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WORLD NATURAL GAS SURVEY

GULF EMIRATES ENJOY OIL BOOM

West Europe oil imports

SPECIAL REPORT

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ARTICLES

FEATURES

NOTES OF THE MONTH

The military demand for oil

by Tom Cutler

The military is a unique player on the world oil market. The paradox of the military oil sector is that its relatively small share of oil demand offers negligible market influence in peacetime, whereas in wartime armed forces are critical national consumers (since meeting military requirements can spell the difference between victory or defeat). The following article reviews the fundamentals of 'military oil' in peacetime. Future articles will describe the role of oil for the military in wartime and assess military oil supply vulnerability.

IT WAS not until late in the last century, when the industrial revolution fostered the invention of the internal combustion engine, that petroleum became militarily significant. Petroleum could fuel machines capable of enhancing on an unprecedented scale military mobility and fighting capability on land, at sea, and with the advent of flight, in the air. By the time of World War I, the mechanisation of war had become inevitable and so had the military's dependence upon petroleum. Access to oil and security of supply became important military considerations before World War II as the strategy of war became revolutionised by the power of petroleum. Although tomorrow's wars could consist of a short-lived nuclear exchange or a distant confrontation in the vacuum of outer space, all military conflicts since World War II have been waged short of the nuclear threshold, in the conventional arena, where petroleum has a vital military role to play.

As a governmental consumer of oil, the military's involvement in private oil markets is not driven by commercial considerations. Its primary objective is to ensure adequate oil supplies for the national defence in peacetime and to develop plans and capabilities to fulfill anticipated requirements in wartime. This results in patterns of market behaviour by the military sector in peacetime that are distinct from standard commercial practices.

Although direct military oil consumption in peacetime generally averages only 2-3% of a nation's total commercial market, most governments regard as confidential the volume and product mix of their military's oil requirements. In the case of the United States, for which detailed military energy information is publicly available, military oil consumption worldwide during 1984 totalled 486 500 b/d, down more than 50% from the 1969 Viet Nam peak of 1.1 mbd. In general, national military oil use varies according to several factors, including the size and structure of the armed forces, the strategic and tactical doctrine, geography, and, of course, the extent to which the military is engaged in hostilities. On a global basis, therefore, the handful of regional conflicts and domestic insurgencies served to boost military demand in 1984 to near 5% of total world consumption, or an estimated 2.5-3.5 mbd.

Petroleum currently accounts for more than two-thirds of direct military energy demand worldwide. In the case of the United States, petroleum accounted for 65% of conventional military energy demand in 1984, followed by electricity (21%), natural gas (7%), steam (4%), coal (2%), and renewables (1%). Petroleum's share in the US military energy mix is slightly under the world average due to that nation's diverse energy resource base and substantial use of nuclear power (*i.e.* submarines and surface ships) for which data are not publicly available.

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Military energy consumption can be categorised according to 'installation' and 'mobility' uses. The 'installation' category consists of commercial grade fuel oils and non-oil energy sources, as well as alternative energy such as solar-powered radar stations in remote locations. In the 'mobility' category — the essence of conventional fighting capability — there are no viable energy substitutes for petroleum for air and ground operations, and even the introduction of nuclear power at sea has not relieved navies from a reliance upon oil. The airplanes, ships and tanks which comprise a modern nation's fighting force make conventional military mobility operations an oil intensive activity that can account for up to 90% of a nation's military oil consumption.

The composition of equipment in military arsenals and their fuel consumption characteristics determine the mix of military petroleum product demand. The most fuel-intensive US military consumer in 1984 was the non-nuclear aircraft carrier, averaging 123 barrels per hour of propulsion fuel while at sea, followed by battleships at 50 barrels per hour. The peak rate of the M-1 tank during pursuit exceeds 7 barrels per hour. A B-52 bomber on average consumes 88 barrels per hour and the F-4 Phantom fighter bomber 41 barrels per hour. Supersonic speed requires use of afterburners which literally dump fuel into the engine. This can triple air speed but increase consumption twenty-fold. For example, at peak thrust, the relatively fuel-efficient F-15 fighter burns fuel at the rate of 4 gallons per second.

