I. INTRODUCTION

Uncertainties about the future production and supply of jet fuels has caused the U.S. Army, as well as other organizations responsible for aviation fuel logistics and specifications, to develop contingency solutions to the problems of obtaining adequate supplies of jet fuel. A major problem is the assurance that future fuels will be compatible with current engines and aircraft fuel systems.

Southwest Research Institute (SwRI), under contract to the U.S. Army Mobility Research and Development Command (MERADCOM), has conducted an impact study of synthetic and alternate fuel usage on Army aircraft propulsion and fuel systems. The study addressed four technical areas:

1. The fuel scenario for Army aviation gas turbine fuels.

2. The effects that critical fuel properties have on the performance and/or durability of engine and fuel-system components.

3. The identification of engines and fuel system components used in Army aircraft and their interface with the fuel.

4. A review and compilation of qualification and certification procedures for the above systems.

This study was conducted with the assistance of personnel from the U.S. Army Aviation Research and Development Command (AVRADCOM) in St. Louis, Missouri. Many of the contacts at the airframe companies were supplied by them as well as most of the identification of the fuel system components and potential areas of fuel sensitivity. Personnel at the Corpus Christi Army Depot (CCAD) were helpful in identifying current maintenance problems with engine and airframe fuel system components thereby also suggesting potential problem areas. Much of the technical information was developed during a recent SwRI study on the development of an "Alternate Test Procedure to Qualify New Fuels For Navy Aircraft." (1) That study concentrated on JP-5 type fuels with DFM as an emergency fuel whereas this report primarily addresses the impact of JP-4 and JP-5 on Army aircraft. The projections of JP-4 properties, whether derived from petroleum or shale oil, was obtained primarily from the Air Force Aero Propulsion Laboratory which has the responsibility for that fuel specification. The projections on JP-5 properties came from the aforementioned SwRI study for the Navy.

II. FUELS FOR ARMY AVIATION GAS TURBINE ENGINES

The gas turbine engines used in Army aircraft were designed to operate on JP-4 type fuels (MIL-T-5624) as the "primary fuel" and JP-5 (also MIL-T-5624), JP-8 (MIL-T-83133), and Jet-A (ASTM D1655) as "alternative fuels." (2) No "emergency fuels" are defined for Army aircraft.

Table 1 summarizes the specifications for these fuels. Tables 2, 3, and 4 summarize the average properties for JP-4, JP-5, and Jet-A for the last eleven years as compiled by the Bartlesville Energy Technology Center of the U.S. Department of Energy; JP-8 is not included because it is not produced in the United States. (3)

The remaining discussion in this chapter will address the anticipated changes in jet fuel properties on which the impact studies will be based.

A. JP-4

The JP-4 specification is not controlled by the Army - it is the responsibility of the Air Force. Discussions were held with personnel of the Fuels Branch of the Aero-Propulsion Laboratory at Wright Patterson Air Force Base and the following conclusions were made about JP-4: (4)

- JP-4 to JP-8 Conversion

  JP-4 will continue to be the primary fuel in CONUS for reasons of cost and availability.

  JP-8 is used exclusively in the United Kingdom.

