select data. We then present summaries of the data for boiler, gas turbine, and diesel fuels and aircraft jet engine fuels. Details of the data, with comments, are presented next, followed by conclusions.

2.2 SCOPE OF FUEL AVAILABILITY AND COST STUDY

2.2.1 Fuels Included

This study addresses shipboard-used boiler, gas turbine, and diesel fuels and ship-based aircraft jet engine fuels. Data for fuels used for posts, camps, and stations are outside the scope of this study, and were not sought. Because the Navy's boiler and diesel fuel usage type changed markedly during the period covered by this study (i.e., pre-embargo to June 30, 1976), data were collected for:

- Navy Special Fuel Oil (NSFO)
- Navy Distillate Fuel (NDF)
- Diesel Fuel Marine (DFM)

However, since the Navy currently uses primarily DFM for its diesels and boilers, civilian fuel availability and price data were sought mainly for fuels comparable to DFM, within the spectrum of potential fuels for civilian boilers, diesels and shipboard turbines. However, Navy carriers and other Navy gas turbine ships receive JP-5 jet fuel. Since the naval aircraft which use JP-5 also burn JP-4 on certain occasions, data on both of these fuels were collected, as well as for the closest analogous civilian fuel to JP-5, Jet A/A1.

In certain cases, the available data are aggregated for several fuels because they could be obtained in no other form.

2.2.2 *Time Period*

Data have been collected, where possible, for the 1974, 1975, and 1976 fiscal year periods and for the 1973, 1974, and 1975 calendar year periods.

2.2.3 Data Variables

For each military specification fuel, data collected from DFSC include amounts procured, absolute and relative amounts lifted* to the Navy, geographical areas to which these liftings took place, and the price paid by DFSC for the fuel.

Data collected for civilian counterpart fuels include the amounts stored in countries outside the United States, domestic demand, production and import quantity, domestic and overseas price data, and selected refinery production and refinery-pipeline tie-in data.

2.3 STUDY METHODOLOGY

Data were collected from the records of the DFSC at Cameron Station as written or printed material or through interviews with personnel. (Acknowledgements are provided in the last appendix.)

The DFSC data presented are for the amounts lifted (i.e., product actually transported and received) rather than for procurement amounts. Until FY 1975, DFSC "procurements" bore little

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*See Glossary for a definition of this term.

relation to the amount of fuel actually purchased and transported to DFSC receiving stations or loaded onto DFSC vehicles at the supply point.

Data on domestic demand, production and imports were also used and were obtained from the Mineral Industry Surveys prepared by the Division of Petroleum and Natural Gas of the U.S. Bureau of Mines. Wholesale price and price index data were obtained from the Bureau of Labor Statistics of the Department of Labor. Supporting data were obtained from reports of the Federal Energy Administration (FEA), the American Petroleum Institute (API), the United States Senate Committee on Interior and Insular Affairs and its subcommittees. In addition, Platt's Oilgram, the Oil and Gas Journal, and various oil company-furnished price and fuel availability lists were used. Overseas data were obtained from the Energy Statistics Office of the United Nations Research Center in New York, the United States Bureau of Mines, various overseas petroleum companies, and the commercial publications listed above. In addition, much data had to be obtained by direct query of individuals who work for both domestic and foreign oil companies.

2.4 SUMMARY OF FUEL PRICE AND AVAILABILITY DATA

2.4.1 Marine Boiler, Gas Turbine, and Diesel Fuels

The Navy's marine boiler, gas turbine, and diesel fuels during calendar years 1973, 1974, and 1975 were NDF, NSFO, and DFM; data for these fuels are summarized in Table 2-1. Although heavy or "residual" fuel oil (i.e., such as Numbers 5 or 6 fuel oil, which are frequently called "Bunker C") are commonly found in ports, distillates are also widely available. Unfortunately, the published UN storage data do not separate residual and distillate fuel oils on a worldwide basis. There is thus no publicly available source of data on distillate fuel storage. When Texaco, Shell, Mobil, Chevron, Caltex, and Exxon were queried about their overseas operations, they would not reveal the actual quantities of distillate fuel in place at various locations. Typical company responses were: "This information is proprietary. Tell us what quantities you want and where you want it. We will quote a price."

The domestic production figures for distillate fuel oils include data for Number 1, Number 2, and Number 4 fuel oils* and Number 1 and Number 2 diesel oils.† Kerosine-type distillate used as jet fuel is not included. It was not possible to separate data for each individual fuel. However,

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*Conforming to ASTM specification D396

†Conforming to ASTM specification D975

TABLE 2-1. AVAILABILITY OF DFM + NDF + NSFO

	Units: MMBBL		
	CY 1973	CY 1974	CY 1975
• Quantity lifted to Navy[a]	Unknown	22	24
• Civilian counterpart fuel availability[b]			
— Amounts of distillate and residual fuel stored in "Free World" countries outside the U.S.[c]	944	907	Unknown
— Domestic production, distillate fuel oils[d]	1,030	947	968

[a] More than 85 percent of the amount lifted by DFSC went to the Navy

[b] Data for civilian counterpart fuel were obtained from Mr. Arthur Ramsdell of the Energy Statistics Office of the United Nations (for noncommunist foreign countries), the United States Bureau of Mines and from Reference 1

[c] The U.N. terminology for "Free World" countries is "noncentrally planned economies"

[d] Includes Nos. 1, 2, and 4 fuel oil and Nos. 1 and 2 diesel oils

since both Number 1 and Number 2 fuel oils or diesel fuels are potential replacements or extenders* to Navy DFM supplies, this data aggregation is deemed acceptable. (About 12 to 13 MMBBL of Number 4 fuel oil are also included in the annual domestic production aggregate values.)

The approximate refinery yield of distillate fuel oils varied in the first quarter of 1976 between 11.5 percent, in PAD 5,[+] and 28.9 percent, in PAD 4, with a United States mean of approximately 22 percent.

2.4.2 Jet Turbine Fuels

As previously stated, Navy jet planes use JP-5 for all ship-based operations. JP-4 is sometimes used for refueling when flying from land bases, particularly within the CONUS. The civilian kerosine-based jet fuel corresponding to JP-5 is Jet A/A1, in worldwide use as a commercial jet fuel. Jet B is the corresponding civilian fuel to JP-4. It is not widely used for flights within the United States and is primarily found and used overseas. Table 2-2 presents a summary of recent availability data for these fuels.

The approximate refinery yield of jet fuel from crude varied in the first quarter of 1976 between 2.9 percent in PAD 1 and 12.8 percent in PAD 5, with a United States mean of approximately 7 percent. These variations in refinery yield of jet fuel among the PADs is due largely to differences in the crudes used, the type of refineries in the PAD, and the local demand. In PAD 5, about 20 percent of the jet fuel produced is naptha-based, and the remainder is Jet A/A1 or JP-5.

2.4.3 Summary

These data show Navy usage of distillate boiler, diesel, and turbine fuels. By themselves, they do not show how much, if any, of the middle distillate production not used by the Navy would be usable (in conformance with the appropriate military fuel specifications or even with minor equipment, maintenance, or use modifications) in a fuel shortage. This issue is addressed in Section 4. The data also do not prove that shortages can not exist. Indeed, some evidence that shortages can exist is presented in the following section.

2.5 SPECIFIC EXAMPLE OF SHORTAGES OR INCREASED AVAILABILITY

In this section several specific examples relating to fuel availability are presented. First, we identify two cases where JP-5 could not be obtained. Then we discuss the potential impact on JP-5

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*Number 1 fuel oil, for example, can serve as a blend fuel with certain high flash point Number 2 oils

[+] BuMines PAD boundaries are shown in Figure 2-1

TABLE 2-2. FUEL AVAILABILITY: JP-4 + JP-5

	Units: MMBBL		
	CY 1973	CY 1974	CY 1975
• Quantity lifted to Navy[a]	Unknown	21	22
• Civilian counterpart fuel availability[b]			
– Jet fuel (Naptha and kerosine-based) stored in "Free World" countries outside the U.S.[c]	97	99	Unknown
– Domestic production, kerosine-based jet fuel	248	234	252

[a] Sixteen to eighteen percent was JP-4; the JP-5 lifted to the Navy represents more than 97 percent of DFSC liftings of JP-5.

[b] Data on foreign noncommunist fuels were obtained from the UN Energy Statistics office and Reference 1. Naptha (Jet B/JP-4 type) and kerosine (Jet A/JP-5 type) – based jet fuels are aggregated together in UN data. The data on domestic production from the Bureau of Mines are for JP-5 and Jet A/A1 only. JP-4 production is separately recorded as "Jet Fuel – Naptha Type." For calendar year 1975, the Bureau of Mines reported refinery output of 66 MMBBL and a domestic demand of about 77 MMBBL of JP-4. (BuMines reported imports of 11 MMBBL during CY 1975.) DFSC reported liftings of 69 MMBBLs and worldwide liftings of 99 MMBBLs to all service agencies during this period.

[c] The U.N. terminology for "Free World" countries is "noncentrally planned economies"

availability of the USAF switching to JP-8. And last, we cite fuels which either meet military specifications, without being identified as such, or which come close to satisfying military specifications.

2.5.1 JP-5 Spot Shortages

Conversations with procurement officers at DFSC elicited the information that spot shortages have already occurred in supplies of JP-5. For example, in a recent attempt to procure JP-5 for use in the Indian Ocean, DFSC solicited the following companies:

- Caltex (Ras Tanura/Bahrain)
- Gulf
- Exxon
- Chinese Petroleum Corporation
- Kuwait
- Banda-Mashar
- and others

Only the Chinese Petroleum Corporation was willing to supply JP-5.

In a second recent attempt to procure JP-5 for use in NATO exercise Kangaroo Rat, neither JP-5 nor Jet A/A1 was procurable, and, according to the information furnished by DFSC procurement officers, the Navy had to bring in fuel by tanker from Subic Bay to meet its needs. As far as we could determine, there appeared to be no official mechanism which would ensure that such information was transmitted to the Navy Energy R&D office.

DFSC procurement recently asked prior overseas suppliers whether they planned to respond to future RFPs for JP-5. As of October 1976, Kuwait had replied that they would not respond to JP-5 solicitations during calendar 1977 (other replies are not known to us). It can never be predicted which companies will respond to an RFP, nor can it be predicted with which companies DFSC will negotiate. However, Kuwait was awarded a contract for 41 percent of the JP-5 procured for delivery during the July through December 1975 period for the Western Pacific (WESTPAC) Area.*

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*The WESTPAC procurements service military needs in Guam, Japan, the Phillipines, Okinawa, Thailand, Korea, and Diego Garcia. Of the 1,610,000 barrels of JP-5 procured for WESTPAC, Contract 76-D-0802 with Kuwait procured approximately 658,000 barrels.

2.5.2 The Potential Effect of Switching from JP-4 to JP-8 by the USAF

The Air Force uses about 20 percent of the combined domestic refinery output of naptha and kerosine-type jet fuels and is currently evaluating the advisability of switching to JP-8 as its jet fuel. If this happens, and if refinery production of JP-8 could directly replace refinery production of JP-4, the availability of JP-5 would be unaffected. However, this is unlikely. It is more likely that the "teakettle" refineries (i.e., those which primarily distill crude oil into separate product fractions and do not have the ability to perform major product modifications) will not be able to provide JP-8 economically in the same quantities as they have provided JP-4. These small refineries provide about one-third of the JP-4 produced in the United States.* If they will no longer provide fuel, the country's capacity for making jet fuel will diminish by about the same amount as the quantity of JP-5 currently being used by the Navy (see Table 2-2). It seems inevitable, therefore, that JP-5 (and JP-8) availability will diminish if the AF follows through with its proposed conversion to JP-8. In addition, the price of JP-5 (and JP-8) will rise (in the absence of artificial constraints). A recent unpublished report issued by the FEA (Mr. Rosenberg, January 11, 1977) to Mr. Frank A. Shrontz, ASD (I&L), has been described by Mr. Eugene Peer, FEA, as agreeing with these conclusions.

2.5.3 Specific Fuel Availability Examples

In contrast, some fuels are more available than heretofore known. Several suppliers have provided data to Aerotherm on the typical measured properties of fuel oils for civilian usage that are produced in their refineries. These data are tabulated and compared to MILSPEC requirements in Section 4; here we note that their fuels either completely satisfy DFM or JP-5 specifications or come very close to satisfying these specifications. In other words, the ASTM specifications are substantially exceeded by the measured fuel values.

One example of increased availability of DFM is the Number 2 fuel oil produced by Amerada Hess. This refinery in the Virgin Islands is the largest in the Western Hemisphere, with a crude oil capacity of 700,000 barrels per day. Amerada Hess supplied 30 percent of the "domestically

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*According to Frank Wood, Jr., President of Pride Refineries and of the American Petroleum Refineries Association, the "teakettle" and other small refineries account for about 30 to 35 percent of the JP-4 produced. This is in agreement with the FEA estimates in Reference 2. These refineries have product yields which currently average about 9 percent JP-4 and 1.7 percent kerosine-based jet fuel. DFSC contracted for about 30 percent of the overall JP-4 procurement from such small (i.e., <50,000 BBLs/day) refineries during fiscal 1977. It is these refineries which are likely to have limited production capacity for JP-8 and JP-5.

produced" DFM during FY 1976. They have informed* Aerotherm that if a solicitation for more DFM is initiated by DFSC, Hess can use their Number 2 fuel oil stock to fill the order meeting all specifications.

In addition, Arco's Number 2 diesel fuel is an example of a fuel which nearly satisfies the requirements for DFM. This civilian fuel reportedly meets all MILSPEC elements except flash point. (The Arco specification is 130°F; MILSPEC is 140°F.) Arco fuels often surpass their own specifications and are thus even closer in flash point to the MILSPEC. Arco makes six times as much diesel fuel as DFM.

These and other suppliers whose product is of equivalent utility to the Navy, will be able to continue to produce usable fuel as long as the crude stocks (or closely similar ones) used to supply these refineries remain unchanged. Substantially greater quantities of MILSPEC, or very-nearly-MILSPEC, fuels, therefore, actually exist in the marketplace than either DFSC or the Navy could determine simply by knowing the amounts of these fuels actually delivered to DFSC. Although measured (i.e., actual) fuel property data are ordinarily highly confidential, Aerotherm was able to obtain data from some suppliers by promising to maintain the data in a proprietary manner. Aerotherm believes that an extensive and thorough investigation of the actual fuels available is needed to establish more carefully the important aspects of availability, both with domestic and selected foreign fuels.

A second category of examples of "hidden" fuel availability is provided by examining the additives required by military specification and additives used commercially. The current specification for JP-5 requires the addition of an anti-icing additive which lowers the flashpoint of the distillate by 6 to 8°F. Thus, to meet the MILSPEC, the base for the final product must use a higher flashpoint cut (i.e., less of the light end of the cut). For some refineries, this requires an additional distillation stage, which raises cost, and at the very least, produces less JP-5 from the input feedstock, which reduces the fuel's availability. However, the Navy is currently examining another anti-icing additive which will not lower flashpoints by the same amount. If use of this additive proves successful, greater fuel availability will result.

In addition, Aerotherm learned that an additive customarily used in SoCal's Chevron Number 2 Diesel Fuel to reduce gum formation, corrosion, etc. rapidly disables the coalescers used in Navy ships to separate sea water from fuel. The use of this additive means less MILSPEC fuel is available in the San Francisco Bay Area, since SoCal must make specific arrangements for tank, line, and

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*Personal communication

lightering facility cleaning and use before any DFM can be supplied to DFSC. (Although the additive raises the cost of the commercial fuel, leaving out the additive does not lower the overall cost, since the company has to charge for cleaning the tanks, etc. to insure no contamination of MILSPEC fuel.) In this instance, the military fuel specification does not formally cover coalescers, although the provisions which disallow nonspecification additives would prevent this additive from being used. Two points can be made:

- The lack of a quick, use-related test prevents Navy ships from determining whether fuel taken on as bunkers anywhere in the world will have an adverse effect on equipment
- An examination of the requirement for separating water from fuel from a "system" viewpoint might provide relief from the problem, thereby definitely, albeit slightly, increasing overall fuel availability

2.6 GENERAL CONCLUSIONS

During this portion of the study, Aerotherm reached the following general conclusions:

- Previous studies which indicated that the Navy currently uses only a few percent of the domestic production of boiler, diesel and turbine fuels (~2 percent of boiler, diesel and marine gas turbine fuels, ~7 percent of kerosine-type jet fuels) have been verified. This verification was obtained by compiling and analyzing data not previously used for this purpose.
- More distillate fuel that meets DFM military fuel specifications is available than the quantity delivered to DFSC by suppliers; the "excess" amount available substantially exceeds current Navy usage of DFM. An even larger amount is available which slightly misses meeting military specifications for DFM (e.g., by about 5°F on flashpoint). Aerotherm recommends that selected data characterizing the MILSPEC-required properties of actual market-place fuels from given refineries (and their feedstocks) be obtained both within and outside the United States, so that the important aspects of fuel availability can be characterized more carefully.*
- If the 10-percent distillation fraction (i.e., the light end) of Jet A/A1 is discarded, the remainder is (approximately) the same as a sample of JP-5. This crude approximation

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*Much of the specific fuel properties information is considered proprietary by refineries; however, based on our experience, we judge that it will be made available, subject to dissemination restrictions, to responsible Navy personnel.

suggests that there is a substantial production capacity for JP-5 in the United States in excess of Navy requirements.

- Spot shortages of JP-5 have occurred overseas, however, and are likely to reoccur. We are not aware of any mechanism at DFSC to communicate such prospective shortages to the Navy. DFSC has begun to gather such data, but, because of the short-term nature of government petroleum product procurements, no supplier can or will provide more than tentative future plans, subject to the multiple, indeterminate, and complex future influences of the marketplace upon each individual supplier.

- The marketplace for petroleum products is neither a "seller's market" nor a "buyer's market." Government actions — such as introducing a new specification for jet fuel and preventing the sale of lead-containing gasoline — will influence segments of the petroleum product marketplace (e.g., a switch to JP-8 may encourage some small refineries, such as Pride, to add reforming capability, and then produce only gasoline). The effect of government actions ripples out through the financial market, the plant construction market, the catalyst-producer market, and so on. No individual at DFSC suggested that DFSC had an organized policy-recommending body considering these matters and their implications for DFSC's mission.

- There is a lack of detailed data publicly available in compiled form on the location and size of fuel storage facilities outside the United States. Many of the necessary data exist at the UN and other locations in piecemeal form. There is also a general concomitant lack of compiled data about the quality of the fuels available (e.g., will the jet fuel ordinarily be comparable to Jet A or Jet B; will the Marine Gas Oil (MGO) be comparable to Number 2 fuel oil, with what additives, etc.) These data also exist, but in fragmentary form. The procurement requirement goals of DFSC to date have not necessitated the gathering of these overseas data in a compiled form which would be useful to the Navy.

- There is no general source of data on, or test procedure for studying, the effects of additives in naval shipboard boilers, diesels, and turbines. Many commercial equivalents to DFM (i.e., Number 2 fuel oil or Number 2 diesel fuel) contain such additives. Except in extraordinary cases (e.g., SoCal Chevron's antigum/anticorrosion additive), their potential effect upon Navy fuel-line, combustor, storage, and fuel-transfer equipment is unknown and cannot readily be determined at the present time. To resolve fuel availability questions requires information on such potential effects. These data should also be useful to Navy captains who require fuel.

- Refineries which can be supplied by pipeline from CONUS oil wells will have to supply the Navy if foreign crude supplies or foreign product supplies are unavailable. Refineries tied into the pipelines which go to, or close to, the major Navy bases would provide the most immediate source of supply. (Product from refineries not tied into such pipelines would have to be tankered or trucked to Navy bases.) Therefore, for Navy strategic planning, it would be useful to know which refineries could readily receive fuel from CONUS oil wells and the ordinary product mix they produce from the United States crudes, as well as the maximum potential production of DFM and JP-5 at these refineries.

All these data on refineries and products referred to above are known or are determinable. Some data are available at the Bureau of Mines, but have not been compiled and published, apparently because no one has ever asked the Bureau of Mines to do so. Aerotherm recommends that these data be compiled and published; the compilation should also include refineries whose ordinary product as actually marketed exceeds, meets or comes close to MILSPEC requirements for Navy DFM or JP-5.

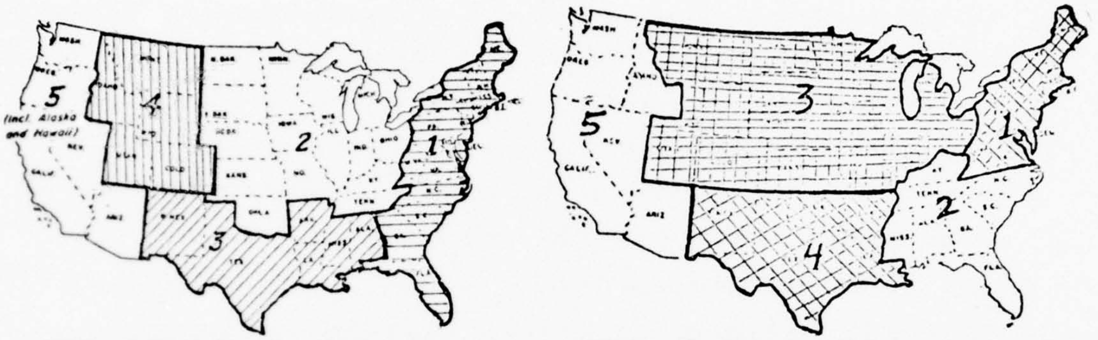
2.7 ADDITIONAL FUEL AVAILABILITY DATA

This section will expand and provide background for material presented in Sections 2.4.1 and 2.4.2, to give the reader a better understanding of the "fuels business". This section and its associated appendices will also make available to the Navy some of the data which were compiled for the first time during this study. The discussion will focus on fuel quantity data provided by DFSC and BuMines and fuel cost data from DFSC, the Bureau of Labor Statistics (BLS) of the Department of Commerce, and Platt's Oilgram.

Data for DFSC are available for each calendar quarter within the quoted year. These data are prone to uncertainties or inaccuracies (from causes described in Subsection 2.7.2.2) and, after discussion with DFSC personnel, only the yearly aggregates are reported here.

2.7.1 Data Aggregation by Geographical Region

Data from DFSC were collected both as regional and worldwide aggregates. The DFSC regions are shown in Figures 2-1 and 2-2 for the CONUS and overseas, respectively. The BuMines uses different geographical boundaries for its Petroleum Allocation for Defense (PAD) regions (see Figure 2-1). BuMines has still other boundaries for refinery regions (not shown). Since BuMines and DFSC data cannot readily be separated and reassembled, comparisons are cited only for the United States as a whole. Similarly, data received from the Energy Statistics office of the United Nations are presented only as worldwide aggregates, since the UN regional aggregations do not correspond to the DFSC regions outside the CONUS.



CONUS: BuMines Petroleum Administration for Defense (PAD) Districts

CONUS: DFSC Reporting Districts

Figure 2-1. DFSC and BuMines CONUS region boundaries.

2.7.2 Additional Data on DFM, NDF, and NSFO from DFSC

2.7.2.1 Liftings and Costs

Figure 2-3 shows how DFSC liftings of various boiler, marine gas turbine and diesel fuels varied between FY 1974, 1975, and 1976. Figure 2-4 shows the percent of DFSC liftings which went to the Navy and, for fuels received by the Navy, also how liftings were distributed between vessels and nonvessels. Table 2-3 provides further aggregate data on marine fuel costs and availability. (Tabular data for each of these fuels are provided separately in Appendix A.)

Comparable data for JP-4 and JP-5 jet fuels are provided in Figure 2-5 and Table 2-4. (Tabular data for each of these fuels are also provided separately in Appendix A.)

Comparison cost data between DFM and commercial distillate fuel oils are shown in Figure 2-6. Comparison cost data for JP-5 and Jet A/A1 are shown in Figure 2-7. Commercial fuel costs are for bulk deliveries and were obtained primarily from Platt's Oilgram. Confirming data came from verbal quotations supplied by various petroleum companies and from the Bureau of Labor Statistics of the Department of Commerce. The data on civilian fuels in Figure 2-6 were developed by averaging separately the highest and lowest prices reported for various locations throughout the United States on January 1 and July 1, respectively, of each year. Price data for the intervening periods were scanned to ensure

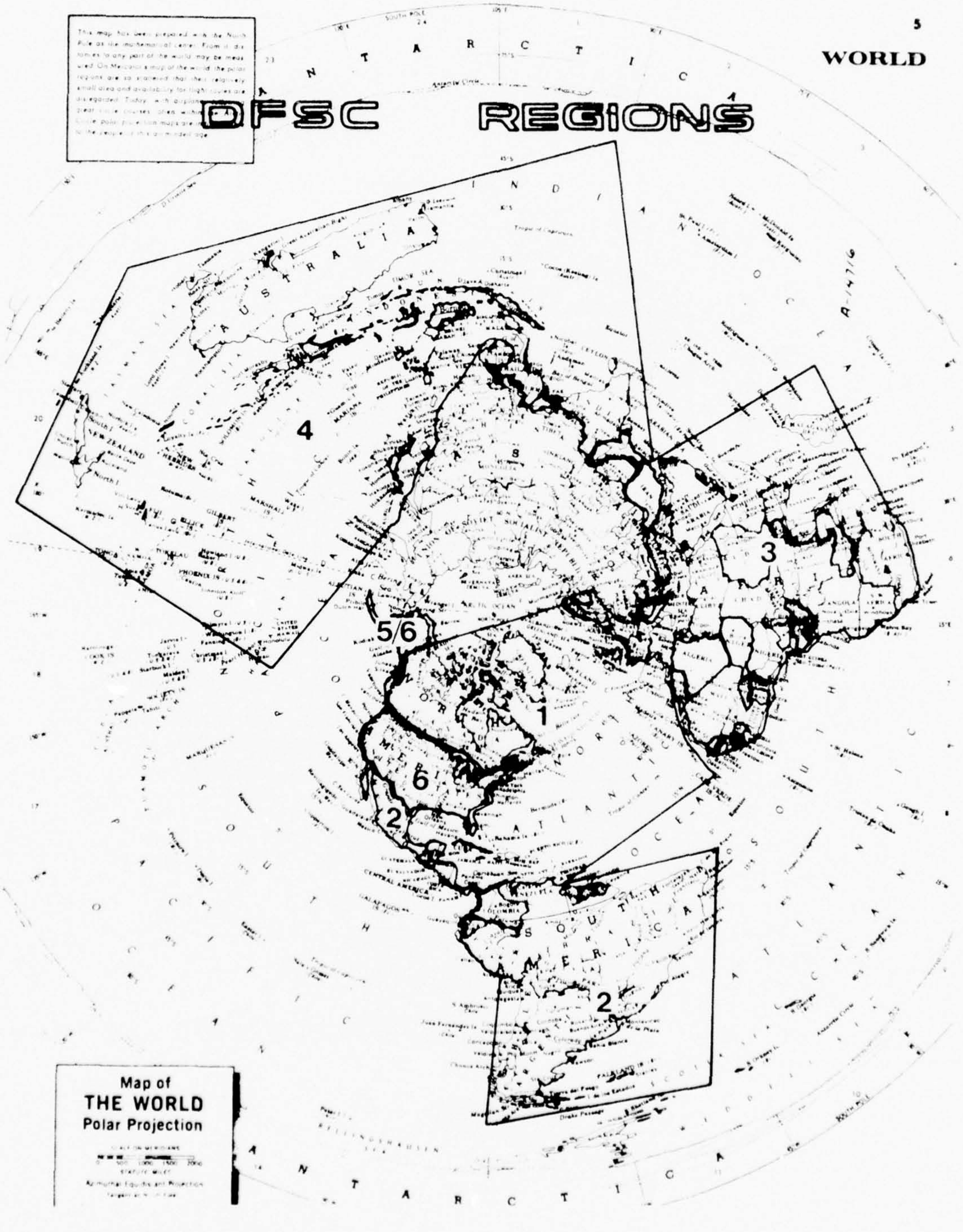


Figure 2-2. DFSC regions overseas.

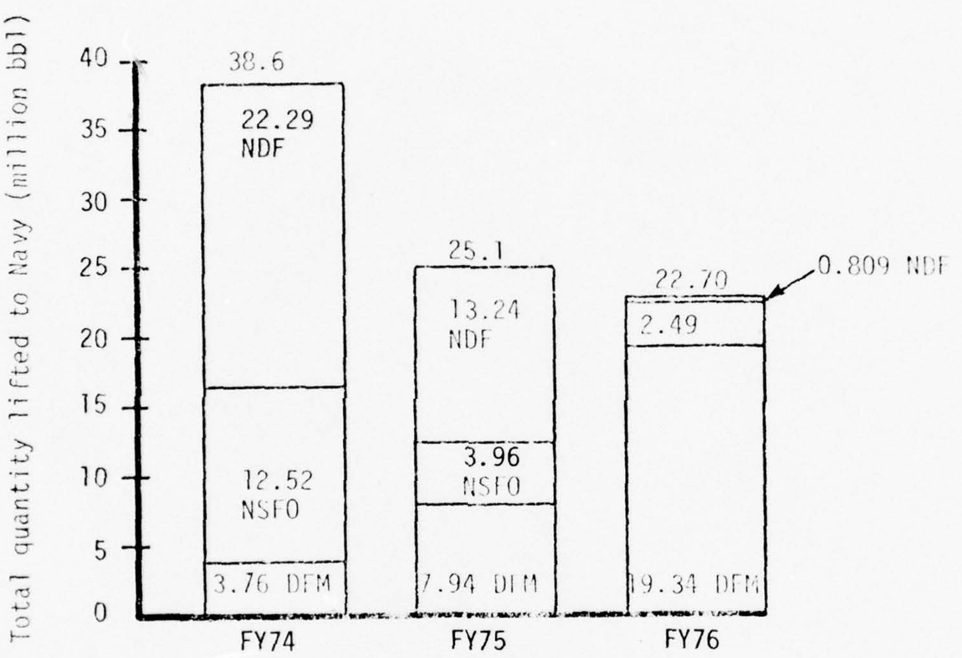


Figure 2-3. Total quantity of standard diesel and boiler fuels lifted to the Navy.

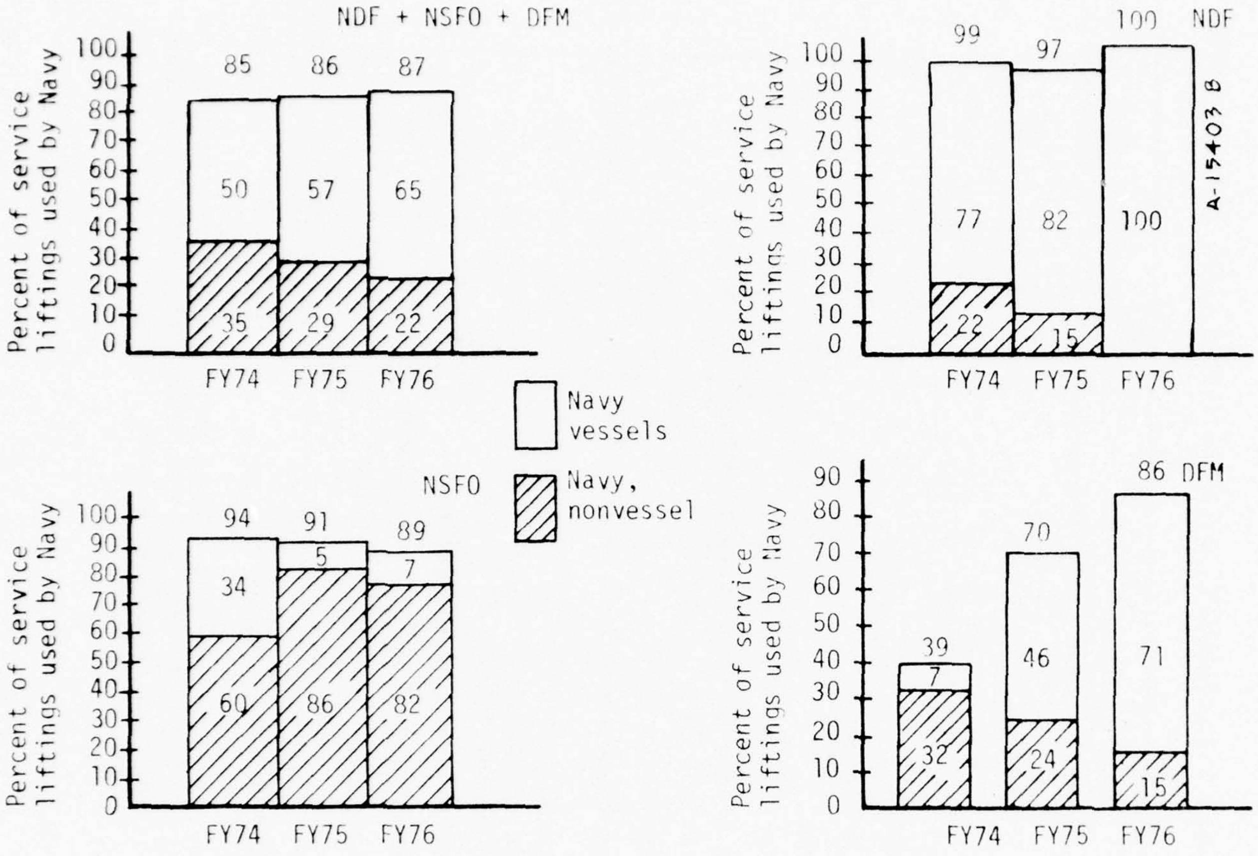


Figure 2-4. Percent of DFSC liftings used by the Navy and the distribution of these liftings within the Navy.

