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FUEL SYSTEM RELIABILITY AND MAINTAIN-
ABILITY INVESTIGATION. VOLUME I

Neva B. Johnson

Ultrasonics, Incorporated

Prepared for:

Army Air Mobility Research and
Development Laboratory

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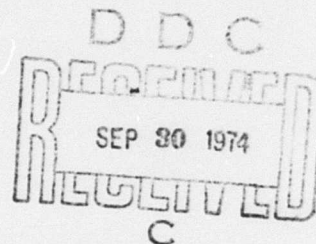
FUEL SYSTEM RELIABILITY AND MAINTAINABILITY INVESTIGATION

Volume I - Final Report

**Neva B. Johnson
ULTRASYSTEMS, Inc.
The Dynamic Science Division
Phoenix, Ariz. 85027**

July 1974

Final Report for period May 1973 to May 1974



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Prepared for

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**U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
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The recommendations presented in this report concerning helicopter fuel system reliability are based on a highly responsive review of a wide range of failure reports and Engineering Change Proposals, and they are believed to provide a rational basis for improving the design, test, and quality assurance aspects of specifications and requirements documents related to Army aircraft fuel systems. The Supplemental Design Guide presented in Volume II is recommended for use as an attachment to appropriate fuel system specifications and standards pending revisions to these documents. The reliability and maintainability (R&M) improvements available through use of the recommended revisions appear to be achievable with virtually no cost and/or weight penalty.

This contract is one of a series of efforts being conducted by this Directorate aimed at investigating and improving the effects of design, test, and quality assurance requirements documents on Army aircraft R&M characteristics. Other efforts include hydraulic, electrical, and flight control systems.

The technical monitor for this contract was Mr. Gene A. Birocco of the Military Operations Technology Division of this Directorate.

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proposed, and two completely revised specifications were drafted to correct the deficiencies. The revisions and newly established requirements, along with other viable alternatives which were considered, are discussed, and the rationale behind the final selections is presented. Volume II, containing all revisions and the two complete draft specifications, can be appended to or referenced by Government and/or industry specifications.

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INTRODUCTION

The U. S. Army has experienced improved reliability and maintainability (P&M) in recently manufactured fuel systems of both conventional and crashworthy designs. However, the cause of this recent improvement has not been readily apparent. To ensure that future Army aircraft continue this trend, Dynamic Science was selected to determine from historical data and experience the changes that have been incorporated in current helicopter fuel system design and testing to improve or influence system reliability and maintainability. These data were then to be utilized to define desirable changes in the design requirements, test requirements, and quality assurance provisions of applicable documents so that they reflect the current state of fuel system technology.

The data reviewed and analyzed during this program consisted of developmental and service (e.g., maintenance and accident) experience and applicable specifications, handbooks, and technical reports pertaining to UH-1, AH-1G, CH-47, CH-54, OH-6, and OH-58 aircraft. Because of other ongoing or planned efforts by the Army, maintenance procedures and practices, maintenance personnel, manuals and training, future fuel system or component state-of-the-art improvements, and environmentally related requirements were not considered during this program.

Based on the results of the data review and analysis, deficiencies were specified in the existing documentation as it related to Army helicopter fuel system R&M, and in each case the revisions or supplements necessary to correct the deficiencies were provided. These changes were justified by a complete consideration of viable alternatives with selection supported by a thorough rationale.

Forty-one military specifications and standards were reviewed in detail. As a group, the specifications were found to be generally satisfactory in their requirements, although five of the older ones were considered outdated as newer and more comprehensive specifications had been issued. No revisions were considered necessary for fourteen of the specifications. Minor, though significant, revisions were recommended for twenty of the specifications. These revisions consisted mainly of modifying test conditions and incorporating additional tests into the requirements. One of the specifications (for crash-resistant self-sealing breakaway valves) was completely revised and rewritten. A new specification, based partly on an existing Air Force specification, was drafted for Army aircraft standard and crashworthy fuel systems.

The recommended changes and newly established requirements, along with complete basic data and supporting rationale, are documented in this report. Volume II contains a listing of the documents applicable to helicopter fuel systems, all recommended revisions to those documents, and the two revised specifications in their entirety.

DATA REVIEW AND ANALYSIS

Three basic categories of data were utilized during this program:

1. Performance data, consisting of maintenance and accident data on current Army helicopters (UH-1, AH-1, CH-47, CH-54, OH-6, and OH-58).
2. Design changes, consisting of Engineering Change Proposals (ECPs) affecting the reliability and maintainability (R&M) of the fuel systems incorporated in the above helicopters.
3. Requirements documentation, consisting of applicable military specifications, design handbooks, and technical reports containing fuel system design, test, and quality assurance provisions.

The data on component performance and design changes were tabulated by component (e.g., fuel pump, shutoff valve, etc.). The components were also cross-indexed by aircraft and applicable specifications. All pertinent information, such as types of failures, specific design changes, effect of design changes on R&M, and dates of failures and changes, was tabulated for each component.

Design requirements, test requirements, and quality assurance provisions were tabulated for each reviewed document. The documents were cross-indexed by fuel system component involved, types of tests required, quality assurance provisions, and other referenced specification documents. The date of initial release and/or revision was also noted for each document.

The component design changes were compared with the accident and maintenance records to determine if any obvious correlations existed. The requirements documents were also correlated with the above data. Complete component histories were organized with all data arranged in chronological order to determine time-phased interactions for each component as well. As failure trends became apparent, specification deficiencies were noted, and the respective data sources were re-evaluated for corrective measures.

The acquired data and the component histories derived from these data are presented in the following pages.

PERFORMANCE DATA

Data on fuel system performance were collected from the following sources:

1. USAAMRDL in-house report titled Fuel System Maintenance Actions.⁽¹⁾
2. Dynamic Science Report 1520-71-14, Analysis of Helicopter Design and Operational Deficiencies⁽²⁾
3. USAAVS FLIGHTFAX circulars⁽³⁾
4. Correspondence with AVSCOM and USAAMRDL personnel

These data were utilized only to help determine changes and define problems in fuel system components which have affected fuel system reliability and maintainability. They are not intended to be statistically definitive of the total R&M situation for Army helicopter fuel systems.

The major source of performance data was the USAAMRDL report⁽¹⁾ which listed maintenance actions and Equipment Improvement Recommendations (EIRs) received from the field for the time period 1 April 1969 to 30 June 1971. These data were extracted from the Army Maintenance Management System (TAMMS) for the CH-47A, AH-1G, UH-1H, and CH-54A.

A component breakdown of the EIRs is presented in Table 1. These data show that three of the eleven types of components (check valve, submerged pump, and fuel tank) accounted for 80 percent of all the EIRs submitted.

Generic (not identifiable to a particular aircraft) failure symptoms for the components are presented in Table 2. Unfortunately, the failure codes generally describe only symptoms of failures, e.g., "leaks", rather than causes. Thus, this information was of limited usefulness.

Failure symptom data reported for the individual helicopters were quite useful, however, as these data identified the individual components written up in the EIRs. Table 3 presents a partial listing of such data for the UH-1H. Comparison of the data in Table 3 with that in Table 2 shows that all of the EIRs submitted for check valves were attributable to a particular check valve in the UH-1H. Tracing the federal stock number in the appropriate Army organizational maintenance manual disclosed that this valve was actually a crash-resistant self-sealing breakaway valve - a completely different type of component designed and tested to different specifications.

TABLE 1. PERCENTAGE OF EIRs BY COMPONENT TYPE ⁽¹⁾	
Component	Percent of Total EIRs Submitted
Valve, Check	41.1
Pump, Submerged	21.1
Tank, Fuel	17.8
Transmitter, Liquid	4.4
Coupling Assembly	3.3
Bracket Assembly	3.3
Cap and Adapter	3.3
Switch, Pressure	2.2
Hose Assembly	1.1
Tube Assembly	1.1
Filter Head Assembly	1.1

TABLE 2. GENERIC EIR FAILURE CODE DISTRIBUTION (1)		
Nomenclature	Failure Code	Number of EIRs
Tank, Fuel	Manufacturer Defect	1
	Chafed	1
	No Defect	1
	Torn	1
	Blistered	1
	Internal Failure	2
	Defective	4
	Leaks	5
Valve, Check	Manufacturer Defect	1
	Cracked	1
	Maintenance Error	1
	Defective	17
	Leaks	17
Pump, Submerged	Manufacturer Defect	1
	Maintenance Error	1
	No Pressure	1
	Bearing Failure	2
	Defective	4
	Internal Failure	10
Hose Assembly	Improper Maintenance	1
Transmitter, Liquid	Seized	1
	Internal Failure	3
Switch, Pressure	Internal Failure	2
Coupling Assembly	Defective	1
	Leaking	1
	Maintenance Error	1
Tube Assembly	Chafed	1
Filter Head Assembly	Defective	1
Bracket Assembly	Cracked	1
	Broken	2
Cap and Adapter	Defective	3

TABLE 3. UH-1H EIRs FOR THE PERIOD 1 APRIL 69 THROUGH 30 JUNE 71 (PARTIAL LISTING) (1)			
Nomenclature	Federal Stock Number	Failure Code	Number EIRs Submitted
Cap and Adapter	16801690533	Defective	3
Pump, Fuel	29159215660	Defective	2
	29159215660	Internal Failure	1
Tank, Fuel	15600739790	Defective	3
		Leaks	2
	15600739790		1
Pump, Submerged	29150128684	Defective	3
		Internal Failure	5
	29150128684	Bearing Failure	2
	15600739790	Leaking	2
		Split	3
	15600739790	No Defect	1
Valve, Check	48201764623	Defective	17
		Cracked	1
		Leaks	17
		Maintenance Error	1
		Other	1

Subsequent correspondence with AVSCOM personnel disclosed that leakage was occurring due to a faulty bond between the internal rubber boot and the valve body. The majority of the defective valves had already been replaced.

The fuel tank and boost pump EIRs were also checked by aircraft and part number. It was found that all but two of the fuel tanks involved were standard fuel tanks as opposed to the newer crashworthy fuel tanks. Part numbers could not be traced for the other two tanks, so it is not known if they were standard or crashworthy. There was no other apparent correlation in the fuel tank data, and no further information on failure mechanisms could be obtained.

The boost pump data are tabulated in Table 4. (The total number of EIRs cannot be compared directly with Table 2 because of a slight difference in the data base.) Table 4 shows that the air-driven pump in the UH-1H accounted for the majority of EIRs submitted on the boost pumps, with the CH-47A electric boost pump being the second highest contributor. The failure mode of the CH-47A pump was subsequently determined as insufficient bearing lubrication from an ECP which had been submitted on the pump in 1966. The pump was later redesigned and retrofitted by attrition. No definitive data were available on the UH-1H pumps.

TABLE 4. BOOST PUMP EIRs FOR THE PERIOD 1 APRIL 69 THROUGH 30 JUNE 71(1)			
Aircraft	Federal Stock Number	Failure Code	Number EIRs Submitted
AH-1G	29159993705	No pressure	1
		Internal failure	2
UH-1H	29159993705	Defective	1
		Internal failure	1
UH-1H	29159215660 (air driven)	Defective	2
		Internal failure	1
UH-1H	29150128684 (air driven)	Defective	3
		Internal failure	5
		Bearing failure	2
CH-47A	29158526813	Mechanical binding	4
		Internal failure	7

Reference 1 also contains a two-year summary of helicopter mishaps attributable to fuel contamination and fuel system failure. These data were obtained from the U.S. Army Agency for Aviation Safety (USAAVS) and are presented in Figure 1. Only three of the mishaps were caused by component failure. The others were caused by fuel contamination.

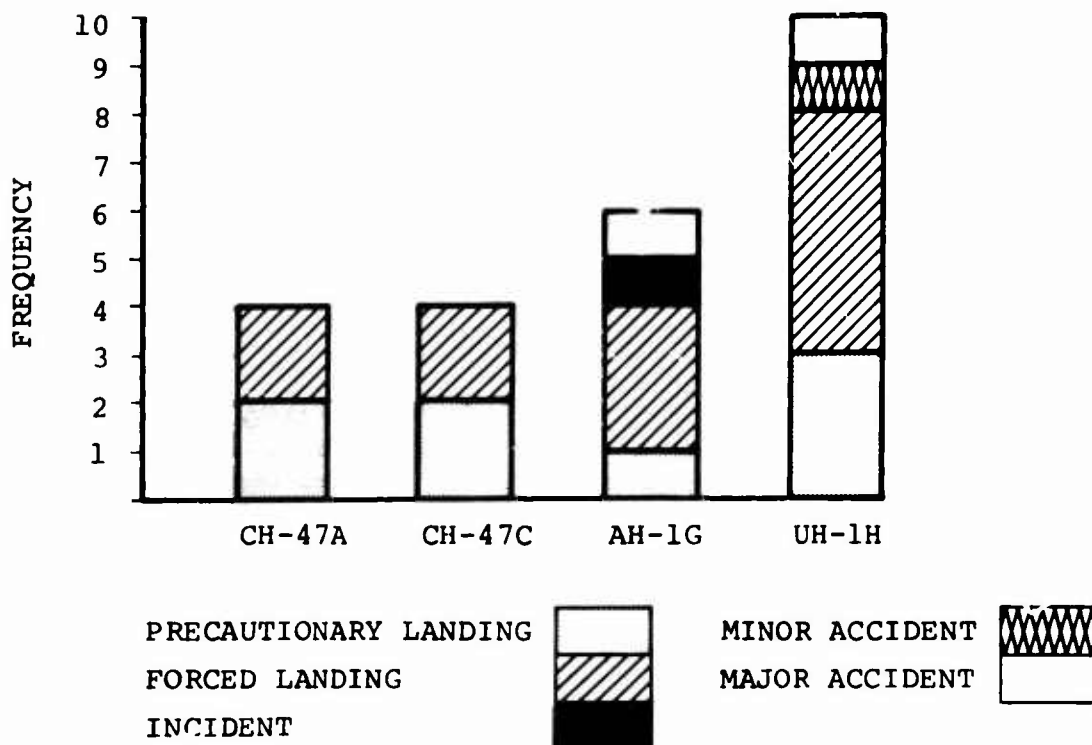


Figure 1. Helicopter Mishaps Attributable to Fuel Contamination and Fuel System Failure.⁽¹⁾

Data extracted from the Dynamic Science report⁽²⁾ were in the form of aircraft mishap reports collected by the U.S. Army Board for Aviation Accident Research (USABAAR) from January 1967 through June 1970. Again, fuel-contamination-induced mishaps were significant (see Table 5). Additional data were also obtained, showing that the boost pump failures in the UH-1 helicopters were not confined to the H model (see Table 6), but were also present in significant numbers for the electric pumps in the earlier models.

In an effort to update the performance data, the 1973 USAAVS FLIGHTFAX weekly circulars⁽³⁾ which contain preliminary mishap information were reviewed. Although this information is subject to change, it is useful as an indication of continuing component problems. The relative occurrence of fuel system component failures during 1973 may be deduced from the listing in Table 7 of reported mishap causes.

TABLE 5. NUMBER OF MISHAPS DUE TO FUEL CONTAMINATION (2)		
Aircraft	Jan 67 to Oct 69	Nov 69 to Jun 70
UH-1A	0	0
UH-1B	6	0
UH-1C	2	1
UH-1D	5	1
UH-1H	8	3
AH-1G	4	1
CH-47A	2	0
CH-47B	0	0
CH-47C	4	1
OH-6A	*	1
*Data for this time period were not available.		

TABLE 6. NUMBER OF MISHAPS DUE TO FUEL BOOST PUMP FAILURES (2)		
Aircraft	Jan 67 to Oct 69	Nov 69 to Jun 70
UH-1A	3	3
UH-1B	4	2
UH-1C	1	0
UH-1D	1	7
UH-1H	0	0
AH-1G	0	1
CH-47A	0	0
CH-47B	0	0
CH-47C	0	0
OH-6A	*	0
*Data for this time period were not available.		

TABLE 7. PRELIMINARY 1973 MISHAPS DUE TO FUEL SYSTEM FAILURES (3)	
Components	Number of Failures Resulting in Mishaps
Boost Pumps	25
Pressure Switches	9
Quick-Disconnect Fittings	3
Fuel Cells	3
Fuel Line	3
Note: These mishaps were all precautionary landings. Components with fewer than three reported failures are not listed.	

Examination of Table 7 shows that boost pump failures are still occurring in significant numbers, accounting for over 50 percent of the reported failures. The majority of pump failures occurred in UH-1 aircraft, with the remaining occurring in the OH-58. There were no boost pump failures reported for the CH-47.

All efforts to obtain definitive data on the failure modes of the UH-1 boost pumps were unsuccessful. The only ECP for the pumps was submitted in January 1972 to change pump models because the old model was no longer available from the vendor. Examination of the Bell Helicopter Company procurement specifications for the pumps, however, disclosed that the top part of the inlet port was left open to act as a bypass rather than being completely screened as required in MIL-P-5238. Whether this deviation from the qualifying specification contributed to the ongoing R&M problems of these pumps cannot be accurately determined. However, this deviation, coupled with the high incidence of contaminated fuel, led directly to a recommended revision for MIL-P-5238.