The key role played by military aircraft accounts for the fundamental disparity in the mix of products supplied by refiners to civil and military consumers. In the case of both the US and the Soviet Union, as shown in Table I, jet fuel accounted for two-thirds of military oil consumption compared with its share in the national market of 7% and 8% respectively. Primarily a buyer of jet fuel, the military sector in peacetime sometimes competes with commercial consumers for a particular cut of the barrel, particularly kerosene-based jet fuels. Generally, however, the military does not consume more than one-third of the kero-jet market. But in some instances the military has a big share of the jet fuel market overall, as in South Korea where consumption of military grade jet fuel (JP-4), naphtha-based, accounted for just over half of the domestic jet fuel market in 1984.

Given the overriding priority of security of supply, longer term contracts (*e.g.* one year) are preferred by the military, even during periods of weak prices where other consumers would resort to spot markets to achieve cost savings. Moreover, military oil procurement and inventory management is not seasonal in the commercial sense, although spring ground offensives certainly accentuate seasonal swings in gasoline and diesel demand. Fulfilment of emergency military requirements can be achieved through commercial contracts providing for future deliveries of fuel under pre-specified conditions. But where this involves foreign-based suppliers, as is often the case for the US, military authorities must also notify host governments of these arrangements to ensure that these supply contracts will be honoured in crisis and that the oil will not be inadvertantly confiscated by the government pursuant to its emergency powers. In other instances, government-to-government Host Nation Support Agreements can be negotiated.

Despite today's soft oil market, military fuel costs can constrain fulfilment of peacetime requirements, as evidenced by the UK's decision this spring to cut by 10% the fuel consumed (and hence flying time) by the Royal Air Force for a one-year period. Designed to save £25 million in fuel costs, this decision was made to offset cost overruns on weapons development projects. Inasmuch as oil prices have been higher before, this suggests that defence budget considerations can be an important factor in the military's peacetime demand elasticity for oil. For the US during 1984, $6.2 billion of oil was purchased by the military, or about 3% of total defence expenditures.

Costs associated with military oil are not limited to buying fuel. The military also leases commercial storage, charters tankers, and utilises commercial pipeline systems to supplement its own internal distribution network. In large nations, the military fuels community often operates its own tankers and oilers, marine terminals, pipeline systems, tank truck fleets, supply depots, and specialized storage facilities.

Stocks of refined products

There are two categories of military oil stocks, both held as refined products. Peacetime operating stocks support current consumption. War reserves are stored to satisfy wartime surge requirements until such time that logistical systems can resupply fuel to the battle area. Measured in terms of 'combat days of supply', war reserve levels are based upon contingency plan estimates of combat oil usage requirements. These stocks are ideally held in hardened underground facilities protected from enemy attack and pre-positioned at strategic locations. The US military, for example, holds in excess of 30 million barrels of peacetime operating stocks and approximately 60 million barrels as wartime reserves. It is interesting to note that the US with its worldwide military responsibilities and commitments, holds the largest portion of its war reserves not domestically but in Europe, and the second largest amount in the Pacific region. Soviet military oil reserves, including those held in Eastern Europe, are estimated to be 380 million barrels.

Access to civil stocks is an option open to the military during nationally declared emergencies, but civil stocks are usually held as crude or as refined products often not meeting military specifications. Nevertheless, use of these stocks become increasingly attractive to the military as its own stocks are depleted. Military access to civil stocks is therefore an important decision for governments in wartime when defence energy needs become a national imperative, particularly during protracted conflicts accompanied by oil supply shortages.

MILITARY FUEL SPECIFICATIONS

Combatants in World War II used a limited variety of petroleum products, but now there is a multitude of fuels and lubricants with unique specifications and additives which have no commercial counterpart. This is due largely to the development of increasingly sophisticated, high-performance propulsion and weapons systems designed to operate under extreme environments.

Safety and mission requirements are largely responsible for the unique technical specifications of military fuels (see Figure I). But the military's use of non-commercial grade,

TABLE I

CIVIL AND MILITARY OIL DEMAND MIX OF THE SUPERPOWERS IN 1984

(thousand barrels daily)

	UNITED STATES				SOVIET UNION			
	Civil		Military		Civil		Military	
Product Type	Amount	*Per Cent Share*	Amount	*Per Cent Share*	Amount	*Per Cent Share*	Amount	*Per Cent Share*
Gasoline (motor & aviation)	6 723	*43*	13	*3*	1 642	*18*	25	*8*
Jet Fuel	1 170	*7*	320	*66*	725	*8*	215	*68*
Diesel Distillate	2 848	*18*	84	*17*	2 015	*22*	70	*22*
Residual Fuel Oil	1 365	*9*	63	*13*	2 564	*28*	(not specified)	—
Other	3 602	*23*	7	*1*	2 307	*25*	5	*2*
TOTAL	15 708	*100*	487	*100*	9 253	*100*	315	*100*

Source: Civil data from US Energy Information Administration; *International Energy Annual 1983*, pp. 38-39 and *Petroleum Supply Monthly December 1984* (published February, 1985), pp. 2,25. Military data from US Department of Defense and US Central Intelligence Agency.