TABLE 2-3. FURTHER AVAILABILITY DATA (DFM, NDF, AND NSFO)[a]

	FY 1974	FY 1975	FY 1976
• Quantity procured	66	38	11 (CONUS)
• Quantities lifted to Navy			
– Vessel	22.6	16.6	17
– Nonvessels	16	8.4	5.7
– Total	38.6	25.1	22.7
• Quantity lifted, all services	45.5	29.2	26.2
• Percent of all service liftings which went to the Navy	85	86	87
• DFSC mean cost, $/BBL[b]	3.20	7.25	10.61
• Civilian counterpart fuel availability	CY 1973	CY 1974	CY 1975
– Stored quantities of distillates and residuals in "Free World" countries outside the U.S.	944	907	N.A.
– Domestic demand, distillates	1,129	1,076	1,040
– Domestic production, distillates	1,030	974	968
– Imports to U.S., distillates	143	106	56

[a] Units MMBBL except where shown

[b] DFSC mean cost obtained by dividing total dollars paid by DFSC to suppliers for all DFM, NDF, and NSFO purchased by the total amount of these three fuels received by DFSC.

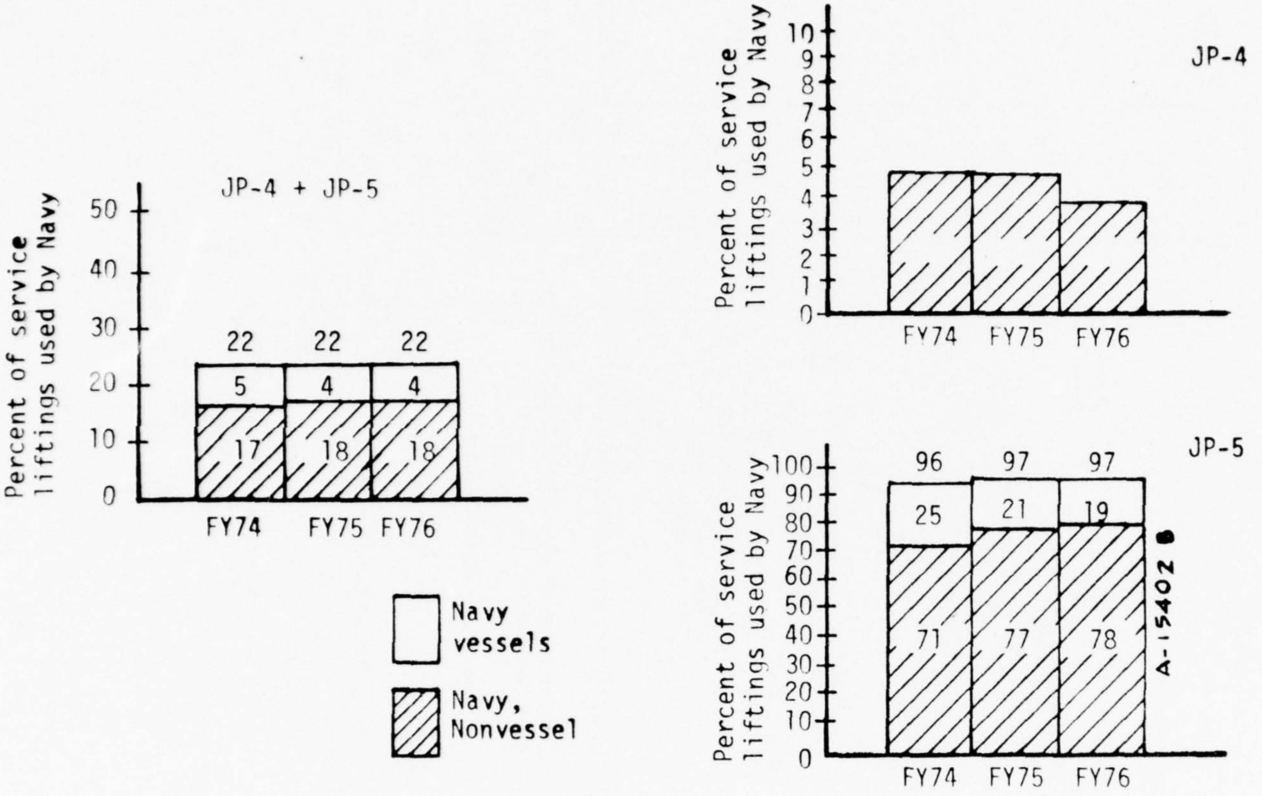


Figure 2-5. Percent of DFSC liftings used by the Navy and the distribution of these liftings within the Navy.

TABLE 2-4. FURTHER AVAILABILITY DATA (JP-5 AND JP-4)[a]

JP-4 + JP-5	FY 1974	FY 1975	FY 1976
• Quantity procured	154	134	94 (CONUS)
• Quantities lifted to Navy			
— Vessels	6.1	4.6	4.1
— Nonvessel	22.3	21.6	20.4
— Total	28.4	26.1	24.6
• Quantity lifted, all services	132.8	119	116.2
• Percent of all service liftings which went to the Navy	21	22	21
• DFSC cost, \$/BBL[b]	4.11	8.44	12.91
• Percent of Navy jet fuel lifted which was JP-4	18	19	16
• Civilian availability of counterpart fuels	CY 1973	CY 1974	CY 1975
— Stored quantities of jet fuel in "Free World" countries outside the U.S.	97	99	N.A.
— Domestic demand, kerosine-based jet fuel	307	281	289 est
— Domestic production, kerosine-based jet fuel	248	234	252 est
— Imports to United States, kerosine-based jet fuel	64	49	38 est

[a] Units: MMBBL except where shown

[b] DFSC mean cost obtained by dividing total dollars paid by DFSC to suppliers for all JP-4 and JP-5 purchased by the total amount of these two fuels received by DFSC.

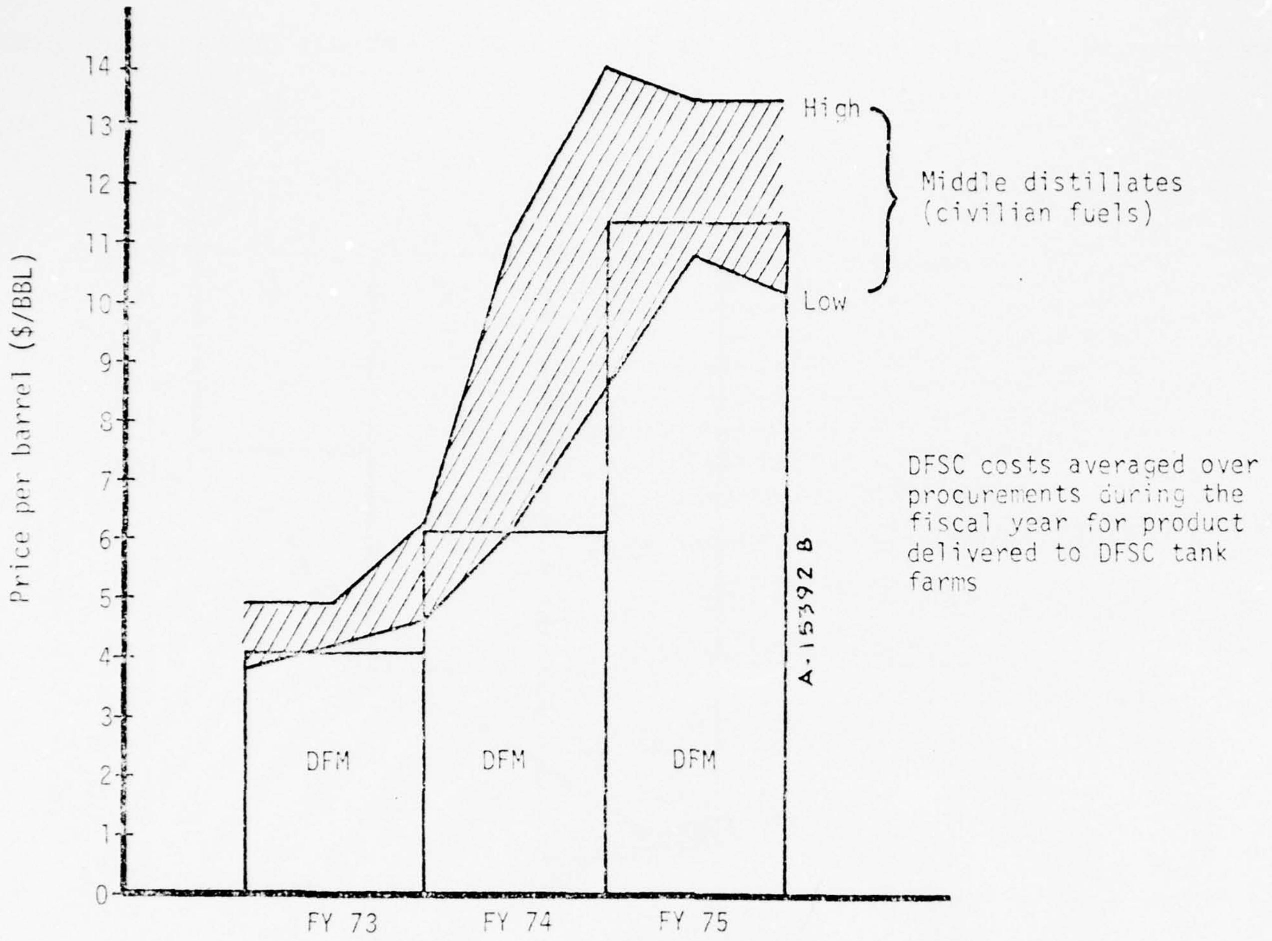
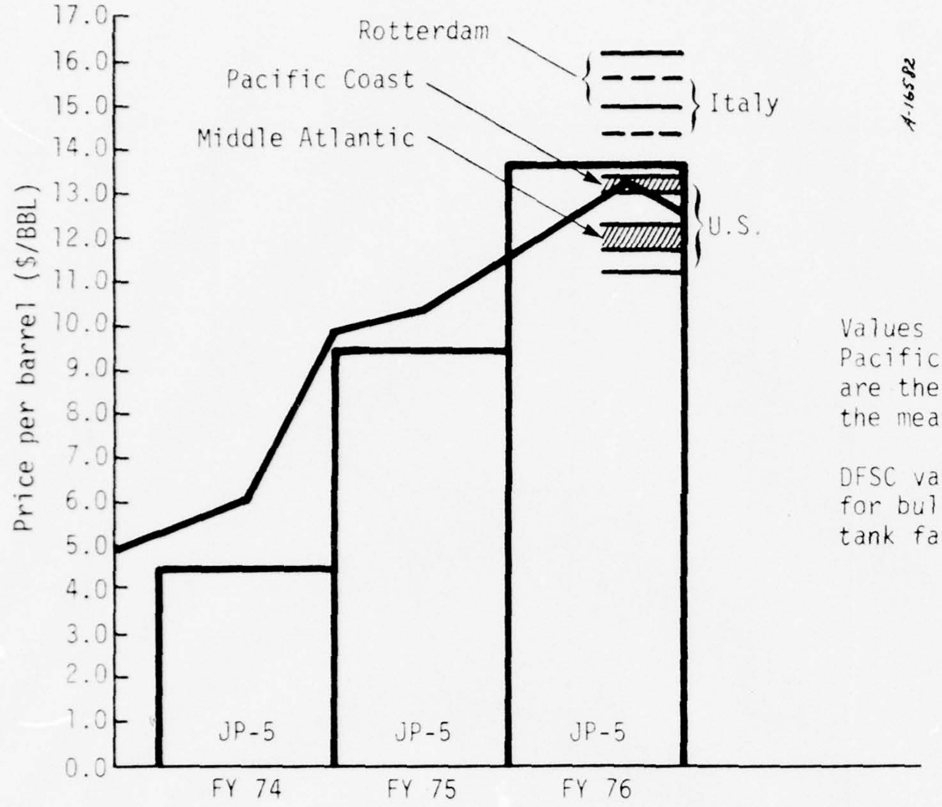


Figure 2-6. DFM and middle distillate fuel oil prices.



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Values for Rotterdam, Italy, U.S., Pacific Coast, and Middle Atlantic are the upper and lower bounds on the mean price in that region

DFSC values are price paid by DFSC for bulk cargos delivered to DFSC tank farms for JP-5 only

Figure 2-7. Price data for quantify lots of JP-5 and of commercial jet fuel, kerosine based.

that no peaks occurred during the half-year intervals. In Figure 2-7 an overall mean is shown for FY74, FY75 and FY76 as well as high-low ranges for the January through June 1977 period at a number of locations. In this case the overall mean was computed on a monthly basis and plotted accordingly. As shown on Figure 2-7, these trends are generally smooth except for a few changes. Liftings to DFSC overseas Regions 1 through 5 are provided by suppliers which vary from one procurement period to another; Table 2-5 shows some recent suppliers.

2.7.2.2 DFSC Data Uncertainties

Navy utilization data can differ from DFSC liftings data by as much as 15 to 25 percent on a short-term (monthly or quarterly) basis. However, on an annual basis, spot checks done at DFSC* suggest about a 5-percent uncertainty. The uncertainties are caused by:

- Excluded information, e.g., the DFSC data presented do not include:
  - In-to-plane fuel contracts (direct purchase of fuel by aircraft from suppliers at civilian airports)
  - Fuel exchanged by the Navy with allied or other friendly navies (on a casual basis)
  - Fuel furnished by the Navy to allied navies for use in joint maneuvers
  - Fuel sold by the Navy to allied or other friendly navies for shipboard use
  - Certain specialized fuels
  - Bunker fuel contracts (direct sales from commercial suppliers to ships)
  - Fuel sold by the Navy to allies for nonshipboard use
- Changes in record keeping or other procedures, as shown by the following examples:
  - Before the embargo, DFSC procurements bore little relationship to actual fuel liftings; differences were as large as a factor of two. Post-embargo procurements correspond much more closely to actual liftings (factors of 0.8 to 0.95).
  - Vietnam-closedown records are suspect
  - Korean refinery diesel fuel shows up as DFM in 1973 through 1974
  - NDF which met DFM specs was relabeled in January 1975 (30 percent of liftings)

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*With the assistance of Lt. Cdr. N. Whitty

TABLE 2-5. PROCUREMENT SOURCES FOR LIFTINGS TO DFSC REGIONS 1-5 DURING FY 77

Contractor, Refinery Location	Product	Destination
Caltex Evergreen, Ras Tanura/Bahrain	JP-4	U.K.
		Azores
		Korea
		Spain
		Donges
		Ascension
		Norway
		Turkey
		Italy
	DFM, JP-4	Japan
	DFM, JP-4	Philippines
	DFM	Okinawa
	DFM	Diego Garcia
Agip, Italy	JP-4	Spain
Motor Oil Hellas, Greece	F54[a]	Donges
Shell, Curacao	JP-5	Scotland
	JP-5	Portugal
	JP-5	Spain
	JP-5	Guantanamo
Hess, Virgin Islands	DFM	Guantanamo
	DFM	Azores
	DFM	Scotland
	DFM	Ascension
Korea Oil, Korea	JP-4, DFM	Korea
Guam Oil, Guam	JP-4, DFM	Guam
	DFM	Kwajalein
	DFM, JP-4	Japan
	DFM, JP-4	Philippines
	JP-4	Okinawa
Chinese Petroleum Company	JP-5	Japan
	JP-5	Diego Garcia
	JP-5	Philippines
	JP-5	Guam
Honam Oil, Korea	DFM	Japan
	DFM, JP-4	Korea

[a] F54 is the NATO designation for a fuel which is the closest NATO fuel corresponding to U.S. grade DF-2 (see NAVSEAINST 10300.1, NAVAIRINST 10300.2, SEC 6101F/ECT, Ser 267, AIR 5364C, dated 14 January 1976); this fuel is called "DIESEL FUEL: Regular"

- The Navy lifts fuel and then sometimes returns it
- In 1973, Cherry Point, N.C. used JP-5 for heating for several months (other oddities are also buried in the records)
- Some DFSC data are not assignable to geographical regions, however, this uncertainty has diminished markedly for Navy vessel use and diminished somewhat less for Navy non-vessel use. Detailed (region by region) liftings data are presented in Appendix B.

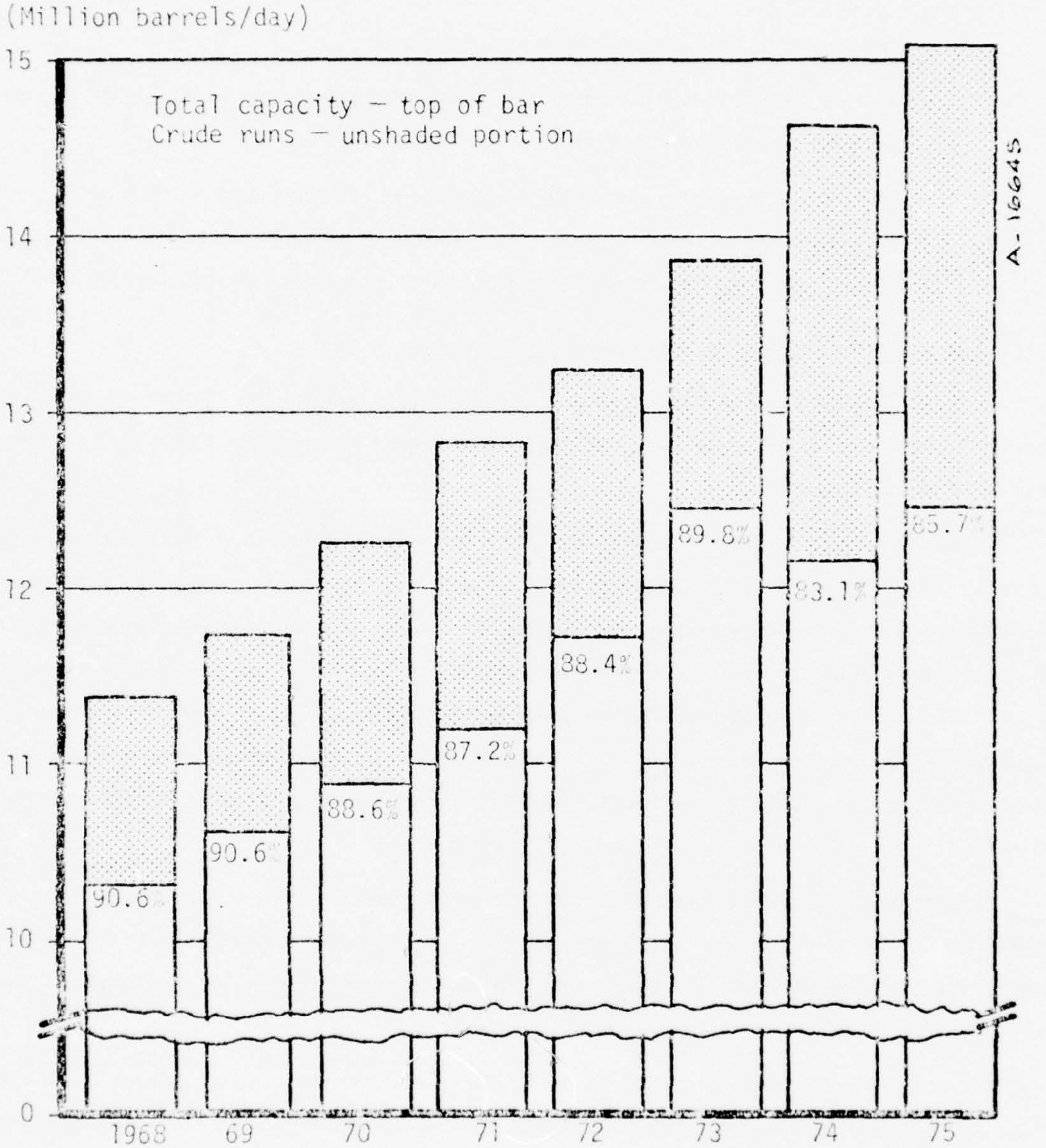
2.7.3 Additional Availability Data on Commercial Counterpart Fuels

This section describes additional data on civilian fuels corresponding to DFM and JP-5. These data will give the reader a better understanding of the "fuels market" and available data sources than was previously presented.

Appendix C contains a 1973 BuMines compilation for the United States of the daily refinery outputs of jet fuel and of Number 2 heating oil and diesel fuel (combined). (Details of the processes available at each United States refinery are published annually by BuMines.) This table was published in 1976 by the Special Subcommittee on Integrated Oil Operations of the Committee on Interior and Insular Affairs of the U.S. Senate. BuMines continues to collect certain of these data at the request of the FEA, but does not publish it. These data will be made available to the Navy Energy R&D Office if a suitable request is made to Mr. James Peterson of the FEA (202) 254-5147. The data in Appendix C are directly relevant to the needs of Section 5.

Appendix D lists marine fuels sold around the world by Shell, Chevron, Exxon, Gulf, and Texaco. (These are not the only possible suppliers.) The fuel labeled Marine Gas Oil (MGO) is closest to DFM. Storage facilities exist at many of these ports, but their size and precise location are not known to us.

Figure 2-8 shows temporal changes in United States refinery capacity and percent utilization. These data roughly indicate the potential increase in refinery output if crude were available. Refinery capacity appears to be increasing at about the same rate as demand, i.e., at about 4 to 5 percent per year. These data suggest that fuel availability is limited more by crude supply than by refinery capacity. Since these data are country-wide averages, they do not preclude localized differences between production capacity and demand, nor do they address inter-region distribution difficulties.



Source: FEA trends in refinery capacity & utilization, December 1975.

Figure 2-8. Refinery capacity and crude runs — percent of utilization.

The average mixed barrel price* is compared to the average crude cost and the refinery distributor gross margin in Table 2-6. At the beginning of this time period, gross margins were typical of industries which processed or modified large volumes of natural products. Although percent margins have shrunk considerably under price control, actual margins in $/BBL have increased independently of OPEC prices. These increases reflect general inflation and, to some degree, the economic health of the petroleum companies. Percent margins may return slowly towards their former levels after decontrol, subject to the conflicting pressures of stockholders, the OPEC nations, the public and the United States Government.

No understanding of the fuel production and supply economy is complete without considering the importance of transportation on delivered cost of the fuel. Table 2-7 provides comparison figures for costs of Saudi Arabian crude and costs of transportation and refining during January, 1976. According to this table, transportation, at $1.94/BBL, is nearly double the cost of refining, and accounts for about 13 percent of the total price of refining products from a foreign crude.

In summary, Aerotherm has found that the BuMines and the FEA have amassed information about the capacities, configuration, and throughputs in the United States petroleum industry. We believe that these data would be useful to the Navy in formulating program plans on fuel availability, and should be obtained. We recommend that liaison be initiated with the Division of Petroleum and Natural Gas and the Division of Fuels Data of BuMines. Further, since questions of fuel distribution capability are also important, such data directly related to Navy needs should be compiled.

2.8 COMPARISON BETWEEN CURRENT STUDY AND "PATTERNS OF ENERGY USAGE IN THE U.S NAVY"

The data gathered during this study from DFSC for liftings were compared to those reported in "Patterns of Energy Usage in the U.S. Navy." That report was prepared by the Energy R&D Office of DWTNSRDC to show how energy usage had changed in the various fuel consuming sectors of the Navy between the pre- and post-embargo periods. Fuel usage data were collected from fleet, air, and shore facilities records and aggregated to show consumption by each major sector (e.g., fighting forces, support ships, shore facilities, etc.) and fuel. The report has been issued annually for several years, the one used for comparison with the present study being dated November 1975. The essential difference between the "Patterns" report and the present study is that the former used consumers' fuel usage records whereas this study used DFSC liftings data.

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*A mixed barrel contains the mean United States refinery yield percent of each major product for a given year.

TABLE 2-6. REFINERY MARGIN

	Average Mixed Barrel Price	Average Crude Cost	Refiner/Distributor Gross Margin	Margin as A Percent of Crude Cost
(All figures in dollars per barrel)				
1968	$ 5.13	$ 3.17	$1.96	61.8
1969	5.24	3.29	1.95	59.3
1970	5.41	3.40	2.01	59.1
1971	5.85	3.60	2.25	62.5
1972	5.75	3.58	2.17	60.6
1973	6.73	4.15	2.58	62.2
1974	11.92	9.07	2.85	31.4
1975	14.02[a]	11.05[a]	2.97[a]	26.9

[a] Represents November 1975 prices

Sources: Mandatory reports (FEO-96) submitted to FEA, Bureau of Mines, Platt's Oilgram and Lundberg Survey Inc.

TABLE 2-7. IMPORTED REFINED PRODUCT PRICE FOR SAUDI ARABIAN CRUDE OIL, REFINED IN CARIBBEAN AND TRANSPORTED TO THE UNITED STATES FOR CONSUMPTION

(January 1976)	
Crude price at Saudi Arabia	$11.51
Trans. to Caribbean	1.42
Landed Caribbean crude cost	$12.93
Refining costs	1.00
Middle distillate cost at the refinery	$13.93
Trans. to U.S.[a]	.52
Landed price	$14.45
Price per gallon	.3440
License fee	.0150
Total per-gallon price of middle distillate	.3590

[a] For the purpose of this example, transportation costs from the Caribbean to the U.S. were taken as those to the Northeastern seaboard (North of Cape Hatteras, N.C.).

<u>Sources:</u> Crude price — market price for 34° gravity Arabian light

Transportation costs — WS 100 — Platts Oilgram, January 14, 1976; AFRA Indices — Petroleum Economist, January 1976

License fee — FEA oil import administration

Refining costs — FEA study

The compilations presented in the two reports were compared by fuel type (DFM vs. DFM, NDF vs. NDF, etc.). Although they are not strictly comparable, since no allowance could be made for materials in transit or any possible changes in stockpile quantities during this time period, they show adequate agreement over the 3-year period FY 1973, FY 1974, and FY 1975. For example, the FY 1975 data for JP-4 and JP-5 agree to within 0.3 percent and those data for DFM and NDF and NSFO agree to within 10 percent. Hence these transients in the supply system do not appear to affect comparison between DFSC liftings and fleet usage data.

The separate data for DFM and NDF, however, show major difference, but these diminish markedly when these two fuels are grouped together. There is some justification for this; in Subsection 2.7.2.2, we noted that a substantial quantity of NDF was relabeled as DFM during January, 1975.

We believe that if allowance could be made for materials in transit and possible changes in stockpile quantities, agreement between the two data sources would be excellent for all of these data.

SECTION 3

COMPARISONS BETWEEN NAVY AND CORRESPONDING CIVILIAN MARINE AND AVIATION COMBUSTION EQUIPMENT

3.1 INTRODUCTION

As discussed in Section 2, shortfalls may occur in the availability of MILSPEC fuels used in naval fleet operations. However, the Navy uses only a small percentage of the fuels produced domestically (only about 2 percent of the domestic production of middle distillates for combustion in marine equipment, and only about 7 percent of the domestic production of kerosine-type jet fuels for combustion in aircraft). Far greater percentages of domestic production are used as fuels in civilian counterparts of Navy marine and aviation combustion equipment. In a fuel shortage, these civilian fuels could theoretically be diverted for Navy use. Although shortages have occurred, civilian fuels, to date, have not been used. This section will examine the reasons why the Navy does not burn civilian fuels.

This section, then, will identify the differences in design, operating conditions, storage and handling requirements, and application between Navy and corresponding civilian combustion equipment, and will describe how these differences affect fuel requirements for Navy systems. An overview of equipment types and applications is presented in Section 3.2. Section 3.3 discusses the general differences between Navy and civilian equipment, while Section 3.4 details specific differences and the impacts of these differences on fuel requirements. Section 3.5 summarizes the discussion of this section.

3.2 EQUIPMENT AND APPLICATIONS

Combustion equipment is used on Navy ships to provide both propulsive power and ship service (hot water, space heating, and electricity). For many years, marine propulsion has been supplied by steam turbines and large-bore diesel engines. These two types of combustion equipment will continue to supply fleet marine propulsion through the foreseeable future, although more recently, aircraft-derivative marine gas turbines have entered fleet service to provide marine propulsion. The use of marine gas turbines will continue to grow, relative to steam turbines and diesel engines.

For aircraft propulsion, the emphasis on jet aircraft for fleet aviation missions has established gas turbines as the major source of propulsion.

For auxiliary power and hotel services, small- to medium-sized diesel engines have been the traditional source, but the smaller aircraft-derivative marine gas turbines are now beginning to be used.

3.3 GENERAL DIFFERENCES BETWEEN NAVY AND CIVILIAN EQUIPMENT

In general, Navy equipment and operating requirements place more stringent constraints on fuels than do the corresponding civilian equipment and operations. Navy equipment is more compact and operates at higher combustion intensities than civilian equipment. It also must supply greater peak power and is subject to larger and more frequent fluctuations in power level.

Moreover, Navy equipment must operate more quietly, produce less visible exhaust, and be able to perform under hostile conditions without subjecting personnel to undue hazard. It must also be able to handle contaminated fuel, since naval fleet handling practices can result in the contamination of fuels by water.

In addition, Navy fuel must have a longer storage stability than civilian fuels, because Navy fuels must be capable of being stored for multi-year periods without deteriorating.

3.4 EQUIPMENT, DIFFERENCES, AND ASSOCIATED IMPACTS ON FUEL REQUIREMENTS

To better appreciate the potential for impacting naval operations when using civilian fuels, it is useful to know what combustion systems the Navy uses, how many they have of each kind, and how these naval systems differ from their civilian counterparts. The available information on types and quantities of combustion systems used by the fleet is presented in Tables 3-1 through 3-4.* In most cases comparable data were not readily available on civilian usage, and an extensive compilation of such information was not possible within the scope of this program. It is known, however, that virtually all of the boiler and diesel models used by the Navy are also used by the civilian sector, although a few of the components may vary (e.g., tube spacing, fuel nozzle size, etc. – see Table 3-5 below, and its associated discussion). The marine gas turbines are either derived from aircraft engines or have a civilian counterpart.

The steam boilers used by the Navy in the fleet are identified in Table 3-1(A). This table also shows their distribution by type, while Table 3-1(B) indicates the distribution by major operating parameters – pressure and temperature. Those classified as superheat control or as one of the

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*Each of these tables has a slightly different format, reflecting the data available to us.

TABLE 3-1(A). STEAM BOILERS IN FLEET USE BY THE NAVY[a]

Boiler Type	Manufacturers	Total Units
3 Drum	Babcock and Wilcox	24
3 Drum Express	Babcock and Wilcox	20
2 Drum	Foster Wheeler, Combustion Engineering, Babcock and Wilcox, Wickes	281
2 Drum D Type	Combustion Engineering, Babcock and Wilcox	52
2 Drum Superheat Control	Foster Wheeler	6
2 Drum Single Uptake	Babcock and Wilcox	40
Single Drum	Foster Wheeler	2
Superheat Control	Babcock and Wilcox	480
Header Drum	Babcock and Wilcox, Combustion Engineering	26
Single Furnace D Type	Foster Wheeler	60
Pressure Fixed Supercharge	Foster Wheeler	38
D Type	Combustion Engineering	92
Unspecified	Foster Wheeler, Combustion Engineering, Babcock and Wilcox	162
TOTAL		1283

[a] Information provided by DTNSRDC.

TABLE 3-1(B). DISTRIBUTION OF BOILER UNITS BY OPERATING CONDITIONS[a]

Pressure Range (psia)	Temperature Range (°F)	Total Units
<400	577	2
400 - 500	719 - 765	130
500 - 600	850	460
600 - 700	675 - 875	229
>1000	940 - 950	462
TOTAL		1283

[a] Information provided by DTNSRDC.

TABLE 3-2. MARINE DIESELS IN FLEET USE BY THE NAVY[a]

Manufacturer[b]	Approximate No. of Units
Allis-Chambers (4)	8
Alco (4)	122
Cooper-Bessemer (4)	12
Cummins Engine Company (4)	14
Davy Paxman (4)	12
Detroit Diesel (2)	2
Fairbanks Morse (2)	43
General Motors (2)	85
Nordberg	2
Packard	34
Waukesha (4)	52
Total	386

[a] Information provided by DTNSRDC.

[b] Figure in parentheses shows the number of strokes per cycle of the engines supplied by that manufacturer.

TABLE 3-3. MARINE GAS TURBINES IN FLEET USE BY THE NAVY[a]

Manufacturer	Turbine Designation	Power Rating	Use	Approximate No. of Units
Avco-Lycoming	TF 40	3350 Hp	Propulsion	14
	TF 35	2880 Hp	Propulsion	4
	TF 12	1150 Hp	Propulsion	2
Detroit Diesel Allison	501K 17	2000 kW	Auxiliary	12
Garrett	ME883	380 Hp	Auxiliary	2
	GTP95	200 Hp	Auxiliary	1
	GTC85	200 Hp	Auxiliary	12
	1E35	125 Hp	Auxiliary	2
General Electric	LM 2500	21500 Hp	Propulsion	19
	LM 1500	15000 Hp	Propulsion	13
Pratt & Whitney Aircraft	FT 12	3500 Hp	Propulsion	3
Rolls Royce	TYNE	3900 Hp	Propulsion	1
	Proteus	3100 Hp	Propulsion	2
Solar	T62	65 kW	Auxiliary	5
United Aircraft — Canada	ST6	500 Hp	Auxiliary	3

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[a] Information provided by DTNSRDC

TABLE 3-4. AIRCRAFT GAS TURBINES IN FLEET USE BY THE NAVY[a]

Manufacturer	Unit
Allison	J33
	T56
	TF41
Garrett	T76
General Electric	J79
	J85
	T58
	T64
	TF34
Lycoming	T53
Pratt & Whitney Aircraft	J48
	J52
	J57
	J60
	JT3D
	JT8D
	TF30
	F401
	F402
Westinghouse	J34
	T50
Wright	J65

[a] Information provided by DTNSRDC.

various 2 drum units account for more than 65 percent of the total. Babcox and Wilcox and Foster Wheeler supply most of the fleet's boilers. The majority (54 percent) of these operate at, or above, 600 psia and 675°F.