Table 1. Jet Fuel Specifications

Requirements	Fuel: Grade JP-4	Grade JP-5	Jet-A
Color, Saybolt	1/*	1/	-
Total acid number, mg KOH/g, max	0.015	0.015	0.1
Aromatics, vol percent, max	25.0	25.0	20
Olefins, vol percent max	5.0	5.0	-
Mercaptan sulfur, weight percent, max 2/	0.001	0.001	0.002
Sulfur, total weight percent, max	0.40	0.40	0.30
Distillation temperature, deg C, (D 2887 limits in parentheses)			
Initial boiling point	1/	1/	-
10 percent recovered, max temp	1/	205(185)	204.4
20 percent recovered, max temp	145(130)	1/	-
50 percent recovered, max temp	190(185)	1/	report
90 percent recovered, max temp	245(250)	1/	report
End point, max temp	270(320)	290(320)	300
Residue, vol percent, max (for D 86)	1.5	1.5	1.5
Loss, vol percent, max (for D 86)	1.5	1.5	1.5
Explosiveness percent, max	-	50	-
Flash point, deg C (deg F), min	-	60(140)	38(100)
Density, kg/l, min (°API, max) at 15°C	0.751(57.0)	0.788(48.0)	0.7753(51.0)
Density, kg/l, max (°API, min) at 15°C	0.802 (45.0)	0.845(36.0)	0.8398(37.0)
Vapor pressure, 37.8°C (100°F) kPa (psi), min	14(2.0)	-	-
Vapor pressure, 37.8°C (100°F) kPa (psi), max	21 (3.0)	-	-
Freezing point, deg C (deg F), max	-58(-72)	-46(-51)	-40(-40)
Viscosity, at -20°C, max centistokes	-	8.5 12/	8.0
Heating value, Aniline-gravity product, min, or Net heat of combustion,	5,250	4,500	
MJ/kg (Btu/lb) min	42.8(18,400)	42.6(18,300)	42.8(18,400)
Hydrogen content, wt percent, min or	13.6	13.5	
Smoke point, mm, min	20.0	19.0	25(20 with 3% Naph.)
Copper strip corrosion, 2 hr at 100°C (212°F) max	1b	1b	No. 1
Thermal stability:			
Change in pressure drop, mm of Hg., max	25	25	25
Preheater deposit code, less than	3	3	3
Existent gum, mg/100 ml, max	7.0	7.0	7
Particulate matter, mg/liter, max	1.0	1.0	-
Filtration time, minutes, max	15	-	-
Water reaction			
Interface rating, max	1b	1b	1b
Water separation index, modified, min	10/	85	-
Fuel system icing inhibitor, vol percent min	0.10	0.10	-
Fuel icing inhibitor, vol percent max	0.15	0.15	-
Fuel electrical conductivity, pS/m, allowable range	200-600 13/		-

*Footnotes not included here

Table 2. Summarized Data for Grade JP-4 Military Aviation Turbine Fuels

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Number of fuels	33	32	35	30	33	30	33	28	23	26	26
Gravity, °API	53.8	54.5	54.6	54.1	54.3	54.0	54.1	53.9	53.9	53.5	53.7
Distillation 1/											
Temperature:											
10% recovered, °F	212	211	215	216	214	211	215	211	209	208	211
50% do. , °F	290	288	285	289	291	287	292	299	289	293	287
90% do. , °F	389	393	394	402	397	390	399	395	400	388	387
Recovered at 400 F, %	89.5	89.4	87.5	84.0	85.9	86.0	85.6	85.7	86.2	86.2	92.5
Reid vapor pressure, lb	2.6	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.6	2.5	2.6
Freezing point, °F	<-76	<-76	-84	-80	-81	-84	-84	-79	-79	-79	-80
Viscosity, kinematic, -30 F, cs	2.80	2.94	3.01	2.83	2.68	2.20	2/ 2.4	4/ 2.4	-	-	-
Aniline point, °F	129.4	130.4	130.7	132.0	132.8	129.9	131.3	130.8	130.3	128.7	128.9
Aniline-gravity constant, No.	6,961	7,107	7,136	7,141	7,211	7,028	7,103	7,061	7,049	6,891	6,948
Water tolerance, ml	0.1	0.2	0.4	0.6	0.5	0.5	0.5	0.3	0.6	0.7	0.7
Sulfur:											
Total, wt %	0.032	0.034	0.032	0.033	0.035	0.036	0.042	0.044	0.035	0.030	0.029
Mercaptan, wt %	0.0005	0.0006	0.0005	0.0005	0.0012	0.0006	0.0005	0.0004	0.0004	0.0004	0.0005
Naphthalenes, wt %	1.45	0.88	0.74	0.9	1.3	0.20	2/0.51	4/ 0.2	-	-	-
Aromatic content, vol %	11.5	10.8	10.7	11.8	10.6	11.2	11.2	12.2	12.3	13.0	13.2
Olefin content, vol %	0.9	0.8	0.9	1.0	0.9	1.0	0.9	0.8	0.8	1.0	1.0
Smoke point, mm	27.6	27.4	28.0	28.2	28.1	27.2	27.7	27.7	27.5	26.0	25.7
Gum, mg/100 ml:											
Existent, at 450 F	0.6	0.6	0.7	0.6	0.8	0.9	0.7	0.7	0.7	0.7	0.7
Potential, at 212 F	1.2	1.2	1.1	1.2	1.2	1.0	1.0	1.0	1.2	5/ 1.0	-
Heat of combustion, net, Btu/lb	18,708	18,721	18,725	18,727	18,733	18,714	18,721	18,715	18,716	18,702	18,707
Luminometer number	63	60	63	64	62	62	3/ 61	5/ 61	-	-	-
Thermal Stability:											
Pressure drop, in. Hg	0.17	0.12	0.06	0.22	0.15	0.26	0.30	0.5	0.2	0.4	0.0
Water separometer index, No.	88	88	90	90	91	90	91	90	91	91	91

