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).

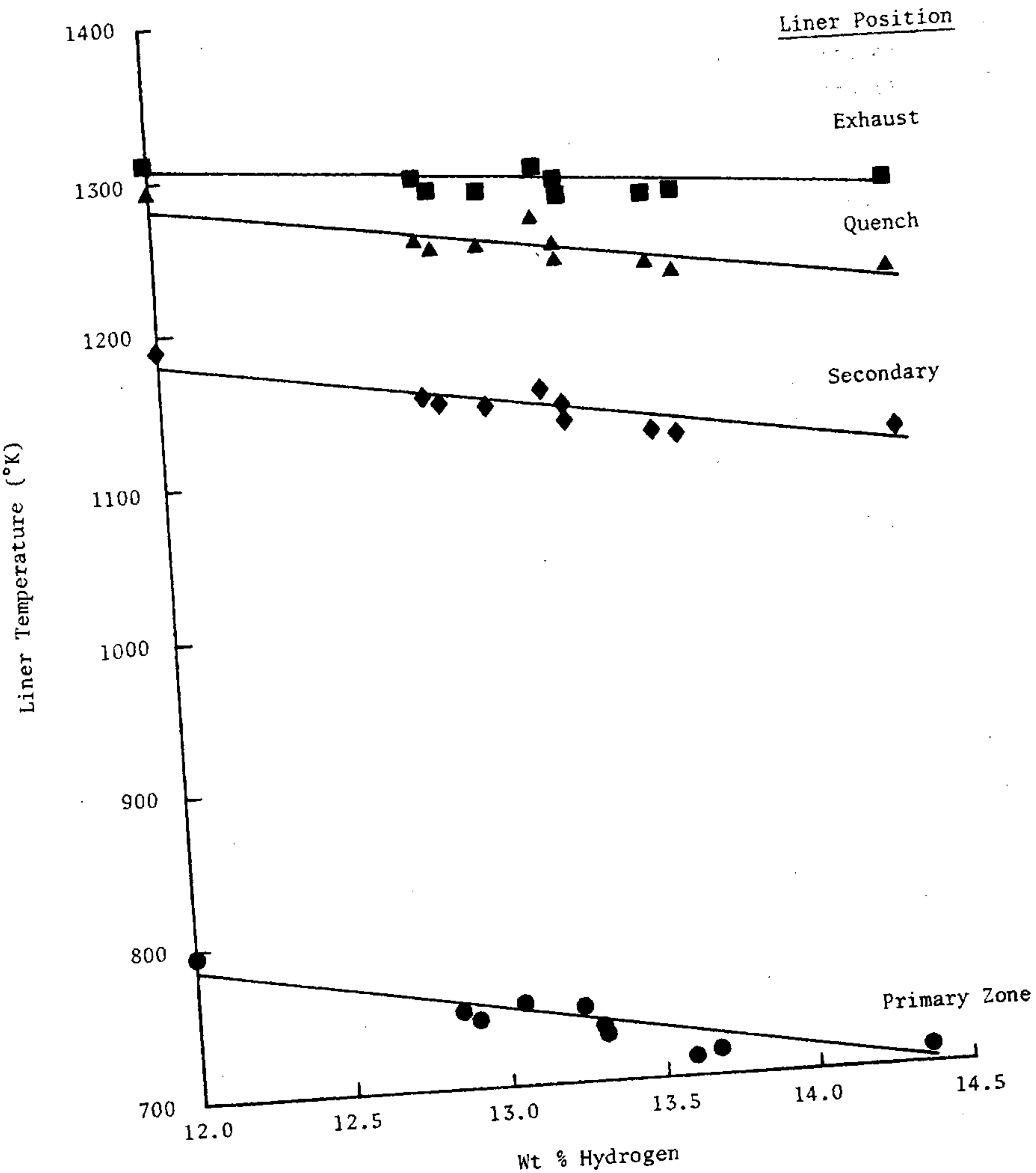


FIGURE 1. EFFECT OF HYDROGEN CONTENT ON T63 COMBUSTOR LINER TEMPERATURES

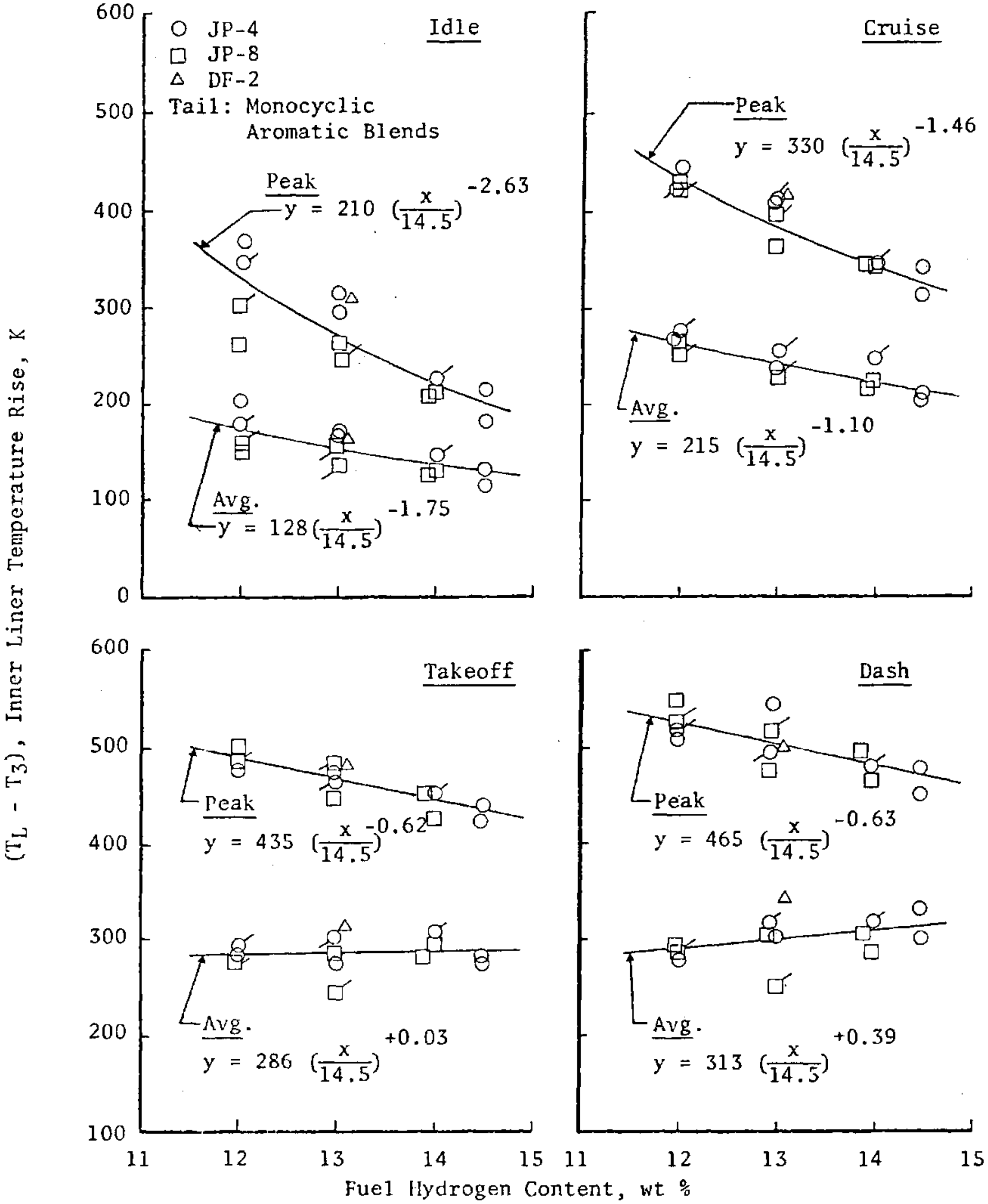


FIGURE 2. EFFECT OF FUEL HYDROGEN CONTENT ON INNER LINER TEMPERATURE RISE: J79-17A (from Ref. 9)

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

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

that as fuels of different hydrogen content are 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.

