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oeing Vertol Company
P.O. Box 16858
Philadelphia, Penn. 19142

March 1977

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Prepared for

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DE
Fort Eustis, Va. 23604

EUSTIS DIRECTORATE POSITION STATEMENT

This investigation is one of a series being conducted by the Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, to improve inspection and maintenance characteristics on current and future helicopter designs.

The results presented in the report are an excellent first-order assessment of causes and solutions for small hardware problems. Furthermore, the findings provide pertinent quantitative data that can be directly used in preparation of improved hardware specifications and design guides. The objective of the tests conducted during this program was to provide generic data regarding small hardware problems and solutions; consequently, the reader is cautioned in using the results as a product comparison. This Directorate concurs in the conclusions presented herein and is currently planning a follow-on effort to develop a general design guide for Army helicopter fasteners.

Messrs. John Ariano and William B. Sweeney, Military Operations Technology Division, USAAMRDL, served as technical monitors for the contract.

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This is a report on a program to define deficiencies of small hardware of helicopters and recommend corrective action.

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SUMMARY

The small hardware problems of eight helicopters were reviewed in this program to find common aircraft reliability problems specifically occurring as the result of maintenance actions. Deficiencies of the hardware and the installation were defined. Design principles and concepts to reduce further helicopter reliability and maintainability problems were developed.

Airframe hardware and furnishing attachments made up the majority of components studied. Fittings, clamps and other small components in the hydraulic, electrical, pneumatic and fuel systems were also reviewed.

Phase I consisted of the identification of problems by a review of the maintenance data reporting systems and the interrogation of helicopter maintenance personnel and field service representatives.

Over a hundred problems were identified. These problems were reviewed to eliminate duplication and to identify characteristics adversely affecting inspection and maintainability. After several reviews, six problem areas were selected as representative of the many small hardware malfunctions and were reviewed in detail to determine failure causes. The six problem areas chosen were: screw head driving recess (all aircraft), fasteners (AH-1G flight control access panel), fasteners (CH-47 induction system fairing), latches (CH-47 battery access panel), retention clip (CH-54 stay rod) and fuel drain valve (CH-47).

During Phase II, a state-of-the-art hardware survey was conducted to determine if new concept development was required. Candidate replacement hardware was selected for each problem area.

In Phase III, present components and candidate replacement components were subjected to a variety of tests, among which were endurance, vibration, environment, maintenance abuse, and static strength tests.

Many of the test failure modes were typical of those experienced in helicopter service, leading to a better understanding of the factors that caused failure than was previously possible. The characteristics of the hardware design, manufacture, or installation that contributed to malfunction were then identified.

Recommendations for improvements in the installation of hardware are made. These define the limitations of present hardware, the necessity for better hardware application data, and additional specification and test requirements to diminish the number of recurrences of identified failure modes.

PREFACE

This helicopter small hardware program was performed under contract to the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia. Phases I and II of this program were under the technical cognizance of Mr. William B. Sweeney and Phase III was under the technical cognizance of Mr. John Ariano of the Military Operations Technology Division.

The author wishes to acknowledge the valuable contributions to this program by the following Boeing Vertol personnel: H. J. M. Smith, Project Engineer for Phases I and II; Kirk Rummel, Technical Manager; and J. W. Woolman, Engineering Test Laboratories Engineer, who was responsible for much of the test planning and test direction.

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INTRODUCTION

OBJECTIVE

The objectives of this report are to define the deficiencies of Army helicopter small hardware relative to the inspection and maintainability characteristics and to define design principles and concepts that will limit further helicopter reliability and maintainability problems.

This report is to provide the airframe designer with design guidelines in a practical and understandable form so that the problems of past and current small hardware designs related to inspection and maintenance requirements will not be repeated in the next generation of aircraft.

There are basically two tasks: first, identifying inherently poor hardware for replacement with better hardware; and second, providing design and application ground rules so that the improper application of good hardware is less likely.

These objectives are accomplished through the analysis of similar hardware on many different aircraft, the study of their problems to identify poor hardware and good and bad hardware applications, and finally, the design and test of current and candidate replacement hardware for known problem installations.

SMALL HARDWARE DEFINED

Small hardware comprises the following types of components.

1. Airframe
   - Latches
   - Quick-Release Fasteners (one-quarter turn and multi-turn removable)
   - Bolts, Screws, Detent Pins, Panel Fasteners
   - Hinges, Stay Rods, Furnishing Attachments, Tie-down Pins, Tie-down Hooks

2. Hydraulics
   - Connectors, Bulkhead Fittings
   - Charging Valves
   - Clamp Blocks
   - Flexible Hoses

3. Electrical
   - Cannon Plugs, Connectors
   - Clamps
   - Bulkhead Fittings

4. Pneumatic

- Hose Connectors
- Marmon Clamps
- Bulkhead Fittings

5. Fuel

- Bulkhead Fittings
- Clamps
- Drain Valves

The typical small hardware problems examined in this program are shown in Figure 1. These are the types of problems whose individual impact on reliability and maintainability (R&M) problems is unexciting, but whose collective impact is significant in terms of cost and additional maintenance.

IMPORTANCE OF THE PROBLEM

It is universally accepted that the development of improved levels of R&M in future Army helicopters is necessary. One parameter for determining the importance of an R&M problem is the unscheduled maintenance frequency in terms of the overall system or aircraft failure rate.

Taken collectively, small hardware is a big problem. As shown in Figure 2, hardware malfunction accounts for 20 percent of the CH-47 airframe system failure rate; nearly 40 percent if rivets are included (Reference 1). The CH-47C airframe failure rate in turn is 37 percent of the entire aircraft. Similarly, as shown in Figure 2, the UH-1F airframe hardware failure rate accounts for 50 percent of the airframe system failure rate. Rivets are included in this figure as the maintenance data reporting system does not permit discrimination between rivets and other hardware. The UH-1F airframe failure rate is 30 percent of the total aircraft rate.

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[1] Aronson, R. B., and Barrett, L. D., RELIABILITY AND MAINTAINABILITY PROGRAM FOR SELECTED SUBSYSTEMS AND COMPONENTS OF CH-47 AND UH-1 HELICOPTERS, Document D210-10846-1, Boeing Vertol Company, Philadelphia, Pennsylvania, September 1974.

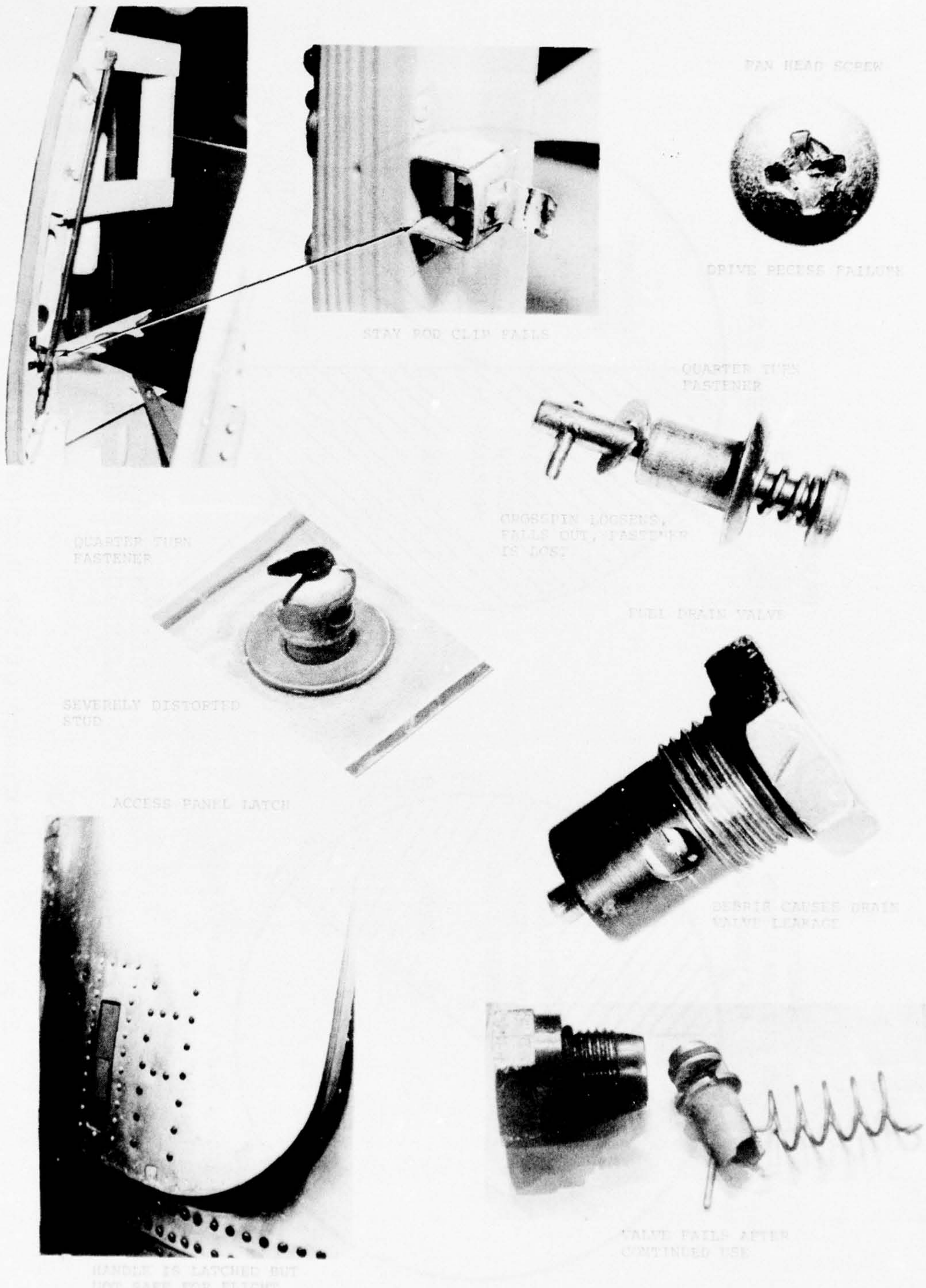

Figure 1. Typical Small Hardware Problems

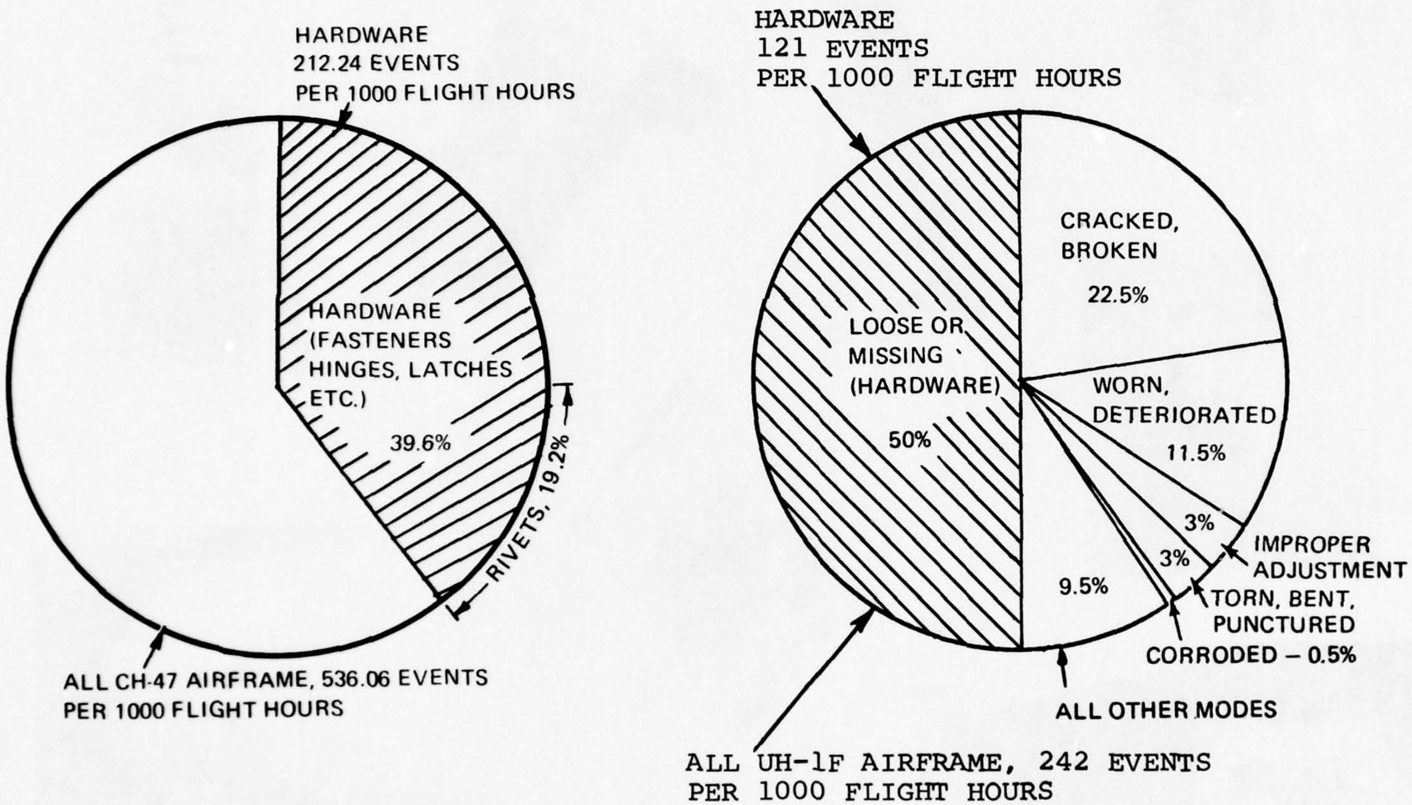

Figure 2. Importance of the Hardware Problem

- Installations do not make clearly evident the success or failure of an operation. For example, latches appear latched and fasteners secured, when, in fact, a mechanism or fastener is partially disengaged.

- The consequence of inadvertent operation is not always a consideration.

In nearly every case examined, proper application of existing hardware would greatly alleviate the causes of malfunction without the need for new hardware development.

A contributing factor to the malfunction of some hardware was found to be inadequate quality control. Surprisingly, "vibration" was not identified as a contributing factor in any of the categories of failure of the components investigated; although it is clearly a significant contributor to the structural chafing and fretting problems of the helicopter.

The following recommendations for minimizing future hardware problems are discussed in detail in the text of this report.

1. More thorough hardware design and application data is needed for the aircraft designer.

2. Design standards should protect against maintenance abuse by quantifying improper maintenance forces in the specifications.

3. Existing aircraft design specifications should be reviewed to eliminate ambiguity in hardware specifications. For example, standardizing fastener sizes is expressed as desirable but not as a requirement.

4. Human engineering features must be considered in the design.

    - The success or failure of an operation should be clearly evident.

    - The function and method of operation of a component should be obvious, and the consequences of improper operation should be benign.

One possible method for the implementation of the above recommendations would be to prepare additional specifications or to modify the existing specifications. While this may work for specialized items such as fuel drain valves, for other items, such as fasteners, the specifications now available to the designer are so numerous that this may be part of the problem.

In the case of fasteners, a better approach might be a fastener design guide. This might contain cross-references of available specifications to aid the designer, discussions of proper hardware application and installation factors, and guidelines to avoid potential hardware malfunctions.

This test program clearly identified the value of component functional tests in the real installation with an analysis of failures, causes and failure modes. Tests of this type carried out early in the prototype stage and followed by corrective action would be cost-effective in terms of reduced maintenance and increased reliability. It is recommended that such tests be required on all new aircraft.

TECHNICAL DISCUSSION

OVERVIEW

This program consisted of three phases. Phase I was the identification of problems common to Army helicopters that occur as the result of inspection and maintenance actions. After a review of over a hundred problem areas, 38 areas considered typical of helicopter small hardware were selected for further investigation.

In Phase II a detailed study of these problems was made to determine probable failure causes. Following this, a state-of-the-art hardware survey determined whether currently available components would improve maintenance and reliability characteristics of these problem areas or whether new concepts were required. One or more approaches were selected for candidate replacement hardware for each of six typical problem areas, and test programs were defined to permit a comparative evaluation of the present and candidate components.

Phase III consisted of the procurement of hardware for evaluation followed by the comparative testing of present production components and the candidate replacement hardware. Limitations of present hardware were then defined, and recommendations were made for improvements in future installations.

PHASE I

The small hardware problems of the following eight helicopters were examined in this study: CH-46, CH-47, CH-54, AH-1, UH-1, BO-105, OH-6, OH-58.

The problems examined were those occurring as the results of inspection and maintenance actions in the areas of organizational, direct, and general support, and whose collective impact was significant in terms of the cost and maintenance burden.

The hardware investigated included:

1. Airframe hardware, such as the many types of fasteners, the door and panel hardware, and the tie-down pins and hooks
2. Hydraulic, electrical, pneumatic, and fuel system fittings, clamps and other small components

Three areas were explored in order to identify problems:

1. A search of the maintenance data reporting systems and other reports

2. Input from field service engineers

3. A field survey

The data search concentrated on the following sources:

1. CH-47C Helicopter

- U. S. Army Aviation Test Board
  Fort Rucker, Alabama
  (100-percent reporting of unscheduled maintenance events)

2. CH-46, UH-1, and AH-1 Helicopters

- U. S. Navy Integrated Maintenance and Material Management System (3M)

The U. S. Army Aviation Test Board Data for the CH-47C gave good definition to identify problems in terms of failure item, rate, and mode. The Navy 3M data did not do so; however, it did define general problem areas. Consequently, the specific problem within the area could not normally be defined, and the quantitative rates could not be considered representative.

Quantitative rates in the 3M system represented rates in the general area of the problem rather than the specific rate for an identified problem.

The maintenance data reporting systems of the U. S. Army (TAMMS) and the U. S. Air Force (AFM66-1) were also examined. These also failed to precisely identify problems. A discussion of the limitations of these data systems for application to this type of analysis was documented in the "Reliability and Maintainability Program for Selected Subsystems and Components of CH-47 and UH-1 Helicopters" (Reference 1).

Other reports were also reviewed in unsuccessful attempts to determine the required problem definition.

The best sources of problem identification were found to be field personnel: the U. S. Army Transportation Training School noncommissioned officers, maintenance supervisors, mechanics, line chiefs, and pilots; and Boeing Vertol field service engineers.

The problems discussed and demonstrated were those of immediate concern to the maintenance personnel or company representatives. They were very specifically defined, but they were identified independently of any data search and could not be quantified in terms of failure rate per flight hour. Attempts were therefore made to quantify them on a perceived frequency basis during discussions with maintenance personnel.

The Army Transportation Training School operations tend to emphasize small hardware problems since mechanic training is involved. For example, during an examination of one helicopter (a CH-54) it was noted that a hydraulic line had been crushed. Since this was an external line on the aircraft, it was suggested to the maintenance personnel that this had probably been caused by being stepped on. The maintenance personnel agreed and, having pulled the hydraulic line back into its original, pre-"stepped-upon" location, assured the writer that this would not happen with the aircraft in actual operations, but only happened because of the training school environment. However, it seems reasonable to assume that problems of this type (occurring during maintenance training) are typical of in-service problems.

Appendix A summarizes the 107 problems that were reported by field personnel for the eight helicopters reviewed.

The reported problems were then subjected to a "filtering" process as follows:

1. Assure that the problems originated as the result of a maintenance or inspection operation.

2. Avoid duplication.

3. "Weigh" the importance of similar problems by the frequency of occurrence in various helicopters.

As a result of this procedure, 38 problems were selected for a more detailed study. These problems are listed in Table 1.

Table 2 shows that these 38 problems fall into nine categories, with latches and quick-release fasteners having the highest reported frequencies of occurrence.

On the basis of the importance of the problem and the duplication on several aircraft, the list was reduced to 15 problems to be examined in Phase II of this program.

PHASE II

The initial effort in this phase was a more thorough analysis of the 15 problem areas selected. The following factors were determined for each problem.

1. Summary of contributing factors and probable failure causes

TABLE 1. 38 SMALL HARDWARE PROBLEMS

CH-47

- INDUCTION SYSTEM PANEL FASTENER
- BATTERY ACCESS PANEL LATCH
- AFT PYLON LATCH FASTENER
- ENGINE WORKPLATFORM RELEASE PIN
- FWD COWLING LATCH
- FUEL DRAIN VALVE
- ACCESS PANEL SCREWS
- ENGINE ANTI-CHAFING SEALS
- HYDRAULIC PIPING CLAMP
- AFT PYLON LOWER FAIRING FASTENERS
- FUEL POD, FOOT STEP LOCK

AH-1

- ACCESS PANEL LATCH
- ENGINE COMPARTMENT LATCH
- ACCESS PANEL FASTENERS

CH-54

- ACCESS PANEL - STAY ROD CLIP
- ACCESS PANEL FASTENERS
- ACCESS PANEL SCREWS

BO-105

- SOUNDPROOF ATTACHING STUD
- CLAMSHELL DOOR STRUT FASTENER

OH-58

- ENGINE COWLING - LATCH
- ENGINE COWL STAY ROD CLIP
- TRANSMISSION COWLING FASTENERS
- BATTERY ATTACHMENT FASTENERS
- TAIL BOOM ACCESS PANEL SCREWS
- CREW DOOR HINGES

CH-46

- FWD PYLON FAIRING LATCH
- SHAFT TUNNEL COVER FASTENER
- AFT SWASHPLATE ACCESS PANEL FASTENER
- AFT PYLON WORK PLATFORM LATCHES
- AFT CLAMSHELL HINGE BOLT

UH-1

- ACCESS PANEL LATCH
- ACCESS PANEL STAY ROD CLIP
- ACCESS PANEL LATCH
- NOSE ACCESS PANEL LATCH
- NOSE ACCESS PANEL HINGE
- ENGINE COWLING LATCH
- TAIL BOOM ACCESS PANEL FASTENER

OH-6

- TAIL BOOM ACCESS PANEL FASTENERS

TABLE 2. 38 PROBLEMS SUMMARIZED BY CATEGORY

PROBLEM A/C	LATCHES	QUICK RELEASE FASTENERS	HINGE PROBLEMS	SCREWS	DRAINS	STAY RODS	CLAMP	BATTERY ATTACH.	SEALS
CH-54		✓		✓		✓			
CH-47	✓✓✓✓	✓✓✓		✓	✓		✓		✓
CH-46	✓✓	✓✓	✓						
UH-1	✓✓✓✓	✓	✓			✓			
AH-1	✓✓	✓							
OH-58	✓	✓	✓	✓		✓		✓	
OH-6		✓							
BO-105		✓✓							
TOTAL	13	12	3	3	1	3	1	1	1

2. Observed failure modes

3. Component design task requirements

4. Design alternates based on a state-of-the-art hardware survey

5. The necessity for new design concept development based on a survey

The results of this investigation were reviewed with the USAAMRDL personnel, and the following six problems were then selected to be laboratory tested in Phase III.

1. Pan Head Screw Driving Recess

2. AH-1G Flight Controls Access Panel Fastener

3. CH-47 Induction System Fairing Fastener

4. CH-54 Stay Rod Clip

5. CH-47 Battery Access Panel Latch

6. CH-47 Fuel Drain Valve

Typical malfunctions of these six items were shown in Figure 1.

In the survey of state-of-the-art hardware, different hardware was found for each of the six problem areas, and the state-of-the-art hardware offered the possibility of greatly reduced malfunction rates. Thus, there appeared to be no need for new hardware concepts.

One or more candidate hardware designs were then selected for each of the six applications, and test plans were prepared for comparing the present and candidate replacement in Phase III. Testing was planned to simulate the aircraft maintenance environment so that representative failure modes would be obtained. The tests included endurance, vibration, environment, maintenance abuse, and static strength tests.

PHASE III

Test quantities of present and candidate replacement hardware were procured for each of the six problem areas studied. Hardware installations used actual aircraft components for four of the areas and used simulated applications for the other two areas. A summary of the testing, results, conclusions and recommendations for each of the six areas follows. The first problem area, dealing with pan head screw driving recesses, is covered in more detail in Appendix B for the benefit of any future investigation.

PAN HEAD SCREW DRIVE RECESSES

OBJECTIVE

To evaluate maintenance problems associated with cross recess screws (Phillips) and to evaluate improved alternate fasteners.

DESCRIPTION OF PROBLEM

Background

The difficulty of removing cross recess head machine screws has been reported as a common Army helicopter hardware problem. Screws used in secondary helicopter structure may be removed as frequently as once every hundred hours, or as infrequently as once every 1200 hours. Nevertheless, the large number of screws used in the helicopter make screw malfunction a significant problem.

The aircraft manufacturer's assessment of the performance of a (cross-head) screw will differ from an Army aviation maintenance crew's assessment. An aircraft manufacturer has experience with and assesses performance of new fasteners. He uses production-type, properly maintained tooling. He uses power screwdrivers and frequently has better access to fasteners than will be available to the Army mechanic, either because of scaffolding used to provide a safe, convenient work place or because equipment that will obscure the fastener and limit its accessibility can be installed after the fastener in question is tightened. He seldom has to remove a fastener, and if a driving recess is damaged at installation, the aircraft is still functional and may be delivered with built-in maintenance headaches.

The Army aviation mechanic uses hand tools for field maintenance and may have restricted access to fasteners. He may be working on curved panels that make the judgment of screwdriver alignment very difficult. The screws may be painted, corroded, or abraded; the recesses may be filled with contaminants and deteriorated from previous use. His assessment of a fastener's performance is quite different from that of the manufacturer.

This program has attempted to assess the performance of a fastener from the point of view of the Army mechanic rather than the aircraft manufacturer.

Contributing factors to screw malfunction as reported from field-service maintenance problem surveys are:

1. Head recesses are filled with paint during production and repair, preventing proper gripping of the screwdriver and resulting in the stripping out of the head recess.

2. Head recesses fill with dirt, sand, and debris, preventing proper gripping of the screwdriver, which then strips the head recess.

3. Corrosion of the screw-head recess prevents the proper gripping of the screwdriver, contributing to the stripping of the head recess.

4. Corrosion of the screw threads causes seizing and increases the breakaway torque for screw removal.

5. Paint fillets between the head and the mounting structure increase the breakaway torque for screw removal.

6. Tools of the wrong size or type or in poor condition that are used to attempt screw removal ruin the head recess.

Design Requirements

The functions of the pan head screw are to provide the following:

1. A semipermanent attachment of panels, fairings or secondary structure to the aircraft structure

2. An aerodynamically acceptable contour and an aesthetically appealing surface for the external skin

3. An attachment for panels with a minimal tendency to impede sliding movement in floor applications

4. A fastener that is reliable when exposed to the helicopter operating environment and that is easily maintained by Army field-level personnel

TECHNICAL APPROACH

Since the problem is not with the screw performance in helicopter operation but with the screw's installation and removal characteristics during field-level maintenance, the following were chosen for test evaluation with the baseline fastener, the alloy-steel Phillips head fastener.

1. Corrosion-Resistant Material

2. Alternate Head Recess Designs

Corrosion-Resistant Materials

The common structural machine screw used in Army helicopters, MS 27039, is alloy steel of either specification MIL-S-8695 or MIL-S-6050, and cadmium plated in accordance with Specification QQ-P-416, Type II, Class B.

A corrosion-resistant steel pan head screw of Specification AMS 5735 (A286) may also be specified in an MS 27039 pan head screw if desired. These two materials specify the same strength level so any difference in performance in an adverse environment should be primarily from the difference in the corrosion-resistance of the materials.

Alternate Head Recess Designs

Malfunction of screwdriving-recesses has been the major factor in the development of the many types of screw head recesses shown in Figure 3. The characteristics of the standard cross recess screw head of Army helicopters, the Phillips head, and the many alternates were reviewed in terms of the Army maintenance environment and the utilization of the Aircraft Mechanic's General Tool Kit (Reference 2).

Five candidate replacement screwdriving recesses were selected for test evaluation with the Phillips head.

1. Slotted Head
2. Hexagonal Recess (Allen) Head
3. Pozidriv®
4. Torq-Set®
5. Tri-Driv®

The backgrounds of the baseline head recess (Phillips) and the five candidate replacement screw head recesses, shown in Figure 3, are given below.

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[2]Supply Catalog 5180-99-CL-A01, TOOL KIT, AIRCRAFT MECHANIC'S: GENERAL, National Stock Number 5180-00-323-4692, Department of the Army, Washington, D. C., 18 May 1973.

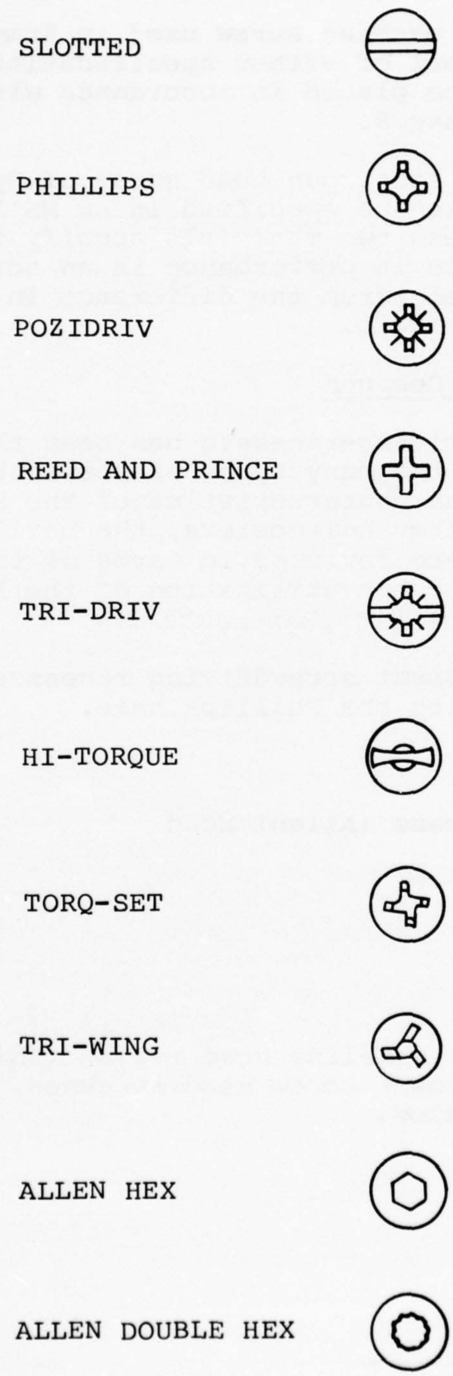

Figure 3. Screw Driving Recess Types

Baseline Fastener - Phillips Head

The Phillips head screw was developed prior to World War II in response to the needs of the automobile industry. The slotted screw head had proven deficient for use in the automobile assembly line in two areas: (1) it was only marginally adaptable to power screwdriving, and (2) a slipping screwdriver frequently damaged the automobile's body paint. Touch-up of this scratch interrupted the assembly line.

The Phillips head screw permitted the use of a power screwdriver with little possibility that the bit would slip and mar the panel. Furthermore, the sides of the recess were slightly tapered so that the driver would tend to "cam-out" if overtorqued, rather than break the fastener, this being before the widespread use of torque-limiting power drivers. This is the standard head recess configuration for the MS 27039 fastener. Dimensional data is given in MS 9006.

Four sizes of Phillips screwdrivers cover the range of machine screw sizes from No. 2 through 9/16-in. diam. These screwdrivers are currently in the Aircraft Mechanic's General Tool Kit.

Candidate Replacement Fasteners

Slotted Head - This screw head needs no description. It is the traditional screw head with a single slot that has been used for well over a century for common hardware. The slot is not completely standard as there are variations in slot width for different diameter screws and some military standards call for different slot widths for the same size screws.* If a screwdriver blade does not closely fit the slot, both in thickness and in width, there is a tendency for the blade to slip and damage the screw head.

There is no current military standard governing application of a screwdriver slot to a pan head screw. Dimensional data for the slotted recess is in accordance with that specified for a pan head screw in ANSI B18.6.3. There are several sizes of flat tip screwdrivers for slotted screws in the Aircraft Mechanic's General Tool Kit.

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* AN508 calls out a 0.040 + .007-in. slot width for a #10-32 screw while AN503, MS35275, and MS35276 call out a slot width of 0.050 to 0.060-in.

Allen (Hexagonal Socket) Head - This hexagonal socket head is another familiar screw head with a long history of application, principally for high-strength bolts. A major advantage of this screw head is that the driver cannot slip unless the torque limit of the screw or driver is exceeded and one or the other becomes deformed. This usually occurs well above the normally applied torque. However, once the parts are deformed, the screw is very difficult to remove.

There is no current military standard governing the application of a hexagonal socket to a pan-head screw. Dimensional data for the hexagonal recess is in accordance with that specified for a No. 10 screw in MS 16996. A key set for socket head screws containing 11 keys varying in width across flats from 0.050 to 3/8-in. is contained in the Aircraft Mechanic's General Tool Kit.

Pozidriv - The Pozidriv fastener (Phillips Screw Company, Licensor) was developed as a successor to the Phillips screw to take full advantage of torque-limiting power screwdrivers. Accordingly, the sides of the recess are vertical so that there is no tendency for the drive to "cam-out" at high torque. The recess appears similar to the Phillips and will accommodate the Phillips drivers, but the Pozidriv driver cannot be used with a Phillips recess as the flutes of the driver are thicker than the Phillips recess will allow. Four sizes of Pozidriv drivers cover the range of machine screw sizes from No. 2 through 9/16-in. dia.

The Pozidriv head system is widely used in Europe, and it is proposed for adoption as the international standard cross recess head for metric fasteners.

There is no current military standard governing the application of a Pozidriv recess to a pan-head screw. Dimensional data for the Pozidriv recess is in accordance with that specified for a pan-head screw in ANSI B18.6.3.

The Aircraft Mechanic's General Tool Kit does not contain Pozidriv screwdrivers. However, as the recess is designed to accommodate the Phillips screwdrivers, maintenance of an aircraft assembled with Pozidriv recess screws can be conducted with the Phillips driver which is in the tool kit.

Torq-Set - The commercial aircraft industry wanted distinctly different screw heads to indicate high-torque, high-strength screws. Two recessed heads which were developed to meet this need are the Hi-Torque (Rudy Vaughn, Licensor) and the Torq-Set (Phillips Screw Company, Licensor).

Use of these two fastener types was restricted to the aircraft industry. The Torq-Set, which was chosen for this evaluation because of its wider use in the industry, uses a 4-fluted driver, while the Hi-Torque uses a single, curved end blade. The Torq-Set has a different screwdriver size for each screw size. Dimensional data for the Torq-Set recess is in accordance with Military Specification MS 33781.

The Torq-Set recess cannot be used with any screwdriver now contained in the Aircraft Mechanic's General Tool Kit although the Torq-Set screwdrivers are available in the military system.

Tri-Driv - This screw head has a slot and a Pozidriv recess so that a conventional flat-bladed, a Phillips or a Pozidriv screwdriver can be used. This is a versatile fastener that may offer considerable time-saving to a mechanic who wants to do "on-the-spot" maintenance with the tools on hand, or if the slotted or the Pozidriv portion of the head recess has been destroyed. The Tri-Driv can be used with power screwdrivers. Dimensional data for the screwdriver slot and the Pozidriv recess is in accordance with the applicable sections of ANSI B18.6.3.

Maintenance of aircraft assembled with Tri-Driv screws can be conducted using either the flat-bladed or the Phillips screwdriver of the Aircraft Mechanic's General Tool Kit.

Tri-Driv is a trademark of the Russell, Burdsall and Ward Bolt and Nut Company.

TEST EVALUATION

Detailed Test Objectives

Evaluate maintainability and reliability problems associated with Phillips cross recess head screws and candidate replacement fasteners. Maintainability and reliability characteristics are to be evaluated under the following simulated operational conditions.

1. Exposure to dirt, mud, rain, and the abrasive effects of foot and forklift traffic.

2. Exposure to high humidity.

3. Endurance with nominal and over-torques applied.

4. Normal helicopter paint systems.

5. Improper tools and other maintenance abuse.

In addition to the above, the screws are to be evaluated for any possible reduction in strength due to the head recess configuration.

Testing and Results

Appendix B describes in detail the testing performed on pan head fastener recesses. While this description appears in an appendix, it is important because it gives an example of the testing that should be performed at the design stage to minimize reliability and maintainability problems with small hardware.

SUMMARY OF RESULTS

Improved Screw Driving Recesses

The performances of the screw head driving recesses in the following aspects are compared in Figures 4A, 4B, and 4C.

1. Number of specimens completing 30 cycles of endurance testing.

2. The ability to re-use the fastener in a limited fashion after screw head recess failure. Screws which failed while being tightened could often be loosened and vice-versa.

3. Ease of cleaning the screw slot. This is an important parameter for floor panel use or other use in contaminated areas.

4. Driving effectiveness, relating to the frequency of "cam-out" of the screwdriver from the head recess since this added to the maintenance time and damaged the head recess.

5. Failure torque. Either the maximum torque experienced in endurance testing for fasteners which did not complete the 30 cycles, or the torque-to-failure value found at the completion of 30 cycles.

6. Ease of driver maintenance. If new tools are not readily available, the ability to rework a damaged screwdriver becomes important.

7. Security from panel damage. If a screwdriver slips from the recess the attaching panel may be scratched. While the damage to the panel is largely aesthetic, the paint system is broken and corrosion can begin unless the paint is touched-up (another maintenance action).

