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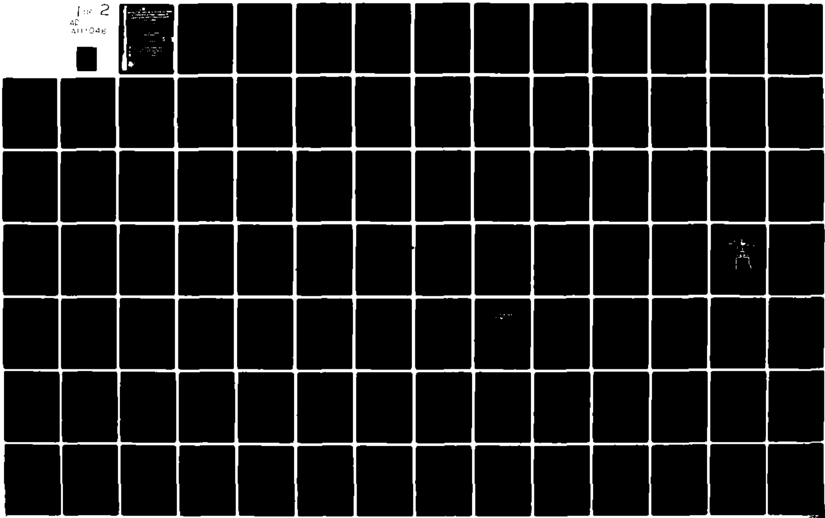

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IMPACT STUDY OF SYNTHETIC AND ALTERNATIVE FUEL USAGE IN ARMY AIRCRAFT PROPULSION SYSTEMS

AD A111046

FINAL REPORT
No. MED134

By

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Under Contract to

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Aircraft fuels	Engine fuel system performance	Fuel hydrogen content
Alternate fuels	Aircraft fuel system durability	Fuel aromatic content
Gas turbine engines	Hot-section durability	Fuel thermal stability
Engine performance	Elastomer Compatibility	Fuel viscosity
Engine durability	Cold-day ignition	Fuel lubricity
		Fuel composition

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

The U.S. Army is concerned about the quality of future aircraft fuels and their compatibility with current engines and aircraft fuel systems. This impact study of synthetic and alternate fuel usage on Army aircraft propulsion and fuel systems addresses four technical areas:

1. the fuel scenario for Army aviation gas turbine fuels ;

20. Abstract (Cont'd)

2) the effects of initial properties or the performance and 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 of qualification and certification procedures.

FOREWORD

This work was conducted during the period October 1980 through June 1981 under Contract No. N00140-80-C-2269 to the U.S. Naval Air Propulsion Center, Trenton, N.J., with monies MIPR'd from the U.S. Army Mobility Equipment Reseach and Develoment Command, Energy and Water Resources Laboratory, Fort Belvoir, Va. The USAMERADCOM technical monitor was Mr. J. V. Mengenhauser and the NAPC technical monitor was Mr. P. A. Karpovich.

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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.

III. IMPACT OF FUEL PROPERTIES ON ARMY AIRCRAFT SYSTEMS

The impact areas associated with the critical fuel properties identified in the previous discussion are given below:

Fuel Property	Area of Impact
Hydrogen content	Hot section durability
Hydrocarbon composition	Elastomer compatibility
Viscosity/volatility	Cold day ignition limits
Lubricity	Pump and fuel control durability
Thermal stability	Flow divider valve/fuel nozzle degradation

The following discussion addresses each of these impact areas describing the problem and using existing data to indicate the severity of the impact to Army equipment.

A. HYDROGEN CONTENT

Hydrogen content has been shown in a number of research and engine combustor studies to be the fuel property most directly related to the burning quality, i.e., soot production, of the fuel. (6-15) Fuels with lower hydrogen content therefore burn with a more luminous flame, and this higher flame radiation increases the heat load to the combustor liner resulting in higher liner temperatures. One of the primary failure modes of hot section parts is low-cycle thermal fatigue (LCF). Each time the metal parts are cycled through their temperature extremes, thermal stresses are built up and relaxed. The combustor liner is designed to withstand a certain number of such cycles before fatigue cracks are initiated and begin to propagate. As the maximum liner temperatures increase, for example by increased flame radiation, this cycle life is decreased. LCF is almost always the life-limiting failure mode according to the engine manufacturers unless there are unusal design problems; LCF is the only one that is significantly affected by fuel properties.

No test data were found which quantitatively relate changes in fuel properties, or even liner temperature, to liner durability. Recent Air Force engine combustor studies at General Electric and Allison have included the effects of fuel properties on liner temperatures; from the liner temperature data, life analyses have been made using computer models. The engines included in these programs were the J79-17A (high smoke) (9), J79-17C (low smoke) (10), F101 (11), and TF41 (16) plus the TF34 and J85 which have not been reported at the time of this writing. No extensive engine or combustor testing has been done on any Army engines except for some T63 combustor work done by the Army Fuels and Lubricants Research Laboratory (AFLRL). (13)

Figure 1 shows the effect of hydrogen content on T63 liner temperatures at four different positions on the combustor. The data was taken at the full-power condition which is the case for highest flame radiation. The temperatures get progessively higher towards the combustor exit; however, the greatest sensitivity to hydrogen content is found at the primary zone where flame luminosity is the greatest.

Figure 2 shows an example of liner temperature data taken from the Air Force J79-17A study. These temperatures are all taken at the primary zone. The fuels represent variations on JP-4 and JP-8 type fuels and a diesel fuel. The variation at constant hydrogen content are basically whether or not polycyclic aromatics (naphthalenes) are present in the fuel. There is quite a bit of data scatter at the idle condition due to vaporization and mixing characteristics but very little at takeoff and dash which are the important conditions for flame radiation and LCF. The average temperatures show much less sensitivity than the peak temperatures, but some of the thermocouples are evidently in regions not affected by flame radiation (high convective cooling).

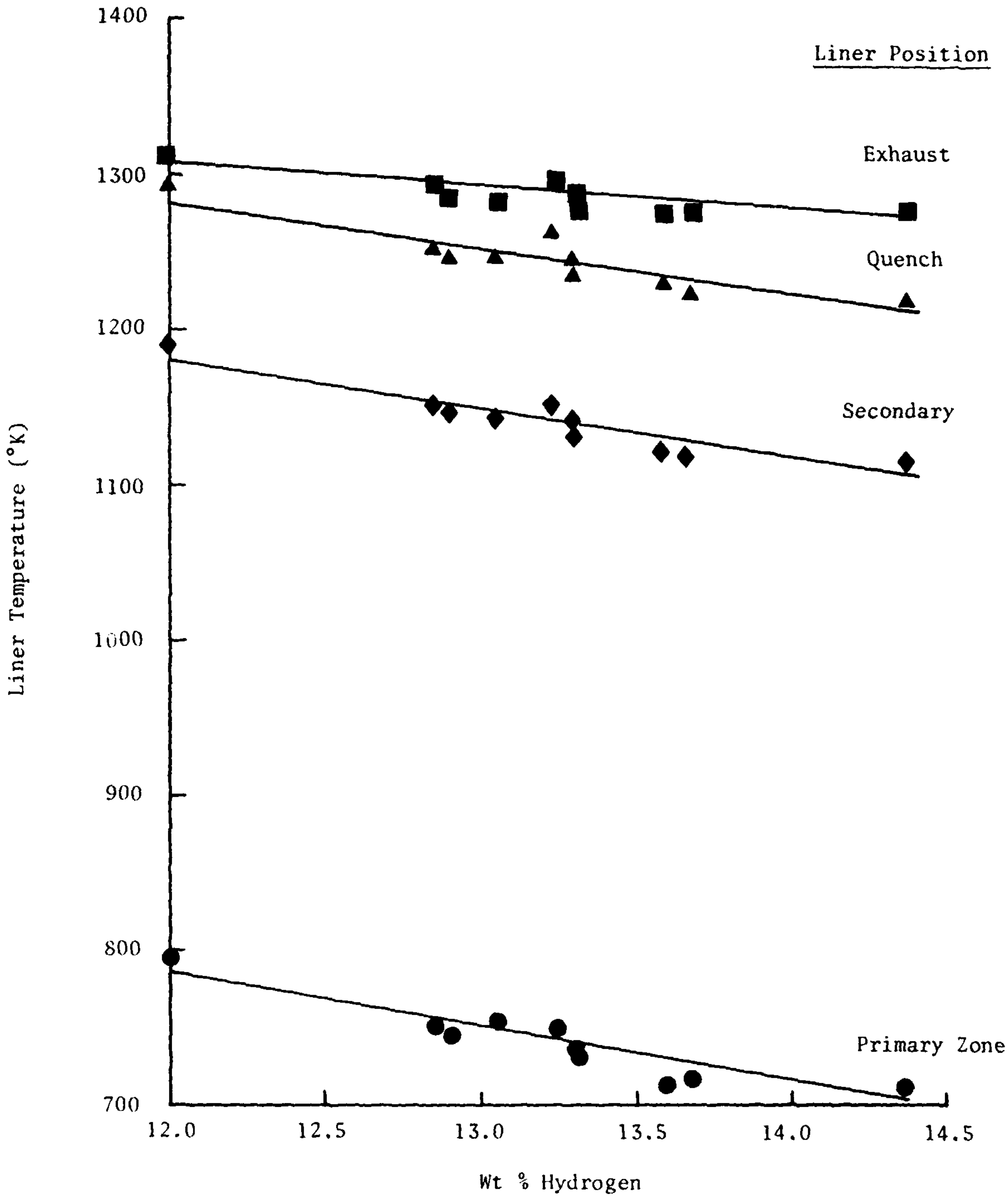


FIGURE 1. EFFECT OF HYDROGEN CONTENT ON T63 COMBUSTOR LINER TEMPERATURES

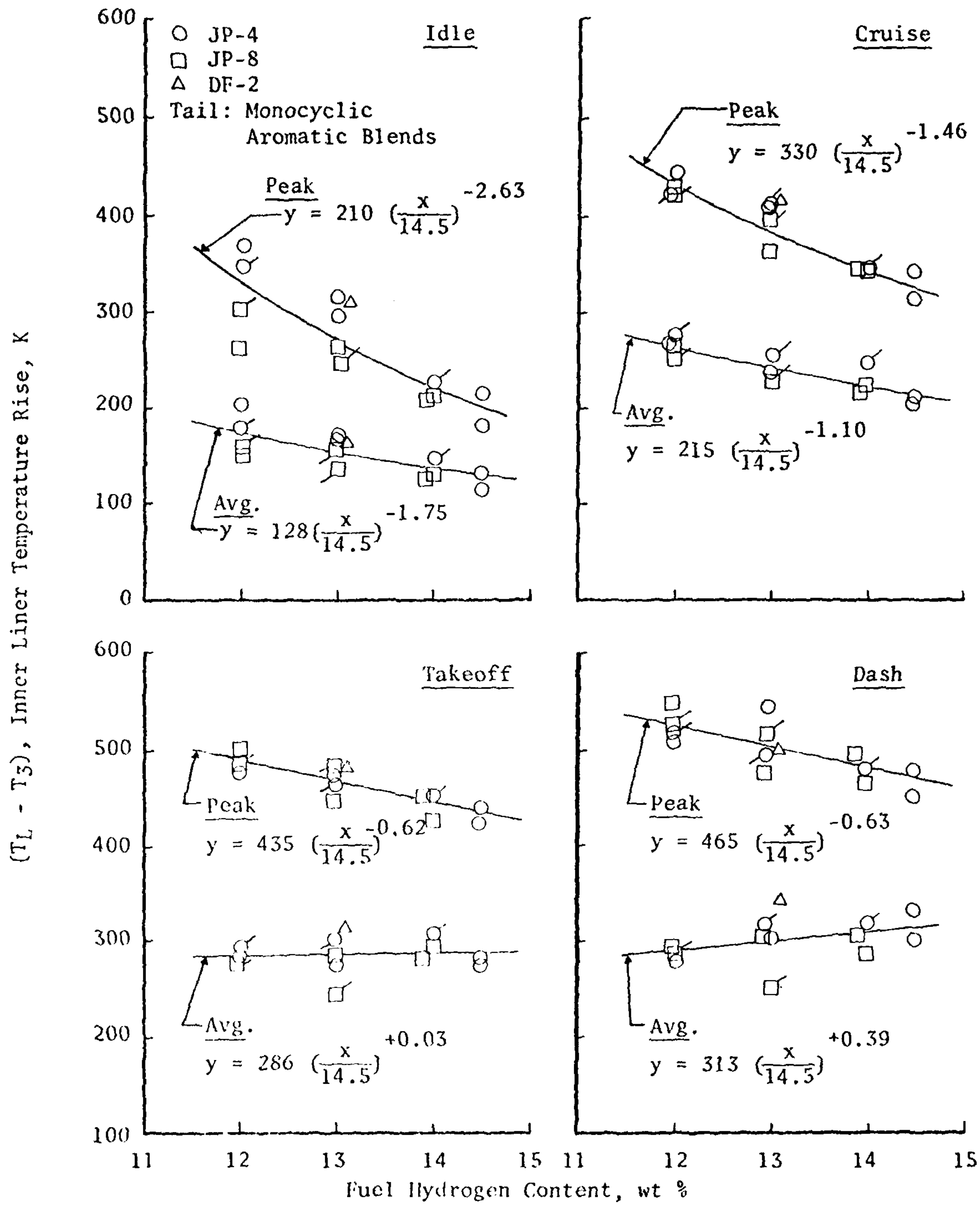


FIGURE 2. EFFECT OF FUEL HYDROGEN CONTENT ON INNER LINER TEMPERATURE RISE: J79-17A (from Ref. 9)

Table 6 summarizes the results on life analysis from the four Air Force engine studies. In the analyses the life-limiting region was determined, and then the temperature changes in that region were used to predict life reduction. The TF41 does not exhibit a life-ratio dependency because the life-limiting region is in the transition duct between the burner can and the turbine inlet nozzles; this section is subject to hot-streaking and burnout, a problem not related to hydrogen content.

Blazowski has developed a non-dimensional temperature parameter that is quite effective in normalizing the differences between a number of combustor designs.(12) The parameter, defined below, assumes

$$\frac{T_{liner}\text{ (test fuel)} - T_{liner}\text{ (ref. fuel)}}{T_{liner}\text{ (ref. fuel)} - T_3\text{ (inlet air)}}$$

that as fuels of different hydrogen content a' used, the basic flame structure and combustor flow patterns remain constant and that any changes in liner temperature are due to changes in radiant heat transfer.

Figure 3 shows the effectiveness of this parameter for five different combustors. All of these combustors are of the older, rich primary zone type. A few newer lean-burning clean combustors, not shown, have been found to have significantly less sensitivity presumably because they are designed to produce relatively little soot. All of the Army's engines except for the T700 have rich primary zones and, for lack of any other data, the correlation line A shown in Figure 3 is recommended. General Electric estimates that line B shown in Figure 3 can be used for the T700 until such time as test data is available.

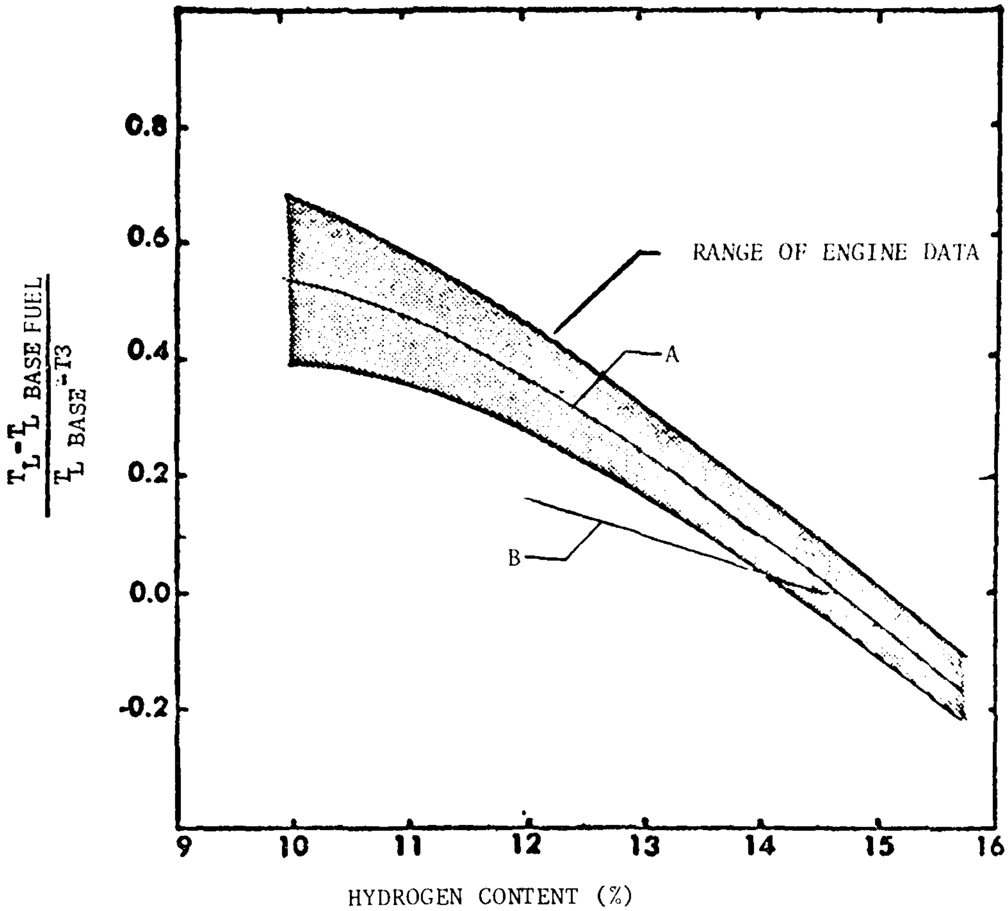
As part of the recent Navy ATP study, General Electric personnel developed a simplified methodology for predicting the effects of fuel hydrogen content on life ratio that can be used for combustors where only

TABLE 6. Comparison of Hydrogen Content Effects on Predicted Liner Life from Various Air Force Studies

Hydrogen Content (H)	J-79-17A (ref. 9)		J79-17C (ref. 10)		F101 (ref. 11)		TF41 (ref. 16)	
	ΔT*	LR**	ΔT	LR	ΔT	LR	ΔT	LR
14.5 (current JP 4)	0	1.00	0	1.00	0	1.00	0	1.00
14.0 (current JP8)	11	0.78	8	0.93	12	0.72	0	1.00
13.0 (ERBS, DF2)	33	0.52	16	0.83	36	0.52	0	1.00
12.0	55	0.35	24	0.74	60	0.47	0	1.00

* ΔT = Temperature change in life limiting region = T(H) - T(14.5)

** LR = Life ratio = $\frac{\text{Life (H)}}{\text{Life (14.5)}}$



A - Rich-Combustor Correlation
B - T700 Correlation

FIGURE 3. LINER TEMPERATURE RISE CORRELATION

limited liner-temperature data are available. (1) It makes use of assumed liner-temperature effects of hydrogen, e.g., the Blazowski parameter of Figure 3, combined with material stress/cycle-life data, combustor overhaul times, and mission profiles, i.e., thermal cycles per hour, to predict new temperatures, stress levels, and finally the reduced cycle life. Seven General Electric combustors were analyzed with this methodology including the T700 which the Navy plans on using. Figure 4 shows the predictions for the T700. Also shown are comparisons of the results from simplified methodology and the extensive computer analyses for the J79-17A and J79-17C engines; this comparison is quite good considering the stage of development of the new methodology and provides credibility to the results.

Figure 5 presents the results of the application of this methodology to predict the effect of reductions in hydrogen content on the life of Army turbine engines. One major difference is that a hydrogen content of 14.5% was used as the baseline rather than 14.0% reflecting the higher hydrogen content of a typical JP-4 over that of JP-5. The correlation line "A" of Figure 3 was used for all of the engines except the T700 for reasons mentioned above. Table 7 lists the overhaul times for the combustors to which an arbitrary factor of three was used to estimate the thermal cycle life. This is obviously an oversimplification since it assumes all aircraft have the same number of thermal cycles (idle - full power - idle) per mission hour. This could be improved by using realistic mission profiles and mission mixes for the different applications. For this reason the results shown in Figure 5 should be considered perhaps as a first approximation. Nevertheless, the significance of reduced-hydrogen-content on low-cycle fatigue life is obvious.

Another way of considering the results shown in Figure 5 is in terms of what a mission hour on a reduced hydrogen content fuel is equivalent to on a 14.5% hydrogen fuel, i.e., if the life of an engine is halved by

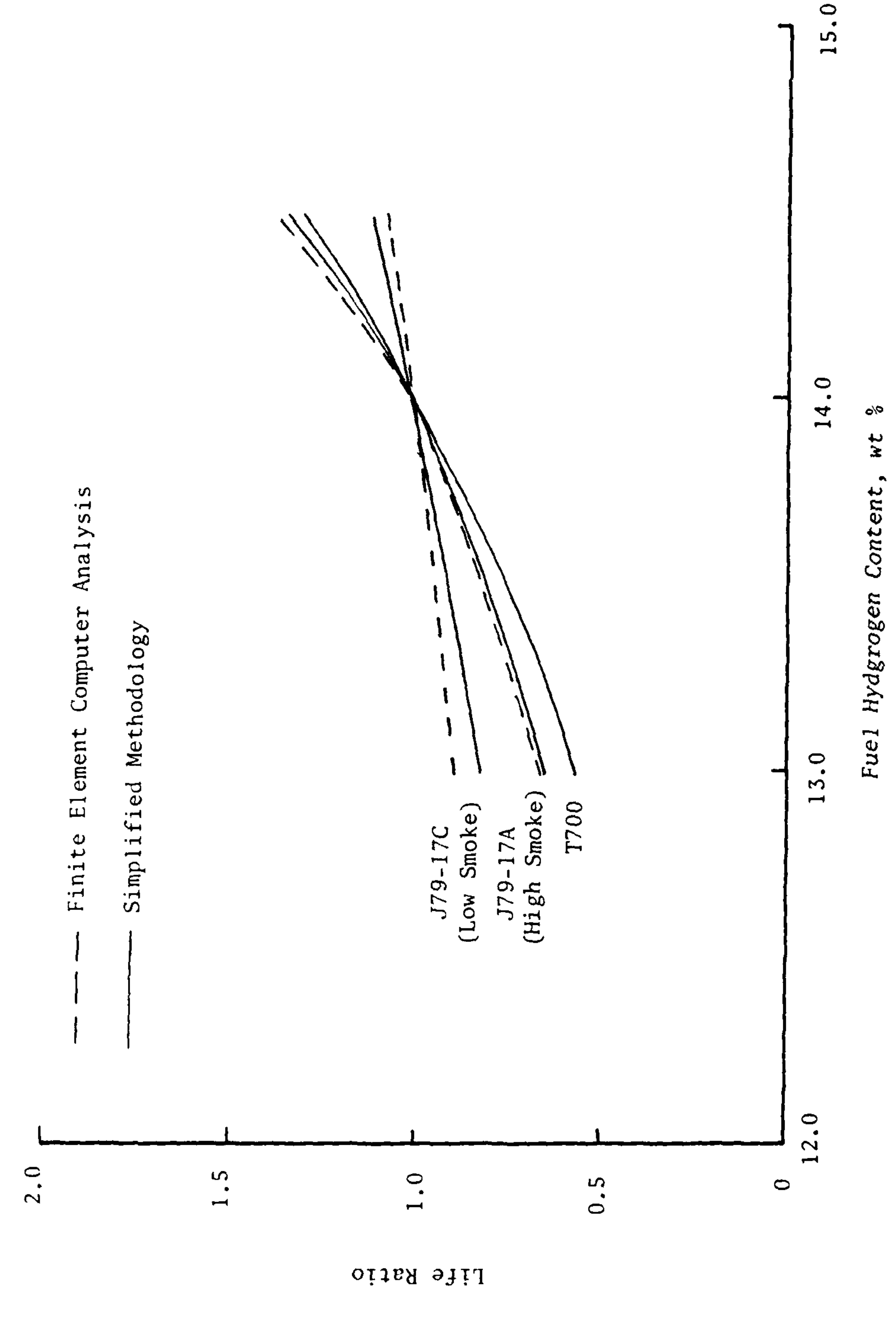


FIGURE 4. COMPARISON OF ANALYTICAL METHODOLOGIES TO PREDICT THE EFFECTS OF FUEL HYDROGEN CONTENT ON COMBUSTOR LINER LIFE

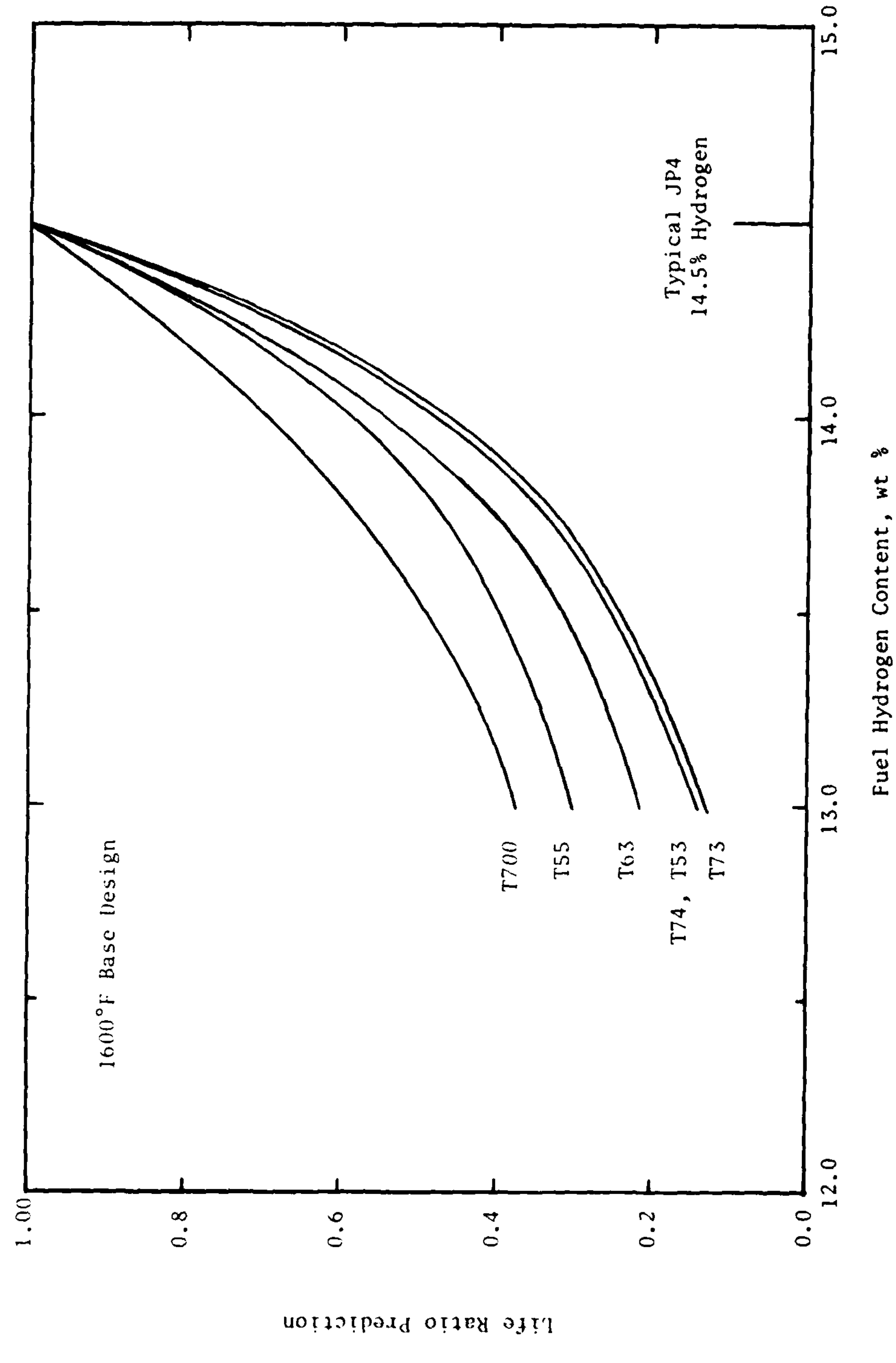


FIGURE 5. PREDICTIONS OF THE EFFECT OF FUEL HYDROGEN CONTENT ON THE COMBUSTOR LINER LIFE OF ARMY AIRCRAFT TURBINE ENGINES