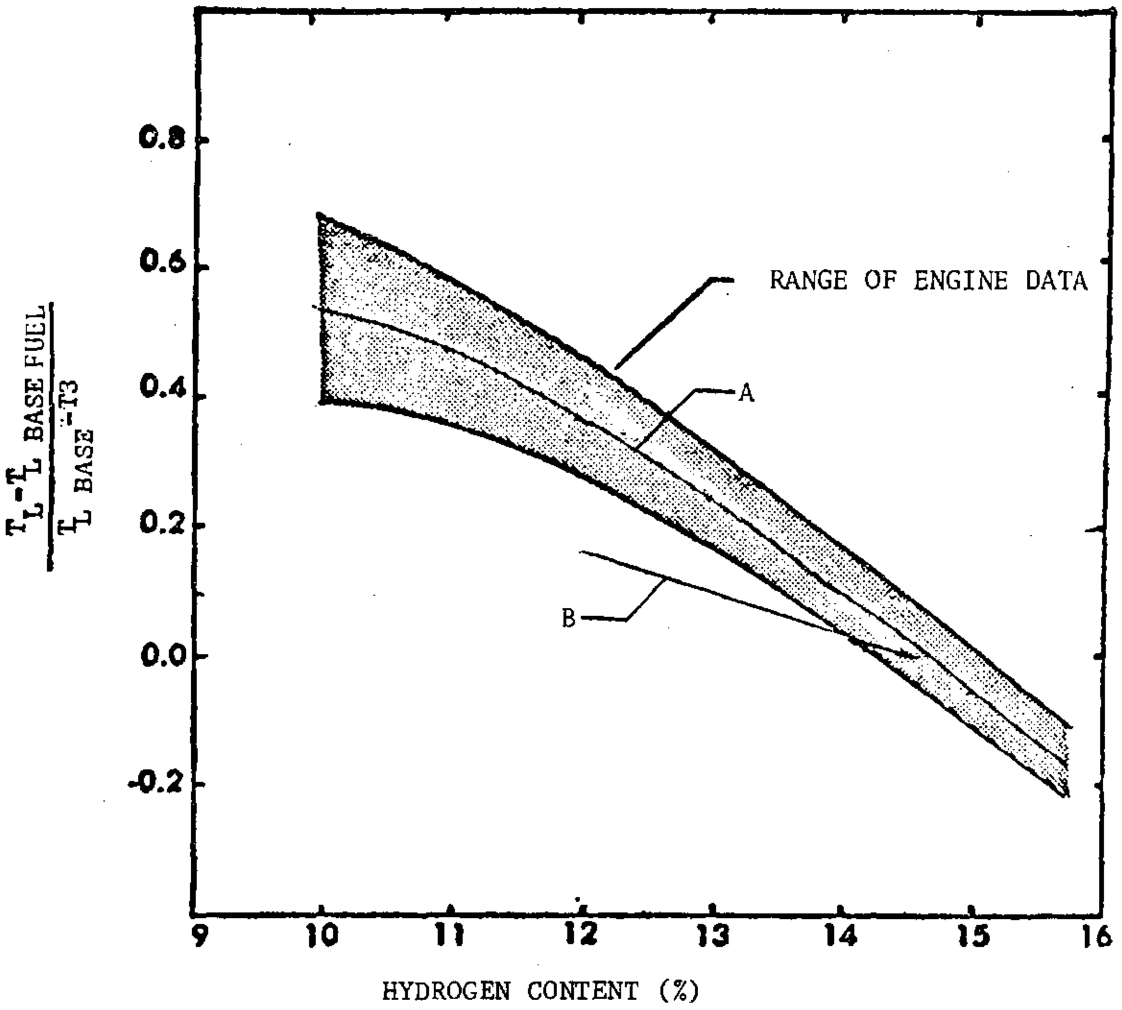
As part of the recent Navy ATP study, General Electric personnel developed a simplified methodology for predicting the effects of fuel hydrogen content on life ratio that can be used for combustors where only

