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,

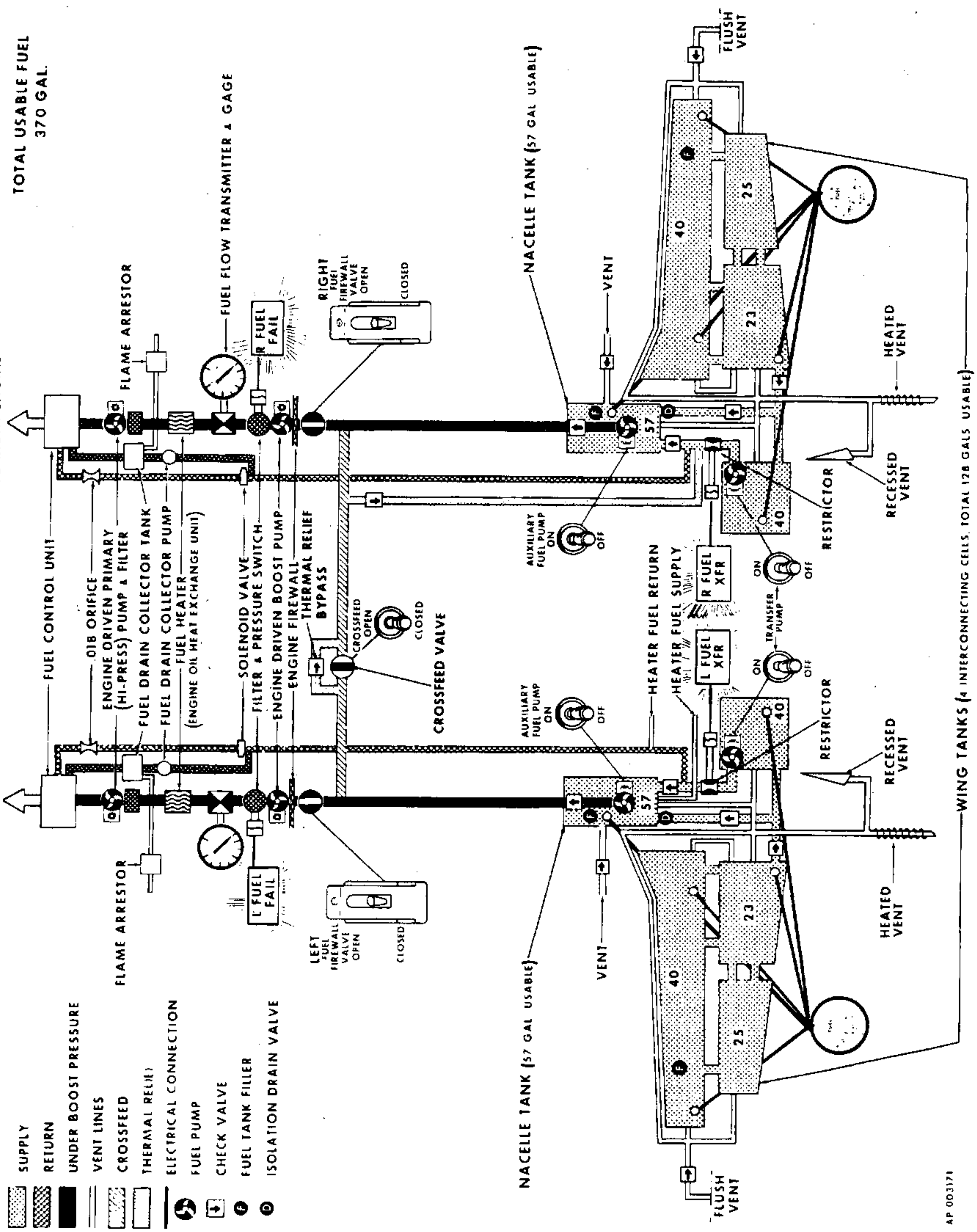


FIGURE 14. RU/U-21 FUEL SYSTEM SCHEMATIC

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 In addition, the airframe manufacturers and the hose manufacturers believe that the MIL-H-7061A specification is out-of-date for current aircraft fuel systems and should be updated.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.