Note: Percentages may not add due to rounding. 'Other' category includes lubricants, greases, other refined products, and refinery fuel and loss. US military oil data is for October 1983-October 1984 and includes consumption worldwide (of which domestic consumption accounts for approximately two-thirds of the total.). All other data for both the US and USSR is for domestic consumption only. Soviet civil data is based on figures for 1982 and assumes no growth since then. Estimates of Soviet military demand are derived from CIA forecasts made in 1978.

specialty fuels can have disadvantages of increased acquisition costs, limited availability, and distribution restrictions. Specialised military fuels cannot be co-mingled with standard commercial fuels while in storage and must often be segregated when being transported by tanker, truck or pipeline. Thus, when possible, many military logisticians delay the introduction of military additives to commercial products until they reach the point of consumption (*e.g.* airbases) so that fuel can be moved conveniently through commercial distribution systems.

Sea and air forces generally require more stringent chemical and physical properties for their fuels and lubricants than ground forces. Fuels for wheeled and tracked-vehicles are pre-dominantly diesel and motor gasoline of a commercial grade with additives rather than uniquely refined military fuels. Efforts among Western powers to achieve total military fuels interoperability by adopting selected jet fuels for ground use and marine propulsion have been held up by cost and availability concerns, and not performance factors.

Ground fuels

Ground fuels standardisation was a key Allied priority early in World War II as the multiplicity of peacetime fuel and lube oil grades was reduced to the minimum possible in order to enhance distribution and interoperability, including battleground scavenging. At the outset, no restrictive specifications were imposed upon industry. The military routinely used the gasoline in the same area where it was procured. Refiners' adjustment of gasoline grades in

FIGURE I

MILITARY SPECIFICATION CONSIDERATIONS FOR SELECTED FUEL PROPERTIES

Fuel Properties	Technical Description	Military Considerations
Flash Point	Lowest temperature at which fuel's vapour-air mixture will ignite when exposed to an open flame; an indicator of fuel volatility and fuel contamination.	High flash point is safer and more stable for handling, storage, and combat vulnerability. Fire and explosions from low flashpoint jet fuel (*e.g.* JP-4) due to crashes and punctures from small-arms fire was a major combat hazard necessitating the development of higher flashpoint JP-8. Safety concern about jet fuel on aircraft carriers necessitates yet another high flashpoint military fuel (*e.g.* JP-5).
Freeze Point	Lowest temperature at which all hydrocarbon crystals disappear when fuel is warmed; after the fuel has been cooled to the point where crystal slurries formed throughout the fuel.	Low freezepoint prevents clogging of fuel systems by ice or fuel crystals. Military aircraft are generally exposed to colder temperature than commercial planes due to extreme climates and higher altitudes at which they fly. Low freezepoint needed for cold starts in cold locations, at night, or while exposed to harsh elements including aerial refuelling and cold weather refuelling at sea. Icing inhibitors can be introduced to lower the freeze point of water contamination in the fuel.
Pour Point	Lowest temperature at which flow is observed under controlled, laboratory conditions.	Low pour point is necessary to ensure high level of fluidity required for high performance engines. Critical for filter separators and fuel lines in gas turbines and diesel engines. A fuel's pour point temperature does not necessarily indicate that the fuel can be handled satisfactorily by the military at that temperature.
Cloud Point	Temperature at which wax crystals appear in a fuel, causing it to become cloudy or hazy.	Wax precipitation can clog engine filters and fuel lines, particularly in gas turbines and diesel engines. The cloud point is often the limiting factor for low temperature operability of diesel fuels used by ground forces.
Smoke Properties	Level of smoke emission during combustion.	Exhaust smoke is primarily an issue of engine combustion design, but additives can affect the density of smoke emissions. Smokeless fuel eliminates visible smoke trails and reduces chance of detection for aircraft, tanks, and ships. However, some tanks are equipped with engine exhaust systems that can spew tactical smoke from vapourized diesel fuel.
Viscosity	Measure of a liquid's resistance to flow. Viscosity is a major determinant of the shape of fuel spray. Low viscosity means high fluidity but can result in impaired combustion, reduced power output, and lower fuel economy because fuel enters combustion chamber as a soft spray and fails to penetrate the chamber sufficiently. High viscosity can result in poor combustion due to fuel mixtures entering engine as a stream and not a spray.	Low viscosity needed for narrow gauge fuel line systems plus aerial and naval refuelling to ensure proper rate of flow at low temperatures. Important for boiler pumps and nozzle injectors in gas turbines and diesel engines.
Conductivity	Measure of electrical charge conductivity in the fuel.	Static dissipator additive used by some nations for safety purposes to dissipate static charge. Static charges build up during movement of fuel which can lead to possible inflammation of fuel/air mixtures. This is particularly true for jet fuels whose purity, high-pumping velocity and movement through microfilters can cause static build-up.
Anti-Oxidizing	Measure of fuel's ability, with or without chemical inhibitors, to resist gum formation over time and retain stable chemical composition.	Oxidation properties are very important military fuel stability specifications. Many military oil stockpiles, particularly war reserves, are not routinely rotated but are held over extended periods of time (*i.e.* years), thereby running the risk of being degraded. In addition, whereas commercial supplies are routinely distributed in bulk, portions of military oil supplies critical for combat are sometimes stored and distributed as packaged products such as in jerricans in which fuel tends to deteriorate more rapidly and have increased gumming. This is because there is relatively greater surface area in the smaller containers compared with larger tanks.