1/ Distillation data reported on evaporated basis prior to 1972.
2/ Represents two samples.
3/ Represents four samples.
4/ Represents one sample.
5/ Represents three samples.

Table 3. Summarized Data for Grade JP-5 Military Aviation Turbine Fuels

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Number of fuels	10	10	12	8	7	8	8	7	7	7	5
Gravity, °API	41.0	42.0	41.6	41.7	41.6	41.5	41.5	41.4	41.7	41.2	40.9
Distillation 1/											
Temperature:											
10% recovered, °F	383	380	388	387	389	388	390	385	390	387	381
50% do. , °F	416	414	419	422	419	418	422	420	419	423	422
90% do. , °F	461	459	460	469	462	462	470	470	465	470	476
Recovered at 400 F, %	31.5	36.2	25.0	23.4	23.2	25.9	21.6	24.1	23.6	24.1	24.1
Reid vapor pressure, lb	-	-	-	-	-	-	-	-	-	-	-
Freezing point, °F	-58	-57	-59	-56	-58	-56	-54	-56	-55	-57	-58
Viscosity, kinematic, -30 F, cs	10.2	10.2	10.1	10.5	10.5	9.0	10.2	9.7	7.1	10.4	-
Aniline point, °F	140.0	140.8	139.7	144.6	144.0	142.1	143.3	143.0	142.9	142.5	141.9
Aniline-gravity constant, No.	5,740	5,914	5,714	6,059	5,990	5,840	5,971	5,920	5,959	5,869	5,804
Water tolerance, ml	0.2	0.03	-	-	0.1	0.1	0.3	3/ 0.0	0.5	0.7	2/ 1.0
Sulfur:											
Total, wt %	0.045	0.053	0.037	0.096	0.065	0.061	0.059	0.068	0.057	0.044	0.020
Mercaptan, wt %	0.0004	0.0003	0.0009	0.0007	0.0015	0.0006	0.0004	0.0006	0.0004	0.0003	0.0004
Naphthalenes, wt %	-	-	1.21	-	-	-	-	2/ 1.0	-	2/ 1.0	-
Aromatic content, vol %	15.9	16.4	15.7	16.0	16.0	15.2	16.9	16.0	15.3	16.4	17.4
Olefin content, vol %	1.0	1.1	0.6	0.8	1.0	1.2	0.8	0.9	1.4	0.8	0.6
Smoke point, mm	22.4	22.2	21.7	22.2	22.3	22.9	22.3	22.6	21.8	21.9	20.9
Gum, mg/100 ml:											
Existent, at 450 F	0.5	0.9	1.3	1.3	0.6	1.0	0.8	1.1	1.0	0.7	0.8
Potential, at 212 F	2.2	2.7	2.2	2.6	-	-	2/ 1.0	2/ 1.0	-	-	-
Heat of combustion, net, Btu/lb	18,514	18,534	18,515	18,526	18,539	18,522	18,538	18,533	18,535	18,530	18,525
Luminometer number	44	-	-	-	-	-	2/ 48	2/ 48	-	-	-
Thermal Stability:											
Pressure drop, in. Hg	0.01	0.08	0.14	0.5	0.2	0.16	0.16	0.4	0.3	0.2	0.2
Water separometer index, No.	95	97	96	94	95	94	92	96	95	94	84