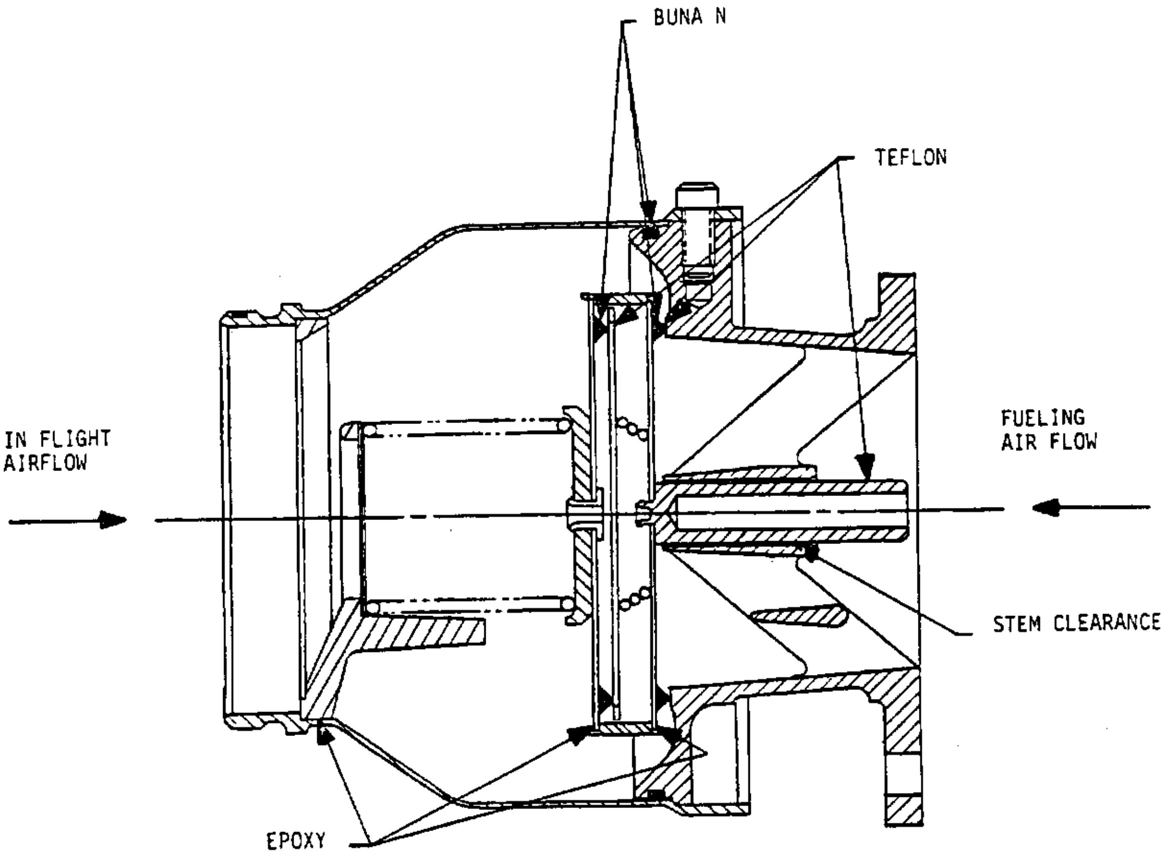
10. Fuel Tank Cover Gasket

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

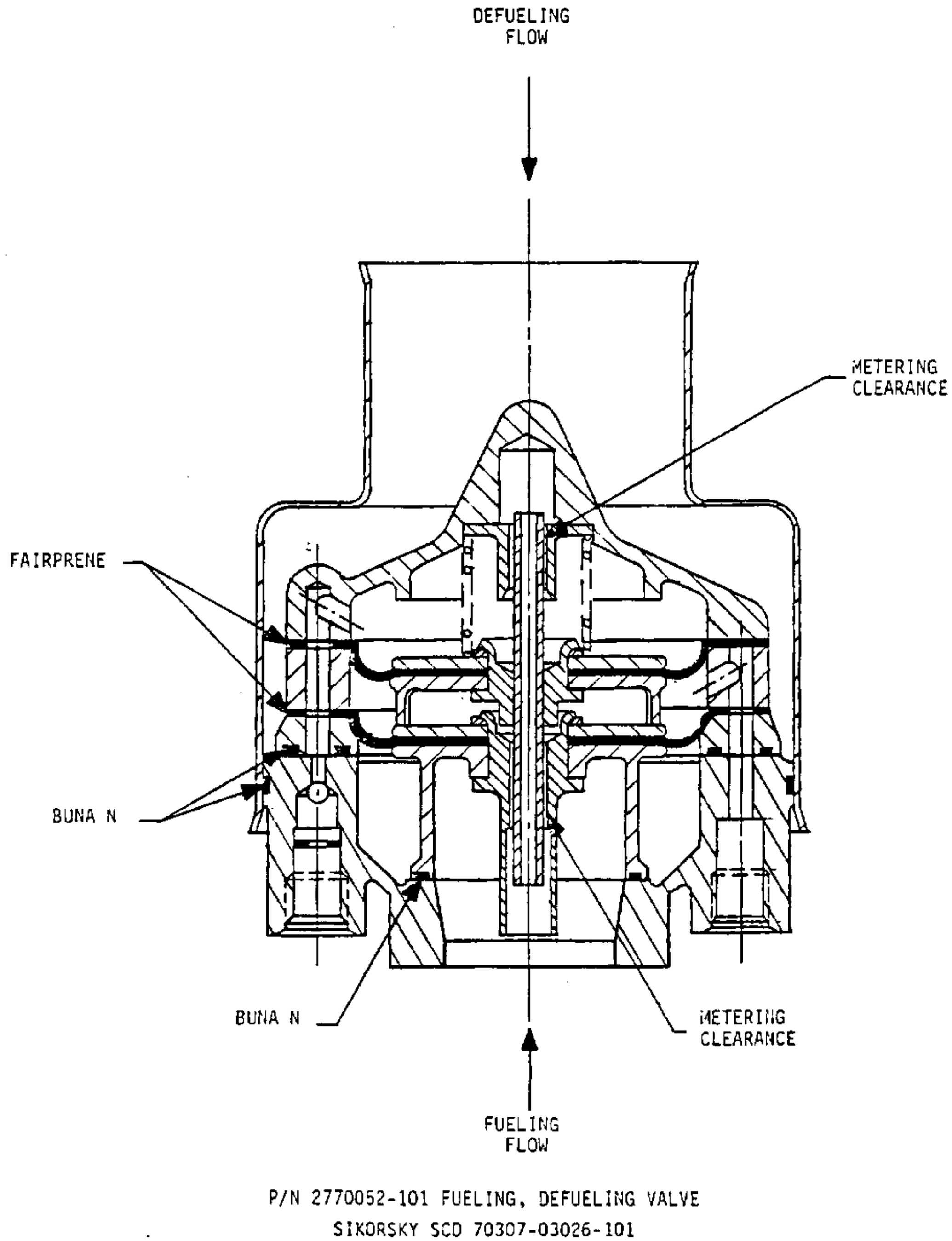


FIGURE 16. FUELING/DEFUELING VALVE USED ON THE UH-60A FUEL SYSTEM

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 the order 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. <u>T63-700/-720 Fuel Control</u>

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. <u>T55-7C Fuel Pump</u>

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. T55-L-11A/-11D Fuel Pump

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. Potential Fuel Sensitive Areas - Auxiliary Power Units

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.