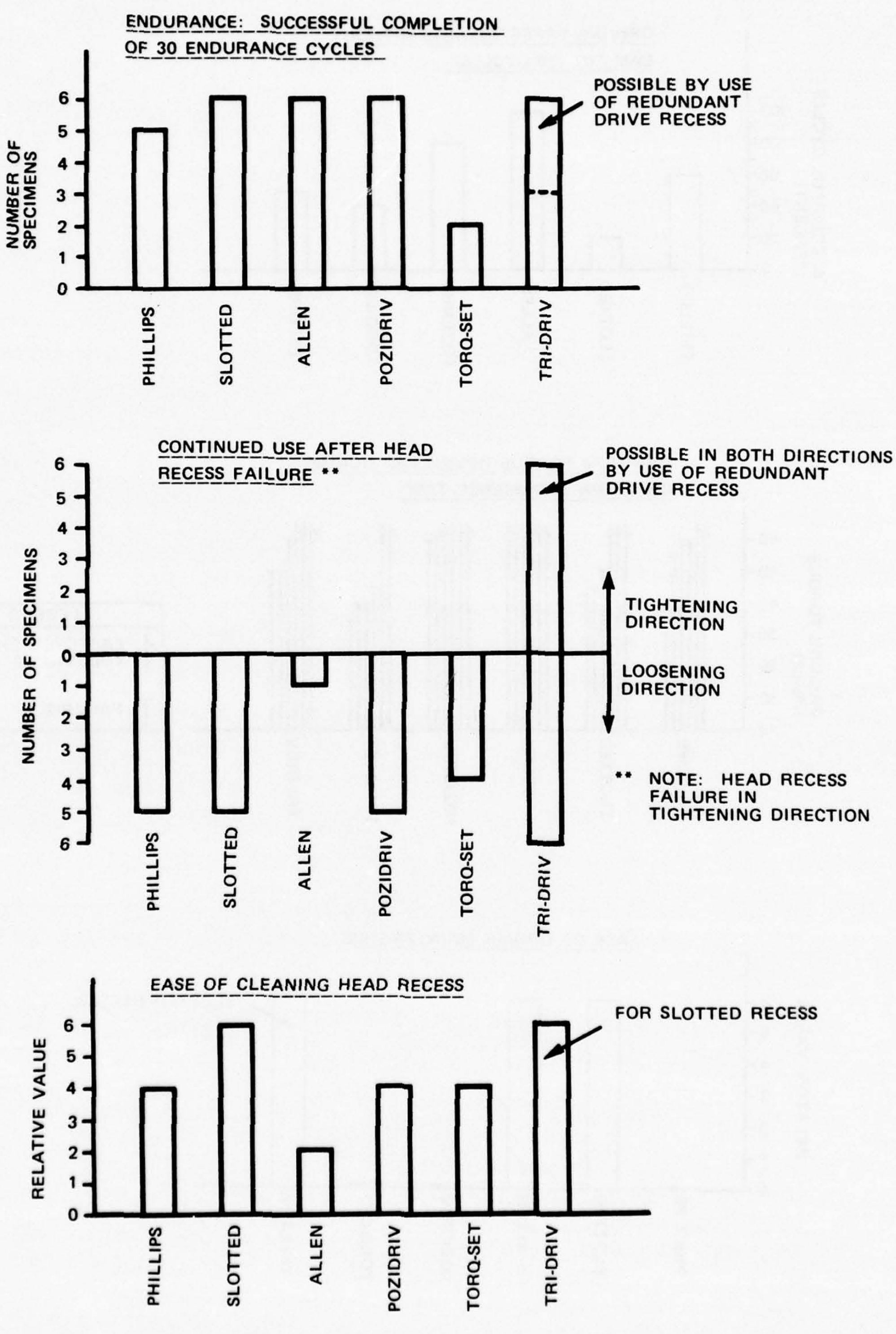


Figure 4A. Drive-Recess Performance

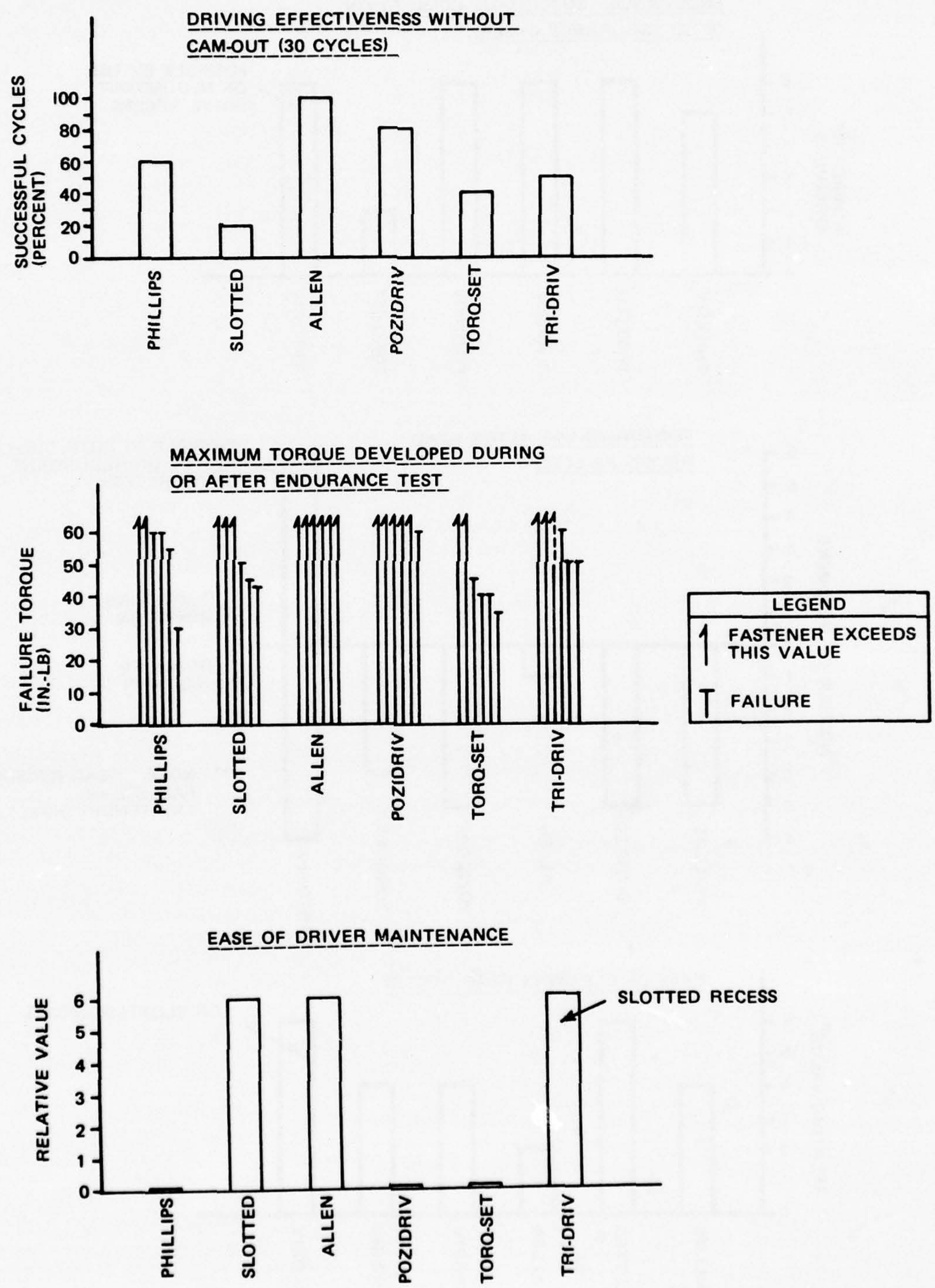
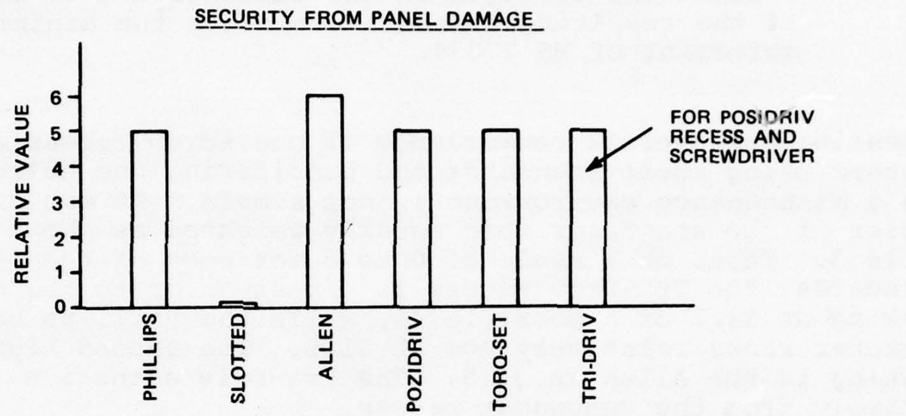
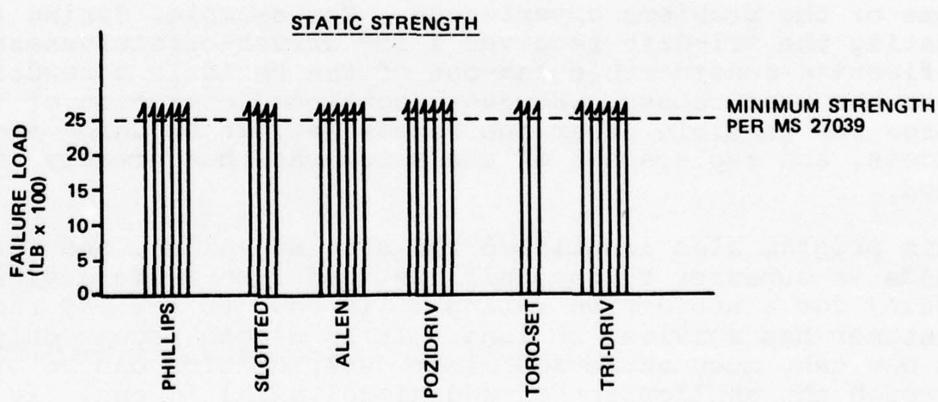


Figure 4B. Drive-Recess Performance





NOTE: DUE TO ALLEN HEAD RECESS DESIGN, FAILURES OCCURRED AT HEAD-SHANK ATTACHMENT AND FAILURE LOADS WERE CONSISTENTLY 10 PERCENT LOWER THAN THE OTHER SCREW FAILURE LOADS.

Figure 4C. Drive-Recess Performance

8. Static strength. A tensile test of the fasteners was made to determine if the head recess configuration reduced the strength of the fastener and to determine if the resulting strength was above the minimum requirement of MS 27039.

Assessing the overall performance of one screw recess against another using these standards and considering the helicopter field maintenance environment is not simple. It would be easier if the standards were equally weighted as shown in Table 3. Then, on a scale of 0 to 6 for each of the eight standards, the Tri-Driv recess is far superior to the others, ranking at 43.7 of a possible 48, while the Phillips baseline fastener ranks relatively low at 31.5. The second highest ranking is the Allen at 38.5. The Tri-Driv earns its rating entirely from the redundant recess.

Subjectively, the author believes that the Tri-Driv is the head recess of the six above that is best for the helicopter field maintenance environment. It can be used with the slotted and Phillips drivers that are in the present Aircraft Mechanic's Tool Kit, and it can be used internationally with the Pozidriv (metric) driver. The redundancy feature of this recess balances some of the problems experienced. For example, during this testing the Tri-Driv received a low driver-effectiveness rating, reflecting considerable cam-out of the Pozidriv screwdriver from the head recess. However, continued operation of the screw was possible after one recess failure by using another recess, and replacement of the screw was thus greatly simplified.

This program also identified the slotted, Allen, and Pozidriv heads as superior to the Phillips head from a field viewpoint. Again, for a subjective rating it is easy to see why the slotted fastener has survived so long. It is a good recess only because it can take much abuse and minor deterioration can be overcome through the application of additional axial forces. It is easily cleaned. However, the fastener must be carefully driven or cam-out will occur; so it is appreciably slower and annoying to use. It is poorly suited for power assembly tools. It makes an excellent redundant drive recess for the Tri-Driv, but otherwise it is a step backward from the baseline Phillips recess which is currently the standard of use.

The Allen recess was very practical to use. No cam-out occurred using this recess, and the recess acted like a spline in aligning the screwdriver. No axial force was needed to develop full torque. This testing was done with a screwdriver bit, although this bit is not presently in the Aircraft Mechanic's Tool Kit. The kit does contain a hex key set. Considerably higher torque

ASPECT OF RECESS EFFECTIVENESS	HEAD RECESS TYPE					
	PHILLIPS	SLOTTED	ALLEN	POZIDRIV	TORQ-SET	TRI-DRIV
ENDURANCE	5.0	6.0	6.0	6.0	2.0	6.0
CONTINUED USE	2.5	2.5	0.5	2.5	2.0	6.0
EASE OF CLEANING	4.0	6.0	2.0	4.0	4.0	6.0
DRIVE EFFECTIVENESS	3.6	1.2	6.0	4.8	2.4	3.0
FAILURE TORQUE	5.4	5.3	6.0	6.0	4.6	5.7
DRIVER MAINTENANCE	0	6.0	6.0	0	0	6.0
PANEL DAMAGE	5.0	0	6.0	5.0	5.0	5.0
STATIC STRENGTH	6.0	6.0	6.0	6.0	6.0	6.0
EQUAL WEIGHTING SUMMARY	31.5	33.0	38.5	34.4	26.0	43.7

TABLE 3. DRIVE RECESS EVALUATION FACTORS

levels are possible with a key set, and the driving characteristics and susceptibility to recess failure may be completely different. The mode of failure exhibited by the Allen recess in the static tension test and the torque-to-failure test (failure of the head shank attachment) is probably one of the least desirable maintenance aspects of any found during this testing. The head recess weakens this area, and it is possible that an Allen recess is impractical in a pan head screw. Additional design and test effort would be needed before this fastener recess would be recommendable.

The Pozidriv recess gave very good performance. It showed much better performance than the Phillips in terms of successful endurance cycles and driver effectiveness. This testing of the Pozidriv recess was conducted with a Pozidriv screwdriver bit. Additional testing might be in order using a Phillips screwdriver to investigate the maintenance problems that could occur during a transition to Pozidriv fasteners.

The optimum screw head recess from the helicopter maintenance and reliability viewpoint may not yet have been found. Other design options are available. At least two other redundant driving methods are in use and deserve evaluation before a final selection is made. These are a combination of slotted and Allen hexagonal socket, and the combination of external hexagonal head and Phillips recess of National Aerospace Standard NAS 1096. Possibly even better combinations could be found. However, this program has shown that improved screw head recesses are currently available for immediate introduction if desired, and of these, the Tri-Driv appears to be superior on the basis of these tests.

<u>Corrosion-Resistant Materials</u>

Benefits of the use of corrosion-resistant steel screw material were in two areas.

1. Torque retention of the corrosion-resistant, self-locking nut, plate-screw assemblies lasted approximately twice the number of screw removal cycles as the alloy steel fasteners after adverse environment exposure. The loss of locknut torque in helicopter service may result in the loss of the screw because of the normal vibration levels.

2. Corrosion-resistant screws exhibited lower breakaway torques after exposure to an adverse environment than did alloy steel screws. It had been reported prior to this study that screw thread corrosion caused seizing and increased breakaway torque, contributing to screw recess failure. Table 4 shows average breakaway torques for corrosion-resistant and alloy

TABLE 4. SCREW BREAKAWAY TORQUE HISTORY

CONDITION	ALLOY STEEL AVERAGE TORQUE (IN.-LB)	NUMBER OF FASTENERS	CORROSION-RES. STL. AVERAGE TORQUE (IN.-LB)	NUMBER OF FASTENERS
FIRST ASSEMBLY/REMOVAL	10.3	18	13.8	18
REMOVAL AFTER FLOOR PANEL TEST	30.7	16	24.8	19
REMOVAL AFTER HUMIDITY TEST	39.1	16	30.0	22

steel screws at an initial assembly, after exposure to the environment in the floor panel test, and after the humidity test. Although a substantial increase in breakaway torque occurred in both the alloy steel screws and the corrosion-resistant screws, the increase for the alloy screws was much larger and approached the throw-away torque values for the screws of 40 in.-lb given in TM-1520-227-20-1 (Reference 3).

Corrosion of the screw head recesses had been reported prior to this testing as a contributing factor in head-recess failure; corrosion prevents gripping of the screwdriver. Although the rusting of the head recesses of the unpainted alloy steel screws occurred during the floor panel and the humidity tests, this could not be confirmed as a significant factor in head recess failure since no failure occurred in any head recess during this testing. One hundred and forty-four screws were involved, seventy-two of which were alloy steel.

It had also been reported prior to this study that paint fillets between the screw head and the mounting structure added to screw breakaway torque and contributed to head recess failure. This effect could not be confirmed by this testing. The painting of the screw head was not observed to have any influence on screw breakaway torque based on testing of 145 painted and 143 unpainted fasteners.

Paint buildup in the screw head recess had also been reported as a factor in screw recess failure. This also could not be confirmed. Possibly the paint buildup on the test screws was not representative of that on an aging helicopter.

CONCLUSIONS

Two approaches were evaluated to obtain improved maintenance and reliability characteristics as compared with the baseline Phillips cross recess head, cadmium-plated alloy-steel, pan-head screw:

1. Use of alternate head recesses.

2. Use of a corrosion-resistant steel material.

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[3]Technical Manual 1520-227-20-1, ORGANIZATIONAL MAINTENANCE MANUAL, ARMY MODEL CH-47B AND CH-47C HELICOPTERS, Department of the Army, Washington, D. C., August 1973.

Both of these approaches were found to have merit. It is concluded that:

1. Improved screw head driving recesses from a maintenance and reliability viewpoint are available.

2. Corrosion-resistant steel screws give significant M&R benefits.

Other contributing factors to the malfunction of screw-head driving recesses were found to be the following:

1. Screwdriver misalignment, which causes the camming-out of the driving surfaces from the screw head recess.

2. The use of self-locking nuts with high friction torques, which require constant axial force on the screwdriver to prevent cam-out from the head recess. Cam-out results in head-recess damage.

3. Sand, dirt and debris fill the head recess and must be removed to prevent cam-out and damage to the recess.

4. While it appeared obvious that excessive torque failed screws, this testing showed that alloy steel screws installed at nominal torque values required breakaway torques approaching recess failure values after exposure to floor panel use or to high-humidity conditions. Corrosion-resistant steel screws exhibited this phenomenon to a much lesser degree.

AH-1G FLIGHT CONTROLS ACCESS PANEL FASTENER

OBJECTIVE

To evaluate maintenance problems associated with access-panel quick-release fasteners by means of an evaluation of the fasteners currently used in the AH-1G flight controls access panel and a candidate alternate fastener for that application.

DESCRIPTION OF PROBLEM

The AH-1G helicopter has a panel on each side of the fuselage underneath the stub wing, as shown in Figure 5. The panels, which are shown in more detail in Figure 6, are attached by quarter-turn fasteners so that they can be quickly removed for inspection and maintenance of the flight control hydraulic-system components. The malfunction of these fasteners is reported as a common Army helicopter maintenance and reliability problem.

The reported failure modes are:

1. Severe distortion of the stud, which interferes with operation. Figure 7 shows a splayed, distorted stud on a panel removed from service.

2. Distortion and pounding out of the stud retaining grommet sometimes results in loss of the stud. Figure 7 also shows a distorted stud retaining grommet on a panel removed from service.

3. Excessive wear of the stud - "Studs wear and drop out."

4. Deterioration of the screwdriver slot.

All reported and observed in-service malfunctions involve the stud assembly (either the stud or the retaining grommet). No deterioration of the receptacle has been reported.

Contributing factors in fastener malfunction are reported to be:

1. Frequency of utilization - daily inspection of flight controls necessitates frequent operation of the fasteners.

2. Vibration - the high vibration environment causes constant cycling of the panel in the panel's surroundings, and severe fretting around the fastener holes frequently occurs as shown in Figure 8.

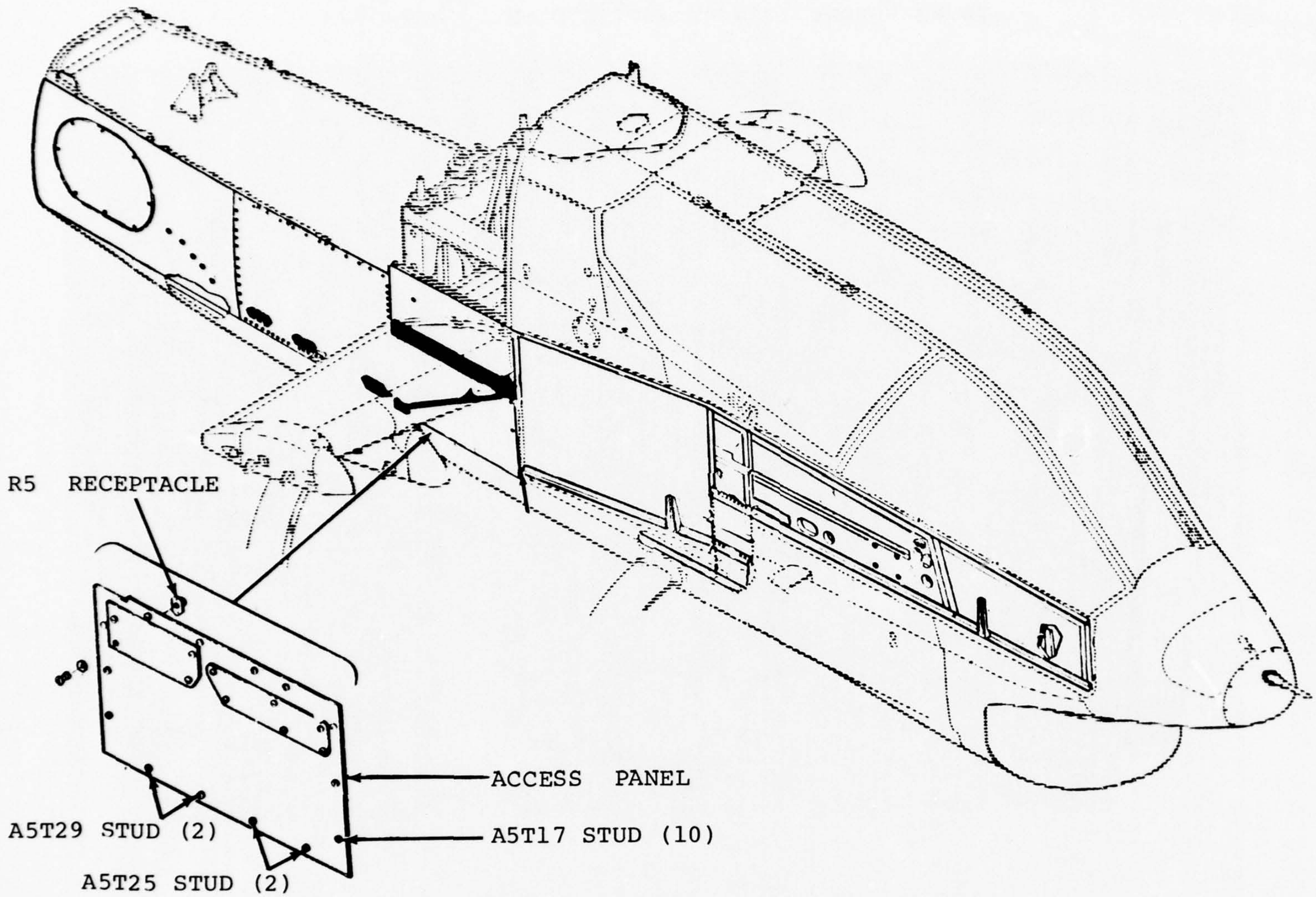

Figure 5. AH-1G Flight Control Access Panel Location (Right Hand)

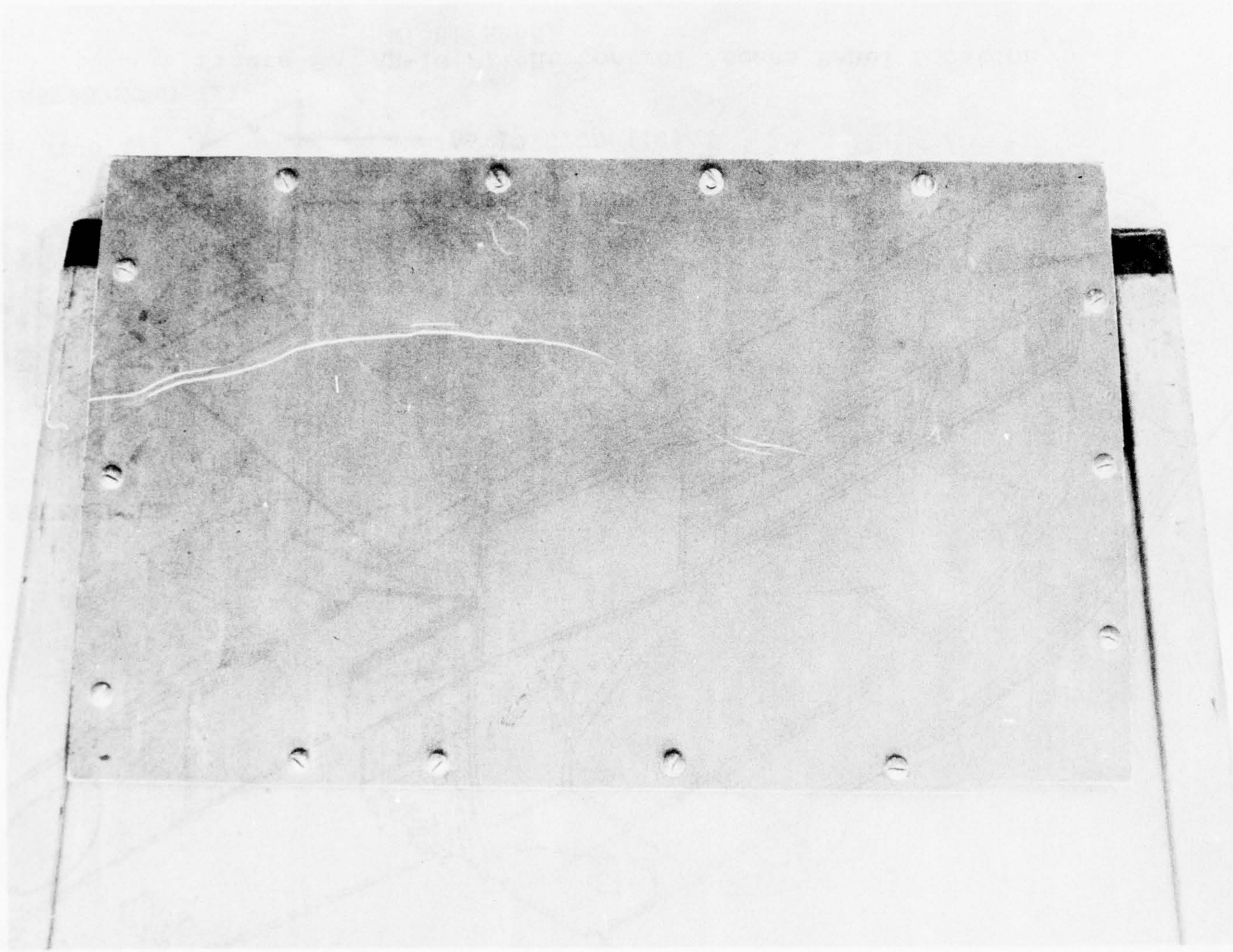

Figure 6. AH-1G Flight Control Access Panel

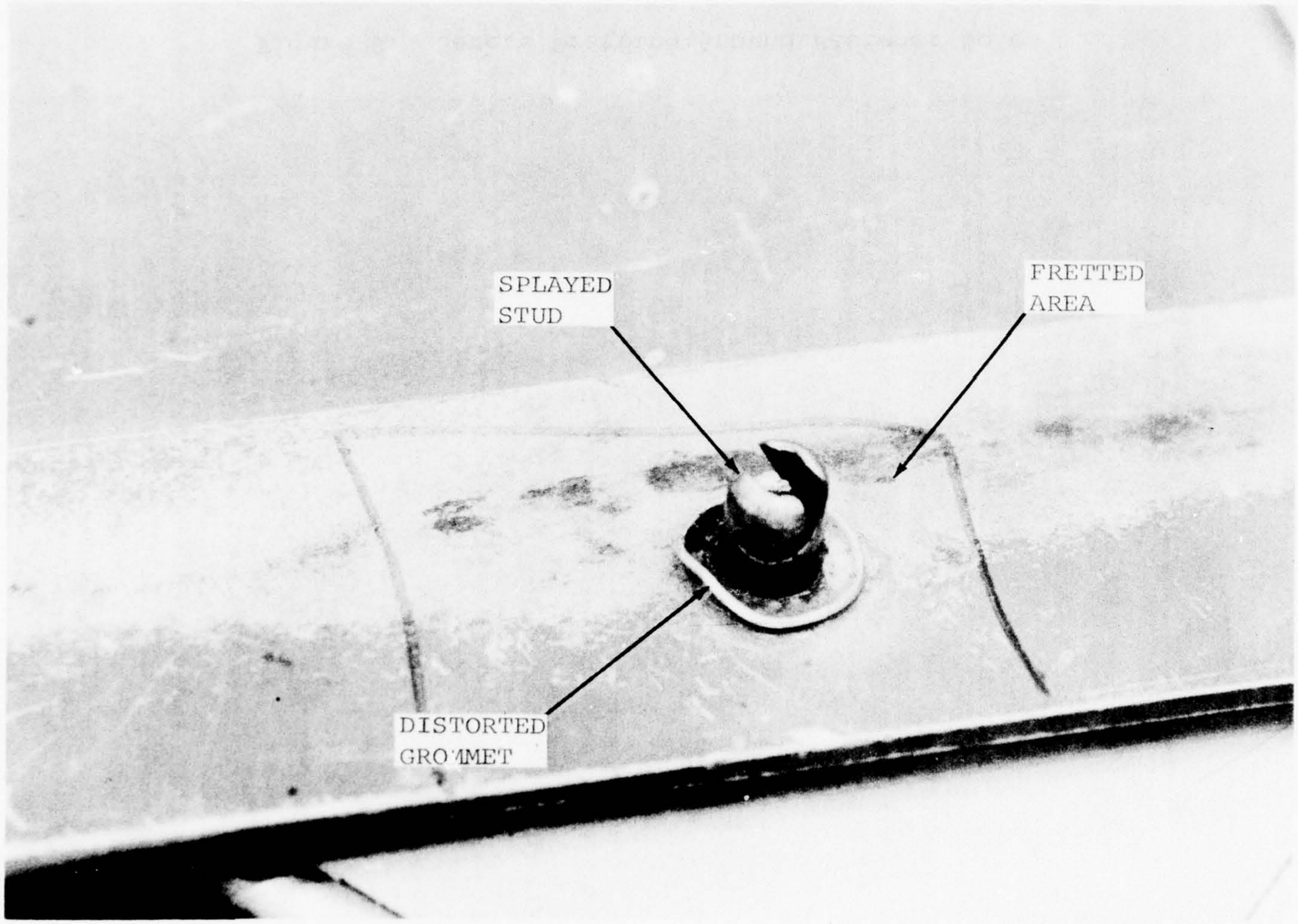

Figure 7. Distorted Stud-Retaining Grommet and Splayed Stud

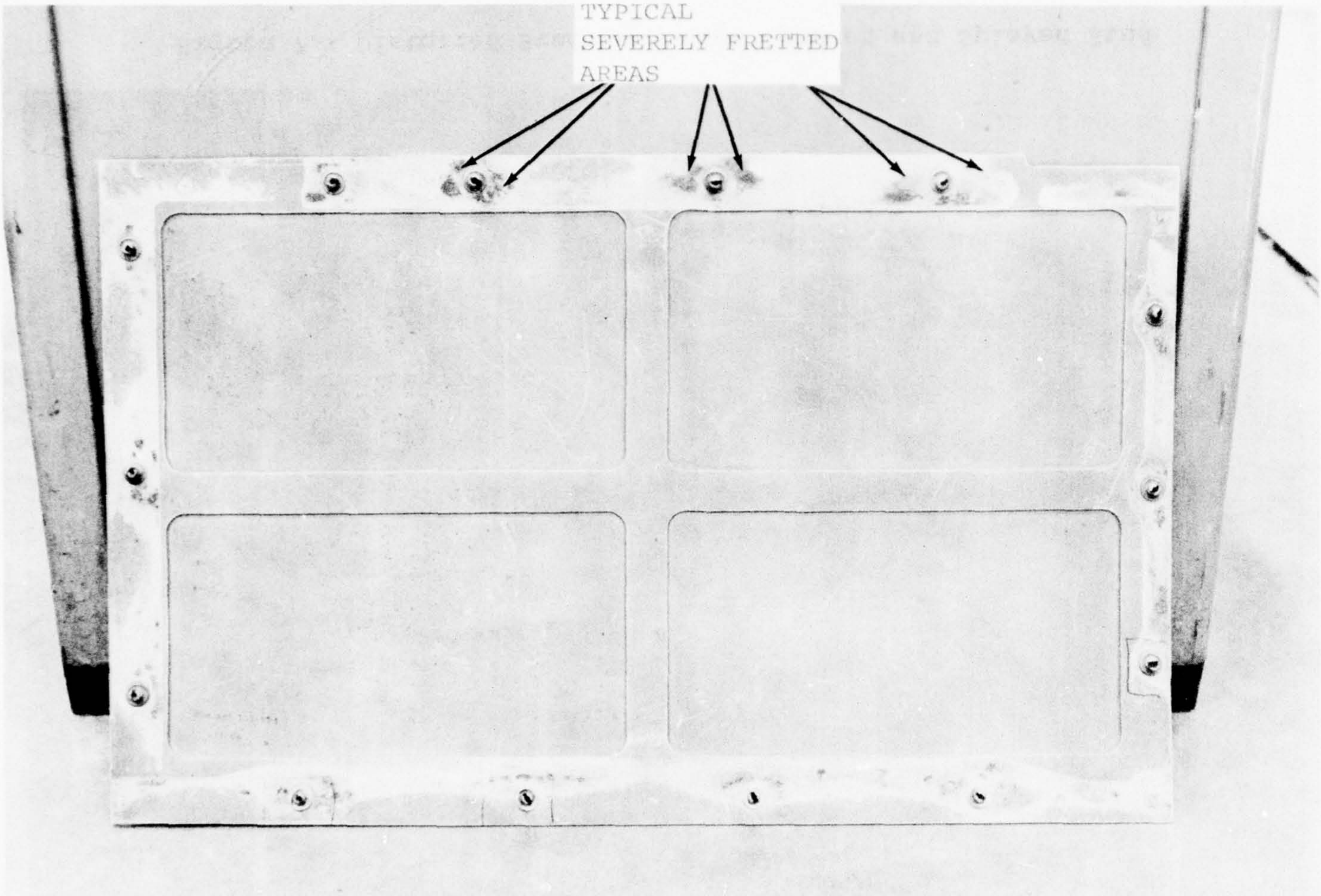

Figure 8. Severe Fretting Around Fastener Holes

3. Fuselage deflection - torsional deflection of the fuselage causes movement and fretting at the panel/structure interface.

4. Weapons delivery causes additional aerodynamic and vibratory loads on the panel.

Application Details

Fastener Characteristics

The AH-1G flight controls access panel currently uses quarter-turn fasteners of the Dzus Supersonic Line as shown in Figure 9. These are AN-5 fasteners that are qualified to the requirements of MIL-F-5591 B, Fasteners, Panel, Size 5, Style 1, Type II. Each fastener consists of a heat-treated alloy steel stud which is secured to the panel by means of an aluminum grommet, and a receptacle which is riveted to the aircraft structure. A spiral slot in the stud engages the receptacle cross pin, drawing the fastener together. The cross pin fits through slots in the receptacle base and spring cap. The spring force on the spring cap permits the cross-pin movement to accommodate differing material thicknesses and an over-center action to prevent the loosening of the stud. The stud body diameter is approximately 1/16 in. less than the panel opening to permit lateral movement and accommodate installation tolerance variations.

The Size 5 Dzus Supersonic Studs are available in a series of part numbers to accommodate different thicknesses of materials. Each part number is designed to accommodate an incremental material thickness of 0.009 in. For example, the manufacturer recommends that, if the thickness of material to be fastened is between 0.161 and 0.170 in., fastener part number A5T17 should be used. If the thickness is between 0.171 and 0.180 in., the part number A5T18 should be used, and so on. Receptacle part number R5 and grommet part number GH5 are used regardless of the length of stud.

MIL-F-5591B gives the following strength, vibration and endurance requirements for this fastener which are summarized here:

- Strength - Rated Tensile Load..................500 lb
  - Rated Shear Load....................500 lb

- Vibration - Twenty-five hours without failure at a frequency of 3600 cpm, an amplitude of 1/16 in. and a load of 175 lb, five hours without failure at the above frequency and amplitude with no load.

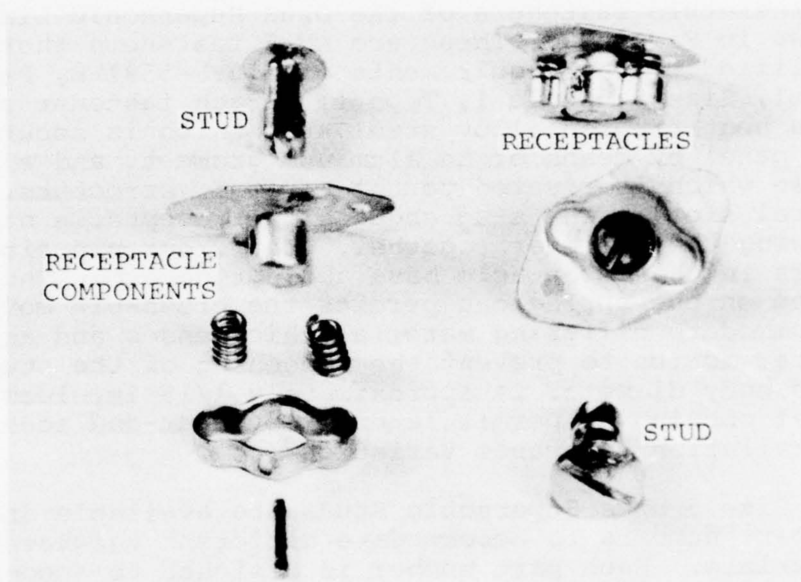

Figure 9. Dzus Fastener

- Endurance - Minimum: 25,000 cycles of operation at 110 cycles per minute without failure.

Panel Application

Fourteen of the Dzus Supersonic fasteners attach each of the flight-control access panels. Variations in structure thickness make it necessary to use several of the available part number fasteners. These fasteners and the manufacturer's recommendations for the thickness of material to be fastened are shown in Table 5.

It is interesting and probably significant that a right hand panel removed from a helicopter in service (P/N 209-030-131-1-203) had three studs of incorrect length. All but one of the 14 fasteners on this panel were apparently replacements, as evidenced by the lack of paint. It was not possible to determine if the airframe structure had been reworked to accommodate the nonstandard lengths.

Design Requirements

The functions of the AH-1G panel fastener are to provide the following:

1. A quickly removable panel for flight controls and hydraulics-bay access

2. An aerodynamically suitable exterior surface

3. A fastener with good maintainability and reliability characteristics when exposed to the Army helicopter operating environment and maintained by Army field-level personnel.

TECHNICAL APPROACH

The reported problems and failure modes indicated inadequate fastener strength and some doubt as to the vibration resistance of the present fastener. The approach taken was to select a candidate alternate fastener which appeared to offer significant improvements in each of these areas of performance and to conduct a comparative evaluation under conditions representative of the aircraft.

Candidate Replacement Fastener

The Hartwell Corporation manufactures a quarter-turn stud-type, size 1, fastener of the "Custodian" line. The fastener, shown in Figure 10, has an upper body which is riveted to the panel and a lower body which is riveted to the structure. The

TABLE 5. AH-1G PANEL FASTENER REQUIREMENTS

PANEL	FASTENER PART NUMBER*	MATERIAL THICKNESS** (IN.)	FASTENER QUANTITY*
LEFT HAND (P/N 209-030-340-21)	A5T17	0.161-0.170	10
	A5T25	0.241-0.250	4
RIGHT HAND (P/N 209-030-340-15)	A5T17	0.161-0.170	10
	A5T25	0.241-0.250	2
	A5T29	0.281-0.290	2
RECEPTACLE (NON-FLOATING TYPE)	R5	(COMMON TO ALL FASTENERS)	

* TM55-1520-221-34P, Figures 28 and 29

** Manufacturer's Literature, Dzus Fastener Co., Inc.

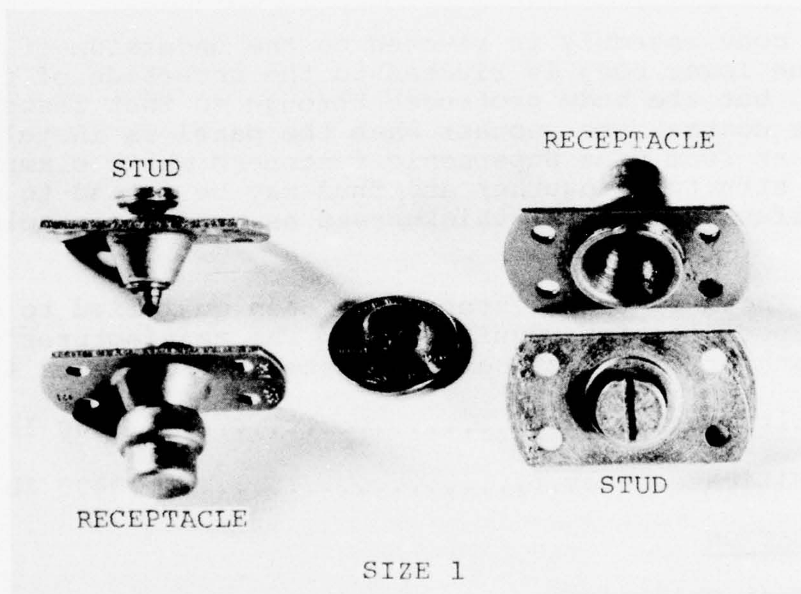

Figure 10. Hartwell Custodian Fastener

conical base of the upper body fits into a conical recess in the lower body. The nesting cones carry any shear load applied to the fastener and accommodate panel curvature. The stud is carried in the upper body. It is spring-loaded out from the panel. This minimizes any tendency for panel fasteners to stick in position after being disengaged and also gives a clear indication that a stud is in the disengaged position. The stud has a strong crosspin that fits through a slotted recess of the lower body and engages camming surfaces when the stud is turned to pull the components together. An over-center action prevents loosening of the stud.

The upper body assembly is riveted to the underside of the panel. The lower body is riveted to the underside of the structure, but the body protrudes through so that fastener components contact one another when the panel is installed. This differs from Dzus Supersonic fasteners which clamp the panel and structure together and thus may be forced to accommodate differing material thicknesses as production tolerances change.

It is not known if this fastener has been qualified to any Military Specification requirements. The manufacturer's rating for strength of this fastener, as listed in Reference 4, is:

- Ultimate Tension.......................1700 lb
- Ultimate Shear.........................3400 lb

TEST EVALUATION

Detailed Test Objectives

Evaluate maintainability and reliability problems associated with the current AH-1G flight control access panel fastener and a candidate replacement fastener for that application under the following simulated operational conditions.

1. Vibration-endurance (Dzus fastener only)
2. Vibration
3. Endurance
4. Grip length
5. Gross contamination

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[4] Bulletin HC 100, Hartwell Corporation, 9035 Venice Boulevard, Los Angeles, California.

In addition to the above, the strength of each fastener is to be evaluated.

Test Plan Outline

The following testing was conducted to meet the program objectives defined above.

Vibration-Endurance

A vibration search of the AH-1G panel with the current (Dzus) fastener was conducted in three axes to determine natural frequencies. The frequency range of the search was from 5 to 500 Hz. A three hour vibration cycling and dwell test was conducted on each axis. The panel was excited at the four frequencies with the highest amplifications for half an hour each. The remainder of the three hours on each axis consisted of cycling from 5 to 500 to 5 Hz. The panel was removed at 15-min intervals during the testing. The vibration amplitudes were 2-g peak except at the very low frequencies where the double amplitude was limited to 0.4 in.

- NOTE -

In order to separate the effects of vibration from endurance, separate testing was concluded subsequent to this test.

Vibration

A vibration search of the AH-1G panel with Hartwell Custodian (candidate replacement) fasteners was conducted in three axes to determine natural frequencies. The frequency range of the search was 5 to 500 Hz. A three hour vibration search and dwell was performed in each axis. The panel was excited at each of the four frequencies with the highest amplification for half an hour. The remainder of the three hours on each axis consisted of cycling from 5 to 500 to 5 Hz. The vibration amplitudes were 2-g peak, except at the very low frequencies where the double amplitude was limited to 0.4 in. Testing was in general accordance with MIL-STD-810, Method 514.1.

Endurance

Seven Dzus and seven Custodian fasteners were subjected to 30 cycles of endurance testing. The fasteners were tested with an AH-1G panel and simulated aircraft mounting structure.