1/ Distillation data reported on evaporated basis prior to 1972.
2/ Represents one sample.
3/ Represents two samples.

Table 4. Summarized Data for Grade Jet A Commercial Jet Fuels

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Number of fuels	57	57	64	65	63	66	65	65	60	60	67
Gravity, °API	42.7	42.8	43.0	42.9	42.9	42.9	43.1	43.2	42.9	42.7	42.6
Distillation 1/											
Temperature:											
10% recovered, °F	371	371	372	369	369	370	371	370	374	375	375
50% do. , °F	417	416	415	415	413	414	415	414	416	416	417
90% do. , °F	477	473	474	473	472	472	474	472	473	473	473
Recovered at 400 F, %	34.2	35.6	35.7	36.3	37.2	36.8	35.3	37.6	33.9	34.5	32.3
Reid vapor pressure, lb	0.3	0.2	0.2	0.1	-	0.2	0.2	0.2	-	-	-
Freezing point, °F	-50	-50	-50	-51	-51	-50	-51	-50	-49	-49	-48
Viscosity, kinematic, -30 F, cs	9.45	9.45	9.38	9.12	9.21	9.22	9.32	9.4	9.2	8.8	8.78
Aniline point, °F	144.4	144.1	144.8	143.2	142.6	143.4	144.2	143.6	143.6	142.4	142.1
Aniline-gravity constant, No.	6,166	6,182	6,241	6,143	6,118	6,152	6,244	6,204	6,160	6,072	6,025
Water tolerance, ml	0.2	0.2	0.3	0.5	0.5	0.4	0.5	0.3	0.4	0.6	0.5
Sulfur:											
Total, wt %	0.049	0.045	0.048	0.045	0.054	0.054	0.060	0.061	0.053	0.050	0.053
Mercaptan, wt %	0.0005	0.0006	0.0004	0.0006	0.0009	0.0008	0.0009	0.0008	0.0007	0.0008	0.0008
Naphthalenes, wt %	1.91	1.85	1.79	1.80	1.82	1.67	1.70	1.70	1.78	1.80	1.99
Aromatic content, vol %	16.4	16.1	16.1	16.3	16.7	16.9	17.0	17.2	17.4	17.9	17.5
Olefin content, vol %	1.1	1.0	1.1	1.2	1.2	1.0	1.1	1.2	1.0	0.9	1.2
Smoke point, mm	23.3	23.4	23.2	23.3	22.9	22.9	23.1	23.1	22.7	22.6	22.5
Gum, mg/100 ml:											
Existent, at 450 F	0.6	0.7	0.8	0.7	0.8	0.9	0.8	0.9	0.8	1.0	1.0
Potential, at 212 F	1.5	1.4	1.6	1.6	1.9	1.9	2.2	1.5	2.3	2.5	-
Heat of combustion, net, Btu/lb	18,586	18,584	18,589	18,583	18,582	18,622	18,609	18,589	18,584	18,598	18,574
Luminometer number	48.9	49	50	49	50	50	50	50	49	49	-
Thermal Stability:											
Pressure drop, in. Hg	0.18	0.21	0.23	0.35	0.33	0.26	0.29	0.3	0.4	0.3	0.2
Water separometer index, No.	95	96	96	95	95	95	96	94	95	95	94

1/ Distillation data reported on evaporated basis prior to 1972.