DESIGN CHANGES

Fifty-eight ECPs submitted by the aircraft manufacturers for the helicopter fuel systems were reviewed in detail. The following data were obtained for each ECP:

- A. Type of aircraft
- B. ECP title
- C. ECP number and date
- D. By whom submitted
- E. Purpose of change
- F. Need for change
- G. Components affected
- H. Effect if not changed
- I. Effect on operational employment
- J. Effect on maintenance
- K. Effect of previous ECPs, if any
- L. Applicable specifications and requirements
- M. Effectiveness of change (were further changes made?)

These data were recorded and cross-referenced by component for easy access and correlation with the appropriate military specifications.

Manufacturers' drawings and literature were used as references with the ECPs to clarify changes and identify parts. In addition, applicable technical manuals and parts lists were scanned to verify changes and dates of effectivity. Serial numbers were noted, and changes not previously documented were examined.

A summary of the ECP data is presented in Table 8. As may be seen in the table, ECPs were submitted for almost all major fuel system components. These data were invaluable in delineating component problems and possible specification deficiencies because of their detail. The most pertinent of the ECPs are mentioned in the Summary section and discussed in conjunction with the recommended specification revisions.

REQUIREMENTS DOCUMENTATION

Most of the documents reviewed were military specifications directly concerned with individual components. These were reviewed for test data, design requirements, and quality

TABLE 8. SUMMARY OF ECP DATA*		
Component	Total Number of ECPs	Reasons for ECPs
Fuel Cells - Tanks	9	Increase capacity; add self-sealing capability; stop leakage at fittings and prevent cell deterioration; remove sump trap.
Fuel Lines - Hoses	4	Replace hose deteriorating in fuel; move hoses away from structural hazards.
Vent Systems	9	Add vent rollover-shutoff valves; improve high point vent systems to reduce spillage; change vent drains and reduce negative internal pressures.
Crashworthy Fuel Systems	6	Install new crashworthy systems.
Filters - Strainers	2	Upgrade filtering requirements.
Quantity Gages	5	System upgrading; shim probes for clearance when cells flex.
Boost Pumps	5	Pump redesign; improve self-lubrication
Fuel Filler Caps and Necks	1	Crashworthy frangible retainer ring redesign.
Fuel Control Valves	4	Contamination; electrical problems; system redesign
Brackets - Mounts	2	Unexpected vibration failures
Auxiliary Fuel Systems	4	Increase capacity; change filling method.
Breakaway Valves, Quick-Disconnect Couplings	4	Change design of quick disconnects in engine compartments, install breakaway valves in engine compartments
Electrics	3	Redesign electrics to prevent shorts, interference.
*ECPs obtained from USAAVSCOM Headquarters, St. Louis.		

assurance provisions. These data were then entered on file cards for quick access. A complete listing of the 41 military specifications and standards reviewed is contained in the Appendix, along with a chart depicting their interrelationship.

Other documents which were used as reference material consisted of:

- AFSC Design Handbook⁽⁴⁾ (recommendations for system design in general)
- USAAMRDL Technical Report 71-22, Crash Survival Design Guide⁽⁵⁾
- Federal Aviation Administration Airworthiness Standards^(6,7)
- USAAVLABS Technical Report 71-8, Crashworthy Fuel System Design Criteria and Analyses⁽⁸⁾
- Various manufacturers' component procurement specifications.

The AFSC Design Handbook replaced HIAD (AFSCM 70-1), which was originally listed for review. Portions of the aforementioned publications pertaining to helicopter fuel systems were excerpted onto file cards and referenced to applicable components.

COMPONENT HISTORICAL RECORDS

Publications, mishap reports, EIRs, ECPs, and other pertinent references to the helicopter fuel systems were organized by component and then listed chronologically in an effort to obtain an overall development view. It was hoped that such time-phased relationships would pinpoint important changes and results. While they did assist in understanding some component changes and pointed out the lack of change to other components, the histories were not as useful as had been originally hoped. The principal reason for this was the short time span of available performance data. EIRs were available only for the period 1 April 1969 to 30 June 1971, and complete mishap reporting was available only from March 1973 on. This severely limited any conclusions which could be drawn in respect to the historical development of R&M improvements. For instance, no EIRs or ECPs are recorded for the crashworthy fuel tanks, a fact which could be interpreted as an excellent reliability record. On the other hand, installation of the new cells began in the latter half of the reporting period mentioned above, and therefore the cells were not adequately represented in the observed

population. It is felt, however, that any major problems occurring after the EIR reporting period would have been uncovered in the FLIGHTFAX reports.

The component histories are included herein for their usefulness as summaries of the total data base utilized during the program.

Valves

- 2-17-53 MIL-V-5018A. Fuel Selector Valves.
Covers manually operated selector valves.
- 2-20-62 MIL-V-25023A issued. Self-Locking Drain Valves.
- 4-19-63 MIL-V-8608A issued. Fuel Shutoff Valves, Electrically Operated.
- 6-3-63 ECP 142. UH-1B fuel system electrics change to prevent accidental shutdown of electric valves in the event of short circuits. Disapproved due to rarity of occurrence.
- 2-24-64 MIL-V-27393A. Crash-Resistant Fuel Cell Safety Valve. Not appropriate for current self-sealing breakaway valves.
- 9-13-65 ECP 001. Vent valve addition to OH-6 design. Installed on original aircraft.
- 4-19-66 MIL-V-38003. General Specification for Fuel Tank Level Control Valves. Controls fuel during transfer and fueling.
- 5-26-66 ECP 389 for CH-47B/C. Adds second crossfeed shutoff valve to allow two-engine operation if crossfeed line is damaged. Previous single valve was in center of line, meaning that at least one of the engines would have to be shut down if the line was damaged.
- 2-28-67 Precautionary landing, UH-1D. Quick-drain valve malfunctioned.
- 8-17-67 MIL-V-25023B. Self-Locking Drain Valve. No major revisions.
- 9-14-67 Precautionary landing. UH-1A sump drain valve loose. Probable maintenance error.

12-11-68 MIL-V-8610A. Solenoid Operated Fuel Shutoff Valves. For use in small flow items (heaters, APUs, etc.).

4-10-69 ECP 631A. Plugged thermal relief valve in CH-47 causing fuel venting. Temporary fix of drilling relief hole from 0.013 inch to 0.032 inch.

5-22-69 ECP 631. Thermal flapper check valve final fix. Replaces old flapper valve in CH-47 with poppet valve.

11-21-69 OH-6 Drain valve stuck open while refueling. Aircraft was total loss.

4-70 Installation of crashworthy fuel systems in UH-1D/H begins.

6-16-70 MIL-V-7839A issued. Aircraft Fuel System Check Valve. For fuel, vapors, or air.

4-01-69
to
6-30-71 EIR Cards submitted on fuel system valves over this period totaled thirty-seven on UH-1D/H breakaway valve (FSN 4820-176-4623) in crashworthy system and one on CH-47C check valve (ECP 631). No applicable military specification for breakaway valves.

8-14-70 ECP 536. Installs breakaway valves in engine compartment fuel lines of UH-1D/H. Tested by contractor - no applicable military specification.

6-27-72 ECP 656. Proposed installation of breakaway valves in engine compartment of UH-1B/C/M. Disapproved due to lack of funds.

Quantity Gages

3-22-50 MIL-G-5672. Float Type Gages. Latest edition.

10-11-64 ECP 292. First notice of CH-47 fuel probe chafing bottom of fuel cell. Fix was to shim probe .81 inch and install chafing guard on probe. See ECP 293.

2-12-64 MIL-G-7940A. Capacitive Gages, Installation and Calibration.

5-12-65 ECP 293 for CH-47. Negative tank pressures were found to exist in flight due to position of vent outlets in airstream. Cells were collapsing and

allowing chafing by quantity probes. Vent outlets were redesigned. Thickness of gasket in probe mount was increased.

- 3-22-67 ECP 101. Float indicator and tank unit of OH-6A switched to replacement type due to vendor ceasing production.
- 2-2-68 MIL-G-7940B released. No major changes.
- 2-2-68 MIL-G-26988B. Transistorized Capacitive Sensing Gage. Mostly electronic testing.
- 11-18-69 ECP 026. Electrical interference between force trim brake and fuel gages in OH-58. Corrected by electronic rewire.
- 69-70 EIRs on gage systems: One on CH-47C.
- 8-20-71 MIL-G-7940C released. No major changes.

Filters

- 12-11-61 ECP 140. Specifies new filter element in UH-1 A/B system. Upgrades from 74-micron element to 5-micron element. ECP disapproved due to improved engine fuel controls capable of operating at higher contamination levels.
- 7-20-67 Precautionary landing of UH-1C due to clogged fuel filter (bypass light on).
- 8-4-67 Precautionary landing of UH-1D due to clogged filter. Maintenance error (element was scheduled for removal).
- 8-17-67 Precautionary landing of UH-1C. Same reason as above (8-4-67).
- 10-14-68 ECP 8095 for CH-54. Adds 10-micron airframe-mounted fuel filter in engine fuel feed line after high rate of engine failure traced to contamination.
- 7-10-69 MIL-S-8710B issued. General Specification for Fuel System Strainer.
- 1969-70 EIRs on filters: Three on CH-47, one on AH-1G, and one on UH-1.

Filler Caps and Adapters

7-14-53 MIL-C-8605. Pressure Fueling Cap. Latest issue.

12-15-65 MIL-C-38373. Tank Filler Cap. Gravity Fill.

10-18-67 Precautionary landing. UH-1D filler cap leaking. Faulty gasket.

2-26-69 MIL-C-38373A issued. No major changes from original.

3-14-69 MIL-A-25896D. Pressure Fueling Adapters. Covers connecting devices, nozzle-to-aircraft, in pressure refueling systems.

1969-70 EIRs on pressure cap and adapter. Three on UH-1H.

3-18-70 Precautionary landing by UH-1D. Cap seal leaked.

3-26-70 Precautionary landing by UH-1B. Cap seal leaked.

8-23-71 ECP 126 for OH-58. Replaces cap and adapter with new assembly similar to one on UH-1D/H which combines gravity and pressure adapters in one unit. Assembly on UH-1D/H has had problems. Will not fit 2-inch nozzles found in Navy, Air Force, and commercial installations. Also damage and overflow problems due to combination adapter. ECP approved with recommendation that two receptacles be used - one for gravity and one for pressure refuel. Recommendation not incorporated.

2-72 ECP 670 to AH-1G. Redesigns frangible filler neck retaining ring after it cracked on hard landings. No specification available for frangible fittings.

Switches

2-13-59 MIL-S-26390 issued. Pressure Switch Assemblies. No contamination tests.

6-15-65 MIL-S-25980A issued. Fuel Level Float Switch.

2-27-67 Precautionary landing of UH-1B. Boost pump switch failed.

4-26-68 Precautionary landing of UH-1D. Main fuel system (pump) switch failed.

5-20-69 MIL-S-26390A issued. Revision still contains no contamination tests.

1969-70 EIRs on switches: One on AH-1G, one on CH-47, and three on UH-1.

5-15-70 Precautionary landing of CH-47A. Pressure switch failed.

3-73 to 12-73 Nine reports of pressure switch failures resulting in precautionary landings.

Vent Systems

7-17-61 ECP 093 for UH-1B. Adds a new vent line from engine fuel control to fuel cell crossover tubing. Designed to prevent flameouts by bleeding trapped air.

11-20-64 ECP 182. Replaced vent manifold on UH-1D with simpler, less expensive one. Previous six-piece assembly replaced by aluminum one-piece assembly.

12-30-64 ECP 189. Proposal to install three-axis vent line or vent valve in UH-1s to prevent fuel spillage during crashes. Previous system leaked in extreme attitudes. Approved concept for study. New vents never installed.

5-12-65 ECP 293. Redesigns vent outboard drains on CH-47 to eliminate negative tank pressures caused by venturi effect. Cells were collapsing under negative pressure and allowing quantity probes to chafe cells.

8-20-65 MIL-F-17874B. Fuel Systems Installation and Test Requirements. Requires a flight test recording fuel cell differential pressures.

9-13-65 ECP 001. Design change prior to production of OH-6A. Installs Shulz valve in vent line to prevent spillage. Valve actuates at 25 degrees from vertical.

9-8-66 MIL-F-38363 issued. Fuel System General Specification. Contains design and test requirements for vent systems.

9-28-67 Precautionary Landing. Vent line out of place on CH-47A.

- 7-26-68 ECP 593 to CH-47. Installs high point in vent system to prevent spillage. Check valve in vent line was one proposal, but disapproved due to possibility of icing.
- 12-23-68 MIL-F-38363A. Fuel System General Specification revision. No major vent system changes.
- 5-5-69 Precautionary landing of UH-1D. Fuel fumes vented into cabin from crack in fuselage skin near vent outlet.
- 10-13-71 MIL-F-38363B released. System General Specification revision. Revised design notes, mostly safety oriented.
- 6-23-72 ECP 657. Proposal to install flapper vent valve in UH-1D/H upper cell vent lines to prevent spillage at > 40-degree angles. Not adopted yet. Due for resubmission.
- 6-27-72 ECP 656. Proposed vent rollover protection for UH-1B/C/M. Not yet adopted. Due for submission.

Tanks

- 2-25-59 MIL-T-5578B issued. Self-Sealing Tanks. Covers full and partially sealing tanks.
- 5-27-59 MIL-F-5577B. Tank Fittings, Removable. General specification.
- 5-27-59 MIL-STD-801. Tank Fittings. Contains tables of defects in fittings and classifies them as critical, major or minor with reference to acceptance testing.
- 2-27-62 ECP-119 submitted. Fills in the tank sump area of UH-1A right-hand fuel cells. (The tank outlet was above sump level, allowing water and sediments to collect and contaminate the fuel.) Fuel cells contained no sump drain. No applicable specifications published yet (F-17874 in 1965, F-38363 in 1966).
- 1-2-63 ECP 136 submitted. Covers top surfaces of UH-1D cells with self-sealing material. Brings these cells to state of the art. FY '62 and subsequent.
- 7-31-63 MIL-T-5578C issued. Self-Sealing Tanks, latest issue.

2-6-64 ECP 156 and 161. Increases size of fuel cells in UH-1B to avoid carrying auxiliary cells in cargo spaces.

3-25-64 MIL-T-27422A issued. Crashworthy Aircraft Fuel Tanks.

4-10-64 MIL-P-8045B. Plastic Self-Sealing and Non-Self-Sealing Tank Backing Material. This is current issue. Mostly gunfire tests.

5-14-65 ECP 8010. Replaces bladder cells with self-sealing ones in CH-54. Tanks are interchangeable with old ones. These cells were tested to MIL-T-5578 and MIL-T-6396 (top portions non-self-sealing).

5-28-65 ECP 38 for CH-47A proposed to increase fuel capacity. Two suggestions - larger tanks and pods, or two new tanks added. ECP was disapproved.

6-7-65 MIL-T-6396C. Non-Self-Sealing Fuel Tanks. Latest issue.

3-31-66 MIL-T-25783C. Tanks, Non-Self-Sealing, High-temperature. For temperatures higher than 160°F.

12-15-67 ECP 553 to CH-47C. Adds auxiliary fuel cells. New engines required more fuel capacity. New cells have lower half self-sealing. Vibration dampeners installed in pods.

69-70 EIRs received on tanks: two on AH-1G, twelve on UH-1H, and three on CH-47. Vague descriptions of failures.

9-7-70 TM-20 for OH-58 issued with cell installation and removal changes. Procedural, to prevent damage.

2-24-70 MIL-T-27422B issued. All new crash-resistant tank specification.

4-70 UH-1D/H. Crashworthy Fuel System (CWFS) retrofit begun.

5-12-71 ECP 8172 to CH-54. Old cells (ECP 8010) were leaking and deteriorating. This ECP replaces them and improves fitting seals. Includes corrugated drainage board under cells so that they do not sit in fuel. ECP disapproved in anticipation of crashworthy system update.

9-71 OH-58A CWFS retrofit begun.

2-72 AH-1G CWFS retrofit begun.
 1-73 UH-1B CWFS retrofit begun.
 5-73 CH-47A,B,C CWFS retrofit begun.
 9-73 UH-1C CWFS retrofit begun.

Fuel Lines and Hoses

3-13-62 MIL-I-18802A. Installation of Fuel and Oil Lines. Latest issue of this specification.
 12-4-64 MIL-H-8794C. Rubber Hose. For hydraulic, fuel, and oil lines.
 9-10-65 ECP 337. Moves heater fuel line in CH-47A to location farther away from vibrating transmission mounts. Line was chafing through.
 3-21-66 MIL-H-8795B. Rubber Hose Assemblies. Incorporates MIL-H-8794 hose.
 2-20-67 MIL-H-25579C. High-Temperature Tetrafluoroethylene Hose.
 5-26-67 UH-1C precautionary landing due to improperly installed fuel line.
 6-29-67 UH-1D precautionary landing when a fuel line chafed through.
 9-27-67 CH-47A precautionary landing for vent line "out of place".
 6-6-68 MIL-H-7061A. Rubber Self-Sealing Hose.
 8-7-68 ECP 1639. Submerged self-sealing hose in OH-6A cells was deteriorating. Replaced by hose conforming to MIL-H-8794. No mention of new self-sealing material.
 11-9-68 ECP 597. Moves APU fuel line in CH-47C away from hazardous areas near loading ramp.
 3-10-69 MIL-H-58089. Hose Assemblies and Hose, Rubber, Medium Pressure.
 69-70 EIRs to fuel lines: one on AH-1G, one on CH-47, labeled "chafed" and "improper maintenance".
 6-29-70 UH-1D precautionary landing due to chafed line.