Grip Length Evaluation

Six Dzus and six Custodian fasteners were operated for 10 cycles each under the following conditions, and malfunctions were noted:

- Maximum rated grip length
- Grip length in excess of maximum by 0.010 in.
- Grip length in excess of maximum by 0.020 in.
- Additional 0.010 in. increments of increased grip length until failure of the fastener

Gross Contamination Evaluation

The test evaluation of the effect of dust and oil contamination on two samples of each of the Dzus Supersonic and the Hartwell Custodian fasteners was conducted. Each specimen was operated in a highly contaminated condition for 20 cycles or until failure, and malfunctions were noted. The contaminants were Arizona road dust and MIL-H-5606 hydraulic fluid.

Static Strength

The ultimate shear strength of three fasteners of the current AH-1G fastener configuration and three of the candidate replacement fastener configuration was tested. One additional specimen of each configuration was given a torque-to-failure or drive-limit test.

Test Specimens and Equipment

Fastener Configuration

The part numbers of the baseline (Dzus Supersonic) fasteners used in testing are:

- Stud..............................A5T17, A5T24, A5T25
- Grommet..........................GH5
- Receptacle.......................R5

The part numbers of the Hartwell Custodian fasteners (candidate replacement) are:

- Upper Body.......................H2467-1-045
- Lower Body.......................H2471-068

Panel Configuration

The AH-1G right-hand flight control access panels that were supplied by the USAAMRDL for this test had the following part numbers:

- Bell P/N 209-030-131-1-203, Fiberglass/honeycomb material
- Bell P/N 209-030-131-1-293, Fiberglass/honeycomb material
- Bell P/N 209-030-131-1-334, Aluminum

The aluminum panel was used for vibration and endurance testing. The fiberglass panels proved to be useful references for the determination of material thickness variations.

Test Equipment

- Electrodynamic Shaker
(Umholtz Dickey; Series 1000; 12,000-lb rating)
- Torque Screwdriver
("Snap-On", Kenosha, Wisconsin; 0-75-in.-lb range; 1-in.-lb increment of graduation; 1/4-in. drive; Model No. TOS-6-FU; Serial No. 1947)

Summary of Testing

The testing of the Dzus Supersonic fasteners is summarized below.

Vibration-Endurance (Dzus Fastener)

The AH-1G flight control access panel was bolted to a fixture simulating the aircraft structure with 15 new Dzus Supersonic fasteners. The fixture was then mounted on a slip table as shown in Figure 11. The electrodynamic shaker was connected to the slip table. Resonance searches were made of the three panel axes from 5 to 500 Hz. Four significant resonant frequencies were found during the search of the vertical axis (normal to the plane of the panel) at approximately 74, 135, 180, and 354 cycles per second as shown in Figure 12. A search in-plane did not disclose any appreciable resonant modes, so four 30-min dwells were conducted at the vertical axis frequencies. The remainder of the vibration testing consisted of frequency sweeps.

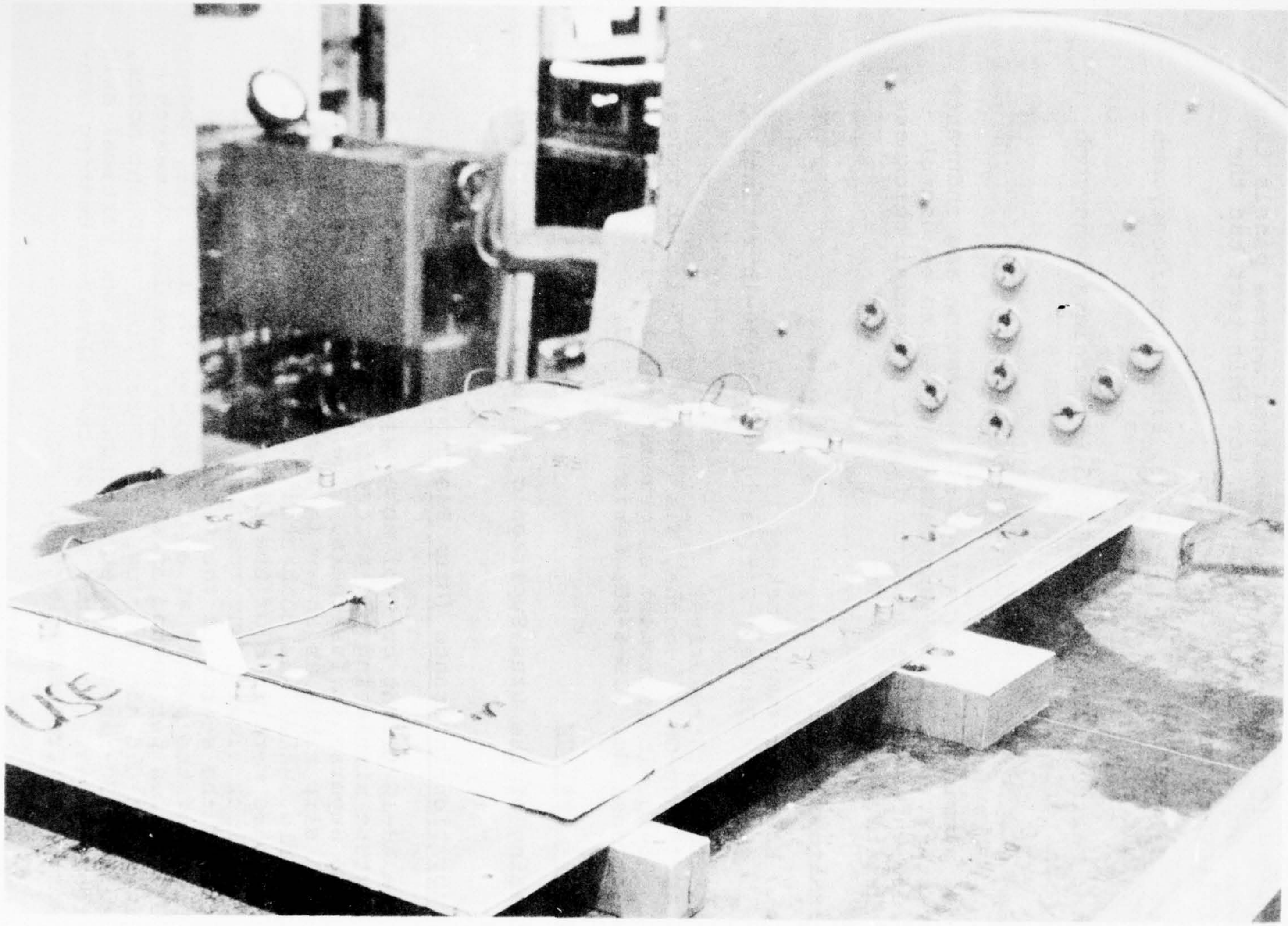

Figure 11. Vibration Test of Access-Panel Fastener

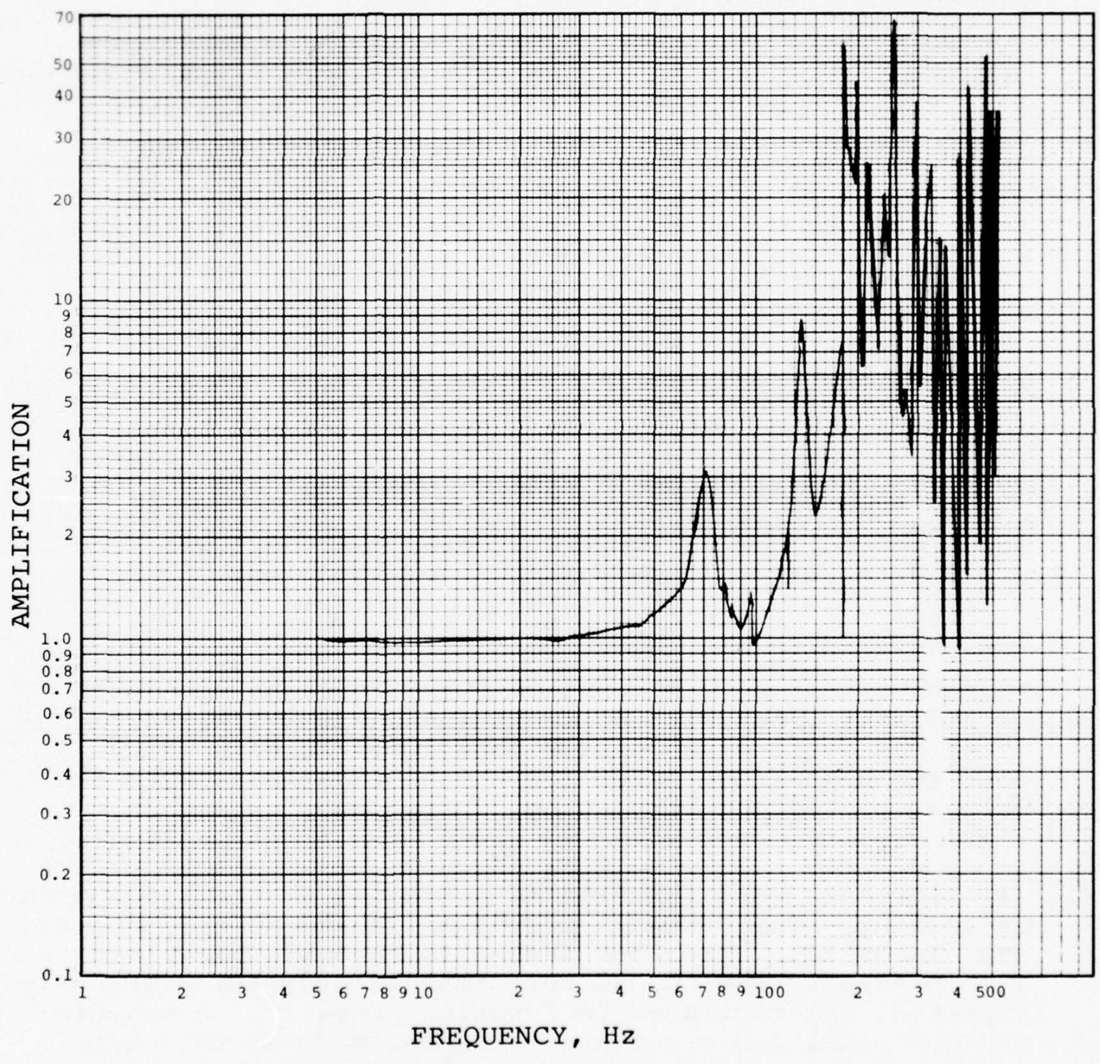

Figure 12. Frequency Response

During this testing the fasteners were loosened and resecured every 15 min for a total of 36 cycles of operation each. No apparent problem occurred with the fasteners, and they functioned properly throughout this testing.

At the conclusion of testing, each fastener's body diameter was measured, as it had been observed that any fastener deformation would show up quite readily as an increase in this dimension. Five fasteners were found with body diameters in excess of the manufacturer's maximum of 0.311 in. per Reference 5 by amounts ranging from 0.008 in. to 0.013 in. These fasteners were still functional.

It could not be determined from a review of the testing whether the fastener deformation was the result of the vibration or the endurance testing since the fasteners were functionally satisfactory throughout the testing. Accordingly, future planned testing was modified to separate endurance and vibration tests.

The vibration testing of the Dzus fastener had been conducted with an aluminum flight-control access panel. As no additional aluminum panels were available for the test of the Hartwell fastener, seven of the Dzus fasteners were removed, and Hartwell Custodian fasteners were installed in their places for the vibration test.

Vibration (Hartwell Fastener)

Vibration testing was repeated for 3 hours on each axis on the same panel with Hartwell fasteners installed. The panel was again given a half-hour dwell at each of the four resonant frequencies for the vertical axis with the balance of testing consisting of frequency sweeps on all 3 axes.

All fasteners were functioning perfectly at the conclusion of testing. The Hartwell Custodian showed no evidence of any distortion. The Dzus fasteners that had been left in from previous testing had the diameter increase previously reported, but continued to function properly. A measurement of panel and structure thickness made at this time disclosed that although nominal thicknesses corresponded to the Dzus-recommended grip length, actual thicknesses

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[5] Trade Literature, Dzus Supersonic Fastener, Dzus Fastener Co., Inc., West Islip, Long Island, New York 11795.

were in excess of the manufacturers recommended maximum grip by 0.014 in. on five of the eight Dzus fasteners. Four of these five fasteners with excessive grips were the ones with excessive body diameters. None of the fasteners with the correct grip was distorted. It was suspected that improper grip rather than endurance or vibration was the cause of the Dzus fastener diameter growth, and so a grip length test was designed to confirm this theory. An endurance test separate from the vibration test was also planned for both the Dzus and Hartwell fasteners.

Endurance (Dzus and Hartwell Fasteners)

Seven Dzus and seven Hartwell fasteners were given 30 endurance cycles each. All of the Dzus fasteners functioned normally. At the conclusion of the test it was noted that the base diameter of one fastener had enlarged. A review of test data showed that the torque required to secure this one fastener had exceeded 40 in.-lb on several of the cycles. This resulted from panel bowing. When the panel was pressed flat, the torque dropped to the normal level of 12 to 15 in.-lb. It is believed that the bowed panel was the cause of the fastener distortion.

Four of the 210 Hartwell fastener engagements resulted in a difficulty in engagement. The fastener which experienced this problem was always the last one on the panel to be engaged, and the problem appeared to involve panel misalignment. The fastener engaged with no difficulty after several tries.

The Dzus studs are not spring-loaded to be self-ejecting when they are disengaged, and the studs tended to bind. It was often necessary to pry the panel off. One of the stud-retaining washers, GH-5, was badly deformed from prying off the panel in almost an exact duplicate of the service failure shown in Figure 13. This is also almost an exact duplicate of the service failure shown in Figure 7.

The Hartwell studs are self-ejecting, making it very easy to remove an unfastened panel and also making it clearly evident that the fasteners are not secure.

Grip Length Evaluation (Dzus and Hartwell Fasteners)

Two lengths of Dzus fastener studs were tested. These were part number A5T24, with a catalog grip range of 0.231 to 0.240 in., and part number A5T17, with a catalog grip range of 0.161 to 0.170 in. The Hartwell Custodian fastener tested had an upper body number 2467-1-045 and lower body number H2471-068. The receptacle or lower body was mounted to the structure in both cases, and the stud or upper body was secured to a simulated panel. Shim stock was added between the panel and structure to simulate the increased grip length.

The six Dzus fasteners showed signs of incipient failure at 0.010 to 0.022 in. above maximum rated grip length. Characteristic of incipient failure was an increase in stud diameter due to the splaying of the spiral slot and a fall-off in engagement torque due to the yielding. The fastener continued to be functional to approximately 0.030 in. above the specified maximum grip, but at this point, the increased diameter of the stud was such that the fastener had splayed and had to be pried out of the fastener hole in the structure, the result of an increase in diameter of over 0.010 in. Torques at yielding were approximately 30 to 40 in.-lb. Testing of one fastener was continued to an extreme overgrip condition. The splayed fastener which resulted (Figure 14) was nearly identical to a fastener returned from helicopter service, shown in Figure 7.

It was very difficult to develop enough torque with a screwdriver to fail the Hartwell fasteners. At a 0.040- to 0.060-in. overgrip, the engagement torque began rising rapidly to approximately 50 to 60 in.-lb, and the screwdriver tip would break in the fastener slot before the fastener could be engaged. The fastener showed no signs of deterioration and functioned properly after this testing. Grip length evaluation test data is reported in Table 6.

The Hartwell fastener accommodated without distortion more than twice the thickness of material above the design maximum grip length than the current fastener could.

Gross Contaminant

Two of the current AH-1G panel fasteners and two candidate replacement fasteners were tested for the effects of severe oil and dust contamination. The fastener studs (or upper bodies) were installed in the aluminum AH-1G panel, and the receptacles were installed in the simulated structure. The contamination consisted of a layer of MIL-H-5606 oil sprayed on the face of the simulated structure and in the receptacle (or lower body) and covered with a layer of Arizona road dust. The contamination was applied while the panel was off. The panel was then installed, and the fastener installation torque and other salient data were recorded.

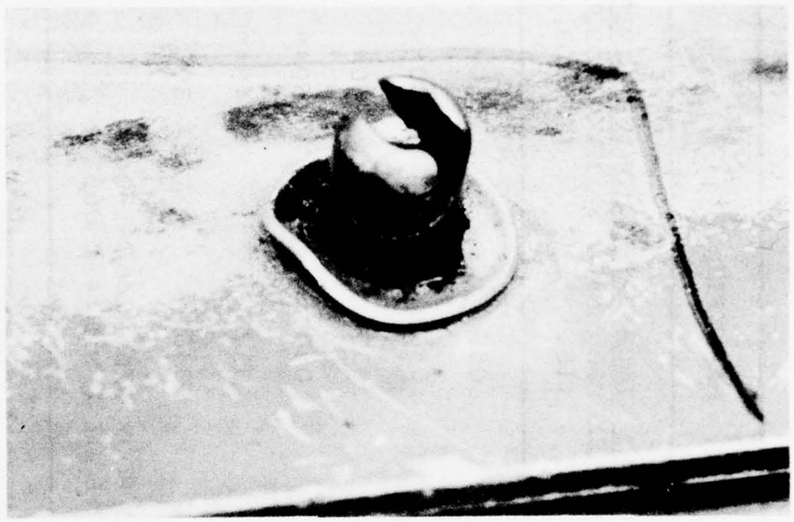

Figure 13. Deformed Dzus Retaining Washer

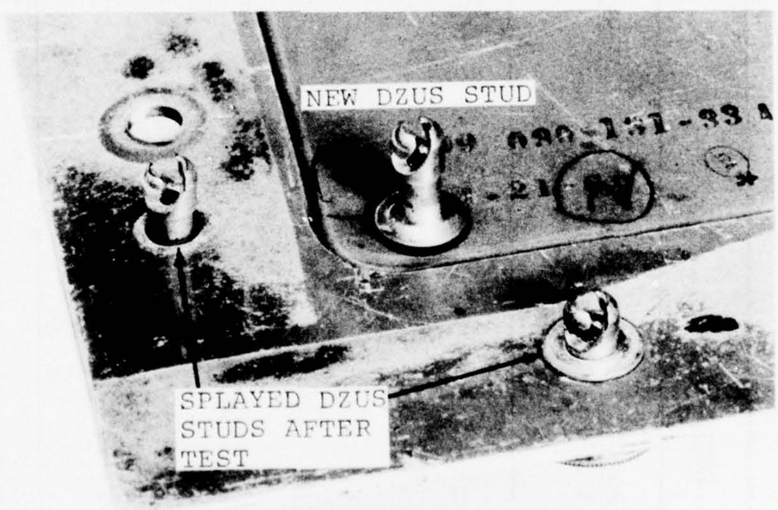

Figure 14. Splayed Fastener From Over-Grip Test

TABLE 6. GRIP LENGTH EVALUATION

DZUS				HARTWELL		
		APPARENT VALUES FOR YIELDING			MAXIMUM VALUE (DRIVE LIMIT)	
SPEC. NO.	STUD P/N	EXCESS. GRIP (IN.)	MAX. TORQUE (IN.-LB)	SPEC. NO.	EXCESS. GRIP (IN.)	MAX. TORQUE (IN.-LB)
1	A4T24	.010	23	1	.050	60*
2	A4T24	.010	40	2	.050	50*
3	A5T24	.020	26	3	.050	50*
4	A5T17	.020	37	4	.040	50**
5	A5T17	.020	30	5	.060	45**
6	A5T17	.020	28	6	.030	30
RECEPTACLE P/N R5				UPPER BODY P/N H2467-1-045 LOWER BODY P/N H2471-068		

<u>NOTE:</u> NOMINAL TORQUE - 12-15 in.-lb
TORQUE YIELD - 23-40 in.-lb

* BROKE SCREWDRIVERS
** WOULD NOT ENGAGE AT THIS TORQUE

This testing disclosed the following:

- Neither type of fastener would function more than seven engagements with continued heavy application of contaminants. Both receptacles "clogged up". The fastener engagement torques for both types increased greatly until the screwdriver blade "cammed-out" of the slotted head recess, the blade actually failed, or the fastener stud body deformed.

- The present AH-1G panel fastener stud was measurably distorted after three engagements.

- The candidate replacement fastener stud stuck in the engaged position after three engagements. The fastener had to be pried out to remove the panel.

Although this was a very severe test, it demonstrated the susceptibility of the fasteners to contamination.

Static Strength

Shear testing of the AH-1G panel fastener and the candidate replacement fastener disclosed that the rivets holding the receptacle to the structure are the weak links in developing fastener shear load. The rivets failed in each case, rather than the fastener. The two rivets of the present AH-1G fastener failed at approximately 1,000 lb; double the shear load required by MIL-F-5591B. The four rivets holding the candidate replacement fastener reacted more than a 2600-lb load before failure. This is less than the manufacturer's ultimate shear rating for these fasteners (3400 lb), but a 150-percent increase in strength over the present fastener. Test values for these fasteners are listed together with the MIL-SPEC or the manufacturer's ratings in Table 7.

Ultimate Torsion Testing

The fully engaged AH-1G panel fastener and the candidate replacement fastener were torqued to 70 in.-lb with no evidence of failure. Screwdriver "cam-out" or screwdriver blade failure made this torque very difficult to develop; therefore, higher torques were not attempted. No deformation was noted. The developed torque was in excess of the MIL-F-5591B requirement of 60 in.-lb locking stop strength.

Static Test Summary

There is no apparent lack of ultimate shear or engaged torsion strength in either the present AH-1G panel fastener

TABLE 7. ULTIMATE SHEAR STRENGTH

FASTENER	ULTIMATE SHEAR STRENGTH (LB)
PRESENT AH-1G FASTENER	
SPECIMEN 1	1000
SPECIMEN 2	1110
SPECIMEN 3	1000
MIL-F-5591B	500 (rated shear load)
CANDIDATE REPLACEMENT FASTENER	
SPECIMEN 1	2680
SPECIMEN 2	2695
SPECIMEN 3	2605
MANUFACTURER'S SPECIFICATION	3400 (ultimate shear load)

NOTE: All failures occurred in the rivet-to-structure attachment rather than the fastener.

or the candidate replacement fastener that would contribute to a malfunction in this flight-control access-panel application.

CONCLUSIONS AND RECOMMENDATIONS

Two major reasons for the malfunction of the AH-1G panel fasteners are:

1. Deterioration of the fastener when operated outside the manufacturer's recommended installation parameters.

2. Design decisions for the panel installation which resulted in an application susceptible to maintenance errors and manufacturing variations.

The primary reasons for the success of the candidate replacement fastener are:

1. The fastener concept differs from most other fasteners in that the factors entering into the grip range of this fastener can normally be controlled by the fastener manufacturer. Only gross installation variations will result in an improper grip length.

2. The fastener has at least double the capability of the present fastener for operating with an improper grip length, should the panel/structure thickness exceed the manufacturer's recommendations.

A fundamental problem in fastener application was found to be that comprehensive design and installation data is not readily available to the aircraft designer. This was true for the present AH-1G fastener and also for the candidate replacement.

The major characteristic of the current AH-1G panel fastener contributing to malfunction is that the fastener stud is easily distorted if the material thickness fastened exceeds the manufacturer's recommendations.

The stud is furnished in a number of incremental lengths to accommodate different thicknesses of material. The manufacturer's application data specified that the variation in material thickness or "grip range" accommodated by any one stud size should not exceed 0.009 in.

Because of the design and installation considerations listed below, the manufacturer's recommendation for grip range is very difficult to meet in this application.

1. Normal sheetmetal thickness tolerances allow variations of approximately ±5 percent (see FED-STD-245, Reference 6). For a built-up sheetmetal panel using the A5T29 fastener (one of the three sizes on the AH-1G panel), a tolerance variation of ±0.014 in. would be anticipated unless precision machining was employed on the panel and aircraft structure.

2. Measurement of the thickness of a fiberglass access panel removed from service showed a tolerance variation of 0.012 in., which is more than the grip range of the fastener.

3. Paint buildup, contaminants, and curved or warped panels and structures add to the difficulties of controlling the grip range of a fastener.

4. Fastener grip lengths do not overlap. This adds to the difficulty of maintaining the nominal material thickness of an installation near the center of a fastener grip range.

The fastener appeared very durable when tested according to manufacturer's recommendations.

Other factors in the failures of the current AH-1G panel fasteners involve installation:

1. Fourteen seemingly identical fasteners are used on each panel. Three different lengths are used on the right-hand access panel, and two different lengths are used on the left-hand panel. This variety of fastener lengths leads to several potential maintenance errors.

    - If a missing fastener is replaced with one based on the part number read from the head of the adjacent fastener, there is a possibility that the wrong part will be installed.

    - The maintenance manual must be very carefully studied to determine that there may be three lengths of fasteners and to determine the exact position of each.

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[6]Federal Standard 245, *TOLERANCES FOR ALUMINUM ALLOY AND MAGNESIUM ALLOY WROUGHT PRODUCTS*, General Services Administration, Washington, D. C., January 1957.

- A fastener that is too short can frequently be deformed to fit the installation. It may appear similar to the one in Figure 14 but will usually engage in the receptacle. The consequences of using such a fastener are unknown.

- In verification of the maintenance error theory, a used right-hand AH-1G panel supplied to Boeing for test after considerable helicopter use was found to have incorrect length fasteners, apparently from field replacement. This is discussed under "Panel Application," on page 49.

2. The current fastener stud is not self-ejecting and tends to remain in the receptacle when unscrewed. If the fastener is installed in a panel, the friction forces between the stud and receptacle may interfere with panel removal. Damage occurred to the soft aluminum stud retaining washer during a test when the panel had to be pried off, duplicating the condition shown in Figure 7.

Both fasteners quickly became nonfunctional when very heavily contaminated with oil and Arizona road dust. The fastener receptacle tended to act as a collector for debris and the fastener could not be engaged. Lower levels of contamination caused deformation of the present panel fasteners.

The candidate replacement fastener was found to be very durable and performed well under all other conditions. The following features contributed to the success of this installation.

1. The fastener stud mounting assembly and the receptacle are designed to contact one another when the stud is secured, rather than the more conventional approach wherein the panel and mounting structure are clamped between the stud and receptacle. In this way, the candidate replacement fastener installation is much less sensitive to grip range problems caused by panel or structure thickness variations, paint buildup, or contaminants.

2. The fastener will tolerate, without distortion, greater than twice the thickness of material above the design maximum grip than will the present fastener.

3. The stud has a very high strength and was not damaged by high applied torque. The limit appeared to be the strength of the screwdriver blade, several of which were broken in the test.

4. The fastener stud is spring-loaded to be self-ejecting from a panel. This gives visual assurance that the fastener either is secured or that it has not been fastened, and aids in panel removal by reducing the tendency of the stud to bind in the receptacle.

5. The fastener stud is conical, fitting into a conical recess in the receptacle. This permits its use on highly curved panels and reduces the tendency of the stud to bind in the receptacle.

Vibration testing was conducted in accordance with MIL-STD-810C (Reference 7). This testing did not clearly show the effect of a vibratory environment on the present fastener. Some distortion of the studs did occur during a combined vibration/endurance test. All malfunctions occurred at locations found to have excessive material thickness and this is the probable failure cause. No deterioration of the candidate replacement fastener occurred during the vibration or the endurance test.

There is a weight penalty of 0.39 lb per AH-1G panel if the candidate replacement fasteners are used to replace the present fasteners on a one-to-one basis. However, the replacement fasteners are stronger than the baseline fasteners, and it is possible that a panel could use fewer fasteners, minimizing any weight penalty and providing for more rapid panel removal and installation.

This program found no deficiencies in the present AH-1G fastener that can be related to any failure to meet the requirements of MIL-F-5591. This program was directed at determining the performance of the fastener in the AH-1G installation where the conditions may be more severe than those intended for fasteners by the specification. The specification requires fasteners to be tested in laboratory conditions to a "nominal" aircraft requirement.

The deficiencies that appeared in the present AH-1G panel fastener installation were associated with a lack of application data for the fastener by either the manufacturer or the military, the inability of the fastener to cope with real requirements of the application (particularly in regard to excessive grip range), and the lack of human engineering features built into the application by the aircraft designer.

It is evident from this program that four areas of improvement are necessary to avoid future similar problems.

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[7] MIL-STD-810C, ENVIRONMENTAL TEST METHODS, Department of Defense, Washington, D. C., March 1975.

1. Panels must employ fasteners of uniform length to avoid the confusion of similar sizes or "Murphy" -type errors in maintenance will occur. (Murphy's Law states that anything that can be done wrong will be done wrong.)

2. Better application information is needed for fasteners. The consequences of violating any of the suggested design parameters should be stated also.

3. Specifications for fasteners must give more consideration to design and manufacturing variables, such as nominal material thicknesses and tolerances.

4. Fasteners should be developed with emphasis on the ability to tolerate "out-of-optimum" conditions.

CH-47 INDUCTION SYSTEM FAIRING ACCESS PANEL FASTENER

OBJECTIVE

To evaluate maintenance problems associated with access panel quick-release fasteners by means of an investigation of the fasteners currently used in the CH-47 induction system and a candidate replacement fastener.

DESCRIPTION OF PROBLEM

Background

Each of the two engines of the CH-47 helicopter has a sheet aluminum fairing assembly to provide an aerodynamic contour for the engine transmission and the drive shafting between the engine and the combining transmissions. This fairing is shown in Figure 15. The same fairing is used for both left and right-hand engines. The opening panels on the assembly, as shown in Figure 16, are secured with a total of twelve quarter-turn fasteners. The top panel is opened for inspection of the drive shafting. This problem relates to loss or malfunction of the seven fasteners securing the top panel.

The reported failure modes are:

1. Loose, out-of-adjustment, broken, or missing studs.
2. "Rounding-out" or "cam-out" of the stud head recess.
3. Missing retaining washers.
4. Broken ejection springs.
5. Loose, broken, or missing receptacles.

Contributing factors in fastener malfunction are reported to be:

1. Frequency of utilization; unscheduled engine and drive shaft maintenance, and intermediate and periodic inspection result in opening at approximately 15-hour intervals.
2. The induction system fairings are used as steps during maintenance operations of the aft pylon and engine area. Although they were not designed as such, the fairings are more convenient than the steps provided for that purpose. The denting and distortion of the opening panels resulting from this abuse make it necessary to force the fasteners into engagement.

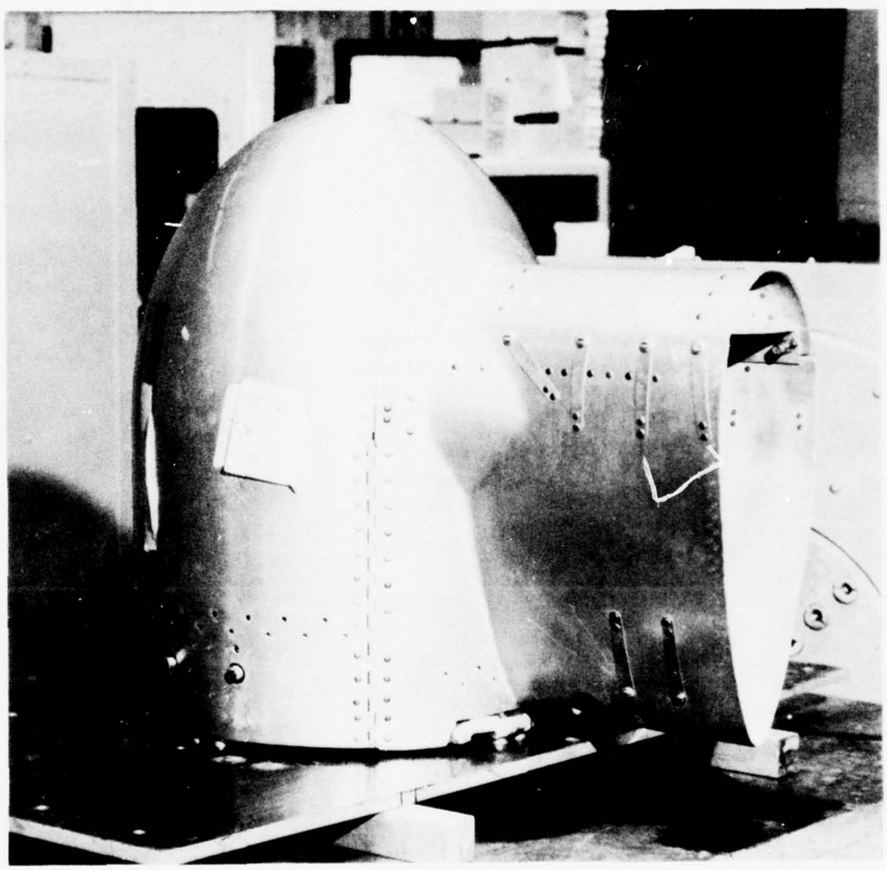


Figure 15. CH-47 Induction System Fairing

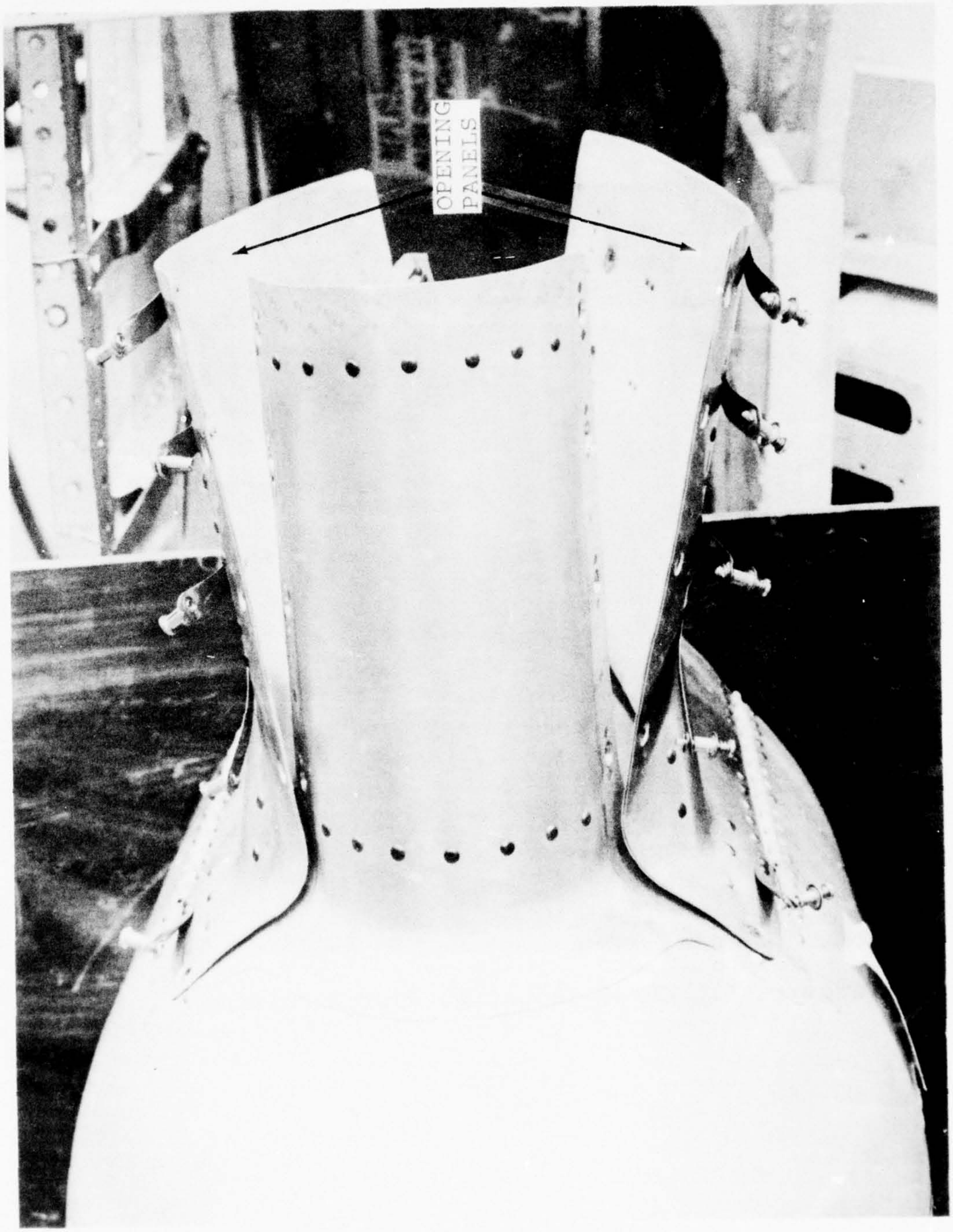


Figure 16. Fairing Showing Two Opening Panels

3. Vibration is thought to be a possible contributing factor as this area experiences high vibration levels and fairings removed from service show severe chafing. Figure 17 shows an example of this chafing around the panel and fairing edges.

Application Details

Fastener Characteristics

The CH-47 induction system fairing access panel currently uses quarter-turn fasteners made by the Specialty Fastener Division of Rexnord, Inc. These "Camloc" Series 2600 fasteners, shown in Figure 18, consist of alloy-steel stud assemblies and stainless steel receptacles. The stud assembly is secured by a retaining washer to an ejector spring which is riveted to the opening panel. The receptacle is riveted to the fairing structure.

The stud assembly consists of a spring-loaded stud assembled in a cylindrical housing. The stud has a screwdriver recess on one end and a cross pin on the other. The cross pin fits through a slot in the receptacle and rides on spiral camming surfaces in the receptacle to tighten the assembly as the stud is turned. The spring permits stud movement to accommodate differing material thicknesses as well as to permit an over-center surface on the receptacle cam to prevent loosening.

The Camloc stud has an approximately 1/16 in. smaller diameter than the mating receptacle to accommodate installation tolerances. This clearance must be taken up by panel movement before the full shear-carrying capability of the panel can be developed.

The Camloc series 2600 stud is available in different sizes to accommodate different thicknesses of material. The manufacturer specifies that each size can accommodate a variation in material thicknesses of 0.029 in. For example, the manufacturer recommends that, if the thickness of material to be fastened is between 0.240 and 0.269 in., the stud part number 2600-8 should be used. Part number 212-12S receptacle is used regardless of length of the stud. The manufacturer rates the 2600 series fastener as having the following strength levels (Reference 8).

- Ultimate Shear and Tensile Strength........300 lb
- Rated Shear and Tensile Strength...........200 lb

[8] Bulletin No. 102, Rexnord, Inc., Specialty Fastener Division, Paramus, New Jersey.

Figure 17. Chafed Fairing Edges From In-Service Vibration

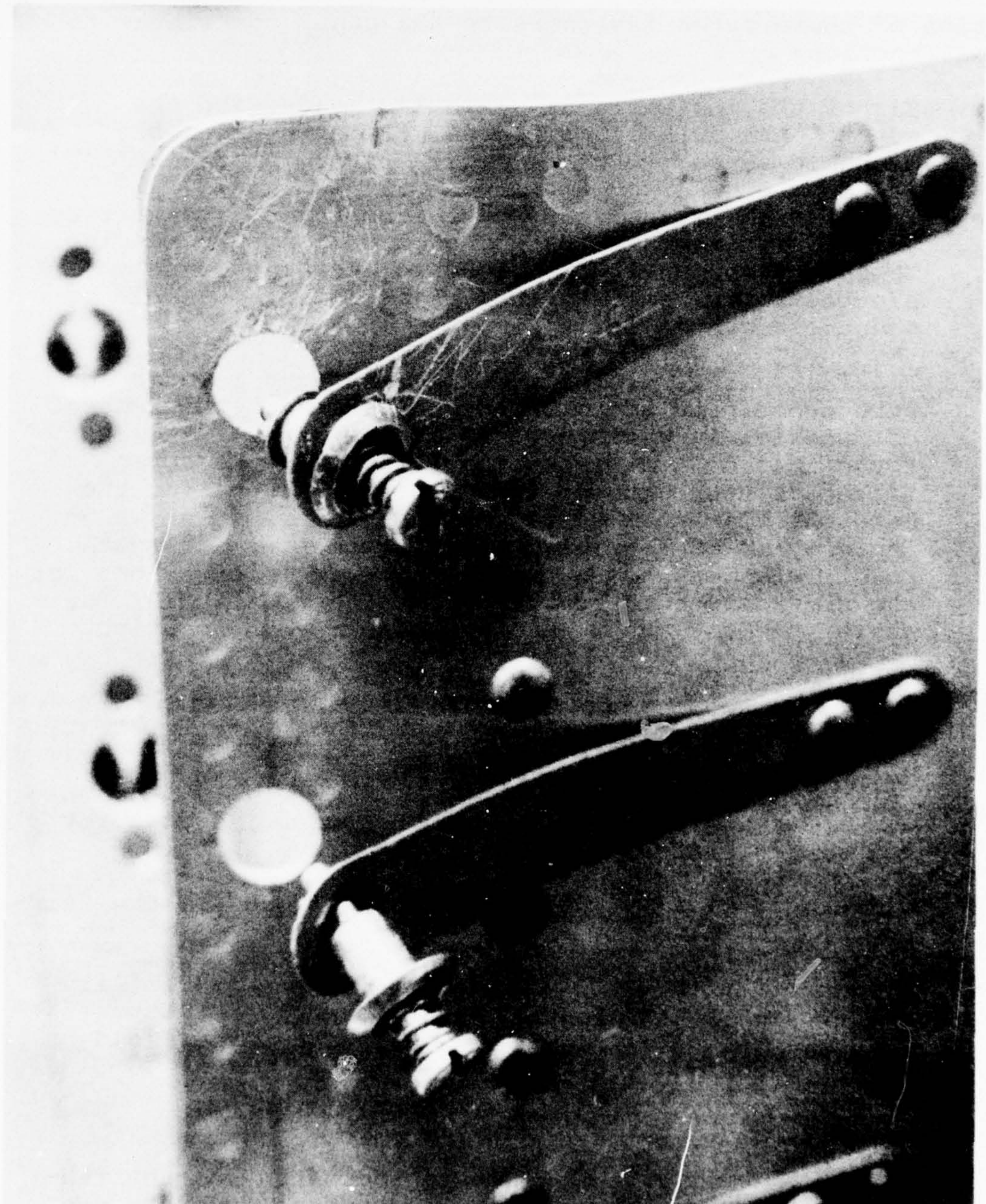


Figure 18. Present Fastener Installation

Panel Application

Seven Camloc fasteners must be disengaged to open one of the CH-47 access panels. Three factors in the application of these seven fasteners to the panel contribute to malfunction:

- Six of the fasteners have slotted heads, and the seventh has a Phillips recess. This requires the mechanic to carry two screwdrivers or "improvise".
- Two of the fasteners are on the bottom of the fairing when the fairing is installed on a right-hand engine. To open this panel, the mechanic must engage the slotted screw heads by feel as it is not possible to see these fasteners.
- The fasteners are of four different grip lengths and part numbers to accommodate the different thicknesses of material in various parts of the panel. It was found that on two new fairings three of the seven fasteners used were of improper grip length for the material thickness to be fastened. This is shown in Table 8, which tabulates the fasteners used at each panel location, the manufacturer's recommendations for the thicknesses to be accommodated by particular fasteners, and the measured thickness at each location.