Table 7. Typical Overhaul Life of Army Aircraft Turbine Engines

Engine	Combustor Liner Life to Repair	Curve on Fig. 3	Assumed Cycle Life*
T53-13	3600 hours	A	10800
T55-11	800 "	A	2400
T63	1500 "	A	4500
T73	4500 "	A	13500
T74	3500 "	A	10500
T700	5000 "	B	15000

*Assumed to be 3 times the overhaul life a 13% hydrogen fuel then each mission hour on that fuel must be equivalent to two mission hours on a 14.5% hydrogen fuel in terms of LCF life. Figure 6 shows this for the six engines. According to this methodology, one mission hour of a T73 engine on a 13% hydrogen fuel will cause the same LCF distress as 7.7 mission hours on a 14.5% hydrogen fuel; the LCF life of the T700 is much less sensitive and one mission hour on 13.0% hydrogen fuel only causes the same LCF distress as 2.6 mission hours on 14.5% hydrogen fuel.

More accurate mission models will improve these predictions and could be used with current maintenance schedules and costs to predict the impact of changing fuel specifications. The methodology also shows the impact on LCF life flying a mission on an alternative fuel of low hydrogen content.

B. HYDROCARBON COMPOSITION

Composition has been distinguished from hydrogen content in this study because of the known effects that aromatics have on some kinds of elastomers. Table 8 summarizes the different types of elastomers found in aircraft fuel systems - some with unique applications, some with multiple applications. There are of course many other kinds of elastomers which are totally unsuitable for fuel usage.

Jet fuels are typically made up of three hydrocarbon types: paraffins, cycloparaffins (naphthenes), and aromatics; all other types are in small concentrations. Future fuels may also contain significant amounts of unsaturated or partially saturated double-ring compounds, e.g., decalin and tetralin, as a result of naphthalene hydrotreatment. Certain contaminants are also important in materials compatibility such as free sulfur, mercaptan sulfur, polysulfides, and peroxides.

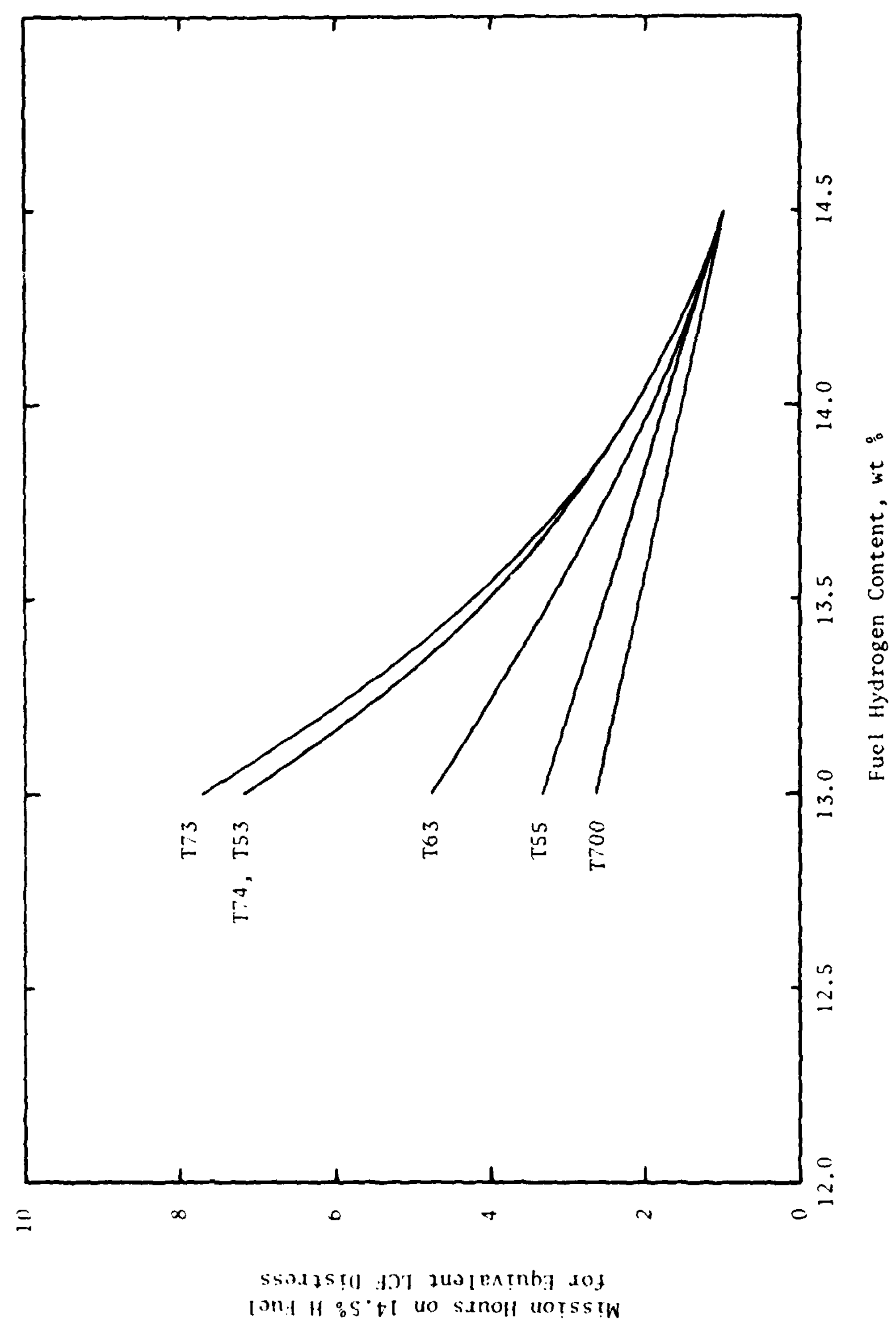


FIGURE 6. RELATIVE MISSION LIFE OF COMBUSTOR LINERS ON FUELS OF REDUCED HYDROGEN CONTENT

Table 8. Elastomer Usage in Aircraft Fuel Systems

Application	Elastomer Types Used
O-rings and seals	Buna-N, Viton, Fluorosilicone, Polysulfide
Diaphrams	Neoprene, Fairprene (Buna-N or Nylon), Fluorosilicone, Impregnated nomex
Hose Lining	Buna-N, Teflon
Fuel cell inner liners	Buna-N, Urethane
Bladder repair adhesives	(details not available)
Fuel tank sealants	Polysulfide
Groove injection sealants	Polysulfide
Fuel tank coatings	Buna-N
Fuel cell foams	Polyurethane, Polyether
Electrical sheet materials	Polyethylene, Nylon
Structural adhesives	Various epoxies

The fuel sensitivities of the elastomers listed in Table 8 can range from "none" to "significant." Such sensitivities are usually due to a particular fuel component, e.g., aromatics, or a contaminant, e.g., sulfur or peroxides. Another general characteristic is that each generic type of elastomer can have a range of formulations depending on the desirable physical and chemical properties of the elastomer. Buna N formulations with low acrilonitrile concentrations have excellent low temperature charac-teristics but are very sensitive to aromatic hydrocarbon; high acrilonitrile rubbers can be made compatible with 50% aromatic fuels but lose flexibility below -10°F.

There are a number of properties used to describe fuel compatibility; the most common are:

Volume swell
Tensile strength
Elongation
Modulus of elasticity
Hardness

Other are used for special applications such as permeability for bladders and peel strength for adhesives.

The data base on the fuel sensitivity of elastomers is surprisingly small. The most highly referenced source of information on the fuel resistance of elastomers among people in the O-ring and seal business, whether it is the rubber supplier, the fabricator, or the user, is the Parker O-Ring Handbook. (17) It provides compatibility ratings for fifteen common elastomers and over 800 fluids. Unfortunately it is just that - a compatibility rating and not quantitative data on sensitivities. Furthermore, this is about all that is available from the industry. They can tell you an elastomer is compatible with a 70/30 blend of iso-octane and toluene because that is a standard test fluid, or JP-5 because they tried it once. They can tell you it passes a particular qualification test, but, in general they have only qualitative information on the effects of changing fuel properties.

Reports on two fairly comprehensive studies on the sensitivities of elastomeric materials to aromatics plus one study on potential problems with peroxides were discussed extensively in the NAPC ATP report. (1) One was conducted by the Army Mobility Equipment Research and Development Command (MERADCOM) for the Naval Air Propulsion Center. (18) Eleven test fuels consisting of JP-5 from various crude sources, JP-5 with various additives, and DFM were used to study the fuel sensitivities of four common O-ring elastomers:

- Low-acrilonitrile rubber (Buna N)
- High-acrilontrile rubber (Buna N)
- Fluorocarbon (Viton)
- Fluorosilicone

In addition, five sealant materials, one foam, and a tank coating were evaluated.

The second study was conducted by the University of Dayton Research Institute for the Air Force Materials Laboratory. (19) The fuels were variations of JP-4 at four different aromatic levels (10-45%) and two sulfur levels (0.1 and 1.0%); two different aromatic blending stocks were used, toluene and xylene. Also a JP-4 and a JP-8 made from shale oil were included for comparison. The elastomers tested represented all of the non-metallic materials found in aircraft fuel systems.

The study on potential peroxide problems was stimulated by a failure of a diaphragm in the fuel control of a Navy A-7E aircraft that was traced to a large concentration (16-32 ppm) of peroxides in the fuel. Elastomer compatibility tests were conducted at the Naval Air Development Center (NADC). (20)

The essence of the Air Force study (19) is shown in Figure 7 which summarizes the effects of fuels composition on the volume swell in O-ring elastomers. The "Buna N" is a high-acrilonitrile type, the type with the greater fuel resistance. Even so it is obvious that aromatics have a significant effect on Buna N elastomers but relatively minimal on the others. Buna N is also affected by sulfur and to some extent by aromatic type with the lower-molecular-weight toluene causing more swell for the same concentration. The shale-oil JP-4 acted no differently than the petroleum JP-4, while the shale-oil JP-8 was much less detrimental than a JP-4 of equivalent aromatic content. The most significant difference between the JP-8 and the rest of the fuels was that the average carbon number of the aromatics was 11.0, whereas for the JP-4's it ranged from 8.5 to 8.8. This is consistant with the relative effect shown for xylene and toluene which have carbon numbers of 8 and 7 respectively.

The effects of different aromatics is further demonstrated in Figure 8. Here the data for the high-acrylonitrile rubber from the Navy study is superimposed on the Air Force data for the similar rubber. Notice that about half of the JP-5 data points correlate very well with the JP-4 data, while the other are less detrimental like the shale-oil JP-8 was in Figure 7. Not as much detail is available on the composition of the Navy fuels, but four of the fuels that fall on the line were blended with xylenes to vary the aromatic content. The other two are iso-octane/toluene blends. Of the points below the line, one is a DFM, which would have higher molecular weight aromatics, and another is a blend of DFM and JP-5. Two others are derived from shale oil differing only in that one has an anti-corrosion additive so they would have carbon numbers similar to the JP-8 in the Air Force study.

The tentative conclusion is that lower molecular weight alkyl-benzenes (single-ring aromatics) cause more swell than those of higher molecular weight. This conclusion is supported by Air Force experience that changing from JP-4 to JP-8 sometimes results in leaking fuel system

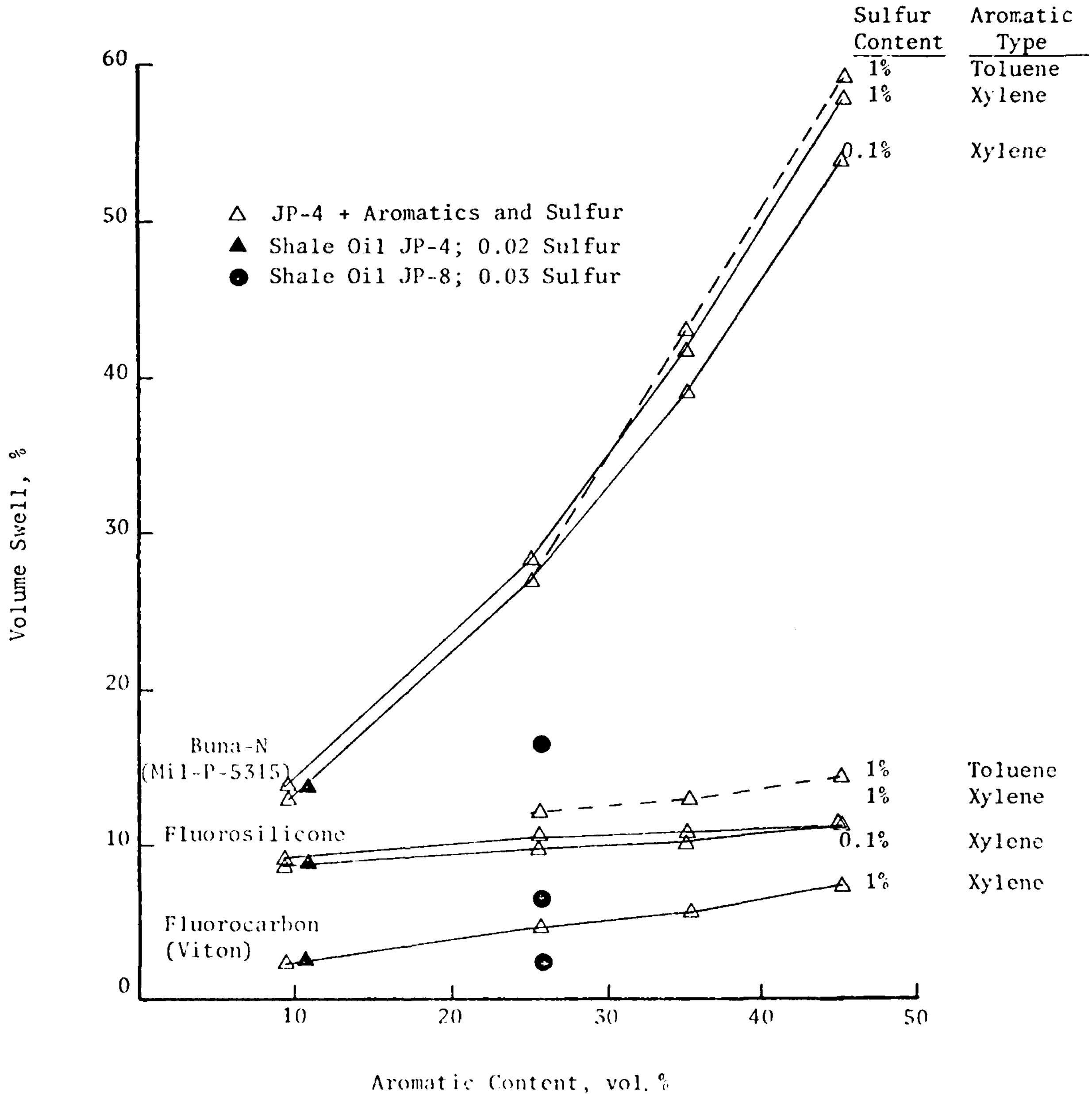


FIGURE 7. EFFECTS OF AROMATIC TYPE AND SULFUR ON VOLUME SWELL AND ELASTOMERS

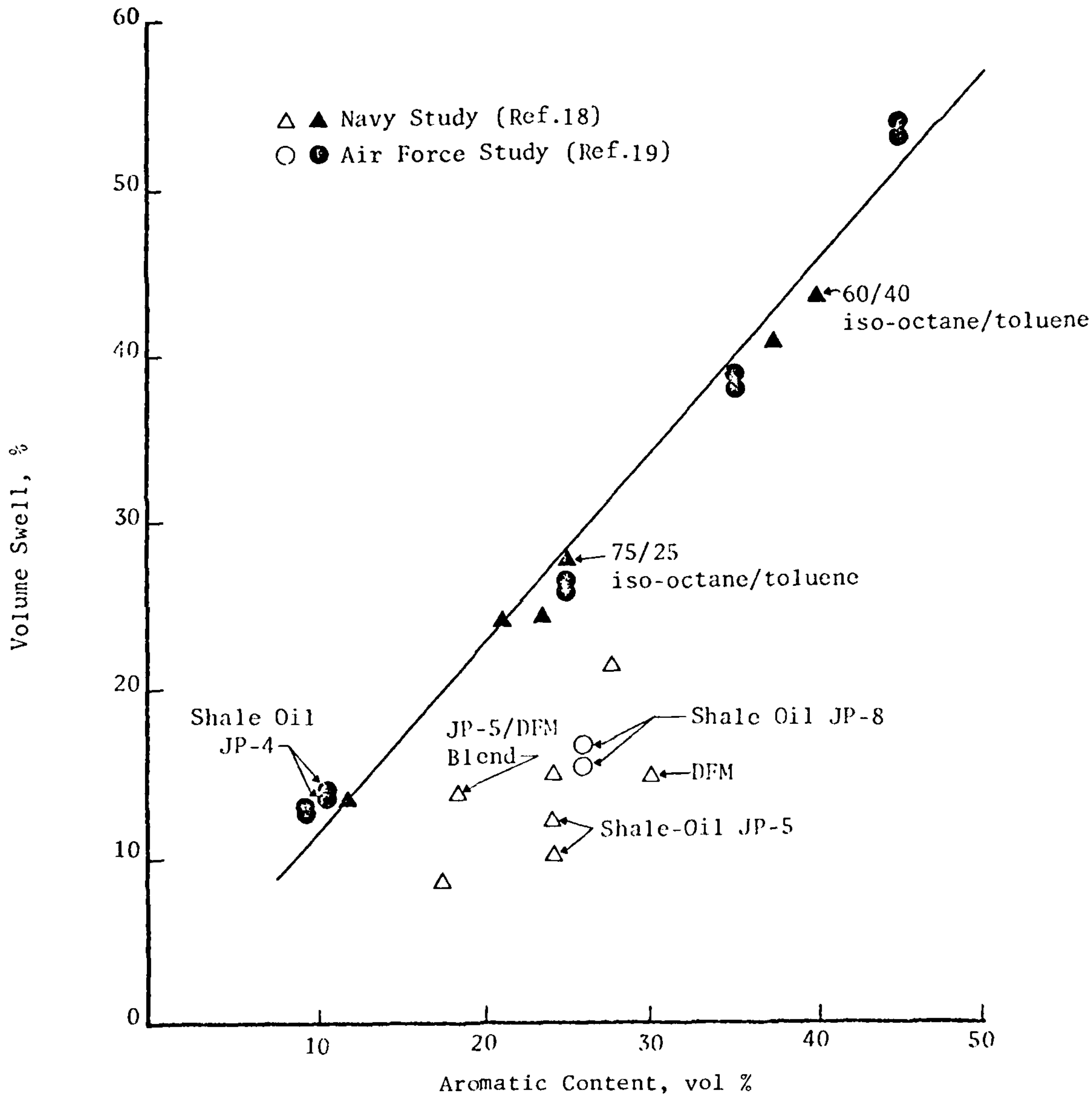


FIGURE 8. EFFECT OF AROMATICS ON VOLUME SWELL IN BUNA N ELASTOMERS

components; for example, channel sealants which had swollen 16% with JP-4 and taken some compression set, shrunk back to a 13% swell with JP-8 and leaks developed. (21) Mr. Nadler from the Navy Air Development Center (NADC) supported this conclusion but said he'd never seen a definitive data base. (22) The people at Polysar, the major supplier of Buna N, are also not aware of any data that either supports or disputes this conclusion. (23)

The significance of this conclusion is this: currently all the alternative fuels (JP-5, JP-8, and Jet A) are limited in aromatic content equal to or less than that allowed in the JP-4 specification. There is pressure to raise the limit of the JP-5 specification, but this may be possible without creating an incompatibility with fuel systems because of the greater tolerance of the higher molecular weight aromatics. Furthermore, the Navy would not alter the specification unless it were compatible with their equipment.

It was also shown that the shale oil derived fuels did not degrade the elastomers any more than the petroleum derived fuels. One problem that did occur in the Air Force conversion program from JP-4 to JP-8 in the United Kingdom was leaks due to reduced swelling, i.e., shrinkage, of some channel sealants in wet-wing tanks and some O-rings; these were easily remedied at forward-level maintenance by injecting more sealant and tightening down on the O-ring retainers.

Since there is no pressure to change the aromatic limit in JP-4 and shale-oil derived JP-4's are expected to be within the current specification limit, the Army should have no difficulty with materials compatibility with these fuels do to high aromatic concentrations that minor maintenance can't handle. JP-4 derived from shale oil may be significantly lower in aromatics than petroleum JP-4. Whether this would cause intolerable shrinkage of elastomers is not known. The major potential problem would be with dynamic seals and unconfined sealants which require a certain amount of swell to establish the seal. There is no data available on the effects of alternately using fuels of very high and very low aromatic content. If this is a problem, the Air Force will also experience difficulties and introduce a minimum aromatic level into the fuel specification.

Thus there is a potential problem for increased impact on elastomers especially Buna N. Static seals should not cause problems that connot be handled by minor maintenance e.g. tightening a fitting. Dynamic seals could be significantly affected as increased swell could lead to sticking, extrusion, and/or fretting; reduced swell from low aromatics could cause leakage. Diaphragms are another potential problem area for which little data exists on degradation. These areas will be identified in the discussion of fuel-system components. While it is believed the impact will be small if not negligible, the data base to support this is insufficient at this time.

C. VISCOSITY AND VOLATILITY

There is no reason to consider that the viscosity and boiling-point distribution of JP-4 derived from shale oil will be any different than JP-4 derived from petroleum, so the greatest impact will come from the use of the alternative fuels JP-5, JP-8, and Jet A. Table 9 summarizes average viscosity vapor pressure and flash point data for JP-4, JP-5, and Jet A for the last eleven years. (3) Of these JP-5 has the highest flash point and generally slightly higher viscosities and can therefore be considered as a worst case.