Marine diesels are used for both propulsion and ship services, and are either 2- or 4-stroke and medium or high speed.

The high speed units are generally used only for ship services and the low speed for propulsion. Data were not available to show which ones are turbocharged, but all of these types of engines can be equipped with turbochargers. The distribution by manufacturer of marine diesels in the Navy is presented in Table 3-2.

At present, there are 37 marine gas turbine units used by the Navy for ship propulsion (Table 3-3). Of these, 51 percent are supplied by General Electric. In the case of auxiliary power, 18 of the 20 units are supplied by Garrett.

Table 3-4 shows the manufacturers of aircraft gas turbines and their respective models. No data were available to indicate the number of units per model or per manufacturer.

Tables 3-1 through 3-4 indicate that there are a large number of types as well as a large number of suppliers of combustion units used by the Navy Fleet. However, in each table, only a few types comprise most of the units. These same generic types are used in civilian ships and aircraft as well as in the Navy. More importantly, differences between naval and commercial units can be adequately characterized on the basis of basic types, rather than on specific models.

Table 3-5 summarizes those differences which may prevent the Navy from using civilian fuels under normal conditions. Probably the most important of these differences concerns safety, since Navy equipment may come under hostile fire. As a result, fuel tanks and supply lines may rupture, allowing fuel to leak into ships' compartments and possibly ignite. The fuel/air mixture's environment would probably also be hot, from fire or exploding ordinance, creating even more safety problems.

To reduce the risk of igniting leaked fuel, or at least to retard ignition, the MILSPEC for fuels carried on ships (i.e., DFM and JP-5) requires a higher flash point than do specifications for civilian or land-based military fuels (e.g., No. 2 diesel or JP-4). For JP-5, the MILSPEC also includes an explosiveness criterion.

Another important difference which may prevent the Navy from using civilian fuels results from the Navy's decision to use DFM fuel in all its marine combustion equipment. All fuel systems on board ships now have pumps that are designed to handle only light-to-middle distillate, not heavier fuels. Fuel pumps that can handle heavier fuels are not used, since they are not lubricated

TABLE 3-5. NAVY AND CIVILIAN COMBUSTION EQUIPMENT[a]

Equipment	Component or Condition That Is Different	Navy/Civilian Difference	Potential Impact From Use of Civilian Fuels
All Types of Equipment	All components	*All Navy equipment is exposed to ordnance* from military opponents; civilian operations are not	*Navy fuel systems may be* subjected to higher ambient temperatures and mechanical shocks which can induce fuel to burn/explode
All Marine Equipment	Fuel supply system	Navy ships have deactivated (or removed) preheaters and have changed pumps => fuel systems made comparable with DFM	Navy ships cannot use the heavier grades of fuels
Steam Boilers	Feedwater temperature	~ 120°C/≥ 137°C	Navy feedwater temperature is below acid dewpoint => corrosion of economizers in Navy equipment
	Superheater tube clearance	Clearance in Navy equipment is ~ 75 percent of that in civilian equipment	Navy equipment is more susceptible to fouling and clogging from contaminants in fuel
	Soot blowers	Do not exist on some Naval ships/usually present on civilian ships	Where soot blowers are missing, carbon deposits can build up to problem levels
	Refractory	From 50 to 400 percent more refractory in Navy ships	Combination of these two differences can lead to more thermal shock spalling and hot corrosive reactions in Navy ships
	Combustion intensity	Navy boilers at 30 percent load (cruise) generate ~90000 Btu/hr-ft^3, while commercial boilers at full load generate 70000 to 80000 Btu/hr-ft^3	
Diesel Engines	Power demands	Naval ships can require more frequent power changes over greater ranges	May cause excessive stack smoke in Navy ships
	Injector size	Nozzle size in Navy injectors may be ~ 70 percent of that in civilian equipment	May cause clogging and coking at the injector ports of Navy equipment
Marine GT	Operating conditions	Navy equipment may operate at higher power and greater combustion intensities than civilian equipment	Higher hot gas path temperatures (~ 38°C) accelerate sulfidation and other corrosion problems in Navy equipment
Aircraft GT	Operating conditions	See marine GT	See marine GT
	Nozzles per burner	Navy equipment may have multiple nozzles per burner	Smaller nozzle orifices in Navy engines => increase potential for coking in Navy engines
	Environment	Navy aircraft engines may operate at higher altitudes than civilian equipment	Navy fuel systems are more susceptable to low temperature effects

[a] Sources: Personal communications with equipment vendors, users, and other cognizant sources (Reference 17).

adequately by light or middle distillate fuel, such as DFM. In addition, pumps for heavier fuels require greater clearances than those used for DFM or corresponding civilian distillates; therefore, current pumps would have to be replaced to use the heavier fuels.

Moreover, DFM fuel, unlike heavier fuels, does not require preheating, and hence, preheaters have been deactivated or removed from ships that once used them when burning NSFO fuel. Therefore, no ships in the Navy fleet, even those once capable of burning NSFO fuel, are currently able to burn heavier fuels, unless preheaters are used and appropriate pump changes are made.

Steam Boilers

The differences between Navy and civilian steam boilers listed on Table 3-5 cover equipment design, materials, and operating conditions. The impact of these differences on requirements for the fuel are discussed below.

The clearance(s) between tubes in the superheater is less in the Navy boilers. Less clearance renders the Navy boilers more susceptible to fouling and clogging from fuel contaminents, and appears to be one of the major reasons that the MILSPEC requires the carbon residue and ash levels in the fuel to be about one-half the amount allowed by civilian specifications.* In addition, the absence of soot blowers on some Navy ships requires fuels to have low carbon residue and ash levels.

In contrast to civilian practice, the Navy operates its boilers at feedwater temperatures below the dewpoint of sulfuric acid. Thus, the economizers are subject to corrosive attack if the sulfur level and/or the acidity of the fuel are too high. Allowable sulfur levels in the civilian distillate which corresponds to DFM are lower than sulfur levels for DFM, but the sulfur content of the heavier fuels can frequently be higher. Also, unlike the MILSPECS, civilian specifications place no explicit requirement on acidity of the fuel.

In addition, Navy boilers contain from 50 to 400 percent more refractory and are operated at greater combustion intensities than corresponding civilian boilers. This combination can lead to more thermally-induced spallation and hot corrosion of refractory material. Therefore, sulfur levels and acidity must again be kept as low as possible.

Diesel Engines

Diesel engines in the Navy are virtually the same as those in civilian fleets, differing only in fuel injector size and power requirements. The nozzle size of injectors in some Navy diesel

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*Detailed comparisons between military and civilian fuel specifications will be presented in Section 4.

engines is 30 percent smaller than that in corresponding civilian equipment. Therefore, Navy diesels are more prone to clogging and coking at the injector tops if carbon residue and ash levels are too high.

Power requirements also differ, because Navy ships must be able to change their power setting frequently and rapidly. Moreover, power fluctuations span a greater range (from cruise at about 30 percent of the engine's continuous rated output to peak steaming conditions at approximately 110 percent rated load) than those on civilian ships. Hence the fuel must have good ignition characteristics. In particular, if the fuel cetane number is too low, ignition may be delayed too long to permit complete combustion of the fuel. This can degrade engine output and also cause excessive stack smoke. Because the civilian specification for cetane number is lower than the MILSPECS, the direct substitution of civilian fuels (e.g., No. 2 diesel oils) may not be feasible. However, the military allows ignition improvers, and therefore this problem may be eliminated.

Gas Turbines

Navy marine gas turbines in fleet use differ from the corresponding civilian equipment only with respect to operating conditions: Navy engines operate at higher power levels and greater combustion intensities. The higher levels promote corrosion of materials along the hot gas path, a problem which can be minimized by using fuels with low sulfur and acidity levels.

Aviation gas turbines in the Navy fleet also must be able to sustain operation at higher power levels than their civilian counterparts and, hence, also require fuels with low sulfur and acidity levels. In general, comparable civilian fuels meet the military's requirement for sulfur and acidity.

Additional differences may arise, however, because Navy aircraft may operate at higher altitudes, and (unlike civilian aircraft) may have more than one fuel nozzle per burner. To function properly at high altitudes, fuel must be able to flow freely at lower ambient temperatures, i.e., the freezing point must be lower in fuels for Navy jets. Also, since Navy aviation gas turbines may have more than one fuel nozzle per burner, the orifices in the Navy nozzles will be smaller. Smaller orifices are more susceptible to coking and plugging, and therefore, need a fuel which is low in particulate matter and existent gum. Typical commercially available alternatives for JP-5 (i.e., Jet A) satisfy the Navy's gum requirements, and probably also satisfy the particulate limits, although these civilian fuels are usually not tested specifically for particulate matter.

Fuel Handling

The differences in fuel handling practices between Navy and civilian operators of combustion equipment also affect the differences between MILSPEC and civilian fuel requirements. The Navy fuels may be stored for multi-year periods, while civilian fuels are usually burned within months of manufacture. DFM must, therefore, have long-term storage stability (as checked by an accelerated stability test), which is not needed in civilian operations. DFM may also require antioxidants, and these must be selected carefully to insure that they do not cause equipment malfunction (e.g., disarming coalescers, as discussed below).

Moreover, since the Navy ballasts their ships by placing sea water in the fuel tanks, some water and other foreign matter contamination will occur in the fuel stored in those tanks. Therefore, fuel such as JP-5, destined for aircraft which fly in environments where the temperature is below the freezing point of water, must be easily separable from the water (as measured by the water reaction requirements). This fuel must also contain only low levels of sulfur and acidity to reduce water soluble corrosive agents. And, since water is removed from the fuel by coalescers which are disarmed by polar materials, additives for MILSPEC fuels must be nonpolar.

3.5 SUMMARY

This section has identified the various models of steam boilers, diesel engines, marine gas turbines, and aircraft gas turbines that the fleet uses for propulsion or ship service. Civilian counterparts were also identified for some of the gas turbines, but this was not done for steam boilers and diesel engines because both Navy and civilian models carry the same designation.

Differences between Navy and civilian combustion equipment and operating conditions lead to different requirements for respective fuels. Fuel safety requirements differ because the Navy may operate under hostile conditions. Different fuel storage requirements and bunkering practices between Navy and civilian fleets lead to different requirements for fuel stability and additives.

Equipment differences between Navy and civilian combustion systems which affect fuel requirements can be adequately characterized by basic equipment types. For steam boilers, these differences lead to more stringent requirements on allowable contamination levels. For diesel engines the differences lead to stricter limits on cetane number, and for aircraft gas turbines more stringent limits on freeze point are required.

The following section looks in detail at differences among the fuels themselves. The specific differences between MILSPEC and civilian fuels are discussed to determine the possibilities of using civilian fuels in Navy combustion equipment.

SECTION 4

COMPARISONS BETWEEN MILSPEC AND CORRESPONDING CIVILIAN FUELS

4.1 INTRODUCTION

In the previous section, Navy combustion equipment and operational requirements were compared to those for similar civilian systems to explain why differences exist between military and civilian fuel specifications. In this section, the disparity between civilian fuels and fuels which conform to the MILSPECS will be examined. Section 4.1 explains fuels specifications and defines the basis and methodology for comparing specifications for different fuels. Section 4.2 discusses qualitatively the potential impacts on military combustion equipment when MILSPECS are not met. In Section 4.3, the DFM MILSPEC is compared with specifications for civilian fuels, while in Section 4.4 a comparison is made for JP-5. Section 4.5 briefly discusses manufacturers' experiences with civilian fuels of varying properties, as well as reports on these fuels in the literature. Finally, Section 4.6 summarizes the whole discussion.

4.2 FUEL SPECIFICATION COMPARISONS

A fuel specification lists the acceptable value(s) for fuel properties or contaminant levels, and may list the types and amounts of approved additives.

To compare fuels on the basis of their properties, it is useful to group the specification elements into the following three categories

- Safety — elements which specify the hazard potential of the fuel
- Performance — elements which specify the fuel ability to deliver required output and the fuel's compatibility with handling equipment
- Maintenance — elements which specify the contamination levels of the fuel, and hence its potential to degrade the performance of the fuel supply or combustion equipment

Table 4-1 categorizes the specification elements for DFM and JP-5. The performance category includes the following subgroups:

- Basic properties — those which define the distillation fraction of the petroleum from which the fuel is derived and those with associated physical properties

TABLE 4-1. CATEGORIES OF SPECIFICATION ELEMENTS

Category	Element	Applicable MILSPEC
Safety	Flash point	DFM, JP-5
	Explosiveness	JP-5
Performance		
Basic Properties	Appearance	DFM
	Color	DFM
	Distillation	
	10 percent fraction	JP-5
	90 percent fraction	DFM
	End point	DFM, JP-5
	Loss and Residue	DFM, JP-5
	Viscosity	DFM, JP-5
	Gravity	JP-5
Combustion Properties	Net heat of combustion	JP-5
	Cetane number	DFM
	Smoke point	JP-5
	Aromatics	JP-5
	Olefins	JP-5
Other Properties	Freezing point	JP-5
	Pour point	DFM
	Cloud point	DFM
	Demulsification	DFM
	Thermal stability	JP-5
Maintenance		
Corrosion Contaminants	Sulfur	DFM, JP-5
	Mercaptans	JP-5
	Acid number	DFM, JP-5
	Copper strip corrosion	DFM, JP-5
	Neutrality	DFM
Erosion Contaminants and plugging or fouling	Carbon residue	DFM
	Ash	DFM
	Particulate matter	JP-5
	Existent gum	JP-5
	Accelerated stability	DFM
Other Contamination	WSIM	JP-5
	Filtration time	JP-5
	Additives	DFM, JP-5

- Combustion properties — those which define the heat content and combustion characteristics of the fuel
- Other properties — those which define the ability of the fuel to flow in the liquid phase

The maintenance category subgroups are:

- Corrosion contaminants — those which induce corrosion, either along the hot gas path or within the fuel supply system
- Erosion or fouling contaminants — those which can plug small openings, foul heat exchanger surfaces, or erode materials that are exposed to the fuel or its products of combustion
- Other contaminants — those contaminants and additives that can block the fuel flow within the supply system or otherwise compromise operation

Thus, Table 4-1 illustrates a framework which can be used to compare fuels by their specifications, showing the differences between the MILSPECS and the requirements made of corresponding civilian fuels, identifying each difference as it affects safety, performance, or maintenance of combustion equipment.

Within this framework, the methodology used to compare fuels considers that civilian fuels may meet a number of specifications, not only ASTM specifications, but even more strict company specifications. Moreover, analyses of actual fuel samples generally show that the fuels even surpass company specifications.

Therefore, the differences between MILSPEC and corresponding civilian fuels will be shown through comparisons. First the MILSPECS will be compared to the ASTM specifications, then to several company specifications, and finally to actual analyses of civilian fuel samples. These comparisons will show:

- How currently acceptable Navy fuels differ from the guaranteed characteristics of comparable civilian fuels (at least most domestic, and many foreign fuels, which are sold conforming to ASTM specifications)
- How the same Navy fuels may differ from the minimum quality fuel that several petroleum companies will guarantee to supply
- How Navy fuels differ from typical fuels delivered to civilian users

The first two comparisons are based on guarantees and show the biggest possible differences between Navy and civilian fuels, while the last comparison shows current differences.

It became evident during the early stages of the study that the distillate fuels, such as the Nos. 1 and 2 heating oils and diesel fuels, satisfied many of the MILSPEC elements for DFM. Therefore, these fuels could be used in lieu of DFM, at least for a short time, without having to replace or modify equipment. Similarly, much of the Jet A/A1 sold commercially differs from JP-5 in only a few specification elements (and possibly also in some properties not measured on civilian fuels). Hence, these fuels, all middle distillate, were considered to be favored alternates and were emphasized in both the availability/cost analyses of Section 2 and the fuel comparisons in this section.

4.3 QUALITATIVE IMPACT OF NONCOMPLIANCE WITH SPECIFICATION ELEMENTS

Before looking at element-by-element differences between the MILSPECS and the corresponding civilian fuels, it is desirable to identify how each element affects combustion equipment. Table 4-2 presents this information by noting the qualitative impact on combustion equipment of individual noncompliance with each MILSPEC element (see Sections 4.3 and 4.4 below). These potential impact(s) are noted separately for the three basic types of naval combustion equipment.

For some specification elements the potential impact(s) vary with equipment type. For example, cetane number has an impact only on diesel engines, while explosiveness impacts only aircraft gas turbines. These variations should be considered when determining the conditions under which a civilian fuel could be substituted for a MILSPEC fuel in a given type of combustion equipment.

4.4 DFM MILSPEC COMPARISONS WITH CORRESPONDING CIVILIAN FUELS

The DFM MILSPEC fuel (MIL-F-16884G) has been designated by the Navy for use in all nonaviation combustion equipment in the fleet, i.e., steam boilers, diesel engines, and marine gas turbines. This MILSPEC defines a very clean middle distillate petroleum fraction, to which ignition improvers, antioxidants, and/or metal deactivators may be added.

Civilian fuels similar to the DFM fuel are classified as heating oils, diesel fuel oils, and gas turbine fuel oils. Table 4-3 presents a breakdown of these classifications by individual fuel grade and includes fuel characteristics and normal applications. On the basis of distillate fractions, Grades 1 and 2 in each civilian fuel classification are lighter (lower viscosity) oils and correspond closely with DFM fuel, while the other grades are heavier fractions or residuals. The viscosity of the oils is an extremely important factor when considering alternates for DFM, because the use of Grades 1 and 2 oils would not require modifications to combustion equipment (i.e. the addition of

TABLE 4-2. IMPACT OF ELEMENTS

Element	Boilers	Diesels	Gas Turbines
Flash point	Safety	Safety	Safety
Explosiveness	Not applicable	Not applicable	Safety for aircraft gas turbines
Viscosity	Pumpability, incomplete combustion, and lubricity	Pumpability, incomplete combustion, power loss due to injection pump and injector leakage, and lubricity	Pumpability, incomplete combustion, and lubricity
Gravity	Endurance	Endurance	Endurance/range
Appearance/color	Plugging and/or corrosion	Plugging and/or corrosion	Plugging and/or corrosion
Demulsification	Potential corrosion, clogging due to organic slimes	Potential corrosion, clogging due to organic slimes	Potential corrosion, clogging due to organic slimes
Cetane number	Not applicable	Ignition speed → smoke and increased fuel consumption	Not applicable
Distillation temperature, 10 percent recovered	*Start up*	*Start up, response to rapidly* fluctuating load/speed demands	*Start up*
Distillation temperature, 90 percent recovered	Elimination of hard to vaporize fractions	Elimination of hard to vaporize fractions	Elimination of hard to vaporize fractions
Distillation temperature, end point	Similar to distillation temperature, 90 percent recovered	Similar to distillation temperature, 90 percent recovered; piston ring and combustion chamber deposits	Similar to distillation temperature, 90 percent recovered
Freezing point Cloud point	*Low temperature formation* of ice/wax crystals can clog filters and other small passages	*Low temperature* formation of ice/wax crystals can clog filters and other small passages	Low temperature formation of ice/wax crystals can clog filters and other small passages
Pour point	Low temperature limit for gravity flow from storage	Low temperature limit for gravity flow from storage	Low temperature limit for gravity flow from storage; not applicable for aviation gas turbines
Olefins	Not applicable	Not applicable	Aviation gas turbine fuel storage; favorable lubricity characteristics
Sulfur (when combined with sodium, potassium, etc.)	Corrosion of tubes and other hot-side metallic surfaces	Corrosion of injectors, piston pins, and rings; liner wear; deposits	Hot-gas path corrosion of metals
Mercaptans	Not applicable	Not applicable	Attacks elastomers; odors
Copper corrosion	Not applicable	Copper alloy corrosion	Copper alloy corrosion
Acid number neutrality	Corrosion of metals	Corrosion of metals	Corrosion of metals and elastomers
Carbon residue	Fouling, clogging, smoke, radiation increases wall and heat transfer surface temperatures	Fouling, clogging, smoke, radiation increases wall temperatures	Fouling, clogging, smoke, radiation increases wall and liner temperatures
Particulate matter Ash	Erosion and wear on pumps, deposits on heat transfer surfaces, tube wall clogging	Erosion on injectors, pumps, pistons, rings; deposits	Fuel system wear and clogging, potential turbine corrosion due to erosive removal of protective coatings
Accelerated stability, *insolubles*	Storage stability erosion *fouling, deposits,* sticking	Storage stability erosion *fouling*, deposits, sticking	Storage stability erosion fouling, deposits, sticking
Water separation index, modified	Polar material present → disarms coalescers	Polar material present → disarms coalescers	Polar material present → disarms coalescers
Fuel system icing inhibitor	Not applicable	Not applicable	Lowers flash point, polar characteristics can disarm coalescers
Corrosion inhibitor	Not applicable	Not applicable	Degrade stability during storage
Antioxidant	Degrade thermal stability	Degrade thermal stability	Degrade thermal stability
Metal deactivator	Degrade stability during storage, source of nutrients for organics → slime clogging	Degrade stability during storage, source of nutrients for organics → slime clogging	Degrade stability during storage, source of nutrients for organics → slime clogging

TABLE 4-3. CIVILIAN FUEL GRADES: CHARACTERISTICS AND APPLICATIONS[a]

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Classification	Grade	Description and Use
Heating Oils	#1	Light distillate; applicable to vaporizing type burners.
	#2	Heavier distillate; applicable to atomizing type burners, domestic burners and medium capacity commercial/industrial burners.
	#4	Heavy distillate or light residual; applicable to atomizing burners designed to handle more viscous fuels than burners for #2 fuel oil; viscosity range such that no preheating unless subjected to extremely cold weather.
	#5L	Residual of intermediate viscosity; applicable to burners able to atomize without preheating; however, preheating permitted in colder climates.
	#5H	Residual of higher viscosity than #5L; similar applicability and handling.
	#6	High viscosity residual (bunker C); applicable in commercial and industrial heating; require preheating for pumping and additional preheating for atomizing.
Diesel Fuel Oils	#1-D	Kerosine to middle distillates; applicable in engines subjected to frequent, wide variations in loads and speeds; also used in regions of very low temperatures, designated as DF-A.
	#2-D	Middle to lower distillates; applicable in engines operating at high loads and uniform speeds.
	#4-D	Lower distillates and residuals; applicable in engines of low to medium speeds subjected to sustained loads at consistant speed.
Gas Turbine Fuel Oils	GT-1	Light distillate; suitable for nearly all gas turbines; like #1 and #1-D.
	GT-2	Heavier distillate, less clean burning; preheating may be required depending upon fuel system and/or ambient temp; like #2 and #2-D.
	GT-3	Heavier than GT-2, may be a blend of distillate/residual or residual that meets Ash spec requirement; application: turbine inlet temperature below 649°C; vanadium, Na+K, Ca requirements can be waived, provided that a silicon-based additive (or equivalent) is used to inhibit ash formation; preheating is necessary.
	GT-4	Similar to GT-3; no ash restriction, vanadium spec relaxed to include nearly all residual fuel oils, but additive required to inhibit Va corrosion.

[a] The actual specifications for these fuels are compared to the specification for DFM on Tables 4-4 and 4-5.

preheaters to current equipment or the replacement of some pumps), whereas the heavier grades could. Hence, Grades 1 and 2 oils will be referred to as preferred alternates.

ASTM specifications for the preferred alternates are compared with the MILSPEC for DFM in Table 4-4. The first column on the table lists those elements found in the MILSPEC which are not satisfied by corresponding requirements for one or more of the alternates on the table. The elements are according to the groups established in Section 4.1 (see Table 4-1). The second column in Table 4-4 lists the MILSPEC criteria for the elements of the first column. The following columns list the corresponding information for an alternate fuel. In these columns, a check (✓) shows that the alternate fuel meets or exceeds a particular MILSPEC requirement, a number designates the value of an element criterion which does not satisfy a corresponding MILSPEC requirement, and an "X" shows that no alternate fuel information exists for a MILSPEC element. The final column lists those MILSPEC elements, along with their criteria, which are satisfied by the corresponding requirements for all alternates on the table. Other symbols in the table are explained in the legend; detailed information on additives exists in Appendix E. (All remaining comparison tables are similar to Table 4-4, including those for JP-5 MILSPECS comparisons.)

Table 4-4 shows that preferred alternates to DFM which just satisfy the ASTM specifications* show differences from DFM in the following specification elements: (1) flash point, (2) cetane number, (3) several elements in the maintenance group, and (4) a number of MILSPEC elements for which there are no corresponding ASTM requirements. Inability to meet the flash point specification can be a serious problem, but a fuel with a lower cetane number than required by the MILSPEC could be used without impact in a boiler or gas turbine. The requirements for additives must be considered carefully to avoid materials which would disarm coalescer equipment.

The preferred alternate and DFM are compatible for two extremely important elements, the 90 percent fraction recovery temperature and viscosity, as well as for a critical maintenance element, the sulfur contamination level. In fact, satisfaction of the 90 percent fraction recovery temperature strongly suggests that the appearance, color, end point, and loss and residue MILSPEC criteria are probably also satisfied, since these criteria are a measure of the quality and quantity of the heavy fractions in the fuel. Moreover, satisfying the sulfur contamination level criterion is a major factor, because sulfur-induced corrosion has been identified as a primary maintenance problem.

Table 4-5 compares the ASTM specifications for the other alternates with the DFM MILSPEC. Here, virtually no compatibilities exist. In particular, the high viscosities suggest that using these alternates will involve costly preheaters and modifications to pumping equipment. Also, the

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*The information presented has been condensed from the ASTM specifications for petroleum products. For full details, the reader should consult the actual specifications.

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TABLE 4-4. SPECIFICATIONS RESTRICTING FLEXIBILITY OF PREFERRED ALTERNATES FOR DFM*

Element	DFM	#2-D	#2	GT-2	#1-D	#1	GT-1
Flash Point (°C)	60	51.7	38	38	38	38	38
Appearance	CLR, BRT	x	x	x	x	x	x
Color	5	x	x	x	x	x	x
End Point (°C)	385	x	x	x	x	x	x
Loss and Residue (%)	3	x	x	x	x	x	x
Cetane Number	45	40	x	x	40	x	x
Pour Point (°C)	-6.7	✓	✓	x	x	✓	✓,a
Cloud Point (°C)	-1.1	b	x	x	b	x	x
Demulsification (min)	10	x	x	x	x	x	x
Acid #(mg_{KOH}/g)	0.3	x	x	x	x	x	x
Copper Strip Corrosion Index	1	3	x	x	3	3	x
Neutrality	Neutral	x	x	x	x	x	x
Carbon Residue (Wt. %)	0.2	0.35	0.35	0.35	✓	✓	✓
Ash (Wt. %)	0.005	0.01	x	0.01	0.01	x	0.1
Acc. Stab., Insol. (mg/100 ml)	2.5	x	x	x	x	x	x
Antioxidant	fn	x	x	x	x	x	x
Metal Deactivator	fn	x	x	x	x	x	x
Ignition Improver	fn	x	x	x	x	x	x

ELEMENTS OF PREFERRED ALTERNATES WHICH SATISFY MILSPEC

Element (MILSPEC Criteria)

90 percent Fraction (385°C)
Viscosity (1.8 - 4.5 cSt at 38°C)
Sulfur (1% by Wt.)

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*The information presented has been condensed from the ASTM specifications for petroleum products. For full details, the reader should consult the actual specifications.

LEGEND

x: No specification element
✓: MILSPEC criterion is satisfied
a: Pour point = Ambient temperature (°C) in zone of usage - 5.56
b: Cloud point = 5.56 + 10th percentile of minimum ambient temperature in zone of usage
fn: See Appendix E for fuel additives

TABLE 4-5. SPECIFICATIONS RESTRICTING FLEXIBILITY OF OTHER ALTERNATES FOR DFM*

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Element	MILSPEC	GT-3	#4-D	#4	GT-4	#5L	#5H	#6
Flash Point (°C)	60	54	54.4	55	✓	55	55	✓
Appearance	CLR, BRT	x	x	x	x	x	x	x
Color	5	x	x	x	x	x	x	x
90% Temperature (°C)	357.2	x	x	x	x	x	x	x
End Point (°C)	385	x	x	x	x	x	x	x
Loss and Residue (%)	3	x	x	x	x	x	x	x
Viscosity @ 38°C (cST)	1.8 - 4.5	5.8 - x	5.8 - 26.4	5.8 - 26.4	5.8 - x	26.4 - 65	65 - 194	92 - 638
Cetane Number	45	x	30	x	x	x	x	x
Pour Point (°C)	-6.7	x	x	✓	x	x	x	15.56
Cloud Point (°C)	-1.1	x	b	x	x	x	x	x
Demulsification (min)	10	x	x	x	x	x	x	x
Suflur (Wt. %)	1	x	2	x	x	x	x	x
Acid #(mg$_{KOH}$/g)	0.3	x	x	x	x	x	x	x
Copper Strip Corrosion Index	1	x	x	x	x	x	x	x
Neutrality	Neutral	x	x	x	x	x	x	x
Carbon Residue (Wt. %)	0.2	x	x	x	x	x	x	x
Ash (Wt. %)	0.005	0.03	0.01	0.1	x	0.1	0.1	x
Acc. Stab., Insol. (mg/100 ml)	2.5	x	x	x	x	x	x	x
Antioxidant	fn	x	x	x	x	x	x	x
Metal Deactivator	fn	x	x	x	x	x	x	x
Ignition Improver	fn	x	x	x	x	x	x	x

*The information presented has been condensed from the ASTM specifications for petroleum products. For full details, the reader should consult the actual specifications.

LEGEND

x: No specification element

✓: MILSPEC criterion is satisfied

b: Cloud point = 5.56 + 10th percentile of minimum ambient temperature in zone of usage

fn: See Appendix E for fuel additives

potential for high contamination levels (see the maintenance elements), particularly sulfur, implies that increased maintenance would be needed to avoid equipment deterioration.

No further comparisons between alternate gas turbine fuels and DFM will be presented after Table 4-5. This decision was based on: (1) the degree of similarity between these alternates and other fuels, particularly the diesel fuel oils, (2) the relatively small production of gas turbine fuel oils compared to that of heating oils or diesel fuel oils, and (3) the lack of readily available company specifications or actual analyses for these fuels.

Differences between selected company specifications for the preferred alternates and the DFM specification are shown in Table 4-6. Comparing this chart with Table 4-4 shows that some oil suppliers produce fuel oils and diesel oils according to company product specifications which come closer to meeting the MILSPEC for DFM than do oils that are sold in accordance with ASTM specifications. With the exception of cetane number and demulsification time, virtually all MILSPEC performance elements are satisfied. (The cetane number disparity is not a problem because cetane improvers are permitted.) Within the maintenance group, only the ash contamination level can be identified as a potential problem, but fewer of the elements in this group are unmeasured than in the corresponding ASTM specifications. Note that flash point remains a potential problem.

Results from measuring the properties of actual fuel samples from the group of preferred alternates are compared with the DFM MILSPEC in Table 4-7 (See Table 4-8(a), following Table 4-8, for an explanation of the column headings). While there is less compatibility between the actual sample and the DFM MILSPEC than that between the DFM MILSPEC and the company specifications as illustrated in Table 4-6, this result is somewhat misleading. There are many more fuels listed in Table 4-7 than in Table 4-6; the apparent lack of compatibility is due to the subset of Table 4-7 formed from the identifiable companies.

On the other hand, fuels from the anonymous companies are at least as compatible as the company specifications of Table 4-6. This is illustrated in Table 4-7 by the diesel fuels of Company "X", where there are no definite problems (assuming that cetane improver is permitted) and very few potential problems. Company "Y" diesel fuels are also similar to the DFM MILSPEC. With a few exceptions where either flash point, ash, or carbon residue do not satisfy the military requirements, the fuels shown on Table 4-7 could be used in Navy systems with no adverse impact, if their unmeasured properties also satisfy the MILSPEC criteria.