- 2-4-71 MIL-H-8794D. Latest revision.
- 9-8-71 ECP 3073. OH-6A fuel line to be moved away from its route above landing gear dampeners. ECP disapproved due to "lack of previous problems", but change included in CWFS in March of '73.
- 8-10-72 MIL-C-83291A. Self-Sealing Hose Covers.

Boost Pumps

- 2-2-61 MIL-P-5238B. Pump, Centrifugal, Fuel Booster. Latest version of only aircraft fuel boost pump specification that applies to helicopters. Contains no contaminated fuel test. 1200-hour endurance test run at rated flow.
- 8-13-65 ECP 246 for UH-1D. Changes sump plate from fabricated sheet metal to cast aluminum alloy to save money and weight. ECP cancelled after retrofit due to installation of crashworthy fuel system.
- 2-28-66 ECP 34. Removes electric boost pump of OH-6A prior to production of the aircraft. Ground tests showed pump unnecessary (tested by running at full power while reducing pressure in tank) to elevations simulated by -5 inches Hg. See ECP 1283.
- 5-18-66 ECP 372 for CH-47A. Boost pumps were failing at 300 to 500 hours. Pump redesigned to improve bearing lubrication by fuel at normal service flow rates. Ball bearings replaced by carbon sleeve bearings.
- 2-23-67 Precautionary landing by UH-1B caused by boost pump failure.
- 2-27-67 Precautionary landing by UH-1B. Caused by broken fuel pump switch.
- 4-67 to 3-68 Seven UH-1 precautionary landings due to boost pump failure.
- 5-2-68 ECP 1238 for OH-6A. Reinstalls boost pump originally planned for OH-6 and removed by ECP 34. Pump is necessary for high ambient temperature engine starts and high-temperature/high altitude flight conditions.
- 1969-70 EIRs involving boost pumps: Fifteen on UH-1D/H, eleven on CH-47, and two on AH-1G.

3-10-69 Precautionary landing by UH-1D/H. Boost pump switch failed.

2-10-70 Precautionary landing by UH-1D/H. Boost pump failed.

3-70 to 5-70 Ten UH-1 precautionary landings due to boost pump failure.

1-5-72 ECP 648 for UH-1, AH-1 boost pump. Changes impellor design for improved performance at higher flows. Reason for change given as "current pump no longer available from vendor".

1-73 to 12-73 Twenty-five precautionary landings due to failed boost pumps: Nineteen on UH-1, six on OH-58. Both air and electric pumps reported.

Mounts - Fittings - Couplings

5-27-59 MIL-F-5577B. General Specification for Tank Fittings.

5-27-59 MIL-STD-801. Acceptance Standards for Tank Fittings. Criteria for classifying defects.

7-27-64 MIL-C-22263A. Flexible Fuel Line Couplings.

10-14-64 ECP 284 to CH-47A. Installs support bracket for defuel valve to prevent vibration failure of fuel line which partially supports valve.

10-31-66 ECP 310. Replaces quick-disconnect coupling in engine fuel inlet line with a different quick disconnect using a ratchet type-B nut. Coupling had been vibrating loose due to improper securing by maintenance personnel.

6-29-67 Forced landing of UH-1D when main fuel supply quick disconnect came off.

8-9-67 Forced landing, UH-1D, when fuel filter quick disconnect came off.

9-27-67 Forced landing, UH-1C, when main supply line quick disconnect came off.

3-11-68 Forced landing, UH-1D, when filter quick disconnect came off.

1969-70 Three EIRs submitted on broken UH-1H fuel probe mounting bracket in upper center tank.

- 2-2-70 MIL-C-7413B. Quick-Disconnect Couplings. Latest revision. Vibration test added which was not in earlier issue.
- 6-24-70 Precautionary landing of OH-6 when fitting came off fuel line inside fuel cell. No record of which fitting.
- 6-28-72 MIL-C-22263B issued. No major changes.

SUMMARY

One of the major causes of fuel system component failure and reduced reliability, as determined by this study, was fuel contamination in excess of design conditions. The magnitude of this problem is illustrated by the following references in addition to the data already presented in Figure 1 and Table 5:

ECP 631 for CH-47, dated 22 May 1969. Redesigns check valves between main and auxiliary tanks to prevent thermal expansion overflow. Old valves were sticking open due to contaminants.

ECP 622 for CH-47, dated 28 May 1969. Proposes an on-board closed-circuit refueling system incorporating sand and dust filter, water separator, and go/no-go moisture detecting gage. This ECP was disapproved due to complexity, partially due to necessary filtering equipment.

ECP 140 for UH-1 A/B, dated 11 December 1961. Upgrades fuel filter requirements from 74 microns to 5 microns due to fuel control failures from contamination. ECP disapproved in anticipation of fuel controls capable of operating under high contamination levels.

ECP 8095 for CH-54, dated 14 October 1968. Adds 10-micron airframe-mounted filters in engine fuel feed lines. High level of engine failures traced to increased contamination levels occurring in the field.

ECP 119 for UH-1A, dated 27 February 1962. Adds filler material to fuel cell sump area to eliminate low spot in cell. Water had been accumulating in sump area, leading to fungus contamination.

Equipment improvement recommendations, involving every fuel system component, contain failure codes of "Internal Failure", "Mechanical Binding", and "Seized", many of which might be attributed to contamination. This conclusion is supported

by the high incidence of boost pump and pressure switch failures, as neither of these components is required to undergo a preproduction contamination test by its individual specification.

Since control of fuel supply sources in the field is difficult, every effort must be made to ensure component operation under adverse fuel conditions. Therefore, many recommendations of this study take the form of increased contamination testing and stressing of this aspect of system design wherever possible.

The results of the data analysis also led to a thorough reevaluation of endurance test conditions. ECP 372 for the CH-47, dated 18 May 1966, brought out the fact that endurance testing at rated pressures and flows may not always be the most severe conditions to which a component is subjected. The ECP revealed that the fuel boost pump easily passed the endurance requirement of MIL-P-5238 (1200 hours @ rated flow), yet continuously failed in service. The pump bearings, which had been found to be the point of failure, were improved to correct the problem. Upon duplicating service condition flow rates, two new pumps promptly failed before completing 319 hours of testing. Subsequent inspection revealed that the bearings in question were lubricated by the fuel being pumped and received sufficient lubrication only at full power. The problem was finally cured by redesigning the pump impellers and installing bearings of a new type.

This same type of problem occurred with the self-sealing breakaway valves in the UH-1H. Testing of the valves under rated pressures apparently forced the rubber boot against the valve body, preventing leakage and masking the inadequate boot bond which allowed the valve to leak at lower pressures.

As a result of these findings, the concept of testing at flows and pressures encountered in service, as well as at full rated conditions, was applied to other fuel system components as well. In many cases (hoses, quantity gaging devices, filler caps, brackets, etc.), no distinction between conditions is necessary, but the differences could well be important with moving parts involved (pumps, valves, etc.). Any cases where lubrication is provided by the fuel are obvious candidates for additional testing at reduced pressures. Fuel filters (which may clog more easily at lower flow rates) and components using rubber seals (which could be held in place artificially by higher pressures and leak at lower ones) might also benefit from testing at more than one set of conditions.

The remainder of the performance data and design changes were generally oriented toward specific fuel system designs and components. As such, they are discussed individually in conjunction with the recommended specification revisions, and no attempt will be made to summarize them here.

DOCUMENTATION ANALYSIS AND REVISION

This section presents the analyses of and recommended revisions to all the military specifications examined during this program. Although all the revisions are discussed and the basis for their recommendation is presented, not all of them are reproduced in detail in this section. For instance, two major specifications drafted during this program (those for the general fuel system and for the breakaway valves) are not presented in their entirety here but are contained in Volume II. However, significant portions of these specifications are presented herein where it is necessary for the purpose of discussion. In addition, wherever there were several viable alternates which could be recommended, each alternate is discussed, and the rationale behind the final selection is presented.

GENERAL FUEL SYSTEM

Three military specifications were placed in this category: two covering fuel systems in general, and one presenting general requirements for fuel system components.

MIL-F-38363B - Fuel System, Aircraft, General
Specification for 13 October 1971

This specification covers requirements for design, performance, installation, and testing of aircraft fuel systems. It is a comprehensive and detailed specification which, if adhered to, would have eliminated many of the problems uncovered during this program. For instance, problems with drainage and contamination in the right-hand UH-1A fuel tanks (ECP 119) would have been eliminated by a sump and drain as specified in paragraph 3.7.1.3. However, the specification was not originally published until 1966, well after the design period of most of the helicopters under study. The problems which could have been prevented had the specification been in existence earlier emphasizes the importance of such a general system specification.

MIL-F-38363B is complete and adequate in most respects; however, it is an Air Force specification which has not yet been coordinated with the other services. Since it was written for the Air Force, it contains many requirements for high-performance aircraft which are not applicable to U. S. Army aircraft. In addition, many of the Army helicopters now incorporate crashworthy fuel systems, and work is in progress to incorporate such systems into the remaining helicopters. Provisions have also been included requiring crashworthy fuel systems in the procurement specifications for new Army

helicopters. At the present time there are no military specifications for these fuel systems or even for crashworthy components other than the fuel tanks.

In view of the foregoing considerations, it was felt that a general fuel system specification which also incorporated crashworthy requirements was necessary for Army aircraft to provide the Army with a contractual document meeting their specific needs. Accordingly, a draft specification was written for the Army during this program. Although this draft is very similar to MIL-F-38363, and intentionally so, it should not be considered a revision since MIL-F-38363 is an Air Force specification, and the new draft specification is strictly for the Army.

The basic format of the new specification follows that of MIL-F-38363, even to incorporating, verbatim, applicable requirements from MIL-F-38363. This was done intentionally so that interservice coordination would be facilitated if and when such coordination is desired. However, high-performance aircraft criteria, aerial refueling, etc., which do not apply to Army aircraft were not included. The fuel system specification covers requirements for both fixed- and rotary-wing aircraft since the majority of the requirements are applicable to both. Crashworthy fuel system requirements were included as optional if such a system was specified by the procuring activity. The following paragraphs present a more detailed discussion of some of the major changes, deletions, and additions related to MIL-F-38363 as incorporated in the Army fuel system specification.

The following fuel subsystems are covered in the draft specification:

1. Engine feed and transfer subsystem
2. Aircraft fuel tank subsystem
3. Explosion suppression subsystems
4. Fuel vent subsystem
5. Fuel quantity gaging subsystem
6. Refueling and defueling subsystem

Subsystems covered in MIL-F-38363, which were deleted as not being applicable to Army aircraft, were the pressurization subsystem, aerial refueling subsystem, and fuel dump subsystem.

The explosion suppression subsystem section includes suppression by either baffle material or nitrogen inerting systems. Consideration was given to eliminating the requirements for a nitrogen inerting system, as this system is not now used in Army aircraft and is fairly complicated for the small aircraft generally found in the Army inventory. Because the use of a nitrogen inerting system should not be ruled out for later use in Army aircraft, specification requirements for this system were retained.

Many minor changes from MIL-F-38363B were made which were concerned with deleting high-performance requirements applicable only to Air Force aircraft and incorporating more realistic requirements for Army aircraft. These include such modifications as changing high-temperature requirements and high-altitude requirements. No effort will be made to detail these changes in this section of the report, as they are all fairly straightforward and self-evident. There are several changes, however (in addition to adding the crashworthy system), which should be mentioned. For instance, there were several reports of precautionary landings and EIRs due to chafed fuel lines. MIL-F-38363 specifically says, "Sufficient clearance shall be provided around fuel lines to prevent chafing of the lines with the aircraft structure or other lines and components." It was felt necessary in view of the problems still being encountered in this area to add further precautions. Thus, immediately after the sentence just quoted, the following sentence was added in the Army specification: "Where necessary, protective covers which have been approved by the procuring activity shall be installed around the lines to protect them from chafing." In addition, the use of unlined metal support clamps was prohibited regardless of the type of fuel line material involved.

Another addition to the Army specification which was not in the Air Force version is a paragraph requiring mandatory gravity defueling provisions for all Army aircraft. This is in conformance with current practice in which many of the Army helicopters, such as the UH-1s, the AH-1G, and the OH-6A incorporate gravity defueling provisions. By the very nature of the operations in which Army aircraft participate, it may be assumed that this requirement will continue, and, indeed, it is required in the AAH procurement specification. Therefore, the following paragraph was incorporated into the draft specification.

"3.11.4 Gravity defueling. It shall be possible to completely defuel the aircraft by means of gravity through a drain valve(s) conforming to the requirements of MIL-V-25023. The defueling rate shall be not less than 20 gpm

unless specified by the procuring activity. In the event of a wheels-up landing or landing gear failure, it shall be possible to defuel the aircraft through the normal fuel servicing adapters or by suction through accessible openings in each tank."

The defueling rate of 20 gallons per minute was based on defueling a medium-sized helicopter containing 300 gallons of fuel within 15 minutes. This is a reasonable time limit which can be readily attained using standard drain valves.

A gravity defueling demonstration was also added as a requirement under the fuel tank subsystem simulator tests (paragraph 4.4.2).

In view of the trend toward incorporating pressure refueling systems in all Army helicopters to help prevent fuel system contamination while refueling with the rotors turning, the pressure refueling requirements of MIL-F-38363 were changed slightly to emphasize incorporation of pressure refueling in all helicopters. Thus, the first sentence under pressure refueling (3.11.1) is written as: "All fixed-wing aircraft with an internal fuel capacity of 600 gallons or more and all helicopters shall incorporate a pressure refueling system."

In response to several problems uncovered with the design of helicopter vent systems, the following requirements were included in the Army specification in addition to those already required in MIL-F-38363B. "The vent line shall start at the highest point in the tank and traverse the three dimensions of the tank, terminating in a suitable location outside the aircraft. Means shall be provided for admitting air to the high point of the vent system." These requirements are common in vent system design and are found in the AFSC design handbook (formerly HIAD). They are reiterated in this specification mainly for emphasis and are intended to prevent a recurrence of the problems which led to three ECPs calling for vent system redesign to prevent fuel spillage. That the emphasis is needed becomes obvious when it is realized that three different manufacturers were involved with these ECPs.

As stated earlier, the crashworthy fuel system requirements were included in the draft specification as optional. A military specification for crashworthy fuel tanks already exists (MIL-T-27422) and is referenced in the draft specification. A specification for the necessary self-sealing breakaway valves was drafted during this program and is discussed in the valve section. This specification is a complete revision of MIL-V-27393A, the existing breakaway valve specification. All references to the valve specification are made as MIL-V-27393B

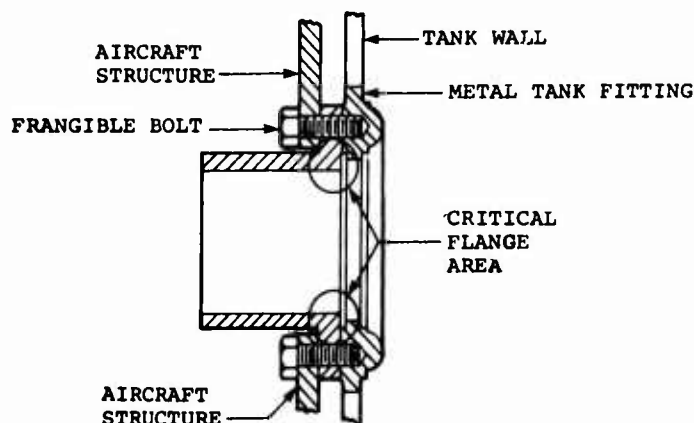
to emphasize that this is the revised specification drafted under this program and not the one which is in publication at the present time.

No military specification exists for the frangible attachments required in crashworthy systems. Frangible attachments are unique for each fuel system location and must be designed by the aircraft manufacturer to meet his specific needs. Thus, it would be very difficult to write a detailed specification for these attachments, and any specification would have to be quite general. The specific criteria and tests necessary for the frangible attachments to function satisfactorily are few and rather general. Thus, it was decided to include the frangible attachment requirements in the general fuel system specification rather than to draft a separate specification for these attachments. Accordingly, paragraph 3.5.3.4 of the original specification was modified in the Army draft as follows:

"3.5.3.4 Components. Components shall comply with the applicable military specification. Fuel system components not covered by specific Government specifications shall conform to the applicable parts of MIL-F-8615. Specifications shall be prepared by the contractor in accordance with the appendix of MIL-F-8615 for all fuel system components except standard hardware such as bolts and O-rings. Whenever possible, components that are used in other aircraft systems shall be utilized even though bracketry to adapt these components may be required. However, in a crashworthy fuel system, frangible structures or frangible bolts shall be used at all attachment points between fuel tanks and aircraft structure to prevent fuel tank components from being torn out of the tank wall during impact. Frangible attachments shall be used at other points in the flammable fluid systems where aircraft structural deformation would lead to system failure. All frangible attachments shall meet the requirements of 3.5.3.4.1. In crashworthy fuel systems, self-sealing breakaway valves, conforming to MIL-V-27393B, shall be installed in all fuel tank-to-fuel line connections and in all tank-to-tank interconnects. Self-sealing breakaway valves shall be installed at all firewall line connections and at other points in the fuel system where aircraft structural deformation would lead to system failure.