the fall and spring ensured the proper fuel blend for that region. However, seasons in Europe and the South Pacific are opposite from one another so gasoline shipped from North America to one region was not satisfactory in another, thereby making it difficult to re-route gasoline shipments during emergencies. Fuel stored in the jungle in drums was susceptible to gumming unless it was sufficiently stable. The use of winter grade fuel in hot climates often stalled vehicles due to vapour lock. Tropical climate fuel did not have adequate volatility or cold start properties in cooler environments. Oxidation stability of commercially available premium gasoline was insufficient as problems arose because armies did not consume fuel as promptly as commercial users.

Naval fuels

Compared to ground fuels, growth in the volume of naval fuel requirements has been moderated by the advent of nuclear propulsion. Fuel specifications remain strict, however, since naval operations can entail periods at sea ranging from arctic waters to the tropics in stages of quiet transit to battle manoeuvring. During World War II, 'Navy Special' (a Burner fuel oil) was introduced by the US with a 40% mixture of distillate grade Cutter Stock to improve the standard Bunker C fuel oil's combustibility, viscosity and pre-heating requirements. A lower fuel viscosity was essential for timely refueling operations at sea since a ship's vulnerability to enemy attack increases the longer its manoeuvrability is restricted by being tied to an oiler. Improved storage stability and water-shedding capabilities, due to the need for seawater ballasting in empty fuel tanks, also needed to be introduced.

Later, in the 1960s, the US Navy decided to establish a single propulsion fuel to simplify logistics. In 1969 the decision was made to convert to a low-ash, distillate fuel suited for boilers, diesels, and gas turbines. A phasing schedule was developed to minimise the impact upon industry, but market conditions subsequently changed such that this distillate fuel became more expensive than the standard diesel fuel. The Navy has therefore returned to buying diesel as its primary ship propulsion fuel.

Fire hazards during refuelling and combat necessitate naval fuels having a high flash point. For example, aircraft carriers operate under the extreme risk of fire or explosion due to flight operations for up to 1 000 air sorties. This has resulted in US Navy fuel specifications of a 140°F minimum flashpoint for some propulsion fuels and its carrier aviation fuel (JP-5) because of shipboard environment.

Aviation fuels

Commercial aircraft fly to a wide range of locations in extreme temperatures like their military counterparts but they do not have the need for accelerated bursts in speed or engage in dog-fight manoeuvres where engine stall and flameout can make relight capability urgent. Nor do civil aircraft fly at altitudes as high as the military or entail in-flight refuelling. There are also differences on the ground. Military aircraft have longer down times than commercial planes and often 'cold soak' outside under harsh climatic conditions or in unheated hangars. This necessitates the retention of critical fuel properties at temperatures below commercial standards.