Table 4-8 shows that the measured properties of other alternates conform closely with their corresponding ASTM specifications shown on Table 4-5. Unlike the lighter fractions, the heavier

TABLE 4-6. COMPANY SPECIFICATIONS RESTRICTING FLEXIBILITY OR PREFERRED ALTERNATES FOR DFM

Element	MILSPEC	ARCO Diesel*	X-2**
Flash Point (°C)	60	54.44	51.7
Loss and Residue (%)	3	x	✓
Cetane Number	45	40	x
Demulsification (min)	10	x	x
Acid #(mg_{KOH}/g)	0.3	x	✓
Neutrality	Neutral	x	x
Ash (Wt. %)	0.005	0.01	0.01
Antioxidant	fn	x	x
Metal Deactivator	fn	x	x
Ignition Improver	fn	x	x
		μ	α

ELEMENTS OF ALTERNATES WHICH SATISFY MILSPEC

Element (MILSPEC)

Appearance (CLR,BRT)
Color (5)
90% Fraction (357°C)
End Point (385°C)
Viscosity (1.8 - 4.5 cSt @ 38°C)
Pour Point (-6.7°C)
Cloud Point (-1.1°C)
Sulfur (1% by Wt)
Copper Strip Corrosion Index (1)
Carbon Residue (0.2% by Wt)
Acc. Stab., Insol. (2.5 mg/100 ml)

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LEGEND

x: No specification element
✓: MILSPEC criterion is satisfied
fn: See Appendix E for fuel additives
α: 5 pounds of company additive per 1,000 barrels of fuel for stability and corrosion protection
μ: Approved rust inhibitors:
    Apollo PRI-19
    DuPont DCI-4A

*ARCO heating oil specifications are identical to ARCO diesel specifications

**No. 2 heating oil, anonymous source

TABLE 4-7. MEASURED PROPERTIES RESTRICTING FLEXIBILITY OF ACTUAL FUELS (AS DELIVERED): PREFERRED ALTERNATES FOR DFM

Element	DFM	CH-2	EX-D2	CH-D	XD_a	XD_b	YD_a	YD_b	Y2	CH-1	EX-D7	CH-D1
Flash Point (°C)	60	✓	✓	✓	✓	✓	✓	✓	✓	48.89	57	57
Appearance	CLR, BRT	x	x	x	✓	✓	✓	✓	✓	x	x	x
Loss and Residue (%)	3	✓	✓	x	✓	✓	x	x	x	✓	x	x
Cetane Number	45	✓	✓	✓	✓	40	✓	✓	✓	✓	✓	✓
Cloud Point (°C)	-1.1	x	b	b	✓	✓	x	x	x	x	b	b
Demulsification (min)	10	x	x	x	x	x	x	x	x	x	x	x
Acid #(mg_{KOH}/g)	0.3	x	x	x	✓	✓	x	x	x	x	x	x
Copper Strip Corrosion Index	1	✓	3	✓	✓	✓	x	✓	x	✓	3	✓
Neutrality	Neutral	x	x	x	x	x	x	x	x	x	x	x
Carbon Residue (Wt. %)	0.2	✓	0.35	✓	✓	✓	✓	✓	✓	✓	✓	✓
Ash (Wt. %)	0.005	✓	0.01	0.01	✓	✓	x	x	x	✓	0.01	0.01
Acc. Stab., Insol. (mg/100 ml)	2.5	x	x	x	✓	✓	x	x	x	x	x	x
Antioxidant	fn	x	x	x	x	x	x	x	x	x	x	x
Metal Deactivator	fn	x	x	x	x	x	x	x	x	x	x	x
Ignition Improver	fn	x	x	x	x	x	β	β	γ	x	x	x

ELEMENTS OF ALTERNATES WHICH SATISFY MILSPEC

Element (MILSPEC Criteria)

Color (5)
90% Fraction (357°C)
End Point (385°C)
Viscosity (1.8 - 4.5 cSt @ 38°C)
Pour Point (-6.7°C)
Sulfur (1% by Wt)

LEGEND

x: No specification element
✓: MILSPEC criterion is satisfied
b: Cloud point = 5.56 + 10th percentile of minimum ambient temperature in zone of usage
fn: See Appendix E for fuel additives
β: May contain conductivity improver, flow improver, and cetane improver additives
γ: May contain conductivity improver and cetane improver

TABLE 4-8. MEASURED PROPERTIES RESTRICTING FLEXIBILITY OF ACTUAL FUELS (AS DELIVERED): PREFERRED ALTERNATES

Element	MILSPEC	EX-4*	EX-4^{+}	EX-4	EX-5^{+}	EX-5	CH-LF	EX-6*	EX-6**	EX-6^{+}	EX-6	CH-IF	BNKR	ELEMENTS OF OTHER ALTERNATES WHICH SATISFY MILSPEC
Appearance	CLR, BRT	x	x	x	x	x	x	x	x	x	x	x	x	
Color	5	x	x	x	x	x	x	x	x	x	x	x	x	Element (MILSEC *Criteria*
90% Fraction (°C)	357	x	x	x	x	x	x	x	x	x	x	x	x	
End Point (°C)	385	x	x	x	x	x	x	x	x	x	x	x	x	Flashpoint (60°C)
Loss and Residue (%)	3	x	x	x	x	x	x	x	x	x	x	x	x	
Viscosity @ 38°C (cSt)	1.8 - 4.5	14.4	15.2	19.6	34.1	38.5	71 @ 50°C	37	42.4	50.6	340	325 @ 50°C	325 @ 50°C	
Cetane Number	45	x	x	x	x	x	x	x	x	x	x	x	x	
Pour Point (°C)	-6.7	✓	✓	✓	✓	✓	✓	12.78	12.78	12.78	-3.89	✓	✓	
Cloud Point (°C)	-1.1	x	x	x	x	x	x	x	x	x	x	x	x	
Demulsification (min)	10	x	x	x	x	x	x	x	x	x	x	x	x	
Sulfur (Wt. %)	1	✓	✓	1.62	✓	1.43	1.03	✓	✓	✓	2.71	1.77	1.77	
Acid #(mg$_{KOH}$/g)	0.3	x	x	x	x	x	x	x	x	x	x	x	x	
Copper Strip Corrosion Index	1	x	x	x	x	x	x	x	x	x	x	x	x	
Neutrality	Neutral	x	x	x	x	x	x	x	x	x	x	x	x	
Carbon Residue (Wt. %)	0.2	1.7	1.9	2.9	1.9	3.5	x	4.9	5.4	7.0	2.4	x	x	
Ash (Wt. %)	0.005	0.01	0.01	0.01	0.01	0.01	0.01	x	x	x	x	x	x	
Acc. Stab., Ins. (mg/100 ml)	2.5	x	x	x	x	x	x	x	x	x	x	x	x	
Antioxidant	fn	x	x	x	x	x	x	x	x	x	x	x	x	
Metal Deactivator	fn	x	x	x	x	x	x	x	x	x	x	x	x	
Ignition Improver	fn	x	x	x	x	x	x	x	x	x	x	x	x	

LEGEND

*: 0.3 percent sulfur
**: 0.5 percent sulfur
+: 1.0 percent sulfur
x: No specifications element
✓: MILSPEC criterion is satisfied
fn: See Appendix E for fuel additives

TABLE 4-8(a). HEADINGS LEGEND FOR TABLES 4-7 AND 4-8

T-204

Symbol	Headings
CH-2	Chevron Heating Fuel #2, El Segundo Refinery
EX-D2	Exxon Diesel 2
CH-D	Chevron Diesel Fuel
CH-1	Chevron Heating Fuel #1, El Segundo Refinery
EX-D1	Exxon Diesel 1
CH-D1	Chevron Diesel Fuel #1
EX-4*	Exxon #4 Fuel Oil, 0.3 percent Sulfur
EX-4^+	Exxon #4 Fuel Oil, 1.0 percent Sulfur
EX-4	Exxon #4 Fuel Oil
EX-5^+	Exxon #5 Fuel Oil, 1.0 percent Sulfur
EX-5	Exxon #5 Fuel Oil
CH-LF	Chevron Light Fuel Oil, Richmond Refinery
EX-6*	Exxon #6 Fuel Oil, 0.3 percent Sulfur
EX-6**	Exxon #6 Fuel Oil, 0.5 percent Sulfur
EX-6^+	Exxon #6 Fuel Oil, 1.0 percent Sulfur
EX-6	Exxon #6 Fuel
CH-IF	Chevron Industrial Fuel Oil, El Segundo Refinery
BNKR	Chevron Bunker Fuel Oil, El Segundo Refinery
XD_A	#2 Diesel Fuel from "A" Refinery of Company "X" (a fuel producer wishing to remain anonymous)
XD_B	#2 Diesel Fuel from "B" Refinery of Company "X"
YD_A	Diesel Fuel from "A" Refinery of Company "Y" (another fuel producer wishing to remain anonymous)
YD_B	Diesel Fuel from "B" Refinery of Company "Y"
Y2	#2 Heating Oil from Company "Y"

TABLE 4-9. BERC/ERDA MEASUREMENTS OF PROPERTIES RESTRICTING FLEXIBILITY OF PREFERRED ALTERNATES FOR DFM

T-2U5

Element	DFM	#2-D	#2	#1-D	#1
Flash Point (°C)	60	✓	✓	59.06	57.14
Appearance	CLR, BRT	x	x	x	x
Color	5	✓	x	✓	x
Loss and Residue (%)	3	x	x	x	x
Viscosity @ 38°C (cSt)	1.8 - 4.5	✓	✓	x	x
Cetane Number	45	✓	✓	x	x
Demulsification (min)	10	x	x	x	x
Acid #(mg_{KOH}/g)	0.3	x	x	x	x
Neutrality	*Neutral*	x	x	x	x
Ash (Wt %)	0.005	✓	x	✓	x
Acc. Stab., Insol. (mg/100 ml)	2.5	x	x	x	x
Antioxidant	fn	x	x	x	x
Metal Deactivator	fn	x	x	x	x
Ignition Improver	fn	x	x	x	x

ELEMENTS OF PREFERRED ALTERNATES WHICH SATISFY MILSPEC

Element (MILSPEC Criteria)

90% Fraction (357°C)
End Point (385°C)
Pour Point (-6.7°C)
Cloud Point (-1.1°C)
Sulfur (1.0% by Wt)
Copper Strip Corrosion Index (1)
Carbon Residue (0.2% by Wt)

LEGEND

x: No specification element
✓: MILSPEC criterion is satisfied
fn: See Appendix E for fuel additives

TABLE 4-10. FUEL PROPERTY RANGES FROM BERC/ERDA ANALYSES OF NO. 2 DIESEL FUEL COMPARED TO DFM

T-206

Element	DFM	#2-D
Flash Point (°C)	60	(47.78 - 98.89)
Color	5	(0 - L3.5)
10% Fraction (°C)	----	----
90% Fraction (°C)	357	(245.56 - 332.22)
End Point (°C)	385	(271.11 - 371.11)
Residue + Loss (Vol %)	3.0	----
Viscosity (cSt)	1.8 - 4.5 @ 38°C	(1.2 - 4.30)
Gravity (°API)	----	----
Net Ht. of Comb. (Btu/lb)	----	----
Cetane Number	45	(40 - 61)
Smoke Point (mm)	----	----
Aromatics (Vol %)	----	----
Olefins (Vol %)	----	----
Freezing Point (°C)	----	----
Pour Point (°C)	-6.7	(-53.89 - -3.89)
Cloud Point (°C)	-1.1	(-51 - 10)
Thermal Stability		
Δp (mm Hg)	----	----
deposit code	----	----
Sulfur (Wt %)	1.0	(0.005 - 1.1)
Mercaptans (Wt %)	----	----
Acid #(mg_{KOH}/g)	0.3	x
Copper Strip Corrosion Index	1	(1a - 1b)
Carbon Residue (Wt %)	0.2	(0.009 - 0.25)
Ash (Wt %)	0.005	(0 - 0.01)
Existent Gum (mg/100 ml)	----	----
Water Reaction		
Interface Rating	----	----
Separation Rating	----	----
WISM	----	----

products delivered by fuel suppliers do not differ much from the minimum requirements for these fuels set forth in the ASTM specifications. Therefore, preheaters, pumps and additional maintenance will be needed when using heavy fuel oils (see discussion of Table 4-5). The MILSPEC flash point specification is satisfied by all the heavy fuels reported here.

To complement the analyses shown on Table 4-7, Table 4-9 presents the results of analyses performed by the Bartlesville Energy Research Center (BERC) of the Energy Research and Development Administration (ERDA) on samples of preferred alternates taken from many suppliers across the country. These BERC/ERDA results are averages of analyses of 100 to 200 individual fuel samples; thus, in one sense, Table 4-9 represents a typical situation. However, one must be careful in using this table, since the values shown are averages for each measured property, not the property values of a typical fuel. Table 4-10 has been included, therefore, to illustrate the extremes present in the analyses of the BERC/ERDA fuel samples with an example (#2-D). With the exception of distillation recovery temperatures and copper strip corrosion index, measurements on all the remaining MILSPEC elements of these fuel samples were found to include extremes that did not satisfy the MILSPEC criteria (although no one fuel sample exhibited the full set of extreme properties). The BERC/ERDA analyses are characterized as follows:

- A number of DFM MILSPEC criteria were not measured: appearance, demulsification time, loss and residue, acid number, neutrality, and the additives requirements
- About 25 percent of the fuel samples passed all DFM MILSPEC criteria measured, as shown in Table 4-10
- Approximately an additional 25 percent of the fuel samples passed all DFM MILSPEC criteria measured, but their copper strip corrosion indices were not measured
- An additional 12 percent of the fuel samples passed all other DFM MILSPEC criteria measured, but had cetane numbers in the range: $40 \leq$ cetane number < 45; these samples also include some for which the copper strip corrosion index was not measured

Thus, these comparisons of analyses of fuel samples with the DFM MILSPEC lead to the following conclusions:

- Company analyses of preferred alternates indicate that with some modification of their properties, the alternates would pass the DFM MILSPEC requirements
- BERC/ERDA analyses of samples of #2 diesel fuel indicate that if cetane improver can be used and the unmeasured DFM MILSPEC criteria are resolved, more than 60 percent of the existing supplies of this product would pass the DFM MILSPEC requirements

- Other alternates cannot pass the existing DFM MILSPEC, but may be acceptable for the short term if preheaters are used and pump changes are made (after long-term use, increased maintenance due to additional corrosion and erosion would be required)

4.5 JP-5 MILSPEC COMPARISONS WITH CORRESPONDING CIVILIAN FUELS

The discussion in this section focuses on the JP-5 MILSPEC fuel (MIL-T-5624K), the fuel designated by the Navy for use in aviation gas turbines in the fleet. This is a kerosine-based petroleum fraction which, like DFM, is a middle distillate. The specifications require it to be very clean, and to contain an approved fuel system icing inhibitor (FSII). Specifications also allow approved corrosion inhibitor(s), metal deactivator(s), and antioxidant(s).

The civilian fuels similar to the JP-5 fuel are classified as aviation turbine fuels. Within this classification, Jet A and Jet Al (a cold weather version of Jet A) are kerosine-based distillate fractions, and Jet B is a naptha-based (wide-cut) distillate fraction. Two additional fuels are JP-4, a military version (also MIL-T-5624K) of Jet B, and JP-8, a proposed USAF fuel (MIL-T-83133) resembling JP-5. To simplify discussing these five fuels, they all will be considered hereafter as alternates for JP-5.

It should be noted that there will be no breakdown of the JP-5 alternates into preferred or other grades. All of these are "preferred", i.e., they can be used without preheaters or extensive equipment modifications.

Table 4-11 compares the JP-5 MILSPEC with the ASTM specifications or the appropriate MILSPEC requirements of the alternate fuels. All alternates satisfy the JP-5 MILSPEC criteria for a number of combustion properties in the performance group, as well as many criteria in the maintenance group. Fuels which are guaranteed to meet these specifications can be used only with reservations, mainly because the fuels do not include a test for explosiveness (safety group), they miss slightly on end point and gravity (performance group), and they fail to meet or measure about one-half of the maintenance criteria, especially those criteria for additives.

ARCO specifications for Jet A and Jet Al are compared to the JP-5 MILSPEC in Table 4-12. The compatibilities between the JP-5 MILSPEC and the ARCO specifications for Jet A/Al are virtually the same as those between the MILSPEC and the Jet A/Al ASTM requirements. Moreover, the compatibility problems associated with both ARCO specifications are largely for unconsidered elements.

TABLE 4-11. SPECIFICATIONS RESTRICTING FLEXIBILITY OF ALTERNATES FOR JP-5*

T-207a

Element	JP-5	Jet A/A1	Jet B	JP-4	JP-8
Flash Point (°C)	60	38	x	x	38
Explosives (%)	50	x	x	x	x
10% Temperature (°C)	205	✓	x	x	✓
End Point (°C)	290	300	x	✓	300
Viscosity @ -20°C (cST)	8.5	(✓)f	x	x	✓
Gravity (°API), min/max	36/48	51	57	57	51
Olefins (Vol %)	5	(✓)c	(✓)c	✓	✓
Freezing Point (°C)	-46	-40,✓	✓	✓	✓
Mercaptans (Wt %)	0.001	0.003	0.003	✓	✓
Acid #(mg_{KOH}/g)	0.015	0.1	x	✓	✓
Part. Matter (mg/l)	1	(✓)d	(✓)d	✓	✓
WSIM	85	x	x	70	70
FSII (Vol %), min/max	0.1/0.15, fn	x	x	✓	✓
Corrosion Inhibitor	fn	x	x	e	e
Antioxidant	fn	fn	fn	fn	fn
Metal Deactivator	fn	fn	fn	fn	fn

ELEMENTS OF SPECIFICATION FOR ALTERNATES WHICH SATISFY THE MILSPEC

(MILSPEC Criteria)

Loss and Residue (1.5% Vol and 1.5% Vol)
Net Heat of Combustion (18,300 Btu/lb)
Smoke Point (19 mm)
Aromatics (25% by Vol)
Thermal Stability
    Pressure Drop (25 mm_{HG})
    Preheater Deposit Code (<3)
Sulfur (0.4% by Wt)
Copper Strip Corrosion Index (1)
Existent Gum (7 mg/100 ml)

Filtration Time (15 min)

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*The information presented has been condensed from the ASTM specifications for petroleum products. For full details, the reader should consult the actual specifications.

LEGEND

x: No specification element
✓: MILSPEC criterion is satisfied
c: Usually below 1 percent according to ASTM
d: Appears to be covered by workmanship criteria
f: From viscosity vs. temperature graphs and value @ -35°C
fn: See Appendix E for fuel additives

TABLE 4-12. SPECIFICATIONS RESTRICTING FLEXIBILITY OF ARCO JET A/A1 AS AN ALTERNATE FOR JP-5

T-208a

Element	JP-5	A	A1	ELEMENTS WHICH SATISFY THE MILSPEC
Flash Point (°C)	60	38	38	
Explosiveness (%)	50	x	x	(MILSPEC)
				10% Fraction (205°C)
End Point (°C)	290	300	✓	Loss and Residue (1.5% + 1.5% Vol)
Viscosity @ -20°C (cST)	8.5	(✓)f	(✓)f	WSIM (85)
Gravity (°API) min/max	36/48	51	51	
Net Ht. of Comb. (Btu/lb)	18,300	✓	✓	
Smoke Point (mm)	19	✓	✓	
Aromatics (Vol %)	25	✓	✓	
Olefins (Vol %)	5	(✓)c	✓	
Freezing Point (°C)	-46	-40	✓	
Thermal Stability				
Δp (mm Hg)	≤ 25	✓	✓	
Deposit Code	≤ 3	✓	✓	
Sulfur (Wt %)	0.4	✓	✓	
Mercaptan (Wt %)	0.001	0.003	0.003	
Acid #(mg_{KOH}/g)	0.015	0.10	0.10	
Copper Strip Corrosion Index	16	✓	✓	
Part. Matter mg/l	1.0	(✓)d	2.11	
Existent Gum (mg/100 ml)	7.0	✓	✓	
Filtration Time (min)	15	x	x	
FSII (Vol %) min/max	0.1/0.15,fn	x	x	
Corrosion Inhibitor	fn	x	x	
Antioxidant	fn	x	x	
Metal Deactivator	fn	x η	x η	

LEGEND

x: No specification element

✓: MILSPEC criterion is satisfied

c: Usually below 1 percent according to ASTM

d: Appears to be covered by workmanship criteria

f: From viscosity vs. temperature graphs and value @ -35°C

fn: See Appendix E for fuel additives

η: May contain anti-static additive if agreed upon by purchaser

In Table 4-13, the specification for JP-5 is compared to fuel analyses reported by the following companies:

- Chevron
  - Jet A
  - Jet A1
- Exxon
  - Jet A
  - Jet A1
  - Jet B
- *Another company for Jet A from Refinery A* (ZA_A)
- Jet A from Refinery B (ZA_B).

This table shows that several fuels, especially the Jet A types, nearly qualify as JP-5. In particular, Jet A from Refinery A of Company "Z" deviates from JP-5 only because a few properties were not measured. More importantly, however, this fuel, unlike all the other alternates reported here, satisfies the flash point criteria for JP-5. Company Z's Jet A from Refinery B meets all the same MILSPEC requirements as the product from Refinery A except flash point. The Chevron and Exxon fuels (as delivered) also satisfy, or nearly meet, all the requirements for JP-5, except for a significant difference in flash point and for several unmeasured properties. All fuels reported here satisfy the JP-5 MILSPEC for the important elements of distillation recovery-fraction temperatures combustion properties, stability characteristics, and major contamination levels.

As with diesel fuels and heating oils, BERC/ERDA tested a large sample of Jet A/A1 fuels. The results are presented first in Table 4-14 as averages of all the samples for each property (and hence do not necessarily represent a typical fuel), and then as ranges of the measured values in Table 4-15.

Table 4-14 shows that property values averaged over a large domestic sample of commercially available Jet A satisfy most JP-5 requirements, except for flash point. However, several contamination levels were not measured by BERC/ERDA.

The BERC/ERDA analyses of Jet A1 fuels show that its compatibility with the JP-5 MILSPEC closely duplicates that of Jet A. However, the flash point problem is greater for Jet A1, as expected

TABLE 4-13. MEASURED PROPERTIES OF SPECIFIC FUELS (BY FUEL SUPPLIER)

Element	JP-5	Chevron A/A1	Exxon A/A1	ZA_A	ZA_B	Exxon B
Flash Point (°C)	60	48.89	46,42	✓	49	x
Explosiveness (%)	50	x	x	x	x	x
Viscosity @ -20°C (cST)	8.5	(✓)f	(✓)f	(✓)f	(✓)f	x
Gravity (°API) min/max	36/48	✓	✓	✓	✓	53.8
Olefins (Vol %)	5	(✓)c	(✓)c	x	x	✓
Freezing Point (°C)	-46	-45,✓	-44,✓	✓	✓	✓
Mercaptans (Wt %)	0.001	≤0.003	✓	✓	✓	✓
Acid #(mg_{KOH}/g)	0.015	✓	0.1	✓	✓	x
Part. Matter (mg/l)	1	(✓)d	(✓)d	x	x	✓
Water Reaction						
WSIM	85	x	✓	✓	✓	✓
Filtration Time (min)	15	✓	✓	x	x	x
FSII (Vol %) min/max	0.1/0.15, fn	x	x	x	x	x
Corrosion Inhibitor	fn	x	x	x	x	x
Antioxidant	fn	x	x	δ	δ	x
Metal Deactivator	fn	x	x	δ	δ	x

ELEMENTS OF ALL THE REPORTED ALTERNATIVES WHICH SATISFY THE MILSPEC

(MILSPEC Criteria)

10% Fraction (205°C)
End Point (290°C)
Loss and Residue (1.5% Vol and 1.5 Vol)
Net Heat or Combustion (18,300 Btu/lb)
Smoke Point (19 mm)
Aromatics (25% by Vol)
Thermal Stability
  Pressure Drop (25 mm_{HG})
  Preheater Deposit Code (<3)
Sulfur (0.4 % by Wt)
Copper Strip Corrosion Index (1)
Existent Gum (7 mg/100 ml)

LEGEND

x: No specification element
✓: MILSPEC criterion is satisfied
c: Usually below 1 percent according to ASTM
d: Appears to be covered by workmanship criteria
f: From viscosity vs. temperature graphs and value @ -35°C
fn: See Appendix E for fuel additives
δ: May contain antioxidant, metal deactivator, and conductivity improver

TABLE 4-14. AVERAGE VALUES OF SPECIFICATION ELEMENTS RESTRICTING FLEXIBILITY FOR JP-5: BERC/ERDA TESTS

Element	JP-5	Jet A	Jet A1	Jet B	JP-4
Flash Point (°C)	60	54	46	x	x
Explosiveness (%)	50	x	x	x	x
Gravity (°API) min/max	36/48	✓	✓	51.8	54.0
Thermal Stability Δp (mm Hg)	25	✓	✓	50.8	76.2
Part. Matter (mg/l)	1	x	x	x	x
Filtration Time (min)	15	x	x	x	x
FSII (Vol %) min/max	0.1/0.15, fn	x	x	x	x
Corrosion Inhibitor	fn	x	x	x	x
Antioxidant	fn	x	x	x	x
Metal Deactivator	fn	x	x	x	x

ELEMENTS OF ALTERNATES WHICH SATISFY MILSPEC

Element (MILSPEC Criteria)

10% Fraction (205°C)
End Point (290°C)
Loss and Residue (1.5% Vol and 1.5% Vol)
Viscosity (8.5 cST @ -20°C)
Net Heat of Combustion (18,300 Btu/lb)
Smoke Point (19 mm)
Aromatics (25% by Vol)
Olefins (5% by Vol)
Freezing Point (-46°C)
Thermal Stability, Deposit Code (3)
Sulfur (0.4% by Wt)
Mercaptans (0.001% by Wt)
Acid Number (0.015 mg_{KOH}/g)
Copper Strip Corrosion Index (1b)
Existent Gum (7 mg/l)
WSIM (85)

LEGEND

x: No specification element
✓: MILSPEC criterion is satisfied
fn: See Appendix E for fuel additives

TABLE 4-15. FUEL PROPERTY RANGES OF ALTERNATES COMPARED TO JP-5: BERC/ERDA TESTS

T-211a

Element	JP-5	Jet A
Flash Point (°C)	60	(43.33 - 65.56)
Color	—	—
10% Fraction (°C)	205	(179.44 - 203.89)
10% Fraction (°C)	—	—
End Point (°C)	290	(227.78 - 287.78)
Loss (Vol %)	1.5	(0 - 1.5)
Residue (Vol %)	1.5	(0.5 - 1.5)
Viscosity (cST)	8.5 @ -20°C	(3 - 4)
Gravity (°API)	36 - 48	(38.5 - 49.2)
Jet Ht. of Comb. (Btu/lb)	18,300	(18,481 - 20,070)
Smoke Point (mm)	—	—
Aromatics (Vol %)	19	(18 - 28)
Olefins (Vol %)	25	(9.6 - 23)
Freezing Point (°C)	5	(0 - 3)
Pour Point (°C)	-46	(-84 - -40)
Cloud Point (°C)	—	—
Thermal Stability	—	—
Δp (mm Hg)	25	(0 - 76.2)
Deposit Code	3	(0 - 2)
Sulfur (Wt %)	0.4	(0 - 0.22)
Mercaptans (Wt %)	0.001	(0 - 0.002)
Acid #(mg_{KOH}/g)	0.015	(0 - 0.04)
Copper Strip Corrosion Index	1b	(1a - 1b)
Carbon Residue (Wt %)	—	—
Ash (Wt %)	—	—
Existent Gum (mg/100 ml)	7	(0 - 3.2)
WSIM	85	(64 - 100)

with a fuel which is more volatile (to operate in cold environments). The naptha-based fuels (JP-4 and Jet B) are slightly less compatible with the MILSPEC, particularly with safety criteria, because they, too, are extremely volatile. In addition, these fuels do not satisfy JP-5 requirements for thermal stability and, less importantly, for gravity.

Table 4-15 shows the range of property values found by BERC/ERDA in this analysis of Jet A samples (this comparison is similar to the one presented in Table 4-10 for Number 2 diesel fuel relative to DFM). A number of elements were always found to be within specifications: all distillation properties, most combustion properties, and a number of important contamination levels. These analyses of samples are characterized as follows:

- Explosiveness, particulate matter level, and the requirements for additives were not measured for any sample
- About 6 percent of the samples passed all JP-5 MILSPEC criteria which were measured, as shown on Table 4-15
- About 15 percent of the samples had flash points ≥54.44°C and passed all other measured JP-5 MILSPEC criteria
- About 10 percent of the samples had freezing points ≤-40°C and passed all other measured JP-5 MILSPEC criteria
- About 27 percent of the samples had flash points ≥54.44°C, freezing points ≤-40°C, and passed all other measured JP-5 MILSPEC criteria

These comparisons of analyses of fuel samples with the JP-5 MILSPEC lead to the following conclusions:

- Company analyses of Jet A samples indicate that they meet most JP-5 MILSPEC criteria; however, some are deficient in flash point, and all must be analyzed with respect to heretofore unmeasured JP-5 MILSPEC requirements
- BERC/ERDA analyses of samples of Jet A indicate that if explosiveness, particulate matter level, and the additives requirements are satisfied, 6 percent of the current fuel supplies will meet JP-5 MILSPEC requirements; this percentage virtually doubles if the flash point requirement is lowered by 5.56°C, and virtually doubles again if the freezing point requirement is raised by 6°C
- BERC/ERDA analyses of the one Jet A1 sample show that it meets the JP-5 MILSPEC freezing point requirement, but it differs more from the flash point requirement than does the weighted average of the Jet A samples.

4.6 EXPERIENCE WITH NON-MILSPEC FUELS

The discussion in this section has qualitatively described the potential impacts of using fuels which do not comply with MILSPECS and has quantitatively detailed the differences between civilian alternate fuels for DFM and JP-5 and the MILSPECS. Some of this information will now be put into perspective by describing actual experiences that manufacturers of combustion equipment or researchers have had with a variety of fuels. These experiences are summarized in this section, arranged by MILSPEC elements for which information was available (detailed in Appendix F). Information was obtained by personal contact with manufacturers and operators of combustion equipment and by a review of the open literature.

Each summary below shows the MILSPEC element and the relevant MILSPEC criteria. Where appropriate, impacts are identified as they affect boilers, diesels, and/or gas turbines.

- Flash Point (DFM, JP-5; ≥60°C) and Explosiveness (JP-5; ≤50 percent): All data relative to flash point are for aircraft only. The percentage of aircraft crashes which lead to post-crash fires may more than double when JP-4 (flash point not specified but frequently <0°C) is used in place of JP-5. The results of 50 caliber gunfire tests show that the incidence of sustained fires went from 0 percent with JP-5 to 68 percent with JP-4. Similarly, when Jet B is used in place of Jet A, the probability of fire increases, and the probability of survival in the event of a fire decreases.

- End Point Recovery Temperature (DFM; ≤385°C; JP-5; ≤290°C): Increased deposits have been observed in both ring zones and combustion chambers of diesel engines when the end point recovery temperature was too high.

- Viscosity (DFM: 1.8 – 4.5 cSt @ 38°C; JP-5: <8.5 cSt @ -20°C): All data on impacts of viscosity differences are for fuel supply systems and burners in boilers. In marine installations, low viscosity fuels (i.e., No. 1 grades) have caused lubrication problems in gear type pumps and have also caused burner problems with unstable flame holding. On the other hand, a change from middle distillate to high viscosity fuels (i.e., ≥ No. 4 grades) has required preheating and pump changes; moreover, high viscosity fuels have been hard to atomize.

- Cetane Number (DFM: ≥45): This specification element is important only for diesel engines. If the cetane number of the fuel is decreased, diesel engines require a higher fuel flow rate to deliver a specified power. A low cetane number (<40), possible with civilian fuels, has also caused hard starting in cold weather and timing problems, which has increased exhaust smoke.

- Aromatics (JP-5: $\leq$25 percent by vol.): High aromatic content in fuels caused a sooty flame in gas turbine combustion chambers which increased liner temperatures; however, aromatics improved the lubricity characteristics and oxidation stability of some gas turbine fuels.

- Olefins (JP-5: $\leq$5 percent by vol.): Olefins have degraded thermal stability of aviation turbine fuels, but, like aromatics, they have also improved lubricity characteristics.

- Sulfur (DFM: 1 percent by wt.; JP-5: 0.4 percent by wt.): Sulfur contamination in fuels is a major concern in maintaining all types of combustion equipment. In boilers, when sulfur levels in the fuel exceeded 2.5 percent by weight, (which could occur in heavier residual grades of fuel) problems have occured with fireside deposits on the tubes, corrosion of the economizers, and damage to equipment on ship decks from stack discharges. In diesels, increased sulfur levels induced ring wear and piston seizure: increasing the sulfur level from 1.0 percent to 1.3 percent (a level excceded in some heavy distillate and residual grades) caused a 250 percent increase in ring wear. In gas turbines, even the accepted sulfur level has led to sulfidation corrosion along the hot gas path, particularly on the vanes in the turbine section.

- Mercaptans (JP-5: $\leq$0.001 by wt.): Mercaptans have unpleasant odors; they also react with elastomers and seals in the fuel systems and remove cadmium plating from fuel strainers

- Acid Number (DFM: $\leq 0.3\ \text{mg}_{KOH}/g$; JP-5: $\leq 0.015\ \text{mg}_{KOH}/g$): Fuel acidity has been responsible for corrosion attack of elastomers and metals in fuel systems of all equipment types. However, since the refineries have switched to an acidless cracking process, problems traceable to acidity are no longer observed.

- Copper Strip Corrosion Index (DFM: $\leq$1; JP-5: $\leq$1b): Gas turbine systems have exhibited no signs of copper corrosion when the index has been less than 2.

- Carbon Residue (DFM: 0.2 percent by wt.): Exhaust smoke from boilers increases significantly when the fuel carbon residue exceeds 12.5 percent, (possible in the heavier fuel grades where it is not measured) with a fuel carbon-hydrogen ratio of 7 or greater.

- Ash (DFM: 0.005 percent by wt.): Plugging between boiler tubes has occurred in Navy boilers when the fuel ash content approached 0.01 percent, a level typical of civilian fuels. This has not been a problem for civilian equipment because of lower combustion intensities and larger passages between boiler tubes.

