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CRASHWORTHY FUEL SYSTEM DESIGN CRITERIA AND ANALYSES

By

Neva B. Johnson

March 1971

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

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This report was prepared by Dynamic Science (The AvSER Facility), a Division of Marshall Industries, under the terms of Contract DAAJ02-69-C-0030.

The purpose of this effort was to analyze and study existing aircraft fuel systems and to develop design criteria to assist aircraft designers in incorporating crashworthy features into fuel systems.

Eight U. S. Army aircraft fuel systems were studied by the contractor, and the characteristics of these systems are summarized in tabular form. Checklists of design criteria are also provided for use in determining the crashworthiness of new fuel system designs.

The program was conducted under the technical management of Mr. H. W. Holland, Safety and Survivability Division.

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13. ABSTRACT

Comprehensive design criteria for crashworthy aircraft fuel systems were developed from the design philosophies of the U. S. Army and several aircraft manufacturers, as well as from Dynamic Science's extensive experience in the development and testing of crashworthy fuel systems. Eight aircraft fuel systems currently in the U. S. Army inventory were analyzed, and unsatisfactory areas in regard to crashworthiness were determined. Most of these areas were common to the majority of the aircraft studied. Recommendations for improving the crash resistance of these hazardous areas were proposed.

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ABSTRACT

Comprehensive design criteria for crashworthy aircraft fuel systems were developed from the design philosophies of the U. S. Army and several aircraft manufacturers, as well as from Dynamic Science's extensive experience in the development and testing of crashworthy fuel systems. Eight aircraft fuel systems currently in the U. S. Army inventory were analyzed, and unsatisfactory areas in regard to crashworthiness were determined. Most of these areas were common to the majority of the aircraft studied. Recommendations for improving the crash resistance of these hazardous areas were proposed.

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INTRODUCTION

The high incidence of postcrash fires in U. S. Army aircraft has resulted in a disproportionate loss of personnel and equipment. As part of a continuing effort to reduce personnel and equipment losses, the U. S. Army has sponsored a crash fire research program at the AvSER Facility of Dynamic Science for the past eight years. During this period, many concepts and new methods of crash fire prevention have been conceived, fabricated, and then tested extensively on a component, system, and full-scale basis. One of the most significant test series culminated in a successful full-scale crash test of a UH-1A helicopter containing a modified crashworthy fuel system. Many of these modifications are now incorporated in the crashworthy fuel systems being installed in production models of the UH-1D/H helicopter.

Current recommendations in Chapter 8 (Postcrash Fire) of the Crash Survival Design Guide* incorporate much of the improved technology and criteria developed by Dynamic Science and other equally concerned agencies. However, no formal design criteria have been available to specifically assist the aircraft designer in incorporating crashworthy features into aircraft fuel systems. To fulfill this need, Dynamic Science, under Contract DAAJ02-69-C-0030, has developed design criteria for an optimum crashworthy fuel system based on analyses of existing systems and optimization of design philosophies.

This report presents the design criteria in design handbook form and provides the designer with the necessary background to design a crashworthy fuel system. Inasmuch as in-flight and crash fire protection overlap, many in-flight fire protection design criteria have also been included.

The program background and source effort and the design criteria are presented herein in the following sequence:

1. Approach to the Problem: A brief account of the source data and the approach taken for development of the design criteria.

2. Fuel System Design Criteria: These criteria are practical and usable within state-of-the-art technology and incorporate performance, reliability, safety, and maintainability considerations throughout.

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*Crash Survival Design Guide, USAAVLABS Technical Report 70-22, U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, August 1969.

3. Design Criteria Checklists: Individual checklists are provided for the major design considerations: e.g., materials; tank location, compartments, construction, outlets, fittings, and mounting; fueling; etc. These enable the designer to quickly evaluate his design against the criteria to insure compliance of the final design with crashworthy standards.

4. Analyses Of Aircraft Fuel Systems: Detailed analyses of the fuel systems of eight existing U. S. Army aircraft are presented. These are:

Rotary-Wing	Fixed-Wing
OH-58A	OV-1
OH-6A	
UH-1C/M	
UH-1D/H	
AH-1G	
CH-47C	
CH-54	

5. Summary And Conclusions: The characteristics of the eight systems analyzed are summarized in tabular format. Commonalities and differences between systems/aircraft are discussed, and the influence of these distinctions on design are analyzed.

6. Recommendations: Specific design action that must be taken to make fuel systems crashworthy is recommended.

APPROACH TO THE PROBLEM

Army operations and maintenance requirements, aircraft company design manuals and philosophies, and specific aircraft designs were used as data for this project. The data were examined in detail along two concurrent paths to determine (1) present design philosophies and (2) representative fuel systems now in use.

Eight representative fuel systems now in use were separated into specific subsystem categories. These subsystems were analyzed and those that were satisfactory were so noted. Solutions using the optimum design philosophy generated during this project were proposed for those subsystems deemed unsatisfactory.

The results of this study were used to formulate design criteria for crashworthy aircraft fuel systems.

FUEL SYSTEM DESIGN CRITERIA

INTRODUCTION

Prevention of in-flight fire has long been of concern to aircraft designers and manufacturers. Criteria for the prevention of in-flight fires are included in most aircraft system design manuals. Although the need for postcrash fire safety has also been recognized, few design criteria have been available which help prevent postcrash fires.

The following criteria emphasize the crashworthiness aspects of fuel system design but also include many in-flight fire safety design criteria. These criteria are presented to aid the designer in designing fire safety features into the aircraft during the initial design phase, thus preventing costly and time-consuming production line changes and retrofit programs. The criteria are presented here in design handbook form. This allows the reasons for the criteria to be explained and thus gives the designer the full background that he needs to properly design a complete crashworthy fuel system.

Checklists of the design criteria are presented in a later section. These checklists are furnished to enable the designer to rapidly assess the criteria that must be considered in the original design, as well as to provide a convenient form with which to check the design against the criteria after the design is formalized.

GENERAL DESIGN FACTORS

The following discussion summarizes the general factors that must be considered in fuel system design. These factors are attainable only to the extent allowed by the detailed design of the specific aircraft system involved. The applicable specifications for the specific aircraft should be used as a basis for determining the practical extent to which these factors may be attained.

Performance

The primary factor to be considered in fuel system design is the performance required of the aircraft. The system must be designed to allow the aircraft to accomplish the mission for which it is intended and to operate successfully during all required operational modes of the aircraft.

Not only must each component be designed to fulfill its purpose in the operation of the aircraft, but the interactions of components among themselves to form the system must also be carefully considered. Any interface of the fuel system with other aircraft systems, such as the propulsion unit, must be examined critically to insure successful accomplishment of the aircraft's mission. Thus, complete performance parameters must be delineated so that the system may be successfully designed to function throughout the whole operational spectrum.

Reliability

The fuel system must be designed so that it will perform its intended function under specified conditions without failure for a specified period of time.

The fuel system as a whole, as well as all fuel system components, must be designed to function under all environmental and operational conditions which might be encountered during the entire flight envelope of the aircraft. Factors which must be considered are temperature extremes, vibration, shock, acceleration, moisture, sand and dust, icing, pressure and pressure extremes, and atmospheric electricity. Careful choice of materials and care in the design can often enable the fuel system to withstand the environment. If this is not possible, then the environment must be controlled to within tolerable limits. In addition, care must be taken to insure that all materials used in the system are compatible with the fuel being used in the aircraft.

Redundancy, in which a duplicate or alternate system or component is provided to take over if the primary element fails, may be used where increased reliability is necessary. This concept is especially valuable in combat aircraft which are exposed to ballistic environments. When it is not practical to protect the fuel system components by armor, redundancy provides a method of circumventing ballistic vulnerability which could lead to the failure of a mission or the loss of an aircraft.

Human factors must also be taken into account in designing reliability into a system. Minimum demands should be made on the skill and training necessary to operate, maintain, or repair a system. Components should be designed so that they are incapable of being reversed or otherwise wrongly installed in the system, if such reversal or installation could lead to failure of the system to perform its function.

Safety

Many hazardous areas in a system can be eliminated by applying a system safety approach during the design phase. Although reliability contributes to system safety by decreasing the probability of component/system failure, safety analysis techniques can lead to reduced hazard levels once a failure occurs.

Hazard level reduction is especially important in respect to fuel system design because of the catastrophic effects of in-flight or postcrash fires. Fuel should be located as far as possible from occupiable areas and ignition sources. The fuel system should be designed to completely contain the fuel during all survivable crashes regardless of aircraft orientation or structural deformation.

Maintainability

The system and its components should be designed so that a minimum amount of time, skill, and special tools are required to maintain or repair these items. A simple design is preferable to a more complicated one, not only from a maintenance standpoint but also from a reliability standpoint. Components should be easily accessible wherever possible consistent with in-flight and postcrash fire safety. If possible, the components should be arranged so that another component will not have to be removed in order to get to the desired component for maintenance and/or repair.

GENERAL FUEL SYSTEM DESIGN

Performance

The fuel system should be designed to function satisfactorily under all possible operating conditions and attitudes of the aircraft. Factors which must be considered are maximum altitude capabilities, maximum operation range, maximum rates of climb, relative location of tanks with respect to the power plants, engine fuel flow consumption and pressure demands, accessory fuel flow requirements such as cabin heaters or de-icing devices, and special environmental requirements such as repeated use under extreme hot or cold climatic conditions.

System Design

Keep the fuel system in the aircraft as simple as possible so that a minimum amount of effort is required on the part of operating and maintenance personnel. Keep the number of fuel tanks to a minimum, although it is desirable to use one tank for each engine in multi-engine aircraft. If a single fuel tank is used on a multi-engine aircraft, independent tank outlets should be provided for each engine, and the system from each tank outlet to any engine should be independent of the system supplying fuel to any other engine.

Design the fuel system for multi-engine aircraft so that it is possible to fuel any engine from any tank, if necessary. The system should also be designed so that it would be possible to cut off fuel flow to any one engine or combination of engines without affecting the fuel flow to the remaining engines.

Materials

Material selection for fuel system components should conform to MIL-F-8615. It should be noted that this specification prohibits the use of magnesium in fuel system components.

This specification also stresses that all materials that are selected for use in the fuel system must be compatible with the intended fuel and also compatible with each other. Dissimilar metals in contact with each other should be avoided.

In addition, the materials should exhibit resistance to deteriorating influences such as shock, vibration, abrasion, temperature changes, and oxidation. If the metals used in the components are not inherently corrosion resistant, they should be treated so as to make them resistant to corrosion. Insulation used in compartments or areas containing fuel tanks or lines should be of a nonabsorbent material so that fuel cannot be retained in or under it.

Component Location

Avoid locating fuel system components and lines in compartments or areas where a single malfunction such as leakage can cause ignition. All compartments containing fuel system components with potential leakage should be drained and ventilated.

Fuel system components and lines should be located below and away from ignition sources. Fuel lines and electrical wiring should be located so that no contact could be made between a broken electrical wire and the fuel line.

Fuel system components should be located where direct impacts with the earth are impossible in a crash environment. In addition, the components should be located so that they are protected as much as possible from ballistic hits.

DETAILED FUEL SYSTEM DESIGN

Fuel Tank Location

Fuel tank location should be carefully considered during the initial design phase of the aircraft. Although the size and configuration of the specific aircraft will influence the location of the fuel tank, the designer should use whatever latitude he has to locate the fuel tank in the safest possible location.

For in-flight as well as crash fire safety, avoid locating fuel tanks in engine compartments, electrical compartments, or any location where spilled or misted fuel could readily be ingested into the engine or ignited by the engine exhaust. Do not locate fuel tanks over the engine compartment or over the tailpipe or afterburner section.

The fuel tanks should be located as far as possible from the engine, electrical, and passenger compartments. If the fuel tank must be located near the firewall, there should be at least 1/2 inch of ventilated and drained space between the fuel tank and firewall.

Locate fuel tanks with the widest lateral clearance possible from the plane of the propeller or the turbines to prevent penetration of the fuel tank from failed propeller blades or bucket fragments.

Some areas in the aircraft are more prone to lightning strikes than other areas. Avoid these areas for fuel tank installation. Since areas of extremities are prone to lightning penetration, fuel tanks should not be installed in these extremities; for example, the fuselage nose or the wing tip.

Crashworthy considerations dictate that the fuel tanks be located so that maximum protection is provided in the event of crash impact. For this reason, fuselage tanks should be located as high as possible in the structure, away from the bottom of the fuselage. Do not locate fuel tanks where a collapsing landing gear may puncture them. Avoid locating tanks under heavy masses such as transmissions and engines which could be torn loose during a crash and crush the fuel tanks.

Wing tanks should not be located in the wing leading edges or in the wing root section as these areas are prone to severe damage during crash impact. Wing tanks should be located behind heavy spars to provide maximum protection.

Fuel Tank Compartments

Isolate fuel tanks in compartments with a liquid- and vapor-tight seal to keep fuel and fuel vapor from electrical equipment, engines, and occupants in case of leakage. These compartments should be drained and ventilated so that any leakage will exit through the drains rather than into other compartments. The drains should be at least 1/2 inch in diameter and located so the effluent cannot enter the exhaust wash or will not be within 5 feet of an exhaust outlet.

The inside of the compartment should be as smooth as possible, with stiffeners, hat sections, and stringers being kept to an absolute minimum. Passage of a projectile through structural members causes them to "flower" during a ballistic hit with the attendant possibility of puncturing the fuel tank.

Fuel Tank Shape

During a crash, the fuel tank must be allowed to displace with the aircraft structure rather than be snagged and torn by the displacing structure. This ability depends greatly on the shape of the tank, and smooth regular shapes are much preferred to irregular shapes. Avoid protuberances in the tank; for instance, the sump area should be gradually contoured into the tank bottom instead of projecting sharply below the tank. Avoid tanks composed of several rigidly interconnected cells, as these cells cannot displace relative to each other. Use a minimum corner radius of 1 inch to preclude high stress loads at the corners of the tanks during crash impact.

Fuel Tank Construction

Fabricate all fuel tanks from flexible crash-resistant material conforming to the requirements of MIL-T-27422B.

Fuel Tank Mounting

A common method of fuel tank failure during crash impact is the tearing out of fuel tank fittings which are rigidly bolted to the aircraft structure. Frangible attachments or frangible bolts must be used at all attachment points between the fuel tanks and aircraft structure to prevent this type of failure. Figure 1 shows some examples of various frangible attachments.

The load required to separate a frangible attachment from its support structure shall be between 25 and 50 percent of the load required to fail the weakest component in the attached system. To prevent inadvertent separation during flight and maintenance operations, the attachment separation load shall be greater than all operational and service loads at the frangible attachment location. Careful analysis must be conducted on each aircraft fuel system to determine the probable failure loads of the system so that frangible attachment breakaway loads may be determined. A sample breakaway load calculation is given in Figure 2. In addition, the frangible

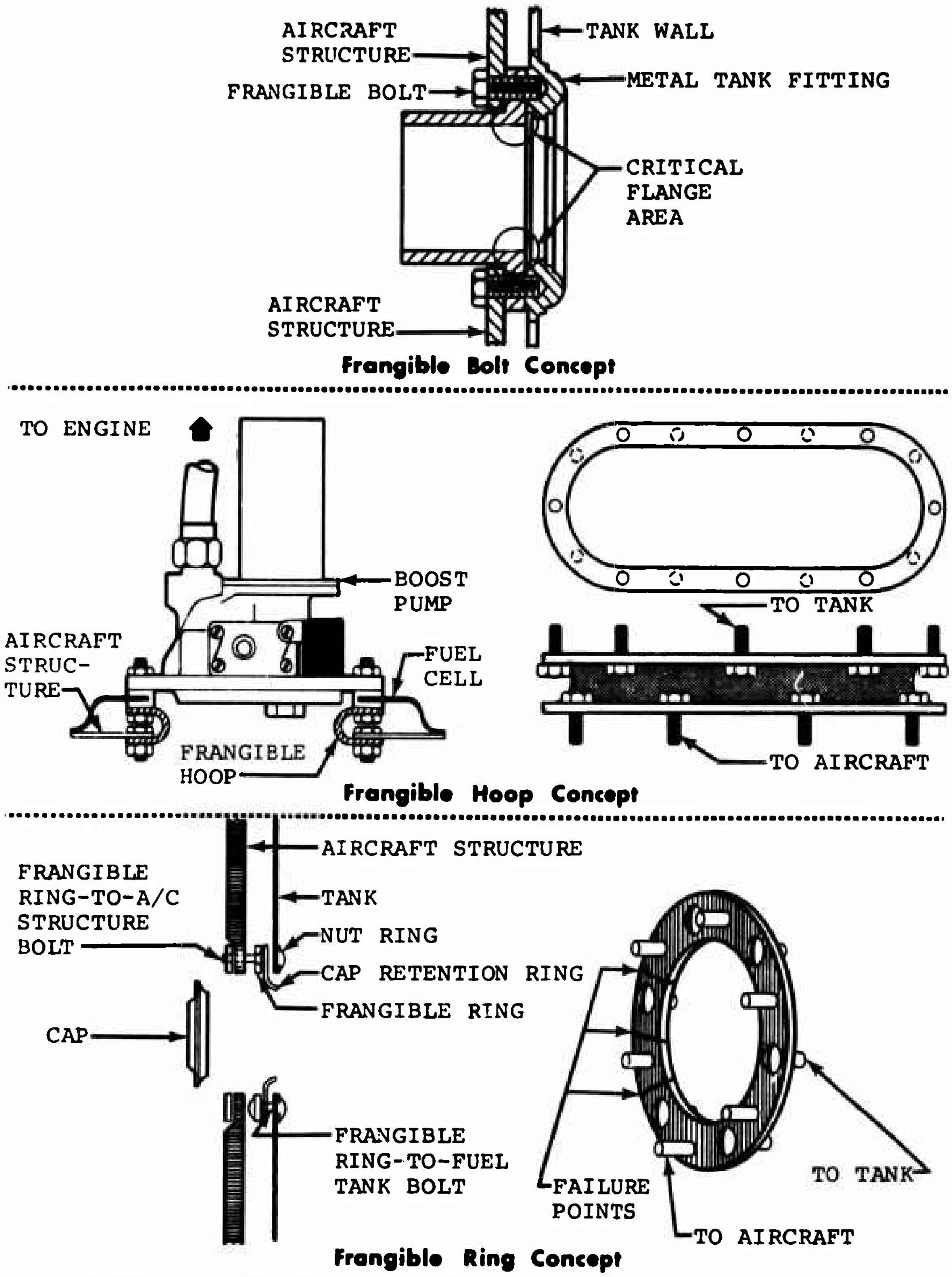
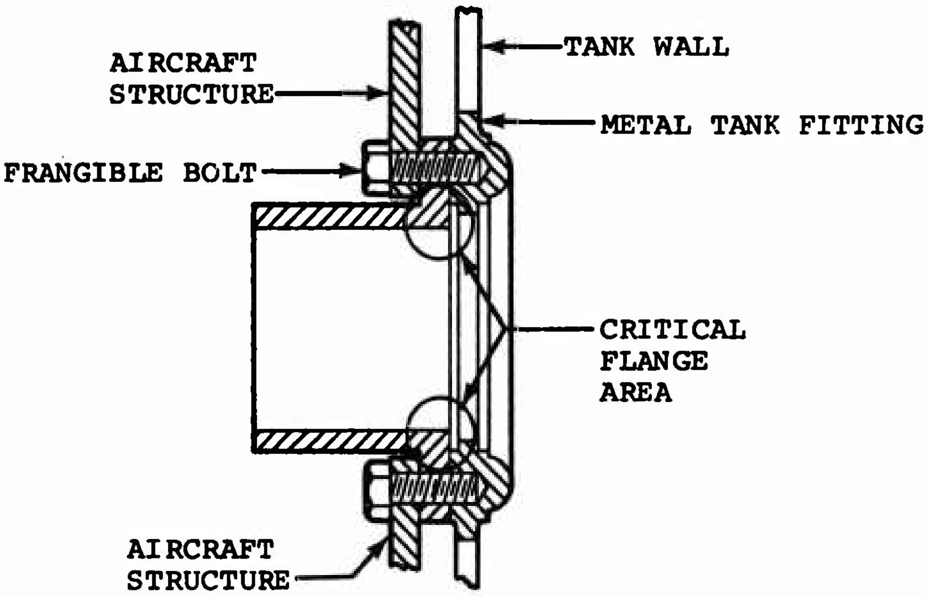


Figure 1. Typical Frangible Attachments for Installing Fuel Tank Components.



ITEM	LOWEST FAILURE LOAD (LB)*	FAILURE MODE
Aircraft Structure	4000	Shear
Tank Fitting	3000	Pull Out of Tank
Flange	5000	Shear
Frangible Bolt	Not more than $\frac{3000}{2} = 1500$ Not less than $\frac{3000}{4} = 750$	Break (Tension-Shear)

*Loads may or may not be representative; values are for explanatory purposes only.

Figure 2. Sample Frangible Attachment Separation Load Calculation.

attachments should separate whenever the required load is applied in the modes most likely to occur during crash impact. These loads, whether tension, shear, compression, or combinations thereof, must be determined for each attachment by analyzing the surrounding aircraft structure and probable impact forces and directions.

Fuel Tank Fittings

The number of fuel tank fittings should be kept to a minimum, as each fitting is a potential leakage area. In addition, the fittings are hard points in the fuel tank, preventing the fuel tank from rearranging its shape in these areas during crash impact.

Fuel tank fittings should be located as high as possible in the fuel tank, preferably at the top since this is the most protected area of the tank during crash impact. In addition, fittings which are located above the fuel level of the tank will not be subject to leakage. The incorporation of as many fittings as possible, such as filler caps, vents, gage units, outlets, etc., in one area is advantageous not only from a crashworthy viewpoint but also from a servicing viewpoint.

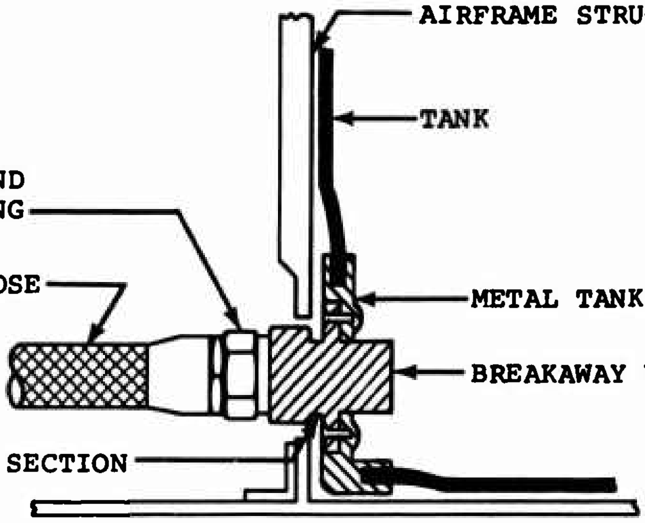
To take advantage of the inherent strength of the crashworthy fuel tank materials, the metal inserts in the tank wall should have a pullout strength of not less than 80 percent of the ultimate strength of the tank wall. MIL-T-27422B gives details of this requirement.

Fuel Tank Outlets

Self-sealing breakaway valves, which will separate and seal each half during excessive crash loads, should be used at all fuel-tank-to-fuel-line connections and at all tank-to-tank interconnects. These valves should be recessed into the tank so that the tank half does not protrude outside the tank wall more than 1/2 inch after valve separation. In addition, the shape of the tank half should be basically smooth to avoid snagging on adjacent structure or cutting the tank wall.

The load required to separate the breakaway valve must be able to meet all operational and service loads of the aircraft but should be between 25 and 50 percent of the load required to fail the weakest component in the attached system. Figure 3 illustrates a sample breakaway load calculation.

The valve should separate whenever the required load is applied in the modes most likely to occur during crash impact. These modes, whether tension, shear, compression, or combinations



ITEM	LOWEST FAILURE LOAD (LB)*	FAILURE MODE
Flex Hose	3000	Tension Breakage
Flex Hose	1500	Pull Out of End Fitting
Tank Fitting	7500	Pull Out of Tank
Hose End Coupling	1650	Break (Bending)
Breakaway Valve	2500	Pull Out of Tank Fitting
Breakaway Valve	Not more than $\frac{1500}{2} = 750$ Not less than $\frac{1500}{4} = 375$	Break at Frangible Section

*Loads may or may not be representative; values are for explanatory purposes only.

Figure 3. Typical Method of Breakaway Load Calculation for Fuel Tank to Line Breakaway Valve.

thereof, must be determined for each aircraft by analyzing the surrounding aircraft structure and probable impact forces and directions.

All breakaway valves should incorporate positive provisions for ascertaining that the valve halves are locked together during normal installation, service, and maintenance inspections.

Electrical Equipment in Fuel Tank Compartments

The number of electrical components and amount of wiring in the fuel tank or the fuel tank compartment should be kept to an absolute minimum.

All electrical equipment and all metal lines within the tank connected to electrical equipment, regardless of size, should be grounded. All electric wires and equipment in fuel tanks should be designed with the highest degree of protection against sparking, arcing, or overheating under normal operating conditions and during maintenance.

All electrical wiring going through the fuel tank compartments should be shrouded to prevent arcing and also to help protect the wires against cutting during crash impact. Wiring in the fuel tank area should not be near the bottom of the fuselage where it would be subject to crash damage.

Route the wires above the tank if possible. In addition, the wires should be 20 to 30 percent longer than necessary to accommmodate structural displacement due to crash impact. This extra length may be in the form of loops or bends in the wires.

Fueling

Design fuel inlets and tanks to prevent or minimize sloshing, thus precluding the buildup of static electricity. A grounding point for connection of a grounding wire from the refueling vehicle should be provided on the aircraft. Filler openings should be located so that fuel vapors cannot be directly ingested into the engine intake during "hot" refueling operations.

Fuel Line Construction

All fuel lines should consist of cut-resistant flexible hose since rigid aluminum tubing is easily crushed or broken during crash impact. This includes fuel lines to the pressure transmitters, as failure of these lines can cause large quantities of flammable fluids to leak into the nacelle or power plant compartment.

All fuel system hose assemblies should meet or exceed the requirements of MIL-H-58089. In addition, the hose assemblies must meet or exceed the cut resistance, tensile strength, and hose fitting pullout strength of those assemblies already qualified to MIL-H-58089. Cut hoses and clamps are unacceptable for use in the fuel system.

Hoses carrying fuel in or close to potential fire zones, such as engine compartments, must be capable of withstanding a temperature of 2000°F for 5 minutes without leakage. Fittings must also have an equal resistance to fire.

The above requirements for flexible hose and fire resistance also apply to vent and drain lines unless a failure of such lines and fittings will not contribute to the fire hazard.

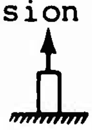
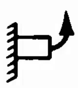
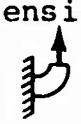
Fuel Line Fittings

Design fuel system lines with as few fittings as possible. Wherever possible, an uncut hose should be run through a bulkhead opening rather than being attached to the bulkhead with rigid fittings. The line may be stabilized at the bulkhead by means of a frangible panel or structure as discussed next under Fuel Line Support. However, self-sealing breakaway valves must be used whenever a line goes through a firewall so that a liquid-tight seal will be maintained at all times.

All fittings must be designed to assure 100-percent reliability of the structural integrity of the joint. The joint must be leakproof throughout the environmental range of its application and must be designed so that critical torque techniques are not required for proper installation.