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

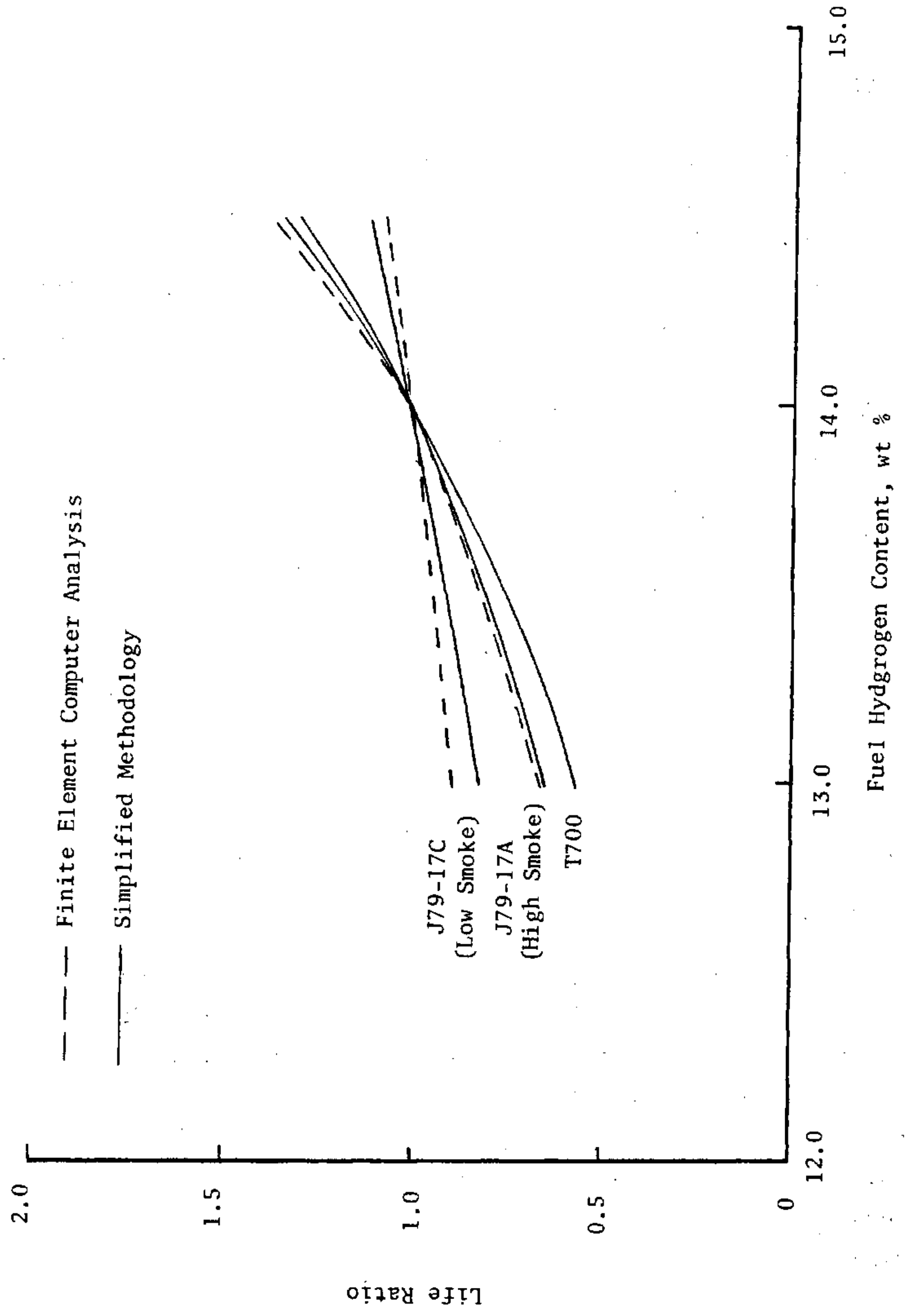


FIGURE 4. COMPARISON OF ANALYTICAL METHODOLOGIES TO PREDICT THE EFFECTS OF FUEL HYDROGEN CONTENT ON COMBUSTOR LINER LIFE

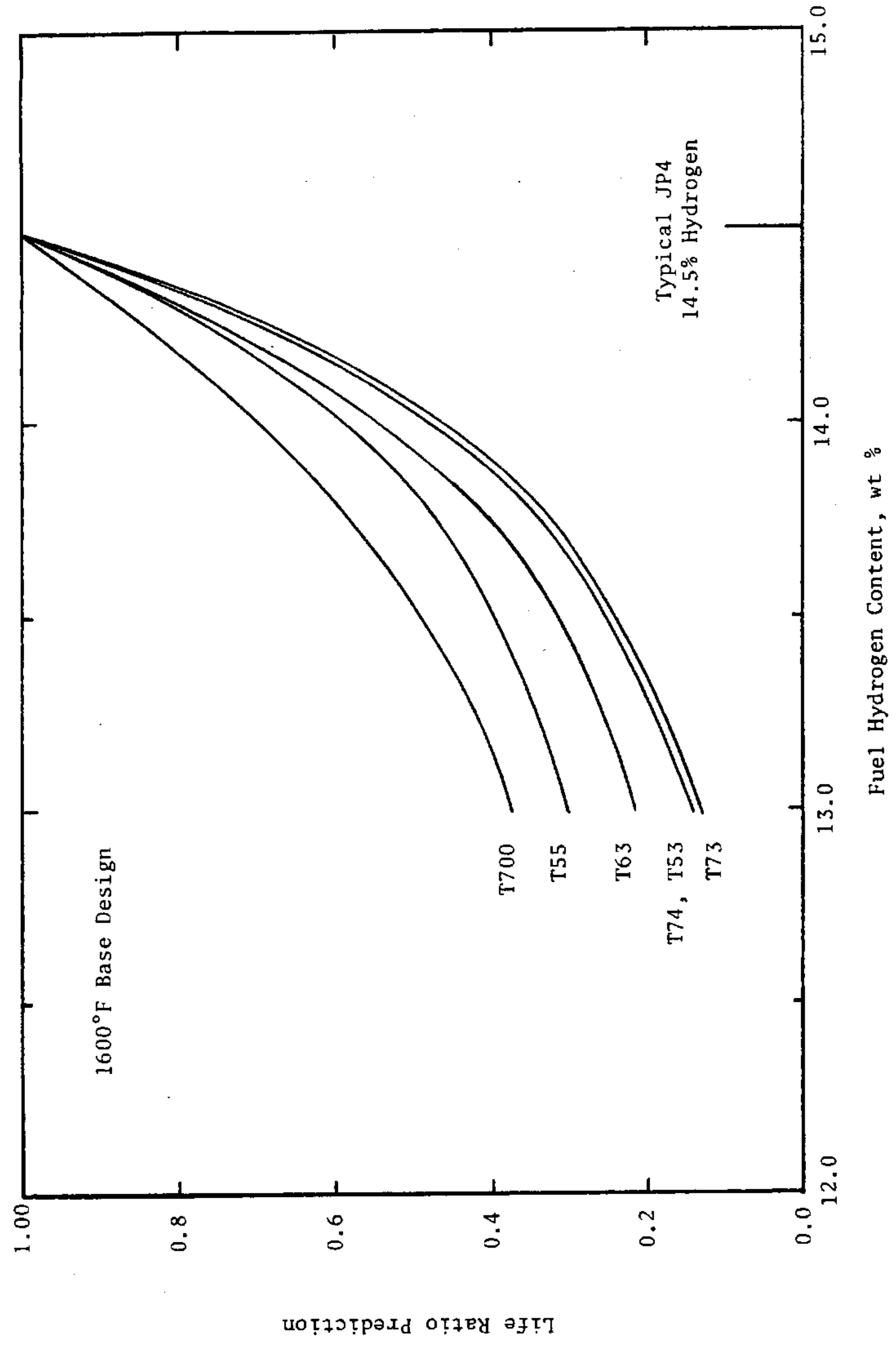


FIGURE 5. PREDICTIONS OF THE EFFECT OF FUEL HYDROGEN CONTENT ON THE COMBUSTOR LINER LIFE OF ARMY AIRCRAFT TURBINE ENGINES

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

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*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.