- Particulate Matter (JP-5: ≤ 1 mg/ℓ): Because current handling practices maintain a high level of cleanliness, particulate matter is not detectable in aviation turbine fuels
- Accelerated Stability, Insolubles (DFM: ≤ 2.5 mg/100 mℓ): Excessive amounts of insolubles have caused diesel system problems with clogging, sticking, and wear in close-tolerance fuel-injection systems; they have also contributed to carbon fouling in combustion chambers. Moreover, insolubles have clogged filtration units installed to remove them from the fuel; however, these problems usually have not occurred until levels of insolubles above 3 mg/100 mℓ were present.
- Corrosion Inhibitor (JP-5: see footnotes to the tables in Subsections 4.3 and 4.4): Corrosion inhibitors have caused degradation in the thermal stability of the treated fuel and made it harder to separate fuel from water. Also, some additives used in civilian fuels are polar and could disarm coalescers, deactivate filters, and cause plugging.

The above summary of experiences with fuels by manufacturers and operators of combustion equipment was not intended to describe all such experiences. It does, however, focus attention on aspects of fuel impacts which are of current interest to operators of combustion equipment.

4.7 SUMMARY

In summary, this section has presented the Navy's requirements for its fuels (MILSPECS), compared these requirements to the properties of available, reasonable alternate fuels, and discussed potential impacts on combustion equipment from using non-MILSPEC fuels in Navy equipment. Fuel requirements were arranged into three groups, safety, performance, and maintenance, to order the discussions on the differences of the various fuels.

The performance group was subdivided into elements describing basic properties, combustion properties, and other elements concerned with the ability of the fuel to flow in the liquid phase. The maintenance group was also subdivided into corrosion contaminants, erosion contaminants, and other contaminants or additives that can adversely affect operation of a combustion system.

The comparison of civilian fuels with Navy fuels first showed the difference between the ASTM specifications for civilian fuels and the MILSPECS. With lighter fuels, such as the Nos. 1 and 2 fuel oils and diesel fuel (preferred alternates for DFM), the major differences are with the flash point, the cetane number, some contamination criteria, and a number of MILSPEC criteria for which no civilian requirements exist. The heavier fuel oils, on the other hand, differ significantly from DFM, and would require installation of fuel heaters, and other equipment modifications. With alternates for JP-5, the major deviations from the MILSPEC are with flash, explosiveness, and a few criteria from the performance and maintenance groups.

Company specifications for civilian fuels were also compared to DFM; flashpoint and ash level are the only known differences. However, a small number of elements in the maintenance group, which are not currently measured for civilian fuels, may differ from the MILSPEC. Differences between the MILSPEC and company specifications for JP-5 alternates are similar to differences between the ASTM specifications and the JP-5 MILSPEC.

Finally, analyses of actual fuel samples were compared with the MILSPEC criteria. These analyses included tests of product both by fuel suppliers and by BERC/ERDA. For DFM preferred alternates, some analyses show that no known deviations exist; the only potential problems are demulsification time, neutrality, and permitted additives. However, analyses of the heavy fuel oil alternates for DFM confirm that these alternates deviate from the MILSPEC in many areas. For JP-5 alternates, there are analyses which show possible problems only with explosiveness, olefin content, acid number, particulate matter, and additives criteria. For No. 2 diesel fuel, BERC/ERDA data show that practically all of the measured DFM MILSPEC elements were deficient in one sample or another of civilian fuel. Although these deficiencies were rare, their existence shows that alternate fuels for DFM may occasionally not satisfy important MILSPEC criteria. On the other hand, BERC/ERDA data for Jet A show the samples all met the MILSPEC criteria for distillation properties, most combustion properties, and a number of contamination levels; however, a number of samples did not meet the important flashpoint criteria.

Limited information was obtained on the impact of variable fuel properties on combustion equipment and fuel supply systems. This information also showed the major concerns of equipment manufacturers and users regarding the impact of fuel quality on their systems. These concerns are listed below:

- Reduced flashpoint relates to increased occurrences of aircraft fire
- Viscosity must be considered, to avoid lubricity, flame stability, pumping, and atomizing problems
- Sulfur levels must be minimized to reduce corrosion in all types of combustion equipment
- Insolubles can foul not only primary combustion equipment, but may also clog fuel flow passages and filters designed to remove them
- Corrosion inhibitors can degrade fuel properties and impair operation of fuel supply equipment

From the discussions presented in Sections 3 and 4, alternate fuel grades for the MILSPEC fuels can be ranked, based on the fuel impacts they produced on Navy combustion equipment. Three levels of impact have been defined for these fuels and are discussed below.

- Fuels with no impact – these alternate fuels would not reduce personnel safety, and would not degrade combustion equipment or equipment operation and performance. Presumably, only fuels which meet all MILSPEC criteria for DFM or JP-5 would cause no impacts. No alternate fuel investigated in this study is known to completely satisfy all criteria for DFM or JP-5. However, a number of possibilities exist, namely, those fuels which pass the appropriate MILSPEC for all measured properties. These fuels would, in effect, be MILSPEC fuels if their (to date) unmeasured properties were found to satisfy MILSPEC criteria. For DFM, these alternates are:

  - Chevron heating oil No. 2
  - Company X No. 2 diesel fuels (including the B refinery if cetane improver is added)
  - Company Y diesel fuels
  - Company Y No. 2 heating oil

  Moreover, the BERC/ERDA analyses indicate that if cetane improver is added where needed, there is a 0.6 probability that any existing batch of domestic No. 2 diesel fuel might also qualify as a potential DFM MILSPEC fuel. For JP-5, the alternate which might be a MILSPEC fuel is Jet A from Refinery A of Company Z; the BERC/ERDA analyses indicate that there is a 0.06 probability that any existing batch of domestic Jet A might also meet the JP-5 MILSPEC.

- Fuels with some impact – these alternate fuels would not reduce personnel safety; however, they may cause long-term degradation to equipment. For example, excessive levels of sulfur, acidity, and mercaptans will progressively corrode fuel supply systems, boiler refractories and economizers, diesel engine piston rings, and hot-gas-path components of gas turbines. Excessive levels of carbon residue, ash, existent gum, and particulate matter will progressively erode, build up deposits in, and clog burners, injectors, fuel nozzles, boiler tubes, diesel engine combustion chambers and gas turbine hot gas path components. In addition, excessive endpoint recovery temperatures could build up deposits in ring zones and combustion chambers of diesel engines. However, these equipment impacts can be reduced by increasing maintenance. These alternate fuels would also impact performance. For example, low cetane number can increase fuel consumption and cause hard starting and excessive exhaust smoke in diesel engines. Low net heat of combustion can degrade output of gas turbines, and excessive gravity can reduce endurance of range of any type of combustion equipment. Any fuel listed in the no-impact level would have to be reclassified to this level if some of its unmeasured properties did not meet the MILSPEC criteria for this level of impact. For DFM, alternates at this level are:

- Exxon diesel No. 2
- Chevron diesel fuel

No additional alternates of JP-5 have been identified for this impact level.

- Fuels with major impact — these alternate fuels could cause difficulties in maintaining personnel safety, could require significant modifications to combustion systems, or could render combustion systems inoperative. Fuels which do not meet the MILSPEC criteria for flashpoint and for explosiveness would pose an additional hazard for personnel. Fuels beyond the MILSPEC limits for viscosity could require preheaters and/or pump changes in the fuel supply systems of marine equipment. Fuels with low viscosity can lead to pump lubrication problems. Fuels which do not meet criteria for freezing point, cloud point, or pour point develop problems at low temperatures, causing an inadequate supply of fuel to the combustor and subsequent combustion failure. Fuels which do not pass MILSPEC requirements for demulsification cannot be easily separated from water, which can lead to problems with fuel flow at low temperatures, from ice formation, water-induced corrosion, or combustion instabilities. Fuels which do not pass the WSIM requirement of JP-5 could induce coalescer failure. Any fuel listed in the preceding impact levels would have to be reclassified to this level, if some of its unmeasured properties failed the MILSPEC criteria associated with the impacts at this level. For DFM, further alternates at this level are:

  - Arco diesel and heating oils
  - Company X No. 2 heating oil
  - Chevron No. 1 heating and diesel oil
  - Exxon No. 1 diesel oil
  - Exxon heating oil Grades 4 through 6
  - Chevron light, industrial, and burner fuel oils

And, similarly, for JP-5 the alternates are:

- Arco Jet A and Jet A1
- Chevron Jet A and Jet A1
- Exxon Jet A and Jet A1
- Company Z Jet A from the B refinery
- Exxon Jet B
- JP-4
- JP-8

SECTION 5

SPECIFIC EXAMPLES OF POTENTIAL FUEL FLEXIBILITY

The previous sections have addressed the question of possible alternates for DFM and JP-5 in a global manner: Section 2 compared total United States and worldwide demand for these fuels and their average prices, Section 3 identified general differences between Navy and comparable civilian combustion equipment to understand why Navy fuels must pass more stringent requirements than their counterpart civilian fuels, and Section 4 showed how and where various civilian fuels differed from DFM and JP-5. This section will assess the potential for using alternate fuels in an actual case, i.e., will bring together the information presented in Sections 2, 3 and 4 and apply it to two specific areas. Norfolk, Virginia, and San Diego, California were chosen because they each have major Navy facilities. Furthermore, they are located on opposite coasts of the United States and, therefore, should provide examples of major differences in fuel availability and cost conditions that the Navy might encounter within the contiguous United States.

5.1 METHODOLOGY

5.1.1 Fuel Availability

Petroleum products are distributed throughout the United States by tank truck, tanker, and pipeline transport. There appears to be no easy way to learn the quantities delivered by various transport methods; like much of the fuel availability data sought for Section 2, this information is available in fragmentary form and has never been compiled.*

Therefore, lacking definitive data, we were forced to base our discussion of alternate fuel availability for Norfolk and San Diego on gross estimates. For example, in the case of San Diego we relied on Mr. W. T. Eskew, General Manager of the San Diego Pipeline Company.[†] He estimated that about two-thirds of the commercial petroleum products which reach San Diego, California flow through the San Diego Pipeline Company system. This pipeline system is connected to many refineries

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*It can be determined for a given polity (e.g., a state or perhaps a county) by examining tax records

[†] 213/624-9461

through the Southern Pacific Pipe Line Watson Pump Stations in Carson and Norwalk. The Norwalk pump station is also connected to DFSC's Norwalk tank farm.

Mr. Eskew's estimate is for commercial petroleum products, but the pipeline can also move DFM and both JP-4 and JP-5 in California. (Although the current public utilities commission tariff does not permit the movement of JP-4, Mr. Eskew said that its inclusion had simply not been requested.) Mr. R. Tanner, Supervisor at the Defense Fuel Supply Plant (DFSP) in Norwalk, told us that JP-5 moves to San Diego by pipeline, but that DFM moves to San Diego primarily by ship. (These tankers formerly loaded at the Navy Fuel Depot in San Pedro but, because of an explosion at the 22nd Street Pier, are currently being loaded at the DFSP docks in Norwalk.) The choice of transport method is made by DFSC.

Information about the quantity of fuel which passes through the Colonial Pipeline Company system to the vicinity of Norfolk, Virginia has not been obtained, nor have we succeeded in learning the quantity of fuel which enters this specific geographical area.

Another practice of pipeline companies limits our ability to attribute potential impacts, i.e., if the Navy were to use civilian fuel delivered by the commercial pipelines that service the local areas (Norfolk or San Diego). Each pipeline is connected to several refineries and delivers fuel at various points along the pipeline. When a customer requests fuel, for example, Number 2 heating oil, the pipeline company will take on this quantity of fuel from one of the refineries, maybe even from the refinery chosen by the customer. But, the pipeline company will deliver to the customer whatever batch of Number 2 heating oil in its pipeline system will optimize the pipeline company's operation. The oil may come from the customer's choice of refinery, or some (or all) of it may come from another refinery. In other words, although the pipeline company takes on as much fuel of each kind as it sells, it does not necessarily match each purchase with a sale. The pipeline log can always, of course, be used to establish the source and end point for all of the fuel which moved through the line between any two time points, but the log is not readily available.

However, despite unobtainable data, a simple procedure allows us to provide an upper limit on the quantities of fuel required and to estimate the quantities available. The procedure is based on the following:

- The fuel required by the Navy for ships or aircraft turbines is DFM, JP-5, or close commercial equivalents
- The quantity of fuel required at Norfolk and San Diego will be no larger than the quantity

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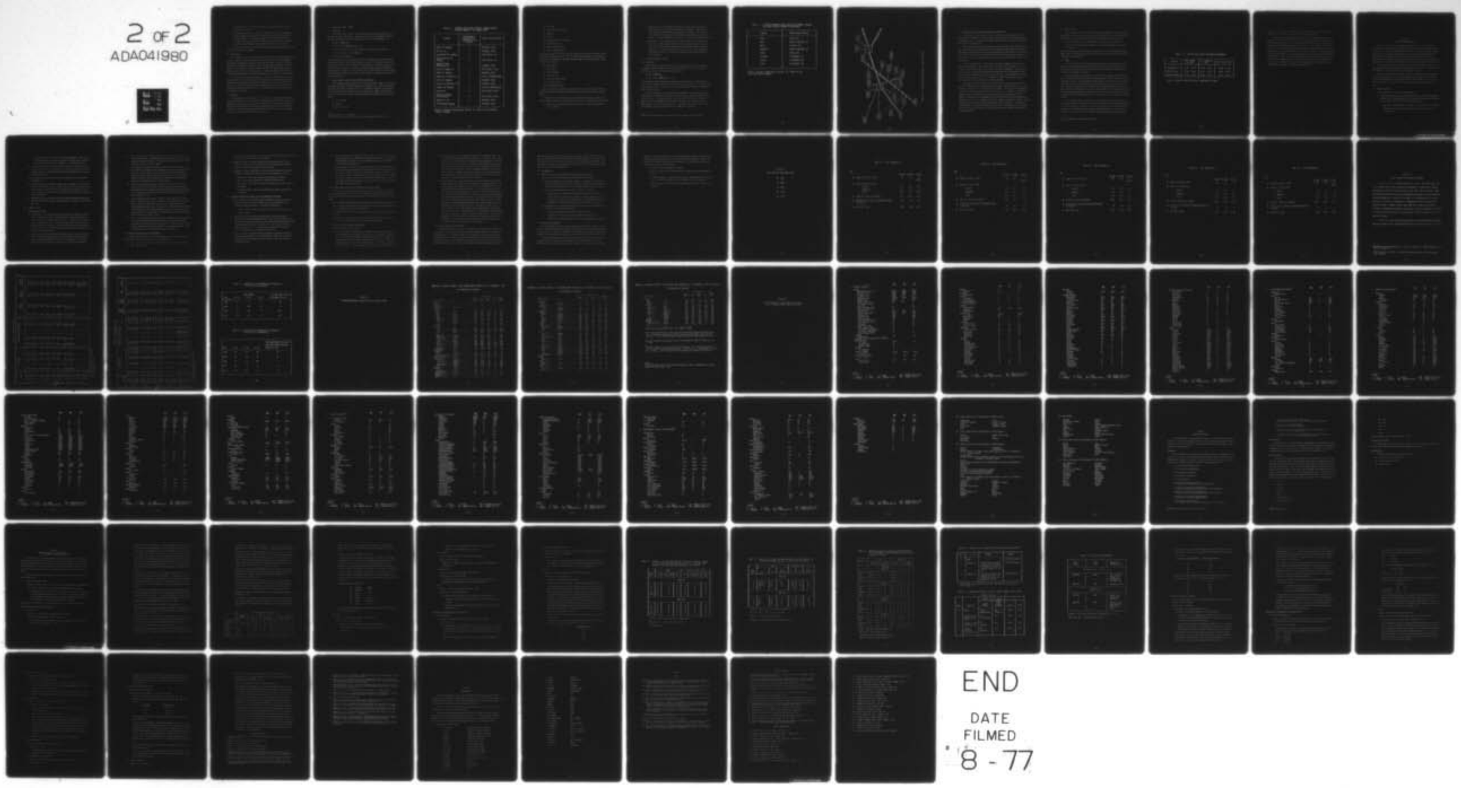

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which the DFSC lifted to the Navy in CONUS Zone 1 (which includes Norfolk) or Zone 5 (which includes San Diego)

- The quantity of commercial fuel available in each of these regions is approximately the amount of commercial fuel available from refineries that connect to the Colonial and San Diego pipelines. This approximation neglects any other method of delivery (e.g., by tanker or tank truck) to either location and assumes that, at least in an emergency, the entire output of commercial fuels from these refineries would go to the Navy.

The discussions of potential fuel availability in Norfolk and San Diego, presented in Sections 5.2 and 5.3, are based on this approach.

5.1.2 Fuels Impacts

As discussed above, the pipeline systems which supply the Norfolk and San Diego areas connect to various refineries. Moreover, the capacities of many of these refineries would be adequate (assuming that crudestocks were available) to supply Navy requirements in either area. Thus, one possible method for determining the potential impacts on Navy systems from switching to locally available civilian fuels is to assume that a specified refinery (with adequate capacity) on each pipeline supplies all the fuel to the Navy facility. Using this assumption, the fuel impacts can be determined immediately from the information reported for specific refineries in Section 4 above.

This approach, used in the next two subsections, is the only feasible approach at this time. Pipeline operations, as described above, do not record analyses of fuel samples reaching a given destination, nor are any simple means available for determining which refineries supplied either area for a given period. Moreover, even if a given batch of fuel could be identified on the basis of relative contributions of refineries, there is no accepted method to predict the properties of the fuel mixture in that batch.

5.1.3 Fuel Costs

DFSC purchases fuel in bulk and stores it in its tank farms. These purchases are based on the overall requirements of the military services (and few related agencies), rather than on specific requirements of a given facility at a given time. Hence, DFSC cannot and does not associate the purchase price of any single lot of fuel with an individual delivery to a user. For this reason we have chosen to compare the average prices paid by DFSC for DFM and JP-5 to prices of comparable civilian fuels in Norfolk and San Diego areas in Section 5.4.

5.2 AN EAST COAST EXAMPLE: NORFOLK

5.2.1 Availability

The refineries shown in Table 5-1 are connected to the Colonial Pipeline Company (CPC) line, which passes through the Norfolk area. Examination of Tables B-1 and B-2 in Appendix B show that the annual requirements for DFM and the combination of JP-5 + JP-4 in DFSC CONUS Zone 1 are:

- DFM, 2.7 MMBBLS/year
- JP-5 + JP-4, 3.6 MMBBLS/year (3.4 + 0.2)

However, the 1973 output* of the Texaco refinery in Port Arthur, Texas, alone, was:

- Diesel and heating oil, 29.9 MMBBLS/year
- Jet fuel, 22.3 MMBBLS/year

Therefore, neglecting all other refineries in Table 5-1, and assuming that the ratio of kerosine-based jet fuel produced to total jet fuel produced is at least 0.7:1,† the Navy would require no more than 9 percent of the distillate fuel oil output and no more than 11 percent of the jet fuel output of just this one refinery. In passing, we note that the Mobile refinery at Beaumont had a greater average daily capacity in 1973 for distillate fuel oil than the Port Arthur Texaco refinery, and the combination of Cities Service, Mobil, and Gulf refineries can refine even more jet fuel than the Texaco refinery does.

5.2.2 Expected Impacts of Using Available Alternates for DFM and JP-5

Among the companies whose fuel analyses are discussed in Section 4, Companies "Y" and "Z" are the only ones which supply the Norfolk area through the pipeline system. This discussion does not include other fuel analysis, because "Y's" and "Z's" "A" refineries' production are sufficient to satisfy the Navy's needs for both DFM and JP-5 in the Norfolk area. Company "Y's" diesel fuel, as sold, fails to meet the specification for DFM only because the following MILSPEC elements are not measured:

- Loss and residue
- Cloud point
- Demulsification time

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*All output quantities are from Appendix C

†Based on average refinery yields by fuel type for each PAD provided by the Bureau of Mines

TABLE 5-1. COMPANIES WHO TRANSMIT PRODUCT THROUGH COLONIAL PIPELINE COMPANY TO THE NORFOLK AREA[a]

Company	Has Tankage in Norfolk Area Connected to the Colonial	Normal Input Location
Amoco Oil Company	X	Pasadena, Texas
BP Oil, Inc.	X	Pasadena, Texas
Continental Oil Company	X	Lake Charles, LA
Cities Service Oil Company	X	Lake Charles, LA
Coastal States Marketing, Inc.		Pasadena, Texas
Gulf Oil Company US	X	Port Arthur, Texas
Mobil Oil Company	X	Beaumont, Texas
Murphy Oil Corporation		Collins, Massachusetts
Shell Oil Company	X	Pasadena, Texas
Texas City Refining, Inc.		Pasadena, Texas
Tenneco Oil Company	X	Collins, Massachusetts
Texaco Inc.	X	Port Arthur, Texas
Union Oil Company of California	X	Port Arthur, Texas
Swann Oil, Inc.	X	Pasadena, Texas
CF Petroleum Company		Pasadena, Texas

[a] Source: Personal communication from Mr. W.L. Nicoll of the Colonial Pipeline Company

- Acid number
- Copper strip corrosion index
- Neutrality
- Ash level
- Accelerated stability, insolubles
- Antioxident additive
- Metal deactivator additive
- Ignition improver additive

This fuel may also contain conductivity and flow improvers which would have to be either certified by a MILSPEC or removed from the fuel. "Z's" "A" refinery could supply Jet A as an alternate for JP-5, but again its fuel does not meet MILSPECS because properties have not been measured. These properties are listed below:

- Explosiveness
- Olefin content
- Particulate matter
- Filtration time
- Fuel system icing inhibitor
- Antioxidant additive
- Metal deactivator additive

In addition, the conductivity improvers would either need to be certified or removed. Neither of these alternate fuels currently have any measured properties which do not satisfy the respective MILSPECS.

Although the fuels described above are very good and would, no doubt, meet a number of the currently unmeasured criteria, the potential impacts of these fuels on Navy equipment should be noted:

- Safety — Failure to meet the explosiveness criterion could impose an unacceptable fire hazard on personnel

- Performance – If the olefin content in the Jet A is too high, the fuel may produce unpleasant odors upon combustion and/or attack fuel system elastomers. The high olefin content could also degrade the fuel thermal stability. In addition, if the cloud point of the diesel fuel is too high, wax crystals may form at low temperature and clog fuel passages. If the demulsification time is too long, it can lead to water induced corrosion.
- Maintenance – If the particulate matter level and/or filtration time of the Jet-A fuel are too high, clogging, plugging, and/or erosion of the combustion equipment may occur. Excessive ash levels and other insolubles in the diesel fuel would have similar results. And finally, if the acidity of the diesel fuel is too high, or if either fuel contains unacceptable additives, fuel instabilities, equipment corrosion, and/or equipment malfunction may occur.

5.3 A WEST COAST EXAMPLE: SAN DIEGO

5.3.1 Availability

Fuel availability in the San Diego area is similar to that in Norfolk. The San Diego Pipeline Company can receive product from the refineries listed in Table 5-2, as shown in Figure 5-1. As before, we note that all of CONUS Zone 5 requires at most:

- DFM, 3.0 MMBBL/year
- JP-5 + JP-4, 7.5 MMBBL/year (7.3 + 0.2)

The Arco refinery can supply more than twice the amount of distillate fuel oil and 85 percent of the jet fuel listed above (assuming that the Arco refinery jet fuel production is at least 89-percent kerosine-based jet fuel*). The remaining jet fuel need can be supplied 10 times over by the Mobil, Shell, and Union refineries.

The discussion above has used the 1973 data given in Appendix C, since these data apply on a consistent basis to both San Diego and Norfolk. More recent data are available for PAD 5 (West Coast United States) alone. The production capacity within the states of California, Washington, and Oregon has grown from 34.3 MMBBL per half year (taken from the 1973 data in Appendix C) to 43.2 MMBBL per half year for all or nearly all jet fuels. The increase for distillate fuel oil has been from 38 MMBBL per half year (from Appendix C) to 42.2 MMBBL for the same period.

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*Based on average refinery yields by fuel type in each PAD provided by the Bureau of Mines

TABLE 5-2. PETROLEUM COMPANIES WHICH CAN DELIVER PRODUCT THROUGH SAN DIEGO PIPELINE COMPANY TO SAN DIEGO[a]

Company	Normal Input Location
ARCO	Carson, CA
Gulf	Santa Fe Springs, CA
Mobil	Torrance, CA
Powerine	Santa Fe Springs, CA
Shell	Carson, CA
Standard	El Segundo, CA
Texaco	Los Angeles, CA
Union	Los Angeles, CA

[a] Source: Personal communication from Mr. C.B. Mitter of the San Diego Pipeline Company

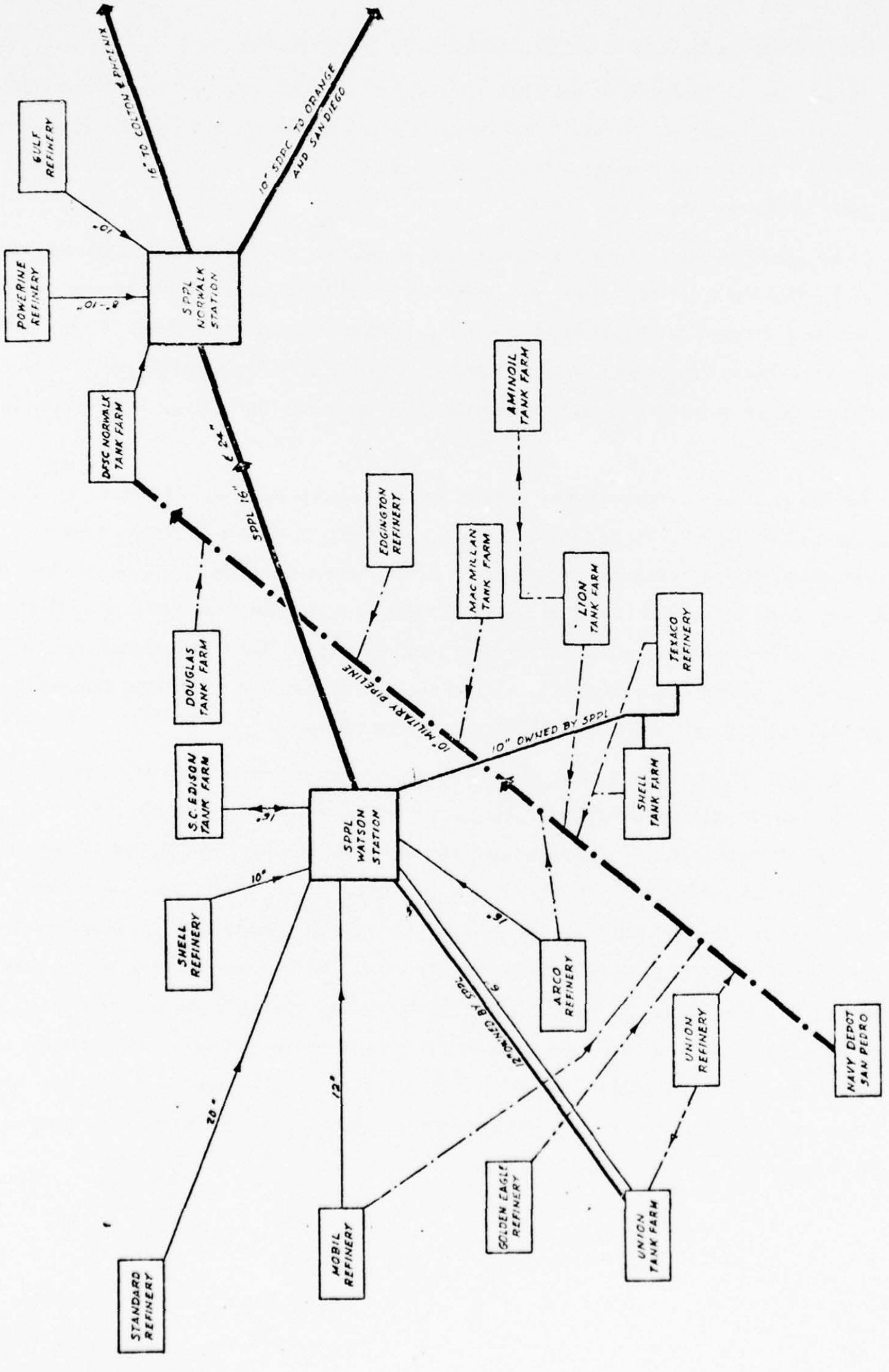

Figure 5-1. San Diego and DFSC Norwalk pipeline systems.

5.3.2 Expected Impacts of Using Available Alternates for DFM and JP-5

The pipeline system supplying petroleum fuels to the San Diego area carries products from the B refineries of Companies "Y" and "Z" and the El Segundo refinery of SoCal (fuels analyses are included in Section 4). The production from either of these refineries is sufficient to supply the Navy's needs in the San Diego area.

Diesel and Jet A fuels from the B refineries have the same analysis as those from the A refineries, except that the B refinery diesel fuel satisfies the MILSPEC copper strip corrosion index criterion and the B refinery Jet A fuel fails to meet the MILSPEC flash point criterion (≥ 60°C) by 10.6°C. Thus, except for the safety problem, potential impacts of alternate fuels supplied via pipeline to the Norfolk area are directly applicable to the alternate fuels supplied from the B refineries to the San Diego area.

For the El Segundo refinery, the alternates could be Number 2 heating oil and Jet A. With respect to the DFM MILSPEC criteria, Number 2 heating oil (CH-2 on Table 4-7) differs from the A refinery diesel fuel from Company "Y" in that it is not checked for appearance. On the other hand, CH-2 not only meets criteria which are met by the A refinery diesel fuel, but also meets criteria for loss and residue, copper strip corrosion index, and ash level. Thus, the potential for problems with CH-2 is only slightly less than it is for Company "Y's" product and the two DFM alternates could be expected to have similar impacts on combustion equipment.

With respect to the JP-5 MILSPEC, the El Segundo Jet A differs from the A refinery Jet A in that it fails the flash point criterion by about one half degree C more (El Segundo Jet A is 11.1°C, Refinery A's criterion is 10.5°C), the freezing point criterion (≤ -46°C) by 1°C, and the mercaptan level criterion (≤0.001 percent by weight) by as much as a factor of 3. In addition, the modified water separation index has not been measured. On the other hand the El Segundo Jet A satisfies the MILSPEC for olefin content, particulate matter level, and filtration time, which refinery A does not measure for its Jet A. Thus, the impacts of the two JP-5 alternates would differ. With the El Segundo product there may be problems with polar material which could disarm coalescers. In addition, at low temperatures, ice crystals may form and restrict fuel flow. On the other hand, this fuel would not be a potential source of odors, and it should not promote clogging, plugging, and/or erosion of combustion equipment.

5.4 FUEL PRICE DATA

Table 5-3 lists price data for civilian fuels purchased in quantity lots* during the January-June 1976 time period. No overall mean price per barrel was available for this period from DFSC for specific regions. However, procurement data for specific refineries indicate that DFSC paid:

- For DFM, from $12.18/BBL to $13.52/BBL; most fuel procured at $12.60/BBL or less
- For JP-5, from $11.26/BBL to $15.16/BBL; most fuel procured at between $12.60/BBL and $13.45/BBL

These data show that DFSC prices and quantity lot commercial prices were not disparate for DFM and Number 2 diesel fuel and heating oil, but that JP-5 prices were slightly higher than Jet A/A1 prices in comparable purchase quantities.

5.5 SUMMARY

This section has shown that a sufficient supply of commercial fuel alternatives is readily available to more than supply the entire needs of the bases in the Norfolk and San Diego areas. It has also shown that DFSC prices during the first half of 1976 did not differ significantly from prices paid for comparable civilian fuels.

Both Norfolk and San Diego are served by a pipeline that is connected to several refineries. When a customer purchases fuel from the pipeline company, he generally does not know which refinery's product he will obtain. The pipeline company schedules purchase, pipeline flow, and distribution to the customer to optimize its own operation, within the constraint of providing the correct grade of fuel. Therefore, the properties of the delivered fuel are not completely known, and, in fact, the batch may contain fuel from more than one refinery. The discussion in this section about the possible impact on Navy combustion equipment of using locally available civilian fuels assumes that the Navy can arrange for the pipeline company to supply it with fuel that does, in fact, come from a specified refinery.

Fuel specification data were available for civilian counterparts to both DFM and JP-5 from one refinery connected to Colonial Pipeline, which services the Norfolk area, and two that are connected to San Diego Pipeline. In both areas of the country, the output of civilian counterpart fuels was as great, or greater than, the Navy's demand in that entire DFSC region. With one exception (flashpoint of the Jet A from both refineries), the fuels meet the MILSPEC's for virtually every

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*Lot sizes comparable to DFSC procurement quantities

TABLE 5-3. CIVILIAN FUEL PRICES FOR QUANTITY PURCHASES

Location	Kero. Based Jet Fuel	No. 2 Heating Oil	No. 2 Diesel Fuel
Contiguous U.S.	11.34 – 13.23	12.30 – 13.27	12.85 – 13.88
Pacific Coast	13.10 – 13.20	12.51 – 12.77	13.63 – 13.77
Middle Atlantic	11.80 – 12.33	13.02 – 13.27	13.14 – 13.88

Source: Bureau of Labor Statistics, Department of Labor element that was measured and may only fail to qualify as DFM or JP-5 because they have not been subject to tests for some of the elements, primarily maintenance elements.

To summarize then, substantial quantities of fuel similar to DFM and JP-5 are available in both the Norfolk and San Diego areas. The jet fuels available from two large refineries, each of which can individually satisfy all of the Navy's needs in the San Diego area via pipeline from Los Angeles, do not meet the MILSPEC requirement for flash point. These jet fuels, as well as similar fuel from a large refinery that can satisfy the Navy's needs in Norfolk, and Number 2 fuel oil or diesel fuel from the Los Angeles refineries all fail to meet the MILSPEC, as currently sold, because they have not been tested for several of the specification elements included in the MILSPEC maintenance elements. Therefore, with some added precautions when using the fuel with lower flash point (or by accepting a somewhat higher risk in a shortfall of JP-5 during a military emergency), the Navy could turn to counterpart civilian fuels in both geographic regions. At most, this could impact equipment maintenance or long-term fuel storage stability.