Insure that hoses do not pull out of their end fittings nor the end fittings break at less than the loads specified in Table I. This will probably require the use of steel fittings for hose end fittings of 3/8-inch I.D. or less.

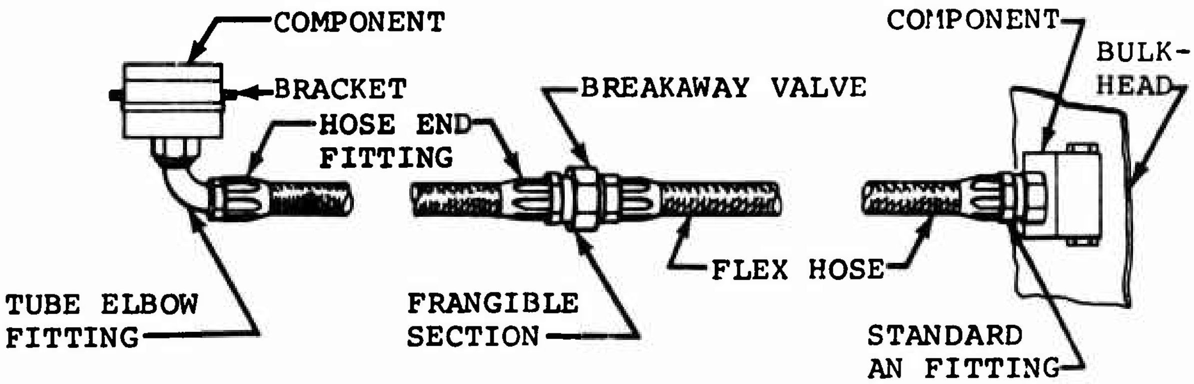
Self-sealing breakaway valves should be used at all points in the fuel lines where aircraft structural deformation could lead to line failure. These breakaway valves must be able to meet all operational and service loads of the aircraft, but they should separate at a load between 25 and 50 percent of the load required to fail the weakest component in the system. Figure 4 illustrates a separation load calculation for an in-line breakaway valve. Table I provides the necessary data for calculating these loads.

TABLE I. REQUIRED MINIMUM AVERAGE AND INDIVIDUAL LOADS FOR HOSE AND HOSE-END FITTING COMBINATIONS					
Hose End Fitting Type	Fitting Size	Tension Load (lb)		Bending Load (lb)	
		Minimum Average Load*	Minimum Individual Load	Minimum Average Load*	Minimum Individual Load
STRAIGHT	-4	600	475	425	400
Tension =	-6	700	575	425	400
	-8	900	650	650	600
	-10	1450	1175	675	625
Bending =	-12	1775	1475	950	850
	-16	2125	1825	1425	1300
	-20	2375	2075	1550	1425
90° ELBOW	-4	600	475	425	400
Tension =	-6	700	575	425	400
	-8	900	650	450	400
	-10	1450	1175	475	425
Bending =	-12	1775	1475	500	450
	-16	2125	1825	775	700
	-20	2375	2075	1100	1000

*Minimum of three tests

In addition, the breakaway valve must separate whenever the required load is applied in the modes most likely to occur during crash impact. These modes, whether tension, shear, compression, or combinations thereof, must be determined for each valve by analyzing the surrounding aircraft structure and probable impact forces and directions.

All breakaway or quick-disconnect valves shall incorporate positive locking provisions and a simple method for ascertaining that the valve is locked together during installation, service, and inspection.



ITEM	LOWEST FAILURE LOAD (LB)*	FAILURE MODE
Flex Hose	3000	Tension Breakage
Flex Hose	1500	Pull Out of End Fitting
Hose End Fitting	1650	Break (Bending)
Standard AN Fitting	1700	Break (Bending)
Tube Elbow Fitting	900	Break (Bending)
Component Structural Attachments	4500	Pull Out of Structure
Breakaway Valve	Not more than $\frac{900}{2} = 450$ Not less than $\frac{900}{4} = 225$	Break at Frangible Section

*Loads may or may not be representative; values are for explanatory purposes only.

Figure 4. Typical Breakaway Load Calculation for In-Line Breakaway Valve.

Fuel Line Support

Provide adequate fuel line support so that lines do not deflect out of position as a result of internal pressure or as a result of aircraft maneuvers. Provide sufficient clearance to prevent chafing against structure or other components. Where chafing cannot be avoided, such as against bulkheads or other structures, clamp the line to the structure.

Care should be taken in the design of the line supports to prevent chafing or cutting of the fuel line. Do not use unlined metal clamps of any type. The fuel line supports should be frangible, either by nature of the material used or by design, so that the supports will release the hose during crash impact, thus allowing the hose to move with the deforming aircraft structure. The frangible clamp breaking load must be high enough to meet all operational and service loads but should be less than 50 percent of the load required to fail the weakest link in the system to which the clamp is attached. The required breakaway load for the frangible clamp supports is calculated in the same manner as for the frangible bulkhead panels (see Figure 5).

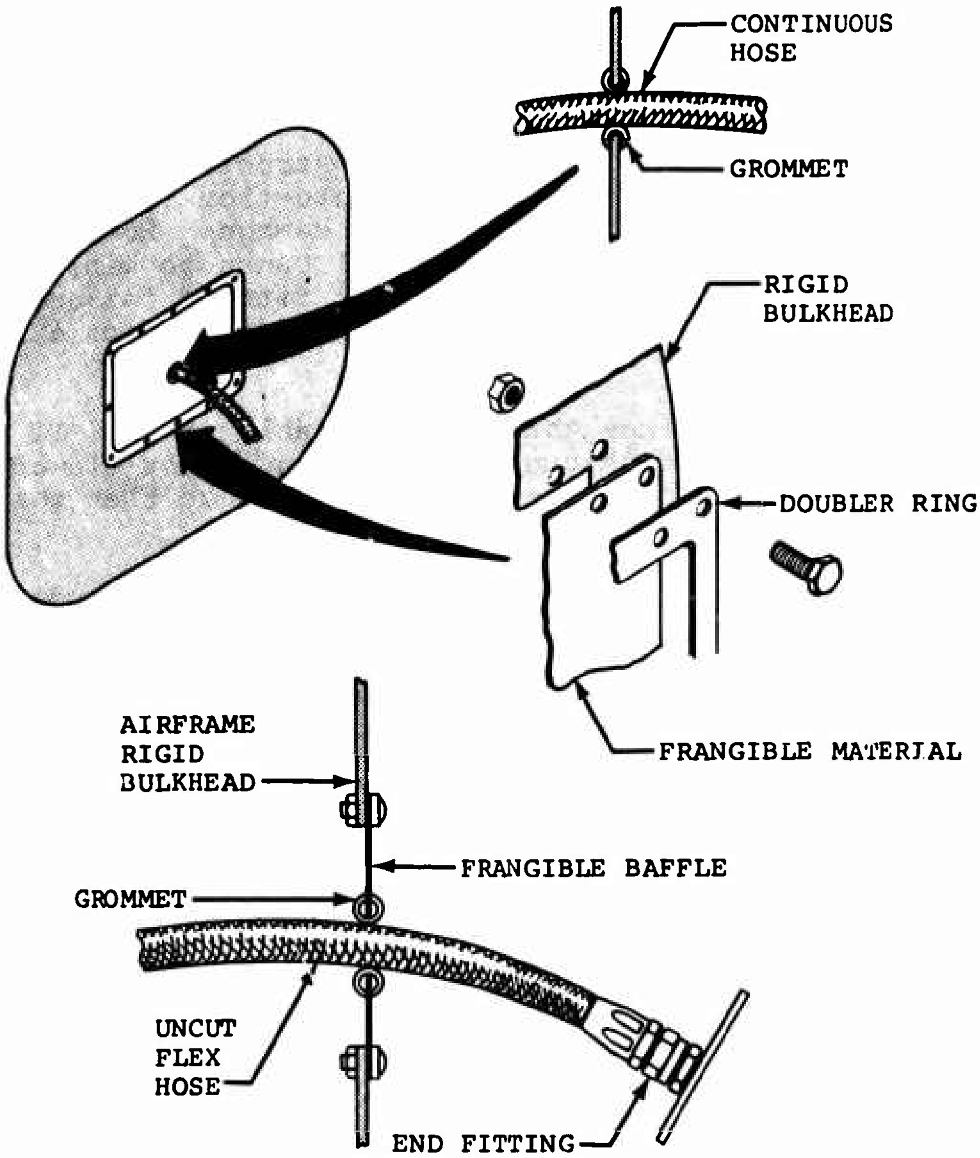
When an uncut hose is run through a bulkhead, the opening in the bulkhead should be several times larger than the hose diameter, with the hose stabilized by a frangible panel or structure as shown in Figure 5. The frangible panel must be able to sustain all flight loads but should fail before crash loads can be transmitted to another part of the system and cause failure. A sample failure load calculation is shown in Figure 5. The frangible panel and large opening will allow the hose to deform during crash impact rather than transmit failure loads to the other components in the system.

Do not use fuel lines for the support of any other line or component. Design fuel lines so that components whose weight can impose adverse stress on the lines are supported from the structure rather than from the lines.

Fuel Line Routing

Route all fuel lines as directly as practicable considering vulnerability, accessibility, and structural obstructions. However, to accommodate structural displacement during crash impact, hoses should be 20 to 30 percent longer than necessary, if this is possible without creating low points in the fuel system. Vapor traps must be eliminated by removing all line bends or slope changes that produce isolated high spots in the supply system. Insure that hose length is consistent with the bend radius as called out in the specification for the particular type of hose being used. Also, insure that installed flexible hose connections are not under tension, compression, or shear stress.

Fuel lines exiting the fuel tank should be grouped together and located in one centralized location. This location should be in the least vulnerable area of the tank from the standpoint of anticipated crash loads and structural deformation.



ITEM	LOWEST FAILURE LOAD (LB)*	FAILURE MODE
Rigid Bulkhead	4000	Bearing
Flex Hose	3000	Tension Breakage
Flex Hose	1500	Pull Out of End Fitting
End Fitting	1750	Bending
Frangible Baffle	Not more than $\frac{1500}{2} = 750$	Bearing

*Loads may or may not be representative; values are for explanatory purposes only.

Figure 5. Hose Stabilizing by Bulkhead Frangible Panel.

The number of fuel lines in the engine compartment should be kept to a minimum. When more than one line enters the engine compartment, the lines should be grouped together and pass through the firewall in one protected location.

Route fuel lines along heavier basic structural members wherever possible. This affords line protection from possible ballistic hits as well as from crash damage. Route as much of the line as possible through the fuel tanks to minimize fuel losses and fire from combat damage or fitting failure as well as to protect the line from structural deformation during crash impact.

Do not route fuel lines through occupiable areas. If fuel lines must be routed through cargo or equipment stowage areas, use fire-resistant conduits and cover them so that they cannot be damaged by movement of cargo.

Avoid routing fuel lines through areas where crash deformation is likely. Whenever possible do not route fuel lines in the following areas: near the bottom of the fuselage, over landing gears, under heavy masses such as transmissions, in the leading edges of wings, in anticipated areas of rotor blade impact, in wing root areas, or in any other anticipated areas of large structural displacement unless self-sealing breakaway couplings are incorporated in the lines.

Route sensing lines, drain lines, or any other line which can be sensitive to water collection and freezing away from the skin or other areas which can become extremely cold or hot at high altitude. If routing protection cannot be provided, consider using heaters and/or insulation.

Route fuel lines so that no lines pass unnecessarily close to components of the exhaust system or to high-temperature heating ducts. If this is unavoidable, insure that the lines are protected against these high temperatures by the hose material itself or by insulation. Do not use insulation materials that will absorb liquids in case of fuel spillage.

Do not route fuel lines through electrical compartments. Fuel lines should be routed as far from all electrical equipment as practicable. Electrical wiring and fuel lines should be kept as far apart as possible, preferably on opposite sides of the aircraft compartment. If this is not possible, the fuel lines should be routed below the electrical lines to insure that fuel leakage from ballistic hits or fitting failure cannot come in contact with electrical wiring. This also insures that spilled fuel will not contact electrical wires during a crash as long as the aircraft remains in an upright or semi-upright position.

Fuel Boost Pumps

Fuel boost pumps are used to deliver the necessary amount of fuel at the desired pressure to the engines. Two general types of systems are in use: (1) a suction system where the pump is mounted on the engine and pulls the fuel up to the engine, as in the CH-53 helicopter, and (2) a pressure system where the pump is mounted in the fuel tank or line and the fuel is pumped up to the engine under pressure.

A suction system with an engine-mounted, engine-driven boost pump is preferred. There are several safety features inherent in this system. The engine-driven boost pump relies on no other aircraft power source for its operation and, therefore, is desirable from a reliability standpoint. The engine affords protection to the pump from ballistic hits. Another safety feature is the absence of pressurized fuel lines, since pressure lines may spray fuel considerable distances should a fitting or line break or be damaged by ballistic hits.

From crashworthy considerations, the suction system is much preferred. The location of the pump outside of the fuel tank eliminates a hard point in the tank which would constrict the deforming ability of the tank during crash impact. In addition, no electrical wiring need be run near the fuel tank to drive the boost pump, thus eliminating the possibility of electrical sparks from broken wires serving as an ignition source for spilled fuel.

If a pressure system must be used, the boost pump may be mounted either within the fuel tank or in the fuel line. Mounting the pump within the fuel tank offers the advantages of increased reliability, protection from ballistic damage, and elimination of pump fuel leaks outside the tank. However, as noted above, there are disadvantages in tank-mounted pumps from a crashworthy viewpoint. Therefore, the following design criteria should be met if the boost pump is located within the fuel tank:

1. An air-driven pump is preferable to an electrically operated pump in order to minimize the number of electrical wires in the fuel tank compartment. If electric boost pumps are used, the electrical wires must be 20 to 30 percent longer than necessary to allow them to deform with structural deformation during a crash rather than being pulled loose. Consider using nonsparking, breakaway wire disconnects which shield each end of a separated wire to prevent arcing. Avoid running wires between the bottom of the fuel tank and the bottom of the fuselage if at all

possible. Any wires within the tank compartment should be shrouded with a flexible cut-resistant material to prevent their damage during crash impact.

2. All tank-mounted boost pumps should be fastened to the structure with frangible attachments so that the fuel tank attachment can break free during a crash, thus precluding the tearing of the fuel tank around the boost pump mounting plate. The frangible attachment strength must be sufficient to meet all operational and maintenance conditions but should be designed to separate between 25 and 50 percent of the weakest link in the attached system. (Refer to Figure 2 for a sample breakaway load calculation.)

Air-driven pumps are also preferable for in-line pumps to eliminate the necessity of electrical wiring in close proximity to fuel lines. If an electric in-line boost pump is used, the same criteria for the electrical wires as given for tank-mounted pumps should be met.

In-line pumps should have a structural attachment capable of withstanding a 30G load applied in any direction. Lines entering and exiting the pump should consist of flexible hose which is approximately 20 percent longer than necessary to allow the hose to deform without failing the pump connections. In lieu of this requirement, breakaway valves may be used at the pump-to-line connections.

Fuel System Drains

Make drain valves easily accessible from the outside of the aircraft so that they permit operation of the valve without spillage on the aircraft or operating personnel and are operable without special tools. Provide suitable remote controls for draining when drain valves must be placed in an inaccessible location.

Insure that all drain lines are free of traps. To avoid the possibility of contaminating the lubricating system by the reverse leakage of fuel across the seals, do not interconnect fuel drains with accessory seal drains.

Arrange drains so that discharged fuel will not cause an additional fire hazard. All drain lines should be terminated at a point outside the aircraft, passing through resilient grommets in the structure to avoid chafing. Locate or design the drains so that drainage cannot be returned to any part of the aircraft structure or enter the exhaust wash from either upstream or downstream. Drains should not be located within 5 feet of an exhaust outlet.

Drain lines in the engine compartment should be able to withstand 2000°F for 5 minutes unless a failure of these lines or fittings cannot result in or add to the fire hazard. Drain lines from fuel cell drains should be made from low-strength materials so that these lines can break free of the structure during a crash and allow the fuel cell to deform with the deforming aircraft structure.

All fuel tank drains should be recessed into the tank so that no part of the drain protrudes outside of the tank wall. This will prevent tearing of the tank wall around the drain by the snagging of the drain on deforming structure during a crash. All attachments of fuel tank drains to aircraft structure should be made with frangible attachments as discussed in Fuel Tank Mounting.

Fuel line drain valves should also be stabilized, if necessary, using frangible attachments so that the fuel lines are free to move with deforming structure during a crash. The number of drains in the fuel lines should be held to a minimum by designing the fuel system to avoid low points in the lines.

Filler Units

Locate and seal the filler opening so that fuel from the opening cannot spill on parts of the aircraft structure, engine or accessories, thus causing damage or a hazardous condition. If necessary, provide fuel tank filler openings with adequate scuppers properly sealed and drained to prevent fuel from spilling back into the fuel tank compartment. In addition, locate the filler opening so that fumes from the filling operation cannot be ingested into the running engine during "hot" refueling operations.

Fasten the filler unit to the aircraft structure with a frangible attachment (discussed under Fuel Tank Mounting), and recess the filler cap into the tank wall to insure that the cap stays with the tank if the tank moves relative to the aircraft structure during crash impact. In addition, the filler cap or adapter should be designed so that it is impossible for fuel to spill from the tank regardless of the aircraft attitude if the filler cap has not been properly attached.

Long filler necks should be avoided if possible. If they must be used, they should be fabricated from frangible materials and designed so that the filler cap stays with the tank, allowing the filler neck to separate from the tank and the structure during crash impact and yet allowing the fuel tank to remain sealed.

Fuel Quantity Indicators

A float-type quantity indicator should be used in preference to a capacitance probe, as the rigid probes have a tendency to cut fuel tanks during crash impact. If a capacitance probe must be used, it should be fabricated from material possessing as low a flexural rigidity as is consistent with operational requirements. Incorporation of a slightly rounded shoe at the probe bottom end minimizes any tank cutting tendency. A frangible attachment should be used in the manner discussed under Fuel Tank Mounting if it is necessary to stabilize the indicator by fastening it to the aircraft structure.

Provide a low-fuel-level warning system which is actuated independently of the fuel quantity gaging system.

Fuel System Valves

The number of fuel valves in a system should be kept to a minimum with respect to reliability and crashworthiness considerations. Every fuel valve has the possibility of malfunctioning; thus, the greater the number of valves, the less reliable is the system. Every fuel-line-to-fuel-valve connection is a possible failure point during crash impact; therefore, these hard points in the lines should be kept to a minimum.

The size of the valves should also be kept to a minimum, as a smaller size lessens the possibility of direct impacts damaging the fuel valve during a crash. Where large valves are necessary, such as fuel shutoff valves, the valve structural attachment should be capable of withstanding a 30G load applied in any direction. Self-sealing breakaway couplings should be used at the valve-fuel line connection if the possibility of line failure at this point is significant. Small valves, such as check valves, should be fastened to the aircraft structure with frangible attachments so the check valves can break loose and move with the flexible line during crash impact.

Shutoff valves are required in the tank-to-engine fuel lines. However, shutoff valves should not be located in the engine compartment unless they are easily operable for a minimum of 5 minutes when exposed to a flame of 2000°F and are capable of holding their valves closed for the duration of the fire. A preferable location for shutoff valves is on the outside face of the engine compartment firewall. However, consideration should be given to locating the shutoff valve immediately outside the fuel tank outlet for gravity-feed fuel systems. This location would prevent the complete draining of fuel from the tank through a broken line.

Shutoff valves must be designed so that any in-service failure of the valve leaves it in the open position. All electrically operated valves must be designed so that there is no possibility of the valve's changing position during flight due to either a short in the aircraft electrical circuitry supplying power to the valve or to electrical power failure. Mounting electrically operated valves on bulkheads so that the electrical wires are on one side of the bulkhead and the valve and fuel lines on the other side minimizes the hazards of fire ignition due to a failure in either the wiring or the valve and lines.

Insure positive identification of all valves to prevent replacement installation of an incorrect valve. Insure that check valves and tank negative pressure relief valves cannot be installed in reverse. If a valve will not function properly if installed incorrectly, design it so that it physically cannot be installed incorrectly.

Fuel Strainers and Filters

Fuel strainers must be provided when necessary to insure satisfactory engine performance. In-line fuel strainers should not be located in the engine compartment unless they are mounted on the engine itself. Engines are often torn loose during crash impact, and strainers located in the compartment are susceptible to damage from the displaced engine. Mounting of the strainer directly on the engine affords some ballistic protection. However, the proximity of the fuel in the strainer to the hot engine provides a hazard, not only during a crash, but also from ballistic hits. Therefore, it is better to mount the strainer outside the engine compartment.

Strainers should have a structural attachment capable of withstanding a 30G load applied in any direction to minimize the possibility of the strainers being torn loose during crash impact. Self-sealing breakaway couplings should be used to attach fuel lines to the fuel strainers if there is a probability of line damage at this point.

Filters and strainers should retain as small a quantity of fuel as possible to minimize the spread of fuel to ignition sources during failure of the strainer due to crash impact or ballistic hits.

All fuel line strainers should be readily accessible and have sufficient clearance to permit easy removal of the cover and element. If possible, locate the strainer with respect to the fuel tanks and lines so that the entire fuel system may be drained by opening the strainer drain, fuel tank sump drain, and booster pump drain plug. If this is not possible, drains must be provided at each low point in the fuel lines since low points constitute water traps that are hazardous during cold-weather operation.

All fuel strainers should be equipped with bypass provisions to prevent engine fuel starvation by icing or plugging of the filter or strainer element with contaminant. Design the bypass to prevent the washing of ice or contaminant from the element into the fuel system.

Vent System

Route vent lines and locate tank vent outlets so as to minimize the spillage of fuel through the vents during all operational maneuvers of the aircraft. Provide a vent line that starts at the highest point in the tank and traverses the three dimensions of the tank, terminating in a suitable location outside the aircraft. Insure that siphoning positively cannot occur by providing means for admitting air to the high point of the vent system, either by system design or by the inclusion of a siphon breaker valve. Figure 6 illustrates suitable vent systems which may be used.

Locate vent terminals so that liquids and vapors emitted from them will not blow back into the aircraft or come in contact with the exhaust gas wake. In addition, avoid locating fuel vent discharge outlets in those areas most prone to lightning strikes, such as the leading and trailing edges of the wings or the wing tips or in extremities and protrusions and in the wake of such extremities and protrusions.

The vent system must be designed to prevent fuel flow through the vent lines regardless of the attitude of the aircraft after crash impact. It should also be designed to preclude any fuel spillage due to structural failure of the vent system. Fuel flow may be prevented either by the design and routing of the vent lines or by the inclusion of a valve at the fuel tank vent outlet which will prevent flow through the system in an other than normal attitude. The valve must be designed with provisions to prevent valve malfunctioning from icing, sticking seals, or any other design or malfunction which can cause excessive positive or negative tank pressures. If tank vent outlets must be supported, support them by means of frangible attachments to the aircraft structure so that excessive stress loads will not be transmitted to the tank wall in vent areas during crash impact.

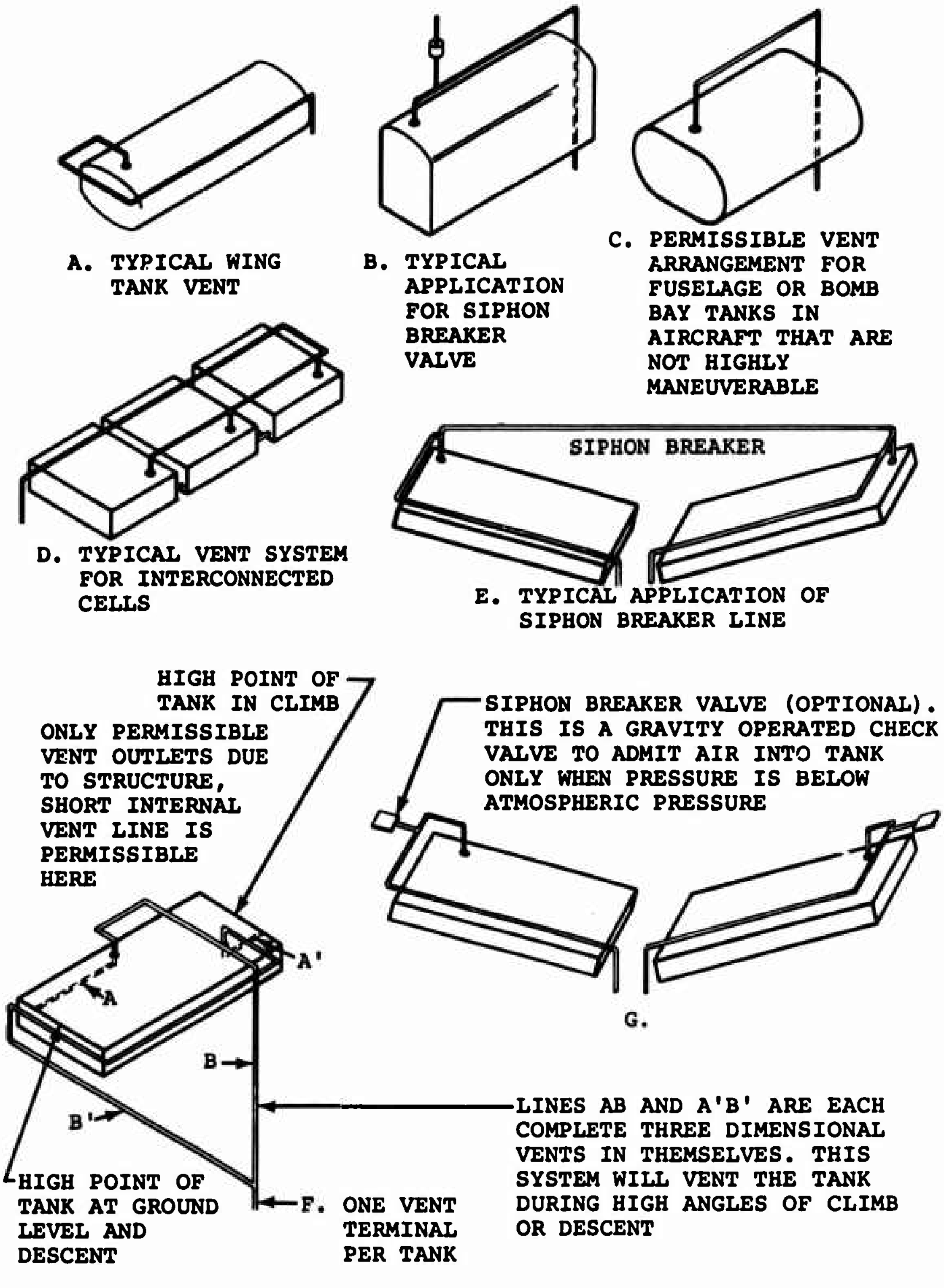


Figure 6. Fuel Tank Vent Systems (From AFSC Design Handbook).

DESIGN CRITERIA CHECKLISTS

INTRODUCTION

The design criteria checklists presented here are based on the design criteria presented in the preceding section. The checklists are intended for use by fuel system designers to insure that all applicable design criteria are considered in the formative stages of design. The checklists also serve as convenient methods of re-checking the design after it has been completed.

The checklist items have been arranged in the same order as the criteria presented in the preceding section. This allows ready reference to the more detailed discussion if the designer feels he needs more background before assessing the applicability or suitability of an item.