Viscosity and vapor pressure, which is related to flash point, are the two fuel properties which control the ignition capability of the engine, i.e., minimum cold day temperature and maximum altitude. Since most of the Army aircraft are helicopters, the following discussion will

Table 9. Summary of Viscosity and Volatility Data for Jet Fuels

	Viscosity[1]			Reid Vapor Pressure[2]			10% Distillation Point[3]		
Year	JP-4	JP-5	Jet-A	JP-4	JP-5	Jet-A	JP-4	JP-5	Jet-A
1970	2.80	10.2	9.45	2.6	-	0.3	212	383	371
1971	2.94	10.2	9.45	2.6	-	0.2	211	380	371
1972	3.01	10.1	9.38	2.5	-	0.2	215	388	372
1973	2.83	10.5	9.12	2.5	-	0.1	216	387	369
1974	2.68	10.5	9.21	2.5	-	-	214	389	369
1975	2.20	9.0	9.22	2.5	-	0.2	211	388	370
1976	2.40	10.2	9.32	2.6	-	0.2	215	390	371
1977	2.40	9.7	9.4	2.6	-	0.2	211	385	370
1978	-	7.1	9.2	2.6	-	-	209	390	374
1979	-	10.4	8.8	2.5	-	-	208	387	375
1980	-	-	8.78	2.6	-	-	211	381	375

1. Viscosity @ -30°F, cSt
2. Reid Vapor Pressure, lb
3. Temperature for 10% recovered, °F

be concerned with cold start rather than altitude relight. The problem of ignition is getting sufficient fuel vaporized and mixed with the air to propagate a flame kernel and sustain combustion. Viscosity controls the drop size distribution of the fuel spray, characterized by the Sauter mean diameter (SMD); vapor pressure determines the rate at which the fuel drops evaporate.

The two problems to consider are the impact of the alternative fuels as they currently exist and how they might change. The NAPC ATP study projected possible increases in the viscosity of JP-5 of 1.5 cSt at -30°F if the end point were allowed to increase by 25°F. This viscosity increase of about 9% was related to increases in the SMD of fuel sprays of about 1.5% for pressure atomizers and 0.5% for air-blast atomizers. Reviewing the data from the Air Force studies (9, 10, 12, 16) resulted in the conclusion that this magnitude of change in viscosity would not have a significant effect on the cold-day ignition characteristics of JP-5.

The major concern therefore is the difference in light-off characteristics, i.e., minimum cold start temperature, of the various engines between current JP-4 and JP-5/JP-8/Jet-A. All of the engines were qualified to start on JP-4 at -54°C (-65°F). The current engine specification (MIL-E-8593A) requires starting capability on JP-5 at that temperature corresponding to a fuel viscosity of 12 centistokes. For a typical JP-5 this would be around -39°C (-38°F). Table 10 lists the maximum viscosity limits for starting as provided by the engine manufacturers. The T53, T55, and T63 engines have not been able to start at 12 cSt. The T63 was not developed to operate on JP-5 fuel; the T53 and T55 engines demonstrated a 12cSt start during development but production models were deficient. Also shown in Table 10 are typical temperatures for JP-5 to have the viscosity limit indicated.

Engine starting limits have been found to be significantly different than aircraft starting limits however. The difference are caused by the cranking power of the batteries and the stiffness of gearboxes etc. at

Table 10. Viscosity Limits for Cold-day Ignition

Engine	Viscosity Limit	Typical Temperature**	
T53*	6 cSt	-25°C	(-13°F)
T55	8	-32°C	(-25°F)
T63	8	-32°C	(-25°F)
T73	12	-39°C	(-38°F)
T74	15	-43°C	(-45°F)
T700	12-15	-39 to -42°C	(-38 to -45°F)

* Atomizer version; older vaporizer versions were higher.

** Typical temperature for JP-5 corresponding to the viscosity limit.

low temperatures. Table 11 summarizes the results from recent Army tests on the cold weather starting capabilities of JP-8 versus JP-4. Minimum aircraft starting temperatures for JP-5 would probably be a little higher than for the JP-8.

The OH-58C, AH-1S, and UH-1H tests were conducted with a 100°F flash point JP-8, right on the specification minimum, i.e., a best case. JP-8's with higher flash points would not fare as well and would have higher minimum starting temperatures. There are no data available for the different engines that map the effects on ignition of volatility and viscosity independently. There are current plans at the Army Fuels and Lubricants Research Laboratory to map the ignition requirements for the T63; tests on the T700 are being contemplated.

In summary, the impact on alternate and synthetic fuels on ignition will continue to be that which is being experienced today. Combustor rig tests are encouraged to develop correlation equations from which quantitative impact statements can be made on the different engines.

D. LUBRICITY

Lubricity is a qualitative description about the relative abilities of two fluids having the same viscosity to resist friction and wear. As mentioned earlier, there is an increasing trend to use hydroprocessing of some level in the refining of petroleum to finished fuels. The syncrudes will require moderate to severe hydroprocessing to produce significant yields of quality jet fuel. This processing acts to reduce the natural lubricity of the fuel. There have been problems, both commercial and military, related to low lubricity fuels, but none have been reported in the Army. There is no specification on lubricity and the problem is generally cured by the anti-corrosion additives added to the fuel. Too much of the additive causes problems with the WISM test so the Navy is

Table 11. Summary of Army Helicopter Cold Start Tests

		Minimum Starting Temperature, °C (°F)			
		Battery Start		APU Start	
Aircraft	Engine	JP-4	JP-8	JP-4	JP-8
UH-1H	T53-13B	-12 (10)	-12 (10)	-34 (-30)	-23 (-10)
AH-1S	T53-703	-17 (0)	-17 (0)	-34 (30)	-23 (-10)
OH-58	T63-700/720	-7 (20)	-7(20)	-34 (-30)	-12 (10)
CH-47C	T55-11D	-40 (-40)	-40 (-40)	(APU wouldn't start)	
		*	*		
CH-47D	T55-712	No test	-34 (30)*	No test	-34 (-30)*
			-45 (-50)		-45 (-50)

*Two engines started at different temperatures reluctant to use any more than necessary. Also, much of the additive may be depleted by activity with storage tanks, pipelines, etc., so that it is questionable how much remains when it reaches the engine.

The Army should not have any unique problems not experienced by the Navy or Air Force who are responsible for the fuel specifications. The development of a lubricity specification is being considered, and if the problem becomes significant it will be taken care of.

E. THERMAL STABILITY

Thermal stability is a measure of the tendency for a fuel to develop deposits under high temperature conditions. Thermal stability problems are generally long-term problems that affect overhaul time rather than performance. The most serious areas for deposits to occur are in the flow-divider valves and fuel nozzles. These are also the areas where the fuel experiences the highest temperatures. Deposits in the fuel nozzle can change the flow rates as well as distort the flow pattern. In annular and can-annular combustors changes in the fuel flow rate in one nozzle compared to others will alter the exhaust-temperature pattern factor leading to high-cycle thermal fatigue problems with the turbine section. Distorted flow patterns can also affect pattern factors and can cause hot spots on the liner. Deposits in flow-divider valves generally cause hysteresis in the valve operation creating non-uniform flow rates among atomizers. Table 12 shows the average JFTOT data for the past eleven years for JP-4, JP-5, and Jet A. (3) Very little argument can be made that JP-4 is any more thermally stable than JP-5 or Jet A based on these data.

Although some of the shale oil fuels that have been produced have had poor thermal stability, it is believed by the Air Force that JP-4 from shale oil will be satisfactory and not cause problems.

Table 12. Summary of Average Jet Fuel JFTOT Data,* 1970-1980

Year	JP-4	JP-5	Jet A
1970	0.17	0.01	0.18
1971	0.12	0.08	0.21
1972	0.06	0.14	0.23
1973	0.22	0.50	0.35
1974	0.15	0.20	0.33
1975	0.26	0.16	0.26
1976	0.30	0.16	0.29
1977	0.50	0.40	0.30
1978	0.20	0.30	0.40
1979	0.40	0.20	0.30
1980	0.00	0.20	0.20
Avg	0.22	0.21	0.28

* Pressure Drop, in. Hg.

F. SUMMARY

In summary, it is believed that the only significant impact from synthetic and alternate fuels will come in the areas of LCF life of the combustor liner as hydrogen content is reduced; this is likely to happen if the JP-5 fuel specification is relaxed to improve availability. Cold-day ignition problems with the alternate fuels, JP-5, JP-8, and Jet-A, should be no worse than they are currently with JP-5 being the worst case. There are potential problems with elastomer compatibility if the JP-5 specification is relaxed to allow higher aromatics, but this is doubtful since the JP-5 type aromatics have low solvent activity due to their high molecular weight; also the Navy would not relax the specifications if their airframe fuel systems, which are similar to the Army's, were not compatible.

IV. ARMY AIRCRAFT ENGINES AND FUEL SYSTEMS

The potential differences in fuel properties relative to current JP-4 properties have been identified, and the impact that these properties can have on the performance and durability of engines and fuel system components have been discussed. The purpose of this chapter is to identify the engines and fuel system components used in Army aircraft, discuss the interface between the components and the fuel, and identify specific potential problems. In general this discussion will address materials compatibility since this is the most significant area of impact with most components.

Materials compatibility can be reduced to elastomer compatibility if one makes the assumption that the synthetic and alternate fuel will meet the same restrictions on corrosion that JP-4 does. This is a reasonable assumption since there is no desire to allow corrosiveness in a fuel whereas there is pressure to increase the aromatic content of JP-5. The sensitivities of elastomers to fuel properties, namely aromatic content, were discussed earlier in this report. It is sufficient here to say that higher aromatic concentrations cause Buna N to swell considerably; while this is generally not a problem in static seals it can be a problem in dynamic applications and perhaps flexing diaphragms. Quite often the compatibility depends on the specific application and whether or not the distress is acceptable or within design limits.

A. Army Aircraft

The U.S. Army has a variety of jet engine aircraft. Table 13 lists the aircraft considered in this program. This list identifies the airframes, engines, auxiliary power units, and their manufacturers. Most of the U.S. Army's aircraft are helicopters that are powered by five different types of engines. Some of the larger helicopters have airborne

Table 13. Army Aircraft, Engines, and APU's

Airframe			Engine		Auxiliary Power Unit	
Model	Name	Manufacturer	Model	Manufacturer	Model	Manufacturer
H-1	Cobra	Bell	T53	Lycoming	--	--
H-6	Cayuse	Hughes	T63	Allison	--	--
H47	Chinook	Vertol	T55	Lycoming	T62T-2A1	Turbomach
H54	Skycrane	Sikorsky	T73	PWA USA	T62T-16A1	Turbomach
H-58	Kiowa	Bell	T63	Allison	--	--
H-60	Black Hawk	Sikorsky	T700	G.E.	T62T-40-1	Turbomach
H-64	Apache	Hughes	T700	G.E.	GTCP36-55H	AiResearch
C-12	Huron	Beech	T74	PWA Canada	--	--
OV-1	Mohawk	Grumman	T53	Lycoming	--	--
U-21	UTE	Beech	T74	PWA Canada	--	--
UV-18	Twin Otter	DeHavilland	T74	PWA Canada	--	--

auxiliary power units. These units usually provide starting capability, electric power, and, in some cases, hydraulic power. All of the fixed-wing aircraft are powered with either T53 or T74 turboprop engines. The effects of reduced fuel hydrogen content on low-cycle thermal fatigue life was discussed earlier in the report as were the impact of viscosity and volatility on cold day ignition. These are the major areas of impact of potential fuel variation on engine performance and durability.

B. Army Aircraft Fuel Systems

There are two basic types of fuel systems used in Army aircraft:

- Pressurized versus suction
- Crashworthy versus non-crashworthy

The first refers to the method of fuel delivery from the fuel cells to the engine. The second is a design criteria for components to improve helicopter crash safety. Other complexities depend upon the aircraft mission requirements, the number of engines used, fuel crossfeed capabilities, fueling/defueling capabilities, and other airframe design requirements.

An extensive survey was conducted with the assistance of AVRADCOM personnel to identify the fuel system components. The detailed component lists are provided as appendices to this report as follows:

Appendix	Contents
A	Airframe Fuel System Components
B	Engine Fuel System Components
C	APU Fuel System Components

1. H-1 Fuel System

The Army has a variety of different models of the H-1 helicopter, as noted below:

Aircraft Type	Engine Used	Popular Name
UH-1B	T53-L-11D	Huey/Iroquois
UH-1C	T53-L-11D	Huey/Iroquois
UH-1D	T53-L-11D	Huey/Iroquois
UH-1H	T53-L-13B	Huey/Iroquois
UH-1Q	T53-L-13B	Huey/Iroquois
UH-1M	T53-L-13B	Huey/Iroquois
EH-1H	T53-L-13B	Huey/Iroquois
AH-1G	T53-L-13B	Cobra
TH-1G	T53-L-13B	Cobra
AH-1S	T53-L-703	Cobra
AH-1Q	T53-L-13B	Cobra

The Huey and Cobra aircraft have similar fuel systems. Figure 9 illustrates the fuel system schematic for the AH-1G. Fuel is contained in two interconnected fuel cells. An electrically-driven, centrifugal boost pump is provided inside each cell. Fuel is directed to a common manifold valve (containing two check valves and two thermal relief valves) and then to the main fuel shutoff valve. From these, the fuel is directed through a fuel filter to the engine fuel pump/fuel control system. The fuel tanks are vented together. Capacitance-type, fuel-level sensors are used for total fuel quantity and low fuel indication. Sump drain valves are provided at low points in each fuel cell. Aircraft fueling is performed at the left fuel-cell filler cap. The incoming fuel will fill both tanks through a crossover pipe. A swing/flapper type check valve is used in the right tank.

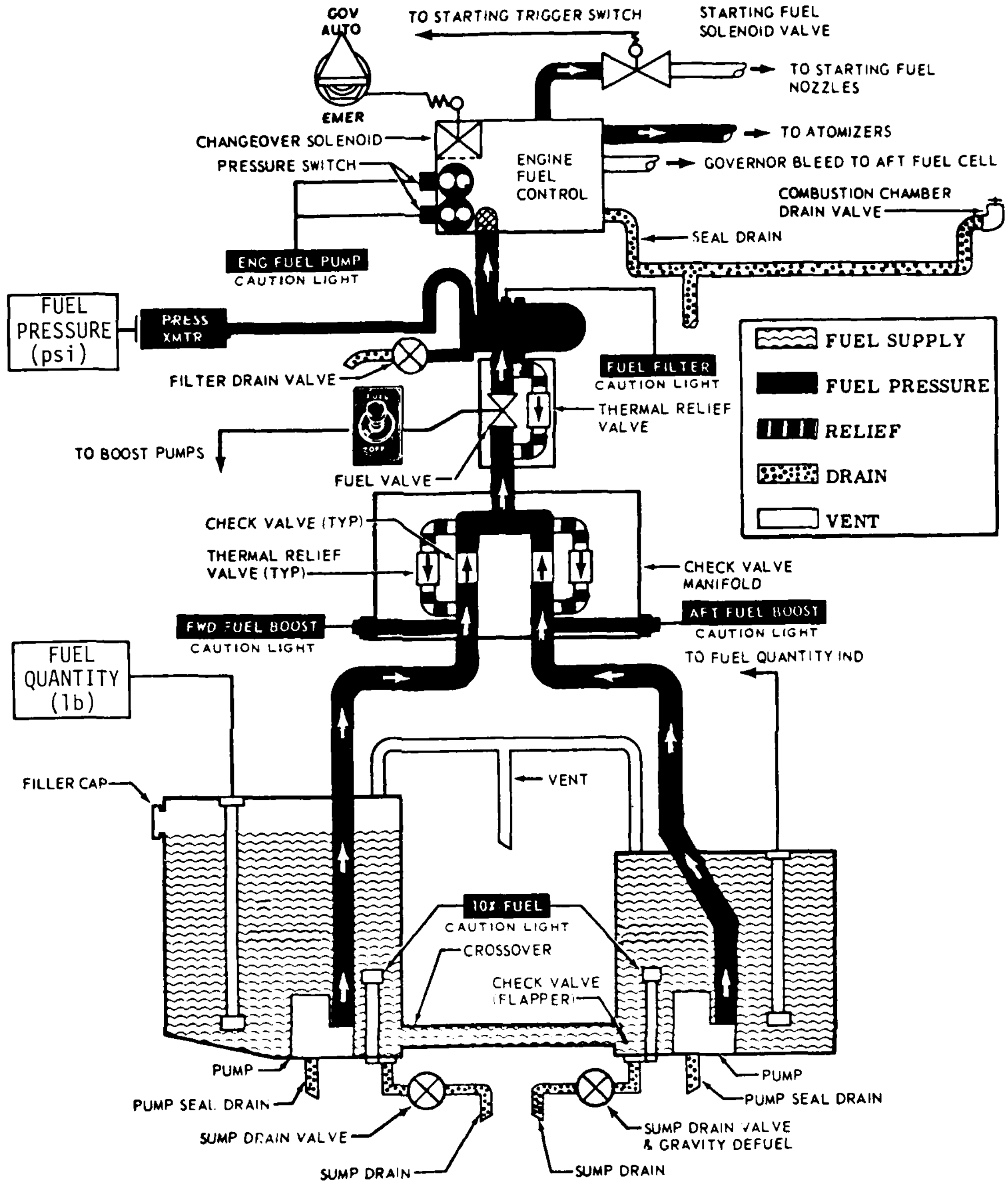


FIGURE 9. AH-1G FUEL SYSTEM SCHEMATIC

The fuel system used in the UH-1 (no figure provided) is somewhat different. The fuel is contained in five fuel cells interconnected to act as a single tank. Three cells are located across the fuselage below the engine deck with a filler cap on the right cell. Two forward cells (located under the cabin floor and gravity fed from the aft cells) are provided with a fuel boost pump. The right pump is electrically operated and the left pump is driven by bleed air from the engine compressor. An ejector pump is also used in the left and right fuel cells. Fuel under pressure is delivered from the boost pumps through separate lines to a check valve manifold located on the front of the engine firewall. The fuel then passes through two check valves in a single outlet manifold to an electrically controlled main fuel shutoff valve. As in the AH-1G fuel system, the fuel then goes to a fuel filter and to the engine. The fuel shutoff valve and each check valve in the manifold have internal bypass valves to relieve thermal expansion of trapped fuel when the system is inoperative. Sump drain valves are provided. The left-hand, center, and right-hand fuel cells are interconnected together and vented to the atmosphere.

2. H-6 Fuel System

The H-6 aircraft is a small, single-engine, observation helicopter designated as the OH-6A.

Figure 10 shows a schematic representation of the fuel system. This crashworthy helicopter has self-sealing hoses and several breakaway fittings. Fuel may be introduced into the aircraft by gravity or through a closed-circuit fuel receiver assembly. Two interconnected self-sealing bladders are used. Fuel is directed from a submerged centrifugal boost pump to a submerged fuel shutoff valve to a fuel outlet valve. The fuel then passes through the other half of the fuel outlet valve (in-line fuel valve) through a self-sealing hose to the engine. Vent valves are

Figure 10. OH6A Fuel System Schematic

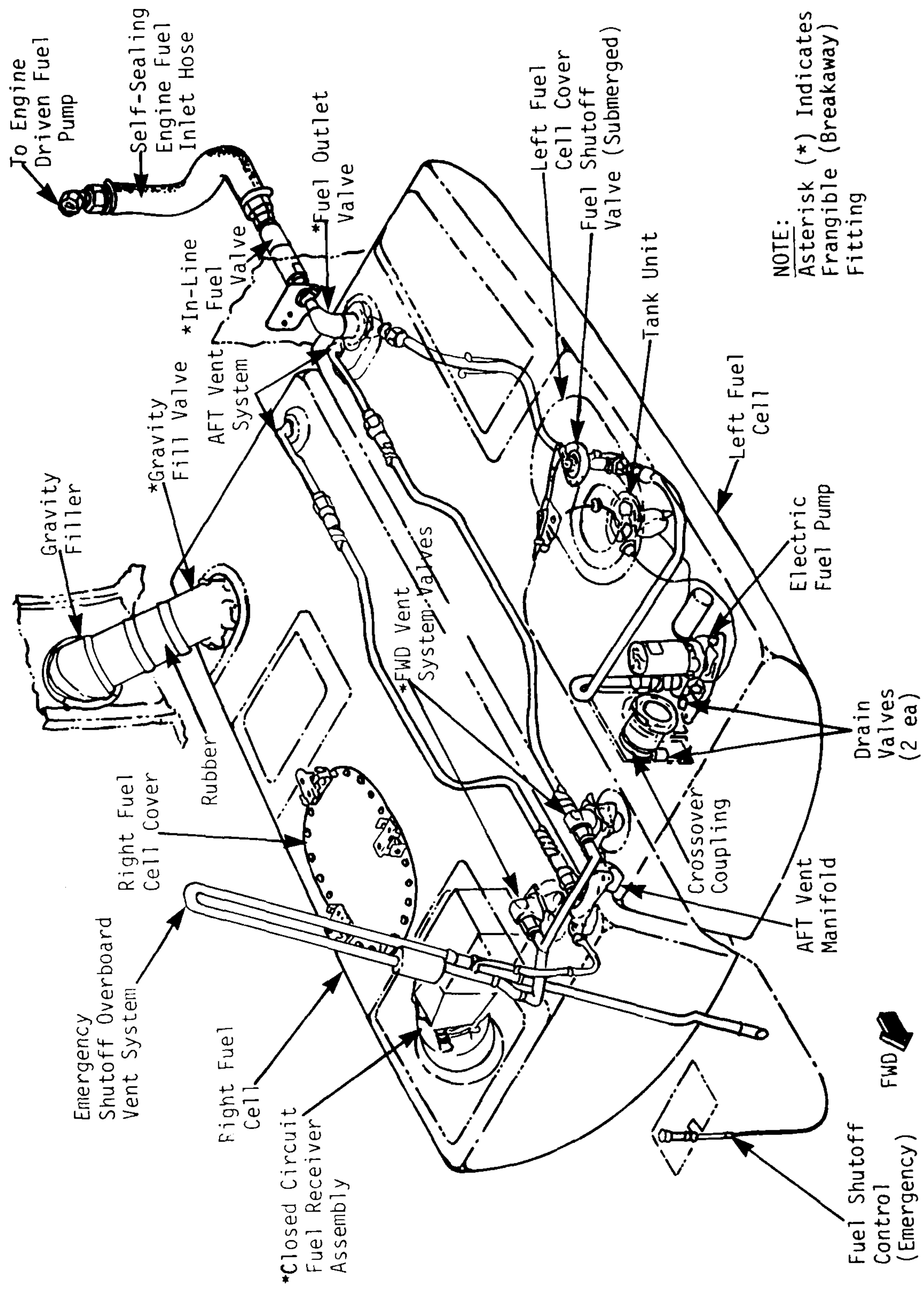


FIGURE 10. OH6A FUEL SYSTEM SCHEMATIC

located forward and aft of the fuel cells and are interconnected to an emergency shutoff overboard vent system. The fuel shutoff valve (mentioned earlier) is actuated from the cockpit by a control cable. The level of the fuel is sensed by a float-lever-electrical system rather than the usual capacitance types. This is the simpliest fuel system used in any of the Army's fixed- or rotary-wing aircraft.

3. H-47 Fuel System

The following models of the H-47 cargo helicopter are used by the Army:

Aircraft Type	Engine Used	Popular Name
CH-47A	T55-L-7C	Chinook
CH-47B	T55-L-7C	Chinook
CH-47C	T55-L-11/11A /ASA/11D/712	Chinook
CH-47D	T55-L-712	Chinook

This twin-engine aircraft has basically the same type of fuel system for all of the models noted above (no figure provided). The aircraft uses a total of six bladder-type fuel cells that are fueled by six independent gravity filler caps. The CH-47D model is being modified to have a closed-circuit fuel receiver for single point fueling. The six fuel tanks are distributed throughout the aircraft, with two auxiliary tanks forward, two main tanks, and two more auxiliary tanks aft. The fuel system has complete crossfeed capabilities for supply fuel to either or both engines from any fuel tank. Each fuel tank has a submerged boost pump with a check valve to ensure proper fuel flow direction. Each of the main fuel tanks has a thermal-relief check valve and other appropriate check valves along with three fuel-level measuring probes. Pressure switches are also provided at the discharge of each of the boost pumps. Each tank has two drain valves located at low points in the fuel cells. Other drain valves are located throughout the system plumbing. A fuel control panel (located in the cockpit) provides fuel quantity indication for the fuel tanks and pump control for normal engine fueling and crossfeed control. The main fuel system also has a connection for a ferry fuel tank which can be carried inside the helicopter.

A separate fuel boost pump, a manual shutoff valve, and a solenoid-operated shutoff valve are also provided for fuel supply to the auxiliary power unit.

4. H-54 Fuel System

The fuel system of the twin-engined UH-54 utility helicopter (no figure provided) has forward, aft, and auxiliary fuel tanks. Two boost pumps are used in each of the forward and the aft fuel tanks. The auxiliary fuel tank has two fuel transfer pumps capable of transferring fuel to the forward or aft tanks. A crossfeed valve is provided along with appropriate engine fuel shutoff valves and an auxiliary-power-unit fuel shutoff valve. The aircraft is fueled through three closed-circuit fuel receivers (one per tank). Appropriate drain valves are also provided at low points in the tanks.

5. H-58 Fuel System

Two models of the H-58 helicopter are used:

Aircraft Type	Engine Used	Popular Name	Fuel System
OH-58A	T63-A-700	Kiowa	Noncrashworthy
OH-58C	T63-A-720	Kiowa	Crashworthy

This small single-engine observation helicopter has a single L-shaped fuel cell located beneath and in back of the pilot's seat. Only the lower half of the fuel cell is constructed of self-sealing material on the non-crashworthy OH-58A aircraft. In the crashworthy OH-58C aircraft, the entire fuel cell is self-sealing, with self-sealing hoses and breakaway fittings.