SECTION 6

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study is to determine whether the Navy could avoid severe operating restrictions in the event of shortages in specification fuels by using other petroleum-based fuels. The answer to this question requires knowledge of the relative availability of potential alternate fuels, the physical and chemical characteristics of these alternates, differences between Navy and comparable civilian equipment or operating procedures that may lead to different fuel requirements for the two types of users, and potential impacts on Navy fuel supply and combustion equipment from the use of fuels which do not meet all the stipulations of the military specifications.

A second question pertains to the relative cost of MILSPEC and alternate civilian fuels — is DFSC paying more for fuel which meets military specifications than it would if it contracted for fuel which meets only civilian specifications (for comparable types of fuel).

The main conclusions which can be drawn from answers to the above questions are presented below, followed by summaries of the findings that support these conclusions. This section then ends with recommendations of actions that should eventually lead to greater fuel flexibility and studies related to fuel availability that should aid the Navy in preparing for fuel shortages.

6.1 PRIMARY CONCLUSIONS

The main conclusions of this study are summarized below:

- Commercial fuels exist which are similar to MILSPEC fuels; the commercial counterpart fuels are used in comparable applications and have properties which may only differ from those required of military fuels in a few areas. Specifically
    - Some civilian counterpart fuels, as delivered, satisfy most elements of the MILSPECS
    - Delivered civilian fuels vary by supplier, but a given supplier tends to have a consistent fuel

  - Differences generally are restricted to the following parameters: safety (flash point and explosiveness), additives, and properties for which limits are specified by the military but not the civilian standards (i.e., "unmeasured properties").

- Fuel shortages have occurred, especially for JP-5, but they have been localized, temporary and not predictable. The conservative view is that this problem will recur with increasing frequency, even though availability exceeds Navy demands at various times in some parts of the world.

- JP-5 shortages will become worse if the Air Force switches to JP-8 (currently under consideration).

- A substantial quantity of "comparable" commercial fuel is available. Given this availability of alternate fuels, the fact that fuel characteristics vary from supplier to supplier, and some recent experiences with fuel shortages, the Navy would be justified in exploring further any potential impacts on their fuel systems and combustion equipment of using such alternates.

- Incremental fuel costs that could be related to the special requirements imposed by the MILSPEC are unpredictable; currently they account for only a relatively small part of the total cost.

6.2 SUMMARY OF RESULTS

6.2.1 Fuel Availability and Cost

- Careful analysis of DFSC data confirmed the belief that the Navy (worldwide) currently uses only a few percent of domestic production of boiler, diesel and turbine fuels (~2 percent of boiler, diesel and marine gas turbine fuels; ~7 percent of kerosine-type jet fuels). Although the Navy and its sister services purchase only a few percent of the domestic fuel production, the DoD, as a whole, is the single largest petroleum consumer in the United States. Therefore the DoD has more influence in the fuels marketplace than its consumption figures might indicate.

- More distillate fuel that meets DFM military fuel specifications is available than the quantity delivered to DFSC by suppliers; the "excess" amount available substantially exceeds current Navy requirements for DFM. An even larger amount is available which slightly misses meeting military specifications (e.g., by about 5°F on flashpoint).

- If the initial 10 percent distillation fraction of Jet A/A1 is discarded (i.e., the light end), the remainder is (approximately) the same as a sample of JP-5. This crude approximation suggests that there is a substantial production capacity for JP-5 in the United States in excess of Navy requirements.
- Spot shortages of JP-5 have occurred overseas, however, and are likely to reoccur. We are not aware of any mechanism at DFSC to communicate such prospective shortages to the Navy. DFSC has begun to gather such data, but, because of the short-term nature of government petroleum product procurements, no supplier can or will provide more than tentative future plans, subject to the multiple, indeterminate, and complex future influences of the marketplace upon each individual supplier.
- Attempts to alleviate future shortages of middle distillate fuels, such as DFM or JP-5, by turning to West Coast refineries processing Alaskan crude will not succeed with current refinery configurations; sufficient advanced refinery capacity does not now exist on the West Coast to process enough of the heavy Alaskan crude to meet the total demand for middle distillate.
- The marketplace for petroleum products is neither a "seller's market" nor a "buyer's market." Government actions – such as introducing a new specification for jet fuel and preventing the sale of lead-containing gasoline – will influence segments of the petroleum product marketplace (e.g., a switch to JP-8 may encourage some small refineries to add reforming capability, and then produce only gasoline). No individual at DFSC suggested that DFSC had an organized policy-recommending body considering these matters and their implications for DFSC's mission.
- There is a lack of detailed data publicly available in compiled form on the location and size of fuel storage facilities outside the United States. There is also a general concommitant lack of compiled data about the qualities of the fuels available. The procurement requirement goals of DFSC to date have not necessitated the gathering of these overseas data in a compiled form which would be useful to the Navy.

6.2.2 Differences Between Navy and Civilian Equipment

Differences between Navy and civilian combustion equipment and operating conditions lead to different requirements for the respective fuels in the following areas:

- Safety: Requirements are more stringent for Navy fuels because the ships may operate under hostile conditions

- Fuel storage: Must not degrade if stored for long periods. This places restrictions on the composition of the fuel and the permissible additives.
- Bunkering practices: Navy operations expose fuels to more water than do civilian practices. This places limits on additives to insure that the water can be removed effectively and does not react chemically with the additive.
- Equipment: Differences between Navy and civilian combustion systems which affect fuel requirements can be adequately characterized by basic equipment types, as follows:
  - Steam boilers: Smaller tube clearances and higher combustion intensities lead to more stringent requirements for allowable contamination levels
  - Diesel Engines: More severe load variation requirements lead to stricter limits on cetane number
  - Aircraft Gas Turbines: Higher altitude operations lead to more stringent limits on freeze point

6.2.3 Differences Between Characteristics of Navy and Comparable Civilian Fuels

- Some civilian fuels can be considered preferred alternates to Navy fuels because they either satisfy, or come close to satisfying, the military specifications and are available in substantial quantities. These preferred alternates are:
  - For DFM: Lighter distillates such as Numbers 1 and 2 fuel oils and diesel fuels
  - For JP-5: Jet A/A1
- Civilian fuels of a given grade must meet ASTM specifications for that grade. In addition, most fuel suppliers guarantee that their fuels will meet a published set of their own specifications, which are usually more stringent than ASTM requirements. ASTM and company specifications define limits, and in fact, most fuels, as delivered, are "better" than these limits – i.e., they come closer in practice to satisfying the military requirements than is indicated by the specification.
- Analyses of actual fuel samples of preferred alternates for DFM show that some fuels exist whose measured properties all satisfy the MILSPEC. However, the following were not measured and could deviate from the MILSPEC: demulsification time, neutrality, and permitted additives.

- Analyses of heavy fuel oil alternates to DFM (e.g., Nos. 4, 5, and 6 fuel oils) confirm the conclusions reached by comparing their ASTM specifications to DFM – i.e., they deviate from the MILSPEC in many areas. The most significant deviations are viscosity and contaminants (particulate matter, etc.).
- Several samples of Jet A that were tested by fuel suppliers or the Bartlesville Energy Research Center (ERDA) satisfied all the MILSPEC requirements for those properties which were measured. However, explosiveness, olefin content, acid number, and particulate matter were not measured, nor was the presence or absence of any additives noted. Although the important flashpoint criteria was not satisfied by a number of samples, all the fuels analyzed met the MILSPEC criteria for distillation properties, most combustion properties, and a number of contamination levels.

6.2.4 Potential Impacts of Variable Fuel Properties on Combustion Equipment

A limited amount of information was obtained about the impact of variable fuel properties on combustion equipment and fuel supply systems. This information indicated that the major concerns of equipment manufacturers and users about the impact of fuel quality on their systems are the following:

- The correlation shown between reduced flashpoint and increased instances of aircraft fire
- The importance of being within a prescribed viscosity range to avoid problems with lubricity, flame stability, pumping, and atomization
- The need to minimize sulfur levels to reduce corrosion in all types of combustion equipment
- The fact that insolubles can foul not only primary combustion equipment, but may also clog fuel flow passages and filters that are designed to remove them

6.2.5 Ranking of Fuels According to Potential Impacts

Alternate fuels can be ranked as follows:

- Fuels with no impact – these alternate fuels would not reduce personnel safety and would not degrade the combustion equipment, its operation, and its performance. Presumably, only fuels which meet all MILSPEC criteria would cause no impacts. No alternate fuel investigated in this study is known to completely satisfy all criteria for DFM or JP-5. However, a number of fuels pass the appropriate MILSPEC for all measured properties and would cause no impacts if their unmeasured properties are found to satisfy the MILSPEC also.

- Fuels with some impact – these alternate fuels would not reduce personnel safety. They may, however, cause long-term degradation to equipment (i.e., corrosion, erosion, deposits build-up, etc.), but these impacts can be reduced by increasing maintenance. Such alternate fuels would also impact performance in areas like fuel consumption and range, smoke emissions, and cold start capability. Any fuel listed in the no-impact level would have to be reclassified to this level if some of its unmeasured properties did not meet the MILSPEC criteria. In addition, two diesel fuels (Exxon No. 2 and Chevron) whose properties were tabulated in Section 4 could be used with minimal impact, but no additional alternates to JP-5 have been identified for this impact level.
- Fuels with major impact – these alternate fuels could cause difficulties in maintaining personnel safety, could require significant modifications to combustion systems, or could render combustion systems inoperative. Fuels which do not meet the MILSPEC criteria for flashpoint and explosiveness (the latter pertains to jet fuel only) belong to this impact level because of the increased hazard. Those which do not satisfy the MILSPEC limits for viscosity could require preheaters and/or pump changes or cause lubrication problems. Fuels which do not meet criteria for freeze point, cloud point, or pour point can reduce fuel flow at low temperatures, causing combustion instabilities or flame out. And fuels which do not satisfy the requirements related to water – reactivity leading to corrosive compounds and ease of separating water and fuel – could cause fuel supply failures. In addition, any fuel listed in the preceding impact levels would have to be reclassified to this level if some of its unmeasured properties failed the MILSPEC criteria associated with impacts at this level. In general, both the very light fuels (i.e., No. 1) and the heavy ones (Nos. 4 to 6) could have a major impact on Navy systems or operations as described here. In addition, some No. 2 and Jet A/A1 products from select companies also fall into this category, usually because of a low flashpoint.

6.2.6 Specific Examples of Fuel Flexibility

Substantial quantities of fuel similar to DFM and JP-5 are available in both the Norfolk and San Diego areas. The jet fuels available from two large Los Angeles refineries, each of which can individually satisfy all of the Navy's needs in the San Diego area via pipeline, do not meet the MILSPEC requirement for flashpoint. In addition, these jet fuels, as well as similar fuels from a large refinery that can satisfy the Navy's needs in Norfolk, and No. 2 fuel oil or diesel fuel from the Los Angeles refineries, all fail to meet the MILSPEC, as currently sold, because they have not been tested for several of the maintenance specification elements included in the MILSPEC. Therefore, with some added precautions when using the fuel with lower flashpoint (or by accepting a somewhat higher safety risk in a shortfall of JP-5 during a military emergency), the Navy could turn to counterpart civilian fuels in both geographical regions. At most, this could impact equipment maintenance or long-term fuel storage stability.

6.3 RECOMMENDATIONS

6.3.1 Specific Actions to Increase Alternate Fuel Availability or Acceptability

Based on the conclusions presented above, Aerotherm recommends that the Navy:

- Develop a standardized fuel qualification procedure. This procedure should be capable of meeting specific needs, such as to test the potential impact of diverse additives on Navy fuel systems and combustors, as well as the general needs of the shale oil program.
- Extend the problem definition phase of the fuels availability program to:
    - Measure properties of alternate fuels (especially foreign) where not known.
    - Further explore fuel flexibility restrictions on a company-by-company basis. This should include identification of companies whose civilian counterpart fuel meets, or nearly meets, the MILSPECS and determination of the availability of such fuels.
- Conduct R&D to find solutions for high ranking alternate fuels (those that nearly meet the MILSPEC). These solutions could include:
    - Minor equipment changes to shipboard fuel and combustion systems
    - Reevaluation of the technical basis for the precise specification value
    - Identification of emergency conditions for which existing alternates can be used now

6.3.2 Additional Fuel Supply Data

As noted elsewhere, more fuel is available that meets the MILSPEC than is currently used by the Navy. Aerotherm believes it would be desirable for the Navy to be informed about the details of this "excess" supply. Therefore, we recommend that the Navy identify those refineries whose ordinary product as actually marketed exceeds, meets, or comes close to MILSPEC requirements for DFM or JP-5.

In addition, Aerotherm has found that the Bureau of Mines and the FEA have amassed information about capacities, configurations, and throughputs in the United States petroleum industry. Aerotherm believes that these data would be useful to the Navy in formulating program plans on fuel availability, and should be obtained. To this end we recommend that liaison be initiated with the Division of Petroleum and Natural Gas and the Division of Fuels Data of BuMines. Further, since questions of fuel distribution capability are also important, such data directly related to Navy needs should be compiled. These data include:

- Capacity, location, and ownership of pipelines
- Refineries connected to these pipelines which could readily receive fuel from CONUS oil wells
- The ordinary product mix (quantity and specification) produced using United States crudes as well as the maximum potential production of DFM and JP-5 at these refineries
- Physical and legal constraints on the pipelines that may restrict their ability to satisfy Navy needs

APPENDIX A

DFSC DATA FOR INDIVIDUAL FUELS

- DFM
- NSFO
- NDF
- JP-5
- JP-4

TABLE A-1. FUEL AVAILABILITY

DFM

	FY 1974	FY 1975	FY 1976
• QUANTITY PROCURED (MMBBL)	15	15	11 (CONUS)
• QUANTITY LIFTED TO NAVY			
– VESSELS	0.7	5.2	16.0
– NONVESSEL	3.1	2.7	3.4
– TOTAL	3.8	7.9	19.4
• QUANTITY LIFTED, ALL SERVICE	9.6	11.3	22.6
• PERCENT OF ALL SERVICE LIFTINGS WHICH WENT TO THE NAVY	40	70	86
• DFSC COST, $/BBL	4.06	6.13	11.32

TABLE A-2. FUEL AVAILABILITY

NSFO

	FY 1974	FY 1975	FY 1976
• QUANTITY PROCURED (MMBBL)	15	10	0 (CONUS)
• QUANTITY LIFTED TO NAVY			
– VESSELS	4.5	0.2	0.2
– *NONVESSEL*	8.0	3.7	2.3
– TOTAL	12.5	4.0	2.5
• QUANTITY LIFTED, ALL SERVICE	13.3	4.3	2.8
• PERCENT OF ALL SERVICE LIFTINGS WHICH WENT TO THE NAVY	94	93	89
• DSFC COST, $/BBL	2.29	5.82	10.40

TABLE A-3. FUEL AVAILABILITY

NDF

	FY 1974	FY 1975	FY 1976
• QUANTITY PROCURED (MMBBL)	36	13	0 (CONUS)
• QUANTITY LIFTED TO NAVY			
– VESSELS	17.4	11.2	0.8
– NONVESSEL	4.9	2.0	—
– TOTAL	22.3	13.2	0.8
• QUANTITY LIFTED, ALL SERVICE	22.6	13.6	0.8
• PERCENT OF ALL SERVICE LIFTINGS WHICH WENT TO THE NAVY	99	97	100
• DFSC COST, $/BBL	35.1	8.32	9.93

TABLE A-4. FUEL AVAILABILITY

JP-5

	FY 1974	FY 1975	FY 1976
• QUANTITY PROCURED (MMBBL)	28	24	18
• QUANTITY LIFTED TO NAVY			
– VESSELS	6.1	4.6	4.1
– NONVESSEL	17.3	17.0	16.7
– TOTAL	23.4	21.5	20.9
• QUANTITY LIFTED, ALL SERVICE	24.3	22.2	21.5
• PERCENT OF ALL SERVICE LIFTINGS WHICH WENT TO THE NAVY	96	97	97
• DFSC COST, $/BBL	4.49	9.41	13.58

TABLE A-5. FUEL AVAILABILITY

JP-4

	FY 1974	FY 1975	FY 1976
• QUANTITY PROCURED (MMBBL)	126	110	76 (CONUS)
• QUANTITY LIFTED TO NAVY			
– VESSELS	0	0	0
– NONVESSEL	5.0	4.6	3.7
– TOTAL	5.0	4.6	3.7
• QUANTITY LIFTED, ALL SERVICE	108.6	96.8	94.7
• PERCENT OF ALL SERVICE LIFTINGS WHICH WENT TO THE NAVY	5	5	4
• DFSC COST, $/BBL	4.02	8.20	12.72

APPENDIX B

DFSC LIFTINGS TO THE NAVY BY REGION

Tables B-1 and B-2 show the quantities of JP-5, DFM, NSFO, NDF, and JP-4 lifted by DFSC to Navy vessels and nonvessels, respectively, during calendar years 1974 and 1975 and fiscal years 1974, 1975, and 1976. These data were provided by DFSC and are broken down according to their worldwide regional boundaries.* Region 6, the CONUS, is subdivided into six zones. Data which could not be assigned to a geographical region are given in a separate column. Summary columns show CONUS Navy nonvessel and vessel liftings, worldwide Navy nonvessel and vessel liftings, worldwide all-service† liftings and the percentage of worldwide Navy liftings relative to the all-service liftings.

Tables B-3 and B-4 describe the extent of the geographically unassignable data (shown in the column headed with an asterisk in Tables B-1 and B-2).

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*Worldwide regional boundaries are given in Figure 2-2; CONUS boundaries are shown in Figure 2-1

†Armed services plus NASA, the Federal Aviation Agency, and miscellaneous other agencies

TABLE B-1. NAVY VESSEL LIFTINGS

	YEAR END	DFSC REGION					CONUS ZONE (IN DFSC REGION 6)						*	ENTIRE CONUS (NAVY VESSEL)	ENTIRE WORLD (NAVY VESSEL)	ENTIRE WORLD (NAVY AGENCIES)
		1	2	3	4	5	1	2	3	4	5	6				
JP-5	12/74	72	17	1,213	1,208	3	609	265	—	—	649	—	78	1,523	4,113	21,546
	12/75	157	3	1,307	1,213	—	963	266	—	—	499	18	25	1,745	4,449	22,533
	6/74	136	6	639	1,623	—	1,059	283	—	—	905	—	1,462	2,246	6,112	24,299
	6/75	68	14	1,578	1,187	3	907	203	—	—	582	—	19	1,692	4,561	22,159
	6/76	182	3	1,016	1,131	—	686	504	—	—	517	17	92	1,724	4,148	21,495
DFM	12/74	58	—	254	178	—	24	199	—	—	170	—	59	393	942	5,824
	12/75	657	18	1,612	4,926	—	2,118	1,063	—	—	1,753	—	416	7,206	12,564	19,993
	6/74	16	—	16	167	—	29	-19	—	—	180	—	132	327	659	9,599
	6/75	297	2	559	2,299	—	738	506	—	—	559	—	248	1,803	5,209	11,300
	6/76	796	23	2,862	5,407	—	2,332	1,558	—	—	2,723	—	281	7,124	15,982	22,574
NSFO	12/74	10	—	129	913	—	54	88	—	—	99	—	-289	242	1,004	7,349
	12/75	—	—	-19	273	—	-43	86	—	—	81	—	17	124	396	3,488
	6/74	43	—	289	1,631	—	517	232	—	—	850	—	947	1,599	4,509	13,301
	6/75	—	—	-13	327	—	42	86	—	—	166	—	-382	294	226	4,303
	6/76	—	—	—	78	—	—	49	—	—	40	—	28	88	195	2,788
NDF	12/74	579	52	3,233	4,621	—	2,851	1,007	—	—	3,128	—	319	6,986	15,791	19,151
	12/75	259	—	1,231	361	—	606	171	—	—	1,495	—	-20	2,272	4,102	4,669
	6/74	382	61	2,111	4,320	—	3,406	938	—	—	3,128	—	3,045	7,472	17,390	22,615
	6/75	460	31	2,814	2,797	—	1,924	650	—	—	2,473	—	40	5,047	11,190	13,584
	5/76	172	—	186	—	—	56	—	—	—	455	—	-60	511	809	809
JP-4	12/74	—	—	—	—	—	—	—	—	—	—	—	1	—	1	100,493
	12/75	—	—	—	—	—	—	—	—	—	—	—	—	—	—	98,819
	6/74	—	—	—	—	—	—	—	—	—	—	—	—	—	—	108,476
	6/75	—	—	—	—	—	—	—	—	—	—	—	1	—	—	96,776
	6/76	—	—	—	—	—	—	—	—	—	—	—	—	—	—	94,737

* These data are geographically unassignable

Units are thousands of barrels

TABLE B-2. NAVY NONVESSEL LIFTINGS

	YEAR END	DFSC REGION					CONUS ZONE (IN DFSC REGION 6)						*	ENTIRE CONUS (NAVY, NONVESSEL)	ENTIRE WORLD (NAVY, NONVESSEL)	ALL NAVY USE	NAVY USE ALL SVC. USE %
		1	2	3	4	5	1	2	3	4	5	6					
JP-5	12/74	418	6	654	1,127	649	2,602	2,843	—	—	6,826	—	1,642	12,271	16,768	20,881	97
	12/75	545	—	945	1,636	337	2,793	2,822	—	—	6,901	303	1,203	12,818	17,484	21,933	97
	6/74	394	7	684	1,368	507	2,444	2,739	—	—	6,562	—	2,589	11,745	17,292	23,404	96
	6/75	459	1	955	1,477	638	2,502	2,739	—	—	6,722	—	1,490	11,964	16,984	21,545	97
	6/76	544	—	890	1,721	280	2,692	2,815	—	—	6,756	313	668	12,576	16,679	20,891	97
DFM	12/74	172	—	—	346	—	138	39	—	—	321	—	308	498	1,323	2,265	39
	12/75	299	56	6	404	—	432	392	—	—	247	1	2,147	1,068	3,985	16,549	83
	6/74	18	—	—	1,200	2	127	120	—	—	313	—	1,316	560	3,096	3,755	39
	6/75	265	3	—	389	—	219	177	—	—	248	—	1,427	644	2,730	7,939	70
	6/76	295	95	20	373	—	331	375	—	—	267	1	1,652	929	3,409	19,391	86
NSFO	12/74	16	2	243	1,622	124	1,632	113	—	—	324	—	1,400	2,086	5,765	6,761	92
	12/75	319	66	-3	736	60	596	125	—	—	52	17	755	790	2,741	3,137	90
	6/74	15	—	128	1,750	134	881	138	—	—	348	—	4,614	1,367	8,007	12,516	94
	6/75	323	2	-19	1,198	95	924	117	—	—	-9	—	1,101	1,032	3,732	3,958	92
	6/76	325	70	87	627	61	310	94	—	—	154	—	573	558	2,303	2,498	90
NDF	12/74	38	180	26	87	—	-12	230	—	—	30	—	2,339	247	2,916	18,707	98
	12/75	—	—	7	-29	—	-30	50	—	—	-25	—	459	-43	433	4,535	97
	6/74	32	252	15	506	—	48	239	—	—	202	—	3,608	489	4,903	22,293	99
	6/75	7	6	16	267	—	12	249	—	—	11	—	1,476	273	2,045	13,235	97
	6/76	—	—	—	-30	—	-29	--	—	—	-17	—	76	-46	—	809	100
JP-4	12/74	299	—	323	654	—	308	1,655	37	1,522	349	—	100	3,871	5,247	5,248	5
	12/75	203	—	-121	516	—	290	1,300	135	1,605	228	—	12	3,558	4,169	4,169	4
	6/74	—	—	179	467	—	182	1,510	43	1,397	300	—	962	3,432	5,040	5,040	5
	6/75	363	—	142	646	—	324	1,418	73	1,400	258	—	20	3,473	4,645	4,646	5
	6/76	32	—	-121	429	—	235	1,093	111	1,607	237	—	64	3,283	3,687	3,687	4

* These data are geographically unassignable

Units are thousands of barrels

TABLE B-3. UNCERTAINTY IN GEOGRAPHICAL ASSIGNABILITY OF FUEL LIFTED TO VESSELS, %

FUEL	YEAR ENDING FY 74	FY 75	FY 76	% OF THIS FUEL LIFTED TO VESSELS (FY 76)
DFM	20	5	2	82
NSFO	21	100	14	8
NDF	18	0.4	7	100
JP-5	24	0.4	2	20

TABLE B-4. UNCERTAINTY IN GEOGRAPHICAL ASSIGNABILITY OF FUEL LIFTED TO NONVESSEL, %

FUEL	FY 74	FY 75	FY 76	TOTAL UNCERTAINTY ALL NAVY USE, BOTH VESSEL AND NON-VESSEL (FY 76)
DFM	43	52	48	10
NSFO	58	30	25	24
NDF	74	73	100	2
JP-5	15	9	4	4
JP-4	19	0.4	2	2

APPENDIX C

PETROLEUM REFINERY CAPACITIES IN THE UNITED STATES

OWNERSHIP, LOCATION, CAPACITY, AND AVERAGE DAILY OUTPUT OF U.S. REFINERIES, 1973

(In thousands of barrels)

Region/State and company	City	Reported capacity	Average daily output			
			Gasoline	Residual fuel oil	Jet fuel	Diesel and No. 2 combined
New England:						
Maine						
New Hampshire						
Vermont						
Massachusetts						
Rhode Island: Mobil	East Providence	7.50	−.10	0	0	1.20
Connecticut						
Middle Atlantic:						
New York:						
Ashland	Buffalo	63.00	10.58	3.28	.36	4.74
Mobil	do	42.80	18.90	5.00	1.90	9.40
New Jersey:						
Exxon	Bayway	268.30	138.50	14.50	15.40	72.40
Mobil	Paulsboro	98.00	33.60	2.90	1.60	29.00
Socal	Perth Amboy	80.00	31.90	6.90	0	32.20
Texaco	Westville	88.00	38.00	26.00	7.00	(1)
Pennsylvania:						
Ashland	Freedom	6.80	0	.36	.36	.73
Atlantic Richfield	Philadelphia	185.00	65.80	14.40	.90	20.60
Gulf	do	169.00	96.00	5.50	0	55.00
Pennzoil	Renco	1.90	.30	0	0	.40
Do	Rouseville	10.00	2.00	0	0	3.00
Do	Karns City	0	.03	0	0	.05
Sohio	Marcus Hook	93.20	52.30	11.30	3.50	28.00
Sun Oil	do	165.00	94.40	14.00	5.00	28.70
East north-central:						
Ohio:						
Ashland	Findlay	20.00	0	0	.36	.36
Do	*Canton*	60.00	1.09	1.82	0	4.74
Gulf	Toledo	49.00	31.00	.30	4.50	10.00
Do	Cleves	42.00	29.00	.10	3.00	7.00
Sohio	Toledo/Lima	264.40	148.10	5.20	15.20	64.50
Sun Oil	Toledo	120.00	80.80	5.90	0	9.50
Indiana:						
Atlantic Richfield	East Chicago	126.00	67.50	12.60	.20	29.50
Mobil	do	47.00	24.20	3.80	0	8.10
Rock Island	Indianapolis	26.26	16.61	1.90	0	4.47
Standard of Indiana	Whiting	315.00	138.50	30.67	23.84	61.52
Illinois:						
Clark Oil & Refining	Blue Island	67.00	56.00	7.00	0	4.00
Do	Hartford	36.00	25.00	1.00	0	10.00
Marathon	Robinson	128.50	86.50	0	0	32.10
Mobil	Joliet	175.00	105.10	2.90	4.30	46.70
Shell	Wood River	255.00	136.60	15.90	37.70	37.80
Standard of Indiana	do	107.00	49.26	5.63	5.48	19.00
Texaco	Lockport	72.00	34.00	1.00	8.00	15.00
Do	Lawrenceville	84.00	43.00	5.00	10.00	20.00
Michigan:						
Total Leonard	Alma	43.30	20.00	3.00	1.00	7.00
Marathon Oil	Detroit	61.30	30.80	5.00	0	14.30
Wisconsin: Murphy Oil	Superior	37.00	17.00	4.00	0	6.00
North west-central:						
Minnesota:						
Ashland	St. Paul Park	66.00	9.76	3.00	1.04	3.63
Conoco	Wrenshall	18.00	11.00	2.00	1.00	3.00
Iowa						
Missouri: Standard of Indiana	Sugar Creek	105.00	46.67	3.45	4.45	32.33
North Dakota: Standard of Indiana	Mandan	48.00	23.23	3.02	2.54	16.23
South Dakota						
Nebraska: Farmland Industries	Scottsbluff	5.00	3.00	.40	0	1.10
Kansas:						
American Petrofina	El Dorado	22.50	12.47	.23	0	3.80
Apco	Arkansas City	24.00	20.00			3.00
Farmland Industries	Coffeyville	35.00	18.00	1.00	0	8.00
Do	Phillipsburg	20.00	11.00	.70	0	4.00
Mobil	Augusta	50.00	26.30	.40	3.30	10.60
National Cooperative Refinery	McPherson	54.00	29.00	1.00	0	14.00
Phillips Petroleum	Kansas City	85.00	47.10	3.70	5.80	14.50
Skelly	El Dorado	72.00	52.40	.30	0	19.00
South Atlantic:						
Delaware: Getty	Delaware City	140.00	72.10	.40	1.40	28.70
Maryland:						
Socal	Baltimore	13.50				
Standard of Indiana	do	10.00	0	0	0	0
District of Columbia						
Virginia: Standard of Indiana	Yorktown	53.00	29.52	1.41	0	18.94
West Virginia: Pennzoil	Falling Rock	5.00	1.00	0	0	1.00
North Carolina						
South Carolina						
Georgia: Standard of Indiana	Savannah	12.00	0	0	0	0
Florida						

OWNERSHIP, LOCATION, CAPACITY, AND AVERAGE DAILY OUTPUT OF U.S. REFINERIES, 1973 (Continued)

(In thousands of barrels)

Region/State and company	City	Reported capacity	Average daily output			
			Gasoline	Residual fuel oil	Jet fuel	Diesel and No. 2 combined
East south-central:						
Kentucky:						
Ashland Oil	Louisville	25.00	3.65	.73	0	1.82
Do	Catlettsburg	136.00	21.53	2.55	.73	11.31
Tennessee						
Alabama: Hunt Oil	Tuscaloosa		1.30	2.80	1.50	2.30
Mississippi:						
Southland Oil	Lumberton	4.27	0	.02	0	.87
Do	Sandersville	8.33	.33	.02	1.43	1.05
Do	Yazoo City	3.14	.06	.06	.31	.51
Socal	Pascagoula	220.00	110.20	12.30	27.40	52.60
West south-central:						
Arkansas: Lion Oil	El Dorado	40.00	7.24	1.05	0	4.90
Louisiana:						
Cities Service	Lake Charles	268.00	147.70	12.60	27.30	44.90
Conoco	West Lake	83.00	41.00	3.00	4.00	31.00
Exxon	Baton Rouge	436.60	208.10	10.70	46.20	87.00
Gulf	Belle Chasse	174.00	94.00	.60	9.00	67.00
Do	Venice	23.00	14.00	0	0	2.00
Kerr-McGee	Cotton Valley	6.00	2.00	1.00	0	0
Murphy Oil	Meraux	93.00	25.00	7.00	11.00	13.00
Pennzoil	Shreveport	20.00	11.10	4.10	.30	2.70
Shell	Norco	240.00	114.70	11.30	38.10	54.80
Tenneco	Chalmette	87.00	52.00	1.00	0	13.00
Texaco	Convent	140.00	71.00	11.00	25.00	34.00
Oklahoma:						
Apco	Cyril	10.00	7.00			2.00
Champlin Petroleum	Enid	48.55	32.53	0	1.28	12.65
Conoco	Ponca City	112.00	61.00	1.00	15.00	21.00
Kerr-McGee	Wynnewood	34.00	25.00	2.00	0	4.00
Sun Oil	Duncan	48.50	28.80	0	1.60	11.80
Do	Tulsa	88.50	48.90	0	0	7.30
Texaco	do	50.00	30.00	5.00	4.00	11.00
Texas:						
American Petrofina	Big Springs	65.00	28.80	.32	2.03	11.00
Do	Mt. Pleasant	26.00	11.69	.71	0	4.94
Do	Port Arthur[3]	84.00	15.93	5.10	0	12.59
Arco	Houston	210.00	97.20	.40	8.20	60.20
Crown Central Petroleum	do	96.00	51.00	2.00	0	22.00
Diamond Shamrock	Sunray	45.00	37.00	0	4.00	11.00
Exxon	Baytown	400.00	164.00	19.90	30.10	84.40
Gulf	Port Arthur	312.10	172.43	6.98	29.47	68.94
Marathon Oil	Texas City	56.40	31.30	4.80	.20	15.50
Mobil	Beaumont	335.00	149.90	19.60	15.80	86.80
Phillips Petroleum	Borger	95.00	90.30	0	9.10	17.10
Do	Sweeny	85.00	60.90	3.90	.90	24.20
Shell	Deer Park	268.00	107.20	25.00	18.60	23.70
Do	Odessa	29.00	19.60	1.80	2.20	4.50
Southwestern O. & R.	Corpus Christi	114.00	20.00	2.00	0	21.00
Socal	El Paso	71.00	38.00	3.00	6.00	18.00
Standard of Indiana	Texas City	333.00	177.10	6.98	.07	68.03
Sohio	Port Arthur	(3)	9.20	3.00	0	6.10
Sun Oil	Corpus Christi	57.00	30.30	0	1.10	17.20
Texaco	Amarillo	20.00	13.00	0	1.00	3.00
Do	El Paso	17.00	10.00	0	1.00	4.00
Do	Port Arthur	406.00	149.00	40.00	61.00	82.00
Do	Port Neches	47.00	0	0	0	0
Texas City Refinery	Texas City	60.00	24.00	2.00	0	16.00
Union Texas Petroleum	Winnie	9.00	8.00	0	0	2.00
Mountain:						
Montana:						
Conoco	Billings	46.00	31.00	1.00	0	7.00
Exxon	do	45.00	22.80	1.70	3.40	9.10
Phillips Petroleum	Great Falls	5.70	2.60	.20	.60	1.20
Idaho						
Wyoming:						
Standard of Indiana	Casper	43.00	15.18	.12	.80	6.06
Texaco	do	21.00	10.00	1.00	1.00	4.00
Colorado: Conoco	Commerce City	27.00	11.00	2.00	4.00	4.00
New Mexico: Shell	Gallup	16.60	12.20	.30	.10	4.30
Arizona						
Utah:						
Phillips Petroleum	Woods Cross	23.00	12.80	.60	.60	6.30
Socal	Salt Lake City	43.00	18.70	3.20	4.40	12.40
Standard of Indiana	do	39.00	21.15	1.06	1.78	11.01
Nevada						

OWNERSHIP, LOCATION, CAPACITY, AND AVERAGE DAILY OUTPUT OF U.S. REFINERIES, 1973 (Concluded)

(In thousands of barrels)

Region/State and company	City	Reported capacity	Average daily output			
			Gasoline	Residual fuel oil	Jet fuel	Diesel and No. 2 combined
Pacific:						
Washington:						
Arco	Ferndale	96.00	49.70	14.10	15.30	13.80
Mobil	do	71.50	35.20	6.10	7.70	13.80
Shell	Anacortes	88.00	51.90	2.40	13.50	12.20
Texaco	do	63.00	34.00	4.00	3.00	15.00
Oregon: Socal	Portland	14.00				
California: ★						
Arco	Carson	165.00	67.20	34.90	22.10	18.90
Beacon Oil	Hanford	12.00	3.00	3.00	1.00	3.00
Exxon	Benica	87.00	61.40	0	9.90	8.70
Fletcher Oil & Refining	Carson		4.33	4.87	1.60	1.68
Gulf	Hercules	27.00	19.00	0	0	5.00
Do	Santa Fe Springs	50.00	26.00	15.00	0	1.50
Mobil	Torrance	123.50	54.70	3.80	8.90	14.00
Phillips Petroleum	Martinez	110.00	58.30	12.50	1.90	17.30
Powerine	Santa Fe Springs	28.50	15.00	9.00	2.00	.50
Shell	Martinez	100.00	43.70	13.40	10.40	5.50
Do	Wilmington	86.00	41.80	16.90	14.70	10.30
Socal	Bakersfield	26.00	2.50	1.30	0	2.10
Do	El Segundo	220.00	75.50	53.60	34.40	27.80
Do	Richmond	190.00	66.90	49.50	24.70	33.20
Texaco	Wilmington	75.00	39.00	19.00	0	6.00
Alaska: Socal	Kenai	20.00	0	.30	3.70	5.90
Hawaii: Socal	Honolulu	35.00	13.20	14.90	8.70	3.30
Puerto Rico:						
Commonwealth Oil & Refining	Penuelas	161.00	58.60	47.10	.20	8.70
Gulf	San Juan	37.60	11.20	9.38		6.44
Sun Oil	Yabuco	85.00	15.70	21.60	0	28.10

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[1] Diesel fuel not available, No. 2 oil equals 18,000.