Design Requirements

The functions of the CH-47 induction system fairing panel fastener are to provide the following:

- A means by which the panel can be quickly opened for inspection and maintenance of the drive shaft.
- An aerodynamically clean exterior surface for the fairing.
- A fastener with good maintainability and reliability characteristics when exposed to the Army helicopter operating environment and maintained by Army field-level personnel.

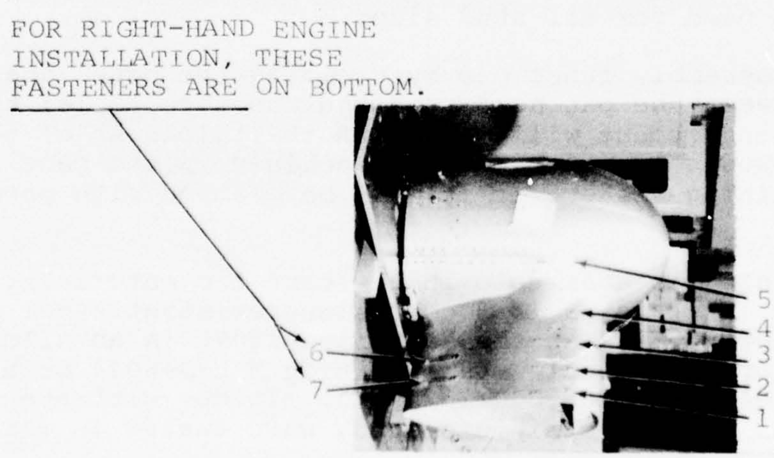
TECHNICAL APPROACH

The reported problems and failure modes indicate that the fastener has insufficient strength to withstand the frequent use and abuse which occurs because of the high maintenance requirements of the engine/aft pylon area. Vibration effects are thought to be augmented by the large internal fastener clearances which permit panel movement relative to the fairing. The

TABLE 8. INDUCTION SYSTEM FASTENER CHARACTERISTICS

PANEL LOCATION (SEE BELOW)	FASTENER PART NUMBER	RECOMMENDED MATERIAL THICKNESS (IN.)	MEASURED MATERIAL THICKNESS (IN.)
1	CAMLOC 2600-6	0.180-0.209	0.187
2	CAMLOC 2600-9	0.270-0.299	0.285
3	CAMLOC 2600-9	0.270-0.299	0.285
4	CAMLOC 2600-9	0.270-0.299	0.285
5	BACS 21Y12R (CAMLOC 2600-12)	0.360-0.389	0.395*
6	CAMLOC 2600-8	0.240-0.269	0.285*
7	CAMLOC 2600-8	0.240-0.269	0.285*

* MATERIAL THICKNESS IS EXCESSIVE FOR THESE FASTENER PART NUMBERS AT THIS LOCATION.



FASTENER LOCATION
(LEFT-HAND ENGINE FAIRING)

approach taken was to select a fastener which appeared to offer significant improvements in each of the areas of performance and to conduct a comparative evaluation under conditions representative of the aircraft.

Candidate Replacement Fastener

The Tridair "Live-Lock" 1800 series fastener made by Tridair Industries was selected. This fastener consists of a pan head stud, which is secured by a retaining washer to the panel or ejection spring, and a receptacle assembly, which is riveted to the structure. The hollow stud has an internal, four-lead thread which engages a similar threaded screw in the receptacle. A spring-loaded ratcheting detent in the receptacle provides positive locking of the stud at any engaged position. The stud fits snugly in the receptacle so that any shear loads do not result in any appreciable movement between the stud and receptacle. The receptacle "floats" in a sheetmetal retainer, and the stud is tapered to accommodate initial variations in tolerance. Once the fastener is assembled, the clamping forces between the components become quite high (400 to 800 lb at 15 to 30 in.-lb fastener torque), thus minimizing deflections under vibration and loads applied to the panel.

The Live-Lock stud is available in a series of different lengths (part numbers) to accommodate different thicknesses of material to be fastened. Each length is designed to accommodate a variation in material thickness of 0.069 in., except the smallest fastener which accommodates a 0.057-in. variation (Reference 9). This accommodation for a range of material thickness is more than double that recommended for the Camloc fastener. The same receptacle is used for all stud sizes.

The fastener assembly functions by clamping the panel and structure between the pan head stud and the receptacle; the screw thread engagement will vary with the thickness of the material clamped. A recess must be machined in the panel for the stud retaining washer, or it will be clamped with panel and structure.

The pan head stud is available in at least two materials: the subseries No. 18161 is an 18-8 corrosion-resistant steel stud, type 300 per QQ-S-764, and the subseries 18091 is an alloy steel stud of 8740 or 4140 steel, specification MIL-S-6049 or MIL-S-5626, heat-treated to 160,000-lb/sq-in. minimum ultimate strength. Both stainless and non-stainless studs were tested in this program.

[9] Trade Literature, Live-Lock Structural Fastener, Tridair Industries, Fastener Division, 3000 W. Lomita Blvd., Torrance, Calif.

The manufacturer rates the strength of this fastener (Reference 9) as follows:

- Ultimate Shear Strength....................2500 lb
- Ultimate Tensile Strength.................1400 lb
- Recommended Torque (no maximum specified)....30 in.-lb

It is not known if this fastener is qualified to a Military Specification.

TEST EVALUATION

Detailed Test Objectives

Evaluate maintainability and reliability problems associated with the current CH-47 induction system fairing fasteners and the candidate replacement fastener under simulated operational conditions that determine the effects of the following:

1. Endurance
2. Vibration
3. Abnormal Loads
4. Grip Length

Test Plan Outline

The following testing was conducted to meet the program objectives defined above.

Endurance

The Tridair Live-Lock fastener (candidate replacement) was installed on one of the two opening panels on a CH-47 induction system fairing. The current Camloc fastener was left on the other, and 500 cycles consisting of one opening and closing were conducted on each. Fasteners were replaced upon failure and malfunctions were noted.

Vibration

A vibration search of the CH-47 induction system fairing was conducted in three axes to determine natural frequencies.

The frequency range of the search was from 5 to 500 Hz. A 3-hr vibration search and dwell was performed in each axis. The fairing was excited at each of the four frequencies with 1/2-hr dwells at the frequencies of the highest amplification. The remainder of the three hours on each axis consisted of cycling from 5 to 500 to 5 Hz. The vibration accelerations were 2 g except at the very low frequencies where the double amplitude was limited to 0.4 in. Testing was in general accordance with MIL-STD-810, Method 514.1 (Reference 7).

Maintenance Abuse

Static loads were applied to each panel in a manner simulating foot traffic. Permanent panel deformations were recorded. The panels were opened and closed, and fastener malfunctions were recorded.

Grip Length Evaluation

Six fasteners of each of the two types were operated for 10 cycles each under the following conditions:

- Maximum rated grip length
- Grip length in excess of maximum by 0.010 in.
- Grip length in excess of maximum by 0.020 in.
- Additional 0.010-in. increments of increased grip length until failure of the fasteners.

Test Specimens and Equipment

Fastener Configuration

The part numbers of the baseline Camloc fasteners used in testing are:

- Stud............................2600-6
  Stud............................2600-8
  Stud............................2600-9
  Stud............................BAC S21Y12R (P/N 2600-12)
- Ejection Spring.................2600-ES
- Stud Retainer Washer............2600-SW2
- Receptacle......................212-12S

The part numbers of the Tridair Live-Lock fasteners are:

- Stud..........................CA18161-HS (several lengths)
  Stud..........................CA18091-HS (several lengths)
- Ejection Spring.............2600-ES (Camloc)
- Retainer Washer.............CA18132
- Receptacle..................CA18157

Panel Configuration

The Boeing Vertol CH-47 induction system fairing assembly (including the panels and fasteners) is part number 114P5003.

Equipment

- Electrodynamic Shaker
  (Umholtz Dickey; Series 1000; 12,000-lb rating)
- Torque Screwdriver
  ("Snap-On", Kenosha, Wisconsin; 0-75-in.-lb range; 1-in.-lb increment of graduation; 1/4-in. drive, Model No. TOS-6-FU; Serial No. 1947)

Summary of Testing

The testing of the fasteners currently used for the CH-47 induction system fairing panel and the candidate replacement fastener is summarized below.

Endurance Test

A new CH-47 induction system fairing assembly with the present panel fasteners was modified by installing the candidate replacement fasteners on one of the two panels. The studs for the candidate replacement fasteners were 18-8 corrosion-resistant steel.

The fairing was then attached to a framework for endurance testing. The panels were mounted vertically to give the mechanic equal opportunities to get at each type of fastener.

Each of the 500 endurance-test cycles consisted of engaging all of the fasteners on both panels and then disengaging the fasteners and opening the panels.

The first 50 cycles resulted in 35 fastener malfunctions; 12 of these involved the present fastener and 23 involved the candidate replacement fastener. No failures of the present fastener occurred, but nine failures occurred on the candidate replacement fastener. Five of these nine cases involved the loss of the stud retaining washer. The other four were disengagements of the stud and receptacle caused by the stripping of the thread.

The malfunctions of the present fastener were caused by the alignment problems of a flexible panel with double curvature. This resulted in the following:

- Fasteners that were hard to engage (one specific order of engagement was found to minimize this problem).

- Fasteners that would not disengage due to frictional shear forces of the panel on the stud.

- Stud retaining washers that caught on the side of the fairing hole and had to be disengaged before the panel could be opened.

The candidate replacement fastener malfunctions were partially caused by the misalignment of the panel. The same three modes of malfunction reported for the present fastener occurred for this fastener. However, the failures were from another cause: the improper installation of the fasteners in the panel. Two deviations from the manufacturer's recommended practice had been made in modifying the present CH-47 fairing for these fasteners:

- Inadequate clearance had been provided for the stud retaining washer. The washer had been clamped between the panel and the fixed structure, and had failed when the stud was rotated. Failures are shown in Figure 19.

- The panel and structure thicknesses were excessive for the fastener stud length chosen in two of the six locations. The four failures had occurred at these two locations. The material was 0.033 in. too thick at one location and 0.046 in. too thick at the other. This had reduced the thread engagement, and the threads had stripped.

The panel was then modified for a proper installation of the candidate replacement fasteners. Clearance was provided for the stud retaining washers. Correct grip-length studs of corrosion-resistant steel were installed.

Figure 19. Candidate Replacement Stud Retaining Washer Failure

During the failure investigation, the candidate replacement studs and receptacles which had been removed from the panel were cut apart for examination of the screw thread. The male threads from a new and a failed receptacle are shown in Figure 20. The first three threads of the stud at the right are rounded as the result of the thread stripping.

Figure 21 shows the threads of the failed stud. Little damage is visible. The thread form is unusual in that the crest is truncated so that the minor diameter is approximately on the pitch diameter. This appears to be a quality problem and would be expected to give a much lower stud strength than if a full thread had been present. The fastener manufacturer was requested to investigate this matter and one of the failed studs was returned to him for his examination.

Testing was continued. The balance of the 500 cycles of testing resulted in three failures of the present fastener studs and five failures of the candidate replacement fastener stud receptacles. Three stud retaining washers for the candidate replacement fasteners also failed.

Two of the candidate replacement fasteners failed in the test period from cycle 50 to cycle 200. At cycle 200, the fastener manufacturer provided some high strength alloy steel studs of the same configuration for evaluation. These were installed at two of the six fastener locations.

Many malfunctions of both fasteners involved a delayed fastener engagement. At times a fastener would refuse to engage for 30 sec or so while various "adjustments" were made. Subsequent engagements would be perfectly normal.

The proper installation of the candidate replacement fastener had greatly improved the performance, but the failure and malfunction rate was still higher than for the current fasteners. The failures and malfunctions will be discussed.

It is interesting that the malfunction rate of the present fastener appeared to diminish following the first fifty cycles. It became apparent that either certain procedures in aligning the panel or an order of fastener engagement would almost assure difficulty of engagement and that other procedures had a high likelihood of success. Rather than try to abuse the panel and fastener, the mechanic would try to operate in the most expedient way. This same tendency was present in the installation of the panel with the candidate replacement fastener.

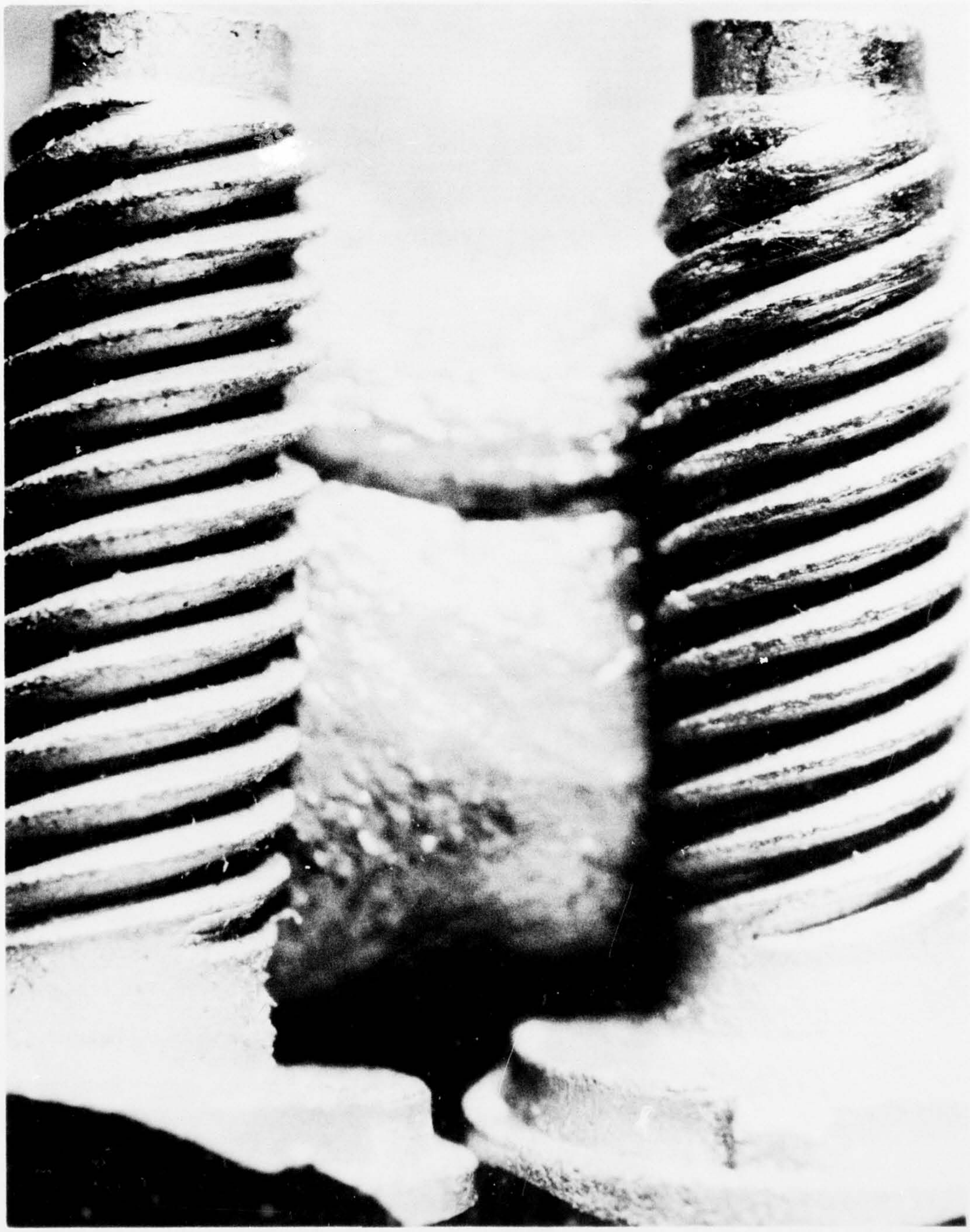


Figure 20. Failed Screw From Receptacle on Right

Figure 21. Truncated Thread Form From Failed Stud

The initial failure of the present fastener stud was a loose stud cross pin (Figure 22). This was thought to be a quality problem. However, the second failure was a bent stud cross pin and occurred at the same panel location as had the first. This second failure was a sign of overload, not quality. Panel and structure thicknesses were checked for all of the present fasteners and compared with the manufacturer's recommendations for grip length of the fasteners installed. It was found that two of the six fasteners on this production component were approximately 0.020 in. short for the component thicknesses present. A second fairing was checked, and the same situation was found. Both failures had occurred at one of these short fastener locations. It was later found that an inadequate length stud will sometimes elongate at the cross-pin hole, resulting in a loose or lost cross pin. This results in the apparent "quality" problem of the first failure.

The third failure of the present fastener was also a failure of the cross pin. The panel location of this failed fastener was the second location with excessive material thickness for the fastener size installed.

In summary, all failures occurred where the wrong grip length fastener had been installed. The majority of malfunctions involving the present fastener were the extreme difficulty in engaging the stud in the receptacle. This problem was erratic, with the alignment of the panel as one of the contributing factors and the cumulative fastener deterioration as another.

Two other malfunctions worth noting are:

- The Phillips recess head of the stud with this drive arrangement was barely functional at test conclusion. This stud had only been exposed to 320 of the 500 test cycles as it was installed following the cross pin failure of the previous fastener. (The slotted screw slots were in good, operable condition.)

- The panels were noticeably scratched in the vicinity of the slotted screw fastener from the driver slipping.

Failures of the candidate replacement fastener were all of the stripped thread type. Both stud and receptacle were damaged and subsequently replaced. All failures were of assemblies using the stainless steel stud with the truncated thread form. No failure of the alloy studs occurred.

The reason for the failure of the stud retaining washer for the candidate replacement fastener could not be determined. Two factors appeared to be involved.

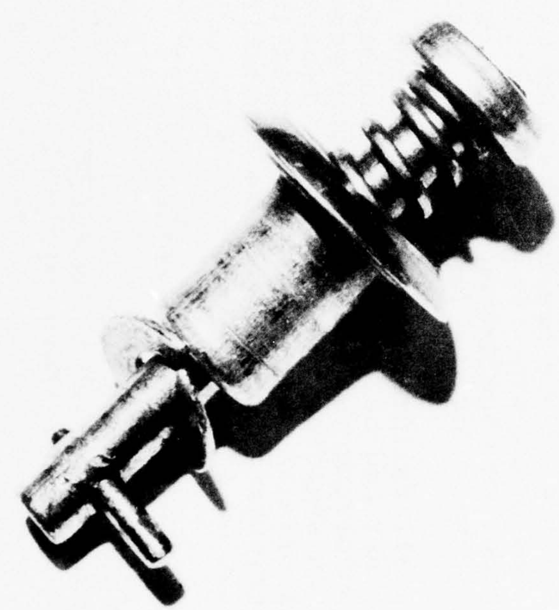


Figure 22. Present Fastener with Loose Cross Pin Caused by the Endurance Test

- Debris generated from the fastener operation (little chips of aluminum abraded from the panel) or other contamination may cause the washer to be clamped between the panel and the structure, as happened in the first 50 cycles of testing. This deforms the retaining tabs on the washer as previously shown in Figure 19.

- Progressive deterioration of retaining tabs from the washer may result in the tabs of the washer catching on structure.

The washer is 0.020 in. thick and the retaining tabs are 0.03 in. wide. This lightweight construction does not appear adequate to withstand service abuse.

Malfunctions of the candidate replacement fastener were of two major types:

- A tendency to cross-thread the stud in the receptacle.

- An apparent erratic operation of the self-locking mechanism of the receptacle.

The cross threading occurred with both the alloy steel and stainless steel fasteners. The truncated screw thread of the stainless fastener may be a factor, but it is not the only cause. If it is not realized that the fastener is cross threaded and more torque is applied, the threads may be damaged, leading to eventual failure by either stripping or the refusal to engage.

The ratcheting mechanism of the self-locking device could not be felt for several periods of operation. Wear was noticed in this area on both the stud and the ratchet but the cause could not definitely be determined. In some cases, the fastener began to function in an apparently normal style during later cycling.

The redundant drive recess of the candidate replacement fastener was very successful. It enables a slotted driver to be used if that was more readily available. The Allen hex recess head was the preferred method of operation as the fastener could be properly aligned and driven with one hand, leaving the other free to align the panel. With the present fastener, three hands would be desirable: one hand for each of the above functions. It is also very difficult to assemble the trailing edge slotted-head fasteners when the aircraft installation results in their being below the fairing, as on the right engine.

Vibration Test

The CH-47C induction system fairing with the two panels, one with the present panel fasteners and one with the candidate replacement fasteners, was bolted to an engine gearbox housing as installed in an aircraft. The housing was then mounted on a slip table as shown in Figure 23. The electrodynamic shaker was connected to the slip table. Resonance searches from 5 to 500 Hz were made of the three axes of the fairing. A typical frequency response is shown in Figure 24 which shows the transmissibility versus the frequency of excitation for the vertical axis of the fairing.

Two significant resonant frequencies are shown at 60 and 90 Hz. A 30-min dwell was conducted at each of these frequencies, followed by two hours of frequency sweeps from 5 to 500 to 5 Hz. During this testing, one of the candidate replacement fasteners was left unfastened. This retaining washer and fastener came off; the washer was never found.

Two similar tests were conducted on the longitudinal and lateral axis of the fairing. Resonant frequencies were observed at 60 and 90 Hz for the longitudinal axis and 91 Hz for the lateral axis, and 1/2-hr dwells were conducted at these frequencies with the balance of testing consisting of frequency sweeps.

No deterioration of any fastener could be observed and all functioned properly at the conclusion of testing.

Abnormal Load Testing

Each panel was operated to insure proper function of the fasteners. The fairing was then positioned with engine and cross-shaft axis being horizontal as in the helicopter. The outboard end of the fairing was unsupported (unlike the helicopter) so that a given load applied to the top panel would do more damage than in the real application.

It was found that a 140-lb person walking on each panel would result in elastic deformations of 3/8 in. and no permanent deformation. All fasteners continued to operate normally.

Then the unsupported outer edge of the panel (inboard to the helicopter as installed) was stepped on until permanent denting of the panel occurred. Elastic deformation just prior to failure was 1/2 in. As the panel is curved, the edge contour was recorded before and after the permanent deformation. Contour differences of 0.1 in. were recorded before and after the test.

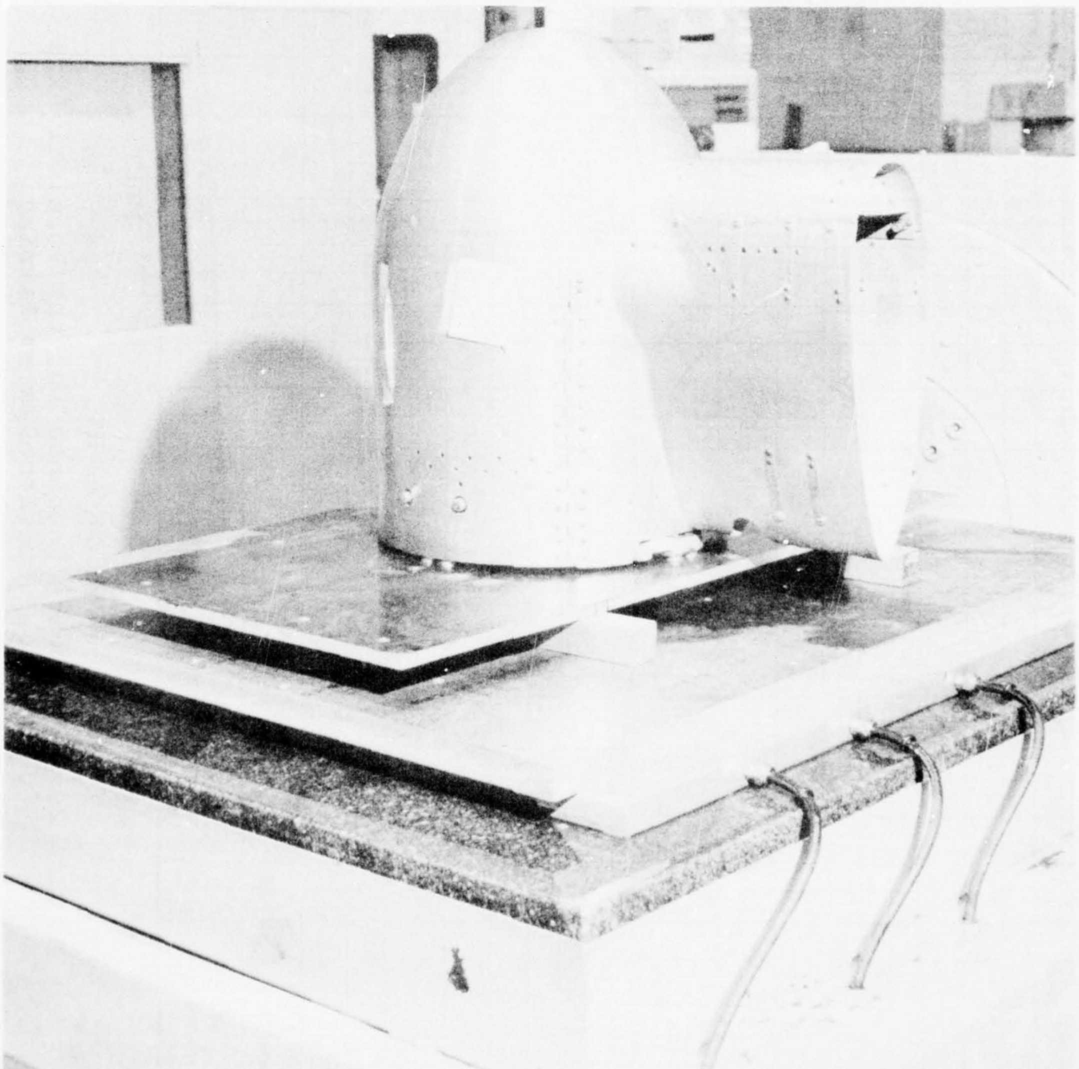


Figure 23. Vibration Test Setup for Induction System Fairing

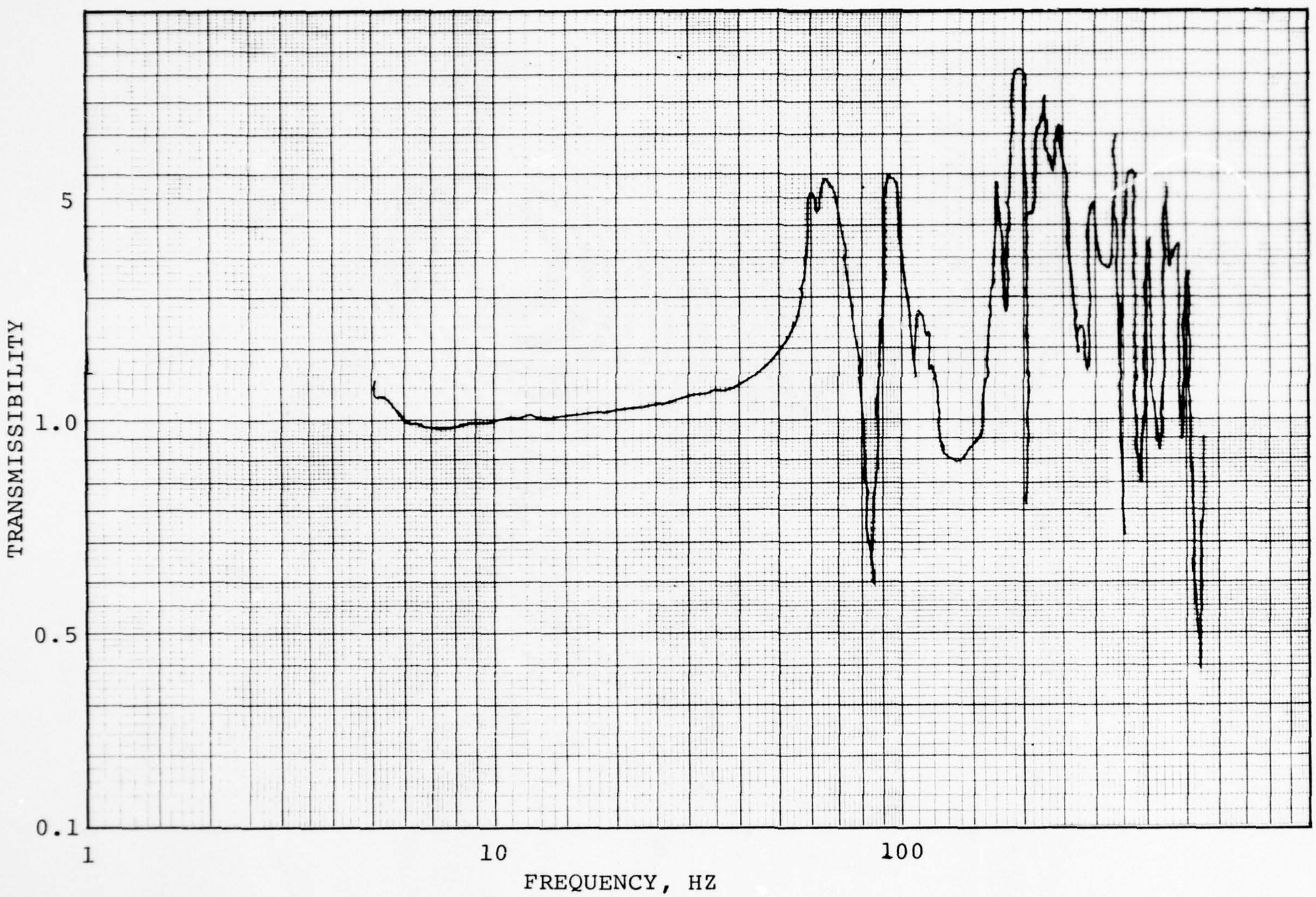


Figure 24. Frequency Response for the Vertical Axis of the Induction System Fairing

The panel would open and close normally, and all fasteners functioned properly after this abuse.

It is concluded that abnormal loads of this type are not major factors in the malfunction of the CH-47 induction system panel fastener compared to other factors previously identified.

Grip Length Testing

Testing was conducted with new fasteners of each configuration; the present CH-47 induction system fairing fastener and the candidate replacement fastener. The fasteners were mounted in the fairing panel and structure. The thickness of all material clamped by the fastener was measured ("grip length") and testing was conducted as follows:

- The fastener was engaged and operating torque recorded at a grip below the maximum recommendation of the manufacturer.
- The fastener was disengaged, the panel opened, a 0.010-in. shim inserted, and the panel closed.
- The fastener was engaged, and operating torque was recorded. Ten fastener operations were conducted at this grip length.
- The process was repeated with 0.010-in. increments of shim added until:

  (1) failure of a fastener component, or

  (2) drive limit, or

  (3) inability to engage fastener.

Six specimens of one grip length of the present fastener were tested. Two grip lengths and two materials of studs (alloy and corrosion-resistant steel) made up the six candidate replacement fasteners tested.

The results were as follows:

- The present fastener failed at grip lengths ranging from 0.026 to 0.039 in. above the manufacturer's recommended maximum. Maximum torques at failure ranged from 35 to 50 in.-lb. Three of the studs broke at the cross-pin attachment (Figure 25). The other three failed by the cam-out of the screwdriver slot in the head.

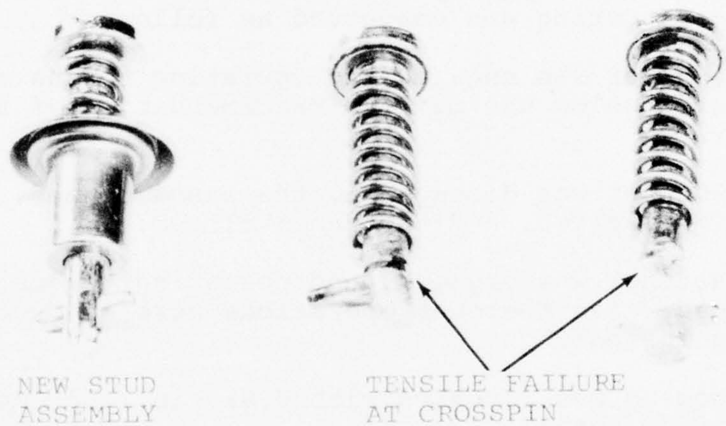


Figure 25. Failed Stud at Cross Pin

- The candidate replacement fasteners varied considerably in capability between the alloy steel and corrosion-resistant steel fasteners. The two alloy steel fasteners failed at 0.061 and 0.065 in. above the maximum rated grip length.

- The corrosion-resistant steel fasteners failed at 0.001, 0.011, 0.021, and 0.040 in. above the maximum recommended grip length, respectively.

- The failure of five of the candidate replacement fasteners occurred when very few threads were in engagement and the threads either stripped or could not be engaged. Torques of 30 in.-lb were applied to determine functional capability at each grip length.

- The alloy steel candidate replacement fastener, on the basis of this limited testing, has nearly double the ability for accommodating an overgrip installation than the present fastener, but the corrosion-resistant candidate replacement fastener appears marginal at the design recommended maximum grip.

CONCLUSIONS AND RECOMMENDATIONS

Two major reasons for malfunction of the present CH-47 induction system fairing panel fastener are:

1. Deterioration of the fastener when operated outside the manufacturer's recommended installation parameters.

2. Design decisions for the panel installation which resulted in an application susceptible to maintenance errors and manufacturing variations.

During this program very few failures occurred when the present fastener's installation complied with manufacturer's recommendations.

The candidate replacement fastener effectively solved several failure modes of the present fastener, but introduced other unanticipated modes. Further development would be required before application of this fastener could be recommended.

Available design and installation information for both the present and the candidate replacement fastener was found deficient from the viewpoint that it did not provide comprehensive design and application recommendations for the aircraft designer. Information was also lacking as to the modes of malfunction which might be expected and how to design to minimize occurrences of these failure modes.

The major factor contributing to malfunction of the current fastener is that the stud will distort if continually operated at material thicknesses in excess of the manufacturer's recommendations. The stud is furnished in a number of incremental lengths to accommodate different thicknesses of material. The manufacturer's application data specifies that the variation in material thickness or "grip range" accommodated by any one stud size should not exceed 0.029-in.

Because of the design and installation considerations listed below, special design treatment may be required to meet the manufacturer's grip range recommendations.

1. Normal sheetmetal thickness tolerances vary approximately ±5 percent (FED-STD-245, Reference 6). For a built-up sheetmetal panel and structure of 0.375-in. nominal thickness, a tolerance variation of 0.037 in. (±0.0185) would be anticipated unless precision machining was employed on the panel and aircraft structure. The manufacturer's recommendation for grip range for the Camloc P/N 2600-12 fastener is 0.360 in. to 0.389 in.: a variation of 0.029 in. and less than the permissible variation of 0.037 in. for sheetmetal. This fastener, P/N 2600-12, is one of the four sizes used in the CH-47 fairing panel.

2. The incremental fastener lengths for the ranges of material to be fastened do not overlap. This makes it difficult to select a fastener whose nominal grip length is somewhat evenly distributed about the nominal panel and structure thicknesses so that sheetmetal tolerance variations will not cause out-of-grip fastener operation.

It is believed that the malfunction rate experienced in CH-47 service by the present panel fastener could be greatly alleviated by the redesign of the installation to reduce susceptibility to maintenance error and manufacturing-originated (tolerance-type) problems. While the same approach could be applied to an installation using the candidate replacement fastener, quality problems and other characteristics of the fastener show the need for further development. These subjects are further discussed, as are additional "lessons learned", for avoiding malfunction of these and other fasteners.

This program identified the following modes of failure of the current CH-47 engine fairing panel fastener.

1. Failure of the fastener resulting from operation with excessive material thickness for the fastener length (grip range). This occurs through:

- The loosening or loss of the stud cross pin as illustrated in Figures 22 and 26.

- The bending or shearing of the stud cross pin as illustrated in Figure 27.

2. Rounding out of the Phillips recess.

3. Panel damage from the slipping of the flat-bladed screwdriver in the slotted recess of the fastener.

4. Failure of the fastener stud to eject from the panel whenever shear forces on the panel provided sufficient frictional resistance to overcome the ejecting spring.

5. Failure of the fastener stud to eject from the panel because the stud retaining washer caught on the edge of the panel hole.

Another factor in fastener failure is the method of fastener length identification. A single number is raised on the head.

There is no simple way of telling whether this number is right side up; consequently the numbers "6" and "9" may be interchanged, resulting in an improper grip fastener.

The panel installation design and manufacture contribute to fastener malfunction as follows:

1. Four of the seven fasteners, which must be operated to remove one panel, are different lengths.

   - Should a fastener be lost and a mechanic looks at the nearest fastener identification to determine the required length, he is very likely to choose the wrong length fastener.

   - The maintenance manual must be very carefully studied to determine that there are four possible lengths of the fastener and the exact position of each. It is not apparent to a casual glance as shown in Figure 28, which appears in Reference 10.

2. Six of the fasteners use slotted screw heads. The seventh has a Phillips cross recess head screw, so that two different screwdrivers are needed to open the panel. If a mechanic only has one type of screw-

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[10]Technical Manual 1520-209-34P-2, DIRECT SUPPORT AND GENERAL SUPPORT MAINTENANCE REPAIR PARTS AND SPECIAL TOOLS LIST: HELICOPTER, CARGO TRANSPORT, CH-47A, CH-47B, CH-47C (VERTOL), Department of the Army, Washington, D. C., September 1974.