Each item contains three boxes immediately preceding it. These boxes provide for "Yes", "No", or "N/A" (not applicable) answers to each checklist item. When the designer has finished reviewing a section, each item should have a check mark immediately preceding it. This method provides a rapid and positive means of determining that none of the criteria have been overlooked.

The items have been stated in positive form, i.e., if the criteria have been complied with, the question will be answered in the affirmative and the block marked "Yes" will be checked. If it has not been complied with, the block marked "No" will be checked and these items will be examined to determine the reason for the noncompliance. Unless the reason involves a more important consideration, the design should be revised to include the requirement. Those items checked "N/A" should also be carefully reviewed to be sure that the item is truly nonapplicable to the system under consideration.

GENERAL FUEL SYSTEM DESIGN

Yes	No	N/A	
			1. Is the system designed to function satisfactorily at the aircraft maximum altitude?
			2. Is the system designed to function satisfactorily at maximum rates of climb?
			3. Is the system designed to function satisfactorily under all normal operating attitudes of the aircraft?
			4. Is the system designed to fully meet engine fuel flow consumption and pressure demands?
			5. Is the system designed to function under all applicable environmental requirements, such as extreme hot or cold climates, sand, high humidity, etc.?
			6. Is the system designed as simply as possible?
			7. Is there one fuel tank for each engine?
			8. If a single fuel tank is used on a multi-engine aircraft, are there independent tank outlets and fuel feed systems for each engine?
			9. In multi-engine aircraft, is it possible to fuel any engine from any tank?

MATERIALS

Yes	No	N/A	
			1. Do all materials conform to MIL-F-8615?
			2. Do all materials exhibit resistance to shock, vibration, abrasion, temperature changes, and oxidation?
			3. Is insulation used in compartments containing fuel tanks or lines nonabsorbent?

FUEL TANK LOCATION

Yes	No	N/A	
			1. Are the fuel tanks located outside of the engine and electrical compartments?
			2. Are the fuel tanks located as far as possible from the engine, electrical, and passenger compartments?
			3. If the fuel tanks are located near firewalls, is there at least 1/2 inch of ventilated and drained space between the tanks and the firewalls?
			4. Are the fuel tanks located with as wide a lateral clearance as possible from the plane of the propeller or turbines?
			5. Are the fuel tanks located away from extremities, such as the fuselage nose or wing tips?
			6. Are fuselage tanks located as high as possible in the aircraft structure?
			7. Are fuel tanks located where there is no danger of collapsing landing gear puncturing the tanks?
			8. Are the fuel tanks located so that transmissions, engines, and similar massive components will not come down and crush the tanks during a crash?
			9. Are wing tanks located away from wing leading edges and wing root sections?
			10. Are wing tanks located behind heavy spars?

FUEL TANK COMPARTMENTS

Yes	No	N/A	
			1. Are fuel tank compartments isolated with a liquid- and vapor-tight seal?
			2. Are compartments drained by at least 0.5-inch-diameter drains?
			3. Are compartment drains located at least 5 feet away from all exhaust outlets?
			4. Are compartment drains located so that effluent cannot enter the exhaust wash?
			5. Are the number of stiffeners, hat sections, and stringers kept to an absolute minimum in fuel tank compartments?

FUEL TANK CONSTRUCTION

Yes	No	N/A	
			1. Do all fuel tanks conform to MIL-T-27422B?
			2. Are all fuel tanks smooth in shape with no sharp protuberances?
			3. Are the fuel tanks separate rather than rigidly interconnected?
			4. Do all fuel tanks have a minimum corner radius of 1 inch?

FUEL TANK MOUNTING

Yes	No	N/A	
			1. Are frangible attachments used at all attachment points between the fuel tanks and aircraft structure?
			2. Do the specified frangible attachment separation loads exceed all operational and service loads?
			3. Are the specified frangible attachment separation loads between 25 and 50 percent of the loads required to fail the attached systems or components?
			4. Are the frangible attachments required to separate whenever the required loads are applied in the modes most likely to occur during crash impacts?

FUEL TANK FITTINGS

Yes	No	N/A	
			1. Are the number of fuel tank fittings kept to a minimum?
			2. Are the fittings located as high as possible in the fuel tank?

FUEL TANK OUTLETS

Yes	No	N/A	
			1. Are self-sealing breakaway valves used at all fuel-tank-to-fuel-line connections and at all tank-to-tank interconnects?
			2. Are the breakaway valves recessed into the tank wall so that the tank half does not protrude outside the tank wall more than 1/2 inch after valve separation?
			3. Are the shapes of the tank halves of the breakaway valves basically smooth?
			4. Do the specified breakaway valve separation loads exceed all operational and service loads?
			5. Are the specified breakaway valve separation loads between 25 and 50 percent of the loads required to fail the attached systems or components?
			6. Are the breakaway valves required to separate whenever the required loads are applied in the modes most likely to occur during crash impacts?
			7. Do all breakaway valves incorporate positive provisions for ascertaining that the valve halves are locked together?

ELECTRICAL EQUIPMENT IN FUEL TANK COMPARTMENTS

Yes	No	N/A	
			1. Are the number of electrical components and amount of wiring in the fuel tanks or fuel tank compartments kept to an absolute minimum?
			2. Are all electrical equipment and all metal lines within the fuel tanks grounded?
			3. Are all electric wires and equipment in the fuel tanks designed with the highest degree of protection against sparking, arcing, or overheating?
			4. Is all electrical wiring going through the fuel tank compartments shrouded?
			5. Is wiring in the fuel tank compartment routed as high in the compartment as possible?
			6. Are electrical wires in the fuel tank compartment 20 to 30 percent longer than necessary?

FUELING

Yes	No	N/A	
			1. Are all fuel inlets and tanks designed to minimize sloshing?
			2. Is a grounding point provided on the aircraft for connection of a grounding wire from the refueling vehicle?
			3. Are filler openings located so that fuel vapors cannot be directly ingested into the engine intake?

FUEL LINE CONSTRUCTION

Yes	No	N/A	
			1. Are all fuel lines made from flexible hose assemblies conforming to MIL-H-58089?
			2. Are all fuel lines in or close to a potential fire zone capable of withstanding a temperature of 2000°F for 5 minutes without leakage?

FUEL LINE FITTINGS

Yes	No	N/A	
			1. Are the fuel system lines designed with as few fittings as possible?
			2. Are the fuel system lines designed so that uncut hoses are run through bulkheads rather than attached to the bulkheads with fittings?
			3. Are self-sealing breakaway valves used wherever a fuel line goes through a firewall?
			4. Are all fittings designed to assure 100 percent of the structural integrity of the joint?
			5. Are all joints leakproof throughout the environmental range of their application?
			6. Are all joints designed so that critical torque techniques are not required for proper installation?
			7. Do all specified hose assemblies meet the strength requirements listed in Table I?
			8. Are self-sealing breakaway valves used at all points in the fuel lines where aircraft structural deformation could lead to line failure?
			9. Do the specified breakaway valve separation loads exceed all operational and service loads of the aircraft?
			10. Are the specified breakaway valve separation loads between 25 and 50 percent of the loads required to fail the attached components or lines?
			11. Do the breakaway valves incorporate positive locking provisions?

FUEL LINE SUPPORT

Yes	No	N/A	
			1. Are all fuel lines adequately supported so that lines do not deflect out of position as a result of internal pressure or aircraft maneuvers?
			2. Is sufficient clearance provided for the lines to prevent chafing against structure or other components?
			3. Are the lines clamped to the structure where chafing cannot be avoided?
			4. Are the line supports frangible so that the supports will release the line during crash impact?
			5. Will the frangible clamps meet all operational and service loads of the aircraft?
			6. Are uncut lines running through bulkheads stabilized by frangible panels?
			7. Are fuel lines free from supporting any other line or component?

FUEL LINE ROUTING

Yes	No	N/A	
			1. Are fuel lines routed as directly as possible?
			2. Are fuel lines 20 percent longer than necessary if possible without creating low points in the lines?
			3. Are vapor traps eliminated by removing all line bends or slope changes that produce isolated high spots in the system?
			4. Is hose length consistent with bend radius as called out in the hose specification?
			5. Are installed hose connections free from tension, compression, or shear stress?
			6. Do fuel lines exit the fuel tank in one protected location?
			7. Is the number of fuel lines in the engine compartment a minimum?
			8. Are fuel lines routed along heavier structural members wherever possible?
			9. Is as much of the fuel line as possible routed through the fuel tanks?
			10. Are fuel lines routed as far as possible from occupiable areas and electrical compartments?
			11. Are fuel lines routed as far from all electrical equipment and wires as possible?
			12. Are fuel lines which are routed through cargo areas covered with fire-resistant conduits?
			13. Are fuel lines routed away from areas where large structural damage is likely during a crash?

FUEL LINE ROUTING (Continued)

Yes	No	N/A	
			14. Are sensing and drain lines routed away from the skin or other areas which can become extremely cold or hot at high altitude?
			15. Are fuel lines routed away from the exhaust system and high-temperature heating ducts?

FUEL BOOST PUMPS

Yes	No	N/A	
			1. Can an engine-mounted, engine-driven boost pump be used in this aircraft?
			2. If an engine-mounted suction system cannot be used, can an air-driven boost pump be used?
			3. Do in-line boost pumps have a structural attachment capable of withstanding a 30G load applied in any direction?
			4. Are lines entering and exiting in-line boost pumps made of flexible hose which is approximately 20 percent longer than necessary?
			5. If fuel lines are not longer than necessary for in-line boost pumps, are self-sealing break-away valves used to attach the lines to the boost pump?
			6. Are wires to electrically operated boost pumps 20 to 30 percent longer than necessary?
			7. If electric boost pumps are mounted in the fuel tanks, are the wires routed away from the bottom of the tanks?
			8. Are all tank-mounted boost pumps fastened to the structure with frangible attachments?
			9. Do the specified frangible attachment separation loads exceed all operational and service loads?
			10. Are the specified frangible attachment separation loads between 25 and 50 percent of the load required to fail the attached system?

FUEL SYSTEM DRAINS

Yes	No	N/A	
			1. Are drain valves easily accessible from the outside of the aircraft?
			2. Are drain lines terminated outside of the aircraft at a point which is at least 5 feet away from exhaust outlets?
			3. Are all drain lines free from traps?
			4. Are all drains designed and located so that drainage cannot be returned to any part of the aircraft structure or enter the exhaust wash from either upstream or downstream?
			5. Can all drain lines in the engine compartment whose failure could add to the fire hazard withstand a temperature of 2000°F for 5 minutes?
			6. Are all drain lines from fuel tank drains made from low-strength materials?
			7. Are all fuel tank drains recessed into the tank so that no part of the drain protrudes outside the tank wall?
			8. Are all structural attachments of fuel tank drains made with frangible attachments?
			9. Is the number of drains in the fuel lines a minimum?
			10. Are all fuel line drain valves stabilized, if necessary, with frangible attachments?

FILLER UNITS

Yes	No	N/A	
			1. Are all filler openings located and sealed so that fuel from the opening cannot spill on parts of the aircraft structure, engine, or accessories?
			2. Are scuppers provided, if necessary, to prevent fuel from spilling back into the fuel tank compartment?
			3. Are filler openings located so that fuel vapors cannot be ingested into a running engine?
			4. Are filler units attached to the aircraft structure with frangible attachments?
			5. Are filler caps recessed into the fuel tank wall?
			6. Are filler caps or adapters designed so that it is impossible for fuel to spill from the tank regardless of aircraft attitude if the filler cap has not been properly fastened?
			7. Are long filler necks avoided?
			8. If filler necks are used, are they made from frangible materials?

FUEL QUANTITY INDICATORS

Yes	No	N/A	
			1. Can float-type quantity indicators be used in this fuel system?
			2. If probe-type indicators are used, are they fabricated from material that either is frangible or possesses as low a flexural rigidity as possible?
			3. Is a slightly rounded shoe incorporated at the probe bottom end of all probe-type indicators?
			4. Are frangible attachments used where it is necessary to stabilize the indicator by fastening it to the structure?
			5. Is a low-fuel-level warning system provided which is actuated independently of the fuel quantity gaging system?

FUEL SYSTEM VALVES

Yes	No	N/A	
			1. Is the number of fuel valves a minimum?
			2. Are the sizes of all valves a minimum?
			3. Are large valves fastened to the structure with an attachment capable of withstanding a 30G load applied in any direction?
			4. Are self-sealing breakaway valves used at all valve-fuel line connections if the possibility of line failure at these points is significant?
			5. Are small valves fastened to the structure with frangible attachments?
			6. Are shutoff valves included in the tank-to-engine fuel lines?
			7. Are shutoff valves located outside the engine compartment, either on the outside face of the firewall or at the fuel tank outlets?
			8. Are all shutoff valves designed so that any failure of the valve leaves it in the open position?
			9. Are all electrically operated valves designed so that there is no possibility of the valve changing position due to a short in the aircraft electrical circuitry or to electrical power failure?
			10. Are electrically operated valves mounted on bulkheads so that the wires are on one side of the bulkhead and the valve and fuel lines are on the other side?
			11. Are all valves positively identified to prevent replacement installation of an incorrect valve?
			12. Are all valves designed so that, if they will not function properly if installed incorrectly, they physically cannot be installed incorrectly?

FUEL STRAINERS AND FILTERS

Yes	No	N/A	
			1. Are fuel strainers and filters mounted outside the engine compartment?
			2. If strainers and filters are mounted in the engine compartment, are they mounted on the engine itself?
			3. Do all strainers have a structural attachment capable of withstanding a 30G load applied in any direction?
			4. Do all strainers and filters retain as small a quantity of fuel as possible?
			5. Are all fuel strainers readily accessible with sufficient clearance to permit easy removal of the cover and element?
			6. Are all fuel strainers equipped with bypass provisions?
			7. Are all fuel strainer bypasses designed to prevent washing of ice or contaminant from the element into the fuel system?

VENT SYSTEMS

Yes	No	N/A	
			1. Are vent lines and tank vent outlets located so as to minimize spillage of fuel through the vents during all operational maneuvers of the aircraft?
			2. Do vent lines start at the highest point in the tank, traverse the three dimensions of the tank, and terminate in a suitable location outside the aircraft?
			3. Are vent systems designed to positively prevent siphoning?
			4. Are vent terminals located so that emitted vapors will not blow back into the aircraft or come in contact with the exhaust gas wake?
			5. Are fuel vent discharge outlets located away from areas prone to lightning strikes?
			6. Are vent systems designed to prevent fuel flow through the vent lines regardless of the attitude of the aircraft?
			7. Are vent systems designed to prevent fuel spillage if structural failure of the vent system occurs?
			8. If tank vent outlets must be supported, are they supported by frangible structural attachments?

ANALYSES OF AIRCRAFT FUEL SYSTEMS

OH-58A HELICOPTER

General Description

The OH-58A is a four-place light observation helicopter manufactured by the Bell Helicopter Company. It is powered by an Allison gas turbine engine which drives a single two-bladed main rotor and a two-bladed antitorque rotor. OH-58A helicopters manufactured after the latter part of 1971 will contain a modified crashworthy fuel system.

Original Fuel System Description

The fuel system contains a single, bladder-type, self-sealing cell with a capacity of 73 gallons. The cell is located below and aft of the passenger seat (see Figure 7). The fuel supply system also contains a submerged boost pump, two fuel quantity transmitters, a low-level fuel transmitter, a sump and defuel drain, a shutoff valve, a fuel feed line, and a vent line (see Figure 8).

The top half of the L-shaped fuel tank is constructed of standard non-self-sealing material, while the bottom half is made of .30 caliber self-sealing material. The fuel tank cavity is constructed of aluminum honeycomb aircraft structure faced with fiberglass. The bottom of the cavity is displaced conically upward from the center by self-extinguishing plastic foam block to provide adequate fuel drainage.

The fuel tank is supported in the structure with nylon lacing. In addition, the filler cap ring, upper fuel quantity indicator, fuel outlet fitting, sump plate, and auxiliary fuel cell connection are rigidly bolted to the aircraft structure. Additional support is furnished at two attachment points located behind the seat back. These attachment points consist of small fittings which are designed to receive screws inserted through the seat panel and seat-back panel, respectively.

The electrically operated fuel boost pump, which is used continuously during aircraft operation, is mounted on the sump plate located at the bottom of the fuel tank. The electrical wiring from the pump runs through a tunnel directly below the fuel tank and forward under the passenger seat.

A probe-type quantity gage, a low-level float switch, and a drain valve are also fastened to the sump plate. The drain

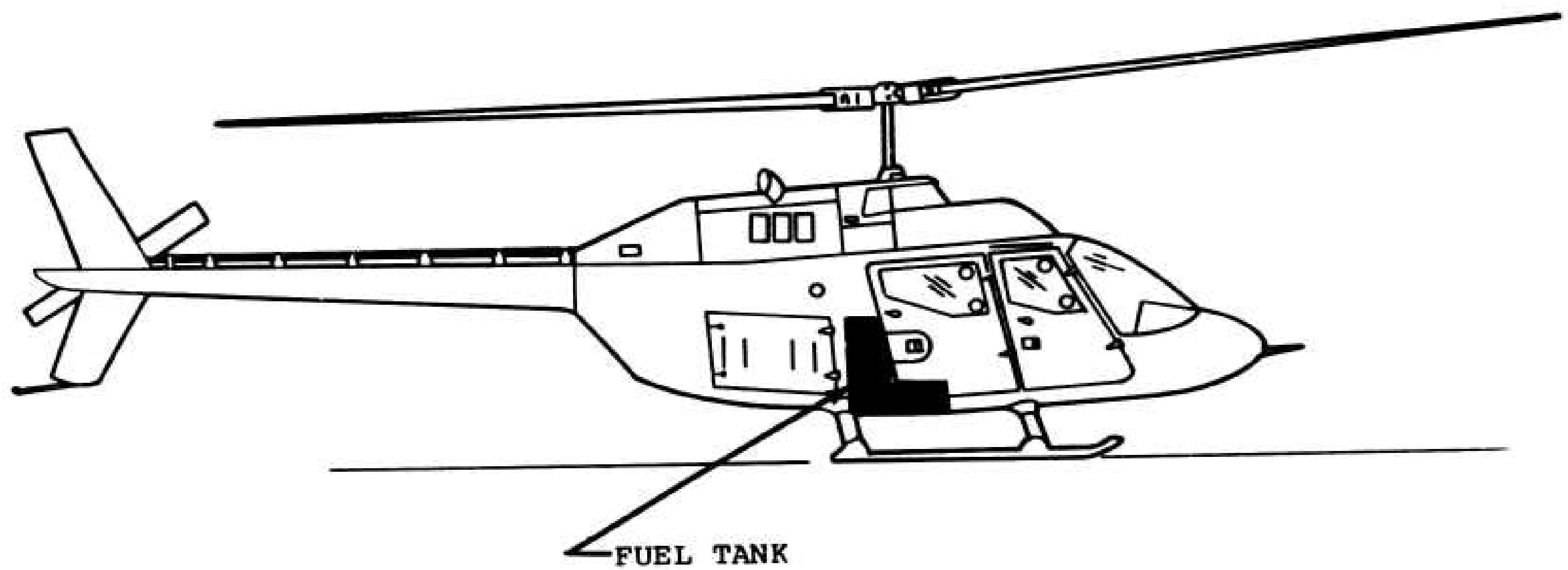
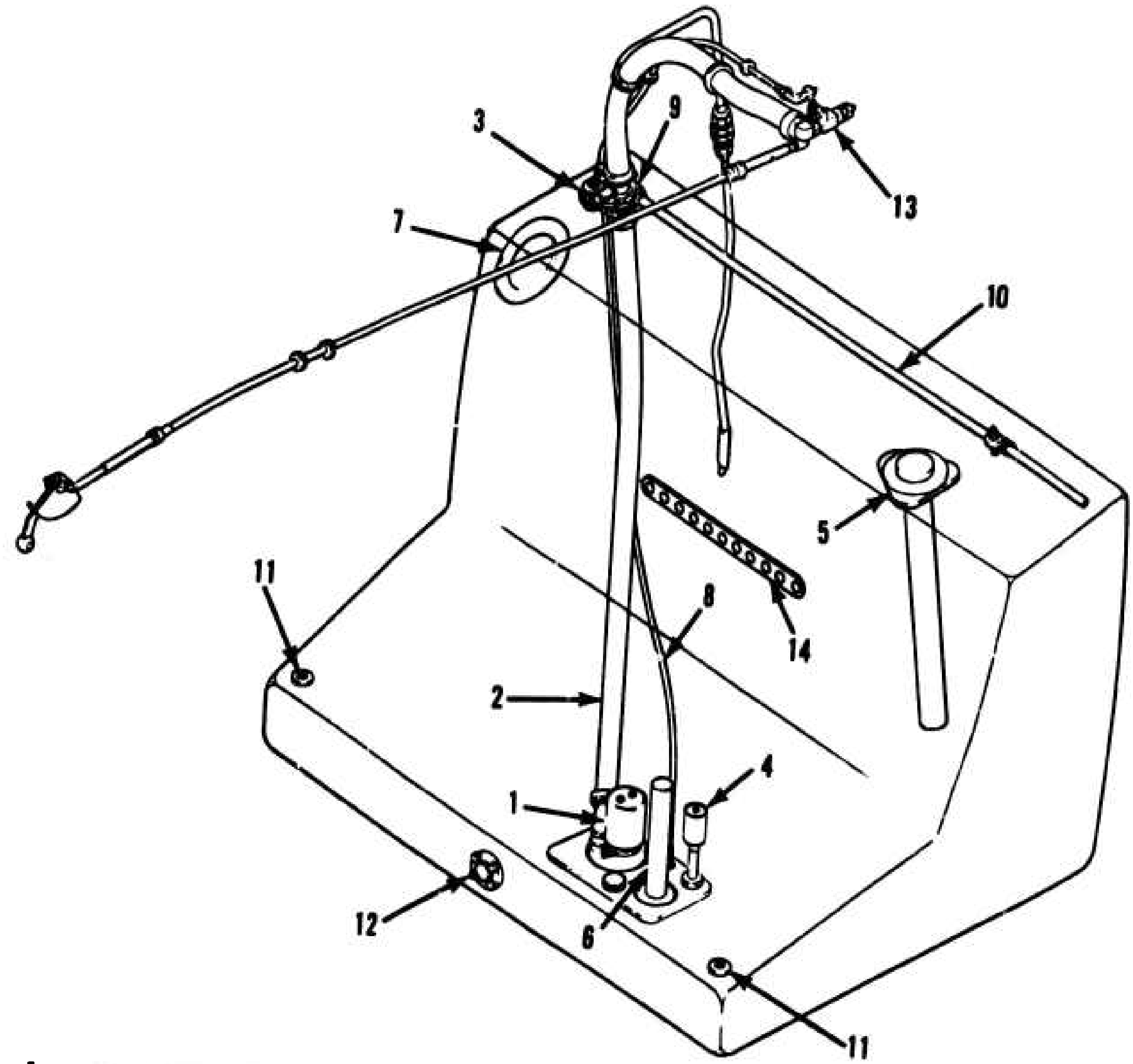


Figure 7. Location of the Fuel Tank in the OH-58 Helicopter.



1. Boost Pump
2. Fuel Hose
3. Pressure Switch
4. Low Level Switch
5. Upper Fuel Quantity Probe
6. Lower Fuel Quantity Probe
7. Filler Cap Adapter
8. Hose
9. Fuel Fittings
10. Vent Line
11. Attachment Point
12. Auxiliary Fuel Cell Connector
13. Shutoff Valve
14. Access Opening

Figure 8. OH-58A Original Fuel Supply System.

valve, which serves as both a sump drain and a defuel valve, protrudes below the tank bottom surface.

The tank access opening is located in the forward face of the fuel tank, behind the seat-back panel. The slit-type access opening is held closed by a bolted pressure clamp. The upper part of the fuel tank also contains a fuel quantity probe which is fastened to the aircraft structural panel above the top of the fuel tank.

Fuel is pumped through a flexible, self-sealing, pump discharge hose to the tank outlet fitting at the top of the fuel tank. Although the outlet fitting is not bolted to the structure, it is held rigidly in place by bulkhead fittings. The fuel line exits the tank through a second flexible self-sealing hose which runs upward and across to the airframe centerline, and is attached to a manually operated shutoff valve mounted on the engine firewall. The fuel then flows from the shutoff valve through a hose to the fuel filter, which is an integral part of the engine fuel pump.

The vent system consists of a single tube which runs laterally across the inside top of the fuel tank to the tank outlet fitting. The vent line is then routed through a structural panel just aft of the fuel tank and down to the underside of the aircraft.

Fuel System Analysis

The fuel tank location is particularly hazardous because of its proximity to the passenger compartment and its location in the bottom of the fuselage. Fuel spilled from a punctured fuel tank would surround the passenger compartment and, should this fuel become ignited, flames would block the possibility of occupant escape. In addition, fuel could be spilled directly into the occupant area should the seat structure fail.

The location of the tank in the bottom of the aircraft places the tank in an area of probable impact damage. Although the honeycomb structure and foam block under the fuel tank protect the tank to a certain extent, the sump plate with its protruding drain valve is located at the very bottom of the fuselage structure without benefit of any structural protection. Localized impact in this area could either fracture the sump plate or boost pump case, or could snag the protruding tank drain, thus tearing the entire fitting from the fuel cell wall. The boost pump wiring in this area is also susceptible to damage, thus furnishing an immediate spark ignition source for any spilled fuel.

Impact survivable accidents have shown that the fuselage structure often breaks open between the seat and seat-back panels, or directly through the center of the fuel tank cavity. Displacement of the separated sections of the tank cavity would certainly lead to fuel tank failure and massive fuel spillage.

The attachment of the aft landing gear crossover tube to the bottom of the bulkhead which serves as the back of the fuel cell cavity is also a hazardous situation. If the fittings are displaced upward, the integrity of the cell cavity will be destroyed. Should the fuel cell protrude through any openings thus produced, structural deformation from a second impact or a roll-over could easily cut the protruding cell wall.

The irregular shape of the fuel tank also contributes to the vulnerability of the tank to crash damage. Any relative displacement of the horizontal and vertical tank cavity walls, coupled with the rigid attachments of the fuel tank to the structure, would result in tearing of the fuel tank wall. Any downward load applied to the upper surface of the fuel tank under the seat area would cause the access opening to shear at the bolt holes in the tank wall and pull out of the pressure clamp that holds the opening in the closed position.

The fuel quantity probe in the lower part of the fuel tank is a hazard because the sharp end of the probe could cut the upper tank wall if either the probe were pushed upward or the top surface of the tank were pushed downward. The upper quantity probe does not pose this hazard to any significant degree since the end of the probe is well above the bottom of the fuel tank. However, the rigid attachment of the probe to both the fuel tank wall and the aircraft structure does pose a hazard since the tank wall would tear away from this fitting if any structural displacement occurred.

The use of flexible hose for the fuel lines is a sound crashworthy practice in that the hose can move with the structure during crash impact, where rigid metal lines will generally break. However, the hose used in this installation will pull out of the end fittings at very low loads. Any amount of relative displacement between the fuel tank outlet fitting, which is rigidly attached to the structure, and the shutoff valve mounted on the firewall would probably pull the fuel hose loose from one of the end fittings. The same situation exists in the engine compartment,where engine displacement could pull the fuel hose loose from its end fittings.