3.5.3.4.1 Frangible attachments

3.5.3.4.1.1 Separation load. The load 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 ultimate 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 as illustrated in Figure 1. (Figure 1 of the specification is reproduced as Figure 2 in this volume of the report.)



ITEM	LOWEST FAILURE LOAD (LB) *	FAILURE MODE
Aircraft Structure	4000	Shear
Tank Fitting	3000	Pullout 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. (Figure 1 of the Draft Fuel System Specification)

3.5.3.4.1.2 Mode of separation. A frangible attachment shall separate whenever the required load (as defined in 3.5.3.4.1.1) 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 attachment by analyzing the surrounding aircraft structure and the probable impact forces and their directions."

Frangible attachments designed to these specifications have functioned very well in the crashworthy fuel systems of the UH-1D/H helicopter. The requirements are based on those specified in References 5 and 8.

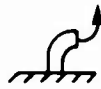
Another basic component of the crashworthy system is the hose assembly. The strength of the hose assemblies must be high enough to transmit the crash loads to the breakaway valves and frangible attachments before the hoses or end fittings fail. Hose assemblies are currently available off the shelf which will meet the crashworthy strength requirements and are covered by MIL-H-58089. However, MIL-H-58089 does not require hose fitting pullout tests which are necessary for the crashworthy systems. Accordingly, the paragraph in MIL-F-38363B specifying hose assembly requirements has been rewritten as follows:

"3.5.3.7.1.3 Hose assemblies. All fuel system hose assemblies shall be in accordance with MIL-H-8795, MIL-H-25579, or MIL-H-58089. Hose shall be installed with a bend radius not less than the minimum radius specified in the applicable military specification. Flexible hose shall not be stretched or twisted during installation. All hose assemblies in a crashworthy fuel system shall meet or exceed the requirements of MIL-H-58089. These assemblies shall also meet the tension and bending strength requirements specified in Table II [Table 9 in this volume of the report] when tested in accordance with 4.6.2."

Testing methods and requirements for the frangible attachments and hose assemblies were added to the quality assurance provisions of the Draft Fuel System Specification as follows:

"4.6 Crashworthy fuel system component testing

4.6.1 Frangible attachments. The aircraft manufacturer shall issue procurement specifications for all frangible attachments which include the following tests (4.6.1.1 and 4.6.1.2).

TABLE 9. 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 Tension =  Bending = 	-4	600	475	425	400
	-6	700	575	425	400
	-8	900	650	650	600
	-10	1450	1175	675	625
	-12	1775	1475	950	850
	-16	2125	1825	1425	1300
	-20	2375	2075	1550	1425
90° ELBOW Tension =  Bending = 	-4	600	475	425	400
	-6	700	575	425	400
	-8	900	650	450	400
	-10	1450	1175	475	425
	-12	1775	1475	500	450
	-16	2125	1825	775	700
	-20	2375	2075	1100	1000
*Minimum of three tests					

4.6.1.1 Static tests. All frangible attachments shall be tested in the three most likely anticipated modes of operation, as defined in 3.5.3.4.1.2. Test loads shall be applied at a constant rate not to exceed 20 inches per minute until failure occurs. The failure loads shall meet the requirements of 3.5.3.4.1.1.

4.6.1.2 Dynamic tests. All frangible attachments shall be proof tested under dynamic loading conditions to ensure that they function satisfactorily in the three most likely anticipated modes of operation. The test load shall be applied in less than 0.005 second, and the velocity change experienced by the loading jig shall be 65 ±5 feet per second.

4.6.2 Hose assemblies. To ensure compliance with the crashworthy requirements of 3.5.3.7.1.3 (Table II) [Table 9, this volume], hose assemblies shall be subjected to tension loads and to bending loads applied at a 90-degree angle to the longitudinal axis of the end fitting, as shown in Figure 2 [Figure 3, this volume]. Loads shall be applied at a constant rate not to exceed 20 inches per minute. The test assembly shall be pressurized to 5 psi with test fluid. The maximum applied load recorded up to the time of steady stream leakage occurring due to hose pullout or hose or end fitting failure shall be designated as the failure load."

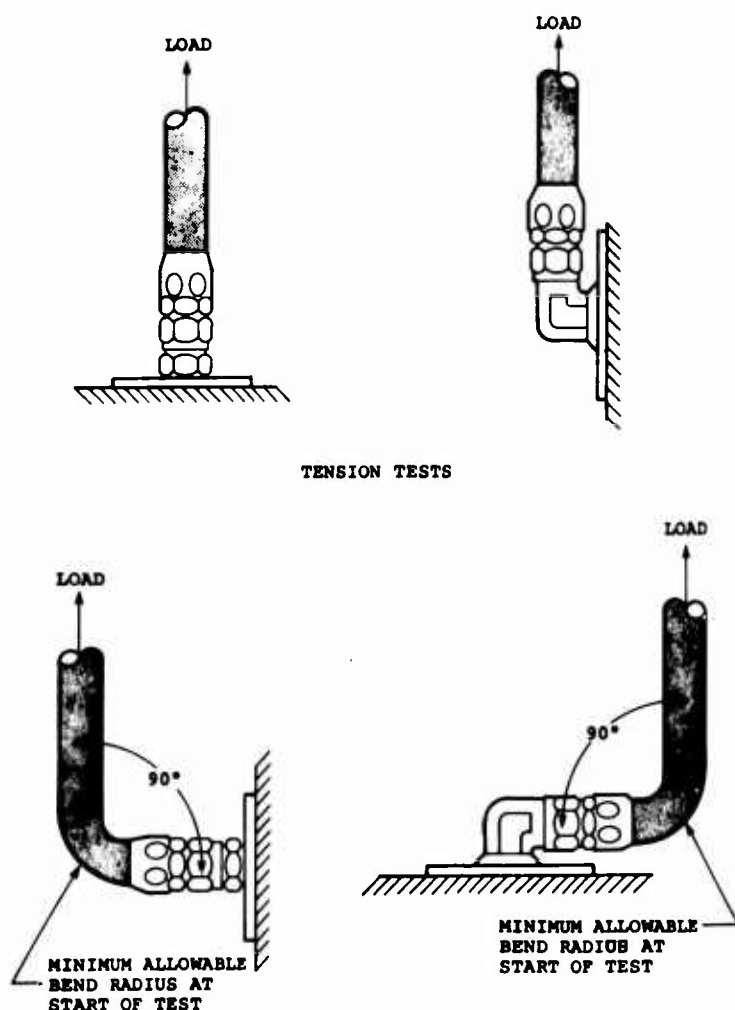


Figure 3. Hose Assembly Tests. (Figure 2 of the draft fuel system specification)

The required tests are standard in the crashworthy fuel system field today. The static tests of the frangible attachments ensure that the attachments will meet all of the operational loads but will separate before they can transmit failure loads to the next weakest link in the fuel system. The dynamic test conditions are based upon typical accident crash pulses as discussed in Reference 5. The dynamic tests are proof tests to ensure that the dynamic loading conditions will not change the operation of the attachment.

The hose assembly tests are designed to ensure that the hose assemblies are strong enough to transmit the crash loads without failing. The effective moment arm for the bending tests is allowed to change primarily with the line size and secondarily as the applied load produces changes in the bend radius. This test procedure is much easier to mechanize than one that requires a constant moment arm, and it has been found to be just as effective.

Other crashworthy fuel system requirements are scattered throughout the draft specification where applicable. Inasmuch as they are not major revisions, they will not be detailed here.

MIL-F-17874B - Fuel Systems, Aircraft
Installation and Test
of

20 August 1965

This specification is a general fuel system specification similar to MIL-F-38363 with the exception that design criteria are not included as in MIL-F-38363. Most of the requirements in this specification are identical to or similar to those in MIL-F-38363, but the specification itself is not as comprehensive and the tests are not as specific. Analysis of MIL-F-17874B disclosed no pertinent areas that were not already covered in the Draft Fuel System Specification just discussed. Thus, there seems to be no reason to consider this older specification in Army helicopter fuel system design. This trend has already been established, as the AAH procurement specification references only MIL-F-38363 as a general fuel system specification. Thus, no recommendations for revisions were made to MIL-F-17874.

MIL-F-8615C - Fuel System Components,
General Specification
for

26 February 1969

Only minor revisions were necessary to this specification. Considering its overall importance and adequacy in relation to fuel system component testing, it is recommended that this

specification be strictly complied with by manufacturers and that its value as a design guide be highly stressed.

Two recommended revisions are related to the major problems uncovered during this study: that of fuel contamination, and the assumption that maximum operating conditions are always the most severe.

The contaminated fuel endurance test of paragraph 4.6.7.1 calls for the component to be flushed with clear fluid following the circulation of contaminated fuel through the component and prior to the functional and leakage tests which determine the component's conformance to the specification requirements. In view of the magnitude of fuel contamination problems, it is recommended that the test be changed to omit the flushing procedure and that the component be drained only. It is felt that this procedure more closely approximates actual field conditions in which contaminants from the fuel gradually build up in a component until they impair the component's operation. The component should, however, be drained immediately following the circulation period to prevent excessive contaminant buildup from the particles settling out of the test fluid. Accordingly, it is recommended that the next to the last sentence of paragraph 4.6.7.1 be rewritten as follows:

"Immediately following the circulation period, the component shall be drained and the functional and leakage tests (4.6.3.1 and 4.6.2, respectively) shall be performed."

The other revision is directly related to the problem with the CH-47 boost pumps in which the endurance testing under the "most severe" conditions of maximum rated flow proved misleading and the pumps failed much sooner under normal service conditions. This problem was directly related to the design of the pump in which fuel lubricated the bearings and is probably unique to this type of situation. Thus, an additional endurance test at normal service flow rates is recommended, but only for those components in which fuel is necessary for lubrication or sealing purposes. An additional test is recommended rather than changing the conditions of the present test for reasons discussed later in the section devoted to the boost pump specification.

It is recommended, therefore, that the following subparagraph (c) be added to paragraph 4.6.5.

"(c) All components in which lubrication or sealing is dependent on fuel flow shall be subjected to an endurance test of 1200 hours of continuous operation at normal service (cruise) flow rates in addition to the 1200-hour test at maximum operating load condition."

Minor revisions should be made to MIL-F-8615 to reflect the different altitude requirement for rotary-wing aircraft. Accordingly, the altitude test setup in Table IV should be changed to read: "Suitable test setup, 60,000 feet pressure altitude (25,000 feet for rotary-wing aircraft)".

The last sentence in paragraph 4.6.5.3 should be changed to read: "Altitude shall be at least 60,000 feet for fixed-wing aircraft and at least 25,000 feet for rotary-wing aircraft." The suggested value of altitude testing was arrived at following reviews of the ARMY AVIATION Materiel Issue and applicable Technical Manuals. The highest service ceiling of any helicopter covered by this study is approximately 17,000 feet. The 25,000-foot requirement should allow an ample safety factor.

Since this specification is referenced by many individual component specifications, it is recommended that the preceding revisions be implemented in a new edition prior to, or coincidental with, the revisions to those individual issues.

FUEL TANKS

The four specifications which are included in this category cover four different types of fuel tanks: crash-resistant, self-sealing, non-self-sealing, and high-temperature. However, the majority of the requirements for all the tanks are very similar and, in general, quite adequate. The following paragraphs present the recommended revisions.

MIL-T-27422B - Tank, Fuel, Crash-Resistant 24 February 1970

This specification as now written contains no leakage tests on individual units. However, ten EIRs were submitted for leaking or defective cells over the period 4-69 to 6-71. Even though the majority of these were submitted for standard cells and not the new crashworthy cells qualified to MIL-T-27422B, the time and effort required to remove and replace a defective fuel cell justify the inclusion of a quality conformance leakage test. Therefore, it is recommended that an individual leakage test be added as follows:

"4.6.1.4 Leakage. The tank, with all openings sealed, shall be subjected to the internal air pressure specified in the manufacturer's approved inspection specification. The tank shall then be completely submerged in water or covered completely with soapy water. Leakage, as indicated by the presence of air bubbles forming in the water or soapy water solution, shall be cause for rejection. If approved by the procuring activity, the tank may be subjected to an unconfined liquid stand test using TT-S-735, type III test fluid at room temperature for 24 hours with a head of 48 inches on the bottom of the tank without evidence of leakage."

This is a standard quick leakage test as used in MIL-T-6396C and MIL-T-25783C, with the option of a phenolphthalein-ammonia leak test deleted due to possible reactions with the barrier materials.

Excess water in the fuel (a fairly common occurrence) will settle in the tank sump area and may remain there for some time if the aircraft is stored without draining the tanks (also a common occurrence). In order to ensure that cell deterioration will not occur under such circumstances, it is recommended that water be added to the test fluid used in the stand test. Thus, paragraph 4.6.2 should be rewritten as follows:

"4.6.2 Stand. Prior to the stand test, type I cells shall be subjected to the fuel resistance of exterior surface test specified in 4.6.6.1. An alternate procedure for conducting this 3-day test may be used if approved by the procuring activity. Upon completion of this test, the outside surface of the cell shall be dried with a cloth, and the cell shall be stored in an airtight bag or immediately installed in the cavity used for the stand test.

Class A cells shall be collapsed and held strapped for 30 minutes in a position comparable to that encountered prior to installation in its respective aircraft cavity, then released, and adequately supported in normal ground attitude. Both class A and class B cells shall be filled with type III fluid containing 0.1 percent water by volume. During the filling process, the capacity test (4.6.7.2) shall be conducted on class B tanks to determine conformance with 3.5.2. Cells shall then be tested in accordance with the following time cycle:

- | | |
|-------------------------|---------|
| (a) First cell selected | 90 days |
| (b) Second cell | 30 days |
| (c) Third cell | 30 days |

This time cycle shall be repeated for additional cells chosen in accordance with 4.4.2.2 for the duration of the contract. Upon completion of the test and at the intermediate inspections, the cells shall be carefully examined for any evidence of failure. After the examination, if faulty performance is indicated, the cell shall be dissected in the sump area (as shown in Figure 2) and inspected for evidence of failure. In the event of failure of this test, the procuring activity and the contractor shall be notified. Bulletin No. 107 or 435 shall apply."

The above rewrite contains three additions to the original specification paragraph. One is the stipulation that the tank be placed in a "normal ground attitude" during the stand test. This duplicates most of the aircraft's service life and is necessary for a valid test since some water will settle out of the test fluid into the bottom of the tank. Precautions should be taken to assure that the sump configuration during testing is representative of the actual production installation.

The volume of water added to the test fluid (0.1 percent) was selected as an amount which could reasonably be encountered during service conditions and which would allow some water to settle out in the sump area during the test.

The third addition is the specific inclusion of the sump area in the dissection sample. This is to ensure that any deterioration or delamination due to the water will be detected.

The stand test revisions of paragraph 4.6.2 pertaining to water should also apply to paragraph 4.6.6.6, the phase I test cubes stand test. Therefore, the following change is recommended:

"4.6.6.6 Stand test (phase I test cubes). Change "type III fluid" in the second line to read "type III fluid containing 0.1 percent water by volume".

This revision does not include the mounting attitude of 4.6.2 since this is a phase I cell and not geometrically representative of production units.

Consideration was also given to including water in the aging and low-temperature leakage test of paragraph 4.6.7.5. However, it was decided that this "hydrocarbons-only" test should be left intact as a separate check on cell resistance. The stand test duration of 90 days should assure an adequate contaminated fuel test.

MIL-T-6396C - Tanks, Fuel, Oil, Water-Alcohol,
Coolant Fluid, Aircraft Non-
Self-Sealing, Removable,
Internal

7 June 1965

Due to the similarity of the fuel cell specifications, the changes recommended for this publication and the reasons for them are identical to those for MIL-T-27422. The stand test of paragraph 4.6.2 should be revised to read:

"4.6.2 Stand test (sampling). The type II cells selected in accordance with 4.4.2.2 shall be subjected to the following test: The cells shall be collapsed and held strapped for 30 minutes in a position comparable to that encountered prior to installation in its respective aircraft cavity, then released and adequately supported in the normal ground attitude. The cells shall then be filled with the applicable test fluid as specified in 4.5.1. The fluid shall contain a satisfactory staining agent. In addition, the test fluid for fuel tanks shall contain 0.1 percent water by volume. The cells shall be stand tested as follows:

- (a) Each cell selected from the lot shall be stand tested for 90 days.
- (b) The cells shall be inspected at approximately 30-day intervals.

Upon completion of the test and at the intermediate inspections, the cell shall be carefully examined for any evidence of failure and to determine conformance with the standards listed in ANA Bulletin No. 435. After the examination, if faulty performance is indicated, the cell shall be dissected at strategic points (such as areas adjacent to fittings, repaired sections, sump areas, and points of abrupt change in contour and corners) and further examined for evidence of failure. In the event of failure of this test, the procuring activity and contractor shall be notified. An alternate method for detecting leakage during this test is acceptable if approved by the procuring activity."

The revisions made in the above test are identical to those for MIL-T-27422 plus extending the test from 30 days to 90 days duration. This time extension is felt to be justified in view of the number of EIRs submitted for defective and leaking fuel tanks.

The phase I stand test of paragraph 4.6.9 should be revised to include water in the fuel tank test fluid. This is the only revision necessary since the phase I test time is already specified to be 90 days. Thus, the words "plus 0.1 percent water by volume for fuel tanks" should be added at the end of the second sentence.