AD-A038 560 BOEING VERTOL CO PHILADELPHIA PA F/G 1/3
SMALL HARDWARE DESIGN FOR EASE OF MAINTENANCE AND INSPECTION.(U)
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UNCLASSIFIED D210-11081-1 USAAMRDL-TR-76-31 NL

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Figure 26. Present Fastener--Loss of Cross Pin

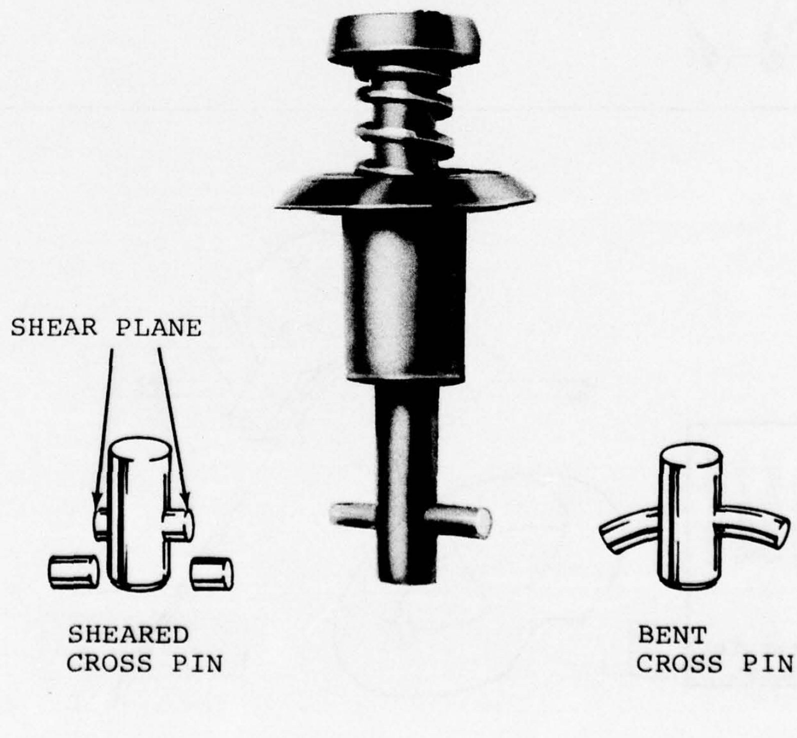


Figure 27. Shearing of Cross Pin

ITEM	PART NO.
1	2600-6
2	2600-9
3	2600-12
4	2600ES
5	2600SW2
6	2600-8
7	212-12S

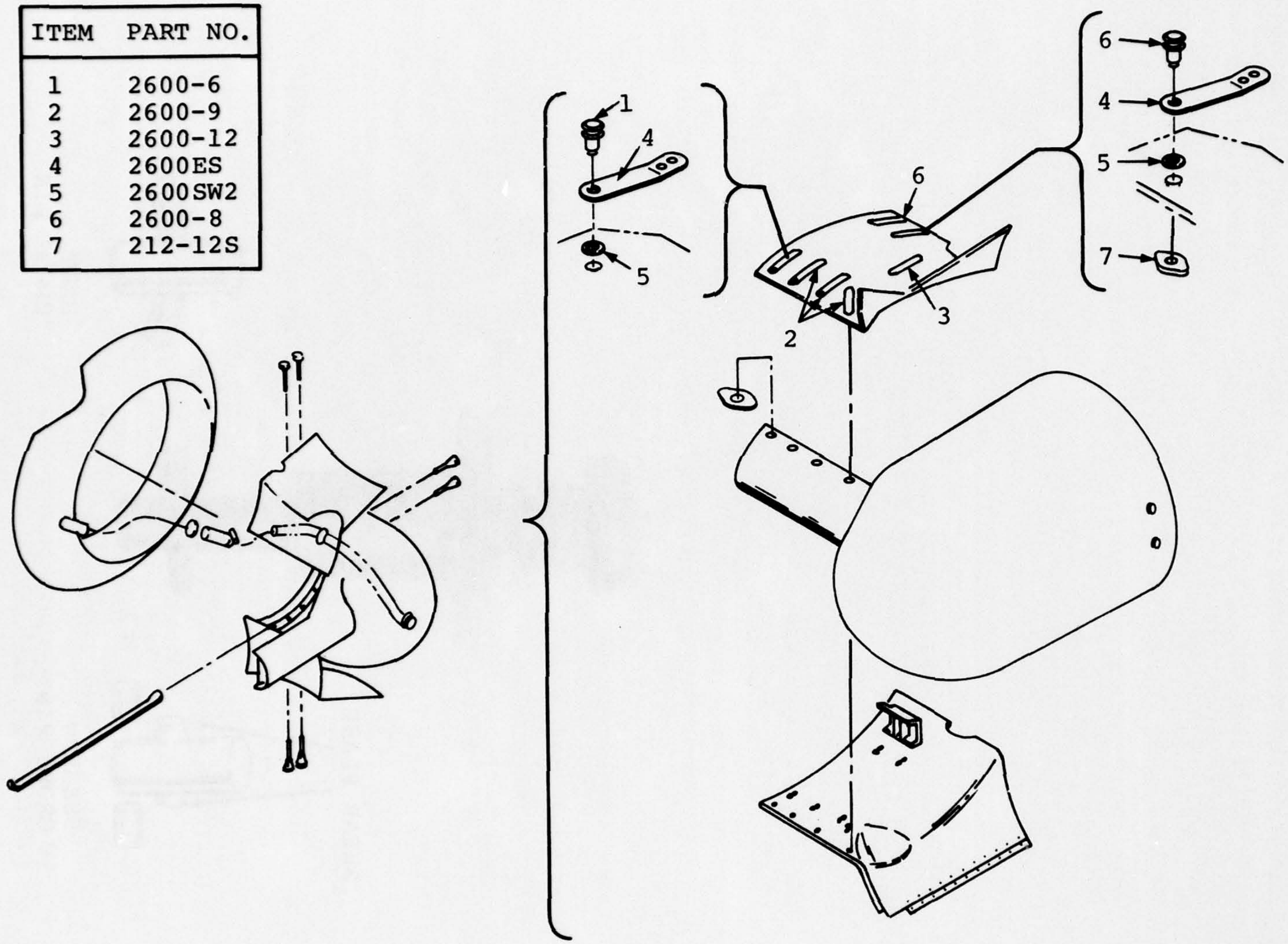


Figure 28. Induction System Fairing and Fastener Designation from Maintenance Manual

driver with him, there is a possibility he will "improvise" and damage the fastener heads.

3. Actual measurement of material thickness on two CH-47 fairing assemblies showed that the component as manufactured was thicker than recommended by the fastener manufacturer for the grip length of six of the thirteen fasteners which had been installed.

4. The fairing is used for both left and right engines by reversing the position. Two of the seven fasteners are on the underside of the fairing for the right-hand installation, and fastener operation has to be done with limited visibility and a short screwdriver. These factors contribute to difficulty in operation and especially to screwdriver slippage.

5. The panel is flexible sheetmetal and must be elastically deformed to engage the fasteners. Because of this flexibility, it is difficult - sometimes impossible - to engage all of the fasteners unless the proper order of panel fastener engagement is followed. Similarly the fasteners would "hang-up" (refuse to disengage if unfastened) if unfastened out of sequence. The reason is that high frictional forces on the fastener are caused by the tendency of the panel to return to its unfastened shape.

The candidate replacement fastener had many desirable features but its overall performance was very disappointing. Some of the desirable features are:

1. The fastener head is excellent. The redundancy of this design (shown in Figure 29) permitted fastener operation with a slotted screwdriver, an Allen hexagonal key or an Allen screwdriver bit.

2. The fastener has double the design grip range of the present fastener so there is less tendency for tolerance variations in material thickness to result in an over- or under-grip condition.

3. The fastener has a ratchet-type device to prevent stud loosening and does not rely on over-center operation. It retains the stud at any position of engagement.

4. The fastener receptacle can be easily field replaced without special tools.

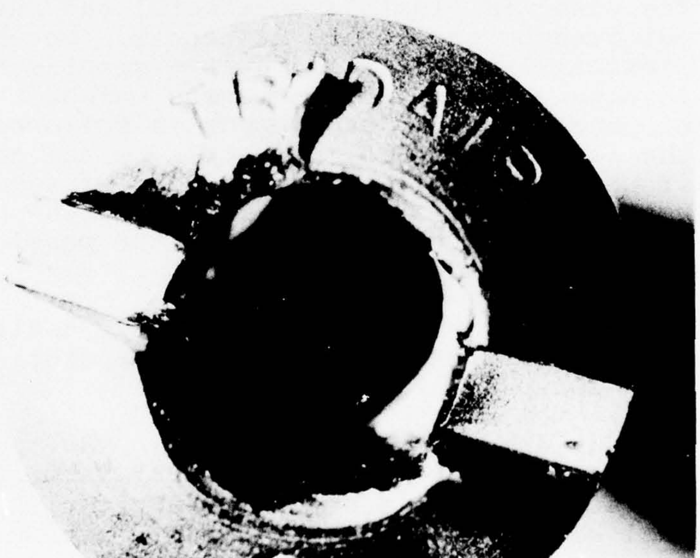


Figure 29. Candidate Replacement Fastener--Redundant Drive Recess

The performance of the candidate replacement fastener in the testing disclosed the following:

1. The hollow stud could be cross threaded on the receptacle multi-lead screw. The screw was then damaged and neither component could be reused. A damaged receptacle screw is shown in Figure 20.

2. The stud retaining washer is easily deformed if pinched between panel and structure, resulting in the condition shown in Figure 19. Loss of the stud then results when the panel is opened. Ideally, this should not happen. There are several reasons why it might:

   - Contaminants on the surface of the panel or structure

   - Out-of-tolerance conditions on the counterbored washer recess

   - Paint buildup on the surfaces of panel or structure

3. The corrosion-resistant fasteners gave poor and erratic performance when tested for ability to withstand excessive grip capability. One fastener failed in 10 cycles at the manufacturer's recommended maximum grip.

A quality problem surfaced with this fastener. During an investigation of several failures of the fastener, several studs were cut apart for examination of the screw threads. As shown in Figure 21, the minor thread diameter is approximately at the pitch diameter of the thread so that full thread strength cannot be developed.

The fastener manufacturer was consulted regarding the possible quality problem, but no analysis was received. Replacement fasteners which were said to be of a stronger configuration were obtained from the manufacturer. They were of a heat-treated alloy steel of 160,000-psi ultimate tensile strength, more than double the strength of the former stud material, which was a type 300 corrosion-resistant steel, in accordance with QQ-S-764.

Two of the alloy steel studs withstood 10 cycles of operation at 0.050 in. and 0.055 in. over the manufacturer's recommended grip with no malfunction. It is possible that a complete new evaluation of these alloy steel fasteners (which appeared to have complete internal threads) would show a significant performance gain over the present fastener.

Another characteristic of the candidate replacement fastener observed during the test was that the fastener ratchet lock appears to disengage at times. The cause of the malfunction could not be determined.

The deficiencies that appeared in the present CH-47 induction system access panel fastener performance were associated primarily with the lack of design appreciation for the importance of grip range on fastener performance and the lack of human engineering features built into the application by the aircraft designer. The latter is evidenced by the four fastener lengths and the two types of screw heads used. Contributing factors are the inability of the fastener to cope with the real requirements of the application (namely, out-of-tolerance installations) and the availability of application data for the designer.

This program showed that several areas of improvement are necessary to avoid future similar problems.

1. Panels must employ fasteners of uniform length to avoid confusion.

2. Better application data is needed for fasteners. The consequence of violating any of the suggested design parameters must be made clear to the designer.

3. Specifications for fastener qualification must give more consideration to design and manufacturing variables, such as nominal material thicknesses and tolerances.

4. Fasteners should be developed with emphasis on the ability to tolerate "out-of-optimum" conditions.

5. Additional requirements appear desirable to insure a consistent quality product.

CH-47 BATTERY ACCESS PANEL LATCH

OBJECTIVE

To evaluate maintenance problems associated with access panel securing devices by means of an evaluation of the latch currently used in the panel for battery access of the CH-47 aircraft and a candidate replacement panel securing device.

DESCRIPTION OF PROBLEM

Background

The CH-47 helicopter has equipment access panels at the forward end of each sponson on the sides of the fuselage. These hinged panels, with double curvature, are each secured by a single trigger-type latch that actuates two hooks that engage in structure-mounted fittings. The left-hand panel, for battery access, is shown in Figure 30. Malfunction of these latches is reported as an Army helicopter maintenance and reliability problem. Flight safety is involved since the panel may break from the hinges if the latch opens in flight. Figure 31 shows a field modification made to prevent in-flight safety problems. Early CH-47 aircraft had experienced problems with this latch. It was believed the trigger was unlatching allowing the handle to open. A secondary latch (quarter-turn fastener) has been incorporated to keep the handle securely closed. Failures of the secondary latch have introduced new reliability and maintainability problems.

The reported failure modes are:

1. Failure of the hooks to engage when the handle is closed
2. Difficult and erratic operation
3. Broken secondary locking feature
4. Phillips recess in secondary lock fails (cams-out)
5. Damaged latches (human abuse)

Contributing factors in latch malfunction are reported to be:

1. Frequency of use - twice daily operation in order to connect and disconnect battery.
2. Compound door curvature - lack of panel hinge rigidity and an inclination of the hinge axis to the latch axis cause alignment problems.

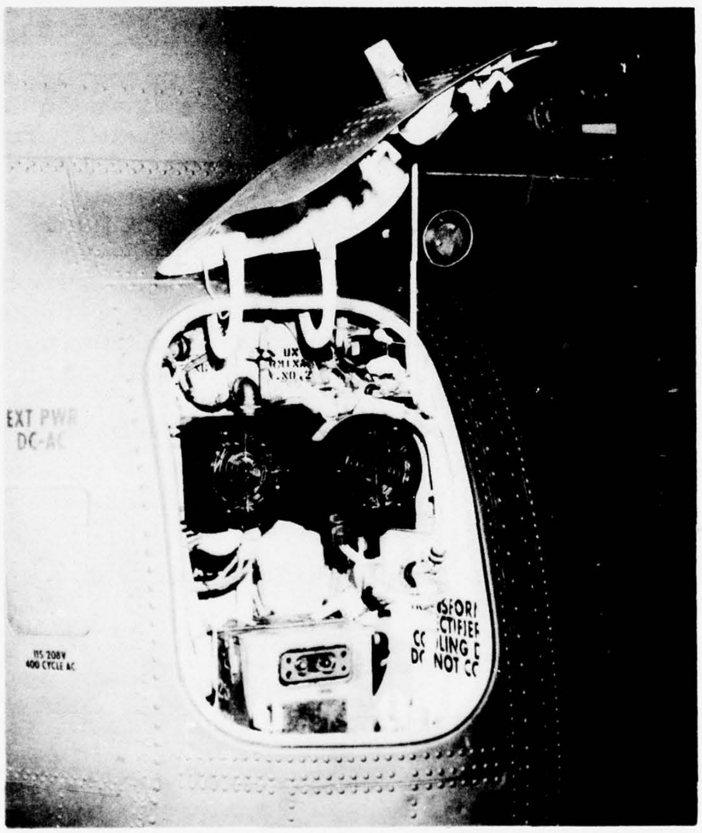


Figure 30. Battery Access Panel Installation

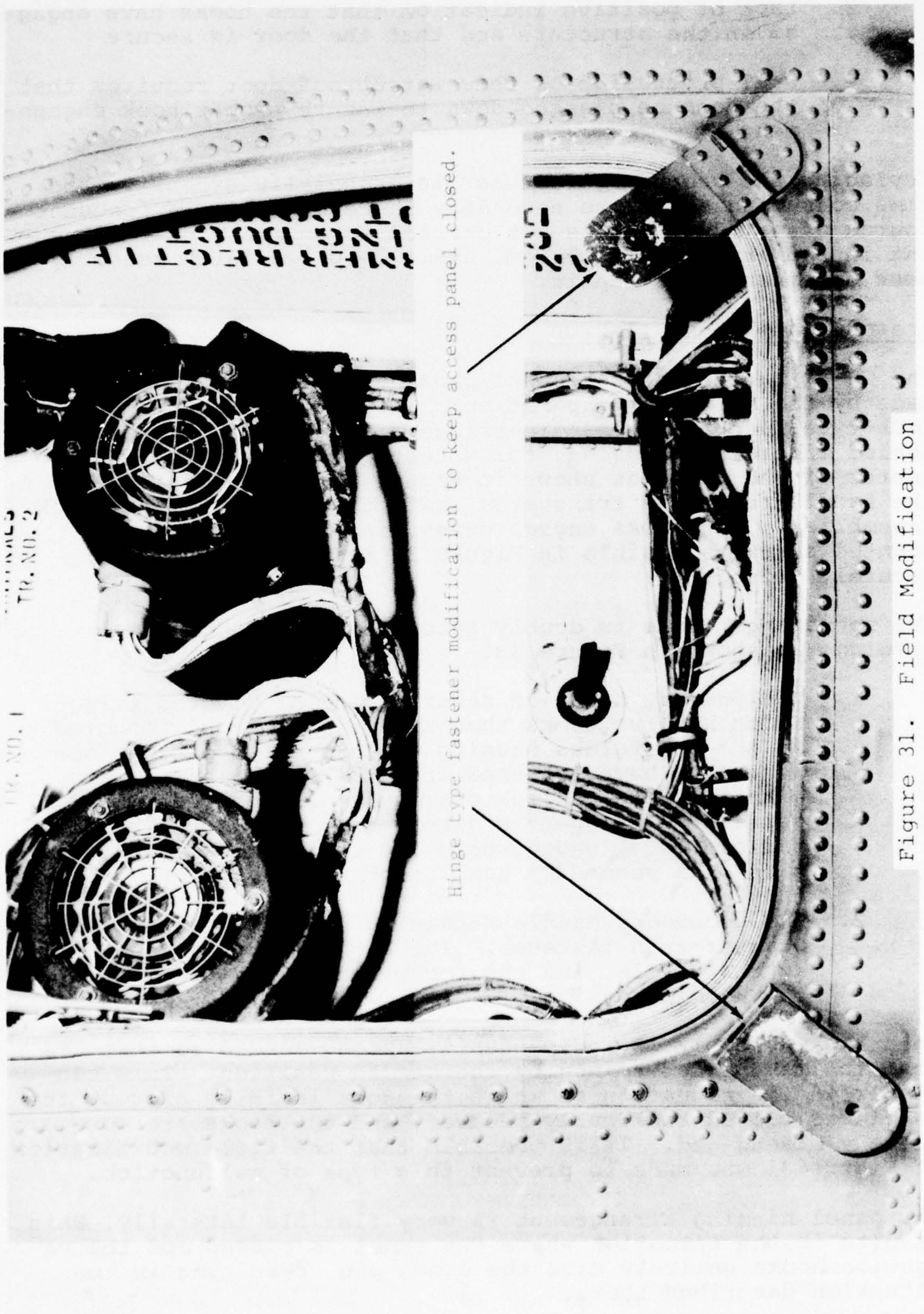


Figure 31. Field Modification

3. Lack of positive indication that the hooks have engaged in the structure and that the door is secure

4. Seal protrusion of this waterproof door requires that the door be pressed down to insure proper hook engagement

Replacing the secondary fastener is especially expensive and time consuming since the secondary fastener, while a frequent source of malfunction, is not carried as an individual component in the Army supply system, and a complete latch assembly must be ordered for repair.

Present Panel Installation

The CH-47 battery access panel presently uses latch components made by the Hartwell Corporation. This is a trigger-action, hook-type latch. The handle-trigger assembly is mounted in a sealed fiberglass housing, for watertightness, in the lower center of the panel as shown in Figure 32. The operation of the handle rotates a transverse shaft to actuate the two hook assemblies. The hooks engage cross pins in the structure-mounted brackets visible in Figure 30 to keep the panel securely closed.

The operating handle is doubly secured against accidental opening, as shown in Figure 33.

1. The primary means of securing is the pivoted trigger which has two hooks that engage a cross pin mounted in the fiberglass housing. (This cross pin was observed to have loosened from the fiberglass in an aircraft returned for overhaul. A loose pin would permit the trigger to disengage. This, or a similar failure mode, undoubtedly led to the recent installation of a secondary handle locking device.)

2. The secondary handle retaining device is an Airloc quarter-turn fastener. The Airloc stud is mounted in the handle, and the receptacle, in a bracket in the handle housing.

Each hook assembly is independently spring-loaded so that its position is not determined by the handle position. This can result in the situation in which the door is fully closed, the handle is closed and doubly secured, and the hooks are completely disengaged. It is probable that the field modification of Figure 31 was made to prevent this type of malfunction.

The panel hinging arrangement is very flexible laterally. This results in the situation where the panel is closed and the retention hooks entirely miss the cross pin, resulting in the situation described above.

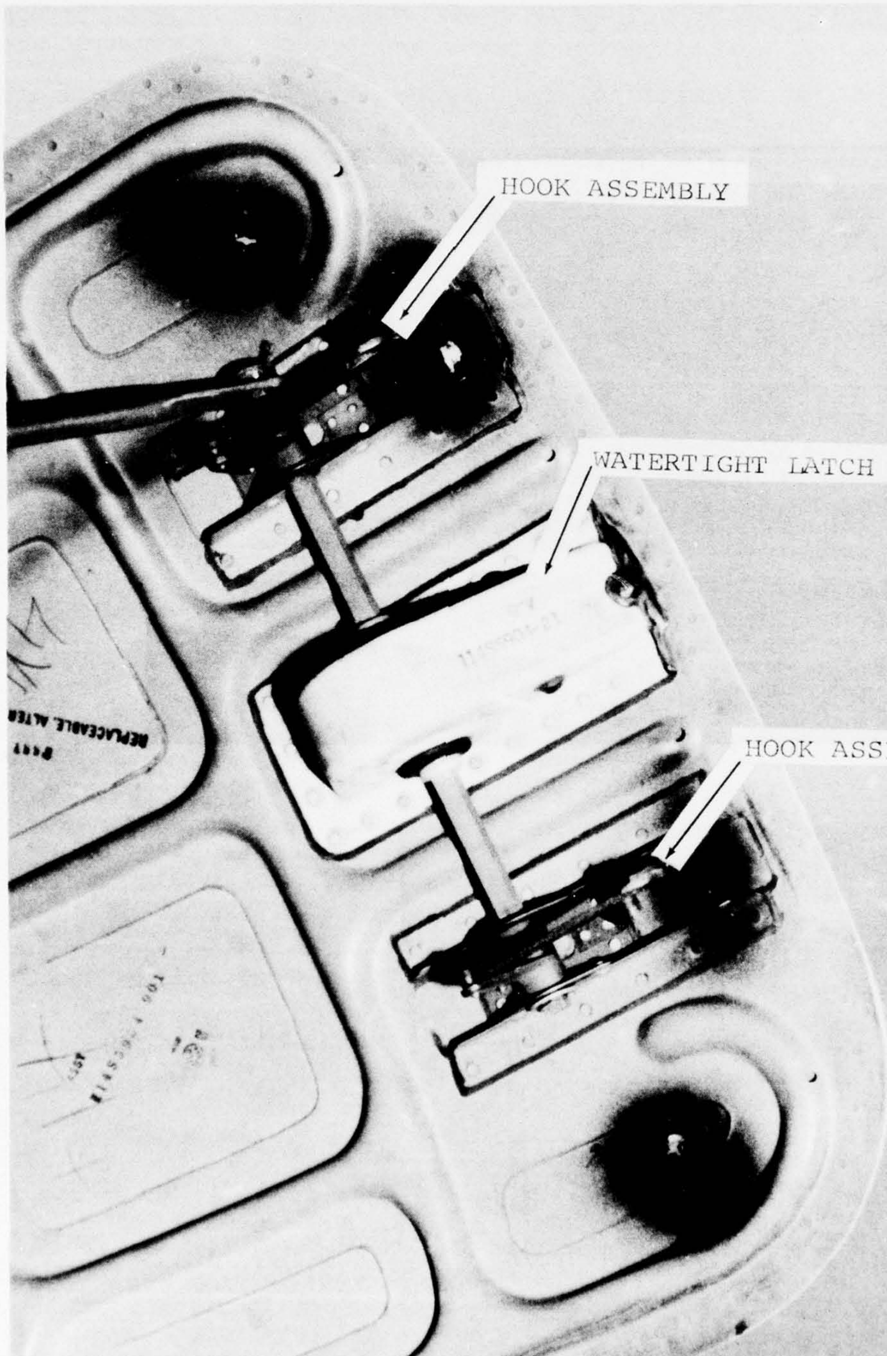
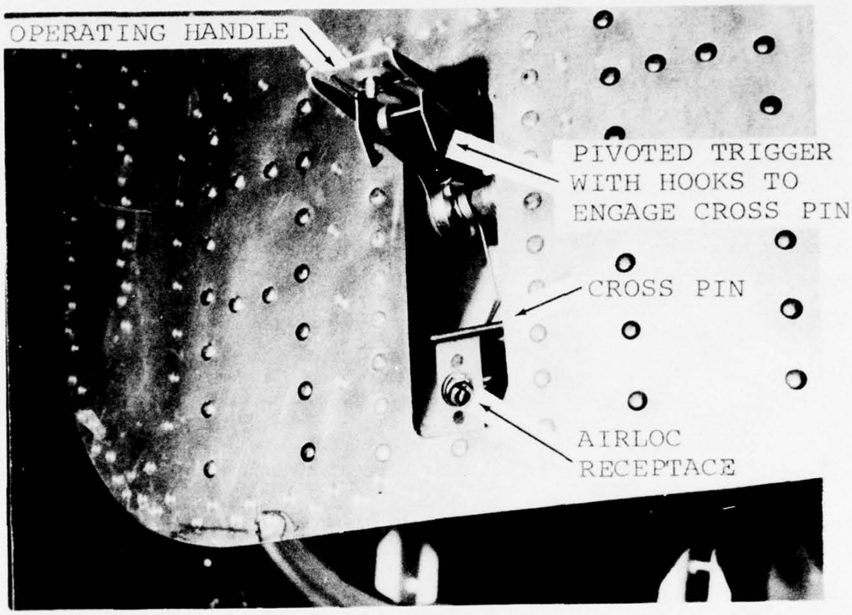


Figure 32. Latch Details



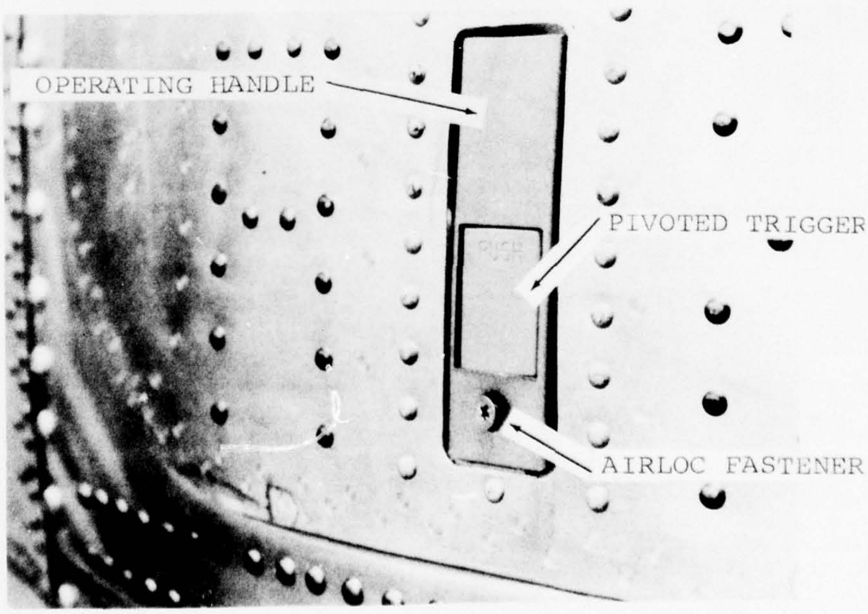


Figure 33. The Double Securing Operating Handle

The panel hinge axis is inclined more than 30 degrees to the latch axis. The panel must be completely closed before a person attempts to operate the latch handle or the hooks will be in the incorrect lateral position.

Design Requirements

The functions of the CH-47 battery access panel latch are to provide the following:

1. A panel that can be easily and quickly opened for frequent access to the battery compartment
2. An aerodynamically suitable exterior surface
3. A watertight panel
4. Assurance to the flight crew that the panel is secure
5. An application with good maintainability and reliability characteristics when exposed to the Army helicopter operating environment and maintained by Army field level personnel.

TECHNICAL APPROACH

The original intent of the present latch installation appeared to be simplicity of operation, as evidenced by the following:

1. One hand engagement of two "latches"
2. Rapidity of operation
3. Operation without tools.

The resulting complexity of the latch installation in this flexibly mounted panel has defeated the original objective and resulted in reliability, maintainability, and safety problems.

The reported problems and failure modes indicate that prime importance should be attached to:

1. Security of panel retention
2. Visual assurance to the flight crew that the panel is secure
3. Design simplicity.

The candidate replacement panel securing device appeared to offer significant improvements in each of the above areas of performance.

A test program was prepared to permit a comparative evaluation of the present and candidate replacement panel securing devices under conditions representative of the aircraft.

Candidate Replacement Design

Two Hartwell "Custodian Super Strength" panel fasteners were selected to replace the present latch. One of these two-piece, quarter-turn fasteners is shown in Figure 34. It is rated at 9000-lb ultimate shear load and 4000-lb ultimate tension load.

The spring-loaded stud is flush with its housing when engaged, and protrudes in an obvious manner, away from the face of the panel, when disengaged. This gives a visual indication of the security of the panel, as shown in Figure 35. The conical face of the stud housing nests in a conical recess in the receptacle so as to be self-aligning and easily engaged in spite of the compound panel curvature and inclined hinge axis.

The fasteners are easily adaptable to a waterproof installation.

TEST EVALUATION

Detailed Test Objectives:

To evaluate maintainability and reliability problems associated with the current CH-47 battery access panel latch and the candidate replacement securing device under the following simulated operational conditions.

1. Repeated use

2. Gross contamination

In addition, the deflection characteristics of the panel and the free play of the present latch shall be determined. A time study shall be conducted to determine the panel operating cycle time with the present latch and with the candidate replacement securing device.

Summary of Testing

Current Hardware

An initial functional test of a new CH-47 battery access panel assembly was conducted, and the following observations were made of the present latch installation.

1. The Airloc stud seldom aligns with its floating receptacle. When they do not align and the handle is pushed closed, the stud prevents complete closure of the handle and the trigger is hard to engage. It can

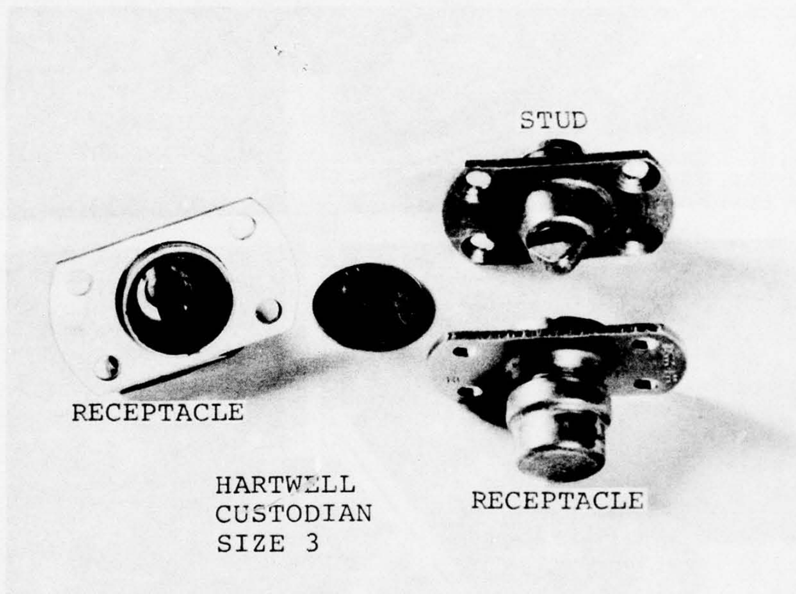


Figure 34. Candidate Replacement Panel Fastener

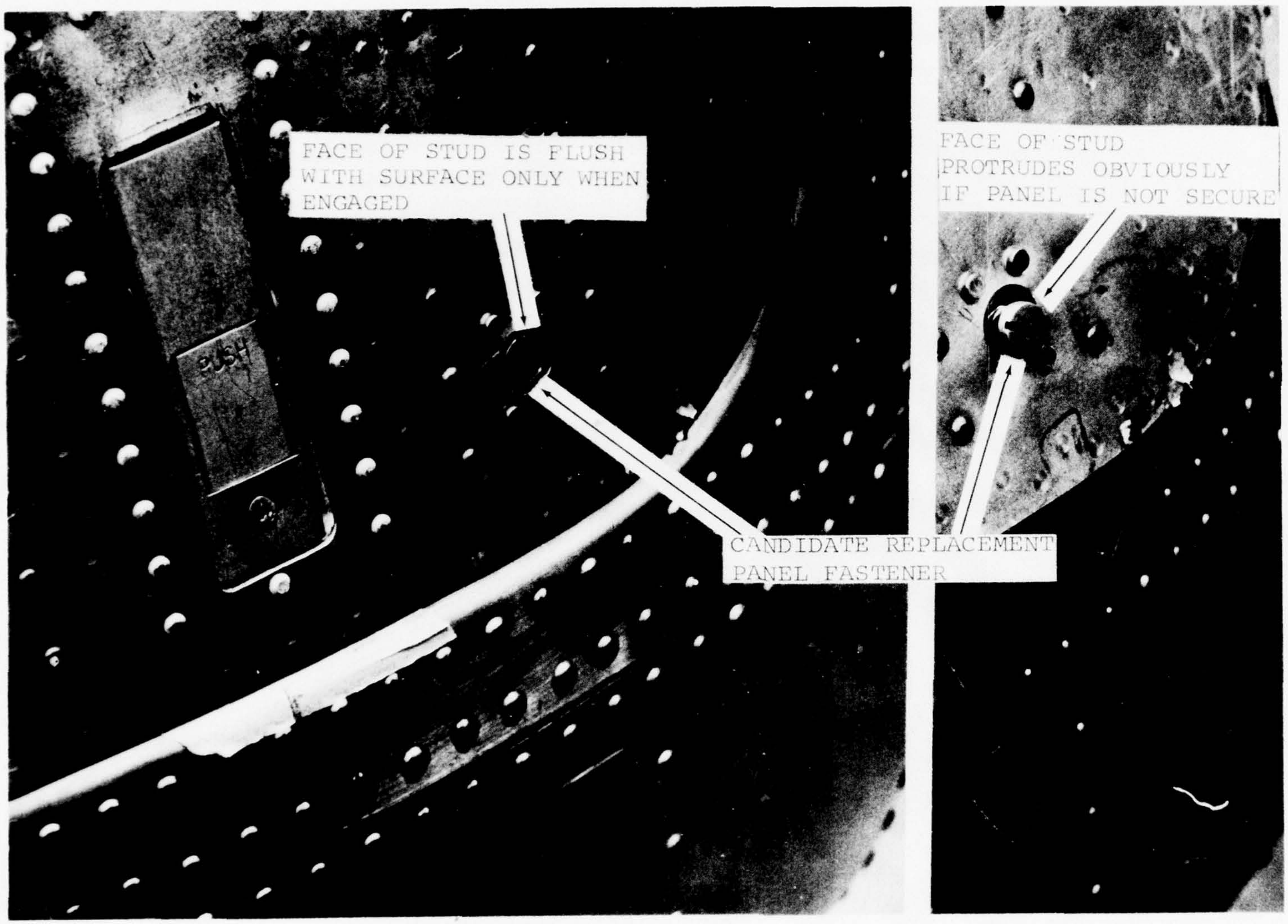


Figure 35. Security of Panel Shown by Fastener Head

sometimes be engaged by pounding or otherwise forcing the latch.

2. The Airloc stud head recess (Phillips type) stripped on this brand new installation after being opened and closed only a few times.

3. The Airloc is not available except as part of the latch assembly. If the Airloc fails, the latch assembly must be discarded.

4. The panel latch must always be in the full-open position when the door is closed in order to successfully lock each hook to its clevis.

5. If the panel latch handle is in the proper position, the panel seal must be compressed while closing the latch in order for the hooks to make proper contact with their female clevises.

6. The trigger will engage in its latching pins and hold the handle closed whether or not the hooks have engaged the structure-mounted pins. This way the panel appears to be securely latched but may be completely unlatched. This is shown in Figure 36.

7. The trigger mechanism forces are affected by latch tension forces. If latch forces are high, it is difficult to engage and disengage the trigger. The trigger is released by pressing with one's thumb or finger. If the release forces are high, the trigger has a tendency to snap "in", and one's thumb gets scraped by the edge of the handle (Figure 37).

8. The panel is torsionally soft and may deflect outward under hook engagement forces, resulting in the engagement of only one of the two hooks. The latch handle will close and the panel appears safely closed when, in fact, it is only partially latched.

9. The panel is very flexible sideways, and unless care is taken to ensure that the panel is perfectly aligned, the latch hooks may completely miss the engaging pins.

It was apparent that this panel latch must be an operational problem area.

A deflection test was run to verify and document the reported panel mounting flexibility. The door proved very flexible. A 4-lb sideways force was enough to prevent the latch hooks from engaging. The spring rate was 16 lb per in. The panel spring rate was even lower for a

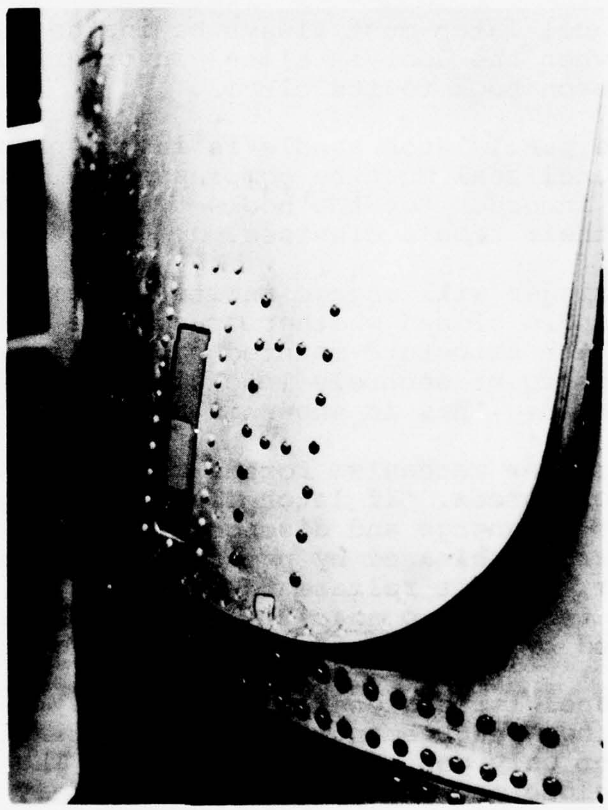
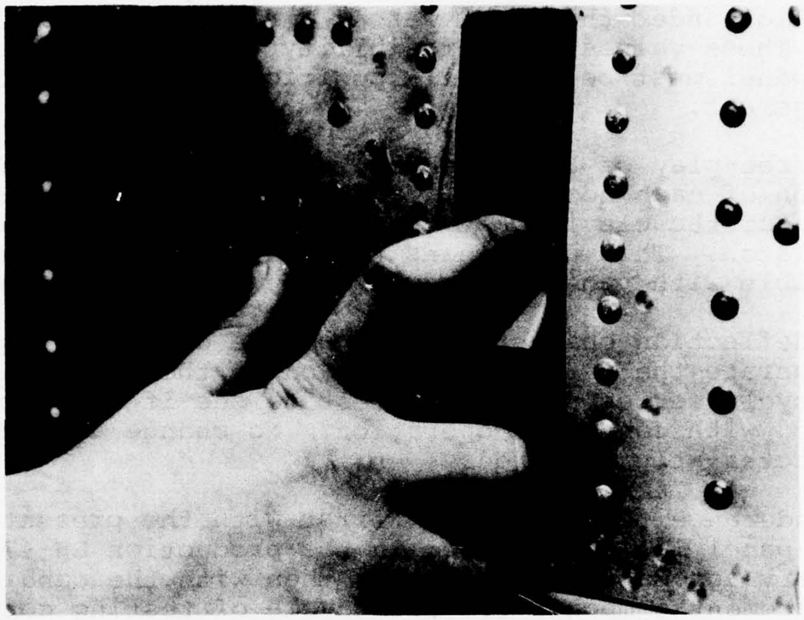
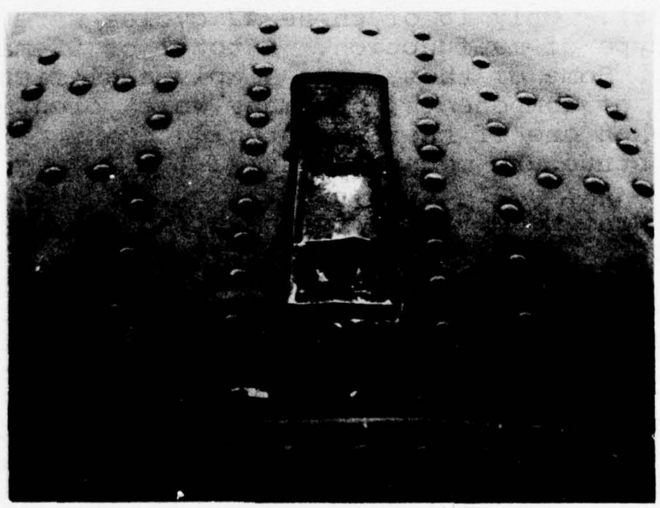


Figure 36. Present Latch Handle is Latched but Door is Open



TO AVOID SCRAPING YOUR FINGER WHEN THE TRIGGER SNAPS IN - USE A SCREWDRIVER



AT LEAST YOUR FINGER DOESN'T GET SCRAPED

Figure 37. Trigger Release Operation

load applied normal to one side of the panel. The deflection under this load was at a rate of 11.8 lb per in. These values give credibility to the reports that the panel must be carefully positioned to assure latch engagement.

The free-play of the latch hooks was measured. The lateral motion of each hook was ±1/8 in., which is half the width of the clevis that the hook must enter to engage the latch. This play means that latch misalignment is possible with panel sideways forces as low as 2 lb.

The deflection characteristics of the door and the force to operate the latch were measured at the end of each 300-cycle series during the test to see if a change occurred with continued operation. No change in either characteristic occurred.

An endurance test was run: first with the present access panel latch installed in the production CH-47 battery access panel assembly, then with the candidate replacement components. Each cycle of testing consisted of unlatching the access panel, completely opening the panel, closing the panel, resecuring the latch, and checking for panel security and the proper functioning of the latch.

After 47 cycles of testing of the present latch assembly, a failure of the secondary handle/lock receptacle occurred (Figure 38). Only 16 of these 47 cycles were "successful" with no type of malfunction. A total of 52 malfunctions occurred. Some of these were simply a difficulty in the alignment of components, but many were potentially serious, such as when one of the two latching hooks fails to engage the structure-mounted clevis.

A replacement receptacle was installed for the secondary handle lock and failed in the first cycle. This was the third failure involving this lock: the Phillips recess in the fastener stud had stripped during functional testing. The fastener was removed for future tests because failure frequency and modes had been well identified.