The fuel system (no figure provided) uses gravity fueling to fill the fuel cell. A submerged boost pump is used to supply the fuel through a breakaway valve to a shutoff valve. A pressure sensor is provided to indicate fuel pressure. The fuel is then directed through a filter to the engine. A tank vent is provided along with a sump drain-defuel valve. Capacitance-type fuel-level sensors monitor the fuel quantity. A fuel low-level switch is also used to indicate that twenty minutes of fuel remains in the tank.

6. H-60 Fuel System

The UH-60A is the Army's newest utility helicopter. Two T700-GE-700 jet engines are used for propulsion along with an airborne T62 auxiliary power unit. Figure 11 illustrates the fuel system schematic for the UH-60A helicopter. This crashworthy fuel system utilizes two self-sealing fuel cells that are supported by fiberglass liners. A 3-inch layer of purple (fire-explosion suppression) foam is used adjacent to the outside of the fuel cell liners. Foam is not used inside the fuel cells. The foam (made by the Foam Division of Scott Paper Company) is used to prevent explosions by acting as a void filler around the outside of the fuel cells.

As noted in Figure 11, the aircraft can be fueled by gravity and pressurized closed-circuit fueling methods. A suction-type fuel system is used in flight. The fuel system serving engine 1 and the left fuel cell is identical to the other half of the fuel system serving engine 2 and the right fuel cell. An electric pump (located outside of the fuel

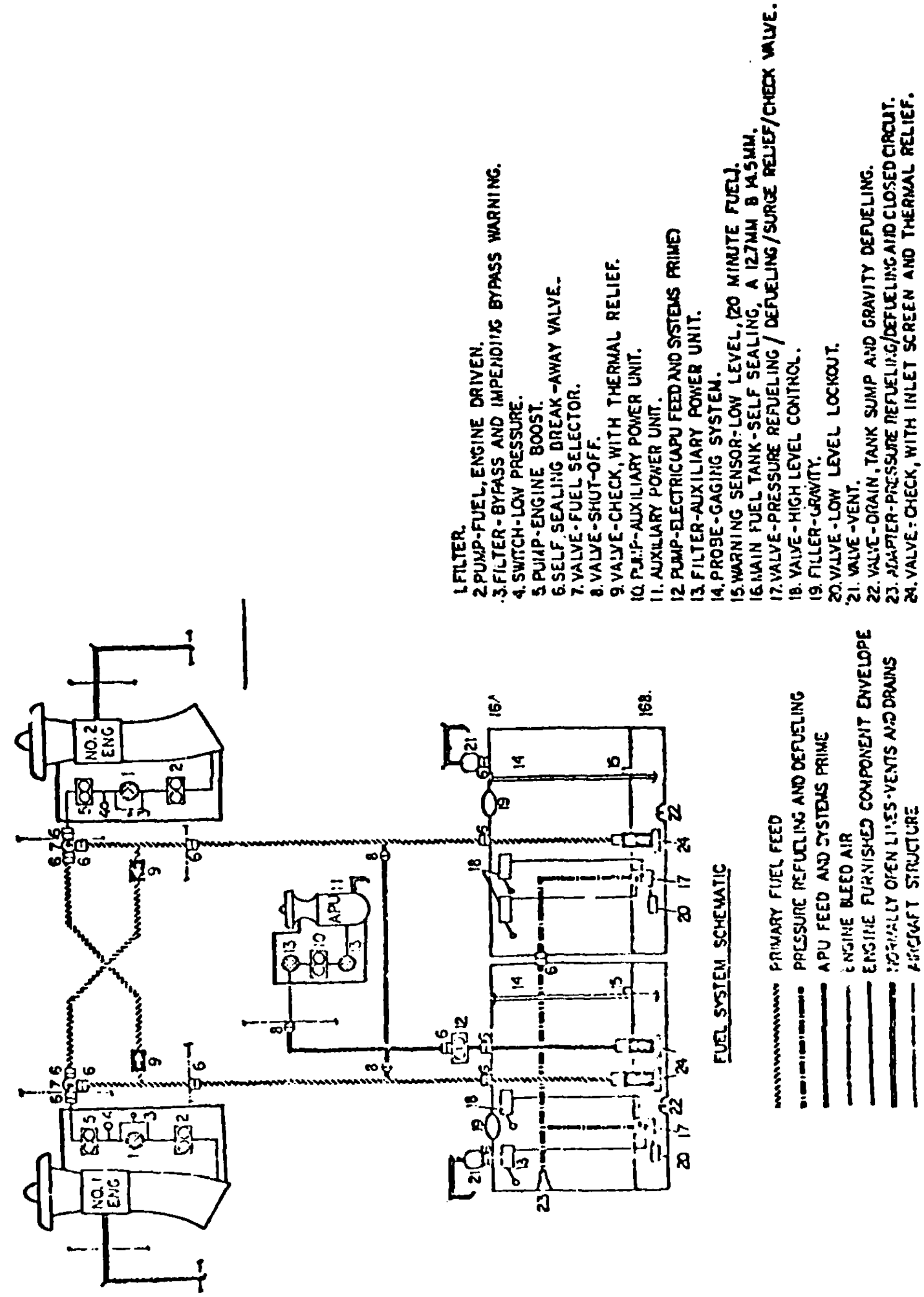


FIGURE 11. UH-60A FUEL SYSTEM SCHEMATIC

bladder) primes all of the fuel lines providing fuel up to the engine boost pump and the APU pump. Once the engine is started, the engine-operated boost pump provides the necessary suction to draw the fuel from the fuel tank. Complete crossfeed capabilities are provided to supply fuel to either engine from either tank. Fifteen breakaway self-sealing valves are used throughout the fuel system while six check valves are used to control the direction of the fuel flow. The fuel level in each tank is monitored by a capacitance probe. High-level float control valves are provided to shut the fuel off during fueling operations. Appropriate vent and fuel tank drain valves are used.

The UH-60A also has the capability of accepting a range extension kit. Figure 12 shows the fuel system schematic for the auxiliary fuel system and its connection to the main fuel tanks. Two self-sealing auxiliary fuel tanks are used with breakaway, self-sealing couplings. A positive-displacement vane pump is used with each auxiliary fuel tanks to lift and transfer the fuel through a check valve. A motor-operated transfer valve is used to allow the fuel to flow to the main fuel tanks. An emergency motor-operated dump valve is also provided. Both of the fuel tanks are filled by gravity. Empty tank sensors and appropriate vent valves are provided for each tank.

7. H-64 Fuel System

The YAH-64 is the Army's newest preproduction attack helicopter called the Apache. This aircraft is also powered by two T700-GE-700 engines and has an airborne GTP36-55H auxiliary power unit.

The crashworthy fuel system (no figure provided) has forward and aft self-sealing fuel cells. Fuel may be introduced by gravity or pressure fueling. An air-driven boost pump is used to direct the fuel to the engine. Fuel is transferred from the forward cell to the aft cell by

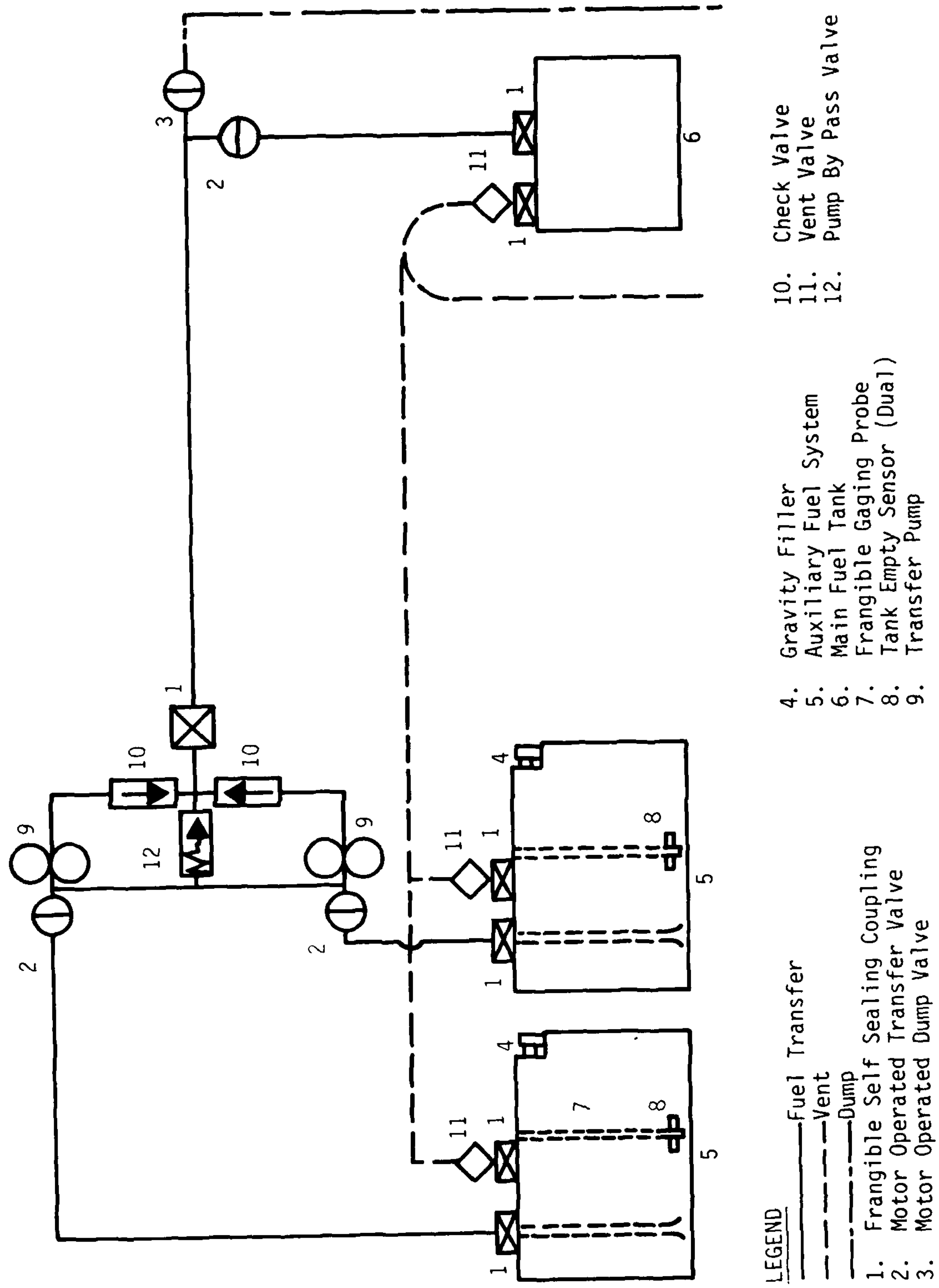


FIGURE 12. UH-60A RANGE EXTENSION KIT FUEL SYSTEM SCHEMATIC

means of an external air-driven transfer pump. An external aluminum fuel tank is also available for mounting on the aircraft pylon. Breakaway valves are used throughout the fuel system along with fuel vent valves, a fuel transfer valve, and engine fuel shutoff valves.

8. C-12 Fuel System

The C-12 aircraft is one of the four fixed-wing aircraft used by the Army. These commercially-purchased aircraft are powered by two PT6 PWA turboprop engines (T74 is the military designation for the same engine).

Figure 13 illustrates one half of the fuel system used in the C-12 aircraft. Each wing has four nonselfsealing bladders interconnected to each other and to a wet wing tank. Fuel from these tanks is gravity fed to a feeder tank (called a nacelle tank). Fuel from the feeder tank is pumped to the engine by a jet-type transfer pump. A crossfeed valve is used to interconnect to the other engine and the other half of the fuel system. Check valves and suction relief valves are used throughout the system along with drain valves and vent float valves. Most of the fuel system components used in the C-12 aircraft are the same as the ones used in the U-21 fixed-wing aircraft.

9. OV-1 Fuel System

There is a total of about 200 OV-1 fixed-wing aircraft in the Army inventory. The twin-engine aircraft is powered by two Lycoming T53 engines of the models noted below:

Aircraft	Engines
OV-1B	T53-L-7A
OV-1C	T53-L-7A/15
OV-1D	T53-L-701A
RV-1D	T53-L-701A

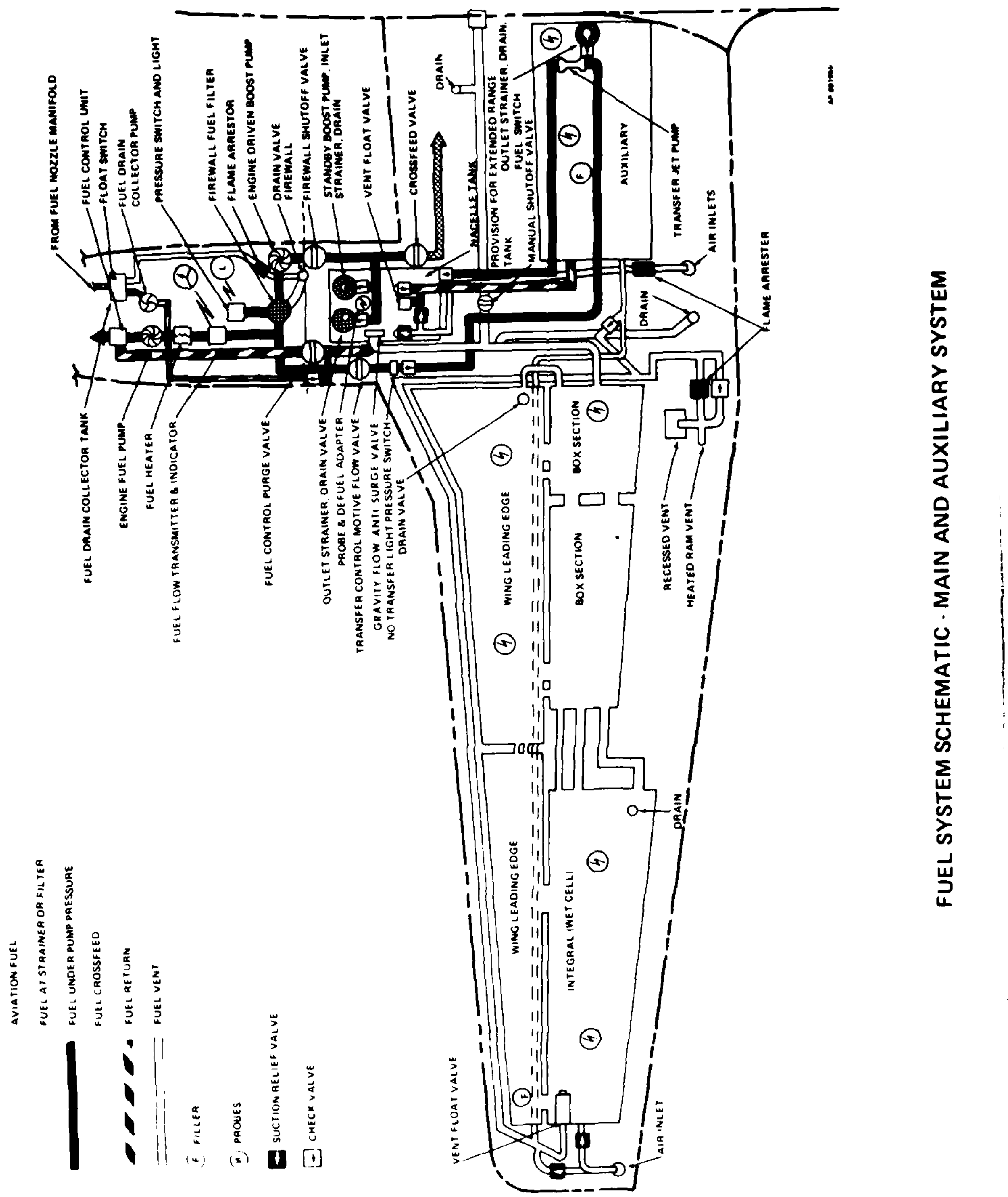


FIGURE 13. C-12 FUEL SYSTEM SCHEMATIC

The OV-1 aircraft is qualified to operate on JP-4, JP-5, JP-8, Avgas, unleaded gas, and leaded fuels. A maximum operation time of 50 hours is allowed for operation using leaded fuel; extended operation with leaded fuels can cause damage to the turbine blades.

The OV-1 fuel system (no figure provided) has one self-sealing, 350-gallon, main fuel tank and two 150-gallon aluminum drop tanks. Vane pumps are used to transfer fuel from the drop tanks to the main fuel tank. The aircraft is generally fueled/defueled through the single-point nozzle (pressure fueling), but gravity fueling capability is also provided.

During a typical pressure-fueling operation, the fuel is directed through the pressure-fueling adapter to the main fuel tank and through a pilot float valve to a solenoid-operated shutoff valve (both of which are located inside the tank). The pilot valve has dual floats. As the fuel rises in the tank the pilot float valve senses the fuel level. Once the fuel reaches the maximum level, the pilot float valve shuts off, creating a pressure difference which actuates the solenoid shutoff valve and stops the fueling operation.

Fuel is directed to the engines by two submerged dual-impeller boost pumps (one forward and one aft in the main fuel tank). An ejector pump is also used as a backup for the forward boost pump. Several check valves (swing- and ball-type) are used to maintain the correct fuel flow direction. Three motorized gate valves are used in this system: 1) between the pressure-refueling and the main fuel tank, 2) between the left engine and the main fuel tank, and 3) between the right engine and main fuel tank. The gate valves for the right and left engines are actuated every time the engine is started.

The main fuel tank has an access port with a cover assembly. This oval access port uses a large Neoprene gasket to seal the port to the cover. The gasket is exposed to fuel vapors and some fuel sloshing which aggravates the Neoprene material causing it to swell.

10. U-21 Fuel System

The Army has about 150 U-21 fixed-wing aircraft powered by two Pratt and Whitney T74-CP-700/702 turboprop engines. The different Army aircraft types and engine models are noted below:

Aircraft	Engine
U-21A/D/F/G/H	T74-CP700
RU-21A/D/H/E	T74-CP700
RU-21B/C	T74-CP702

Figure 14 illustrates the fuel system used for the RU/U-21 aircraft. A total of 370 gallons of usable fuel is stored in several nonself-sealing fuel cells. Each wing has four interconnected fuel cells. The fuel from these cells is directed to a feed tank by gravity and pumped by a transfer pump to another fuel cell (nacelle tank). Fuel from the nacelle tank is pumped by a boost pump to the engine. A complete duplicate system is used for the other wing-to-engine fuel system. Crossfeed capabilities are provided to transfer fuel to either engine. Since the fuel system uses a large number of fuel cells and has crossfeed capability, a large number of check valves are used.

11. UV-18 Fuel System

The Army has less than five of the UV-18A fixed-wing aircraft, each powered by two T74 engines. No additional information was obtained.

C. Airframe Fuel System Components

Most of the fuel systems described above are composed of the same types of components. The following discussion addresses the design,

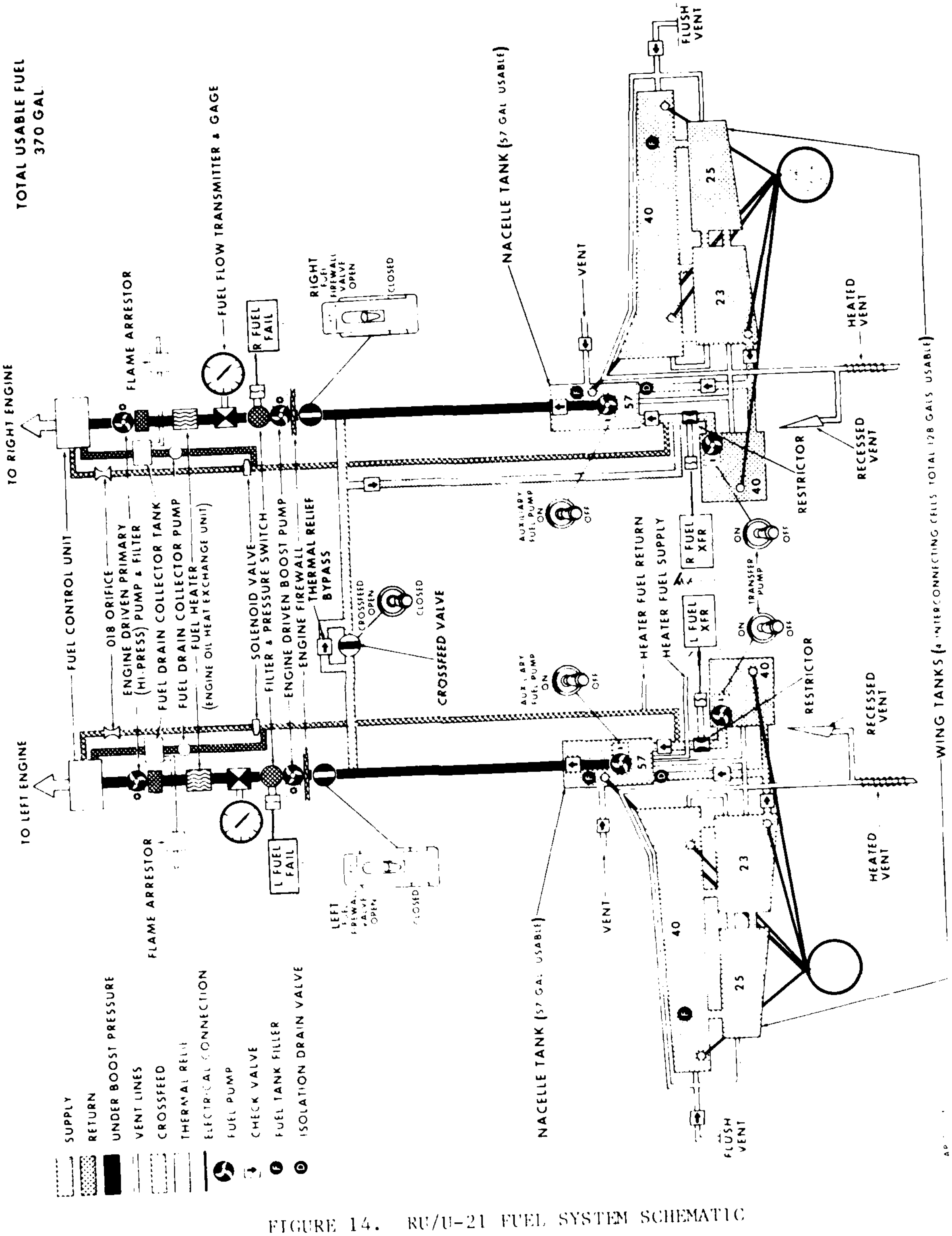


FIGURE 14. RU/U-21 FUEL SYSTEM SCHEMATIC

function, and materials generally used in these components. In most cases the designs and materials are similar even though the manufacturers may be different.

During discussions with the Army maintenance people and the airframe and component manufacturers, several actual and potential problems that could be related to fuel sensitivities were identified; these are mentioned and assessed in the following discussion.

1. Self-sealing Hoses

Virtually all of the Army helicopters and the OV-1 fixed-wing aircraft use self-sealing hoses in the fuel system. Old type (World War II vintage) self-sealing hoses used a Buna N liner (adjacent to the fuel)surrounded by a wire braid and a special butyl-rubber outer hose. These hoses comformed to the following specifications:

MIL-H-83796	Hose assembly
MIL-H-83797	Hose material
MIL-H-83798	Fittings used

The special butyl rubber would act as the self-sealing member. (24)

Current Army self-sealing hoses are designed in accordance with MIL-H-7061A, dated 6 June 1968. These hoses are usually supplied by Aeroquip and/or Stratoflex Incorporated. The hose usually has a nylon or wire braid on the outside conforming to MIL-C-83291 or MIL-C-83797. Two hose designs are used: 1) an outer braid with a thick innerliner or, 2) a medium thickness self-sealing outer rubber hose , a nylon or wire braid, and a Buna N innerliner. Bulk self-sealing hose materials are usually supplied by the B.F. Goodrich Company.

Generally the airframe manufacturers, such as Bell, Boeing Vertol, Hughes, and Sikorsky, have their own control specification drawings for self-sealing hose testing. In addition, the airframe manufacturers and the hose manufacturers believe that the MIL-H-7061A specification is out-of-date for current aircraft fuel systems and should be updated. It has been recommended that the Army ask the SAE G3 committee to update the self-sealing hose specification. The Air Force is custodian for the MIL-H-7061A specification; however, the Air Force does not use any self-sealing hoses. (25)

Only one isolated problem area was reported on a self-sealing hose: that used on the YAH-64A preproduction helicopter. The problem was with a 5/8-inch self-sealing hose used inside a fuel cell (submerged). The hose operates in a suction-type fuel system and reportedly collapsed internally, restricting the fuel flow and thereby preventing engine starting. The reason the hose collapsed could not be verified; however it is believed that a high aromatic fuel could have been the problem. The thick innerliner hose material is said to be a combination of acrylonitrile and SBR (styrene and butadiene) rubber. The hose manufacturer has since discontinued the 5/8 inch hose and recommends a 3/4 inch hose or a modified hose having lower swell characteristics. Although this is an isolated case, it is definitely a potential problem area.