MIL-T-5578C - Tank, Fuel, Aircraft,
Self-Sealing

31 July 1963

An individual leakage test identical to that added to MIL-T-27422 is recommended for the same reasons as outlined therein.

The revisions made to the stand test of MIL-T-27422 also are recommended for inclusion under Section 4.6.2 of this specification.

It is recommended that the fluid resistance of exterior surfaces test (4.6.5.1) be revised to require immersion for 3 days instead of 24 hours as presently stipulated. An identical change was made to MIL-T-27422B in 1971 because many of the crashworthy self-sealing cells were not sufficiently resistant to spilled fuel. (The fuel was penetrating the exterior barrier and activating the self-sealing material in the cell wall.) It is entirely possible that some of the EIRs submitted for blistered or defective cells were a result of similar problems with the standard self-sealing cells qualified under this specification.

The addition of water to the test fluid (as in the quality conformance stand testing) should also be incorporated in paragraph 4.6.5.5, phase I stand testing, by rewriting the paragraph as follows:

"4.6.5.5 Stand. Following the slosh resistance test (4.6.5.2), a 90-day stand test shall be conducted on the No. 3 test cell. For this test, the cell shall be properly supported, completely filled with type III fluid containing 0.1 percent water by volume, and allowed to stand. The cell shall be carefully examined every 30 days for any evidence of failure. After 90 days, if no evidence of failure is found, the cell will be considered as satisfactorily conforming to this test."

This specification does not call for a phase II preproduction stand test as does MIL-T-6396C, but since it does include a 97-day total aging and low-temperature leakage test during phase II testing, it is felt that the latter should adequately compensate for the lack of a stand test. However, the aging and low-temperature leakage test (4.6.10) should be altered to include water in the fluid used for the 80-day stand portion. The revision should read: "The tank shall then be filled with type III fluid, containing 0.1 percent water by volume and a staining agent, and allowed to stand at ambient temperature...."

The dissection test following paragraph 4.6.10 should also be modified to specifically include the sump area in the dissection sample as follows:

"4.6.10.1 Dissection. After completion of the above test, the cell shall be dissected in the sump area, as shown in Figure 2. The sectioned portion of each cell shall be examined for conditions outlined in Bulletin No. 107."

MIL-T-25783C - Tank, Fuel, Aircraft and
Missile, Non-Self-Sealing,
High-Temperature, Removable

31 March 1966

Specification MIL-T-25783C was reviewed for possible revisions and found to be not presently applicable to Army helicopter fuel systems since it is a specification for high-temperature fuel tanks. The review also disclosed that all the test requirements were very similar to those of MIL-T-6396. The only major difference is that MIL-T-25783 allows higher temperature limits for testing which are often up to the procurer, while MIL-T-6396 sets limits of -65°F to 135°F. If future developments require high-temperature tanks in Army aircraft, the same revisions concerning stand tests as were recommended to MIL-T-27422 should be incorporated in this specification.

FUEL LINES AND HOSES

Eight military specifications for fuel lines and hoses were examined during the program. Suggested revisions and/or comments for each specification are contained in the following paragraphs.

MIL-H-18288 - Hose and Hose Assemblies,
Aircraft, Self-Sealing,
Aromatic Fuel

2 December 1954

Although still listed in the Department of Defense Index of Specifications and Standards, this 20-year-old specification does not seem viable at the present time. It was deleted from the applicable specifications listed in MIL-I-18802 (Fuel and Oil Lines, Aircraft, Installation of) in December 1962. In addition, MIL-F-18287, which covers the end fittings for these hoses, is no longer listed in the Index.

All of the hose tests are contained in a newer specification (MIL-H-7061) for self-sealing hose. The newer specification also contains two additional hose tests: insoluble residue and flexing. However, it is mainly for hoses and does not contain sufficient hose assembly tests. Therefore, it is recommended that hose assembly tests be included in MIL-H-7061 to make it a complete specification for assemblies as well as hoses. MIL-H-18288 may then be disregarded.

MIL-H-7061A - Hose, Rubber: Aircraft,
Self-Sealing, Aromatic
Fuel

6 June 1966

Two changes are recommended for this specification. One change would incorporate additional hose assembly tests as discussed above. At present, the only assembly tests (which validate the strength and nonleaking capabilities of the hose-end fitting attachments) are burst pressure tests performed during qualification. Tests to be added are similar to those required by MIL-H-18288 for self-sealing hose assemblies and require assembly quality conformance tests as well as initial qualification tests. Therefore, it is recommended that the following paragraphs be added to MIL-H-7061A.

"3.5.7 Performance of hose assemblies. Hoses assembled with applicable end fittings shall satisfy the performance requirements specified in Section 4 when subjected to the following tests:

- (a) Proof pressure (4.6.2)
- (b) Burst pressure (4.6.6, 4.6.6.1) "

"4.4.1.2 Additional samples. The qualification test samples shall also include a sufficient length of hose of each size upon which qualification is desired to make up three test assemblies with each of the end fittings conforming to MS28752, MS28753, MS28754, MS28755, and MS28756. The test assemblies shall have a free length of 12 inches between fittings."

Paragraphs 4.5.1, 4.6.1, and 4.6.2 should be rewritten as follows:

"4.5.1 Individual tests. Each length of hose and each hose assembly submitted for acceptance under contract shall be subjected to the following tests:

(a) Examination of product

(b) Proof pressure (4.6.2) "

"4.6.1 Examination of product. All hoses and hose assemblies shall be carefully examined to determine conformance with this specification with respect to materials, workmanship, construction, and marking."

"4.6.2 Proof pressure. Each length of hose and each hose assembly shall be subjected to 100 $\pm$ 5 pounds per square inch, using fuel conforming to TT-S-735, or water, for 5 minutes. The hose shall show no signs of leakage through the hose wall or cover, and hose assemblies shall show no signs of leakage through the hose or between the hose and end fittings. Proof pressure tests of hose only may be accomplished with any suitable end fittings."

The other change is the inclusion of a fuel immersion test to validate the fuel resistance of the outer cover when the hose is used in submerged locations. The necessity for this requirement was demonstrated by the deterioration of the submerged self-sealing hose in the OH-6A. This hose was replaced by a hose conforming to MIL-H-8794 which requires a fuel immersion test for 72 hours at room temperature in TT-S-735 (type III) fluid. Although this study did not reveal any major fuel resistance problems with MIL-H-8794 hose, no information was available on component lifetimes. The 72-hour immersion at room temperature does not seem sufficient to guarantee a reasonable lifetime for the hose in a submerged application. Elevating the temperature or lengthening the immersion time would serve to approximate longer in-use conditions. Elevating the temperature is generally more effective than simply extending the time, and therefore this is the option that is taken in the recommendation. The temperature chosen (135°F) is the maximum fuel temperature specified for Class A fuel system components in MIL-F-8615. Therefore, it is recommended that the following paragraph be added to MIL-H-7061A:

"4.6.15 Fuel immersion. A 12-inch length of hose shall be immersed in fluid conforming to TT-S-735, type III, for 72 hours at a temperature of 135°F. Upon completion of this period, the sample shall be removed and, at room

temperature, shall pass the proof pressure test of 4.6.2. The hose shall then be dissected longitudinally, and any indication of disintegration such as ply separation, solubility of component parts, porosity, blistering, or collapse shall be cause for rejection."

In addition to the above changes and additions, paragraphs 4.6.5.2 and 4.6.5.3 should be deleted, as these tests are already required in paragraphs 4.6.5 and 4.6.5.1.

MIL-H-8795B - Hose Assemblies, Rubber,
Hydraulic, Fuel and Oil
Resistant

21 March 1966

This specification deals with hose assemblies only and not with the separate assembly components, which are required to be MIL-H-8794 hose and MIL-A-5070 adapters (end fittings). This specification details acceptance test requirements only. Qualification test requirements are those specified in the hose and adapter specifications. As such, MIL-H-8795B seems satisfactory and no changes are recommended. However, a change is recommended to the fuel immersion test of MIL-H-8794 as discussed in the following paragraph.

MIL-H-8794D - Hose, Rubber, Hydraulic,
Fuel and Oil Resistant

4 February 1971

This specification seems adequate in all respects except for the fuel immersion test. In order to more closely approximate the effect of fuel on a submerged hose over long periods of time, it is recommended that the temperature of this test be raised to accelerate any damaging effects on the test sample. Therefore, it is recommended that paragraph 4.5.3.5 be revised as follows:

"4.5.3.5 Fuel immersion test. A hose assembly having 12 inches of free hose between the adapters shall be immersed in fluid conforming to TT-S-735, type III, for 72 hours at a temperature of 135°F. Upon completion of this period, the assembly shall be subjected to a static pressure for 5 minutes at the proof pressure specified for fuel in Table I. The test fluid used for pressure checking shall be lubricating oil conforming to MIL-L-6082, grade 1100, or MIL-H-5606 hydraulic fluid. The hose shall then be dissected longitudinally, and any indication of disintegration such as ply separation, solubility of component parts, porosity, blistering, or collapse shall be cause for rejection."

The rest of the specification seems adequate, and there are no further recommendations.

MIL-H-58089 - Hose Assemblies and Hose,
Rubber, Lightweight, Medium
Pressure, and End Fittings 10 March 1969

This specification seems adequate in all respects for both the hoses and hose assemblies, including end fittings. Therefore, no revisions are recommended.

MIL-H-6000A - Hose, Rubber (Fuel, Oil,
Coolant, Water, and
Alcohol) 7 January 1960

Hoses covered by this specification are intended for use in engine installations. The specification also notes that this hose has a tendency to collapse if used in lengths over 18 inches; thus, this type of hose could not be used in the airframe fuel system. In view of the newer, stronger hose now available (as specified in MIL-H-8794 and MIL-H-58089), it is recommended that MIL-H-6000A hose not be used in the fuel system and that this specification not be referenced in aircraft procurement documents.

MIL-H-25579C - Hose Assembly, Tetrafluoro-
ethylene, High Temperature,
Medium Pressure 20 February 1967

There is no external fuel resistance test required by this specification. However, the internal fuel resistance test seems quite adequate. Inasmuch as the hose is constructed entirely of one material reinforced by corrosion-resistant wire, the internal test should serve adequately to determine the resistance of the entire hose. In addition, it is very unlikely that this high-temperature hose would ever be used in a submerged location in Army aircraft. Thus, no external fuel immersion test is required, and no other specification revisions are necessary.

MIL-I-18802A - Fuel and Oil Lines, Aircraft,
Installation of 13 March 1962

All fuel system requirements in this specification are contained in MIL-F-38363B (12 October 1971). The fact that MIL-F-38363B is more comprehensive and specifies quality assurance tests not contained in MIL-I-18802A dictates that

preference be given to MIL-F-38363 or, rather, to the new Army fuel system specification drafted during this program. Therefore, it is recommended that MIL-I-18802 be disregarded and the new draft fuel system specification be used instead.

BOOST PUMPS

MIL-P-5238 is the only military specification which pertains to airframe-mounted fuel boost pumps. Since the latest issue is 13 years old, there are several major revisions which should be incorporated in view of more recent Army aircraft experience. These recommendations are discussed in the following paragraphs.

MIL-P-5238B - Pump, Centrifugal, Fuel
Booster, Aircraft,
General Specification
for

2 February 1961

The large number of boost pump failures may be attributed to a combination of manufacturer deviations from MIL-P-5238 and several deficiencies in the specification itself. For instance, although MIL-P-5238 was specified in the Bell procurement specifications for the UH-1 boost pumps, an exception was made in regard to the fuel inlet screen. MIL-P-5238 requires that the inlet port be completely covered by a number 8 mesh screen and that an inlet bypass be incorporated in the pump in case the inlet screen becomes clogged. The Bell specification for the air-driven pump specifies that the inlet screen extend to a height of 0.5 to 0.75 inch above the mounting flange, with the area above the screen left open to act as a bypass. The electric boost pump may have either a full inlet screen with a separate bypass or a partial screen as in the air-driven pump. Thus, the possibility exists that, especially at high flow rates, a significant amount of fuel may enter the pump without passing through the screen and carry contaminants into the pump mechanism.

Obviously, no revision to the specification will prevent a manufacturer and the procuring activity from requesting and granting specification deviations. However, adequate specification test requirements will help reduce field problems associated with specification design deviations by catching operational problems which might arise due to the design change. The effect of the inlet screen design in the UH-1 pumps, coupled with the presence of contaminated fuel, would not be assessed under MIL-P-5238 requirements, as no contaminated fuel tests are included in the specification.

Since the data gathered during this study showed that fuel contamination is definitely a problem and since the boost pumps function continuously in the highest contamination levels encountered in the fuel systems, it is recommended that the contaminated fuel endurance test of MIL-F-8615, including entrained saltwater solution, be incorporated in this specification. In view of the short field service lifetimes of many of the pumps, it is felt that the duration of the contaminated fuel test should be lengthened from that specified in MIL-F-8615. Accordingly, the following paragraph should be added to MIL-P-5238:

"4.6.14.3 Contaminated fuel endurance. The contaminated fuel test shall be conducted in accordance with MIL-F-8615. The pump shall be operated 12 hours at rated flow and 12 hours at 10 percent rated flow. Upon completion of the test, the pump shall be recalibrated and shall conform to the calibration requirements of the model specification."

Another major revision which is recommended for MIL-P-5238 is the addition of a second 1200-hour endurance test at normal service (cruise) flow rates. ECP 372, discussed in a previous section of this report, was brought about by the failure of the CH-47A boost pumps to run more than 350 hours at normal service flow rates, although the pumps easily passed the endurance test of MIL-P-5238, which specifies 1200 hours of testing at 90 to 100 percent of rated flow. In view of the high failure rates and low service lives of other fuel boost pumps, it is possible that the same phenomenon of insufficient bearing lubrication at lower flow rates is a general problem. Thus, it was felt that some endurance testing under normal service conditions must be incorporated into MIL-P-5238.

Several options were available for incorporating such a test. One was to simply change the present endurance test conditions from 90 to 100 percent of rated flow to normal service (cruise) conditions. This option was rejected immediately, as it would seriously degrade the test requirements for both endurance and operating capability.

Another option, which was seriously considered, was specifying that part of the 1200-hour endurance test be conducted at maximum rated flow and the remainder be conducted at cruise flow. Since the failure of the CH-47 pumps occurred after 350 hours, it was recognized that a significant part of the total 1200 hours would have to be run at cruise flow rates. Thus,

consideration was given to specifying 720 hours (60 percent) at normal rates and 480 hours (40 percent) at maximum rates. This distribution was selected as it gave more weight to actual operating conditions but did not neglect full load or emergency conditions. Careful analysis of the results of such a change, however, showed that decreasing flow rates would also decrease total pump wear and result in a less demanding test than now exists. Thus, this option was also discarded.

The option selected was that of requiring a 1200-hour test at normal flow rates on another pump in addition to the 1200-hour test at maximum flow rates now specified. (The extra 1200 hours was not added to the original endurance test because it was felt that a total of 2400 hours of endurance testing for a single pump was unrealistic.) Examination of the preproduction test schedule showed that the added endurance test could be incorporated following the negative G and dry run test conducted on pump sample number 2. Thus, no additional test samples are required.

It is recommended, therefore, that the following paragraph be added to MIL-P-5238:

"4.6.14.2 Service flow rate endurance test. Pumps shall be operated continuously for 1200 hours at normal service (cruise) flow rates at sea level. The fuel temperature and ambient air temperature shall be held between 60° and 105°F throughout the test. Upon completion of the test, the pump shall be recalibrated and shall conform to the calibration requirements of the model specification."

The contaminated fuel test recommended previously should be conducted on pump number 2 immediately following the added endurance test.

One other revision is recommended to bring the specification up to date. The altitude requirements of the maximum flow rate endurance test should be amended to also specify test chamber altitudes for helicopter pumps. At present the required altitudes are 80,000 or 50,000 feet, which are applicable only for fixed-wing aircraft. Individual helicopter manufacturers have been specifying their own altitudes for pumps in their procurement specifications, and thus altitudes are subject to some variation. Therefore, it is recommended that the altitudes presently required in the MIL-P-5238 endurance tests be specified as applying to fixed-wing aircraft only and that a minimum of 25,000 feet be required for rotary-wing aircraft.

FITTINGS AND COUPLINGS

Four documents are included in this category: two for fittings and two for couplings. The fitting documents are MIL-STD-801 and MIL-F-5577, which are discussed in the following paragraphs.

MIL-STD-801 - Acceptance Standards for
Powerplant Fluid Tank
Fittings

27 May 1959

This publication establishes classifications of defects, standards of finish, limits of conditions requiring no repair, and dissection test inspection criteria for fuel and oil tank fittings. The standard appears to be adequate for its purpose, and no revisions are recommended.

MIL-F-5577B - Fitting, Tank, Powerplant
Fluid, Removable, General
Specification for

27 May 1959

This specification covers general requirements for fittings used on or with removable powerplant fluid tanks. As such, it is advisable that these fittings be able to withstand the same environment for the same length of time as the fluid tanks themselves. One instance of tank fitting leakage was documented (ECP 8172) wherein a design change was requested to the fuel cell compartment in the CH-54 to provide a runoff area for fuel leaking from the fuel tank fittings. It is also possible that several of the maintenance actions reported for leaking fuel tanks could have actually been for leakage from the fittings.