Malfunctions continued at a high rate: nine of the next 12 cycles involved one of the latching hooks hanging up on or missing its clevis entirely. It gradually became evident that certain procedures had a very high probability of successful latching and others would increase the chance of malfunction. Several series of approximately 50 cycles each were carefully carried out and no malfunctions resulted. It appeared impossible to avoid

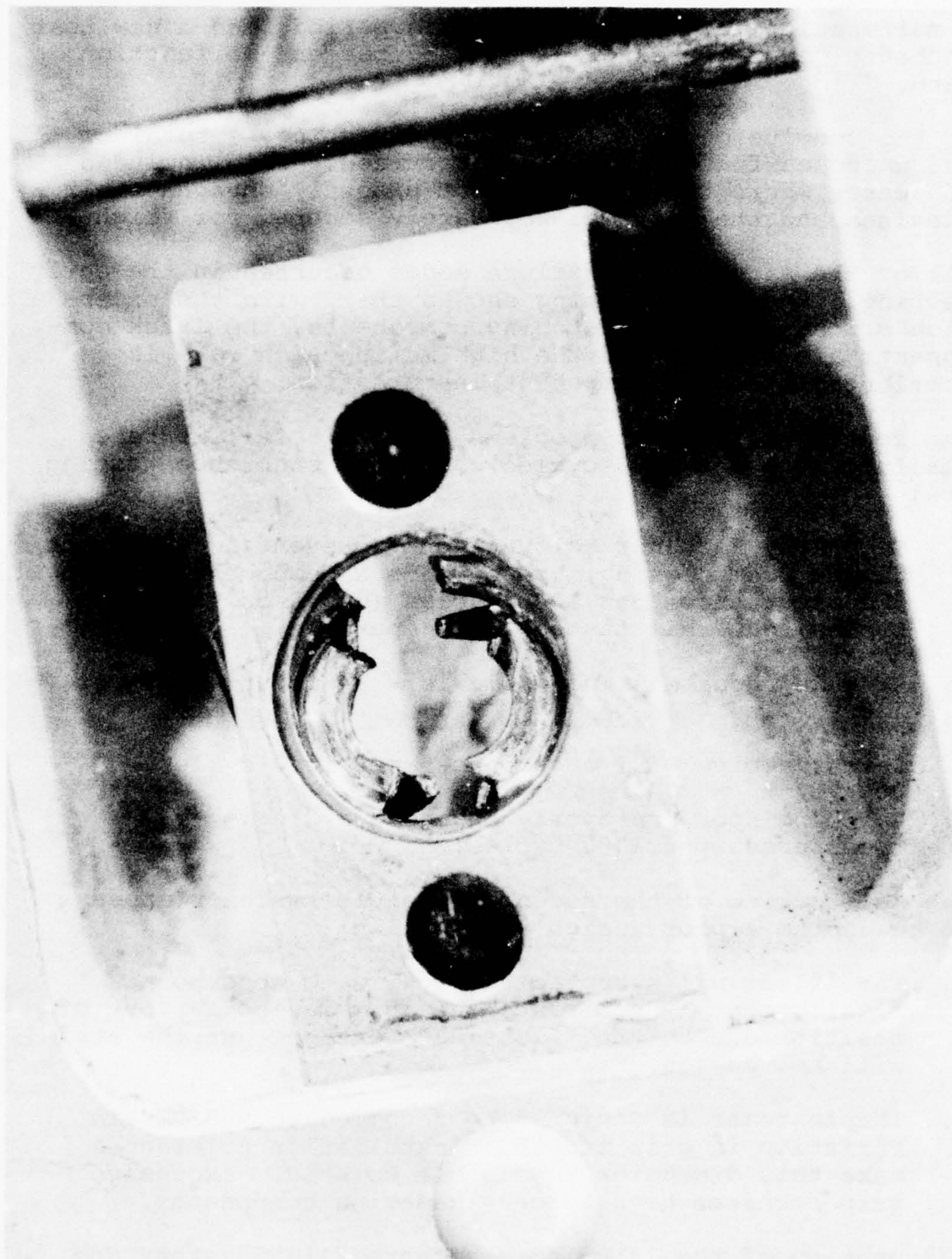


Figure 38. The Failure of the Receptacle of a Secondary Handle Lock

a malfunction much longer than this period, and a new test mechanic generally experienced a 50 percent malfunction rate.

At the conclusion of 3000 cycles of testing, a total of 406 unsuccessful latchings had occurred. This included 365 cases where the hooks had not properly engaged their clevises and the door was not safely secured for flight.

All of the significant failure modes occurred in the early testing. Endurance testing showed that, with the exception of the secondary latching components, the latch components are durable and the high malfunction rate is attributable to the component installation.

The four most frequent problems and their failure rates (malfunctions per 1000 cycles) for this endurance testing are:

1. Secondary Fastener Malfunction - preventing the latch handle from closing, opening, or a component failure, 480 occurrences per 1000 cycles (based on the 48 cycles that this fastener was operable).

2. Latching Hook Missing a Clevis - 84 occurrences per 1000 cycles.

3. Latch Jamming - 47 occurrences per 1000 cycles.

4. Latching Hook Improperly Engaging a Clevis - 37 occurrences per 1000 cycles.

The malfunction of the secondary handle fastener appears to be due to a poor design application:

1. The "floating" receptacle which is to accommodate misalignment is not centered and moves so far out of position due to the "floating" feature that the stud will not engage.

2. The fastener is designed to accommodate a 0.010-in. variation in grip length. Installation tolerances make this dimension impossible to hold. Excessive grip requires high forces, damaging components.

Malfunction of the latch hook affects flight safety and also results in an improper panel seal. This could be a serious problem in a water landing since the panel is very near the waterline.

Candidate Replacement Components

At the completion of 3000 cycles of testing, the candidate replacement component was installed for test. The upper bodies were mounted in the panel used in the previous test. The lower bodies were mounted in test brackets at the approximate location of the brackets for the present latch (Figure 39).

Two types of minor discrepancies occurred in the 2236 cycles of testing of this panel fastener.

1. A stud would refuse to engage freely in the receptacle until a realignment was made. This happened six times in the 2236 cycles.
2. The screwdriver would occasionally slip from the slot head of the stud and scratch the panel. This was such a minor problem that the frequency of occurrence was not recorded, but several scratches were visible after the test.

The Hartwell "Custodian Super Strength" fasteners are a simple, reliable means of panel latching. Initial costs are estimated at less than a quarter of the cost of the present latch installation, and life-cycle costs would be reduced even more because of the high reliability.

Two other test comparisons were conducted.

1. A time study of the panel operating cycle for each latch arrangement showed that a panel opening and closing sequence with the candidate replacement components took less than 80 percent of the operating time of the present latches.
2. A gross contamination test consisting of over 100 cycles of operation of each latch system with a coating of MIL-L-5606 oil and Arizona road dust showed no malfunction of either latch due to this cause.

CONCLUSIONS AND RECOMMENDATIONS

A functional test of the CH-47C battery access panel latch confirmed that this must be a problem area. Nine modes of malfunction were quickly apparent. Endurance testing of the panel documented the magnitude of the problem. More than 400 of the 3000 cycles resulted in unsuccessful latching, and many other "nuisance problems" occurred.

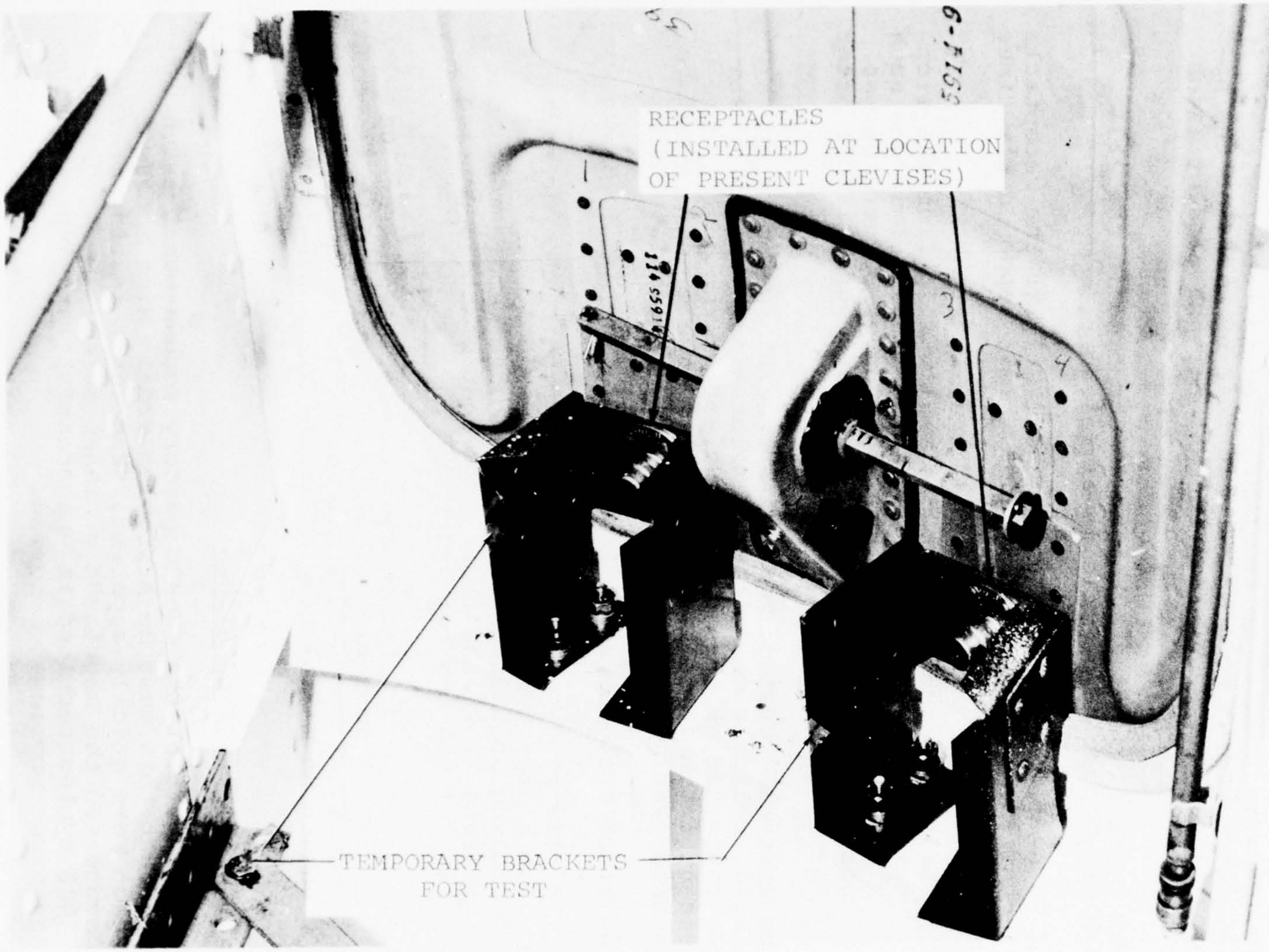


Figure 39. Candidate Replacement Latch Receptacle Installation

The panel provides a difficult latching problem:

1. It must be waterproof.

   - This requires a compressible seal which adds to the panel closing forces.

   - The latch must be compatible with a watertight installation. Certain types of latches are very difficult to use in a sealed assembly.

2. It is subject to high aerodynamic loads. If a panel should open in flight it might well break off and result in a safety problem.

3. It is frequently opened, and it is desirable to open it without tools.

4. The panel has two degrees of curvature, and the nominal plane is inclined approximately 30 degrees from the centerline of the aircraft and the structural members. The hinging and latching of such a panel is difficult.

5. The hinging arrangement chosen added to the complexity.

   - The hinge axis was parallel to the aircraft structure rather than the plane of the panel.

   - The hinges proved to be very flexible laterally.

   - As a result of these two factors, the action of closing the panel tended to misalign the latch sideways.

The present latch installation design violates a fundamental design principle in that the latch may appear to be engaged and safe for flight when, in fact, it is completely disengaged.

This characteristic, in addition to the many possible modes of malfunction and the frequency of malfunction, resulted in a highly undesirable installation.

The candidate replacement latch arrangement used two, size 3, Hartwell Custodian panel fasteners. These fasteners have the following characteristics:

1. The upper body stud is spring-loaded away from the panel face so that it is visually apparent whether the latching has been successful or not.

2. The upper and lower bodies are conical so that a misalignment of the panel and the structure will be eliminated by self-centering.

3. The panel fastener, as configured for this test, had a screwdriver slot.

4. This is a high-strength device with a rated ultimate tensile strength of 4000 lb and an ultimate shear strength of 9000 lb.

5. Although the installation was not made waterproof for this test, it is easily adaptable to a waterproof application.

This configuration was virtually free of malfunction for over 2200 panel operations. The installation proved to be easy to use and positive in operation, gave visual indication that the latching was complete, and was actually quicker to use than the present latch. About the only problem that occurred during the endurance testing was several scratches from slipping screwdrivers.

Both latches showed a high resistance to gross contamination by repetitive applications of MIL-L-5606 oil and Arizona road dust. The two latches were operated for over a hundred cycles with no sign of malfunction due to this cause.

Initial costs of the candidate replacement latch are estimated to be less than 25 percent of the present latch installation, and life-cycle costs should be affected to a much greater extent.

Although this panel fastener may not be an ideal latch for all applications, the basic design principle demonstrated by this installation should be a requirement for any helicopter exterior panel latch.

- It must be safe for flight or give visual indication of the unsafe condition.

This essential requirement is not met by the present panel latching assembly.

This program clearly identified the value of a component functional test in the real installation with an analysis of failures, causes and failure modes. Had such a test of this installation been carried out early in the prototype stage and been followed by corrective action, it would clearly have been cost-effective in terms of reduced maintenance and increased reliability.

CH-54 AVIONICS ACCESS PANEL STAY ROD STOWAGE

OBJECTIVE

To evaluate maintenance problems associated with access panel stay rod retention clips and a candidate replacement self-storing stay rod design by a simulated operational test and a static strength evaluation.

DESCRIPTION OF PROBLEM

Background

Problems with access panel stay rod retention have been reported on the OH-58, the UH-1, and the CH-54 helicopters. The latter problem involved the avionics access panel (Figure 40).

The stay rod on the avionics access panel is currently retained by a simple, inexpensive, lightweight beryllium-copper fuse clip. The free end of the rod is pressed into this clip. The factors associated with the malfunction of this clip are reported to be:

1. The panel (and stay rod) is used frequently for access, inspection, and maintenance of the avionics gear.

2. The clip is not tolerant of "maintenance abuse".

3. The clip and attached stay rod are subjected to the aircraft vibration environment.

The reported failure mode is fuse-clip breakage. The CH-54 stay rod and a typical failed retention clip are shown in Figure 41.

Present Installation Characteristics

The present stay rod retention device is a Littlefuse Company Part No. 123002, silver plated beryllium-copper fuse clip specifically designed for fuse applications but also recommended for the holding of spare components, friction catches for latches and wire cables, and a variety of other uses. This clip is designed for a 9/32-in.-diameter fuse and has a 0.173-in. mounting hole for retention by a No. 8 screw.

Design Requirements

1. To retain the access panel support rod when the panel is closed

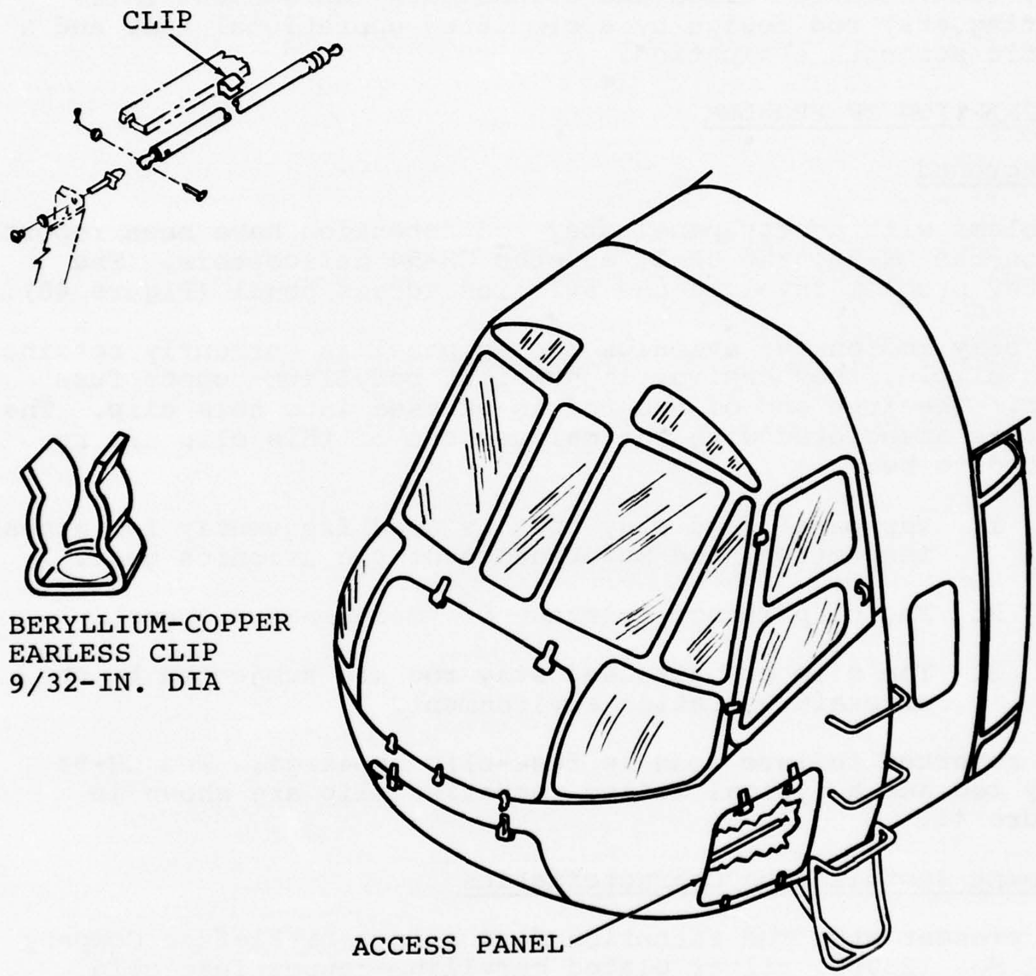


Figure 40. CH-54 Avionics Access Panel Location

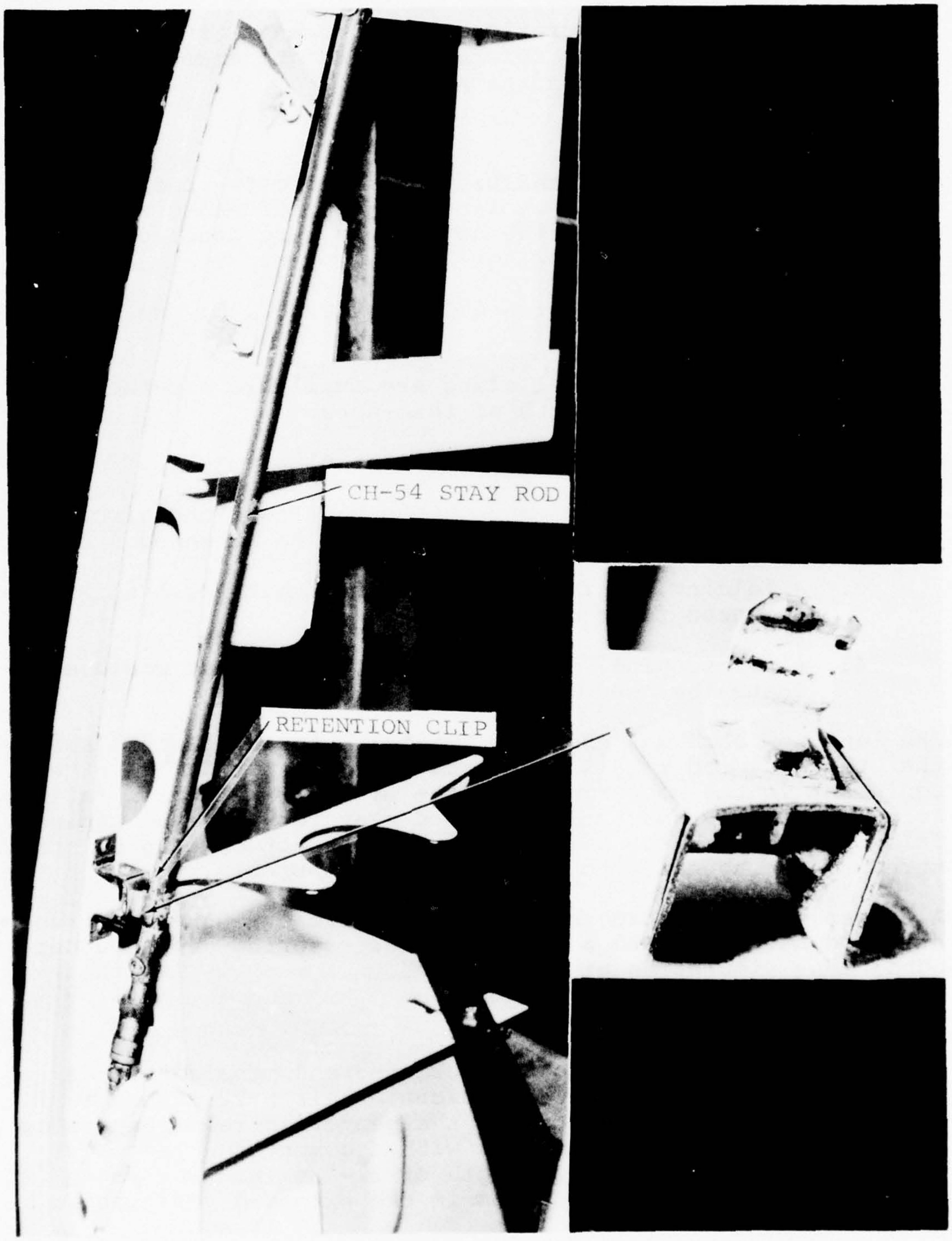


Figure 41. Test Installation--CH-54 Stay Rod, Retention Clip, and Typical Failed Clip

2. To withstand operational requirements of maintenance personnel, to be tolerant of "maintenance abuse" and environmental conditions.

TECHNICAL APPROACH

The reported problem and failure modes indicate inadequate strength for the repeated cycling and operational conditions of this application. Several approaches were considered, among which were the following:

1. A clip retainer of a different material, and of heavier construction.
   - Stainless-steel clips are available off-the-shelf for applications of this sort.
   - An elastomeric or resilient plastic clip.
2. A loop-type clip on both the panel and the aircraft structure to which the rod would be attached.
3. A folding, self-storing stay rod that would eliminate the need for a clip.
4. A telescoping, self-storing stay rod that would eliminate the need for a clip.

The last approach was chosen. The self-storing feature assures that the stay rod remains in place and will not damage other equipment in the compartment in the event of retention failure. Furthermore, a permanently attached stay rod prevents a panel from being opened too far, damaging hinge attachments or structure. These appeared to be desirable features.

A comparative test program was prepared to evaluate the present stay rod retention and a candidate self-storing design under conditions simulating aircraft usage.

Telescopic Stay Rod

This self-storing stay rod was designed and manufactured by Norco, Inc., Georgetown, Connecticut; their part number is A1412-7. It is designed to fit the geometric requirements of the CH-54 avionics access panel with a compressed length of 12-1/2 in. and an extended length of 21-1/4 in. The rated load in tension and compression in the extended position is 150 lb.

The stay rod latches automatically when extended and has a knurled sleeve on the barrel that must be moved axially to release the latch and compress the stay rod.

TEST EVALUATION

Detailed Test Objective

Evaluate maintainability and reliability problems associated with the current CH-54 avionics access panel stay rod retention clip and the candidate replacement self-storing stay rod for that application by means of testing with the following simulated helicopter conditions.

1. 2000 cycles of operation
2. Vibration

In addition, the static strength of the two approaches is to be evaluated, and the effects of gross contamination of oil and dust on the candidate replacement configuration will be determined.

Summary of Testing

The avionics access panel stay rod and retention clip, and the candidate replacement self-storing stay rod were installed for testing on the CH-47 battery access panel. This enabled the stay rod retention endurance tests to be run concurrently with the battery access panel latch endurance testing. The two stay rod installations are shown in Figures 41 and 42.

Each endurance cycle consisted of opening the panel until it was supported by the self-storing stay rod, removing the avionics panel rod from the fuse clip, reinstalling it in the fuse clip, releasing the self-storing rod, and closing the panel.

During 2200 cycles of endurance testing, one failure of the present stay rod retention clip occurred. This occurred at cycle 963. The second clip had accumulated over 1200 cycles with no evidence of failure when testing was stopped.

The force required to remove the stay rod from the retention clip was measured at approximately 100-cycle intervals during one test period. The force varied from a maximum of 10 lb at the start to a low of 5 lb during later cycling. These forces are significantly high in view of a later static test evaluation. The static test evaluation showed that a side force of 16 lb was sufficient to fail the clip: a very low value in view of the required operating forces.

Just prior to the endurance testing, a mechanic attempted to close the candidate replacement stay rod for storage and failed the release assembly. He explained that he did not understand

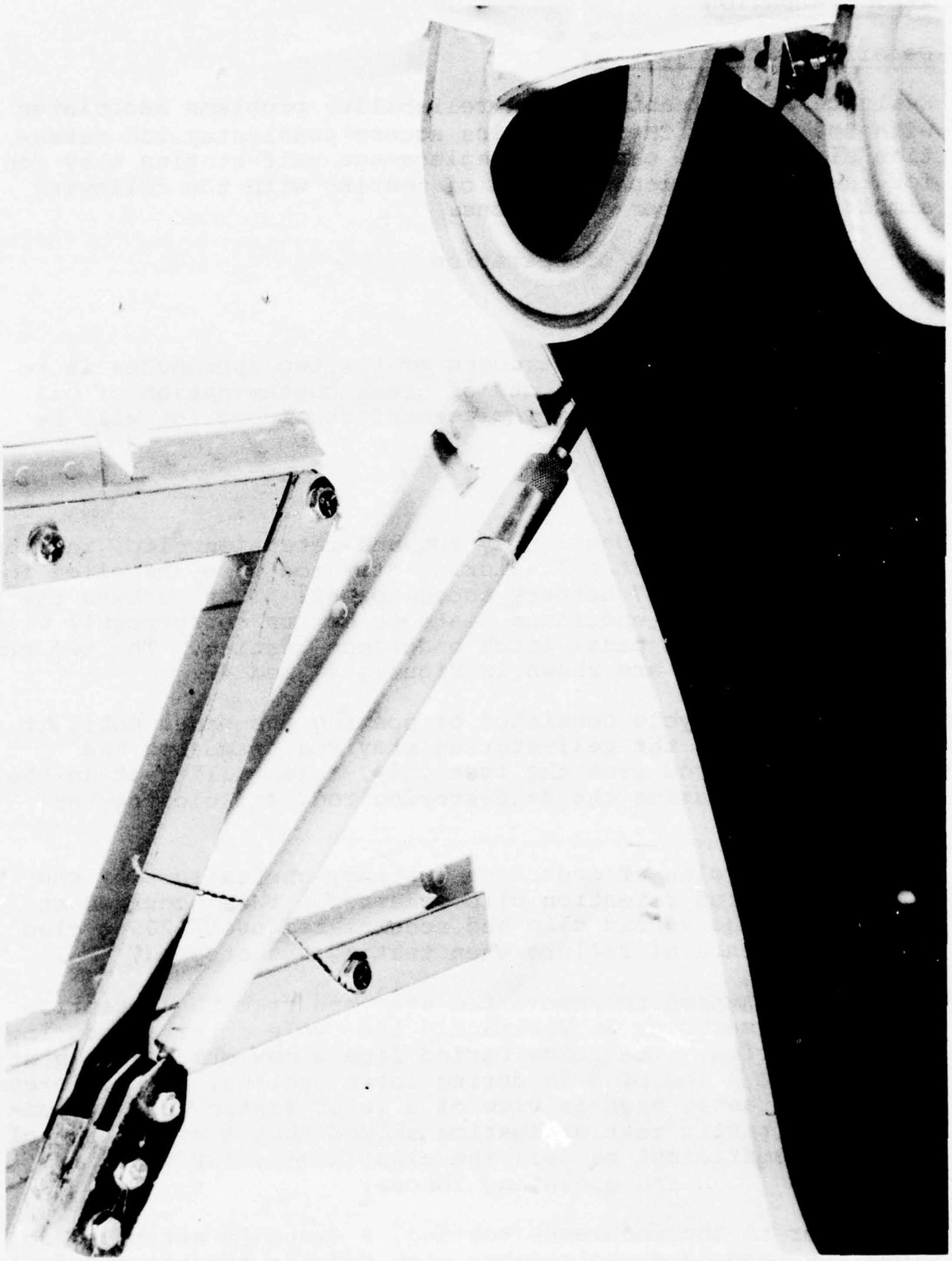


Figure 42. Candidate Replacement Stay Rod Installed for Test

the method of operation of the rod and that he pushed, pulled and twisted the release sleeve until the rod failed.

This accident proved very revealing. It is now quite apparent that any system of this type must clearly show the method of operation or similar failures are inevitable. Furthermore, the rod should be designed so that any attempts to operate it in an improper manner will not cause failure.

The failed rod was returned to the manufacturer for his analysis. There was no apparent defect and all components were functional and reusable. The rod was reassembled and returned to Boeing Vertol for further testing. The manufacturer stated that he did not fully understand the failure but made the following two changes to reduce the chance of problem recurrence:

1. A large arrow was mounted next to the release collar to indicate the direction of collar motion.

2. A rather light-weight retaining ring was added to the release collar to prevent it from being operated improperly.

In an attempt to verify the cause of failure, the release sleeve was purposely operated improperly. The sleeve disengaged and the retaining ring was detached from its groove. The cause of failure (pushing the release sleeve in the extended direction) was clear. Examination of components showed no definite barrier existed for this type of motion. The retaining ring had been improperly positioned to be an effective barrier.

The endurance test of this stowable stay rod proved extremely successful. In 2200 cycles, only one minor malfunction occurred. The release sleeve stuck one time and was operated successfully on the next try and on all subsequent cycles.

A vibration search of the present stay rod system and the candidate replacement rod was conducted in all 3 axes to determine natural frequencies. The two test components were mounted on a slip table as shown in Figure 43, and resonance searches were made over the range of 5 to 500 Hz. A half-hour dwell was made at 250 Hz for the lateral axis and at 350 Hz for the longitudinal axis. Frequency sweeps were made over the range from 5 to 500 Hz until three hours of testing had been accumulated on each of the three axes. The vibration accelerations were 2 g at the peak, except at the very low frequencies, where the double amplitude was limited to 0.4 in. Testing was in general accordance with MIL-STD-810, Method 514.1.

A gross contamination test was conducted on the candidate replacement stay rod. The release sleeve and rod were coated with MIL-L-5606 oil and Arizona road dust and then cycled.

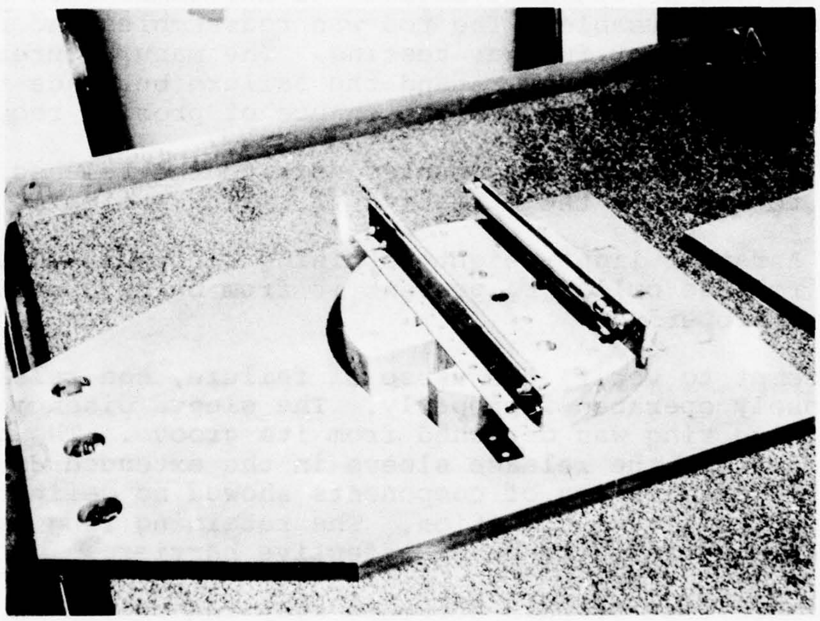


Figure 43. Stay Rods Installed for Vibration Test

This process had been repeated for 131 cycles when the locking detents failed to hold the door in the extended position, and further testing was discontinued. This is a very severe test in view of the intended use. Although the test demonstrated that this stay rod is susceptible to gross contamination, the durability demonstrated in this abnormal environment does not appear to justify adding seals to the mechanism.

Static strength tests of the stay rod retention clip were made as previously reported. Tests of the stowable stay rod resulted in a tension failure at 1175 lb and a compression failure at 165 lb (when in the extended position). Permanent deformation occurred at a side load of 42 lb. These strengths are consistent with current practice.

CONCLUSIONS AND RECOMMENDATIONS

One failure of the present CH-54 stay rod retention clip was experienced after less than 1000 cycles of operation during this program. The failure appeared representative of service-reported failures as well as those resulting from static test overloads. Vibration was not found to have an influence on the malfunction of the stay rod retention device.

The design decision to use an easily available fuse clip for stay rod retention was instrumental in causing this problem. The beryllium-copper fuse clip appeared to be a simple and inexpensive design but proved to be a maintenance and reliability problem. The static test showed that a 16-lb side force was sufficient to fail the clip. This is well within the probable range of applied forces during helicopter servicing.

A self-storing, collapsible stay rod was found to perform satisfactorily for over 2000 endurance cycles with no discernible wear or other deterioration. This stay rod was subjected to a vibration test with no effect on performance, proving the validity of this concept. Operation in an environment of severe oil and dust contamination did eventually result in malfunction.

Interestingly and significantly, however, the self-storing stay rod was inadvertently broken by a frustrated mechanic in an attempt to collapse it while making a test setup. Failure occurred when the mechanism release sleeve was forced in the wrong direction. No failure occurred in the 2000 cycles of operation because the method of operation was understood and the design worked flawlessly when operated as intended by the designer. Static strength of this self-storing rod for panel applied loads was not a factor in the failure.

The real lessons of this program were learned from the latter incident.

1. The method of operation of a device must be clearly apparent to the operator. Figure 44 shows four stay rods. The method of operation is not clearly evident on any of the rods and even less so in the installation.

2. The design must be tolerant of improper operation ("maintenance abuse"). The manufacturer of the stay rod did not visualize that anyone would try to collapse the rod by pushing the release sleeve in the "wrong" direction.

A further consideration in design is that of the consequence of inadvertent operation. If a heavy door can be inadvertently released by a crew member grasping the stay rod as a handhold, injury may result. The designer must then consider means of releasing the door in a simple manner without making the design susceptible to accidental release.

A simple modification of the candidate replacement stay rod could be made to insure its compliance with these human engineering requirements. Future design specifications should incorporate requirements of this type. A minor modification of an "off-the-shelf" stay rod was procured for this small hardware program with the consequence described above.

In general, it appears that the use of a self-stowing stay rod is preferable to the stowable type with its attendant stowage hardware problems. In those cases where a loose rod could contact electrical or moving components, the need is even clearer. A door/panel that could be opened too far also increases the desirability of the self-stowing rod with its associated extension limits.

On the other hand, there may be a few cases where a self-stowing rod is not desirable. For instance, if the door is very heavy and inadvertent release must be avoided, the stowable type might be preferred. Also, the initial costs of the self-stowing design are obviously higher. If a particular system/design cannot tolerate this higher cost, the stowable design might be more appropriate.

However, all factors considered, it appears that for most installations of Army helicopters the alternative design approach tested herein or a similar type of self-stowing device should be specified for new production aircraft.

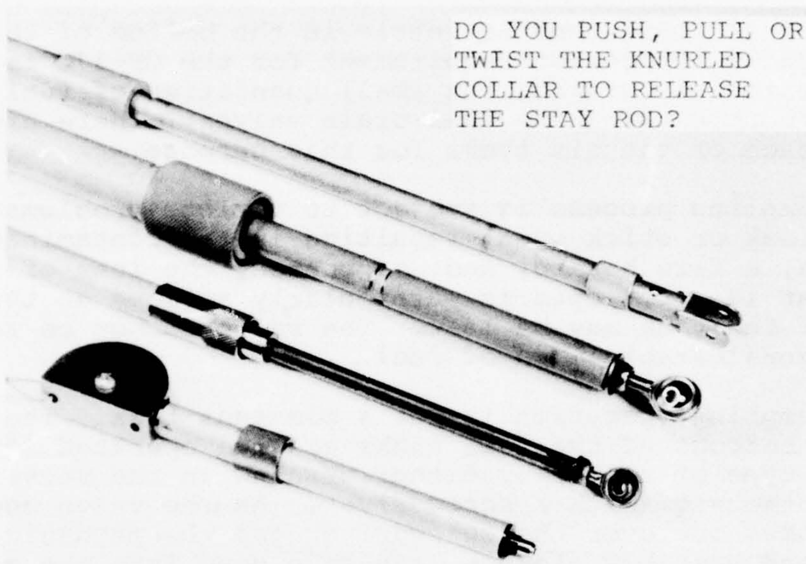


Figure 44. Stowable Stay Rods Whose Operating Procedures Are Vague

FUEL DRAIN VALVE EVALUATION

OBJECTIVE

To evaluate maintenance problems associated with fuel drain valves and evaluate candidate replacement designs.

DESCRIPTION OF PROBLEM

Background

Moisture and sediment tend to settle in the bottom of the fuel tanks. A daily inspection requirement for the CH-47C is to inspect the fuel by drawing out small quantities of fuel into a sampling bottle using the fuel drain valves. There are two valves in each of the six tanks for this purpose.

The fuel-sampling process is subject to various problems. The valve may leak or stick open, resulting in the contamination of the area, a fire hazard, and, of course, the loss of fuel. A valve that is stuck open is particularly serious as the entire contents of the tank may be lost. The valve cannot be replaced without a considerable loss of fuel.

The fuel sampling operation is not a pleasant task. The valves are on the bottoms of the fuel tanks and are operated (depending on the type of valve) by either pushing in the valve stem or turning the stem with a screwdriver. As the valve opens, the fuel comes out over the screwdriver and the mechanic's hand, arm and possibly clothes, and some goes into the container. The valve is reportedly subjected to "maintenance abuse".

The valve may frequently be operated with contaminated fluid so it is important that no sediment be retained on the sealing surfaces. Debris entrapment is reported to damage seals.

Other reported failure modes are:

1. Seals or the valve seats are damaged by contact with tools during operation, causing leakage.
2. Seals deteriorate, resulting in low life.
3. Reduced valve spring tension is believed responsible for leakage.

Design Requirements

The drain valve is required to do the following:

1. Provide a quick, clean means of draining contaminants from the fuel tank.

2. Provide consistent, leak-free sealing of the fuel system in the helicopter environment.

3. To be crash-resistant to reduce the chance of fuel spillage during an emergency.

4. Function properly when exposed to any applied force or operating tool.

TECHNICAL APPROACH

The reported problems and failure modes indicate that the valve is particularly susceptible to contaminated fuel and that the strength is too marginal to endure the repeated abuse which occurs in the fuel drain operation. The approach taken was to compare the baseline valve with two alternate valves thought to offer significant improvements in these areas of performance. A comparative evaluation of these valves was made under conditions representative of aircraft operation.

Fuel Drain Valve Selection

The baseline valve, Boeing Vertol Part Number 114PS410-2, has been used on all CH-47C aircraft prior to the introduction of the crash-resistant fuel system. The two alternate valves meet crash-resistant fuel system requirements. Both alternate valves are qualified under Boeing Vertol Part Number 114PS465-1 and related Specification D210-10223-1. The design requirements of this valve for the crash-resistant fuel system call for the demonstration of no leakage after impact accelerations of 800 "g's" are applied along the axis and normal-to-the-valve axis. In addition, the crash-resistance specifications emphasize that seal design should prevent trapping contaminants in the area of the seal and that the valve endure 5000 cycles with contaminated fluid.

The baseline valve, Boeing Vertol Part Number 114PS410-2, is produced by the Parker Hannifin Corporation, Los Angeles, California, Part Number 3-114324. The first alternate valve, Boeing Vertol Part Number 114PS465-2, is produced by E. W. Wiggins, Inc., Los Angeles, California, Part Number B7V. The second alternate valve, Boeing Vertol Part Number 114PS465-2, is produced by the Accessory Products Co., Pacoma, California, Part Number 772500-1.

TEST EVALUATION

Detailed Test Objective

Evaluate maintenance and reliability problems associated with the current CH-47C fuel drain valve and the two candidate replacement configurations. The maintainability and reliability characteristics are to be evaluated under the following simulated operational conditions.

1. Repeated Use - operated manually as operationally used, with contaminated fuel. The fuel is JP-4. The contaminant levels used in the test and those defined by Military Specification as typical of contaminated fuel are given in Table 9.

2. Maintenance Abuse - simulate actions and forces that may be applied to the valve.

Summary of Results

Endurance Test Results

Baseline Valve - Two of the four valves tested successfully completed 1500 cycles of endurance testing with no malfunction. One of the two remaining valves leaked during cycles 450 to 460 and again during cycles 535 to 540. The leakage was not severe and corrected itself. In actual service, the valve would probably have been removed at this time. The valve continued to function properly for the balance of the 1500 cycles. The fourth valve was removed at cycle 1005 for an examination to determine the cause of consistent leakage and was not reinstalled since a large metal chip was found embedded in the elastomeric seal (Figure 45). No reason could be determined for the malfunction of valve No. 3, and it was assumed that the fuel contamination had caused incomplete sealing of the valving surfaces and that this contamination had later been washed away.