The first uniquely military aviation grade gas turbine engine fuel (JP-1) was introduced in 1944 but its specification of a −76°F freeze point and its narrow boiling range (300°F-500°F) during refinery processing limited commercial incentives to produce it in quantities sufficient to satisfy US defence requirements. The next year, JP-2 was adopted in order to expand supply availability, but as a high-viscosity, experimental fuel it was soon to be replaced by JP-3 in 1947. This fuel was easily obtained commercially since it was essentially a gasoline-kerosene blend, but aircraft performance problems, eventually attributed to JP-3 vapour pressure characteristics, arose at high rates of climb and at high altitudes. A new specification was developed for a lower-vapour pressure fuel and in 1951 JP-4 was introduced. On a modified basis, JP-4 is still in widespread military use.

JP-4 is a wide cut mixture of heavy naphtha and kerosene with an unusually low flash point of approximately −20°F and an explosive range from approximately −20°F to 70°F under equilibrium conditions.[1] The dangers inherent in JP-4's volatility prompted the development of a less hazardous fuel (JP-5) which was later adopted by the US Navy in 1952 for use on aircraft carriers and is now used by the US President's Air Force One. However, economic disincentives such as JP-5's narrow boiling range (300°-550°F) precluded refiners from justifying production in sufficient quantities for it to become a standard fuel for all land-based military aircraft. From a military perspective this was perhaps unfortunate since problems with JP-4's volatility intensified during the Viet Nam war as the US began losing planes due to small-arms fire. The search for a fuel that would not explode when a fuel tank was punctured by bullets culminated in 1967 with the introduction of JP-8 — a derivative of commercial jet A-1 with corrosion additives, icing inhibitors, and static disipators. (The NATO Europe JP-8 (F-34) conversion issue will be considered in a future article).

FIGURE II
SPECIALISED MILITARY AVIATION AND AEROSPACE FUELS

User	Product Grade	Basic Components	Representative Price (per gallon)
Reconnaissance Aircraft			
SR-71	JP-7	Highly Refined Kerosene	$1.70
U-2	JP-TS (thermally stable)	Highly Refined Kerosene	$1.80
Cruise Missiles			
Main fuel for Air Launched Cruise Missile (ALCM)	JP-10	Exo-Tetra Hydro-di (Cyclopentadiene)	$11
First Generation Starter Slug for ALCM	JP-9	— RJ-5, Perhydro-di (Norbornadiene) — JP-10, Exo-Tetra Hydro-di (Cyclopentadiene) — Methylcyclo-hexane (MCH)	$30
Second Generation Starter Slug for ALCM	PF-1	— Methylcyclo-hexane (MCH) — JP-10	$12
Main fuel for Sea and Ground Launched Cruise Missiles (*i.e.* SLCM and GLCM)	RJ-4	Tetrahydromethyl Cyclopentadiene	$13.70

Source: US Department of Defense.

Aerospace fuels

Long-range reconnaissance aircraft such as the American U-2 and SR-71 use high-BTU speciality fuels to attain the high altitude and speed required by their mission (over 2 000 mph at over 100 000 feet for the SR-71). As shown in Figure II, the U-2 uses JP-TS (Thermally Stable) which is a highly refined kerosene mix produced in limited quantities. The more sophisticated SR-71 has a large fuel-carrying capacity and uses JP-7 which has a low volatility and high flashpoint for safety reasons. This fuel has 'heat sink' properties allowing it to be circulated throughout the plane as a coolant for the engine, airframe, and avionics. Its unique thermal stability specification ensures that other critical fuel properties are maintained at a broad range of temperatures. Since JP-7 is not easily ignited, engine start procedures must also include injecting triethyborane (TEB) into the engine once RPMs have been built up by the air turbine starter. In-flight afterburners are also ignited in this manner.

Chemical fuels

Cruise missiles use high-BTU fuels (*e.g.* JP-10) which are not refined petroleum products but are instead blends of synthesised chemicals. Utilisation is small for these fuels since, unlike airplanes, missiles are used only once and in most cases are fuelled during final assembly. Technical requirements for cruise missile fuel varies with engine type (gas-turbine or ram-jet) and whether it is launched from air, land, or sea. Air Launched Cruise Missiles (ALCM), for example, require a starter fuel that has extreme cold weather capabilities due to high-altitude ignitions.