The thin-walled metal vent line is also a crash fire hazard. This line could be easily broken outside of the fuel tank during crash impact. If the line is broken and the aircraft comes to rest on its right side or in an inverted position, the entire contents of the fuel tank could be lost.

The incorporation of the fuel filter into the engine boost pump is a sound crashworthy concept. This installation eliminates additional fittings and hose which would be required if the filter were a separate component. In addition, the filter is fairly well protected in its location under the engine. It is unlikely that it would be damaged unless the engine mounts failed completely and allowed the engine to drop straight downward.

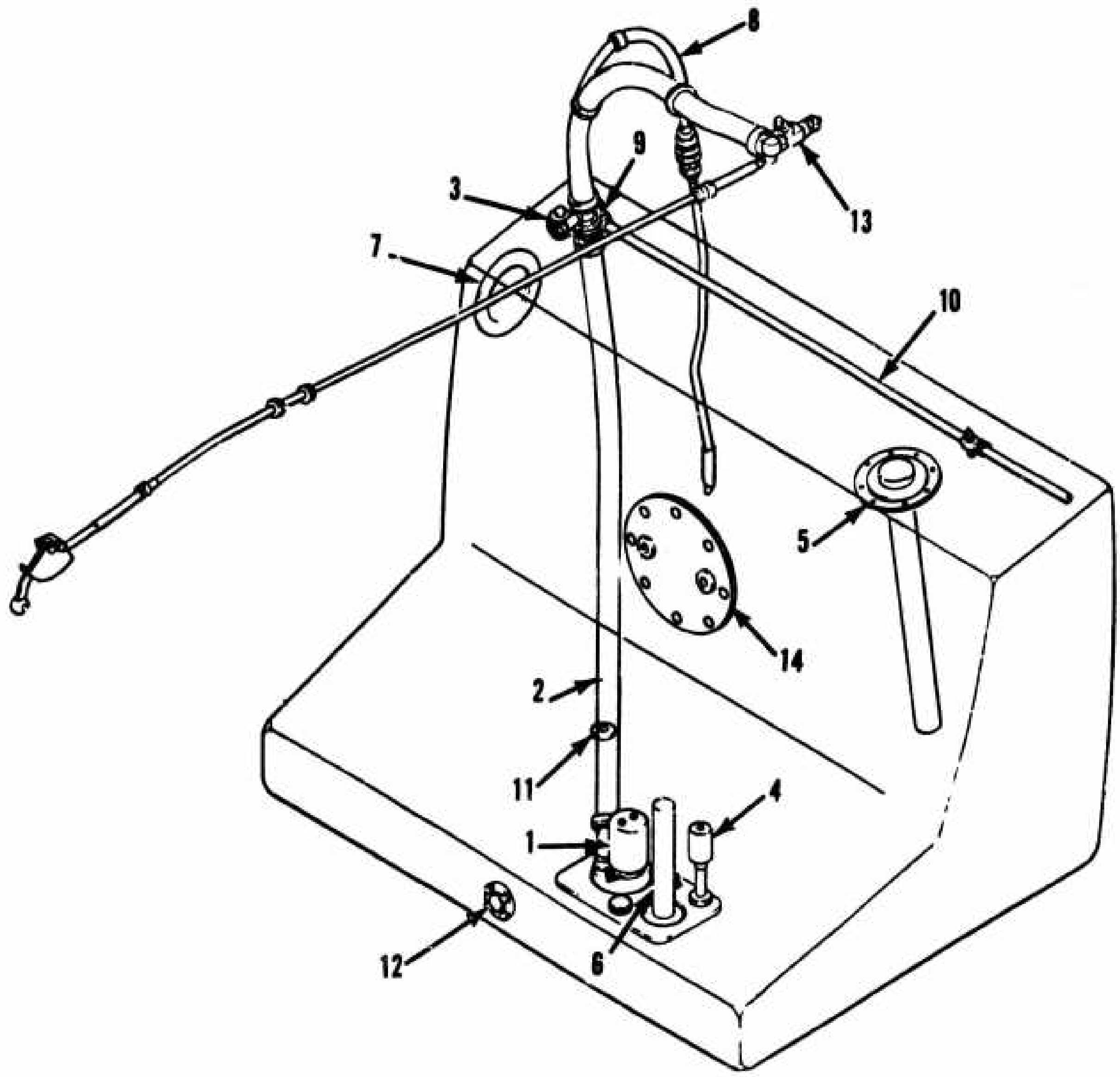
Crashworthy Fuel System

The crashworthy fuel system which will be installed in later models of the OH-58A will retain the same basic fuel system design but will incorporate many modifications to significantly increase the crashworthiness of the aircraft (see Figure 9).

The fuel tank will be replaced with a crashworthy fuel tank conforming to MIL-T-27422B. Not only will the tank material resist impact loads and cutting to a much greater degree than the present tank, but all tank fittings will have a pullout strength of not less than 80 percent of the tank wall strength.

All structural attachments between the fuel tank and the aircraft structure will be frangible in nature. Frangible rings will be used to attach the filler cap ring and the upper quantity indicator to the structure. A retainer bar will be used to stabilize the sump plate in the aircraft. This retainer bar is designed to break during crash loads, thus allowing the whole sump area to move with the fuel tank. The auxiliary fuel cell connection will no longer be fastened to the structure, and the two forward attachments in the lower part of the fuel cell will be eliminated. A single retainer in the top wall of the underfloor part of the cell will be used to stabilize this part of the cell in the structure. The retainer is bonded to the fuel tank wall in such a manner that it will break away during crash loading.

The access opening has been redesigned and will incorporate a circular metal plate bolted to the fuel cell wall. The plate will be attached to the seat back panel by means of adhesively bonded retainers similar to that used in the underfloor portion of the cell. The strength of the adhesive bond is such that it will release during crash impact, thus freeing the access plate from any structural attachment. This design will eliminate the possibility of the fuel tank wall being torn in this area.



1. Boost Pump
2. Fuel Hose
3. Pressure Switch
4. Low Level Switch
5. Upper Fuel Quantity Probe
6. Lower Fuel Quantity Probe
7. Filler Cap Adapter
8. Vent Tube
9. Fuel Fittings
10. Vent Line
11. Attachment Point
12. Auxiliary Fuel Cell Connector
13. Shutoff Valve
14. Access Opening

Figure 9. OH-58A Crashworthy Fuel Supply System.

The crashworthiness of the sump area will be increased by several modifications in addition to the frangible retainer. A frangible section will be incorporated into the drain valve just below the poppet. This will allow the protruding part of the valve to break off during impact without affecting the integrity of the closed valve. A thin-walled section in the sump-mounted quantity indicator will allow column failure of the probe in the event that the top of the probe contacts the upper wall of the tank. This will preclude the possibility of the probe cutting the tank wall.

The boost pump and fuel pressure sensing system will be modified to allow the pilot to turn the pump off during normal aircraft operation, using the pump only for takeoff and high-altitude operation. This contributes significantly to the crashworthiness of the aircraft, as a major crash ignition source (i.e., sparking of damaged live electrical wires) is eliminated when the boost pump is turned off.

The fuel feed line and vent line outlet fittings will no longer be attached to the structure as the structure has been cut away in this area to allow the fittings to move with the tank. This should prevent either line fitting breakage or tank fitting pullout during crash conditions.

The fuel feed line from the tank to the shutoff valve will be replaced with a self-sealing, high-strength, cut-resistant hose assembly. A self-sealing breakaway valve will be located at the fuel line tank outlet. The combination of the high-strength hose and the breakaway valve will allow the hose to separate from the fuel tank during crash impact with no fuel loss.

The metal vent line will be replaced in part by high-strength, steel-braided, flexible hose. This hose will extend from the tank outlet up through a grommet in the thin, vertical structural panel just aft and above the fuel tank and down to a bulkhead fitting level with and aft of the top of the fuel tank. Metal tubing will be used to extend the vent line from the bulkhead fitting overboard. The flexibility and high strength of the hose, coupled with the additional hose length provided, should prevent the failure of the vent line during crash impact, thus minimizing fuel loss through the vent system.

Crashworthy Fuel System Analysis

The incorporation of the crashworthy fuel system into the OH-58A will eliminate much of the postcrash fire hazard of this aircraft by successfully containing the fuel during the majority of all survivable crash impacts. Under certain crash conditions, however, some fuel spillage could still occur.

The replacement of the present fuel tank by a highly crash-resistant fuel tank which can break free from the aircraft structure during crash conditions will significantly reduce the hazards associated with the fuel tank location. Should the fuselage separate through the tank cavity, however, there is a high probability that the irregularly shaped tank would be caught in the deforming structure, thus causing failure of even this tough tank wall material. Although the tank location in this aircraft cannot be changed now without extensive redesign of the entire aircraft, efforts should be made in the initial design of future aircraft to avoid similar installations.

The design of the vent system should prevent fuel spillage through the vent line in practically all situations. However, should the aircraft come to rest on its right side with a full tank of fuel, several gallons of fuel would be spilled. A check valve placed in the tank outlet of the vent line would prevent this spillage.

The fuel feed line in the engine compartment would be broken should any appreciable amount of engine displacement occur, thus releasing fuel in close proximity to the hot engine. This hazard could be eliminated by placing a self-sealing breakaway valve at the fuel line firewall connection.

OH-6A HELICOPTER

General Description

The OH-6A is a four-place light observation helicopter manufactured by Hughes Tool Company, Aircraft Division. It is powered by an Allison turbine engine driving a four-bladed main rotor and a tail-mounted antitorque rotor.

Fuel System Description

The basic fuel supply system is comprised of two interconnected self-sealing fuel cells, a shutoff valve, an engine-driven fuel pump, a fuel filter mounted on the engine, and a fuel quantity indicating system. A submerged type electric fuel pump is installed in the left fuel cell of some Series 1 and 2 aircraft and in all Series 3 aircraft.

The two interconnected fuel cells are enclosed within the lower fuselage section, directly under the cargo compartment floor (see Figure 10). The rigid interconnect coupling between the two fuel cells runs through the center beam of the aircraft (see Figure 11). The fuel cells are supported by contoured fiberglass support skins and are secured by lacing through nonmetallic hangers on the fuel cells and eyelet brackets on the underside of the cargo floor.

The fuel inlet mounting pad in the left-hand fuel cell, the vent outlets in both cells, and the filler neck shield in the right cell are all rigidly bolted to the aircraft structure. In addition, both fuel cells are rigidly attached to the aircraft center beam at the mid-line of the cells where baffles (not shown) are fastened to the sides of the fuel cells. Each cell contains an access cover on the top surface of the cell, with the left fuel cell cover being fastened to the aircraft structure by thin aluminum brackets.

The sump drain is located on the fuel inlet mounting pad in the left fuel cell and protrudes below the aircraft structure. The electric boost pump (where included) is also mounted on the inlet pad. The boost pump is used for starting and high-altitude or hot-weather operation. The boost pump wires run beneath the fuel tank at the bottom of the aircraft. Those aircraft without the electric submerged boost pump operate on fuel pulled directly from the tank to the engine by the engine-driven fuel pump.

A float-type fuel quantity indicator is mounted to the left fuel cell access cover. This unit also incorporates provisions for triggering a caution light in the cockpit when the fuel quantity is 35 pounds or less.

Fuel cell vents are located in the forward and aft end of each fuel cell. The metal tubing vent lines run forward and are connected to the vent line emergency shutoff valve. This shutoff valve remains open as long as the aircraft is within 30 degrees of vertical. If this limit is exceeded, the vent valve closes to prevent loss of fuel.

Fuel is supplied to the engine from the left fuel cell only. The fuel line exits the tank from the mechanically actuated shutoff valve which is mounted on the access cover on top of the left-hand fuel cell. The rigid metal fuel line is then routed aft above the left-hand fuel cell to the bulkhead just aft of the tank in the armored aircraft or to the firewall in the unarmored aircraft. Flexible hose is then used for the remainder of the fuel line (up to the engine fuel pump). The

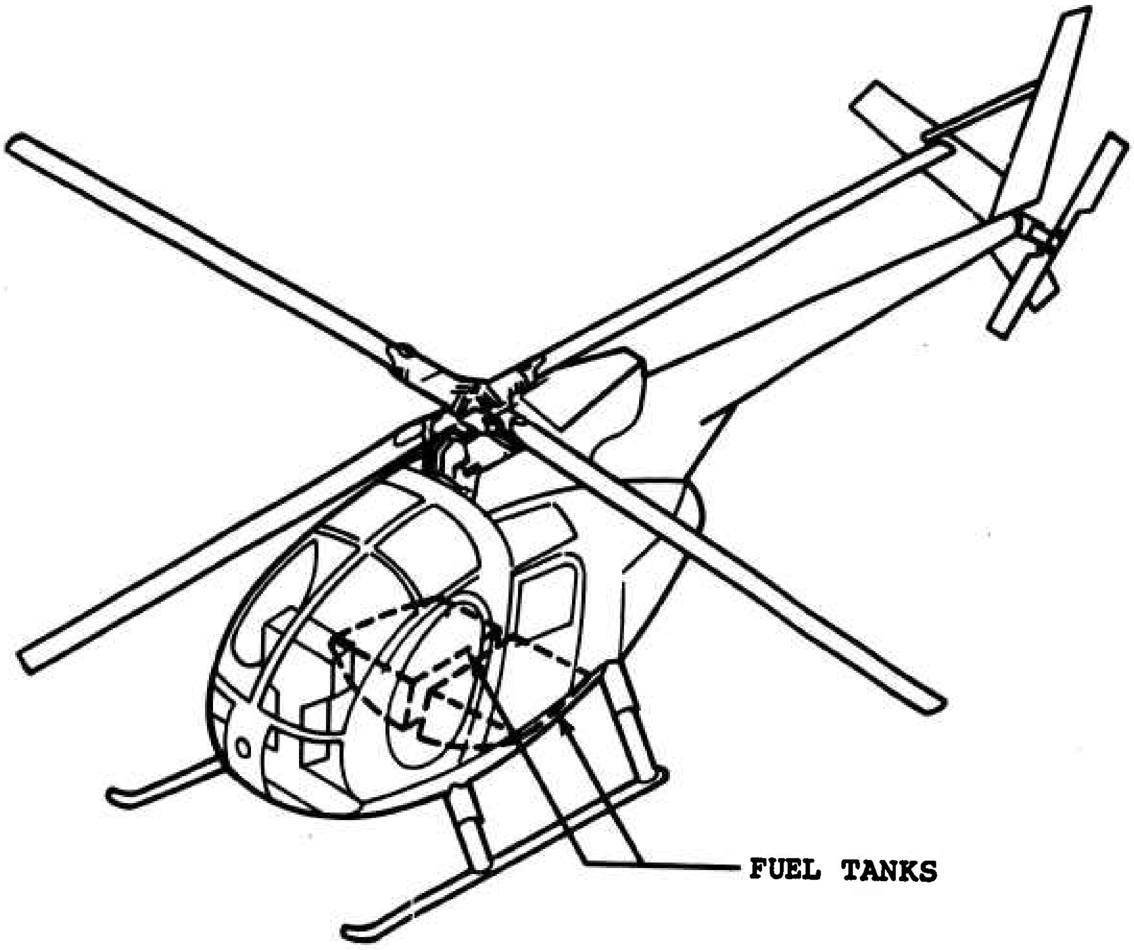
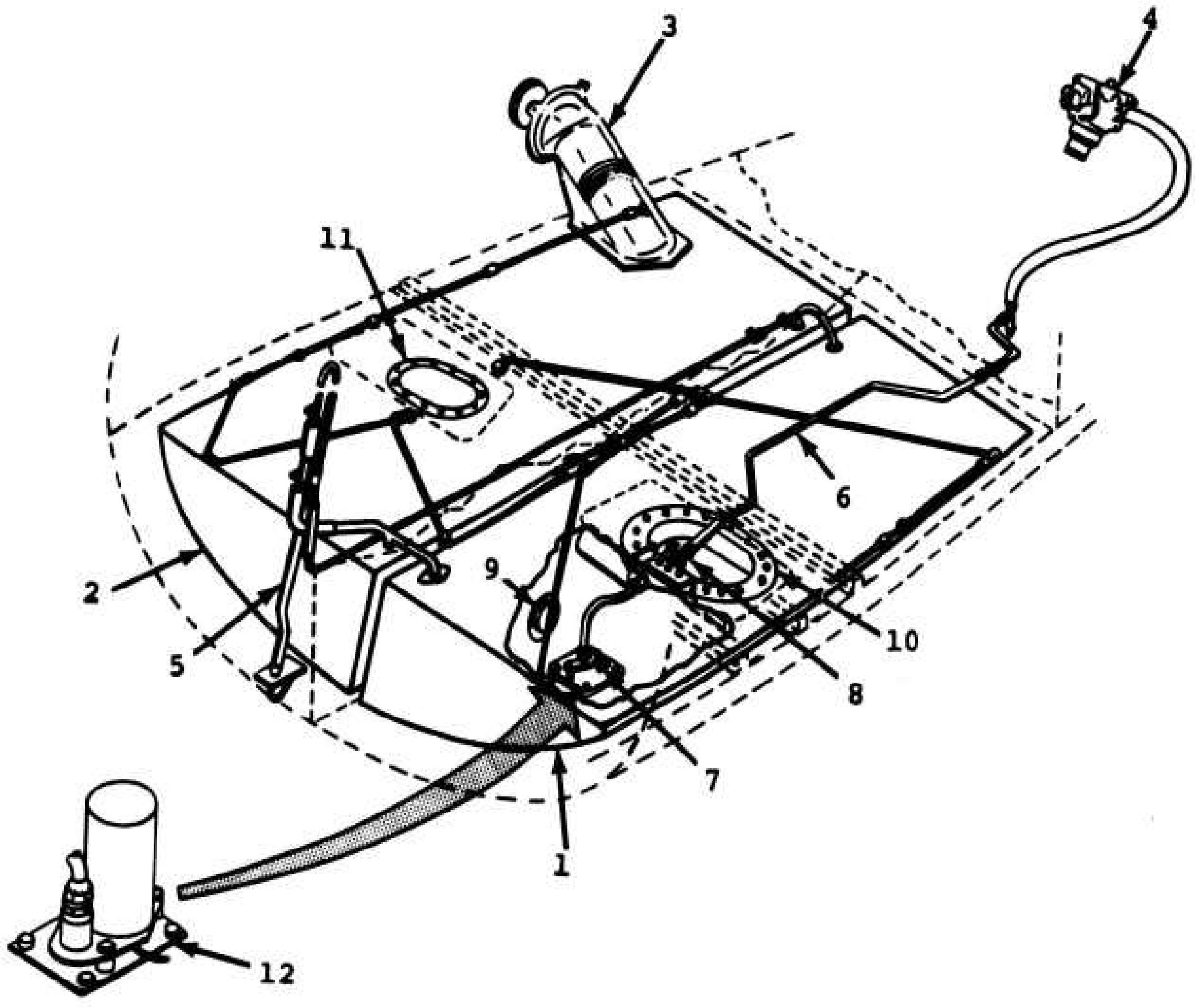


Figure 10. OH-6A Fuel Tank Location.



1. LEFT FUEL CELL
2. RIGHT FUEL CELL
3. FILLER ASSEMBLY
4. ENGINE FUEL PUMP/FILTER
5. VENT LINE
6. FUEL LINE
7. DRAIN VALVE
8. FUEL SHUTOFF VALVE
9. INTERCONNECT COUPLING
10. LEFT FUEL CELL COVER
11. RIGHT FUEL CELL COVER
12. ELECTRIC FUEL PUMP (PROVIDED ON SOME SERIES 1 AND 2 AND ALL SERIES 3 AIRCRAFT)

Figure 11. OH-6A Fuel Supply System.

fuel passes through the filter, which is an integral part of the engine fuel pump, and then into the pump itself.

Fuel System Analysis

The fuel cells are located in a primary impact area and, therefore, could be subjected to a great deal of damage during crash impact. In addition, the engine is mounted low in the fuselage and just behind the fuel cell compartment. This arrangement would provide a ready ignition source for any spilled fuel during a crash.

Although the fastening of the fuel cell into the compartment by hangers is a crashworthy method, the many rigid attachments between the fuel cells and the aircraft structure are particularly hazardous. The fuel cells are unable to move relative to the structure without placing high stress concentrations around these fittings, thus leading to fuel tank failure.

The interconnect coupling is especially vulnerable, and a severe but survivable crash could very well pull the coupling from the thin material to which it is attached.

The filler neck arrangement is particularly vulnerable. Any movement of the cell or filler neck relative to the outside skin could break the filler neck or pull it loose from the tank, while the filler cap would stay with the aircraft skin.

Although the emergency vent shutoff valve is an excellent idea, the installation of the valve negates its effectiveness in a crash, as the rigid vent tubes between the fuel cell and the valve would likely be crushed or broken during crash impact.

There are many crashworthy features incorporated in this system, however. While the self-sealing tank material used is much preferred to the standard thin-wall bladder type, it is doubtful that even this material would survive crash impact due to the tank location.

The attachment of the left fuel cell access cover to the structure is an apparently crashworthy installation as the brackets should yield under moderate loads, allowing the access covers to move with the tank rather than remain rigidly attached to the helicopter floor. The mounting of the fuel shutoff valve and the exiting of the fuel line from this access cover is also a crashworthy installation, as the access cover is in the most protected area of the fuel tank.

Although the fuel line is made of rigid metal tubing, extra length is provided which would allow the tubing to bend and deform rather than break. The use of flexible hose in the engine compartment is a crashworthy idea, although the hose is routed near the left aft landing gear support members. Should these members deflect upward, it is possible that the fuel line would be severed.

The location of the fuel filter on the engine as an integral part of the fuel pump is a very sound idea, as the filter is well protected from crash damage in this location.

Those aircraft which do not contain the submerged electric fuel pump are much more crashworthy than those with the pump. The fuel pump electrical wiring runs beneath the fuel cell, between the cell and the bottom aircraft skin. In the event of a crash, the likelihood of these electrical wires being severed is high. Sparking of these electrical wires would serve as a ready ignition source for any spilled fuel from damaged fuel cells.

UH-1C/M HELICOPTER

General Description

The UH-1C/M is a nine-place utility helicopter manufactured by the Bell Helicopter Company. The helicopter is powered by one Lycoming gas-turbine engine. The UH-1C and UH-1M helicopters are identical with the exception of the engines; the UH-1M contains a larger, although similarly designed, engine than the UH-1C.

Fuel System Description

The fuel system (see Figures 12 and 13) consists of two interconnected self-sealing fuel tanks with a maximum capacity of 245 gallons. The fuel tanks are located in the fuselage behind the crew/cargo compartment and are filled through the top of the left tank. Each fuel tank contains a sump and an electrical fuel boost pump. The left tank also contains a gravity defuel valve, a low-level warning switch, and a fuel quantity transmitter.

The fuel cells are supported in the structure with nylon lacing running through metal clips fastened to the tank walls. In addition, the sump plates, quantity indicator, fuel outlet line fittings, filler cap ring, and vent fittings are all bolted to the aircraft structure.

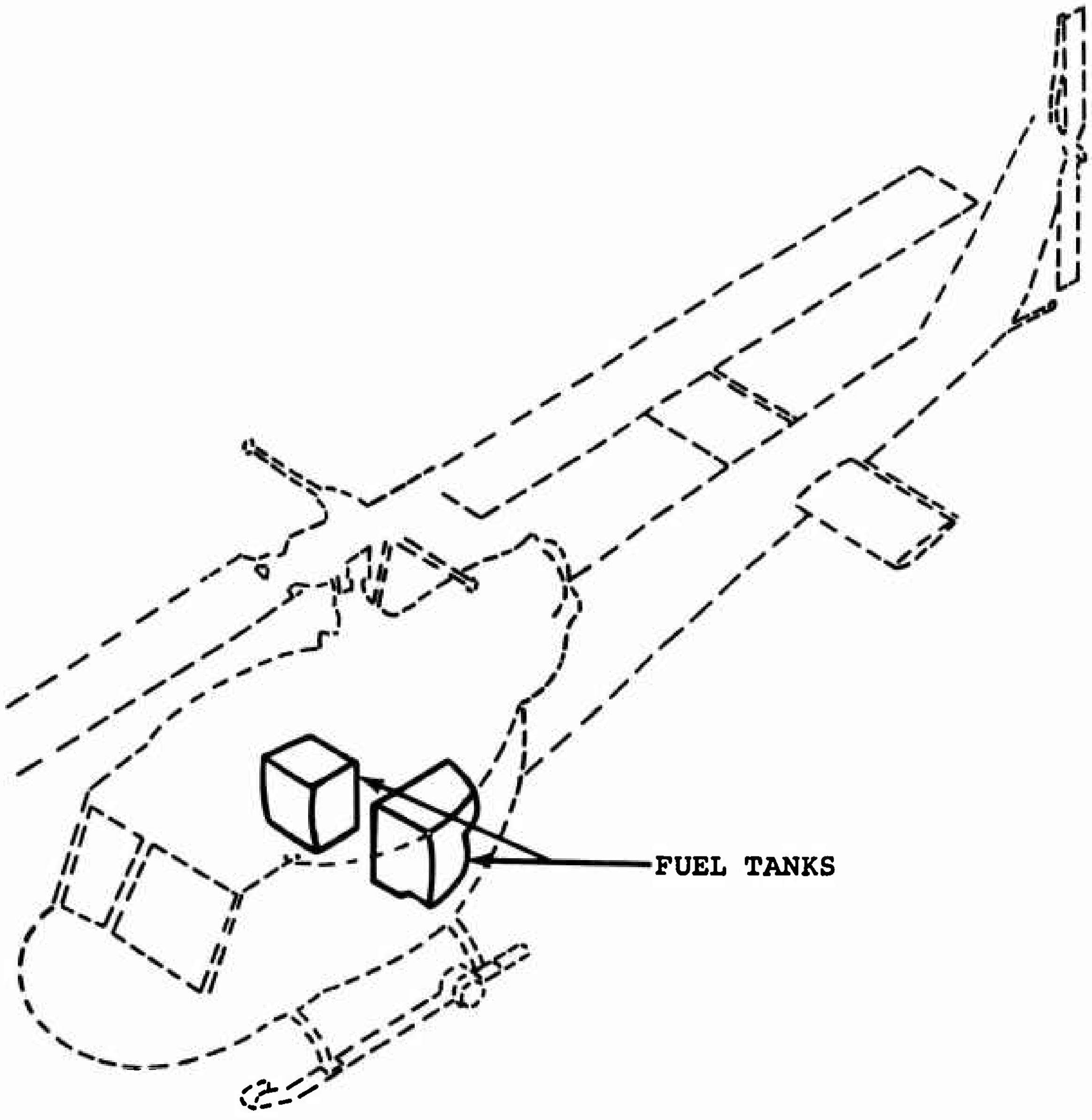
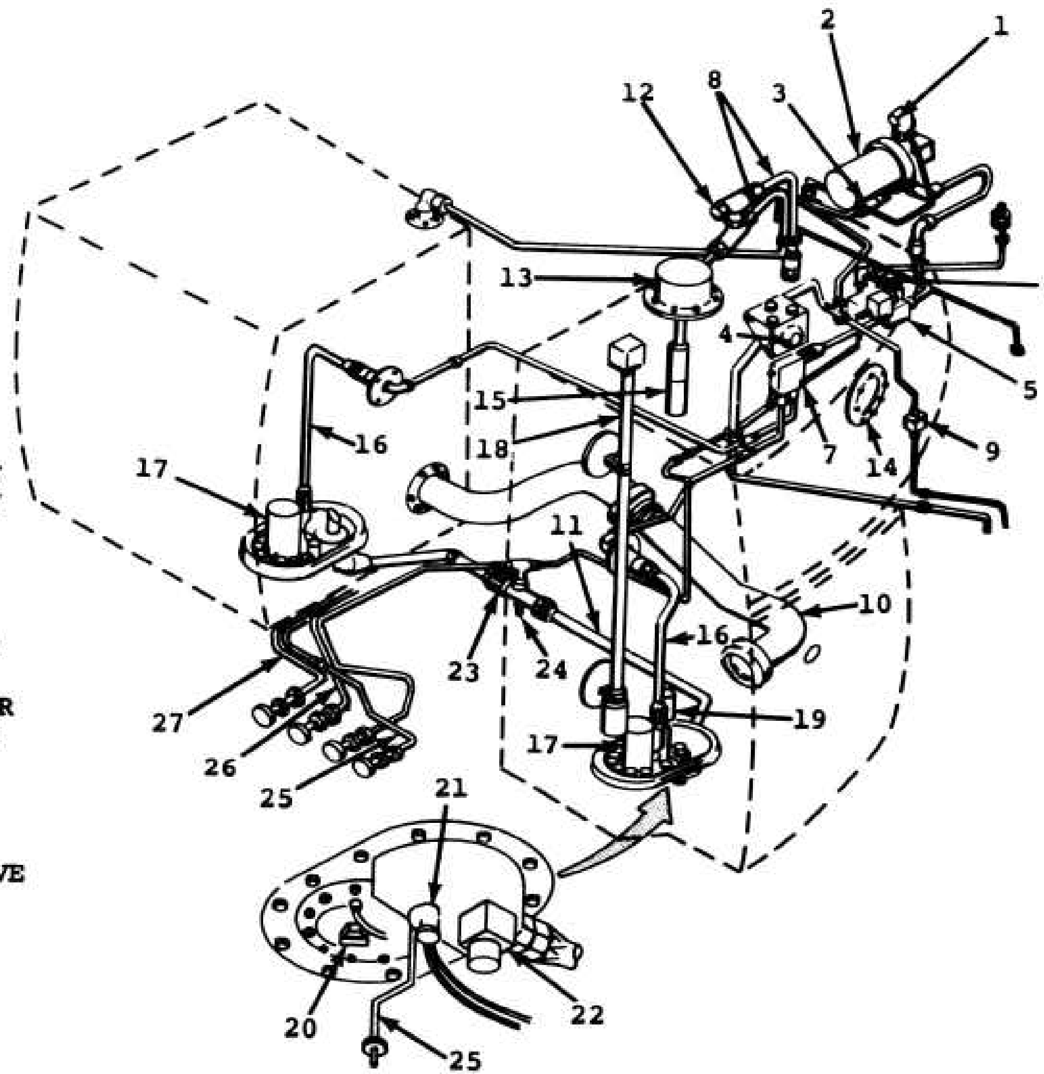


Figure 12. UH-1C/M Fuel Tank Location.