Candidate Replacement Valve 1 - None of these valves completed the 1500 cycles of endurance testing. The ruptures of the four valves occurred at cycles number 1229, 1330, 1371, and 1425. These failures resulted in complete loss of fuel from the test fuel tank as the flow could not be stopped.

Prior to the rupture of these four specimens, four of the eight valves installed at the time failed to spring shut and a considerable quantity of fuel was lost before the valves could be broken loose with a screwdriver and closed. This type of malfunction occurred intermittently for 50 cycles. After each valve was shut, no leakage occurred.

TABLE 9. COMPARISON - CONTAMINANT LEVEL
SPEC. MIL-E-5007-C AND TEST

JP-4 Jet Fuel Contaminant					
Contaminant/1000 gal - per MIL-E-5007C			Actual Test Contaminant/20 Gal Fuel		
Contaminant	Particle Size	Quality	Contaminant	Quantity	Cycles Used
Iron oxide Iron oxide	0-5 microns 5-10 microns	28.5 gm 1.5 gm	Crushed rust	30 gm	0-1500
Sharp silica sand Sharp silica sand	300-420 microns 150-300 microns	1.0 gm 1.0 gm	No. 70 silica sand	2 gm	0-1500
Prepared dirt conforming to A.C. Spark Plug Co. part no. 154637 (coarse Arizona road dirt)	0-5 microns (12%) 5-10 microns (12%) 10-20 microns (14%) 20-40 microns (23%) 40-80 microns (30%) 80-200 microns (9%)	8.0 gm	A.C. coarse sand	8 gm	175-1500
Cotton linter	Staple below 7 (U.S. Dept. of Agriculture grading standards)	0.1 gm	Chopped cotton cloth	1 gm	0-1500
Crude nathenic acid		0.03% by volume	Sunapthic acid A	23 cc = 0.03% by volume	900-1500
Salt water prepared by dissolving salt in distilled water or other water containing not more than 200 parts per million of total solids	4 parts by weight	0.01% by volume	Salt water (4% salt by weight)	400 cc = 0.5% by volume	0-1500

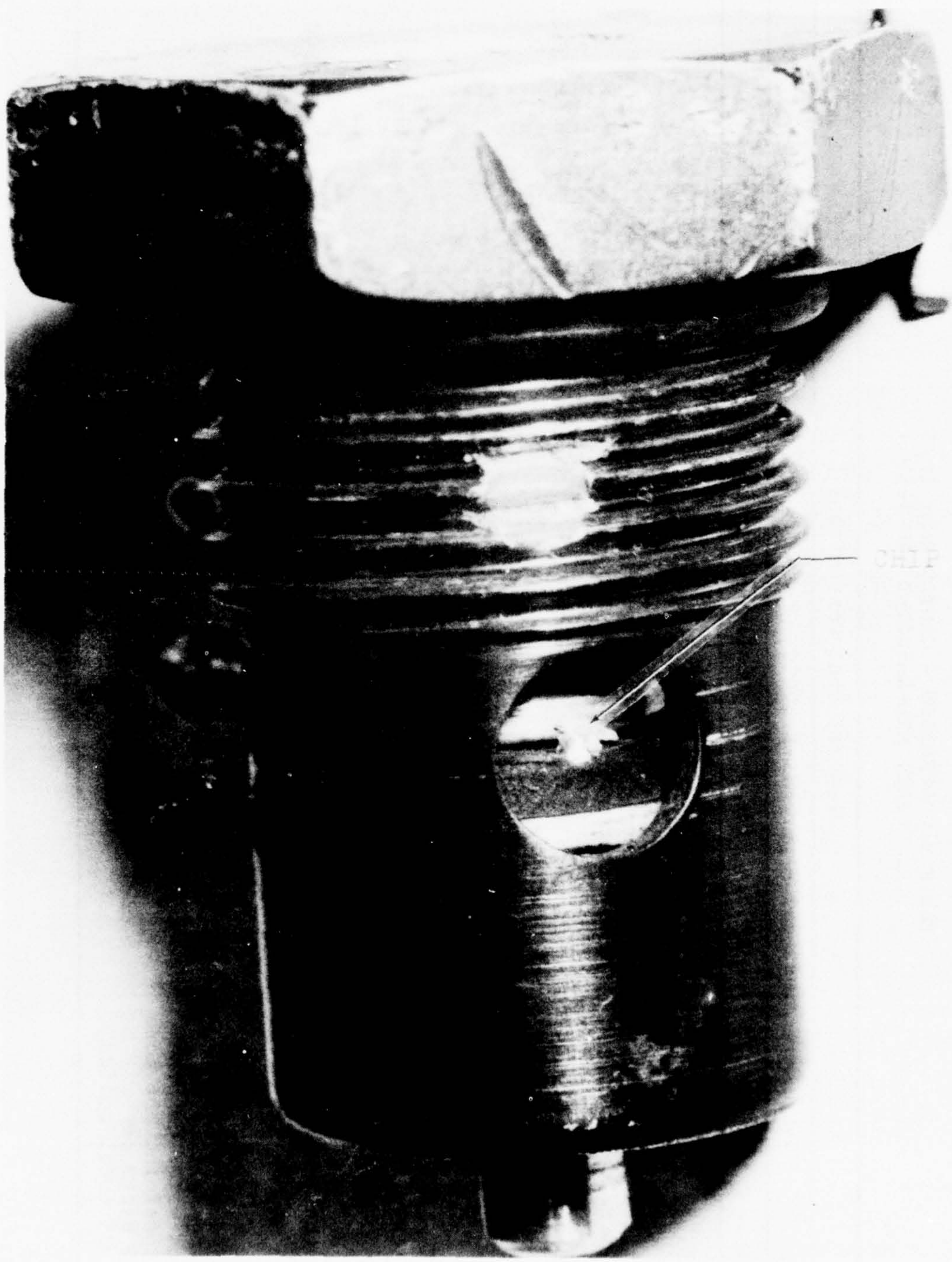


Figure 45. Baseline Valve With Chip Embedded in Elastomeric Seal

The failure causes were as follows: The rupture of the valve occurred due to a gradual yielding in bearing of the valve retaining pin holes in the valve body, P/N B7V-1, as shown in Figure 46. The pin then slipped out of the holes and all pieces fell into the tank.

The sticking valve appeared to be caused by a buckling of the poppet valve spring, Part Number C. W. 105-47, which rubbed on the valve poppet, B7V-8, and caused sufficient friction to prevent the valve from closing. This has happened to "dry" valves. Normally the presence of fuel provides sufficient lubrication to prevent this from happening; however, the highly contaminated fuel appeared to have sufficient friction to cause malfunction during the endurance test.

Candidate Replacement Valve 2 - All four of these valves completed the 1500 endurance cycles with no malfunction of any sort.

Maintenance Abuse Test Results

Baseline Valve - This valve is operated by applying direct axial force on the valve stem with a screwdriver. "Maintenance abuse" consisted of the application of the maximum possible axial force (unquantified) that could be exerted by the mechanic. No failure occurred in five cycles on any of the four valves.

A second test of the baseline valve was conducted to quantify the applied axial forces. Loads were applied to a valve in increments until over 150 lb had been applied. When the load was removed, the valve stuck open for a short time but then closed without leaking or apparent distortion.

Candidate Replacement Valve 1 - This valve is operated by twisting a slotted valve stem using a screwdriver. A combination of torque plus axial force can be applied in this manner. One valve was tested using the maximum possible force and tension that the mechanic could exert (unquantified). The valve malfunctioned by sticking open on the first cycle and rupturing on the second cycle. The poppet valve retaining pin was found to have become distorted as shown in Figure 47, and pulled free from the body, allowing the poppet to fall out of the body.

A second valve was then tested with static load and torsion applied separately to quantify the component strength. An axial load of over 150 lb was exerted on the valve poppet with no apparent damage or effect on operation noted after the removal of the load. A torsional load was

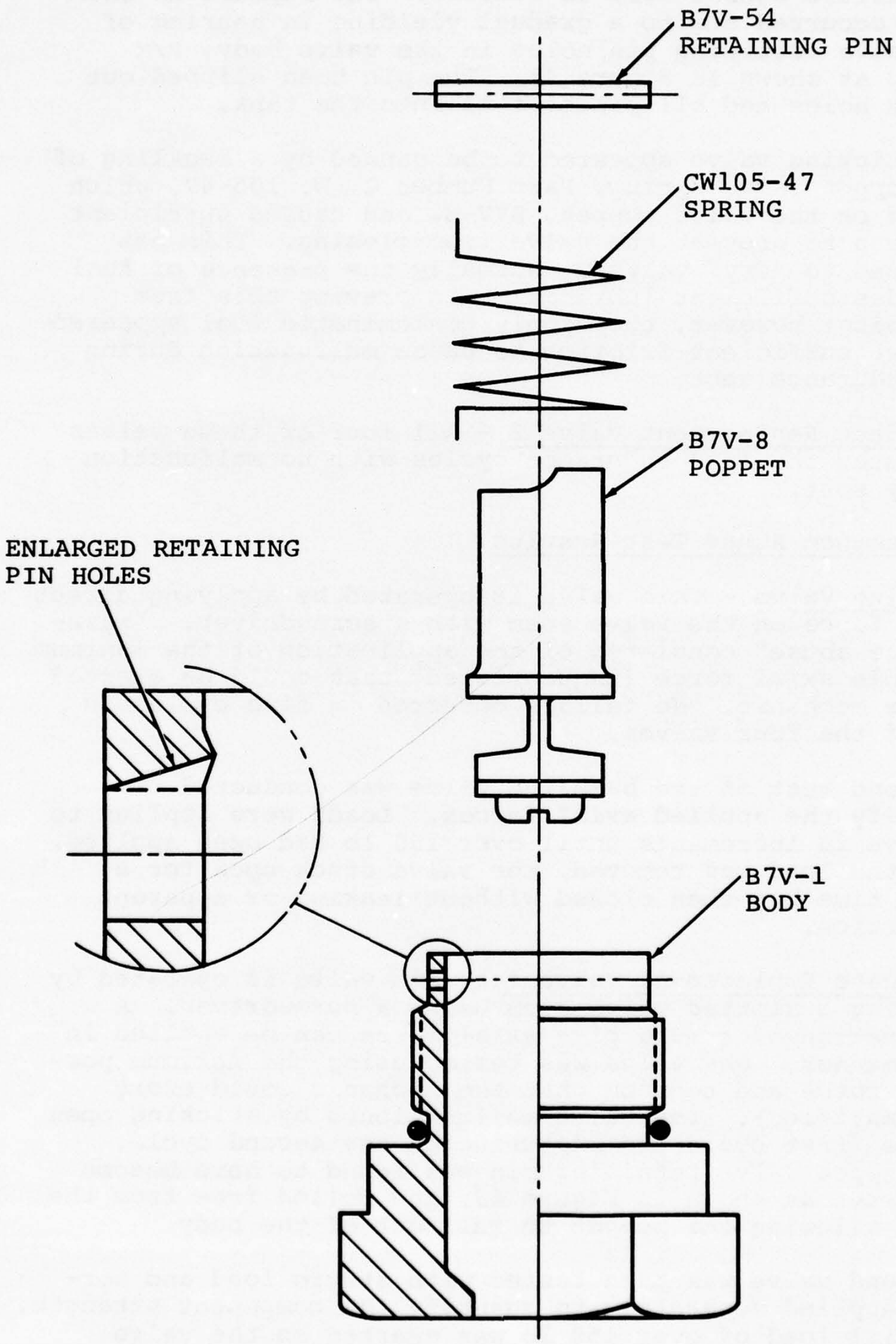


Figure 46. Endurance Test Failure of Candidate Replacement Valve 1 due to the Loss of the Retaining Pin

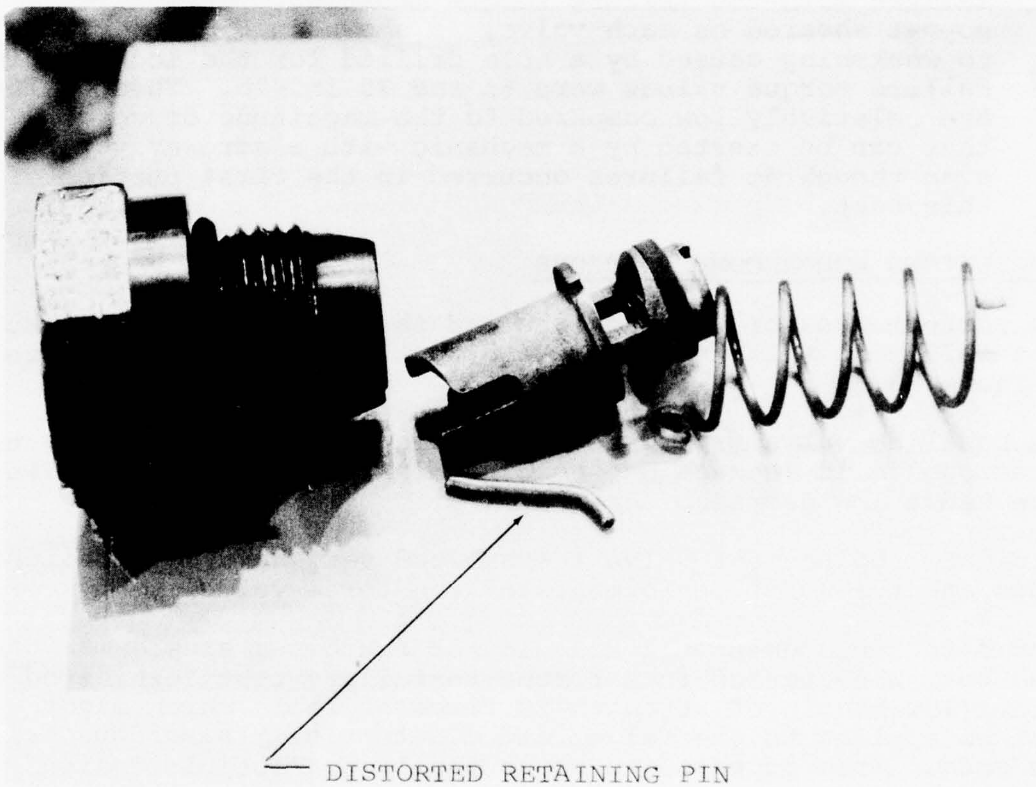


Figure 47. Candidate Replacement Valve 1--Failure in Maintenance Abuse Test

then applied. A torque of 105 in.-lb was applied without failure. At this point, the screwdriver blade "cammed-out" of the valve recess.

Candidate Replacement Valve 2 - This valve is operated by twisting a slotted valve stem using a screwdriver. A combination of torque plus axial force can be applied in this manner. Four valves completed five cycles each with the maximum torque and axial force that the mechanic could exert on the head (unquantified). No failure or malfunction occurred. Two more valves were torqued to failure with the failure torque measured. The valve poppet sheared on each valve, as shown in Figure 48, due to weakening caused by a hole drilled for the locking pin. Failure torque values were 65 and 75 in.-lb. These values are relatively low compared to the magnitude of torque that can be exerted by a mechanic with a screwdriver, even though no failures occurred in the first portion of this test.

CONCLUSIONS AND RECOMMENDATIONS

The performances of the baseline and the two candidate replacement valves in this small hardware test program are summarized in Table 10.

The baseline valve proved to be durable but with a tendency to occasional mild leakage due to contaminated fuel. This failure mode had a low degree of hazard.

Candidate replacement valve 1 exhibited very hazardous failure modes and the worst performance of the three valves.

Candidate replacement valve 2 did not exhibit a single malfunction but, when tested in a torque-to-failure test, exhibited a rather low margin of strength in terms of loads which might well be applied to the valve, and a potentially hazardous failure mode. This appeared to be an easily correctable design change once this hazard was understood.

Both candidate replacement valves are qualified to a Boeing Vertol Crashworthy Fuel Valve Specification, while the baseline valve is not crashworthy and cannot be used in this system. Consequently, CH-47 aircraft with crashworthy fuel system installations have almost all been equipped with the candidate valve 1. This latter situation arose from the price difference between the candidate valves. Both had exhibited satisfactory compliance with the requirements of the crashworthy valve specification so the decision on which to buy was based on price.

Figure 48. Candidate Replacement Valve 2--Failure During Maintenance Abuse Test

TABLE 10. FUEL DRAIN VALVE PERFORMANCE SUMMARY

TEST PROGRAM	BASELINE SPEC.	BASELINE	CANDIDATE 1 SPEC.	CANDIDATE 1	CANDIDATE 2 SPEC.	CANDIDATE 2
ENDURANCE (1500 CYCLES)	1	NO MALFUNCTION	1	RUPTURE AT CYCLE 1229	1	NO MALFUNCTION
	2	NO MALFUNCTION	2	VALVE STUCK OPEN 3% RUPTURE, CYCLE 1330	2	NO MALFUNCTION
	3	MILD LEAKAGE 1%	3	RUPTURE, CYCLE 1371	3	NO MALFUNCTION
	4	REMOVED AT 1005 FOR LEAKAGE; EMBEDDED CHIP	4	VALVE STUCK OPEN 3% RUPTURE		
MAINTENANCE ABUSE - MECHANIC OPERATION	1	NO FAILURE, 5 CYC.	1	STUCK OPEN, CYCLE 1 RUPTURE, CYCLE 2	1	NO FAILURE, 5 CYC.
	2	NO FAILURE, 5 CYC.			2	NO FAILURE, 5 CYC.
	3	NO FAILURE, 5 CYC.			3	NO FAILURE, 5 CYC.
	4	NO FAILURE, 5 CYC.			4	NO FAILURE, 5 CYC.
- STATIC LOAD	1	DELAYED CLOSING AFTER 150-LB AXIAL LOAD	1	NO FAILURE AFTER 150-LB AXIAL LOAD	1	RUPTURE AT 65-IN.-LB TORSION
			2	NO FAILURE AFTER 65-IN.-LB TORSION	2	RUPTURE AT 75-IN.-LB TORSION

A detailed look at the crashworthy valve specification shows that it permits an automated type of valve actuation for the endurance test and requires only that the valve not leak at the conclusion of the testing. This specification has no requirements for components to demonstrate strength to resist normal maintenance operational forces, forces often considered synonymous with "maintenance abuse".

Testing in this small hardware program did not automate valve operation, and valve weaknesses became apparent. With a rapid, automated endurance test of a valve, intermittent leakage is difficult to observe. Yet, prevention of leakage is one prime function of the valve.

It is concluded that better design specifications are necessary; specifications which:

1. Emphasize human factors,

2. Require testing in a realistic manner by applying the type and magnitude of loads and the contaminants to be experienced in service,

3. Demand and quantify the level of performance consistent with the intended use.

Until design and qualification test requirements are consistent with intended use, the components will be supplied by the lowest bidder regardless of operational performance.

CONCLUSIONS AND RECOMMENDATIONS

This program showed that the majority of small hardware problems are preventable by state-of-the-art techniques.

The six typical problems of this program appear generic to helicopter hardware and were found to have few unique causal factors. Solutions derived for alleviating the failure of test components are applicable "across the board" to the small hardware field.

The major factor in hardware malfunction was found to be operation in a manner not intended by the manufacturer or the aircraft designer. The principal reasons for this were found to be:

1. Hardware application data is inadequate

   - Neither the manufacturers' literature nor the military specifications give comprehensive installation information to the aircraft designer.
   - Many instances were found where an improper installation would make well designed, inherently reliable hardware completely ineffective.
   - At least one type of widely used quarter-turn fastener was considered only marginally acceptable for application with aircraft standard-tolerance sheetmetals.

2. Human engineering factors are not properly considered in the design

   - The function and method of operation of the hardware is not always apparent.
   - Two different types of tools may be required for similar fasteners on the same panel.
   - Hardware is intolerant of "maintenance abuse" (use of wrong tool, improper operation or application of excessive load).
   - Several length increments of otherwise identical fasteners (grip length) are used in the same panels, leading to errors in the installation and replacement of fasteners.

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APPENDIX A

INITIAL SMALL HARDWARE PROBLEM SUMMARY

This appendix contains the results of a review of small hardware field problems with:

- U.S. Army Transportation School Personnel Fort Eustis, Virginia for CH-54, OH-58, OH-6, UH-1, and AH-1 Aircraft, in September 1973.

- Boeing Vertol Field Service Engineers for CH-46, CH-47, and BO-105 aircraft, in August 1973.

It is important to note that these problems and recommendations are "as reported" and were later reviewed for accuracy of component description and to determine whether the problem originated as the result of a maintenance or an inspection requirement.

CH-47 HELICOPTER

1. Engine Induction System Fairing Fasteners - The fasteners break or fall out when fairing is opened. The fasteners are not properly retained. In general, the fastener is very poor.

2. Battery Access Compartment Door - One never knows if it is latched.

3. Aft Pylon Clamshell Door Latch - The Phillips recess of the Airloc fastener used for double latching rounds out.

4. Armor Plate Attaching Screws - These are often loose and missing.

5. Honeycomb Shelves in Aircraft - The pop bolt and nut is not satisfactory.

6. Honeycomb Shelves - The rubber terminal strip cover is not self-retaining.

7. Generator Terminal Wiring - The boots on generator lead wires deteriorate rapidly.

8. Steps on CH-47C Fuel Pod - The lock pin falls out.

9. Seat Quick-Disconnect Floor Fittings - They accumulate dirt and are hard to latch.

10. Cargo Hatch Lower Door Latch - It is inadequate.

11. Engine Transmission Barrel Nut - It should be retained in position when the bolt is not installed.

12. Aft Engine Lower Work Platform Quick-Release Pin - It frequently pops out.

13. Pip Pins - They are very poor in general and should not be used for structural applications.

14. Thomas Coupling Bolts - They seize or score if the bolt turns when the nut is tightened.

15. Synchronizing Shaft Hardware - Different type nuts and hardware are used which become interchanged and require balancing.

16. Forward Transmission Cowling Latch - The new latch is not adequate.

17. Grease Fittings - Covers are desirable for the majority of these fittings.

18. Accumulator Valves - A valve core should be designed so that air can be added. Color code it to indicate air pressure.

19. Wheel Bearings - Modify the lubrication systems so the wheel bearings do not have to be repacked with grease after a water landing.

20. Fuel Filler Caps - Redesign so that the opening will accommodate gravity type refueling rather than requiring pressure refueling.

21. Fuselage Drain Cocks - Improvement is needed.

22. Fuel Cell Drain Valves - The present valve sticks open and the O-ring rolls off.

23. Window Seals - The extruded rubber used on windows and escape hatches should be changed so that the windows can be replaced more rapidly and without special tools.

24. Engine RPM Beep Resistor - The old type of rotary slide, which is operated with a screwdriver, gives no indication that you are approaching the end of the travel. Before you know it, you have come against the stops (which are weak), and they break off.

25. Electrical Connectors (DPD2 Type) - The electrical connector on the AC box disconnect, which is located on the firewall behind the pilot's seat, is not "all weather" and

shorts out. In addition, the small pins bend easily because of the large size connector. The pin numbers are so small that they cannot be identified.

26. Velcro Tape - The adhesive used to attach the hook and pile tape does not hold up.

27. Factory Packed Bearings - They are said to be good for life; however, the grease ages, backs away from the balls and the bearing fails. A better type of lubricant is needed.

28. Transmission Accessory Mount - Improve the mounting concept for the auxiliary gearbox, the engine accessory gearbox, and the forward transmission filters. The present design is flange-mounted, and access is difficult.

29. Screw Head Recesses - The pod access panels and flooring screws rust and seize. Screw slots round out when the screws are removed.

30. Bushings - The standard bushings used in magnesium bellcranks are corroding.

31. Swaged Rod Ends - They come loose on push-pull tubes; rivets should be installed.

32. Adel Clamps for Electrical Wire Harnesses - A better material and better retention of the padded material used on the clamps is needed. One type of insulation should be used which will stand up under all conditions.

33. Oil Level Gauges for Dampers and Reservoirs - Dirt settles out of oil and obscures sight glass.

34. Wire Harnesses - Protection for wires in excess-oil areas is needed. The wire bundles are covered along much of the length but oil penetrates at the ends.

35. Standard Washers - One cannot determine the material (stainless, alloy steel or aluminum). Suggest color coding.

36. Flareless Fittings - Excessive leakage occurs on high-pressure fittings: a new design is needed.

37. O-Rings - Reusable O-rings are needed that are made of a material that is more universal and can be used in many different environments.

38. Generator on Auxiliary Gearbox - A mounting nut whose washer is attached is needed. The present loose washer gets hung up in the slot.

39. Auxiliary Gearbox Output Seals for the Generator and Hydraulic Pump Drive - They frequently leak. They need improvement.

40. Cowling Anti-Chafe Seals - A better material and a better bonding process are needed.

41. High Shear Fastener - Standardize to reduce the number of special tools needed.

42. Cannon Plugs With Strain Relief Clamps - The screws on the strain relief clamps are not positive lock screws and loosen.

43. Fasteners Used to Retain Cockpit Boxes in Console - There is no way to tell if they are fastened.

44. Beep Slide Switches - They become contaminated.

45. Common Electrical Connectors - They are not identified, or the identification is worn off. The result is that they are often plugged into the wrong receptacle on the SAS actuator links.

46. Solder Connection Relays - They are no good and need improvement.

47. Screw Terminal Relays - They need better locking features.

48. Hydraulic Line Clamp Stand-Offs - They should be of a nut-plate design. The present loose washer and nut are usually dropped and lost.

49. Self-Retained Fasteners - The self-retained fasteners in fiberglass skin and panels tend to work loose and fall out.

50. Cannon Plugs - They are a problem. They stick and pliers must be used to remove them. Then, they become damaged and must be replaced.

CH-54 HELICOPTER

1. Fairings Around Main Oleo Legs - They must be removed for each periodic inspection (100 hours) to check oleos for cracks, leaks, etc. This use causes the screw heads to round out.

2. Automatic Flight Control System Access Panel - It must be removed at the intermediate (25 hour) and periodic inspections. The screw heads round out. The screws frequently fall out.

3. Hydraulic System Flex Hoses - The flex hoses, below and forward of the oil cooler, chafe.

4. Screw Head Recesses - The screw heads on the internal access panels for the nose oleo round out.

5. Stay Rod Clip - The clip on the left-hand avionics access panel breaks.

BO-105 HELICOPTER

1. Aft Clamshell Doors Strut (P/N 105-23-151-11) - The Dzus fasteners are hard to operate and spread open while in use, preventing their acceptance into the latch receptacle.

2. Door Assembly Latch (Hartwell latch P/N 5000-2) - The latch swings out when the door is opened and contacts the attaching fairing, chipping the paint and fiberglass.

3. Hartwell Nylatch - This fastener is used to attach soundproofing in the cabin area but leg or legs break off the body and the latch falls out.

4. Pilot's Ashtray - It is bonded to the door but falls off from frequent door opening.

5. Rubber Boot, F0156 - It deteriorates from oil and slips down the push-pull tube.

6. Temp Plate (P/N 240) - The temperature indicator deteriorates and falls off, and the high side turns black from oil leakage.

CH-46 HELICOPTER

1. Forward Clamshell Door Latches - They are a continuing problem.

2. Engine Access Doors (inside cabin) - The fasteners are not adequate for this area and keep falling out.

3. Tunnel Cover - The loss of Camloc studs causes foreign object damage (FOD) to engine.

4. Engine Screen Nut-Plate Rivets - They shear and the nut plate turns when one is removing screws.

5. Cable for Cabin Door - The retriever chafes the cable.

6. Forward Upper Latch of the Forward Pylon, A02S8067-71 - It is difficult to see if it is latched. It opens in flight when not latched.

7. Aft Clamshell Doors Hinge Bolts - They receive excessive wear from opening and closing.

8. Aft Pylon Swashplate Access Door - The fasteners and the door deteriorate, and the holes elongate due to extensive use.

9. Aft Pylon Work Platform Latches (Hartwell H120P1-032-312) - They wear due to high usage rate. They bend and do not latch properly.

10. Aft Pylon Work Platform Support Cable - This holds the door in the open position. The ball corrodes and freezes, causing the cable to do all the flexing and it breaks.

11. Fuselage Drain Plug - It breaks off, deteriorates and plugs up with dirt.

12. Cargo Floor Rollers - The rollers seize due to dirt in the roller (P/N A02S4166-1).

13. Pilot and Copilot Seat Armor - The locking pins rust and seize, and they cannot be removed for emergency exits.

14. Pilot and Copilot Seat - The adjustment rollers and linkage are difficult to adjust.

15. Hydraulic Quick Disconnects - They have a frequent leakage problem. The complete disconnect must be replaced if the O-ring leaks. There is a high wear rate on small disconnects; they need indicators for positive connection.

<u>AH-1 HELICOPTER</u>

1. Battery Access Door (Nose) - The Hartwell latch is unreliable (See UH-1).

2. Cockpit Canopy Hinges - They wear out from opening/closing and other frequent maintenance. The jettison mechanism must be checked each 100 hours.

3. Engine Access Panel Latches - The Chinook-type latches wear excessively.

4. Dzus Fasteners - The fasteners on the flight control and hydraulic access panel and the engine exhaust cowling wear and fall out. The access panel fasteners are operated daily for inspection.

5. Screw Head Recesses - A "mechanic's MWO" (a field fix) changed Phillips headed screws on avionics and the boom underside access panels to hex headed bolts because the recesses rounded out.

6. Flex Hose - Chafing of hydraulic and flight controls hoses is a problem.

OH-6 HELICOPTER

1. Fiberglass Panels - The skid cuff fairings are removed daily to inspect the landing gear strut. The fiberglass panel breaks at the fairing fastener.

2. Camloc Fasteners - The fasteners for the tail boom access panels are a problem.

UH-1 HELICOPTER

1. Battery Access Door Latches (Hartwell 6055-063-123) - The latch breaks out of fiberglass panel, the "push" cover breaks off, and the spring breaks.

2. Dzus Fasteners - The fasteners used on the FOD screen surrounds and the tunnel covers malfunction.

3. Phillips Head Screws - The screw heads on access panels round out when they are removed for periodic inspection. The screws below the cabin were replaced with hex head bolts.

4. Engine Cowling Stay Rod Clip - It comes open.

5. Cowling Hook Latches - The catch plate wears.

6. Horizontal Stabilizer Trailing Edge Guards - They won't stay glued on.

OH-58 HELICOPTER

1. Engine Cowl - The snaplock spring breaks on the Hartwell H5000-2 fastener.

2. Access Panel - The stay rod retainer clips break; they are opened daily.

3. Dzus Fasteners - The fasteners on the transmission cowlings malfunction.

4. Engine Compartment Drain Tee - It stops up with debris. There is no drain on the transmission deck; it goes to the engine compartment.

5. Engine Lower Leg Support Bolts - They keep loosening up and the torque cannot be maintained.

6. OH-58 Fuel System Drain Valve - It works poorly.

7. Hydraulic Flight Control Flex Hose - It chafes at the C-clamp and breaks at the bends.

8. Tail Rotor Drive Shaft Hanger Bearing Bracket - The mounting bolts lose torque.

9. Battery Plug - The screw wears out; it is removed daily.

10. Battery Hold-Down Screws - They are inaccessible, yet they must be inspected weekly to make sure the battery case is not cracked.

11. Battery Compartment Door Chain Retainer Bolt - The bolt is glued in but the glue does not always hold and the bolt comes out.

12. Magnetic Chip Detector - The detector on the engine free wheel (clutch) has a daily requirement for inspection. It leaks at the O-ring seal.

13. Oil Cooler Drain - It becomes blocked because it is too small.

14. Tail Boom Attaching Access Panel - It must be removed to check torque on attaching bolts. The screw heads round out.

15. Cockpit Door Hinges - They wear badly. They are used about equally for maintenance and operation.

16. Pilot's Door Latch Spring - It is not strong enough.

APPENDIX B

PAN HEAD SCREW DRIVE RECESS TESTING AND RESULTS

This appendix describes in detail the testing performed on pan head fastener recesses. Besides showing how the testing was performed in this program, it gives an example of the sort of testing that is recommended during the design of equipment to minimize maintenance and reliability problems. Similar testing was performed for the other fasteners studied in this program, but since the descriptions of their testing are shorter, their testing programs are detailed in the main text. The objectives of the testing covered in this appendix were to determine the effects of exposure to the following simulated operating conditions:

1. Dirt, mud, rain, and the abrasive effects of foot and forklift traffic
2. High humidity
3. Application of nominal and excessive torques
4. Normal helicopter paint systems
5. Use of improper tools and other maintenance abuse.

The effect of the head recess configuration on fastener strength was also investigated.

TEST PLAN OUTLINE

The following testing was conducted to meet the program objectives defined on page 25, in the PAN HEAD SCREW DRIVE RECESS section.

FLOOR PANEL TEST

A panel containing the test fasteners was located in a high-usage outside area, and the screw heads were exposed to foot and fork lift traffic to duplicate the natural environmental conditions of dirt, dust, and rain. Corrosion-resistant steel and alloy steel, painted and unpainted fasteners were contained in the test panel. A nominal torque value was used for the installation of half of the fasteners. The other half were torqued to a value well above specification requirements. At the conclusion of two months of exposure, the conditions of the fasteners were noted and the removal torques were measured.

HUMIDITY

The test panel was then exposed to a 10-day humidity test in accordance with MIL-STD-810B, Method 507.1. Fastener installation torque was controlled. The removal torques were noted after exposure. This is a more severe test than required by MIL-STD-1312.

ENDURANCE

The test screws were repetitively installed and removed from the test panel. At the conclusion of 30 cycles, the specimens were torqued to failure or to the drive limit.

ABNORMAL LOAD

The Aircraft Mechanic's General Tool Kit was reviewed to see what tools could be misapplied in driving or removing each screw configuration. These inappropriate tools were used to install and remove the test specimens. After inspection for damage, the screws were torqued to failure or to the drive limit.

STATIC STRENGTH

Tension, shear, and torsion tests were conducted to determine if the ultimate strength of each configuration was influenced by the head recess. The effect of applied axial force to the screwdriver during the torque to failure test was evaluated.

The detailed plan of this test is contained in Enclosure 5 of Boeing Vertol Test Memorandum Report No. 1399.

TEST SPECIMENS, EQUIPMENT, PARAMETERS

FASTENER CONFIGURATION

The part numbers of the baseline Phillips cross recess pan head fasteners are:

- MS 27039-1-08 cadmium plated alloy steel, Specification AMS 6300 or MIL-S6050, 125,000-psi ultimate tensile strength.
- MS 27039C1-08 corrosion and heat resistant steel, passivated, Specification AMS5735 (A286), 125,000-psi ultimate tensile strength.

These are No. 10 size fasteners with 0.531-in. length under the head and 0.062-in. nominal grip length.

Candidate replacement fasteners were procured to the same configuration and materials but with the driving recesses previously defined.

TEST PANEL

The same test panel was used for the floor panel test, humidity test, endurance test, and maintenance abuse test. This panel consisted of two aluminum sheets supported by a 1/2-in.-thick plywood backup panel. The upper sheet was 0.020 in. thick and the lower sheet was 0.040 in. thick. One hundred forty-four plate nuts were riveted to the lower sheet. The only function of the plywood was being a base for resting the panel on the pavement. Seventy-two dry film lubricated, cadmium-plated, alloy-steel, self-locking plate nuts, MS 21059L3, were installed for the alloy steel test screws. An equal number of dry film lubricated, corrosion-resistant steel, self-locking plate nuts, MS 21060L3, were installed for each corrosion-resistant steel test screw. These plate nuts are designed for utilization with screws of 125,000-psi ultimate tensile strength.

EQUIPMENT FOR TORQUE APPLICATION

3/8-in. drive, 0-to 150-in.-lb range, 5-in.-lb increment of graduation torque wrench (manufacturer - "Snap-On", Kenosha, Wisconsin, Boeing Vertol Tool No. 8459) was used in the initial torque-to-failure testing and the first cycle of floor panel testing.

The tests used a 1/4-in. drive, 0- to 75-in.-lb range, 1-in.-lb increment of graduation torque screwdriver (manufacturer - "Snap-On", Model No. TQS-6-FU, Serial No. 1947).

TENSION TEST FIXTURE

A fixture was prepared to the requirement of MIL-STD-1312, Test 8, Figure 2. The test screw was installed in the fixture, and the fixture was loaded in a Baldwin Southwark tensile test machine, Boeing Vertol Serial No. 12454, with BLH load cell U-1, Serial No. 238010, range 0 to 5000 lb.

SHEAR TEST FIXTURE

A test fixture to load the fastener in single shear was prepared in accordance with Figure B-1. This fixture was installed in the tensile test machine described above.

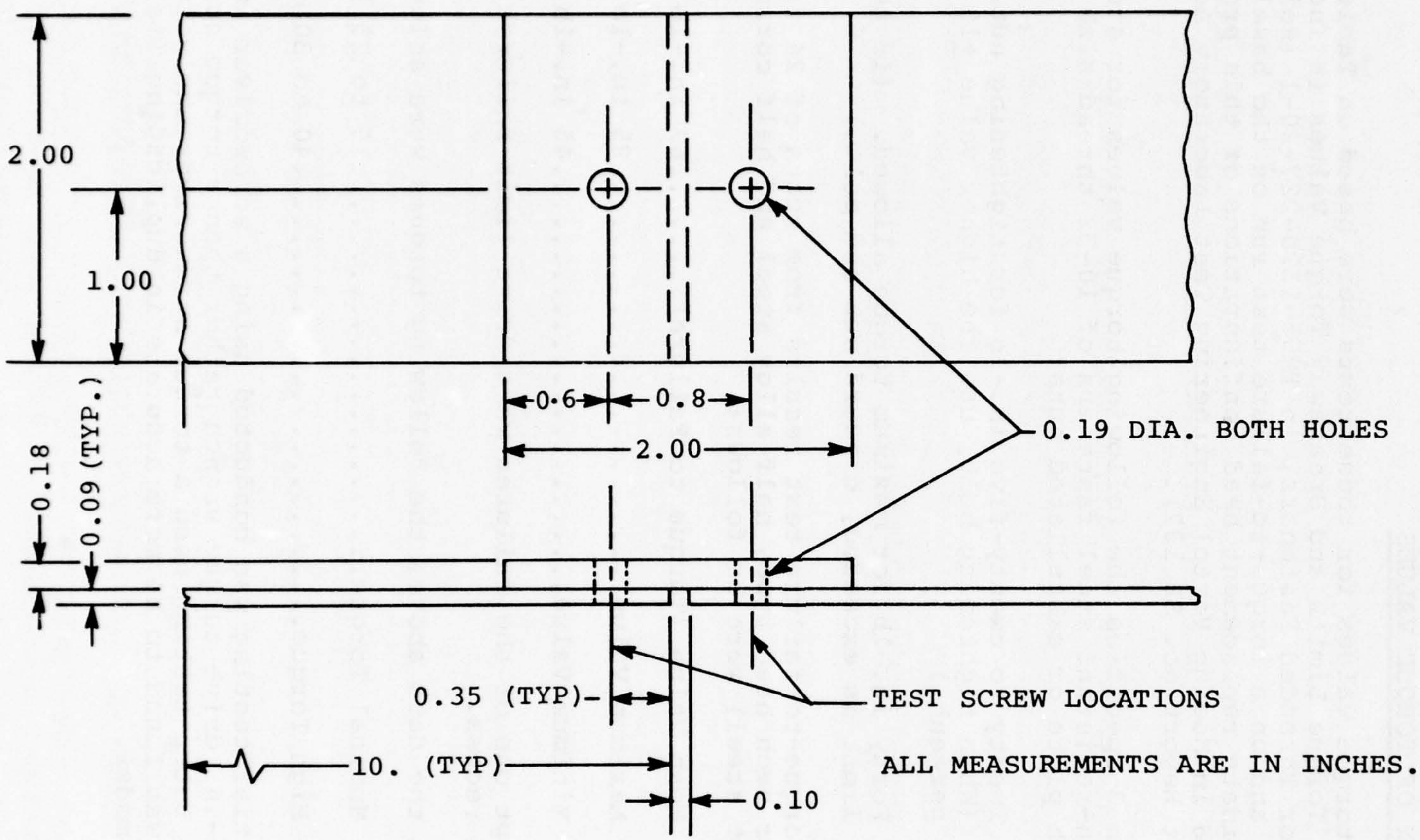

Figure B-1. Shear Specimen

SELECTION OF TORQUE VALUES

Applied torque values for these tests were based on Table 1.5, Standard Torque Limits and Breakaway Torque Values in Inch-Pounds for Threaded Fasteners, in TM55-1520-227-20-1 (Reference 3), and on a torque-to-failure test run on the baseline and candidate replacement head configurations of this program (reported in Boeing Vertol Engineering Test Laboratory Accomplishment Report No. SB 137).

Reference 3 specifies the following torque values for steel or corrosion-resistant steel fasteners of 10-32 thread size when used with plate or castellated nuts:

- Twenty to twenty-five in.-lb for tightening nut. (When tightening bolt, use the higher value ± 10 percent.)
- Forty in.-lb for maximum torque allowed. (If this limit is exceeded, discard nut and bolt.)

Boeing torque-to-failure test results from tests of 24 fasteners (four each head type, half alloy steel and half corrosion-resistant steel) were as follows:

- Mean Value (Torque to Failure)........69 in.-lb
- Maximum Value........................85 in.-lb
- Minimum Value........................45 in.-lb

All except one of the failures were drive limit failures of the head recess.