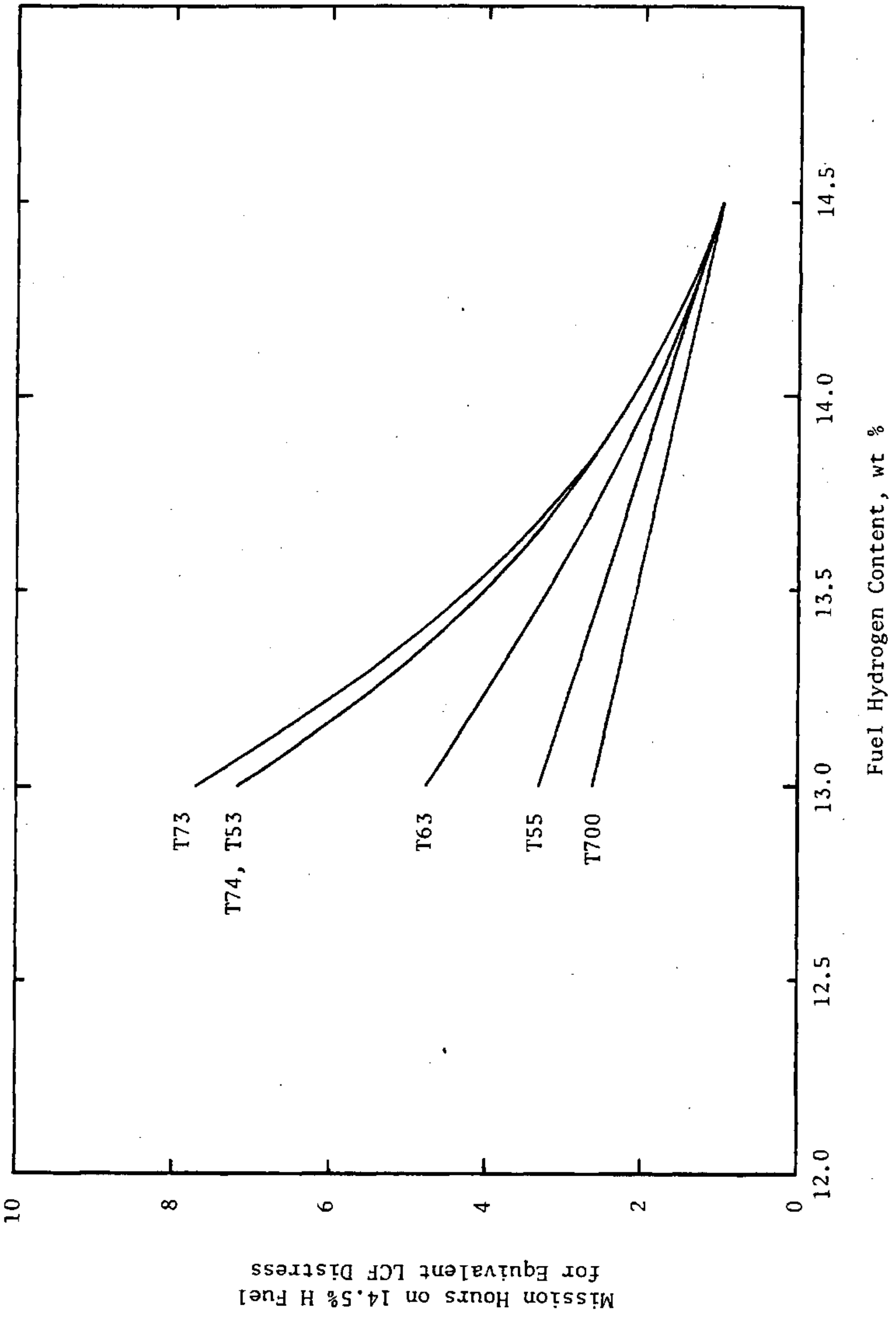

FIGURE 6. RELATIVE MISSION LIFE OF COMBUSTOR LINERS
ON FUELS OF REDUCED HYDROGEN CONTENT

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 alkylbenzenes (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