1. ENGINE LINE DISCONNECT
2. FUEL FILTER
3. FILTER DRAIN VALVE
4. PRESSURE TRANSMITTER
5. MOTOR-OPERATED SHUTOFF VALVE
6. GOVERNOR BLEED CHECK VALVE
7. MANIFOLD ASSEMBLY (CHECK VALVES, PRESSURE SWITCHES AND THERMAL RELIEF VALVES)
8. VENT LINES
9. FUEL LINE DRAIN VALVE
10. UPPER CROSSOVER ASSEMBLY
11. LOWER CROSSOVER ASSEMBLY
12. SIPHON BREAKER VALVE
13. COVER
14. FILLER CAP
15. FLOAT SWITCH
16. FUEL PUMP DISCHARGE HOSE
17. FUEL PUMP
18. FUEL QUANTITY TRANSMITTER
19. LOW-LEVEL WARNING SWITCH
20. FUEL PUMP DRAIN VALVE
21. EXTERNAL AUXILIARY FUEL FITTING
22. DEFUEL VALVE
23. AUXILIARY FUEL CHECK VALVE
24. TRAP DRAIN VALVE
25. PUMP SEAL DRAIN LINE
26. VENT LINE
27. SUMP AND PUMP DRAIN LINE

Figure 13. UH-1C/M Fuel Supply System.

The boost pump and the lower crossover line connections are mounted on the sump plates. The left sump plate also contains a gravity defueling valve. The sump plates are formed with a large cup which protrudes beneath the fuel tank (Figure 13). The lower crossover line connections and the drain valve are fastened to this protrusion. The boost pumps mounted to the sump plates are electrically operated and are used continuously during aircraft operation.

The probe-type fuel tank quantity indicator mounted in the left-hand fuel cell is fastened to the deck panel above the top of the fuel cell and is also supported at two places along its length by brackets fastened through the fuel cell wall to the aircraft structure. A low-level warning system is incorporated in the indicating system.

Fuel flows between the fuel cells by means of two crossover assemblies. The upper crossover assembly is made of metal tubing with a flexible section in the center of the assembly. The end fittings are bolted through the structure to the tank fittings. The lower crossover assembly consists of flexible hose with a rigid center section where a line from the external auxiliary fuel tank is connected. As noted before, the lower crossover assembly exits from the sump plate protrusions.

Fuel is pumped through the pump discharge hose to the tank outlet fittings and then through separate rigid metal lines from each cell to a manifold assembly which contains check valves, pressure switches, and thermal relief provisions. The fuel then flows from the manifold through a single line to an electrically operated shutoff valve and thence to the fuel filter, which is mounted above the engine compartment service deck at the left side of the engine. Fuel then flows from the filter through a flexible hose to the engine fuel control assembly.

Both fuel cells are vented through the top to the atmosphere. The rigid metal vent lines from each tank are joined together at a siphon breaker valve, and from there a single vent line exits overboard.

Fuel System Analysis

The location of the fuel tanks, well up in the fuselage away from the bottom of the aircraft, protects them from direct crash impacts. However, the proximity of the fuel tanks to the electrical compartment, which is directly behind the left-hand fuel cell, is not as desirable since fuel spilled from the tank could easily run into the compartment and be ignited by sparks from damaged electrical equipment.

The rigid bolting of the tank fittings to the aircraft structure is very hazardous, as these fittings will more than likely be torn from the fuel cell as the fuel cell moves relative to the structure around it during crash impact. The sump plates pose a special hazard because the deep protrusion beneath the tanks can easily be snagged on aircraft structure, thus putting excessive stresses on the tank wall around the sump plate.

The location of the lower crossover hose assembly fittings underneath the sump plate makes them very vulnerable to being damaged during a crash. The large metal upper crossover tube is also vulnerable to being smashed or torn from the tank during impact because of its construction and location. In addition, all of the fuel lines which are made of rigid aluminum tubing can be easily crushed or broken by impinging structure.

The vent lines, also made of rigid metal tubing, can be easily broken. If the vent lines were broken during an impact, or if the aircraft came to rest inverted or on its side, total release of the fuel could occur through the vent lines.

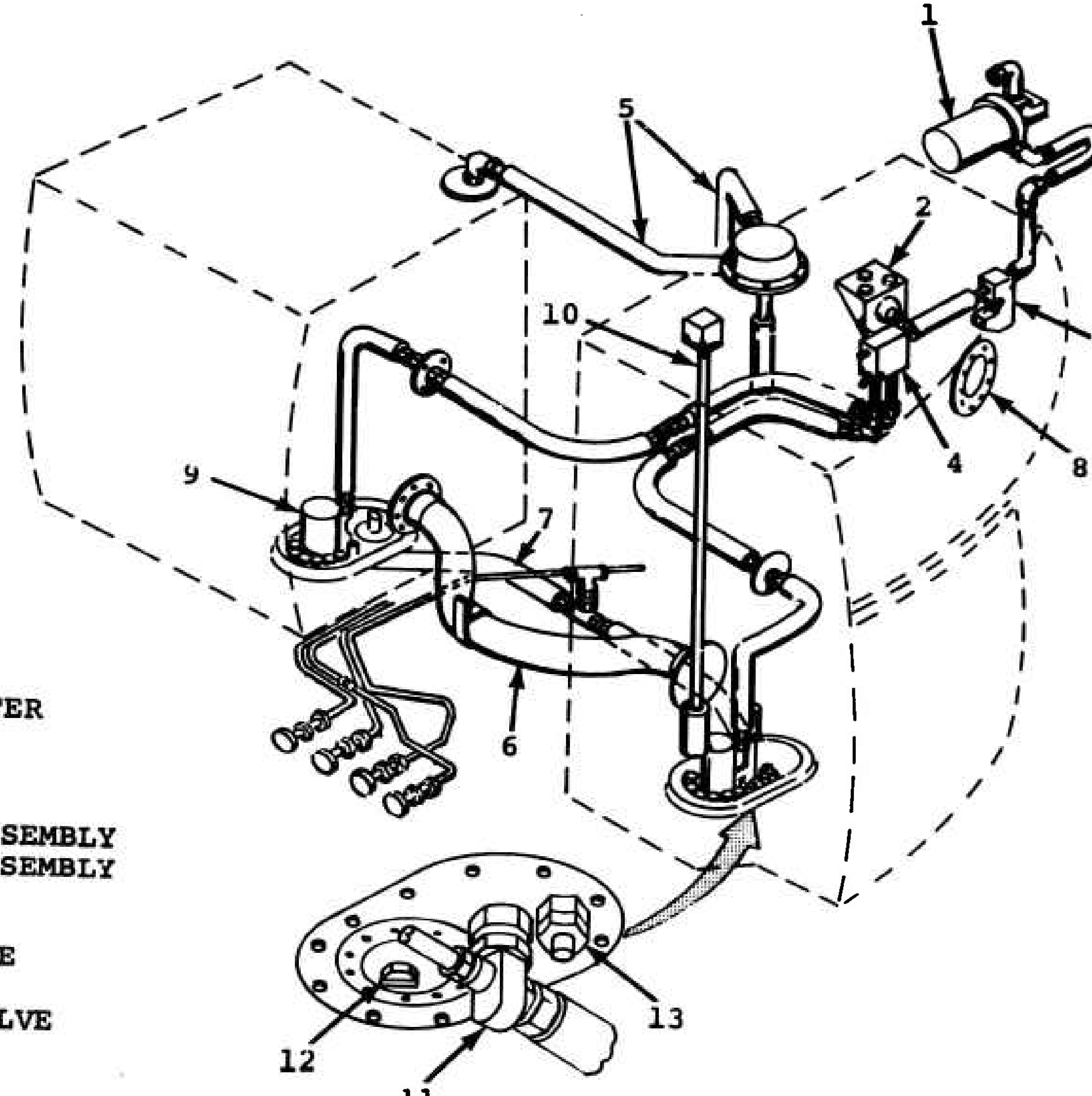
The electrical boost pumps also pose a crash fire hazard. The tearing loose of these pumps from the fuel cells would not only release fuel from the tanks but break the wires leading to the pumps, thus placing spilled fuel and ready ignition sources in close proximity.

The location of the fuel filter in the engine compartment, although it is convenient for maintenance purposes, does pose an additional crash fire threat. Any displacement of the engine during a crash could easily dislodge or crack the filter, thus leading to fuel spillage which could be ignited by the hot engine components.

Proposed Crashworthy Fuel System Modifications

Although the basic fuel system configuration for the crashworthy fuel design is similar to the original fuel system, several changes will be made which will tremendously improve the fluid containment capabilities of the system. These changes involve both the fuel cells and the vent and fuel feed lines (see Figure 14).

The fuel cells will be made from crashworthy tank material corresponding to MIL-T-27422B. This material is highly resistant to crash impacts and has high penetration and cut resistance. In addition, the tank fittings are bonded into the tank material so that the pullout strength is at least 80 percent as strong as the tank material itself.



1. FUEL FILTER
2. PRESSURE TRANSMITTER
3. SHUTOFF VALVE
4. MANIFOLD ASSEMBLY
5. VENT LINE
6. UPPER CROSSOVER ASSEMBLY
7. LOWER CROSSOVER ASSEMBLY
8. FILLER
9. BOOST PUMP
10. FUEL QUANTITY PROBE
11. BREAKAWAY VALVE
12. FUEL PUMP DRAIN VALVE
13. DEFUEL VALVE

Figure 14. UH-1C/M Helicopter Proposed Crashworthy Fuel Supply System.

Frangible attachments will be used to fasten the sump plates, vent outlets, fuel line outlets, and filler cap ring to the aircraft structure. The use of these frangible attachments enables the fuel tank to break free from the structure before the fittings are pulled out of the tank wall, thus preserving the integrity of the tank.

The sump plate has been redesigned to eliminate the large protrusion on the bottom, thus lessening the probability of the plate being trapped in damaged structure. Unfortunately, the drain valve and lower crossover connections still protrude below the tank. However, breakaway valves will be used at the lower crossover connections to eliminate the possibility of end fitting failure at this point.

The upper crossover assembly will be rerouted so that it does not enter the left fuel cell at the rear but enters on the inside of the cell at a protected location. In addition, the crossover line will be made from crashworthy fuel cell material and will be attached to the tanks with the same strength fitting as is used to attach the other tank fittings to the tank wall. This area will be stabilized by using frangible attachments between the tank fitting and the aircraft structure. A frangible support attachment will also be used at the center of the crossover line to provide additional support.

The fuel lines from the fuel tanks up to the manifold will be replaced with flexible hose. Steel tubes will be used from the manifold to the shutoff valve and from the valve up to the service deck. The line from the service deck to the fuel filter will be made from flexible hose. This will allow the fuel lines to displace with the deforming structure rather than being trapped and cut during the crash.

The vent lines, which are now rigid tubing, will also be replaced with flexible hose from the tank vent fittings up to the overboard line. In addition, the vent line arrangement has been greatly simplified with the right tank vented to the left tank and the siphon breaker valve eliminated. This will greatly reduce the possibility of the vent lines being broken with consequent fuel spillage from the tanks.

Crashworthy Fuel System Analysis

Although the proposed modifications will result in a much more crashworthy fuel system than the original system, and will certainly eliminate many postcrash fires, several areas could use further modification in order to have a completely crashworthy system.

One of these areas is the sump plate and the fittings that extend below the fuel tank. The defuel valve protrudes below the sump plate and could easily be snagged on displacing structure during a crash, possibly breaking the valve or tearing it out, leading to complete fuel spillage from the tanks. The breakaway valves which have been installed at each end of the lower crossover assembly protect the assembly itself from damage. However, the valves protrude below the tank, and further study is necessary to determine if the tank half of the valve could be fractured by displacing structure similar to the defuel valve.

Although replacing the vent line with flexible hose and simplifying the vent system reduce the probability of vent line damage, a weak tube elbow exists where the right vent enters the left tank. Tube elbows are easily broken during crash impact, and the possibility exists that this elbow might likewise be broken, even though it is in a fairly protected area. The lack of check valves in the fuel tank vents is a much more serious problem, however. If the fuel tanks are nearly full, the hydraulic surge from a severe vertical impact could send fuel through the vent lines to come into contact with the many ignition sources present during a crash.

Standard bulkhead fittings are used in the fuel feed lines between the tank and the manifold where the lines go through the bulkhead just aft of the tanks. These fittings are susceptible to being broken during crash impact. This area could be made truly crashworthy by running uncut hose through a frangible baffle in the bulkhead. This would allow the hoses to displace during crash impact, thus absorbing the energy before transmitting it to the end fittings and breaking them.

Although the steel tubing used in the fuel feed line around the manifold and shutoff valve is much stronger than the thin aluminum tubing previously used, a better crashworthy installation would use flexible hose in this area to prevent the transmission of high stress loads to the end fittings.

Another area that is still definitely a crash hazard is the fuel system in the engine compartment area. A standard AN fitting exists in the fuel feed line at the firewall. Although flexible hose is installed between this fitting and the fuel filter, high stress loads could still be transmitted to this fitting, thus breaking it. In addition, engine displacement could also damage this fitting. Therefore, a self-sealing breakaway valve should be used in the line where it enters the engine compartment.

Consideration is being given to placing a breakaway valve at the filter in the outlet line to the engine. However, the proposed installation consists of the breakaway valve being attached to a standard AN elbow on the filter. This area needs more study to determine if the AN elbow can handle the stresses imposed on it without breaking before the breakaway valve separates.

The filter, which is still in close proximity to the engine, is susceptible to damage if the engine displaces. The filter should ideally be located in the fuel feed line outside of the engine compartment. However, if it must remain in the engine compartment, it should be moved as far away as possible from the engine.

UH-1D/H HELICOPTER

General Description

The UH-1D/H is a 12- to 15-place tactical transport helicopter manufactured by the Bell Helicopter Company. This helicopter is powered by one Lycoming gas-turbine engine. The UH-1D and UH-1H models are identical with the exception of the engine. Although the engines are similar in design, the UH-1H possesses a larger engine than does the UH-1D model. UH-1H models manufactured since April 1970 contain a modified crashworthy fuel system.

Original Fuel System Description

The fuel supply system consists of five interconnected rubber fuel cells with submerged fuel pumps in the forward cells (see Figures 15 and 16). The fuel supply system also includes a fuel filter, fuel pressure switches, a fuel quantity system, a motor-operated shutoff valve, pressure transmitter and gage, a low-fuel-level warning system, drain valves, defuel valves, and interconnecting fuel lines and hoses. Total capacity of the fuel system is 224 gallons.

Three non-self-sealing bladder-like cells are located across the fuselage below the engine deck, and two self-sealing bladder cells are located under the cabin floor (Figure 15). The three aft cells are interconnected with rigid interconnect fittings bolted through the tank walls and the structural bulkheads. The aft cells gravity feed into the underfloor forward cells through flexible crossover lines (Figure 16). The tanks are filled through one filler opening which is bolted to the structure and is contained in the right aft fuel cell.

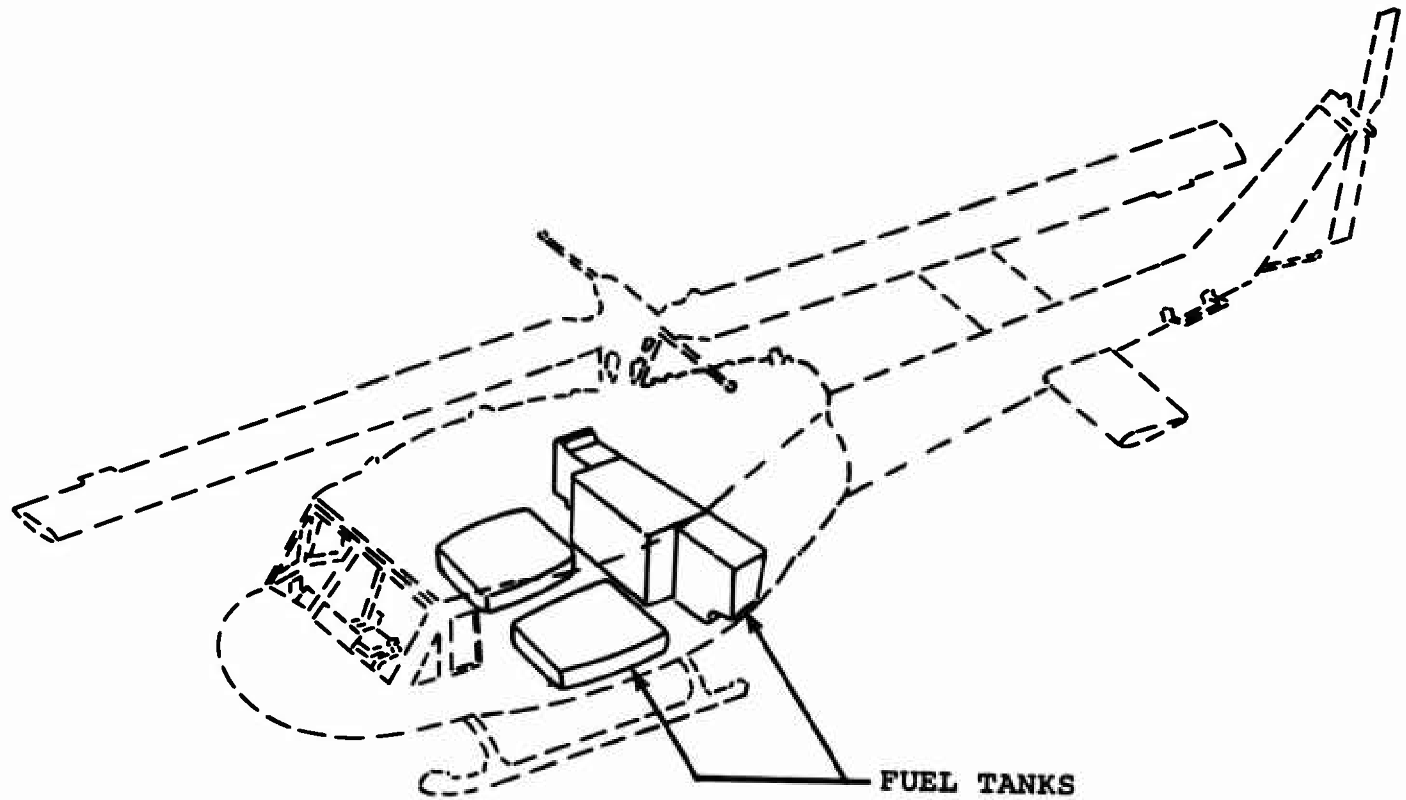
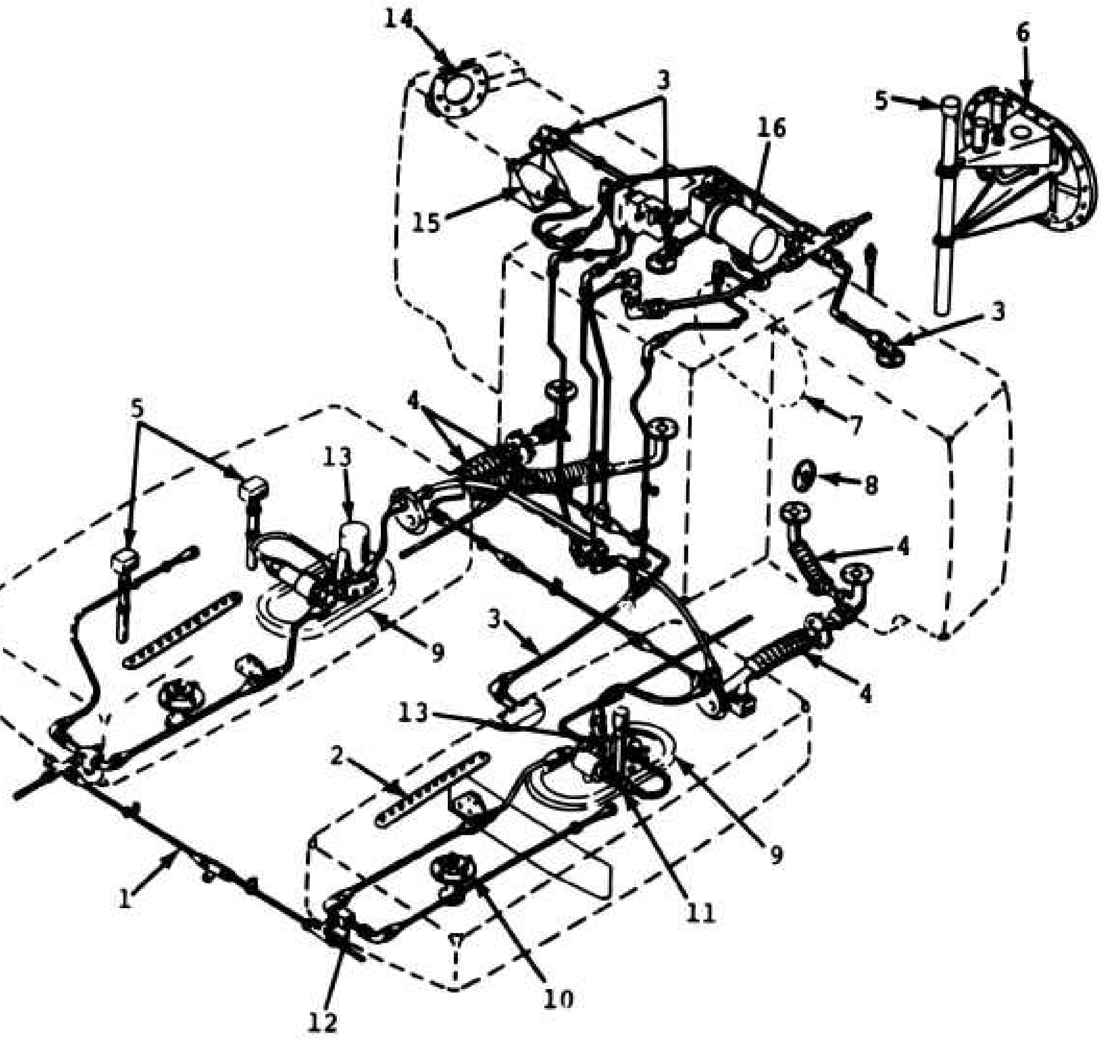


Figure 15. UH-1D/H Fuel Tank Location.



1. CROSS-FEED LINE
2. ACCESS PORT
3. VENT LINE
4. CROSSOVER LINES
5. FUEL QUANTITY PROBE
6. ACCESS DOOR
7. ACCESS PORT
8. INTERCONNECT FITTINGS
9. SUMP ASSEMBLY
10. DRAIN VALVE ASSEMBLY
11. CHECK VALVE
12. EJECTOR PUMP
13. BOOST PUMP
14. FILLER
15. PRESSURE TRANSMITTER
16. FUEL FILTER

Figure 16. UH-1D/H Original Fuel Supply System.

Two small cross-feed lines fore and aft link the two underfloor cells. The forward cross-feed line is composed entirely of rigid metal tubing. The aft cross-feed line, which is connected to the large fittings at the aft end of the tanks, is composed of flexible hose up to the longitudinal bulkheads adjacent to each tank, and then is composed of rigid metal tubing across the center of the aircraft.

The fuel cells are secured in the structure by means of nylon lacing and metal clips attached to the outside of the fuel cell walls. However, the filler ring, sump plates, drain valves, fuel line outlets, vent outlets, and the large rear access plate in the center aft cell are all bolted rigidly to the aircraft structure.

Each forward cell is divided into compartments by a lateral baffle fitted with a flapper valve to allow fuel flow from front to rear. The boost pump is mounted on a sump assembly near the aft end of the cell. The right pump is electrically operated, and the left fuel cell pump is driven by bleed air from the engine compressor.

The sump drains, which are mounted to the sump plates, extend below the bottom of the fuel cell. The forward part of the cell also contains a drain valve which is bolted rigidly to the aircraft structure and protrudes below the tank bottom.

Two probe-type quantity gage tank units are located in the right forward cell. Another probe-type quantity gage is located in the center aft cell and held by brackets attached to the access door in the rear of this cell. A low-fuel float switch is mounted on the left cell sump.

The fuel feed lines exit the rear of each forward tank from a large tank fitting which also attaches the crossover line from the aft tanks and the aft cross-feed line. The fuel lines are composed of flexible hose until the lines reach the center of the aircraft. From this point rigid metal lines are routed upward to a check valve manifold above the center aft tank. A single line then goes from the check valve manifold through the firewall to the fuel strainer which is mounted on the firewall at the left side of the engine.