Based on the data above, the following torques were selected.

- Nominal Torque.......................15 to 25 in.-lb
- High Torque..........................40 to 50 in.-lb

This initial testing was conducted using a screwdriver insert in a 3/8-in. drive torque wrench rather than a torque screwdriver. Later testing used a torque screwdriver exclusively as this was found to be more accurate in duplicating field failure modes.

DISCUSSION OF TESTING AND RESULTS

FLOOR PANEL

The floor panel is shown in Figure B-2. The 144 test screws consisted of 24 of each of the six head styles (Phillips, Slotted, Allen, Pozidriv, Torq-Set, and Tri-Driv).

Twelve screws of each head style were alloy steel and 12 were corrosion-resistant steel. Half of the screw heads of each material and head style were painted after installation. The other screw heads were left unpainted. Half of the painted and half of the unpainted screws of each screw type and material were installed at high torque (40 to 50 in.-lb), and the others were installed at nominal torque (15 to 25 in.-lb).

An initial assembly and removal of all screws was made prior to the exposure of the floor panel to the environment and abuse. This initial assembly was conducted using a torque wrench with the appropriate screwdriver bit (see Test Equipment). Controlled torques were applied as outlined above.

TEST DISCUSSION

During the removal of the screws, six head recess failures were experienced as listed in Table B-1. All of the failed screws had initially been installed at the high torque value. Four of the failed screws had Torq-Set driving recesses. The other two had Allen hexagonal socket recess heads. It is significant that five of the six failed fasteners occurred in the screws of alloy steel material since it was later confirmed by tension testing that the alloy steel screws developed only 80% of the load of the corrosion-resistant steel screws.

A summary of screw removal (breakaway) torque data for this initial cycle is given in Table B-2. There appears to be little difference in removal torque between alloy and corrosion-resistant steel screws for a given level of installation torque. Not only do the painted screw heads not exhibit higher removal torques than the unpainted screws, but the data shows that they exhibit a slight reduction in breakaway torque.

Following this test cycle, the failed screws were replaced, and all screws were properly torqued and were painted when appropriate. The panel was then installed outside entrance E-2 on the east side of the Boeing Engineering Test Laboratory, Building 3-31.

The panel installation is shown in Figure B-3. After one month of exposure, the panel was rotated 180 degrees to equalize the exposure of the various screws to abrasive wear. A 4,000-lb fork lift truck was deliberately driven

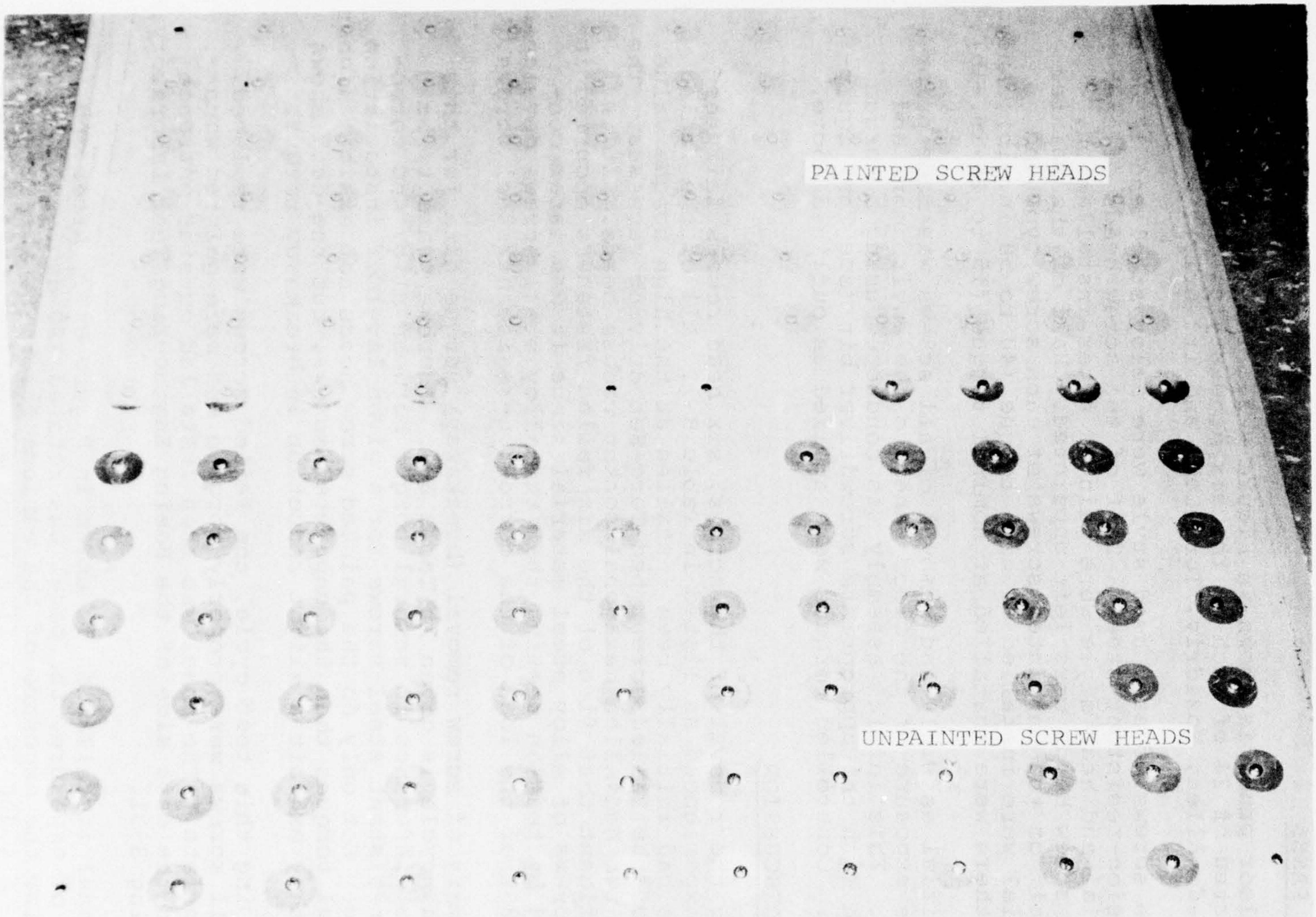

Figure B-2. Floor Panel

TABLE B-1. SCREW RECESS FAILURE - INITIAL ASSEMBLY - REMOVAL FROM FLOOR PANEL

FAILED HEAD RECESS TYPE	MATERIAL		PAINTED	
	ALLOY STEEL	CORROSION-RESISTANT STEEL	YES	NO
TORQ-SET		X	X	
TORQ-SET	X		X	
TORQ-SET	X		X	
TORQ-SET	X			X
ALLEN	X		X	
ALLEN	X			X

TABLE B-2. SCREW REMOVAL TORQUES - FLOOR PANEL PRETEST CYCLE

	HIGH INSTALLATION TORQUE (40-50 IN.-LB)				NORMAL INSTALLATION TORQUE (15-25 IN.-LB)			
	ALLOY STEEL		CORROSION-RESISTANT STEEL		ALLOY STEEL		CORROSION-RESISTANT STEEL	
	AVERAGE REMOVAL TORQUE	NUMBER OF SCREWS	AVERAGE REMOVAL TORQUE	NUMBER OF SCREWS	AVERAGE REMOVAL TORQUE	NUMBER OF SCREWS	AVERAGE REMOVAL TORQUE	NUMBER OF SCREWS
PAINTED	24.1	18	23.3	18	10.0	18	10.8	18
UNPAINTED	25.8	18	25.7	18	10.3	18	13.0	18
ALL	24.9	36	24.5	36	10.1	36	11.9	36

Figure B-3. Floor Panel Installation

across the panel 30 times during the test period. The panel was removed after two months' exposure (Figure B-4).

Observation of the screws disclosed the following:

- Superficial rust was present on the heads of six of the unpainted cadmium-plated screws and seven of the painted cadmium-plated screws. Both the paint and the cadmium plate had worn away from the abrasive effects of foot and fork lift traffic in conjunction with contamination.

- No thread rusting or other deterioration was apparent.

- The head driving recesses were packed with dirt and grit.

Cleaning of the driving recesses of the screws was necessary before the screws could be removed; otherwise, the debris accumulated would prevent proper entry of the screwdriver, and damage to the screw head would occur when screw removal was attempted. There was no evidence of wear, and only light corrosion of the head recesses was found after the screw heads were cleaned. The ranking of the screw recesses in terms of ease of cleaning was as follows:

1. Slotted, Tri-Driv (slotted recess only)

2. Phillips, Torq-Set, Pozidriv

3. Allen

The slotted screwdriver worked well for cleaning the slots in the plain and Tri-Driv screw heads, and no special tools were necessary for those heads.

An extra tool, such as an awl or ice pick, had to be used to clean the head recesses of the Phillips, Pozidriv, Torq-Set, and Allen screws before the appropriate screwdriver could be completely inserted. The Allen recess was most difficult to clean because the vertical walls of the recess made it difficult to eject the debris.

The paint accumulation did not appear to have any effect on the recess driving characteristics.

No head recess failures were experienced during the screw removals. The removal (breakaway) torques are summarized in Table B-3. The alloy screws were found to require approximately 25 percent more breakaway torque than the corrosion-resistant screws for a given level of installation torque. After the environmental exposure, the values of breakaway

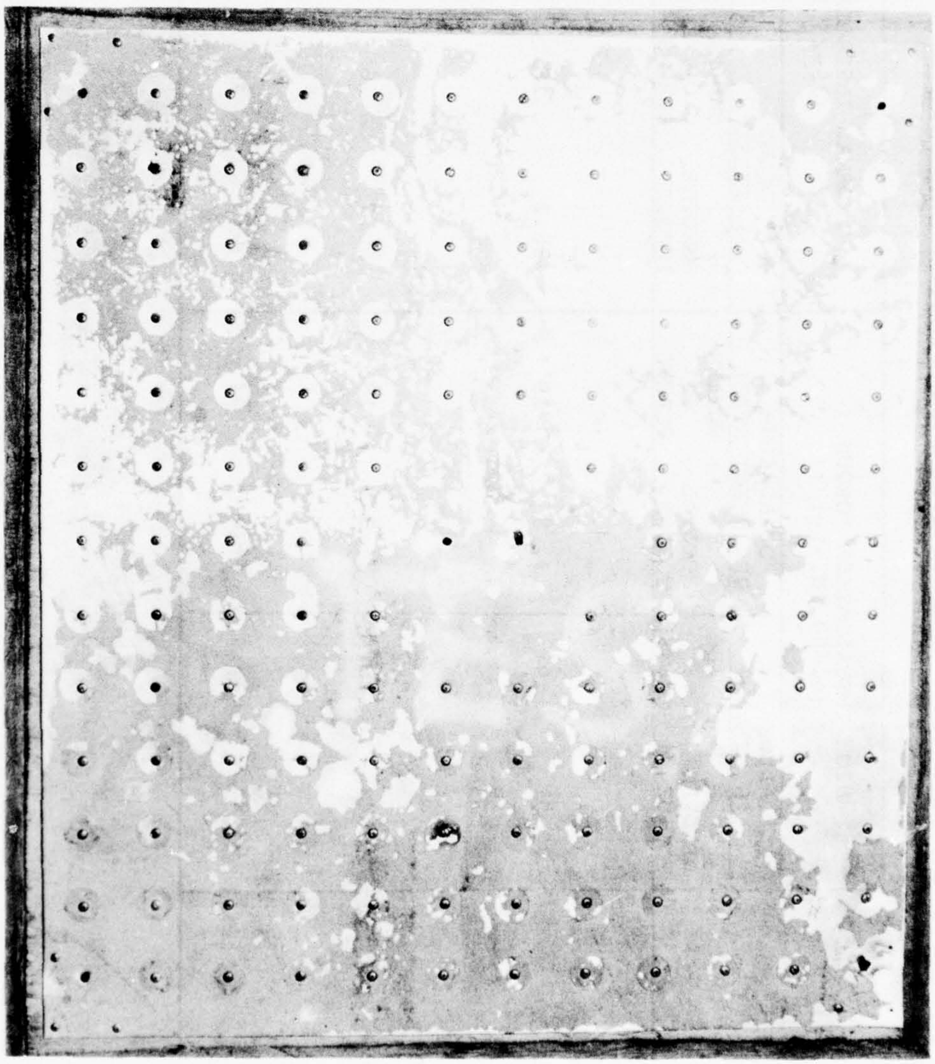

Figure B-4. Floor Panel After Removal

TABLE B-3. SCREW REMOVAL TORQUES - FLOOR PANEL AFTER TWO MONTHS EXPOSURE

	HIGH INSTALLATION TORQUE (40-50 IN.-LB)				NORMAL INSTALLATION TORQUE (15-25 IN.-LB)			
	ALLOY STEEL		CORROSION-RESISTANT STEEL		ALLOY STEEL		CORROSION-RESISTANT STEEL	
	REMOVAL TORQUE	NUMBER OF SCREWS	REMOVAL TORQUE	NUMBER OF SCREWS	REMOVAL TORQUE	NUMBER OF SCREWS	REMOVAL TORQUE	NUMBER OF SCREWS
PAINTED								
AVERAGE	42.0	19	34.8	19	30.2	18	22.5	17
UNPAINTED								
AVERAGE	42.4	18	34.3	18	30.7	16	24.8	19
ALL	42.2	37	34.6	37	30.4	34	23.7	36

torque were found to be approximately 10 in.-lb higher for the corrosion-resistant screws and 20 in.-lb higher for the alloy steel screws than for the values obtained at initial assembly recorded in Table B-2. No significant differences were noted in breakaway torques for the painted and unpainted screws of the same material and corresponding levels of installed torque.

HUMIDITY TESTING

This test was conducted using the panel and fasteners from the floor panel test. The fasteners were examined after the floor panel test and found to have only mild deterioration. However, the likelihood of developing problems with these fasteners was considered greater than if new fasteners were used, so this choice better met the test objectives.

The panel and fasteners were cleaned and degreased, the panel was alodized, and a minimum of 12 (six alloy steel and six corrosion-resistant steel) screws of each of the six types were torqued to the nominal torque of 23 in.-lb. Half of the panel was painted with a zinc chromate primer and a gray finish coat, as used for the CH-47 floor panel.

The panel was then placed in an environmental chamber and exposed to the 10-day cyclic variation of temperature and humidity specified in Method 507.1 of MIL-STD-810C.

At the conclusion of testing, the panel was removed from the chamber. The following observations were made about fastener conditions.

- Corrosion occurred on 11 of 16 of the unpainted alloy-steel screw heads (the cadmium plating had undoubtedly been worn off in previous testing).
- Corrosion was evident on 36 of the 38 alloy steel screw threads. (No paint was applied to any screw threads.)
- No deterioration of the corrosion-resistant fasteners was evident.

Each screw was then removed, and the breakaway torque was recorded. A summary of this torque data is contained in Table B-4. The average breakaway torque values are higher than those experienced after floor panel testing (Table B-3) for the same configuration and installed torque. As in the floor panel testing, the breakaway torque values for the alloy-steel screws exceeded the torques of the corrosion-resistant steel screws by approximately 25 percent. The average breakaway torques exceeded the assembly torque by 25 to 70 percent. There are no differences between the screw removal

TABLE B-4. SCREW REMOVAL TORQUES - FLOOR PANEL AFTER HUMIDITY TEST

MATERIAL	ALLOY STEEL		CORROSION-RESISTANT STEEL	
PAINT SYSTEM	UNPAINTED	PAINTED	UNPAINTED	PAINTED
AVERAGE BREAKAWAY TORQUE (IN.-LB)	39.1	34.4	30.0	28.5
MAXIMUM REPORTED TORQUE (IN.-LB)	50	43	38	37
STANDARD DEVIATION	3.95	3.94	3.91	4.65
NUMBER OF SCREWS TESTED	16	22	22	20

torques for the fasteners with painted heads and those for the unpainted fasteners.

As no head recess failures were experienced during screw removal, no significant data relevant to screw head performance was obtained during this testing.

ENDURANCE TESTING

The floor-panel screws were examined at the completion of the humidity testing. The head recesses showed little wear, so it was felt appropriate to use these fasteners for the endurance testing. In this way, 33 installation removal cycles would be experienced by the fasteners (three cycles had already been experienced), and the chance of malfunction would be increased.

Initial testing was conducted with both stainless-steel and alloy-steel screws. The screw tightening torque was established at 25 in.-lb above the lock-nut friction. Fasteners of the two materials exhibited quite different characteristics. The alloy-steel plate nuts consistently lost most of their self-locking torque in about five endurance cycles, while the stainless-steel plate nuts retained a substantial locking torque through 20 and frequently all 30 of the endurance cycles. It was also found that much of the driving recess damage was caused by the screwdriver camming out of the head recess during screw removal. This damage was greatly aggravated by high locknut torques and was nearly non-existent with a free-spinning nut. Accordingly, six stainless-steel fasteners of each head recess type continued in the endurance testing, while no further alloy steel fastener testing was conducted.

A summary of the performance of each of the endurance test specimens is given in Table B-5. Figure 4A shows that only three of the six fastener types tested completed the 30 endurance test cycles without failure of a specimen. These were the Pozidriv recess, the Allen hexagonal socket, and the slotted screw. The Tri-Driv fastener completed 30 cycles on all six specimens by virtue of its redundancy; after one recess failed, it was possible to complete cycling using one of the other two means. One Phillips recess rounded out, and four of the six Torq-Set recess screws failed.

Figure 4B, Driving Effectiveness, is an index of performance inversely proportional to the frequency with which the screwdriver slipped from the screw head recesses of the various specimens. This slipping or camming-out of the screwdriver appeared to be the major source of head recess failure; therefore these ratings are a good index of potential problems with a fastener.

TABLE B-5. PAN-HEAD SCREW ENDURANCE TEST SUMMARY

Head-Recess Type	Mtl[1]	Paint	Complete 30 Cycles? Yes	Complete 30 Cycles? No	Failure Torque (in.-lb)	Successful Removal After Failure? (removal torque, in.-lb)	Comments
Phillips	CRS	Yes	X		60	No	Head recess failed while loosening screw.
	CRS	No	X		75+[2]	Yes	Broke screwdriver bit at 75 in.-lb. Recess not damaged.
	CRS	Yes	X		70	Yes (60)	Locknut torque low but steady through 30 cycles.
	CRS	Yes	X		60	Yes	Moderate erratic locknut torque retained for 30 cycles.
	CRS	Yes	X		55	Yes (45)	Locknut torque lost entirely.
	CRS	Yes		X (19)	30[3]	Yes	Maximum torque during test 30 in.-lb. Frequent screwdriver slipping.
Slotted	CRS	Yes	X		43/70[4]	Yes (50)	Torque is highly dependent on high axial force and accurate alignment.
	CRS	Yes	X		50	Yes	Locknut wore out in 18 cycles.
	CRS	Yes	X		45	Yes	Locknut torque high/erratic; very frequent slipping of screwdriver.
	CRS	Yes	X		65	Yes (55)	Locknut wore out in 20 cycles.
	CRS	Yes	X		65+	Yes (70)	Screwdriver frequently slipped. Locknut erratic.
	CRS	Yes	X		65+	No	Could not fail during tightening; tried to remove and the screw recess failed.
Allen	CRS	Yes	X		90	No	Screw recess rounded out at 90 in.-lb.
	CRS	Yes	X		90+	X	Did not fail; exceeded screwdriver capability.
	CRS	Yes	X		90+	X	Did not fail; exceeded screwdriver capability. Locknut torque high.
	CRS	Yes	X		85	No	Screw recess rounded out at 85 in.-lb, could not loosen; very erratic locknut torque.
	CRS	Yes	X		95+	X (80)	Did not fail; exceeded screwdriver capability.
	CRS	Yes	X		65	No	Locknut torque lost entirely, rounded out screw recess.
	Alloy	No	X		65	No	Screw recess rounded out.
Pozidriv	CRS	No	X		70	No	No. 2 Pozidriv screwdriver.
	CRS	Yes	X		64	Yes (65)	No. 2 Pozidriv screwdriver; locknut torque retained for 20 cycles.
	CRS	Yes	X		65	Yes (60)	No. 2 Pozidriv screwdriver; locknut torque erratic.
	CRS	Yes	X		64	Yes	No. 2 Pozidriv screwdriver; bent screwdriver bit, removed with new bit.
	CRS	Yes	X		65	Yes (60)	No. 2 Pozidriv screwdriver; bent screwdriver bit, removed with new bit.
	CRS	Yes	X		60	Yes (70)	No. 2 Pozidriv screwdriver; locknut lost torque at 24 cycles.
	Alloy	No	X		95[2]	Yes	No. 2 Pozidriv screwdriver; broke screwdriver bit, locknut wore out in approximately 7 cycles.

TABLE B-5 - Continued

Head-Recess Type	Mtl[1]	Paint	Complete 30 Cycles Yes	Complete 30 Cycles No	Failure Torque (in.-lb)	Successful Removal After Failure? (removal torque, in.-lb)	Comments
Torq-Set	CRS	Yes		X(3)	40[3]	Yes	Screwdriver constantly slipped.
	CRS	Yes		X(13)	33[3]	Yes	Screwdriver frequently slipped.
	CRS	No		X(7)	45[3]	Yes	Screwdriver frequently slipped while removing screw.
	CRS	Yes	X		80	No	Locknut did not wear out.
	CRS	Yes		X(3)	40[3]	Yes	Screwdriver constantly slipped.
	CRS	Yes	X		70	No	Locknut torque moderate entire test.
	Alloy	Yes	X		60	Yes	Locknut wore out.
	Alloy	Yes	X		75	Yes(60)	Locknut wore out in 5 cycles.
Tri-Driv	CRS	Yes	X		60	Yes	Phillips screwdriver for tightening; loosened after failure with slotted screwdriver.
	CRS	No	X	(20)	50	Yes	Wore out Posidriv recess, finished test with slotted screwdriver.
	CRS	Yes	X		50	Yes(30)	Pozidrive screwdriver.
	CRS	Yes	X	(11)	65	Yes	Pozidrive Plus Phillips plus slotted (sequentially after recess failure).
	CRS	Yes	X		65	Yes	Pozidrive plus Phillips plus slotted (sequentially after recess failure).
	CRS	Yes	X	(2)	65	Yes(48)	Pozidrive recess failed; completed test with slotted screwdriver.
	Alloy	No	X		35	Yes	Slotted screwdriver; locknut lost torque after 10 cycles.

NOTES:
1. Material code: CRS = corrosion-resistant steel
   Alloy = alloy steel
2. Screw recess did not fail. Screwdriver bit broke or deformed.
3. Maximum torque during testing.
4. Two values of torque represent different axial forces applied.
5. All screw failures occurred in screw-head recess.

Figure 4B shows the results of the torque-to-failure test performed at completion of the endurance cycles or the maximum torque applied to the screw during any endurance cycle.

Figure 4A shows another index for the evaluation of screw head recess performance from the maintenance standpoint; the ability to remove a screw if a driving recess failure occurs when the screw is tightened. The Tri-Driv recess gave the best performance; the redundant recess permitted the removal and even re-use of the screw after the first recess failure. The Allen recess gave the poorest results. Figure B-5 shows failure was by rounding out of the screw recess, and it was unusual to be able to remove a failed Allen head screw. Figure B-6 hints at some of the problems of removing a failed Allen recess head screw. Other head recesses were also difficult to remove, if severe damage occurred.

Some of the more pertinent observations of screw recess performance during endurance testing are listed below.

- Alignment of the screwdriver with the screw axis is essential to avoiding "camming-out" of the driver from the screw recess. Some driving recesses, Pozidriv and Torq-Set, for example, are made with the driving flutes aligned with the axis to reduce the camming-out tendency. This is excellent for assembly line operations where the power screwdriver can be carefully aligned with the screw axis, but in repetitive installation of screws with a hand screwdriver, misalignment frequently occurs, and "cam-out" tends to result regardless of the wall-recess and driver-flute angles.

- Most failures of the driving recess occurred from continual "cam-out" of the screwdriver from the driving recess. Each cam-out damages the head and the damage is progressive until a high torque cannot be maintained. As the head recesses start to wear, the walls of the recess are deformed and higher axial forces are required to prevent the screwdriver from camming out. However, this is not true of the Allen recess screw; generally, when this recess rounds out, the recess is no longer usable. Damage from screwdriver "cam-out" is shown in Figure B-5.

- Self-locking nuts with high friction torques are responsible for much of the head recess damage. The screwdriver will cam-out of the slot if misaligned at any time while tightening or loosening unless a substantial axial force is applied. Use of a self-locking nut requires nearly constant axial force on

Figure B-5. Recess Damage From Screwdriver Cam-Out

Figure B-6. Problems With Screw Removal After Recess Failure the screwdriver during the entire tightening or loosening cycle with all but the Allen recess heads.

- More damage to screw recesses occurred during the removal of screws than during installation for two apparent reasons: one, there is a tendency to apply less axial screw force during screw removal, and two, the average locknut friction of the plate nuts was consistently greater during screw removal than during installation.

- The flat-bladed screwdriver tends to walk sideways out of the slot. Three hands would be desirable when reacting high locknut torque: one hand to apply torque, one to apply axial load, and one to guide the base to counteract the "walking" tendency.

- Considerable damage in the form of severe scratches occurred to the panel in the vicinity of the slotted-head screws from the slipping screwdriver.

- Slotted-head screws took considerably longer to install and remove than any other head recess type (estimated 25 percent).

- Slotted and Allen drivers can be field-dressed to maintain good condition. None of the other screwdrivers could be trued-up if any wear or distortion occurred.

ULTIMATE STRENGTH

TENSION TESTING

The Allen recess head screws were the only ones in which failure was influenced by the recess configuration. All other failures occurred in the screw thread. The loads at failure are plotted in Figure B-7. All screws exceeded the 2500-lb minimum-strength requirements of specification MS 27039; however, the Allen alloy-steel screws were only four to eight percent above the minimum strength. A typical Allen-head failure is shown in Figure B-8. The corrosion-resistant steel screws were consistently 20 percent stronger than their alloy counterparts.

SHEAR TEST

The head recess did not affect failure of any of the screws in single shear: all failures occurred in the screw thread. The minimum load at failure was 1745 lb. There is no MS 27039 specification requirement for single-shear strength. (The requirement for minimum double-shear load is 4250 lb.) The

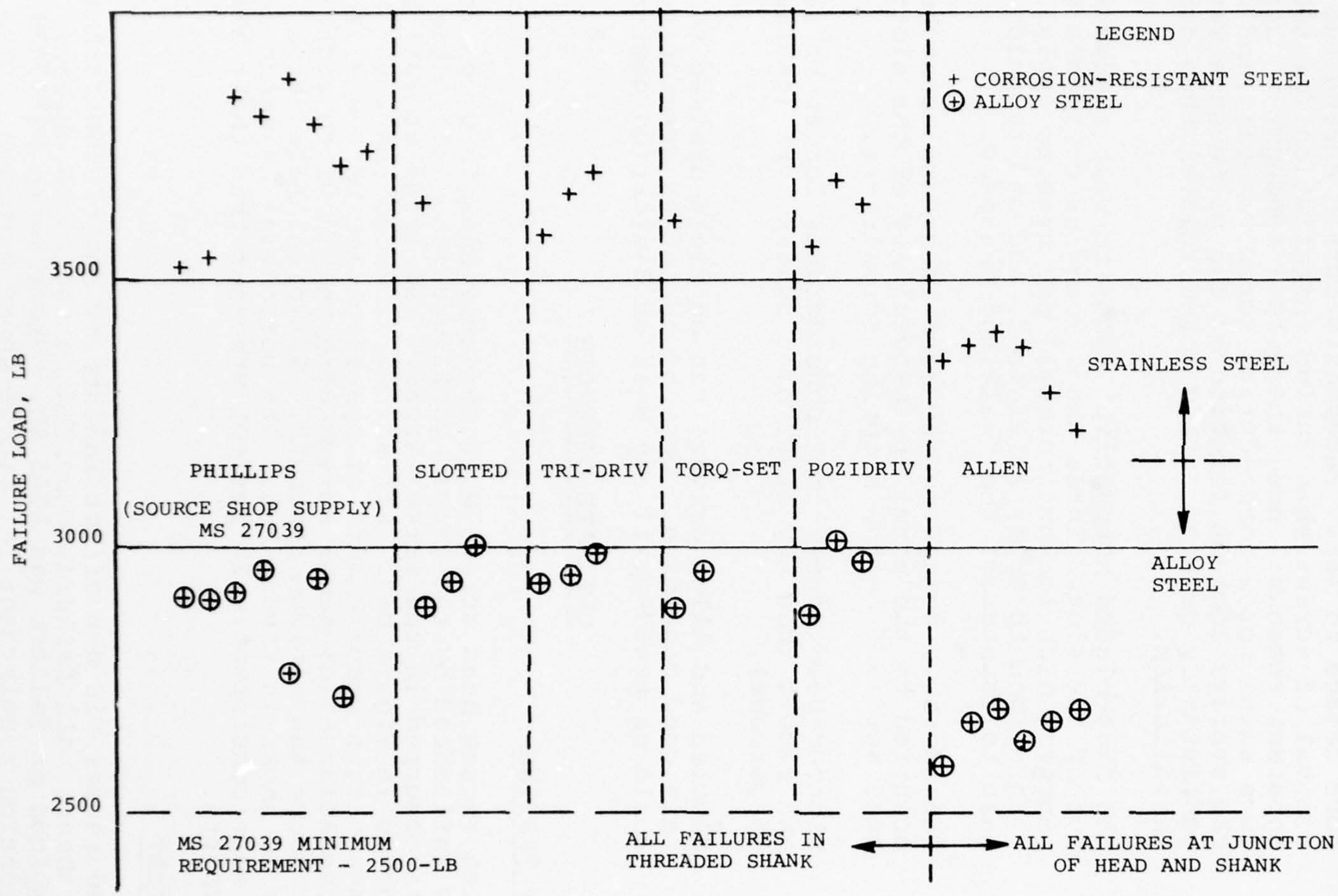

Figure B-7. Pan Head Screw Ultimate Tension Test

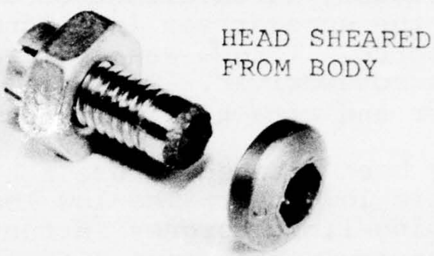

Figure B-8. Allen Head Tension Failure

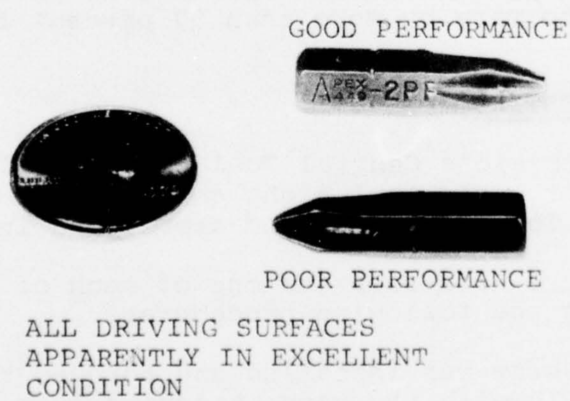

Figure B-9. Two Phillips Screwdriver Bits in Seemingly Good Condition corrosion-resistant steel screws averaged a 20-percent greater strength than their alloy steel counterparts.

TORQUE TO FAILURE

All new screws were used in this test. Screwdriver bits were either new or obviously in excellent condition. A guide ring was used to keep the screwdriver in alignment with the screw axis within ±1 degree. Torque was applied so as to minimize axial load on the screwdriver. The axial load was that of the torque screwdriver and attaching components (1-1/2 lb).

It had originally been planned to use a high axial load level in addition to this low load. The low load proved to be adequate for developing limit torques in four types of fasteners and tended to make any performance differences more pronounced.

Test history is summarized in Table B-6, which shows:

- The Phillips and slotted recesses developed only half to two-thirds the torque developed by the other four fasteners.
- The Allen recess weakened the screw, and the head sheared off in three of six specimens.
- Screwdriver condition greatly affects the torque developed. Two "very good" condition Phillips driver bits differed by a factor of five to one in the torque developed. These bits are shown in Figure B-9. Similarly, the slotted screwdriver performances were found to vary by more than 50 percent from the average.

ABNORMAL LOAD TESTING

The Aircraft Mechanic's General Tool Kit, as well as other sources, were examined for tools that might conceivably be used for screw removal. The tools selected are listed in Table B-7.

Three slotted screw recesses and one of each of the others were tested with the following procedure:

1. A new screw was installed and torqued to approximately 50 in.-lb with the correct screwdriver.
2. An inappropriate tool was used to attempt to remove the screw. If the screw could be removed, it was reinstalled and secured "tightly".

TABLE B-6. TORQUE-TO-FAILURE OR DRIVE LIMIT

SCREW RECESS CONFIGURATION		TEST NUMBER 1	2	3	4	5	6	7	8	9	FAILURE MODE
PHILLIPS	TORQUE	5	10	20	30	45	48	48	48	55	SCREWDRIVER CAMMED OUT OF HEAD
	*MATERIAL	A	A	C	C	C	A	A	A	A	
	NOTE	1	2	3	2	2	4	2	2	4	
SLOTTED	TORQUE	35	35	40	43	48	50	56	58	60	SCREWDRIVER CAMMED OUT OF HEAD
	*MATERIAL	C	A	C	A	C	A	A	C	C	
	NOTE	5	6	7	8	5	8	8	8	8	
ALLEN	TORQUE	55	62	85	90	90	95	95			HEAD SHEARED OFF DUE TO WEAKENING OF HEAD RECESS
	*MATERIAL	A	A	C	C	C	C	C			
	NOTE	9	9		9						
POZIDRIV	TORQUE	60	62	65	70	72	75	80			BROKE SCREWDRIVER BIT
	*MATERIAL	A	C	A	C	C	C	C			SCREWDRIVER CAMMED OUT OF HEAD
	NOTE	10	10		11						
TORQ-SET	TORQUE	50	60	75	78	80	80				SCREWDRIVER CAMMED OUT OF HEAD
	*MATERIAL	C	A	A	C	C	A				STRIPPED SCREW THREAD
	NOTE			12		12					
TRI-DRIVE (POZIDRIV SCREWDRIVER))	TORQUE	65	65	68	75	85	88				SCREWDRIVER CAMMED OUT OF HEAD
	*MATERIAL	A	A	A	A	C	C				STRIPPED NUT
	NOTE	13	12	12	12						STRIPPED SCREW THREAD

* A = ALLOY STEEL
C = CORROSION-RESISTANT STEEL

NOTES

1. SCREWDRIVER "A" USED. "CAMMED OUT" AT 5-10-IN.-LB. SAME SCREW TESTED WITH SCREWDRIVER "B" GAVE 55-IN.-LB TORQUE BEFORE "CAM-OUT". (TEST 9)
2. SCREWDRIVER "A"
3. SCREWDRIVER "A". VISEGRIPS NEEDED TO REMOVE FASTENER
4. SCREWDRIVER "B"
5. SCREWDRIVER "C"
6. SCREWDRIVER "C" "CAMMED OUT" AT THIS VALUE. SAME SCREW WAS TESTED WITH SCREWDRIVER "D" AND GAVE 56-IN.-LB TORQUE BEFORE "CAMMED OUT". (TEST 7)
7. SCREWDRIVER "C" "CAMMED OUT" AT THIS VALUE. SAME SCREW WAS TESTED WITH SCREWDRIVER "D" AND GAVE 60-IN.-LB TORQUE BEFORE "CAM-OUT". (TEST 9)
8. SCREWDRIVER "D".
9. HEAD SHEARED OFF DUE TO WEAKENING OF RECESS.
10. PURPOSELY MISALIGNED 6 DEGREES.
11. BROKE SCREWDRIVER BIT.
12. STRIPPED SCREW THREAD.
13. STRIPPED NUT, SCREW RECESS NOT DAMAGED.

TABLE B-7. TOOLS USED IN ABNORMAL LOAD TEST	
SCREWDRIVER TYPE	DESCRIPTION
SLOTTED	3/8x.050-IN. BLADE (USED WITH TORQUE SCREWDRIVER) DESIGNATED #1, VERY GOOD CONDITION
SLOTTED	5/8x.050-IN. BLADE, 9-1/2-IN. LONG. DESIGNATED #2
SLOTTED	3/16x.040-IN. BLADE, 7-1/2-IN. LONG. DESIGNATED #3, FAIR CONDITION AT START, BECAME POOR
SLOTTED	9/32x.045-IN. BLADE, STUBBY - 3-1/2-IN. LONG. DESIGNATED #4
SLOTTED	1/4x.025-IN. BLADE (DZUS KEY #259)
REED & PRINCE	NO. 1 SIZE: USAATS REJECT, POOR CONDITION
PHILLIPS	NOS. 3, 2, 1, GOOD CONDITION
PHILLIPS	NO. 2 SCREWDRIVER BIT, USED WITH TORQUE SCREWDRIVER
PHILLIPS	NO. 1 USAATS REJECT, POOR CONDITION
PHILLIPS	NO. 2 STUBBY - 3-1/2-IN. LONG
POZIDRIV	NOS. 3, 2, SCREWDRIVER BITS, USED WITH TORQUE SCREWDRIVER
ALLEN	5/32-IN. BIT FOR TORQUE SCREWDRIVER
ALLEN	OFFSET KEY SET

3. The proper screwdriver was used to loosen the screw, and then an attempt was made to retorque the screw to 50 in.-lb, noting any reduced capability of the screw.

From the abuse viewpoint, the Allen recess appears relatively invulnerable. No other size other than the correct-size hex key can be used with an Allen recess, and no other tool was found that would either be effective in or do serious damage to the recess. A small slotted screwdriver was tried, but it only damaged the blade, not the fastener. Worn Allen keys (Figure B-10) would be the most probable threat, but this type of deterioration is very hard to quantify, so no testing of this type was conducted.

The redundancy of the Tri-Driv recess permitted functional use of this head even though 10 different tools had been used with varying degrees of success, resulting in considerable abuse.

Seven different drivers were tried with the Phillips recess and six with the Pozidriv. The screw heads were still functional, but it was apparent that the frequent cam-out had badly deteriorated the fastener and that continued abuse with tools that had little chance of success (Reed and Prince and slotted blades) would eventually break down the head.

The Torq-Set head was ruined in the same manner as the Phillips head when the Pozidriv No. 2, Reed and Prince No. 1, and Phillips No. 2 screwdrivers were used to attempt to remove the fastener. The constant cam-out progressively destroyed the recess until the Torq-Set screwdriver would no longer develop sufficient torque to overcome the locknut friction.

The three slotted screws were quickly damaged. One was damaged by the No. 3 (thin blade) screwdriver, one by the No. 4 (stubby) screwdriver, and one by the Dzus key. Damage was evidenced by progressive cam-out of the No. 1 screwdriver at lower and lower torques. An unquantifiable factor in the slotted-screw failures was an extremely high (30 in.-lb) plate nut locking torque. This is two to three times the normal torque and makes it very difficult to use any screwdriver without cam-out.

The abnormal load testing did show the value of a redundant recess (Tri-Driv) and the advantage of a recess that works only with the proper tool (Allen), and indicates the value of standardizing fastener recesses so that the mechanic will have the correct tool available and will not have to "improvise" a solution.

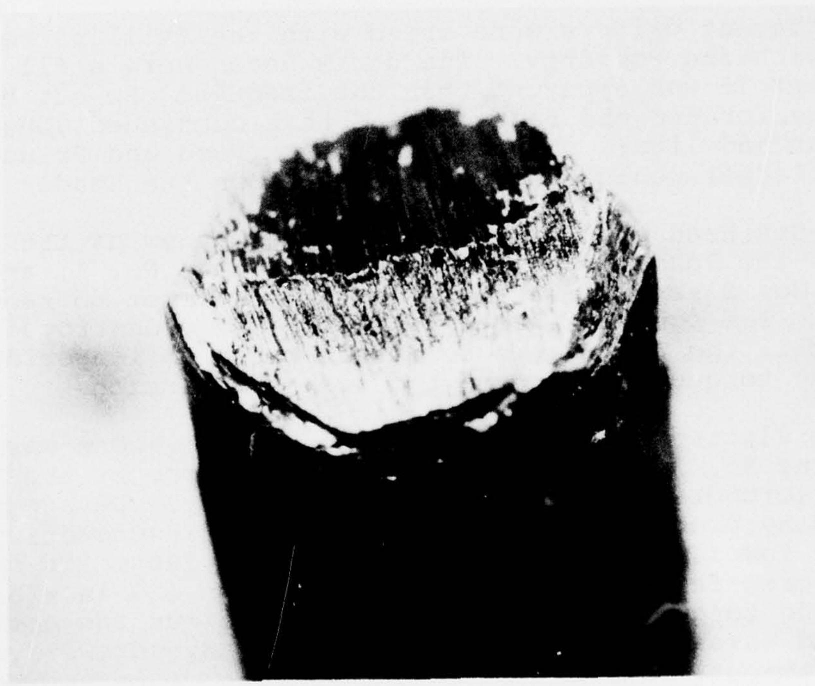

Figure B-10. Worn Allen Key

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