The first starter fuel developed for American ALCMs was JP-9, a blend of synthesised chemicals whose main components were RJ-5, JP-10, and methylcycohexane (MCH). Developed in Germany during the 1960s, RJ-5 has high energy properties (160 000 BTU/gallon), a high flashpoint, but poor low temperature characteristics. This blend requires as its main feedstock the chemical norbornadiene (bicycloheptadiene) made in the Free World only at a small but securely guarded company plant in the Netherlands. High production costs for RJ-5 accounted for much of the $30/gallon price of JP-9 and prompted the US development and conversion to PF-1 as a domestically available substitute for RJ-5.

Intercontinental Ballistic Missiles (ICBMs) are generally fuelled before they are deployed, another example of wartime fuel requirements being provided for in peacetime. However, the trend has been away from petroleum fuels and hypergolic blends (that do not need external source of combustion) to solid propellants. Of the ICBMs operational today, only the CSS-1 introduced by China in 1966 uses a petroleum-based fuel (kerosene and liquid oxygen). The Chinese CSS-2 and the US Titan missiles use a hypergolic mix of unsymmetrical dimethylhydrazine (UDMH) and nitrogen tetroxide. Solid propellants are better suited than liquid fuels for underwater submarine launches of strategic missiles and, for other reasons, are increasingly used in current ICBM deployments by the major nuclear powers.

Oil market impacts

Some members of the military fuels community at large are concerned about the implications of a changing world crude oil mix, and industry's resort to new, highly sophisticated refinery processes to meet new patterns of commercial demand. Most military fuel specifications were originally developed for straight-run distillation products from light, sweet crudes. However, over time, the mix of world crudes has changed with the depletion of mature oilfields, increased OPEC production of heavy crudes, and the growing availability of non-OPEC crudes that are relatively heavier and more sour. Meanwhile, there has been a worldwide decline in residual fuel demand relative to distillates. Refiners have responded by adjusting their product slates accordingly and investing in cracking facilities to get more light ends out of the bottom of the barrel. By cracking their excess residual bottoms they have been able to blend increasing proportions of heavier crudes and recycled cracked products into their diesel and jet fuels. As a result, less and less fuel purchased by the military has come from straight-run distillation and greater amounts from cracking. Although the quality of cracked fuels is improved by hydrogenation, caustic scrubbing, and by chemical additives, the final product is still different in molecular composition from straight-run products, leading to problems of fuel stability and aircraft performance.[2)]

Commercial developments in the world oil scene in peacetime can alter the strategic premises of military planning for the supply of oil in war. The military must adjust to these oil market changes like any customer, even when they have an adverse impact upon its oil supply posture. Indeed, the unique fuel properties specified by the military have often required that a compromise be made between the extremes of having equipment design and performance objectives dictate fuel specifications or allowing petroleum fuel considerations to determine the course of conventional weapons development and deployment. To date, private industry has certainly met the challenge, but in war surges in the volume of military oil consumption and logistical requirements may be difficult for industry to satisfy, due to a disrupted market place and/or destruction of key industrial facilities. Thus, in war, a nation's political leadership must take due account of its military oil supply vulnerability. □

Footnotes:

1) The volatility of JP-4 is further enhanced by its vapour pressure properties. Produced at an average 140°F-460°F boiling range, broader than most jet fuels, it also possesses a militarily desirable low freeze point of −72°F. The −20°F flashpoint is not a specified military requirement but rather a characteristic of the fuel. See *Assessment of JP-8 As a Replacement Fuel for the Air Force Standard Jet Fuel JP-4,* Part I, Air Force Aero Propulsion Laboratory, June 1975, p. 5.

2) Degradation in the stability and, hence, performance of hydrotreated military jet fuels has been attributed to substandard lubricosity caused when the oil's natural corrosion and oxidation inhibitors were removed during hydrogenation, and standard additives did not maintain the fuel up to specification. A survey of fuel purchased by the US Navy worldwide during 1979-82 found that viscosity and eight other chemical and physical fuel properties exhibited significant degradation over this period. *The Past and Future of Navy Ship Fuels* by N.F. Lynn, E.W. White, J.F. Boyle, and R.P. Layne at A.S.T.M. Symposium on Marine Fuels, December, 1983, pp. 9-21.