Each fuel cell is vented separately. The two underfloor vent lines join together in front of the center aft fuel cell and are run up through a siphon breaker valve to a vent manifold. The vent lines from the three aft cells also run into this vent manifold. From the manifold, a single vent line exits overboard. The vent lines from the underfloor tank vent outlets to the bulkhead just aft of the underfloor tanks are composed of flexible hose. The rest of the vent lines are made from rigid aluminum tubing.

Fuel System Analysis

The location of the forward tanks under the cabin floor is particularly hazardous from a crashworthiness viewpoint. These tanks are located in the bottom of the fuselage and would be subject to extensive damage during a crash. In addition, cargo being carried in the helicopter would restrict any surging movement of the fuel upward and would tend to smash the tanks between the cargo and the ground. The rigid attachment of the tank fittings and the protrusion of drain valves below the bottom of the tank further increase this hazard. These fittings would more than likely be torn from the tank during a severe but survivable crash, and massive fuel spillage would result.

The aft cells, although in a protected location, are made of very thin cell material. This fact, coupled with the rigid attachments of the fuel crossover outlets, fuel interconnects, the access door, and the filler cap ring, also make these tanks prone to failure around the fittings during crash impact.

The crossover lines from the aft to forward tanks are located directly over the landing gear support members. This is a very hazardous location, in that a relatively hard landing could drive the support members upward and puncture the thin flexible line, again leading to massive fuel spillage.

Although the incorporation of some flexible hose in the fuel lines and the vent lines is a crashworthy feature, the extensive use of rigid aluminum tubing in these lines still permits a hazardous situation to exist.

The incorporation of an air-driven boost pump in the left-hand cell is a noteworthy improvement over the use of an electrical pump. The electrical pump in the right-hand cell makes necessary the routing of electrical wires beneath the cell, where they are very vulnerable to crash impact damage, thus presenting a ready ignition source for any spilled fuel. It is unfortunate, from a crashworthiness viewpoint, that helicopters commencing with serial number 69-15292 no longer incorporate the air-driven boost pump but use two electrically operated fuel pumps.

The mounting of the fuel strainer in the engine compartment at the side of the engine is a crash hazard. In the event of engine displacement, this fuel strainer could be badly damaged, leading to fuel spillage in close proximity to the hot engine ignition source.

Crashworthy Fuel System

The crashworthy fuel systems now being installed in the UH-1H production model helicopters incorporate many modifications which make these helicopters much safer with respect to post-crash fires.

All fuel tanks have been replaced with crashworthy tanks corresponding to MIL-T-27422B. In addition, all tank fittings have a pullout strength of not less than 80 percent of this tougher tank wall material strength.

The filler ring, sump plates, drain valves, and fuel line outlets are now fastened to the structure with frangible attachments which will allow these fittings to break from the structure during crash impact without placing excessive loads on the fuel tank walls.

Breakaway valves have been installed in all of the aft tank fuel outlets and at the crossover inlets to the underfloor tanks. A breakaway valve is also incorporated in the center of the aft cross-feed line between the two underfloor tanks (see Figure 17). These breakaway valves will allow the lines to separate from the tanks during crash impact, sealing the tanks with no fuel loss.

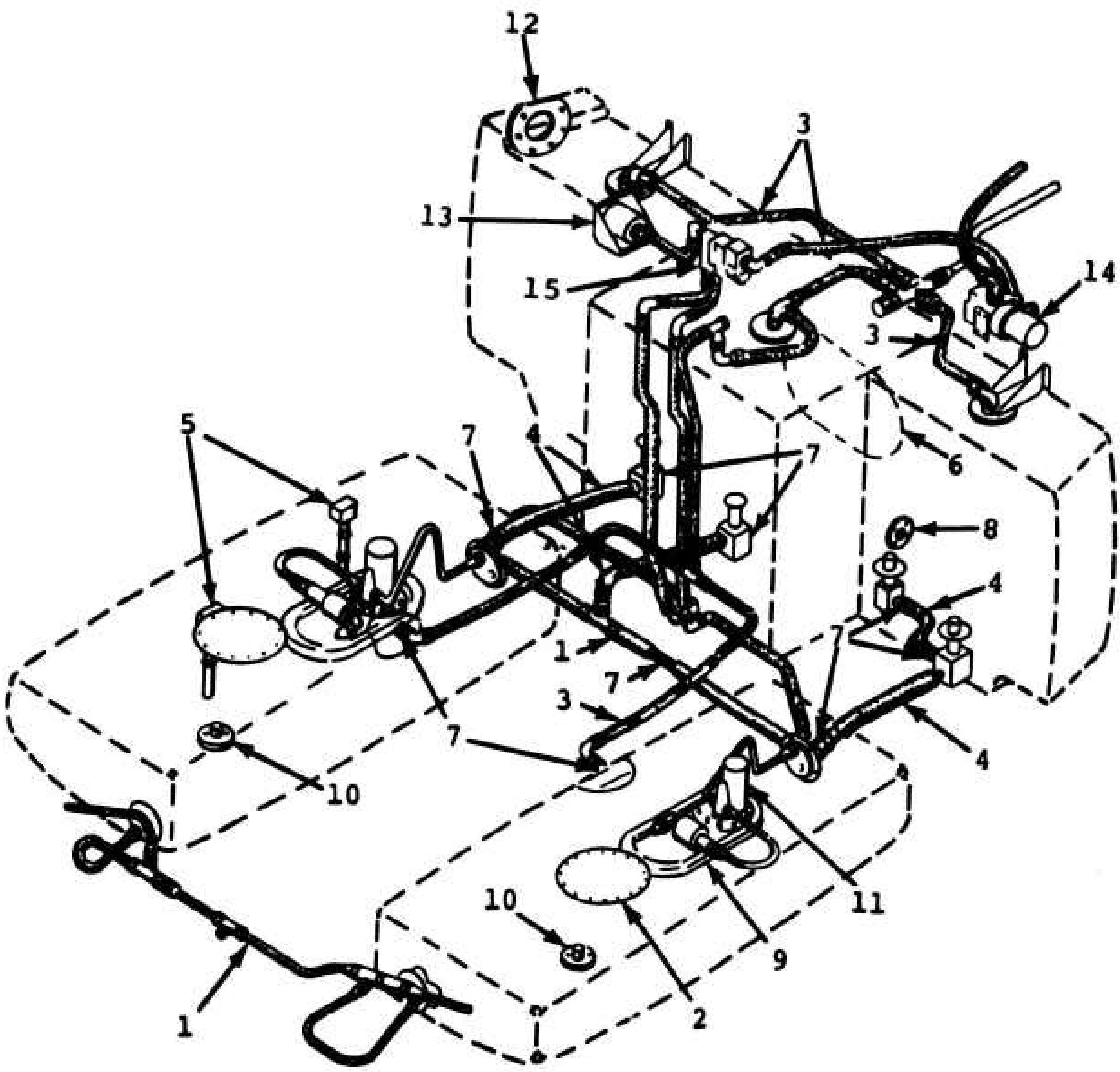
All fuel lines, including the two cross-feed lines between the forward tanks, have been replaced with flexible hose. In addition, the crossover lines from the aft to the forward tanks are now made from a much tougher flexible material than was used in the original fuel system.

The drain valves, besides being frangibly attached to the structure, have been recessed so that they are flush with the bottom of the fuel cells. This will avoid the possibility of the drains' snagging on deforming structure during a crash.

The vent outlets in the forward underfloor tanks now incorporate self-sealing breakaway valves. These valves will separate and seal the tank should structural displacement in this area put excessive stresses on the vent outlet fitting. In addition, all vent lines up to the vent manifold have been replaced with flexible hose.

Crashworthy Fuel System Analysis

Although the crashworthy vent system installation is a major improvement over the original system, additional modifications should be considered to achieve maximum crash fire safety. A UH-1D/H helicopter containing the modified fuel system crashed



1. CROSS-FEED LINE
2. ACCESS COVER
3. VENT LINE
4. CROSSOVER LINE
5. FUEL QUANTITY PROBE
6. ACCESS DOOR
7. BREAKAWAY VALVE
8. INTERCONNECT FITTING
9. SUMP ASSEMBLY
10. RECESSED DRAIN VALVE
11. BOOST PUMP
12. FILLER
13. PRESSURE TRANSMITTER
14. FUEL FILTER
15. CHECK VALVE MANIFOLD

Figure 17. UH-1D/H Crashworthy Fuel Supply System.

recently and came to rest in an inverted position*. Although the crash was not severe enough to actuate the breakaway valves or frangible attachments and the fuel system was essentially undamaged, a sizeable amount of fuel was spilled through the vent system. A serious fire would have resulted if this fuel had been ignited. The installation of check valves in the vent outlets would preclude this type of fuel spillage in future crashes.

The fuel filter, although still mounted on the firewall of the engine compartment, has been moved farther away from the engine. This is an improvement over the original system, although it would be more desirable for the filter to be completely removed from the engine compartment.

Although the use of flexible hose for all fuel feed lines and the incorporation of breakaway valves in the tank outlets considerably improve the crashworthiness of this aircraft, there are still several areas in the fuel feed system that should be modified for maximum crash safety.

Breakaway valves should be used where the fuel feed line enters the engine compartment and at the filter outlet. This would allow for engine displacement without breaking the standard fittings now used. Breakaway valves should also be installed at the engine compartment service deck where the compressor and fuel control seal drain hose goes through the service deck on its return to the aft center tank.

The rigid interconnects used between the aft cells should be replaced with self-sealing breakaway valves. Although the fuel tanks are made from a much stronger material than they were previously, a severe crash could still place high stresses on the tank walls around these rigid interconnects and tear the fuel cells. This is an area which definitely needs modification in order to have a truly crashworthy system.

AH-1G HELICOPTER

General Description

The AH-1G is a two-place armed helicopter manufactured by Bell Helicopter Company. It is a high-speed combat helicopter powered by one Lycoming gas-turbine engine.

*"Postcrash Evaluation of a UH-1D/H Helicopter", Dynamic Science, Memorandum Report AvSER M1520-70-29, August 7, 1970.

Fuel System Description

The helicopter fuel system (see Figures 18 and 19) consists of two interconnected bladder-type fuel cells with a total capacity of 270 gallons. Each cell contains a sump and a submerged fuel boost pump. The fuel system also includes a fuel pressure switch, fuel quantity and low-level warning systems, fuel filter, a motor-driven shutoff valve, drain valves, defuel valves, and associated hose and tubing.

The two interconnected cells are located forward and aft of the pylon and wings, well up in the fuselage structure (Figure 18). The aft cell is of a smooth, regular shape, whereas the forward cell is somewhat irregular with shoulders which protrude over the aircraft structure. The lower portions of both cells are self-sealing.

A self-sealing crossover hose allows free flow of fuel from the forward to the aft cell. The aft cell has a check valve that restricts flow from the aft to the forward cell to avoid sudden shifting of balance in nose-down flight attitude. The crossover hose is attached to long, thin aluminum tube elbows that exit each tank (Figure 19).

The fuel cells are supported in the structure by hangers and nylon cords. Both cells are filled through one filler neck located in the forward cell. All metal tank fittings, including boost pump, drain valve, vent outlet, quantity indicator, and filler neck fittings, are rigidly bolted to the aircraft structure.

Each fuel cell contains a probe-type indicator and low-level float switch, as well as an electrically operated boost pump which is bolted to a metal fitting at the fuel cell bottom. Drain valves are located in the sump areas of both fuel tanks, with the large drain valve in the aft tank used for defueling.

Fuel is pumped through rigid metal lines from each fuel tank to a manifold containing flow check valves and thermal relief bypass provisions. A single line exits the manifold outlet and runs to an electrically operated shutoff valve located on the front of the firewall. A metal line conducts fuel from the shutoff valve to the fuel filter which is mounted on the engine compartment deck at the left side of the engine. A flexible hose conducts fuel from the filter to the engine fuel control unit.

Rigid aluminum vent lines exit each cell and are connected together to form a single overboard line.

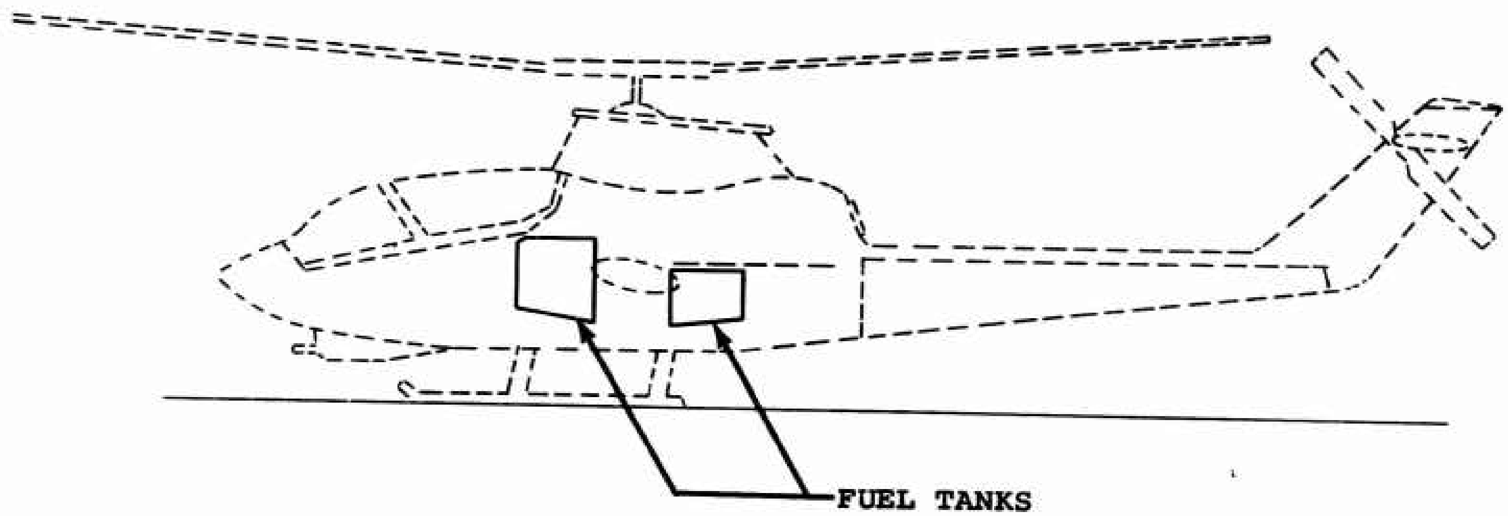
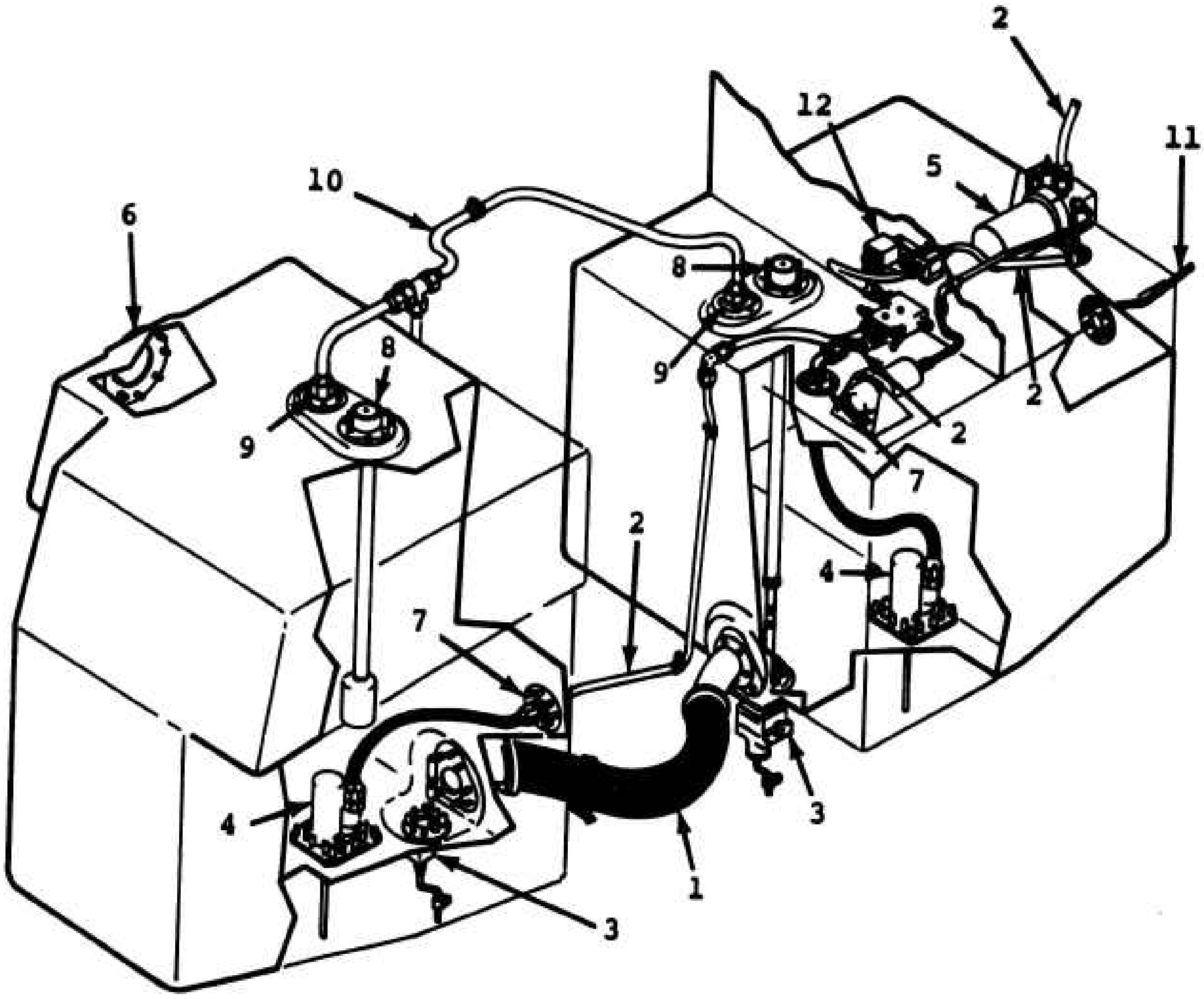


Figure 18. AH-1G Fuel Tank Location.



1. CROSSOVER HOSE (BALLISTIC SELF-SEALING, 2.5-INCH DIAMETER)
2. TANK-TO-ENGINE LINE
3. TANK DRAINS
4. BOOST PUMP
5. FILTER
6. FILLER
7. BOOST PUMP TANK OUTLET
8. QUANTITY INDICATOR
9. VENT OUTLET
10. VENT LINE
11. GOVERNOR BLEED RETURN LINE
12. SHUTOFF VALVE

Figure 19. AH-1G Fuel Supply System.

Fuel System Analysis

The fuel cells are fairly well located from a crashworthiness viewpoint, both being located up in the fuselage away from the bottom. Although the fuel cells are located above the landing gear, the probability of the cells' being punctured by broken landing gear supports is slight because of the rigid structure surrounding the tank area. However, the aft cell is directly under the engine compartment, and this does pose a hazard since this cell could be crushed if the engine is torn loose during a crash.

Another hazard which exists is the shoulders in the forward fuel tank. The strain in these shoulders caused by severe vertical impact deceleration may tear the fabric, especially since the wall thickness in the upper part is thinner and the filler ring fitting is bolted rigidly to the aircraft structure in this area.

Another hazard is the location of the filler neck which is near the engine intake. It is possible that fuel vapors from the filling operation could be ingested into the engine during "hot" refueling operations, thus causing a fire.

Possibly the greatest hazard to the integrity of the fuel system during a crash is the rigid attachment of the metal fuel cell fittings to the structure. During a severe but survivable crash, the fuel tank wall could easily be torn around these fittings, particularly in the top thin-walled portion of the cells.

Although the self-sealing crossover hose between the fuel cells, with its additional length, is a crashworthy concept, the thin aluminum attachments between the hose and the fuel cells are especially vulnerable to damage since they pass through structural bulkheads immediately adjacent to the fuel cell walls.

The use of rigid metal tubing for the fuel lines and vent lines also presents a crash hazard, as these lines could be easily crushed or broken during a severe crash.

The engine compartment location of the fuel filter is not desirable from a crashworthy viewpoint, as displacement of the engine could damage the filter or the aluminum tube running from the firewall to the filter, thus allowing fuel spillage in close proximity to the hot engine components.

The use of electrically operated boost pumps mounted in the fuel cells necessitates the routing of electrical wiring adjacent to the fuel cell wall. This presents a hazard if fuel should be spilled and wires broken at the same time, since the fuel could easily be ignited by electrical sparks from the broken wires.

CH-47C HELICOPTER

General Description

The CH-47C is a medium transport helicopter manufactured by the Vertol Division of the Boeing Company. The helicopter is a tandem-rotor aircraft powered by two Lycoming turbine engines mounted on the aft fuselage. A gas-turbine auxiliary power unit hydraulically drives the aft transmission accessory gear-box.

Fuel System Description

The fuel supply system furnishes fuel to the two engines, the heater, and the auxiliary power unit. The system consists of two separate fuel systems connected by a cross-feed line. The supply system on one side of the helicopter supplies the engine on that side, although provisions are made through the cross-feed to supply the engines from either fuel system.

Each fuel system consists of three fuel tanks contained in a pod on each side of the fuselage (see Figure 20). The main tank, located in the center, has a capacity of 302 gallons. The forward and aft auxiliary tanks have a capacity of 131 gallons each. This makes a total capacity for the helicopter of 1,131 gallons of fuel.

Each main tank contains two fuel boost pumps, while each auxiliary tank contains one fuel boost pump (see Figure 21). During normal operation, with all boost pumps operating, fuel from all three tanks will supply fuel to the engine. The fuel in the auxiliary tanks is consumed at a faster rate than the fuel in the main tank; when the fuel is depleted in either auxiliary tank, a check valve closes to prevent air from being pumped into the fuel system. Should a fuel boost pump fail in an auxiliary tank, the fuel in that tank is not usable. However, should both fuel boost pumps fail in the main tank, fuel can be drawn through the check valve by the engine-driven boost pump as long as the helicopter is operated below 6,000 feet pressure altitude.

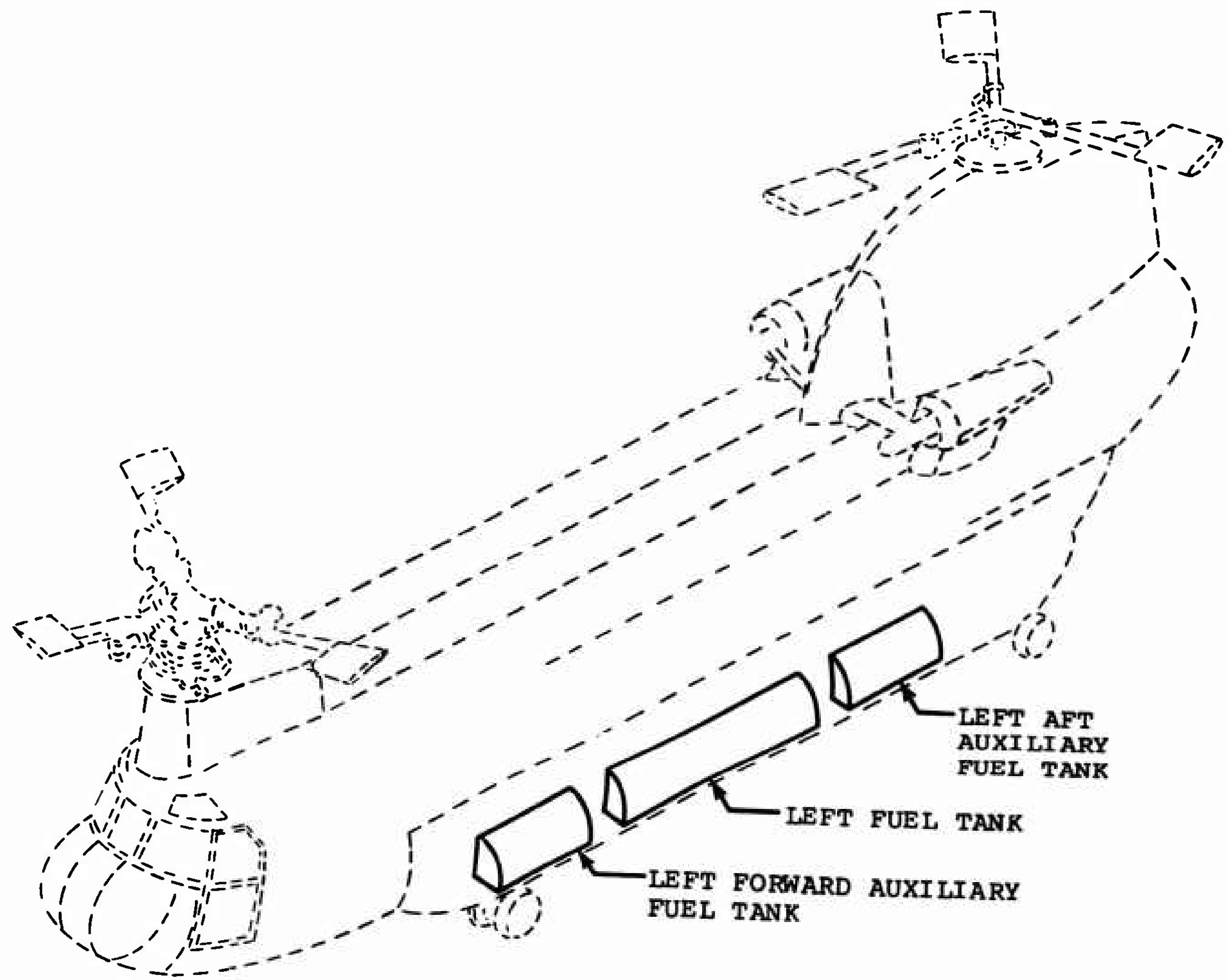


Figure 20. CH-47 Fuel Tank Location. Note: Identical Configuration on Right Side.