[2] State total percents may total more than 100 percent because operating capacity, supplied by the Bureau of Mines was used rather than total reported capacity. Total reported capacity may or may not include shutdown capacity.

[3] American Petrofina purchased this British/Standard of Ohio refinery on July 1, 1973.

★ Union Oil Company is also located in California. It's refinery production of jet fuel and of combined diesel and No. 2 heating oil is 15,000 bbls a day for each. Source: Mr. J. Hayt, Union Oil Company, Los Angeles, California.

Source:
"The Structure of the U.S. Petroleum Industry," Special Subcommittee on Integrated Oil Operations, 1976.

APPENDIX D

LIST OF MARINE FUELS SOLD AROUND THE WORLD BY SHELL, CHEVRON, EXXON, GULF, AND TEXACO

1. ATLANTIC REGION(1)

	MGO	MDF	BFO
Canada			
New Westminster, B.C.	CGES	CGES	CGES
Vancouver, B.C.	CESG	CESG	CESG
Victoria, B.C.	CGES	CGES	CGES
Halifax, N.S.	GETC	ET	ET
Montreal, Que.	ESTCG	ESTG	ESTCG
Quebec, Que.	ECGS	S	ESC
Saint John, N.B.	EC	EC	EC
St. Pierre Island	C		
Hamilton			S
Port Colborne, Ont.	ES		SE
Holyrood Refinery	S		
Sarnia, Ont.	ES	ES	ES
Sorel/Contrecoeur	SGET	SGET	SGET
Sydney, N.S.	GES	S	GS
Three Rivers	GSE		GSE
Toronto, Ont.	GES		GES
Port Hawkesbury, N.S.	G		G
Port Cartier, P.Q.	G		G
Clarkson	G		G
Sept Isle, Que.	E		E
Baie Comeau, Que.	E		E
St. Pierre et Miquelon	S		
Churchill, Manitoba	E		
Point Tupper, N.S.	G		G
Iceland			
Reykjavik	ES		ES
Labrador (listed separately by DFSC)			
Newfoundland			
St. John's	GES		SE
Corner Brook	G		
Harbour Grace	E		
Bermuda	S		S
St. George's	E		
Canary Islands			
Las Palmas	CSTG	CSTG	CSTG
Cape Verde Islands			
St. Vincent	E	GE	GE
Aruba			
San Nicolas	ES	ES	ES
Oranjestad	E	E	E

LEGEND:

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	MGO	MDF	BFO
Bahamas			
Freeport	CTS		CTS
Barbados			
Bridgetown	E	E	E
Colombia			
Cartagena	E	E	E
Buenaventura	E	E	E
Dominican Republic			
Santo Domingo	T	T	T
Jamaica			
Grand Caymen	T		
Kingston	TSE	TSE	TSE
Montego Bay	E		
Puerto Rico			
San Juan	GTSEC		GTSEC
Guayanilla	GT		G
Mayaguez	T		T
Ponce	T		T
Trinidad			
Point Fortin	S	S	S
Port of Spain	SE	SE	SE
Venezuela			
Puerto La Cruz	GE	GE	GE
La Salina	E	E	E
Maracaibo	E	E	E
Caripito	E	E	E
Amuay Bay	E	E	E
Norway			
Oslo	E	E	E
Dramnen	E	E	E
Stagenstagen	E	E	E
Fredrikstad	E	E	E
Kristiansand, S.	E	E	E
Stavanger	E		E
Bergen	E	E	E
Trondheim	E	E	E
Mo-i-Rana	E		E
Harstad	E		E
Tromso	E		E
Honninsvaag	E	E	E
Oslo/Kambo	E	E	E
Langesund	E	E	E

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	MGO	MDF	BFO
Portugal			
Lisbon	ETCS	ETCS	ETCS
Leixoes	S	S	S
United Kingdom			
Manchester	GTE	GTE	GTE
Liverpool	GSTE	GSTE	GSTE
Ellesmere Port	G	G	G
Swansea	GE	GE	GE
Port Talbot	GTE	GTE	GTE
Cardiff	GTE	GTE	GTE
Milford Haven	GE	GE	GE
Barry	GSTE	GTE	GSTE
Penarth	G	G	G
Newport	GE	GE	GE
Sharpness	GE	GE	GE
Avonmouth	GSTE	GTE	GSTE
Bristol	G	G	G
London	GCTE	GCTE	GCTE
Grimsby	G	G	G
Immingham	GTE	GTE	GTE
Goole	G	G	G
Hull	GSTE	GSTE	GSTE
Middlesborough	GE	GE	GE
Sunderland	GE	GE	GE
Leith	G	G	G
Aberdeen	STE	STE	SE
Ardossan	S	S	S
Belfast	SE	SE	SE
Clyde	S	S	S
Dover	SE		
Falmouth	S	S	S
Finnart	S	S	S
Grangemouth	S	S	S
Great Yarmouth	S		S
Heysham	S	S	S
Ipswich	SE		SE
Eastham		S	S
Tranmere		S	S
Isle of Grain	S	S	S
Purfleet	S	S	S
Shellhaven	S	S	S
Thameshaven	S	S	S
Londonderry	S		S

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	MGO	MDF	BFO
United Kingdom (Continued)			
Partington	S	S	S
Stanlow	S	S	S
Portslade	S		S
Southampton	SE	SE	SE
Swansea	ST	ST	ST
Teesport	S	S	S
Tyne	SE	SE	SE
Newport	T	T	T
Pembroke	T	T	T
Brighton	E		
Portsmouth	E	E	E
Plymouth	E	E	E
Portishead	E	E	E
Glasgow	E	E	E
Dundee	E		
Leith	E	E	
Blyth	E	E	E
Hartlepool	E	E	E
Kings Lynn	E	E	
Felixstowe	E		E
Spain			
Pasajes	ETCS	C	ETCS
Bilbao	ETCSG	C	ETCSG
Santander	ETCS	C	ETCS
Gijon	ETCS	C	ETCS
Aviles	ETC	C	ETC
Ferrol	ETCS	C	ETCS
Ceuta	TS	TS	TS
La Caruna	ECTSG	C	ECTSG
Vigo	ETCS	C	ETCS
Huelva	ETCG	C	ETCG
Seville	ETCS	C	ETCS
Cadiz	ETCS	C	ETCS
Algeciras	ETCS	C	ETCS
Malaga	ETCS	C	ETCS
Almeria	ECS	C	ECS
Alicante	ETS		ETS
Valencia	ETCS	C	ETCS
Castellon	ETS		ETS
Terragona	ETCS	C	ETCS
Barcelona	ETCSG	C	ETCSG
Palma, Majorca	ETCS	C	ETCS
Mahon, Minora	ETCS	C	ETCS
Almeria	T		T
Santurce	C	C	C

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2. LATIN AMERICAN REGION(2)

	MGO	MDF	BFO
Argentina			
Buenos Aires		S	S
Brazil			
Recife	ES		ES
Rio de Janeiro	ESG	G	ESG
Santos	ESG	G	ESG
Rio Grande Do Sul	ES		ESG
Belem	T		T
Fortaleza	T		T
Manaus	T		T
Paranagua	T		T
Porto Alegre	T		T
Salvador	T		T
Sao Sebastio	TG	G	TG
Vitoria	T		T
Guyana			
Georgetown	T		T
Chile			
San Vicente	E		E
Valparaiso	E		E
Antofagasta	ES		ES
San Antonio	ES		ES
Punta Arenas	ES		ES
Equador			
Guayaquil		G	G
Honduras			
Puerto Cortes	T		T
Mexico			
Tampico	E		E
Vera Cruz	E		E
Minatitlan	E		E
Guaymas	E		E
Mazatlan	E		E
Manzanillo	E		E
Salina Cruz	E		E
Acapulco	E		E
Panama			
Balboa	CGS	CGS	CGS
Cristobal	CGS	CGS	CGS
St. Pierre Et Miguelon	G		
Colon	E	E	E
Paraguay			
Asuncion	E		E
Uruguay			
Montevideo	SGE	SGE	SGE

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3. EUROPE-AFRICAN REGION(3)

	MGO	MDF	BFO
Belgium			
Antwerp	ECGST	ECGT	ECGST
Ghent	ECGST	ECGT	ECGST
Ostende	EG	EG	EG
Zeebrugge	EG	EG	EG
Denmark			
Aalborg	SE	SE	SE
Copenhagen	SCE	SCE	SCE
Fredericia	S	S	S
Klaksvik	S		S
Torshavn	S	S	S
Aarhus	GE	GE	GE
Frederikshavn	G	G	G
Esbjerg	GE	GE	GE
Stigsnaes	G	G	G
Kalundborg	E	E	E
Solmundefjord		E	
Ostero		E	
Faroes		E	
Finland			
Turku	GS	S	GS
Helsinki	GS	S	GS
Kotka	GS	S	GS
France			
Ambes	TSC	G	TSGC
Bayonne	TSC	G	TSGC
Bordeaux	TSC	G	TSGC
Donges	TSC	GE	TSGEC
Dunkirk	TSC	GE	TSGEC
Fos Sur Mer	TS		TS
La Pallice	TS	G	TSG
Le Havre	TSC	GE	TSGEC
Le Verdun	TSC	G	TSGC
Lavera	TSC		TSC
Marseilles	TSC		TSC
Nantes	TSC	GE	TSGEC
Pauillac	TSC	G	TSGC
Rouen	TSC	GE	TSGEC
St. Nazaire	TSC	E	TSEC
Sete	TSC	G	TSGC
Antifer	S		S
Berre	S		S

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	MGO	MDF	BFO
France (Continued)			
La Mede	S		S
Petit Couronne	S		S
Port St. Louis du Rhone	S		S
Port Jerome		GE	GE
Fos/Lavera		G	G
Germany			
Flensburg	E	E	E
Luebeck	ES	ES	ES
Travemuende	ES	ES	ES
Kiel	ES	ES	ES
Kiel Canal: Kiel-Brunsbuttle	ECST	ECT	ECT
Hamburg	ECGST	ECGST	ECGST
Cuxhaven	EGST	EGST	EGST
Bremerhaven	EGST	EGST	EGST
Farge	EGST	EGST	EGST
Vagesack	EGST	EGST	EGST
Bremen	EGST	EGST	EGST
Brake	EGST	EGST	EGST
Nordenham-Blexen	EGST	EGST	EGST
Wilhemshaven	E	E	E
Emden	EGS	EGS	EGS
Holtenau	S	S	S
Ireland			
Cork	SE	S	SE
Dublin	SE	SE	SE
Netherlands			
Amsterdam	TSGCE	TSGCE	TSGCE
Rotterdam	TSGCE	TSGCE	TSGCE
Flushing	C	C	C
Sweden			
Gothenburg	EGS	EGS	EGS
Helsingburg	EG	G	EG
Oxelosund	E		
Stockholm	EGS	GS	EGS
Malmo	GS	GS	GS
Trelleborg	G	G	G
Karlshamn	G	G	G
Gavle	T	T	T
Halmstad	T	T	T
Algeria			
Algiers	T	T	T
Crete			
St. Nicholas	E		E

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	MGO	MDF	BFO
Italy			
Augusta	SCGE	SCG	SCGE
Genoa	STCGE	STCGE	STCGE
Naples	SGE	SGE	SGE
Trieste	SGE	SGE	SGE
Venice	SGE	SGE	SGE
La Spezia	TGE	TGE	TGE
Leghorn	TE	TE	TE
Milazzo	T	T	T
Savona	TGE	TGE	TGE
Vado	T	T	T
Bari	E		E
Ravenna	E	E	E
Cagliari Harbour	E	E	E
Sarroch	E		E
Morocco			
Agadir	C	C	C
Casablanca	C		C
Tunisia			
Tunis	E		E
Sfax	GT	GT	GT
Turkey			
Izmit	CT	CT	CT
Derince	T	T	T
Istanbul	T	T	T
Tutunciftlik	T	T	T
Angola			
Luanda	SG		SG
Lobito	G		G
Gabon			
Port Gentil	SC	C	SC
Ghana			
Takoradi			TS
Tema	T		
Ivory Coast			
Abidjan	STE	STE	STE
Kenya			
Mombasa	ETS	ETS	ETS
Malagasy Republic			
Tamatave	ETS	ES	ETS
Mauritius			
Port Louis	ET	ET	ET

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	MGO	MDF	BFO
Nigeria			
Lagos	E		E
Senegal			
Dakar	SEGC	SEGC	SEGC
Sierra Leone			
Freetown	S	S	S
South & Southwest Africa			
Durban	GSTE	GSTE	GSTE
Capetown	STE	STE	STE
East London	S		S
Port Elizabeth	ST		ST
Richards Bay	S	S	S
Walvis Bay	ST		
Tanzania			
Dar-Es-Salaam		T	T
Aden	TCGSE	TCGSE	TCGSE
Bahrain-Mina Sulman	T	T	T
- Sitra	T	T	T
Eritrea-Ethiopia			
Assab	ES	ES	ES
French Somaliland			
Djibouti	ESGT	EST	ESGT
Iran			
Abadan	EGSC	EGSC	EGSC
Bandar Mah-Shahr	EGSCT	EGSCT	EGSCT
Kharg Island	C	EGSCT	EGSCT
Irag			
Basrah	S	S	S
Kuwait			
Mina Al Ahmadi		G	G
Lebanon			
Sidon			T
Beyrouth	G	G	G
Saudia Arabia			
Dammam	CTE	CTE	CTE
Ras Tanura	CTE	CTE	CTE
Jiddah	TE	TE	TE
United Arab Republic			
Suez	CT	CT	CT
Port Said	CTG	CTG	CTG
Alexandria	CTG	CTG	CTG

LEGEND:

S = SHELL
C = CHEVRON
G = GULF
T = TEXACO
E = EXXON
MGO = MARINE GAS-OIL
MDF = MARINE DIESEL FUEL
BFO = BUNKER FUEL OIL

4. PACIFIC REGION(4)

	MGO	MDF	BFO
Sri Lanka (Ceylon)			
Colombo	TSG	TSG	TS
Trincomalee	G	SG	S
India			
Bombay	TC		TC
Calcutta	TC		TC
Cochin	TC		TC
Madras			TC
Vizagapatam	TC		TC
Indonesia			
Balik Papan	S	S	S
Djakarta	S	S	S
Pladju	S	S	S
P. Sambu	S	S	S
Sourabaya	S	S	S
Malayasia			
Penang	TECS	TCS	TECS
Labuan	S		
Miri	S	S	
Singapore			
P. Bukom	S	S	S
Port Jurong	SE	SE	SE
T. Pagar	E	SCET	SCET
Tandjong Penjuru	CT	CT	CT
Harbor	CT	CT	CT
Penang	C	C	C
Pulau, Ayer Chawan	E	E	E
Thailand			
Bangkok	TEGS	TEGS	TEGS
Sattahip	E	E	E
Koh Srihang	E	E	E
Pakistan			
Karachi	EGSTC	EGS	EGSTC
Australia			
Fremantle	ETC	ETC	ETC
Burnie			E
Adelaide	ESTC	ES	ESTC
Port Stanvac	E	E	E
Melbourne	EGSTC	EGSTC	EGSTC
Geelong	EST	ES	EST
Port Kembla	E		E
Botany Bay	ETC		ETC

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MGO = MARINE GAS-OIL
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	MGO	MDF	BFO
Australia (Continued)			
Sydney	EGSTC	GST	EGSTC
Newcastle	EGSTC	GS	EGSTC
Brisbane	ESTC	S	ESTC
Townsville	ESC	S	ESC
Cairus	STC	S	STC
Albany	SC	S	STC
Darwin	S	S	S
Geraldton	S	S	S
Hobart	STC	S	STC
Port Kembla	S	S	S
Portland	STC		STC
Gladstone	T		C
Mackay	TC		TC
Japan			
Tokyo/Chiba	G	EGTC	EGTC
Yokohama/Kawasaki	G	EGC	EGC
Kitmitsu/Sodegaura		E	E
Uraga/Yokosuka	S	ESTC	ESTC
Nagoya/Yokkaichi	GS	EGS	EGSC
Kobe/Amagasaki	GST	EGSTC	EGSTC
Kobe Port Island		E	E
Sakai/Hannan		E	E
Kishiwada		E	E
Shimotsu/Kainan	G	EG	EG
Aioi/Himeji		E	E
Higashi/Harima		E	E
Hirohata/Shikama	G	EG	EG
Kakogawa/Onomichi	G	EG	EG
Mihara/Fukuyama	G	EG	EG
Tsuneishi/Innoshima		E	E
Kure/Mukaishima	G	EG	EG
Kanokawa		E	E
Kudamatsu		E	E
Tokuyama/Kasado	G	EG	EG
Iwakuni/Sakaide		E	E
Takamatsu/Niihama		E	E
Kikuma/Imabari		E	E
Matsuyama		E	E
Uno/Tamano		E	E
Mizushima/Ube		E	E
Hiroshima		E	E
Kokura/Makiyama		E	E
Moji/Yawata	GST	EGSTC	EGSTC
Kanda/Matsure		E	E

LEGEND:

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	MGO	MDF	BFO
Japan (Continued)			
Shimonoseki/Tobata	S	ESTC	ESTC
Wakamatsu/Kurosaki	S	ESTC	ESTC
Osaka	GS	GSTC	GSTC
Hakodate	S	S	S
Nagasaki	S	S	S
Sasebo	S	S	S
Yokohama	S	ST	ST
Yawata		C	C
Korea			
Inchon	CTG	CTG	CTG
Pusan	CTG	CTG	CTG
Ulsan	CT	CT	CT
Yosu	CT	CT	CT
Wulsan	G	G	G
New Guinea			
Lae	TC		
Madang	TC		
Port Moresby	TC		
Wewak	TC		
New Zealand			
Auckland	CTSGE	CTSGE	CTSGE
Bluff	CTSE		CTSE
Dunedin	CTSE		CTSE
Lyttleton	CTSE		CTSE
Mount Mauviganui	CTSE		CTSE
Napier	CTSE		CTSE
Nelson	CTS		CTS
New Plymouth	CTSE		CTSE
Wellington	CTSGE	CTSGE	CTSGE
Whangarei	CTSE		CTSE
Refinery Wharf			CT
Timaru	E		E
Philippines			
Cebu	ESTC		ESTC
Manila	ESTC		ESTC
Davao	S		S
Iloilo	S		S
Batangas	TC		TC
Ryukyus-Okinawa			
Naha		E	E
Taiwan			
Kaohsiung	G	EG	EG
Keelung	G	EG	EG
Hualien	G	EG	EG

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	MGO	MDF	BFO
American Samoa			
Pago Pago	C		
Fiji Islands			
Suva	ES	S	ES
Hawaii			
Honolulu	CG		CG

5. CONTINENTAL UNITED STATES REGION(5)

Connecticut			
Groton	G		
New Haven	G		
Maine			
Portland	EG TC	T	EGSTC
Massachusettes			
Boston	TE	T	TE
Gloucester	G		
Rhode Island			
Providence	TGE		T
New Jersey			
Westville	T	T	T
Paulsboro	E	E	E
New York			
New York	EG CT	EGSCT	EGSCT
Maryland			
Baltimore	EG CT	EGSCT	EGSCT
Pennsylvania			
Philadelphia	T GE	CTSGE	CTSGE
Virginia			
Norfolk	EG TC	EGSTC	EGSTC
Alabama			
Mobile	EGT	GT	GT
Florida			
Jacksonville	CE	CE	CE
Tampa	TCGE	E	TCGE
Fernandina	CE	CE	CE
Miami	CE	CE	CE
Port Canaveral	CE	C	CE
Port Everglades	CE	CE	CE
Port Manatee	CGE	C	CGE
Port Tampa	CE	CE	CE
Key West	G		
Pensacola	G		G
West Palm Beach	E		E

LEGEND:

S = SHELL G = GULF E = EXXON MDF = MARINE DIESEL FUEL
C = CHEVRON T = TEXACO MGO = MARINE GAS-OIL BFO = BUNKER FUEL OIL

	MGO	MDF	BFO
Georgia			
Savannah	GECT	EC	EC
Brunswick	EC	EC	EC
Kings Bay	EC	EC	EC
Louisiana			
Baton Rouge	EG	E	E
Burnside	E	E	E
Gramercy	E	E	E
New Orleans	EGCT	EGCTS	EGCTS
Ostrica			G
Lake Charles	T	T	GT
Convent			T
Mississippi			
Pascagoula	TC	T	TC
North Carolina			
Morehead City			E
Wilmington	EGT		EG
South Carolina			
Charleston	TGE		TGE
Michigan			
Detroit	EGC	GC	EGC
Minnesota			
Duluth	GE		GE
Ohio			
Cleveland	EG		EG
Toledo	EG		EG
Wisconsin			
Superior	GE		GE
Texas			
Port Arthur	TG	T	TG
Beaumont	TG	T	TGE
Corpus Christi	CGE	G	TCG
Galveston	TGE	TSGE	TSGE
Houston	TCGE	TSCGE	TSCGE
Texas City	CE	CE	CE
Orange	G		G
Baytown	E	E	E
Freeport	E	E	E
Point Comfort	E		
Brownsville	E		
California			
Long Beach	E		E
Los Angeles Harbor	EGCT	EGCST	EGCST
San Francisco	EGCT		EGCST
Eureka	C		C

LEGEND:

S = SHELL   G = GULF   E = EXXON   MDF = MARINE DIESEL FUEL
C = CHEVRON   T = TEXACO   MGO = MARINE GAS-OIL   BFO = BUNKER FUEL OIL

	MGO	MDF	BFO
Oregon			
Astoria	TCG	TG	TCG
Portland	TCG	T	TSCG
Washington			
Aberdeen	GC		
Bellingham	GCT	T	GCT
Longview	GCT	T	GCT
Seattle	GCT	T	GCST
Tacoma	CT	T	CT
Anacortes	T	T	ST
Everett	T	T	T
Olympia	T	T	T
Port Angeles	T	T	T
Vancouver	T	T	T
Alaska			
Cordova	C		
Dutch Harbor	C		
Juneau	C		
Ketchikan	C		

LEGEND:

S = SHELL G = GULF E = EXXON MDF = MARINE DIESEL FUEL
C = CHEVRON T = TEXACO MGO = MARINE GAS-OIL BFO = BUNKER FUEL OIL

(1) These areas have no listed ports in DFSC Region 1

Greenland
Ascension Islands
Azores
Costa Rica
Cuba
Haiti
Leeward Islands
Virgin Islands
Windward Islands

(2) These areas have no listed ports in DFSC Region 2

Bolivia
El Salvador
Guatemala
Nicaragua
Panama Canal Zone
Peru
Surinam

(3) These areas have no listed ports in DFSC Region 3

Andora
Austria
Luxembourg
Liechtenstein
Norway (Norway included in this DFSC Region as well as in Region 1: Atlantic Area)
Switzerland
United Kingdom (United Kingdom included in this DFSC Region as well as in Region 1: Atlantic Area)
Cyprus
Egypt (Egypt included in this DFSC Region as United Arab Republic)
Gibraltar
Greece
Portugal
San Marino (listed separately by DFSC)
Sardinia (listed separately by DFSC)
Sicily (listed separately by DFSC)
Syria
Spain (Spain is included in this DFSC Region as well as in Region 1: Atlantic Area)
Yugoslavia
Burundi
Cameroon
Central African Rep.
Chad
Brazza
Congo, Republic of
Dahomey
Gambia
Guinea
Equatorial Guinea
Kenya
Lesotho
Liberia
Mali
Malawi
Mauritania
Niger

(3) (Continued)

Rwarida
Seychelles Islands
Swaziland
Togo
Uganda
Upper Volta
Zaire
Zambia
Afghanistan
Israel
Jordan
Oman
Quatar
Saudi Arabian National Guard
Somali Republic
Somalia
Southern Yemen
Sudan
United Arab Emirates
Yemen

(4) These areas have no listed ports in DFSC Region 4

Burma
Bhutan
Brunei
Khmer Republic
Diego Garcia
East Pakistan
Hong Kong
Indochina
Laos
Maldive Island
Nepal
Taipei
Vietnam
Antartica Territories
Guam

(5) These areas have no listed ports in DFSC Region 6

New Hampshire
Vermont
Delaware
District of Columbia
West Virginia
Kentucky
Tennessee
Illinois
Indiana
Iowa
Kansas
Missouri
Nebraska
Colorado
Montana
North Dakota
South Dakota
Utah
Wyoming
Arkansas
Louisiana
New Mexico
Oklahoma
Arizona
Nevada
Idaho

APPENDIX E

MILSPEC FUEL ADDITIVES

This appendix presents both the MILSPEC restrictions and the requirements for additives for DFM and JP-5. This information supports those tables in Section 4 which show comparisons between military and civilian fuel specifications and are given here, rather than on the tables, to avoid making the tables overly complex.

Antioxidants

Any of the following active inhibitors may be blended separately or in combination into JP-5 (as well as JP-4 and JP-8) in total concentrations not to exceed 8.4 pounds of inhibitor (not including weight of solvent) per 1,000 barrels of fuel (9.1 g/100 gas (US)), in order to prevent the formation of gum. Additives a through f, inclusive, are also permitted in DFM.

a. N,N' diisopropyl-*p*-phenylenediamine*

b. N,N'-di-*sec*-butyl-*p*-phenylenediamine

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

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

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

f. 75 percent min-2,6-di-*tert*-butylphenol
25 percent max *tert*-butylphenols and tri-*tert*-butylphenols*

g. 72 percent min 6-*tert*-butyl-2,4-dimethyphenol
28 percent max *tert*-butyl-methylphenols and *tert*-butyl-dimethylphenols*

h. 55 percent min 6-*tert*-butyl-2,4-dimethylphenol
45 percent max mixture of *tert*-butylphenols and di-*tert*-butylphenols*

i. 65 percent N,N'-di-*sec*-butyl-*p*-phenylenediamine
35 percent N,N'-di-*sec*-butyl-*o*-phenylenediamine

j. 60 to 80 percent 2,6-dialkylphenols
20 to 40 percent mixture of 2,3,6-trialkylphenols and 2,4,6-trialkylphenols

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*These are also expressly permitted in Jet A/A1 and Jet B.

k. 35 percent min 2,6-di-tert-butyl-4-methylphenol
65 percent max mixture of methyl-, ethyl-, and dimethyl-tert- butylphenols

l. 60 percent min 2,4-di-tert-butylphenol
40 percent max mixture of tert-butylphenols

m. 30 percent min mixture of 2,3,6-trimethylphenol and 2,4,6-trimethylphenol
70 percent max mixture of dimethylphenols

n. 65 percent min mixture of 2,4,5-triisopropylphenol and 2,4,6-triisopropylphenol
35 percent max mixture of other isopropylphenols and biphenols

Metal Deactivator

A metal deactivator, N,N'-disalicylidene-1,2 propanediamine, may be blended into JP-5 (also JP-4, JP-8, Jet A/A1, and Jet B) and DFM in an amount not to exceed 2 pounds active ingredient per 1,000 barrels of fuel (2.2 g/100 gal (US)). In addition N,N'-disalicylidene-1, 2-cyclohexanediamine may be blended into all these jet fuels up to the same 2 lb/1,000 barrel limit.

Corrosion Inhibitor

"A corrosion inhibitor conforming to MIL-I-25017 shall be blended into the JP-4 fuel [and JP-8, too; author] by the supplier. The amount added shall be equal to or greater than the minimum effective concentration and shall not exceed the maximum allowable concentration listed in the latest revision of QPL-25017. Unless prior approval has been obtained from the procuring activity, a corrosion inhibitor conforming to MIL-I-25017 shall not be added to JP-5 grade fuel by either the supplier or transporting agency. The supplier or the transporting agency, or both, shall maintain and upon request shall make available to the Government evidence that the corrosion inhibitors used are equal in every respect to the qualified products listed in QPL-25017."* These products are:

- AFA I
- Lubrizol 541
- Tolad 244
- Tolad 245
- PRI 19
- Hitec E515 (Sant. C)
- Hitec E534 (Sant. CM)

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*Quoted from MIL-T-5624K.

- Nalco 5400A
- Nalco 5401
- Conoco T-60
- DCI-4
- Unicor 5

Corrosion inhibitors are not required for Jet A/Al or Jet B.

Fuel System Icing Inhibitor

The MILSPECs require that both DFM and JP-5 contain a fuel system icing inhibitor (FSII) which conforms to MIL-I-27686. ASTM specifications do not require such an additive.

Ignition Improver

The following ignition improvers are permitted for DFM:

- Amyl nitrate (mixed primary nitrates)
- Hexyl nitrate (N-hexyl nitrate)
- Cyclohexyl nitrate

APPENDIX F

SUMMARY OF EXPERIENCES WITH VARYING PROPERTIES OF BOILER, DIESEL, AND GAS TURBINE FUELS

This appendix presents the information Aerotherm obtained from combustion equipment vendors and the literature on observed impacts when burning fuels with varying properties. The discussion is divided by equipment type and gives more detail than the summary included in Section 4. The purpose of this appendix is to present all the readily available data on these types of impacts in one place and not to analyze it; hence much of the information is presented as direct quotes from the reports.

The following format was used to present these data for each specification element that we found information on.

- Specification element (name)

  Purpose: The reason a limit is specified for this fuel characteristic is explained briefly.

  Specification: The actual limits imposed by the relevant MILSPEC are given here.

  — A summary statement is presented here which identifies (1) the type of impact that has been encountered when noncomplying fuels are used or (2) the equipment or operating change that may be necessary to use the fuel. Summary statements are generally followed by quotations from the literature that support the statement.

Each data source is identified by its reference number in the list at the end of this appendix.