Most of the concern with JP-5 type fuels has been with fuels having high aromatic content, i.e., above 25%. Future shale-derived JP-4 fuel will probably have a relatively low aromatic content, on the order of 5 - 10%. Although no tests have been performed using very low aromatic content fuels, B.F. Goodrich believes that under normal operation self-sealing hoses will operate satisfactorily. The most crucial time for the self-sealing hoses (as far as sealing) will be during the gunfire tests. These tests are usually performed at Aberdeen Proving Grounds and

Aeroquip. It is possible the self-sealing hoses would not seal under gunfire tests with low aromatic fuels, particularly at low temperatures. Controlled tests have been recommended to determine the effectiveness of the self-sealing hose with low-aromatic fuels. (26) Such testing should have been conducted in the qualification testing, however, per MIL-H-7061A.

2. Gate Valve, Motorized

The electrically-operated, motorized gate valve is used primarily as an engine fuel shutoff valve. From one to four of these valves are used on essentially all of the Army aircraft. The valve consists of a metal blade (called the gate) connected to a geared-down electric motor. Most gate valves have an external lever on the valve for manual operation. The lever will also identify whether the valve is open or closed. Sealing of the fuel is provided by two cylindrical seals, one on each side of the blade.

It was suggested that excessive swelling of the seal material might cause an increase in friction leading to extrusion and failure of the seal.

These valves are manufactured by ITT/General Controls. The gate seals are fabricated by Royal Seals from a thiokol-based material which is said to be much more resistant to aromatics than Buna N. (27)

3. Check Valve, Poppet

Check valves of several designs are used extensively in all aircraft fuel systems. Poppet-type check valves are the most popular and are generally used in pressure relief applications. This type of valve usually consists of a thin rubber disc attached to an inline, spring-loaded plunger; only a light spring force is required. Buna N is quite often used for the seal but it is a face seal and essentially static in application. A problem could occur if the adhesive bond between the rubber and metal were weakened by the fuel.

4. Check Valve, Swing/Flapper

Swing- or flapper-type check valves are usually used when a low pressure drop is important. The swing check valve usually consists of a disc that is hinged inside a cylindrical tubing connector. A rubber disc is bonded onto the metal disc (flapper). The disc is usually spring loaded (light spring force) closed. A few of the swing valves use a captive (static) O-ring in the valve. Too much swell can cause the O-ring to come out of the groove when the valve opens. The face seals are very similar in action to those described above and no problems are foreseen with the fuels included in this study.

5. Closed-Circuit Receivers

Several Army aircraft types have provisions for single-point or pres-surized refueling. A standard closed-circuit fuel receiver (CCR) is used. The CCR has a spring-loaded poppet seal with a float mechanism and a diaphragm. Both static and dynamic O-rings are used. Some concern was expressed about sealing on the AH-1 and UH-1 helicopters. There have been some field problems with the CCR on the OH-6A such that the receiver does not always shut off the fuel resulting in the rupture of both bladder tanks; consequently, gravity fueling is generally used on the OH-6A.

6. Electric Fuel Pumps

All Army aircraft use electric fuel pumps either to deliver fuel from the fuel cell to the engine or APU or to transfer fuel from one cell to another. Most of the motors are dry and therefore require shaft seals from the fuel; a few are wet motors. The shaft seals on all but one of the pumps are either carbon-faced seals or silicone and as such should have no fuel sensitivity. The one exception is the transfer pump on the "range extender kit" used on the U-21; this pump has Buna N shaft seals and could be a problem area.

7. Self-sealing Breakaway Valves

Breakaway valves are designed to break in-half at a frangible section upon impact. After breaking in half, both valve ends are designed to contain the fuel. Some designs use spring-loaded swing/flapper valves; others (on the AH-1 and UH-1) use a boot arrangement. Neither is considered to be a potential problem area.

8. Drain Valve, Poppet

Drain valves are used at low points on the fuel cells. Two types are used as noted below:

Type	Seal
Push axial	Static O-ring
Push-and-twist	Dynamic O-ring

A heavy spring is used to provide pressure against the O-ring for sealing. The axial push-type will only allow fuel to drain while the plunger is held in. The plunger can be actuated by a screwdriver or a special fuel collector jar. The push-and-twist-type drain valve can be locked open, allowing all of the fuel to drain. Depending upon the specific drain valve design, swelling could cause the O-ring to come out of the groove when the valve is opened.

9. Vent Valve, Poppet

Vent valves are used in virtually all airframe fuel systems. Figure 15 shows a poppet-type vent valve used on the UH-60A helicopter. This valve uses Buna N and Teflon seals as noted, but the Buna N seals are either static seals or face seals. A compression spring is used to keep the poppet closed.

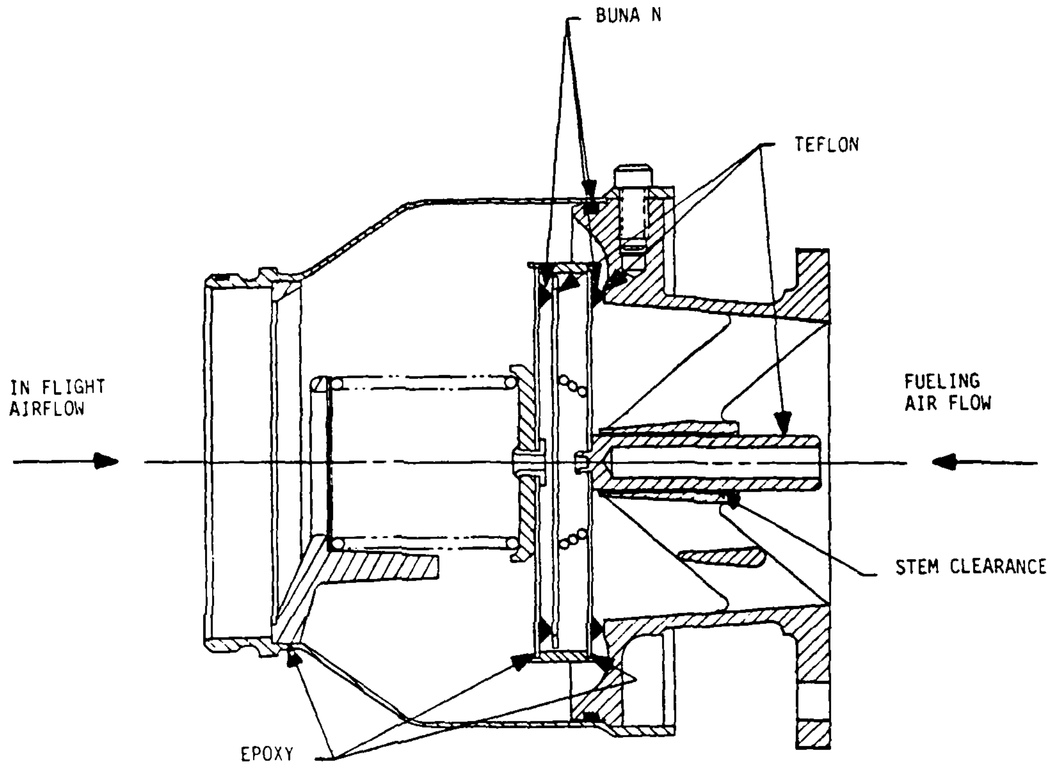
10. Fuel Tank Cover Gasket

The OV-1 fixed-wing aircraft has an oval cover assembly. The cover uses a large oval neoprene gasket in this access port. This neoprene gasket is exposed to fuel vapors and some fuel sloshing which causes the gasket to swell. Neoprene is known to be sensitive to peroxide formation and swelling when in contact with high aromatic fuels.

11. Shutoff Valves

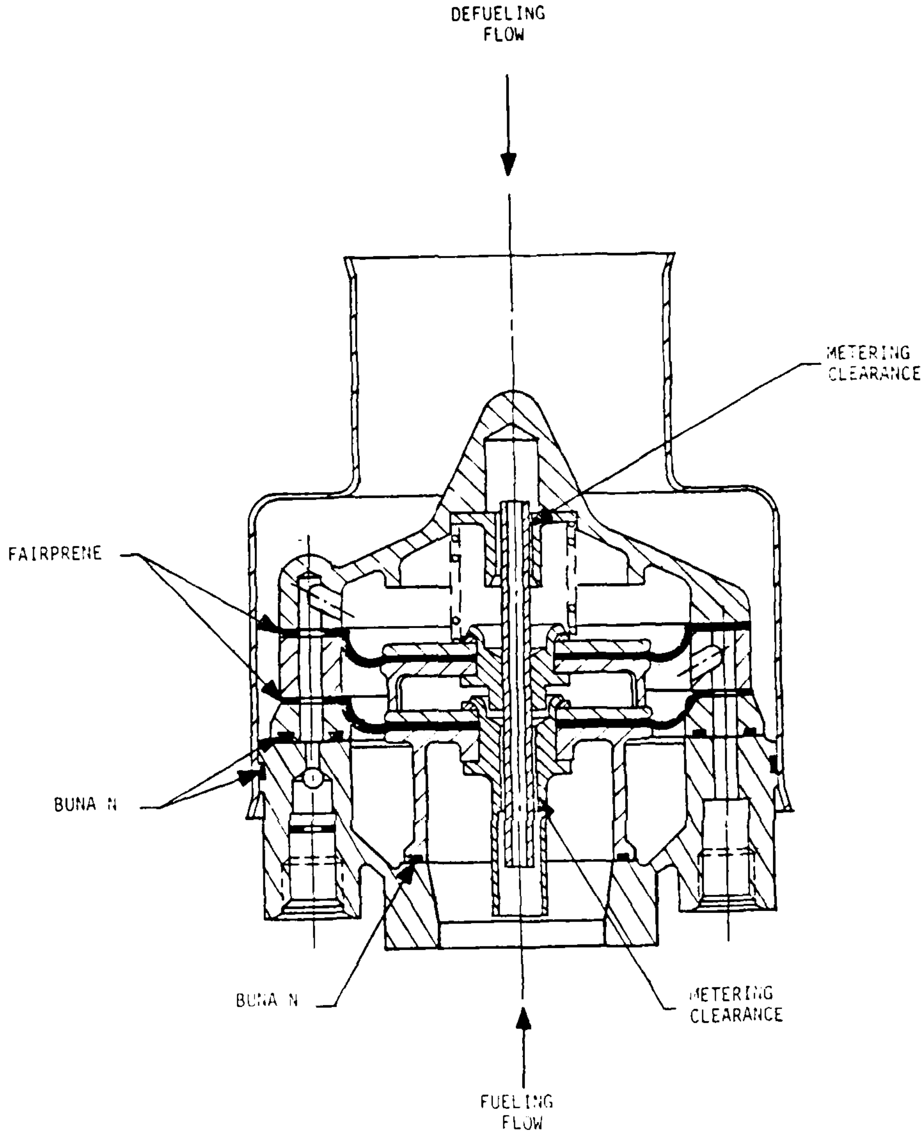
A large number of the Army aircraft use a fueling/defueling valve similar to the one used on the UH-60 helicopter (see Figure 16). This valve is used between the closed-circuit fuel receiver and the fuel cell. During fueling, its main purpose is to shut off the fuel flow. In addition, during defueling, its main purpose is to shut off the fuel flow whenever the tank is empty in order to prevent the boost pump from operating without fuel.

The main reason for including this figure is to show the different types of seals. This valve has three static O-rings, two dynamic diaphragms and one dynamic O-ring seal. Double diaphragms are used in the event one diaphragm fails. A compression spring is used to keep the valve closed. Pressure taps are provided for the high and low-level float valve connections. During fueling, the inlet fuel pressure raises



P/N 2750088-102 VENT VALVE
SIKORSKY SCD 70307-03007-103

FIGURE 15. EXAMPLE OF VENT VALVE USED ON UH-60A



P/N 2770052-101 FUELING, DEFUELING VALVE
SIKORSKY SCD 70307-03026-101

FIGURE 16. FUELING/DEFUELING VALVE USED ON THE UH-60A FUEL SYSTEM

the poppet valve (with the dynamic seal) allowing the fuel to flow. The fuel flows in an annular area around the valve to the fuel tank. As the tank fills, the high-level float valve closes, creating a pressure difference which is transmitted to the fueling/defueling valve lowering the poppet thereby shutting off the flow.

There are no current problems with valves of this type. Although, it is possible that the diaphragm could be affected by high-aromatic fuels particularly since considerable flexing occurs during fueling and defueling operations, these diaphragms are generally made of DuPont Fairprene which DuPont claims would have no difficulties with 30% aromatic fuels. The floats on the remote float valves are usually made of polyurethane foam or a nitrile rubber foam; in this application the nitrile rubber compound is not fuel sensitive.

12. Fuel Cell Bladders

Fuel cell bladders have the largest contact area with the fuel of any fuel system component. There are basically two types of bladder fuel cells:

- Nonself-sealing
- Self-sealing

In addition, many of the army aircraft have crashworthy designs which basically means that the fittings attached to the bladder are of a breakaway design that seal off the fuel flow. This has nothing to do with the rest of the bladder construction and the fuel interface.

Both the self-sealing and nonself-sealing designs have Buna N liners. This liner may consist of Buna N rubber, Buna N coated square-woven fabric, or Buna N coated cord fabric. The purpose of the liner is to contain the fuel and provide protection for nylon film barrier which provides the mechanical strength. The difference is that the self-sealing bladders have two layers of of natural gum rubber sealant separated and protected by nylon fabric exterior to the nyon film barrier. These sealant layers are readily attacked by fuel regardless of composition. The purpose of the sealant is to effect the immediate closure of punctures in the fuel cell, thereby preventing the loss of fuel. The natural gum rubber sealant layers remain dormant until activated by exposure to fuel. The sealant acts to prevent leakage in the following manner. A mechanical reaction results at time of damage from the fact that rubber, both natural and synthetic, will "give" under the shock of impact, thereby limiting damage to a small hole in the fuel cell. The fuel cell materials will allow the projectile or other object to enter and leave the cell and then will closely approximate their original positions. This mechanical reaction is almost instantaneous. An accompanying chemical reaction occurs as soon as fuel vapors penetrate the inner-liner material and reach the sealant. The sealant, upon contact with the fuel vapors, will activate or swell to many times its normal size. This effectively closes the rupture and prevents the fuel from escaping. Typically, the self-sealing area of a fuel cell construction comprises two natural-gum-rubber sealant layers and one or two fabric layers. The fabric layers separate the two sealant layers and add support, particularly on the occurrence of damage that exposes the sealant to fuel. The exposed sealant is weakened by the fuel but the cord fabric aids in the retention of its shape and the alignment of the wound edges. (28) All three manufacturers of fuel bladders regularly test their bladders with the Type II fluid (40% aromatics). The Type I fluid (0% aromatics) is used in the qualification.

D. Potential Fuel Sensitive Areas - Engine Components

The main areas of concern are those having dynamic O-ring seal applications. Increased elastomer swell could cause:

- o Extrusion
- o Leakage
- o Increased friction force
- o Longer response times

Areas in the fuel controls and fuel pumps were studied in regard to dynamic seal applications. The information from a few examples are summarized below:

1. T53 Fuel Control

Information obtained from Corpus Christi Army Depot regarding dynamic O-ring applications on the T53 fuel control was discussed with the manufacturer, Chandler Evans. Most fuel controls have a large number of linkages which are external to the fuel control providing small axial or angular movement through various shafts to within the fuel-wetted fuel control. In the case of the T53 fuel control, these shafts are sealed by small O-rings. The other end of the shaft usually has a dual leather piston to provide a pressure or a flow change within the fuel control.

The following is a listing of the dynamic O-ring applications identified for the T53-L-13/-703 fuel control:

Fuel Control Area	Axial Movement	Angular Movement
Throttle shaft	No	Yes
RPM servo piston	Yes	No
Governor servo piston	Yes	No
P1 multiplier assembly (altitude compensator)	Yes	No
Change over piston assembly (automatic to emergency)	Yes	No
Emergency metering valve	No	Yes

All of the O-rings used in the T-53 fuel control are made of nitrile rubber (Buna N). Chandler Evans agrees that the dynamic O-ring areas noted above could be sensitive to high aromatic fuels.

2. T55-L-11A Fuel Control

The T55 fuel control is manufactured by Hamilton Standard. A study of the fuel control indicated that dynamic O-rings are used in the following areas:

Fuel Control Area	Axial Movement	Angular Movement
Min. pressure housing	Yes	No
Temperature control (actuating rod)	Yes	No
Windmill bypass valve	Yes	No
Compressor air (bleed assembly)	No	Yes
Linkage housing group		
N_1 Throttle shaft	No	Yes
N_2 Throttle shaft	No	Yes
Actuator shaft (for inlet guide vane)	No	Yes
Ratio servo cap (with Teflon guide)	Yes	No

Most of the axial movements are on [illegible] of 1/4 inch or less. Angular movement is only about 5 degrees,for the compressor air control while the N_1 throttle shaft is 55 degrees, N_2 throttle shaft is 100 degrees, and the actuator shaft is 45 degrees. All of the areas listed above are potential problem areas if too much swelling occurs in the O-rings.

3. T63-700/-720 Fuel Control

The T63 uses a simple pneumatic-hydraulic fuel control made by Bendix. There are several areas that have dynamic O-rings and diaphragms as follows:

Fuel Control Area	Axial Movement	Angular Movement
Torsion shaft (O-ring)	No	Yes
Cut-off valve linkage (O-ring)	No	Yes
Bypass valve (diaphragm)	-	-
PG&PR area on housing (diaphragm)	-	-

4. T55-7C Fuel Pump

The fuel pump used on the T55 engine is made by Sundstrand. Dynamic O-rings are used in the following area:

Fuel Pump Area	Axial Movement	Angular Movement
Journal thrust bearing (four areas)	Yes	No

The fuel pump also has a static diaphragm used in the N_1 spline drive shaft. The N_2 boost pump drive also has a static O-ring seal.

5. <u>T55-L-11A/-11D Fuel Pump</u>

The fuel pump used on the T55-L-11A/-11D engines is also made by Sundstrand. CCAD personnel identified the following dynamic O-ring seal areas:

Fuel Pump Area	Axial Movement	Angular Movement
N_1-N_2 drive (two areas)	No	Yes (very fast)
Journal thrust bearing	Yes	No
Spline shaft (between F/P & F/C)	No	Yes

E. <u>Potential Fuel Sensitive Areas - Auxiliary Power Units</u>

It is anticipated that very few problems will arise in the Army's airborne auxiliary power units in relation to elastomer compatability with higher aromatic content fuels. The types of elastomers used in the auxiliary power units may be summarized as follows:

Aircraft	Auxiliary Power Unit	Primary Elastomers
H-47	T62T-2A1	Buna N
H-54	T62T-16A1	Buna N
H-60	T62T-40-1	Fluorosilicone
H-64	GTCP36-55H	Fluorosilicone

The fuel systems for the APUs have very few fuel-wetted components, and the fuel controls have very few parts since the engines operate at a constant speed.

F. Non-metallic Materials Used In Fuel-wetted Systems

Based on the survey of fuel-wetted components (Appendix A, B, and C), the following non-metallic materials have been identified:

Elastomers	
Buna N	Most Common
Fluorosilicone	
Teflon	
Nylon	
Silicone	
Epoxy	
Glassfiber	
Dyallyl Phthalate	
Delrin	
Vespel	
Fluorocarbon	
Neoprene	Least Common

1. Buna N

The most commonly used elastomer used in the Army jet aircraft fuel systems is a nitrile-type rubber designated Buna N. Nitrile, chemically, is a copolymer of butadiene and acrylonitrile. Acrylonitrile content is varied in commercial products from 18% to 48%. As the nitrile content increases, resistance to hydrocarbon fuels increases but low temperature flexibility decreases. Buna N has a temperature range of -65 to +250°F (-54 to +121°C). (17) Generally Buna N works well in the current fuel system.

Trade Name	Supplier
Chemigum	Goodyear Tire & Rubber Co.
FR-N	Firestone Synthetic Rubber & Laytex Co.
Paracril	Uniroyal
Hycar	Goodrich Chemical Co.
Krynac	Polysar, Ltd.
Ny Syn	Copolymer Rubber & Chemical Corporation

2. Fluorosilicone

Fluorosilicone combines the good high-and-low temperature properties of silicone with basic fuel resistance. The primary uses of fluorosilicones are in fuel systems at temperatures up to 350°F (177°C) and in applications where the dry-heat resistance of silicone is required. Fluorosilicones have excellent fuel restriction but are subject to compression set. High strength fluorosilicones have been recently developed, and certain of these exhibit much improved resistance to compression set. (17) Fluorosilicone elastomers are used in the Army aircraft fuel system for the UH-60, YAH-64, fuel pumps, fuel controls, and some APUs.

Typical trade name is:

Trade Name	Supplier
Silastic L.S.	Dow Corning

3. Teflon

There is a family of (fluoroplastic) thermoplastic materials called polytetrafluoroethylene (PTFE/TFE) and fluorinated ethylene propylene (FEP) that are commonly referred to as Teflon (trademark for E.I. duPont de Nemours Company). Teflon can be used successfully in hydrocarbon fuels and has a usable temperature range of -275 to 500°F (-171 to 260°C).

Teflon is generally not used as a sealing material because of its lack of resiliance but is very effective as a bushing in a poppet valve, an electrical insulation in a capacitance probe, a diaphragm in a pressure switch, or a ball in a fuel shutoff ball valve. No particular problems are anticipated with Teflon regarding high or low aromatics.

4. Nylon

Rigid nylon is used in many areas where Teflon is used in fuel system components. In addition, nylon is also used as spacers, guide bushings in float switches, and centrifugal pump impellers. The material has excellent fuel resistant.

5. Silicone

The silicones are a group of elastomeric materials made from silicone, oxygen, hydrogen, and carbon. As a group, the silicones have poor tensile strength, tear resistance, and abrasion resistance. Special compounds have been made which have exceptional heat and compression set resistance. High strength compounds have also been developed, but their strength does not compare to conventional rubber. Silicones possess excellent resistance to temperature extremes. Flexibility below -175°F (-114°C) has been demonstrated. The maximum temperature at which silicones are recommended for continuous service in dry air is 450°F (232°C). Silicone's retention of properties at these high temperatures is uperior to other elastic materials. Silicone compounds are not normally recommended for dynamic sealing applications due to relatively low tear strength and high coefficient of friction (17).

Typical trade names are:

Trade Name	Supplier
Silastic	Dow Corning Group
No Trade Name	General Electric
No Trade Name	Union Carbide
No Trade Name	Stauffer Chemical Company

6. Epoxy, Fibers, Diallyl phthalate, Delrin, and Vespel

There are a variety of plastic materials that are used within the fuel-wetted systems. Epoxy is used in filters, capacitance gages and in sealing applications. Diaphragms may be made of nylon, Teflon, or Mylar materials with glass fibers incorporated for added strength. Boost and transfer pump impellers are sometimes made of a thermoset plastic called diallyl phthalate. One manufacturer uses Delrin as a poppet material on a manual-type ferry pump. Vespel (a polyimide thermoset plastic) is used as a vane material in an electric vane pump used on the ferry fuel system for the RU/U-21 aircraft.

7. Fluorocarbon

Fluorocarbon elastomers are being used in some fuel-wetted areas because of their very good resistance to hydrocarbon fuels. Their working temperature range is considered to be -40 to 400°F (-40 to 204°C). Some sources indicate that fluorocarbon seals have been known to seal at -65°F (54°C) in some static applications. (17) Most fuel system designes are reluctant to use fluorocarbon because of its problems iwth low temperature flexibility and compression set characteristics.

Typical trade names are:

Trade Name	Supplier
Neoprene	E.I. duPont de Nemours Company
Butaclor	Distugil
Petro-Texneoprene	Petro-Tex Chem. Co.

G. Summary

In summary, it is believed that the only significant impact from synthetic and alternate fuels will come in the area of LCF life of the combustor liner as hydrogen content is reduced; this is likely to happen if the JP-5 fuel specification is relaxed to improve availability. Cold day ignition problems with the alternate fuels, JP-5, JP-8, and Jet-A, should be no worse than they are currently with JP-5 being the worst case. There are potential problems with elastomer compatibility if the JP-5 specification is relaxed to allow higher aromatics, but this is doubtful since the JP-5 type aromatics have low solvent activity due to their high molecular weight; also the Navy would not relax the specification if their airframe fuel systems, which are similar to the Army's, were not compatible.

V. QUALIFICATION PROCEDURES FOR ENGINE AND FUEL SYSTEM COMPONENTS

In the previous chapter the engine and fuel-system components were discussed relative to their interface with the fuel, i.e., materials compatibility which was further reduced to elastomer compatibility. Buna N was found in numerous applications most of which were static seals, but a few included dynamic seals and disphragms where increased swelling could cause problems in performance or durability.