1. VENT TUBE
2. VENT TUBE
3. TANK UNIT
4. PRESSURE SWITCH
5. HIGH-POINT VENT TUBE ASSEMBLY
6. CHECK VALVE
7. TEE
8. VENT TUBE
9. VENT TUBE
10. ENGINE FUEL LINE
11. CHECK VALVE
12. GATE (SHUTOFF) VALVE
13. COUPLING
14. GATE (CROSS-FEED) VALVE
15. SYSTEM PRESSURE SWITCH
16. CROSS-FEED LINE
17. APU FUEL SOLENOID VALVE
18. APU FUEL LINE
19. APU FUEL SHUTOFF VALVE
20. APU FUEL BOOSTER PUMP
21. APU FUEL LINE
22. APU PUMP DRAIN LINE
23. SYSTEM DRAIN POPPET COCK
24. TANK DRAIN POPPET COCK
25. CHECK VALVE
26. BOOSTER PUMP
27. EXTENDED RANGE TRANSFER LINE
27A. CHECK VALVE
28. CHECK VALVE
29. BELLMOUTH ASSEMBLY
30. DEFUELING VALVE

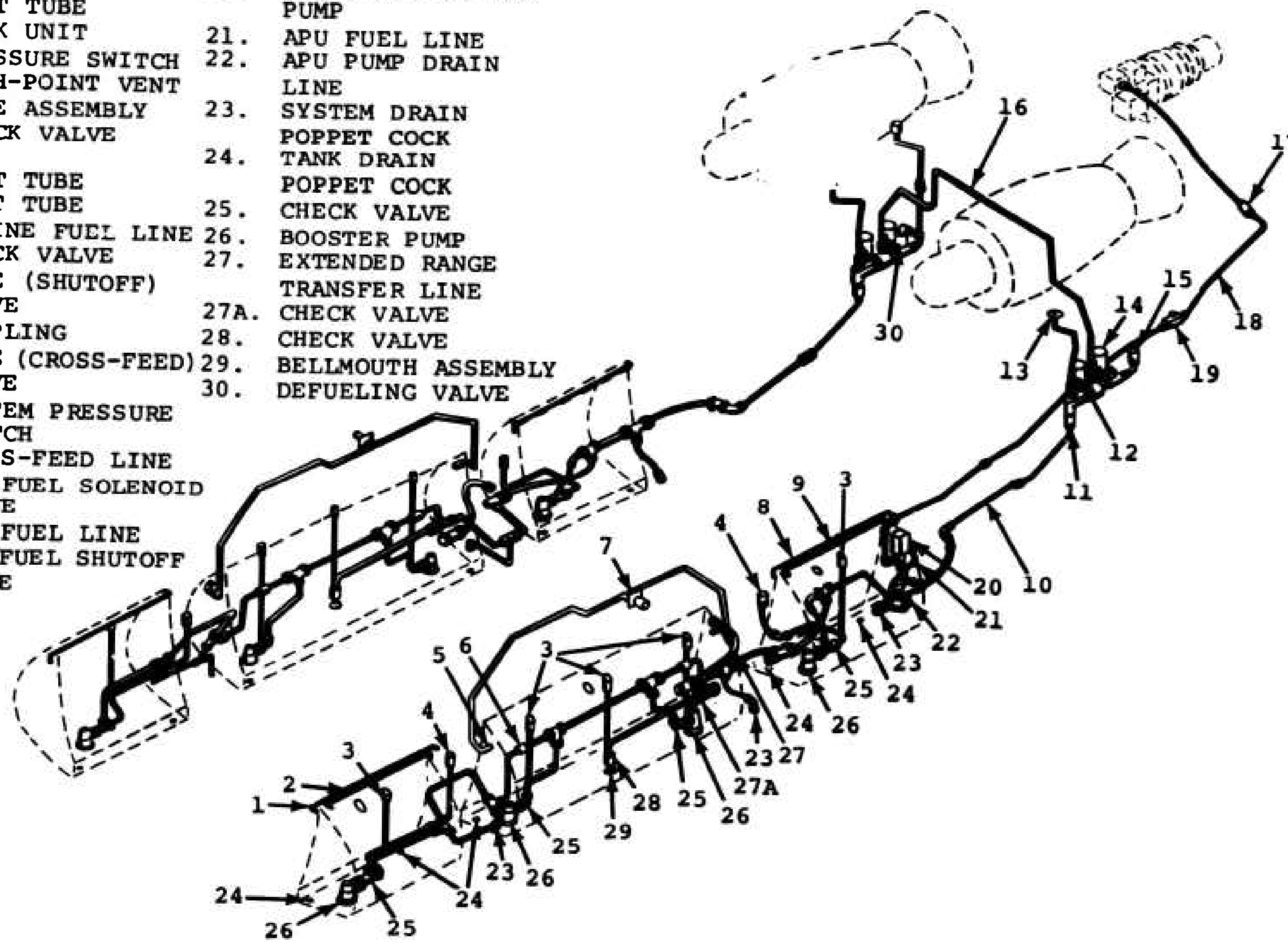


Figure 21. CH-47 Fuel Supply System.

All of the fuel cells are bladder type cells with the lower half made of self-sealing material. The cells are supported in the pod structure with nylon laces and fasteners. Access doors are located at both ends of each cell.

The main fuel cells each contain two electrical boost pumps mounted to brackets on the access doors, three probe-type quantity indicators, two drain valves, and a filler. The access doors, drain valves, quantity indicators, and filler cap ring, as well as the vent outlet fittings, are all rigidly bolted to the pod structure. In addition, each main tank contains a thermistor which senses the fuel level, triggering a light on the instrument panel when 20 percent of the fuel remains.

Each auxiliary fuel cell contains an electric fuel boost pump fastened to a bracket on the access door, one fuel quantity probe, two drain valves, and a filler. As in the case of the main fuel cells, the access plates, quantity probe, filler cap ring, drain valves, and vent outlets are all rigidly bolted to the pod structure.

The fuel line outlets from each tank are located on the access doors. All fuel lines connecting the fuel cells in the pods are made from flexible hose. The engine fuel line from the exit of the aft auxiliary tank to its entrance into the aft fuselage is also made of flexible hose. After the fuel lines enter the fuselage, they are routed up both sides of the aft fuselage, inside the occupiable area, to the engines. All of the fuel lines within the fuselage, including the cross-feed line, are made from rigid metal tubing. The fuel lines in the engine compartments are made from flexible hose.

Three system drains are included in each fuel system. These drains are located between the auxiliary and main fuel cells and aft of the rear auxiliary cell. In addition, a manual defueling valve is located in the fuel line in the aft cargo compartment.

A gate-type shutoff valve is contained in each engine fuel supply line and is located in the line just forward of the engine compartment. These valves are operated either electrically or manually. There is also a manual shutoff valve for the auxiliary power unit located in the fuel feed line to this engine. In addition, two electrically operated cross-feed valves are located in the aircraft, one just upstream from each engine shutoff valve.

The static fuel filter is located on the left side of the engine directly above the igniter fuel solenoid valve. Fuel entering the engine compartment is routed to the engine-mounted boost pump, through the filter, and into the fuel control unit.

The main tanks and the auxiliary tanks are each vented separately. The vent lines from the main tank fittings to the fuselage attachments are made from flexible hose. The remainder of the main tank vent lines are made from rigid metal tubing, as are all of the vent lines for the auxiliary cells.

Fuel System Analysis

The location of the fuel tanks in this aircraft leaves them particularly vulnerable to crash damage. The bottom of the pods are even with the bottom of the fuselage, and thus the pod areas are susceptible to puncture by stumps and rocks.

In addition, accident experience has shown that the fuel pods break free of the main fuselage structure during moderate crash impacts. The fuel cells are particularly vulnerable to damage during pod failure because of the many rigid attachments between the fittings and the pod structures, as the fuel cell material tears around the attachments, thus allowing massive fuel spillage.

Ignition sources are readily available and could easily ignite any fuel spilled from the tanks. One ignition source is the electrical wiring to the submerged boost pumps. Electrical sparks generated by the failure of these wires could easily ignite fuel vapors in the pod area.

Other ignition sources are the engines located above the aft auxiliary fuel cells. Failure of the engine mountings will allow the engine to impact these aft tanks, not only causing tank failure but also functioning as an ignition source for the spilled fuel.

The rigid aluminum vent tubes are also particularly susceptible to failure. In the event of pod failure or overturning of the aircraft, fuel would be spilled through broken vent lines.

The use of flexible fuel lines in the pod area is a sound crashworthy concept. However, the rigid attachments of the fuel line outlets to the tank access doors and the rigid attachments of the drains to the pod structure will produce high stress concentrations at the hose end fittings, with a high probability of breaking these fittings during a crash.

The use of rigid metal fuel lines in the aft part of the cargo compartment is especially hazardous. These lines are easily broken during crash impact and would spray fuel into the occupiable area. In addition, these lines are vulnerable to ballistic hits, which also spray high-pressure fuel into the area. Many in-flight fires have been caused in this manner.

The mounting of the fuel filter directly on the engine is a good concept from a crashworthiness viewpoint, as the filter is well protected from crash damage in this area. However, this location would be hazardous from a ballistic vulnerability viewpoint, as a projectile hit on the fuel filter would allow fuel to spray directly on the hot engine parts.

The smooth, regular shape of the fuel cells is a good crashworthy feature of this aircraft. However, as noted above, the rigid attachments of the fuel cells plus the fairly easily torn fuel cell material make the cells prone to failure. The use of frangible attachments at the cell fittings, crashworthy cell materials, and self-sealing breakaway valves would eliminate this problem.

Another crashworthy concept is the use of flexible lines between the auxiliary and main fuel cells rather than having the cells rigidly interconnected to form one huge fuel reservoir. In addition, this system allows fuel to be furnished to the engine from more than one fuel tank, thus incorporating a degree of redundancy to protect against ballistic or operational failures.

CH-54 HELICOPTER

General Description

The CH-54 is a heavy-lift helicopter manufactured by Sikorsky Aircraft Division of United Aircraft Corporation. The helicopter is powered by two Pratt and Whitney gas-turbine engines and is designed to carry detachable pods for transporting personnel and cargo or to carry externally attached loads.

Fuel System Description

The fuel system (see Figures 22 through 24) consists of forward and aft main tanks, an auxiliary tank, boost pumps, fuel management valves, vent lines and fittings, pressure fueling and defueling equipment, interconnecting hoses and tubes, and the engine-mounted components.

The two main tanks are installed in the fuselage, one forward and one aft of the cargo hoist well (Figure 22). Each tank is

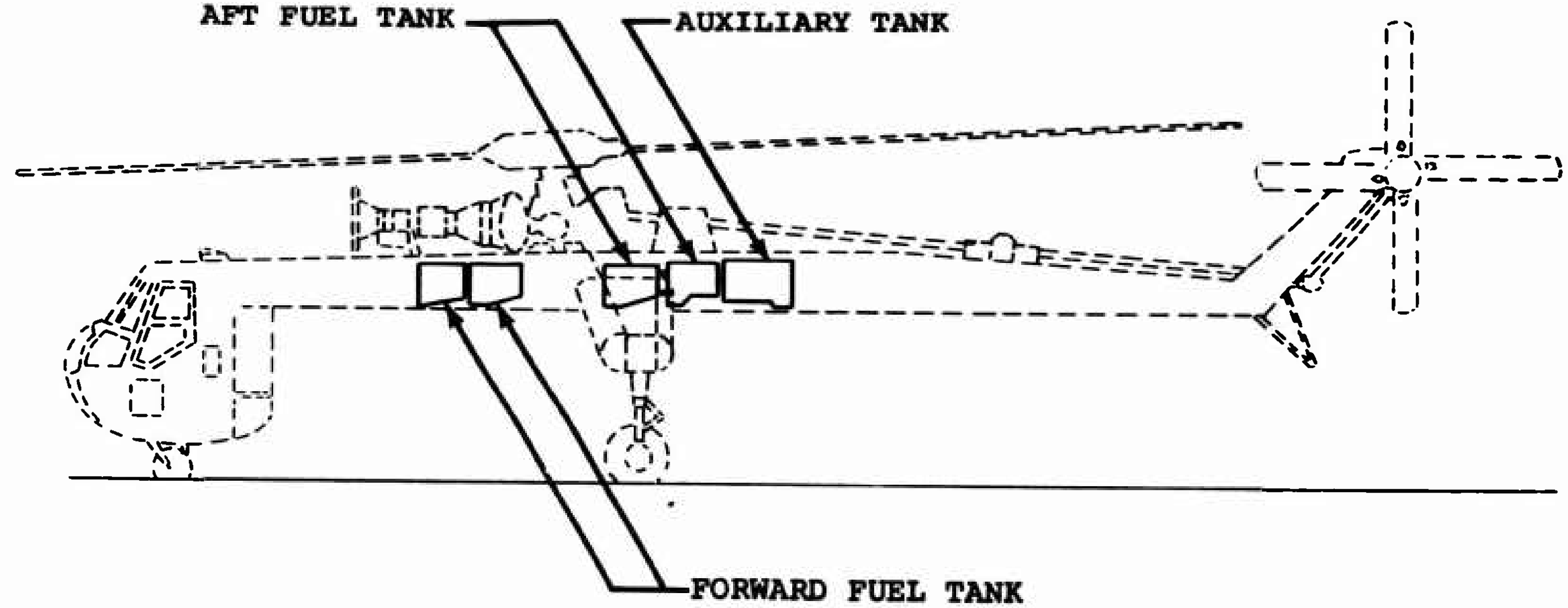


Figure 22. CH-54 Fuel Tank Location.

1. MAIN FUEL CELL
2. AUXILIARY FUEL CELL
3. FITTING ASSEMBLY
4. BOOST PUMP
5. NO. 1 BOOST PUMP
6. NO. 2 BOOST PUMP
7. HEATER TUBE
8. MANUAL DEFUELING VALVE
9. PRESSURE FUELING AND DEFUELING VALVE
10. HIGH-LEVEL SHUTOFF VALVE
11. LOW-LEVEL SHUTOFF VALVE
12. AUXILIARY FUEL SHUTOFF VALVE
13. SUMP PUMP DRAIN
14. SUMP DRAIN VALVE
15. SUMP AND SCREEN DRAIN VALVE
16. TUBE ASSEMBLY
17. MANIFOLD ASSEMBLY
18. FUEL QUANTITY PROBE

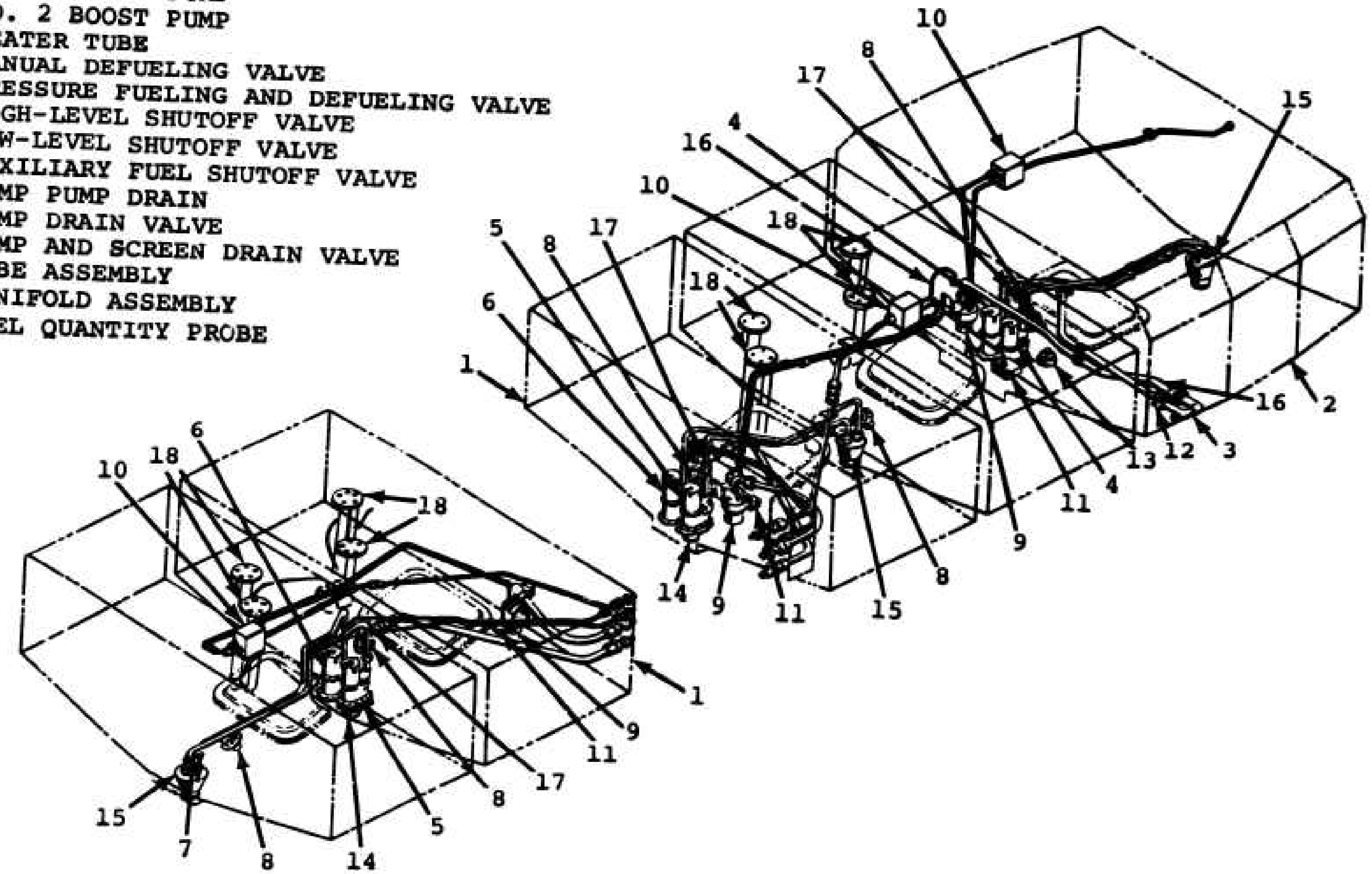


Figure 23. CH-54 Fuel Supply System - Internal Tank Components.

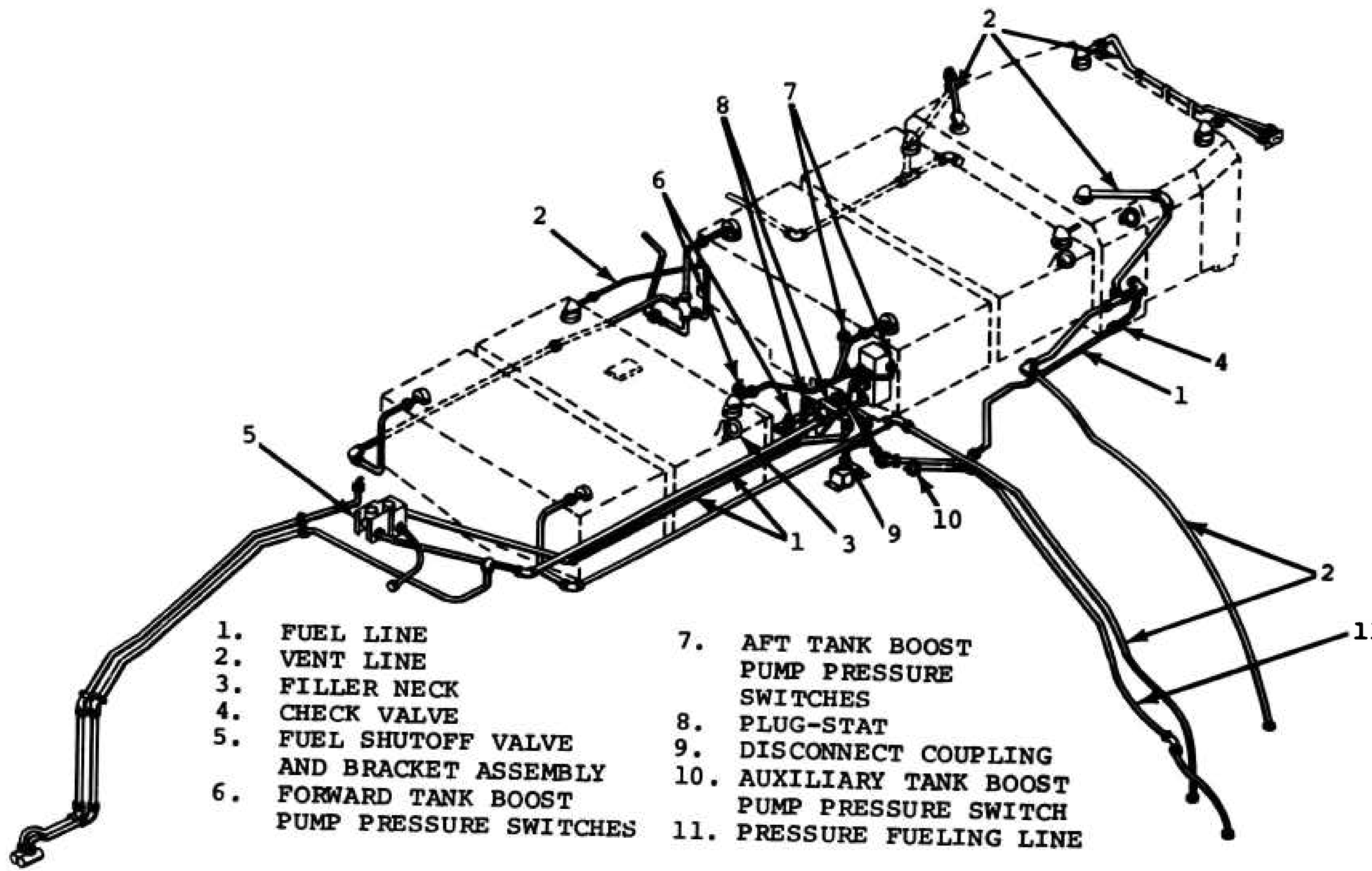


Figure 24. CH-54 Fuel Supply System - External Components.

composed of two self-sealing 226-gallon interconnected cells. The auxiliary fuel tank, comprised of a single cell having a capacity of 450 gallons, is located aft of the main tank. Although the auxiliary tank on early models was not self-sealing, the auxiliary tank on later models is self-sealing.

The cells are supported on the top and side walls by being bolted to the aircraft support structure. In addition, the fuel cell fittings, such as the access covers, boost pumps, drain valves, etc., are all rigidly bolted to the aircraft structure.

Two electrical boost pumps are installed in the aft cell of the forward tank and two boost pumps in the forward cell of the aft tank (Figure 23). In addition, each main tank contains a high-level shutoff valve, a pressure fueling and defueling valve, four quantity indicator probes, two manual defueling valves, two sump drains, and two access covers. Each tank is filled through one filler neck, which is made of flexible tank material, with the fuel flowing through the rigid interconnects into both cells.

The auxiliary tank contains two electrical boost pumps, two sump drains, a manual defueling valve, a high-level shutoff valve, an auxiliary fuel shutoff valve, and an access cover. The auxiliary tank also contains a flexible filler neck between the tank and the filler cap.

Each engine is supplied from a separate tank via a separate line (Figure 24). The forward tank supplies fuel to the Number 1 engine, and the aft tank supplies the Number 2 engine. A cross-feed system allows fuel from one main tank to be supplied to both engines or fuel from both main tanks to be supplied to one engine. The auxiliary fuel tank transfers fuel to the main tanks through the pressure fueling line and valves.

Fuel flows from the fuel tank outlets to manually operated shutoff valves located in the top of the helicopter. The fuel then passes through engine-mounted fuel filters before being delivered to the engine. Most of the critical fuel lines which connect the engine to the tank are made of flexible hose.

The two main tanks are vented separately, with the vent lines joining together between the two tanks and then venting overboard through a single line. The aft auxiliary tank is vented completely separately from the main tanks. All the vent lines are made from rigid metal tubing.

Fuel System Analysis

The location of the fuel tanks away from the occupiable area is a sound crashworthy concept, as is the empty space under the main rotor transmission. This space is between the forward and aft main tanks, and any downward displacement of the transmission is not likely to penetrate the fuel cells. However, the location of the forward fuel tank underneath the engines is not desirable. Should the engines be torn loose or pivot on their mounts during a crash, fuel from a fuel tank failure could be ignited either by the hot engine components or by being ingested into the engine intake.

Although the fuel tanks are located well above the ground level and there is little likelihood of the tanks' impacting upon the ground, their proximity to the underbelly of the fuselage is not desirable if the helicopter is carrying slung cargo. If this cargo should be an irregular object, such as a howitzer or a truck, it is possible that protrusions from the cargo could penetrate the fuel cell during a crash.

The attachment of the fuel cell fittings to the structure is also a crash hazard. The fuel cells could easily be torn away from these fittings. This is especially true in the filler neck area where the filler cap and ring are rigidly attached to the structure and the filler neck is made from thin fuel cell material.

The use of flexible hose for the fuel lines is a sound crashworthy practice. However, the rigid aluminum tubing used for the vent lines does present a hazard since these lines can be easily damaged, leading to fuel spillage should the helicopter end up in an other than normal attitude.

Another hazardous area in the fuel cell is the presence of a large number of rigid points in the bottom of the fuel cell. The boost pump plate, the protruding drain valves, and the large access cover plates take up almost the whole center section of the bottom fuel cell wall. Since these are all rigidly fastened to the aircraft structure, it is impossible for the fuel cell to deform around this area during a crash, and high stress concentrations will be transmitted to the fuel cell material. The likelihood of the material tearing in this area is thus extremely high.

The presence of electrically operated boost pumps in each cell provides a ready ignition source in the event of fuel spillage. If the boost pump wires, which run outside of the fuel tanks, are severed, electrical sparks could easily set off a post-crash fire.

OV-1 AIRPLANE

General Description

The OV-1 is a two-place observation/surveillance airplane manufactured by the Grumman Aircraft Engineering Corporation. The aircraft is powered by two Lycoming gas-turbine engines and is capable of operating from small fields and unimproved runways.

Fuel System Description

The fuel system in the OV-1 consists of one 297-gallon self-sealing main fuel tank and, if required, two external 150-gallon drop tanks. Fuel is supplied to the engines only from the main fuel tank, with the fuel from the drop tanks being transferred to the main tank before it can be fed to the engines. Also included in the fuel system are drop tank transfer pumps and main tank boost pumps, fuel transfer valves, fuel quantity indicators, a low-level indicating system, an individual tank gravity filler, a single-point pressure fueling and defueling system, interconnecting hoses and tubes, and the engine-mounted components.

The main fuel tank is located within the fuselage mid-section over the wing (see Figure 25). Two electrically operated fuel boost pumps are located in the forward and aft ends of the main tank (see Figure 26). The forward boost pump feeds a negative G can in which the aft boost pump is mounted. The engines are fed from the aft boost pump. If the aft boost pump fails, the forward pump will supply sufficient fuel for engine operation. An ejector pump located in the forward end of the fuel cell will supply the negative G can in case of forward boost pump failure with the aircraft in a nose-down attitude. The boost pumps are rigidly mounted to the aircraft structure. The ejector pump is fastened to the forward boost pump attachment ring.

Each main cell also contains three fuel quantity indicator probes. The forward probe is mounted to the top fuel cell wall only. The center probe is mounted to the fuel tank access cover, while the aft probe is fastened to the fuel cell wall and also bolted to a fuselage bracket.

A gravity-type filler is provided in the top of the fuel tank for use when the pressure fueling system is not in use. A short standpipe connects the filler cap in the fuselage skin to the fuel cell itself. The cap fitting is bolted through the fuselage skin, standpipe fitting, and the fuel tank cell wall.