Experience with Varying Properties of Boiler Fuels

- Viscosity

  Purpose: To insure pumpability, combustion quality, lubricity

  Specification: Must be between 1.8 to 4.5 cSt at 38°C

  — Special precautions may be necessary in addition to preheating for pumping certain residual fuel oils (Reference 1, p. 100)

"Most of the low-sulfur residual fuels will come from paraffinic type crudes. Some of the *high-melt paraffinic compounds*, in the 4.44°C pour fuels, can carry into the residual fuels. The paraffins may have a melting temperature of 37.78°C to 43.33°C. It is thus desirable, with a No. 4 or No. 5 oil, to have some type of preheat ahead of the suction line strainer to raise the oil temperature to 48.89°C ahead of the suction line strainer, preventing wax plugging of the strainer. The No. 6 fuels, of course, require preheating in the tank to a range of 54.44°C to 60°C for pumping, and the possible wax precipitate is automatically melted. It is advisable to consult the fuel supplier to determine the waxing characteristics of the low-sulfur residuals.

"The high-melt, 43.33°C to 54.44°C, low-sulfur fuels will require provisions for heating the entire fuel system – from tank to burner. This material will be solid at normal room temperatures. The question must be asked, 'Have provisions been made for heating every part of the system?' For instance, in the event of a power failuse, the fuel could solidify in the pump-set. It will be necessary to heat jacket the pump.

"It is possible that the high-melt fuels will be quite thin at a few degrees above the melting temperature. High suction line vacuum, above 8 inches Hg could cause vapor bubbles in the suction line. It is preferable to mount the circulating pumps as close as possible to the storage tank with a minimum suction line pressure – above ground storage is preferable with the pump adjacent to the tank."

- Pump changes are necessary for heavier residual fuels (Reference 1, p. 100)

"With the lower viscosity fuels, the pumps must be purchased for handling the proper viscosity. In general, a regular No. 6 fuel pump would have excessive clearances for properly pumping the less viscous fuels.

"Preheat temperature for No. 6 fuel to obtain these low viscosities at the burner will range from 116°C to 113°C. One engineer is reported to be preheating to 177°C without soot blowing or tube brushing throughout the entire heating season."

- Low viscosity may cause flame stability problems (Reference 1, p. 100)

The ability of the burner to hold the flame in a stable position becomes critical when the oil viscosity is reduced to obtain small droplet size. The lack of stability has been known as "gasifying" in residual burners. The oil must "gasify" (vaporize) before it will burn. "Gasifying" is a misnomer and is more properly called "pulsation."

Pulsation is caused by the fine droplets being blown away from the atomizer by either primary or secondary air streams. The droplets ignite some distance downstream from the nozzle and, in turn, ignite droplets closer to the nozzle. The flame then is not stable. The flame front can jump from the back to the front of the boiler with, at times, extreme vibration, noise and smoke. Indeed, the pulsation can become severe enough to rock a boiler from its base or extinguish the flame.

Pulsation was a plague of residual equipment and was cured through the use of flameholders or stabilizing devices located in the proximity of the burner nozzle. Such stabilizing devices, swirlers or diverters have been used for many years on properly designed industrial boilers.

Another method of flame stabilizing to eliminate pulsation is to induce sufficient swirl in either the primary or secondary sir streams, making a low-pressure area in front of the atomizer (a tornado effect). The low-pressure area, in effect, holds some of the spray in the low-pressure center, thus stabilizing the flame front.

— Low-sulfur (<0.36 percent by weight) residual fuel oils may need extensive preheating (Reference 1, p. 99)

"It is possible for the extremely low-sulfur, below 0.36 percent, residual type fuels to be solid at temperatures below 43.33°C to 54.44°C. On the other hand, low-sulfur, below 2.5 percent, fuels can have physical characteristics similar to regular residual fuels."

	Fuel Type and Sulfur Content, Wt. %						
	High Melt Low Sulfur	No. 6			No. 5		No. 4
		0.60%	1%	Regular	1%	Regular	Regular
Gravity, °API	43	13.9	12.8	9.4	17.0	17.9	26
Vis., cSt @ 38°C	17 (extrap.)	1,320	1,160	1,090	56	56	20
Sulfur, Wt. %	Nil	0.56	0.82	2.1	1.2	1.7	0.75
BS&W	Nil	0.4	0.3	0.2	0.2	0.2	0.3
Flash, °C	177	110	105	109	101	87	69
Pour Point, °C	49	8	0	1.7	-23	-23	-23

- Pumping difficulty is experienced when the viscosity becomes >65 cSt (Reference 2)
- Burner atomizers experience difficulties when the viscosity becomes >32 cSt (Reference 2)
- Desirable viscosity at burner (Reference 1, p. 99)

  "A desirable viscosity at the burner is certainly no more than 32 cSt. Good combustion generally requires a viscosity of 20.5 cSt while superior or desirable combustion requires a viscosity of 13 cSt or less. At the lower viscosity, close to theoretical CO_2 can be maintained without smoke, high efficiency is experienced, and the entire combustion system requires less maintenance — soot blowing is not necessary.

  "*One installation for 36,000-lb/hour steam*, burns fuel at a 13 cSt viscosity. There are no soot blowers. Approximately 300,000 gallons of oil are used between nozzle cleaning. Fireside maintenance consists of 5 minutes per week for cleaning the suction line strainers.."

- Preheat recommendations (Reference 3)

Fuel	Atomizer	Preheat
#5H	Mechanical	98°C
#5H	Steam	74°C
#5H	Rotary	38°C
#6	Mechanical	102°C to 113°C
#6	Steam	74°C to 91°C
#6	Rotary	44°C

- Low viscosity may cause lubrication problems with gear type pumps; centrifugal pumps are not affected (Reference 2)

- Sulfur

Purpose: To minimize corrosion, deposits, stack discharge

Specification: *≤1 percent by weight*

- Problems with sulfur contents above 2.5 percent by weight (Reference 2)
  - Fireside deposits (in combination with other contaminants such as sodium or potassium)

- Economizer corrosion if feedwater temperature drops below dewpoint ~135°C
- Stack discharge may damage materials on open decks

- Acid number

  Purpose: To minimize corrosion in fuel system (metal components)

  Specification: $\leq 0.3\ mg_{KOH}/g$

  - Modern refinery methods use acidless processes, so acidity is a vanishing problem (Reference 2)

- Carbon residue

  Purpose: To minimize fouling, clogging, smoke, radiation

  Specification: ≤ 0.2 percent by weight

  - If carbon residue exceeds 12.5 percent in conjunction with C/H_2 greater than 7 there may be unacceptable opacity with stack exhaust (Reference 2)

- Ash

  Purpose: To minimize erosion and wear, deposits, clogging

  Specification: ≤ 0.005 percent by weight

  - At about 0.01 percent, plugging can occur between boiler tubes (Reference 2)
    - No problem for commercial operations where gas flow is usually about 50 ft/sec at cruise
    - Problem for naval operations because gas flow approaches 350 ft/sec during high speed operations

Experience with Varying Properties of Diesel Fuels

- Cetane number

  Purpose: To maintain proper ignition speed and, hence, fuel consumption

  Specification: ≥ 45

  - At a cetane number of 40, the fuel rate increases; this can be partially corrected by timing adjustment, but then combustion is less complete, causing smoke. This problem is of concern mainly when operating under high speed and/or load conditions (Reference 4).
  - Lowering cetane number will cause starting problems in cold weather (Reference 5)

- Distillation temperature, end point

  Purpose: An upper limit is specified to preclude fuels containing hard to vaporize fractions, which are prone to form deposits

  Specification: $\leq$385°C

  - DFM will cause more deposit formation than typical #2-D in the ring zone and combustion chamber. This leads to a higher rate of piston seizure in engines burning DFM than in those using #2-D (see Tables F-1, F-2, and F-3) (Reference 6).

- Sulfur

  Purpose: To minimize corrosion, deposits, lube oil contamination

  Specification: $\leq$1 percent by weight

  - One percent is a reasonable operational limit
  - Sulfur attack on silver components may be reduced by sodium treatment (Reference 7)

    "The increased corrosive wear of silver bearing and wrist pins in diesel engines, caused by use of crude oil fuel high in corrosive sulfur, can be eliminated by treating the lubricating oil with metallic sodium (or potassium). Fresh sodium surface must be exposed continuously, otherwise it becomes inactivated by accumulated corrosion product. The effectiveness of sodium was attributed to the large free energy of formation of sodium sulphide relative to silver sulphide and sodium oxide. Other alkaline-reacting metals and compounds do not protect against corrosion except for sodium oxide and hydroxide which protected in laboratory tests but still have to be evaluated in engine performance. No deleterious effects of the sodium treatment were observed." (See Tables F-4 and F-5.)

  - Piston ring surfaces are susceptible to corrosive attack of sulfur (Table F-6) (Reference 6, p. 14)
  - Liner wear increases with sulfur, as shown by the following test results of wear as a function of fuel sulfur content (Reference 8, p. 1-6-31).

Sulfur, (%)	Wear (mm/1,000 hours)
0	0.10
1	0.10
2	0.12
4	0.24
5	0.39

TABLE F-1. IMPACT OF FUEL AND LUBRICANT ON PISTON RING FREEDOM: NUMBERS OF TESTS RESULTING IN NO SEIZURE ("FREE"), IN SEIZURE UPON COOLING, AND IN SEIZURE WHILE RUNNING ("HOT STUCK")[a]

Ring No.	DFM			Reference fuel: #2-D		
	Free	Cold stuck & pinched	Hot stuck	Free	Cold stuck & pinched	Hot stuck
REO 205[b]						
1	3	1	2	5	0	1[c]
2	5	0	1	6	0	0
3	5	1	0	6	0	0
4	6	0	0	6	0	0
Total	19	2	3	23	0	1[c]
REO 203[b]						
1	6	0	0	6	0	0
2	6	0	0	6	0	0
3	6	0	0	6	0	0
4	6	0	0	6	0	0
Total	24	0	0	24	0	0

[a] Engine: 6V53T army tank diesel (Reference 6)

[b] REO 205, 203: Lube oils, MIL-L-2104C

[c] Valve failure

TABLE F-2. IMPACT OF FUEL AND LUBRICANT ON DEPOSITS IN THE BACK OF THE PISTON RING GROOVE (percent of space filled by carbon)[a]

Ring No.	DFM			Reference Fuel: #2-D		
	Max	Avg	Avg (w/o Max)	Max	Avg	Avg (w/o Max)
			REO 250[b]			
1	100[c](3)[d]	58	15	100[c]	21	6
2	100[c](1)	77	72	90	72	68
3	100[c](1)	27	12	40	19	15
4	10	2	1	3	1	<1
			REO 203[b]			
1	3	1	1	15	7	5
2	85	63	59	75	70	69
3	20	12	11	5	4	3
4	0	0	0	0	0	0

[a] Engine: 6V53T army tank diesel, Reference 6

[b] REO 205, 203: Lube oils, MIL-L-2104C

[c] Stuck = 100 percent volume fill

[d] Numbers in parentheses indicate number stuck

TABLE F-3. IMPACT OF FUEL AND LUBRICANT ON CARBON DEPOSITS IN PISTON GROOVE (inside diameter percent of ring supporting carbon)[a]

Position	DFM			Ref No. 2 DF		
	Max[c,d]	Avg	Avg (w/o max)	Max[c,d]	Avg	Avg (w/o max)
REO 205[b]						
Ring No. 1						
Thrust	100 (3)	50	0	100 (1)	17	0
Rear	100 (3)	57	13	100 (1)	17	0
Antithrust	100 (3)	57	13	100 (1)	17	0
Front	100 (3)	53	7	100 (1)	17	0
Ring No. 2						
Thrust	100 (1)	49	39	100	49	24
Rear	100 (1)	68	51	90	42	32
Antithrust	100 (1)	76	52	100	64	56
Front	100 (1)	62	43	100	57	48
REO 203[b]						
Ring No. 1						
Thrust	0	0	0	0	0	0
Rear	0	0	0	0	0	0
Antithrust	0	0	0	0	0	0
Front	0	0	0	0	0	0
Ring No. 2						
Thrust	90	63	50	80	36	27
Rear	85	52	45	60	18	9
Antithrust	100	58	49	100	49	39
Front	90	37	26	70	38	31

[a] Engine: 6V53T army tank diesel (Reference 6)

[b] REO 205, 203: Lube oils, MIL-L-2104C

[c] 100 percent volume fill means the piston is stuck.

[d] Number in parentheses indicates number stuck.

TABLE F-4. BEAKER TESTS OF SILVER STRIP IN 50/50 OIL/FUEL MIXTURES[a]

TEST	ADDITIVE	METHOD	RESULT
1	None	----	Silver blackened
2	Sodium, 3%	Single lump of sodium stationary in bottom of beaker. Addition of silver delayed for 20 min.	Silver blackened
3	Sodium, 3%	Pellets of sodium agitated vigorously. Addition of silver delayed for 20 min.	Silver bright

*SAE 40 diesel engine lubricating oil and Canadian crude (copper strip index: 4)

TABLE F-5. CORROSIVE WEAR TESTS IN 3-CYL. DIESEL ENGINE, 500 HR. RUNS

ENGINE: 65 Bhp

RUN	ADDITIVE	WEIGHT LOSS IN MG/CM^2		pH	
		SILVER BEARING	COPPER-LEAD BEARINGS	INITIAL	FINAL
1	None	Large (blackened)	Not measured	10.4	10.8
2	Phenyl-alpha naphthylamine 0.5%	13.7 (blackened)	0.4	10.4	3.9
3	Sodium pellets, 50 g/gal. oil	0.1 (bright)	0.5	10.4	10.8
4	Sodium emulsion, 21 g/gal. oil	0.0 (bright)	0.4	10.4	10.8

TABLE F-6. POSSIBLE SULFUR IMPACT[a]

Oil codes[b]	Test hours	Reason for stopping test
Reference fuel: #2-D (0.42% S)		
REO 205	209.5	OK - (exhaust valve seat breakage in cylinder 2R)
REO 203	210	Completed test
DFM (1.2% S)		
REO 205	194	Power loss; burned exh. valve-2L
REO 203	196	Rising crank-case pressure & blow-by flow

[a] Engine: 6V53T army tank diesel (Reference 6, p. 14)

[b] REO, 205, 203: Lube oils, MIL-L-2104C

- High sulfur fuels can be used without excessive ring wear if high alkaline cylinder lubrication oil is present. This is demonstrated by the following results (Reference 8, p. 1-6-27).

Oil Alkalinity Index (ASTM 2896)	Ring Wear (mm/1,000 hours)
10	2.5
20	1.75
40	1.40
60	1.20
80	1.15

- Ring wear is increased slightly, however, as lube oil alkalinity is increased when low sulfur fuels are used. This is shown below (Reference 8, p. 1-6-27).

10	0.15
20	0.20
40	0.25
60	0.30
80	0.35

- Accelerated stability, insolubles

Purpose: To improve storage stability, thereby decreasing deposits and sticking of fuel injectors, valves, and pistons

Specification: $\leq$2.5 mg/100 ml

- Gum formation and insolubles (Reference 9, p. 17)

  "This matter of gum and gum formation is critical for two reasons:

  1. Gum formation is a primary indicator of fuel deterioration in diesel fuel. That is, gum is generated in some relationship both to initial quality or composition of the fuel and to the conditions of storage.
  2. The gum formation processes lead eventually to generation of materials which are insoluble in the fuel. That is, the more extensive the degree of gum formation during storage, the more likely that such insoluble materials will be generated.

  "Insoluble materials in diesel fuel, whatever the sources, can definitely hamper engine operation by causing clogging, sticking and/or wear in the close-tolerance fuel-injection system. And by virtue of their usually high molecular weight, organic insolubles will contribute to carbon fouling of the combustion chamber.

"Of course, in-line filtration of the fuel is normally employed to remove most of the particulate matter (ca. > 5μ). But one important question remains. This concerns the ease of filtration of fuels which contain significant amounts of "organic sediment." Such insoluble materials tend to be amorphous and waxy, and under some circumstances they can rapidly clog filtration units.

"It is therefore obvious that the fuel supply system must be so arranged that a catastrophic amount of organic sediment will not develop in the fuel during storage and that it will provide protection against contamination. Filtration should not be expected to compensate, in this connection, for either fuel of low initial quality or for excessive compromise in protection afforded during storage. That is, the dependability factor should be a dominating consideration.

Accordingly, there emerges the key requirement for an optimum emergency fuel supply system based on diesel fuel:

THE SEDIMENT (OR INSOLUBLES) CONTENT OF DIESEL
FUEL IN THE SYSTEM SHOULD NEVER EXCEED 0.1 – 0.2
mg/100 ml and 5 MICRONS MAXIMUM PARTICLE SIZE

"These contaminant levels are accepted under military cleanliness requirements for aircraft fuels which are considered to provide "excellent" fuel system reliability. Considerably higher sediment levels (2 – 3 mg/100 ml) do not necessarily cause filter plugging, as demonstrated by tests run by the Naval Engineering Experiment Station. The suggested limit would automatically provide a desirable and possibly necessary degree of dependability for an emergency system."

Experience with Varying Properties of Gas Turbine Fuels

- Flash point/explosiveness

  Purpose: To reduce the chance for ignition and/or explosion during handling in the hot, close confines of engine rooms or during combat conditions and other emergencies

  Specifications: ≥60°C/<50 percent

  - The likelihood of a post crash fire increases as the flash point decreases. This is shown by the following tabulation of percent post crash fires with each fuel.

JP-5	35 percent
Jet A, A1	34 percent
Jet B	49 percent
JP-4	83 percent

- As shown below, the likelihood of sustained fires resulting from 0.05 cal gunfire tests also increases with decreasing flash point (Reference 10, p. 15).

JP-5	0 percent
JP-8	3.1 percent
JP-4	68.6 percent

- Similarily, crash damage probabilities depend on flash point (Reference 11, p. 6).

	Jet A, Al	Jet B
Fire	0.66	0.73
Survival of fire	0.67	0.53

- The average minimum fuel temperature at which a flame will climb a column of fuel depends on flash point, too (Reference 12, p. 2).

	Min. Temp., °C	
	JP-5	JP-4
0 wind velocity	105	10
@ spark ignitor	65.5	<-17

- An FAA directive requires that only one fuel nozzle be used if kerosine type fuel is loaded into a tank already containing a quantity of widecut fuel, or vice versa. This restriction is necessary because the vapors of the two fuel types form a composite mixture which is highly explosive, and the danger of static electric discharge through these vapors is minimized if only one fuel nozzle is used.

- Olefins

Purpose: To minimize storage stability degradation

Specification: ≤5 percent by volume (probably satisfied by preferred alternates)

- Olefins, however, are a lubricity improver (Reference 12, p. 32)

"Thus, the demand for fuels of better thermal stability has had two undesirable effects so far as lubricity is concerned. The refining process removes the unstable molecules (such as olefins) which are fair lubricity agents. It also removes the heavy aromatics which are both good in lubricity and stable toward oxidation. The most stable fuel would be one from which all polar molecules were removed and then the heavy aromatics added back. However, from a practical point of view it would probably be cheaper to use lubricity additives rather than aromatics."

- Mercaptans (Reference 14)

  Purpose: To minimize reactions with elastomers and unpleasant odors

  Specification: ≤ 0.001 percent by weight

  - Usually the mercaptan content of the fuel is substantially below the limit. Therefore, no one has reported on experiences using fuels whose mercaptan content is near, or above, the limit in the specification.
  - Mercaptans can cause cadmium plate removal on older aircraft fuel strainers. The problem is diminishing, however, since newer aircraft do not use cadmium plated strainers

- Acid number

  Purpose: To minimize corrosion of elastomers and metals

  Specification: $0.015\ \mathrm{mg}_{KOH}/\mathrm{g}$

  - Acidity in fuel is no longer believed to be a problem since refineries now use an acidless cracking process
  - Oleic acid reduces abrasive wear (Reference 15, p. 47)

    "It has generally been assumed that additives such as oleic acid function as antiwear agents by chemisorbing on the surface, thus inhibiting corrosive wear and also decreasing adhesion. It was therefore quite unexpected to find that oleic acid could (also) eliminate abrasive wear. A vickers pump test was run on Bayol 35 containing 200 ppm oleic α-Fe_2O_3 and 500 ppm oleic acid. Without oleic acid, only 100 ppm α-Fe_2O_3 would cause severe abrasive wear, 7079 mg. Adding oleic acid reduced the wear to 5 mg."
  - Acidity may assist mercaptans in removing cadmium plating (Reference 14)

- Particulate matter

  Purpose: To minimize erosion, potential corrosion

  Specification: ≤ 1 mg/l

  - Particulate matter is usually not present in detectable quantities because of modern housekeeping methods (Reference 14)

- Water separation index, modified

  Purpose: To limit polar material (surfactants) which disarm coalescers

  Specification: ≥ 85

- Although not a specification requirement for most alternates, there should be no problem because it is a routine practice to pass fuel through clay filters which will remove surfactants upstream of coalescers. *These filters are usually located at fuel* dock (Reference 14).

- Fuel system icing inhibitor (FSII)

  Purpose: To reduce ice formation

  Specification: Must be between 0.1 to 0.15 percent by volume

  - A deleterious side effect of current FSII's is to reduce flash point. This is illustrated by the following example with ethylene glycol monomethyl ether (EGME) (Reference 16, p. 8).

Percent EGME	Flash Point of JP-5
0.0	60°C
0.1	57.78°C
0.15	56.67°C

  - Another side effect is that FSII's are polar compounds and, hence, can disarm coalescers (Reference 17).

    In a small-scale investigation of low-temperature plugging of filter media (of a test coalescer), it was found that addition of fuel system icing inhibitor (FSII) increased the plugging rates, and that elimination of the glycerol component of the FSII did not solve the problem completely. An example of this is where clean nonadditive fuel gave a W.S.I.M. value of 99 which dropped to 97 on adding 0.75 ppm of A.S.A. 3 and 0.15 percent of FSII. The visible difference in water separation performance between clean nonadditive fuel and that on which a W.S.I.M. of 97 had been measured was quite noticeable.

  - A positive side effect of FSII's is that they have been found to inhibit microbial growth (Reference 18, p. 2)

    Fuel system icing inhibitor can reach 10 percent to 20 percent concentrations in bottoms of storage tanks; 20 percent was lethal to Cladosporium Resinae (the most common fungal contaminant of jet fuel)

- Corrosion inhibitors

  Purpose: To inhibit corrosion

Specification: None permitted unless specifically authorized by type and amount

- Corrosion inhibitors can degrade the thermal stability of the fuel and contribute to filterable deposits (Reference 19, p. 11).
- They can also contribute to coalescer disarming (Reference 20).

"Single-element filter-separator tests were conducted to study the effects of fuel corrosion inhibitors on element performance in removing water and solid contaminants from jet fuel. Most of the tests were "life tests" of 125 hours in which a fuel supply of about 12,000 gallons was pumped through the element at 20 gpm in 8-hour cycles, with continuous injection of red iron oxide at a concentration of 0.33 mg/ℓ in the fuel upstream of the test element. This contamination level is typical of fuel encountered by filter-separator elements in field service. The coalescing ability of the test element was checked periodically by injecting water upstream of the element. All corrosion inhibitors that were tested did impair element performance as measured by downstream fuel cleanliness and by element plugging rate, and also gave decreases in the fuel's WSIM (water-separometer rating) and fuel-water interfacial tension. Based on the criteria used in qualifying filter-separator elements under current specifications, most tests indicated element failure. Element failure modes in order of decreasing frequency were coalescence failure, filtration failure, and solids retention failure, and solids retention failure (plugging). Sampies taken at time of transient flow disturbance such as the start of fuel or water injection showed increased contaminant levels in the downstream fuel."

REFERENCES FOR APPENDIX F

1. Safford, D. E., "Burner Changes vs. Fuel Changes," Hydrocarbon Processing, Vol. 49, No. 2, pp 99-100, February 1970.
2. Weidman, G., Babcock and Wilcox. Personal Communications.
3. Chevron Research Co., Personal Communications.
4. Monterno, R., Colt Manufacturing Co. Personal Communications.
5. Omar, R., Colt Manufacturing Co. Personal Communications.
6. Frame, E. A., et al., "Engine-Fuel Lubricant Compatibility Tests and MIL-L-2104C Oils Using Engine Model 6V53T and High Sulfur Fuel," Interim Report AFLRL No. 26, U.S. Army Fuels and Lubricants Research Laboratory, Southwest Research Institute, San Antonio, Texas, September 1974.
7. Farnand, J. R., et al., "Reduction of Corrosive Wear in Diesel Motors Operated on Crude Fuel High in Corrosive Sulphur," *Journal of the American Society of Lubrication Engineers*, April 1966.
8. du Jeu, J. "A Prospect of Marine Fuels and Lubricating Oils for Diesel Engines," pp 1-6-26 to 1-6-35, Technical Papers Presented at the International Symposium on Marine Engineering, Tokyo 1973, November 12-15, 1973.

9. Trayser, D. A., et al., "Final Report – Deterioration of Fuels and Fuel-Using Equipment," Battelle Memorial Institute, Columbus, Ohio, August 1967.

10. Beery, G. T., et al., "Assessment of JP-8 as a Replacement Fuel for the Air Force Standard Jet Fuel in Noncombat Environment," Technical Report AFAPL-TR-74-71, Part 1, Air Force Aero Propulsion Laboratory, Wright-Patterson AFB, Ohio, June 1975.

11. Coordinating Research Council – Aviation Fuel Safety Report Task Force, "Aviation Fuel Safety – 1975," CRC Report No. 482, Aviation Fuel, Lubricant and Equipment Research Committee, Coordinating Research Council, November 1975.

12. Zinn, S. V., Jr., "Crash Fire Hazard Evaluation of Jet Fuels," SAE 720324, March 1972.

13. Stockton, W. W., et al., "Feasibility of Burning Emulsified Fuel in a 7LM100 Engine," USAAVLABS TR-67-74, U.S. Army Aviation Material Laboratory, Fort Eustis, VA, February 1968.

14. Marsh, A., P&W Personal Communications.

15. May, W. S., et al., "Combustion in Diesel Engines," Report ATR No. 4, The British Internal Combustion Engine Research Institute Limited, England, September 1964.

16. Affens, W. A., et al., Flammability and Ignition Properties of JP-5 Jet Fuel from Alternate Sources," NRL – Memorandum Report 3191, Naval Research Laboratory, Washington, D.C., December 1975.

17. Johnson, R. K., et al., "Variables Affecting the Performance of Jet Fuel Filter – Separator," AFAPL-TR-70-36, Air Force Aero Propulsion Laboratory, Wright-Patterson AFB, Ohio, June 1970.

18. Henday, N. I., et al., Biocidal Properties of an Anti-Icing Additive," NRL Report 7337, Naval Research Laboratory, Washington, D.C., November 1971.

19. Whisman, M. L., et al., "Storage Stability of High Temperature Fuels – Part III. The Effect of Storage Upon Thermally Induced Deposition of Selected Fuel Components and Additives," AFAPL-TR-68-32, Air Force Aero Propulsion Laboratory, Wright-Patterson AFB, Ohio, June 1970.

20. Johnson, R. K., et al., "Effect on Corrosion Inhibitors on Fuel Behavior in Filter – Separator Life Tests," AFAPL TR-70-7, Air Force Aero Propulsion Laboratory, Wright-Patterson AFB, Ohio, March 1970.

APPENDIX G

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APPENDIX H

GLOSSARY

bunker fuel: A fuel available at a port or airfield for use in providing motive power to the ship or plane rather than as its cargo. Bunker fuels thus can be of any fuel type. (Bunker C is a particular type of Bunker fuel.) Synonym: Bunkers

cost of fuel to Navy: Price paid by DFSC plus storage, delivery, and administrative charges levied by DFSC on the Navy (all dollar figures in this report are price paid by DFSC).

diesel fuel: A subset of fuel oils with stricter specifications for certain properties to insure proper performance in the intermittent combustion cycle of a diesel engine.

distillates: Fuel, heating, and diesel oil and jet fuel from the fractional distillation of crude oil. It has very little carbon residue and ash forming materials.

fuel oils: The category of distillate and residual petroleum products used in boilers and furnaces, typically sold in accordance with ASTM specifications.

liftings: Fuel transported from a supplier to a receiving point. DFSC can lift fuel from the refinery to a DFSC tank farm. DFSC can also lift fuel from its tank farms or fuel transport vehicles to Navy bases or Navy fuel transport vehicles. Fuel "lifted" actually moved from one point to another or ownership of the fuel container changes.

PAD: Petroleum Allocation for Defense regions; i.e., the geographical boundaries used by the Bureau of Mines for record keeping purposes when compiling and publishing petroleum supply and consumption data.

preferred alternates: Fuels which satisfy or nearly satisfy MILSPECS and can be used in Navy combustion equipment without serious impact.

price of fuel: Actual amount paid by DFSC to the fuel supplier.

procurements: Quantity of fuel specified in a contract between DFSC and a fuel supplier. Indicates the maximum amount that DFSC may require the supplier to deliver (or lift — see above).

residuals: The residuum left from the various processes in a refinery or blends of this residuum and distillate. This product is a black viscous material with a gravity in some cases heavier than water. Common residuals are Bunker C, or No. 6 fuel oil.

GENERAL REFERENCES

1. World Energy Supplies 1950-1974, Series J, No. 19 Statistical Papers of Department of Economic and Social Affairs, United Nations, 1976.
2. Preliminary Findings and Views Concerning the Exemption of Naptha Jet Fuel from the Mandatory Allocation and Price Regulations, Federal Energy Office, Washington D.C., August 13, 1976.
3. Military Specification, Fuel Oil, Diesel, Marine, MIL-F-16884G, March 7, 1973.
4. Military Specification, Turbine Fuel, Aviation, Grades JP-4 and JP-5, MIL-T-5624K, April 1, 1976.
5. Atlantic Richfield Specification, Aviation Turbine Fuel, November 1976 (from a private communication).
6. Heating and Fuel Oil, Chevron Research Company, 1973 (from a private communication).
7. Guide to Aviation Products, Exxon Corporation, 1973.
8. ASTM Specifications for Petroleum Products, Fuels and Oils, Bituminous Materials, Solvents, 1976.
9. Military Specification, Turbine Fuel, Aviation, Kerosine Type, Grade JP-8, MIL-T-83133, FSC9130.
10. "Automotive Diesel Fuel for Trucks, Buses, Construction Equipment, Portable Power Plants, and Pleasure Boats," Exxon Company, U.S.A., Data Sheet DG-1D, January 1973.
11. "Residual Fuel Oils," Exxon Company, U.S.A., Data Sheet DG-IG, January 1973.
12. "Diesel Fuel Oils, 1975," Shelton, Ella Mae, BERC/PPS-75/3, November 1975.
13. "Heating Oils, 1976," Shelton, Ella Mae, BERC/PPS-76/4, August 1976.
14. "Aviation Turbine Fuels, 1975," Shelton, Ella Mae, BERC/PPS-76/2, March 1976.
15. "Diesel and Burner Fuels – Power Test Codes," ASME PTC 3.1-1958.
16. "Recent Experiences with Sulfur in Distillate Type Fuels Burned in U.S. Navy Diesel Engines," Perry, C. F. and William Anderson, ASME, 74-DGP-4, January 1974.

PERSONAL COMMUNICATIONS

1. G. Weidman, Babcox & Wilcox, Telecon: August 1976.
2. H. Hazard, Battelle (Columbus Laboratories), Telecon: September 1976.
3. E. Shelton, BERC/ERDA: Telecon: September 1976.
4. N. Ledwan, Detroit Dieser, Telecon: August 1976; letter: December 16, 1976.
5. J. Brandeis, Detroit Diesel, Telecon: August 1976.
6. F. Salb, Allison, Telecon: August 1976.
7. R. Duzan, Allison, Telecon: August 1976.
8. R. Devine, Allison, Telecon: August 1976.
9. A. Fleisher, Enterprise, Telecon: August 1976.
10. R. Monterno, Fairbanks-Morse, Telecon: August 1976.
11. Mr. Fogarty, Foster Wheeler, Telecon: August 1976.
12. W. Day, General Electric, Telecon: August 1976; letter: August 24, 1976.

13. R. Stancliff, General Electric, Telecon: August 1976; letter, August 25, 1976.

14. R. Norris, General Electric, Telecon: August 1976.

15. J. Grorman, NASA/Lewis, Telecon: August 1976; letter, September 8, 1976.

16. A. Marsh, Pratt & Whitney Aircraft, Telecon: 1976.

17. R. Roberts, Pratt & Whitney Aircraft, Telecon: August 1976.

18. J. Vincent, Standard Oil of California, Telecon: August 1976.

19. Mr. Pitman, Solar, Telecon: August 1976.

20. P. Carlson, Solar, Telecon: August 1976.

21. J. Esterbrook, Velcon, Telecon: August 1976.

22. P. Campbell, United Airlines, visit: May 1976.

23. B. Honsberger, Boeing, Telecon: May 1976.

24. D. Hartline, Trans World Airlines, Telecon: May 1976.

25. T. Maland, Exxon, Telecon: May 1976.

26. R. Omar, Detroit Diesel, Telecon: May 1976.

27. D. Schnack, Mobil Oil, letter: December 3, 1976.

28. P. Petrie, Mobil Oil, Telecon: October 1976.

29. *R. Brumwell, Commander (USSN), letter: September 8, 1976.*

30. C. Grover, Exxon, Telecon: May 1976.

31. P. Beaudette, Exxon, Telecon: May 1976.

32. C. Stone, Exxon, Telecon: May 1976.

33. R. Nelson, Coordinating Research Council, Telecon: May 1976.