Although Buna N can be affected by aromatics depending on the composition of the elastomer, it is the specific application that determines the suitability, depending on temperatures, pressures, design, etc. The military uses standard qualification procedures for all engines, fuel system hardware, and elastomeric materials to ensure compatibility with fuels with the application and utilization of the components. For the discussion here the important military specifications are:

MIL-E-8593A	Engines, Aircraft, Turboshaft and Turboprop General Specification for (15 Oct 1975)
MIL-F-8615D	Fuel System Components, General Specification for (29 March 1976)
MIL-H-7061A	Hose, Rubber: Aircraft, Self-Sealing, Aromatic Type (6 June 1968)
MIL-T-5578C	Tank, Fuel, Aircraft, Self-Sealing (1 March 1974)
MIL-T-6396D	Tanks, Fuel, Oil, Water-Alcohol, Coolant, Fluid, Aircraft, Nonself-sealing, Removable Internal (30 August 1974)
MIL-P-5315B	Packing, Preformed, Hydrocarbon Fuel Resistant (2 December 1964)
MIL-R-6855	Rubber, Synthetic, Sheets, Strips, Molded For Extruded Shapes (8 September 1977)

MIL-R-25988	Rubber, Fluorosilicone Elastomers, Oil- and Fuel-Resistant, Sheets, Strips, Molded Parts, and Extruded Parts (4 June 1975)
MIL-R-83248	Rubber, Fluorocarbon Elastomers, High Temperature, Fluid and Compressor Set Resistant (15 January)
TT-S-735	Standard Test Fluids; Hydrocarbon (11 March 1964)

These specifications along with other documents itemized in them control the qualification/certification procedures for all the engines, fuel system components, fuel cells, hoses, and elastomeric seals used in the Army aircraft.

A. Engine Qualification

The qualification procedures for turboshaft and turboprop engines stress a variety of operational and environmental problem areas such as the performance of hydraulic, lubrication, and control systems; endurance of rotating and hot sections; and temperatures and vibrations. Most of these areas have little or no interface with the fuel. The requirements which are directly related are component tests for the fuel pump and fuel control, the low- and high-temperature starting tests, and the alternate and emergency fuel tests. Also, minimum performance requirements are established for the engine fuel system in terms of fuel temperatures, viscosities, and vapor/liquid ratios. Fuel contamination is also addressed in the specification but is not really pertinant to this discussion as that is a fuel handling problem totally independent of the fuel properties with which this study is concerned.

For reference, the primary, alternate, and emergency fuels are defined in section 3.7.3.2 of the engine specification as follows:

Primary Fuel. "The engine shall function satisfactorily throughout its environmental conditions and operating envelope for all steady-state and transient operation conditions when using fuel conforming to and having any of the variations in characteristics permitted by MIL-T-5624 of the grades specified in the engine specification."

Alternate Fuel. "When required by the Using Service, the engine shall also start and operate using the alternate fuels specified. The operating limits, power outputs and power transients specified in the engine specification shall not be adversely affected when using alternate fuel. The effects on the engine performance characteristics, changes in SFC, changes in starting and stopping time, and effects on the aircraft missions when using alternate fuels shall be specified. There shall be no effect on the established time between overhaul for the engine from that specified in 3.2.4.2. Only those external adjustments permitted in 3.7.2.3.1.1 shall be allowed in order to meet this requirement. The engine shall function satisfactorily with the alternate fuels specified containing anti-icing additive conforming to MIL-I-27686 and added in a concentration up to 0.15 percent by volume."

Emergency Fuel. "When required by the Using Service, the engine shall also start and operate using the emergency fuels specified. The engine shall function satisfactorily for a time period of at least 6 hours from sea level to 10 km altitude, at least throughout a range from idle to 90 percent of maximum power, at no greater than 120 percent of the specification rated or estimated specific fuel consumption when using fuels conforming to MIL-G-5572, MIL-G-3056, and VV-G-1690. Only the external control adjustments permitted in 3.7.2.3.1.1 will be allowed to meet this requirement. If applicable, operating limitations, special inspections or maintenance actions required as a result of using this fuel shall be specified."

The main differences are that an "alternate fuel" shall not adversely affect the operating limits, the power outputs, the power transients, and the overhaul time; "emergency fuels" are allowed to cause performance and power degradations within specified limits. Since the Army does not specify emergency fuels for its aircraft turbine engines, they will not be further addressed here.

Several requirements are placed on the fuel system to establish minimum performance criteria under temperature and pressure extremes. At low temperature this means the system must operate with fuels of higher viscosity and lower vapor pressure than on a standard day; typical problems would be engine starting and control. At high temperatures, the system must be able to accomodate high vapor pressures and hence high vapor/liquid ratios; problems in priming pumps and fuel control are typical.

The fuel pump and fuel control systems have specific qualification tests. Other engine fuel system components are addressed in more general terms. "Accelerated aging" and "high temperature" tests are specified for fuel compatibility of all components containing non-metallic parts. They are first dried and placed in an oven at 71°C (160°F) for 168 hours. The components are then subjected to a 100-hour or 600-cycle test (whichever is longer) during which the ambient temperature is cycled between 71°C and the maximum temperature for the component. The fuel used is the specified primary fuel doped with toluene to give an aromatics content of at least 25%, representing the most detrimental fuel allowed by the fuel specification.

Other testing is done at low and room temperatures, but these are for elastomer performance and fuel contamination respectively and do not stress fuel compatibility.

For overall engine performance and compatibility, a 60-hour cycle test run is made on each of the alternate fuels specified in the engine specification. "The test is considered satisfactory when, in the judgement of the Using Service, engine performance meets the requirements specified...and the results of the hot section inspection do not reveal abnormal hot section distress."

B. Fuel System Component Qualification

The discussion here will focus only on the fuel compatibility requirements of the pertinent specifications. To begin with, the standard hydrocarbon test fluids used in the qualification tests are defined in TT-S-735. Four test fluids for fuel systems are defined and have the following composition:

Ingredient Material	Volume%			
	Type I	Type II	Type III	Type VII
Iso-octane	100	60	70	10
Benzene	0	5	0	0
Toluene	0	20	30	30
Xylene	0	15	0	0
Cyclohexane	0	0	0	59
Butyl disulfide (tertiary)				1
Total Aromatics	0	40	30	30

Types I and III are the two test fluids most commonly required for fuel resistance and aging qualification tests. They represent extremes of aromatic content, 0 and 30%. (Note: the fuel specifications for JP-4, JP-5, and JP-8 allow maximums of 25% aromatics while Jet-A allows only 20%.) Furthermore, the aromatics used, i.e., toluene, have a low molecular weight representing about the lowest weight aromatics of JP-4 type fuels and much lower than the aromatics found in JP-5. Recalling from Figure 8 on page 30 that the lower weight aromatics have a higher solvent activity and that the aromatics found in JP-5 have relatively low solvent compared to JP-4, it is concluded that the Type III test fluid is a conservative test fluid for fuel compatibility.

Type II fluid is required in the fuel resistance, aging, and gunfire tests for the self-sealing hoses along with Type I fluid. Here an even more extreme case of 0 and 40% aromatics are used. (The reasoning for the use of the Type II fluid was not determined in this study.)

The Type VII fluid is used primarily as a qualifying fluid for the polysulfide sealants used in wet-wing fuel tanks, none of which are found on Army aircraft.

Figure 17 shows the effects of aging time on six major properties of O-rings; the materials are two nitrile rubbers of different fuel resistance, and two aromatic levels are shown. The conclusion from this data is that in every case with the exception of "hardness," all of the changes stabilized in less than two days regardless of aromatic content. Table 14 reproduces the "Temperature Classifications" and "Soak Period/ Test Fluid" requirements from MIL-F-8615D, to general specification for fuel system components. Alternating soak and dry periods are very determental to elastomers. The first high temperature soak period is 96 hours or four days which according to the data of Figure 17 should be sufficient to stabilize the degradation. The components are also required to pass an endurance test simulating the operating consitions of the component for its design operational life between overhauls; at least 20% of this test must be at the high temperature and using the test fluid in accordance with the classifications shown in Table 14. It is the concerted opinion of design and test engineers from component

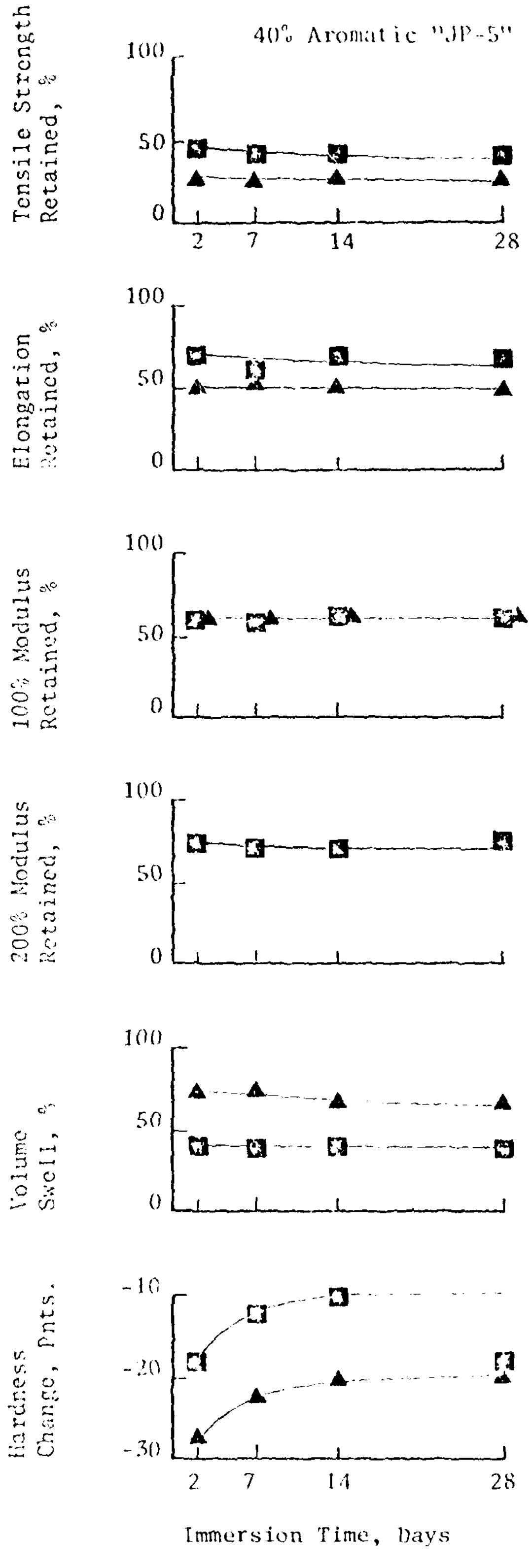


FIGURE 17. EFFECT OF IMMERSION TIME IN PHYSICAL PROPERTIES OF HIGH (▲) AND LOW (■) ACRILONITRILE RUBBERS (BUNA N)

Table 14. Temperature Classifications and Soak Tests for Fuel System Component Qualification

Temperature classification.

Class	High Temperature °C			Low Temperature Fuel and Air °C
	T	T_t	T_a	
A	60°C ±3	75°C ±5	75°C ±5	-57°C ±4
B	95°C ±5	115°C ±5	175°C ±5	-57°C ±4
C	150°C ±5	180°C ±7	315°C ±10	-57°C ±4

T - High operational fuel temperature

T_t - High fuel test temperature

T_a - High ambient temperature

TEST FLUIDS AND SOAK PERIODS

Test Period	Phase I		Phase II		Phase III
	Soak	Dry	Soak	Dry	Soak
Ambient and fluid test temperature (Table 1)	T_t	T_a	T_t	T_a	-57° ±4°C
Test Fluid During Soak					
Class A	Type III		Type III		Type I
Class B	Type III		Type III		Type I
Class C	JP-5		JP-5		Type I
Period Duration	96 hours minimum	24 hours	18 hours minimum	30 hours	18 hours minimum
Test fluids to be used for tests immediately after period	Type III	Type I	Type III	Type I	Type I

manufacturers that from their experience most elastomer degradation occurs in less than 50 hours and that any fuel/elastomer incompatibilities will show up in the test life of the qualification tests.

In summary it is felt by component design and test engineers that the components tests for fuel compatibility are not accelerated tests and hence that their components are, in fact, compatible with the 30% toluene test fluid and therefore 30% aromatic fuels.

VI. SUMMARY

There are no significant pressures to change the JP-4 fuel specifications especially in the areas of hydrogen content, aromatics, and boiling point distribution. Futhermore the Air Force projects that JP-4 derived from shale oil should meet the current JP-4 fuel specification, and the hydrogen content may be higher than the average JP-4 today; however, there may be a problem with aromatic contents that are too low. The "alternative fuels" JP-5, JP-8, and Jet-A have the obvious difference of reduced volatility and higher viscosity; JP-5 is seen as generally a worst case because of its higher flash point requirement and historically higher viscosity. There are pressures to increase the aromatic limit on JP-5 to improve availability in some marketing areas. End point increases also improve availability if the higher freeze point could be accepted; this could also lead to a higher viscosity. No differences are seen in thermal stability. Lubricity could be a problem that will have to be solved by additives.

If low aromatic concentrations prove to be a problem the Air Force, which controls the JP-4 specification, will also experience difficulties and will undoubtedly establish a minimum aromatic content in the specification. The potentially higher aromatics in JP-5 are not seen as a problem to Army systems. The higher molecular weight makes them less detrimental to elastomers than the aromatics found in JP-4; futhermore, the higher limit would have to be compatible with Navy aircraft which have components and elastomer systems similar to Army systems.

Projections were made on the impact of reduced hydrogen content fuels on the relative low-cycle-fatigue life of the combustors. The T700 combustor was seen as the least affected by reduced hydrogen content. The results could be improved by using actual mission profiles.

The higher viscosity and lower volatility of the alternative fuels will affect the cold start capabilities but the problems will not be any different than is being experienced today. Combustor tests to determine the sensitivities to volatility and viscosity of various combustors are desirable; T63 tests are currently planned for FY82 and T700 tests are being considered.

With the exception of some recent field problems with the T700 engine, no current maintenance problems were found that were related to fuel properties nor were any potential problems identified that could be aggrevated by synthetic or alternative fuel usage other than those mentioned above. Some coking has been seen in the fuel nozzles of the T700 engines recently. While no details were available for this study, it is a problem that would be aggrevated by deteriorating fuel thermal stability.

Qualification procedures for engines and fuel system components stress compatibility with a current fuel specification rather than the sensitivity of a design to changing fuel properties. The test fuels are designed to be worst cases however and are believed adequate for currently identified problems.

AD-A111 046 SOUTHWEST RESEARCH INST SAN ANTONIO TX ENERGY SYSTEM--ETC F/G 21/4
IMPACT STUDY OF SYNTHETIC AND ALTERNATIVE FUEL USAGE IN ARMY AI--ETC(U)
JUL 81 C A MOSES, M L VALTIERRA N00140-80-C-2269
UNCLASSIFIED SWRI-MED134 NL

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VII. RECOMMENDATIONS

This study addressed only fuels that met current specifications for JP-4, JP-5, JP-8, and Jet A and potential modifications to those specifications; these fuels are the ones currently authorized as "primary" or alternate" fuels for Army aircraft gas turbine engines. During combat or in other periods of extreme emergency, specification fuels may not be available. It is therefore recommended that a similar study be conducted to address the potential use of emergency specification and off-specification fuels; the scope of the study should include the impact of such fuels on aircraft performance, durability, and safety; it should also attempt to define allowable limits for critical properties and identify inspection and maintenance procedures to be taken following the use of such fuels. Since very little sensitivity data was found relating performance and durability to fuel properties, experimental programs to develop such a data base will be necessary to support the above recommendation. It is also recommended that a methodology for qualifying future Army aviation fuels be developed to reduce the level of full scale engine and airframe testing necessary to ensure compatibility between new fuel specifications and aircraft designed to operate the current fuel specifications.

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APPENDIX A

AIRFRAME FUEL-WETTED SYSTEM COMPONENTS

APPENDIX A TABLES

TABLE A-1. AH-1 COBRA AIRFRAME (BELL HELICOPTER)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Self-sealing Hose		209-060-668-1	
	Aeroquip	(AE1007402J0264)	Innerliner Buna N (A5235).
	Stratoflex	(156672-10-0264)	Innerliner Buna N (ST 156).
Manifold Valve, Fuel Check		205-060-611-3	
(two poppets)	Circle Seal Controls	(P13-389)	O-ring Buna N (dynamic)
	Ronson Hydraulic Units	(42C42603)	A four port two poppet check valve. O-rings Buna N (static) by MS 29513 - Parker No. N602-70. *Light* spring force.
Self-sealing Valve,* Breakaway		205-063-601-15	
(two poppets)	Aeroquip	(AE96056M)	O-rings fluorosilicone. Boot - Buna N.
	Wiggins	(CW118/15)	
Defuel/Sump Drain Valve, Manual		209-060-655-5	
(poppet)	Auto-Valve	(96C-5)	O-ring Buna N (static).
	Shaw Aero Devices	(A-440-2)	O-ring Buna N (dynamic).
Filter Drain Valve (poppet)		209-060-656-1	
	Auto-Valve	(375C-62S)	O-ring Buna N (dynamic). Cup-seal Teflon (static).

* Potential fuel-sensitive area

TABLE A-1. AH-1 COBRA AIRFRAME (BELL HELICOPTER)(CONT'D)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Check Valve, Bleed (poppet)		209-060-657-1	
	Stellar Hydraulic	(69250)	
	Circle Seal Controls	(2632T-4TT-5)	O-ring Viton (static). O-ring Viton (dynamic).
Closed Circuit Receiver		209-060-694-3	
	Hydraulic Research	(745000-3)	Diaphragm made of fluorosilicone on nylon fabric (dynamic). O-ring Buna N (static).
Hose, Inter-Tank Fuel Crossover		209-060-653-1	
	Goodyear	(AFA8000362)	Innerliner.
	Uniroyal	(FCE-55262)	Innerliner.
	Firestone	(50051)	Innerliner.
Boost Pump, Electric		205-060-606	
	Lear-Siegler	(RG12240D2)	Centrifugal pump with dry motor. Shaft seal silicone (static). O-rings Buna N (static).
	Globe	(164A168-1)	Centrifugal pump impeller made of dyallyl phthalate plastic (dynamic). Sealed motor-magnetic drive. Diaphragm stainless steel or dyallyl phthalate plastic (static).

TABLE A-1. AH-1 COBRA AIRFRAME (BELL HELICOPTER) (CONT'D)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Fuel Filter Assembly, With Pressure Differential Switch		204-040-760-5	
	Michigan Dynamic	(100103)	Diaphragm is Dacron fabric impregnated with fluorinated silicon (Dow Corning LS-53/63). Aluminum end caps with O-ring seals (static) Buna N.
	Fram	(165516)	ΔP switch has a $2\frac{1}{4}$" silicon impregnated diaphragm (dynamic). Cover seal O-ring (static).
Low Level Float Shut Off Switch	Revere Corporation of America	(F74356)	Torus type float made of Buna N with magnet impregnated Nylon guide bushing fixed to inside of torus. Float rides around a sealed aluminum tube.
Fuel Shut Off Valve, Motorized (gate)	ITT General Controls	(AV16B1748D)	Seals made of Thiokol for gate. O-rings Buna N.
Sump Drain Valve (poppet)		209-060-661-1	
	Auto-Valve	(96C-4)	O-ring Buna N (static).
	Shaw Aero Devices	(A-470)	O-ring Buna N (dynamic).

TABLE A-1. AH-1 COBRA AIRFRAME (BELL HELICOPTER) (CONT'D)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Check Valve, Breakaway		205-063-601-11	
	Aeroquip	(AE963115)	
	Wiggins	(CW118/11)	
Fuel Gage, Tank Unit Transmitter		209-060-602	
	Simmonds	(393008-032)	Capacitance type gage. Sleeve at top Teflon.
	Gull	(200-040-005)	
Crashworthy/Self-sealing Fuel Tank		209-060-652-1/3	
	Uniroyal	(FCR-56293/4)	Innerliner.
Cap, CCR Filler*		206-062-660-1	
	Shaw Aero Devices	(416-635)	O-ring large size Buna N (static). O-ring small on rod Buna N (dynamic).
		(FC-3500-286)	O-ring Buna N (static). O-ring Buna N (dynamic).
Adapter		209-062-660-1	
	Shaw Aero Devices	(416-636)	No elastomers.
Pressure Switch		204-062-542-3	
	Custom Components	(7G44)	

* Potential fuel-sensitive area

TABLE A-2. UH-1 HUEY AIRFRAME (BELL HELICOPTER)*

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Self-sealing Hose		205-062-650-9	
	Stratoflex	(B6671-10-0336)	Innerliner Buna N (Stratoflex 156).
	Aeroquip	(AE1007399J0336)	Innerliner Buna N (Aeroquip 235).
Check Valve, Self-** sealing (dual poppets)		205-063-601-11	
	Aeroquip	(AE 96311J)	O-ring fluorosilicone.
	Wiggins	(CW 118/11)	Boot - Buna N (dynamic).
Sump Drain Valve, Manual (poppet)	Auto-Valve	(967B12)	O-ring Buna N (static).
Drain Valve, Manual (poppet)		205-062-651-1	
	Auto-Valve	(967B-5)	O-ring Buna N (static).
	Shaw Aero Devices	(A-470-1)	O-ring Buna N (dynamic).
Fuel Shutoff Valve, Motorized (gate)		205-060-612-3	
	ITT General Controls	(AV 16B1667D)	Thiokol seal for gate. O-rings Buna N.
Siphon Breaker Valve		204-061-689-1	
	Circle Seal	(P13-262-1)	
	Ronson Hydraulic Units Corp	(42C42604)	

* Not all breakaway couplings are included
* Potential fuel-sensitive area

TABLE A-2. UH-1 HUEY AIRFRAME (BELL HELICOPTER) (CONT'D)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Fuel Quantity Gage, Capacitance		204-060-683-3	
	Simmonds Precision	(39 3004-01699)	Capacitance type gage. Sleeve at top Teflon.
Gravity/CCR Receptacle		209-060-651-5	
	Wiggins	(CCR101/5)	
	Hydraulic Research	(744000-5)	Diaphragm made of fluorosilicone or nylon (dynamic). O-ring Buna N (static).
Crashworthy Self-sealing, Fuel Cell		205-062-635-7	
	Goodyear	(2F1637014)	Innerliner, nitrite rubber.
Boost Pump, Electrical		205-060-606	
	Lear-Siegler	(RG 12240D2)	Centrifugal pump with dry motor. Shaft seal is silicone (static). O-rings are Buna N (static).
	Globe	(164A168-2)	Centrifugal pump impeller made of dyallyl phthalate (dynamic). Sealed motor-magnetic drive diaphragm is stainless steel or dyallyl phthalate plastic.
Boost Pump, Air Motor		205-060-607-5	
	Hydro-Aire	(60-3515)	
	Lear-Siegler	(RG 12470)	Carbon face seal on shaft. O-rings Buna N (static).

TABLE A-2. UH-1 HUEY AIRFRAME (BELL HELICOPTER) (CONT'D)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Jet Pump (ejector pump)		205-061-634	
	Arkwin Industries	(13A006-1)	No elastomers inside.
	Allen Aircraft	(610E100)	No elastomers inside. O-ring Buna N (static)/ Connects jet pump to plumbing.
Quick Disconnect Coupling, Self-sealing		205-062-651-1	
	Aeroquip	(AE 956 27N)	O-ring MS29512-20.
Filler Cap, Gravity CCR			
	Shaw Aero Devices	(FC 3500-30)	O-ring Buna N (static). O-ring Buna N (dynamic).
		(PC 3500-159)	O-ring Buna N (static). O-ring Buna N (dynamic).
Fuel Filter Assembly With Pressure Differential Switch		204-040-760	
	Michigan Dynamics	(100103)	Epoxy resin impregnated pleated filter element. Aluminum end caps with O-ring seals (static) material. Cover seal O-ring (static) material. ΔP switch 2¼" silicon impregnated diaphragm (dynamic).
	Fram	(165516)	
Crashworthy Fuel** Cells		205-061-621-3/4	
	Uniroyal	(FCB-55121)	Innerliner, fabric.

** Components are used on the auxiliary fuel system

TABLE A-2. UH-1 HUEY AIRFRAME (BELL HELICOPTER) (CONT'D)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Vent Valve** (poppet)		204-061-689-1	
	Ronson Hydraulic Unit	(42C42604)	A spring loaded ball vent valve. Ball (dynamic) made of nylon (Zytel 101 MIL-P-17091).
	Circle Seal Controls	(P13-262-1)	Should be OK for increased aromatics.
Transfer Pump,** Electric		205-061-626-3	
	Lear-Siegler	(RG 125802)	Centrifugal pump with dry motor. Shaft seal is silicone (static). O-rings are Buna N (static).
	Globe Industries	(164A166)	Centrifugal pump impeller made of dyallyl phthalate (dynamic). Sealed motor-magnetic drive. Diaphragm is stainless steel or dyallyl phthalate plastic (static).
Float Switch,** Shutoff (dual level reed switch)		204-062-613	
	Revere Corporation Of America	(F-74070-2)	Torus type float made of Buna N with magnet impregnated in float. Nylon guide bushing fixed to inside of torus. Float rides around a sealed aluminum tube (dynamic).

** Components are used on the auxiliary fuel system

TABLE A-2. UH-1 HUEY AIRFRAME (BELL HELICOPTER) (CONT'D)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Check Valve** (poppet)		205-061-623	
	Vinson	(A-62083)	
	Circle Seal Controls	(869A-12BB-54)	O-ring Buna N (dynamic).
Pressure Switch**			
	Consolidated Controls	(R6607-1-46)	Diaphragm 11 ml. thick Teflon impregnated glass, 1¼" diameter.