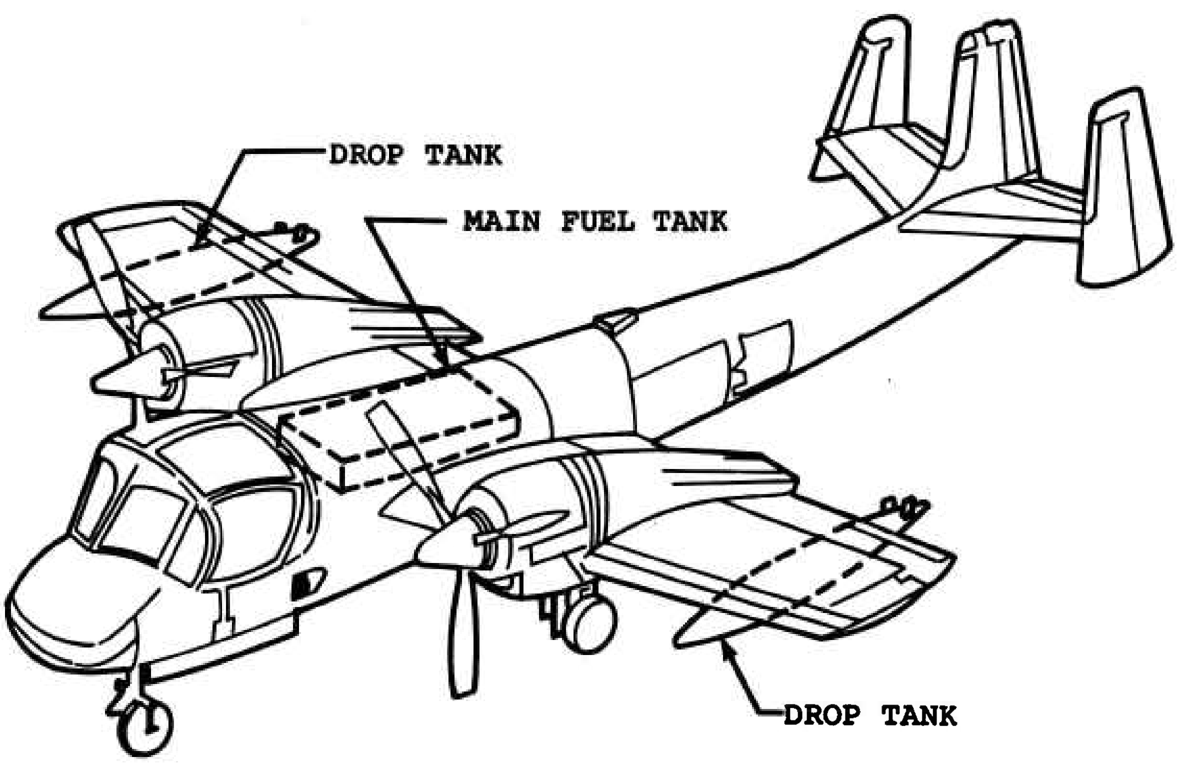
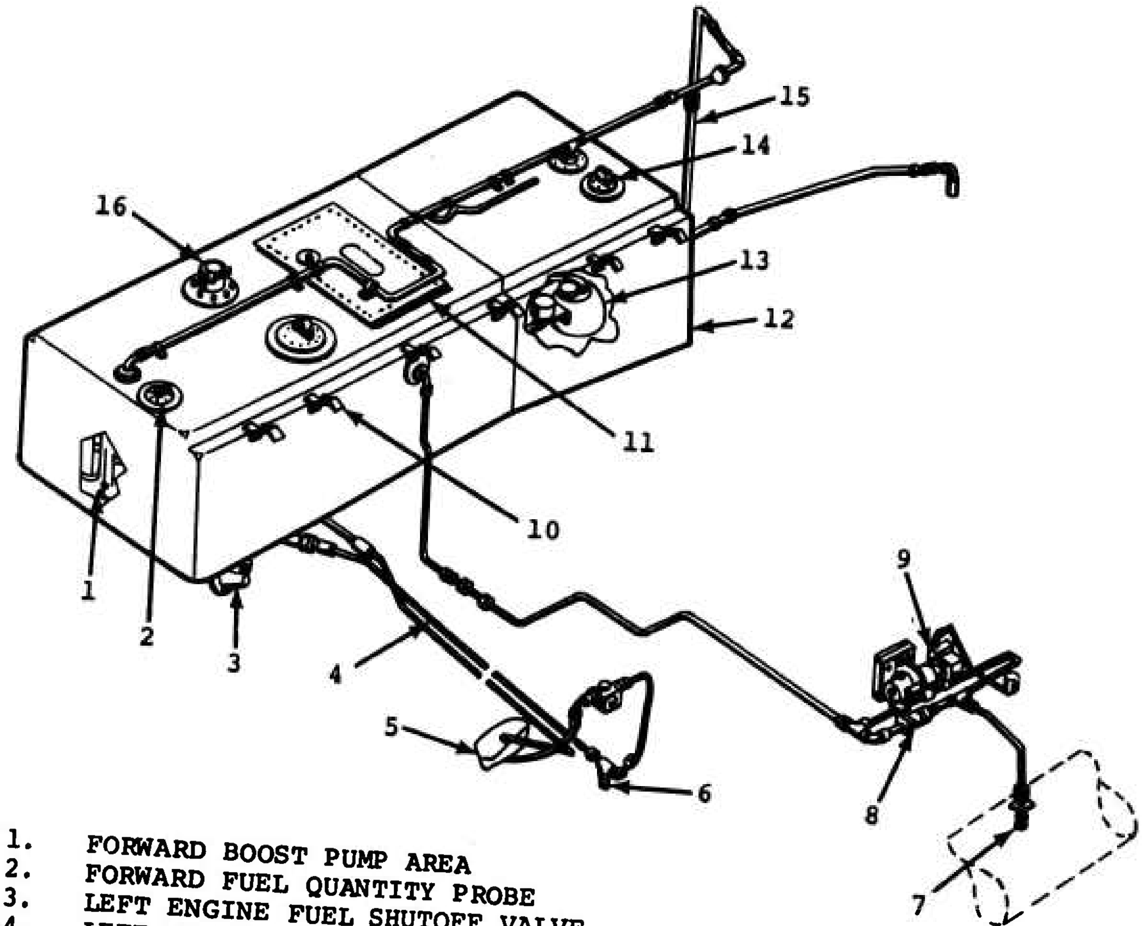


Figure 25. OV-1 Fuel Tank Location.



1. FORWARD BOOST PUMP AREA
2. FORWARD FUEL QUANTITY PROBE
3. LEFT ENGINE FUEL SHUTOFF VALVE
4. LEFT ENGINE FUEL LINE
5. LEFT ENGINE FUEL CONTROL
6. FUEL FILTER
7. DROP TANK FUEL DISCONNECT
8. DROP TANK FUEL SHUTOFF VALVE
9. DROP TANK FUEL TRANSFER COMPONENTS
10. TANK SUPPORT BRACKETS
11. TANK ACCESS OPENING
12. FUEL TANK
13. AFT BOOST PUMP AREA
14. AFT FUEL QUANTITY PROBE
15. VENT LINE
16. FILLER CAP

NOTE: FUEL SYSTEM ON AIRCRAFT RIGHT SIDE IS BASICALLY THE SAME AS ITEMS 3, 4, 5, 6, 7, 8, AND 9.

Figure 26. OV-1 Fuel Supply System.

The top access cover and the fuel line inlets from the drop tanks are rigidly bolted to the tank wall and to the aircraft structure. In addition, the tank is bolted along the top edges through tank hangers to the aircraft structure.

The electrically operated pressure fueling valve is located between the pressure fueling adapter and the fuel tank. The pressure fueling shutoff valve is located in the bottom of the fuel tank. This valve is bolted to the fuel tank and to the fuselage structure and protrudes below the tank wall.

Two electrically operated shutoff valves are located in the main fuel tank, one in each of the tank outlet lines to the engine. These valves project below the tank surface and are bolted rigidly to the aircraft structure.

The fuel lines are routed from the fuel tank through the leading edge of the wings to the engine nacelles. Most of the lines to the engine nacelles are made of rigid tubing, while those in the nacelle area are made from flexible hose.

The fuel filter, which is made of cast metal, is mounted in the fuel line in the very bottom of the engine nacelle in some models, while on other models the filter has been relocated to the side of the engine.

The main tank contains two vent outlet fittings. The vent line runs from the forward fitting aft across the top of the tank and connects into the line from the aft vent fitting. The aft vent fitting incorporates a check valve, and the fitting is rigidly bolted to a structural bracket on the airframe.

<u>Fuel System Analysis</u>

The location of the fuel tank in the top of the fuselage and away from the occupiable area is a sound crashworthy concept. It is unlikely that the fuel tank would be subjected to any direct impact unless the aircraft was inverted. However, the integrity of the fuel tank is compromised by the many tank fitting attachments which are bolted to the aircraft structure. If structural displacement should occur in these areas, the fuel tank wall would be subjected to tearing around the fittings. In addition, the protrusion of the shutoff valves below the tank bottom makes the tank susceptible to snagging should it move relative to the aircraft structure.

The routing of the fuel lines through the leading edges of the wings is particularly hazardous, as impacts against the wing's leading edge are quite common in fixed-wing aircraft crashes.

Should these lines be damaged, which would be quite probable with rigid lines, the entire contents of the fuel tank may be lost. In addition, fluid line damage will probably result if the nose gear is severely damaged or pulled from the airplane. Also, any crushing impact on the nacelle bottom will easily damage the cast metal fuel filter when it is located in the nacelle area. The filter mounted directly on the engine is in a much safer location.

SUMMARY OF CHARACTERISTICS

Tables II through XIII have been prepared to summarize the characteristics of all of the aircraft fuel systems. Presentation of the data in this manner also allows commonalities between the fuel systems to become readily apparent. The aircraft have been arranged in groups with the small observation helicopters first, the medium-size Bell helicopters following, and the larger CH-47 and CH-54 at the end of the helicopter listing. The one fixed-wing aircraft is presented last in the tables. This facilitates a comparison of various fuel system configurations according to aircraft type and size. In addition, hazardous postcrash fire areas have been delineated.

As may be seen from these tables, no common pattern of total fuel system arrangement is apparent. In fact, even at the subsystem level, detailed common characteristics are few even when aircraft of only one class are compared.

Tables XIV through XVI list the most common characteristics found in the aircraft. Table XIV lists characteristics found in all 8 of the aircraft analyzed. As may be seen from Table XIV, over half of these characteristics are a definite postcrash fire hazard. Certainly the most hazardous of these characteristics is the practice of bolting the fuel tank fittings directly to the aircraft structure. As pointed out during the fuel system analyses, this type of installation places high stresses in the tank wall around the fittings during a crash, and tearing of the fuel tank material in these areas is a common failure mode.

Tables XV and XVI list the commonalities between at least 50 percent of the aircraft but not common to all the aircraft studied. Again, the hazardous areas are delineated, and it can be seen that almost half of these common characteristics add to the postcrash fire hazard. Thus, the large incidence of postcrash fires in Army aircraft is not surprising in view of the unsatisfactory commonality in the design of fuel systems now in use.

Only one-tenth of all of the characteristics listed are common to all of the aircraft, and only one-third of the characteristics are common to 50 percent or more of the aircraft. Obviously, the configuration of the aircraft is the determinant of many uncommon characteristics. Certainly a fuel system suitable for a large helicopter cannot be used in a small observation helicopter. Also, fixed-wing aircraft not only have entirely different configurations than helicopters, but also have differing operational characteristics and limits. Thus, a certain number of variations must be expected in comparing the various fuel systems.

TABLE II. FUEL TANK CONFIGURATION

Aircraft	One Tank	Two or More Tanks - Not Interconnected (1)	Two or More Tanks - Interconnected With Flex Hose (2)	Two or More Tanks - Interconnected With Metal Tubing (2)*	Two or More Tanks - Rigid Interconnects (2)*	Smooth Shape (excluding filler neck and sump)	Irregular Shape*	Protruding Sump*
OH-58A								
Original	X						X	
Crashworthy	X						X	
OH-6A					X	X		
UH-1C/M								
Original			X	X		X[3]	X[4]	X
Crashworthy			X			X[3]	X[4]	
UH-1D/H								
Original			X	X	X[5]	X[6]	X[7]	
Crashworthy			X		X[5]	X[6]	X[7]	
AH-1G			X			X[6]	X[7]	
CH-47C		X				X		
CH-54		X			X	X		X
OV-1	X[8]					X		

* Hazardous
(1) Feed separately, although may feed simultaneously
(2) Interconnected tanks form a single reservoir
(3) Right tank
(4) Left tank
(5) Aft tanks only
(6) Forward tanks
(7) Aft tanks
(8) Excludes drop tanks

TABLE III. FUEL TANK LOCATION									
Aircraft	Bottom of Fuselage*	Middle of Fuselage	Top of Fuselage	Outside Fuselage (Helicopters Only)	Wing Tip*	Above Landing Gear*	Under Engine*	Near Engine*	Near Electrical Compartment*
OH-58A									
Original	X								
Crashworthy	X								
OH-6A	X							X	
UH-1C/M									
Original		X							X
Crashworthy		X							X
UH-1D/H									
Original	X(1)	X(2)				X			X
Crashworthy	X(1)	X(2)				X			X
AH-1G		X				X	X		
CH-47C				X(3)				X(4)	X(5)
CH-54	X(7)						X		
OV-1			X		X(6)				X

* Hazardous
(1) Forward tanks
(2) Aft tanks
(3) Even with bottom of fuselage (hazardous)
(4) Aft auxiliary tanks
(5) Forward auxiliary tanks
(6) Drop tanks only
(7) Considerable crushable structure provided by landing gear and support structure

TABLE IV. FUEL TANK CONSTRUCTION

Aircraft	Metal*	Bladder - Non-Self-Sealing*	Self-Sealing Material - Lower Part Only*	Self-Sealing Material - Entire Tank	Crashworthy Material	Standard Tank Fittings*	High-Strength Tank Fittings
OH-58A							
Original			X			X	
Crashworthy					X		X
OH-6A				X		X	
UH-1C/M							
Original			X			X	
Crashworthy					X		X
UH-1D/H							
Original		X (1)		X (2)		X	
Crashworthy					X		X
AH-1G			X			X	
CH-47C			X			X	
CH-54				X		X	
OV-1	X (3)			X (4)		X	

* Hazardous
(1) Aft tanks
(2) Forward (underfloor) tanks
(3) Drop tanks
(4) Main tank

TABLE V. FUEL TANK MOUNTING

Aircraft	Supported by Hangers and Lacing	Supported by Hangers Bolted to Structure	Tank Bolted to Structure*	Fitting Bolted to Structure*	Fittings Fastened to Structure With Frangible Attachment	Sump Plate Bolted to Structure*	Sump Plate Fastened to Structure With Frangible Attachment	Access Door Bolted to Structure*	Access Door Fastened to Structure With Frangible Attachment
OH-58A									
Original	X	X		X		X			
Crashworthy					X		X		X
OH-6A	X			X		X			
UH-1C/M									
Original	X			X		X			
Crashworthy					X		X		
UH-1D/H									
Original	X			X		X		X	
Crashworthy					X		X		X
AH-1G	X			X					
CH-47C	X			X				X	
CH-54			X	X		X		X	
OV-1		X	X	X				X	

* Hazardous

TABLE VI. FUEL LINES

Aircraft	Tubing in Lines Outside of Engine Compartment*	Flexible Hose in Lines Outside of Engine Compartment	Tubing in Engine Compartment*	Flexible Hose in Engine Compartment	Breakaway Coupling(s) in Line	Breakaway Coupling(s) at Fuel Tank Outlets	Line Located Over Landing Gear*	Fuel Outlet Fittings Rigidly Fastened to Structure**	Fuel Outlet Fittings Fastened to Structure With Frangible Attachments	Fuel Outlet Mounted on Tank Access Cover	Lines Run Through Leading Edge of Wing*
OH-58A											
Original		X		X				X (1)			
Crashworthy		X		X		X					
OH-6A	X			X			X			X	
UH-1C/M											
Original	X	X	X	X				X (2)			
Crashworthy		X		X		X			X		
UH-1D/H											
Original	X	X	X	X			X	X (2)			
Crashworthy		X		X	X	X	X		X		
AH-1G	X	X (1)	X	X				X (2)			
CH-47C	X	X		X						X	
CH-54		X		X				X (2)			
OV-1	X			X				X (2)			X

* Hazardous

** Hazardous unless high-strength fittings and breakaway valves used at outlet

(1) Fastened with bulkhead line fittings

(2) Bolted through tank wall to structure

(3) Tank interconnect line only

TABLE VII. BOOST PUMPS

Aircraft	Located in Fuel Tank(s)**	Auxiliary Pump Only	Electrically Operated**	Air Driven	Bolted to Structure*	Frangible Attachment to Structure	Mounted on Fuel Tank Sump or Access Plate
OH-58A							
Original	X		X				X
Crashworthy	X	X	X				X
OH-6A	X(1)	X	X				X
UH-1C/M							
Original	X		X				X
Crashworthy	X		X			X	X
UH-1D/H							
Original	X		X	X(2)			X
Crashworthy	X		X			X	X
AH-1G	X		X		X		X
CH-47C	X		X				X
CH-54	X		X		X		
OV-1	X		X		X		

* Hazardous
** Combination hazardous
(1) Provided on some Series 1 and 2 and all Series 3 aircraft
(2) In left-hand forward cell on helicopters prior to Serial No. 69-15292

TABLE VIII. QUANTITY INDICATORS						
Aircraft	Probe Type	Float Type	Not Fastened Directly to Aircraft Structure	Bolted to Structure*	Frangible Attachment to Structure	System Contains Low-Level Warning Switch
OH-58A						
Original	X		X(1)	X(2)		X
Crashworthy	X		X(1)		X(2)	X
OH-6A		X	X			X
UH-1C/M						
Original	X			X		X
Crashworthy	X				X	X
UH-1D/H						
Original	X		X			X
Crashworthy	X		X			X
AH-1G	X			X		X
CH-47C	X			X		X
CH-54	X		X			X
OV-1	X		X(3)	X(4)		X

* Hazardous
(1) Lower probe
(2) Upper probe
(3) Forward and center probe
(4) Aft probe

TABLE IX. FUEL FILTERS AND STRAINERS		
Aircraft	Located in Engine Compartment (Not on Engine)*	Mounted on Engine
OH-58A		
Original		X(1)
Crashworthy		X(1)
OH-6A		X(1)
UH-1C/M		
Original	X	
Crashworthy	X	
UH-1D/H		
Original	X	
Crashworthy	X(2)	
AH-1G	X	
CH-47C		X
CH-54		X
OV-1	X(3)	X(4)

* Hazardous
(1) Integral part of engine fuel pump
(2) Moved farther from engine, but still in engine compartment on firewall
(3) With T53-L-3, T53-L-3A engines
(4) With T53-L-7 engines

TABLE X. FILLER UNITS

Aircraft	Filler Cap Ring Bolted to Structure*	Filler Cap Ring Fastened to Structure With Frangible Attachment	Filler Opening Located Near Engine Intake*	Filler Neck Installed Between Cap and Tank*
OH-58A				
Original	X			
Crashworthy		X		
OH-6A	X			X
UH-1C/M				
Original	X		X	
Crashworthy		X	X	
UH-1D/H				
Original	X		X	
Crashworthy		X	X	
AH-1G	X		X	
CH-47C	X		X(1)	
CH-54	X		X	X
OV-1	X			X

* Hazardous

(1) Aft auxiliary tanks

TABLE XI. DRAIN AND DEFUELING VALVES									
Aircraft	Tank Drains in Sump Area	Contains Tank Drains in Areas Other Than Sump	Contains In-Line Drains (Filter Drains not Included)	Tank Drains Protrude Outside Tank Wall*	Tank Drains Recessed - Flush With Tank Wall	Tank Drains Bolted to Structure**	Tank Drains Fastened to Structure With Frangible Attachments	Tank Drains Fastened to Sump Plate	Tank Drain Contains Frangible Section
OH-58A									
Original	X			X				X	
Crashworthy	X			X				X(2)	X
OH-6A	X		X(1)	X				X	
UH-1C/M									
Original	X		X	X				X	
Crashworthy	X			X				X(2)	
UH-1D/H									
Original	X	X	X	X		X		X	
Crashworthy	X	X			X		X	X(2)	
AH-1G	X			X		X			
CH-47C		X(3)	X	X		X			
CH-54	X	X		X		X			
OV-1	X(4)	X(5)		X		X			

* Hazardous unless drain contains a frangible section
** Hazardous
(1) On unarmored aircraft only
(2) Sump plate fastened to structure with frangible attachments
(3) No pronounced low sump area in tank
(4) Water drain valves only
(5) Pressure defueling

TABLE XII. FUEL SHUTOFF VALVES

Aircraft	Located in Fuel Tank**	Located In-Line Between Tank and Engine Compartment	Valve in Tank Bolted to Structure*	Electrically Operated**	Mechanically Operated
OH-58A					
Original		X			X
Crashworthy		X			X
OH-6A		X(1)			X
UH-1C/M					
Original		X		X	
Crashworthy		X		X	
UH-1D/H					
Original		X		X	
Crashworthy		X		X	
AH-1G		X		X	
CH-47C		X		X	
CH-54	X(2)	X(3)	X	X(2)	X(3)
OV-1	X		X	X	

* Hazardous
** Combination hazardous
(1) Mounted on fuel cell access cover
(2) Auxiliary tank
(3) Main tanks

TABLE XIII. VENT LINES AND FITTINGS							
Aircraft	Vent Fittings Not Fastened to Structure	Vent Fittings Rigidly Fastened to Structure	Vent Fittings Fastened to Structure With Frangible Attachments	Breakaway Valves at Tank Vent Outlets	System Contains Emergency Fuel Shutoff Valve	Vent Lines Consist of Tubing*	Vent Lines Consist of Flexible Hose
OH-58A							
Original		X(1)				X	
Crashworthy	X						X
OH-6A		X(2)			X(3)	X	
UH-1C/M							
Original		X(2)				X	
Crashworthy			X			X	X(4)
UH-1D/H							
Original		X(2)	X(5)			X	X
Crashworthy			X(5)	X(6)		X	X(7)
AH-1G		X(2)				X	
CH-47C		X(2)				X	
CH-54		X(2)			X(8)	X	
OV-1	X(9)	X(10)				X	

* Hazardous
(1) Fastened with bulkhead line fittings
(2) Bolted through tank wall to structure
(3) Mounted in-line outside fuel tank
(4) Hose from tanks to overboard connection at service deck
(5) Aft tank fittings fastened to thin aluminum brackets
(6) Underfloor tank fittings only
(7) Hose from tanks to vent manifold
(8) Mounted at tank vent outlets
(9) Forward vent outlet
(10) Aft vent outlet fastened to structural bracket

TABLE XIV. COMMON FUEL SYSTEM CHARACTERISTICS IN ALL 8 AIRCRAFT
● Standard tank fittings
* ● Tank fittings bolted to structure
● Flexible hose fuel lines in engine compartment
* ● Electrically operated boost pumps in fuel tanks
* ● Tank drains protrude outside tank wall
* ● Vent fittings fastened to aircraft structure
* ● Vent lines consist of rigid metal tubing
● Fuel system contains low-level warning switch
* Hazardous

The configuration of the aircraft shows up most specifically in the area of the fuel tanks. This area weighs heavily in the fuel system as 40 percent of all the variables are concerned with fuel tank location, configuration, support, and mounting. Certainly these variables would be expected to differ most significantly from aircraft type to aircraft type. For instance, fuel tanks are commonly located in the bottom of the fuselage in light observation helicopters simply because there is no room for them anywhere else, while fixed-wing aircraft commonly carry their fuel in the wings, although the OV-1 is an exception to this practice.

It is also instructive to look at the commonalities and differences between those aircraft in a single class. Thirty percent of the variables are common to all helicopters in the large helicopter class, which includes the UH-1C/M, UH-1D/H, AH-1G, CH-47C, and CH-54, as compared to only ten percent for all the aircraft studied. However, in considering only the three large helicopters made by Bell Helicopter Company (UH-1C/M, UH-1D/H, AH-1G), it may be seen that 47 percent of the characteristics are identical in these three aircraft. This significantly higher percentage of commonalities for a single aircraft manufacturer is not surprising, as each manufacturer has evolved his own particular design philosophies. However, the practice of allowing each aircraft company full latitude in the design

TABLE XV. COMMON FUEL SYSTEM CHARACTERISTICS IN 5 TO 7 AIRCRAFT

- Smooth-shaped fuel tank (7)
- Fuel tanks supported by hangers and lacing (6)
- * Sump plate bolted to structure (5)
- * Fuel lines outside engine compartment contain rigid metal tubing (6)
- Fuel lines outside of engine compartment contain flexible hose (6)
- * Quantity indicators bolted to structure (5)
- Quantity indicators not fastened directly to aircraft structure (5)
- * Quantity indicators are probe type (7)
- Fuel filter mounted on engine (5)
- * Filler opening located near engine intake (5)
- Tank drains located in sump area (7)
- * Tank drains bolted to structure (5)
- Fuel shutoff valves located in fuel line (7)
- Fuel shutoff valves electrically operated (6)

* Hazardous
Note: Numbers in parentheses indicate number of aircraft involved.

TABLE XVI. COMMON FUEL SYSTEM CHARACTERISTICS IN 4 AIRCRAFT
* ● Irregular-shaped fuel tanks
* ● Fuel tank located in bottom of fuselage
* ● Fuel tank located near electrical compartment
● Entire tank self-sealing
* ● Only lower part of tank self-sealing
* ● Fuel tank access door bolted to structure
* ● Fuel filter located in engine compartment (not mounted on engine)
● Tank drains located in areas other than sump
● System contains in-line drains
* Hazardous

of their aircraft fuel systems may be seen to contribute significantly to the wide range of variations in the aircraft fuel systems in each class.

CONCLUSIONS

The fuel system design criteria presented herein should be used during the initial design phase of all U. S. Army aircraft fuel systems. Designing crashworthiness into the aircraft in the initial stages will save costly retrofit programs necessary later to reduce the postcrash fire hazard.

Retrofit modifications should be made to all existing U. S. Army aircraft to reduce the high incidence of postcrash fire which now exists. The fuel system designer can determine which areas should be retrofitted by going to the fuel system analysis for the appropriate aircraft. Tables II through XIII present in tabular form the areas which need modification. These tables enable the designer to determine needed modifications quickly and easily. By applying the design criteria to those areas designated as hazardous, the designer can modify the fuel system to enhance its crashworthy characteristics significantly.

In order to assist the designer in making crashworthy retrofits, the following abbreviated list of the most important crashworthy design criteria is presented. This study has shown that these criteria are the ones most often disregarded in current operational aircraft.

1. Use flexible hose assemblies for all tank-to-tank interconnect lines and all fuel lines.

2. Install self-sealing breakaway valves where rigid tank-to-tank interconnects now exist.

3. Eliminate tank protrusions by recessing all drain valves and gradually contouring sump areas into the tank.

4. Locate fuselage tanks as high in the structure as possible but away from engine and electrical compartment and occupiable areas. Do not locate the tanks over the landing gear members or under transmissions and engines.

5. Locate wing tanks behind heavy spars and away from the wing root areas, wing tips, and wing leading edges.

6. Use crashworthy tank materials and high-strength fittings per MIL-T-27422B for <u>all</u> fuel tanks.

7. Use frangible attachments for all attachments of fuel tanks to aircraft structure.

8. Use self-sealing breakaway valves in all tank outlets and in the fuel lines where large structural crash displacement is probable.

9. Use engine-mounted, engine-driven fuel boost pumps, if possible. If this is not possible, then air-driven boost pumps are preferred to electrical pumps. If electrical boost pumps are installed in the tank area, insure that electrical wires are not run between the bottom of the fuel tank and the fuselage skin or between the wing tank and the wing leading edge.

10. Use float-type fuel quantity indicators, if possible. If probe type indicators are used, manufacture these from as low a flexural strength material as possible or provide frangibility in the probe/tank attachment interface.

11. Locate the fuel filter outside of the engine compartment.

12. Eliminate filler necks wherever possible. Recess the filler cap into the tank wall so that it will stay with the tank during structural deformation.

13. Use flexible hoses for all vent lines and install check valves at all vent outlets to prevent fuel spillage from the tanks.

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