The decision to convert to JP-8 in NATO Europe has been delayed pending a study on cost and availability but could be made at any time.

- JP-4 Fuel Properties

  There are currently no refinery pressures to change the JP-4 specification to increase the availability of JP-4 derived from petroleum.

  Relaxing the freeze-point limit could increase the availability of JP-4 if the demand were greater than the supply but only at the expense of other kerosene-based jet fuel. (5)

- JP-4 from Shale Oil

  The properties of JP-4 derived from shale oil are process dependent.

  In general they contain more normal parraffins which makes it difficult to meet the freeze point limit.

  The levels of hydroprocessing necessary to remove the nitrogen and hydrocracking to increase the JP-4 yield is sufficient to produce a fuel with 5 to 10% aromatics and a hydrogen content well in excess of the specification limit of 13.6%.

JP-4 fuels over the next twenty years or so are therefore not likely to be significantly different from the JP-4 fuels used today with the following exceptions:

- The aromatic content might be lower for shale-oil derived fuel.

- Lubricity improvers may be used to restore the natural lubricity removed by the hydroprocessing.

B. JP-5, JP-8, Jet-A

Currently these kerosene jet fuels differ from JP-4 primarily in a higher viscosity and a higher flash point (lower volatility or vapor pressure) with JP-5 having the highest flash point and generally a higher viscosity. They also tend to have higher aromatic contents but are within the JP-4 specification. Unlike JP-4, there are pressures to change the JP-5 fuel specification to improve availability in some producing regions. The scenarios and projections for changes in JP-5 were addressed in depth in a recent report conducted by Southwest Research Institute for the Naval Air Propulsion Center (NAPC). (1) The commercial Jet-A fuel specification is essentially the same as JP-8 except that JP-8 allows 25% aromatics rather than 20 but requires a lower freeze point. The pressures to change the Jet-A specification are less than that for JP-5 so only JP-5 will be discussed here as a worst case for "alternate fuels." The NAPC study considered the following potential property changes in JP-5 as important to aircraft performance and durability:

- Increased aromatics
- Decreased hydrogen content
- Decreased lubricity

Other property changes such as viscosity and thermal stability were addressed primarily for emergency fuels.

The higher aromatics expected in petroleum-derived JP-5 give the fuel a lower hydrogen content. When JP-5 is produced from shale oil, less hydroprocessing is done so the product would not have the same high hydrogen content expected in JP-4 from shale oil. The average molecular weight of the aromatics found in JP-5 (and JP-8/Jet-A) is higher than that of JP-4. The higher molecular weight aromatics are thought to have less solvent action on elastomers and therefore are tolerable in higher concentrations.

Extra processing used to increase the hydrogen content or remove sulfur during refining act to reduce the natural lubricity of the fuel. Lubricity improving additives are available but the Navy does not like to use them as they reduce the water separometer number, i.e., the ability to separate water from the fuel on-board ship. The development of a lubricity specification is being considered for JP-5.

Summary

The projected trends in the properties of fuels which the Army might use relative to that of current JP-4 is summarized in Table 5. JP-8 and Jet-A were not included but are expected to follow the trends of JP-5 only to a lesser degree. These properties will be the basis of the fuel impact studies addressed in the remainder of this report.

Table 5. Fuel Property Trends Relative To Current Petroleum JP-4

Fuel	Crude Source	Hydrogen Content	Aromatics	Lubricity	Viscosity	Thermal Stability	Remarks
JP4	Petroleum	---*	---	---	---	---	No Change
JP4	Shale Oil	---	lower	lower(?)	---	---	---
JP5	Petroleum	lower	higher	---	higher	---	higher molecular weight aromatics
JP5	Shale Oil	lower	higher	lower	higher	---	higher
molecular							weight aromatics

*"---" indicates no significant difference from current JP-4 experience.