** Components are used on the auxiliary *fuel system*

TABLE A-3. OH-6A CAYUSE AIRFRAME (HUGHES HELICOPTERS)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Self-sealing Hose		369A8486	
	Aeroquip	(AE1008247J0132)	Innerliner Buna N (AE 235).
	Stratoflex	(156755EEF0132)	
Fuel Valve, In-line Breakaway (dual poppet)		369A8468	
	Wiggins	(CW108/01)	
	Aeroquip	(AE 97124H)	O-rings fluorosilicone. Seat fluorosilicone.
Fuel Cell Vent Valve, Breakaway (dual poppet)		369A8467	
	Wiggins	(CW 107/01)	
	Aeroquip	(AE 97122J)	O-rings fluorosilicone. Seat fluorosilicone.
Emergency Fuel Vent Line Shutoff Valve		369A8420	
	Hydraulic Research	(701100-1)	O-ring Buna N (static). Poppet valve metal to metal.
Fuel Shutoff Valve Assembly (ball valve, manual)		369A8469	
	Allen Aircraft	(8D146)	Ball seal Teflon. O-rings Buna N.
	ITT General Controls	(AV24D1128)	Ball Seal Teflon. O-rings Buna N.

TABLE A-3. OH-6A CAYUSE AIRFRAME (HUGHES HELICOPTERS) (CONT'D)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Fuel Quantity-Transmitter *	Hughes Aircraft AC Spark Plug Div.	369A4245 GG-6427515	Not a capacitance type.
Fuel Drain Valve-Crashworthy *		369A8482	Problem with sealing.
	Wiggins	(H56F)	
	Hydraulic Research	(773100-3)	
Gravity Valve, Breakaway		369A8470	
	Wiggins	(CWH57F)	
Closed Circuit Receiver Assembly, Single Point Refueling		369A8471	
	Hydraulic Research	(744100-1)	
Fuel Cell, Self-sealing		369A8465	
	Goodyear	(AJA8000758)	Innerliner Buna N.
Electric Boost Pump		369A8143	
	TRW	(IC3-40)	
	Globe	(164A-134)	Centrifugal pump impeller made of dyallyl phthalate plastic (dynamic). Sealed motor-magnetic drive. Diaphragm stainless steel or dyallyl phthalate plastic (static).

* Potential fuel-sensitive area

TABLE A-3. OH-6A CAYUSE AIRFRAME (HUGHES HELICOPTERS) (CONT'D)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Gravity Filler Cap Assy.	Shaw Aero Devices	(35001-2)	O-ring Buna N (static).
CCR Filler Cap*	Shaw Aero Devices	(416-50)	O-ring (big) Buna N (static). O-ring (small) Buna N (static).

* Potential fuel-sensitive area

TABLE A-4. CH-47C CHINOOK AIRFRAME NON-PRESSURIZED FUELING (BOEING VERTOL)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Self-sealing Hose		114PS466	
	Aeroquip	(AE 502)	Innerliner Buna N.
Check Valve, Thermal Relief * (swing/flapper)		114PS456	
	Hydraulic Research	(314400-1)	Nylon piston with Dynamic O-ring. Bonded seal in thermal relief Buna N (dynamic). O-ring seal Buna N (static).
Drain Valve (poppet)		114PS465	
	Hydraulic Research	(772500-1)	O-ring seal fluorosilicone (dynamic).
	Wiggins	(B7V)	
Check Valve (swing/flapper)		114PS462-4	
	Hydraulic Research	(220400-1)	Bonded seal on disc Viton A (dynamic) O-ring seal Buna N (static)
Fuel Probe, Tank Unit		114PS471	Capacitance type.
	Gull Airborne	(012-003-004)	
	Simmonds Precision	(391057-148)	Sleeve at top Teflon.

*Potential fuel-sensitive area

TABLE A-4. CH-47C CHINOOK AIRFRAME NON-PRESSURIZED FUELING (BOEING VERTOL) (CONT'D)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Fuel Cells, Main Self-sealing		114PS458-1	
	Goodyear	(AJA8000705)	Innerliner Buna N.
	Uniroyal	(FCR56562)	Innerliner fabric.
Fuel Cells, Auxiliary Self-sealing		114PS459-1	
	Goodyear	(AJA8000704)	Innerliner Buna N.
	Uniroyal	(FCR56563)	Innerliner fabric.
Boost Pump, Electric *		114P4111	
	Lear-Siegler	(RG12200B)	Centrifugal pump with wet A.C. motor. Seals Buna N. Potting compound Shell Epon 828. Activator General Mills Versamid 125.
Gravity Filler Cap			
	Shaw Aero Devices	(416-50)	O-ring Buna N.
Auxiliary Power Pump, Motor Driven		114P4010	
	Lear-Siegler	(RG 15150G)	Vane pump with dry D.C. motor. Carbon face seal on shaft. Seals Buna N. Diaphragm DuPont Fairprene.
Gate Valve, Motor Driven *		114PS401-2	
	ITT General Controls	(AV16B1568D)	Gate seals Thiokol. O-rings Buna N.

*Potential fuel-sensitive area

TABLE A-4. CH-47C CHINOOK AIRFRAME NON-PRESSURIZED FUELING (BOEING VERTOL) (CONT'D)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Fuel Selector Valve (solenoid operated poppet)		114PS402-2	
	Valcor Engineering	(V36100-05)	Poppet disc material Buna N (dynamic). O-rings Buna N (static).
Vent Valve (poppet)		114PS457-1	
	Hydraulic Research	(760300-1)	O-ring fluorosilicone.
	Purolator	(7542049)	
Pressure Switch		114PS407-1	
	Hydra-Electric	(1129-1) (1129-2) (1129-3) (1129-4)	Diaphragm actuated switch of Teflon, Mylar, or H-film (DuPont). Interlaced glass fiber for strength. O-ring silicone or Buna N (static).

TABLE A-5. CH-47 C/D CHINOOK AIRFRAME WITH PRESSURE REFUELING (BOEING VERTOL)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Tank Sump And Vent Condensate Drain Valve		114PS509	
	Hydraulic Research	(777300)	O-rings Buna N on poppet drain valve (static).
Self-sealing Hose		114PS466	
	Aeroquip	(AE502)	Innerliner Buna N.
Fuel Probe, Tank Unit		114PS471	
	Gull Airborne	(012-003-004)	
	Simmonds Precision	(391057-148)	Sleeve at top Teflon. Capacitance type gage.
Fuel Cells (Main) Self-sealing		114PS458-1	
	Goodyear	(AJA800705)	Goodyear cell has nitrile liner.
	Uniroyal	(FCR56562)	Uniroyal cell has fabric liner.
Fuel Cells (Auxiliary) Self-sealing		114PS459-1	
	Goodyear	(AJA800704)	Goodyear cell has nitrile liner.
	Uniroyal	(FCR-56563)	Uniroyal cell has fabric liner.

TABLE A-5. CH-47 C/D CHINOOK AIRFRAME WITH PRESSURE REFUELING (BOEING VERTOL)(CONT'D)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Boost Pump, Electric*		114P411	
	Lear-Siegler	(RG12200B)	Centrifugal pump with wet A.C. motor. Seals Buna N. Potting compound Shell Edon 828 (activator general Versamid 125.)
Gravity Filler Cap			
	Shaw Aero Devices	(MS 416-50)	O-ring Buna N.
Breakaway Fitting, 2" Poppet Valve		114PS408	
	Hydraulic Research	(711800)	O-rings fluorosilicone (static). O-ring poppet fluorosilicone (static).
Pressure Refueling Shutoff Valve		114PS409-1	
	Hydraulic Research	(787800)	O-ring fluorosilicone (static). Lip seal Teflon impregnated glass fiber (dynamic). O-ring Viton in poppet check valve (dynamic).
Pressure Refueling Adapter		114PS412	
	Hydraulic Research	(714300-1)	O-ring Buna N in adapter (static). O-ring fluorosilicone for poppet vent valve (dynamic).

*Potential fuel-sensitive area

TABLE A-5. CH-47 C/D CHINOOK AIRFRAME WITH PRESSURE REFUELING (BOEING VERTOL) (CONT'D)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Manifold Scavenge Ejector Pump	Hydraulic Research	114PS413 (710800-1)	O-ring fluorosilicone seal on breakaway poppet valve (static).
Breakaway Fitting Poppet Valve (some with swing check)	Hydraulic Research	114PS414 (711900)	O-ring on poppet fluorosilicone (static). O-ring fluorosilicone (static). Disc seal on swing check valve is fluorosilicone on nylon fabric (dynamic).
Manifold Assembly (check refuel transfer)	Hydraulic Research	114PS415 (320800)	Disc seal on swing check valve is fluorosilicone on Dacron fabric (dynamic). O-ring fluorosilicone (static).
Fuel Level Control Assy. (float type valve)	Hydraulic Research	114PS478 (776600)	Gasket is Buna N on nylon fabric.
Pressure Switch	Hydra-Electric	144PS407-1 (1129)	

TABLE A-5. CH-47 C/D CHINOOK AIRFRAME WITH PRESSURE REFUELING (BOEING VERTOL) (CONT'D)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Gate Valve, Motor Operated*	Whittaker Controls	114PS494 (233454/233455)	O-rings Buna N (static). Seals unk.
Float Valve (condensate drain)	Derogene	114PS419-2 (79001601-101)	O-rings Buna N (static). Seat is of nylon (static). Ball is of steel.
Thermistor (tank empty - pump shutoff)	Simmons	(473344)	Housing - glass filled nylon.
Couplings (quick disconnect)	Symetrics	114PS491 (BV15016-3)	O-ring Buna N (static). O-ring backup Teflon (static).

*Potential fuel-sensitive area

TABLE A-6. UH-54 SKYCRANE AIRFRAME (SIKORSKY AIRCRAFT)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS

ITEMIZED LISTING OF UH-54 AIRFRAME FUEL WETTED COMPONENTS WAS NOT AVAILABLE FROM SIKORSKY AIRCRAFT. THE MAJORITY OF THE COMPONENTS ARE THE SAME AS THE ONES USED ON THE UH-60A BLACK HAWK, ALSO MANUFACTURED BY SIKORSKY AIRCRAFT.

TABLE A-7. OH-58C KIOWA AIRFRAME (BELL HELICOPTER)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Self-sealing Hose, Breakaway		206-062-610	
	Stratoflex	(161-10)	Innerliner Buna N (ST 156).
Fuel Check Valve (poppet)		206-062-6041	
	Wiggins	(CW 101/01)	
	Hydraulic Research	(780300-1)	Poppet type. O-ring fluorosilicone (dynamic).
Shutoff Valve, Manual		206-062-603	
	Shaw Aero Devices	(A-870-1)	O-ring Buna N (static).
Quantity Transmitter (capacitance)		206-062-605	
	Simmonds Precision	(391089-001)	Capacitance type gage. Sleeve at top Teflon.
Quantity Transmitter, Low Fuel (capacitance)		206-062-605	
	Simmonds Precision	(391057-129)	Housing - glass filled nylon.
Fuel Tank, Crashworthy		206-062-602	
	Firestone	(37945)	Innerliner fabric.
	Goodyear	(AJA8000566)	Innerliner Buna N.

TABLE A-7. OH-58C KIOWA AIRFRAME (BELL HELICOPTER) (CONT'D)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Closed Circuit/Gravity Fuel Receptacle		206-060-651-9	
	Wiggins	(CCR 101/09)	
	Hydraulic Research	(744000-9)	Diaphragm made of fluorosilicone on nylon (dynamic). O-ring Buna N (static) seals.
Sump Drain Valve (poppet)		206-062-640-1	
	Auto-Valve	(96C-16)	O-ring Buna N (dynamic).
Boost Pump, Electric		206-062-628-1	
	Lear-Siegler	(RR-12240L)	Centrifugal pump with dry D.C. motor. O-rings Buna N (static). Shaft seal silicon (static).
	Globe Industries	(164A137)	
Low Level Float Switch		206-062-	
	Revere Corporation of America	(F-74070-2)	Torus type float made of Buna N with magnet impregnated in float. Guide bushing nylon. Float rides around a sealed aluminum tube.

TABLE A-8. UH-60A BLACK HAWK AIRFRAME (SIKORSKY AIRCRAFT)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Self-sealing Hose	Aeroquip	(AE502)	Innerliner Buna N.
Inlet Check Valve,* Nonbreakaway (1¼" swing)	Allen	65307-08007-101 (8C157)	Seal on flapper Buna N (dynamic). O-ring Buna N (static). O-ring fluorocarbon (static).
Manual Valve, Fuel Selector (ball crossfeed)	Allen	65317-03006-112 (16BS106-11/-12)	Ball seals against a vulcanized Buna N housing (static). O-rings Buna N (static). Ball sleeve is Teflon.
Self-sealing Breakaway Valves (flapper)	Aeroquip	70307-03002-103 (AE80606G)	Piston covered with nitrile rubber (dyanmic). Buna N seal (static).
Vent Valve* (poppet)	Parker-Hannifin	70307-03007-104 (2750088-102)	O-ring seal Teflon (dynamic). O-ring seal Buna N (static). Constantly opening and closing.
Prime Shutoff Valve (sol. operated gate valve)	Valcor	70307-03024-101 (V5000-114)	Gate valve seal is bonded carbon (static). O-rings fluorosilicone (static).

* Potential fuel-sensitive area

TABLE A-8. UH-60A BLACK HAWK AIRFRAME (SIKORSKY AIRCRAFT) (CONT'D)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Low Level Shutoff Valve	Parker-Hannifin	70307-03025-101 (1323-585285)	Float is rigid urethane foam. Needle seat - no elastomers.
Fuel/Defuel Valve (poppet)	Parker-Hannifin	70307-03026-101 (2770052-101)	Poppet has bonded Buna N seal O-ring Buna N. Diaphragm uses a nylon fabric coated with Buna N.
High Level Pilot Shutoff Valve	Parker-Hannifin	70307-03012-103 (2770076-106)	Float is synthetic foam. Needle seat - no elastomers.
Check Valve, Crossfeed (swing check)	Parker-Hannifin	70307-03043-101 (2770057-101)	Retainer assembly has bonded Buna N seal. Insert nylon, ball Buna N. O-ring Buna N.
Fuel Inlet Valve, Main (swing check)	Parker-Hannifin	70307-03045-101 (2770006-101)	Retainer assembly has a Buna N seal. Insert nylon, ball Buna N. O-ring Buna N.
Level Sensor (capacitance)	Simmonds Precision	70307-03004-108 (391057-289)	Capacitance type gage. Sleeve at top Teflon.
Low Level Warning Gage (capacitance)	Simmonds Precision	70307-03004-110 (472580-010)	Housing - glass filled nylon.

TABLE A-8. UH-60A BLACK HAWK AIRFRAME (SIKORSKY AIRCRAFT)(CONT'D)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Sump Drain Valve,* Manual (poppet)	Auto-Valve	70307-03018-103 (971D-22)	Leaks, push to drain. O-ring fluorosilicone (in a contaminant environment) sand.
Refueling Receptacle (CCR & SPR) (poppet)	Parker-Hannifin	70307-03011-101 (2730535)	Poppet assembly has fluorosilicone seal. Packing and poppet both use Buna N seals. Seals fluorosilicone and Buna N.
Nozzle Assembly	Wiggins	(CCN101/01)	
Receiver Assembly	Wiggins	(CCR101/03)	
Self-sealing Crashworthy Fuel Tank	Goodyear	70307-03003-102 (2F1-6-42416)	Innerliner Buna N.
Prime Pump for APU	Lear-Siegler	70307-03005-102 (RR36680B)	Vane pump with wet D.C. motor. Seal Viton (static). Potting compound 3M Scott Cast 9.

* Potential fuel-sensitive area

TABLE A-8. UH-60A BLACK HAWK AIRFRAME (SIKORSKY AIRCRAFT)(CONT'D)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Shutoff Valve,** Motorized		65307-03065-103	
	ITT General Controls	(AV 16B2067D)	O-ring silicon (static). Seals are Teflon (static). O-ring Buna N (static).
Self-sealing Breakaway Valves ** (flapper type)		70070-30103-104	All valves have the following:
	Aeroquip	(AE8061GP)	Round seal is Buna N. O-rings fluorosilicone.
		70070-30103-103	Aluminum piston is covered with nitrile rubber.
	Aeroquip	(AE80615P)	
		70070-30802-102	
	Aeroquip	(AE80614M)	
Pressure Relief Valve **		70070-30901-102	
	Wiggins	(RVS21K)	
Fuel Quantity Gage** (capacitance)		70070-30102-10/102	
	Simmonds Precision	(391057-246/247)	Sleeve at top Teflon.
Nonself-sealing Crashworthy Tank **		70070-30101	
	Goodyear	(2F1-6-42523)	Innerliner Buna N.

** Components listed here are used on the auxiliary tank range extension kit.

TABLE A-8. UH-60A BLACK HAWK AIRFRAME (SIKORSKY AIRCRAFT)(CONT'D)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Pressure Switch	Consolidated Controls	(R6607-1-46)	Diaphragm 11 ml. thick Teflon impregnated glass (dynamic).
Transfer Pump,** Electric	Lear-Siegler	61300-63188-101 (RR 36260)	Vane type pump. Carbon face seal on shaft. Buna N elastomers. Lip seal of Sirvine (Chicago *Rawhide*).

** Components listed here are used on the auxiliary tank range extension kit.

TABLE A-9. YAH-64 APACHE AIRFRAME (HUGHES HELICOPTERS)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Hose, Self-sealing	Aeroquip	7-211642021-22/23 (AE705219-3)	Innerliner Buna N.
Breakaway Valve (flapper type)	Aeroquip	7-211642041 Typical (AE81358K)	Round seal Buna N. O-rings Buna N. Aluminum piston is covered with nitrile rubber (dynamic).
Level Control Shutoff	Hydraulic Research	7-211642002 (736300)	Diaphragm activated valve Material Buna N on nylon fabric. Buna N O-ring (static).
Fuel Pilot Valve	Hydraulic Research	7-211642003 (743900)	Diaphragm activated valve Material Buna N on nylon fabric. Poppet check valve. Viton O-ring. Other O-rings Buna N.
Firewall Shutoff Valve (cylindrical plug)	ITT General Controls	7-211642045 (AV16E1291)	Seal Teflon (dynamic).

TABLE A-9. YAH-64 APACHE AIRFRAME (HUGHES HELICOPTERS)(CONT'D)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
APU Shutoff Valve (ball valve)	ITT General Controls	7-211642059 (AV24B1291AR)	Seal Teflon (dynamic).
Check Valve, Fwd Cell	Parker-Hannifin	7-211642032 (2770103)	Molded Buna N seal on flapper. O-rings Buna N (static).
Check Valve, Aft Cell	Parker-Hannifin	7-211642033 (2770104)	Molded Buna N seal on flapper. O-rings Buna N (static).
Auxiliary Fuel Check Valve	Lord Industries	7-117420063 (L81400-8CC)	
Shutoff Transfer Valve (ball valve)	ITT General Controls	7-211642004 (AV24B1293)	Seal is Teflon (dynamic).
Fuel Quantity Sensor	Simmonds Precision	7-211642075 Typical (391001-372)	Capacitance type gage. Sleeve at top Teflon.
Fuel Tank, Fwd	Firestone	7-211641001 (37832)	Innerliner fabric.

TABLE A-9. YAH-64 APACHE AIRFRAME (HUGHES HELICOPTERS)(CONT'D)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Fuel Tank, Aft	Firestone	7-211641002 (37833)	Innerliner fabric.
Boost Pump, Air Driven	Pnu-Devices	7-211642078 (2307)	Gear (geroter) pump with carbon seal. Vespel vanes on air side not in fuel. O-rings fluorocarbon per MS3248.
Boost Pump For APU, Electric	Lear-Siegler	7-211642062 (RG36810)	Vane pump with dry D.C. motor. Carbon face seal for shaft. Seals Buna N. Diaphragm of DuPont Fairprene.
Transfer Pump, Air Motor	Pnu-Devices	7-211642052 (2284)	Gear (geroter) pump with carbon seal. Vespel vanes on air side not in fuel. O-rings fluorocarbon per MS3248.
Pressure Switch	Hydra-Electric	7-211642074 (9111)	Diaphragm actuated switch. Seal outside edge fluorosilicone. Basically static, but some small movement.
Breakaway Coupling (two poppets)	Aeroquip	7-117420069 (AE98102H)	Boot Buna N (static).
Pullaway Coupling (two poppets)	Aeroquip	7-267100011 (XAE80861H)	Boot Buna N (static).

TABLE A-9. YAH-64 APACHE AIRFRAME (HUGHES HELICOPTERS)(CONT'D)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Drop Tank, Metal			
	Seargent Fletcher	(7-211642081)	
Check Valve, Controllable Filter (swing type)		7-117420021	
	Shaw Aero	(457-780)	O-ring on flapper Buna N (dynamic).

TABLE A-10. C-12 HURON AIRFRAME (BEECH AIRCRAFT)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS

ITEMIZED LISTING OF THE C-12 AIRFRAME FUEL-WETTED COMPONENTS WAS NOT AVAILABLE FROM BEECH AIRCRAFT. THE MAJORITY OF THE COMPONENTS ARE THE SAME AS THE ONES USED ON THE RU/U-21 UTE, ALSO MANUFACTURED BY BEECH AIRCRAFT.

TABLE A-11. OV-1B/C MOHAWK AIRFRAME (GRUMMAN AEROSPACE)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Self-sealing Hose	Aeroquip	134SCP804 (AE502-12)	Innerliner of Buna N with two polyester reinforced braids.
Check Valve (poppet)	Brunswick	(8869A4TT56)	O-ring Buna N (dynamic). No problem sealing. High cracking force.
Float Valve, Pilot	Parker-Hannifin	134SCP119 (1323-585905)	Pilot valve main tank.
Motorized Gate* Valve (for pressure fueling)	ITT General Controls	GV500BG18960 (AV16B1296D)	Seals are of Thiokol for gate. O-rings are Buna N.
Valve, Solenoid Actuated (part of drop tank system)	Parker-Hannifin	134SCP112-3 (19-758-51)	Shutoff valve drop tank transfer.
Check Valve, Cylinder	Parker-Hannifin	(1111-548189-1)	Main tank aft vent outlet.

* Potential fuel-sensitive area

TABLE A-11. OV-1B/C MOHAWK AIRFRAME (GRUMMAN AEROSPACE) (CONT'D)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Fuel Gage, Quantity		134SCP114-3	
	Honeywell	(FG200A-50)	Probes, capacitance type.
Adapter & Cap, CCR		134SCP125-1	
	Carter	(6450)	Moulded rubber seal on cap is synthetic rubber per MIL-R-6855, class 1, grade 60. Dust cap gasket is Fareprene 5029A.
Fuel Tank, Fuselage (self-sealing)		134SCP103-7	
	Uniroyal	(FCR-46312)	Innerliner fabric.
Shutoff Valve*	45681	1321-517310	
			Pilot valve operated by main tank fuel valve.
Motorized Gate Valve*			
	ITT Aerospace Controls	(GV500BG12990)	Main fuel tank to engine.
		(CAV16B129401)	
Check Valve			
		(MS28885)	

* Potential fuel-sensitive area

TABLE A-11. OV-1B/C MOHAWK AIRFRAME (GRUMMAN AEROSPACE) (CONT'D)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Ejector Pump	Allen Aircraft	(612E501)	No elastomers - all metal.
Boost Pump, Electric (2 ea.)	Lear-Siegler	134SCP115 (RR11970A)	Centrifugal pump with dry motor. O-rings Buna N. Shaft seals silicone.
Pressure Switch	Consolidated Controls	134SCP108-7 (R6607-1-46)	11 mil thick - glass woven Teflon impregnated diaphragm (dynamic) 1¼" diameter.
Gravity Fueling Filler Cap	Several	(15600V1-156-1) (MS2952611)	Hardly ever used.
Sump Drain Valve (poppet)	Auto-Valve	(1100B52Z-G)	O-ring Buna N on shaft per MIL-R-6855 (dynamic).
Drop Tank, ** Aluminum	Sargent-Fletcher	(134P10150-1)	No elastomers.

** Components are used on the range extension kit with aluminum drop tanks

TABLE A-11. OV-1B/C MOHAWK AIRFRAME (GRUMMAN AEROSPACE) (CONT'D)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Rotary Pump,** Electric	Lear-Siegler	134SCP123-3 (RG16550A)	Vane pump line mounted. Buna N elastomers. Diaphragm of DuPont Fairprene.
Fuel Quantity Probe**	Sargent-Fletcher	(50179) 72429	Capacitance type.
Fuel Cap And Adapter** (gravity fueling)	Sargent-Fletcher	(50251)	Flat gasket in cap.
Relief Valve, ** Pressure/Vacuum	Sargent-Fletcher	(50233)	Vents overboard for drop tank.
Gasket, Cover** Assembly (under 39099)	Grumman	(39018)	Neoprene oval gasket.
Fuel Hose,** Medium Pressure	Aeroquip	(AE601)	Fuel system hose.