The fuel aging test of paragraph 4.5.2.2.1 for type I fittings is now only 72 hours long. In order to better approximate service conditions, it is recommended that the immersion time be lengthened to at least one week, but preferably one month. The one-month period would then correspond to the shortest fuel tank stand test period now required. Accordingly, it is recommended that paragraph 4.5.2.2.1 be rewritten as follows:

"4.5.2.2.1 Fuel aging. Specimens of rubber stocks for type I fittings shall be subjected to immersion in TT-S-735, type III, fluid for 30 days. After aging, the specimen shall be tested for the physical properties listed in Table III within three minutes after removal. Calculation of tensile strength and adhesion shall be based on the cross-section areas of the specimen before immersion."

The existing fuel resistance and extreme temperature test of paragraph 4.5.3.1.1 lasts a total of 10 days and is run using only clean fuel. Since contaminated fuel is to be expected routinely in service, it is recommended that 0.01 percent water by volume be added to the test fluid occasionally and that total test time be increased. The following revised test schedule is recommended:

Temperature, pressure, and vibration instructions of Table 10 remain as originally specified.

The changes in this test extend total test time by six days and incorporate the contaminated fuel entrained water volume of MIL-F-8615.

There are no other obvious deficiencies in this specification, and no other revisions are recommended.

The two coupling specifications include one for quick-disconnect couplings and one for flexible couplings. Revisions are recommended to both specifications as presented on the following page.

TABLE 10. FUEL RESISTANCE AND EXTREME TEMPERATURE (TYPE 1 FITTINGS ONLY)			
Cycle	Test Fluid	Time	Instructions
1	TT-S-735 (type III)	5 days	As is
2	Air	1 day	As is
3	TT-S-735 (type III) with 0.01% by volume entrained water	5 days	Fitting assembled, agitate 3 times daily
4	Dry Air	20 hours	As is
5	JP-4	3 days	As is
6	Dry Air	120 hours	As is
7	TT-S-735 (type I)	24 hours	As is
8	TT-S-735 (type I)	48 hours	As is

MIL-C7413B - Couplings, Quick-Disconnect,
Automatic Shutoff, General
Specification for

2 February 1970

One of the major failure modes of quick-disconnect couplings has been found to be a combination of vibration, axially applied coupling loads, and maintenance error, causing the coupling to disconnect in flight. MIL-C-7413 was upgraded considerably in this 1970 revision to help alleviate the problem by adding preproduction vibration and contaminated fuel endurance tests as well as functional and pressure tests on each individual coupling. However, instances of precautionary and forced landings are still occurring due to loosening of these couplings; thus, several further revisions are recommended as follows:

3.6.1.1.1 Locking. Add the following sentence to paragraph 3.6.1.1.1.

"The locking mechanism shall be designed to reduce the possibility of human error during assembly and maintenance."

This addition to the design requirements is an attempt to remind manufacturers of the continuing occurrences of "maintenance error" found in incident reports involving quick-disconnect failures. It is realized that this problem cannot be cured by specification revisions, but continuous reminders may help reduce it.

Add a sentence to the end of paragraph 4.6.14.3 so the paragraph reads as follows:

"4.6.14.3 Endurance test procedure. The hose and coupling assemblies shall be subjected to a minimum of 200 hours of fluid circulation and vibration with a minimum of 10 cycles of temperature and pressure; each cycle shall consist of at least 20 hours duration. The total amplitude of the vibration shall be 0.060 inch, and the frequency of vibration shall be 55 $\pm$ 2 hertz. The temperature and pressure readings shall be recorded at least once every hour. The last three cycles (60 hours duration) shall be conducted with a 5-pound tensile load applied on the coupling through the hose."

There is a definite possibility that in-service hose/coupling assemblies can be installed incorrectly so that there is a load on the coupling in addition to the weight of the hose. Even a small load would be expected to stress the coupling in an unpredictable manner and might contribute to failure of the

coupling connection. Thus, it is recommended that the last sentence above be added to 4.6.14.3.

Two alternatives to the three cycles under load were also considered. One alternative was to conduct the entire 200-hour test under load. However, it was felt that the loading might interfere with the vibrations transmitted through the hose to the coupling and that it is necessary to test with these vibrations. An additional 60 hours above the 200 hours was also considered. However, it was felt that the extra time and expense involved in additional testing was not warranted and that the endurance testing would be valid for both conditions under the 140-60 hour combination.

The value of the applied tensile load was arrived at as a minimum requirement. No figures were found which would apply to quick-disconnect loadings, so the 5-pound value was selected as a reasonable minimum load which would result from incorrect hose installations.

A blow-off test of quick-disconnect couplings was considered as a means of setting maximum conditions for their use, but this revision was not recommended since these couplings are not normally used in extreme pressure conditions in Army fuel systems. Therefore, such a test would not justify the additional time and expense to the procurer.

MIL-C-22263B - Couplings, Fuel Line,
Flexible, 125 psi,
General Specification
for

28 June 1972

In an attempt to strengthen leakage requirements and thus reduce the number of incidents and EIRs involving leakage at couplings, it is recommended that leakage be added as a failure criterion in the proof pressure test. Paragraph 4.6.1.2 should be rewritten as follows:

"4.6.1.2 Proof pressure. The test assembly shall be subjected to the proof pressure specified in 4.5.1 for a period of 5 minutes. Any rupture, leakage, permanent set, permanent deformation or damage of any part of the test coupling shall be cause for rejection."

Due to the presence of flexible seals in these couplings, it is recommended that an incremental leakage test similar to that in MIL-F-8615 be added to the first article tests as shown on the following page.

"4.6.1.3 Leakage. The test assembly shall be subjected to pressures ranging from 0 psi to 120 psi in 10-psi increments and held at each level for 1 minute. During this time period the coupling shall be flexed at a frequency of 60 cycles per minute with a 1/2° flexure in any direction. No visible leakage or wetting of the external surface shall be permitted."

The gradual pressure increase of this new requirement should test the ability of the flexible seals to seat well during normal aircraft operations without any aid from the high proof pressure (250 psi).

MIL-C-22263B includes fuel aging and flexure tests with the proof pressure test repeated as the failure criteria. It is recommended that the leakage test of paragraph 4.6.1.3 also be included as post-test criteria for the aging and flexure tests.

In addition to testing the couplings under various pressures, a contaminated fuel test should be added to ensure proper operation of the flexible portion of these couplings and the seals under adverse fuel conditions. Since this specification now contains no such test, the following new paragraph would be necessary.

"4.6.2.5 Contaminated fuel. The test assembly shall be subjected to the contaminated fuel endurance test of MIL-F-8615, followed by the leakage test of 4.6.1.3."

The remainder of the tests appear adequate.

VALVES

There are seven specifications in this category covering a wide variety of valves, including the crash-resistant self-sealing breakaway valves. Very few problems were reported with valves except for a large number (37) of EIRs submitted on the breakaway valves. However, recommendations for revisions have been made to most of the specifications in view of the contamination problems uncovered during the program to prevent similar problems occurring with new designs. The specification for the breakaway valves was completely rewritten.

MIL-V-5018A - Valves, Fuel Selector

17 February 1953

One recommended revision to this specification is to change the contaminated fuel endurance test conditions of paragraph 4.5.7 to read as shown on the following page.

"4.5.7 Contaminated - fuel endurance. Fuel containing the quantity and type of contaminant specified in MIL-F-8615 shall be pumped through the valve in a recirculating system. The valve shall be rotated at an average speed of 1 revolution per minute for 2000 revolutions (1000 clockwise and 1000 counterclockwise). Rotation shall be step-wise, pausing at each valve position for an equal time period. Fuel shall be circulated at the rated flow specified in 4.5.3.6 for the first 500 revolutions, then at 10 percent rated flow for the remaining 500 revolutions. Repeat these flow rates in the opposite direction. Fuel pressures shall not exceed 60 psi. The fuel shall be properly agitated to keep the contaminant uniformly distributed in the circulating fuel. After this test the valve shall be drained and tested for leakage and torque in accordance with paragraphs headed: Interport air-pressure leakage, Interport air-suction leakage, Normal torque, and Torque under pressure. The leakage and torque shall not exceed the values specified therein."

This rewrite contains several basic changes. The fuel flow rate was changed from rated flow throughout the entire test to half the time at rated flow and the remaining time at 10 percent of rated flow, as specified in MIL-F-8615. The reasons for this change are mainly based on the "most severe conditions" testing problems encountered in this study. (Reference ECP372 to the CH-47A, wherein it was found that testing the boost pumps at maximum rated flows and pressures produced entirely different conditions in the devices from those encountered in normal service, so much so that the devices failed as early as 25 percent of tested (endurance) life.)

In the case of the selector valves, the maximum flow rate conditions used during the room-temperature, high-temperature, and low-temperature endurance tests should remain in force as a test of the rotating sealing mechanism, but the contaminated fuel endurance test should be a test of the self-cleansing ability of the valve, and therefore not be assisted by high flow rates and increased fluid turbulence. The 10 percent flow rate is not unrealistic and, in fact, approximates actual normal flow (cruise) rates in some of the smaller observation helicopters.

The valve rotation speed was changed from 8 rpm to 1 rpm in order to increase the time of fluid flow in each position before disrupting the flow while changing positions. This is an attempt to more closely approximate actual service conditions.

The existing test rotation speed of 8 rpm allows only 7.5 seconds per revolution, or 1.25 seconds per position for a six-position valve and 2.5 seconds per position for a three-position valve. The total test time is only 4 hours, 10 minutes. At 1 rpm the six-position valve gets 10 seconds per position, and the three-position valve gets 20 seconds per position. The total test time is thus increased to 33 hours, 40 minutes and should approximate actual mean-time-between-replacement contamination accumulations closer than the 4-hour test. Although a 24-hour contamination test would probably be sufficient in time span and was considered, the desired rpm would have resulted in a decrease from a total of 2000 revolutions to 1440 revolutions. It was felt that this reduction could result in a substantial reduction in valve wear caused by the contaminants and was thus rejected.

The existing contamination test calls for the valve to be flushed out with clear fuel and drained prior to the leakage and torque tests. This has been reduced to just draining the valve, as a clear fuel rinse compromises the validity of contamination testing. In addition, the contaminants specified in MIL-F-8615 have been substituted for the contaminants originally listed in the valve specification. The MIL-F-8615 list contains not only more solid particles but also 0.01 percent salt water, which the MIL-F-5018 list does not. The presence of water in contamination testing is strongly recommended because of the common occurrence of free water as a fuel contaminant.

Another recommended revision is to rewrite the burst pressure test as follows:

"4.5.9 Burst pressure. With valve in the closed position, a fluid pressure of 180 psi shall be applied for a period of 1 minute successively to each port. There shall be no evidence of distortion or other injury to any part of the valve. When the pressure is lowered to 60 psi and to 15 psi and held at each pressure for 5 minutes, there shall be no evidence of external leakage from any portion of the valve. The test shall be repeated with each port of the valve successively in the open position and all other ports plugged."

The purpose of this change - adding a leakage test pressure of 15 psi following the burst pressure test - is to more closely approximate actual conditions for Army aircraft. Army helicopters operate at 5 to 20 psi fuel pressure normally, and damaged seals in the valve under test may be held in place artificially by a high pressure leakage test. However, the

higher pressure test (60 psi) was retained for its applicability to high-performance Air Force and Navy aircraft.

It is also recommended that a paragraph 3.2.4 be added under the "Requirements" section of the specification to read:

"3.2.4 Cable-operated valves. Cable-operated remote valves shall be provided adequate end gap to compensate for cable flex in the compression mode."

This addition is in reference to a change made in the 1972 TM-20 Maintenance Manual for the OH-6A helicopter, wherein it was mentioned that failure to provide adjustment for cable flex could result in partial valve activation instead of the intended precise positioning.

MIL-V-8608A - Valves, Fuel Shutoff, Electric
Motor Operated

19 April 1963

The contaminated fuel endurance test is adequate as it now stands. However, ECP 631 on the CH-47 related problems concerning valves equipped with thermal relief provisions and the clogging of these devices by contamination. Therefore, it is recommended that valves incorporating thermal relief mechanisms be tested for proper operation after the contamination test. Thus, the following subparagraph should be added to paragraph 4.6.8, contaminated fuel endurance:

"(e) Valves equipped with thermal relief provisions shall be subjected to the thermal relief operation test (4.6.5)."

The remainder of the tests appear adequate.

MIL-V-8610A - Valves, Fuel Shutoff Solenoid
Operated, 28 Volt DC

11 December 1962

Recommended changes in the contaminated fuel test procedure for this specification are very similar to those previously recommended for MIL-V-5018A. They consist of changing the test fluid contaminant to that specified in MIL-F-8615 and conducting the test at 10-percent rated flow as well as full rated flow. Thus, paragraph 4.6.4 should be rewritten as follows:

"4.6.4 Contaminated fuel endurance. Fuel containing the quantity and type of contaminant specified in MIL-F-8615 shall be pumped through the valve in a recirculating system. The valve shall be operated at the rate of 6 cpm with the solenoid energized approximately 75 percent of the time for 1000 cycles at rated flow and 1000 cycles at

10 percent of rated flow. The fuel shall be properly agitated to keep the contaminant uniformly distributed in the circulating fuel. An inlet pressure of 25 psi shall be maintained on the valve with the valve discharge restricted to obtain flow rates. The dynamic leakage test, using a shutoff pressure of 25 psi instead of the 60 psi specified in 4.6.6.1, shall be conducted periodically at least once every 200 cycles. At the conclusion of the test, the valve shall be subjected to the calibration tests of 4.6.2."

There are no further recommendations to this specification.

MIL-V-38003 - Valves, Fuel Level Control,
Fuel Tank, Aircraft,
General Specification for

19 May 1966

There is only one recommended revision to this specification. In accordance with the previously outlined findings regarding contaminated fuel test validity, it is recommended that Table II, "Contaminants for the contaminated fuel endurance test" be amended to include the 4-percent saltwater solution (.01 percent entrained in the test fluid) specified by MIL-F-8615C. This addition is extremely important to this component specification since the valve operates in unfiltered fuel received from various refueling sources.

MIL-V-7899A - Valves, Check, Aircraft
Fuel System

16 June 1970

All tests appear adequate. The contaminated fuel test is already required in accordance with MIL-F-8615, and thus no revisions to this test are necessary.

MIL-V-25023B - Valve, Fuel Drain, Self-
Locking

17 August 1967

The major portion of this specification is adequate; however, the contaminated fuel test (4.6.6) specifies that the valve be flushed with clear fuel and drained after the contamination test and before being subjected to the following tests. Inasmuch as these valves are located in low points of the fuel system where contaminants will concentrate, it is recommended that the flushing procedure be omitted to more realistically duplicate service conditions.

MIL-V-27393A - Valve, Safety, Fuel Cell
Fitting, Crash Resistant,
Aircraft, General
Specification for

24 February 1964

MIL-V-27393, which was first published in 1960 and later revised, with minor changes, in 1964, is not adequate for the current technology in this area. This specification was written around a fairly complex valve design and contains dimensions and loads specific to this design. However, since the specification was released, fuel system components, especially the crashworthy fuel tanks, have been upgraded considerably. Thus, the low loads required to actuate the valves in MIL-V-27393 are obsolete. In addition, the rigid dimensional requirements of the valves are not applicable to all helicopter fuel systems. The exceptional performance of the crashworthy fuel system installed in the UH-1D/H shows that the design of these valves need not be specified so rigidly nor is it desirable to do so.

As a result of the stringent and also obsolete requirements of MIL-V-27393, the helicopter manufacturers and the vendors of self-sealing breakaway valves now in use have designed and tested their valves without benefit of any applicable military specification. In fact, there was not even a manufacturer's procurement specification written for the valves in the UH-1D/H. These valves were qualified to a vendor report and MIL-F-8615. The large number of equipment improvement recommendations submitted on the UH-1D/H valves underscores the need for a viable self-sealing breakaway valve specification.

Subsequent to the UH-1D/H crashworthy fuel system design, each aircraft manufacturer has drawn up procurement specifications for the breakaway valves in each aircraft. These specifications have been subjected individually to assessment and approval by the procuring activity. Although this arrangement has proven satisfactory, it is certainly far from optimum as far as efficiency and standardization of the valves are concerned. Therefore, a revision to MIL-V-27393 (MIL-V-27393B) was drafted during this program to specify the requirements for self-sealing breakaway valves.

The need for a viable military specification was recognized several years ago; accordingly, Dynamic Science was awarded a contract in 1970 to develop the necessary requirements for breakaway valves functioning under all conditions and to assemble these requirements into a draft military specification. The results of this report are presented in USAAMRDL Technical Report 71-65, Evaluation of Self-Sealing Breakaway Valves for Crashworthy Aircraft Fuel Systems.⁽⁹⁾ Although a draft specification was written during this contract (Dynamic Science Report 4820-71-23),⁽¹⁰⁾ it has not yet been published.

The experience of the aircraft manufacturers and Dynamic Science over the last several years has contributed to further advancements in the state of the art and a better understanding of the requirements necessary for the valves. Accordingly, the specification drafted earlier has been extensively rewritten during the current program. In addition to extensive editorial changes, rewrite was necessary to provide more detailed requirements for valve performance and, at the same time, to assure the most practical valve requirements from a cost benefit standpoint and especially from a reliability and maintainability standpoint.