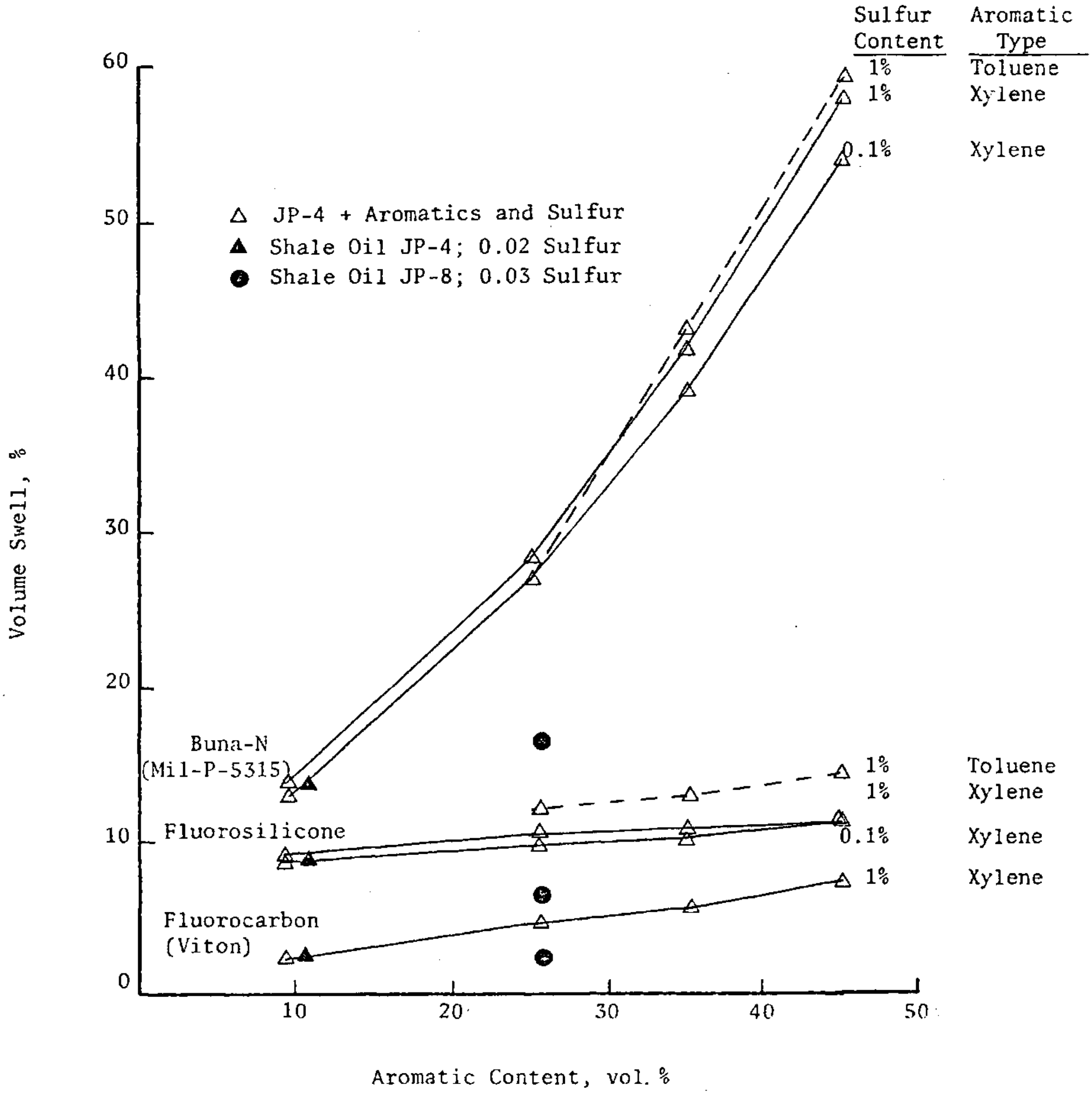

FIGURE 7. EFFECTS OF AROMATIC TYPE AND SULFUR ON VOLUME SWELL AND ELASTOMERS

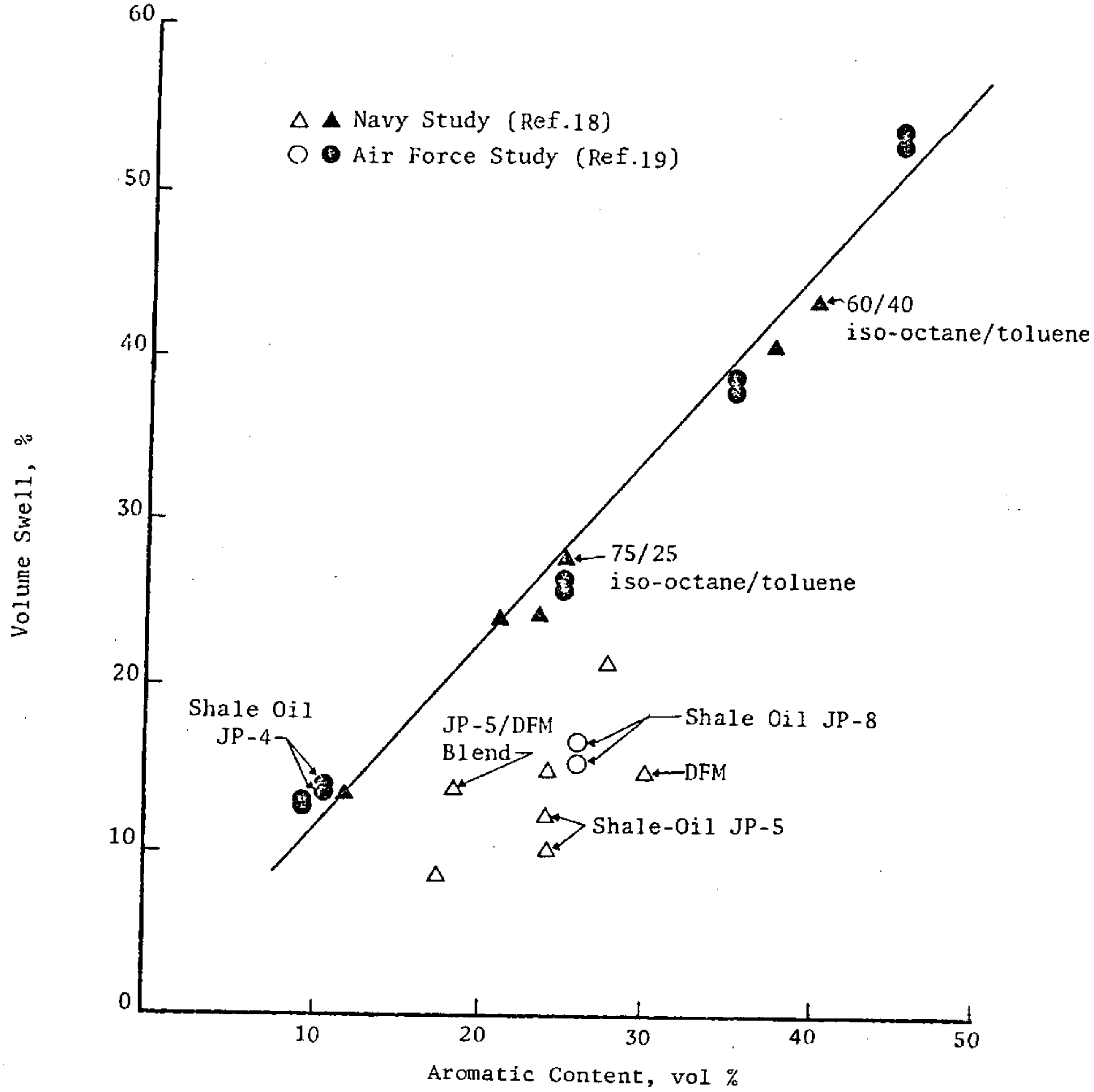

FIGURE 8. EFFECT OF AROMATICS ON VOLUME SWELL IN BUNA N ELASTOMERS

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

Aircraft	Engine	Minimum Starting Temperature, °C (°F)			
		Battery Start		APU Start	
		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)* -45 (-50)	No test	-34 (-30)* -45 (-50)

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*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.