**Components used on the range extension kit with aluminum drop tanks

TABLE A-12. RU/U-21 UTE AIRFRAME (BEECH AIRCRAFT)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Nonself-sealing Hose	Aeroquip	(701012-12D0170)	Innerliner of Buna N with single stainless steel wire braid reinforcement.
Check Valve* (poppet)	Circle Seal Controls	(8869A-12BT-2)	O-ring Buna N (dynamic).
Transfer Feed Valve, Solenoid Actuated	ITT General Controls	50-389095 (AV1B1602)	Two crossfeed valves.
Shutoff Valve, Solenoid Actuated	Dukes	(3153-00-9)	One crossfeed valve. Poppet type. Molded Buna N. O-rings Buna N (static).
Gate Valve, Motorized*	ITT General Controls	(AV16B170B)	Buna N O-rings (static). Thiokol gate seals (static).
Check Valve (swing/flapper)	Parker-Hannifin	(1111-595272)	
Check Valve (swing/flapper)	Dukes	(3298-00)	O-rings Buna N (static). Seal molded Buna N.

* Potential fuel-sensitive area

TABLE A-12. RU/U-21 UTE AIRFRAME (BEECH AIRCRAFT) CONT'D

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Check Valve, Safety Relief (poppet)	Circle Seal Controls	(5132A-4TT-55)	O-ring Viton (dynamic).
Fuel Quantity Transmitter	Simmonds Precision	(B1239-3636)	Capacitance type gage. Sleeve at top Teflon.
Fuel Flow Transmitter	Bendix Corporation	(9133-25B1)	Probably turbine meter.
Boost Pump, Electric*	Airborne	(1D2-12)	Boost pump with wet electric motor.
Pressure Switch	Aircraft Controls	50-389055-2 (GP-8000-50-1)	Seals (static), old design. Diaphragm seal stainless steel, new design.
Fuel Filter With Pressure Relief Valve	Air-Maze	(02W05847)	Filter made of stainless steel screen cloth with aluminum end caps. O-rings AMS 7270. Poppet relief valve is metal to metal.

* Potential fuel-sensitive area

TABLE A-12. RU/U-21 UTE AIRFRAME (BEECH AIRCRAFT) CONT'D

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Gravity Filler Cap	Koehler-Dayton, Inc.	(37810-1)	O-ring in cap Buna N (static).
Sump Drain	Curtis Dyna-Products	(CCA3400)	4 valves.
Ferry Fuel Pump,** Electric	Dukes	(1132-00-1)	Centrifugal pump with dry electric motor. Vane-type pump with vanes of Vespel. Poppet check valve O-ring fluorosilicone. Shaft seal has Buna N O-ring Plug seal Buna N.
Ferry Fuel Pump,** Manual	Christen	(30264)	Stainless steel center shaft and screws. Series of 4 poppets of Delrin. Wobble pump. O-ring Buna N.
Manual Selector Valve** (ball valve)	Auto-Valve	(73C-8-B1)	Ball seals are MIL-S-6855 (Buna N) and Teflon per AMS3651. O-ring Buna N (dynamic and static).
Aluminum Ferry Tank**	Beech		No liners. All aluminum.

** Components are used on the range extension kit

TABLE A-12. RU/U-21 UTE AIRFRAME (BEECH AIRCRAFT) CONT'D

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS
Fuel Cells,** Nonself-sealing			
	Goodyear		Innerliner Buna N.
	Uniroyal		
Vent Float Valve **		50-380135-1/2	
	Beech	(2F1-6-34055)	Float lifts up to close the check valve.

** Components are used on the range extension kit

TABLE A-13. UV-18 TWIN OTTER AIRFRAME (DEHAVILLAND AIRCRAFT)

COMPONENT	MANUFACTURER	AIRFRAME P/N (MFG. P/N)	COMMENTS

ITEMIZED LISTING OF THE *UV-18 AIRFRAME FUEL-WETTED* COMPONENTS WAS NOT OBTAINED FROM DEHAVILLAND AIRCRAFT.

APPENDIX B

ENGINE FUEL-WETTED SYSTEM COMPONENTS

APPENDIX B TABLES

TABLE B-1. T53-L-13B/703/7A/15/701A LYCOMING ENGINE

COMPONENT	VENDOR'S PART NUMBER (ENGINE CO. P/N)	VENDOR	BRIEF DESCRIPTION (UNIQUE FEATURES)	COMMENTS (SENSITIVITY TO FUEL CHANGES)
Starting Solenoid Valve	AV1F1155-1 AF56C-39A (1-300-191-02)	ITT Genl Conts (Aerospace Prods) Eckel Valve Corp	Internal Rubber Packing Conforms on MIL-P-5315 Two Position Electrically Opened, Spring-Loaded Closed Valve with an Internal 100 Mesh Filter	Contaminants and corrosion.
Starting Fuel Manifold Assembly	(1-170-430/420-01)	Kreisler Industrial Corp		Corrosion.
Starting Fuel Nozzle	6660042 24143 (1-300-405)	Parker Hannifan Delavan	Atomizing Nozzle, Incorporates a Starting Fuel Purge System to Help Eliminate Clogging of Start Fuel Nozzle Due to Coking	Contaminants, thermal stability and viscosity
Igniter Plug	10-390045-1 5611387 FHE 211-2 (1-300-348)	Bendix AC Champion		May require change if viscosity causes starting problems.
Combustor Drain Valve	(1-160-220-03)	Foremost Precision Reb Ind		Comtamination, thermal stability.
Main Manifold Assembly	(1-160-160-09/10)	Lycoming	Two-Section, Dual-Channeled Assembly	Corrosion.
Main Fuel Injector	26518 6660001 (1-300-347)	Parker Hannifan Delavan	Atomizing Dual Orifice Nozzle	Particulates or Contamination Can Accumulate in Swirl Chamber and Change Flow Characteristics, Thermal Stability and Viscosity.

* T53 engine models 7A, 15, and 701A use a fuel filter and fuel heater included on the next page.

TABLE B-1. T53-L-13B/703/7A/15/701A LYCOMING ENGINE (CONT'D)

COMMENTS	VENDOR'S PART NUMBER (ENGINE CO. P/N)	VENDOR	BRIEF DESCRIPTION (UNIQUE FEATURES)	COMMENTS (SENSITIVITY TO FUEL CHANGES)
Fuel Control with Integral Pump	84200A7A/100770A	Chandler-Evans	Consists of a Power Turbine Governor and a Computer Assembly Plus High Pressure Pump (87352/7E820/85034) Which Is a Rotary Gear (-701A uses a vane for better protection against contamination).	Low Lubricity and Contaminants Will Affect the Gear Pump, Buna-N O-rings and Seals in Pump and Control Will Be Affected By Increased Level of Aromatics or Peroxides. Comtaminants Could Also Create Problems in Close Tolerance Parts in the Control.
Flow Divider (Linear Directional Valve)	(1-180-190-03)	Arkwin Industries, Inc. Lycoming Pro sser Industries, Inc.	Controls Flow to the Engine Nozzles According to a Pre-Determined Schedule of Primary vs Secondary Air	Particulates Could Cause Stickage, Also Could be Affected by Low Lubricity and by a Decrease in Thermal Stability.
Fuel Filter	045468	Bendix Filter Corp	Incorporates an Impending Bypass 10m Nominal	Could Be Affected by Viscosity Changes. An Increase in Particulates (Less than 10 Micron Size) May Require A Change in Element Filtration Moisture Absorbancy.
Fuel Heater	5A470-001 VA5267586	Tavitrol United A/C Products		Thermal Stability and Corrosion

TABLE B-2. T63-A-700/720 DETROIT DIESEL ALLISON ENGINE

COMPONENT	VENDOR'S PART NUMBER	VENDOR	BRIEF DESCRIPTION (UNIQUE FEATURES)	COMMENTS (SENSITIVITY TO FUEL CHANGES)
Fuel Pump and Filter	6854292 (5A/700) 23003114 (720) 386500-5 (TRW)	Sundstrand TRW (alternate vendor)	Gear dual element on -700, single element on -720.	Low lubricity and contamination. Moisture absorbancy.
Gas Producer Fuel Control	6871111 (5A/700) 6895672 (720)	Bendix	Pneumatic communication with power turbine governor (Model DP-D3)	Lubricity and contamination (non-rotating metering valve). Aromatics and peroxides.
Fuel Nozzle	6852020 (5A/700) 5233333 (720)	DED Diesel Equipment Division GM	Dual orifice atomizing with built in metering valve	Contamination (fluted metering valve), thermal stability.
Igniter	FHE-161-9 5611071	Champion AC		Will require change if viscosity increases and causes starting problems.
Combustor * Drain Valve (Plug and Check)	6854255(CV) MS9015-03 (Plug)			Contaminants and Corrosion
Check Valve	252402-1	Bendix		Contaminants and corrosion.

* Two ports for different applications OH-58 (Engine sits horizontally), OH-6 (Engine is at a 45° Angle)

TABLE B-3. T55-L-11ASA/11D/712 LYCOMING ENGINE

COMPONENT	VENDOR'S PART NUMBER (ENGINE CO. PART NUMBER)	VENDOR	BRIEF DESCRIPTION (UNIQUE FEATURES)	COMMENTS (SENSITIVITY TO FUEL CHANGES)
Start Fuel Nozzle	6660039 (2-300-216-02)	Parker Hannifan Delavan		Contamination, thermal stability, viscosity
In-Line Filter	21350 (2-300-311-01)	Mectron	712 Engine has an impending bypass	Particulates, viscosity and moisture absorbancy
Flow Divider	(2-161-390-01)	Arkwin Ind. Inc.		Contaminants, lubricity and thermal stability
Start Fuel Solenoid	AV1F11 55-1 (1-800-191-06)	ITT Genl Controls Aerospace Products		Contaminants and Corrosion
Main Manifold Assembly	2-160-950-14/15	Lycoming		Corrosion
Boost Pump	025028-107 (2-160-790-04)	Chandler Evans	Centrifugal	Contamination
Main or Static Fuel Filter	048757-01 (2-300-277-01)	Facet Enterprises, Inc. Filter Products Div.		Particulates, viscosity and moisture absorbancy.
Oil Cooler Assembly	2-160-750-02	Lycoming		Thermal stability could cause fuel breakdown and deposition all along the line.
Fuel Control	739222-6 (2-161-620-11) (2-161-620-39*)	Hamilton Standard	Contains Buna-N O-rings and seals	Particulates, increase in aromatics and peroxides.
High Pressure Pump		Sundstrand	Gear pump	Low lubricity fuel will affect gear wear

TABLE B-3. T55-L-11ASA/11D/712 LYCOMING ENGINE (CONT'D)

COMPONENT	VENDOR'S PART NUMBER (ENGINE CO. PART NUMBER)	VENDOR	BRIEF DESCRIPTION (UNIQUE FEATURES)	COMMENTS (SENSITIVITY TO FUEL CHANGES)
Igniters	2-300-217-02			May require change if viscosity increases and causes starting problems.
Main Fuel Injectors	2-300-677-03 (712) 2-300-216 (11D)	Delavan	Dual orifice atomizing on the 11D and airblast on the 712.	Contamination, thermal stability and viscosity.

* Preferred for T55-L-11D (without inlet guide vane controller)

TABLE B-4. T700-GE-700 GENERAL ELECTRIC ENGINE

COMPONENT	VENDOR'S (ENGINE CO.) PART NUMBER	VENDOR	BRIEF DESCRIPTION OF (UNIQUE FEATURES)	COMMENTS (SENSITIVITY TO FUEL CHANGES)
Boost Pump (centrifugal, mixed flow)	RR 53150E1 (P/N 3033T33G02)	Lear-Siegler	Anodized Al housing, fluorosilicone O-ring (static), carbon in stainless steel case (dynamic)	Extremely sensitive to contaminants (no filter ahead of it). Fuel vapor pressure (cavitation)
Fuel Filter (10u nominal, 30u absolute) (impending bypass pop-up)	AD-9985-55 (P/N 5035T76P07)	Aircraft Porous Media, Inc.	Viton and fluorosilicone O-rings. Adhesive: Epoxy-ISO Chem. 130819546 (APMS-PM-0010).	Affected by viscosity changes. Increa: in fine contaminants may require chang in element filtration.
Hydromechanical Unit (HMU)	763700-3 (P/N 6038T62P04	Hamilton-Standard	Many critical parts - spool valves, cam followers, flapper valves, bearings, gears, & seals. Sliding seals - graphite filled teflon	Corrosion, contaminants, lubricity, aromatics. Viscosity could affect scheduling.
Fuel-Oil Cooler	(P/N 4046T25601	United Aircraft Products		Thermal stability, coking, (no problem: to this date)
Sequence Valve*	0212021 (P/N 3033T32G01)	Arkwin Industries	O-rings: nichols 6072 compound teflon impregnated fluorosilicone	Contaminants, lubricity, thermal stability
Primer Nozzles (atomizing)	Primer (P/N 4046T78P05)	Parker-Hannifan	Primer nozzle has insulating tube to help prevent coking	Contamination, thermal stability, viscosity
Fuel Injectors (airblast)	Injector (P/N 6035T64602)	Parker-Hannifan		Contamination, thermal stability, viscosity
High Pressure Fuel Pump** (vane type)	PF4-038-6B	Vickers	Adhesive wafer ((3M, AF-31) on end plate	Lubricity and contamination (due to rubbing of vanes on cam ring and rotor on end plates)

* This valve is being redesigned (to be called pressurizing and overspeed unit (POU)

** Installed in HMU

TABLE B-5. T74-CP-700 PRATT & WHITNEY AIRCRAFT CANADA ENGINE

COMPONENT*	ENGINE MFGR. NO. (Vendor Part No.)	VENDOR	BRIEF DESCRIPTION (Unique Features)	COMMENTS (Sensitivity to Fuel Changes)
Main Fuel Control Unit	2524245-3 2524546-1	Bendix	Same Basic Control as in T63 (Model No. DP-F2. Incorporates starting Fuel Function	Lubricity and contamination (non-rotating metering value) Aromatics and peroxides.
Fuel Pump	(4V146R100)	Vickers	Vane type pump	Lubricity and contamination (due to rubbing of vanes on cam ring and rotor on end plates).
Oil to Fuel Heater	8426B	Southwind Div. of Stewartwarner Corporation		Reduced thermal stability could cause fuel breakdown and deposition
Fuel Nozzles	3013635	**	Pressure Atomizing Simplex	Comtamination, thermal stability, viscosity
Igniters	3014054	**		May require change if viscosity increases and causes starting problems.
Automatic Dump Valve	DV 1003-40	Lucas Rotox, Ltd.		Contaminants
Compressor Drain Valve	3007009	**		Contaminants
Transfer Tube	3010146	**		Stainless steel, seals could be affected by aromatics or peroxides.
Fuel Manifold (Adapter Assy.)	3011098 3011099	**		Stainless steel, seals could be affected by aromatics or peroxides.
Flow Divider				Contaminants, lubricity and thermal stability.

* Commercial designation is PT6A-20/21.
** Vendor information is not available.

TABLE B-6. T74-CP-702 PRATT & WHITNEY AIRCRAFT CANADA ENGINE

COMPONENT	ENGINE MFGR. NO. (Vendor Part No.)	VENDOR	BRIEF DESCRIPTION (Unique Features)	COMMENTS (Sensitivity to Fuel Changes)
Main Fuel Control Unit	2524389-1 2524547-1	Bendix	Same Basic Control as in T63 (Model No. DP-F2)	Lubricity and contamination (non-rotating metering value) Aromatics and peroxides.
Fuel Pump	0 24800-104-01	Sundstrand	Gear type pump	Lubricity and contamination
Starting Fuel Control	11011563	Lucas Rotax, Ltd.	Incorporates Flow Division Function	Lubricity, contamination, Aromatics and Peroxides.
Oil to Fuel Heater	VA 525193-6	United Aircraft Product		Reduced thermal stability could cause fuel breakdown and deposition.
Fuel Nozzle	3010036	**	Pressure Atomizing	Contamination, thermal stability, viscosity
Igniter	3014054	**		May require change if viscosity increases and causes starting problems.
Transfer Tube	3011155	**		Stainless steel, seals could be affected by aromatics or peroxides.
Primary Adapter	3014704	**		Stainless steel, seals could be affected by aromatics or peroxides.
Secondary Adapter	3014705	**		Stainless steel, seals could be affected by aromatics or peroxides.
Adapter Drain Valve	3011071	**		Contaminants.

* Commercial designation is PT6A-27/28.
** Vendor information is not available.

TABLE B-7. T73-P-1 PRATT & WHITNEY AIRCRAFT, USA ENGINE

COMPONENT	ENGINE MFGR. NO. (Vendor Part No.)	VENDOR	BRIEF DESCRIPTION (Unique Features)	COMMENTS (Sensitivity to Fuel Changes)

ITEMIZED LISTING OF THE T73-P-1 ENGINE FUEL-WETTED COMPONENTS WAS NOT AVAILABLE FROM PRATT & WHITNEY AIRCRAFT.

APPENDIX C

AUXILIARY POWER UNIT FUEL-WETTED SYSTEM COMPONENTS

TABLE C-1. T-62T-2A1 SOLAR AUXILIARY POWER UNIT

COMPONENT	VENDOR'S PART NUMBER	VENDOR	BRIEF DESCRIPTION (UNIQUE FEATURES)	COMMENTS (SENSITIVITY TO FUEL CHANGES)
Fuel Control	100829-100	Solar		Corrosion, contaminants, lubricity, aromatics and peroxides
Fuel Pump (Gear Type)	102-203-1	DeLaval		low lubricity and contaminants
Fuel Filter	2250-4005 75 75486	Carborundum Corp Purolator Products		Contaminants, viscosity and moisture absorbancy.
Start Fuel Solenoid Valve	37695-100	Solar		Contaminants and corrosion
Main Fuel Solenoid Valve	37696-100	Solar		Contaminants and corrosion
Start Fuel Nozzle	28022-4	Delavan Mfg Co		Contamination, thermal stability and viscosity
Main Fuel Injectors	19050	Delavan Jay Craft Engr		Contamination, thermal stability and viscosity

APPENDIX C TABLES

TABLE C-2. GTCP36-55H GARRETT AIRESEARCH AUXILIARY POWER UNIT

COMPONENT	Engine MFGR. P/N (VENDOR'S PART NUMBER)	VENDOR	BRIEF DESCRIPTION (Unique Features)	COMMENTS (Sensitivity to Fuel Changes)
Gear Pump Fuel Control	3882660-1	Garrett AiResearch design made by Aero Hydraulics Division	Control contains, integral gear pump and 3 micron filter (electronic torque motor made by Servotronics).	Will be sensitive to increase in level of contaminants and low lubricity fuel. Uses only fluorosilicone seals and O-rings so relatively insensitive to increase in aromatics or peroxides.
Fuel shutoff solenoid	692545-6	Valcor		Contaminants and corrosion
Piloted air blast atomizer	3830061-2	Delevan	Start fuel is supplied through primary (simple pressure atomizing), run fuel through a secondary air blast orifice.	Contamination, thermal stability, viscosity.
High energy igniter plug	369964-5	Champion		
Fuel Manifold			Stainless steel tube running to the single atomizer.	

APPENDIX D

PERSONNEL CONTACTED FROM AIRFRAME, ENGINE, AUXILIARY POWER UNIT, AND COMPONENT MANUFACTURERS

Aeroquip Corporation, Aeroquip Aerospace Division; 300 South East Avenue; Jackson, Michigan, 49203; Mr. Rick Walsh, Sales Energy Service Coordinator; (517) 787-8121.

Airborne Manufacturing Company; 711 Taylor Street, Elyria, Ohio, 44035; Mr. K.R. Kelly, V.P. Sales; (216) 323-4676.

Air-Maze International, Inc.; 25002 Miles Road; Cleveland, Ohio, 44128; Mr. George Slater; (216) 292-6800.

Allen Aircraft Products, Inc; P.O. Box 271-T; Ravenna, Ohio, 44266; Mr. E.P. Vigluicci, Design Engineer; (216) 296-9621.

Arkwin Industries, Inc.; 686 Main; Westbury, New York, 11590; Mr. Bob Newman; (516) 333-2640.

Auto-Valve, Inc.; 1707 Guenther Road; Dayton, Ohio, 45427; Mr. Ralph Drew; (513) 759-0870.

Beech Aircraft Corporation; 9700 East Central; Wichita Kansas, 67201; Mr. Irwin Johnson, Department 86, Executive Project Administrator; (316) 681-7184.

Brunswick Corporationk Technetics Division; Box 3668; 1111 North Brookhurst; Anaheim, California, 92803.

J.C. Carter Company, Division of ITT; 673 West 17th Street; Costa Mesa, California, 92626; Mr. Dick Cornwell; (714) 548-3421.

Chandler-Evans, Control Systems Division; West Hartford, Conneticut; L.A. Difford, Section Supervisor, Pumps Engineering.

Christen Industries; 1048 Santa Anna Road; Hollister, California; (408) 637-7405.

Circle Seal Controls; 1111 North Brookhurst Street; Anaheim, California, 92801; Mr. Don Ogilive; (714) 774-6110.

Consolidated Controls Corporation; 15 Durant Avenue; Bethel, Conneticut, 06801; Mr. Walter Uhl, Seniro Project Engineer, Pressure Switches; (203) 743-6271.

Custom Components, Inc.; 21111 Plummer Street; Chatsworth, California, 91311.

Derogene, Inc., 885 West 16th Street; Newport Beach, California, 92663; Mr. Pat Patrick; (213) 998-9811.

Firestone; Magnolia, Arkansas; Mr. Lou Reddick, Product Engineer; (501) 234-3381.

Globe Industries, Division of TRW; 2275 Stanley Avenue; Dayton, Ohio, 45404; Mr. Jack Hohne; (513) 228-3171.

B.F. Goodrich Company; P.O. Box 182; Green Camp, Ohio, 43322; Mr. Oren Linger, Technical Manager; (614) 383-31111.

Goodyear Aerospace Corporation; Rockmart, Goergia, 30153; Mr. G.A. Steffensen, Manager Product Support Engineered Fabrics Division; (404) 684-7055.

Grumman Aerospace Corporation; P.O. Box 1137; Stuart, Flordia, 33494, Mr. Clifford Fenwick, Project Engineer; (305) 287-5300, ext: 213.

Gull Airborne; 55 Engineers Road; Smithtown, New York, 11781; Mr. S. Sporn, Director of Engineering; (516) 231-3737.

Hydro-Aire, Division of Crane Company; 30000 Winona Avenue; Burbank, California, 91510; (213) 842-6121.

Hydra-Electric, Inc.; 3151 Kenwood Street; Burhanic, California, 91503; Mr. Frank Davis; (213) 843-6211.

Hydraulic Research and Manufacturing Company, Division of Textron, Inc.; APCO Filter Division; 10445 Glenoaks Boulevard; Pacoima, California, 91331; Mr. Jerry Steel; (213) 896-2411.

ITT General Controls Aerospace Products; 1200 South Flower; Burbank, California, 91502; Mr. O.V. Roberts, Marketing Manager; (213) 842-6131.

Lear-Siegler; 241 S. Abbe Road; P1O. Box 4014; Elyria, Ohio, 44036; Mr. Tony Klimczak; (216) 323-3211.

Lord Industries

Michigan Dynamics Division, Ambac Industries, Inc.; 32410 Ford Road; Garden City, Michigan, 48135; Mr. Jim Hopkins - Mr. Jim Chaplin; (313) 522-4000.

Parker-Hannifin; Irvine, California, Mr. Jim Deklotz; (714) 833-3000.

PNU-Devices, Inc.; 72 Santa Felicia Drive; Goleta, California, 93117; Ms. Carla Zimmerman; (805) 968-0272.

Revere Corporation of America; 845 North Colony Road; Wallingford, Conneticut; Mr. Gary Buteau; (203) 269-7701.

Ronson Hydraulic Units Corporation; 530 Sugar Creek Road; Charlotte, North Carolina, 28225; Mr. Walter Karasiewicz; (704) 596-3311.

Shaw Aero Devices, Inc.; 1 Industrial Road; East Hampton, New York; Mr. Dave Jones - Mr. Harry DeRosa; (516) 537-1404.

Simmonds Precision; Panton Road; Vergennes, 05491; Mr. Cecil Franklin; (802) 877-2911.

Stellar Hydraulic Company; 11310 Sherman Way; Sun Valley, California, 91352.

Stratoflex, Inc.; 220 Roberts Cutt-off Road; Fort Worth, Texas, 76114; Mr. Ken Parks, Standards Engineer; (817) 738-6543.

Symetrics, Inc.; 2524 Calcite Circle; Newbury Park, California, 91320; (805) 498-4586.

TRW Incorporated; 23555 Euclid Avenue; Cleveland, Ohio, 44117; (216) 383-2930.

Turbomach, Division of Solar Turbines International; 4400 Ruffin Road; San Diego, California, 92123; Mr. Vern Wolcott; (714) 238-6976.

Uniroyal Corporation; 312 North Hill Street; Mishawaka, Indiana, 46544; Mr. Charles McGregor, Quality Control Manager; (219) 256-8145.

Valcor Engineering Corporation; 4 Lawerence Road; Springfield, New Jersey, 07081; Mr. Larry Anderson; (201) 467-8400.

Whittaker Controls; 12838 Saticoy Street; North Hollywood, California, 91605; (213) 765-8160.

Wiggins Connector Division, Transamerica DeLaval, Inc.; Los Angeles, California; Mr. Cliff Cannon, Manager Sales and Engineering; (213) 269-9181.

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