The crashworthy criteria in the specification are based on Dynamic Science's experience in the development and testing of self-sealing breakaway valves as exemplified in USAAVLABS Technical Report 71-8 Crashworthy Fuel System Design Criteria and Analysis,⁽⁸⁾ and USAAMRDL Technical Report 71-22, Crash Survival Design Guide,⁽⁵⁾ as well as the report referenced above. In addition to the crashworthy criteria, the specification contains the necessary requirements to assure satisfactory performance during all operating conditions of the aircraft and a satisfactory level of reliability and maintainability. Thus, such requirements as leakage, proof and burst pressure, vibration, corrosion resistance, shock, contaminated fuel, endurance requirements, etc., are contained in the specification as they were in the original draft, although the requirements have been made much more specific in the newer version. These are fairly standard procedures and follow general fuel system and valve practices common to the aeronautical industry. Most of these requirements conform to those of MIL-F-8615, General Specification for Fuel System Components. However, exceptions have been taken to several of these procedures. The following discussion is confined to these paragraphs and to the tests which have been incorporated in the specification for crashworthy requirements. The valve specification is presented in its entirety in Volume II.

Table 11 duplicates Table 1, First Article Tests, in the new draft specification for the breakaway valves. The types of tests required and the number of first article samples are shown in this table. Many of the tests are standard fuel system tests as mentioned above. Examination of the table shows that the first five valves are subjected to the static separation tests after they have been subjected to all the environmental tests to ensure the crashworthiness of the valves following exposure to these conditions. The last three valves are subjected to leakage, pressure, and dynamic separation tests only. The purpose of these latter tests is to assure that the valves function as well under high rates of loading and separation as they do under the static separation tests.

TABLE 11. FIRST ARTICLE TESTS (TABLE 1 IN DRAFT SPECIFICATION)

Examination or Test	Require- ment	Method	Sample Number							
	Paragraph	Paragraph	1	2	3	4	5	6	7	8
Examination of Product	3.11, 3.12	4.5.1	X	X	X	X	X	X	X	X
Pressure Drop	3.9.3	4.5.2	X							
Leakage Before Valve Separation	3.9.4.1	4.5.3	X	X	X	X	X	X	X	X
Proof Pressure	3.9.5	4.5.4	X	X	X	X	X	X	X	X
Burst Pressure Before Valve Separation	3.9.6.1	4.5.5	X	X	X					
Vibration	3.9.7	4.5.6	X							
Fuel Resistance and Low Temperature	3.9.8	4.5.7	X							
Corrosion Resistance	3.9.9	4.5.8		X						
Shock	3.9.10	4.5.9		X						
Surge Flow	3.9.11	4.5.10			X					
Contaminated Fuel Endurance	3.9.12	4.5.11			X					
Acceleration	3.9.13	4.5.12				X				
Fungus	3.9.14	4.5.13				X				
Icing	3.9.15	4.5.14					X			
Static Separation (T = Tension, B = Bending, S = Shear, A = Tension or Bend)	3.9.16 3.9.17	4.5.15	T	B	S	A	A			
Dynamic Separation (T = Tension, B = Bending, S = Shear)	3.9.16	4.5.16						T	B	S
Leakage After Valve Separation	3.9.4.2	4.5.17	X	X	X	X	X	X	X	X
Burst Pressure After Valve Separation	3.9.6.2	4.5.18	X	X	X	X	X	X	X	X
Disassembly and Inspection	3.9.20	4.5.19	X	X	X	X	X	X	X	X

That this is necessary was demonstrated during the breakaway valve evaluation program where parts of a self-sealing valve mechanism became trapped, bent, and subsequently lodged in the valve, preventing actuation of the self-sealing mechanism during the dynamic tests. This phenomenon had not occurred with the valve during the slower separation rates encountered under the static separation tests.

Several major changes were made in the test schedule of the original draft to arrive at that in Table 1 of the new draft. Fuel-resistance and low-temperature tests originally required on valve number 1 after separation were deleted as being unnecessary. The fungus test proposed on valve number 4 following separation was moved ahead in the revised schedule so that it comes before the static separation test. It is felt that this will give a truer indication of the effect of fungus on the crashworthy performance of the valve. However, special precautions had to be incorporated into the test procedure to ensure that the fungus solution saturated the inside as well as the outside of the valve. This had not been necessary when the fungus test was specified on the separated sections of the valve.

Proof pressure tests following valve separation were deleted in the newer draft as it was felt that the required burst pressure tests were all that were necessary to ensure the integrity of the sealed valve half. Similarly, the pressure drop test originally required on all eight valves is now required on only one valve. Inasmuch as the pressure drop is dependent upon the design of the valve, one test should be sufficient to establish the drop for any specific valve design.

The paragraphs of the draft specification dealing with the separation requirements and tests for the valves have been amplified considerably from the requirements contained in the original draft specification of several years ago. Much more detail has been included because subsequent experience showed that the original specification could be misleading to those individuals not intimately connected with the development and philosophy of the crashworthy fuel systems. Although the necessary requirements could have been ascertained in conjunction with the technical reports previously mentioned, it seemed more desirable for the draft specification to be as self-sufficient as possible. The following two paragraphs dealing with separation modes and separation loads are taken directly from the revised draft specification and are presented here for the purpose of discussion.

"3.9.16 Separation modes. Each valve shall separate and seal upon application of a predetermined load (3.9.17) caused by a force producing tension, bending, shear, or combinations thereof in the frangible section of a valve when subjected to the static separation test of 4.5.15. Each valve shall also separate and seal under these modes during the dynamic separation tests of 4.5.16. No load requirements are imposed during the dynamic tests except that the valve must separate and seal before any of the attached hardware fails. If an analysis of the surrounding aircraft structure and probable impact forces and directions indicates that a valve cannot be loaded in a particular direction, that separation mode requirement may be waived subject to the approval of the analysis by the procuring activity and at the discretion of the procuring activity."

"3.9.17 Separation loads. Each valve shall meet all operational and service loads of the aircraft but shall separate and seal at a force between 25 and 50 percent of the force required to fail the weakest component of the fuel system adjacent to the valve. The separation forces for each valve shall be determined by analyzing the surrounding aircraft structure and the probable impact forces on the fuel system components as illustrated in Figures 1 through 4. Moment arms used in bending load calculations shall be those determined by the aircraft manufacturer's analysis of the fuel system configuration and are constant for the standard and crashworthy system. The results of such analyses shall be subject to the approval of the procuring activity. All valves which are located where they are subject to direct impact during a crash by aircraft structure or components, or by objects outside the aircraft, shall separate and seal at a shear force between 25 and 50 percent of the load required to fail the adjacent fuel system components or the valve housing, whichever is smaller. All separation loads shall be verified by the static separation tests of 4.5.15."

There are two points which should be discussed in Section 3.9.16. The first of these is the stipulation that the separation loads need not be measured during the dynamic separation tests. (This is not completely clear in the original draft.) The dynamic separation tests have historically been proof tests only to assure that the valve will separate and seal under dynamic conditions before any of the attached hardware fails. The purpose of eliminating the load requirement is to simplify greatly the test conditions and necessary instrumentation. Experience with breakaway valves in use to date has been that, if a valve meets the required separation loads during the static

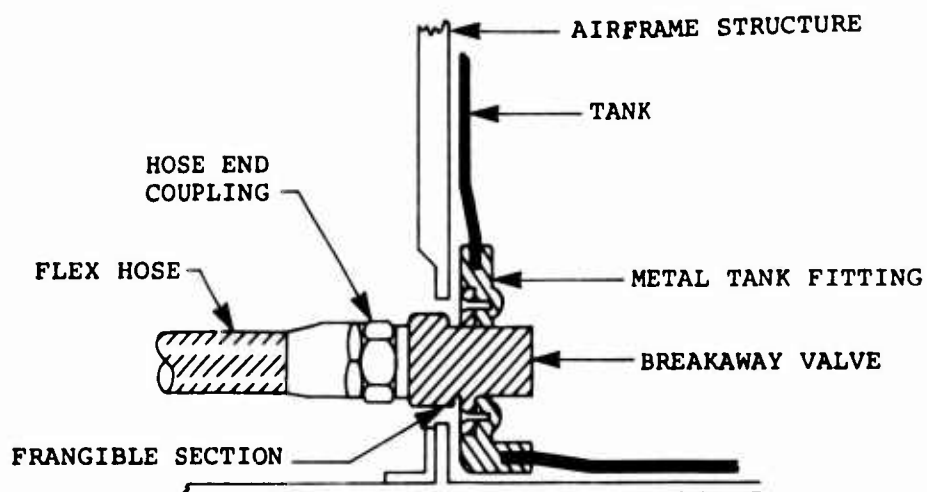
tests, it will separate at appropriate loads during dynamic tests also. As pointed out earlier, however, the dynamic tests are still necessary to ensure that the failure mechanism of the valve during dynamic conditions is not detrimental to functioning of the valve in any way.

The second point to be discussed is the requirement in the last sentence that a particular separation mode may be waived if the analysis of the fuel system and the aircraft structure and impact forces indicates that a valve cannot be loaded in a particular direction. This waiver is designed not only to simplify and shorten the testing of the valve but also to simplify the design of the valve. The experience of the last several years has shown that designing for only two directions is generally sufficient to assure the proper functioning of the valve. This is dependent to a large extent, however, upon the location of the valve, the type of fuel system, and the type of aircraft in which the valve is incorporated. Therefore, this waiver should never be approved except after a very careful and thorough analysis of the probable impact forces, types of impacts, and anticipated crash-induced movements of the fuel system.

Paragraph 3.9.17 on separation loads has been written in as much detail as possible in order to remove any confusion or ambiguity from the load requirements of the valve. For the same reason, Figure 4 illustrates the types of figures included in the specification to describe the conditions which must be taken into account during the analysis used in arriving at the breakaway loads for the valve. The figures illustrate that it is not absolutely necessary to have identical failure loads in all of the failure modes. In some cases it may be necessary, but experience has shown that it is not a general criterion. The necessary loads and the corresponding failure modes of the valve should instead depend upon the analysis of the fuel system and the types of failure modes and loads in the system itself. Allowing different values in different failure modes simplifies the design of the valve considerably.

Specific separation load requirements have not been placed in the draft military specification because these loads are unique for each valve. Because of the wide variety of aircraft and different strengths of fuel system components, as well as a vast difference in operational conditions, it is felt that the valves will perform their functions more efficiently if they are designed for each fuel system application.

Specifications for relative displacement of the valve halves before closure are detailed in paragraph 3.9.18 of the draft specification. This paragraph states that the self-sealing mechanisms of the valve assembly must close before maximum relative displacement of .125 inch occurs between the



Item	Lowest Failure Load (lb)*	Failure Mode**
Flex Hose	3000	Tension Breakage
Flex Hose	1500	Pullout of End Fitting
Tank Fitting	7500	Pullout of Tank
Hose End Coupling	1650	Break (Bending)
Breakaway Valve	2500	Pullout of Tank Fitting
Breakaway Valve	Not more than $\frac{1500}{2} = 750$	
	Not less than $\frac{1500}{11} = 375$	
Breakaway Valve	Not more than $\frac{1650}{2} = 825$	Break at Frangible Section - Bending Mode
	Not less than $\frac{1650}{11} = 412$	
*Loads may or may not be representative; values are for explanatory purposes only.		
**Conduct similar calculations for shear failure mode.		

Figure 4. Sample Separation Load Calculation for Type I (Cell-to-line) Breakaway Valve. (Figure 1 of draft specification)

separating valve sections at the point of fracture. This requirement is contained in the specification to prevent partial separation of the valve with the self-sealing mechanism still in the open position. Although some previous valves have used an internal rubber boot to help guard against such an event, this is not always a satisfactory answer, as was shown in Reference 9.

Only minor modifications were made to the separation test procedures in the original draft specification. However, illustrations of the necessary test setups were added in the revised draft to clarify the procedures. Figure 5 shows one of these illustrations.

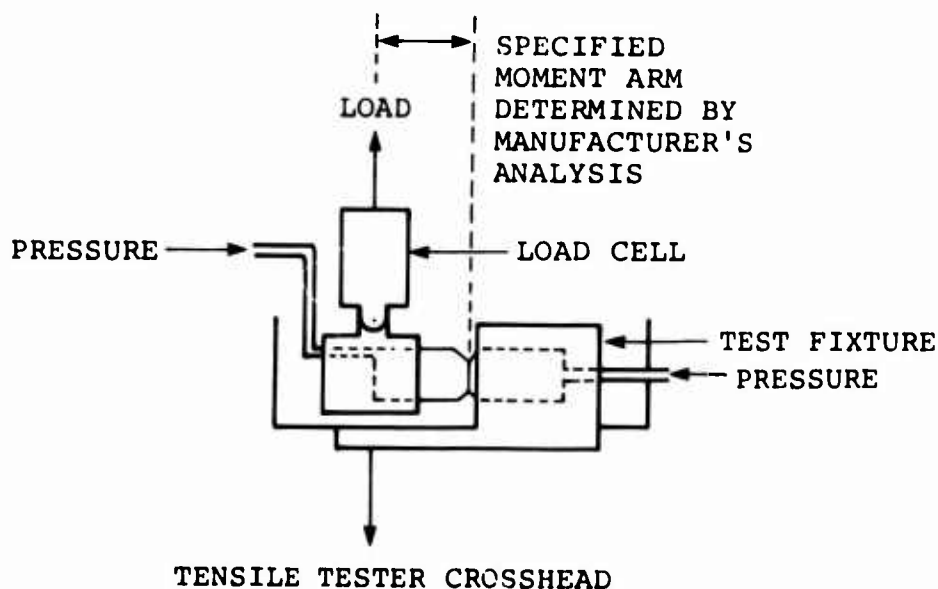


Figure 5. Typical Test Setup for Static Bending Separation. (Figure 6 in draft specification)

Paragraphs 4.5.17 and 4.5.18 (reproduced below) of the draft specification detail leakage and burst tests to be run following valve separation. The leakage test after separation is self-explanatory to assure that the valve has indeed closed and will contain the fuel. The burst pressure test is specified as a convenient means of testing the integrity of each valve half to pressures simulating those which might be encountered during impact. This is to assure that once the mechanism closes, it will remain closed throughout the crash.

Up to 15 cc per minute leakage is allowed during each test as contrasted to the zero leakage specified for these tests before valve separation. The allowable leakage is identical to that specified in the original draft. This amount of leakage following a crash is not considered significantly hazardous to the occupants and greatly simplifies the design requirements as compared to those of valves which must meet zero leakage following separation.

"4.5.17 Leakage after valve separation. Each valve section shall be pressurized over the entire rated pressure range. An initial pressure of -6 psi shall be applied to the valve section and shall be gradually increased to 60 psi over a period of 1 minute for the quality conformance tests and 30 minutes for the first article tests. Leakage shall not exceed that specified in 3.9.4.2."

"4.5.18 Burst pressure after valve separation. Each valve section shall be pressurized to 180 psi and held for a period of 15 seconds, after which the pressure shall be reduced to 60 psi and held for an additional 1 minute. Leakage shall not exceed that specified in 3.9.6.2."

The leakage test required before valve separation is as specified in paragraph 4.5.3 of the draft specification and is presented below. Leakage from this test is held to zero.

"4.5.3 Leakage before valve separation. Each valve shall be pressurized over a range of -6 psi to +60 psi. The pressure shall be brought to -6 psi and held at that pressure for 1 minute. The pressure shall then be gradually increased to 60 psi over a period of 1 minute and held at that pressure for an additional 1 minute for the quality conformance tests and 30 minutes for the first article tests. Leakage shall not exceed that specified in 3.9.4.1."

It may be seen in paragraph 4.5.3 that the initial conditions of pressure are somewhat different from those specified for the leakage test after separation. The leakage test before separation requires that the pressure be brought to -6 psi and held at that pressure for 1 minute. This is a departure from the more general requirements of the original draft. The reason for the time increment at the negative pressure is specifically related to the leakage problems of the UH-1D/H breakaway valves uncovered during this program. The design of these particular valves included a rubber boot bonded to the inside of each valve half. This boot was designed to contain fuel between the time of separation and valve closure. The valves discovered leaking in the UH-1D/H contained faulty bonds

between the rubber boot and the valve body, thus allowing the fuel to leak between the valve body and the boot. This condition was not discovered during regular leakage testing because testing under pressure apparently forced the boot against the metal and no leakage occurred. During later investigation, however, when the valves were tested under vacuum conditions, leakage did occur. This problem is somewhat analogous to that discovered with the boost pumps, in that what might be thought of as worst conditions actually masked the problem that would occur at conditions more nearly equal to operating conditions. To assure that the valves are satisfactory, the leakage test before separation has been required of each valve manufactured. This is common practice for fuel system valves as well as many other fuel system components.

The contaminated fuel endurance test contained in the draft military specification is presented below.

"4.5.11 Contaminated fuel endurance. Test fluid containing the types and concentrations of contaminants specified in MIL-F-8615 shall be circulated through the valve at rated flow for 2-1/2 hours, followed by an additional circulation period of 2-1/2 hours with the test fluid flow rate reduced to 10 percent of rated flow. Following this 5-hour circulation period, the valve shall be subjected to the static separation test of 4.5.15. If a recirculating fluid system is used, the minimum fluid quantity in the system shall equal the total fluid flow for 2 minutes at the rated flow of the valve plus 10 gallons."

The test conditions stated above are essentially those contained in MIL-F-8615. The circulation period of 2-1/2 hours with 10 percent of rated flow is necessary to more closely simulate actual operating conditions seen in the aircraft. Maximum flow rates could easily wash out contaminants which would otherwise be left in the system. The flushing of the component with clear fuel after the test as originally required in MIL-F-8615 has been deleted in the breakaway valve specification. Again, this has been done to more closely simulate the actual conditions that would be present in a valve which is called upon to function during a crash. If flow stagnation areas existed in the valve due to its design, resultant deposits of contamination could possibly build up on a self-sealing mechanism of the valve during operating conditions. This contamination might prevent actuation of the self-sealing mechanism upon separation. This type of problem was in fact experienced during the evaluation of self-sealing breakaway valves reported in Reference 9.

QUANTITY GAGES

Three military specifications are contained in this category: two for gages and one for installation and calibration of gages. These specifications are discussed below.

MIL-G-5672 Gages; Fuel and Oil Quantity,
Float Type Aircraft, General
Specification for

22 March 1950

In general, quantity gaging devices have exhibited good reliability, and this study found no reported problems with the only float type gage in use in Army helicopters: the one in the OH-6A.

Upon reviewing the 24-year-old specification, the only recommendation (aside from updating terminology and document references) is the addition of a solid particle contaminated fuel endurance test to ensure that solid contaminants cannot be deposited in an area which would cause gage malfunction.

It is not necessary to add a gum contaminated fuel test, as one is already incorporated in the specification as the tank unit immersion at room temperature test (4.3.2.1). The gum test is presently run for 200 hours and consists of immersing the unit in a tank of fluid for 2 to 4 hours, then removing and drying the tank unit. This is repeated 50 times with the fuel subjected to sunlight to decompose it. Consideration was given to adding the solid particle contaminants to the gum test fluid, but this was rejected because of the possibility of the solid particles interfering either with the formation of the gum or its deposition on the gage.

The addition of the solid particle test necessitates a change in paragraph titles and numbers to accommodate the test in the proper order. Thus, the following changes are recommended:

1. Change "4.3.2.1 Tank unit immersion at room temperature" to "4.3.2.1.1 Fuel immersion".

2. Add "4.3.2.1 Contaminated fuel endurance".

3. Add the following paragraph

"4.3.2.1.2 Solid particle contamination. The tank unit shall be immersed for 5 hours in TT-S-735, type III, test fluid containing the types and concentrations of contaminants specified in MIL-F-8615. The test fluid and contaminant shall be circulated for 1-minute periods every 30

minutes during the test period. Any corrosion, binding, or tendency to stick shall be cause for rejection of the lot of tank units."

MIL-G-26988B - Gage, Liquid Quantity,
Capacitor Type, Transistorized,
General Specification for 2 February 1968

The design section of this specification should be updated to incorporate crashworthy concepts by adding a paragraph 3.11.8 as follows:

"3.11.8 Crashworthy tank units. - If the gage is to be installed in a crashworthy fuel tank or system, the construction of the tank probe unit shall include a slightly rounded shoe at the bottom of the probe. The probe shall be of low flexural rigidity or include a frangible section which allows column failure of the probe at a load no greater than 75 foot-pounds per inch of circumference."

The recommendations for this addition are derived from those contained in References 5 and 8. The purpose of the requirements is to prevent the probe from puncturing the fuel tank wall before impact. The failure load is based on the requirements for crashworthy fuel tank impact penetration resistance contained in MIL-T-27422B.

In accordance with the findings of this study regarding contaminated fuel problems, it is recommended that a contaminated fuel test be added as a qualification test and as a sampling test under Plan B. Recalibration of the gage after the test will determine if any deposit of sediments has formed between the conductors. Therefore, the following changes should be incorporated:

1. Change "4.6.22 Tank unit water immersion test" to "4.6.22.1 Water"
2. Add "4.6.22 Tank unit immersion test"
3. Add "4.6.22.2 Contaminated fuel. The tank unit assembly of the gage shall be mounted in a suitable tank and the tank filled three-quarters or more with fuel conforming to TT-S-735, type III. The capacitance reading and fuel level shall be noted. Solid particle contaminants as specified in MIL-F-8615 shall then be added to the fuel. The fuel and contaminants shall be circulated for 1-minute periods every 30 minutes during a 5-hour test period. At the end of the test period, the unit shall be removed and placed in clean

type III fluid at the same level recorded at the beginning of the test. The indicator reading shall be noted, and the change of capacitance from the original reading shall not exceed 1.0 percent of the reference capacitance."

MIL-G-7940C - Gages, Liquid Quantity,
Capacitor Type, Installation
and Calibration of

20 August 1971

The only recorded problem applicable to this specification was design oriented and involved quantity probes contacting and chafing cell interiors due to negative internal cell pressures arising from venturi effects at cell vent discharge points. In flight, the angle of the vent outlets in the airstream caused negative cell differential pressures, and the cell deformed sufficiently to allow the quantity probes to contact the inner liner. This problem was detected by performing a flight test similar to that later required by MIL-F-38363, Fuel System, Aircraft, General Specification for, first issued in 1966.

Since a problem of this type is not due primarily to the design of the quantity gage or its installation, but is rather a system problem detectable only by flight tests specified by a general fuel system specification, there are no recommended revisions to MIL-G-7940.

FILTERS

MIL-S-8710 is the only specification which falls into this category.

MIL-S-8710B - Strainer, Airframe Fuel System
General Specification for

10 July 1969

To aid in the reduction of contamination-induced component failures, it is recommended that an additional test be added to this specification for commonly encountered contaminants (the specification tests for maximum contaminant passage size by means of glass beads). The contaminants specified in MIL-F-8615 should be circulated through the strainer to ensure that any internal bypass valves do not stick and that the bypass system operates satisfactorily after heavy contamination. Therefore, the following paragraph should be added as 4.6.9, and current paragraphs 4.6.9 through 4.6.14 should be renumbered as 4.6.10 through 4.6.15.

"4.6.9. Functional-contamination test. Fuel contaminated according to MIL-F-8615 shall be circulated through the strainer at normal cruise flight flow rates until the

bypass system activates. The pressure drop through the strainer shall be monitored, and full bypass must occur within the pressure range specified by the procurer. Any evidence of strainer malfunction, as reflected by sudden changes in the pressure drop prior to bypass, shall be cause for discontinuing the test. The strainer shall then be disassembled and inspected in accordance with 4.6.15."

This test should be run as a preproduction test after the fuel resistance and extreme temperature test.

Another problem relating to fuel strainers, as discovered by this study, was the necessity for installation design changes in filtering requirements associated with the increasing supply and variety of contaminated fuels encountered in the field. ECP 140 (to UH-1 A/B, December 1961) and ECP 8095 (to CH-54, October 1968) both concern new filter elements designed to upgrade filtering capabilities to compensate for higher contamination levels than had been expected. Although contributing to reliability and maintainability problems, the solution lies in the overall design of the aircraft and is directly related to engine performance capabilities, it is thus outside the scope of the revision to MIL-S-8710. Instead, emphasis must be placed on increasing the awareness of designers to contamination problems in order to reduce the number of design changes.

FILLER CAPS AND ADAPTERS

Three specifications were reviewed in this category. They are:

MIL-C-8605 Cap; Pressure Fuel Servicing 14 July 1953

MIL-C-38373A Cap, Fluid Tank Filler 26 February 1969

MIL-A-25896D Adapter, Pressure Fuel
Servicing, Aircraft
Nominal 2-1/2 Inch Diameter 14 March 1969

Although two problems in this area were uncovered during the study, no revisions are recommended to any of the specifications. The following discussion explains the rationale behind this decision.

Filling problems (damage and overflow) using the combined gravity/pressure refueling receptacle in the UH-1D/H undoubtedly accounted for the three EIRs submitted for the pressure cap and adapter. This adapter design is not standard and deviates in size and configuration from the requirements. Thus,

it could not be corrected by any revisions to the specification which seems entirely satisfactory for its purpose.

The other problem consisted of leaking filler cap seals causing three precautionary landings in the 3-year period from 1967 to 1970. One of these was a gravity filler cap, but it is not known whether the other two were gravity or pressure caps. No instances of filler cap seal leakage were reported in the Flightfax during 1973.

The most likely causes for cap seal failure would be excessive wear or environmental and/or fuel aging. However, both cap specifications have quite adequate endurance tests, consisting of 1250 cycles of removing and replacing the cap with fuel exposures of 1 minute each between cycles. In addition, both specifications meet or exceed MIL-F-8615 requirements for fuel resistance and extreme temperature tests.

The seeming adequacy of the specification requirements and the minor nature of the problem (as far as this study was able to ascertain) does not warrant revision of the specification requirements at this time. If this type of failure escalates in frequency or if more data on the types of caps and failures are obtained, the specifications should be reexamined for possible revisions.

SWITCHES

Two types of switches are included in this category: pressure switches and fuel level float switches. The two specifications covering these switches are discussed below.

MIL-S-26390A - Switch Assemblies, Pressure,
Aircraft Fuel

20 May 1969

The high rate of failure of fuel system pressure switches five precautionary landings in 1968-1970, nine from March 1973 to December 1973) prompted a thorough investigation of this specification and other applicable data such as maintenance manuals and manufacturers' specifications and drawings. This study discovered that, like fuel boost pumps, the pressure switches were always installed in the fuel system stream before any filtering devices. Further investigation revealed that MIL-S-26390A contains no provisions for contaminated fuel testing, although the remainder of the specification appears complete and thorough.

To further determine if contamination could be suspected of causing the high failure rate, a helicopter mechanic with gas turbine fuel systems experience was contacted. He

confirmed the possibility, citing several instances of switch failure due to dust contaminating the fuel while refueling at forest fire camps.

With these references in mind, it is recommended that the contaminated fuel endurance test of MIL-F-8615C, as revised by this report, be included as preproduction tests to samples 1 and 3. The test should be accomplished following the endurance and fuel resistance tests on those samples respectively. Thus, the following paragraph should be added as 4.6.11, with the numbers for the current paragraphs 4.6.11 through 4.6.13 being changed to 4.6.12 through 4.6.14, respectively.

"4.6.11 Contaminated fuel endurance. The contaminated fuel endurance tests shall be conducted as specified in MIL-F-8615. Immediately following the test, the switch shall be drained and subjected to the functional (4.6.4) and leakage tests (4.6.5)."

As mentioned previously, the remainder of this specification appears to be adequate.

MIL-S-25980A - Switch, Float, Aircraft
Fuel, Level, General
Specification for

15 June 1965

There were very few reported problems with this type of switch, and analysis of the specification did not reveal any obvious deficiencies. Therefore, no revisions are recommended for this specification.

MISCELLANEOUS

Five specifications are grouped in this category. There were no related problems or obvious deficiencies in the following four specifications:

MIL-T-5624H - Turbine Fuel, Aviation,
Grades JP-4 and JP-5

30 October 1970

MIL-C-7024B - Calibrating Fluid, Aircraft
Fuel System Components

19 May 1969

MIL-I-6181D - Interference Control Requirements,
Aircraft Equipment

25 November 1959

MIL-P-8045B - Plastic, Self-Sealing and
Non-Self-Sealing Tank Backing
Material

10 April 1964

Thus, there are no recommended revisions to the above specifications. The other specification in this category is:

MIL-C-83291A - Covers, Self-Sealing,
Fuel Line, Aircraft

10 August 1972

The only recommendation for improving this specification is to upgrade the fuel resistance test of paragraph 4.5.8. The present test is for 1 hour at 135°F. The recommended change adds a 72-hour test at the same temperature if the cover is to be immersed as follows:

"4.5.8 Fuel Resistance. The covers shall be immersed for 1 hour in TT-S-735 (type III) fluid at 135°F. Any swelling, over deterioration, or cover activation shall be cause for rejection. If the cover is to be used in an immersed location, the test time shall be lengthened to 72 hours."

This change is identical to that recommended earlier for self-sealing hoses (MIL-H-7061A) and is designed to prevent a recurrence of the deterioration of the submerged self-sealing hose in the OH-6A.

CONCLUSIONS

1. No obvious historical trends in design changes or design requirements which have affected the R&M of helicopter fuel systems could be ascertained from the data studied during this program.
2. Analysis of design changes and operational performance data is useful in determining component specification deficiencies.
3. The data analyzed during this program indicate that fuel contamination has been a major cause of fuel system R&M problems in recent years.
4. Fuel boost pumps have been and continue to be prime sources of R&M problems.
5. Endurance testing of components at rated pressures and flow is not always indicative of the components' performance at normal operational pressures and flow.
6. There are no published military specifications applicable for current crashworthy fuel system designs or components with the exception of MIL-T-27422B for crashworthy fuel tanks.
7. Many of the R&M problems uncovered by this study can be alleviated in the future by revising the applicable military specifications.

RECOMMENDATIONS

It is recommended that:

1. Volume II, containing the recommended fuel system specification revisions and new requirements generated during this study, be referenced in all new Army helicopter procurement specifications.
2. The applicable military specifications be revised and the draft specifications be issued as soon as possible.
3. Contaminated fuel endurance testing be included in every fuel system component specification.
4. Endurance test conditions be carefully evaluated for each fuel system component and tests conducted at normal operating as well as rated conditions if warranted.
5. R&M field data be continuously monitored and ECPs requested for those components contributing significantly to R&M problems.
6. R&M data and component engineering changes be utilized on a continuing basis to upgrade specification requirements so that they reflect current fuel system technology.

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APPENDIX

REVIEWED MILITARY SPECIFICATIONS

MIL-STD-801 Acceptance Standards for Powerplant Fluid Tank Fittings

MIL-V-5018 Valves: Fuel Selector

MIL-P-5238 Pump, Centrifugal, Fuel Booster, Aircraft, General Specification for

MIL-F-5577 Fittings, Tank, Powerplant Fluid, Removable, General Specification for

MIL-T-5578 Tank, Fuel, Aircraft, Self-Sealing

MIL-T-5624 Turbine Fuel, Aviation, Grades JP-4 and JP-5

MIL-G-5672 Gages, Fuel and Oil Quantity, Float Type, Aircraft, General Specification for

MIL-H-6000 Hose; Rubber (Fuel, Oil, Coolant, Water and Alcohol)

MIL-I-6181 Interference Control Requirements, Aircraft Equipment

MIL-T-6396 Tanks, Fuel, Oil, Water-Alcohol, Coolant Fluid, Aircraft, Non-Self-Sealing, Removable, Internal

MIL-C-7024 Calibrating Fluid, Aircraft Fuel System Components

MIL-H-7061 Hose, Rubber: Aircraft, Self-Sealing, Aromatic Fuel

MIL-C-7413 Couplings, Quick Disconnect, Automatic Shutoff, General Specification for

MIL-V-7899 Valves, Check, Aircraft Fuel System

MIL-G-7940 Gages, Liquid Quantity, Capacitor Type, Installation and Calibration of

MIL-P-8045 Plastic, Self-Sealing and Non-Self-Sealing Tank Backing Material

MIL-C-8605 Cap; Pressure Fuel Servicing

MIL-V-8608 Valves, Fuel Shutoff, Electric Motor Operated

MIL-V-8610 Valves; Fuel Shutoff Solenoid Operated, 28 Volt DC

MIL-F-8615 Fuel System Components, General Specification for

MIL-S-8710 Strainer, Airframe Fuel System, General Specification for

MIL-H-8794 Hose, Rubber, Hydraulic, Fuel, and Oil Resistant

MIL-H-8795 Hose Assemblies, Rubber, Hydraulic, Fuel and Oil Resistant

MIL-F-17874 Fuel Systems: Aircraft, Installation and Test of

MIL-H-18288 Hose and Hose Assemblies, Aircraft, Self-Sealing, Aromatic Fuel

MIL-I-18802 Fuel and Oil Lines, Aircraft, Installation of

MIL-C-22263 Couplings Fuel Line, Flexible, 125 PSI, General Specification for

MIL-V-25023 Valve, Fuel Drain, Self-Locking

MIL-H-25579 Hose Assembly, Tetrafluoroethylene, High Temperature, Medium Pressure

MIL-T-25783 Tank, Fuel, Aircraft and Missile Non-Self-Sealing, High Temperature, Removable

MIL-A-25896 Adapter, Pressure Fuel Servicing, Aircraft, Nominal 2-1/2 Inch Diameter

MIL-S-25980 Switch, Float, Aircraft Fuel Level, General Specification for

MIL-S-26390 Switch Assemblies, Pressure, Aircraft Fuel

MIL-G-26988 Gage, Liquid Quantity, Capacitor Type, Transistorized, General Specification for

MIL-V-27393 Valve, Safety, Fuel Cell Fitting, Crash-Resistant, Aircraft, General Specification for

MIL-T-27422 Tank, Fuel, Crash-Resistant, Aircraft

MIL-V-38003 Valves, Fuel Level Control, Fuel Tank, Aircraft General Specification for

MIL-F-38363 Fuel System, Aircraft, Design, Performance, Installation, and Data Requirements, General Specification for

MIL-C-38373 Cap, Fluid Tank Filler

MIL-H-58089 Hose Assemblies and Hose, Rubber, Lightweight, Medium Pressure, and End Fittings

MIL-C-83291 Covers, Self-Sealing, Fuel Line, Aircraft